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DOCUMENT

Sentinel-3 Mission Requirements Traceability Document (MRTD)

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EXECUTIVE SUMMARY

Global Monitoring for Environment and Security (GMES) has been established to fulfil the growing need amongst European policy makers to access accurate and timely information services to better manage the environment, understand and mitigate the effects of climate change and ensure civil security. It is essential that an appropriate European Earth Observation capacity is available to ensure the development operation and sustainability of a vibrant and effective portfolio of GMES Services. Sentinel-3 is a European Earth Observation satellite mission to support GMES services for the Marine Environment with contributions to Land, Atmospheric Emergency, Security and Cryospheric services. The Sentinel-3 mission requires a series of satellites providing a commitment to consistent, long-term collection of data of uniform quality, generated and delivered in an operational manner for numerical ocean prediction, ocean state analysis, forecasting and service provision. Measurement requirements have been established as follows:

- Sea surface topography (SSH), significant wave height (Hs) and surface wind speed derived over the global ocean to an accuracy and precision exceeding that of Envisat RA-2.
- Enhanced surface topography measurements in the coastal zone, sea ice regions and over inland rivers, their tributaries and lakes.
- Infrared, and Thermal Infrared radiances ("Sea and Land Surface Temperature") determined for oceanic and coastal waters globally to an equivalent accuracy and precision as that presently achieved by ENVISAT AATSR over the ocean i.e. <0.3 K), at a spatial resolution of 1 km.
- Visible radiances ("Ocean Colour") for oceanic and coastal waters, determined to an equivalent level of accuracy and precision as ENVISAT MERIS and AATSR data with complete Earth coverage in 2 to 3 days, a spatial resolution of ≤ 0.3 km simultaneously and co-registered with SST measurements.
- Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances ("Land Colour and Temperature") for land surface (including sea ice and ice sheets), with complete Earth coverage in 1 to 2 days, with products at least equivalent to those derived from ENVISAT MERIS, AATSR and similar to SPOT Vegetation, together with those from their combination.

Essential GMES operational requirements of the Sentinel-3 mission concept are:

- The use of a high inclination polar orbit, to achieve near-complete global coverage.
- Optimised coverage for ocean surface topography measurements in constellation with existing satellite altimeter systems.
- Optical instrumentation requires a sun-synchronous orbit with a descending node equatorial crossing time to complement existing platform measurements and their long-time series, to mitigate the impact of thermal stratification of the ocean in the afternoon, sun glint, morning haze and cloud-cover.
- Measurement time that optimises both sea surface temperature and ocean colour measurements.
- Complete global coverage from optical instrumentation every 1 to 3 days.
- Near-real-time data processing and operationally robust delivery of all processed products for operational users in a timely manner
- Continuous flow of data of at least the same quality as delivered by Envisat, for programme duration of 20 years.
- Launch of a first satellite in the 2013 timeframe (with a series of platforms to meet observational requirements and requirements for robust, continuous operational data provision).

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The GMES Sentinel-3 system incorporates the following components:

- An advanced Radar Altimeter concept (with a baseline altimeter performance of ENVISAT RA-2, Jason-2 and CryoSat).
- Multi-channel optical imager (VIS, IR) either as one instrument or separate for ocean and land colour and surface temperature operational applications (with equivalent ENVISAT AATSR and MERIS minimum baseline performance).
- Appropriate system components for high-accuracy atmospheric water vapour, aerosol, and ionospheric corrections (with appropriate on-board redundancy).
- Appropriate system components for accurate/precise orbit determination (i.e. 3-d position), and on-orbit pointing knowledge (with appropriate on-board redundancy).

This Mission Requirement Traceability Document (MRTD) elaborates and further clarifies in detail Sentinel-3 Mission Requirements specified in the Sentinel-3 Mission Requirements Document [AD-2] (MRD) through the definition of unambiguous and traceable numbered requirements used by Sentinel-3 implementation teams. The Sentinel-3 MRTD and MRD are managed by the Sentinel-3 mission scientist according to the procedure set out in [AD-1].

Following an introduction and section outlining the justification for a Sentinel-3 Mission, GMES Service user requirements are presented that are at the origin of the Mission Requirements for the Sentinel-3 Mission. Annex I traceability matrix allows mapping key GMES requirements to the applicable Sentinel-3 MRD.

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1 INTRODUCTION

1.1 Scope of this document

The Global Monitoring for Environment and Security (GMES) Sentinel-3 Mission ('S3' or 'the mission' in the text that follows) Mission Requirement Traceability Document (MRTD) elaborates and further clarifies in detail Sentinel-3 Mission Requirements specified in the Sentinel-3 Mission Requirements Document [AD-2] (MRD) through the definition of unambiguous and traceable numbered requirements. The mission system requirements that are used by Sentinel-3 implementation teams are specified in a Sentinel-3 System Requirements Document (SRD) and in the GSC operation concept [RD-209] derived from the MRD. The MRTD is used by implementation teams to verify the traceability between the MRD and the implementation of the Sentinel-3 Mission according to the specifications stated in the SRD and the operational constraints captured in the GSC operation concept.

The MRTD for Sentinel-3 covers the end-to-end Earth observation system including high-level requirements, mission operations, data product development and processing, data distribution and data archiving. The Sentinel-3 MRTD and MRD are managed by the Sentinel-3 mission scientist according to the procedure set out in [AD-1].

1.2 Organisation of the Sentinel-3 MRTD

Following [AD-1], the Sentinel-3 MRTD is organised into the following sections:

- 1. Introduction (this section)
- 2. Background and Justification to the Sentinel-3 mission
- 3. User Information and Service Requirements for the Sentinel-3 mission
- 4. Mission Objectives
- 5. Mission Requirements and Elements
- 6. A System Concept Overview
- 7. Summary and Conclusions
- 8. A traceability matrix to GMES requirements
- 9. Appendices

1.3 Applicable and Reference Documents

1.3.1 Applicable documents (AD)

The applicable documents are identified within this MRTD as [AD-n] or by the first author and date of publication.

- AD-1 Procedure for Earth Observation Mission Requirements Definition and Management, QMS-PR-MMAN-2050-EOP
- AD-2 Drinkwater, M and H Rebhan, 2007, Sentinel-3 Mission Requirements Document (MRD) Issue 2 revision 0, EOP-SMO/1151/MD-md



1.3.2 Reference Documents (RD)

The reference documents are identified within this MRTD as [RD-n] or by the first author and date of publication.

- RD-1 Proposal for a European Policy for Earth Observation from Space (ESA/PB-EO (95)7, rev. 2).
- RD-2 Proposal for the Earth Observation Envelope Programme (ESA/PB-EO (98)14, rev.1).
- RD-3 Towards an ESA Long-Term Plan for 2004-2013 (ESA/C (2004)30).
- RD-4 GMES Earth Observation Component, Preparatory Activities (ESA/PB-EO (2004)48).
- RD-5 Lindstrom, E., J-L Fellous, M.R. Drinkwater, R. Navalgund, J. Marra, T. Tanaka, J.J. Johannessen, and C. Sumerhayes, 2001, An Ocean Theme for the IGOS Partnership, IGOS Ocean Theme Team Report, National Aeronautics and Space Administration, Washington DC., 39pp., Jan 2001. <u>http://www.unep.ch/earthw/IGOS-Oceans-Final-0101.pdf</u>
- RD-6 IOC (Intergovernmental Oceanographic Commission), 1998, The Global Ocean Observing System 1998. GOOS Publication No. 42, IOC, UNESCO, Paris, 144pp. http://ioc.unesco.org/goos/Prospe98/Contents.html
- RD-7 EuroGOOS Space Panel, 5-6 Oct 2000, 2001, Eumetsat, Darmstadt, Germany, EuroGOOS Publication No. 16, Southampton Oceanography Centre, Southampton, ISBN 0-904175-44-8, 131pp.
- RD-8 EuroGOOS Space Panel, 1996, EuroGOOS Strategy, EuroGOOS Publication No. 1, Southampton Oceanography Centre, Southampton, ISBN 0-904175-22-7, p. 10.
- RD-9 GODAE Steering Team, 2001, Global Ocean Data Assimilation Experiment (GODAE), Strategic Plan, GODAE Report No 6, GODAE International Project Office, Bureau of Meteorology, Melbourne, 3001 Australia, 23pp.
- RD-10 ESA, 2007, "Initial considerations on an Earth Watch mission concept for the monitoring of marine, coastal ice areas and hinterland", EOPP reference JP/97-5-1451/AT, Issued 25 Sept. 1997.
- RD-11 Flemming, N., 2001, EuroGOOS analysis of the need for operational remote sensing. In Operational Ocean Observations from Space, Report of the EuroGOOS Conference on Operational Ocean Observations from Space, 5-6 Oct 2000, Eumetsat, Darmstadt, Germany, EuroGOOS Publication No. 16, Southampton Oceanography Centre, Southampton, ISBN 0-904175-44-8, 6-12.
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- RD-13 Koblinsky, C.J. and N.R. Smith (ed), 2001, Observing the Oceans in the 21th Century, Proc. from OceanObs99, GODAE Project Office.
- RD-14 IOCCG, 1998, Minimum Requirements for an Operational, Ocean-Colour Sensor for the Open Ocean. Dartmouth, Canada, IOCCG Report No.1. See: <u>http://www.ioccg.org/reports/report1.pdf</u>
- RD-15 IOCCG, 2000, Remote Sensing of Ocean Colour in Coastal, and Other Optically-Complex, Waters, IOCCG Report No. 3. See: <u>http://www.ioccg.org/reports/report3.pdf</u>
- RD-16 Fischer, J., and N.C. Flemming, 2001, Operational Oceanography: Data Requirements Survey, EuroGOOS Publication No. 12, Southampton Oceanography Centre, Southampton, ISBN 0-904175-36-7, 59pp.
- RD-17 LeTraon, P-Y, M. Rienecker, N. Smith, P. Bahurel, M. Bell, H. Hurlburt, and P. Dandin, 1999, Operational Oceanography and Prediction - a GODAE Perspective, OceanObs'99 Conference, San Raphael, France.
- RD-18 ESA Study on "The impact of sea state on nadir looking and side looking microwave backscatter", ESTEC Contract Number 12934/98/NL/GD (available by request only).

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- RD-19 ESA Study on "Concept for Future Visible and Infrared Imager" (Alcatel), ESTEC Contract Number 15373/01/NL/MM (available by request only).
- RD-20 ESA Study on "Concept for Future Visible and Infrared Imager" (Astrium), ESTEC Contract Number 15374/01/NL/MM (available by request only).
- RD-21 EU FP5 Project Marine Environment and Security for the European Area (MERSEA) Strand-1 web page, see <u>http://strand1.mersea.eu.org/</u>
- RD-22 EU FP6 Project MERSEA Integrated Project web page, see http://www.mersea.eu.org
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- RD-24 GODAE High Resolution SST Pilot Project User Requirements, available from <u>http://www.ghrsst.org/GHRSST-PP-User-Requirements.html</u>
- RD-25 ESA Study on "Impact and Relevance of ESA's Missions in operational Oceanography and Climate Research and Monitoring", ESTEC Contract Number 14992/01/NL/MM
- RD-26 ESA Study on "Definition of Scenarios and Roadmap for Operational Oceanography", ESTEC Contract Number 18034/03/NL/CB. (http://www.cls.fr/html/oceano/general/applications/roadmap_en.html)
- RD-27 Cotton et al., 2004, Global Altimeter Measurements By Leading Europeans (GAMBLE) Final Report, (http://www.altimetrie.net)
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- RD-31 GMES Sentinel-1 Mission Requirements Document, ES-RS-ESA-SY-0007, Mission Experts Division, European Space Agency, 2005.
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- RD-33 Goes et al.,2004, Exploiting MODIS Data for estimating sea surface Nitrate from space EOS, vol. 85, No. 44, p. 449, 2 Nov 2004.
- RD-34 CryoSat Mission Requirements Document, MRD_CS-RS-UCL-SY-0001, 21 Nov 1999. See <u>http://www.esa.int/cryosat</u> under publications.
- RD-35 WCRP, 2004, WCRP Satellite Working Group Report: WCRP Space Mission Requirements: Space Mission Requirements for WCRP, WMO/TD-No. 1243, Jan. 2004. See: <u>http://www.wmo.ch/web/wcrp/documents/wcrpsatreport.pdf</u>
- RD-36 Global Observation for Forest and Land Cover Dynamics (GOFC-GOLD) fire monitoring and mapping. See: <u>http://www.fao.org/gtos/gofc-gold/f_fire.html</u>
- RD-37 EC, 2002, Towards a Strategy to Protect and Conserve the Marine Environment, Commission of the European Communities, COM(2002) 539 final, 2 Oct. 2002.
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- RD-45 Vasquez-Cuervo, J., E. Armstrong, and A. Harris, 2004, The effect of Aerosols and Clouds on the Retrieval of Infrared Sea Surface Temperatures, J. Climate, 17, 3921-3933.
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- RD-201 NOAA AVHRR web site, available at http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html
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| AATSR | Advanced Along Track Scanning Radiometer (ESA) |
|----------|--|
| AD | Applicable document |
| ADEOS | ADvanced Earth Observing Satellite (NASDA, Japan) |
| Alticore | ALTImetry for COastal REgions |
| AMSR | Advanced Microwave Scanning Radiometer |
| AOD | Aerosol Optical Depth |
| AOT | Aerosol Optical Thickness |
| ATSR | Along Track Scanning Radiometer (ESA) |
| AVHRR | Advanced Very High Resolution Radiometer |
| BRDF | Bi-directional Reflection Distribution Function |
| BS | Burn Scars |
| BUFR | Binary Universal Form for the Representation of meteorological data (of WMO) |
| Cal/Val | Calibration and Validation |
| CAP | Common Agriculture Policy (of the EC) |
| CDS | Coordinated Data Access System |
| CEOS | Committee on Earth Observation Satellites |
| CLW | Cloud Liquid Water |
| CNES | Centre National d'Etudes Spatiales |
| CORINE | Coordination of Information on the Environment |
| COASTALT | Coastal altimetry (project of ESA) |
| DAG | Data Access Gateway |
| DAP | Data Access Portfolio |
| DAP-R | Data Access Portfolio Requirements |

1.4 Acronyms and abbreviations

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| dB | decibel |
|------------|--|
| DG | Directorate General |
| DUE | Data User Element (of ESA) |
| DUP | Data User Program (of ESA) |
| DMSP | Defense Meteorological Satellite Program (of the US Department of Defense) |
| DORIS | Doppler Orbit and Radio Positioning Integration by Satellite |
| EC | European Commission |
| ECSN | European Climate Services/Support Network |
| EEA | European Environment Agency |
| EO | Earth Observation |
| ENSO | El Nino Southern Oscillation |
| ENVISAT | ENVIronmental SATellite (ESA) |
| EOL | End Of Life |
| EOS | Earth Observing System |
| EPS | EUMETSAT Polar System |
| ERA | ECMWF Re-Analysis |
| ERS | European Remote-sensing Satellite (ESA) |
| ESA | European Space Agency |
| ESOC | European Space Operations Centre |
| ESTEC | European Space Research and Technology Centre |
| EuroGOOS | European Global Ocean Observing System |
| EU | European Union |
| EUMETSAT | EUropean Organisation for the Exploitation of METeorological SATellites |
| FAO | United Nations Food and Agriculture Organisation |
| FAPAR | Fraction of Absorbed Photosynthetic Active Radiation |
| FOAM | Forecasting Ocean Assimilation Model |
| FOS | Flight Operations Segment |
| FOV | Field of View |
| FP-6, FP-7 | EC Framework Program (6 or 7) |
| FR | Full Resolution |
| FTP | File Transfer Protocol |
| FTS | Fast Track Service |
| FVC | Fraction of Vegetation Cover |
| GCOS | Global climate Observing System |
| GDR | Geophysical Data Record |
| GHRSST | GODAE High Resolution SST Pilot Project |
| GMES | Global Monitoring and Environmental Security |
| GMFS | Global Monitoring for Food Security |
| GNSS | Global Navigation Satellite System |
| GSC | GMES Space Component |
| GSCDA | GMES Space Component Data Access |
| GSE | GMES Service Element |



| GSS | GMES Service Segment |
|----------|--|
| GOCE | Gravity Field and Steady-State Ocean Explorer Circulation |
| GOME | Global Ozone Monitoring Experiment |
| GOOS | Global Ocean Observing System |
| GPS | Global Positioning System |
| HLOP | High Level Operating Plan |
| IATA | Air Transport Association |
| IFOV | Instantaneous Field Of View |
| IGBP | International Geosphere / Biosphere Programme |
| IGDR | Intermediate Geophysical Data Records (of the altimeter) |
| IGOS | Integrated Global Observing Strategy |
| IOC | Inter-governmental Oceanographic Commission |
| IPCC | Inter-governmental Panel on Climate Change |
| IR | InfraRed |
| IST | Ice Surface Temperature |
| ISP | Instrument Source Packets |
| JASON | Not an acronym but the name of a joint EU/US altimeter mission |
| JRC | Joint Research Centre (of the EC) |
| L1b | Level-1 b product |
| L2 | Level-2 product |
| L2P | Level 2 pre-processed (of GHRSST) |
| L3 | Level-3 product |
| LAI | Leaf Area Index |
| LCM | Land Cover Maps |
| LEO | Low Earth Orbit |
| LMCS | Land Monitoring Service |
| LRM | Low Resolution Mode |
| LST | Land surface Temperature |
| LTAN | Local Time of Ascending Node |
| LTDN | Local Time of Descending Node |
| LWST | Lake Water Surface Temperature |
| MARCOAST | Marine & Coastal Environmental Information Services |
| MERIS | Medium Resolution Imaging Spectrometer |
| MERSEA | Marine Environment and Security for the European Area |
| METOP | METeorological OPerational satellite (EUMETSAT) |
| MCS | Marine Core Service |
| MFS | Mediterranean Forecasting System |
| MGVI | MERIS Global Vegetation Index |
| MMUS | Multi-Mission User-Services |
| MODIS | Moderate Resolution Imaging Spectro-radiometer |
| MOS | Modular Optoelectronic Scanner |
| MRD | Mission Requirements Document |



| MRTD | Mission Requirements Tracability Document |
|----------------------|--|
| MSG | Meteosat Second Generation |
| MTCI | MERIS Terrestrial Chlorophyll Index |
| MTG | Meteosat Third Generation |
| MWR | Microwave Radiometer |
| N/A | Not Applicable |
| NAO | Northern Atlantic Oscillation |
| NASA | National Aeronautics and Space Administration (USA) |
| NDVI | Normalised Differential Vegetation Index |
| NEDT (NE Δ T) | Noise Equivalent Differential Temperature |
| NIR | Near InfraRed |
| NMHS | National Meteorological and Hydrological Service |
| NOAA | National Oceanic and Atmospheric Administration (USA) |
| NOP | Numerical Ocean Prediction |
| NRT | Near Real Time |
| NTC | Non-Time Critical |
| NWC | Nowcasting |
| NWP | Numerical Weather Prediction |
| OI | Optimum Interpolation |
| OLC | Ocean and Land Colour |
| OLCI | Ocean and Land Colour Instrument (of sentinel-3) |
| OSI | Ocean and Sea Ice |
| OZA | Observation Zenith Angle |
| PAR | Photosynthetic Active Radiation |
| POD | Precise Orbit Determination |
| PRF | Pulse Repetition Frequency |
| RA-2 | Radar Altimeter-2 (on ENVISAT) |
| RD | Reference Document |
| REDD | Reduced Emission from Deforestation and Degradation in Developing |
| RF | Radio Frequency |
| RFI | Radio Frequency Interference |
| RMS | Root Mean Square |
| RTM | Radiative Transfer Model |
| S-3 | Sentinel-3 |
| SA | Surface Albedo |
| SAF | Satellite Application Facility |
| SAR | Synthetic Aperture Radar |
| SAR (alternative) | Search And Rescue |
| SC | Snow Cover |
| SCIAMACHY | Scanning Imaging Absorption Spectrometer for Atmospheric Cartography |
| SEVIRI | Spinning Enhanced Visible InfraRed Imager |
| SIRAL | Sea Ice Radar Altimeter |

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| SLST | Sea and Land Surface Temperature |
|----------------|--|
| SLSTR | Sea and Land Surface Temperature Radiometer (of Sentinel-3) |
| SNR | Signal-to-Noise Ratio |
| SPOT | Satellite Pour l'Observation de la Terre (CNES) |
| SRAL | SAR Radar Altimeter (of Sentinel-3) |
| SRD | System requirement Document |
| SSH | Sea Surface Height |
| SSI | Solar Surface Irradiance |
| SST | Sea Surface Temperature |
| STC | Short time Critical |
| SW | Short-Wave |
| SWH | Significant Wave Height (Hs) |
| SWIR | Short-Wave Infra Red |
| T/P | Topex-Poseidon |
| TBC | To Be Confirmed |
| TBD | To Be Determined |
| TIR | Thermal Infrared |
| ТОА | Top Of the Atmosphere |
| TOGA | Tropical Oceans Global Atmosphere |
| TOPAZ | Towards an Operational Prediction system for the Atlantic and European |
| TOPEX/POSEIDON | TOPography EXperiment satellite (launched on 10 August 1992 on behalf of NASA and CNES dedicated to the monitoring of ocean circulation) |
| ТРМ | Third Party Missions |
| UN | United Nations |
| UNCBD | UN Convention on Biological Diversity |
| UNCCD | UN Convention to Combat Desertification |
| UNESCO | United Nations Education, Scientific and Cultural Organisation |
| UNEP | United Nations Environment Programme |
| URD | User Requirements Document |
| URL | Universal Resource Locator (Internet address) |
| UTC | Universal Time Coordinated |
| UV | Ultraviolet |
| VAAC | Volcanic Ash Advisory Centre |
| VGT | Vegetation like (product) |
| VIIRS | Visible/Infrared Imager and Radiometer Suite |
| VIS | Visible |
| VIS/IR | Visible/Infrared |
| VNIR | Visible and Near Infrared |
| WAM | Wave Model |
| WCRP | World Climate Research Programme |
| WMO | World Meteorological Organization (Geneva, Switzerland) |
| WOCE | World Ocean Circulation Experiment |

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1.5 Definitions

Daytime: Part of the satellite orbit where the sun zenith angle at satellite ground track is lower than 80°.

Delivery Timeliness definitions:

Near real-time (NRT) products made available to the users in less than 3 hours after measurement at the satellite

Short time critical (STC) products made available to the users in less than 48 hours measurement at the satellite

Non-time critical (NTC) products made available less than 1 month after measurement at the satellite and archived.

Emergency: An unpredictable event that shall be sensed by the satellite and data distributed as soon as possible to the user (e.g. civil protection).

<u>Goal:</u> The term "goal" denotes a non-mandatory requirement, the implementation of which shall be studied to allow for an assessment of the system impacts. The implementation or not of the goal requirements will be decided by the Agency after proper analysis of the implications.

Level o product

Level o (L-o) optical products: Reconstructed and time sorted instrument Source Packets (ISP), at full space-time resolution. All communications artefacts (e.g. synchronization frames, communications headers and duplicate data) and invalid packets are removed.

Level o Topography Product: Reconstructed and time sorted ISP at full space-time resolution. Invalid ISP, time overlaps, and communication artefacts are removed.

Level 1b (L1b) product

Level 1B Optical product: Top-Of-Atmosphere (TOA) radiometric measurements, radiometrically corrected, calibrated and spectrally characterised. Quality controlled and orthogeolocated (with latitude and longitude coordinates, Altitude), with accurate inter-channel corregistration, annotated with satellite position and pointing, landmarks and preliminary pixel classification (e.g. land/water/cloud masks).

Level 1B Topography Product: geo-located engineering calibrated data, i.e.:

- Altimeter L1b geo-located and calibrated radar echoes (i.e. waveforms) with all ancillary information annotated.
- MWR L1b geo-located, radiometrically and geometrically corrected brightness temperature measurements (at each of the antenna frequencies)

Level 2 (L2) products

Level 2 optical product: geo-located geophysical products. Level 2 products consist of geophysical quantities derived from the processing of the measurements data provided in the corresponding L1b product. More than one level-2 product can be generated from the same Level 1b input data.

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Level 2 topography Product: altimeter range, (1 Hz and 20 Hz waveform data) orbital altitude, time, water vapour from the MWR and geophysical corrections, along with significant wave height and wind-speed information.

Level 2P product: L2 SST data product, with the addition of a quantitative confidence value attached to every data point [RD-110].

Level 3 (L3) products

Spatially and/or temporally re-sampled biophysical variables and maps.

Systematic Acquisition: Continuous and uniform operation of the instrumentation with uninterrupted acquisition.

<u>Threshold</u>: A requirement that is considered a boundary that defines the point at which utility and quality will be significantly reduced for a given situation (i.e. compulsory limit for the mission).

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2 BACKGROUND AND JUSTIFICATION

2.1 Global Monitoring for Environment and Security (GMES)

GMES is a European initiative to implement a European capacity that provides independent and permanent access to reliable Earth Observation data [RD-1, RD-3, RD-4, RD-170, RD-171] in support of GMES services. GMES has been established to fulfil the growing need amongst European policy makers to access accurate and timely information services to better manage the environment, understand and mitigate the effects of climate change and ensure civil security. In 2004, an Action Plan for GMES was published [RD-50] and in 2005 an implementation strategy for delivering GMES was established [RD-51]. A complete description of GMES services can be found at [RD-170, RD-171].

GMES is designed to provide strategic information to European decision-makers by delivering information derived from sustained measurement systems including satellite measurements, in-situ infrastructure, data integration and information management systems and dedicated user driven services. Key focus areas for GMES include:

- Systematic monitoring and forecasting the state of the Earth's subsystems at regional and global levels;
- Monitoring climate change, assessing mitigation measures and, contributing to the knowledge base for adaptation policies and investments;
- Providing support in the event of emergencies and humanitarian aid needs, to civil protection authorities,
- Production of accurate information on security related aspects (e.g. maritime surveillance, border control, global stability, etc.);
- Enhancing the security of European citizens.

GMES established an initial set of 'core¹' services, building on activities within the 5th, 6th and 7th Framework Programmes (FP-5, FP-6, FP-7) of the European Union and the GMES Service Element (GSE) of ESA's EarthWatch Programme [RD-172]. These services process and disseminate generic, pan-European core information derived from GMES components on an operational basis. GMES services include:

- **Marine Services** that focus on marine safety and transport, oil spill monitoring, water quality, weather forecasting and the polar environment (the Marine Service (MCS) [RD-52, RD-53] see http://myocean.eu.org).
- Land Services that focus on water management, agriculture and food security, land-use change, forest monitoring, soil quality, urban planning and natural protection services (the Land Monitoring Service (LMCS) [RD-54] see http://www.gmes-geoland.info/).
- Atmospheric Services that focus on air quality, ultraviolet radiation forecasting, and climate change studies (the GMES Atmosphere Service (GACS) [RD-55, RD-120] see <u>http://www.gmes-atmosphere.eu/about/</u>).

¹ Core services have eviolved into 'GMES services' are pan-European in scope and generic in nature. More specialized 'downstream services' to meet the needs of a range of different users (e.g. national, regional or local) can be derived from them by further value-adding and customization by service providers and/or the use of additional data streams.



- **Emergency Response Services** that provide help to mitigate the effects of natural and manmade disasters, flood, forest fire, earthquakes and support to humanitarian aid (the Emergency Response Service (ERCS) [RD-56, RD-139] see <u>http://www.emergencyresponse.eu</u>).
- **Security Services** that provide support to peacekeeping operations, nuclear non-proliferation activities, systems that mitigate piracy at sea, illegal immigration, drug trafficking, support to activities providing protection of vital infrastructure such as pipelines, and assistance to European residents in crisis areas (e.g. GMES services for Management of Operations, Situation Awareness and Intelligence for regional Crises (G-MOSAIC) [RD-88] see <u>http://www.gmes-gmosaic.eu/project-overview.html</u>).

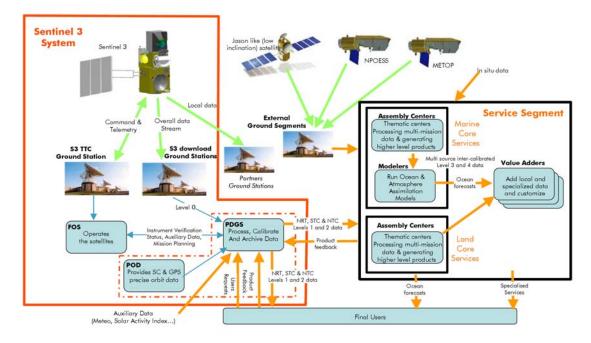


Figure 1: Schematic diagram showing the end to end GMES service chain including the Marine service (MCS) and the Land Monitoring Service (LMCS) as examples.

Substantial investments have been committed to GMES Earth Observation (EO) by the EU, the European Space Agency (ESA) and their respective Member States. Research and development projects have steadily contributed to the development of the GMES infrastructure and services over the last 10 years funded under the EU FP-5, FP-6, FP-7 and ESA GSC programmes. The first GMES services in pre-operational mode for land monitoring, marine monitoring, atmosphere monitoring, emergency response and security commenced in September 2008. These and new GMES services are expected to mature and grow in the coming decade to provide an enhanced European capacity to manage European responsibilities for disasters, health, energy, climate, water, weather, ecosystems, agriculture and biodiversity within the framework of the Global Earth Observation System of Systems (GEOSS) [RD-89].

Satellite measurements provide unique, consistent, regular and synoptic data with quasi-global coverage from which a wide variety of fundamental GMES data products and services can be derived. For the marine environment, satellite measurements, together with specific supporting *in situ* infrastructure (particularly for sub-surface ocean measurements) are the only data source that is capable of delivering

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the quality and coverage of data required by GMES services. It is essential that an appropriate European Earth Observation capacity is available to ensure the development operation and sustainability of a vibrant and effective portfolio of GMES Services.

Sentinel-3 is a European Earth Observation satellite mission designed specifically to support GMES services for the Marine Environment with contributions to Land, Atmospheric, Emergency, Security and Cryospheric services. Figure 1 provides a schematic overview the Sentinel-3 system and the relationship to GMES Services using the example of ocean and land services. It summarises an operational flow of global satellite observation data from Sentinal-3 satellite instruments to end users including:

- Management and control of the spacecraft, data acquisition and downlink via a flight Operations Centre (FOS);
- The dissemination of data through a Payload Data Ground Segment (PDGS);
- A Service Segment including specialised Thematic Assembly Centres (TAC), modelling groups and, value adding activities providing specific services to end users in near real time;
- Interfaces to GMES contributing missions providing additional data to the Service Segment.

The concept for Sentinel-3 was drafted in 2001 in the framework of ESA's Ocean Earth Watch mission and is complemented by the science driven ESA Earth Explorer missions [RD-2]. The mission is flown in a sun-synchronous orbit and provides measurements of surface topography, colour and temperature based on optical and microwave instrumentation. It is focussed primarily on the marine environment where the relevant GMES policy drivers have been identified as the Regional Conventions, the 6th Environmental Action Plan (in particular its Climate Change and Marine Environmental Strategy components), the EU Marine Strategy Framework Directive [RD-37, RD-57], the Integrated Maritime Policy of the European Union [RD-69] and relevant existing EU Directives, and ongoing concerns over civil security [RD-51]. European policy drivers for land monitoring include those related to soils [RD-106], biodiversity [RD-107], forestry [RD-108], and agriculture and rural development [RD-109].

To satisfy the requirements of the GMES services, Sentinel-3 is a mission to continue the legacy of moderate spatial resolution (~300-1000 m) optical measurements (*e.g.*, ENVISAT MERIS, (A)ATSR, SPOT Vegetation and MetOp AVHRR) for marine, atmospheric land services including generic land cover mapping and bio-geophysical parameters [RD-103]. The S3 mission will also provide continuity to the CryoSat-2 SIRAL and ENVISAT Radar Altimeter systems contributing to the global constellation of altimeters used to measure sea state and wind speed in support of maritime safety, measure ocean circulation, constrain ocean forecast systems and measure sea level rise. ENVISAT and SPOT Vegetation are at the end of their operational lifetimes and expected to end in the 2010-2014 timeframe. Sentinel-3 is well suited and well timed to provide continuity of these missions for GMES.

2.2 Justification for GMES Sentinel-3

Operational oceanography, as defined by the European Global Ocean Observing System (EuroGOOS [RD-7, RD-8]), the Global Ocean Data Assimilation Experiment (GODAE, [RD-9]) and follow on GODAE-Ocean View (GOV, [RD-68]), is the routine measurement, dissemination, and interpretation of quantitative data on the marine environment in order to:

- Provide a useful and accurate description of the present state of the marine environment including living resources;
- Facilitate forecasts of future marine conditions with as long a lead time as possible;
- Assemble uniform, consistent, long-term climatic data set that provides an accurate description of past states, trends and changes.

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The successful evolution of operational oceanography and rapid development of Numerical Ocean Prediction (NOP) has led to the development of a critical mass of well established ocean services [RD-53]. In fact scientific and operational meteorological satellite missions (such as NOAA-, ERS, ENVISAT, Jason and TOPEX/Poseidon) have stimulated the steady development of global ocean models [RD-9].These require near real time (NRT) access to sustained, global coverage measurements of ocean surface topography, ocean colour and sea surface temperature. The EU 5th (Strand 1) and 6th (Strand 2) Framework Programme projects such as the Mediterranean Forecasting System (MFS [RD-90]) and "Marine Environment and Security in the European Area" (MERSEA [RD-91]) have provided the essential developments for a transition to pre-operational ocean services within the 7th EU Framework Program, the MyOcean Project [RD-53].

In order to sustain and further develop marine services based on NOP it is necessary to develop an increased capacity to provide value added services that deliver information to users in a timely and routine operational manner. GMES will increase the capacity and utility of European marine services based on:

- Deployment of a European global ocean observing satellite (Sentinel-3) with near-real time data transfer capabilities providing a sustained, consistent, reliable and accurate long-term operational measurement capability,
- Operational data processing, data management and unrestricted data distribution,
- Robust and validated satellite products including uncertainty estimates required by data assimilation systems [RD-52, RD-54] and,
- Operational long-term validation and verification of all data products throughout the mission lifetime [RD-52, RD-54] to assure mission quality and performance.

Marine services in Europe use data from international space agencies including the European ERS, ENVISAT, Meteosat, JASON and, MetOp satellites have provided an expanding capability to monitor the marine environment since 1992. More recently, through international collaboration, a multimission ocean surface topography constellation [RD-65] has been proposed to address ocean surface topography measurement requirements that cannot be met by single satellite missions. Similar activities have consolidated the requirements for sea surface temperature (SST) constellations [RD-67]. Sentinel-3 will make a significant contribution to the international ocean surface topography and SST satellite constellations delivering considerable benefits to GMES.

Sentinel-3 measurements can be used to address user community requirements for all GMES services but is focussed on core domains as follows:

• Numerical Ocean Prediction (NOP): Operational availability of ocean observations is a prerequisite to consistent, improved predictions of atmospheric and oceanic conditions, thereby enabling safer use of the sea and the exploitation of the economically important regions such as the coastal zone. More accurate forecasting in turn helps protect people from the impacts of extreme weather events such as hurricane winds, storm surges and flooding. Satellite ocean measurements will improve existing predictive capability by providing a better understanding of global ocean processes that govern ocean and weather patterns especially when using data assimilation systems. This is particularly important as a new generation of coupled ocean-atmosphere model systems are now being developed and implemented. A network of global ocean (satellite and in-situ) measurements is required to specify boundary conditions in advanced NOP models. Operational availability of ocean observations (Altimetry, L1-b radiance/reflectance data and derived geophysical parameters together with uncertainty

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estimates) is a prerequisite for effective data assimilation and generation of consistent, improved predictions of atmospheric and oceanic conditions.

- **Maritime Safety and Security:** Monitoring of ocean conditions for security and safety at sea are a high priority. At National and EU level, recognition of the importance of solving problems associated with pollution as a consequence of shipping accidents, passenger vessel safety, and, potential terrorist actions, has led to the formation of institutions responsible for coordinating legislation. At EU level the European Maritime Safety Agency (EMSA) was set up in 2002 to provide technical and scientific assistance to the European Commission and Member States on matters relating to the proper implementation of European Union legislation on maritime safety and pollution by ships. This includes actions aimed at improving safety at sea for oil tankers and passenger ships, as well as bulk carriers, container ships and, fishing vessels.
- **Coastal Zone Monitoring:** Demands for information on the status of the coastal zone water quality and health are growing in response to population pressure and EU legislation [RD-57, RD-167]. Thus, there is a requirement for environmental monitoring of water quality and phenomena such as harmful algal blooms (HAB) and habitat assessment and management in addition to weather and ocean now-casting and forecasting. The characteristics of the coastal phenomena and the importance of the area for aquaculture, sea-defences, and tourism each justify the observation of coast related parameters with enhanced accuracy, uncertainty estimation and resolution particularly for sea surface heights, surface wind and sea state that significantly impact the coastal environment (e.g. storm surge tides, coastal shipping, coastal damage).
- **Open Ocean and Ice Monitoring:** The health and state of the oceans can only be assessed with the aid of globally comprehensive, integrated observations. Satellite measurements from polar orbiting platforms such as Sentinel-3 provide a core component of an integrated observing system as they provide consistent, synoptic coverage of the global ocean on a daily basis. With such data, together with measurement uncertainty estimates, working in synergy in the framework of ocean modelling systems and data assimilation, it will be possible to increase the predictability of characteristics such as sea-state, ice formation, ocean circulation, and the impact of physical conditions on ocean biogeochemistry. The open ocean also provides important boundary conditions for coastal regions.
- Atmospheric Services: Sentinel-3 L1b data streams and geophysical products will provide inputs to NWP models [RD-55] through advanced data assimilation schemes. SST, surface wind speed and sea state (Hs) are all essential inputs to NWP and associated wave forecast model systems. Consistent [RD-75] global coverage aerosol products (covering ocean and land), L1b cloud imagery, lake water surface temperature, land surface temperature, ice surface temperatures and fire information are also required.
- **Global Land Monitoring Applications:** Sentinel-3 will provide daily coverage of the Earth, facilitating global fast revisit observation of the land surface. These data will allow the monitoring of parameters such as regional and continental-scale land cover, vegetation state or vegetation productivity, fire location, intensity and effects (such as burnt scar area) in support of emergency services and European policies. Inland rivers and lake height levels can be monitored and digital elevation models of the earth's surface can be derived using advanced altimetry processing providing new information for hydrological services. Sentinel-3 will compliment other missions (e.g. SPOT Vegetation, Landsat, and Sentinel-2) that provide higher spatial resolution measurements and longer revisit times, with more frequent measurements having enhanced spectral capabilities in the visible spectrum, dual-view infrared bands for land surface characterisation, atmospheric correction, and fire observation capabilities.
- **Environmental Policy and Law:** Through international negotiations, governments have agreed to numerous conventions which, although not in all cases explicitly stated, embody the requirements for measuring various ocean parameters globally in a concerted, systematic way.

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The United Nations Kyoto Protocol, the Framework Climate Convention, the European Water Framework Directive [RD-130], the Biodiversity Convention, the EU Marine Strategy [RD-57], the soil thematic Strategy and other such agreements all make it obligatory for states to monitor and manage the exploitation of the marine, coastal and land environment.

- Climate Change monitoring: In support of developing European Commission position on adaptation to climate change [RD-112, RD-113], satellite data products and services are required to support the sustained provision of European Climate Services [RD-114]. Many of the products requested by the communities indicated above will be of interest to the scientists studying global and climatic change. Monitoring climate using global climate Observing system (GCOS) Essential Climate Variables (ECV) and according to GCOS climate monitoring principles [RD-58] is prerequisite to formulating evidence-based strategies to adapt to and mitigate climate change impacts. Accurate and stable operational missions are the only way to provide a long term, consistent quality data-base required to monitor and study the regulating effect that ocean processes exert on climate. Improved analysis of climatological data sets will also support and enhance operational NRT forecasting applications. The importance of satellite data working in synergy with in situ data cannot be overstated as the two observing system components provide complementary data. Accordingly, Sentinel-3 measurements should extend existing climate records from ENVISAT for climate applications and adhere to the GCOS climate monitoring principles [RD-58].
- Support to European Security, Humanitarian and Emergency Services: Sentinel-3 products are not optimised for the rapid-task, high spatial (<10 m) and temporal (hours) requirements typical of these services (*e.g.*, floods, forest fires, earthquakes, humanitarian aid in emergencies). But they will provide a baseline wall-to-wall mapping capability at reduced resolution (0.3-1 km) prior to and following emergencies that are used in support of GMES ERCS services [RD-98]. Forest fires (*e.g.*, Greece wildfires in 2009/10, Australian fires of 2009), the impact of volcanic eruptions (*e.g.*, the Iceland Eyjafjallajoekull eruption in 2010 and impact on European aviation), storm surge impacts (*e.g.*, deaths and significant property damage associated with storm Xynthia, France 2010) all provide sobering examples of how important effective measurement, modelling, forecasting and information dissemination is in terms of saving lives and property. The economic cost of these examples taken only from 2009/10 alone is significant.

The domain of GMES operational land services is less mature than that for the oceans. Nevertheless, during the last years the operational use of the SPOT Vegetation instrument has allowed the development of operational land services [RD-54, RD-179]. These services provide routine information for global land monitoring (agriculture and forestry), moderate resolution mapping, regional and continental scale land cover mapping, global land productivity, agriculture or vegetation status and determination of biophysical vegetation parameters. Such parameters are needed for climate modelling, carbon flux estimation, crop yield estimation and, land degradation mapping that can all change rapidly with time. The regular daily revisit and large number of optical bands including thermal infrared proposed for Sentinel-3 are strong assets that compensate their proposed moderate spatial resolution.

The Sentinel-3 mission has strong economic and social value, noted during initial considerations for an Earth Watch ocean concept [RD-10] and in further assessments of the need for operational marine remote sensing [RD-11]. The socio-economic benefit of GMES has been accurately evaluated [RD-44] and concludes that benefits accrue to producers, customers, and the European community at large. The sum total of benefits estimated by EuroGOOS for the European region has been estimated to be of the order of $\pounds 2-5B$ per year [RD-8]. This figure includes mainly commercial, economic and social benefits. A combination of seasonal and decadal forecast techniques incorporating (for example) ENSO analysis, the Pacific Decadal Oscillation and the North Atlantic Oscillation (NAO) may also provide benefits

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measured in hundreds of millions of Euro per year for each of several management sectors related to fresh water reservoirs, power management and infrastructure, transport planning and infrastructure, agriculture, oil and gas storage, agriculture and tourism [RD-47, RD-23].

Economic Importance of the Oceans

The health of the oceans can only be assessed with the aid of globally comprehensive EO and *in situ* integrated measurements working together with NOP and NWP systems. With such data it will be possible to increase the predictability of phenomena such as sea-state, ice formation, coastal erosion and harmful algal blooms. This facilitates more efficient management of food sources from the ocean and of input of waste products into the oceanic and coastal waters: to reduce the possibility of accidents and associated risks of major pollution incidents. Further, model output and measurements will enable more effective mineral prospecting and offshore platform operations. The El Niño/La Niña phenomenon of the tropical Pacific has a widespread impact on the economics of crop production in the tropics and mid-latitudes with connections to world-wide climate. As the ocean exerts a major control upon climate, observation-based prediction over longer periods will help advance monitoring, understanding and forecasting of climate change using a variety of prediction tools and measurements. The state of the ocean influences climate via carbon sequestration or uptake, via the energy and water cycles. Consequently it affects agriculture as well as water and energy supplies. The state of the ocean also affects the intensity of hurricanes and tropical cyclones, which cause hundreds of millions of dollars in property damage and alter the economic fortunes of businesses in the affected areas. European weather is similarly dependent on the state of the Atlantic Ocean.

World-wide trade, 90% of which goes by sea, is expected to double over the next decade, requiring improved now-casting and forecasting services in order to ensure safe navigation and cost-effective operations. As the oil and gas industry operates in ever-deeper waters it demands improved marine nowcasts and forecasts. In addition these industries require accurate and reliable forecasts of the ocean and coastal zones state during marine emergency and disasters such as the Deep Water Horizon disaster in the Gulf of Mexico in 2010. Accurate and timely forecasts of the ocean state (and trajectory of pollutant, damaged infrastructure or people) are required for planning rescue, containment, shoreline protection and cleanup operations.

Demands for information on the state of coastal waters are also growing in response to population pressure, increases in the runoff of waste products and fertilisers from land, and in response to the increased use of coastal seas for recreational activities, fishing, and aquaculture. This sets a requirement for environmental monitoring and habitat assessment in addition to weather and ocean now-casting and forecasting. Concerns such as the health of coral reefs, migration of marine species, or the destruction of mangroves must all be addressed. In coastal seas, an increasing number of well-instrumented, local-area, observation networks are being set up to meet these various demands. Satellite data provide complementary data to *in situ* measurements that are synoptic, regular and consistent for coastal zone applications. However, it is increasingly apparent that, to exploit information provided by local networks, a better understanding of transfers with the open ocean is essential because conditions far away from coasts frequently influence coastal conditions.

These are all issues of significant European economic importance and of direct relevance to GMES. **Environmental Policy and Law**

Through international negotiations, national governments have agreed to numerous conventions which, although not always explicitly stated, embody the requirements for measuring various ocean parameters globally in a concerted, systematic way. The list of relevant conventions is growing and includes:

• United Nations Convention on the Law of the Sea (UNCLOS);

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- United Nations Framework Convention on Climate Change (UNFCC);
- Biodiversity Convention; Agenda 21 (agreed at the United Nations Conference on Environment and Development in Rio in 1992);
- Global Plan of Action for the Protection of the Marine Environment from Land-Based Activities;
- London Dumping Convention;
- Agreement on Highly Migratory and Straddling Stocks.

The Conventions identify requirements and needs which can only be satisfied by the concerted action of a large number of countries. Governments need coherent information and improved understanding of the ocean to meet their obligations under these Conventions. The UNFCCC, at its fourth meeting in Buenos Aires in November 1998, called for increased sampling of the ocean, especially to fill present data gaps, as essential for monitoring climate change. In this context, significant developments have taken place in the ocean observation community under the guidance of GCOS and GOOS resulting in a suite of requirement documents to address Essential Climate Variables (ECV) [e.g., RD-41,RD-81, RD-82, RD-35, RD-103] that are now being addressed by concerted programmes within agencies around the world.

The operational and integrated global ocean, land, Cryosphere and atmospheric observing system of the future will be built initially by capitalising on the observing systems of today [RD-11, RD-12, RD-13], many of which were developed for research purposes. As research continues, there will be further improvements to the system as can be demonstrated with the EU MERSEA project [RD-21, RD-22] that piloted the development and application of an EU NOP system. Indeed, experience from this kind of project has confirmed that the full involvement of academic institutions and scientists is essential for the establishment of a GOOS, since the technology and research available at such institutions is needed to guide its development and continuously refine and improve the system as the observing system changes (e.g. as satellites fail, new ones are brought on-line and must be continually assessed for quality). Commercial communications expertise and other user community expertise are also required to refine present observing systems for optimum effectiveness in the operational NOP forecasting environment within Europe.

These developments and the GMES context demonstrate the need for a global ocean observing system. However, the long-term availability and reliability of marine earth observation information (ocean colour, sea surface topography and temperature) is not guaranteed. In order to contribute to improve its response to ever growing challenges of global safety and climate change, Europe requires an independent, sustained, and reliable Earth observation system that includes a dedicated capability to monitor the marine environment. In this context, the primary justification for Sentinel-3 is to provide continuity of ENVISAT type measurement capability in Europe to determine sea-surface topography, sea- and land-surface temperature and ocean- and land-surface colour with high accuracy and reliability and in a sustained operational manner for existing and future GMES users. The operational character of the mission implies the provision of services and products in a routine timely, long-term and continuous fashion. This means that data products and services are required with consistent quality, a very high level of availability and timely delivery according to agreed user specifications. Definitions for delivery timeliness criteria are provided in Section 1.5.

Building on the experience of ERS and ENVISAT it is appropriate to develop (both technically and in terms of GMES requirements) a dedicated operational oceanography and land-surface mission to satisfy the requirements of rapidly developing GMES Services.

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3 GMES USER REQUIREMENTS

The following sections of this MRTD review GMES User Service needs and by analysis, assures that Sentinel-3 mission requirements are developed from a GMES user perspective. It includes by design, some historical services that have laid solid foundations for those in development and operation today.

3.1 Introduction

In accordance with [AD-1], the following Services are considered core users of the Sentinel-3 mission and their requirements form the basis of this Sentinel-3 MRTD:

- GMES Services,
- GMES Service Implementation Group reports on space infrastructure,
- Data Access Requirements Review Reports,
- Preoperational predecessor mission requirements documents,
- GMES space Component Program documentation,
- Mission requirements in support of national services,
- GMES Downstream services,
- GMES Service Elements (GSE) projects, as potential precursors of future GMES Services and,
- S-3 calibration and validation users.

User requirements and their definition evolve with time; they are formulated in terms of information needs and have to be translated into measurement requirements suitable to develop and implement a satellite mission. Matching user requirements and measurement capabilities requires the establishment of an interface between system designers and data providers with the user community. As it is not feasible to satisfy all user requirements for all services, an order of priorities has to be established. The choice of initial services to establish the foundations of GMES is based on three main criteria: (1) availability/maturity; (2) reliability/usefulness, and (3) long-term sustainability. These criteria and consideration of potential new services and service evolution over time lead to priority GMES services for which the Sentinel-3 mission is tailored:

- Open Ocean and Ice monitoring;
- Numerical Ocean Prediction (NOP) and Numerical Weather Prediction (NWP) including cryospheric services;
- Coastal Zone monitoring;
- Global Land Monitoring applications (including land cover mapping, fire detection, lake and river water availability monitoring, Emergency and humanitarian services);
- Global climate change applications.



3.1.1 ESA GMES Service Providers

The ESA GMES Service Element (GSE)² focuses upon the delivery of policy-relevant services to endusers, primarily, but not exclusively, based on Earth Observation data sources. Several consolidated service portfolios at European level and Regional level, express data requirements relevant to Sentinel-3:

- At the European Level:
 - Marine and coastal environmental information services (MARISS, MarCoast)³
 - Atmospheric pollution services (GSE PROMOTE)
 - Polar environment information services (PolarView)
 - Land cover and Land use change information services (GSE-Land)
 - Information services for Humanitarian aid and crises (GSE RESPOND)
- At the Regional level:
 - Forest monitoring information services (GSE-FM)
 - Flood and Fire risk management services (Risk-EOS)
 - Food Security information services (GFMS)

In addition to these services, there are GSE services for Atmospheric Pollution, Maritime Security, and Humanitarian Aid which will also benefit from the information provided by Sentinel-3. Mappings and conclusions regarding transition of GSE project components to GMES services can be found in [RD-172].

3.1.2 EU GMES Services

The main relevant European Union efforts dedicated to the GMES Marine Service (MCS) and Land Monitoring Service (LMCS), Emergency Response Service (ERCS) and GMES Atmospheric Service (GACS) are taking place within the FP-6 and FP-7 structure managed by the European Commission. Activities financed under FP-6 include Integrated Projects, Networks of Excellence, Strategic Targeted Research Projects (STREPs) and Specific Support Actions addressing various aspects of GMES. Examples include the MERSEA [RD-21, RD-22] and GEOLAND FP-6 Integrated Projects [RD-105] addressing the development and testing of "fast track" oceanographic and land cover information services by 2008. FP-7 has successfully developed GMES Service projects for marine, land, atmosphere, emergency response and security. Further and extensive details about these EU Projects and Services may be found at http://www.gmes.info.

 $^{^{2}}$ Note that, while some GSE projects have finished, their user needs are included in this document as they were instrumental in settin priorities early on in the Sentinel-3 definition phase.

³ ESA Data User Element (DUE) marine projects of relevance include Medspiration (European SST service), GlobColour and CoastColour (Ocean and coastal zone colour products and services), GlobWave (wave forecasting pilot services). For land applications DUE projects include GlobAlbedo (Global land surface albedo from satellite), GlobCorine (Corine-compatible land cover/use service), GlobSnow (Global Snow Monitoring for Climate Research), GlobCover (Global Land Cover Service), GlobIce (Information System on Sea Ice Dynamic for Climate Research), amongst others – see http://dup.esrin.esa.it/projects.asp for a full list of DUE projects.



Table 1 indicates a matrix indicating the general classes of GMES requirements together with the corresponding Services with those requirements relevant to Sentinel-3. The following section provides detailed service requirements for Sentinel-3 based on an analysis of service project user requirements for EO data.

| Type of Service | GMES Service Provider* | | | | | |
|---------------------------------|---|--|--|--|--|--|
| Marine & Coastal Environment | EC MCS, GMES MyOcean, GSE MarCoast, PolarView, MARISS, | | | | | |
| | FP6/7 MERSEA, NHMS, MACC, GSE Coastwatch | | | | | |
| Land Cover state & changes | EC LMCS GMES GEOLAND, GEOLAND-2, SAFER, G-MOSAIC, | | | | | |
| | GSE-LAND, GSE RESPOND, | | | | | |
| Atmospheric Pollution | EC GAS, GMES MACC, GSE-PROMOTE | | | | | |
| Management | | | | | | |
| Risk Management (Fires & Flood) | GMES MACC, SAFER, GEOLAND, Risk-EOS, RESPOND, | | | | | |
| | GOFC-GOLD | | | | | |
| Forest Monitoring | GEOLAND, GSE-FM | | | | | |
| Food Security | GMES SAFER, GSE-GMFS, EC MARS Food | | | | | |
| Emergency services | GMES G-MOSAIC, GSE Risk-EOS, GSE-RESPOND | | | | | |
| Maritime Security (Transport, | EC MCS, GMES MyOcean, GSE-MarCoast, GSE-PolarView, | | | | | |
| Coastal, Ice Monitoring) | FP6/7 MERSEA | | | | | |
| Humanitarian Aid | SAFER, GSE-RESPOND, FP6 LIMES | | | | | |
| Climate & Global Change Issues | National climate centres, Includes elements of most above | | | | | |
| | services | | | | | |

Table 1: Summary of GMES services and GMES projects expressing Sentinel-3 data requirements.

At programmatic level, the GMES Programme Office and the GMES Advisory Council help ensure that activities financed by different stakeholders and programmes are managed in the most efficient manner possible and respond to programmatic and political priorities. At individual project level, workshops such as GMES Services Element Collocation meetings ensure that mechanisms are agreed for exchange of information and capabilities, such as to establish a common approach to the delivery of services to GMES user organisations identifiable via Service Level Agreements [*e.g.*, RD-173].

The following sections present key GMES services that have been developed through ESA and EU programmes. These are used to establish and justify mission requirements for Sentinel-3.

3.2 GMES Marine Service (MCS)

Within the EU FP-7, the MyOcean Project [RD-53] is implementing the NOP component of the GMES MCS as an integrated pan-European Service [RD-52]. The purpose of the MCS is to make available and deliver a set of core, generic services and information based upon common-denominator ocean state variables that are required by those responsible for environmental and civil security policy making, assessment and implementation. MyOcean includes dedicated internal services to process satellite data for specific NOP systems in the form of Thematic Assembly Centres (TAC) for satellite data products including individual TAC for ocean colour, SST, sea ice and SSH (sea-level). Continuity and consistency of space-based measurements in these domains is critical to the maturation and maintenance of a fully operational system and is fundamental to the success of the GMES MCS.

The Policy drivers for MCS have been identified [RD-52] as:



- Regional Conventions between Member States and the EC (*e.g.*, OSPAR / HELCOM /Barcelona);
- 6th Environmental Action Plan; in particular its Climate Change and Marine Environmental Strategy components;
- The Sustainable Development imperative which is written into the Rome Treaty and Maritime Policy;
- Relevant existing EU Directives, such as the Water Framework Directive in its application to coastal waters.
- Concerns over civil security which manifest themselves in particular for safety of life and property in the marine environment, and the recognition that whilst there are risks to be managed through well designed warning systems, defences and other preventive measures, major natural hazards and man made accidents will occur that also need to be managed. The Prestige oil spill accident (2003), storm surge flooding in Holland and England (1953), New Orleans (2005), and France (2010), the Deep Water Horizon oil spill in the Gulf of Mexico (2010) are useful examples.
- The growing requirement to prevent and police illegal activity, much of which centres on drug and human trafficking or piracy via the marine domain.

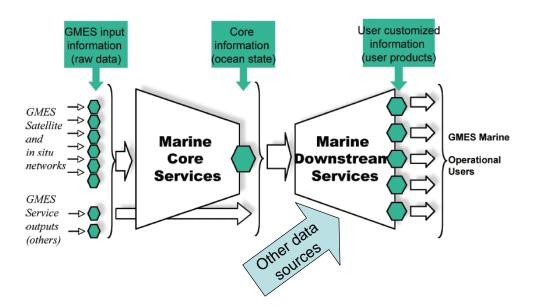


Figure 2: Role of the Marine Services in the end-to-end delivery of operational oceanography services. The Marine Services act as integrator of the data provided by all the space and on-ground instruments delivering optimal predictions on ocean state and evolution. These predictions are converted in customized products by specialized downstream service providers who also use other data sources to provide products tailored to the end user community. (Credit: RD-52)

All of these require long time-series data sets to define the mean state of the marine environment, fluctuations about that, past trends and future predictions of change (particularly in era of uncertainty about climate) to establish baselines for environmental management and design criteria for structures operating in the environment. In addition, short range predictions (out to several days ahead and with a

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few hours lead time with greater accuracy) are required for hazardous conditions and for the efficient conduct of every day marine operations.

Figure 2 shows a schematic overview of the MCS highlighting the flow of data products within the MCS service architecture. This architecture design consolidates a variety of input data and extracts knowledge through NOP, data pre-processing and analysis systems to provide core information (measurements, forecasts, hindcasts, nowcasts etc) that are used by downstream services that in turn address end user requirements.

A particularly important component of the GMES downstream service provision is the use of other data sources (e.g. socio economic data) together with MCS core information for the marine environment to address the end user requirements of GMES marine users. Typical end user applications include:

- Improved numerical weather and ocean forecasts for marine operations (including seasonal, inter-annual, and decadal forecasts) by including a better understanding of global ocean processes that govern weather patterns.
- Improved maritime safety services, marine accident and emergency response services, sea ice services, and maritime security services.
- Improved (global) coastal zone monitoring required by aquaculture managers, coastal management agencies, fisheries and ecosystem management agencies, water quality managers and tourism in response to growing population pressure.
- Improved global open-ocean and ice monitoring services to develop better assessment of ocean health.
- Better verification of numerous marine related conventions that oblige states to monitor and manage the exploitation of the marine and coastal environment through better global measurements of ocean parameters in a concerted, systematic way.
- Improved marine climate services. Operational missions are the only way to provide the long term, consistent quality data-bases required to study the regulating effect that ocean processes exert on climate and how climate is changing.

The main MCS requirements of the space-based measurement infrastructure relevant to Sentinel-3 are [RD-52]:

- Continuity of tried and tested observational methods is of crucial importance. This is particularly important around 2010 when data gaps could occur for several of the most critical observations.
- It is more important to establish satellite series for sustainable service availability than to try optimize the specifications and design for any one satellite and its instruments, if the latter leads to expensive, non renewable satellites. Establishing satellite series should lead to significantly lower production costs.
- The Jason series (high accuracy altimeter system for climate applications and as a reference for other missions) is an essential and critical component of the GMES satellite programme for MCS.
- The MCS requires a high resolution altimeter [constellation] system with at least three altimeters in addition to the Jason series [some in high inclination orbits to provide coverage of the ocean at higher latitudes than low inclination 'reference orbit' altimeters such as JASON]. Sentinel-3 should include a constellation of two satellites, flying simultaneously, providing adequate coverage and operational robustness.

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- Instrumentation costs for S3 should be reduced as much as possible to allow for a two satellite system.
- The priority for SST is for high accuracy dual view measurements (as implemented by ENVISAT AATSR). A large swath requirement has a much lower priority, in particular (but not only), if S3 is a two satellite system.
- For Ocean Colour, a sensor having a similar spectral resolution to ENVISAT MERIS is essential to meet the important shelf and coastal ocean water quality measurement requirements.
- Access to other European and non-European satellite data (e.g. ENVISAT, JPSS) in real time is fundamental for the MCS.
- GMES should allow for research and technological developments. In particular, the possibility of embarking new instruments with the potential to meet GMES needs should be considered. Wide Swath altimetry and geostationary ocean colour are the two most important new technology developments that will benefit the GMES MCS in the long run.
- The GMES ground segment should develop robust operational interfaces with relevant GMES elements.

The MCS Strategic implementation plan [RD-52] also provides a detailed specification of products to be provided from Sentinel-3 that are captured in Table 3 of this document. What follows is a review of marine applications in order to properly understand the scope of the MCS user community and their requirements.

3.2.1 Numerical Ocean Prediction (NOP) requirements

Numerical Ocean prediction⁴ uses measurements of the ocean/atmospheric state as input into mathematical models of the ocean (or a coupled ocean-atmosphere model system) to forecast the ocean 'weather'. Important products derived from NOP include:

- Nowcasts providing the most usefully accurate description of the present state of the ocean and atmosphere including living resources,
- Forecasts providing continuous forecasts of the future condition of the ocean as far ahead as possible (typically 1-14 days for the ocean),
- Hindcasts assembling long term data sets which will provide data for description of past states, and time series showing trends and changes,
- Reanalysis operations that make maximum use of all available measurement data sets to provide a consistent representation of the ocean state for a specific period (typically used for climate studies).

Examples of final products include warnings (of sea state, sea ice conditions, visibility, synoptic weather forecasts, ocean forecasts of surface current, coastal floods, ice and storm damage, harmful algal blooms and contaminants, etc.), electronic charts, optimum routes for ships, prediction of seasonal or annual primary productivity, ocean currents, ocean climate variability etc. The final products and forecasts are prepared and distributed rapidly to industrial users, government agencies, and regulatory authorities.

NOP provides an essential foundation for marine services because it integrates EO and in situ data using data assimilation frameworks [RD-9] that maximise the impact of measurements on hindcast, analysis and forecast products and services. Both satellite surface measurements in situ sub-surface ocean measurements are required. NOP models (with increasingly finer model grids from global to high-

⁴ Note that similar model and data assimilation frameworks exist for numerical weather prediction (NWP).



resolution local model domains) are initialized using measurement data from in situ and satellite systems obtained in near real time. The development of computers has allowed NOP systems to operate in real-time. Managing the vast datasets and performing the complex calculations necessary to do this on a resolution fine enough to make the results useful requires the use of some of the most powerful supercomputers in the world. Many NOP systems use an approach where successively finer scale models over smaller regions are 'nested' within each other to minimise the computing costs, complexity of system and management of very large data sets. Each model then feeds the higher-resolution level model embedded within its domain a set of boundary conditions to constrain its trajectory.

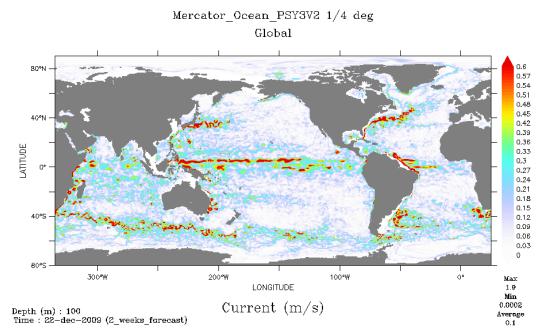


Figure 3: Global 2 week forecast of ocean currents at a depth of 100m from the Mercator Ocean NEMO NOP model system (<u>http://www.mercator-ocean.fr/html/mod_actu/public/welcome_en.php3</u>). Such forecast products rely on extensive satellite and in situ measurement data to initialise and constrain the trajectory of the model system. (Credit: Mercator Ocean)

Irregularly-spaced observations are processed by data assimilation and objective analysis methods that quality control and pre-process measurements in an analysis computed within an appropriate model horizontal and vertical grid coordinate system. The model forecast run is then initialized from the analysis and rates of change for model fields are determined for a number of time-steps to predict the state of the ocean/atmosphere for successively short times into the future. As more measurement data is made available, further data assimilation is used to constrain the evolution and trajectory of the model forecasts. Data assimilation techniques **require that accurate observational uncertainty estimates are available with all measurements**. This implies a dedicated and sustained activity across the Sentinel-3 mission to monitor the quality of output and assign meaningful uncertainty estimates to all measurements [RD-52, RD-55]. Use of model ensemble forecasts (where the ensemble is computed from multiple runs of the same model using different initialisation conditions or by combining the output from many different models from different centres – the so called multi-model ensemble) can help to define the forecast uncertainty and extend confidence in forecast products farther into the future.

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Stand-alone Sentinel-3 data products (i.e. data not assimilated by NOP systems) and NOP/model outputs (including analyses, forecasts, hindcasts and long consistent reanalyses) provide fundamental inputs to a variety of value adding downstream services for industry, government agencies, commercial users, service providers and appropriate regulatory authorities which include: indicators of marine pollution and contamination; movement of oil slicks; prediction of water quality; concentrations of nutrients; primary productivity; surface and sub-surface currents; temperature and salinity profiles; sediment transport; and erosion. In addition to producing ocean state estimates or analysed fields (e.g. flow fields), hindcasts and forecasts, the outputs from NOP are used to generate secondary value-added data products for special applications, often at regional or local level. This information will also provide design criteria for structures and operations in the marine environment that are fit for purpose. In addition short range predictions (out to several days ahead in general and with a few hours lead time with greater accuracy) are required for the efficient conduct of every day maritime operations (e.g., offshore industries, shipping, maritime safety services, marine accident and emergency response, water quality services etc.).

The primary ocean measurement requirements for the GMES MCS NOP [RD-53, RD-173] service (comprised of global and regional ocean modelling centres, SST, ocean colour, sea level and sea ice thematic assembly centres (TAC)) are:

- Sea surface topography (dynamic topography and derived currents) at mesoscale resolution;
- Surface wind speed and direction;
- Sea surface temperature;
- Biological parameters (e.g. Total Suspended Sediment, maps of Harmful Algal Blooms, Chlorophyll-a, Water Leaving Radiance and inherent optical properties) required for ecosystem modelling and forecasts (e.g. Harmful Algal Bloom evolution, water quality assessment) with high resolution in the coastal zones;
- Vertical profiles of temperature and salinity (NOP);
- Sea state (ocean wave spectral distribution, Significant wave height);
- River runoff;
- Pollutants (e.g., oil spills);
- Sea surface salinity;
- Sea ice conditions especially at the sea ice edge (sea ice concentration, thickness, dynamics, type, and edge).

There is a strong requirement for near real-time operational and timely transmission of measurement data to NOP data assimilation centres within the GMES MCS MyOcean project [RD-53]. The need for operationally robust and timely measurement data sets underpins the quality of NOP systems and Sentinel-3 must provide measurement data to these systems using operationally robust systems and in NRT. Measurements must be of a high accuracy and resolution, have global coverage including high space and time sampling in the coastal and shelf seas (order ~100 -300 m). It is critical that uncertainty estimates are provided with all measurements for use by data assimilation systems. Timeliness requirements call for observations to be available to the data assimilation system within 3 hours of measurement at the satellite platform because many operational systems operate NOP models at agreed synoptic times of 00:00, 06:00, 12:00 and 18:00 UTC with intermediate model runs between these times. Note that time must be allocated within the end-to-end (3 hour) delivery service chain to download, prepare and process raw measurement data, disseminate the data to NOP centres, allow NOP centres to perform quality control and pre-processing of measurement data before the data can be used successfully within the NOP system. Finally, it must be recognised that data arriving late at NOP

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centres may never be used in a forecast system (although these measurements will be used in delayed mode hind-casts, climatologies and for climate work).

3.2.2 Marine surface wind and sea state (significant wave height)

Marine surface wind and sea state (significant wave height, Hs) products are arguably the most useful and critical products required by the maritime community; Sea state and wind information are the two most important parameters for all maritime safety and rescue operations.

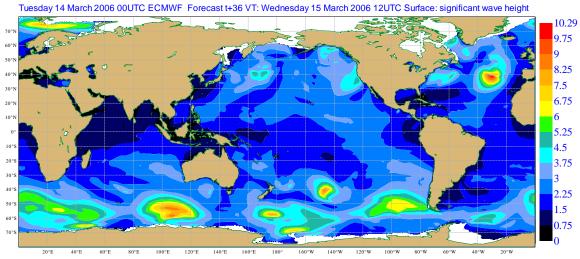


Figure 4: Hs forecast from the ECMWF global wave model for the 14th March 2006. (Credit: ECMWF)

The main users of wind and wave data include:

- Shipping industry (coastal and ocean),
- Coastguards and Safety Of Life At Sea (SOLAS convention) operators,
- Offshore industry operations (e.g. oil, gas, wind and wave power etc),
- Marine engineering development and operations (e.g. structure design, cable laying, dredging, ship design etc.),
- Agencies tasked with marine and atmospheric pollution operations (prediction, cleanup and monitoring) such as EMSA,
- Coastal defence and management agencies,
- Security applications,
- Pleasure boating community,
- National Governments and local authorities,

In the GMES context, wind and wave information products and services are mature and well developed activities that are largely self-funded via the National Meteorological Services (NMS's), ECMWF and commercial operators (e.g. Figure 4). Users often require highly customized forecast services at both global and regional scales. Wind and wave information has an extremely high economic value (compared to other ocean parameters) and is therefore disseminated largely by private weather industry or commercial divisions of NMS's. Such a GMES downstream value-adding industry can effectively tailor and add value to 'standard' products and services tuned to specific applications. For example, the shipping industry and offshore logistics industry use strategic voyage planning and tactical guidance, both of which require vessel-specific wave response predictions, dedicated grid systems and

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communications systems. Consequently, the needs of the wind and wave users are often better met by the GMES intermediate and end users that utilise core wind and wave forecast and satellite data products adding value through dedicated service provision.

| User | Wind/Wave data requirements and application | | | | | | |
|---|---|--|--|--|--|--|--|
| Danish Meteorological Institute (Denmark) | Jason-1, 2 and Envisat wave observations for operational validation of wave models (see <u>http://ocean.dmi.dk/validations/waves/satellite/2009_01-06/index.php</u>). | | | | | | |
| | NRT merged and gridded SSH anomalies and Hs data from AVISO. Along track GDR observations of Jason 1 and 2 and Envisat from Aviso for the North Sea/Baltic Sea region. | | | | | | |
| | Regional sea level trends and the differences between tide gauges based on Jason-1 and 2 and Envisat data. Scatterometer winds and altimeter data for assimilation by NWP and ocean modelling systems. | | | | | | |
| Deutscher Wetterdienst (Germany) French Navy | Altimeter NRT-data from ERS2, Envisat, Jason1 and 2 for verification and validation of wave model output. Implicitly these data and all Scatterometer data are used in the complete DWD atmospheric assimilation system. All altimeters (multi-mission product developed by IFREMER and carried | | | | | | |
| (SHOM) | forward by ESA GLOBWAVE for Hs and U10. | | | | | | |
| | JASON 1 data for σ° in C-band and Ku-band (for mean square slope validations) Level 2 SAR data for SAR wave spectra. | | | | | | |
| | Scatterometer winds and altimeter data for assimilation by NWP and ocean modelling systems. | | | | | | |
| Met Office (UK) | Envisat RA2 wave height and wind speed (RA2_WWV_2P product) and the ASAR wave mode 2D spectral (level 2 fast delivery) data (ASA_WVW_2P) for validation of the wave models for model development. | | | | | | |
| | The system also performs a validation of the ASAR 2D spectra with other observations (RA2 wave height and buoy wave spectra) together with the wave model (reported in [RD-84 and RD-85]. | | | | | | |
| | ENVISAT RA2 Hs are used for key operational validation work, including wave model development, new model implementation and new model wind forcing assessments and are essential to the development and validation operational system. ENVISAT ASAR 2D spectra are the only available 2D ocean wave spectra of global coverage and are essential to the operational system. | | | | | | |
| | Scatterometer winds and altimeter data for assimilation by NWP and ocean modelling systems. | | | | | | |
| European Centre for Medium Range forecasting | Radar Altimeter Hs from ENVISAT, Jason-1, and Jason-2 both for operational assimilation in the model as well as for model verification and for R&D. | | | | | | |
| (ECMWF) | ENVISAT ASAR Wave Model Level 1b spectra both for operational assimilation in the model and for model verification and for R&D. | | | | | | |

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| | Scatterometer wind vectors (inverted from backscatter) from ERS-2, QUIKSCAT and ASCAT both for assimilation, model verification and R&D. |
|------------------------------------|---|
| | The radiances from Microwave Radiometers of AMSR-E onboard AQUA, and SSM/I onboard DMSP F-13 and DMSP F-15 are operationally assimilated. This implies updates to the model surface wind speed, as a proxy to the sea surface roughness (indirect assimilation of surface winds). Those products are also used for R&D. |
| | Radar Altimeter Hs from ERS-2 for model verification. |
| | Radar Altimeter surface wind speed from: ENVISAT, ERS-2, Jason-1 and Jason-2 for model verification and R&D. |
| | ENVISAT ASAR Wave Model Level 2 ocean spectra for model verification. |
| | For R&D activities all of the above data products in addition to few others like Radar Altimeter (ENVISAT, Jason-1 and Jason-2) backscatter (σ°). |
| European Maritime Safety Agency | Wave and wind data from model systems used in oil spill response decision making processes. |
| (EMSA) | Wave and wind products from model systems used for oil spill trajectory modelling and oil weathering. |
| | EO data as verification and NRT validation of model outputs. |
| JCOMM: Joint | In support of Met-Ocean Information and Maritime Safety Services, in particular, |
| Commission for | JCOMM operates an Operational Wave Forecast Verification Project [RD-86]. |
| Oceanography and | The project now includes 12 centres. The project is expanding to include the use |
| Marine Meteorology (WMO/IOC) | of satellite altimeter data as part of the ESA GlobWave project. Outputs are available at http://www.jcomm-services.org/Buoy-Verification-Results- |
| | examples.html |

Wave and sea-state forecasts are not an initial value problem and, unlike NWP and ocean forecasting systems, do not generally rely on direct data assimilation techniques to improve products. Assimilation of EO data (for improved wind and wave products) is performed in the NWP and ocean forecast systems that are used as part of wave forecasting systems. Few global wave models have the facility to assimilate radar altimeter wave height data. Instead, they rely on accurate and high temporal resolution wind fields derived from NWP systems (which assimilate ocean vector winds derived from EO measurements together with ice concentration in the marginal ice zone and SST inputs from EO) and/or ocean forecasting systems used for the stability correction for wave growth and, surface currents ocean forecasting systems for wave-current interactions. The effects of time-varying currents on waves can result in differences in wave height of as much as 20 to 40 cm. Sea state forecast systems thus integrate data from NWP, NOP systems (e.g. MyOcean) and ice analysis systems that are all components of GMES.

Wave model products are mature for the open ocean and well understood, providing statistical outputs of wave spectrum (distribution of wave energy by direction and wavelength (period)) at all model grid points, Hs, peak wave period, wind sea wave height, wind sea period, primary and secondary swell wave height, primary and secondary swell period, wind speed and direction as analysis and forecast products. Shallow water (coastal and shelf seas) products are less mature and require dedicated physics which is

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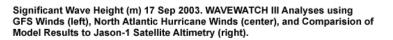


steadily evolving. Coastal region and surf zone modelling is less well developed despite key users including defence, safety of life (beaches) and coastal zone protection and management. In the case of sea state prediction in severe event scenarios, the ability to use wind forcing developed with expert nowcast interactive systems that augment standard NWP outputs (e.g. by utilising altimeter, scatterometer and SAR satellite observations) is extremely important.

Limited in situ data available for validation and monitoring of wind, sea state and wave products. Though the spatio-temporal coverage of altimeter wind measurements makes them of limited value in numerical weather forecasting models, accurate measurements are extremely useful as independent validation of the accuracy of marine forecasts. Such products become of greater interest and practical value with multi-satellite measurements including scatterometers, combined with in-situ measurements. This provides improved time-space sampling for resolving temporal and spatial variability. Altimeter, SAR and scatterometer data sets provide essential data for this purpose and to guide wave model development. Wave model output spectra and product maps are operationally validated against retrieved observations of satellite spectral wave data from SAR and from Hs derived from altimeter data sets. In this case, satellite data from altimeters provide a unique source of global sampled data for operational validation. Altimeter estimates of Hs are used routinely at many operational centres and by many uses for wave verification activities. Figure 5 provides an example of altimeter data used to validate wave model forecasts of Hurricane Isabel in 2003.

In summary EO data are used operationally in wave forecasting operations to:

- Calibrate forecast models using the measurements,
- Verify and validate systems and operational outputs in NRT,
- Together with model data, provide forecasters with data to prepare text based forecasts for use in operational GMDSS systems,
- Provide guidance for operational model development and upgrades.



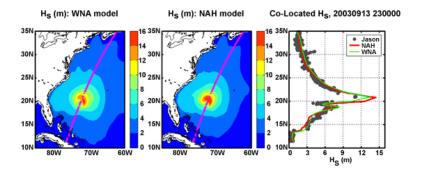


Figure 5: Significant wave height from Wavewatch III wave model (NAH and WNA) on 17th September 2003 and validation using JASON-1 altimeter estimates of Hs. Hurricane winds have been used together with NWP in a dedicated forcing run of the model in the centre panel giving a better validation against satellite altimetry. (Credit: NOAA/NASA/NCEP/MMAB)

The altimeter proposed for Sentinel-3 will contribute to improved wind- and wave sampling. Sentinel-3 ocean altimeter products will provide continuity of ENVISAT altimeter data which is an essential input

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to operational wave forecasting directly (for validation and verification) and indirectly (through ocean modelling). Operational delivery of EO products is required with timeliness (3 hours) specified by the synoptic forecasting times (00, 06, 12 and 18Z). Table 2 summarises applications and user requirements for EO wind and wave data in Europe. Future wind and wave systems will require more EO data as they develop better capability in the coastal and surf zone regions. They will also provide higher spatial, temporal and spectral information, address wave-current interactions in a more complete manner, and consider wave surge interactions in coastal regions. Fully coupled systems where NWP, Ocean forecast systems and wave models are being developed to provide a more optimised framework for higher resolution products which are dominated by mesoscale variability. Sentinel-3 (together with Sentinel-1) will therefore remain at the forefront of sea state provision for GMES services.

3.2.3 Coastal altimetry requirements

In many cases satellite measurements provide the only feasible way to retrieve regular and consistent information for coastal regions; satellite altimetry in the coastal region has enormous strategic importance (e.g., coastal currents, sea state, storm surges, surface wind speed, tidal elevation). Measurements of sea level, sea state and surface wind derived from satellite altimeters are invaluable for monitoring coastal circulation, sea level change and their impacts in the coastal zone. In addition, they provide an essential link between the land-based geodetic measurements and the oceanic mean sea surface height [RD-190].

An uninterrupted flow of altimeter data has accumulated since 1992 but large quantities of potentially useful data, e.g. around coasts and inland waters are not exploited [RD-186, RD-187]. This is part because conventional satellite altimetry has been developed for global open ocean applications and is not optimized for coastal ocean applications. In addition, access to high-resolution altimeter waveform echo data remains a challenge limiting the potential to develop coastal altimetry applications and services [RD-189]. Open access to the correct level of altimeter data for coastal zone applications is a key requirement for the operational provision of coastal altimeter products developed within GMES services. Several projects have developed the discipline of coastal altimetry and are worth noting in the context of Sentinel-3 mission requirements.

3.2.3.1 ESA COASTALT Project

COASTALT is an ESA funded project [RD-191] for Development of Radar Altimetry Data Processing in the Coastal Zone. The main objective is to transition pulse-limited coastal altimetry towards a mature, pre-operational status by defining and testing new coastal radar altimeter products [RD-186]. The project lays a foundation for routine generation and distribution of coastal altimeter products from the ENVISAT RA-2, ERS-1, ERS-2 and Sentinel-3 altimeters. COASTALT has developed and validated a coastal altimeter processor that provides the capability to produce long-term coastal altimeter products from Low Resolution Mode (LRM) conventional pulse-limited altimeter systems. The processor includes full waveform re-tracking and wet tropospheric corrections using altimeter, microwave radiometer and NWP input data. The processor requires access to high-resolution altimeter data records (at least the 18 Hz data from ENVISAT). The COASTALT processor is producing global coastal altimeter products from 2002 at a resolution of ~350 m along track. COASTALT has defined a product specification for coastal altimeter products (the Coastal Geophysical Data Record, CGDR) based on the netCDF product format conforming to the climate Forecast conventions [RD-194]. This format is of relevance to Sentinel-3 as it is based on a consensus of coastal altimeter specialists.

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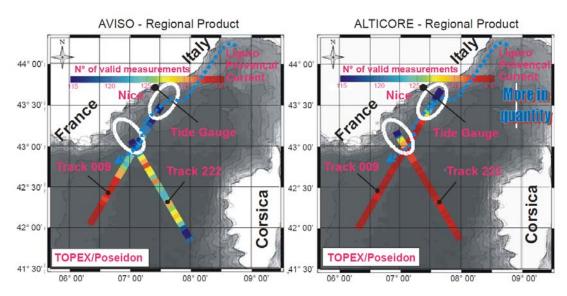


Figure 6: Comparison between the number of valid data obtained along two selected TOPEX/Poseidon tracks in the test area when using official regional AVISO (left panel) and improved coastal altimeter data set from the Alticore project (right panel). Only cases with more than 75 % of cycles are plotted. (Credit Alticore project)

3.2.3.2 ALTImetry for COastal REgions (Alticore)

ALTICORE [RD-190] was a research programme funded for a period of two years (2007-2008) by the International Association for the promotion of co-operation with scientists from the New Independent States of the former Soviet Union (INTAS), an independent association supported by the European Community and the European Union members. ALTICORE improved the quality and availability (e.g. see Figure 6) of LRM altimeter data along the coasts of some European Seas including the Mediterranean, Black, Caspian, White and Barents Seas. ALTICORE also developed more effective methods of reliable data exchange, through the development of Web services- and Grid-compliant data management infrastructure, that ensure long-term continuity and interoperability of coastal altimetry data, in response to rapidly growing usage of coastal altimetry for sea level and sea state monitoring.

Key coastal altimetry requirements for Sentinel-3 operating in the coastal zone include:

- High resolution along track (~250 m) capability in the coastal zone (e.g. using delay-Doppler SAR techniques and/or coastal zone re-tracking of low resolution mode altimeter data).
- Access to high-resolution echo waveform data from the Sentinel-3 altimeter in order to process waveform data in the coastal zone with regional characteristics, develop uncertainty estimates and, new local/regional corrections.
- Access to passive microwave radiometer and/or appropriate NWP data for wet tropospheric delay corrections in the coastal zone.
- Consideration of the COASTALT coastal Geophysical Data Record (CGDR) product specifications as a convention for coastal altimeter products
- Pull through of COASTALT type altimeter processor capability for LRM data processing in the coastal zone if/where SAR mode data are unavailable.

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3.2.4 National Coastguard services

Coast Guards are typically responsible for maritime search and rescue operations intercepting illegal incursions into sovereign waters, fisheries protection and search and rescue. In some cases, they may also be responsible for detecting illegal pollution activities and for monitoring water quality. Information requirements include NRT wind and wave forecasts, surface current forecasts for drift modelling, SST and HAB/Water Quality forecasts. In addition, sea ice forecasts are required for countries bordering polar seas while the detection of vessels or pollution incidents through the systematic surveillance of the Exclusive Economic Zone (EEZ) must be conducted, usually by airborne surveys. Sea ice maps (sea ice edge, concentration, thickness, drift and icebergs) are of importance to ships operating in the polar environment.

For maritime search and rescue services NOP/NWP forecasting systems provide forecast maps and charts which themselves require satellite and in situ observations of sea ice parameters (edge, concentration, thickness, drift and icebergs), SST (to estimate immersion survival times), SSH, water quality (ocean colour), Hs, surface wind direction and speed together with uncertainty estimates for use in data assimilation schemes. High along track resolution products from coastal altimetry will be of particular benefit. Products should be available in less than 3 hours of the measurement time and in a format suitable for ocean forecasting centres (e.g. netCDF, BUFR, L2P). For NOP, NWP and drift model systems (used to develop search and rescue strategies) using data assimilation data must be available in less than 3 hours of the measurement time and in a format suitable for NWP centres (currently BUFR, netCDF, L2P). For maritime search and rescue operations observations need to be made available in an emergency mode where they are available as soon as possible but at least within 3 hours of observation.

3.2.5 Shipping operators and marine safety services

Maritime transport is of fundamental importance to Europe and to the rest of the world. The main objective of European Maritime Safety Agency (EMSA) [RD-183] is to provide technical and scientific assistance to the European Commission and Member States in the proper development and implementation of EU legislation on maritime safety, prevention of pollution by ships and security on board ships. As reported by EMSA, over 90% of European Union external trade travels by sea and more than 3.7 billion tonnes of freight a year are loaded and unloaded in EU ports making shipping the most important mode of transport in terms of volume in the whole continent. Maritime transport will continue to be the most important transport mode in developing EU trade for the foreseeable future [RD-183].

Oil tanker traffic is rapidly growing as more and more oil is progressively being brought to the global market place through EU waters. The consequence of this significant growth in tanker traffic, added to the existing level of hazardous goods traffic in general, is a corresponding growth of the environmental risk that the European Union is facing in most of its main sea areas. Specifically, these are the Mediterranean area and the Black Sea, the Baltic Sea, the North Sea, the Northern channels between Sweden, Denmark, Germany, the Netherlands, Belgium, France and the UK and the Atlantic sea area [RD-183]. Recent and significant sea ice retreat in the Arctic Ocean suggests that the North West passage could be come a viable trade route in the near future.

EMSA has developed the CleanSeasNet service [RD-198], a satellite based monitoring system for marine oil spill detection and surveillance in European waters. This operational service, which started in April 2007 and is the first sustainable GMES operational service, provides a range of detailed information including oil spill alerts to Member States, rapid delivery of available satellite images, oil slick positions as well as information on possible polluter vessels. As part of the requirements for CleanSeasNet, a variety of satellite data products for SAR based oil-spill detection are required. The reliability of satellite

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SAR image interpretation for oil spill detection is increased by cross-referencing with meteorological and oceanographic information derived from additional EO data including SST, Chl-a concentration, wind speed and direction, sea surface current speed and direction. Weekly maps of consolidated SST and Chl-a (Level 3 and 4), together with Level 2 type data (daily maps) in near real time are required by CleanSeasNet. In addition, surface wind speed and sea ice parameters (concentration, edge and thickness) are required.

Shipping operators require wind and wave forecasts to avoid regions where conditions are liable to slow progress or endanger the ship or the crew, particularly in coastal waters. Such information is vital especially during severe weather events where any information on sea state and wind speed is useful (e.g. during the MCS Napoli disaster off the UK coast in 2007 where the ship suffered catastrophic failure in the English Channel due to heavy seas). In addition, oceanic and meteorological data are used to identify the course to steer to ensure a ship can obtain maximum profit from prevailing conditions. For this purpose, and as the basis for many commercial ship-routing services, extensive use of ocean, atmosphere and wave forecast systems is made. These systems provide forecast maps and charts and themselves require satellite and in situ observations of SST, SSH, water quality, surface wind direction and speed together with uncertainty estimates for use in data assimilation schemes. As an example, SST data are extremely useful to plan and manage voyages of perishable goods that are affected by warm temperatures aboard commercial vessels, ocean colour derived maps of marine surface marine biomass is useful to prevent water filters from clogging. Both types of information provide advice on the selection of appropriate anchorages and passage routes. For shipping operators moving or towing large structures, additional information on wave period and propagation direction is also required.

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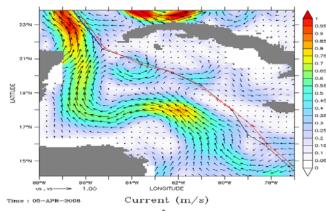


Figure 7: Example of a ship route recommendation to BROSTROM in the Gulf of Mexico for the route Houston to Pozos taking advantage of NOP outputs to optimize potential ship routes (shown by blue and red lines) and take advantage of surface circulation features (Credit: F. Davidson, GODAE final symposium)

Sea ice maps (sea ice edge, concentration, thickness, ice drift and icebergs) are of importance to ships operating in the polar environment. Icebergs are a constant navigational hazard in the Arctic region. For example, the cold Labrador Current carries some icebergs south to the vicinity of the Grand Banks and into the great circle shipping lanes between Europe and the major ports of the United States and Canada. Vessels navigating this area try to make their voyage as short and as economical as possible and ships will pass just to the south of the "limit of all known ice" boundary. In this area, the Labrador Current meets the warm Gulf Stream where the temperature differences between the two water masses are ~20°C, frequently producing dense fog. The combination of icebergs, fog, severe storms, fishing vessels and busy trans-Atlantic shipping lanes makes this area one of the most hazardous for mariners. The sinking of the R.M.S. TITANIC in 1912 highlighted the dangers of navigating this region after it struck an iceberg and over 1500 people were killed. As a consequence of this disaster, the International

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Ice Patrol [RD-174] was initiated that today, serves the large volume of European ships transiting the iceberg infested area of the North Atlantic from EU Maritime States.

Sentinel-3 should provide a variety of core products (e.g., SST, sea state, wind, sea ice, surface current) products in support of shipping operators and maritime safety services.

3.2.6 Offshore oil and gas operators

The evolution of the offshore oil and gas industry is dominated by an increasing reliance on new deep water fields (e.g. Gulf of Mexico, Congo, Angola). Timely and accurate NOP and environmental parameter forecasts and nowcasts constitute a vital contribution to the cost effective extraction of oil and gas in these regions. Regions experiencing stress forces generated by intense internal waves require forecasts of expected internal wave regimes; several major oil companies have ceased development activity in the Andaman Sea area due to the difficulties associated with handling the harsh internal wave conditions.

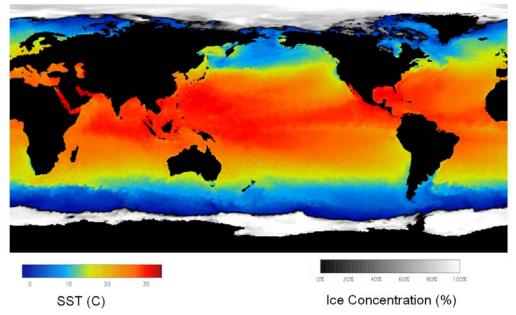


Figure 8: SST outputs from the Operational SST and Sea Ice (OSTIA) system providing operational daily blended SST maps and sea ice concentration based on satellite [RD-42] and in situ SST measurements. The OSTIA system uses ENVISAT AATSR data as a reference data source due to its stability and accuracy. (Credit: MetOffice, UK).

Operations management teams require NOP products and supporting information to support decisions on scheduling, production levels etc. Surface current information and sea state are critical parameters required for service vessel logistics. Requirements include wind and wave forecasts (and nowcasts), information on the distribution and structure of surface currents and the variation of current with depth, water transparency and temperature for diving operations, SST maps for flight planning operations and marine emergency operations. Helicopter operators require SST maps to prepare flight plans (flights can overfly only regions where the SST is sufficiently high to ensure crew survival in the event of a forced landing, Survival suits are required when flying over requires where SST < 10° C). Arctic operations (and activities in the Northern Caspian Sea) require very timely forecasts and

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nowcasts of icebergs, sea ice edge, sea ice concentration, ice thickness, and sea ice drift for maritime safety and ship route planning.

In response to changes in the operating and production licences, offshore operators are increasingly required to implement environmental impact monitoring and protection systems. Environmental management system operators require surface topography, ocean colour and SST data (as well as other data) to identify, model and monitor accidental discharges (e.g. the recent Deep Water Horizon disaster in the Gulf of Mexico, 2010). Operations include the real time detection of oil discharges and the systematic monitoring of water quality and SST in the surrounding environment to ensure timely detection of any operational impacts. Offshore exploration requires measurements of natural oil seeps that result in surface oil slicks that can be used to plan new operations. Surface oil slick mapping is also required to monitor environmental impact of drilling operations.

Offline environmental information is also necessary when planning operations or developing infrastructure. Wind/wave/current/SST/marine biological activity and visibility measurements together with associated climatologies are essential for this purpose. Long-term climatology versions of these products are required to establish baseline environmental status and assess potential environmental impacts used in audits prior to actually initiating operations.

3.2.7 Offshore and coastal engineering operators

Marine engineering operations such as platform movement and platform installation require wind, wave and ocean current forecasts (full column) for the short term planning of operations. Climatological data are also required for use in the optimised design of coastal and offshore structures (together with detailed observations of extreme events that dictate return period statistics) and the planning of

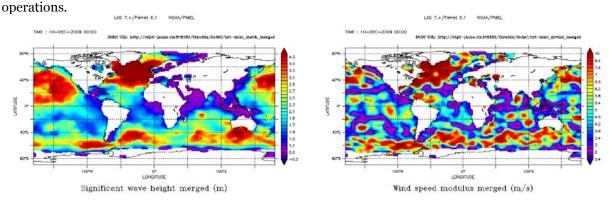


Figure 9: Left: Significant wave heights derived from multiple altimeter data sets December 11, 2009 - April, 18 2006 (right) altimeter derived wind speed modulus (wind expressed as a function of significant wave height and radar backscatter). Data derived from live access server at http://www.aviso.oceanobs.com. (Credit: NOAA/PMEL)

Towing, lifting and installation operations are particularly vulnerable to long wavelength swell conditions (both period and propagation direction are important). Dredging operators require information on local water quality as well as wind, wave and current forecasts to ensure the safety of operations and to detect any accidental discharge arising from operations (e.g. for certain classes of mud, dredging operators must ensure no dispersion of the material into the surrounding environment). Regular maintenance operations also require access to timely forecast information to secure the safety of maintenance teams and infrastructure working in the field. Operations in the polar environments (and activities in the Baltic and Northern Caspian Sea) require timely forecasts and nowcasts of

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icebergs, sea ice edge, sea ice concentration, thickness and sea ice drift for maritime safety and operational planning.

3.2.8 Marine survey operations

Seismic survey and acoustic seabed mapping operators require wind/wave/current/SST/water quality measurements and climatologies to support the planning and execution of operations. Many companies require timely and accurate NOP/NWP forecasts to ensure safe operation of equipment and safety of operating teams especially in shallow/coastal waters. In addition, the increasing use of autonomous underwater vehicles (which use acoustic communication and ranging systems) requires more accurate knowledge of ocean conditions including sediment and organic matter concentrations, temperature and salinity structures, the local internal wave environment and ambient noise due to wind/wave and current conditions. Extensive use of ocean atmosphere and wave forecast systems that provide forecast maps and charts require satellite and in situ observations of SST, SSH, water quality, surface wind direction and speed together with uncertainty estimates for use in local NOP data assimilation schemes. Coastal altimeter products will be particularly useful for these applications. Arctic operations require small scale knowledge of a range of sea ice conditions including iceberg location, "grease" ice formation and SST and ice surface temperature to ensure that the icing of equipment, such as hydrophone arrays, does not reach a level that would endanger the mother ship.

3.2.9 Naval operations support

The support of naval operations includes a wide range of operational responsibilities and extensive use of NOP/NWP and wave forecast systems providing a variety of products is standard practice.

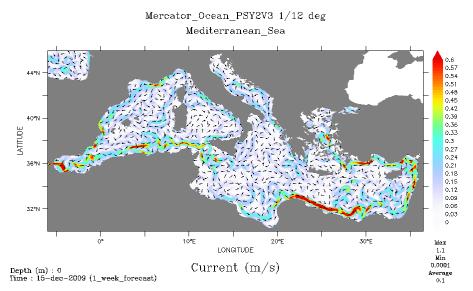


Figure 10: Forecast ocean surface currents in the Mediterranean Sea from the MERCATOR ocean model at 1/12 degree resolution for 15th December 2009. The NOM assimilates satellite altimeter and SST data together with in situ measurements within the ocean water column. (Credit: Mercator Ocean)

These systems require satellite and in situ observations of sea ice parameters (edge, concentration, thickness, drift and icebergs), SST, SSH, water quality, surface wind direction and speed together with uncertainty estimates of each measurement for use in data assimilation schemes. Surface roughness signatures of transiting vessels from SAR are also required. Routine environmental parameters provided to fleets include wind and wave forecasts as well as ocean forecasts (SST structures form a key input to

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operational planning, current structure (both large scale and mesoscale), internal wave regimes, and water clarity and salinity structure). Of particular interest is a description of the dynamic behaviour of the subsurface ocean sound channel and vertical structure of the mixed layer.

Information is required to support day to day operational decisions by ship commanders and by the managers responsible for the operation of specific systems (e.g. radar, sonar, mine countermeasures). SST and local diurnal stratification are particularly important as they have an impact on RADAR system ducting that modifies the propagation of ship RADAR signals. Sea ice conditions are also important in polar region operations both for safety and to predict the operational performance of surveillance systems. In addition, atmospheric parameters such as visibility and total column amounts of atmospheric water vapour are important in predicting the behaviour of particular surveillance and targeting systems. Water quality and both surface and sub-surface temperature are required for diving operations, flight operations and marine search and rescue. To support littoral operations, additional information such as oil-slick distribution, water depth/sea surface height, wind speed, sea state, bioluminescence and sediment loading, are required to support decisions on whether to initiate and plan a particular operation. Coastal altimeter products will be particularly useful for these applications. Operations in the polar environments require timely forecasts and nowcasts of icebergs, sea ice edge, sea ice concentration and sea ice drift for operational planning. For NOP assimilation applications the data must be available in less than 3 hours of the measurement time and in a format suitable for ocean forecasting centres (e.g. netCDF and BUFR).

3.2.10 Port authorities

Port management is usually responsible for the provision of MetOcean information including dedicated measurement stations for the immediate surroundings that is often integrated with national or regional NOP/NWP forecasts of environmental conditions. Depending on location, port authorities will be responsible for the provision of information on winds, waves and currents, sea-ice conditions, water quality, SST and water depths (for approach channels). Coastal altimeter products at high resolution will be particularly useful for these applications. In addition, the port authorities themselves must regularly assess sediment transport in relation to the silting up of access channels and water quality for environmental impact assessment. Very high resolution models for marine ports are now beginning to emerge that are typically nested within local area coastal models (themselves often nested in regional/global ocean forecasting systems). Satellite data are required to constrain the nested NOP systems and for use in data assimilation systems that require uncertainty estimates with each measurement. High resolution satellite SAR data can themselves provide useful information that can be used for vessel management systems and for monitoring marine pollution and water quality in port areas.

3.2.11 Coastal/environmental management agencies

The responsibilities of these agencies are complementary to those of the coast guard and cover the monitoring of coastal water quality, harmful algal bloom (HAB) detection, oil spill detection and notification, SST monitoring (e.g. for coral ecosystem protection) and civil protection applications such as coastal wind, wave and current monitoring and storm-surge forecasting and warning. Coastal management activities are regulated by International and European laws implemented through National Legislation. Relevant international and national laws, conventions, and directives directly relevant to the GMES are (see ESA MarCoast project [RD-134] for more details):

• **OPRC (International Convention on Oil Pollution Preparedness and Response):** Adopted in November 1990, it is designed to help Governments combat major oil pollution incidents by facilitating international co-operation and mutual assistance in preparing for and

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responding to a major oil pollution incident and to encourage States to develop and maintain an adequate capability to deal with oil pollution emergencies. The Convention became an international law in May 1995.

- Convention on the Protection of the Marine Environment of the Baltic Sea Area (The Helsinki Convention): It was adopted in 1992, and entered into force on 17 January 2000. Its governing body is the Baltic Marine Environment Protection Commission, also known as HELCOM. The Helsinki Convention covers the whole Baltic Sea area, including inland waters as well as the water of the sea itself and the sea-bed. Measures are also taken in the whole catchments area of the Baltic Sea to reduce land-based pollution.
- OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic): It is the current instrument for international cooperation on the protection of the marine environment of the North-East Atlantic. It represents a combination of the 1972 Oslo Convention on dumping waste at sea and the 1974 Paris Convention on land-based sources of marine pollution. It is organised in the following strategies: Protection and Conservation of Marine Biodiversity and Ecosystems, Eutrophication, Hazardous Substances, Offshore Oil and Gas Industry, Radioactive Substances, Monitoring and Assessment
- **Kyoto Protocol (UNFCCC)**: The Kyoto Protocol is an agreement made under the United Nations Framework Convention on Climate Change (UNFCCC). Countries that ratify this protocol commit to reduce their emissions of carbon dioxide and five other greenhouse gases, or engage in emissions trading if they maintain or increase emissions of these gases.
- **Programme VI of the Community Action on the Environment (Climatic Change, Biodiversity, Health, Natural Resources)**: This establishes the Community framework for environment policy for the period from July 2002 to July 2012. It represents the environmental dimension of the EU's Sustainable Development Strategy and sets out environmental priorities with a particular focus on four priority areas: climate change, nature and biodiversity, health and the quality of life, and natural resources and waste.
- Environmental Impact Assessment Directive (EIA Directive): The EIA Directive on Environmental Impact Assessment of the effects of projects on the environment was introduced in 1985 and was amended in 1997. It affects EU Member States. The EIA procedure ensures that environmental consequences of projects are identified and assessed before authorisation is given. The public can give its opinion and all results are taken into account in the authorisation procedure of the project. The public is informed of the decision afterwards.
- **Strategic Environmental Assessment Directive (SEA Directive)**: this aims to improve and complement the EIA by providing a system to incorporate environmental considerations into policies, plans and programmes. It aims at introducing systematic assessment of the environmental effects of strategic land use related plans and programs. It typically applies to regional and local development, waste and transport plans, within the European Union.
- Water Framework Directive (WFD): The Water Framework Directive (WFD) is a European Union directive which commits member states to making all water bodies (surface, estuarine and groundwater) of good qualitative and quantitative status by 2015. It describes the steps to reach the common goal rather than adopting the more traditional limit value approach.
- **Coastal Zone Policy: Integrated Coastal Zone Management (ICZM)**: Integrated Coastal Zone Management is a joint programme by EU institutions from the following sectors: Agriculture and Fisheries, Environment, and Regional and Structural Policy, each in a separate guide. From 1996 to 1999, the European Commission operated a Demonstration Programme on ICZM designed around a series of 35 demonstration projects and 6 thematic studies. Based on the experiences and outputs of the Demonstration Programme, the Commission adopted two documents: a communication and a recommendation.

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• **Natura 2000 Network, Habitat and Bird Directives**: With the purpose to combat the serious decline in biodiversity and following closely on the 1992 Rio conference, the European Union adopted the Birds directive of 1972 and the Habitat directive of 1992 on the conservation of habitats and species. The Natura 2000 network has been established as a result. Its objective is to promote the conservation of natural habitats and the habitats of wild fauna and flora while taking into account the economic, social and cultural requirements and specific regional and local characteristics of each EU Member State.



Figure 11: Envisat MERIS FR (300 m) image of western France, including the regions of Brittany, Western Loire, Normandy and Loire Valley, located in Western Europe acquired by on 11 February 2008. Rich fine structure is clearly visible in the coastal zone. (Credit: ESA)

Information requirements are for systematic surveillance of the exclusive economic zone to detect oil spills and algal blooms, the regular and comprehensive sampling of water quality and the measurement of SST, the compilation of coastal MetOcean conditions and the forecasting of storm surges in coastal waters. The main application is to verify that conditions do not exceed pre-defined threshold levels (e.g. concentrations of certain chemicals are below legal levels). Additional responsibilities may include the monitoring of sediment transport levels and patterns and shore-side activities such as the monitoring of land cover change and beach erosion. Sentinel-3 water quality measurements, SST and high-resolution (CryoSat SAR type) altimeter data are required for effective coastal monitoring together with dedicated in situ infrastructure.

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New coastal zone forecasting systems are now starting to provide high-resolution forecasts of water quality and dynamic state of the coastal areas. These systems are nested in larger ocean forecasting system outputs which provide boundary conditions for the local area models and new data assimilation techniques are being developed to assimilate ocean observations in shelf seas regions. Some systems are already operational but do not yet assimilate ocean observations from space but instead use these for validation and verification exercises. It is expected that these systems will develop capacity to assimilate data from ENVISAT (and Sentinel-3 as a follow on) in the near future.

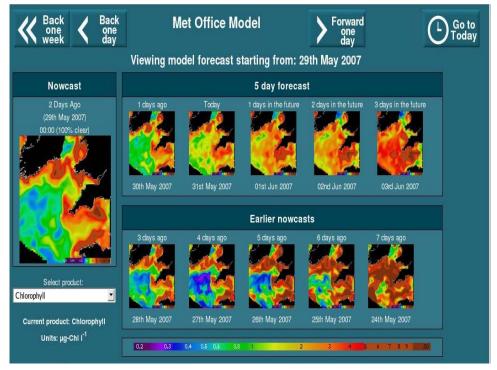


Figure 12: AlgaRisk '08 Pre-Operational Tool for Identifying and Predicting the Movement of Nuisance Algal Blooms. The service is developed in anticipation of the European Union's revised Bathing Waters Directive (2006) that will require the Environment Agency to provide water quality forecasting by 2012. The pilot service aims to help provide the Environment Agency sufficient forewarning to ensure response teams can anticipate a bloom event and put in place targeted monitoring programmes. The AlgaRisk tool combines satellite imagery, ecosystem modelling and a decision support spreadsheet, and are available via the internet. (See http://publications.environment-agency.gov.uk/pdf/SCH00809BQVE-e-e.pdf) (Credit: PML, UK)

Sentinel-3 measurement requirements include water quality Inherent Optical Properties (IOP), the concentration of the pigment Chlorophyll-a (Chl), total suspended material (TSM), the optical diffuse attenuation coefficient (K), and the photosynthetically active radiation (PAR). The latter are required to define the in-water light field that stimulates photosynthesis in ecosystem models. Open ocean models are rapidly developing towards assimilation of near-real time Chl, K and PAR for estimates of global primary productivity. Products describing the IOP of water are increasingly used as the basis for many water quality and ocean colour algorithms and should be available form Sentinel-3. In the shelf seas, water quality monitoring is a high priority, IOP, K and PAR are required assimilation inputs to marine ecosystem models. Near real time Chl and TSM products are needed for marine environment

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management and for reporting on algal biomass distribution and evolution, harmful algal blooms (HAB), eutrophication, sediment distribution, concentration and transport.

3.2.12 GSE Marine and Coastal Environmental Information Services (MARCOAST)

GSE MarCoast (Marine and Coastal Environmental Information Services) [RD-134] delivers satellitebased services in the field of marine and coastal applications. Services integrate detection and monitoring technologies within a robust operational network. MarCoast is refining standards and working practices for GMES services in the area of oil pollution and water quality. Integration and Sustainability are essential aspects within the project, which consolidates services already developed as part of previous ESA projects. International and national laws, conventions, and directives (see Section 3.2.11) underpin MarCoast Services. Services include:

- **Oil spill alert and polluter identification:** to establish and to provide an operational oil spill detection information service meeting the needs for both routine surveillance and customised information of regional European waters including the Bonn agreement area, the Aegean Sea, part of the French ecological zone and selected parts of Spanish waters. The distributed information includes identified spill information and supporting information, e.g. on source and meteorological and sea state conditions when available.
- **Oil spill drift forecast:** The MarCoast surveillance service provides a drift forecast service with oil spill alerts and basic spill parameters. An essential element to drift forecast services is a drift model and NOP systems, and MetOcean data with which to drive the model. The service requires oil spill imagery and met-ocean forecast data.
- Water quality monitoring: Combining met-ocean data and in-situ measurements usually provided by the users, water quality monitoring services provide NRT surveillance of water quality indicators, such as chlorophyll, transparency, TSM, Yellow substance or Gelbstoff, and SST on daily, weekly or monthly basis. The service is regionalised over almost all of the European seas which include the Mediterranean, the Black sea, the North and Baltic seas, the Channel and the Northern Atlantic Sea.
- Algal Bloom detection and alert: The pan-European algae bloom service provides a basic daily detection of algae blooms for the whole European sea region and automated email alert to registered users. The service covers the coastal and offshore waters of all European Union countries plus Norway (from Spain, Portugal and Ireland in the West to Greece in the South-East to Finland and Norway in the North-East). The Black Sea and all inland waters are excluded.
- Water quality indicators: The service is targeted to end-users providing information to support decisions regarding measures to take to protect life, property and loss of natural habitat in protected areas. The service will assist end-users in a number of ways:
 - to help the provision of the required policy-compliance information,
 - to answer questions from policy makers, and
 - to assist in the formulation of new environmental policies.

Representative monitoring of phenomena such as eutrophication, one of the major issues in terms of anthropogenic pressure, requires information on phytoplankton (composition, abundance, biomass, blooms) and as supportive/interpretative parameters, the concentration of



pigments (Chlorophyll a), transparency, temperature, salinity, oxygen, nutrients, and the hydromorphological parameters as currents and wave exposure.

- Met-Ocean data: this service distributes MetOcean data for all the European seas for:
 - Oil Spill detection, to improve the false alarm rate and customise the service with ancillary data;
 - Water Quality and Algae Bloom alert to provide global ocean physical parameter;
 - Oil Spill and Harmful Algae Bloom forecast models to provide currents and nest drift models.
 - The portfolio of data available ranges from NRT observations (e.g., ocean colour, SST, sea state, surface winds) to analysis and forecasts produced by NOP/NWP models (e.g., winds, waves, currents, 3D ocean temperature)

In addition, to the availability of data, the service can provide tailored processing of data allowing an easy, robust and accurate interfaces to user's forecasting applications.

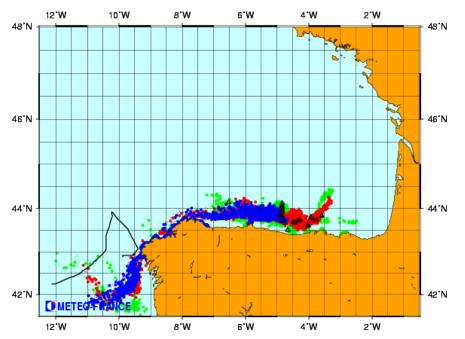


Figure 13: Prestige oil spill simulations at Meteo-France showing a case snapshot for 2002-12-13 12 UTC. Prestige ship trajectory = black line; MOTHY model (wind only) = blue; MOTHY and Mercator model = green; MOTHY and FOAM model = red. Observed slicks = black triangles. NOP surface current data have a positive impact in waters where the large-scale circulation has a significant impact. SSH and SST measurements from satellites form an essential input to NOP. (Credit: Meteo France)

MarCoast water quality and algal bloom information services depend critically on the resolution, update frequency, coverage and quality of the underlying ocean colour and SST products. A spatial resolution of at least 1 km is needed for monitoring European coastal waters. EC Water Framework directive reporting will require 300 m or better spatial resolution. Regional capabilities are needed (e.g. for the Mediterranean, Baltic, North and Black Seas, each of which have very different optical properties) [RD-172] and for merging data from different ocean colour sensors.

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MarCoast requires sustained NRT access to:

- Satellite ocean colour data and derived products (Chl-a, total suspended matter (TSM), suspended particulate matter (SPM), water transparency, turbidity, algae bloom maps, Yellow Substance (YS), Coloured Dissolved Organic Matter (CDOM), vertical attenuation coefficient maps (K), harmful algal bloom (HAB) and floating algae bloom intensity maps) at 1 km and 300 m resolution daily. Continuity of ENVISAT MERIS is essential.
- Satellite high resolution SST and temperature front maps (1 km, daily). Continuity of ENVISAT AATSR is essential.
- Satellite derived Information on water levels (SSH) in the coastal zone and open-ocean (for NOP boundary conditions). Continuity of ENVISAT RA-2 and other complementary altimeter systems (e.g. Cryosat-2, JASON) in constellation is essential. High resolution coastal altimetry products will be extremely useful.
- Co-incident high accuracy observations of ocean colour with high accuracy SST observations (for the accurate estimation of oceanic carbon fluxes, coastal and water quality management) are required.



Figure 14: MERIS Reduced Resolution (1.2 km) image acquired on 11 July 2010 showing a summer marine plankton bloom that fills much of the Baltic Sea. Such blooms are common at this time of year in the Baltic Sea due to the combination of warm weather and waters rich in phosphorous nutrients that originates from the sea floor, having been released for surface layer plankton to consume when autumn and winter storms mix the water mass. Algal blooms in this region are an annual phenomenon and impact the fisheries stocks of Cod, Sprat Salmon and Herring. (Credit: ESA)

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3.2.13 Fisheries operators

The masters of fishing boats require reliable wind and wave forecasts to support decisions as to when and how to deploy nets and lines. Sea state and surface wind information is essential to safe fishing operations. In addition, to help manage fishing zones, SST and ocean colour maps are required. The location of frontal and upwelling zones (related to high nutrient concentrations, hence high fish population) through temperature, nutrient concentration or low surface wind signatures, is expected to enhance the quality of such management services. Maritime safety information is also required to support fishing fleets by the provision of NOP/NWP forecast outputs and drift models based on data assimilation of satellite and in situ marine observations.

Fishing crews operating in polar ocean regions require additional information describing the location of ice edge, ice concentration, iceberg reports, sea ice maps and SST maps (to determine local icing conditions). Managers involved in aquaculture require information on SST and water quality, especially the occurrence of algal bloom events and forecasts of their advection in coastal zones in NRT and at high resolution. Sentinel-3 data products will provide a wide variety of products to support fisheries management.

3.2.14 Meteorological/Oceanographic institutes/services

Public meteorological (National Meteorological and Hydrological Services, NMHS) and/or oceanographic institutes are typically responsible for the provision of NOP/NWP forecast and nowcast services covering marine areas under national responsibility. This activity is supported by a range of forecasting models which can be local, regional or global in scope. In Europe, such agencies generally run at least a regional atmospheric model to support meteorological forecasting. The operation of NOP/NWP systems requires the regular assimilation of a range of observations [RD-118] to ensure forecast accuracy. In terms of oceanographic data, meteorological models assimilate subsurface data, SST and sea ice extent as boundary conditions and also sea surface wind vectors to ensure the accurate location of depressions. NWP and NOP systems at these agencies require SST, SSH, current vectors, sea-surface wind vectors as well as wave height, period and propagation direction. Ocean colour data are required for the present and future generation ecosystem and environmental models that provide marine environmental information to operators. Salinity measurements and vertical profile data from moorings, drifters and floats are also assimilated where available. Information on Lake Surface Water Temperature (LSWT), river and lake heights (RLH) are required for NWP and hydrological services.

Some NHMS (e.g. ECMWF, MetOffice) require NRT access to level 1b brightness temperatures and/or radiances including uncertainty estimates for the following applications:

- To be able to assimilate the radiances directly in NWP and ocean models to improve the model surface, total column water vapour and aerosol fields;
- To be able to apply the users own SST retrieval algorithm to make use of new retrieval science quickly and to have control over when the retrieval algorithm is changed;
- To compare radiances with climate model simulated radiances (validation);
- To allow radiances to be used as part of the Global Space-Based Inter-Calibration System (GSICS) [RD-133] comparison in real time to inter-calibrate other satellite sensors;
- For NWP assimilation applications the data must be available in less than 3 hours of the measurement time and in a format suitable for NWP and ocean forecasting centres (currently BUFR, netCDF and L2P).

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3.2.15 Ocean data centres

Most countries have designated national oceanographic data centres. Responsibilities vary amongst countries but often include the compilation and archiving of baseline regional and global geophysical variables to support analyses and research. Typical parameters include SST, SSH anomalies, temperature-salinity profiles, ocean primary productivities, wind and/or wave atlases, tide gauge measurements and bathymetry and sea-bed lithology measurements. Such centres often maintain dedicated in-situ data gathering capabilities and devote significant efforts to the development and operation of local and regional models. Satellite data can be used provide climatologies that are used to quality control in situ observations. In some areas, satellite data provide the only measurements of surface ocean data. Satellite SST, SSH and ocean colour data are required in delayed mode to the highest accuracy together with accompanying uncertainty estimates.

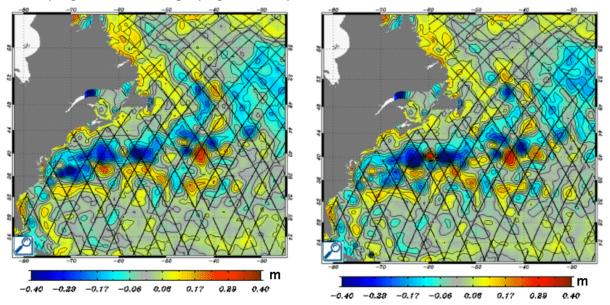


Figure 15: Sea level anomalies on 8 January 2003 from the medium-resolution Mercator model (1/3°), with assimilation of *in situ* SST measurements and (left) Jason-1 data only, (right) all available altimetry satellite data (Jason-1, ERS-2 and GFO). More detail can be seen in the right-hand figure due to the better coverage provided by altimeter systems working in constellation. (Credit: Mercator Ocean)

3.2.16 Oceanographic researchers

The objectives of oceanographic research include advancing understanding and modelling of ocean processes and of air-sea interactions and the more precise characterisation of the role of the oceans in the various Earth system and climate cycles. Research teams are fundamental to the on-going validation of Sentinel-3 products bringing high quality (sometimes dedicated) in situ measurements for EO validation experiments. Examples of on-going analyses include:

- The description and characterisation of the main features of ocean circulation, their dynamics and their interactions;
- The determination of intra-seasonal and intra-annual variability;
- The measurement of mesoscale and coastal variability associated with ocean current movements and the formation and propagation of eddies important in heat transport;

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- The analysis of biochemical processes and their correlation with physical parameters;
- Assessment of mean sea-level, SST and ocean biological trends;
- Analysis of the polar environment requires information on the distribution and dynamics of icebergs, sea ice edge, sea ice concentration and sea ice drift;
- Validation of satellite data sets over the ocean;
- Development of a new generation of NOP/NWP models and data assimilation systems.

The oceanographic research community exploits large volumes of satellite remote sensing data and is sufficiently expert to specify information requirements in terms of satellite and instrument operating parameters. For those users monitoring the performance of satellite data products and those pioneering new radiance assimilation methods at operational centres access to lower level products in near real time is required including:

- level 1b brightness temperatures and/or radiances including uncertainty estimates
- Instrument level waveforms from altimeter systems for re-tracking in complex areas (such as the coastal zone, sea ice and land surfaces).

3.2.17 Snow and Ice marine requirements (GSE Polar View)

The use of satellites is becoming increasingly important as marine traffic increases, particular in the Arctic Ocean (North-West Passage), Baltic Sea area and the Southern Ocean, and as ice and snow patterns change rapidly and unpredictably due to the impact of global warming. Services offer many benefits to both business and society including providing safe and efficient transportation routes for merchant vessels, icebreakers and cruise ships; guiding fishing and hunting expeditions for northern residents; improving flood protection and water resource management; monitoring polar fresh water cycles; and tracking sources of pollution.

The GSE Polar View [RD-117] program is focused on both the Arctic and the Antarctic supported by ESA and the European Commission with participation from the Canadian Space Agency. Polar view promotes the utilization of satellites for public good and in support of public policy in the areas of sustainable economic development, marine safety, and the environment. Polar View services [RD-117] are designed to address polar concerns on environmental protection, maintenance of traditional way of life, and safety and efficiency of marine transportation as well as sustainable development. Monitoring and forecasting services provide accurate, real-time information that in many cases is not available from any other source and offer cost savings over existing monitoring alternatives.

Polar View delivers services to stakeholder groups including policy makers, government departments, northern residents, and public agencies. Service products include

• Sea Ice Monitoring and Forecasting: Timely information on sea ice and other met-ocean conditions is essential for all types of marine operations in Polar Regions. This service builds on existing capabilities by providing global sea ice products at improved spatial resolutions for the entire Arctic Ocean. High-resolution ice charts covering local areas in the European Arctic provides fine scale information about sea ice concentration in fjords, straits and marginal ice zone for marine safety and habitat research. Medium resolution ice charts covering all Greenland waters are provided on a weekly basis. Sea ice thickness charts provide users at sea with timely ice thickness charts based on SAR data and ground truth in an appropriate resolution for ice navigation. Regional sea ice services provide forecasts of ice motion, concentration, thickness, ridges and deformations for the Baltic Sea area using numerous multi-category sea ice models.

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- **Iceberg Monitoring**: This service supports safe shipping and offshore operations by providing near real-time detection of icebergs based on satellite synthetic aperture radar (SAR) imagery. The service is geared towards end-users concerned with transportation and offshore operations safety and compliance with regulations.
- **Ice Edge Monitoring**: The ice edge monitoring service provides up-to-date image maps showing the location of the floe edge based on SAR data.
- **Ice Drift Trajectories**: Backward Sea Ice Drift Trajectories and sea ice drift products are derived from satellite passive microwave radiometer data and scatterometer data.

The project also collaborates with world National ice centres to generate and provide more detailed information sets and to commercial downstream activities: iceberg information to yacht races around the Antarctic and to hunters and trapper who travel and work in the North. Key PolarView users include:

- Merchant vessels and icebreakers in need of detailed ice information to safely and cost effectively navigate ice-covered areas,
- Environmental scientists operating in polar regions and those requiring input to polar research on topics such as wildlife habitats and pollution tracking,
- Maritime safety services,
- Inuit hunters requiring up-to date ice-edge information to improve the safety and efficiency of their hunting expeditions,
- Hydro utilities working to understand and improve the management of their water resources,
- Government agencies reliant on detailed forecasts to improve flood prediction and protection.

Cryospheric elements of climate system research include the modelling of ice mass balance and the monitoring of changes in sea ice cover. Current climate and NWP requirements [RD-118] require ice surface temperature (IST) over the high-latitude oceans, for model boundary conditions. IST is a critical bottom boundary condition when retrieving vertical profiles of temperature and humidity form satellite vertical sounders helping to minimise retrieval errors in the lower troposphere [RD-82]. The NASA MODIS sensor provides L2 and L3 sea ice temperature products at 1-km (Level 2) and 4.6 km, 36 km, and 1 km (Level 3) resolutions over the global oceans [RD-150] including quality parameters. The Level 2 product is produced daily and consists of global day and night coverage every 24 hours. It is used to generate the gridded Level 3 products daily, 8-day weekly, monthly, and yearly for day and night conditions. A quality parameter is provided for each data set.

Timely information on sea ice and other met-ocean conditions is essential for all types of marine operations in Polar Regions. Polar waters represent a significantly higher degree of risk to operators of ships and offshore structures than most other waters, because of the presence of ice fields, wind and waves, icing of vessels and darkness in the winter. The safety and efficiency of sea transportation, off-shore operations, fisheries, and other marine activities have been the motivation to establish operational sea ice monitoring in the Arctic, Antarctic, and Baltic Sea. In addition, the routine mapping of sea ice on a global scale is important for scientific and regulatory users in the areas of climate monitoring, environmental protection, and sustainable resource management. The Polar View ice service portfolio [RD-149] has evolved to meet the key information needs of polar stakeholders that can be addressed with EO data.

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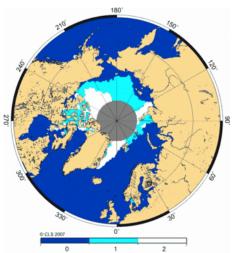


Figure 16: Sea ice coverage averaged in 1° x 1° boxes over September 2007 with respect to a mean over the previous years (2003-2006) derived from ENVISAT RA-2 data. Dark blue is open water (0), White (2) is the ice in September as usual; light blue (1) shows where ice has been observed previously and is not in 2007. (Credits: CLS)

Sea-ice monitoring and forecasting is an essential part of operational oceanography at high latitudes. Ice parameters (ice edge location, ice motion, ice deformation and ice thickness) in combination with atmospheric-ocean parameters (temperature, wind, waves, currents, etc.) are of importance for all types of marine operations in and near ice-covered regions. This includes ice navigation, commercial shipping, offshore operations, such as oil and gas extraction, and fisheries, all of which require reliable monitoring and forecasting of sea ice. Observing sea ice and ocean parameters are also important for management of fishery resources and marine mammals. Long-term statistical information on key ice parameters (extent, thickness, types, etc) needs to be improved for certification and insurance of vessels and marine structures operating in polar waters.

Sentinel-3 will provide estimates of elevation/thickness of floating sea-ice, together with sea-ice extent and ice-surface temperature in high-latitude oceans. Whilst the latter can be accomplished under cloud-free conditions using the visible and infrared sensors, it is also feasible to use an altimeter to obtain high along-track resolution (< 300 m), ice surface elevation profile measurements with an instrument concept such as the SIRAL altimeter used by CryoSat [RD-34]. This requires a beam-limited altimeter with resolution enhancement capability, and absolute calibration of sigma-naught (for discrimination between ice and water waveforms).

Within the MyOcean MCS project [RD-53] a Sea-ice Thematic Assembly Centre (SI-TAC) has been implemented to support Arctic and Antarctic GMES services as well as to provide improved boundary conditions for global and basin scale ocean modelling. The SI-TAC should include iceberg surveillance services, ice concentration, ice edge and ice thickness at global level with a spatial resolution, temporal update frequency, coverage and quality level equal or superior to the global sea ice products presently generated within Polar View [RD-172], building on the EUMETSAT OSI-SAF products. PolarView services are continued at present for the benefit of international operational ice forecasting centres.

Key Sentinel-3 requirements for GMES services (MyOcean, MACC, and G-MOSAIC) that use sea ice products as part of routine operations include:

- Sea Ice Monitoring and Forecasting (Ice charts, sea ice concentration)
- Ice thickness
- Iceberg Monitoring
- Ice Edge Monitoring

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- Ice Drift Trajectories
- River Ice Monitoring
- Lake Ice Monitoring
- Glacier Monitoring
- Snow Monitoring (Snow Covered Area)
- Snow Albedo

Ice parameters including sea ice edge, ice thickness, ice drift, presence of lake and river ice can be retrieved from altimeter measurements such as those from CryoSat [RD-34] and Sentinel-3. Additional use of optical sensors covering the visible and infrared spectrum can be used to determine sea ice concentration, type, edge, IST, presence of icebergs, lake ice snow monitoring, river and lake ice presence, and snow Albedo.

3.2.18 Summary of Marine Service Requirements

The MCS Strategic Implementation Plan [RD-52] notes the fundamental role that satellite measurements have in NOP systems – without satellite data it is difficult to make any meaningful forecasts of the ocean state, water quality and ocean health. RD-52 provides a summary of GMES MCS marine service user requirements applicable to the Sentinel-3 mission. High spatial resolution measurements are required in the coastal zone with reduced resolution over the open ocean. Ideally Sentinel-3 products shall have a spatial resolution of 1-4 km over the global ocean and ~0.3-0.5 km in the coastal zone. Revisit times shall be ~1 day in the coastal regions and 2-3 days over the global ocean. Observation time for optical measurements shall be optimised to minimise diurnal thermal stratification, sun-glint, morning haze effects and cloud cover. A summary of data products required by the GMES MCS is given in Table 3.

| Table 3: Summary of GMES Marine Service and operational oceanography service requirements taken |
|--|
| from the GMES MCS Implementation Plan [RD-5, RD-52], and [RD-24, RD-14, RD-27, RD-32, RD-53, RD- |
| 67, RD-66 , RD-118, RD-134, RD-173]. |

| Service/ User | Application | Measureme nt Parameter | Accuracy | Spatial resolution | Geographical Coverage | Delivery | Revisit Time |
|--|---|--|----------|--------------------|--------------------------|----------|-----------------|
| NOP development community | Development of NOP assimilation systems, validation of EO data, new data assimilation schemed | Access to L1b and altimeter instrument waveform (IGDS) products | - | - | - | NRT | - |
| MCS, MyOcean, MarCoast, GOOS, NMHS | NOP, ocean nowcasting/ forecasting mesoscale applications | Sea Surface Height (SSH) | < 3 cm | 25-100 km | Global | NRT | 7-15 days |
| MCS, MyOcean, MarCoast, GOOS, | NOP, coastal zone | Sea Surface Height (SSH) | 3 cm | 0.2-1 km | Global coastal zone | NRT | 1 day |

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| NMHS | | | | | | | |
|---|---|---|---|---------------|-----------------------------------|---------|---|
| MCS, MyOcean, MarCoast, GOOS, NMHS, climate centres | Climate applications and topography reference | Sea Surface Height (SSH) | ~1 cm | 300-500 km | Global | NRT | 10-20 days |
| MCS, MyOcean, MarCoast, GOOS, NHMS | NWP | SST | 0.2 – 0.5 K | 10 -50 km | Global | NRT | 6 – 12 hours |
| MCS, MyOcean, GOOS, NHMS, Climate centres | Climate monitoring, climate services | SST | ~0.1 K (stability better than 0.1 K/decade) | 20 – 50 | Global | NTC | 8 days |
| MCS, MyOcean, MarCoast, GOOS, NHMS | NOP (global) | SST | 0.2 K | 1 – 10 km | Global | NRT | 6 – 12 hours |
| MCS, MyOcean, MarCoast, GOOS, NHMS | NOP (coastal) | SST | < 0.5 K | < 0.3 km | Regional (global coastline) | NRT | 1 day |
| MCS, MyOcean, MarCoast, GOOS, NHMS | NOP (global operational) Case 1 waters | Chl K PAR Lw(λ) | 30 % 5 % 5 % 5 % | 2 – 4 km | Global case-1 waters | NRT | 1 – 3 days |
| MCS, MyOcean, MarCoast, GOOS, NHMS | NOP (coastal and shelf seas operational) Case-2 waters | K PAR Lw(λ) Chl TSM CDOM | 5 % 5 % 30 % 30 % 30 % | 0.5 – 2 km | Global Case-2 waters | NRT | 1 day (goal, 3-5 days (threshold) |
| MCS, MyOcean, MarCoast, GOOS, NHMS, National marine managers | Marine management in coastal seas (case-2 waters) | K PAR Lw(λ) Chl TSM CDOM | 30 % 5 % 5 % 30 % 30 % | 0.25 – 1 km | Global Case-2 waters | NRT | 1 day (goal, 3-5 days (threshold) |
| MCS, | Climate | Chl (IOP) | 10-30 % | 5 – 10 km | Global Case-1 | NTC (8- | 1 day (goal, |

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| MyOcean, | monitoring | | | | waters | day | 3-5 days |
|-------------------|-----------------------------|--------------|-------------|---------------------|-----------------|----------|-------------|
| MarCoast | in global | K | 5 % | | waters | average) | (threshold) |
| GOOS, | ocean Case-1 | | | | | | (|
| NHMS, | waters | | | | | | |
| Climate | | PAR | 5 % | | | | |
| centres | | | | | | | |
| MCS, | | Chl (IOP) | 10 - 30 % | | | | |
| MyOcean, | Climate | TSM | 10 - 30 % | | | | |
| MarCoast | monitoring | CDOM K | 10 - 30 % | | | | |
| GOOS, | In coastal | | | 1- 5 km | Global Case-2 | NRT | Daily (goal |
| NHMS, | ocean Case-2 | PAR | 5 % | | waters | | 3 hourly) |
| Climate | waters | 17 | - 0/ | | | | |
| centres | | К | 5 % | | | | |
| MCS, | Coastal and | | | | | | |
| MyOcean, | estuarine | | | | | | |
| MarCoast | | | | o.1 o. - | Global coastal | | 0- |
| GOOS, | water quality monitoring | Lw(λ) | 5 % | 0.1 – 0.5 | and estuarine | NRT | 0.5 – 2 |
| NHMS, | in Case-2 | | | km | Case-2 waters | | hours |
| EEA, climate | | | | | | | |
| centres | waters | | | | | | |
| | | | 20 cm or 4 | | | | |
| MCS, | | | % of SWH | | | | |
| Mcs, MarCoast, | | Significant | for 1 s | | Regional- | | |
| GOOS, | NWP, NOP | Wave Height | averages (5 | <10 km | Global | NRT | 6 hours |
| NMHS | | (Hs) | cm or 1 % | | Giobai | | |
| INIMITIS | | | goal [RD- | | | | |
| | | | 28]. | | | | |
| MCS, | | | | | | | |
| MarCoast, | | | | | | | |
| GHRSST, | | | | | | NRT 1/2 | |
| GODAE- | NWP, NOP | Surface wind | <2 m/s | 25 km | Local, Regional | hour-6 | 3 hours |
| Ocean View, | , | speed | / - | U | and Global | hours | 0 |
| EEA, | | | | | | | |
| EuroGOOS, | | | | | | | |
| NMHS | | | | | | | |
| MCS, NWP, | | | | | | | |
| NOP, GOOS, | NOD NUT | | | | | | |
| GHRSST, | NOP, NWP | | | | Destand C | | |
| GODAE- | Sea Ice | Sea Ice | 1.5.0(| a = 1 | Regional (ice | NRT | D.1 |
| Ocean View, | Services, | Thickness | 10 % | 0.5 km | infested | Daily | Daily |
| PolarView, | Maritime | | | | waters) | - | |
| climate | safety | | | | | | |
| services, | | | | | | | |
| NMHS | | | | | | | |
| MCS, MarCoast | | | | | | | |
| MarCoast, | NOP, NWP, | Ice Surface | | c = lem (c | Regional (ice | NRT | |
| GOOS, | Sea Ice | | 1 K (10 %) | < 5 km (1 | infested | | Daily |
| GHRSST, GODAE- | Services | Temperature | | km goal) | waters) | daily | |
| | | | | | | | |
| Ocean View, | | | ļ | | ļ | ļ | |

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| PolarView, NMHS | | | | | | | |
|--|---|--------------------------------|-----------------------|----------------------------|--------------------------------------|--------------|-------------------------|
| MCS, MarCoast, GOOS, GHRSST, GODAE- Ocean View, PolarView, NMHS | NOP, NWP, Sea Ice Services, Maritime safety | Sea Ice Concentration | < 10 % (<5 % goal) | <15 km (<10 km goal) | Regional (ice infested waters) | NRT daily | Daily |
| MCS, MarCoast, GOOS, GHRSST, GODAE- Ocean View, PolarView, NMHS | NOP, NWP, Sea Ice Services, Maritime safety | Sea Ice Extent | 15 km | < 10 km | Regional (ice infested waters) | NRT Daily | Daily |
| MCS, MarCoast, GOOS, GODAE- Ocean View, PolarView, NMHS | NOP, NWP, Sea Ice Services, Maritime safety | Sea ice velocity | 3 km/day | < 25 km | Regional (ice infested waters) | NRT Daily | Daily |
| MCS, MarCoast, GOOS, GODAE- Ocean View, PolarView, NMHS | NOP, NWP, Sea Ice Services, Maritime safety | Sea ice edge | 10 % | 5 – 15 km | Regional (ice infested waters) | NRT Daily | Daily (goal 3 hours) |
| MCS, MarCoast, GOOS, GODAE- Ocean View, PolarView, NMHS | NOP, NWP, Sea Ice Services, Maritime safety | Iceberg Fractional Cover | 10 % | 1 – 4 km | Regional (ice infested waters) | NRT Daily | 1 – 3 days |
| MCS, MarCoast, GOOS, GODAE- Ocean View, PolarView, NMHS | NOP, NWP, Sea Ice Services, Maritime safety | Ice type | Classes | 10-25 km | Regional (ice infested waters) | NRT Daily | Daily (goal 3 hours) |

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3.3 GMES Land Monitoring Service (LCMS)

The domain of GMES operational land services is less mature than that for the oceans. Operational use of SPOT Vegetation (VGT) products (e.g. Figure 17) during the last years [RD-152, RD-153, RD-154] supported by ENVISAT MERIS measurements, has allowed the development of global operational land products and services that provide a foundation for GMES. Example GMES and GMES pre-cursor projects include FP-6 Geoland [RD-119], Global Landcover 2000 (GLC2000) [RD-159] and Globcarbon [RD-157].

For 10 years, the SPOT Vegetation mission has played an important role in meeting this need for information by offering high quality global data of the entire terrestrial surface on a daily basis to operational users – both institutional and commercial - requesting data in near real time. SPOT Vegetation products have been distributed to 7500 users [RD-154] for applications such as: forestry, low resolution mapping, regional and continental scale land cover mapping and, fundamentally, for global land productivity, agriculture or vegetation status and determination of biophysical vegetation parameters. These parameters are needed for climate modelling, carbon flux estimates, crop yield estimations, and land degradation, all of which may change rapidly with time. Continuity of these products, particularly Vegetation P- products is essential for GMES. Complementary EO Services and ESA DUE or DUP projects rely on the same class of optical image data. In addition, GEOLAND will make full use of moderate resolution sensors (0.3 – 1km spatial resolution) for daily monitoring purposes [RD-119].

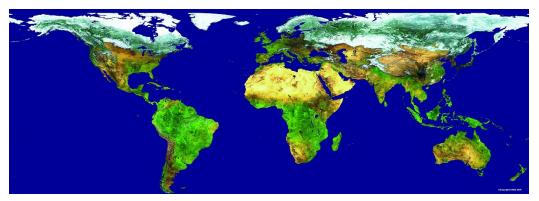


Figure 17: Example SPOT 10-day synthesis of Vegetation data (31st March 1999) available from <u>http://www.vgt.vito.be/VEGETATION%20samples/album/other/slides/i22 31031999 world.jpg</u>

The GMES Land Monitoring Service [RD-120] pre-operational land service is currently provided through the EU FP-7 project GEOLAND2 [RD-119, RD-120]. GMES Geoland2 [RD-93] is based on Geoland [RD-96], GMES Service Element (GSE) Land [RD-94] and GSE Forest Monitoring (FM) [RD-95]. Within the framework of GMES a considerable number of established services and applications rely on the use of low/moderate resolution EO optical image data (Table 4). These services are mostly situated in the framework of global services and are directed primarily towards the support of policies addressing global change and sustainable development. The Policies and regulations that the LCMS and GEOLAND2 projects address include:

- The EC Water Framework Directive;
- The EC Common Agricultural Policy;
- The EC Soil Thematic Strategy;

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- The EC Nitrate Directive;
- Nature and Biodiversity ;
- EC International cooperation (Africa);
- Multilateral environment agreements.

The project aims at providing geo-information data on the regional, European and global scale and is evolving from core activities that simply map parameters to policy relevant information services to support policy impact and to serve as common reference for sector-specific analysis and/or national reporting. GEOLAND2 provides a variety of information services that require moderate and highresolution, multi-spectral satellite measurements for:

- Agri-Environmental indicators: Agricultural land use changes, cropping patterns, crop rotation patterns, land abandonment, intermediate crop coverage rate Mapping forest areas (masks of forest and non-forest), forest types (basic distinctions of deciduous, coniferous and mixed etc.), crown cover density (estimate of the proportion of tree crowns) and historical forest area change. Monitoring and mapping grassland regions that are not distinguished or characterised adequately today including maps of separate arable, managed grasslands and natural grasslands, seasonal change in vegetation cover and the exploitation of high temporal frequency medium to high resolution biophysical parameters.
- **Crop monitoring and food security**: Crop growing conditions, potential crop production, crop yield assessment Multi-temporal HR / MR biophysical parameters are also used to capture the dynamics of growth and management helping the management and security of land resources (soil erosion, food and water, environment, energy, properties, infrastructure etc) including estimates of carbon storage, soil degradation, protection and sealing.
- **Monitoring and mapping wetlands and water resources**: mapping areas by overcoming difficulties due to mixed surface characteristics (e.g. bare ground, vegetation, water), monitoring the impact of water abstraction by irrigation, hydrological prediction, long-term water resource management, monitoring nutrient surplus, nutrient loads to seas and source apportionment. Small water bodies are particularly susceptible to the impacts of environmental changes. These are typically regions where the largest changes occur especially in Southern Europe. Monitoring inland water quality and availability (*e.g.* river stage height and lake levels). Characterization of river catchment areas, prevention of groundwater pollution from diffuse and local soil contamination;
- Land use and land cover inventories: Designated areas and habitats, change in ecosystems, fragmentation, Landscape diversity and management, agriculture and forest habitats, rural area development. Natural, public and private assets, land use conflicts, territorial planning. Development of land use and land cover inventories, change detection, cross-border coordination of urban area planning. Monitoring changes in built-up intensity (and area) including urban sprawl, rural-urban relationships, Urban Audits, spatial planning, road mapping, car navigation, and location based services.

GEOLAND2 also has a focus on variables identified as GCOS ECVs [RD-41] (including LAI, FAPAR, Albedo, Burnt areas, Soil moisture) at scales ranging from regional, continental (Africa) and global. Long time-series data are required that are reprocessed/processed using with consolidated algorithms. The project also address the consistency between historic and NRT products conducting validation according international protocols using international inter-comparison exercises, ground campaigns with consistency cross-checks across variables. GEOLAND Service products include those addressing:

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Requirements in these application areas range from continental coverage satellite data products that are available 1 year after satellite data acquisition that are updated at least every 3-5 years (a more frequent update is required for urban areas) and those applications such as to daily monitoring of active fires in NRT. The geographical coverage includes the EU 25+ countries and must be well coordinated with national/regional/urban monitoring activities, in line with the principle of subsidiarity. Products must be compatible with the Corine Land Cover specifications [e.g. RD-159] for continental monitoring, MOLAND [RD-97] for urban monitoring and FAO for global monitoring.

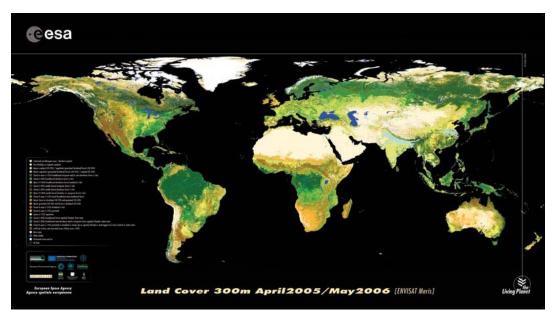


Figure 18: Global land cover map produced from the ENVISAT MERIS sensor at 300m resolution for April 2005 – May 2006. (Credit: ESA)

Monitoring of land areas in Europe today relies on classification of land cover using optical imagery from ENVISAT MERIS and AATSR, AVHRR, SPOT-High Resolution Visible (HRV) and Landsat-Thematic Mapper (TM) type sensors. These are complemented by very high spatial resolution sensors such as Ikonos and SPOT-5 for mapping of small features (small roads/rivers) [RD-96 and RD-119]. The service will provide ortho-rectified continental coverage satellite images and mosaics (at moderate resolution) and local very high resolution (< 1 km) scales. 3-5 yearly updates of core land cover/land use data with minimum mapping units of 1-5 ha and, land cover/land use data of 500 functional urban areas with a minimum mapping unit 0.1 ha is required. The basic spatial resolution needed for identification of land cover and the variability in vegetation indices such as NDVI is at least 1 km but preferably better.

Sentinel-3 will provide continuity to land products derived from ENVISAT, AVHRR, and SPOT Vegetation that are complementary to Sentinel-2 outputs and having similar or improved capability. The mission shall meet basic global land requirements for land services, including related climate and meteorological studies, where boundary conditions have to be prescribed (e.g. land surface component of General Circulation Models (GCMs) or NWP models). Surface albedo, surface roughness, resistance to heat exchanges (sensible and latent), fires, burned areas, lakes and rivers and surface temperature are important variables that can be determined together with measurements that identify land cover characteristics. The seasonal and long-term variations of these variables are related to vegetation dynamics, and thus the capability to identify physical characteristics of land cover is important. Scales

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addressed in GCMs or forecasting models (typically about 1 km (regional) to 100 km (global)) require that land cover and its variability must be determined with a sampling of about 1 to 10 km.

3.3.1 GSE Land monitoring projects

The GSE Forest Monitoring (GSE FM [RD-95]) service was specifically established to address the policy related demands of the forestry and land use sector. Already consolidated services relate to information needs of environmental policies such as the United Nations Framework Convention on Climate Change (UNFCCC) [RD-135]. In addition, forest monitoring services are under development to deliver information such as yearly carbon balance information, forest disturbance data, as well as products for practical forest and land use management. These services deliver products to enhance governance and sustainable management within the forestry sector. Sentinel-3 observations could also contribute to the baseline mapping service for the UN collaborative programme on Reduced Emissions from Deforestation and Degradation in developing countries (REDD) [RD-161].

For agricultural monitoring the objective of the GSE Global Monitoring for Food Security (GMFS [RD-101]) project is to improve the provision of sustainable information services to assist food aid and food security decision makers from local to global level. Daily to weekly EO data products at sub-kilometre resolution are required at continental or global scale to complement existing regional information and early warning systems on food and agriculture. Sentinel-3 multi-spectral measurements of land parameters at resolutions ≤300 m are required for these applications.

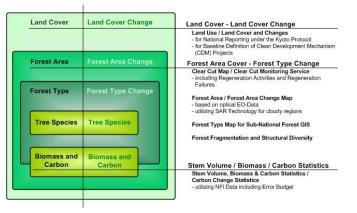


Figure 19: GSE Forest monitoring product categories (Credit: GSE-FM)

The GSE Land [RD-162] project builds on the outcomes of SAGE (Service for the Provision of Advanced Geo-Information on Environmental Pressure and State) [RD-163], GMES Urban Services (GUS) [RD-166] and CoastWatch [RD-165] projects. GSE Land provides a set of services addressing the land mapping requirements of European users on all levels (DGs, national ministries of environment, regional authorities, municipalities, etc.) that are working within European policies (given priority to Water Framework Directive[RD-130], Soil Thematic Strategy [RD-164], Integrated Coastal Zone Management [RD-167], Urban Environment Thematic Strategy [RD-168]). Four baseline services are provided:

• Urban Atlas Service: providing very high resolution land cover mapping and further downstream services (Urban Atlas Indicators such as urban sprawl, environment and regional development indicators and fine-tuning of maps to local needs).

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- **Inland Water Quality Service:** providing high resolution regional land cover and agricultural land use mapping and further downstream modelling related to nutrient loss and pesticides.
- **Impervious Area Service:** providing land and lake maps, trend analysis and social-economical impact assessments.
- Water Abstraction / Irrigation Service: providing maps of arable acreages and the downstream modelling of irrigation volumes.

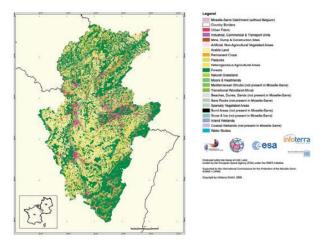


Figure 20: Example land cover maps for the Saar-Mosel catchment developed for the International Commission for the Protection of the Moselle and the Saar (Credit: © Infoterra GmbH, 2006)

The service relies on classification of land cover using optical imagery of the SPOT-High Resolution Visible (HRV) or Landsat-Thematic Mapper (TM) type sensors. These are complemented by very high spatial resolution sensors such as Ikonos and SPOT-5 for mapping of small features (small roads/rivers). Integration of these land cover maps with ancillary data and models lead to the specific downstream services. Sentinel-3 can support these services by providing daily ~300m resolution background maps in support of complementary high resolution mapping capabilities provided by other satellite systems including Sentinel-1 [RD-31] and Sentinel-2 [RD-92].

Additional GMES Services Element services to be sustained beyond continuity to SPOT VGT products and applications include meeting global monitoring requirements of, for example, the GEMS, GEOLAND, GLOBCARBON [RD-157], GLOBCOVER [RD-158, and GMFS [RD-101] studies in a largescale to global 0.3 -1 km mode. Land product requirements include provision of Normalised Difference Vegetation Index (NDVI) or equivalent atmosphere-corrected MERIS Global Vegetation Index (MGVI), Fraction of Absorbed Photosynthetically Active Radiation (fAPAR), and Leaf Area Index (LAI) for characterisation of vegetation amount and coverage. To complement these products the MERIS Terrestrial Chlorophyll Index (MTCI) provides information on Chlorophyll content of vegetation and vegetation condition. Each of these products is required at a minimum resolution of 500m (\leq 300 m goal) on a global scale every few days. Fraction of Absorbed Photosynthetically Active Radiation (fAPAR) products are also useful in a number of applications ranging from crop yield forecasting and forestry, to environmental stress and sustainability monitoring with impacts in terms of food security, land degradation (e.g. desertification) and land cover mapping. Leaf Area Index (LAI) measures the amount of leaf area in an ecosystem, which imposes important controls on processes such as photosynthesis, respiration, and rain interception. These processes couple vegetation to climate, and

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hence LAI is a key variable required to describe vegetation-atmosphere interaction in most land surface models.

Sentinel-3 can support these services by providing continuity and enhancements to ENVISAT MERIS and AATSR capability working in synergy with Sentinel-2 high resolution products.

3.3.2 Fire monitoring

Fire management (see Figure 21) aims to safeguard life, property, and resources through the prevention, detection, control, restriction, and suppression of fire in forest, vegetation and other areas. It includes prevention, preparation, and early warning activities prior to a fire event. Fire manager's often use controlled burning to maintain the status and integrity of ecosystems, and to manage fire risk by reducing the accumulation of natural fuel and residues from commercial and non-commercial activities [RD-72]. Early detection of active fire is critical in order to mobilize services to suppress and control the fire. Fire management also includes services to monitor and restore burned areas.

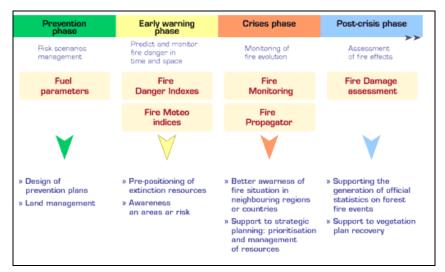


Figure 21: Phases of Fire management project highlighting the need for a variety of fire related products. (Credit: GOFC-GOLD)

Fires play an important role in ecosystem dynamics as the diversity of plant and animal life because fire breaks down organic matter that is then washed into the soil providing a rich nutrient source. Fire is also a significant factor in the ecology of savannas, forests and tundra, and plays a central role in deforestation in tropical and sub-tropical regions. In addition extensive fire occurs in many temperate biomes such as forests, grasslands, and chaparral [RD-70] on a periodic basis.

A variety of chemically-reactive gases are released through biomass-burning that strongly influence physical and chemical processes within the troposphere. The release of soot and other aerosol particulate matter during fires leads to significant physical changes down-wind from the fire affecting air quality and the number of available cloud condensation nuclei (CCN). Fire is thus an important component of trace gas and particulate emission modelling, climate modelling, atmospheric transport and chemistry models, ecosystem dynamic models and models of land use change and is thus an input to the GMES Atmospheric Service project MACC [RD-76], Emergency (SAFER project) and Security (G-MOSAIC) services.

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Figure 22: ENVISAT MERIS image acquired on Saturday August, 22nd 2009 showing fires burning in Greece (Copyright ESA)

Fire has been identified by the international community as being an important variable for the Global Climate Observing System and an essential climate variable for the UNFCCC [RD-135]. Large spatial variations in fire-induced carbon emissions exist due to the spatial variability of climate, forest types, and fire regimes. Spatial and temporal patters appear to be related to the state of climate modes: the 1998 El Niño correlates with an increase in fires across Borneo which emitted up to 2.5 billion tonnes of carbon into the atmosphere, equivalent to Europe's entire carbon emissions that year. Burning of tropical forests contributes significantly to the global carbon emission budget [RD-47]. Mapping the total area of forests and grass land burned each year are required to precisely estimate the amount of resulting emission products including CO_2 , CO, and CH_4 and their role and impact on climate change and air quality. Global change researchers, NWP systems, natural resource managers and policy decision-makers require better information on the causes, location, extent and impacts of fire and the sources, volumes and impacts of the associated fire emissions.

Several International, EC and ESA projects have developed fire monitoring and mapping capabilities that are relevant to Sentinel-3. The ATSR World Fire Atlas (WFA) [RD-136] is the first multi-year (1995 – present) global fire atlas ever developed and provides data approximately six hours after acquisition.

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The WFA provides a resource to map the spatial and temporal distribution of globally detected fires and is an important resource for fire monitoring.

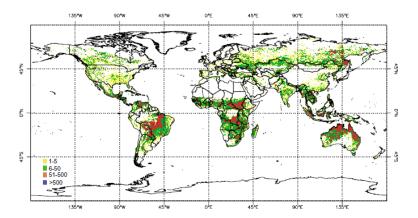


Figure 23: ATSR World Fire Atlas hot spots (hot spot identified if $3.7\mu m > 312$ Kelvin (Saturation)) used to map global hot spots for 1997-1999 [RD-151].

The EC FP-6 project Prevention, Information and Early warning (PREVIEW [RD-123]) Integrated Project developed new geo-information services for atmospheric, geophysical and man-made risk management on a European level. PREVIEW developed enhanced information services for forest fire risk management on a European scale supporting European Civil Protection units, local, regional, national and European authorities.

The European Forest Fire Information System (EFFIS) [RD-124] supports the services in charge of the protection of forests against fires in the EU countries. EFFIS has been established by the Joint Research Centre (JRC) and the Directorate General for Environment (DG ENV) of the European Commission (EC) to support the services in charge of the protection of forests against fires in the EU and neighbour countries, and also to provide the EC services and the European Parliament with information on forest fires in Europe [RD-71]. EFFIS addresses forest fires in Europe in a comprehensive manner, providing EU level assessments from pre-fire to post-fire phases, thus supporting fire prevention, preparedness, fire fighting and, post-fire evaluations. The core of EFFIS includes scientific and technical infrastructure conducting research on forest fires supported by a network of Experts on Forest Fires from 22 EU countries that meet regularly with the EC services. An on-line web based system [RD-124] is maintained providing timely information on European fire parameters underpinned by a large EFFIS fire database. Reports on forest fires in Europe are produced yearly. During the main fire season (June to September), maps of forecasted fire danger disseminated daily to forest services and civil protection services of EU, fire statistics for the on going fire season are exchanged quarterly and newsletters are issued monthly. In addition the EFFIS team responds to ad hoc requests of specific assessments during major forest fire crisis in EU.

For more than 50 years, the UN Food and Agriculture Organisation (FAO) has provided information and technical assistance in the area of forest fire management, including fire terminology, data collection and dissemination, preparation of guidelines on forest fire management, status reports on forest fires and provision of direct advice to member countries. Special attention has recently been given to information and public awareness on related policy, legal and institutional issues. In the framework of the Global Forest Resources Assessment 2005, FAO prepared a thematic study on forest fire management summarizing regional fire management information provided by FAO member countries

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and has recently published Fire Management Voluntary Guidelines [RD-72]. FAO has further been involved in activities in a forest fire research network established within the framework of the Committee on Mediterranean Forestry Questions-Silva Mediterranean, the African Forestry and Wildlife Commission (AFWC) of FAO, European Forestry Commission (EFC) and Near East Forestry Commission (NEFC). Over the past decades, FAO has organized a series of meetings and workshops. The Forestry Department and the FAO Remote Sensing Centre collaborate with the EC JRC as part of the EFFIS.



Figure 24: MERIS Reduced Resolution mode image acquired on 11 December 2005 at 10:45 GMT showing the smoke cloud from the UK Buncefield oil depot fire plume. The depot is located on the edge of Hemel Hempstead, above the cloud around the middle of the image crop seen here (about where the tendril of white cloud touches the black smoke) with the conurbation of London to the south. Also clearly visible in this image is the rich marine environment in the coastal zones (Credit: ESA).

The Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD [RD-36]) is a coordinated international effort working to provide ongoing space-based and in-situ observations of forests and other vegetation cover, for the sustainable management of terrestrial resources and to obtain an accurate, reliable, quantitative understanding of the terrestrial carbon budget. GOFC-GOLD promotes a systematic program for coarse resolution (250 - 1000 m) land cover mapping on a five year cycle, combined with periodic mapping and monitoring of forested areas at fine resolution. The GOFC-GOLD implementation strategy is designed to develop and demonstrate operational forest monitoring at regional and global scales by conducting pilot projects and developing prototype products within three primary themes:

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- Forest Cover Characteristics and Changes
- Forest Fire Monitoring and Mapping
- Forest Biophysical Processes

The GOFC-GOLD-Fire Mapping and Monitoring Theme [RD-74] is aimed at refining and articulating the international requirements for fire related observations and making the best possible use of fire products from the existing and future satellite observing systems, for fire management, policy decision-making and global change research [RD-73]. Full use of data from polar orbiting satellite instruments (e.g. AVHRR, MODIS, ATSR, SPOT Vegetation, Landsat, ASTER) is made for detecting active fires, mapping burned area, assessing fire susceptibility and estimating fire emissions. GOFC-GOLD requires high resolution reflectance and thermal data to provide information to monitor and characterize active fires, to assess fire damage and to monitor post fire recovery. Recent development in active fire detection have included calculation of Fire Radiative Power (FRP) that is related to biomass consumed [RD-59].These data are also required in support of requirements for Active fires and FRP as supplementary products to the Fire Disturbance ECV laid out in the GCOS Implementation Plan [RD-41]. In addition, GOFC-GOLD highlights the need to transition high resolution polar orbiting fire monitoring capability into the operational domain [RD-74].

Satellite observation needs for fire can be divided into three types:

- 1. pre-fire early warning;
- 2. active fire detection; and
- 3. post-fire monitoring.

Monitoring fire characteristics such as active fires (those fires that have flames) and smouldering fires (those fires without flames), burned area, smoke and trace gas emissions and the pre-cursor conditions necessary for large wild-fire outbreaks such as dry areas rich in fuel require specific satellite measurement capability. The distinct flaming and smouldering fire stages are characterized by different fire intensity, temperature, and emission ratios. Smouldering and flaming can be distinguished using infrared remotely-sensed measurements only if the fire temperatures vary significantly between these two stages. Fire early warning requires a time-series satellite vegetation indices at 500 m-1 km provide input for both early warning and vegetation modelling [RD-48]. Fires vary in size, duration, temperature and humidity with some tropical fires having a strong diurnal cycle. High spatial (0.1 - 1 km) and temporal resolution (ideally to resolve diurnal variability) is required over a large range of surface temperatures greater than 750 K depending on the FoV [RD-49]. In a given fire pixel there may be areas that are not burned, areas that are smouldering and areas that are in flame. Many users are interested in the area of land that is burned. This can be obtained through detection and mapping of burn scar area. Based on a review of fire properties [RD-80] flaming temperature can be anywhere between 800 K and 1200 K, and as hot as 1800 K. Smouldering fires are typically 450 - 850 K although the range is probably smaller. NASA MODIS fire products [RD-70] use infrared measurements in the 3.9 and 11 µm with 1 km resolution for this purpose. Fire observations are made four times a day from the Terra AM (10:30 and 22:30) Aqua and PM (13:30 and 01:30) platforms. As there is no on-board calibration for the high-temperature detectors, the pre-launch calibration of the high gain channels is augmented with post-launch vicarious calibration. NASA MODIS algorithm and sensitivity studies [RD-70] assumed that flaming temperature is 1000 K \pm 200 K and smouldering temperature is 600 \pm 100 K.

In support of fire applications, Sentinel-3 should carry a similar capability to the MODIS sensor. However, the priority should be given to marine applications over fire monitoring and additional capability beyond that already provided by ENVISAT should not drive the mission design. The channels used for fire detection need to be capable of detecting flaming fires at \sim 750 K without saturation.

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Burned area mapping is currently performed using data from the near-IR and SWIR parts of the spectrum at $\leq 500 \text{ m}-1 \text{ km}$. For rapid post-burn assessment of fire impact in ecologically sensitive areas, high-resolution data (10–30 m) are ideally required within 48 hours of the fire to assess fire extent, severity and ecosystem and hydrological impact [RD-48].

Sentinel-3 data products should continue the WFA record and ideally improve the fire monitoring capability provided by ENVISAT AATSR. Improvements in dynamic range and spatial resolution would significantly enhance GMES fire related services. Sentinel-3 fire monitoring capability should not drive the Mission design and any implementation should be a secondary priority compared to the primary SST mission.

3.3.3 Inland water surface height data.

Water resources are under great pressure due to major population change/migration and increased demand. There is a growing variability of surface water availability and increasing level of water pollution that is exacerbated by extensive use of groundwater resources that are used at unsustainable rates and/or affected by pollution. Water diversions to serve population centres and intensive agriculture cause a disruption of social and economic development leading to a reduction of ecosystem health in many areas. Climate change is expected to have significant impact on weather patterns and hydrological cycle, affecting surface water availability, soil moisture, and groundwater recharge. Rivers and their tributaries, lakes and wetlands are important resources because major economic activity and development takes place close to their shorelines. Services related to the use and status of major lakes and river systems cover a wide range of user applications including as transport, flooding hazard, water and food resource management, studies of the hydrological cycle, and addressing the impact of land use and climate change.

In 2002, responding to the urgent need for action in Africa stressed by the Johannesburg World Summit on Sustainable Development (WSSD), ESA within the context of the Committee of Earth Observation Satellites (CEOS), launched the TIGER initiative [RD-129]. The aim of the initiative is to assist African countries to overcome problems faced in the collection, analysis and use of water related geoinformation by exploiting the advantages of EO technology. Discussions for GMES-Africa discussions [RD-128] highlight the need for earth observation information to indicate trends in the state of water (and other) resources at continental, regional and local scales.

As a consequence, the effective management of inland water is a major challenge facing governments worldwide. Improved monitoring and forecast information related to the status and dynamics of rivers and lakes provides large benefits in terms of reduced population stresses, preservation of property, and improved economic productivity. Services for hydrological information describing the status and trends of water resources include [RD-125]:

- Assessing a Nations water resources (quantity, quality, distribution in time and space), the potential for water-related development, and the ability to supply actual and foreseeable demands;
- Planning, designing and operating water projects;
- Assessing the environmental, economic and social impacts of water resources management practices—existing and proposed—and adopting sound policies and strategies;
- Assessing the impacts on water resources of other non-water sector activities such as urbanization or forest harvesting;
- Providing security for people and property against water-related hazards, particularly floods and droughts.

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Hydrologists require River and Lake Hydrology (RLH) information (e.g. lake area, lake height differences from reference height, lake volume change, water quality [RD-125, RD-125]). Climatologists and climate modellers require delayed mode time series limnographs for large rivers, their tributaries and lakes with STC and NTC delivery timeliness. These products will support GMES activities related to the implementation of the Water Framework Directive [RD-130], thematic strategies on soil and marine environment, further development of the Community information systems for nature and biodiversity and forests and to the Civil Protection Community Action Programme on Accidents and disasters. These data will complement the European Environment Agency's (EEA) Monitoring and Information Network for Inland Water Resources (Eurowaternet [RD-131]) in situ station network.

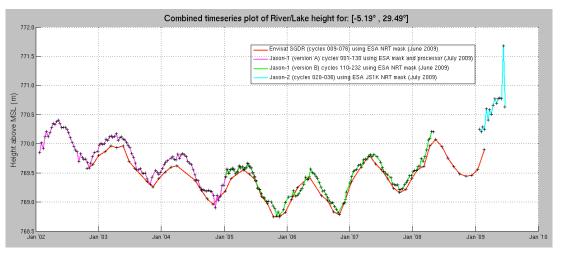


Figure 25: Combined limnograph time series over lake Tanganiyka using data from Envisat, Jason-1 and Jason-2. (Credit: ESA)

In situ hydrological information can often be difficult to obtain due to the inaccessibility of the region, the sparse distribution of gauge stations, or the slow dissemination of data. Unfortunately as the demand for water resources continues to grow, the number and distribution of in-situ hydrological gauge stations is steadily falling and many catchments basins in the developing world have limited measurements [RD-127]. Satellite altimeter data provide quasi global coverage and regular temporal sampling over inland water. Satellite altimetry coverage over land surfaces has been improved as a consequence of additional tracking modes on the ERS and Envisat altimeters, which enable the instruments to track rapidly changing surfaces [RD-79]. Many rivers flood periodically, and/or have a usual wet/dry season cycle, with the extreme situation being intermittent flow. Floods and dry riverbeds are also detectable by satellite altimetry and provide extremely useful information to the hydrological community. Hydrological data derived from satellite altimeter echoes returned from inland lakes can be translated into height estimates by carefully re-tracking individual RADAR altimeter waveforms to monitor their height variation [RD-78] (e.g. Figure 25). The altimeter can also provide useful data for rivers and their tributaries although more complicated processing is required and access to the full resolution waveform data is required in NRT. Using this technique, changes in river and lake heights can be monitored on a global scale. River and Lake Altimetry products (RLA, containing individual retracked radar echo waveforms) delivered to the hydrological services in a timely and operational manner provide complementary data to the limited traditional in situ data in areas that are challenging to measure. Hydrological products from satellites avoid political and logistical problems and can give an accurate height measurement for lakes and large rivers. The ability to obtain altimeter data regardless of

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geo-political location provides water resource planners with additional information beyond river gauge stations [RD-127].

Recognizing the past achievements and current improvements in this field, ESA has developed an easyto-use and accurate product to monitor River and Lake levels [RD-79]. Using satellite altimetry, particularly the near-real-time capability, it is now possible for water resource managers to access both the NRT data and its context -decadal historical information. Figure 25 shows a limnograph produced over Lake Tanganiyka using data from Envisat, Jason-1 and Jason-2 and clearly highlights diurnal and longer term variability in the lake height. Time series limnographs can be constructed long the entire length of a river system to provide a comprehensive overview of water flow (e.g. Figure 26). A satellite based RLH measurement capability directly supports GMES Africa requirements [RD-128] that are now in discussion. The use of Altimeter data for river and lake height monitoring is recognised by the joint IGWCO / WMO / GEO Hydrological Applications and Run–Off Network (HARON) Project as described in the GEO work-plan (sub-task WA-08-01b: Runoff, "Strengthen ...satellite monitoring networks of estuaries, rivers, lakes, reservoirs, and groundwater levels") [RD-137].

The key requirement to enable operational RLH products to mature within GMES is access to individual high resolution altimeter waveforms over rivers, their tributaries and lake targets in NRT. These are then used in advanced altimeter re-tracking algorithms to extract elevation data. Access to L1b altimeter echo waveform data should be provided to users on request (in NTC delivery mode) to allow better validation and uncertainty estimation for the RLH products from Sentinel-3.

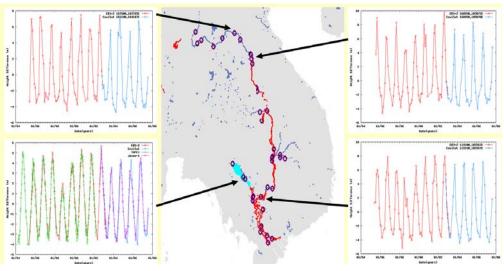


Figure 26: Location of measurements and corresponding ERS, TOPEX, JASON and ENVISAT satellite RADAR altimeter derived limnographs for Mekong River and Tonle Sap Lake 1994-2000. (Credit: ESA J Benveniste)

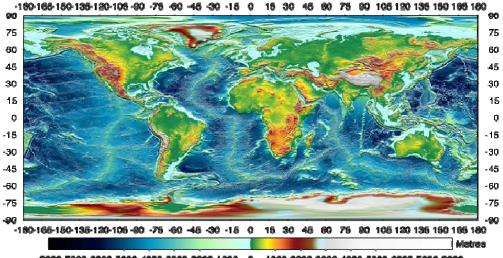
High spatial resolution (1 km or better) lake water surface temperatures (LWST) are required by NWP modelling systems [RD-132] and hydrological services that are tasked with monitoring inland water quality parameters. The GSE Land Information Service [RD-94] provides water quality products including thematic maps and time series of Lake Water quality concentrating on turbidity are provided based on satellite images and in-situ water quality observations. These products serve users of GSE Land services including the Finnish Environment Institute (SYKE) and regional environment centres (RECs). RECs are responsible for national and regional monitoring programmes of surface waters in

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Finland and for the implementation of the Water Framework Directive [RD-130]. Eutrophication is one of the main problems in Finnish lakes and in the coastal waters of the Baltic Sea, resulting from excessive nutrient loading. Reducing nutrient loads to surface waters is a key priority for the Finnish Agri-Environmental Programme. The implementation of agri-environmental measures is followed by interviewing farmers about their cultivation practices at study catchments. In order to calculate potential nutrient losses from these catchments runoff models and are combined with EO based data on seasonal vegetation status and land cover. The results are calibrated and validated with the aid of network of in-situ observations.

Lake colour and temperature (and derived water quality products) are required at high spatial resolution (300 m or better) for these applications. Sentinel-3 should provide VIS data at 300 m resolution (ENVISAT MERIS baseline) for river and lake water quality mapping. Lake Waster Surface Temperature (LWST) could also be provided by Sentiunel-3 at a resolution of 1 km based on the proposed ENVISAT AATSR capability continuity.



3.3.4 Digital elevation models from radar altimetry

8000-7000-8000-5000-4000-3000-2000-1000 0 1000 2000 3000 4000 5000 5000 7000 5000

Figure 27: ACE2 global digital elevation model (DEM) derived from the Space shuttle Radar Topography Mission (SRTM) fused with bathymetry data over the ocean (Credit: ACE2RD-195)

Detailed accurate Digital Elevation Models (DEM) are widely used in earth sciences and form an essential tool for hydrologists working with river networks. DEM data derived from in situ and aircraft measurements have historically been available on a regional scale, and often have uncertainties in both vertical and horizontal precision. Satellite altimeter measurements can be used to derive DEM products and will be of use to GMES services. Satellite radar altimetry height estimation over land targets require careful classification of each waveform according to shape followed by the application of retracking algorithms to obtain the best range to surface measurement [RD-197] (in a similar manner to coastal altimetry discussed in Section 3.2.3). Over flat terrain the processing is relatively simple but over varying topography the retracking process must identify and account for slope components in order to retrieve the nadir range.

The first altimeter-informed Global Digital Elevation Model (GDEM), Altimeter Corrected Elevations (ACE), was created by fusing altimeter derived heights (produced using a system of multiple altimeter

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re-trackers) with ground truth available from a range of publicly available datasets to create an enhanced GDEM [RD-196]. A new ACE2 dataset has been created by synergistically merging the Shuttle Radar Topography Mission (SRTM) dataset together with Satellite Radar Altimetry within the region bounded by $\pm 60N$ [RD-197]. A vertical accuracy of better than 16 m is achieved using this data set at a resolution of ~1 km (Figure 27).

The main altimetry dataset used in the generation of the ACE-2 dataset was the ERS-1 Geodetic mission; which due to its small across track spacing presents a uniquely dense spatial distribution of tracks of Radar Altimeter data over land surfaces. Over the areas lying outside the SRTM latitude limits new matrices derived from reprocessing the ERS1 Geodetic Mission dataset with an enhanced retracking system were used together with data from other satellite altimeters (ERS-2 and Envisat Ku-band are included where appropriate). Altimetry data are better suited to returning ground values within forested areas (as the SRTM data return is somewhere within the canopy). Over both the Amazon and the Congo the areas of rainforest have been completely replaced by an altimetry defined surface within the ACE2 data set.

The Sentinel-3 topography mission should acquire data over land surfaces in support of DEM mapping for use in GMES. Key requirements are:

- Access to high-resolution echo waveform data from the Sentinel-3 altimeter in order to process waveform data over land surfaces for DEM production, develop uncertainty estimates and new local/regional corrections
- Access to passive microwave radiometer and/or appropriate NWP data for wet tropospheric delay corrections over land surfaces.

3.3.5 Snow monitoring Requirements

In order to derive land parameters in high latitudes or for areas of high elevation, maps of snow cover are required. Terrestrial snow has the largest geographic extent of the Cryosphere components. Snow is a crosscutting component of the Cryosphere and influences surface water and energy fluxes, atmospheric dynamics and weather, frozen ground and permafrost, biogeochemical fluxes, and ecosystem dynamics. The high albedo of snow reduces solar energy inputs and promotes lower surface temperatures. The low thermal conductivity of snow allows it to insulate the land surface from large energy losses in winter and reduce the severity of soil frost. Snow also reduces surface friction reducing wind stress and modifying energy exchanges with the atmosphere. These interactions and the large latent heat of fusion strongly influence the land-surface energy budget, with local and regional effects on atmospheric circulation that are now known to propagate globally. The magnitude and timing of snow accumulation and melt are also primary controls on ecosystem carbon exchange in many seasonally snow-covered areas. Snow must be accurately represented in water, weather and climate, and ecosystem models for a wide variety of science and decision-support applications.

Operational hydrology is concerned with water quantity which is the basis also for water quality modelling: this is required by MyOcean, MarCoast, SAFER, G-MOSAIC and GEOLAND activities and as input to MyOcean NOP (river runoff) and MACC NWP systems. Improvements in snow monitoring products will also directly be beneficial for operational water quality assessment. Measurements of several key snow properties are essential to support these models. The consistent, systematic, nature of satellite remote sensing helps overcome some of the functional inconsistencies of surface-based snow observations [RD-82].

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Snow covered Area (SCA) is used in many models as a fundamental control on hydrologic, atmospheric and ecosystem processes. Measurements of the daily geographic extent of SCA extent are essential. Measurements of snow-cover area from satellite visible, near infrared, and microwave sensors have been widely used since 1966 and are reasonably mature, but there are remaining difficulties in discrimination of snow and clouds [RD-82]. SCA is also important for climate change applications [RD-41] and GCOS states that target accuracies should be to 5% located to 1/3 of a IFOV of 100 m in areas of complex terrain or 1000 m elsewhere. A daily revisit is required and stability of the measurements should be 5%.

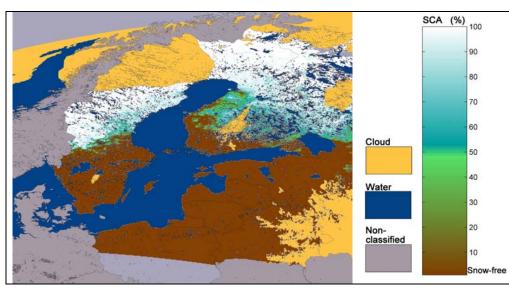


Figure 28: PolarView snow service Snow Cover Area (SCA) map compiled for 24th March 2007. (Credit: PolarView)

Polar View snow monitoring services are provided in three geographical regions: 1) the Baltic Sea Area, 2) Central Europe, and 3) Northern Eurasia. The service supports 11 users from 6 countries (Austria, Estonia, Finland, Germany, Norway and Sweden) including the Austrian General Administration of the federal state of Vorarlberg, Estonian Environment Data Centre, the Finnish Hydrological Service Division of SYKE, the German Flood Forecast Centre HVZ Baden-Württemberg, Flood Information Service Rhineland-Palatinate, Federal Institute of Hydrology, German Weather Service DWD and University of Munich LMU, the Norwegian Water and Energy Directorate (NVA) and Ealat (Reindeer Herders Vulnerability Network Study) and Swedish Meteorological and Hydrological Institute (SMHI).

The NRT service for mapping in the Baltic Sea drainage area is based on daily Terra/MODIS imagery providing SCA for 5 x 5 km grid cells. The processing line includes radiometric and geometric corrections, cloud masking and the actual SCA estimation. Daily geographic coverage is required during the winter season (November to May) for the geographic regions: Scandinavia, Central Europe (including the Alps) and the Baltic Sea basin. Products are currently provided within 1 hour to the end users. It is expected that the SCA snow service will be expanded across the Arctic (circumpolar).

Sentinel 3 L1b and L2 products from the visible and infrared instruments are required over land at a resolution of 1 km or better. A combined L3 product would be of great interest if provided in real time. In order to have best sun conditions and to be in line with flood forecasting centres operational working hours acquisitions over Europe should be made early in the morning (10:00-11:00 am local time).

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Delivery of Sentinel -3 data products must be in NRT and ideally within 1 hour of acquisition in order to meet Polar View requirements.

Observation of snow albedo is required to accurately determine radiation and energy budgets used in NWP and other forecasting services. Snow albedo is also important for climate change applications. Snow albedo varies widely (between 35-95%) and is sensitive to dynamic snow conditions that can be difficult to model and are not normally observed, including grain size and contamination by dust and soot. Snow albedo observations help avoid these difficulties. The observation of broadband snow albedo from satellite sensors, including AVHRR, MODIS, and Multi-angle Imaging Spectro-Radiometer (MISR) is sufficiently accurate (5-10%) for many applications, but snow energy exchanges can be sensitive to small albedo differences. Increasingly, modelling applications require both visible and shortwave-infrared albedo, which is achieved now by compositing multiple scenes with an associated loss of resolution due to geo-registration limitations. Improvements in optical sensors and geo-registration accuracy are required to support multi-band albedo with sufficient resolution [RD-82].

Observation of snow surface temperature is also important for determination of energy budgets and related processes such as snowmelt. Modelled temperatures for the snow surface and internal volume are sensitive to errors in model forcing and fluxes; they propagate to subsequent radiative and turbulent fluxes, impacting estimates of water and energy budgets and the timing of snowmelt. Accurate temperature observations help constrain such errors and increase confidence in model results. Satellite derived snow surface temperatures could be very useful to help constrain the energy components of contemporary snow and land-surface models, but the currently attainable accuracies over snow are insufficient for this purpose. The nonlinear behaviour of snow near 273 K and the tendency for propagation of errors in snow surface temperature requires observation accuracy on the order of 1 K or less [RD-82].

The GSE Polar View [RD-117] program also provides services for rivers, lakes and glaciers:

- **River Ice Monitoring**: River ice monitoring services deliver EO-derived information about the location and extent of river ice covers to decision makers in near real-time. This information is typically used to in conjunction with other data sources to assess the level of threat posed by the formation of ice dams and to facilitate early warning and risk mitigation.
- **Lake Ice Monitoring**: the lake ice monitoring service delivers EO-derived information about the location and extent of ice covers to decision makers in near real-time. This information is typically used in conjunction with other data sources to assess the level of threat posed by the freezing and melting. The freeze-up and the break-up dates are an indicator of the impact climate change is having on the environment.
- **Glacier Monitoring**: The glacier monitoring service provides decision support tools for endusers using earth observation (EO) and numerical modelling. End-users are typically water resource regulators with links to the hydropower industry, environmental managers and related policy administrators. To this end, the service provides monitoring products and integrated glaciological analyses focusing on the impact of climate change on glacial discharge, current mass balance distribution and glacier dynamics and stability. Products and services employ a combination of EO data processing and analysis and surface energy balance modelling. Opticalthermal data will be used to support the energy balance modelling.

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3.3.6 Summary of GMES Land Service Requirements

Table 4 provides a summary of GMES land service requirements based on the previous examples given in this document.

| Table 4: Summary of GMES Land service Requirements [RD-120 RD-119, RD-123, RD-124, RD-128, RD- |
|--|
| 129, RD-136, RD-152, RD-154, RD-172]. |

| Service/User | Application(s) | Measurement Parameter | Spatial resolution | Geographical Coverage | Delivery Requirement | Revisit Time |
|--|---|--|--------------------|--------------------------|-------------------------|---|
| LCMS, GEOLAND, GMFS, GlobCarbon, RESPOND, GSE-Land, GSE-FM, GMES-Africa, SAFER | Global land and ocean monitoring in Plate-Carrée projection (PLC) | SPOT/Vegetation P-product like TOA reflectance in bands similar to SPOT/ Vegetation | ≤300 m | Global | NRT, 3 hours | Daily |
| LCMS, GEOLAND, GMFS, GlobCarbon, RESPOND, GSE-Land, GSE-FM, GMES-Africa, SAFER | Vegetation and crop monitoring | LAI, fCover, fAPAR, Dry Matter Productivity (DMP), NDVI | 0.3 -1 km | Global | Daily, NRT | 10 days |
| LCMS, GEOLAND, GMFS, GlobCarbon, RESPOND, GSE-Land, GSE-FM, GMES-Africa | Vegetation, forest and crop monitoring | Time series of vegetation products (e.g. MTCI, VGT-P) | 4 km | Global | NTC (10 days) | 10 days |
| EEA | Corine land cover specifications | MERIS FR biophysical products. | 300 m | Europe | NTC | Annual (updates every 3-5 years) |
| LCMS, GEOLAND, GMFS, GlobCarbon, RESPOND, GMES-Africa | Biophysical monitoring, | MERIS FR biophysical products, VGT-P. | 300 m | Europe | NRT | 10 days |
| LCMS, GEOLAND, | Biophysical monitoring | Land Surface Temperature | <1 - 5 km | Global | NRT | 3 hours, Daily and 10 days |

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| GMFS, GlobCarbon, RESPOND, GMES-Africa | | | | | | |
|---|---------------------------|---|-----------------------------------|--------|-----|-------------|
| LCMS, GEOLAND, GMES-Africa | Biophysical monitoring | Surface Albedo | 1 - 5 km | Global | NRT | 10 days |
| LCMS, GEOLAND, GMES-Africa | Biophysical monitoring | Water Bodies + seasonality | 1 km (goal ≤300 m) | Global | NRT | 1 - 10 days |
| LCMS, GEOLAND, GMES-Africa | Biophysical monitoring | Soil Moisture + Freeze/Thaw | < 1 km (goal 100 m) – 25 km | Global | NRT | Daily |
| LCMS, GEOLAND, NWP GMES- Africa and Hydrological Services, GSE Land Information Service | Biophysical monitoring | Lake surface Temperature | 1 km (goal ≤300 m) | Global | NRT | Daily |
| LCMS, GEOLAND, GMES-Africa, NWP and Hydrological Services, GSE Land Information Service | Biophysical monitoring | Lake water Quality | 1 km (goal ≤300 m) | Global | STC | Daily |
| PREVIEW, FAO, GOFC- GOLD, EFFIS, MACC, GMES- Africa | Fire early warning | Global vegetation index maps | 0.5 – 1 km | Global | NRT | Daily |
| PREVIEW, EFFIS, GOFC- GOLD, FAO, MACC, GMES- Africa | Fire Monitoring | Active fire detection (Fire Radiative Power) and hot spots. | <0.5 - 1 km | Global | NRT | Daily |
| LCMS, GEOLAND, GMFS, GlobCarbon, RESPOND, | Fire monitoring | Burnt areas and seasonality, Active Fire Monitoring (FRP) and | 1 km | Global | NRT | Daily |

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| SAFER, GOFC-GOLD, Risk EOS, GMES-Africa | | effects, | | | | |
|--|--|--|---|----------------------|---|---------|
| PREVIEW, EFFIS, GOFC- GOLD, FAO, MACC, GMES- Africa | Fire monitoring | Post fire monitoring (Burned area mapping/Fire disturbance) | 0.5 - 1 km | Global | NRT | Daily |
| NWP and Hydrological Services, GSE Land information, GMES-Africa Service | Monitoring changes in river and lakes [RD- 78, RD-79] | River and lake height data referenced to an orthometric height | <1 km | Regional- Global | NRT/NTC | 10 days |
| NWP and Hydrological Services, GSE Land information, GMES-Africa Service | Monitoring changes in river and lakes [RD- 78, RD-79] | Full resolution altimeter L1b echo waveform data | - | Regional | NTC | |
| NWP and Hydrological Services, GSE Land information, GMES-Africa Service | DEM mapping | Full resolution altimeter L1b echo waveform data | - | Regional | NTC | |
| PolarView, Hydrological services, Land monitoring | Snow Monitoring | Snow Covered Area | at 250m – 10km resolution with 10- 25% accuracy respectively [RD-82] for climate: 5% located to 1/3 using a IFOV of 100 m in areas of complex terrain or 1000m elsewhere RD-41] | Regional coverage | NRT (1-24 hours from acquisition) | Daily |

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| | | | | | | 000 |
|--|------|-------------|------------|----------|----------|-------|
| MACC, NWP, Climate Centres, land services | Snow | Snow Albedo | 5% [RD-41] | Regional | RD-1 NRT | Daily |

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3.4 GMES Atmospheric Service

The GMES Atmospheric Service (GACS) [RD-55] has developed based on the ongoing pre-operational activities of EU-funded Global and regional Earth-system (Atmosphere) Monitoring using Satellite and in-situ data (GEMS) project [RD-64] and ESA PROtocol MOniToring (PROMOTE) project [RD-77]. The GACS [RD-55] aims to integrate the monitoring and modelling of every atmospheric constituent at global and regional scales, and enabling further services at more local scales in an operational manner by 2014.

The GEMS project [RD-64] has developed comprehensive data analysis and modelling systems for monitoring the global distributions of atmospheric constituents important for climate, air quality and UV radiation, with a focus on Europe. The systems provide the basis for value-added data and information services to be developed as part of GMES that:

- Provide global data in support of conventions and protocols on climate change, depletion of stratospheric ozone and long-range transport of atmospheric pollution;
- Provide information in support of development and implementation of European environmental policy;
- Address areas of key uncertainty in climate forcing identified by the Intergovernmental Panel on Climate Change (IPCC);
- Provide improved operational air-quality forecasts and a means for assessing the impact of climate variability and change on regional air quality;
- Provide improved monitoring and forecasting of UV radiation and solar-energy resources;
- Support downstream services for end-users;
- Complement the weather and climate services provided by the European Meteorological Infrastructure.

GEMS built on existing infrastructure and in particular the global weather forecasting system operated by the European Centre for Medium-Range Weather Forecasts (ECMWF). ECMWF and its partners in the project have added a capability for analysing and modelling the distributions of key greenhouse gases, chemically reactive gases and aerosols. The resulting integrated system is capable of assimilating a wide range of meteorological measurement data, associated ocean-wave and land-surface data, and the increasing amount of data on atmospheric trace constituents provided by satellite instruments. The broad-scale air-quality products of the global system are complemented by products from an ensemble of finer-resolution forecasts generated by ten regional air-quality models that have been adapted to run over a common European domain. The regional models use common meteorological driving conditions from ECMWF's operational weather forecasts and take lateral boundary values of trace constituents from the global GEMS system. This ensemble system is run daily, and is also being used in studies of particular events from the extreme year of 2003.

The GSC PROMOTE project [RD-77] provides GMES services for the ozone layer, UV-exposure on the ground, air quality, aviation, climate change and special applications. Services are directed at the needs for information on environment and climate by public authorities and governmental agencies and the general public. PROMOTE provides services in the following areas:

- Ozone monitoring and forecast,
- UV monitoring and forecast,
- Air Pollution monitoring and forecast,
- Climate Change monitoring and emissions,

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• Special services (e.g. volcanic ash cloud warnings, dedicated products for aviation),

The Modelling Atmospheric Composition and Climate (MACC) [RD-76]) together with other projects (e.g. GEMS and PROMOTE) serve as platforms for GACS implementation. MACC is the current preoperational atmospheric service of the European GMES programme funded under FP-7. MACC operates a value-adding chain which extracts information from as wide a range of observing systems as possible (including extensive use of satellite data). The system combines information in a set of data and graphical products that have more complete spatial and temporal coverage and are more readily applicable than the data provided directly by the observing systems. The products delivered by MACC are based on the requirements established for the atmospheric component of GMES and include:

Global service lines:

- monitoring of aspects of climate, climate forcing and the sources and sinks of key species;
- monitoring of stratospheric ozone;
- providing forecasts of reactive gases and aerosols;
- providing boundary conditions for regional models.

European service lines providing:

- air quality forecasts from high-resolution regional systems;
- air quality assessments based on retrospective running of the regional systems using validated observational data;
- UV radiation assessments and forecasts;
- solar-energy resource assessments and forecasts.

Although the primary application of MACC boundary conditions for regional models provided by the global system is in support of the regional models run for Europe as part of MACC, they may be used to drive other models for the European region or models run over other regions of the world. For example to support humanitarian aid activities or because of European special interest in a specific region. MACC provides both "primary" and "derived" products. Primary products are defined to be the direct outputs of the global and regional data assimilation and forecasting systems employed in MACC. Derived global and regional products are the results of further processing of the primary outputs. MACC also provides derived observational and emission products based on the satellite data retrievals and estimates of fire and other emissions that it generates primarily to meet the input needs of its global and regional processing systems.

MACC is developing services to support institutions that are providing advice and warnings related to atmospheric composition. For example nine international Volcanic Ash Advisory Centres (VAAC) are responsible for advising international aviation of the location and movement of clouds of volcanic ash (e.g. see <u>http://www.metoffice.gov.uk/aviation/vaac/</u>). MACC has the capability to make pre-operational volcanic ash plume forecasts using its advanced data assimilation system for atmospheric composition. Assumptions have to be made about the amount of gas and ash, particle size and weight, and the height of the volcanic injection of constituents into the atmosphere. The latter depends to a large extent on the explosiveness of the eruption. Figure 29 shows the plume of a sulphur-dioxide-like tracer (total columns) as forecasted by the MACC system using a London VAAC injection height estimate. When MACC reaches its operational phase, by 2014, it will be able to use actual information for specific volcanic eruptions in combination with operational observations of atmospheric constituents (e.g. derived from Sentinel-3) to produce plume forecasts in a timely manner. These will be provided on request to the relevant institutions to help them assess the situation and provide detailed information. This would include the VAAC but also agencies dealing with the impact on public health.

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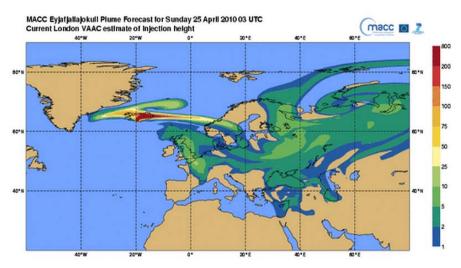


Figure 29: Plume of a sulphur-dioxide-like tracer (total columns) as forecasted by the GMES MACC system with a London VAAC injection height estimate. (Credit: MACC)

3.4.1 Numerical Weather Prediction (NWP) and GMES Atmospheric services

Underpinning the GMES atmospheric services are NWP models and associated data assimilation systems. These systems require that an uncertainty estimate is provided with all satellite measurements for use in the assimilation process. Output from such models (particularly from ECMWF) also provides a core input to satellite geophysical retrieval algorithms and forcing for other models in the marine domain (e.g. MyOcean NOP systems require surface winds and atmospheric flux data, wave and storm surge forecast models). MACC requires satellite data from many instruments supplying information on atmospheric dynamics, thermodynamics and composition to constrain the underlying NWP model. Satellite data are supplemented by in-situ data from meteorological networks and a limited amount of data from networks providing in-situ measurements of atmospheric ozone, and UV radiation at the earth's surface and resources for solar power generation. Additional in-situ data are used for validating the processing systems and the products they supply. Data from ENVISAT instruments is used widely in satellite radiance product data assimilation schemes (e.g., ECMWF and the Met Office UK) that underpin NWP and climate re-analysis systems.

Primary products that are required by the GMES Atmospheric services include access to optical L1b data products (with uncertainty information) in NRT for use by NWP assimilation systems and the analysis and forecast of aerosols, both global and with a higher-resolution European focus. Atmospheric aerosol has the widest range of impacts affecting the forcing of climate, air quality, atmospheric visibility and cloud/precipitation processes. The need of satellite based monitoring of the aerosol optical thickness and aerosol type for air quality and climate protocol monitoring, near-real time services and assessment have been identified in an ESA study [RD-60]. Global aerosol data coverage is required from Sentinel-3 including products that are contiguous over land and sea: it is highly undesirable to have step changes between products produced by algorithms developed for land and those used over the ocean. Other products required by NWP systems include information on fires, and column water vapour over land, Hs and SST. These parameters have been explicitly requested by the GMES Atmospheric Service

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coordinator [RD-75]. Lake and river surface temperatures are also required for NWP modelling [RD-132]. Sea ice (already discussed in the context of the MCS in Section 3.2) and snow information (e.g. snow water equivalent, snow cover area/fraction, albedo) are important for the surface schemes in NWP models providing forecasts in areas with potential snow cover. In addition, snow cover also changes the albedo of the surface, which has a strong influence on the radiation budget of the model. Other key requirements include continuous atmospheric aerosol with global coverage and fire products over land.

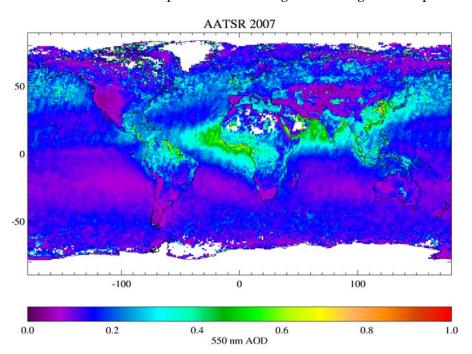


Figure 30: An example of a GlobAerosol product: aerosol optical depth for the year 2007, derived from Envisat AATSR data using 550 nm channel data using the ORAC (Oxford-RAL Aerosol and Cloud) system (http://www.globaerosol.info/). (Credit: GlobAerosol)

The atmospheric service has a key interest in using aerosol data products derived from Sentinel-3 data products. Atmospheric trace gas retrievals from the Sentinel 4/5 system in UV-Vis-SWIR rely on auxiliary information on the aerosol [RD-61]. The Sentinel 5 mission concept includes a dedicated aerosol instrument, which is an imager with multi-angle polarimetric hyper-spectral capabilities. However, before this aerosol instrument becomes operational (which will be earliest 2018), Sentinel 3 ENVISAT AATSR and MERIS follow-on instruments are very suitable for aerosol characterization in the context of GMES. The atmospheric trace gas retrievals from Sentinel 4 and Sentinel 5 Precursor will profit from a synergetic aerosol product from the Sentinel 3 Ocean and Land Colour (OLC) Imager and the dual view Sea and Land Surface Temperature (SLST) instruments. A synergetic aerosol product can be developed combining the column integrated aerosol data from Sentinel 3 with the aerosol information from Sentinel 4/5. Observations with high spectral resolution in the O_2A band from the Sentinel 4/5 can add information on the vertical distribution of aerosol [RD-62], while observations in the UV are suitable to constrain the aerosol absorption also over bright surfaces including clouds [RD-63].

The GMES atmospheric service project recognises that atmospheric aerosol products has the widest range of impacts affecting the forcing of climate, air quality, atmospheric visibility and cloud/precipitation processes. L1b optical instrument radiance data products from infrared and visible

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channels are routinely used in NWP and re-analysis model runs and should be made available from Sentinel-3 in NRT together with uncertainty estimates [RD-55]. As NWP systems assimilate data on 3-6 hourly (typical) cycles, revisit and timeliness requirements are particularly high. While Sentinel-3 is not optimised for these requirements, the mission will provide valuable data for NWP systems in the context of the global constellation of meteorological satellites.

3.4.2 Summary of Atmospheric Service Requirements

Table 5 provides a summary of GMES atmospheric service requirements based on the previous examples given in this document.

| Table 5: Summary of GMES Atmospheric Service Requirements taken from [RD-55, RD-64, RD-76, RD- |
|--|
| 77, RD-82 , RD-118 , RD-172] |

| Service/User | Application(s) | Measurement Parameter | Spatial resolution | Geographical Coverage | Delivery Requirement | Revisit Time |
|--------------|--------------------------------|---|----------------------------------|--|-------------------------|--------------|
| GACS, MACC | NWP, air quality monitoring | Atmospheric aerosol Optical Thickness (AOT) (optical and chemical properties). Products shall be consistent over land and ocean. | 15 km global | Global, higher resolution in EU. | NRT | 3 hours |
| GACS, MACC | NWP | VIS, SWIR, NIR and IR radiance data (L1b) | 1 - 5 km global | Global, higher resolution in EU | NRT | 3 hourly |
| GACS, MACC | NWP | Column water vapour over land | 5 km global,0.5- 2 km EU | Global, higher resolution in EU | NRT | 3 hourly |
| GACS, MACC | NWP | Hs | 15 km global, 5 – 10 km EU | Global, higher resolution in EU | NRT | 3 hourly |
| GACS, MACC | NWP | SST | 5-10 km | Global, higher resolution in EU | NRT | 3 hourly |
| GACS, MACC | NWP | Lake Water Surface Temperature | 0.1 – 1 km | Global, higher resolution in EU | NRT | 3 hourly |
| GACS, MACC | NWP | LST | 1 – 5 km | Global, higher resolution in EU | NRT | 3 hourly |
| GACS, MACC | NWP | Snow albedo | 1 – 5 km | Global | NRT | 3 hourly |
| GACS, MACC | NWP | Snow Covered | 1 – 5km | Global | NRT | 3 hourly |

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| | | Area | | | | |
|--|--------------------|--|---|----------------------|---|----------|
| GACS, MACC | NWP | Fire products | 0.01 – 10 km | Global | NRT | 3 hourly |
| GACS, MACC | NWP | Cloud optical properties (from L1b Imagery) | 1 – 5 km | Global | NRT | 3 hourly |
| GACS, MACC | NWP | Sea Ice Thickness 20 – 50 cm accuracy | 15 – 50 | Global | NRT | 1 5 days |
| MACC, NWP, Climate services, Hydrological services | Snow Monitoring | Snow Covered Area | at 250m – 10km resolution with 10- 25% accuracy respectively [RD-82] for climate: 5% located to 1/3 using a IFOV of 100 m in areas of complex terrain or 1000m elsewhere RD-41] | Regional coverage | NRT (1-24 hours from acquisition) | Daily |
| MACC, NWP, Climate Centres | Snow Monitoring | Snow Albedo | 5% [RD-41] | Regional | RD-2 NRT | Daily |

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3.5 GMES Emergency Response Service (ERCS)

Vulnerability to natural disaster impacts is one of the greatest obstacles to sustainable development. Disasters cause major setbacks to economic and social development. GMES addresses these issues within a GMES Emergency Response Service (ERCS).

3.5.1 GSE-Global Monitoring for Food Security (GMFS)

GSE-GMFS [RD-101] is a project to monitor global vegetation and food security with a focus on the Africa [RD-128]. It addresses three priority themes:

- Global vegetation monitoring, contributing to assessment of food security world wide.
- Support to regional development aid, focusing on land applications in Africa, and including technology transfer.
- Systems for crisis management and humanitarian aid.

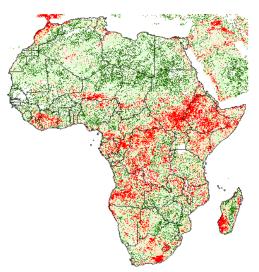


Figure 31 GMFS Vegetation Productivity Indicator (VPI) for 2009 dekad 36. Red colours indicate a very low probability VPI (0-20%) and green areas indicate a very high probability VPI (81-100%). Data from http://www.gmfs.info/service/dynmap.php.

GMFS initially concentrated on Sub-Saharan Africa and focused on end-users from regional and national organizations with a mandate for agricultural monitoring for food security and early-warning of food crises. The project tries to meet the needs of users in international organizations such as the EC JRC MARS-FOOD unit, the UN FAO and the World Food Programme(WFP). All these users play a major role in defining and assessing the services offered by the project. GMFS products and services are tailored to meet the information requirements of these core users and include:

• **Early Warning**: Vegetation Productivity Indicator (VPI) and fAPAR products based on MERIS reduced resolution (~1 km) data. VPI is used to assess the overall vegetation condition and is a categorical type of difference vegetation index, referenced against the NDVI percentiles of a historical year. The VPI method is a statistical distribution of the NDVI for each 10-day period of the year by applying techniques commonly used in hydrology for the prediction of extreme

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events. Products cover different geographic areas, depending upon the user requests including Africa, West Africa, Southern Africa, Senegal and Sudan.

- **Agricultural mapping**: Dedicated products provide an estimate of cultivated area over selected local areas based on satellite SAR, optical and ground measurements. Extent of Cultivation products provide a map of cultivation at country level, based on a combination of medium resolution optical data, calibrated with SAR, high resolution optical data and ground observations.
- **Crop Yield Assessments**: Crop yield forecast products derived at (sub-) national level up to the administrative boundary level are based on a yield model obtained from a statistical analysis (stepwise regression). This relates yield to phenological, meteorological and EO derived variables.
- Support to joint FAO/WFP Crop and Food Supply Assessment missions (CFSAM): Geo-information packages are provided based on a compilation of satellite derived data products. Each package is tailored to the specific requirements of FAO and WFP, the country considered and based upon the available data. In 2005 this included forecast of crop yield at the end of the growing season, or an analysis of the crop state indicators (e.g. VPI) in relation to available yield and production statistics. Quick assessments of cropped areas are also provided based on a combination of high resolution and medium resolution data in relation to available area statistics.

In May 2010 ESA approved a follow on GMFS proposal that started in June 2010 and will last for three years (May 2013). The key requirement from Sentinel-3 is continuity of MERIS FR data products and reflectance's, continuity of AATSR data. Altimeter derived river and lake height products could also be of use.

3.5.2 GSE RISK-EOS

The ESA GSE RISK-EOS project [RD-121] is a network of European service providers delivering geoinformation services to support the management of flood, fire and other risk throughout all phases including prevention, early warning, crisis and post crisis phases. The RISK-EOS services combine satellite observation data with external data and modelling techniques to develop products and services for all risk management actors at European, National and Regional levels including:

- Civil protections, fire fighting and rescue services,
- Land planning and risks prevention services,
- Territorial communities.

Services have been defined during the first stage of Risk-EOS (2003-2004) based on priorities expressed by a "core users" spread throughout Europe. Risk-EOS stage 2 (2005-2008) extended this service portfolio with additional services to new users and European regions. For example, flash flood risk maps are provided based on previously recorded events. The risk of flash floods is classified into three different levels representing the return period to be expected. The classes represent a return period of 2 to 10 years, 10 to 50 years and over 50 years. RISK-EOS services have been developed and qualified in close synergy with operational users in European countries, federated by the National Civil Protection services of France, Germany, Italy, Spain and Sweden.

RISK EOS provides services for flood early warning mapping and support products for current flood events, assisting crisis management planning for civil protection services and regional authorities. Structural and dynamic basin parameters of river catchments are derived from satellite observation including topography, land cover, soil moisture and snow cover. The service provides rapid mapping

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products showing the instantaneous extent and impact of the flood at very high resolution and short timescales (the first products are delivered within 8 h after crisis EO data reception). Services support major events under the International Charter for Space and Major Disasters [RD-138] both directly to local organisations (city, department or region) and for events with narrower geographical extent. NRT products are provided for information support during the crisis, and NTC products are developed by regional correspondents for post-crisis exploitation. All products are geo-referenced according to the users map projection system and can be directly integrated into user Geographic Information Systems.

Satellite requirements focus on the provision of high resolution (1-250 m) measurements over land (e.g. MODIS, Landsat, SPOT etc), including river, river tributary and lake surface heights (stage). While this resolution is beyond the optical instrument capability proposed for Sentinell-3, the Mission can provide baseline moderate spatial resolution (but with high spectral characteristics) maps and further contribute to fire and flood monitoring activities. During fire crises, Sentinel-3 can provide reliable information on the extent of fires and support damage assessment. For fire prevention, Sentinel-3 can support the preparation of fire area risk maps (at 0.3-1 km resolution) to prepare strategies for fire management including emergency service deployment and civilian rescue plans. In addition, seasonal burn scar mapping services provide seasonal information products to support Fire Fighting Plans at Regional/Provincial scale, Environment and Natural Resources Planning at Regional/Provincial Scale (yearly or less frequently) and of Land Conservation Planning at Regional/Provincial Scale.

In the case of flood prevention mapping, river, river tributary and lake height levels can be used to monitor the river/lake stage status of river systems prone to flooding. Land colour measurements (at 300m) can be used to monitor the extent of flooding complementing other higher resolution satellite measurements.

3.5.3 GSE RESPOND

The GSE RESPOND project provides GMES services in support of humanitarian relief, disaster risk reduction and reconstruction [RD-169] RESPOND is an alliance of European and International organisations working with the humanitarian community to improve access to maps, satellite imagery and geographic information. The RESPOND service provides:

- guaranteed access to global mapping for crisis hotspots,
- access to an archive of detailed base mapping and thematic mapping,
- access to rapid assessment maps for major crisis.

The RESPOND project increases the efficiency and effectiveness of European and international humanitarian community through the appropriate and reliable application of geographic information. Respond aims to work:

- In all parts of the disaster risk management cycle (Figure 32) where geographic information (GI) is useful
- In both slow (e.g. famine) and Fast (e.g. earthquake) onset crises
- Where GI is useful in the better deployment of development aid
- With pure mapping as well as satellite derived information
- To provide support services training and in field support
- To provide support to forecasting and alerting services

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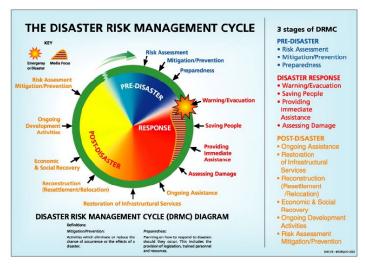


Figure 32: Disaster Risk management cycle (DRMC) used by the RESPOND Service (Credit: RESPOND) RESPOND provides the following core services:

- **Basic Mapping Service** (providing a baseline set of products for other services using satellite and paper maps),
- **Crisis and Damage Mapping Service** (rapidly available maps based on EO and other detailing the effects of a given crisis),
- **Situation Mapping Service** (maps and GIS layers made available to field users for rapid update, these maps particularly rely on field information to ensure update accuracy),
- **Refugee and Internally Displaced People (IDP) Support Mapping Service** (includes both maps and GIS layers, detailing Refugee camps, water sources, health resources etc),
- **Thematic Mapping Service** (information such as health mapping, environmental mapping, maps for prevention/reconstruction purposes),
- Alert Services (complementing web alert systems with map information),
- Communication / Reporting Services (ad hoc mapping and graphics),
- **In-Field Data Collection and Field Mapping Service** (support to RESPOND services by providing in situ data and to train users/potential users during a crisis situation).

Refugee Camp and other Situation Maps [RD-169] are important for field, regional and coordination staff to take informed decisions within a common reference frame. Situation maps provide relevant and up-to-date thematic information; for example, location of actors and what they do in the operational environment (who-what-where), road access, climatic conditions, destroyed health centres, security zones, etc. Tailored maps help to form the basis of this common decision-making frame. However, in rapidly evolving operations, situation maps change frequently and services are designed specifically to fit this type of dynamic humanitarian operation.

The primary source of EO data required is optical high and very high resolution imagery with resolutions of 1-10 m although spatial scale requirements vary between various RESPOND services. Sentinel-3 can provide 0.3 - 1 km resolution background maps in the VIS, SWIR and TIR spectral region together with Inland River and Lake Heights in support of complementary high resolution mapping capabilities provided by other satellite systems including Sentinel-1 [RD-31] and Sentinel-2 [RD-92].

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3.5.4 GMES Emergency Response Service (SAFER project)

The pre-operational emergency service of GMES is currently provided through the FP-7 project GMES Services and Applications for Emergency Response (SAFER) project [RD-139] which builds on the activities of RISK-EOS [RD-121] and RESPOND [RD-169]. SAFER services address a wide range of emergency situations such as floods, fires, landslides, earthquakes, volcanic eruptions and humanitarian crisis:

- **The SAFER flood service** [RD-139] provides services at European level and includes plain flood and flash flood risk analysis. The Plain Flood Risk Management service provides decision-making tools which include the mapping of past floods, potential flood damage maps and flood information service. The Flash Flood service is a demonstrator service to be implemented within the framework of each local or national hydro-meteorological operator having specific responsibilities in a country, region or basin prone to flash floods.
- The SAFER fire service [RD-140] includes Fire Monitoring at moderate resolution (FMM), Burnt Scar Mapping (BSM) and Global Fire Risk (GFR). The FMM service provides maps of fire hot spots and a rapid mapping of burnt area. The BSM service provides burnt scars maps based on high resolution satellite imagery. The service help users in analysing fire impacts, performing vegetation damage assessment and designing recovery plans. The GFR service provides forecast of danger maps and is useful to support prevention activities, with special emphasis during active fire management providing information identifying and evaluation the fire risk area.
- **SAFER Earthquakes and Volcano services** [RD-141] include earthquake monitoring and damage assessment services provides soil displacement maps for the prevention phase. During crisis phases, it also monitors co-seismic displacements and performs damage detection in urban areas. The volcano-related service addresses risk management during the whole management crisis cycle (pre-crisis / crisis / post crisis)
- **The SAFER Humanitarian Crisis service** [RD-142] provides a rapid mapping capacity when crisis occur. It also supports preparatory activities through the collection and mapping of spatial and socio-economic data.

The first priority of SAFER is the short term improvement of response when crisis occurs, including a rapid mapping capacity after disastrous events and the support to the relevant preparatory services (i.e. development of baseline reference maps). The main performance criterion is the response time of the service. The second priority of the project is to extend the service components before and after the crisis. It targets the longer term service evolution, through the provision of thematic products, to be added in the portfolio of services. The main performance criterion is the added-value of products with risk-specific information. In SAFER, thematic products will cover mainly the meteorological and geophysical risks.

GMES SAFER is configuring services that guarantee that Europe can provide adequate information capabilities to support early warning, urgent assistance, relief operations, humanitarian aid and, reconstruction activities in a long-term sustained manner. SAFER requires high-and medium (0.001 - 1 km) resolution rapid mapping capability using satellite data after disastrous events occur in a timely manner and measurements for preparatory services to map spatial and socio-economic data in areas at risk. The operational timely integration of satellite, airborne and ground survey are essential to the service.

Atmospheric aerosol maps from the Sentinel-3 optical mission will be extremely useful during major volcanic eruptions helping to map the spread of aerosols that pose a threat to aviation. The eruption of Icelandic Volcano Eyjafjoll on Wednesday Apr 14th 2010 closed over 100,000 flights in Europe

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(expected to carry around 10 Million passengers) for 3 days when volcanic ash clouds spread across the European continental area [RD-143]. IATA [RD-145] estimates suggest ~\$1.7 billion damage to airlines as a consequence of the volcanic ash cloud. New procedures to manage volcanic ash cloud emergency events were introduced by EUROCONTROL [RD-144] during the Eyjafjoll event that made full use of satellite volcanic ash plume maps to constrain NWP transport modelling systems during the crisis.

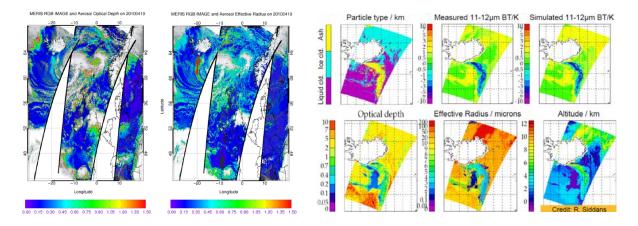


Figure 33 Example volcanic ash products from MERIS (left) showing AOD and effective aerosol radius for 19th April 2010 and AATSR (right) showing retrieved parameters from the Oxford-RAL retrievals of aerosol and cloud (ORAC) system. From [RD-147].

A recent workshop ESA/EUMETSAT Workshop on Volcanic Ash Plume Monitoring [RD-146] showed that showed the use of ENVISAT AATSR and MERIS data used in synergy to map the Eyjafjoll plume spatial extent and dispersion. The MERIS wide swath provides good spatial coverage which is complemented by the dual-view AATSR that can estimate plume height using stereo imaging techniques. The AATSR NIR-TIR bands can be used in the detection of large particles, as well as plume height from brightness temperature difference maps. Both instruments provide qualitative information to discriminate between ash and water/ice clouds. AOD can be estimated by column integrated extinction in clear sky conditions providing quantitative information (although no distinction between ash and liquid/ice clouds and other aerosols can be made when they are mixed in the column). MERIS estimates of the Ångström exponent provide information on the effective radius of the aerosol load. ENVISAT AATSR and MERIS when used together with other satellite instruments provide unique observations of volcanic ash plume characteristics over the ocean, an area which otherwise would only be accessible by airborne observations and in the initial stage of plume evolution [RD-147].

Recommendations from the ESA/EUMETSAT Workshop on Volcanic Ash Plume Monitoring [RD-148] relevant to Sentinel-3 call for:

1 Access to all data sources for volcanic plume observations in Europe should be accelerated, improved and open

4. Concerted developments should be undertaken to integrate existing advanced retrieval methods into operational systems:

4.6) TIR and shortwave (UV and VIS) ash cloud observations should be combined to derive particle size distribution. TIR are mainly sensitive to large particles (> 1 micron) and shortwave are sensitive also to small particles l (< 1 micron).

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6. Relevant satellite observation systems and data products should be formally validated with observations from other sources and should, where appropriate, be certified versus quantitative requirements for volcanic plume monitoring

6.2) Satellite retrievals and dispersion model results should be inter-compared to each other e.g.:

- AOD, particle type, effective radius, cloud height and location;
- AOD and range of heights from SEVIRI, PARASOL, MISR and AATSR;
- Effective radius from SEVIRI, MISR, MODIS, AATSR, MERIS

7. Actions should be taken to ensure that planned future European satellites will provide more efficient and guaranteed support for ash cloud related crises; both operational (MTG, Sentinels) and research missions

7.9) Consistent aerosol information products should be provided from SLST and OLCI on Sentinel-3.

Sentinel-3 visible and infrared radiances will provide measurements that can be used to map the spatial extent of volcanic ash plumes in the same manner as ENVISAT AATSR and MERIS but with improved coverage and spectral resolution. The key requirement is the continuity and operational availability of L1b optical data for use in advanced rapid-prototype algorithms and NWP data assimilation systems for volcanic ash plume tracking.

Sentinel-3 can provide land colour and surface temperature data at medium resolution (0.3 - 1 km) to support SAFER activities throughout emergency crises with global coverage and a revisit of 1-3 days. In addition river and lake height data will also be useful to SAFER flood activities.

3.5.5 Land and Sea Monitoring for Environment and Security (LIMES)

The EU FP-6 LIMES (Land and Sea Monitoring for Environment and Security) project [RD-102] focuses on the development of applications and services relating to security, applying innovative solutions based on Earth Observation systems and satellite Communication and Positioning technologies. LIMES addresses three main groups of services:

- 1. **Maritime Surveillance:** monitoring of vessel and cargo movements over coastal and open ocean areas. The services include Open, Coastal Water and Sensitive Cargo surveillance. They combine Synthetic Aperture Radar with other monitoring systems (e.g. Automatic Identification System, AIS)
- 2. Land and Infrastructure Surveillance: Land Border Monitoring, Critical Infrastructure Surveillance, support to Event Planning and to Non Proliferation Treaty (NPT) monitoring. The services are based on the capacity of Very High Resolution satellites, used in conjunction with medium to high resolution data and aerial imagery
- 3. **Humanitarian Relief and Reconstruction:** Risk Analysis and Disaster Preparedness (e.g. population distribution monitoring, water resource monitoring), Humanitarian Crisis Operational Support (e.g. Damage Assessment), Reconstruction Planning and Monitoring.

The activities of LIMES improved existing fusion techniques of multispectral, hyper-spectral and SAR data. They make full use of high resolution optical satellite data to detect, classify, and analyse temporal and spatial changes through data mining, feature extraction and change detection (e.g. vegetation classification for pipelines and land borders) and develop innovative data fusion techniques. Integration and fusion of satellite and other data improve the added value information provided to user (e.g. real–time sensor output with archived geospatial data).

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LIMES has improved the ability of EU authorities (such as coast guard services and customs) to react faster in cases of emergency, suspicious/illegal activity or environmental threat. The project has increased the dissemination of data to interested parties through improved information sharing and the capability of authorities to provide evidence in cases of fraud or illegal activity. It has also provided information to aid conflict resolution through improved information sharing in the open sea and, provided a sound statistical basis on which to test and justify legislation through repeated and reliable information acquisition and management.

3.5.6 GMES Security Services (G-MOSAIC project)

The pre-operational security service of GMES is currently provided through the FP-7 project GMES services for Management of Operations, Situation Awareness and Intelligence for regional Crises (G-MOSAIC [RD-88]) and FP6 LIMES [RD-102]. These two projects combine Earth observation technologies with communication and positioning technologies to provide GMES services in following domains:

- **Maritime surveillance**: sea border surveillance in and outside Europe, illegal immigration and illegal trafficking surveillance, safety sea lane/piracy/sensitive cargo...
- Infrastructure Surveillance: land border surveillance, critical infrastructure (e.g. pipelines).
- Support to peace-keeping: population monitoring, resources (water),
- Support intelligence and early warning
- Support crisis management operations

Different aspects of security have been funded by several pre-cursor projects including the Global Monitoring for Security and Stability (GMOSS) project [RD-99], MARitime Security Service project (MARISS) project [RD-100] and the Global Monitoring for Food Security (GMFS) project [RD-101].

G-MOSAIC will provide the European Union with intelligence data that can be applied to early warning and crisis prevention as well as to crisis management and rapid interventions in hot spots around the world. It aims at identifying and developing products, methodologies and pilot services for the provision of geo-spatial information in support to EU external relations policies and at contributing to define and demonstrate the sustainability of GMES global security services. The project will produce robust indicators for crisis cycle characterization integrating EO core and downstream service outputs. Crisis indicators are input to assessments at the regional and national level. They provide mappings of geospatial processes that are relevant as crisis triggers (e.g. exploitation of natural resources, land degradation, population dynamics), which need to be combined with socio-economic information for impact assessment. The expected outcomes of G-MOSAIC are:

- New organised service chains and infrastructure for the provision of pre-operational pilot services in support to security activities, in particular focusing on External Regional Crises based on the use of crisis indicators.
- Development of pre-operational Services for Security, and identify related Downstream Services, based on what was developed in previous GMES security and emergency response projects.
- Development of a prototype portal for the management and harmonisation of the different service cases in a secure service network.

Key earth observation requirements from Sentinel-3 include: access to multi-spectral measurements over land and sea across the visible to thermal infrared region at high spatial resolution in a timely manner. There requirements are expected to evolve as the G-MOSAIC project matures.

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3.5.7 Summary of GMES Emergency and Security Service requirements

Table 6 provides a summary of GMES emergency service requirements based on the previous examples given in this document.

Table 6: Summary of GMES Emergency Service requirements taken from [RD-88, RD-101, RD-121, RD-138, RD-139, RD-141, RD-142, RD-147, RD-148, RD-172]

| Service/User | Application(s) | Measurement Parameter | Spatial resolution | Geographical Coverage | Delivery Requirement | Revisit Time |
|------------------------------|---|--|--------------------|---------------------------------------|-------------------------|--------------|
| SAFER, G- MOSAIC | Land cover maps, maps of water resources, maps of disaster areas (pre and post crises) | Continuity of SPOT Vegetation like capability | 1 km | Global | NRT/STC | Daily |
| SAFER, G- MOSAIC | Humanitarian Aid (Land use mapping) | Land cover maps, maps of water resources, maps of disaster areas (pre and post crises) | 0.001 -1 km | Global | NRT | 3 hours |
| MACC, SAFER, G- MOSAIC | Volcanic ash cloud mapping | Visible and infrared L1b radiances plus uncertainty estimates | 1 -5 km | Global, higher resolution in EU | NRT | 3 hours |
| MACC, SAFER, G- MOSAIC | Volcanic ash cloud mapping | Ångström exponent | 1 -5 km | Global, higher resolution in EU | NRT | 3 hours |
| MACC, SAFER | Volcanic ash cloud mapping | AOD,particletype,effectiveradiusandcloudtopheight. | 1-5 km | Global, higher resolution in EU | NRT | 3 hours |
| SAFER, G- MOSAIC | Flood mapping | Visible and infrared inland water maps and heights (RLH) products. | 0.01 – 1 km | Global, higher resolution in EU | NRT | 3 hours |
| SAFER, G- MOSAIC | Fire mapping | Burnt areas and seasonality, Active Fire Monitoring (FRP) and effects, Post fire | 0.01 – 1km | Global | NRT | 3 hours |

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| monitoring (Burned area mapping/Fire | | |
|--|--|--|
| disturbance) | | |

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3.6 GMES Climate Monitoring Requirements

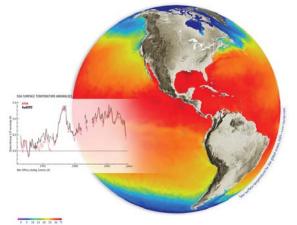
The GMES contribution to addressing climate change [e.g., RD-112, RD-113, RD-114] will be provided based on the three Earth System GMES Services: Land, Marine and Atmosphere. All three will seek to provide added value on the essential climate variables as identified by GCOS [RD-41, RD-58] using Sentinel data sets in synergy with other mission data. The FP-7 project MyOcean [RD-53] and MACC [RD-76] include the collection of ECVs and their re-analysis within their program of work. For the Land service, essential climate variables will be included in the course of service development. In addition, GMES will strive to support socio-economic analysis and the derivation of impacts.

3.6.1 Marine Climate Users

Climate research has relied heavily on Earth Observation satellites for over the last three decades (primarily since the operational AVHRR instruments were deployed). Examples of current activities include the systematic long-term observation of ocean topography and sea-level using uniform sea surface height altimetry products from inter-calibrated altimeter mission data referenced to accurate and precise geoid information. The analysis and modelling of the El Nino Southern Oscillation (ENSO), and North Atlantic Oscillation (NAO) dynamics, for example are of considerable interest to many nations and are addressed within several international collaboration efforts.

In conjunction with altimetry, systematic measurements of sea-surface temperature (SST) data have been carefully assembled from (A)ATSR, with which to robustly detect systematic climate-related changes in ocean heat storage on timescales up to and exceeding a decade (requiring better than 0.1K/decade accuracy). To ensure contingency of such valuable climate research data sets it is essential to aim for overlap in satellite operations with comparable instrumentation as required by the GCOS climate monitoring principles [RD-58].

Figure 34: Global Sea surface temperature trends from ATSR and the Hadley Centre HadISST2 SST data set (inset) together with a global daily synthesis of satellite and in situ SST measurements). Sentinel-3 will maintain and extend the climate quality SST measurements for the (A)ATSR series. (Credit: ESA)



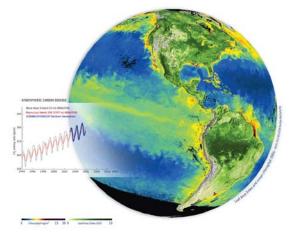
Sentinel-3 will contribute all measurements to climate change but it is worth noting that the proposed SST mission shall continue the legacy of the ENVISAT AATSR to provide a 'gold standard' directly addressing the requirements for the GCOS SST ECV specification [RD-41, RD-58]. In addition, the Sentinel-3 visible imager shall directly contribute to the ocean colour ECV and the Sentinel-3 topography mission, working in concert with other reference altimeters shall make a direct contribution to and ice mass balance and sea level estimates.

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Developments in determination of the associated climate impacts of air-sea exchange processes require collocated observations of quantities contributing to the fluxes of momentum, heat, water vapour and greenhouse gases. Physical oceanography variables such as mixed-layer depth, sea-surface temperature, surface winds, and horizontal and vertical advection and mixing, play a critical role in the cycle of carbon and other biogeochemical tracers via their influences on the carbonate chemistry and biological processes in the ocean. Physical variability is a dominant driver of biogeochemical variability on diurnal, seasonal and inter-annual time scales, and requires higher resolution in coastal zones, where mesoscale circulation patterns, tidal-mixing and river inputs dominate biogeochemical activity.

Figure 35: Ocean chlorophyll and leaf Area Index derived using the ENVISAT MERIS sensor (ACRI-ST/CNES/ESA/GeoEyes/NASA/VITO). Sentinel-3 will maintain and extend the measurements of MERIS. Atmospheric carbon dioxide measurements from the ENVISAT SCIAMACHY instrument are also shown (inset) together with in situ observations at Mace Head (Ireland) and Mauna Loa (Hawaii) from 1994. Main image shows Leaf Area Index over land and. (Credit: ESA)



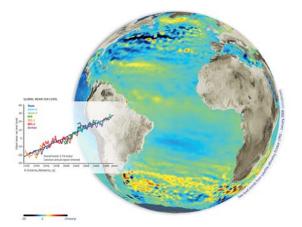


Figure 36: Global mean sea level changes derived from satellite altimetry since 1992 (inset) shown with a map of sea level trends in the Atlantic Ocean derived from satellite altimetry computed for October 1992 – January 2008 (CLS/LEGOS/CNES). The Sentinel-3 altimeter system will extend the satellite record of sea level and improve coverage in the coastal regions. (Credit: ESA)

Ocean uptake and transport of carbon (and other biogeochemical tracers) is generally regulated by the "solubility pump" (i.e. partial pressure pCO₂ in surface waters), the "biological pump" (i.e. phytoplankton photosynthesis), and the dynamical state of the ocean. Quantification of the solubility pump requires knowledge of SST and wind speed [RD-32] while quantification of the biological pump requires knowledge of the primary production, derived from estimates of near surface Chl a. In locations and instances where the biological pump dominates over the solubility pump, such as in coastal upwelling zones, specific knowledge of the limiting impact of Nitrate in surface seawater is required [RD-33] Determination of Nitrate relies on temporally and spatially coincident Chl-a and SST measurements.

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Despite climate products requirements generally calling for 1 km or lower resolution, evidence from OCTS data on ADEOS-1 indicates that coverage of simultaneous, collocated Chl a and SST with a resolution finer than several hundred metres, is required to effectively capture the time-space variability in ocean characteristics which regulate Carbon flux in the high-productivity coastal zones. Generally, simultaneous and co-located measurements of both SST and ocean colour at 1 km resolution are required as essential parameters in order to estimate the distribution of pCO_2 and Nitrate [RD-32, RD-33] in the remainder of the global ocean. Simultaneous and contemporaneous measurements of SST and ocean colour should be adopted by Sentinel-3.

Climate users demand the highest accuracy and stability (over decades) from S3 satellite data products and access to L1b and L2 data products will be required in a delayed mode (typically 1 month delay). Care should be taken to ensure that high stability is a feature of Sentinel-3 instrument design and that long term stability is maintained and known throughout the lifetime of each Sentinel-3 instrument.

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4 MISSION OBJECTIVES

GMES will make full use of Sentinel-3 together with other satellite systems to provide a comprehensive suite of consistent measurements of uniform quality addressing oceans, atmosphere, and land application domains. Access to EO data and services defined by the GMES shall be ensured already before the Sentinel era by relying on the set of EO missions capable of satisfying the data requirements of GMES [RD-115, RD-116]. The missions contributing to the GMES Space Component are generically referred to as GSC (or GMES) Contributing Missions (GCMs) and include ENVISAT.

The aim⁵ for the Sentinel-3 mission is:

To provide continuity of ENVISAT type measurement capability in Europe to determine sea, ice and land surface topography, sea, ice and land surface temperature, ocean and land surface colour and atmospheric measurements with high availability, high accuracy, with timely delivery and in a sustained operational manner for GMES users.

In addition, the mission will be designed to generate land optical, ice topography, vegetation and land hydrology measurements and provide continuity to SPOT Vegetation-like products to meet GMES user needs. These measurements are essential to maintain and improve operational ocean state analysis, forecasting and service prevision in the context of GMES serving applications in the domains of open ocean and ice monitoring, global land monitoring, coastal zone monitoring , NOP and NWP and global climate change monitoring. In order to meet GMES user needs, the Sentinel-3 satellite data shall support the operational generation of a generalised suite of high-level geophysical products. The Sentinel-3 mission objectives also include the operational provision of data, with adequate revisit frequency, coverage, timeliness and reliability.

Not all mission requirements over the earth system domain can be met with a single satellite solution. Sentinel-3 shall prioritize the provision of information needed to constrain and drive global and local NOP models and provide medium resolution land measurement capability by providing (at a minimum) continuity to ENVISAT instruments. To achieve this, the Sentinel-3 spacecraft will carry a set of optical and microwave instruments, and will ensure the provision of ocean measurements in routine, long term and continuous manner with a consistent quality and a very high level of availability.

The specific objectives for the Sentinel-3 mission are presented in Table 7: Mission objectives for Sentinel-3.

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⁵ The mission aim is the intended outcome that is desired from the end-to-end mission. The mission aim has a set of objectives that are directly aligned with the aim.



| Ref. | Туре | Sentinel-3 Objectives |
|---------|-----------|--|
| S3-OB-1 | Primary | Sentinel-3 shall provide continuity of an ENVISAT type ocean measurement capability for GMES Services with a consistent quality, a very high level of availability (>95%), high accuracy and reliability and in a sustained operational manner for GMES users, including: Ocean, inland sea and coastal zone colour measurements to at least at the level of quality of MERIS on Envisat; Sea surface temperature measurements to at least at the level of quality of AATSR on Envisat; Sea surface topography measurements to at least at the level of quality of the Envisat altimetry system, including an along-track SAR capability of CryoSat heritage for improved measurement quality in coastal zones and over sea ice. |
| S3-OB-2 | Primary | Sentinel-3 shall provide continuity of medium resolution ENVISAT-type land measurement capability in Europe to determine land-surface temperature and land-surface colour with a consistent quality, a very high level of availability (>95%), high accuracy and reliability and in a sustained operational manner for GMES users. |
| S3-OB-3 | Primary | Sentinel-3 shall provide, in a NRT operational and timely manner, L1b visible, shortwave and thermal infrared radiances and L2 topography products for use by GMES Services with a consistent quality, a very high level of availability (>95%), high accuracy and reliability and in a sustained operational manner for GMES users. |
| S3-OB-4 | Primary | Sentinel-3 shall provide, in a NRT operational and timely manner, a generalised suite of high-level primary geophysical products with a consistent quality, a very high level of availability (>95%), high accuracy and reliability and in a sustained operational manner for GMES users. Products shall include as priority: Global coverage Sea Surface Topography (SSH) for ocean and coastal areas, Enhanced resolution SSH products in the Coastal Zones and sea ice regions, Global coverage Sea-Surface (SST) and sea ice surface temperature (IST), Global coverage Ocean Colour and Water Quality products, Global coverage Significant Wave Height measurements, Global coverage atmospheric aerosol consistent over land and ocean, Global coverage Vegetation products, Global coverage Land Ice/Snow Surface Temperature products, Ice products (e.g., ice surface topography, extent, concentration) |
| S3-OB-5 | Secondary | Sentinel-3 shall provide continuity of medium resolution SPOT Vegetation P-like products by providing similar products over land and ocean with a consistent quality, a very high level of availability (>95%), high accuracy and reliability and in a sustained operational manner for GMES users. |
| S3-OB-6 | Secondary | Sentinel-3 shall provide in an operational and timely manner, a generalised suite of high-level secondary geophysical products with a consistent quality, a very high level of availability (>95%), high accuracy and reliability and in a sustained operational manner for GMES users. Products shall include as priority: Global coverage Fire monitoring products (FRP, burned area, risk maps etc), Inland water (lakes and rivers) surface height data. |

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5 MISSION REQUIREMENTS AND ELEMENTS

5.1 Introduction

Mission Requirements for the Sentinel-3 mission are based on the user information requirements (summarized in section 3) and programmatic constraints. Mission Requirements cover the end-to-end Earth observation system including high-level instrument requirements, mission operations, data product development and processing, data distribution and data archiving. Mission requirements are traceable to information requirements defined and agreed with the users.

Sentinel-3 has two primary mission components in support of GMES ocean, land, atmospheric, hydrologic and cryospheric applications:

- A Sentinel-3 **topography mission** providing altimeter height measurements.
- A Sentinel-3 **optical mission** providing Sea, Land and ice Surface Temperature (SLST) and Ocean and Land Colour (OLC) measurements in the visible and infrared region of the electromagnetic spectrum simultaneously and contemporaneous with the topography mission. The mission should also support continuity of SPOT Vegetation-like products.

The primary focus of Sentinel-3 is for ocean measurements serving the GMES Marine Service. The Global Ocean Observing System (GOOS) has specified space-based data requirements [RD-7, RD-8] that have been compiled with particular reference to the needs of the GMES MCS implementation plan [RD-52]. Additional requirements are derived from GMES marine services [RD-24, RD-14, RD-27, RD-32, RD-53, RD-67, RD-66, RD-134], the Global Ocean Data Assimilation Experiment (GODAE) [RD-9, RD-42], GMES Land service Requirements [RD-120 RD-119, RD-123, RD-124, RD-128, RD-129, RD-136], GMES Atmospheric Service Requirements [RD-55, RD-64, RD-76, RD-77], GMES Emergency and Security Service requirements [RD-88, RD-101, RD-121, RD-138, RD-139, RD-141, RD-142, RD-147, RD-148], requirements addressing the GMES contribution to climate change [RD-112, RD-113, RD-114] and requirements in support of GMES services for snow products [RD-82, RD-117] as set out in Section 3 of this document. In addition, a wide variety of projects and services have been consulted as set out in <u>Appendix A-H</u>.

Considering these requirements, the following sections identify and articulate Sentinel-3 Mission Requirements. Formal numbered requirements are captured in tables that are collated together in Section 7. Finally, a traceability matrix is presented in Section 8. In this manner, the Sentinel-3 MRTD conforms to the specifications set out in [AD-1].

5.2 Synergy with external mission concepts

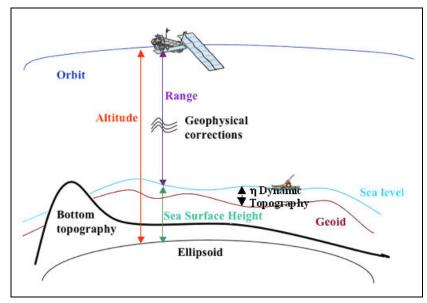
In addition to synergy aspects with similar instrumentation on other satellites, the instrument and performance requirements of the Sentinel-3 mission have considered the potential complementary with other satellite missions:

- A wind scatterometer is operationally provided by Eumetsat/ESA on the METOP series.
- High resolution SAR observation will be covered by the GMES Sentinel 1 concept [RD-31] as well as by future Radarsat satellites from the Canadian Space Agency.

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- High resolution optical land image data will be covered by the Sentinel-2 mission concept [RD-92].
- Further passive microwave sensors for SST and sea ice monitoring) will be covered with existing JAXA commitments (e.g. GCOM-W AMSR2 instrument).
- Sentinel-3 will be complementary and provide continuity to the high-resolution along track marine and land ice surface measurements of CryoSat providing a continued ability to derive sea-ice thickness and ice sheet topography from altimeter derived elevation profiles.
- Sentinel-3 will be complementary to other satellite infrared imagers providing a unique dualview capability allowing the mission to continue the 'gold-standard' reference system legacy of ENVISAT AATSR.
- Sentinel-3 will provide continuity to SPOT Vegetation producing Vegetation-like products based on synergy between optical and infrared bands.



5.2.1 Topography Mission

Figure 37: Schematic diagram highlighting the key aspects of measuring sea surface topography using a satellite altimeter.

The radar altimeter determines the range between the satellite (flying at an altitude above an arbitrary earth reference ellipsoid) and the surface by transmitting microwave pulses, which hit the surface of the Earth and return back after a certain delay. This time delay is derived very precisely after on-ground processing of the altimeter data. Knowing the speed of the propagation, the delay is then converted into range. The depth of the ocean is not known accurately everywhere but by choosing an appropriate reference ellipsoid accurate, homogeneous measurements are derived. The sea surface height (SSH) is the altimetric range at a given instant from the sea surface to the reference ellipsoid. The sea level is then the difference between the satellite height and the altimetric range. The SSH measurement includes dynamic contributions from ocean circulation and variations in the geoid with respect to the reference ellipsoid. The dynamic topography (the variable part of the ocean signal) of the ocean is derived by subtracting the height of the geoid from the SSH. This is shown schematically in Figure 37.

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Sentinel-3 will fly within a constellation of other EO satellite missions that are complementary to the mission. The specification for the topography component of Sentinel-3 is influenced by the availability of third-party missions (particularly JASON). All applications gain from an increase in time and space sampling and a minimum of 2-3 altimeter missions must be available to fully satisfy GMES requirements [RD-52]. Currently the planning for Jason 3 aims for a launch in the 2014 timeframe, and together with JASON-2 should satisfy this minimum requirement.

The AltiKa mission [RD-199], which was developed by CNES, is based on a wideband Ka-band altimeter (35.75 GHz, 500 MHz), which will be the first oceanography altimeter to operate at such a high frequency, is expected to launch in 2011. Sentinel-3 data will be complementary to Sentinel-3, JASON altimeter data. The unique technical characteristic of the AltiKa instrument operating in a high inclination orbit will offer higher performance both in terms of spatial and vertical resolution with improved observation of ice, coastal areas, inland waters and wave height.

The CryoSat Earth Explorer mission now provides for the first time (in addition to sea-surface topography) very accurate observations of marine ice surface topography in ice-covered polar oceans with high-spatial resolution. CryoSat-2 [RD-34] was launched on 8 April 2010 in a highly inclined polar orbit, reaching latitudes of 88° north and south, to maximise its coverage of the Polar Regions. Its main payload is the Synthetic Aperture Interferometric Radar Altimeter (SIRAL) that is optimised to measure changes at the margins of ice sheets and marine floating ice in the polar oceans including accurate measurements of thickness changes in both types of ice. SIRAL includes a delay-Doppler Synthetic Aperture Radar (SAR) capability that increases the along track sampling of the altimeter to <300 m that is particularly useful for ice freeboard measurements and applications in the coastal zones and sea ice margins. If a SAR-mode for the altimeter on the Sentinel-3 is implemented (to provide enhanced along-track resolution and coverage in the coastal zone and sea ice regions) a major improvement for ocean mesoscale feature detection can be expected giving significant advances with respect to conventional altimeters. CryoSat is now (2010) providing NRT ocean data delivery using its conventional altimetry mode, in response to a GAMBLE Study recommendation [RD-27].

5.2.2 Optical mission

With the loss of GLI (Global Land Imager) and POLDER (POLarisation and Directionality of the Earth's Reflectance) on ADEOS-2 (2002/2003), there has been a significantly reduced capability for operational development of ocean colour measurements [RD-35]. The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) was launched August 1, 1997 on GeoEve's OrbView-2 SeaStar satellite as a follow-on experiment to the Coastal Zone Color Scanner (CZCS) on Nimbus 7 and is still operating in autumn 2010. The sensor resolution is 1.1 km (local area coverage) and ~4 km (global area coverage) and provides measurements in 8 spectral bands between 402 - 885 nm. The Modular Optoelectronic Scanner (MOS) was launched on the IRS-P3 satellite in March 21, 1996 until 2004 in a sun-synchronous orbit [RD-203]. The instrument provided 13 channels in the 408 - 1010 nm spectral waveband at a spatial resolution of ~0.75 km. The ENVISAT Medium Resolution Imaging Spectrometer (MERIS) instrument [RD-182] has operated since 2002 MERIS is a programmable, medium-spectral resolution, imaging spectrometer operating in the solar reflective spectral range. Fifteen spectral bands can be selected by ground command between 390 – 1040 nm and the instrument has a 300 m full resolution field of view. Products are provided at 300m over selected regions and 1.1 km over the global ocean. The NASA Moderate Resolution Imaging Spectroradiometer (MODIS) [RD-200] is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites operating in polar sun-synchronous orbits (Terra's has a morning orbit while Aqua has an afternoon orbit). Terra MODIS and Aqua MODIS provide global

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geographical coverage every 1 to 2 days, acquiring data in 36 spectral bands in the visible to thermal infrared spectral region $(0.405 - 14.385\mu m)$ with a spatial resolution of 250 - 1.1 km.

For SST capability, the NOAA Advanced Very High Resolution Radiometer (AVHRR/2) series [RD-201] have provided continuous global coverage since 1981 on a daily basis from two satellites operating in morning and afternoon sun-synchronous orbits. The instrument has a spatial resolution of 1.1 km and provides measurements in 5 spectral channels ($0.58 - 12.5\mu$ m). The series is continued by the European MetOp satellites and the NOAA-NASA Joint Polar Satellite System (JPSS) until ~2018. The ENVISAT Advanced Along Track Scanning Radiometer (AATSR) is a dual view radiometer with a spatial resolution of 1.1 km operating in a sun synchronous orbit. AATSR provides measurements in 7 spectral bands ($0.55 - 12 \mu$ m) and is a continuations of the ERS-1 and ERS-2 ATSR instrument that have operated since 1991. The AATSR provides extremely accurate measurements of SST over a narrow swath of 512 km that are today used as a reference for other satellite systems (in the same manner that a JASON class altimeter is used to control the relative calibration of other altimeters). No other satellite instrument provides dual-view functionality at present.

Several passive microwave imagers have flown in the last decade that have delivered SST and sea ice measurements in all weather except rain. These include the Tropical Rainfall Mapping Mission (TRMM) Microwave Imager (TMI) launched in 1997 and flown in a low inclination orbit optimised for tropical regions [RD-202]. SST products are derived from a 10.7 GHz channel with a product resolution of 25 km with coverage extending to 40° north and south (constrained by the satellite orbit). The Advanced Microwave Scanning Radiometer (AMSRE-E) was successfully launched on the NASA Aqua satellite in 2002 which provides global coverage passive microwave measurements of SST based on measurements made at 6.6 GHz. AMSRE has a product resolution of 25 km with near daily coverage.

SeaWiFS, MODIS, MERIS, AATSR, TMI and AMSRE are all nearing their end of their operational life (many have already far exceeded their design lifetime) with a significant risk that insufficient satellite ocean colour and SST measurements will be available to satisfy the needs of GMES services in the very near future. For optical imagers in the VIS/IR range, commitments have been made by several Agencies to fly sensors in the future. However, in the 2014 timeframe of the first Sentinel-3 satellite, only AMSR2 on the Japanese GCOM-W, S-GLI on GCOM-C and VIIRS on the NASA-NOAA Preparatory mission will address the global needs of the ocean biology and ocean carbon community. Given the position of EUMETSAT with respect to the requirement for purchasing AVHRR instruments for METOP, and the need for an operational European successor to AVHRR beyond METOP, it is necessary to develop a European operational instrument in this class.

5.3 Measurement heritage

5.3.1 Heritage of RADAR Altimeter measurements

The development of altimetry has been steady and the benefits to outstanding in the operational NOP/NWP and scientific domains (e.g. sea level rise, understanding ocean circulation, the importance of mesoscale oceanography, recent developments of coastal altimetry, production of DEM, river and lake height measurements, sea ice thickness measurements, ice sheet mass balance measurements). There have been a quasi-continuous series of missions, starting with GEOSAT (1985), and followed by ERS-1/2 (1991 and 1995) and Topex-Poseidon (1992). Such missions have continued with GEOSAT Follow-On (1998), JASON-1 (2001), Envisat RA-2 (2002), JASON-2 (2008) and CryoSat-2 (2010). At present, only altimeter systems are capable of measuring sea-surface height (SSH) from which ocean

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circulation patterns and sea level are determined on a global scale. From a user perspective, the GOOS (and GMES NOP systems) "requires global, near real-time, high accuracy and high resolution observations of sea surface topography" from "at least three (and preferably four) altimeter missions with one very accurate long term altimeter system". Sentinel-3 shall make a significant contribution to the required altimeter constellation requested by the GOOS community.

Altimeter systems also provide estimates of wind speed and significant wave height (Hs) through relatively well understood geophysical inversion algorithms based on peak backscattered power and the shape of the waveforms. Hs measurements have been shown to compare satisfactorily with collocated in situ buoy wave height estimates. Systematic bias is less than 0.1 m and random bias on individual passes is \approx 0.25 m, but these accuracies are understood to decrease for very low and high wind conditions [RD-27]. Wind and wave estimates are also required for correction of 'sea-state bias' uncertainty on the altimeter range measurement. SSH is usually estimated from the centre point of the waveform leading edge, but estimates of sea surface height are affected by the skewness of the wave statistics, or non-Gaussian statistics of wave elevation and slope. Due to the non-linear processes that generate such ocean waves, the mean sea level is typically underestimated. This error is currently corrected in operational altimeters using an empirical dependence on the altimeter wind speed and significant wave height data.

Sentinel-3 shall address these issues building on the heritage of the ENVISAT RA-2 and CryoSat-2 altimeters. Sentinel-3 shall build on the technical developments acquired during the CryoSat-2 SIRAL project and provide both high resolution SAR data in coastal zones and over sea ice in addition to conventional low resolution altimeter measurements over the open-ocean.

5.3.2 Heritage of Sea Surface Temperature measurements

Since the late 1970's, SST measurements have been operationally available from the AVHRR imagers flown on the NOAA/TIROS meteorological satellites. Although AVHRR was not tailored to this mission, it is still providing valuable data underpinning the bulk of data in the GCOS SST ECV. Significant improvements in performance were introduced in the early 1990's by the dual-view ATSR-class instruments on the ERS satellites to be followed by a second generation instrument, the AATSR, on Envisat. Routine high-quality SST observations from these polar orbiting instruments are also complemented by high temporal frequency SST data from instruments such as SEVIRI on the MSG geostationary platform, AVHRR on MetOpA, MODIS on EoS AQUA and TERRA and low resolution all-weather, global data from the TRMM-TMI and AMSR-E microwave sensor on EOS Aqua. The development of the GHRSST project has capitalised on the complementary strengths of each data set to provide enhanced SST products providing clear recommendations on future SST capability evolution at OceanObso9 [RD-67].

The requirements formulated for GOOS call for "continuation of the geostationary and low-earth-orbit meteorological satellites that produce merged sea-surface temperature data products" and for "continuity of the higher accuracy ATSR-class measurements". Atmospheric correction schemes are critical for accurate SST estimates and an ATSR-type dual-view instrument is unique in its ability to assure this quality in particular for times with high aerosol loadings in the atmosphere (i.e. Pinatubo volcano events). Though AVHRR continuity is assured by the MetOp series, only AATSR-class measurements approach the accuracy required for climate modelling and climate change prediction/detection (i.e. a high absolute accuracy < 0.3 K combined with long-term radiometric stability of 0.1 K/decade). A dual view capability is a key requirement form the GMES MCS Implementation Group [RD-52] and shall be implemented on Sentinel-3.

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| Spectral Bands for sea and land surface | Minimum of 7 bands (ENVISAT AATSR heritage) spanning spectral range from 1.6-13.0 μ m for SST, LST, and atmospheric corrections: |
|---|---|
| temperature | Bands required for cloud clearing and vegetation measurements (0.555, 0.695 and 0.865 μm) 1.61 μm (SWIR): cloud clearing, cloud/snow discrimination 3.74 μm (Mid-Wave IR): for night-time SST retrieval and Active Fires 10.85 and 12.0 μm (TIR): for SST, Land Surface Temperature, Active Fires 0.865 μm common band requirement multi-instrument pixel coregistration Additional SWIR bands required at 1.375 μm and 2.25 μm for cirrus cloud clearing and aerosol corrections are desired. |

The spectral channels that are required for Sentinel-3 building on the heritage of ENVISAT AATSR for ocean, lake, land and ice surface temperature measurements are described in Table 8.

In the ice covered hi-latitude oceans, under clear sky conditions, ice surface temperatures (IST) are also derived from thermal infrared sensors on polar-orbiting satellites such as AVHRR using $10.3 - 11.3 \mu m$ measurements. Ice surface temperatures (IST) are presently used as surface boundary conditions in both climate models and numerical weather forecasting models. Land Surface Temperatures (LST) is also derived in a similar manner from AATSR, MODIS and AVHRR. Sentinel-3 should have the capability to measure IST and LST using an AATSR follow on instrument. Furthermore, Sentinel-3 should have the capability to make meaningful measurements of Lake Surface Water temperature (LSWT) that is required by GMES land and atmospheric services.

5.3.3 Heritage of Ocean and Land Colour measurements

Since the success of Coastal Zone Colour Scanner (CZCS) on Nimbus-7 a number of overlapping missions have been launched, that focus on ocean colour observations to serve climate research and coastal monitoring. SeaWIFS, MOS on IRS-P3, MODIS on the EOS AQUA and TERRA spacecraft, and MERIS on Envisat have provided a wealth of valuable data upon which valuable operational services have been built. Beyond Envisat, the VIIRS sensor, planned to fly on the JPSS satellites and the GCOM-C S-GLI instrument (2013-2016) will provide global coverage ocean colour data.

A combination of satellite derived physical ocean data (dynamics) and biological data (colour) have led to new scientific insights with respect to circulation in the upper layer of the ocean, such as the occurrence of algae blooms along internal waves. Algal blooms driven by the underlying processes of photosynthesis and phytoplankton productivity could (derived by the combination of ocean colour and sea surface temperature data) be key inputs to carbon modelling. Information on suspended sediments, toxic algal blooms and yellow substance are important for those concerned with coastal zones and inland waters, and particularly in estuarine environments, thus requiring a high resolution (\leq 300 m) measurements. High signal to noise Modern ocean colour satellite sensors have used on-board calibration systems to provide accurate measurements and this should be a feature of the Sentinel-3 payload.

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Table 9: Sentinel-3 Spectral Measurement Requirements for SPOT Vegetation

| Spectral | The 4 spectral channels of the SPOT/Vegetation mission are: |
|------------|---|
| Bands for | • band Bo: blue (0.43-0.47 µm), |
| SPOT | • band B2: red (0.61-0.68 µm), |
| Vegetation | • band B3: near-infrared (NIR,0.78-0.89 μm) and |
| | • band MIR: shortwave infrared (SWIR, 1.58-1.74 μm). |

Table 10: Sentinel-3 Spectral Measurement Requirements for Land Colour

| Spectral | Minimum of 15 bands (ENVISAT MERIS heritage) spanning spectral range | | | | |
|------------|---|--|--|--|--|
| Bands for | from 443-1085 nm for Land surface and vegetation properties, and | | | | |
| land cover | atmospheric corrections: | | | | |
| | 0.443 μm (Blue): for MGVI, aerosol optical depth | | | | |
| | 0.560 μm (Green): for Chl, NDVI | | | | |
| | • 0.665, 0.681, and 0.709 μm (Red): for Chl absorption peak, fAPAR, fCover | | | | |
| | 0.753, 0.779 and 0.865 μm (NIR): Chl, fCover MGVI, MTCI, fAPAR 1.61 μm (SWIR): cloud clearing, cloud/snow discrimination | | | | |
| | 3.74 μm (Mid-Wave IR): for Active Fires | | | | |
| | 10.85 and 12.0 μm (TIR): for Land Surface Temperature, Active Fires | | | | |
| | 865 μm common band requirement for OLC-SLST pixel co- registration | | | | |
| | • Additional band >1000 nm required for atmospheric correction algorithms | | | | |
| | Additional SWIR bands required at 1.375 μm and 2.25 μm for cirrus cloud clearing and aerosol corrections | | | | |

Table 11: Sentinel-3 Spectral Measurement Requirements for Ocean Colour

| Spectral | Minimum of 15 bands from 400-1050 nm. The role of the bands for Case 1 | | | | |
|--------------|--|--|--|--|--|
| Bands for | (open ocean) and Case 2 (coastal) waters is: | | | | |
| ocean colour | 413 nm: CDOM discrimination in open ocean | | | | |
| | • 443, 490, 510, 560 nm: Chl retrieval from blue-green ratio algorithms | | | | |
| | 560, 620, 665 nm +: Retrieval of Case 2 water column properties using red-green algorithms | | | | |
| | • 665, 681, 709 nm +: Use of fluorescence peak for Chl retrieval | | | | |
| | • 779, 870 nm for atmospheric correction | | | | |
| | • Additional band required above 1000 nm to improve atmospheric correction over turbid water. | | | | |
| | • Additional SWIR bands required at 1.375 μ m and 2.25 μ m for cirrus cloud clearing and aerosol corrections. | | | | |
| | • Additional bands in the O2A spectral region may be considered for improved cloud top pressure (height) and water vapour retrieval. | | | | |
| | • Additional bands may be considered for fluorescence measurements | | | | |
| | over land (again in the O2A spectral region) and to improve land and ocean geophysical retrievals. | | | | |

The spectral channels that are required for Sentinel-3 building on the heritage of ENVISAT MERIS and SPOT Vegetation for ocean and land colour measurements are described in Table 9, Table 10 and Table 11.

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5.4 Service Availability

Operational service availability is a measure of the average availability of a service over a period of time and it includes all sources of downtime (excluding the effects of non-recoverable failures). Operational availability is the ratio of the system uptime and potential time a system should have been available. Operational availability is a function of time or operating cycle (i.e. the operating cycle is the overall time period for the service being measured and uptime is the total time the service was functioning during the operating cycle). When there is no specified logistic downtime or preventive maintenance, operational availability represents the Mean Availability of the service.

Operational availability is the availability that a GMES service actually experiences. It is essentially the *a posteriori* availability based on actual events that happened to the system. At EUMETSAT, availability for the EPS service specification is calculated from the service output received by a user via the defined dissemination mechanism, in the correct format and meeting specified quality criteria over a given time period; after taking due account of any scheduled outages. Any scheduled activities that will affect the availability of the EPS Services must be notified to the users at least 36 hours in advance [RD-160]. There are other definitions for operational availability that may be applied to Sentinel-3 depending on user requirements.

It is clear that in order to prepare for the Sentinel-3 mission, operational services within the GMES Service component should be ensured based on the use of existing EO data sets (e.g. ENVISAT and other third Party Missions). A high level of operational availability of ocean, land and atmospheric measurements from Sentinel-3 is a prerequisite to the success of GMES Services. NOP and NWP Services rely on timely provision of measurements in an operational manner for use in data assimilation systems and ultimately consistent, improved predictions of atmospheric and oceanic conditions. Emergency response and humanitarian aid services have extremely demanding service availability and timeliness delivery requirements. Timeliness requirements for Sentinel-3 are given in Section 5.17. It must be recognised that measurements that are unavailable or delivered outside agreed timeliness specifications may not be used in forecasting systems and may result in a negative impact on the forecast system output.

The Sentinel-3 Mission Objectives (as described in Section 4) require an operational capability to support reliable uninterrupted services. This requires that the end-to-end Sentinel-3 system (i.e. including space and ground segment) is operationally available to >95% and robust with back up systems in case of failures. Conflict-free operations are essential.

The GMES MyOcean project has not yet defined the operational availability of its service (measured as the number of outages during the core availability time [RD-53]. For the operational meteorological services providing weather forecasts to public, commercial, military government, maritime and aviation sectors (and MACC components) operational availability figures exceed 95% measured over an annual period. EUMETSAT EPS Operations Services Specification [RD-160] quotes operational availability figures of 95% for many products.

A facility to provide direct broadcast of Sentinel-3 optical mission data to local ground stations in the line-of-sight of Sentinel-3 would provide GMES users with localised NRT measurements. Direct broadcast capability provides an alternative local (non-global) access and partial archive capability for Sentinel-3 data. Operational direct broadcast capabilities can be useful in regions that have limited bandwidth to access data from central facilities. Furthermore, the development of local GMES services based on the use of direct broadcast capabilities could help ease timeliness issues for some users. A capability for direct broadcast of Sentinel-3 mission data to line-of sight receiving stations would be a

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significant asset to the mission. However, the primary down link system shall take priority and inclusion of any direct broadcast capability shall not drive the mission design.

| MR-ID | Туре | Description | Ref |
|----------|-------------------------|--|---|
| S3-MR-10 | Service availability | Sentinel-3 products with specified temporal and spatial coverage, fully compliant with specified product quality metrics, and delivered according to specified timeliness requirements, shall be available to the end user with >95% operational availability, measured over any 12 month period with no systematic geographical gaps. | RD-65, RD-160 |
| S3-MR-20 | Service availability | The Sentinel-3 system shall be designed for a duration of 15- 20 years. | RD-1, RD-3, RD-4 |
| S3-MR-30 | Service availability | Access to EO data and services by the GMES Service Component shall be ensured before the Sentinel era relying on the set of EO missions capable already contributing to the GMES Services. | RD-52, Table 3, Table 4, Table 5, Table 6 |
| S3-MR-40 | Service availability | A facility to provide direct broadcast of Sentinel-3 optical mission data to local ground stations in the line-of-sight of Sentinel-3 shall be considered. Direct broadcast capability shall not drive the mission design. | Section 5.4 |

5.5 Service Continuity

The primary focus of the Sentinel-3 Mission is for ocean measurements serving the GMES Marine Service [RD-52]. GOOS has specified Space-Based Data Requirements [RD-7, RD-8] that have been compiled with particular reference to the needs of GODAE [RD-68] and related on-going space-based projects [e.g., RD-42] that have now been pulled through to the GMES Marine Service MyOcean project [RD-53]. MyOcean now underpins NOP within the GMES MCS [RD-52] responding directly to the needs of European policies on marine environment [RD-57, RD-69] and maritime security [RD-100]. MyOcean requires a sustained ocean measurement capability in Europe to monitor sea-surface topography (e.g. SSH, Hs, wind stress), SST and a range of ocean colour products (e.g., water leaving radiances, Chl-a, TSM, HAB, CDOM), and sea ice products (e.g. ice surface temperature (IST), ice concentration, drift, thickness, edge) with a consistent quality, a very high level of operational availability, high accuracy and reliability and in a sustained operational manner in accordance with [S3-OB-1, S3-OB-3, S3-OB-4 and S3-OB-6]. Enhanced resolution products are required in the coastal zones and over sea ice regions.

GMES land services are being consolidated through the GMES fast track process as a Land Monitoring Service [RD-54] by the Geoland2 project [RD-105]. The LMCS is designed support European policies and regulations [e.g., RD-71, RD-107, RD-109] by providing satellite land products [RD-96], specific analysis and support to national reporting obligations according to GMES user requirements. The LMCS requires a sustained a moderate spatial resolution (~250-1000 m) land measurement capability in Europe to monitor land colour and derived vegetation/biophysical products (e.g. land use maps, LAI, FAPAR, land surface temperature (LST), surface albedo, burnt areas and fire radiative power (FRP), Lake Surface Water Temperature (LWST), lake water quality, river and lake heights (RLH), altimeter heights over land for DEM development) with a consistent quality, a very high level of operational

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availability, high accuracy and reliability and in a sustained operational manner in accordance with [S3-OB-5, S3-OB-4 and S3-OB-6].

The continuity in optical instrument capabilities equivalent to those of presently operating space infrastructure (MERIS, MODIS, AATSR, and SPOT Vegetation [RD-111]) is critical to the continuity of existing GMES land and environment services. By 2010-2012, it is foreseen that all of these low-moderate resolution optical instruments will have reached the end of their operating lifetime, potentially leaving a gap in data streams for dedicated global land applications. For continuity in GMES land applications the OLC and SLST instruments shall satisfy a resolution of between 0.25 and 0.5 km at nadir, and provide at a minimum continuity to channels allowing reproduction of MERIS and SPOT Vegetation-like land products. This requires continuity in existing MERIS and AATSR channels, together with additional channels to allow co-registration and improved cloud clearing. Sentinel-3 shall provide continuity of the 4 spectral channels on the SPOT Vegetation mission through a combination of OLC and SLST measurements working in synergy if necessary.

GMES atmospheric services are led by the GMES MACC project [RD-76] that developed the products, developments and pilot services of the ESA GMES Service element PROMOTE project [RD-77] and EU FP-6 project GEMS [RD-64]. GMES atmospheric services [RD-76] require a sustained measurement capability in Europe [RD-75] to monitor and assimilate data into NWP systems including visible and infrared L1b radiance data, continuous and consistent atmospheric aerosol over land and ocean, columnar water vapour over land, fire products SST, IST, LWST, LST, and significant wave height with a consistent quality, a very high level of operational availability, high accuracy and reliability and in a sustained operational manner in accordance with [S3-OB-3, S3-OB-4 and S3-OB-6].

The GMES Emergency Response Service developed by the SAFER project [RD-56] and the GMES services for security developed by the G-MOSAIC project [RD-88] both have very demanding requirements in terms of spatial resolution, revisit and coverage. Sentinel-3 is not optimised for the rapid-task, high spatial and temporal requirements typical of these services (e.g., flood, forest fire, earthquakes and humanitarian aid, peacekeeping). Instead, Sentinel-3 shall provide continuity of wall-to-wall mapping using an enhanced suite of spectral channels at reduced resolution with a consistent quality, a very high level of operational availability, high accuracy and reliability and in a sustained operational manner in accordance with [S3-OB-5, S3-OB-3, S3-OB-4 and S3-OB-6].

Based on these requirements, measurement continuity is required for ENVISAT MERIS, AATSR and RA-2 and Cryosat-2 type measurement capabilities to guarantee the success and performance of ongoing services within GMES ocean, land, atmosphere, emergency and security services. Continuity of data as provided by existing missions serving GMES users is essential to ensure effective exploitation of user investment. Any gap in data availability will have a significant impact within on-going monitoring programs.

| MR-ID | Туре | Description | Ref |
|----------|-----------------------|--|---|
| S3-MR-50 | Service continuity | Sentinel-3 shall commence operations in a timely manner (target 2013/14) in order to ensure continuity of ENVISAT MERIS, AATSR and RA-2 measurement data sets and minimise potential gaps in EO service to GMES. | RD-52, RD-179, RD-180, |
| S3-MR-60 | Service continuity | Sentinel-3 shall provide continuity of SPOT/Vegetation-like instrument capability (Table 9) with a spatial sampling of ≤1000 m (0.3 km goal) to minimise potential gaps in service to GMES. | RD-152, RD-154, Table 5, Table 6 |

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| S3-MR-70 | Service continuity | Sentinel-3 shall provide continuity CryoSat high-resolution along track marine and land ice surface measurements used to derive sea-ice thickness and ice sheet topography. | RD-52, RD-54, RD-181, RD-56, Table 3, Table 5, Table 6 |
|----------|-----------------------|---|--|
| S3-MR-80 | Service continuity | Sentinel-3 shall provide continuity to radiance (L1b) and geophysical (L2) products based on existing ENVISAT MERIS, AATSR and RA-2 sensors and enhance them to cover the user information needs expressed by GMES users in the domains of: Ocean Monitoring, Land Monitoring, Atmospheric Monitoring, Emergency Response and Security. | RD-52, RD-54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6 |
| S3-MR-90 | Service continuity | Sentinel-3 shall provide continuity to services based on existing SPOT Vegetation P-like product line to cover the user information needs expressed by GMES services in the domains of: Land Monitoring, Emergency Response and Security. | RD-152, RD-154, Table 5, Table 6 |

5.6 Performance

Continuity of measurement capability implies that the performance of existing (e.g. ENVISAT, SPOT Vegetation) mission services should be maintained as a minimum baseline. Deviations from technical parameters such as spectral bands for observation and their resolution/sampling and spatial performance should be carefully analysed in order not to jeopardise established GMES Services and applications that rely on these measurements. A balance between primary and secondary mission objectives (able 7) shall be used to prioritise Sentinel-3 performance and capability.

| MR-ID | Туре | Description | Ref |
|-----------|----------------------|--|---|
| S3-MR-100 | Performance | Sentinel-3 shall include a dual frequency (nominal frequency of ~13.5 GHz (Ku Band)) nadir pointing altimeter instrument based on the heritage of ENVISAT RA-2 and CryoSat-2 SIRAL. | RD-52, RD-54, RD-181, RD-56, Table 3, Table 5. |
| S3-MR-110 | Spectral sampling | The Sentinel-3 altimeter system shall include a passive microwave radiometer (MWR) for correction of range delay errors due to tropospheric water vapour. The MWR shall measure the amount of water vapour and liquid water content in the atmosphere, within a field of view centred immediately beneath the spacecraft track making measurements simultaneous and coincident with the altimeter footprint. | RD-52 |
| S3-MR-120 | Performance | Sentinel-3 shall provide Visible and Short-Wave Infrared radiance measurements over the ocean (ocean colour) to at least the quality of MERIS on ENVISAT with improved spectral capability. | RD-52, Table 3, Table 5, Table 6 |



| S3-MR-130 | Performance | Sentinel-3 shall provide Visible and Short-Wave Infrared Short-Wave Infrared, and Thermal Infrared radiance measurements to at least the quality of AATSR on ENVISAT with improved coverage and spectral capability. | RD-52, RD-54, RD-181, Table 3, Table 5, Table 6 |
|-----------|-------------|--|--|
| S3-MR-140 | Performance | Sentinel-3 shall provide Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances over land surfaces equivalent to ENVISAT MERIS, AATSR and similar to SPOT Vegetation, together with those from their combination. | RD-54, RD-181, RD-56 Table 4, Table 5, Table 6 |
| S3-MR-150 | Performance | Sentinel-3 shall provide ocean surface topography measurements (SSH, Hs, and surface wind speed) exceeding the level of quality of the ENVISAT RA-2 altimeter system. | RD-52, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6 |
| S3-MR-160 | Performance | An along track delay-Doppler SAR capability (similar to CryoSat-2 SIRAL) shall be included in the Sentinel-3 altimeter measurement system to provide improved resolution in the coastal zone and sea ice regions. | RD-52, RD-54, RD-181, Table 3, Table 5, |
| S3-MR-170 | Performance | Sentinel-3 shall provide VIS and TIR measurements suitable for pre-fire early warning (satellite vegetation indices), active fire detection (Fire Radiative Power); and post-fire monitoring (Burned area mapping) to at least the quality of AATSR on ENVISAT. <i>Note: Fire monitoring is a secondary objective [S3-OB-6] for</i> <i>the Sentinel-3 mission and shall not drive the system design.</i> | RD-54, RD-181, RD-56, Table 4, Table 5, Table 6 |
| S3-MR-180 | Performance | Sentinel-3 shall provide measurements of River and Lake Heights (RLH) for large rivers, their tributaries and lakes to at least the quality of the RA-2 on ENVISAT. <i>Note: Inland water monitoring is a secondary objective [S3- OB-6] for the Sentinel-3 mission and shall not drive the</i> <i>system design.</i> | RD-54, RD-181, RD-56, Table 4, Table 5, Table 6 |
| S3-MR-190 | Performance | Sentinel-3 TIR measurements shall be acquired continuously around the satellite orbit (i.e. during day and night time). | RD-52, RD-54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6 |
| S3-MR-200 | Performance | Sentinel-3 VIS measurements shall be available for the part of the orbit that covers solar illuminated earth surfaces and acquired only during the sun illuminated part of the orbit | RD-52, RD-54, RD-181, |



| (when the Solar Zenith Angle (SZA) < 80°). | RD-56, Table 3, Table 4, Table 5, Table 6 |
|--|---|
|--|---|

5.7 Topography Instrument Requirements and Performance

Sentinel-3 topography measurements must satisfy the requirements of the GMES operational, institutional and climate research communities that are summarised in Table 4, Table 5 and Table 6. Recent advances in coastal altimetry [RD-185] have been a driver to derive new satellite altimeter instrumental specifications that answer new performance requirements both in terms of noise and along-track spatial resolution. Several projects within Europe have developed the capability to retrieve and exploit enhanced altimeter data in coastal zone regions (<5 - 30 km from the coast) to monitor coastal water dynamics, surface wind speed, tidal elevation (with the benefit of better proximity to reference tide gauges) and Hs retrieval. These are relevant to the specification of Sentinel-3 requirements for coastal altimetry.

Traditional altimeter processors do not consider the impact of side-lobe contamination via land effects, water vapour gradients in the coastal zone, calm water effects on waveforms due to land shading of winds and coastal zone data are normally flagged as bad and are rejected. Data can be recovered in these regions based on improved processing of high-resolution altimeter echo waveform data. Typical reprocessing in the coastal zone includes re-tracking of the altimeter waveforms and correction for atmospheric effects; both are all difficult to model and account for in the coastal zone. The fundamental activities required to make full use of coastal altimeter data are:

- 1. Waveform retracking: This accounts for the effects of varying topography and geometry and deviations from traditional Brown [RD-192] waveforms. Specialized retracking algorithms have been developed [RD-191] that make full use of new waveform models, accounting for waveform change of shape in the coastal environment. The wave spectra (Hs) are different in coastal zones (due to refraction and reflection) and sea state bias corrections must also be developed for the coastal zone. Wind speeds are different in the coastal zone with areas of calm and crossed winds due to land topography effects. This modifies the distribution of surface scatterers on the sea surface. Typically, re-trackers for the coastal environment use specialized (2-D, sequential, Bayes probabilistic, waveform classification) retracking techniques. 1 Hz data sampling rate is not optimal for coastal altimetry retracking [RD-193] and access to higher-resolution altimeter echo waveform data are required for this purpose.
- 2. Wet Tropospheric correction: Improved correction for water vapour path delay errors ("wet tropospheric" correction) is critical for coastal altimetry because strong water vapour gradients are characteristic of the coastal zone and typically require larger wet tropospheric correction. Options to address this wet tropospheric correction include the use of MWR data that is interpolated across land contaminated segments, the use of NWP outputs (e.g. ECMWF) to estimate tropospheric water vapour loads, and the use of SST products and GPS derived water vapour data [RD-186].

These aspects cannot be calculated globally (models for a "global coastal zone" do not exist) and the key GMES service challenge is to provide core data products that will allow the development and operation of coastal altimeter services that, depending on the location of topographic land features, regionally tune

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processors to local atmospheric situations (vertical water vapour and temperature), local high frequency geoid variations, local tides and local wind and wave conditions.

The Cryosat-2 [RD-34] mission uses a delay-Doppler/SAR (DDA/SAR) altimeter instrument design (SIRAL) that is extremely attractive to satisfy Sentinel-3 resolution requirements in the coastal zone. A delay Doppler/SAR altimeter differs from a conventional radar altimeter in that it exploits coherent processing of groups of transmitted RADAR pulses [RD-34]. Unlike traditional pulse-limited altimeters the full Doppler measurement bandwidth can be exploited to optimise the power reflected from the surface back to the altimeter antenna. The DDA spotlights along-track resolved footprint (cell) as the altimeter passes overhead and processes the stacked multi-look data using synthetic aperture processing techniques. This approach increases resolution and offers the option for multi-look processing including along-track and across-track (range) dimensions [RD-34]. The DDA/SAR mode altimeter offers many potential improvements over conventional altimetry for measurements over the oceans, coastal zones and inland waters using re-trackers adapted to the specific nature of DDA/SAR altimeter echoes.

It is proposed that Sentinel-3 deploy an altimeter capable of providing continuity to ERS, Envisat, and CryoSat altimeter measurements. It is also proposed to consider incorporating a high spatial resolution mode of the altimeter to ensure continuity of the CryoSat-type DDA/SAR capability. This would also facilitate operation in coastal and inland waters and the gauging of large river flows, due to the improved along-track resolution when used in SAR modes. This concept was already considered during the Coastal Zones Earth Watch mission (studied in 1995/1996), recalled at the GMES meeting held in Lille in October 2000. The DDA/SAR technique is now being successfully demonstrated by CryoSat-2.

SSH measurements from the altimeter must support operational global ocean circulation structure and variability analysis, and research on improving an understanding of mesoscale variability and mean sea level trend analysis. Since spatial and temporal sampling characteristics for an altimeter are determined by the Sentinel-3 orbit, the orbit shall be optimised with respect to the planned altimeter-bearing missions and be able to observe Kelvin/Rossby waves in the equatorial regions, and mesoscale eddies in mid-latitudes. The principal SSH goals are to capture global variability on the following scales:

- Large scale: 100 km resolution maps every 10 days to 1-2 cm accuracy,
- Mesoscale: 25 km resolution maps every 7 days accurate to 2 cm,
- Coastal zone: Improved along track resolution (~250 m) every day accurate to 2-3 cm.

The above requirements necessarily rely on an optimal combination of available multi-mission altimeter data working in constellation to be able to achieve these goals. The main requirement identified by the Working Group on Space Infrastructure for the GMES Marine Service (see [RD-52]) for medium to high resolution altimetry is to fly three polar orbiting altimeters in addition to at least one a low inclination reference mission (e.g. JASON). This would yield a track separation of about 80 km at the Equator and an effective repeat period of about 10 days (e.g. the same ground track as ENVISAT with a pseudo repeat period of 35 days/3). The recommendation for S3 mission is to fly the second satellite as soon as possible (e.g. one year after the first launch) [RD-52]. This would set a requirement for Sentinel-3 to measure coherent mesoscale ocean structures with a track separation at the equator of 80 - 150 km with a revisit interval of 20-35 days [RD-52].

| Parameter | Range | NRT Delivery | NTC Delivery |
|-----------|------------|--------------|--------------|
| SSH | - | 10 cm** | 3.5 cm |
| Hs | 0.5 – 20 m | 4 % | 1 % |

| Table 12: Measurement Rec | miromonte for Altimot | ry Specified for 1-Hz ave | and along-track complex |
|---------------------------|-------------------------|-----------------------------|----------------------------|
| Table 12. Measurement Rec | un cincints ior Anninet | I y Specificu for 1-112 ave | ageu along-ti ack samples. |

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| | | (= 8cm @ 2m) | (= 2 cm @ 2 m) |
|----------------------|--------------------------|-------------------------|-------------------------|
| σ° | -10dB - +50 dB | ± 1 dB rms. | ± 0.5 dB rms. |
| | | 0.017 dB/s stability*** | 0.017 dB/s stability*** |
| Wind speed | 0 – 20 m s ⁻¹ | 2 m s ⁻¹ | 1.5 m s ⁻¹ |
| | | < 10 km open ocean | < 1 km open ocean |
| Along track sampling | - | < 300 m over sea ice | < 300m over sea ice |
| | | and in coastal zones | and in coastal zones |
| Coverage | | 3 - 10 | |
| Coverage | - | (to be optimised with o | ther altimeter missions |
| Revisit time | _ | 2-3 | days |

** Note that sea-state bias remains a significant source of uncertainty that is instrument/frequency dependent. This could have a particular influence on any decision to change from the more traditional heritage Ku-band altimetry of the previous missions.

*** Stability computed using averages over 30 second intervals.

The typical amplitude of mesoscale SSH signals is 4 to 8 cm rms. in the open ocean, and 20 to 40 cm rms. in the high eddy energy regions [RD-27]. A 2 to 4 cm measurement noise (for a 1 second average; or 1 Hz sampling) is thus satisfactory but a smaller noise and/or improved along-track resolution may allow better estimation of the along-track sea level gradients (and thus cross-track velocity fields), or a more detailed analysis of eddy structure in the along-track direction.

Observation requirements shall support operational wave and wind-speed forecasting using retrievals derived from sigma naught (σ^{o}) measurements. This requires measurement of Hs and σ^{o} to certain degrees of precision and accuracy. The accuracy of Envisat RA-2 or Jason altimeters is considered an adequate baseline for this purpose. This would indicate a required threshold SWH accuracy of 20 cm or 4 % of SWH for 1 second averages for a 1 - 20 m Hs range. A goal of 5 cm or 1 % (whichever is greater) is expected based on further processing such as retracking [RD-28]. The Sentinel-3 altimeter system shall also be capable of measuring river and lake heights (including the tributaries of rivers) and measurements of sea ice thickness in support of GMES services.

The Sentinel-3 altimeter shall be capable of working in various modes of operation, which together will allow the main measurement objectives to be achieved. Two modes of operation are proposed as follows:

- **Low resolution mode (LRM)**: employs conventional pulse-limited altimeter operation. The LRM mode is useful over open ocean surfaces where the topography is homogeneous over areas at least as large as the antenna footprint (~15km). The altimeter echoes have a predictable shape and the mean surface level of this area can be derived by an appropriate model fitting algorithm after averaging several echoes to smooth out the noise resulting from speckle.
- **High resolution sea-ice mode (HRM)**: this mode of the altimeter is designed to achieve high along-track resolution of order ~ 250 m over relatively flat surfaces. This property can be exploited to increase the number of independent measurements over a given area and is a prerequisite for sea ice thickness measurements and could be an interesting option for mesoscale ocean applications particularly in the complex coastal zone. A CryoSat DDA/SAR altimeter design would satisfy this requirement.

It is to be noted that there is no conflict amongst operational modes of the instrument as these modes are specified according to the target under the satellite path.

As for the ENVISAT RA-2 incorporating a MWR as part of the Sentinel-3 topograpic instrument package will provide co-located integrated water vapour measurements to correct tropospheric range-

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delay errors. MWR measurements can also be used to constrain numerical weather prediction models and information on rainfall may also be derived from combinations of the altimeter and radiometer data. The requirement for a MWR is discussed in more detail in Section 5.7.1.1

It is recognised that rigorous inter-satellite calibration and external calibration will be required to correct for calibration biases, and in order to maintain long-term uniform performance over a 20 year operational lifetime.

5.7.1 Altimeter Accuracy

Geophysical error estimates for the altimeter are summarised in Table 13 indicating our best knowledge from recent altimetry missions such as Envisat and Jason. Geophysical corrections from ECMWF analysis fields are not available for fast delivery (NRT) products within a few hours after acquisition, but are expected to be available within two days for Intermediate Geophysical Data Record (IGDR) and Geophysical Data Record (GDR) processing.

Table 13: Major error terms for altimeter height estimation* [RD-204]. All data in this table are derived using a 1 Hz integration time and a 2 m Hs.

| | NRT (~ 3hrs) | | IGDR (1-3 | days) | GDR(~1 mo) | |
|------------------------|-------------------|--------------|-------------------|--------------|-------------------|--------------|
| | Threshold [cm] | Goal [cm] | Threshold [cm] | Goal [cm] | Threshold [cm] | Goal [cm] |
| Range Noise | 3.0 | 2.0 | 3.0 | 2.0 | 3.0 | 2.0 |
| Sea state bias | 5.0 | 3.0 | 3.0 | 2.0 | 2.0 | 1.4 |
| Ionosphere | 3.0 | 2.0 | 1.4 | 1.0 | 0.7 | 0.7 |
| Dry troposphere | 3.0 | 2.0 | 1.4 | 1.0 | 1.4*** | 1.0*** |
| Wet troposphere | 4.0 | 3.0 | 2.0 | 1.4 | 1.0 | 1.0** |
| RSS Range Error | 8.3 | 6.0 | 5.0 | 3.5 | 4.1 | 2.9 |
| Radial Orbit Error | 10.0 | 8.0 | 4.0 | 3.0 | 3.0 | 2.0 |
| RSS SSH Error | 13.0 | 10.0 | 6.5 | 4.6 | 5.1 | 3.5 |

*Values derived from cal/val and performance analyses for RA-2 and Jason-1, assuming 1 Hz sampling, 1s along-track averages, 2 m SWH and σ^{0} =11 dB [RD-39].

** Goal assuming 3-frequency microwave radiometer.

*** for the dry troposphere correction the same values are proposed for IGDR product and GDR product because actually only one assimilation study was performed during the study [RD-204] used to develop the result.

For ocean altimetry the tracker bias shall be minimised by tuning performance of the tracking algorithm. Tracking bias over the ocean is proportional to the Hs, and shall not be higher than 1 cm, with a goal of 0.25 cm resulting from improvements in tracking algorithm performance, and use of dual-frequency measurements. More complex tracking issues are characteristic of complex surfaces such as those in the coastal zone.

The requirements for measurements of SWH, wind and currents in Section 3 demand for stable and accurate amplitude parameters. The threshold absolute accuracy of σ° shall be better than 1 dB, with a resolution of better than 0.1 dB. The drift in σ° should be characterised with an accuracy of better than 0.2 dB with a goal of 0.1 dB over a period of 1 year. The resulting derived wind-speed accuracy shall be



better than 2 m s⁻¹ for 1 sec. averages (for a range between 3 and 20 m s⁻¹). A goal of 1.5 m s⁻¹ accuracy is expected from improved ground processing.

5.7.1.1 Microwave Radiometer for altimeter Atmospheric Corrections

Table 13 shows that trophospheric attenuation is a significant error term in the altimeter path-delay error budget and must be corrected. Wet tropospheric corrections are even more challenging in the coastal zones RD-186]. An optimal altimeter instrument configuration requires that the altimeter path delay correction due to the wet tropospheric component is estimated directly from the σ° information from the radar altimeter, from independent instrument data, or from atmospheric models. Given the continuous improvements of ECMWF wet tropospheric corrections, studies should be undertaken to quantify the degradation of results for an altimeter without a radiometer. Wet tropospheric and ionospheric corrections are associated with medium and large scale signals where high precision data from a Jason class altimeter could be exploited to assess the performance of independent sources of corrections indicate that NWP analysis fields currently do not provide the spatial resolution to resolve mesoscale variability in the troposphere. Moreover, jumps or drifts occurring in NWP analysis products over the long-term preclude their use as correction data in long-term climate or sea-level change analyses [RD-27].

The path correction due to the wet tropospheric component can be estimated brightness temperature measurements made by a multi-channel MWR and from the sigma-naught information derived from the radar altimeter itself. Experience shows that this would give a residual error of \sim 1-2 cm. Sentinel-3 requires a threshold correction accuracy of 2 cm with a goal of 1 cm rms. Given the problems of using NWP fields, the addition of a MWR is regarded mandatory for Sentinel-3 to achieve the required accuracy shown in Table 13.

The Sentinel-3 MWR shall measure the amount of water vapour and liquid water content in the atmosphere, within a field of view centred immediately beneath the spacecraft track simultaneous and coincident with the altimeter footprint. This information provides the only means with which to make the wet tropospheric path delay correction for the radar altimeter on <100 km scales. Additional processing will be required in the coastal zones where strong water vapour gradients are typically present. The MWR measurements can also be employed for the determination of surface emissivity, and "soil moisture" over land and in support of studies on surface energy budget, atmosphere and ice characterisation [RD-40].

Recent results from comparisons of performance of corrections using 2 versus 3 frequency radiometers indicate a significant variance reduction on crossover range differences and on Sea Level Anomaly (SLA) using the 3 frequency radiometer [RD-46]. Both are consistent with 1 cm² or 1% of total and global SLA variance reduction, and thus a significant improvement in the retrieved sea surface height. Locally the improvement can reach 10% of the SLA variance. The same study showed that on ENVISAT the variance reduction using a 2-channel radiometer correction (as opposed to a model-based wet Tropospheric correction) was about 5 cm². A three channel algorithm would provide an additional improvement of up to 20%. The better performance observed for the three channel algorithm is also stable in time (no seasonal signal). The performance inter-comparison also showed that the 2 frequency results are more susceptible to biases from ocean-wave characteristics, σ^0 anomalies (often encountered in coastal regions) and convective rain cells. Though globally, the 2 frequency radiometer results do not show a bias, regional effects can be significant. Thus, a 3 channel MWR is preferred over a 2 channel instrument provided that accommodation of a larger antenna is feasible on the spacecraft and final choice of launch vehicle.

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The baseline Sentinel-3 instrument concept shall be based on the Envisat MWR with a minimum of two passive channels operating in Ka- and Q-band. The option for inclusion of a 3-frequency MWR will depend on the accommodation of a larger antenna. The MWR shall measure the amount of water vapour and liquid water content in the atmosphere, within a field of view centred immediately beneath the spacecraft track, simultaneously and contemporaneous with the altimeter measurements.

5.7.1.2 Precise Orbit Determination Package

Precise orbit determination is a prerequisite to the success of the Sentienl-3 altimetry package. The threshold performance for NRT orbit determination shall be 10-20 cm, with a goal of 2 cm rms. residual orbit accuracy after offline processing. For the high accuracy orbit to be useful in accompaniment to the altimetry data used in operational ocean models, the delivery timeliness requirement shall be 2-5 days.

Sentinel-3 shall include a precise 3-d positioning instrument (e.g. laser retro-reflector) which allows the possibility to reduce orbit errors (for the purpose of meeting the altimetry performance goals). For independent orbit determination to an accuracy demanded by the specified performance of the altimeter payload it will be necessary to carry a support payload like Doris or a geodetic quality GNSS receiver. Because of its significant contribution to precise orbit determination, and capability to provide a fail-safe back up solution in case of failure of other on-board orbit positioning systems, a laser retro-reflector shall be included as a minimum baseline requirement.

5.7.2 Summary of Sentinel-3 altimeter requirements

Sentinel-3 shall deploy a dual frequency altimeter instrument similar to the ENVISAT RA-2 including a SAR measurement capability in ice and coastal zones similar to CryoSat SIRAL. The altimeter shall be capable of operating in low (open-ocean) and high (ice and coastal zones) resolution modes. The altimeter shall make measurements conforming to the specifications set out in Table 12. The topography mission shall include a multi-channel MWR radiometer and a laser retro reflector to minimise SSH errors. The instrument shall operate over sea, land and ice surfaces and shall be capable of measuring river and lake heights including the tributaries of rivers and contribute to global DEM mapping. The altimeter shall also be capable of providing measurements of sea ice thickness. Sentinel-3 shall participate in rigorous inter-satellite calibration and external calibration activities to correct for calibration biases, and in order to maintain long-term uniform performance over a 20 year operational lifetime.

| MR-ID | Туре | | Description | Ref |
|-----------|----------------------|----|--|------------------|
| S3-MR-210 | Signal | to | The Sentinel-3 topography instrument shall have a noise | Section |
| 53-MR-210 | noise | | level better than 3 cm (1-sigma) for a 1 second average. | 6.3.3 |
| S3-MR-220 | Absolute accuracy | | The Sentinel-3 topography instrument range accuracy shall allow the recovery of meso-scale circulation signals. As a starting point, the absolute range determination accuracy shall be $0.1 - 1$ m. | Section 6.3.3 |

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| S3-MR-230 | Performance | The Sentinel-3 altimeter shall be capable of operating in a low resolution mode (LRM) over the open ocean and a high resolution mode (HRM) (~300 m along track resolution) over sea ice and in coastal zones. | RD-52, Table Table 5 | 3, |
|-----------|-------------------|---|---|----------------|
| S3-MR-240 | Performance | The Sentinel-3 altimeter instrument shall acquire data over sea, inland water and ice surfaces. | RD-52, RD-54, RD-181, RD-56, Table Table Table Table | 3, 4, 5, |
| S3-MR-250 | Performance | The Sentinel-3 altimeter shall be capable of providing measurements of sea ice thickness. | RD-52, Table Table 5 | 3, |
| S3-MR-260 | Spectral sampling | The Sentinel-3 MWR system shall have a minimum of two passive channels operating in Ka- and Q-band. An option to use a 3-frequency MWR will depend on the accommodation of a larger antenna. | RD-52, Table Table 5. | 3, |
| S3-MR-270 | Performance | The Sentinel-3 MWR shall be capable of providing a wet tropospheric delay correction for the altimeter with an accuracy 2 cm (goal 1 cm) rms | Section 6.3.3 | |
| S3-MR-280 | Performance | Sentinel-3 shall include a precise 3-d positioning instrument to reduce orbit errors to an accuracy goal of 2 cm residual orbit accuracy after offline processing (2-3 cm threshold) required to reach altimeter accuracy targets. Because of its significant contribution to precise orbit determination, and to provide a fail-safe back up solution in case of failure of other on-board orbit positioning systems, a laser retro-reflector shall be included as a minimum requirement. | RD-53, RD-65 | |
| S3-MR-290 | Performance | The Sentinel-3 altimeter threshold absolute accuracy for σ° shall be better than 1 dB, with a resolution of better than 0.1 dB. | Section 6.3.3 | |
| S3-MR-300 | Performance | The Sentinel-3 altimeter drift in σ° shall be characterised with an accuracy of better than 0.2 dB with a goal of 0.1 dB over a period of 1 year. | Section 6.3.3 | |
| S3-MR-310 | Performance | The Sentinel-3 altimeter tracker bias shall be minimised by tuning performance of the tracking algorithm. Tracking bias over the ocean is proportional to the Hs, and shall not be higher than a goal of 0.25 cm (1 cm threshold). | RD-52, Table Table 5. | 3, |
| S3-MR-320 | Performance | The Sentinel-3 altimeter derived Hs threshold accuracy shall be 20 cm or 4 % of Hs for 1 second averages over a range of 1 - 20 m. A goal of 5 cm or 1 % (whichever is smaller) is expected after STC/NTC data processing (retracking). | Section 6.3.3 | |



| S3-MR-330 | Performance | The Sentinel-3 altimeter derived wind-speed accuracy shall be better than 2 m s ⁻¹ for 1 sec. averages over a range of 3 and 20 m s ⁻¹ . A goal of 1.5 m s ⁻¹ accuracy is expected from improved ground processing. | Section 6.3.3 |
|-----------|-------------|--|------------------|
| S3-MR-340 | Performance | Sentinel-3 shall participate in rigorous inter-satellite calibration and external calibration activities to correct for calibration biases, and maintain long-term uniform performance over the satellite operational lifetime. | RD-52, RD-41 |

Other requirements (e.g., coverage, spectral, radiometric etc) articulated in this section are captured formerly in following subsections.

5.8 Sea and Land Surface Temperature Instrument Requirements and Performance

SST, LST and IST measurements must satisfy the requirements of the GMES operational and institutional communities and also the climate research community that are summarised in Table 14 (derived from the information provided in Table 3, Table 4, Table 5, and Table 6). SST is a key climate variable and a parameter explicitly required in GMES NOP and NWP assimilation systems.

| Table 14: Summary of | requirements | for | sea | and | land | surface | temperature | derived | from | user |
|-------------------------|--------------|-----|-----|-----|------|---------|-------------|---------|------|------|
| requirements in Section | 3. | | | | | | | | | |

| Application | Temperature accuracy [K] | Spatial resolution [km] | Revisit Time |
|---|-----------------------------|----------------------------|--------------|
| Weather prediction | 0.2 - 0.5 | 1 - 50 | 6 – 24 hrs |
| Climate monitoring Climate stability | 0.1 <0.1 K/decade (goal) | 10 - 50 | 8 d |
| Ocean forecasting | 0.2 | 1 - 10 | 6 – 24 hrs |
| Coastal/local | 0.5 | < 0.5 | ≤1 d |
| Land Surface Temperature | < 1 K @ 1 km resolution | 1 km | Daily |
| Ice surface Temperature | 1 K (10 %) | < 5 km (1 km goal) | Daily |
| Active Fire detection | < 3 K | 0.5 – 1 km | Daily |
| Fire burned area | < 3 K | 0.5 – 1 km | Daily |
| Lake Water Surface Temperature | <1 K (10 %) | < 1 km | Daily |

To support the climate change community, the strongest mission driver is the measurement precision, accuracy and stability requirements which should support the capability to retrieve sea surface skin temperature (SSTskin) changes with zero bias and an uncertainty of \pm 0.3 K (1 σ) for a 5 x 5 degree latitude longitude area, having a temporal stability of 0.1 K/decade. These requirements should be met even for occasional atmospheric events like higher aerosol loads due to volcanic eruptions. A potential secondary supplement could be a microwave SST sensor (e.g. AMSR type) to complement the infra-red sensor by providing global low resolution but all-weather (no cloud problems or aerosol impacts) SST measurements.

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On board calibration is required to achieve this accuracy and the instrument design shall follow the calibration principles used by ENVISAT AATSR. An along-track view (bi-angular observation) is mandatory to make the atmospheric correction robust to changes in aerosol and water vapour loading. Visible channel data is required for effective cloud flagging which is the largest source of error for SST products derived from infrared satellite instruments. Improved cloud clearing could be achieved if additional channels (e.g. at ~1.3-2.2 μ m) are included to detect thin cirrus clouds. Dual-view visible channels, accurately collocated with the SWIR and TIR bands, will allow aerosol corrections to be coestimated with SST retrievals and over land surfaces. Continuity of the ATSR heritage visible channels provides the capability to fully meet the stringent SST requirements shown above. The utility of aerosol information derived from the overlapping dual-view channels also permits significant improvements to the accuracy of land surface temperature and vegetation products.

The Sentinel-3 Sea and Land Surface Temperature (SLST) capability shall be optimised for SST measurements. However, the design shall include an active fire detection and characterisation capability including a 3.7 micron channel that does not saturate in the presence of fire (i.e. saturation limit of ~650 K, and equivalent to JPSS VIIRS fire channel), coupled with non-saturating thermal infrared band at 11 or 12 microns. Calibration of fire channels is expected to be a particular challenge due to the large dynamic range of measurements; full fire channel characterisation and pre-flight calibration will be critical to maintaining in flight calibration if fire channels using hot earth targets (e.g. sunglint, hot desert areas) as the on-board black body calibration targets will be optimised for SST retrievals. Fire requirements are secondary mission objectives and shall not drive the mission design or compromise the quality of the primary SST mission.

Sentinel-3 shall be able to measure Land Surface Temperature to an accuracy of ~1 K with a resolution of 1 km at nadir. This capability shall not reduce the quality of the SST retrievals. In addition, Sentinel-3 shall be able to measure Ice Surface Temperature to an accuracy of 10 % with a resolution of < 5 km (1 km goal) at nadir. This capability shall not drive the mission design or reduce the quality of the SST retrievals.

The spatial resolution of the existing AATSR instrument (1 km) is adequate for open ocean SST derivation, as is its geolocation accuracy [RD-23] although improvements in the coastal zone would be advantageous. These capabilities can be maintained for Sentinel-3.

As for all imaging systems the revisit time (i.e. time gap between two subsequent observations of an area not necessarily with the same observation geometry) and the coverage (i.e. elapsed time until orbit revolutions have covered the maximum observable area) are mainly driven by the swath width. A revisit time of 1 day is a goal which requires large swaths (> 2000 km) (e.g. equivalent to MODIS). Ideally, the system should deliver high quality SST measurements over a wide swath (~1000km), as well as dual view over a narrower swath as a "gold standard" for all other SST measurements (over as broad a portion of the central swath as possible). For coastal and regional applications the accuracy requirement are less stringent. However, because the main aim of the SST sensor on the Sentinel-3 mission is to provide a stable, absolute reference for global SST measurements, the space/time coverage requirements shall take second priority compared to the climate accuracy requirement.

It should be noted that for both SST and Ocean Colour, the revisit time criteria does not take into account the problem of cloud cover and is not indicative of the actual revisit time (the merging of several missions is required to achieve an effective revisit time of 1 day – see GHRSST strategy [RD-24, RD-67]). It is assumed that SST observations of the Sentinel-3 mission will be complemented by other IR and MW measurements to derive a combined SST product for long term climate applications. A

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reasonable compromise for revisit time is 2-3 days (i.e. similar to the requirements for Ocean Colour with an effort to optimise for European latitudes).

Co-incident high accuracy observations of ocean colour with high accuracy SST observations (e.g., for the accurate estimation of oceanic carbon fluxes, coastal and water quality management, fisheries research, ease of data assimilation) are required. This presents a direct challenge to Europe, namely to ensure the long term provision of collocated high accuracy ocean colour (of MERIS class) and sea surface temperature measurements (of ATSR-class). The use of common visible channels between OLC and SLST will allow co registration of the individual pixel radiances derived from each respective instrument channel and will permit cross calibration between instruments. The advantage is the benefit of having precise SLST dual-view atmospheric corrections for superior correction of OLC products and operational redundancy. Sentinel-3 shall generate high-quality Land surface products from SLST and OLC data working in synergy providing a SPOT Vegetation-like product. Stringent sub-pixel coregistration between ocean and land colour (OLC) measurements and SST products is required so that:

- SPOT Vegetation-like products can be generated based on synergy processing of the OLC and SLST instrument measurements.
- Other synergetic products may be developed for GMES users,
- OLC products may benefit from improved atmospheric and aerosol corrections from the dualview instrument concept, as well as its complementary spectral bands for cloud detection, cloud properties and snow/cloud discrimination.

In summary, Sentinel-3 shall have a similar capability to the ENVISAT AATSR instrument providing 1 km resolution data at nadir with channels similar to those set out in Table 8. The instrument shall be optimised for SST measurements. A dual-view capability shall be included in the instrument design in order to account for atmospheric attenuation. Sea surface skin temperature (SSTskin) measurements shall be accurate to <0.3 K with a stability goal of <0.1 K/decade. On board calibration shall follow the principles used by ENVISAT AATSR. Additional channels could be included to address improved cloud clearing of thin cirrus clouds. The instrument shall provide global coverage in 2-3 days at the equator with a goal revisit time of 1 day (2-3 days threshold) at European shelf sea latitudes. The observation time shall be consistent with ENVISAT AATSR which limits the impact of surface ocean diurnal stratification. The instrument shall have stringent sub-pixel co-registration of OLC and SST measurements.

Other requirements (e.g., coverage, spectral, radiometric etc) articulated in this section are captured formerly in following subsections.

| MR-ID | Туре | Description | Ref |
|-----------|-------------|--|---|
| S3-MR-350 | Performance | The Sentinel-3 near infrared and thermal infrared channels shall be optimised for SST retrieval. <i>Note: Active Fire, IST and LST requirements shall be</i> <i>considered in the design but shall not drive the system design</i> <i>or reduce the quality of the SST retrievals.</i> | RD-54, RD-181, RD-56, Table 4, Table 5, |

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| S3-MR-360 | Performance | Building on ENVISAT AATSR heritage, Sentinel-3 shall provide an along-track view (bi-angular observation) for VIS/nearer and TIR channels to make the atmospheric correction for SST products robust to changes in aerosol and water vapour loading and to allow aerosol corrections/retrievals over land surfaces. | RD-52, RD-54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6, |
|-----------|-------------|--|---|
| S3-MR-370 | Performance | The Sentinel-3 SLST instrument on board calibration system shall follow the principles used by ENVISAT AATSR (i.e. two reference black body cavities and a visible channel calibration system). | RD-54 |
| S3-MR-380 | Performance | The Sentinel-3 SLST instrument shall make simultaneous and co-incident measurements with ocean colour measurements. | RD-54, |
| S3-MR-390 | Performance | The Sentinel-3 SLST instrument shall have stringent sub- pixel co-registration with OLC measurements. | Section 5.8 |
| S3-MR-400 | Performance | Sentinel-3 shall provide SST measurement capability to at least the quality of AATSR on ENVISAT: SST shall be accurate to < 0.3 K @ 1 km spatial resolution and with improved swath coverage. | RD-52, RD-67, Table 3, Table 5 |
| S3-MR-410 | Performance | Space time coverage requirements for the Sentinel-3 SLST instrument shall take second priority with respect to absolute accuracy requirements. | Section 5.8 |
| S3-MR-420 | Performance | Sentinel-3 shall be able to measure Land Surface Temperature (LST) to an accuracy of < 1 K with a resolution of 1 km at nadir. This capability shall not reduce the quality of the SST retrievals. | RD-118, Table 4, Table 5, Table 6, Table 6 |
| S3-MR-430 | Performance | Sentinel-3 shall be able to measure Ice Surface Temperature (IST) to an accuracy of 10 % with a resolution of < 5 km (1 km goal) at nadir. This capability shall not reduce the quality of the SST retrievals. | Table 3, RD-118, |
| S3-MR-440 | Performance | Sentinel-3 shall be capable of measuring Lake water Surface Temperature (LWST). This capability shall not drive the mission design. | RD-54, RD-181, RD-56 |
| S3-MR-450 | Performance | Sentinel-3 shall be capable of measuring Fire Radiative Power and fire burned area using infrared measurements over land. This capability shall not drive the mission design. | RD-181, RD-56, Table 4, Table 5, Table 6 |

5.9 Ocean and Land Colour (OLC) Instrument Requirements and Performance

Ocean and Land Colour (OLC) measurements must satisfy the requirements of the GMES operational and institutional communities and also the climate research community that are summarised in Table 3, Table 4, Table 5, and Table 6. The principal limitation on ocean and land optical product performance is the stability and radiometric performance of the instrument, the quality of atmospheric corrections and

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quality of flagging atmospheric contamination (e.g. clouds and aerosol). The key mission drivers are to continue the heritage of the ENVISAT MERIS instrument and to provide continuity to the SPOT Vegetation capability.

In 2010-2012 the SPOT Vegetation instruments will be nearing the end of their operating lifetime. In direct response to the needs of the user community (e.g., [RD-152, RD-153, RD-154, RD-154]) Sentinel-3 shall provide continuity to SPOT Vegetation P-like product line, by making full use of the moderate spatial resolution and wide swath capability. Daily global coverage TOA reflectance measurements are required in the bands of SPOT/Vegetation mapped to a Pate-Carrée projection. This can be achieved through the use of Sentinel-3 OLC and SLST instruments working in synergy [RD-155] to provide a mapping between SPOT Vegetation channels and those of Sentinel-3. A trade-off exercise is required to determine the best spectral mapping based on the final choice of bands used by the OLC and SLST instruments noting that these bands are optimised for ocean colour and SST measurements respectively. This requires as a minimum continuity in existing MERIS and AATSR channels, together with additional channels to allow co registration and improved cloud clearing. These channels should not saturate over land, snow or active fires.

Geophysical ocean colour parameters ("Level 2 products") are derived from radiances in different spectral bands and the main bands commonly exploited from existing sensors are summarized in Table 11. The intention is to meet a product resolution goal of 30 classes of Chlorophyll and suspended matter, and 15 classes of dissolved organic matter in these typical Level 2 products. The instrument shall also be able to accomplish this task in both oceanic Case 1 and turbid Case 2 waters. The Sentinel-3 OLC instrument shall be optimised to measure the ocean colour over the open-ocean and coastal zones, however, it shall not saturate over land targets.

A careful selection of channels in the near-infrared domain is essential for atmospheric correction schemes over case-1 and case-2 waters. Atmospheric correction of both SST and Ocean Colour data requires aerosol/particulate measurements as well as water vapour measurements and synergy between OLC and SLST instrument data could be particularly beneficial (also for continuous and consistent aerosol products over land and sea). At least 7 channels are necessary to cover the oceanographic and atmospheric correction measurement elements with sufficient accuracy in the open ocean [RD-14] (i.e. Case 1 water). An extended baseline set of 15 channels similar to MERIS would ensure the presence of the signals to ensure sufficient atmospheric correction with which to retrieve the various products over case 2 waters [RD-15]. Recent studies have refined these channels sets that could in practice meet most of the ocean colour, SST, and atmospheric correction requirements in one single instrument package [RD-19, RD-20]. Additional channels in the red and infra-red may be exploited to observe turbid Case 2 waters, and to provide improved estimations of cloud cover. The SLST Visible channels provide additional capability for this purpose and to deliver cloud and aerosol products to complement those of OLC. However SLST measurements will be made at a lower spatial resolution than the proposed OLC channels. For this reason, and to improve the quality of both ocean case-1 and case-2 atmospheric correction and land product retrievals, a channel at 1.02 µm is required in addition to the standard suite of ENVISAT MERIS channels.

The spectral bands for the proposed Sentinel-3 OLC instrument are presented in Table 20. Atmospheric correction for ocean colour data is very critical as only about 4% of the radiation measured by the Sentinel-3 instrument originates from the water surface. Because of the low noise-equivalent radiance from ocean surfaces, the OLC signal to noise ratio (SNR) shall be high, particularly for the 'blue' bands (~400 nm). To avoid errors in the blue/green chlorophyll algorithms, it is also necessary to closely corregister channels 442, 490 and 510 nm. To minimise errors in the atmospheric correction procedures, channels at 620 and 665nm shall be co-located and have as little difference as possible in the atmospheric paths. An additional channel at 1.02 microns has been added upon recommendations to

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improve the existing MERIS atmospheric and aerosol correction capabilities. Additional bands in the O2A spectral region may be considered for improved cloud top pressure (height) and water vapour retrieval. Other bands may be considered for fluorescence measurements over land (again in the O2A spectral region) and to improve land and ocean geophysical retrievals, provided the instrument complexity is not increased.

Sun glint specular reflection of sun light over ocean waves contaminates ocean colour data and limits the quality of ocean colour measurements. Sun glint can be used as a calibration target (e.g. for interband calibration with respect to a reference band a reference spectral band) and recently, techniques have been developed to exploit sun-glint signatures providing estimates of surface roughness features. However, data lost due to sun glint represents a considerable cost both financially and scientifically: in the case of ENVISAT MERIS glint-contaminated pixels are masked, causing complete loss of the affected pixels and affects almost half the observations at sub-tropical latitudes. Sun glint algorithms typically use surface wind speed and direction, and the illumination and observation geometry of each measurement, to estimate the level of Sun glint contribution to the surface reflectance. When that contribution is below a "low threshold" value it is neglected. When above that threshold and below a "high threshold" it is subtracted from the signal; when above the "high threshold" pixels are flagged and not processed further. The best approach to treating sun-glint is to develop Sentinel-3 in a manner that avoids sun-glint as far as possible by appropriate off-nadir pointing of the instrument.

The radiometric performance of Sentinel-3 OLC must be excellent and an absolute radiometric accuracy goal of < 2 % with reference to the sun for the 400-900 nm waveband and < 5% with reference to the sun for wavebands > 900 nm RD-182] is required. The relative radiometric accuracy goal shall be 0.2 %. Comparison of SeaWiFS and Terra-MODIS data shows differences in the retrieved water leaving radiances of 20 % to 30 % in the southern hemisphere. This difference translates to a 2-3% error in total top of the atmosphere radiance measured by the sensor and is by far the largest unresolved factor remaining in the MODIS calibration effort [RD-184]. The long-term stability and degradation of the OLC instrument must be known for the entire mission lifetime and should be considered in the design in order to address long term climate monitoring requirements of GMES. In order to achieve these challenging radiometric requirements an on-board calibration system is required and the principles used in the ENVISAT MERIS instrument shall be followed for this purpose. Extensive pre-launch characterisation of the OLC instrument is also required. Adequate dynamic range is required to accommodate both low oceanic signals for cloud clear atmospheres and higher signals in the presence of high aerosol loading hat there is a trade-off to be performed as not all saturation requirements can be satisfied for all applications). For all Sentinel-3 VIS channels, following MERIS heritage, radiances should have a polarisation error less than 1 % and the polarisation sensitivity of each spectral channel shall be known.

The OLC instrument ground resolution depends whether the data are acquired above open ocean, or coastal zones and land. Ocean Colour products require a spatial resolution at sub-satellite point of 1 km over open-ocean and sea Ice and ≤ 0.3 km (ENVISAT MERIS capability) over coastal zones, while land products require a resolution of ≤ 0.3 km globally. The coastal zone area is defined by the coastline and its extension outward into the ocean by 300 km (i.e. corresponding to a distance between the shelf limit of 150 km and of the Economic Exclusion Zone limit of 200 nautical miles). The instrument shall have geolocation precision better than 0.5 pixels. Precise co-registration of SST and ocean colour pixel measurements can be useful for monitoring of coastal up-welling zones and for carbon fluxes estimates. The main parameters commonly exploited from existing sensors over land are summarized in Table 10 together with typical ranges. For land measurements, the Sentinel-3 OLC shall have a spatial resolution of ≤ 300 m (goal) at nadir (<500 m threshold). A revisit time of 1 day (goal) is required and 2-3 days at

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equatorial latitudes over global land areas, including islands and ice surfaces. Global coverage at the equator is required in 2 days.

Requirements on overpass time depend on the availability of alternative sources of ocean colour data but should be optimised to maximise the solar elevation, minimise the impact of sun-glint, morning haze and cloud cover. The instrument shall improve over ENVISAR MERIS by mitigating the impact of sun-glint over the ocean. The observing time shall be optimised to a local time around 11:00 optimal (but synergy with other satellites is essential).

In summary, the Sentinel-3 OLC instrument shall have the following characteristics:

- Provide continuity to ENVISAT MERIS ocean and land colour measurements,
- Provide continuity to SPOT Vegetation P-like products in synergy with sea and land surface temperature data,
- The instrument shall improve over ENVISAR MERIS by mitigating the impact of sun-glint over the ocean.
- The OLC instrument should have a spatial resolution at sub-satellite point of 1 km over Open Ocean, and Sea Ice and ≤ 0.3 km over coastal zones. Land products require a resolution of ≤ 0.3 km globally,
- Include a minimum set of channels identified in Table 9, Table 11 and, Table 10, either as dedicated channels or via synergy with the SLST instrument
- Provide low noise-equivalent radiances in all channels,
- Have an absolute radiometric accuracy threshold of 2 5%,
- Have a relative radiometric accuracy goal of 0.2 %,
- Include a precise internal calibration system,
- Have adequate dynamic range to accommodate both low oceanic signals in the case of clear atmospheres and higher signals in the presence of relatively high aerosol loading (optimised for ocean colour measurements),
- Ensure geolocation precision better than 0.5 pixels,
- Have known polarisation errors less than 1 % for VIS channels.

| MR-ID | Туре | Description | Ref |
|-----------|-------------|--|---|
| S3-MR-460 | Performance | The Sentinel-3 OLC instrument shall be optimised for measurement of water quality and ocean colour parameters including open ocean (case-1) and coastal shelf (case-2) waters, inland seas and lakes. | RD-52, RD-54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6, |
| S3-MR-470 | Performance | The Sentinel-3 OLC instrument shall include a precise internal calibration system to maintain instrument calibration and stability. | RD-52 |
| S3-MR-480 | Performance | The Sentinel-3 OLC instrument shall improve over ENVISAT MERIS by mitigating the impact of sun-glint over the ocean. | RD-52 |

Other requirements (e.g., coverage, spectral, radiometric etc) articulated in this section are captured formerly in following subsections.

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5.10 Revisit and Geographical Coverage

For all imaging systems the revisit time and the coverage are mainly driven by the swath width. A geometric revisit time of 1 day is a goal for Sentinel-3 which requires large swaths (> 2000 km, e.g. equivalent to MODIS). It is important to realise that for such large swath widths the necessary viewing geometry introduces large slant angles that are not optimal for ocean and land colour measurements. Sentinel-3 aims to provide a stable, absolute reference for global SST measurements in support of climate change applications and therefore the space/time coverage requirements shall take second priority for the climate requirement. The required revisit time for SST and Ocean Colour measurements is 1 day in coastal regions and 2-3 days globally with an effort to optimise more frequent coverage for European latitudes. This will result in swath widths of >1000 km, so performance degradation effects at swath edges will have to be considered for both SLST and OLC. The use of multiple satellites and/or merging of several missions alleviate this issue and multiple satellites are required to achieve an effective revisit time of ~1 day [e.g., RD-42].

Sentinel-3 shall provide daily coverage of the Earth, facilitating global fast revisit observation of the land surface. The revisit requirements of 1 day over land surfaces are driven mainly by vegetation monitoring for services included in the GMES LMCS [RD-105] the GSE GMFS, RISK-EOS and Land. In this context the observing system should be better than SPOT and Landsat as these systems do not have high enough revisit frequencies.

Observation requirements for SSH from the Sentinel-3 altimeter must support operational global ocean circulation structure and variability analysis, and research on improving an understanding of meso-scale variability and mean sea level trend analysis. Since spatial and temporal sampling are determined by the orbit, the orbit shall be optimised with respect to planned altimeter-bearing missions [RD-65], such as to be able to observe Kelvin and Rossby waves in the equatorial regions, and meso-scale eddies in mid-latitudes [RD-27]. Particular attention is required to maximising the measurement revisit in coastal zones. The principal SSH goals of GODAE [RD-9] and MyOcean [RD-52, RD-53] are to capture global variability on the following scales:

- Large scale climate applications: High priority 100-500 km resolution maps every 10-20 days to 1 cm accuracy [RD-53]
- Ocean now-casting and NOP meso-scale applications: High priority 25-100 km resolution maps every 7-15 days accurate to 2 -3 cm [RD-53]
- Coastal and local NOP applications: Lower priority (limited by feasibility only) 10 km resolution maps every day accurate to 2-3 cm [RD-53]

The above requirements rely on an optimal combination of the available multi-mission altimeter data to be able to achieve these goals. To further improve mapping (required for some scientific and operational applications which have been proposed), it is necessary to resolve the high frequency and high wavenumber signals, i.e. sample the ocean with a time sampling below 5-7 days and 25 km. Such a sampling density would require a constellation of altimeter satellites and/or the development of different concepts for satellite altimetry (e.g. wide swath techniques) [RD-27, RD-65].

Sentinel-3 revisit requirements require a system with a constellation of more than one satellite operating at the same time.

GMES services are provided for areas all over the world. Operational land monitoring [RD-54], ice services [RD-53, RD-117], NOP [RD-53] and NWP [RD-75] systems providing GMES Services (e.g., MyOcean, MACC, SAFER, G-MOSAIC, GSE Coastwatch, GSE PolarView, GSE GMFS and GSE

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RESPOND) all require access to high resolution global coverage data products over land, ice, ocean, coastal zones and inland seas every 1-3 days. Note that although this document refers top global coverage, it is acknowledged that the S3 sun-synchronous orbit inclined at 98.6° results in gaps centred over the North and South Pole.

| MR-ID | Туре | Description | Ref |
|-----------|------------------------|--|---|
| S3-MR-490 | Geographic Coverage | Sentinel-3 topography measurements shall be acquired globally in low resolution mode (to support measurements of RLH and production of altimeter DEM). High resolution mode data shall be acquired in the coastal zone, sea ice regions and other selected areas required by GMES users. | RD-52, RD-54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6, |
| S3-MR-500 | Geographic Coverage | Sentinel-3 Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances shall have complete global coverage including oceanic, coastal waters and inland seas, and ice infested waters. | RD-52, RD-54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6, |
| S3-MR-510 | Geographic Coverage | Sentinel-3 Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances shall have complete global coverage over all land surfaces including lakes, rivers, islands and ice sheets. | RD-54, RD-181, RD-56, Table 4, Table 5, Table 6, |
| S3-MR-520 | Geographic Coverage | Sentinel-3 Ice Surface Temperature (IST) products shall have complete global coverage over ice covered surfaces including oceanic, coastal waters and inland seas. | RD-52, RD-181, RD-56, Table 3, Table 5, |
| S3-MR-530 | Geographic Coverage | Sentinel-3 LST and inland Lake Water Surface Temperature (LWST) products shall have complete global coverage over land covered surfaces. | RD-54, RD-181, RD-56, Table 4, Table 5, Table 6, |
| S3-MR-540 | Geographic Coverage | Sentinel-3 SST and, ocean colour products shall have complete global coverage over oceanic, coastal waters, rivers and their tributaries, and inland seas. | RD-52, RD-181, Table 3, Table 5, |
| S3-MR-550 | Geographic Coverage | Sentinel-3 Fire monitoring products shall have complete global coverage over all land surfaces. | RD-54, RD-181, RD-56, |

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| | | Table 4, Table 5, |
|--|--|----------------------|
|--|--|----------------------|

5.11 Geometric Coverage

The geometric coverage time represents the temporal frequency of systematic acquisition of a given area disregarding cloud cover with potentially different viewing geometries. The effective coverage time represents the temporal frequency of systematic acquisition of a given area where cloud cover is below a specified threshold with potentially different viewing directions (excluding thin cirrus if thin cirrus clouds can be detected and their effect corrected). Based on European cloud cover statistics, a ratio of 3 between the geometric and effective revisits is considered adequate in the context of optical measurements [RD-92]. The impact of sun-glint should be taken into account in all coverage calculations.

GMES operational and pre-operational land monitoring [RD-54], ice services [RD-53, RD-117], NOP [RD-53], NWP [RD-75] Emergency and Security [RD-98, RD-99, RD-100, RD-101, RD-88], systems serving GMES Services require access to high resolution global coverage data products every 1-3 days.

The Working Group on Space Infrastructure for the GMES Marine Service [RD-52] sets a priority on augmenting the sampling regime of a future altimeter constellation. The main requirement for medium to high resolution altimetry is to fly three altimeters in high inclination orbit in addition to at least one altimeter in a low inclination orbit (e.g. Jason) that is used as a reference for bias correction. This would yield a track separation of about 80 km at the Equator and an effective repeat period of about 10 days (e.g. the same ground track as ENVISAT with a pseudo repeat period of 35 days/3). The recommendation for S3 mission would be to fly as soon as possible a second satellite (e.g. one year after the first launch) [RD-52]. The recent de-scoping of the JPSS altimeter (which was assumed to provide an additional altimeter) makes the recommendation even more important. Such a scenario would also provide an improved operational reliability (e.g. in case of a satellite failure, continuity of service -albeit in a degraded mode- would be guaranteed). Moreover, it would enhance the spatial and temporal sampling for monitoring and forecasting Hs.

| MR-ID | Туре | Description | Ref |
|-----------|-------------------------|---|--|
| S3-MR-560 | Geometrical Coverage | Sentinel-3 Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances shall have complete global coverage every 1 to 3 days over oceanic and coastal waters. | RD-75, Table 3, Table 5, Table 6, |



| S3-MR-570 | Geometrical Coverage | Sentinel-3 Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances over land and ice surfaces shall have complete global coverage in 1 (goal) to 2 days. | RD-54, RD-53, RD-117, RD-75, RD-98, RD-99, RD-100, RD-101, RD-88, Table 4, Table 5, Table 6, |
|-----------|-------------------------|--|---|
| S3-MR-580 | Geometrical Coverage | Sentinel-3 land products shall have complete global coverage in ≤2 days at the equator. | RD-54, RD-117, RD-75, RD-98, RD-99, RD-100, RD-101, RD-88, Table 4, Table 5, Table 6, |
| S3-MR-590 | Geometrical Coverage | Sentinel-3 SST and ocean colour products shall have complete global coverage every 2-3 days at the equator. | RD-53, RD-75, Table 3, Table 6, |
| S3-MR-600 | Geometrical Coverage | Sentinel-3 topography products shall provide global ocean coverage every 3-10 days optimised with complementary altimeter missions to deliver maps of SSH at 25-50 km resolution. | RD-75, Table 3, Table 5, Table 6 |
| S3-MR-610 | Performance | The Sentinel-3 mission shall launch a second satellite (if required) within 1 year of launch of the first satellite. | RD-52 |

5.12 Instantaneous coverage

Sentinel-3 coverage requirements dictate the use of large swath width for optical instruments that are not optimal for optical measurements at the edge of the swath. The negative impact of sun-glint on visible measurements shall be mitigated by appropriate off-nadir instrument pointing. Optical VIS/IR/TIR measurements shall also be acquired contemporaneously and simultaneously facilitating their utility and application in data assimilation systems in support of GMES services. Furthermore, topography measurements shall be acquired within the swath of optical measurements; they can be used for synergy studies including the use of altimeter wind and wave parameters on ocean colour and SST measurements and RLH in synergy with optical data over rivers and lakes.

| MR-ID Type Description | Ref |
|------------------------|-----|
|------------------------|-----|

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| S3-MR-620 | Instantaneous coverage | Sentinel-3 Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances shall have co-located and simultaneous coverage. | | | |
|-----------|---------------------------|--|-------------------|--|--|
| S3-MR-630 | Instantaneous coverage | Sentinel-3 Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances shall have a wide swath width >1000 km. | | | |
| S3-MR-640 | Instantaneous coverage | Sun glint conditions for the Sentinel-3 visible channels shall be mitigated to the largest extent possible by choice of instrument pointing and final orbit configuration. | RD-52, Table 3 | | |
| S3-MR-650 | Instantaneous coverage | Sentinel-3 topography measurements shall be acquired within the swath of optical measurements to facilitate synergy application. | RD-52 | | |

5.13Single or Multiple Platform Concepts

While SST, Ocean Colour and altimetry are quite complementary, there is no requirement for flying an altimeter on the same SST/Ocean Colour platform. The sampling characteristics of altimetry and optical imagers are quite different (swath versus along-track) and do not allow the measurement of SSH, SST and Ocean Colour contemporaneously and simultaneously for all positions and times (except for the sub-satellite point where altimeter along-track data are co-located with optical data). There is thus no particular advantage to fly the topography mission on the same platform as the optical mission.

The mission requirements for Sentinel-3 may be met using either multiple satellite platforms with narrower-swath, lower risk instrument concepts, or alternatively by a single platform with wide-swath optical instruments. In the context of multiple platform concepts it is assumed that the proposed launch and replenishment scenario allows typical operational service availability requirements to be met.

The use of multiple satellites and/or merging of several missions are required [RD-55] to achieve an effective revisit time of 1 [e.g., RD-42] day for optical instruments over land and coastal regions required by GMES users: *"Sentinel-3 should include a constellation of two satellites, flying simultaneously, providing adequate coverage and operational robustness"*.

Due to the conflicting requirements between optimal time of observation for ocean colour (~11:00 time of ascending node LTAN) and SST (~10:00 LTAN), there is a trade off to be performed to determine how multiple Sentinel-3 satellites (e.g., A and B) could be configured ensure optimal performance from both the OLC and SLST sensors.

As noted previously, the GMES Working Group on Space Infrastructure for the GMES Marine Service recommends that Sentinel-3 fly a second satellite as soon as possible about one year after the first satellite launch [RD-52] to ensure adequate altimeter coverage.

| MR-ID | Туре | Description | Ref |
|-------|------|-------------|-----|
|-------|------|-------------|-----|

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| | Number of satellites | The use of multiple satellites and/or merging of several missions is required to achieve an effective revisit time of 1 day over land and coastal regions required by GMES users. | RD-42, RD-52 RD-55, Table 3, Table 5, Table 6. |
|--|-------------------------|---|---|
|--|-------------------------|---|---|

5.14 Sentinel-3 Orbit

The altimetry component of the GMES Sentinel-3 mission is considered as essential and is most demanding with respect to continuous, well-calibrated, long-term observations. In order to support the ongoing products derived from altimetry, there is a need for continuity of an ENVISAT polar-orbiting altimeter to enhance the temporal/spatial coverage of the global ocean. The existing Jason series of high precision altimeters (with an inclination of 66° and 10-day repeat orbit) do not meet the requirement for altimeter coverage of all of the high-latitude European shelf Seas. Their coverage is limited to the Atlantic region between the equator and 66° North and thus the region south of Iceland. In order to successfully resolve ocean mesoscale activity and tidal processes in shelf seas, the Jason sampling grid (300 km orbit track spacing at mid latitudes) must be supplemented by at least one (and preferably three) satellite altimeters acquiring intersecting ground tracks. For this reason it is acknowledged that GMES Sentinel-3 shall provide complementary ocean altimeter coverage in a high inclination orbit, for optimal merging with Jason-2/3. Since spatial and temporal sampling are determined by the orbit, the Sentinel-3 orbit shall be optimised with respect to planned altimeterbearing missions [RD-65], such as to be able to observe Kelvin and Rossby waves in the equatorial regions, and meso-scale eddies in mid-latitudes [RD-27]. Sentine-3 requires appropriate system components for accurate/precise orbit determination (i.e. 3-d position), and on-orbit pointing knowledge (with appropriate on-board redundancy) to achieve altimeter SSH accuracy targets.

The most preferred option would be to fly on the same sun-synchronous repeat orbit as Envisat. This would allow continuation of the ERS/Envisat time series and also would benefit from the precise ERS/ENVISAT mean SSH tracks, which are needed to extract the Sea Level Anomalies (SLA) from altimetry. Errors of existing mean sea surfaces are about 3 cm rms. (1 sec average) in the open ocean (and up to 5 cm rms. in coastal areas); if a mean sea surface is used as a reference for a non-repeat orbit, the altimeter error budget will be significantly increased. ESA's GOCE mission will improve the situation but will not resolve the small scales of the geoid (below 100 km). A non-repeating orbit is a potential option but with the caveat that the accuracy for SLA products will be degraded. The constraint of a repeat ENVISAT type orbit for altimetry should be maintained. There is no preferred local equatorial crossing time (LTAN) for the topography mission.

For the altimeter to reach GMES performance targets accurate knowledge of the spacecraft orbit is required. The Sentinel-3 threshold performance for NRT orbit determination shall be 10-20 cm, with a goal of 2 cm rms. residual orbit accuracy after offline processing. Improvements to altimeter products can be made following data processing of orbit determination data that are typically applied to STC altimeter data products. Following such data processing, high accuracy orbit data shall be delivered for use by the altimeter system in ≤ 2 days (goal) and < 5 days (threshold).

As previously discussed, a high-inclination orbit brings the added benefit of routine altimetric and optical measurements of marine and land ice in the Arctic and Antarctic high-latitude regions. For the optical mission, Sentinel-3 requires a high inclination polar orbit, to achieve near-complete global coverage. Ice Surface Temperature (IST), snow and sea-ice type, extent, concentration, thickness edge,

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and albedo are recognised as important variables for Sentinel-3. Though these should not override and drive the mission design, the resulting mission concept shall be able to address additional snow/ice parameters through the combination of a high-inclination orbit and appropriate instrument capabilities (i.e. altimeter with appropriate along-track sampling resolution, and optical instruments with appropriate spectral bands for day/night cloud/ice/snow/water discrimination).

The orbit for the optical payload demands a sun-synchronous orbit that allows a 2-3 days revisit, bearing in mind instrument swath widths. Sun glint and general illumination conditions for the VIS channels need to be carefully considered and sun-glint mitigated to the largest extent possible by choice of instrument pointing and final orbit configuration. In summary:

- GMES global coverage requirements including those for Polar Regions require a high inclination orbit.
- Appropriate system components for accurate/precise orbit determination (i.e. 3-d position), and on-orbit pointing knowledge (with appropriate on-board redundancy) are required,
- The Sentinel-3 topography mission must optimise the mission orbit with respect to other planned altimeter bearing missions.

| MR-ID | Туре | Description | | | |
|-----------|-------|--|---------------------------|--|--|
| S3-MR-670 | Orbit | The Sentinel-3 orbit shall be optimised with respect to other planned altimeter-bearing missions. The aim is to measure coherent mesoscale ocean structures with a track separation at the equator of ~80 km. | | | |
| S3-MR-680 | Orbit | Sentinel-3 shall use a high inclination orbit for optimal coverage of ice and snow parameters in high-latitudes, coverage of the European shelf Seas and merging with complementary altimeter missions. | | | |
| S3-MR-690 | Orbit | The Sentinel-3 orbit shall be a polar sun-synchronous orbit with a descending node equatorial crossing time similar to ENVISAT. The final choice of orbit shall consider the Solar Zenith Angle for ocean colour measurements, the impact of sun glint, diurnal surface ocean thermal stratification, morning haze and cloud-cover on optical measurements. | | | |
| S3-MR-700 | Orbit | The Sentinel-3 threshold performance for NRT orbit determination shall be 10-20 cm, with a goal of 2 cm rms. residual orbit accuracy after offline processing. | Section 5.7 | | |
| S3-MR-710 | Orbit | High accuracy orbit data shall be delivered for use by the altimeter system in ≤ 2 days (goal) and ≤ 5 days (threshold). | RD-53, RD-65, RD-52 | | |

5.15 Spatial Resolution

GMES Sentinel-3 User Requirements set out in Section Table 3, Table 4, Table 5 and Table 6 show spatial resolution requirements between 1 m and 50 km depending on the service and product required. For high resolution requirements over land, the Sentinel-3 mission will work in synergy with Sentinel-2 (which provides spatial resolution <300 m).

All user requirements cannot be satisfied and the following requirements are considered a reasonable compromise.

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| MR-ID | Туре | Description | Ref | | | | |
|-----------|-----------------------|---|---------------------------------|--|--|--|--|
| S3-MR-720 | Spatial resolution | Sentinel-3 topography measurements over the open ocean shall have an along track sample characteristics as follows: NRT/STC NTC <10 km (open ocean) | | | | | |
| S3-MR-730 | Spatial resolution | The Sentinel-3 altimeter measurements shall provide sufficient along-track resolution over inland rivers, their tributaries and, lakes although this shall not be a mission driver. | Table 4, Table 5, Table 6 | | | | |
| S3-MR-740 | Spatial resolution | Sentinel-3 surface topography measurements shall have enhanced along-track resolution (<300 m) surface topography measurements over relatively flat ice surfaces and in ice-covered and ice free coastal waters. | Table 3, Table 5 | | | | |
| S3-MR-750 | Spatial resolution | Sentinel-3 SST, IST and LST measurements shall have a spatial resolution of \leq 1000 m at nadir. | | | | | |
| S3-MR-760 | Spatial resolution | Sentinel-3 visible measurements shall have a spatial resolution of \leq 1.2 km over the global ocean and \leq 0.3-0.5 km in the coastal regions at nadir. | | | | | |
| S3-MR-770 | Spatial resolution | Sentinel-3 land colour measurements shall have a spatial resolution of \leq 0.3-0.5 km (threshold) at nadir globally. | | | | | |
| S3-MR-780 | Spatial resolution | Sentinel-3 shall provide SPOT vegetation-type land products at a spatial resolution of \leq 1000 m (0.3 km goal) at nadir. | Table 4, Table 6, | | | | |
| S3-MR-790 | Spatial resolution | Sentinel-3 fire monitoring measurements shall have a spatial resolution of ≤ 1 km at nadir. | RD-49, Table 4, Table 5 | | | | |

5.16 Time of Observation

Detection and monitoring changes on the earth surface using optical sensors is greatly facilitated by using identical or similar solar illumination and measurement view directions particularly for land monitoring applications. Sentinel-3 should provide measurements with identical (or similar) illumination directions (or local solar time) and with an identical (or similar) viewing direction. The periodicity of identical viewing directions is given by the temporal revisit requirement. The illumination directions of two different acquisitions should be kept as close during the longest possible duration.

Requirements for Sentinel-3 time of observation depend on the availability of alternative sources of satellite data. If measurements from other ocean and land colour and SST satellite instruments are available in an operational context and of a quality suitable for GMES Services, there is a trade off to be performed between the probability of cloud cover and the optimal sampling time to mitigate the impact of diurnal variability on SST product quality, sun glint and morning haze on ocean colour product quality. There are no requirements for the time of sea surface topography measurements.

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Optical instrumentation requires a sun-synchronous orbit with a local time of ascending node to complement existing platform observations, minimise diurnal SST variability and to mitigate the impact of sun glint, morning haze and cloud-cover. Taking into account also the service provided by other operational meteorological satellites planned for the period of the GMES Sentinel-3 mission there are two main possibilities:

- To fly late in the afternoon, e.g. 15:00 hrs LTAN. This provides the best alternative for sampling diurnal cycle coverage with other satellites flying a morning orbit, but it will degrade the performances of the optical payload (worst illumination angles and more clouds).
- To fly between 10:00 and 11:00 hrs LTAN. This option still provides complementary local time coverage with other satellites while optimising the viewing conditions for the optical payload (smaller diurnal SST variation, avoids afternoon clouds and morning haze conditions).

The first solution does not allow the existing climate records from ERS and Envisat data products to be continued. The second solution is favoured because it allows a sun-synchronous orbit configuration very close to that of Envisat, and would provide continuity in existing data records of climate significance.

All user requirements cannot be satisfied and the following requirements are considered a reasonable compromise.

| MR-ID | Туре | Description | Ref |
|-----------|------------------------|---|-------------------------------------|
| S3-MR-800 | Time of Observation | The observing time of Sentinel-3 ocean and land surface temperature measurements shall be ~10:00 LTAN to be consistent with the ENVISAT AATSR, to minimise the impact of diurnal thermal stratification of the upper ocean layers, the impact of afternoon cloud cover, morning haze and sun glint over the ocean. <i>Note: This requirement maintains the configuration and stability of historical AATSR SST measurements contributing to the SST ECV.</i> | RD-52, RD-53, Section 5.14 |
| S3-MR-810 | Time of Observation | The LTAN observing time of Sentinel-3 ocean colour measurements shall be optimised to maximise the solar elevation and minimise the impact of cloud development, morning haze and sun glint over the ocean. <i>Note: Due to the conflicting requirements on the time of observation between ocean colour (10:30-11:30) and SST (10:00 - 11:00), there is a trade off to be performed to determine how multiple Sentinel-3 satellites (e.g., A and B) could be configured ensure optimal performance from both the OLC and SLST sensors.</i> | Section 5.9 and 5.14 |
| S3-MR-820 | Time of Observation | The observing time of Sentinel-3 land colour measurements shall be optimised to minimise the impact of morning haze and cloud cover. | Sections 5.8, 5.9 and 5.14 |

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5.17 Timeliness

Timeliness is the temporal span between data acquisition and product delivery to the user. The primary aim of the Sentinel-3 mission is to acquire data on a continuous basis with high frequency, and to make available all products on a Near Real Time (NRT) basis to GMES users in order to meet operational data assimilation requirements. A fundamental requirement is to provide NRT access to altimeter waveforms with at least 20 Hz resolution.

Timely availability of Sentinel-3 data products is an essential requirement [RD-52, RD-181] for operational GMES forecasting services that will assimilate measurements on a regular schedule. Data that are not available within agreed assimilation window periods is unlikely to be used in operations leading to potentially reduced forecast quality. Sentinel-3 data are provided at three level of timeliness:

- Near real-time (NRT) products, made available to the users in less than 3 hours after measurement by the satellite instrument,
- Short time critical (STC) products, made available to the users in less than 48 hours after measurement by the satellite instrument and,
- Non-time critical (NTC) products made available within 1 month after measurement by the satellite instrument and archived.

The Sentinel-3 mission is designed to acquire data on a continuous basis with high frequency, and to deliver products in a NRT and/or STC basis to meet operational data assimilation and product requirements of GMES services (documented in Section 3). Some Sentinel-3 land products have a more relaxed non-time critical (NTC) timeliness requirement. Higher level altimetry products (wind, wave, RLH, coastal altimeter products etc.) must be available in NRT, STC and NRT. Off-line altimeter products shall be processed and delivered as soon as a precise orbit becomes available which is typically within a window of 2-3 days. Optical mission SLSTR and OLCI synergy products will be made available as soon as all data are available and have been processed.

| MR-ID | Туре | Description | Ref |
|-----------|------------|---|---|
| S3-MR-830 | Timeliness | Sentinel-3 Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances (L1b products) and Altimeter L2 products shall be available to users in NRT. | RD-52, RD-54, RD- 181RD- 56, Table 3, Table 4, Table 5, Table 6 |
| S3-MR-840 | Timeliness | Sentinel-3 products for GMES Services shall be made available according to the timeliness requirements described in Table 17 and Table 18. | |



5.18 Spectral Sampling

A summary of GMES service user requirements that highlight the need for continuity of the spectral channels of ENVISAT MERIS and AATSR is provided in Table 3, Table 4, Table 5 and Table 6.

The requirements that land applications place on the mission concept design shall, in so far as possible, be optimised for consistency with existing MERIS and AATSR spectral bands, provided that they allow maintain continuity of global data products such as NDVI from SPOT Vegetation, MERIS Global Vegetation Index (MGVI) and MERIS Terrestrial Chlorophyll Index (MTCI). Further details of complementary, yet non-global, high resolution land requirements are covered in the Mission Requirement Document of the Sentinel-2 mission [RD-92].

Continuity to sensor packages such as that onboard SPOT Vegetation mission would meet the basic land requirement for continuity in these data [RD-154]. SPOT Vegetation bands (Table 9) include relatively coarser spectral resolution with a blue band, a red band to capture the chlorophyll absorption peak at 665 nm, and accompanying Near Infrared and Short-wave infrared bands to characterise the fractional coverage of vegetation, canopy structural properties and the cloud discrimination. Sentinel-3 shall provide TOA reflectance similar to the bands of SPOT Vegetation in direct response to the needs of the user community to enable a continuation of the SPOT/Vegetation P-product line.

| Channel | Centre Wavelength (nm) | Approx. Band (nm) | Band- width (nm) | Signal to Noise Ratio* | Application |
|---------|------------------------------|-------------------------|------------------------|------------------------------|--|
| O1 | 400 | 392.5- 407.5 | 15 | 2180 | Aerosol correction, improved water constituent retrieval |
| 02 | 412.5 | 408-418 | 10 | 2050 | Yellow substance and detrital pigments (Turbidity). |
| O3 | 442.5 | 437·5- 447·5 | 10 | 1810 | Chl absorption max., Biogeochemistry, Vegetation |
| 04 | 490 | 485-495 | 10 | 1540 | High Chl, Other pigments |
| 05 | 510 | 505-515 | 10 | 1490 | Chl, Sediment, Turbidity, Red tide. |
| 06 | 560 | 555-565 | 10 | 1280 | Chlorophyll reference (Chl minimum) |
| 07 | 620 | 615-625 | 10 | 1000 | Sediment Loading |
| 08 | 665 | 660-670 | 10 | 880 | Chl (2 nd Chl abs. max.), Sediment, Yellow Substance / Vegetation |
| 09 | 673.75 | 670.5-678 | 7.5 | 705 | For improved Fluorescence retrieval and to better account for Smile together with the bands 665 and 680nm |
| 010 | 681.25 | 677.5-685 | 7.5 | 750 | Chl fluorescence peak, red edge |

Table 15: Baseline band selection and performances for Ocean and Land Colour measurements.

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| 011 | 708.75 | 703.75- 713.75 | 10 | 790 | Chl fluorescence baseline, red edge transition. |
|-----|---------|--------------------|------|-----|---|
| 012 | 753.75 | 750-757.5 | 7.5 | 600 | O2 absorption /Clouds, vegetation |
| 013 | 761.25 | 760-762.5 | 2.5 | 230 | O2 absorption band/Aerosol corr. |
| 014 | 764.375 | 762.5- 766.25 | 3.75 | 300 | Atmospheric correction |
| O15 | 767.5 | 766.25 – 768.75 | 2.5 | 330 | O2A used for cloud top pressure, fluorescence over land. |
| O16 | 778.75 | 771.25- 786.25 | 15 | 810 | Atmos. Corr. / Aerosol corr. |
| 017 | 865 | 855-875 | 20 | 680 | Atmos. Corr. / Aerosol corr., Clouds, Pixel co-registration. |
| O18 | 885 | 880-890 | 10 | 400 | Water vapour absorption reference band. Common reference band with SLST instrument. Vegetation monitoring. |
| O19 | 900 | 895-905 | 10 | 300 | Water vapour absorption / Vegetation monitoring (max. reflectance) |
| 020 | 940 | 930-950 | 20 | 205 | Water vapour absorption, Atmos. / Aerosol corr. |
| 021 | 1020 | 1000- 1040 | 40 | 150 | Atmos. / Aerosol corr. |

*Simulated SNR threshold values assume a spatial sampling distance of 1.2 km and standard atmosphere over openocean.

**Ocean bands have a noise-equivalent differential radiance, NE $\Delta\rho$ goal of < 5 x 10⁻³.

Based on this discussion, Sentinel-3 shall provide at a minimum continuity to channels on ENVISAT MERIS, AATSR and SPOT Vegetation (through synergy between the SLST and OLC instruments) allowing reproduction of land products as shown in Table 11. Following ENVISAT MERIS, the OLC instrument shall have the capability to change its band position, band width and gain throughout its lifetime. This capability is justified due to the diversity of spectral and radiometric properties of ocean colour spectral signatures. Furthermore, Sentinel-3 OLC will be able to tune the spectral channels and dynamic range adapting to different priority target requirements during the Sentinel-3 mission if required. The mission shall aim to select and maintain a suite of defined band settings throughout the mission as far as possible. In the spectral region between 400-1050 nm, a minimum of 15 spectral bands (Table 10) are required for ocean colour measurements in Case-1 and Case-2 waters. The desired spectral resolution shall be at least 1.25 nm (MERIS baseline). Table 15 provides a baseline for the spectral channels of the Sentinel-3 OLC instrument. Additional band requirements are discussed in Section 5.8 and 5.9.

Channel selection for SST, LST and IST products shall retain the visible, SWIR and TIR channels from AATSR. Visible channels are required for cloud screening and atmospheric corrections as shown in Table 8. Thin cirrus clouds are difficult to detect, particularly over land, in images taken from current satellite platforms. Improvements for cloud screening using additional channels could be considered to improve thin cirrus cloud detection using channels near the centre of the 1.38 μ m water vapour band [RD-175, RD-176]. At this wavelength cirrus clouds are located above almost all the atmospheric water vapour. Because of the strong water vapour absorption in the lower atmosphere, channels near 1.38 μ m receive little scattered solar radiance from the surface or low level clouds. When cirrus clouds are present these channels receive large amounts of scattered solar radiance from the cirrus clouds and these differences can be used to improve thin cirrus cloud flagging. The 2.25- μ m band, in conjunction

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with other bands, will enable cloud particle size estimation; cloud particle growth provides an indication of cloud development and intensity of that development [RD-177]. Other applications of the 2.25- μ m band include use in a multispectral approach for aerosol particle size estimation (by characterizing the aerosol-free background), fire hot-spot detection, and snow detection [RD-178].

| Channel | Centre wavelength (µm) | Bandwidth (nm) | Application |
|---------|---------------------------|-------------------|---|
| S1 | 0.555 | 20 | Cloud screening, vegetation monitoring, aerosol |
| S2 | 0.659 | 20 | NDVI, vegetation monitoring, aerosol |
| S3 | 0.865 | 20 | NDVI, Cloud flagging, Pixel co- registration |
| S4 | 1.375 | 15 | Cirrus detection over land |
| S5 | 1.61 | 60 | Cloud clearing, Ice and snow, vegetation monitoring |
| S6 | 2.25 | 50 | Vegetation State and Cloud Clearing |
| S7 | 3.74 | 380 | SST, LST, Active Fire |
| S8 | 10.85 | 900 | SST, LST, Active Fire |
| S9 | 12.0 | 1000 | SST, LST |

Table 16: Baseline band selection for the Sea and Land Surface Temperature (SLST) instrument.

Active fire channels [RD-47, RD-48, RD-49] shall also be considered as part of Sentinel-3 although these shall not drive the mission design. Spectral requirements for active fire detection include channels at ~3.5 μ m and in the 11-12 μ m region. Continuity with ENVISAT AATSR for fire detection shall be considered. A baseline for the spectral channels of the Sentinel-3 SLST instrument is provided in Table 16.

For continuity of the SST and ocean colour data sets generated by Sentinel-3, all channels shall have as similar a spectral shape as practicable to those on ENVISAT MERIS and AATSR. The exact channel responses need to be accurately known to model the radiances measured by the instrument in terms of geophysical quantities. The spectral responses of Sentinel-3 channels shall be known before flight to 5% of their peak response at any wavelength. In order to retrieve geophysical parameters with adequate sensitivity and accuracy from radiance, measurements must not be contaminated by out of band signals. The peak out of band response for each of the channels shall be characterised [RD-23].

| MR-ID | Туре | Description | Ref |
|-----------|----------------------|--|-----------------------------------|
| S3-MR-850 | Spectral sampling | Sentinel-3 OLC instrument Visible, Near Infrared, radiances shall include as a minimum the band spectral characteristics set out in Table 15 taking into account optional bands as follows: A channel at 1.02 microns to improve the existing MERIS atmospheric and aerosol correction capabilities, Additional channels in the O2A spectral region for improved cloud top pressure (height) and water vapour retrieval. | RD-182, Section 5.8 and 5.9 |



| | | • Other bands may be considered for fluorescence measurement (e.g. 673nm) and to improve land and ocean geophysical retrievals, provided the instrument complexity is not increased. | |
|-----------|----------------------|--|--|
| S3-MR-860 | Spectral sampling | Sentinel-3 SLST instrument Visible, Near Infrared, radiances shall include as a minimum the band spectral characteristics set out in Table 16. | RD-52, RD-23, Section 5.8 and 5.9 |
| S3-MR-870 | Spectral sampling | Sentinel-3 SLST and OLC shall use at least one common band for instrument pixel co-registration in overlapping swath regions. | Section 5.8 |
| S3-MR-880 | Spectral sampling | Sentinel-3 active fire detection and characterisation capability requires a channel at \sim 3.7 µm and one other at 11 or 12 µm providing continuity to ENVISAT AATSR measurements. These channels shall not drive the mission design or development. | RD-47, RD-48, RD-49 |
| S3-MR-890 | Spectral sampling | For continuity of the SST and ocean colour data sets generated by Sentinel-3, all channels shall have as similar a spectral shape as practicable to those on ENVISAT MERIS and AATSR. | RD-52 |
| S3-MR-900 | Spectral sampling | The spectral shape of Sentinel-3 channels shall be known before flight to 5% of their peak response at any wavelength. | RD-182 |
| S3-MR-910 | Spectral sampling | The peak out of band response for each of the channels shall be characterised. | RD-23 |
| S3-MR-920 | Spectral sampling | Following ENVISAT MERIS, the OLC instrument shall have the capability to change its band position, band width and gain throughout its lifetime. | RD-182 |
| S3-MR-930 | Spectral sampling | The desired spectral resolution for the OLC instrument shall be at least 1.25 nm (MERIS baseline). | RD-182 |

5.19 Radiometric Requirements

The radiometric characteristics for Sentinel-3 optical instruments shall be at least equivalent to that of ENVISAT MERIS and AATSR instruments [RD-182, RD-52].

Sentinel-3 VIS measurements shall be optimised to measure the ocean colour over the open-ocean and coastal zones. The radiometric performance of Sentinel-3 OLC instrument is extremely challenging because water leaving reflectance signals are extremely weak. Because of low radiance from ocean surfaces the signal to noise ratio (SNR) has to be high, in particular for the blue/green bands (see Section 5.3.3). OLC ocean bands shall build on and improve over MERIS heritage noise-equivalent different radiance (NE Δ L) specifications [RD-182] The instrument shall also have sufficient dynamic range to measure ocean colour and bright targets such as clouds and land surfaces, throughout its spectral range. The latter requirement must be considered carefully as there is a trade off to be performed to maintain an optimal configuration for ocean colour measurements while not significantly



reducing the quality and performance of land measurements. Over bright-target areas (e.g. sun-glint), the instrument design shall allow for a rapid recovery of detector elements.

Section 5.9 provides background information relating to OLC radiometric requirements. The radiometric resolution of Sentinel-3 OLC VIS measurements shall be <0.03 Wm⁻² sr⁻¹ mm⁻¹ (MERIS baseline [RD-182]) for a discrimination of 1 mg/m³ pigment concentration. The radiometric performance of Sentinel-3 OLC must be excellent and an absolute radiometric accuracy goal of <2 % with reference to the sun for the 400-900 nm waveband and <5% with reference to the sun for wavebands > 900 nm [RD-182] is required. The relative radiometric accuracy of the ocean colour measurements shall be 0.1% (goal) and this includes all instrumental error sources including, e.g., stray light, but excludes errors in radiometric standards. The specification is for the overall radiometric error. Contributions shall be combined by root sum-squares for random errors and linearly for bias errors.

The Sentinel-3 SLST instrument shall have a radiometric specification to at least that provided by ENVISAT AATSR [RD-23]. An absolute radiometric accuracy of Sentinel-3 TIR measurements shall have a NE Δ T < 50 mK. This includes all instrumental error sources including, e.g., stray light, but excludes errors in radiometric standards. The specification is for the overall radiometric error. Contributions shall be combined by root sum-squares for random errors and linearly for bias errors.

Section 5.8 provides background information relating to SLST radiometric requirements. The need for Sentinel-3 channels in the 3.5 μ m and 11 μ m infrared band for active fire monitoring is clear with requirements set such that saturation levels are no lower than 500 K (with a goal of 750 K) based on the MODIS and VIIRS sensor specifications and depending on the spatial resolution of the sensor. The SLST 11 μ m bands should saturate at a level comparable with MODIS (350 K). The dynamic range of the TIR channels shall be optimised to cover the spectral radiances for nadir SST measurement scenes ranging from a clear-sky low wind speed situation (where significant diurnal warming of the ocean surface may occur), to a cold icy target (cloud tops). Requirements shall be met over a minimum dynamic range from 200 to 324 K. Extreme situations such as clouds (~200 K), hot desert targets and fire events (>324 K) are not driving this requirement.

To accurately model the retrieval of geophysical parameters from measurements of radiance, the instrument responsivity must not be significantly affected by the polarisation of the radiance, and any responsivity variation must be known. For the OLC instrument polarisation must be < 1% [RD-182]. For the SLST instrument, the difference in responsivity between any two orthogonal polarisations shall not be more than 4% for the thermal channels and 6% for the reflection channels and for all channels, the responsivity variation with plane of polarisation shall be known to better than 0.5% [RD-23].

| MR-ID | Туре | Description | Ref |
|-----------|---------------------------|--|---------------------------------------|
| S3-MR-940 | Dynamic range | Sentinel-3 TIR channels shall have a dynamic range optimised for SST retrieval but also allow the retrieval of IST, LWST, LST and cloud top temperature (at least equivalent to ENVISAT AATSR instruments). | RD-52, RD-23 |
| S3-MR-950 | Dynamic range | Sentinel-3 VIS channels shall have a dynamic range at least equivalent to ENVISAT MERIS and AATSR instruments. | RD-182, Section 5.9 and 5.19 |
| S3-MR-960 | Radiometric Saturation | Sentinel-3 channels used for snow, cloud and fire monitoring shall not saturate for these targets although this is not a driving requirement. The saturation limit over | Section 5.19 |

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| | | fire is 750 K (goal). | |
|-------------|-------------------------|---|---------|
| | | ine is /50 K (goal). | |
| | | Note: fire measurements are a secondary mission | |
| | | objective and shall not drive the system design \$3-OB-6. | |
| | | Sentinel-3 OLC instrument VIS measurements shall be | |
| | Radiometric | optimised to measure the ocean colour over the open- | Section |
| S3-MR-970 | Saturation | ocean and coastal zones but shall not (as a goal | 5.9 and |
| | | requirement) saturate over bright targets such as clouds | 5.19 |
| | | and land surfaces, throughout its spectral range. Sentinel-3 SST measurements shall have a long-term | |
| S3-MR-980 | Radiometric | radiometric stability goal of 0.1 K/decade (<0.2K/decade | RD-23, |
| 53-MIX-960 | stability | threshold) for a $5 \times 5^{\circ}$ latitude longitude area. | RD-58 |
| | | Sentinel-3 infrared channels shall have a radiometric | |
| S3-MR-990 | Radiometric | accuracy goal of 0.1 K over a range of 270-320 K traceable | RD-23 |
| | accuracy | to international reference standards. | Ū |
| | Relative | Sentinel-3 infrared channels shall have a relative | |
| S3-MR-1000 | radiometric | radiometric accuracy of <0.08 K (threshold) with a goal of | RD-23 |
| 55 MIX 1000 | accuracy | 0.05 K over a range of 210-350 K expressed as NE Δ T | KD 23 |
| | | traceable to international reference standards. | |
| | Absolute radiometric | Sentinel-3 VIS reflectance's at TOA shall have an absolute | RD-182, |
| S3-MR-1010 | | radiometric accuracy goal of <2 % with reference to the sun for the 400-900 nm waveband and <5 % with reference | Section |
| 53-MIX-1010 | accuracy | to the sun for wavebands > 900 nm traceable to | 5.9 and |
| | uccurucy | international reference standards. | 5.19 |
| | Relative | Sentinel-3 OLC instrument VIS reflectance's at TOA shall | Section |
| S3-MR-1020 | radiometric | have a relative radiometric accuracy threshold of 0.2 % | 5.9 and |
| | accuracy | (goal) traceable to international reference standards. | 5.19 |
| | | Sentinel-3 OLC instrument VIS channels shall have a high | |
| S3-MR-1030 | Signal to noise | signal to noise specification building on and improving on MERIS heritage. | RD-182 |
| | | Sentinel-3 OLC instrument VIS channels shall have a | |
| S3-MR-1040 | Polarization | known polarisation error less than 1 %. | RD-182 |
| | | For the SLST instrument, the difference in responsivity | |
| S3-MR-1050 | Polarisation | between any two orthogonal polarisations shall not be | RD-23 |
| | | more than 4% for the TIR channels. | Ŭ |
| | | For the SLST instrument VIS and SWIR channels, the | |
| S3-MR-1060 | Polarisation | responsivity variation with plane of polarisation shall be | RD-23 |
| | | known to better than 7% with a goal of 5%. | |
| | Characterisati | For the SLST instrument, the responsivity variation with | |
| S3-MR-1070 | on | plane of polarisation shall be known to better than 0.5% for all channels. | RD-23 |
| | | for an channels. | |

5.20 Geolocation requirements

Measurements that are made using a satellite instrument need to be processed to provide a data product that is easily manipulated by GMES Services in the form of a geo-located data set, where each pixel can be annotated with its geographical coordinates. Accurate geometric correction of earth observation

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measurements is a fundamental task for GMES in which multi-source and multi-temporal data integration, management and analysis are core activities.

Inter-channel spatial co-registration specifies the maximum equivalent ground distance between the positions of all pairs of spatial samples acquired in two spectral channels and related to the same target on Earth. Inter-channel temporal co-registration specifies the maximum time interval between the acquisitions of spectral channels related to the same target on Earth. As a baseline the Geolocation accuracy of ENVISAT AATSR and MERIS shall be the starting point for Geolocation accuracy [RD-182].

To improve the geo-location process for Sentinel-3 in an operational manner, accurate automatic geolocation is required. Sentinel-3 shall be designed to ensure geo-location accuracy better than 1.0 rms. of the spatial resolution of the sensor for optical measurements over land and coastal zones and without the need for any Ground Control Points. Improved geo-location accuracy is possible when using ground control points and Sentinel-3 shall be designed to ensure a geo-location accuracy of better than 0.5 rms. of the spatial resolution of the optical sensor when using ground control points.

Care is required when mapping larger FoV SLST TIR and SWIR channel data onto higher resolution OLC visible channel data and inter-channel co-registration requirements must be analysed in detail.

The geo-location accuracy for the altimeter measurements is particularly demanding in the coastal and ice edge regions when operating in SAR mode.

| MR-ID | Туре | Description | Ref |
|------------|---|--|--------------------------------|
| S3-MR-1080 | Geo-location accuracy | Sentinel-3 shall be designed to ensure geo-location accuracy better than 1.0 rms. of the spatial resolution of the sensor for optical measurements over land and coastal zones and without the need for any Ground Control Points. | Section 5.20 |
| S3-MR-1090 | Geo-location accuracy | Improved geo-location accuracy is possible when using ground control points and Sentinel-3 shall be designed to ensure a geo-location accuracy of better than 0.5 rms. of the spatial resolution of the optical sensor when using ground control points. | Section 5.20 |
| S3-MR-1100 | Inter- channel co- registration | The inter-channel spatial co-registration for Sentinel-3 visible measurements shall be < 0.5 of the spatial resolution of the sensor over the full spectral range (goal of 0.3 of the spatial resolution of the sensor). | Section 5.95.20, Section |
| S3-MR-1110 | Inter- channel co- registration | The inter-channel spatial co-registration for Sentinel-3 SWIR and TIR measurements shall be sufficient to allow these channels to be co-registered with visible channels at higher spatial resolution data. | Section 5.9 |
| S3-MR-1120 | Inter- channel temporal co- registration | The co-registration between Sentinel-3 optical images acquired at different times (e.g. from different Sentienl-3 spacecraft) shall be accurate to 1.0 rms. of the spatial resolution of the sensor. | Section 5.9 |
| S3-MR-1130 | Inter- channel co- registration | Sentinel-3 OLC channels 442, 490, and 510 nm shall be closely co-registered to avoid errors in blue/green chlorophyll retrieval algorithms. | Section 5.20 |
| S3-MR-1140 | Inter- channel co- | Sentinel-3 OLC channels 620 and 665 shall be co-located and have as little difference as possible in the atmospheric | Section 5.9 |

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| | registration | paths to minimise errors in the atmospheric correction procedures. | |
|------------|--------------------------|--|--|
| S3-MR-1150 | Geo-location accuracy | Sentinel-3 shall be designed to ensure sufficient geo- location accuracy of topography measurements in the coastal and ice zones and for inland water (river and lake) monitoring applications. | |

5.21 Calibration and validation

The requirements on VIS, TIR and altimetry accuracy requirements can be fulfilled (including calibration of long term drifts) with a proper and integrated calibration concept including on-ground calibration prior to launch, innovative instrument design, in-flight calibration hardware, in-flight calibration measurements and careful optical monitoring of the instrument in flight over mission. Regular solar measurements (e.g., via diffuser) are needed for calibration of Earth reflectance and for spectral calibration. See Sections 5.9 for more details.

| MR-ID | Туре | * | | Description | |
|------------|-------------|--|-----------------|-------------|--|
| S3-MR-1160 | Calibration | The Sentinel-3 instrument payload shall be characterised and calibrated prior to launch as required to meet the instrument performance requirements specified for each instrument. | RD-52 | | |
| S3-MR-1170 | Validation | Sentinel-3 measurements on-orbit shall be validated to demonstrate conformance to GMES user requirements. Operational long-term validation and verification of all data products throughout the mission lifetime is required to monitor product uncertainty estimates. | RD-52, RD-54 | | |

5.22 Service Data Products

Level 1b, L2 and L3 products must be made available to GMES Service providers and to final users. Service providers are officially recognised entities in charge of elaborating more refined products or products specific for some applications in the frame of the GMES programme. Final users are defined as any generic user benefiting from GMES monitoring data. Definitions of the product levels can be found in Section 1.5 of this document. A list of potential Sentinel-3 data products is provided in Table 17.

| MR-ID | Туре | Description | Ref |
|------------|--------------------------|---|--|
| S3-MR-1180 | Service Data Products | Sentinel-3 shall provide data products required by GMES services. A non-exhaustive list of high-priority products from Sentinel-3 is provided in Table 17. A non- exhaustive list of additional products from Sentinel-3 is provided in Table 18. | RD-52, RD-54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6 5, |



| S3-MR-1190 | Service Data Products | All Sentinel-3 measurements and products shall include product uncertainty estimates. | RD-52, RD-181, RD-56, Table 3, Table 5, Table 6 |
|------------|--------------------------|--|---|
| S3-MR-1200 | Service Data Products | Sentinel-3 shall provide River and Lake Hydrology (RLH) (e.g. lake area, lake height differences from reference height, lake volume change) and River and Lake Altimetry (RLA, containing individual re-tracked radar echo waveforms) products shall be delivered to the hydrological services in a timely and operational manner. <i>Note: These products shall not drive the mission design.</i> | RD-52, RD-54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6 |
| S3-MR-1210 | Service Data Products | Sentinel-3 shall provide global coverage atmospheric aerosol products that minimise differences between retrieval algorithms over land and over ocean surfaces. Products shall make full use of S3 optical channels and dual view capability. <i>Note: These products shall not drive the mission design.</i> | RD-75, RD-148, RD-52, RD-54, RD-181, RD-56, Table 3, Table 4. |
| S3-MR-1220 | Service Data Products | Sentinel-3 shall provide data products in acceptable formats used by operational NOP and NWP systems (e.g., netCDF, L2P, BUFR). | RD-52, RD-181, RD-56, Table 3, Table 5 |
| S3-MR-1230 | Service Data Products | Sentinel-3 data Level-0 products shall be archived adhering to good data stewardship principles for use in long term climate monitoring studies. | RD-52, RD-54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6, |
| S3-MR-1240 | Service Data Products | Access to Sentinel-3 L1b altimeter high resolution echo waveform data shall be provided to users on request to allow necessary regional development of RLH, and coastal altimetry products including better validation and uncertainty estimation. | Section 3.3.3, 3.2.35.7 |

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| NY | | | | | Goal Accuracy | | Prod. | |
|---|---|-------|---|-------|---------------|---------|----------------|------------------------|
| Name | Description | Units | Resolution | Range | Case-1: | Case-2 | Prod. Level | Delivery |
| Sea and Land Surface Temperature Radiometer (SLSTR) instrument TOA L1b | Top of atmosphere brightness temperatures and radiances, calibrated to geophysical units, and their associated uncertainty estimates. Measurements are geo-referenced onto the Earth surface, spatially re-sampled onto an evenly spaced grid – common to the Nadir and Inclined Views – and annotated. Annotations include: Illumination and Observation geometry, environment data (meteorological data), and quality and classification flags. | - | VIS: 0.5 km TIR: 1 km | - | - | - | Lıb | NRT and NTC |
| Ocean and Land Colour Instrument (OLCI) TOA L1b | Top of atmosphere radiances, calibrated to geophysical units, and their associated uncertainty estimates. Measurements are geo-referenced onto the Earth surface, spatially re-sampled onto an evenly spaced grid and annotated. Annotations include: Illumination and Observation geometry, environment data (meteorological data), and quality and classification flags. | - | 0.3 km | - | - | - | L1b | NRT And NTC |
| SRAL waveforms | 1 Hz and 20 Hz Ku and C band parameters (LRM/SAR), the waveforms and the associated parameters. | - | ~300 m along track in SAR mode >2 km along track in LRM | - | - | - | L2 | NRT, STC and NTC |
| Marine Reflectance (R) | Surface directional reflectance, corrected for | - | 0.3 - 1.2 | 0.001 | 5 x 10- | 5 x 10- | L2 | NRT |

Table 17: List of core products for the Sentinel-3 mission. Other potential future data products are described in Table 18.

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| | | | | | | 1 Clara | | |
|--|---|-------------------------|-----------------|----------------|---|---|----|----------------|
| | atmosphere and Sun specular reflection, at all channels except those dedicated to atmosphere | | km | - 0.04 | 4 | 4 | | |
| | absorption measurements, and associated error estimates. (atmospherically corrected) | | | | | | | |
| Photosynthetically available radiation (PAR) | Quantum energy flux from the Sun in the spectral range 400-700 nm and associated error estimates. | µmol quanta/ m2/s | 0.3 - 1.2 km | 0 – 1400 – | 5% | 5% | L2 | NRT and NTC |
| Diffuse attenuation coefficient (Kd) | Diffuse attenuation coefficient for downwelling irradiance, and associated error estimates | m ⁻¹ | 0.3 - 1.2 km | 0.001 - 0.1 | 5% | 5% | L2 | NRT and NTC |
| Chlorophyll (Chl) | Chlorophyll-a concentration, and associated error estimates in coastal and open ocean waters. | mg/m ³ | 0.3 - 1.2 km | 0.001 - 150 | Thresh. 30 % goal 10 % | Thresh. 70 % goal 10 % | L2 | NRT and NTC |
| Total Suspended Matter (TSM) | Total suspended matter concentration, and associated error estimates | g/m³ | 0.3 - 1.2 km | 0 - 100 | Thresh. 30 % goal 10 % 10 | Thresh. 70 % goal 10 % | L2 | NRT and NTC |
| Coloured Dissolved Organic Material (CDOM) | Absorption of Coloured Detrital and Dissolved Material, and associated error estimates, at 443 nm. | m-1 | 0.3 - 1.2 km | 0.01 – 2 | Thresh. 50 % goal 10 % 10 | Thresh. 70 % goal 10 % 10 | L2 | NRT and NTC |

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| | | | | | Ille . | | |
|------------------------------------|--|----|--|---------------|-------------------|----|------------------------|
| Altimeter backscatter (Sigma-0) | SRAL sigma-o backscatter | dB | ~300 m along track (SAR mode) for coastal waters - >2 km along track (LRM) for open ocean | - | - | L2 | NRT, STC and NTC |
| Sea Surface Height (SSH) | Height of the sea surface with respect to a reference datum (reference ellipsoid). | m | ~300 m along track (SAR) for coastal waters >2 km along track (LRM) for open ocean | NRT: 10 cm | NTC: 3.5 cm | L2 | NRT, STC and NTC |

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| | | | | | | Ille | | |
|--------------------------------------|---|---|---|--------|------------------------------------|------------------------------------|----|------------------------|
| Sea Surface Height Anomaly (SSHA) | Variations of the SSH with respect to a mean sea surface. | m | ~300 m along track (SAR) for coastal waters >2 km along track (LRM) for open ocean | ±1.5 | - | - | L2 | NRT, STC and NTC |
| Significant Wave Height (Hs) | The average wave height (trough to crest) of the one-third largest waves in a given sample period | m | ~300 m along track (SAR mode) for coastal waters >2 km along track (LRM) for open ocean | 0 – 20 | NRT: 4% (= 8 cm @ 2 m) | NTC: 1% (= 2 cm @ 2 m) | L2 | NRT, STC and NTC |

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| | | 1 | | | | 1000 | r | |
|--------------------------------------|--|-----|---|--------|------------------------------------|------------------------------------|----|------------------------|
| Surface wind speed over ocean | SRAL derived surface wind speed modulus | m/s | ~300 m along track (SAR) for coastal waters >2 km along track (LRM) for open ocean | 0-20 | | | L2 | NRT, STC and NTC |
| Sea Surface Height Anomaly (SSHA) | Variations of the SSH with respect to a mean sea surface. | m | ~300 m along track (SAR) for coastal waters >2 km along track (LRM) for open ocean | ±1.5 | | | L2 | NRT, STC and NTC |
| Significant Wave Height (Hs) | The average wave height (trough to crest) of the one-third largest waves in a given sample period | m | ~300 m along track (SAR) for coastal waters >2 km along track (LRM) for open ocean | 0 - 20 | NRT: 4% (= 8 cm @ 2 m) | NTC: 1% (= 2 cm @ 2 m) | L2 | NRT, STC and NTC |

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| Surface wind speed over ocean | SRAL derived surface wind speed modulus | m/s | ~300 m along track (SAR) for coastal waters >2 km along track (LRM) for open ocean | 0-20 | | | L2 | NRT, STC and NTC |
|--|--|----------------|---|---------------|---------------------------------|--------------------|----|------------------------|
| Sea Surface Temperature (SSTskin) | Sea surface skin Temperature and associated error estimates | К | 1 km | 270- 321 K | < 0.3 (thresho) 0.1 K (go | ld) | L2 | NRT and NTC |
| Surface Reflectance's over Land (SLSTR and OLCI Synergy product) | Ratio between the irradiance (flux per unit surface area) in all the upward directions at wavelength λ ; and the irradiance in all the downward directions, at the same wavelength and depth. This product is computed using the SLSTR and OLCI instruments in synergy. | $n \sqrt{m/s}$ | 0.3 km | | Goal | Thre. | L2 | NTC |
| OLCI global Vegetation Index:(OGVI) | Fraction of Available Photosyntheticically Active Radiation (FAPAR) | - | 0.3 km and 1 km | 0 - 1 | <5% at 0.3 km | <10% at 1 km | L2 | NRT and NTC |
| OLCI terrestrial chlorophyll Index (OTCI) | Monitoring vegetation condition based on terrestrial chlorophyll content | - | 0.3 km and 1 km | 0 - 3 | <5% at 0.3 km | <10% at 1 km | L2 | NRT and NTC |

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| ESA UNCLASS: | IFIED – for Official Use | | | | | | es | a |
|---|---|---|-----------------------|--------|--------|-------|----|-----------------|
| TOA Reflectance product provided for the continuity of the SPOT VGT P- like product | TOA reflectance in the bands similar to SPOT/Vegetation in Plate-Carrée projection. SPOT/Vegetation L1P bands are: band B0: blue (0.43-0.47 μm), band B2: red (0.61-0.68 μm), band B3: near-infrared (NIR, 0.78-0.89 μm) band MIR: shortwave infrared (SWIR, 1.58-1.74 μm). | - | 1 km | | 3% | 15% | L2 | NTC |
| Daily Normalised Difference Vegetation Index (NDVI, 1 day Synthesis) | Daily Normalised Difference Vegetation Index (NDVI) derived from for the four SPOT channels synthesised from OLCI and SLSTR channels (nadir view only) in Plate-Carrée projection. This is a SPOT VGT S1-like continuation product. | - | 1 km | | 3% | 15% | L2 | NTC |
| 10-day Normalised Difference Vegetation Index (VGT S10 NDVI, 10 day Synthesis) | 10-day Normalised Difference Vegetation Index derived from for the four SPOT channels synthesised from OLCI and SLSTR channels (nadir view only) in Plate-Carrée projection. This is a SPOT VGT-S10-like continuation product. | - | 1 km | | 3% | 15% | L2 | NTC |
| 1-day synthesis of surface reflectance provided for the continuity of the SPOT VGT P- like product | 1 day synthesis surface reflectance in the bands similar to SPOT/Vegetation in Plate-Carrée projection. | | 1 km | | | | L2 | NTC |
| 10-day synthesis of surface reflectance provided for the continuity of the SPOT VGT P- like product | 10 day synthesis surface reflectance in the bands similar to SPOT/Vegetation in Plate-Carrée projection. | | 1 km | | | | L2 | NTC |
| River and Lake Heights | Inland River and Lake Heights. | m | 300 m (in SRAL SAR | 0 - 20 | 0.01 m | 0.2 m | L2 | NRT, STC and |

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| | | | | | | alle - | | |
|--|--|----------------------|---|----------------|---------------------|--------------------|----|------------------------|
| | | | mode) | | | | | NTC |
| Land Surface Temperature (LST) | Land surface temperature, associated error estimates and exception flags, and contextual information. | К | 1 km | 210 – 350 K | <1 K at 1 km | <1 K at 1 km | L2 | NRT and NTC |
| Integrated Water vapour column (IWV) | Global coverage of total amount of water vapour integrated over an atmosphere column, and associated error estimates over land and ocean (global). | kg.m ⁻² . | 0.3 – 1.2 km | 0 - 50 | | | L2 | NRT and NTC |
| Aerosol Optical Depth (AOD (τ)) over water at 865 nm | Global coverage over water of aerosol load, expressed in optical depth at 865 nm, and associated error estimates. | - | 0.3 – 1.2 km | 0-3 | 50% [RD- 118] | 10% | L2 | NRT and NTC |
| Aerosol Angstrom exponent (Å) over water at 865 nm | Global coverage over water of spectral dependency of the Aerosol Optical Depth with associated error estimates. | | 0.3 – 1.2 km | 0 - 3 | | | L2 | NRT and NTC |
| Aerosol Optical Depth (AOD (τ)) over land at 550 nm | Global coverage over land of aerosol load, expressed in optical depth at a given wavelength and associated error estimates. The product is derived from synergy between SLSTR and OLCI and will be available as soon as the processors have all available data. | - | 0.3 km | 0-3 | | 10% | L2 | NTC |
| Aerosol Angstrom exponent (Å) over land at 550 nm | Global coverage over land of spectral dependency of the Aerosol Optical Depth with associated error estimates. The product is derived from synergy between SLSTR and OLCI and will be available as soon as the processors have all available data. | | 0.3 km | 0 - 3 | | | L2 | NTC |
| Sea Ice thickness | Thickness of sea ice (freeboard): accuracy 20-50 cm | cm | ~300 m along track (SAR) for coastal waters | | 10 % | 50 | L2 | NRT, STC and NTC |
| Sea Ice Surface Height (SSH) | Height of the sea ice surface with respect to a reference datum (reference ellipsoid). | m | ~300 m along track | | | | L2 | NRT, STC and |

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| | | | (SAR) for | | | NTC |
|---|--|---|---|--|----|------------------------|
| | | | coastal | | | |
| | | | waters | | | |
| Sea Ice Surface Height Anomaly(SSHA) | Variations of the Sea Ice Surface Height with respect to a mean sea surface. | m | ~300 m along track (SAR) for coastal waters | | L2 | NRT, STC and NTC |

Table 18: List of potential Sentinel-3 data products.

| N T | | | | Goal Accu | iracy | Prod. | | |
|---|--|------------------------------|-----------------|--------------|---------|--------|-------|----------|
| Name | Description | Units | Resolution | Range | Case-1: | Case-2 | Level | Delivery |
| Normalised Water leaving radiance (Lw(λ)) | Ratio between the irradiance (flux per unit surface area) in all the upward directions at wavelength λ and depth z; and the irradiance in all the downward directions, at the same wavelength and depth. | mW/cm 2/µm/S r | 0.3 - 1.2 km | 0.0 - 1.0 | 5% | 5% | L2 | NRT |
| Heated Layer Depth (Z <i>hl</i>) | Depth of the water body layer heated by the solar radiation, and associated error estimates. | m | | 0-30 m | 5% | 5% | L2 | NRT |
| Water transparency (Secchi depth) | Maximum depth of Secchi disk visibility from Sea surface, and associated error estimates. | m | | 0- 30 m | 5% | 5% | L2 | NRT |
| Total backscattering coefficient (b) | Backscattering coefficient of the whole water body, excluding the pure water contribution, and associated error estimates. Closely related to suspended particulate matter (sediments). | m ⁻¹ at | | | | | L2 | NRT |
| Total absorption coefficient (a) | Absorption coefficient of the whole water body, excluding the pure water contribution, and associated error estimates. | m ⁻¹ at 443 nm | | | | | L2 | NRT |
| Phytoplankton absorption coefficient | Absorption coefficient due to the phytoplankton, and associated error estimates. | m ⁻¹ at 443 nm | | | | | L2 | NRT |

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| (a_{ph}^{+}) | | | | | | | |
|---|---|------------------------------|----------------|------------------|---------------------|----|-----|
| CDM absorption coefficient (ag) | Absorption of Coloured Detrital and Dissolved Material, and associated error estimates. | m ⁻¹ at 443 nm | | | | L2 | NRT |
| Humic material absorption coefficient (a _{dg}) | Absorption coefficient due to matter transported by rivers into the coastal sea, and associated error estimates. It comprises non-living particulate organic material, living particles such as bacteria, inorganic minerals and bubbles. | m ⁻¹ at 443 nm | | | | L2 | NRT |
| Fraction of Absorbed Photosynthetically Active Radiation (fAPAR) | Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) in the plant canopy1. Its by- products, the so-called red and NIR Rectified Reflectance, are virtual reflectance largely decontaminated from atmospheric and angular effects, and good proxy to Top of Canopy reflectance. | µmol quanta/ m²/s | 0 - 1 | <5% at 0.3 km | <10% at 1 km | L2 | NRT |
| Fraction of Vegetation Ground Cover (fCover) | The fraction of ground surface covered by vegetation | - | 0 - 1 | <5% at 0.3 km | < 10% at 1 km | L2 | NRT |
| Leaf Area Index (LAI) | Leaf Area Index (LAI) is defined as the one sided green leaf area per unit ground area in broadleaf canopies, or as the projected needle leaf area per unit ground area in needle canopies. | - | 0 - 10 | <5% at 0.3 km | < 10% at 1 km | L2 | NRT |
| Fire Radiative Power (FRP) | Fire radiative power, detection probability, associated error estimates and exception flags, and contextual information | W | 0 – 650 K | TBD at 1 km | TBD at 1 km | L2 | NRT |
| Lake water Surface Temperature (LWST) | Lake Water Surface Temperature | K | 210 – 350 K | <1 K at 1 km | <1 K at 1 km | L2 | NRT |
| Iceberg Fractional Cover | Fractional cover of icebergs in ice infested waters at a spatial resolution of 1-3.7 km | % | 0-100 | 10% | | | |
| Sea ice Edge | Estimates of the sea ice edge position | Km | 5-15 | 10 % | | L2 | NRT |
| Sea ice velocity | Daily estimates of the velocity of sea ice movements | Km/day | 0-50 | <25 | | L2 | NRT |

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| | | | | | 10000 | | |
|-----------------------------------|---|----|----------------|------|-------|-------|-----|
| Sea Ice Extent | Extent defines a region as either "ice-covered" or "not ice-covered." For each pixel, it is a binary term; either the cell has ice (usually a value of "1") or has no ice (usually a value of "0") at 30% concentration threshold | - | 0 - 1 | 10% | | L2/L3 | NRT |
| Sea ice concentration | Based on synergy between optical and topographic mission data | % | 0 – 100 % | <5% | <10% | L2 | NRT |
| Ice surface Temperature (IST) | Skin temperature of sea ice. | К | 260 – 273 K | 10 % | | L2 | NRT |
| Snow coverer area extent (SCA) | Measurements shall be made between 10:00 and 11:00 am local solar time. | km | | | | L2 | NRT |
| Snow albedo | Based on the use of visible and infrared radiance data products. Measurements shall be made between 10:00 and 11:00 am local solar time. | | 0 - 1 | | | L2 | NRT |
| Lake ice concentration | Based on synergy between optical and topographic mission data | % | 0 – 100 % | | | L2 | NRT |
| River ice concentration | Based on synergy between optical and topographic mission data | % | 0 – 100 % | | | L2 | NRT |

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6 SYSTEM CONCEPT OVERVIEW

6.1 Mission Overview

In response to mission and user requirements, the Sentinel-3 system has been defined to support in a long-term sustainable operational fashion four core observing missions: surface topography, ocean colour, ocean and land surface temperature and land surface optical monitoring at medium resolution. Being an operational mission, it is based on the use of demonstrated observing techniques and existing data processing heritage. The Sentinel-3 mission aim to provide EO data products and data in routine, long term (20 years of operations) and continuous fashion with a consistent quality and a very high level of availability primarily supporting GMES operational oceanography and global land applications.

6.2 Space Segment

Sentinel-3 is a low Earth orbit moderate size satellite compatible with small launchers like Vega and Rockot. The main satellite characteristics are given in Table 19. Sentinel-3 is designed for a 7-year lifetime, with consumables for up to 12 years of operations, including de-orbiting at the end of mission activities. The layout is driven by the need to provide a large cold face for optical instrument thermal control and a modular accommodation for a simplified management of industrial interfaces. The optimised satellite mechanical configuration and its flight attitude result from intensive mission analysis studies and system trade-offs performed during the definition phase in collaboration with ESA system team, leading to an improved system capacities (with respect to ENVISAT) including features such as an altimeter Delay-Doppler SAR mode (Cryosat-2 heritage), and additional spectral bands for the optical payload.

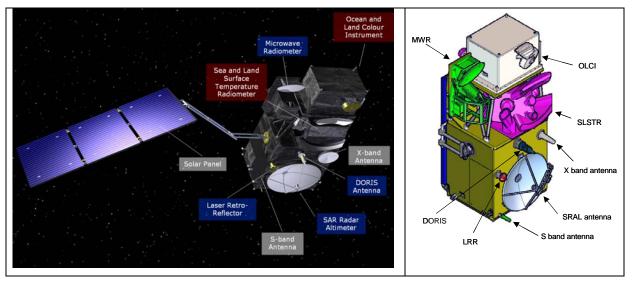


Figure 38: Artists impression of the Sentinel-3 satellite. Left shows Sentinel-3 fully deployed and right shows Sentinel-3 in a stowed configuration.

The satellite accommodates six different payloads with specific sizes, interfaces, severe Earth and calibration field of view constraints, and thermal requirements for radiator cold space access. The large

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number of payloads drives the satellite configuration. The resulting satellite architecture is shown in Figure 38. The main sub-systems of the satellite include

- An Electrical Power System (EPS), comprising one solar array wing providing power to the spacecraft and payload.
- A satellite Attitude and Orbit Control System(AOCS) composed by a set of dedicated sensors (Coarse Sun Sensor, Magnetometers, Coarse Rate Sensors, Star Tracker and Global Navigation Satellite System Receiver) and actuators (thrusters, magneto-torquers and reaction wheels).
- A data handling subsystem for Satellite Management and Payload Data Handling.
- Mass Memory Units for the satellite and payload.
- Satellite telecommunication subsystems including and S-Band subsystem for both TC uplink and TM downlink, and an X-Band subsystem (unique antenna) for mission data downlink.

In order to satisfy the large coverage and high revisit requirements, the Sentinel-3 mission is designed as a constellation of (at least) two identical satellites, Sentinel-3A and Sentinel-3B. Both Sentinel-3A and 3B are designed for a nominal life-time of ~7 years.

A Sun-synchronous orbit has been selected at 814 km altitude (14+7/27 revolutions per day) with a local equatorial crossing time of 10:00 a.m. This is a compromise between the needs of the optical instrument and altimeter. The baseline of two satellites supports full imaging of the oceans within 2 days (even allowing for ocean sun-glint effects), while delivering global land coverage in just over a day at the equator and improving with latitude. Each satellite will operate in a reference orbit with a repeat cycle of 27 days for the overall duration of the mission. The Sentinel-3B will be in the same orbit, but with a different mean anomaly. In addition, in order to meet the time reach requirements, a larger number of spacecrafts are needed over the full duration of the mission.

| Satellite characteristic | Value |
|------------------------------|--|
| Maximum mass | 1250 kg |
| Volume | 3.89 m x 2.202 m x 2.207 m |
| Average power consumption | 1100 W |
| Lifetime | 7.5 years (fuel for 5 add. years) |
| Launch | Sentinel-3A 2013 and Sentinel-3B expected between a minimum of 1 year and a max. of 30 months after the launch of the first satellite |

Table 19: Main characteristics of the Sentinel-3 satellite

6.3 Sentinel-3 Payload

The Sentinel-3 satellite carries the following instruments:

• An Ocean and Land Colour Instrument (OLCI), a spectrometer imaging in pushbroom mode with an across-track electronic scan, strongly inherited from the Alcatel Alenia Space flight-proven MERIS of Envisat, with same class of performance in the visible bands, associated with a larger coverage accounting for Sun glint.

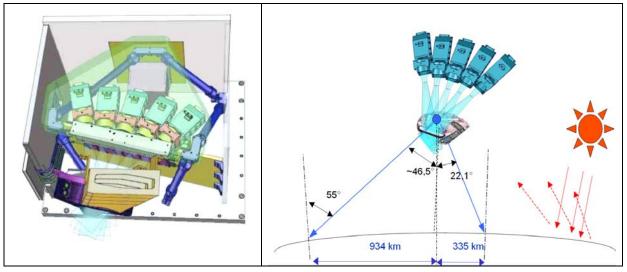
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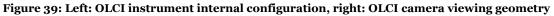


- A Sea and Land Surface Temperature Radiometer (SLSTR) instrument, a conical imaging radiometer with a dual view (near-nadir and inclined) capability, presenting design heritage from the AATSR of Envisat with same class of performance, associated with a larger coverage.
- A SAR Radar ALtimeter (SRAL) instrument, a dual-frequency altimeter, derived from the Alcatel Alenia Space line of products such as SIRAL of CryoSat, and Poseidon-3 of Jason-2, providing Low Resolution Sea surface measurements in the continuity of the RA-2 ones of Envisat, and sea-ice monitoring in Nadir SAR mode.
- A Microwave Radiometer (MWR) instrument, which supports the SRAL to achieve the overall altimeter mission performance by providing the wet atmosphere correction.
- A Global Navigation Satellite Systems (GNSS) assembly, suitable for the Precise Orbit Determination (POD) processed on ground to achieve the overall altimeter mission performance. Real time navigation and dating information from this equipment will provide spacecraft navigation and dating functions as well as the control of the Radar Altimeter open-loop tracking function.
- A Doppler Orbit determination and Radio-positioning Integrated on Satellite (DORIS) assembly as a Customer Furnished Item, which constitutes a complementary POD data provider for the Ground Segment as well as a potential (TBC) backup to the GNSS Assembly for the specific commanding of the SRAL Open Loop tracking mode.
- A Laser retro-reflector (LRR) to support satellite ranging for precise orbit determination and SRAL range measurement calibration. Laser tracking provides the distance between the spacecraft and the station and is assimilated in precise orbit determination.

6.3.1 Ocean Colour and Land Instrument (OLCI)

OLCI is a push-broom imaging spectrometer including channels in the visible – near infrared bands benefiting from MERIS heritage. The design aim is for an instrument capable of measuring sea and land colour with high absolute (relative) accuracy.





The instrument design configuration is based on 5 cameras splitting the wide field-of-view mounted on a common structure with a dedicated calibration assembly. The instrument has been de-pointed to the

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west in order to mitigate sub-glint contamination. An overview of the OLCI instrument and viewing geometry is provided in Figure 39.

Each camera consists of a Scrambling Window Element to comply with the polarisation requirement, a Camera Optical Sub Assembly for the spectral splitting of the different wavelengths, a Focal Plane Assembly (FPA) with a CCD for the signal detection and a Video Acquisition Module (VAM) for the monitoring of the analogical signal. Each camera optical sub assembly includes its own grating and provides 21 spectral bands (including bands for MERIS and SPOT Vegetation legacy products) providing measurements with high absolute radiometric accuracy. OLCI will have 0.1% stability for radiometric accuracy over each orbit and 0.5% relative accuracy for the calibration diffuser BRDF. Details of OLCI bands are provided in Table 20. The OLCI programmable acquisition design allows in principle the redefinition of spectral bands, in both location and width. A single calibration assembly including a rotation wheel allowing a radiometric and spectral calibration will be used on OLCI as proven by MERIS.

| Band # | λ centre | Width | Lmin | Lref | Lsat | SNR@Lref |
|-----------|------------------|-------|--------------|--------------|--------------|----------|
| | nm | nm | W/(m².sr.µm) | W/(m².sr.µm) | W/(m².sr.µm) | |
| Oa1 | 400 | 15 | 21.60 | 62.95 | 413.5 | 2188 |
| Oa2 | 412.5 | 10 | 25.93 | 74.14 | 501.3 | 2061 |
| Oa3 | 442.5 | 10 | 23.96 | 65.61 | 466.1 | 1811 |
| Oa4 | 442 | 10 | 19.78 | 51.21 | 483.3 | 1541 |
| Oa5 | 510 | 10 | 17.45 | 44.39 | 449.6 | 1488 |
| Oa6 | 560 | 10 | 12.73 | 31.49 | 524.5 | 1280 |
| Oa7 | 620 | 10 | 8.86 | 21.14 | 397.9 | 997 |
| Oa8 | 665 | 10 | 7.12 | 16.38 | 364.9 | 883 |
| Oa9 | 673.75 | 7.5 | 6.87 | 15.70 | 443.1 | 707 |
| Oa10 | 681.25 | 7.5 | 6.65 | 15.11 | 350.3 | 745 |
| Oa11 | 708.75 | 10 | 5.66 | 12.73 | 332.4 | 785 |
| Oa12 | 753.75 | 7.5 | 4.70 | 10.33 | 377.7 | 605 |
| Oa13 | 761.25 | 2.5 | 2.53 | 6.09 | 369.5 | 232 |
| Oa14 | 764.375 | 3.75 | 3.00 | 7.13 | 373.4 | 305 |
| Oa15 | 767.5 | 2.5 | 3.27 | 7.58 | 250.0 | 330 |
| Oa16 | 778.75 | 15 | 4.22 | 9.18 | 277.5 | 812 |
| Oa17 | 865 | 20 | 2.88 | 6.17 | 229.5 | 666 |
| Oa18 | 885 | 10 | 2.80 | 6.00 | 281.0 | 395 |
| Oa19 | 900 | 10 | 2.05 | 4.73 | 237.6 | 308 |
| Oa20 | 940 | 20 | 0.94 | 2.39 | 171.7 | 203 |
| Oa21 | 1020 | 40 | 1.81 | 3.86 | 163.7 | 152 |

| Table 20: Band characteristics of the Sentinel-3 Ocean and Land cold | our Instrument (OLCI) |
|--|-----------------------|
|--|-----------------------|

Control of the OLCI instrument is realised by a common electronic (OEU), which assumes the function of Instrument Control, Power Distribution and Digital Processing. OLCI has an approximate mass of 150 kg and a volume of 1.3 m³ and is an "autonomous" instrument with simple interfaces with the spacecraft, thus allowing an easy integration and minimising the development risks.

Key Improvements of OLCI over the MERIS design include:

• An increase in the number of spectral bands (from 15 to 21),

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- Improved long term radiometric stability,
- Mitigation of sun glint contamination by tilting cameras in westerly direction,
- Complete Full Resolution (FR, 300m) coverage over both land and ocean,
- Reduced Resolution (RR, 1200m) over Ocean binned on ground (L1B),
- Improved instrument characterisation, e.g., stray light, camera overlap,
- Improved coverage (Ocean < 4 days, Land < 3 days c.f. MERIS eff. 15 days),
- Improved data delivery timeliness: 3 hours NRT Level 2 product,
- 100% overlap with SLSTR,
- Improved L2 products (e.g., Chl-a, HAB, Transparency, Sediment loading, Turbidity, NDVI, MGVI, MTCI, faPAR, LAI).

6.3.2 Sea and Land Surface Temperature (SLSTR) Instrument

The main objective of the Sentinel SLSTR instrument mission is to maintain continuity with the (A)ATSR series of instruments to measure Sea and Land temperature retrieval with typical performance equivalent to or exceeding that of the ENVISAT AATSR (absolute accuracy of 0.2 K \pm 0.08 K). Consequently, wherever possible, the SLSTR proposed design and development are based on the reuse of ATSR concepts, supported by existing and qualified technologies.

The instrument includes channels in the visible and the infrared spectrum, including thermal (TIR) and short wave (SWIR) infrared. The channel selection (1.6, 3.7, 10.8 and 12 μ m in the IR and 0.55, 0.66 and 0.85 μ m in the visible) include the AATSR and ATSR-2 channels for continuity. Additional channels at 1.378 and 2.25 μ m enhance cloud detection. New channels dedicated to active fire measurements are also included in the SLSTR design although these do not derive the design. Details of SLSTR channels are provided in Table 21 and Table 22.

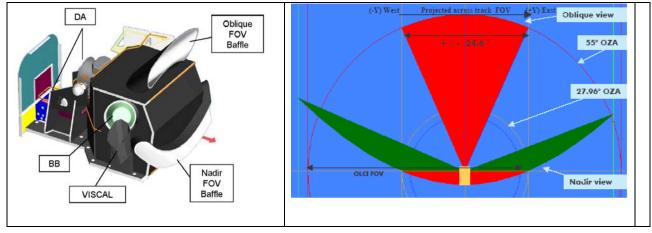


Figure 40: Left: SLSTR instrument configuration, right: SLSTR camera viewing geometry showing nadir and oblique views. Note that the nadir only coverage of SLSTR is limited to the OLCI FoV.

The SLSTR instrument is a conical scanning imaging radiometer with dual view capability including an oblique and near-vertical nadir view to provide robust atmospheric correction over the dual-view swath. The nadir and oblique views are generated using separate scanners to allow for a wider swath than possible with the single conical scan ATSR design. The scan cone will intersect the Earth view, two

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calibration black bodies, and a Visible Calibration (VISCAL) Unit, so that the line of sight will encounter each of these once during a complete rotation.

The requirement for a wider nadir swath, and for enhanced resolution in coastal regions, means that the number of instrument pixels to be measured per scan will exceed the corresponding figure for AATSR. Unlike AATSR (which scans at a rate of 400 scans per minute, corresponding to the along track resolution of 1 km), the SLSTR instrument will use two independent scan mirrors each scanning at 200 scans per minute, but each scan will measure 2 along-track pixels of 1 km (and 8 pixels at 500 m resolution) simultaneously. This configuration increases the swath width in both views, as well as providing 500 metre resolution in the reflectance channels. The nadir swath is ~1420 km and provides identical coverage to the OLCI instrument. The oblique view swath is ~750 km centred at the SLSTR nadir point.

| SLSTR Band | L Centre [µm] | ΔL [μm] | SNR [-] / Ne∆T [mK] | SSD [km] | SLSTR Band |
|---------------|------------------|---------|------------------------|----------|------------|
| S1 | 0.555 | 0.02 | 20 | 0.5 | S1 |
| S2 | 0.659 | 0.02 | 20 | 0.5 | S2 |
| S3 | 0.865 | 0.02 | 20 | 0.5 | S3 |
| S4 | 1.375 | 0.015 | 20 | 0.5 | S4 |
| S5 | 1.61 | 0.06 | 20 | 0.5 | S5 |
| S6 | 2.25 | 0.05 | 20 | 0.5 | S6 |
| S7 | 3.74 | 0.38 | 80 mK | 1.0 | S7 |
| S8 | 10.95 | 0.9 | 50 mK | 1.0 | S8 |
| S9 | 12 | 1.0 | 50 mK | 1.0 | S9 |

Table 21: Band characteristics of the Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR)

Table 22: Active Fire Channel band characteristics of the Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR)

| Active Fire Band | L centre [µm] | ΔL [µm] | Ne∆T [mK] | SSD [km] | Active Fire Band |
|------------------------|------------------|---------|-----------|----------|------------------|
| F1 | 3.74 | 0.38 | 500 | 1.0 | F1 |
| F2 | 10.95 | 0.9 | 400 | 1.0 | F2 |

The proposed sensor design is based on the following main elements:

- Photo Conductive detectors with two elements for TIR channels and on small multi-element arrays of Photo Voltaic detectors for the other channels. Infrared detectors are operated at 80 K.
- A dual view capability (oblique and near-nadir) to provide ATSR-style robust atmospheric correction over a 750 km swath.

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- Both oblique and near nadir views share common focal plane optics and detectors in such a way as to ensure spectral and radiometric probity of the design and the resulting data.
- Rotary scan mirror mechanisms to produce a wide swath running at constant angular velocity. A recombination flip mirror mechanism manages translations between the two views
- Ground Sampling Distance at nadir for the TIR channels is ~1 km, and 0.5 km for Visible and SWIR channels.
- The complete suite of AATSR and ATSR-2 spectral channels is included in order to maintain continuity with the previous sensors.
- Accurate and stable in-flight calibration performed onboard. The instrument includes on-board radiometric sources (2 x black body cavities and 1 x VIS diffuser) for accurate and stable in-flight calibration.
- Coverage identical and contemporaneous with OLCI ocean/land colour measurements (coregistration of instrument data based on one visible channel).
- A cryogenically cooled focal plane array housing infrared detectors cooled to 80 K.
- The instrument is integrated on a single plate with its control electronics and cooling radiators.

6.3.3 Surface Topography Mission (STM) Payload: Instruments Characteristics and Modes

The aim of the Sentinel-3 topography mission is to retrieve orbit altitude information with an end-toend range accuracy of 3 cm (ocean) to determine SSH, Hs, sea ice thickness estimates, wind speed over the ocean, and other ocean/land parameters. The Sentinel-3 topography payload is composed of a SAR Radar Altimeter (SRAL), a Microwave Radiometer (MWR) and a Precise Orbit Determination (POD) package (including a GNSS receiver supplemented by a laser retro-reflector (LRR)). Their purpose is to determine very accurately the height of the Earth surface, and in particular the sea surface height relative to a precise Earth reference frame.

The propagation speed of microwave pulses through the atmosphere is variable. The ionosphere and the troposphere introduce additional delays dependent on the density of electrons in the ionosphere, the density of gases (dry troposphere) and the moisture content (wet troposphere) in the troposphere. The wet troposphere delay is removed using the MWR data. The MWR determines the amount of water contained in the propagation path of the radar pulses. The RA transmits pulses alternatively at two different carrier frequencies. Comparing the relative delay of both measurements, the frequency-dependent part introduced by the ionosphere is then derived and compensated for. The influence of the dry troposphere (density of atmospheric gases) is less variable and can be determined sufficiently accurately using meteorological data and models. In order to achieve the ultimate aim of precision measurement of the surface height relative to the terrestrial reference frame, accurate measurements of the satellite location are needed. To this end, a geodetic-quality GNSS receiver, complemented by the laser retro-reflector, are included and guarantee the overall centimetre accuracy required for the Sentinel-3 topography mission. An estimated SSH error budget for the Sentinel-3 topography mission is shown in Table 23.

The Sentinel-3 SRAL instrument is a fully redundant dual-frequency, nadir-looking microwave radar which employs technologies inherited from the CryoSat and Jason altimeter missions. The main range measurements are performed in Ku-band, while a second frequency at C-band is used to compensate the effects of the ionosphere. Calibration modes include both pulse and noise injection approaches. The main features of the Sentinel-3 SRAL are given in Table 24.

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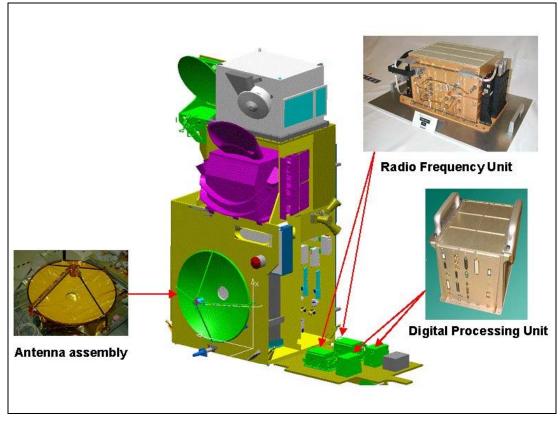


Figure 41: The Sentinel-3 RADAR Altimeter shown with the Sentinel-3 satellite

SRAL altimeter measurements are performed either in Low Resolution Mode (LRM) or in Synthetic Aperture Radar (SAR) mode. For both LRM and SAR modes, the tracking function may be a closed loop or an open loop function. "Closed loop" means that the range tracking parameters are computed by the tracking algorithm, while in "Open loop" means that these parameters are computed directly from altitude values read from a file stored in the instrument coupled with the position/velocity coordinates of the navigation bulletin sent every second to the platform by the GPS receiver.

LRM mode is the conventional altimeter pulse limited mode with interleaved Ku-band and C-band pulses, while SAR mode is the high along track resolution mode based on Synthetic Aperture Radar processing. A conventional pulse-limited, low-resolution mode (LRM) employs an autonomous closed-loop echo tracking technique, and is the primary operational mode for observing level surfaces with homogeneous and smooth topography, like that of the open ocean or the smooth central ice-sheet plateaux. In LRM mode, pulses are transmitted at the Pulse Repetition Frequency (PRF about 1924 Hz) rhythm, following a typical pattern of 3 Ku-band pulses / 1 C-band pulse / 3 Ku-band pulses. These pulses are processed and averaged on-board to provide a power waveform (128 I2+Q2 samples) about every 50.9 ms, corresponding to the averaging of 84 Ku-band pulses and of 14 C-band pulses. This measurement is called an elementary measurement or a 20-Hz measurement. It contains Ku-band and C-band waveforms and associated parameters.

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| Source | ENVISAT error [cm] | 83 error [cm] | Contributor |
|-----------------------------|-----------------------|---------------|-------------|
| Altimeter noise | 1.8 | 1.4 | SRAL |
| Sea state bias | 2 | 2 | SRAL |
| Ionosphere | 0.5 | 0.5 | SRAL |
| Dry troposphere | 0.7 | 0.7 | SRAL |
| Wet troposphere | 1.4 | 1.4 | MWR |
| Total range error | 3.1 | 2.9 | |
| Radial orbit error | 1.9 | 1.9 | POD |
| Sea Surface height error | 3.1 | 2.9 | |

Table 23: Estimated SSH error budget for the Sentinel-3 topography mission

Table 24: Main features of the Sentinel-3 Synthetic Aperture Radar Altimeter (SRAL)

| | LRM | | SA | R |
|------------------------|----------------|---------------|----------------------|---------------|
| | Ku-band C-Band | | Ku-band | C-band |
| Frequency (GHz) | 13.575 | 5.41 | 13.575 | 5.41 |
| Bandwidth (MHz) | 350 | 320 | 350 | 320 |
| PRF (Hz) | 1650 (average) | 275 (average) | 17800 (burst) | 157 (average) |
| Pulse length (us) | 50 | 50 | 50 | 50 |
| Tracking window (m) | 60 | 66 | 60 | 66 |
| RF power – peak (W) | 7 | 32 | 7 | 32 |
| Antenna beam width (°) | 1.28 | 3.4 | 1.28 | 3.4 |
| Data rate (Mbits/s) | 0.1 | | 11800 (uncompressed) | |
| Power (W) | 86 95 | | 5 | |
| Mass (Kg) | < 60 | | | |

Other applications require topography data over more variable surfaces, so two features are implemented in Sentinel-3 SRAL which can be used independently or in combination: the SAR mode, similar to that of the CryoSat SIRAL instrument, and the *open-loop* tracking mode. In the SAR mode, the horizontal spatial resolution is enhanced in the along-track direction. This is achieved by a high pulse repetition frequency (about 10 times higher than in LRM) and by processing the received echoes on-ground by exploiting the Doppler information. This mode will be mainly used over sea-ice and ice-sheet margins, as well as in-land water and coastal ocean. The open-loop tracking mechanism is mainly used over discontinuous surfaces (like land-sea transitions) or fast varying topography (i.e. ice margins). In this mode, the tracking window of the SRAL is controlled based on the a-priori knowledge of the surface height, from existing high resolution global Digital Elevation Models (DEM), combined with

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knowledge of the location of the satellite from the GNSS receiver. The main advantage is that the acquisition of the measurements is continuous, avoiding the data gaps typical of closed-loop tracking, which has difficulties to track rapid topographic changes experienced at coastal margins or in mountainous regions. In SAR mode, the Pulse Repetition Frequency (PRF) is about 17 800 Hz. Pulses are transmitted by a series of 66 (1 C-band pulse / 64 Ku-band pulses / 1 C-band pulses), called a burst, corresponding to a duration of about 12.74 ms. A burst corresponds thus to a 80-Hz measurement, and contains 64 Ku-band and 2 C-band waveforms (128 I and Q samples for each of them).

6.3.3.1 Microwave Radiometer (MWR)

The Sentinel-3 MWR measures the thermal radiation emitted by the atmosphere and the sea surface, and permits the determination of the wet troposphere induced propagation delay experienced by the altimeter pulses. The instrument aims to provide data that will provide an altimeter wet troposphere correction with typical accuracy of 1.4 cm.

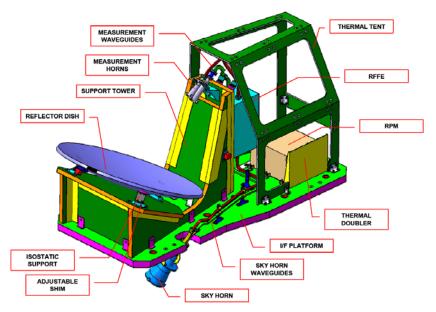


Figure 42: Main features of the Sentinel-3 Microwave Radiometer (MWR)

The Sentinel-3 MWR is a Dual Frequency Noise Injection Radiometer (NIR), with cold sky calibration developed from the CryoSat and Jason heritage MWR instruments. The noise injection operation consists of adding noise to the antenna branch in order to equal the temperature of the internal load noise temperature. This balanced condition takes places at a common plane for all involved temperatures, which has been defined at the output of the Dicke switch. The amount of injected noise allows the retrieval of the brightness temperature.

The baseline design of the microwave radiometer includes 2 channels each addressing a different geophysical parameter. A channel at 23.8 GHz is for tropospheric water vapour determination, while the channel at 36.5 GHz addresses the influence of non-precipitating clouds. The MWR has an integration time of 150 ms and a footprint of 20 km co-located with the SRAL instrument. The observed signals are calibrated by comparison to a stable and precisely known reference noise source, which in the MWR is based on the noise injection concept. The expected radiometric performance is: Sensitivity: <0.4 K,

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Stability: <0.6 K, and absolute accuracy: <3 K over a brightness temperature range of 150 K - 313 K. The MWR mass is approximately 26 kg and its power consumption is 38 W. Figure 42 shows the main features of the Sentinel-3 MWR.

6.3.3.2 Precise Orbit Determination (POD)

The Sentinel-3 POD equipment provides the satellite altitude over a reference frame to an accuracy of 2 cm after post processing. It consists of a geodetic GNSS receiver and a laser retro reflector (LRR). The GNSS receiver is designed to operate with the Global Positioning System (GPS) satellites for the first generation of the Sentinel 3 and with the GPS and the Galileo satellite systems for the following generations. The receiver can track up to 12 GNSS satellites at the same time. The signals transmitted by the navigation satellites are disturbed by the ionosphere through electromagnetic interaction, in a similar manner as the altimeter pulses. This effect is corrected through a differential technique that uses two signals at different frequencies in the range between 1160 and 1590 MHz. The GNSS receiver produces an on-board (i.e. real-time) position to around 3 m accuracy in satellite altitude. This is needed to control the operation of the open-loop tracking mode of the SRAL and is also used for platform navigation. Ground processing provides the satellite altitude to < 8 cm accuracy within 3 hours for operational applications and 2 cm after some days. The mass of the GNSS receiver is approximately 11 kg and the power consumption is 20 W.

The laser retro reflector (LRR) is a small, passive optical device consisting of a number of corner cube mirrors designed to reflect laser signals from Satellite Laser Ranging stations. Laser tracking provides ranging to an accuracy of < 2 cm and will be used in the commissioning phase and regularly during the mission to validate the POD solutions. The LRR mass is approximately 1kg.

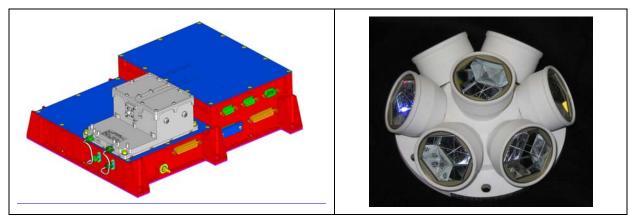


Figure 43: The Sentinel-3 Global Navigation Satellite System (GNSS) receiver (right) the Sentinel-3 Laser retro-reflector (LRR).

6.4 Ground Segment

The sesntinel-3 Mission ground segment includes:

Satellite Ground Stations. Dedicated S-band ground stations will be required for satellite command, control and management. Dedicated X-band ground stations will be required for science data downlink.

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A Flight Operations Segment (FOS). The FOS will perform Sentinel-3 command and control tasks including the uplink and downlink of tele-command and telemetry (S-band link) as well as satellite maintenance support (e.g. on-board software maintenance, collision avoidance etc.).

A Payload Data Ground Segment (PDGS). The PDGS will perform payload data processing for Sentinel-3 instruments, instrument calibration management, archival and long-term preservation of mission data, mission planning, mission performance and monitoring of data products. Processing of NRT, STC and NTC data will be managed by the PDGS.

A Precise Orbit Determination (POD) Service. The POD service will make optimal use of all data derived from Sentienl-3 GNSS, LRR and DORIS systems as well as the generation of information for FOS operations and PDGS ground processing.

A Data Access Service. Data products may be ordered and retrieved from an operationally robust data access service serving operational GMES users in NRT, STC and NTC timeliness modes.

6.5 **Performance Aspects**

Performance aspects are presented in Section 5.

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7 SUMMARY AND CONCLUSIONS

This mission requirements traceability document elaborates high-level requirements for the Sentinel-3 Mission within the framework of GMES. The proposed Sentinel-3 satellite system is dedicated to marine observations and will provide an essential measurement capacity that will be used to manage European and global seas and oceans, for monitoring and predicting changes and variability of climate and formulating strategies to adapt and mitigate climate impacts. Considering a long-term (at least 20 year) perspective, the sustained operational measurement systems of Sentinel-3 will ultimately lead to improved long range ocean, biogeochemical and atmospheric forecasts and land monitoring capability based on new technology and new understanding of the marine environment.

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8 ANNEX-1 MTRD REQUIREMENTS LIST AND TRACEABILITY TO MRD REQUIREMENTS

Table 25: GMES Service – Sentinel-3 traceability matrix.

| Title | Requirement | Service | Compliance | Reference |
|----------------------------|---|--|--|---|
| Title Availability | Requirement"Priority 1 is to ensure the continuity of the Jason [altimeter] (reference mission and climate applications) and ENVISAT [altimeter] time series" [RD- 52]"Maximise the lifetime of the ENVISAT atmospheric chemistry instruments and of the AATSR and MERIS instruments" [RD-55]."Sentinel 3 with its medium resolution multispectral images is essential to ensure beyond 2010 the delivery of the continuity of data today delivered by other mission such as VEGETATION, MERIS and ATSR" [RD-54]"The following missions are relevant to the Emergency service ENVISAT" [RD- 56] | | Compliance Full (depending on final Launch date) | Reference S3-MR-50, S3-MR-100, S3-MR-110, S3-MR-120, S3-MR-130 |
| Availability | "The MCS must be designed and implemented to meet identified needs in a reliable, easy to use manner, having guaranteed 24- hour/7-day-a-week availability, and providing information of useful precision and stability" [RD- 52]. This equally applies to all other services | EC MCS, GMES MyOcean, GSE- MarCoast, GSE- PolarView, MARISS, FP6/7 MERSEA, NHMS, GSE Coastwatch, EC LMCS GMES GEOLAND, GSE-LAND, GSE RESPOND, GSE- FM, Risk-EOS, RESPOND, GOFC- GOLD, FP6 LIMES, NHMS, EC GAS, GMES MACC, GSE-PROMOTE, | Full | S3-MR-10 |

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| Continuity | Sentinel-3 shall provide continuity of tried and tested observational methods, processing and products, particularly ENVISAT MERIS, AATSR, RA-2, and MWR. [RD-52, RD-54, RD-55, RD- 56] | EC ERCS, GMES SAFER, GSE-GMFS, EC MARS Food, GMES G-MOSAIC, GSE Risk-EOS, GSE- RESPOND. EC MCS, GMES MyOcean, GSE- MarCoast, GSE- PolarView, MARISS, FP6/7 MERSEA, NHMS, GSE Coastwatch, EC LMCS GMES GEOLAND, GSE-LAND, GSE RESPOND, GSE- FM, Risk-EOS, RESPOND, GOFC- GOLD, FP6 LIMES, NHMS, EC GAS, GMES MACC, GSE-PROMOTE, | Full | S3-MR-80, S3-MR-100, S3-MR-110, S3-MR-120, S3-MR-130, S3-MR-130, S3-MR-150, S3-MR-150, S3-MR-170, S3-MR-180, S3-MR-180, S3-MR-180, S3-MR-90, S3-MR-920, S3-MR-940, S3-MR-950, |
|-------------|---|--|------|--|
| Continuity | Sontingly shall provide | EC ERCS, GMES SAFER, GSE-GMFS, EC MARS Food, GMES G-MOSAIC, GSE Risk-EOS, GSE- RESPOND. | Evil | S3-MR-1180 |
| Continuity | Sentinel-3 shall provide continuity of SPOT Vegetation capability. [RD- 54, RD-56] | EC LMCS GMES GEOLAND, GSE-LAND, GSE RESPOND, GSE- FM, Risk-EOS, RESPOND, GOFC- GOLD, FP6 LIMES, NHMS, EC GAS, GMES MACC, GSE-PROMOTE, EC ERCS, GMES SAFER, GSE-GMFS, EC MARS Food, GMES G-MOSAIC, GSE Risk-EOS, GSE- RESPOND. | Full | S3-MR-60, S3-MR-90, S3-MR-1180 |
| Performance | Sentinel-3 shall include an ENVISAT RA-2 class altimeter system. [RD-52, RD-54, RD-55, RD-56] | EC MCS, GMES MyOcean, GSE- MarCoast, GSE- PolarView, MARISS, FP6/7 MERSEA, NHMS, GSE Coastwatch and services using RLH products. | Full | S3-MR-100 |

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| Service | "The GACS has a need to | EC GACS, GMES MACC, | Full | S3-MR-1220 |
|-------------|--|---|---|--|
| bervice | acquire satellite observations delivered by other GMES services, specifically those related to land or ocean parameters." [RD-55] | GSE-PROMOTE | i un | 03 MIX 1220 |
| Performance | "The global component of the LMCS will include production of biophysical parameters at global scales and more elaborated products to support the EU international development co-operation policies and the implementation and monitoring of international conventions. This component will be mainly based on low (LR) or medium (MR) spatial resolution images (1 km-250 m) with a high time resolution from near real time monitoring systems to 5 yearly products (e.g. GLOBCOVER)."[RD-54] | EC LMCS GMES GEOLAND, GSE-LAND, GSE RESPOND, GSE- FM, Risk-EOS, RESPOND, GOFC- GOLD, FP6 LIMES, NHMS, EC GAS, GMES MACC, GSE-PROMOTE, EC ERCS, GMES SAFER, GSE-GMFS, EC MARS Food, GMES G-MOSAIC, GSE Risk-EOS, GSE- RESPOND. | Full | S3-MR-770, S3-MR-1180 |
| Performance | "There is a need to develop/test innovative instrumentation to better answer existing and future MCS requirements for high resolution." [RD-52] | EC MCS, GMES MyOcean, GSE- MarCoast, GSE- PolarView, MARISS, FP6/7 MERSEA, NHMS, GSE Coastwatch | Full (new technologies included) | S3-MR-160, S3-MR-630, S3-MR-640 |
| Performance | "A priority is to fly in constellation with JASON class altimeters." [RD-52] | ECMCS,GMESMyOcean,GSE-MarCoast,GSE-PolarView,MARISS,FP6/7MERSEA,NHMS,GSE Coastwatch | Full (assuming JASON altimeter is flying) | S3-MR-340, S3-MR-670 |
| Performance | "Sentinel-3 should include a constellation of two satellites, flying simultaneously, providing adequate coverage and operational robustness." [RD-55] | EC GAS, GMES MACC, GSE-PROMOTE | Two satellites used | S3-MR-660 |
| Products | "The interest of ESA Sentinel-3 and of relevant MTG and Post-EPS instruments for the | EC GAS, GMES MACC, GSE-PROMOTE | Full | S3-MR-170, S3-MR-360, S3-MR-1210 |

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| | characterization of aerosols and clouds (and fires) deserves to be emphasized." [RD-55] | | | |
|------------------------------------|---|--|------|---------------------------------------|
| SST Instrument | Sentinel-3 shall include an ENVISAT AATSR class TIR radiometer system. [RD-52, RD-54] "The priority for Sea Surface Temperature is for high accuracy dual view measurements." [RD-52] "The large swath requirement has a much lower priority, in particular (but not only), if S3 is a two satellite system." [RD-52] | MarCoast, GSE- PolarView, MARISS, FP6/7 MERSEA, NHMS, GSE Coastwatch, EC LMCS GMES | Full | S3-MR-130, S3-MR-360, S3-MR-630 |
| Ocean/Land Colour instrument | Sentinel-3 should have an Ocean and Land Colour sensor having a similar spectral resolution to MERIS. This is essential to meet the important shelf and coastal ocean water quality measurement requirements. [RD-52, RD-54] | EC MCS, GMES MyOcean, GSE- MarCoast, GSE- PolarView, MARISS, FP6/7 MERSEA, NHMS, | Full | S3-MR-120 |
| Data products | "Access to raw [L1b] satellite data is required in NRT for use in NWP data assimilation systems." [RD- | EC GAS, GMES MACC, GSE-PROMOTE | Full | S3-MR-830, S3-MR-1180 |

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| | 55] | | | |
|------------------------|--|---|------|---|
| Timeliness | Delivery of data products from Sentinel-3 shall be defined in terms of timeliness criteria including NRT, STC and NTC. NRT data products will e made available within 3 hours of measurement, STC within 48 hours. [RD-52, RD-54, RD-55, RD-56] | MyOcean, GSE- MarCoast, GSE- PolarView, MARISS, FP6/7 MERSEA, NHMS, GSE Coastwatch, EC LMCS GMES GEOLAND, GSE-LAND, GSE RESPOND, GSE- FM, Risk-EOS, RESPOND, GOFC- GOLD, FP6 LIMES, NHMS, EC GAS, GMES MACC, GSE-PROMOTE, EC ERCS, GMES SAFER, GSE-GMFS, EC MARS Food, GMES G-MOSAIC, GSE Risk-EOS, GSE- RESPOND. | Full | S3-MR-10, S3-MR-840 |
| Geographic Coverage | Sentinel-3 shall provide global coverage including land, ocean and ice covered regions. [RD-52, RD-54, RD-55, RD-56] | EC MCS, GMES MyOcean, GSE- MarCoast, GSE- PolarView, MARISS, FP6/7 MERSEA, NHMS, GSE Coastwatch, EC LMCS GMES GEOLAND, GSE-LAND, GSE RESPOND, GSE- FM, Risk-EOS, RESPOND, GOFC- GOLD, FP6 LIMES, NHMS, EC GAS, GMES MACC, GSE-PROMOTE, EC ERCS, GMES SAFER, GSE-GMFS, EC MARS Food, GMES G-MOSAIC, GSE Risk-EOS, GSE- RESPOND. | Full | S3-MR-490, S3-MR-500, S3-MR-510, S3-MR-520, S3-MR-530, S3-MR-540, S3-MR-550 |
| Spatial Resolution | Sentinel-3 shall have a spatial resolution of: Optical VIS: ≤300 – 1000 m Optical TIR: 1 km Enhanced altimeter resolution is required in the | EC MCS, GMES MyOcean, GSE- MarCoast, GSE- PolarView, MARISS, FP6/7 MERSEA, NHMS, GSE Coastwatch, EC LMCS GMES GEOLAND, GSE-LAND, | Full | S3-MR-720, S3-MR-730, S3-MR-740, S3-MR-750, S3-MR-760, S3-MR-770, S3-MR-780, S3-MR-790 |

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| | coastal zone [RD-52, RD-54, RD-55, RD- 56] | GSE RESPOND, GSE- FM, Risk-EOS, RESPOND, GOFC- GOLD, FP6 LIMES, NHMS, EC GAS, GMES MACC, GSE-PROMOTE, EC ERCS, GMES SAFER, GSE-GMFS, EC MARS Food, GMES G-MOSAIC, GSE Risk-EOS, GSE- RESPOND. | | |
|--------------------------|--|--|------|---|
| Time of Observation | "The preferred orbit to meet the primary SST objective is for a morning overpass before diurnal warming has developed significantly. A 10.00-10.30 equator crossing is not optimal but is an acceptable compromise." [RD-52] | EC MCS, GMES MyOcean, GSE- MarCoast, GSE- PolarView, MARISS, FP6/7 MERSEA, NHMS, EC GAS, GMES MACC. | Full | S3-MR-800, S3-MR-810, S3-MR-820 |
| Spectral sampling | Sentinel-3 spectral sampling shall be at least equivalent to ENVISAT AATSR and MERIS. [RD-52, RD-54, RD-55, RD-56] | EC MCS, GMES MyOcean, GSE- MarCoast, GSE- PolarView, MARISS, FP6/7 MERSEA, NHMS, GSE Coastwatch, EC LMCS GMES GEOLAND, GSE-LAND, GSE RESPOND, GSE- FM, Risk-EOS, RESPOND, GOFC- GOLD, FP6 LIMES, NHMS, EC GAS, GMES MACC, GSE-PROMOTE, EC ERCS, GMES SAFER, GSE-GMFS, EC MARS Food, GMES G-MOSAIC, GSE Risk-EOS, GSE- RESPOND. | Full | S3-MR-850, S3-MR-860, S3-MR-870, S3-MR-880, S3-MR-890, S3-MR-900, S3-MR-920 |
| Service Data Products | Continuity of ENVISAT data products is essential for NOP, NWP, land monitoring, and emergency and security services [RD-52, RD-54] | EC MCS, GMES MyOcean, GSE- MarCoast, GSE- PolarView, MARISS, FP6/7 MERSEA, NHMS, GSE Coastwatch, EC LMCS GMES | Full | Potential data products required by GMES services are presented in |

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| | | GEOLAND, GSE-LAND, GSE RESPOND, GSE- FM, Risk-EOS, RESPOND, GOFC- GOLD, FP6 LIMES, NHMS, EC GAS, GMES MACC, GSE-PROMOTE, EC ERCS, GMES SAFER, GSE-GMFS, EC MARS Food, GMES G-MOSAIC, GSE Risk-EOS, GSE- RESPOND. | | Table 17 and Table 18 |
|----------|--|---|------|---|
| Orbit | "The Sentinel-3 orbit shall be high inclination and sun- synchronous providing continuity with ENVISAT." "Since neither MERIS nor MODIS can be expected to operate beyond about 2010, it is clear that a Class B sensor must be the priority for Sentinel 3. This should have a sun synchronous orbit, and provision for tilting to avoid sun glitter at low latitudes" [RD-52, RD-54] | EC MCS, GMES MyOcean, GSE- MarCoast, GSE- PolarView, MARISS, FP6/7 MERSEA, NHMS, GSE Coastwatch, EC LMCS GMES | Full | S3-MR-670, S3-MR-680, S3-MR-690, S3-MR-700, S3-MR-710 |
| Products | "For all services provided, uncertainty assessments are crucial, in particular for assimilation Modelling" [RD-55] "In order to be fit for purpose, an essential component of Sentinel-3 level 2 data products is pixel-by-pixel error estimates. This implies a well planned programme to acquire independent validation observations, | EC MCS, GMES MyOcean, GSE- MarCoast, GSE- PolarView, MARISS, FP6/7 MERSEA, NHMS, GSE Coastwatch, EC LMCS GMES GEOLAND, GSE-LAND, GSE RESPOND, GSE- FM, Risk-EOS, RESPOND, GOFC- GOLD, FP6 LIMES, NHMS, | Full | S3-MR-1190 |

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| includ | ng in | situ | EC ERCS, GMES SA | AFER, | |
|--------|-----------------|---------|------------------|-------|--|
| measu | ements, on wh | ich the | GSE-GMFS, EC I | MARS | |
| error | atistics can be | based. | Food, | | |
| It mu | continue as l | long as | GMES G-MOSAIC, | GSE | |
| operat | onal product | ts are | Risk-EOS, | GSE- | |
| being | elivered." [RD- | -52] | RESPOND. | | |

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APPENDIX A: EU ACTORS IN OPERATIONAL OCEANOGRAPHY

| Category | Actor/Company | Contact person |
|----------------------|--|----------------------|
| MetOcean Forecasting | BSH Model | Gerd Becker |
| | UK Met Office Model | Mike Bell |
| | Meteo-France Model | Herve Roquet |
| | ECMWF Model | Director |
| | Met-No Model | |
| Ocean Forecasting | FOAM Model | Mike Bell |
| | MERCATOR Model | Pierre Bahurel |
| | TOPAZ Model (NERSC) | Laurant Bartino |
| | MPI Model | Jochem Marotzke |
| | MFS Model (INGV) | Nadia Pinardi |
| | G-ECCO (IFM) | D. Stammer |
| | POSEIDON Model (NCMR) | L. Perivoliotis |
| ESA GMES | ROSES (ALCATEL) | Roberto Aloisi |
| | COASTWATCH (ACRI) | Phillipe Bardey |
| | NORTHERN VIEW (C-CORE) | Charles Randell |
| | ICEMON (NERSC) | Stein Sandven |
| | MARCOAST | Jerome Bruniquel |
| ESA DUP/DUE | TIDAL (ARGOSS) | Han Wensink |
| | MOCCASSIN (ARGOSS) | Cees de Valk |
| | MEDSPIRATION (SOC) | Ian Robinson |
| | FLOMON (SYNOPTICS) | Hans Van Leeuwen |
| | POWERS (MUMM) | K. Ruddick |
| | BABEL (ARGOSS) | |
| ESA EOMD | SAR-based oil spill and fishing vessel detection | KSAT- Lina Stainback |
| ESA EOMD | EO Exploitation in the sector of Marine | KSAT- Lina Stamback |
| | Information Systems, BMT Marine | |
| | Information Systems, Divit Marine | |
| | Integration of Envisat data into iceberg | C-CORE |
| | management | COM |
| | Near real time sea-surface winds from SAR data | KSAT |
| EU | COASTMON | E. Svendsen |
| | DECLIMS & DISMAR | |
| | MERSEA Strand 1 (NERSC) | J. Johannessen |
| | MERSEA IP (Ifremer) | Y. Desaubiers |
| | NAOC, OCEANIDES | |
| | OROMA, REVAMP | |
| SMEs | Satellite Observing System (SOS) | David Cotton |
| SMLS | CLS | Pierre-Yves Le Traon |
| | OCEANOR | Jan-Petter Mathisen |
| | ARGOSS | Cees de Valk |
| | MeteoMer | Pierre Lasnier |
| | Starlab | Giulio Ruffini |
| | InfoSar | Christian Oliver |
| | NPA Group | Ren Capes |
| | NIA GIOUP | Ken Capes |

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| | Infoterra | Alexander Kaptein |
|----------------------|---|-------------------|
| | VEGA Group PLC | Phil Cartmel |
| | Systems Engineering & Assessment Ltd | Paul Phillips |
| | ACRI | |
| | BOOST | Vincent Kerbaol |
| | Plymouth Marine Applications | |
| Industrial companies | Qinetiq | Roger Robbinson |
| | Fugro Global Environmental & Ocean Sciences | Robin Stevens |
| | Telespazio | Alessandro Voli |
| | KSAT | Lina Stainback |

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APPENDIX B: SOURCES OF REQUIREMENTS FOR MARINE OPERATIONS

| Name | Project Leader | Brief Description | Date |
|-------------------------------------|--|--|-------------|
| GMES MyOcean | Mercator | Implementation of the GMES MCS | 20008- |
| Project | Ocean | http://myocean.eu.org | |
| GMES GSE | Thales Alenia | Implementation of the GMES services for coastal | 2008- |
| MarCoast | | regions. http://www.marcoast.com | |
| OCEAN EYE | EDISOFT | development of global European ocean monitoring capacity | 2007 |
| GMES MCS Implementation Group | P Ryder | Strategic Implementation plan for the GMES MCS with detailed requirements for Sentinel-3 | 2007 |
| COMKISS EU framework 4 | University of Lund, Sweden, | Study of applications of EO data in 3 sectors of offshore shipping: Design, Unusual loads, fast ferries. | 1998-2000 |
| ESA Innovative Altimeter Study | Alcatel Space Industries, France | Specification for "Innovative" altimeter instrument for potential future deployment | 2002-2004 |
| ESA Innovative Altimeter Study | Alenia, Italy | As above | 2002-2003 |
| SEAROUTES EU framework 5 | Technical University of Berlin, Germany | Advanced Decision Support for Ship routing based on Full-scale Ship-specific Responses as well as Improved Sea and Weather Forecasts including Synoptic, High Precision and Real time Satellite Data | 2002-2004 |
| INMAREEU framework 5 | CONS A.R. , Italy | To develop more efficient maritime transport services in an integrated inter-modal transport chain. | 2004-2006 |
| ICEMON ESA GSE | NERSC, Norway | To implement a coherent European operational oceanography system for the high latitudes, consisting of sea ice, meteorological and oceanographic services <u>http://www.nersc.no/ICEMON/index.php</u> | 2003-2004 |
| Northern View ESA GSE | C-CORE, Canada | To provide users with a 'one-stop-shop' for northern information, integrating EO and other information as needed. Now part of PolarView project. | 2003-2004 |
| GAMBLE | Satellite | Investigation of future requirements for satellite | 2002-2003 |
| EU framework 5 | Observing Systems, UK | altimetry over the oceans. <u>http://www.altimetrie.net</u> | |
| OSIMS EU framework 4 | NERSC, No | Feasibility and cost benefits of using satellite data in operational ice monitoring, propose concepts for optimal use of satellite data in future sea ice monitoring and forecasting. | 1994-1998 |
| SSALTO/DUACS | CLS, Fr | Operational system dedicated to the unification | operational |



| | | and the combination of altimeter data in near real time. Since early 2004, four missions have been routinely processed: Jason, ENVISAT, TOPEX/Poseidon, and GEOSAT Follow On. <u>http://www.aviso.oceanobs.com/en/data/product- information/duacs/index.html</u> | |
|--------|---|--|-----------|
| EMOFOR | NERSC, No CLS, Fr Fugro Geos, UK | European Space Agency project, whose main objective is to integrate Earth Observation data into numerical model used by the offshore industry. NERSC is responsible for the numerical models implementation, CLS provides satellite data and Fugro Geos is the product provider. <u>http://www.eomd.esa.int/contracts/contract51.asp</u> | 1993-1995 |

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APPENDIX C: SOURCES OF REQUIREMENTS FOR SECURITY APPLICATIONS

| Name | Project Leader | Brief Description | Date |
|--------------------------------------|--|---|-----------------|
| ESA Innovative Altimeter Study | Alcatel Space, France | Specification for "Innovative" altimeter instrument for potential future deployment | 2002- 2004 |
| SEAROUTES EU framework 5 | Technical University of Berlin, Germany | Advanced Decision Support for Shiprouting based on Full-scale Ship-specific responses as well as Improved Sea and Weather Forecasts including Synoptic, High Precision and Realtime Satellite Data. http://www.searoutes.sg/project.php | 2002- 2004 |
| COMKISS EU framework 4 | University of Lund, Sweden, | Study of applications of EO data in 3 sectors of offshore shipping: Design, Unusual loads, fast ferries. http://www.maths.lth.se/matstat/staff/georg/comkiss \angle | 1998- 2000 |
| MERCATOR | Mercator- Ocean France | System of global and regional operational ocean model, assimilating EO data. <u>http://www.mercator-ocean.fr/</u> | operation al |
| FOAM | UK Met. Office | FOAM produces real-time analyses and forecasts of the temperature, salinity and currents of the deep ocean for up to five days ahead for the UK Navy. <u>http://www.metoffice.gov.uk/science/creating/daysahead/ocean/</u> | operation al |
| GAMBLE EU framework 5 | Satellite Observing Systems, UK | Investigation of future requirements for satellite altimetry over the oceans. <u>http://www.altimetrie.net</u> | 2002- 2003 |
| MISEC | Satellite Observing Systems, UK | BNSC programme to test the integration of EO-based data and services into marine information products used for security. The resulting products can improve the operational effectiveness of maritime security activity. | 2003- 2004 |
| CAMMEO | Satellite Observing Systems, UK | ESA EOMD project. Using NRT EO data to enhance forecasts for search and rescue and special operations. | 2003- 2004 |
| GFO | Geosat Follow-On | http://ibis.grdl.noaa.gov/SAT/gfo/bmpcoe/default.ht m | operation al |
| NRL / Stennis | Naval Research | NRL at Stennis Space Center generated user products from a number of ocean circulation models, and | |

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| | Laboratory, US | processed altimeter data. http://www7320.nrlssc.navy.mil/global_nlom32/skill. html | |
|--|--|--|------------------|
| IMPAST | JRC Ispra | IMPAST SAR based vessel detection, combined with vessel monitoring system (VMS) to monitor fishing. | 2000 - 2003 - |
| DECLIMS | IPCS, JRC, ISPRA | FP5 project Detection and Classification of Marine Traffic from Space. Based on use of SAR. | 2003- |
| Fishing Vessel Detection Services | Ksat / QinetiQ | To integrate a SAR based oil spill monitoring service into the North Sea Directorate and to develop the customer base for a SAR based vessel monitoring service. <u>http://www.eomd.esa.int/contracts/contract54.asp</u> | 2002- |
| Remote Sensing Applications in Search and Rescue | ASA/Martec for Candian Coastguard, Rescue and Environmen tal Branch | Report on use of remote sensing data for search and rescue. | |

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APPENDIX D: SOURCES OF REQUIREMENTS FOR COASTAL ZONE MONITORING

| Name | Project Leader | Brief Description | Date |
|-----------------|--------------------------|--|-------------------|
| COAST- DRIVE | HR Wallingford, UK | COASTDRIVE is an ESA Earth Observation Market Development Programme. As part of the project, HR Wallingford compiled a report on Data requirements of Coastal Zone Management. | |
| COAST- WATCH | EADS | ESA GMES programme addressing policy requirements of coastal zone management. | 2002 - 2003 - |
| COASTMO N | NERSC, Norway | Project supported by EC Environment and Climate Programme: To explore and test methods for use of synthetic aperture radar (SAR) and other new satellite data, in monitoring environmental/metocean conditions in regions close to harbours, to improve navigational safety, to aid coastal zone management (CZM), and to improve utilization of satellite observations in the user community <u>http://www.nersc.no/COASTMON/Products/oilspill.htm</u> 1 | Finishe d 1999 |
| EUROSION | RIKZ, NL | EUROSION was commissioned by the EC General Directorate Environment. The objective is to provide a recommendations for policy-making and information management practices to address coastal erosion in Europe, after thorough assessment of knowledge gained from past experiences and of the current status and trends of European coasts <u>http://www.eurosion.org</u> | Finishe d 2004 |
| EUCC | EUCC, NL | The EUCC "Coastal Union", has members from over 4 European Countries, and provides background and links to many ongoing, recent and past initiatives <u>http://www.eucc.nl</u> | |
| MARCOAST | AAS, F | MarCoast is an ESA GMES Services Services Element Study consortium comprising a core group of service providers delivering 6 core services in the areas of oil spill surveillance and water quality assessment and monitoring. <u>http://gmes-marcoast.com</u> | ongoing |

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APPENDIX E: SOURCES OF REQUIREMENTS FOR ALGAL BLOOM MONITORING

| Name | Project Leader | Brief Description | Date |
|--|---|--|-------------------------|
| ROSES | ALCATEL, France | GMES Service Element project. Delivering water quality monitoring services – in 2003-4 algae bloom and oil spill monitoring. | 2002- 2004 |
| COAST- WATCH | EADS | ESA GMES programme addressing policy requirements of coastal zone management. | 2002 - 2004 - |
| Decide-HAB | NERSC, Norway | Web based HAB information site for North Sea, Skaggerak, and Kattegak. <u>http://hab.nersc.no/</u> | Operationa 1 service |
| Algeinfo | Institute for Marine Research, Norway | Web based HAB information site for Norwegian Coast, produced by the Institute of Marine Research (IMR) with the Directorate of Fisheries (FD), OCEANOR AS and the Norwegian Institute for Water Research (NIVA). http://algeinfo.imr.no/eng | Operationa 1 service |
| Alg@line / Baltic Sea portal | Institute of Marine Research, Helsinki, Finland | Web portal to marine environmental information for the Baltic Sea around Finland <u>http://www.itameriportaali.fi/en/tietoa/algaline_seura</u> <u>nta/algaline/en_GB/Algaline10years/</u> | Operationa 1 service |
| Algaware | SMHI, Sweden | Web page with algal bloom information for Baltic. | Operationa 1 service |
| Moncoze Live Access Server | Meteorologi sk Institut, Norrway | Pilot system monitoring and modelling Norwegian Coastal environment. | Operationa l service |
| PML Image Browser | Plymouth Marine Laboratory, UK | Image browser (registration required), giving SST and parameters from SEAWIFS data (chlorophyll-A, rgb composite, water leaving radiance, aerosol radiance, optical depth (at 865 nm), in water pigment concentration, in water diffuse attenuation coefficient (at 490 nm). <u>http://www.neodaas.ac.uk/</u> | Operationa 1 service |
| IFREMER Bay of Biscay browser | IFREMER, FR | Image Browser giving SST, Chlorophyll-A, suspended matter, solar irradiance. <u>http://www.ifremer.fr/cersat/en/news/2002/Dec/bisc</u> <u>ay/overview.htm</u> | Operationa 1 service |
| ADRISCOS M | GOS,ISAC Sez, Rome, Italy | Image browser, giving SST and ocean colour parameter from SeaWiFS data (chlorophyll, true colour images, case I/case 2 water maps). SST and chlorophyll data are available for the Adriatic (registration required). <u>http://gos.ifa.rm.cnr.it/</u> | Operationa l service |
| ECOMAR | JRC, IT | FP6 Programme. "Monitoring and Assessment of Marine Ecosystems:. Aims to develop tools for a better harmonization of coastal and marine monitoring, specifically to support role in the definition and | Finished Dec 2006 |



| | | implementation of a Community Marine Strategy. http://www.oceanlab.abdn.ac.uk/research/ecomar.php | | | |
|--------|---------|--|------------------|--|--|
| DISMAR | JRC, IT | FP5 Programme. "Data integration system for marine pollution and water quality." http://www.nersc.no/dismar/dismar_news.html | | | |
| COAST | JRC, IT | FP5 Programme. "Coastal Monitoring and Management." | Finished 2003 | | |

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APPENDIX F: SOURCES OF REQUIREMENTS FOR OIL SPILL MONITORING

| Name | Project Leader | Brief Description | Date |
|---|-----------------------------|---|---------------------|
| ROSES | ALCATEL, France | GMES Service Element project. Delivering water quality monitoring services – in 2003-4 algae bloom and oil spill monitoring. | 2002-2004 |
| Northern View | C-CORE | ESA GMES programme addressing environmental policy requirements of the Northern Regions. Now part of PolarView. | 2002 - 2004 |
| KSAT | KSAT, Norway | SAR analysis for oil spill monitoring, ERS-2, ENVISAT and RADARSAT. http://www.ksat.no | Operational service |
| Telespazio | Telespazio, Italy | SAR analysis for oil spill monitoring, ERS-2, ENVISAT. | Operational service |
| Oilwatch | QinetiQ | SAR analysis for oil spill monitoring. | Operational service |
| Ocean Monitoring Workstation | Satlantic, Canada | A suite of software which can analyse SAR images and provide estimates of vessel location, oil spill location and extent, and wind and wave fields. | Application |
| Oil Spill and ship detection. | KSAT, QinetiQ | ESA EOMD project which aims integrate an Envisat based oil spill monitoring service into the portfolio of the North Sea Directorate (Market Owner), and to expand the customer base for SAR based fishing vessel monitoring services. http://www.eomd.esa.int/contracts/contract54.asp | Start up 2002 |
| EO exploitation in Marine Information Systems | BMT, UK | ESA EOMD project which aimed to to integrate oil spill data from ERS SAR imagery into the marine information system which would then propagate forwards or backwards in time to provide an indication of where a large slick would be likely to beach or to identify the probable source of the slick. http://www.eomd.esa.int/contracts/contract86.asp | Start up 2000 |
| CLEAN SEAS | SOS, UK | EC environment and climate programme "To evaluate the contribution that EO data in surveillance of marine pollution and establish how observations may be integrated to create a single information source'. http://www.satoc.eu/sos/projects/CSeas/ | 1997-99 |
| ISTOP | Canadian Space Agency | ISTOP (Integrated Satellite Tracking of Oil Polluters) using RADARSAT SAR for marine oil spill detection off Canada's east coast. | 2002-03 |
| OCEANIDES | JRC, IT | FP6 GMES wide ranging project looking at all aspects for requirements to establish a pan-European oil pollution monitoring nd information reporting capability. | 2002-03 |



APPENDIX G: SOURCES OF REQUIREMENTS FOR SUSTAINABLE EXPLOITATION OF THE SEA

| Name | Project Leader | Brief Description | Date |
|--|--|--|-----------------|
| WEMSAR | NERSC, | EC Framework RTP programme. Use of (mainly) SAR, | 2000- |
| | Norway | also scatterometry and altimetry to map wind energy resource for potential offshore wind farms. | 2003 |
| IMPAST | JRC Ispra | The project aims to develop tools that will allow near real time access to space borne synthetic aperture radar (SAR) imagery and the integration and comparison of this information with the vessel monitoring system (VMS) position reports in order to improve and support control fishing activities. | 2000- 2003 |
| UK/SADC Fish Resource Assessment Project | South Africa Development Community | High-resolution SST data used as input to ecosystem models. Outputs from these models were then used to characterise the potential pelagic fish resource <u>http://ceos.cnes.fr:8100/cdrom-</u> <u>00b2/ceos1/casestud/malawi/malawi1.htm</u> | 1992-94 |
| AlgeInfo | IMR Norway | Harmful Algal Bloom monitoring and warning system. Combines satellite data, circulation and ecosystem models and in-situ data. <u>http://algeinfo.imr.no/eng</u> | ongoing |
| ISOLE | Vitricoset, Italy | EC framework project aimed at evaluating the impact of mass tourism on marine environment by applying Earth Observation techniques | |
| EOFISS | EADS S & DE | An ESA EOMD project to establish prototype fishing support services <u>http://www.eomd.esa.int/contracts/contract94.asp</u> | 2000- 2001 |
| ENVISEA | EADS S & DE | An ESA EOMD follow up project to EOFISS, to further develop the SEAMAPPER service. http://www.eomd.esa.int/contracts/contract105.asp | 2001- 2002 |
| CATSAT | CLS | Fisheries service, based upon operational provision of SST, altimeter data and MERCATOR products <u>http://www.catsat.com/</u> | operatio nal |
| Fishing Vessel Detection Services | QinetiQ | To promote a SAR based vessel monitoring service to fisheries monitoring centres. http://www.eomd.esa.int/contracts/contract90.asp | 2002- |
| Fishing Vessel Detection Services | KSat / QinetiQ | To integrate a SAR based oil spill monitoring service into the North Sea Directorate and to develop the customer base for a SAR based vessel monitoring service. http://www.eomd.esa.int/contracts/contract54.asp | 2002- |



APPENDIX H: SOURCES OF REQUIREMENTS FOR LAND USERS

| Name | Project | Brief Description | |
|-------------------|-------------|---|--------|
| | Leader | | |
| GOFC- | GTOS | Global Observation for Forest and Land Cover Dynamics | 1999- |
| GOLD | | GOFC-GOLD): <u>http://www.fao.org/gtos/gofc-gold/</u> | |
| GEOLAND | EC/ESA | EU FP6: <u>http://www.gmes-geoland.info/</u> | |
| GlobCarbon | Marc | ESA DUE: <u>http://www.gofc-gold.uni-</u> | 2005- |
| | Leroy/MEDI | jena.de/sites/globcover.php | |
| | AS-France | | |
| SAGE | Infoterra | ESA GSE: <u>http://www.gmes-sage.info</u> | 2003- |
| | GmbH | | 2005 |
| CYCLOPES | | FP5: | |
| | | http://postel.mediasfrance.org/en/PROJECTS/R&D/CY | |
| | | <u>CLOPES/</u> | |
| ELDAS | KNMI | FP5: <u>http://www.knmi.nl/samenw/eldas/</u> | 2002- |
| EWBMS | EARS, The | EU DGXII: European Energy and Water Balance | |
| | Netherlands | Monitoring System Project: <u>http://www.ears.nl/</u> | |
| GSE-Land | Infoterra | ESA GSE: <u>http://www.gmes-gseland.info/</u> | 2006 - |
| | GmbH | | |
| GSE-Forest | GAF AG | ESA GSE: <u>http://www.gmes-forest.info</u> | 2006 - |
| Risk-EOS | ASTRIUM | ESA-GSE: <u>http://www.riskeos.com/</u> | 2006 - |
| GMFS | VITO | ESA-GSE: <u>http://www.gmfs.info/</u> | 2006 - |

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APPENDIX I: SENTINEL-3 NUMBERED MISSION REQUIREMENTS

| MR-ID | Туре | Description | Ref | v2.0 MRD Ref |
|----------|-------------------------|--|--|--|
| S3-MR-10 | Service availability | Sentinel-3 products with specified temporal and spatial coverage, fully compliant with specified product quality metrics, and delivered according to specified timeliness requirements, shall be available to the end user with >95% operational availability, measured over any 12 month period with no systematic geographical gaps. | RD-65, RD- 160 | Pg. 5, Para 3. Pg. 23, Para 2. Section 4.1.2 |
| S3-MR-20 | Service availability | The Sentinel-3 system shall be designed for a duration of 15-20 years. | RD-1, RD-3, RD-4 | Pg. iv Para.2 Bullet 5 |
| S3-MR-30 | Service availability | Access to EO data and services shall be ensured before the Sentinel era relying on the set of EO missions capable already contributing to the GMES Services. | RD-52, Table 3, Table 4, Table 5, Table 6 | Section 6.1, Bullet 1 |
| S3-MR-40 | Service availability | A facility to provide direct broadcast of Sentinel-3 optical mission data to local ground stations in the line-of-sight of Sentinel-3 shall be considered. Direct broadcast capability shall not drive the mission design. | Section 5.4 | Pg.4 Para. 1 Section 4.12 |
| S3-MR-50 | Service continuity | Sentinel-3 shall commence operations in a timely manner (target 2013) in order to ensure continuity of ENVISAT MERIS, | RD-52, RD- 179, RD-180, | Pg. iv Para.2 Bullet 6 |

Table 26 All Sentinel-3 mission requirements from this document

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| | | - | | |
|----------|-----------------------|--|---|--|
| | | AATSR and RA-2 measurement data sets and minimise potential gaps in EO service to GMES. | | |
| S3-MR-60 | Service continuity | Sentinel-3 shall provide continuity of SPOT/Vegetation-like instrument capability (Table 9) with a spatial sampling of ≤1000 m (0.3 km goal) to minimise potential gaps in service to GMES. | RD-152, RD- 154, Table 5, Table 6 | Pg.iv Para.1 Bullet 4 Section 4.1.2 Pg. 17, Para. 3 Pg. 34, Para. 2. Section 5.3.4 |
| S3-MR-70 | Service continuity | Sentinel-3 shall provide continuity CryoSat high-resolution along track marine and land ice surface measurements used to derive sea-ice thickness and ice sheet topography. | RD-52, RD-54, RD- 181, RD-56, Table 3, Table 5, Table 6 | Pg. iv Para. 3, Bullet 1. Pg. 24. Para. 2 Section 4.10 Section 5.1.2 |
| S3-MR-80 | Service continuity | Sentinel-3 shall provide continuity to radiance (L1b) and geophysical (L2) products based on existing ENVISAT MERIS, AATSR and RA-2 sensors and enhance them to cover the user information needs expressed by GMES users in the domains of: Ocean Monitoring, Land Monitoring, Atmospheric Monitoring, Emergency Response and Security. | RD-52, RD-54, RD- 181, RD-56, Table 3, Table 4, Table 5, Table 6 | Pg. iv, Para. 1 Bullet 5, Pg. iv, Para 2. Bullet 1,2,3 and4 Section 4.2 Section 5.1.2 |
| S3-MR-90 | Service continuity | Sentinel-3 shall provide continuity to services based on existing SPOT Vegetation P-like product line to cover the user information needs expressed by GMES services in the domains of: Land Monitoring, Emergency Response and Security. | RD-152, RD- 154, Table 5, Table 6 | Pg. 25, Para. 3 Pg. 34, Para. 2 |

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| S3-MR-100 | Performance | Sentinel-3 shall include a dual frequency (nominal frequency of ~13.5 GHz (Ku Band)) nadir pointing altimeter instrument based on the heritage of ENVISAT RA-2 and CryoSat-2 SIRAL. | RD-52, RD- 54, RD-181, RD-56, Table 3, Table 5. | Section 5.1.4 |
|-----------|----------------------|--|---|--|
| S3-MR-110 | Spectral sampling | The Sentinel-3 altimeter system shall include a passive microwave radiometer (MWR) for correction of range delay errors due to tropospheric water vapour. The MWR shall measure the amount of water vapour and liquid water content in the atmosphere, within a field of view centred immediately beneath the spacecraft track making measurements simultaneous and coincident with the altimeter footprint. | RD-52 | Section 5.2 |
| S3-MR-120 | Performance | Sentinel-3 shall provide Visible and Short- Wave Infrared radiance measurements over the ocean (ocean colour) to at least the quality of MERIS on ENVISAT with improved spectral capability. | RD-52, Table 3, Table 5, Table 6 | Pg. iv Para. 1, Bullet 3. Pg. iv Para. 3, Bullet 2. Pg. 22 Bullet 4 Section 4.5.3 Section 4.8 Pg. 31 Para. 3 Pg. 34, Para. 2 |
| S3-MR-130 | Performance | Sentinel-3 shall provide Visible and Short- Wave Infrared Short-Wave Infrared, and Thermal Infrared radiance measurements to at least the quality of AATSR on ENVISAT with improved coverage and spectral capability. | RD-52, RD- 54, RD-181, Table 3, Table 5, Table 6 | Pg. iv Para. 1, Bullet 2. Pg. iv Para. 3, Bullet 2. Pg. 24 Para 4 Section 4.9 |
| S3-MR-140 | Performance | Sentinel-3 shall provide Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances over land | RD-54, RD- 181, RD-56 Table 4, | Section 4.3 Pg. 34 Para. 2 |

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| | | surfaces equivalent to ENVISAT MERIS, AATSR and similar to SPOT Vegetation, together with those from their combination. | Table 5, Table 6 | |
|-----------|-------------|--|---|---|
| S3-MR-150 | Performance | Sentinel-3 shall provide ocean surface topography measurements (SSH, Hs, and surface wind speed) exceeding the level of quality of the ENVISAT RA-2 altimeter system. | RD-52, RD-181, RD- 56, Table 3, Table 4, Table 5, Table 6 | Pg. iv Para. 1, Bullet 1. Section 4.5.1 Section 4.5.4 Section 4.7 |
| S3-MR-160 | Performance | An along track delay-Doppler SAR capability (similar to CryoSat-2 SIRAL) shall be included in the Sentinel-3 altimeter measurement system to provide improved resolution in the coastal zone and sea ice regions. | RD-52, RD- 54, RD-181, Table 3, Table 5, | Section 4.1.3 Section 5.1.2 |
| S3-MR-170 | Performance | Sentinel-3 shall provide VIS and TIR measurements suitable for pre-fire early warning (satellite vegetation indices), active fire detection (Fire Radiative Power); and post-fire monitoring (Burned area mapping) to at least the quality of AATSR on ENVISAT. <i>Note: Fire monitoring is a secondary</i> <i>objective [S3-OB-6] for the Sentinel-3</i> <i>mission and shall not drive the system</i> <i>design.</i> | RD-54, RD- 181, RD-56, Table 4, Table 5, Table 6 | Section 4.3 Table 11 Pg. 34 Para. 2 Table 13 Pg. 34 Para. 4 Table 16 |
| S3-MR-180 | Performance | Sentinel-3 shall provide measurements of River and Lake Heights (RLH) for large rivers, their tributaries and lakes to at least the quality of the RA-2 on ENVISAT. | RD-54, RD- 181, RD-56, Table 4, Table 5, Table 6 | Pg. 23, Para. 3 Bullet 3. Section 4.4.2 Section 5.1.2 Para. 1 |

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| | | Note: Inland water monitoring is a secondary objective [S3-OB-6] for the Sentinel-3 mission and shall not drive the system design. | | |
|-----------|----------------------|--|---|---|
| S3-MR-190 | Performance | Sentinel-3 TIR measurements shall be acquired continuously around the satellite orbit (i.e. during day and night time). | RD-52, RD- 54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6 | Section 4.1.2 Para. 1 |
| S3-MR-200 | Performance | Sentinel-3 VIS measurements shall be available for the part of the orbit that covers solar illuminated earth surfaces and acquired only during the sun illuminated part of the orbit (when the Solar Zenith Angle (SZA) < 80°). | RD-52, RD- 54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6 | Section 5.3.1 |
| S3-MR-210 | Signal to noise | The Sentinel-3 topography instrument shall have a noise level better than 3 cm (1-sigma) for a 1 second average. | Section 6.3.3 | Table 14 Pg. 29 Para. 1 |
| S3-MR-220 | Absolute accuracy | The Sentinel-3 topography instrument range accuracy shall allow the recovery of meso-scale circulation signals. As a starting point, the absolute range determination accuracy shall be $0.1 - 1$ m. | Section 6.3.3 | Pg.22, para. 1, Bullet 1 Section 4.6 |
| S3-MR-230 | Performance | The Sentinel-3 altimeter shall be capable of operating in a low resolution mode (LRM) over the open ocean and a high resolution mode (HRM) (~300 m along track resolution) over sea ice and in coastal zones. | RD-52, Table 3, Table 5 | Section 5.1.2 |

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| S3-MR-240 | Performance | The Sentinel-3 altimeter instrument shall acquire data over sea, inland water and ice surfaces. | RD-52, RD- 54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6, | Section 5.1.2 |
| S3-MR-250 | Performance | The Sentinel-3 altimeter shall be capable of providing measurements of sea ice thickness. | RD-52, Table 3, Table 5 | Section 5.1.2 |
| S3-MR-260 | Spectral sampling | The Sentinel-3 MWR system shall have a minimum of two passive channels operating in Ka- and Q-band. An option to use a 3-frequency MWR will depend on the accommodation of a larger antenna. | RD-52, Table 3, Table 5. | Section 5.1.3 Section 5.2 |
| S3-MR-270 | Performance | The Sentinel-3 MWR shall be capable of providing a wet tropospheric delay correction for the altimeter with an accuracy of 2 cm (goal 1 cm) rms. | Section 6.3.3 | Section 5.2.2 |
| S3-MR-280 | Performance | Sentinel-3 shall include a precise 3-d positioning instrument to reduce orbit errors to an accuracy goal of 2 cm residual orbit accuracy after offline processing (2-3 cm threshold) required to reach altimeter accuracy targets. Because of its significant contribution to precise orbit determination, and to provide a fail-safe back up solution in case of failure of other on-board orbit positioning systems, a laser retro-reflector shall be included as a minimum requirement. | RD-53, RD- 65 | Section 5.4 |

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| S3-MR-290 | Performance | The Sentinel-3 altimeter threshold absolute accuracy for σ° shall be better than 1 dB, with a resolution of better than 0.1 dB. | Section 6.3.3 | Section 5.1.4 Para. 3. |
|-----------|-------------|--|-----------------------------|---------------------------------|
| S3-MR-300 | Performance | The Sentinel-3 altimeter drift in σ° shall be characterised with an accuracy of better than 0.2 dB with a goal of 0.1 dB over a period of 1 year. | Section 6.3.3 | Section 5.1.4 Para. 3. |
| S3-MR-310 | Performance | The Sentinel-3 altimeter tracker bias shall be minimised by tuning performance of the tracking algorithm. Tracking bias over the ocean is proportional to the Hs, and shall not be higher than a goal of 0.25 cm (1 cm threshold). | RD-52, Table 3, Table 5. | Section 5.1.4 Para. 2 |
| S3-MR-320 | Performance | The Sentinel-3 altimeter derived Hs threshold accuracy shall be 20 cm or 4 % of Hs for 1 second averages over a range of 1 - 20 m. A goal of 5 cm or 1 % (whichever is smaller) is expected after STC/NTC data processing (retracking). | Section 6.3.3 | Section 4.7, Para. 1 Table 6 |
| S3-MR-330 | Performance | The Sentinel-3 altimeter derived wind- speed accuracy shall be better than 2 m s ⁻¹ for 1 sec. averages over a range of 3 and 20 m s ⁻¹ . A goal of 1.5 m s ⁻¹ accuracy is expected from improved ground processing. | Section 6.3.3 | Table 6 |
| S3-MR-340 | Performance | Sentinel-3 shall participate in rigorous inter-satellite calibration and external calibration activities to correct for | RD-52, RD-41 | Pg. 30, Para. 1 |

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| | | calibration biases, and maintain long- term uniform performance over the | | |
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| | | satellite operational lifetime. | | |
| S3-MR-350 | Performance | The Sentinel-3 near infrared and thermal infrared channels shall be optimised for SST retrieval. <i>Note: Active Fire, IST and LST</i> <i>requirements shall be considered in the</i> <i>design but shall not drive the system</i> <i>design or reduce the quality of the SST</i> <i>retrievals.</i> | RD-54, RD- 181, RD-56, Table 4, Table 5, | |
| S3-MR-360 | Performance | Building on ENVISAT AATSR heritage, Sentinel-3 shall provide an along-track view (bi-angular observation) for VIS/nearer and TIR channels to make the atmospheric correction for SST products robust to changes in aerosol and water vapour loading and to allow aerosol corrections/retrievals over land surfaces. | | Pg. 44, Para. 2 Pg. 44, Para. 3 Section 4.5.2 Section 5.3.3 |
| S3-MR-370 | Performance | The Sentinel-3 SLST instrument on board calibration system shall follow the principles used by ENVISAT AATSR (i.e. two reference black body cavities and a visible channel calibration system). | RD-54 | Pg. 22 Bullet 2 Section 4.5.2 Section 5.3 Para. 1 |
| S3-MR-380 | Performance | The Sentinel-3 SLST instrument shall make simultaneous and co-incident measurements with ocean colour measurements. | RD-54, | Pg. iv, Para. 1 Bullet 3 Section 5.3 Para. 1 Section 4.5.3 |
| S3-MR-390 | Performance | The Sentinel-3 SLST instrument shall have stringent sub-pixel co-registration with OLC measurements. | Section 5.8 | Pg. 31, Para. 3 |

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| S3-MR-400 | Performance | Sentinel-3 shall provide SST measurement capability to at least the quality of AATSR on ENVISAT: SST shall be accurate to < 0.3 K @ 1 km spatial resolution and with improved swath coverage. | RD-52, RD-67, Table 3, Table 5 | Pg. iv, Para. 1 Bullet 3 |
|-----------|-------------|--|---|---|
| S3-MR-410 | Performance | Space time coverage requirements for the Sentinel-3 SLST instrument shall take second priority with respect to absolute accuracy requirements. | Section 5.8 | Pg. 32, Para. 2 Section 5.3.3 |
| S3-MR-420 | Performance | Sentinel-3 shall be able to measure Land Surface Temperature (LST) to an accuracy of < 1 K with a resolution of 1 km at nadir. This capability shall not reduce the quality of the SST retrievals. | RD-118, Table 4, Table 5, Table 6, Table 6 | Table 13 Pg. 35 Para. 3 |
| S3-MR-430 | Performance | Sentinel-3 shall be able to measure Ice Surface Temperature (IST) to an accuracy of 10 % with a resolution of < 5 km (1 km goal) at nadir. This capability shall not reduce the quality of the SST retrievals. | Table 3, RD- 118, | Pg. 2, Para. 1 Pg.11 Para. 1 Pg.12 Para. 1 Pg. 16 Para. 3 Pg. 25 Para. 4 Section 4.5.2 Para. 2 Section 4.10 |
| S3-MR-440 | Performance | Sentinel-3 shall be capable of measuring Lake water Surface Temperature (LWST). This capability shall not drive the mission design. | RD-54, RD- 181, RD-56 | Pg. 24 Para. 3 Pg. 25 Para. 4 |
| S3-MR-450 | Performance | Sentinel-3 shall be capable of measuring Fire Radiative Power and fire burned area using infrared measurements over land. This capability shall not drive the mission design. | RD-181, RD- 56, Table 4, Table 5, Table 6 | Table 13 Pg. 35, Para 3 |

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| S3-MR-460 | Performance | The Sentinel-3 OLC instrument shall be optimised for measurement of water quality and ocean colour parameters including open ocean (case-1) and coastal shelf (case-2) waters, inland seas and lakes. | RD-52, RD- 54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6, | Pg. 22, Bullet 4 Table 7 Pg. 31 Para. 1 |
|-----------|------------------------|---|--|--|
| S3-MR-470 | Performance | The Sentinel-3 OLC instrument shall include a precise internal calibration system to maintain instrument calibration and stability. | RD-52 | Section 5.3.2, Bullet 2, 3 and4. |
| S3-MR-480 | Performance | The Sentinel-3 OLC instrument shall improve over ENVISAT MERIS by mitigating the impact of sun-glint over the ocean. | RD-52 | Pg. iv, Para. 2 Bullet 2 Section 5.3.1, Para. 1 |
| S3-MR-490 | Geographic Coverage | Sentinel-3 topography measurements shall be acquired globally in low resolution mode (to support measurements of RLH and production of altimeter DEM). High resolution mode data shall be acquired in the coastal zone, sea ice regions and other selected areas required by GMES users. | RD-52, RD-54, RD- 181, RD-56, Table 3, Table 4, Table 5, Table 6, | Section 5.1.2 Pg. 38 Bullet 1 and 2 |
| S3-MR-500 | Geographic Coverage | Sentinel-3 Visible, Near Infrared, Short- Wave Infrared, and Thermal Infrared radiances shall have complete global coverage including oceanic, coastal waters and inland seas, and ice infested waters. | RD-52, RD- 54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6, | Pg. 4 Para. 2, Bullet 1 |

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| S3-MR-510 | Geographic Coverage | Sentinel-3 Visible, Near Infrared, Short- Wave Infrared, and Thermal Infrared radiances shall have complete global coverage over all land surfaces including lakes, rivers, islands and ice sheets. | RD-54, RD- 181, RD-56, Table 4, Table 5, Table 6, | Section 3.7.4 Pg. 21 Para. 1 Table 5 Section 4.1.2 Section 4.3 Section 5.3.4 |
|-----------|-------------------------|---|--|---|
| S3-MR-520 | Geographic Coverage | Sentinel-3 Ice Surface Temperature (IST) products shall have complete global coverage over ice covered surfaces including oceanic, coastal waters and inland seas. | RD-52, RD- 181, RD-56, Table 3, Table 5, | Pg. 16, Para.3 Pg. 25, Para. 4 Pg. 27, Para. 3 Section 4.10 |
| S3-MR-530 | Geographic Coverage | Sentinel-3 LST and inland Lake Water Surface Temperature (LWST) products shall have complete global coverage over land covered surfaces. | RD-54, RD- 181, RD-56, Table 4, Table 5, Table 6, | Pg. 23, Para. 2, Bullet 5 Pg. 23, Para. 3, Bullet 2 and 3 Pg. 25, Para. 2 |
| S3-MR-540 | Geographic Coverage | Sentinel-3 SST and, ocean colour products shall have complete global coverage over oceanic, coastal waters, rivers and their tributaries, and inland seas. | RD-52, RD- 181, Table 3, Table 5, | Pg. iv, Para. 1 and Bullets 2, 3 and 4 Pg. iv, Para. 2 and Bullet 3 Table 5 (Biophysical parameters) Section 4.9 Table 10 |
| S3-MR-550 | Geographic Coverage | Sentinel-3 Fire monitoring products shall have complete global coverage over all land surfaces. | RD-54, RD- 181, RD-56, Table 4, Table 5, | Section 3.7.4 Table 5 |
| S3-MR-560 | Geometrical Coverage | Sentinel-3 Visible, Near Infrared, Short- Wave Infrared, and Thermal Infrared radiances shall have complete global | RD-75, Table 3, Table 5, Table 6, | Table 8 Table 10 |

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| | | coverage every 1 to 3 days over oceanic and coastal waters. | | |
| S3-MR-570 | Geometrical Coverage | Sentinel-3 Visible, Near Infrared, Short- Wave Infrared, and Thermal Infrared radiances over land and ice surfaces shall have complete global coverage in 1 (goal) to 2 days. | RD-54, RD- 53, RD-117, RD-75, RD- 98, RD-99, RD-100, RD- 101, RD-88, Table 4, Table 5, Table 6 | Section 4.10 Section 4.11 Table 11 |
| S3-MR-580 | Geometrical Coverage | Sentinel-3 land products shall have complete global coverage in ≤ 2 days at the equator. | RD-54, RD- 117, RD-75, RD-98, RD- 99, RD-100, RD-101, RD- 88, Table 4, Table 5, Table 6, | Section 4.11 Table 11 |
| S3-MR-590 | Geometrical Coverage | Sentinel-3 SST and ocean colour products shall have complete global coverage every 2-3 days at the equator. | RD-53, RD- 75, Table 3, Table 6, | Section 4.8 Table 8 Section 4.9 Table 10 |
| S3-MR-600 | Geometrical Coverage | Sentinel-3 topography products shall provide global ocean coverage every 3-10 days optimised with complementary altimeter missions to deliver maps of SSH at 25-50 km resolution. | RD-75, Table 3, Table 5, Table 6 | Section 4.6 Pg 29. Para. 1 Table 6 |
| S3-MR-610 | Performance | The Sentinel-3 mission shall launch a second satellite as soon as possible following the launch of the first satellite. <i>Note: ideally this should be within 12-18</i> | RD-52 | Pg. iv, Para. 2 Bullet 6 Section 5.5 |

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| | | months of the first satellite. | | |
| S3-MR-620 | Instantaneous coverage | Sentinel-3 Visible, Near Infrared, Short- Wave Infrared, and Thermal Infrared radiances shall have co-located and simultaneous coverage. | RD-75, Table 3, Table 5, Table 6, | Pg. iv, Para. 1 Bullet 3 Section 5.3 Pg. 24, Para. 3 |
| S3-MR-630 | Instantaneous coverage | Sentinel-3 Visible, Near Infrared, Short- Wave Infrared, and Thermal Infrared radiances shall have a wide swath width >1000 km. | RD-52, RD- 54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6 | Pg. 23, Para. 1 Pg. 32, Para. 2 Pg. 33, Para. 1 Section 5.3.3 |
| S3-MR-640 | Instantaneous coverage | Sun glint conditions for the Sentinel-3 visible channels shall be mitigated to the largest extent possible by choice of instrument pointing and final orbit configuration. | RD-52, Table 3 | Section 5.3.1 |
| S3-MR-650 | Instantaneous coverage | Sentinel-3 topography measurements shall be acquired within the swath of optical measurements to facilitate synergy application. | RD-52 | Pg. 22, Bullet 3 (fluxes need wind and SST) Pg. 24, Para. 3 Section 5.1.1 |
| S3-MR-660 | Number of satellites | The use of multiple satellites and/or merging of several missions is required to achieve an effective revisit time of 1 day over land and coastal regions required by GMES users. | RD-42, RD- 52 RD-55, Table 3, Table 5, Table 6. | Section 5.5 |
| S3-MR-670 | Orbit | The Sentinel-3 orbit shall be optimised with respect to other planned altimeter- bearing missions. The aim is to measure coherent mesoscale ocean structures with a track separation at the equator of ~80 - 150 km. | RD-52, RD- 65 | Section 4.2 Section 5.1.1 |

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| S3-MR-680 | Orbit | Sentinel-3 shall use a high inclination orbit for optimal coverage of ice and snow parameters in high-latitudes, coverage of the European shelf Seas and merging with complementary altimeter missions. | RD-52, Table 3, Table 5 | Pg. iv, Para. 2, Bullet 1 Pg. 22, Bullet 1 Pg. 24, Para. 1 and Para 2 Pg. 25, Para 2 Section 4.6 |
|-----------|-----------------------|---|--|--|
| S3-MR-690 | Orbit | The Sentinel-3 orbit shall be a polar sun- synchronous orbit with a descending node equatorial crossing time similar to ENVISAT. The final choice of orbit shall consider the Solar Zenith Angle for ocean colour measurements, the impact of sun glint, diurnal surface ocean thermal stratification, morning haze and cloud- cover on optical measurements. | Table 3, Table 4, Table 5, Table 6 | Pg. iv, Para. 2 Bullet 2 Section 5.1.1 Section 5.3.1 |
| S3-MR-700 | Orbit | The Sentinel-3 threshold performance for NRT orbit determination shall be 10-20 cm, with a goal of 2 cm rms. residual orbit accuracy after offline processing. | Soction 5 7 | Table 14 Section 5.4, Para. 2 |
| S3-MR-710 | Orbit | High accuracy orbit data shall be delivered for use by the altimeter system in ≤ 2 days (goal) and ≤ 5 days (threshold). | RD-53, RD- 65, RD-52 | Pg. 36, Bullet 3 and 4 Section 5.4 |
| S3-MR-720 | Spatial resolution | Sentinel-3 topography measurements over the open ocean shall have an along track sample characteristics as follows: NRT/STC NTC <10 | RD-52, Table 3, Table 5 | Section 4.6 Section 4.7 Table 6 |

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| S3-MR-730 | Spatial resolution | The Sentinel-3 altimeter measurements shall provide sufficient along-track resolution over inland rivers, their tributaries and, lakes although this shall not be a mission driver. | Table 4, Table 5, Table 6 | Section 4.4.2 |
| S3-MR-740 | Spatial resolution | Sentinel-3 surface topography measurements shall have enhanced along- track resolution (<300 m) surface topography measurements over relatively flat ice surfaces and in ice-covered and ice free coastal waters. | Table 3, Table 5 | Pg. 24, Para 2 Section 4.5.1 Table 6 Section 4.10 |
| S3-MR-750 | Spatial resolution | Sentinel-3 SST, IST and LST measurements shall have a spatial resolution of \leq 1000 m at nadir. | RD-52, Table 4, Table 5, | Pg iv, Para. 1, Bullet 2 Section 4.9 Table 10 Table 13 Section 5.3.3 |
| S3-MR-760 | Spatial resolution | Sentinel-3 visible measurements shall have a spatial resolution of \leq 1.2 km over the global ocean and \leq 0.3-0.5 km in the coastal regions at nadir. | RD-52, Table 3, Table 5, Table 6 | Pg iv, Para. 3, Bullet 2 Pg. 22, Bullet 4 Table 8 |
| S3-MR-770 | Spatial resolution | Sentinel-3 land colour measurements shall have a spatial resolution of $\leq 0.3-0.5$ km (threshold) at nadir globally. | Table 3, Table 5, Table 6, | Pg iv, Para. 3, Bullet 2 Pg. 22, Bullet 4 Table 11 |
| S3-MR-780 | Spatial resolution | Sentinel-3 shall provide SPOT vegetation- type land products at a spatial resolution of ≤ 1000 m (0.3 km goal) at nadir. | Table 4, Table 6, | Section 4.11 Table 11 Pg iv, Para. 1, Bullet 4 Pg. 23, Para. 1 |

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| S3-MR-790 | Spatial resolution | Sentinel-3 fire monitoring measurements shall have a spatial resolution of ≤1 km at nadir. | RD-49, Table 4, Table 5 | Section 4.11 Table 13 |
|-----------|------------------------|---|-----------------------------------|---|
| S3-MR-800 | Time of Observation | The observing time of Sentinel-3 ocean and land surface temperature measurements shall be ~10:00 LTAN to be consistent with the ENVISAT AATSR, to minimise the impact of diurnal thermal stratification of the upper ocean layers, the impact of afternoon cloud cover, morning haze and sun glint over the ocean. <i>Note: This requirement maintains the</i> <i>configuration and stability of historical</i> | RD-52, RD- 53, Section 5.14 | Pg. iv, Para. 2 Bullet 2 Section 5.3.1 |
| | | AATSR SST measurements contributing to the SST ECV. | | |
| | | The LTAN observing time of Sentinel-3 ocean colour measurements shall be optimised to maximise the solar elevation and minimise the impact of cloud development, morning haze and sun glint over the ocean. | | Table 8 |
| S3-MR-810 | Time of Observation | Note: Due to the conflicting requirements on the time of observation between ocean colour (10:30-11:30) and SST (10:00 - 11:00), there is a trade off to be performed to determine how multiple Sontinel 3 satellites (a.g. A and B) could | Section 5.9 and 5.14 | Table 10 Table 11 Table 12 Section 5.3.1 |
| | | Sentinel-3 satellites (e.g., A and B) could be configured ensure optimal performance from both the OLC and | | |

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| | | SLST sensors. | | |
| S3-MR-820 | Time of Observation | The observing time of Sentinel-3 land colour measurements shall be optimised to minimise the impact of morning haze and cloud cover. | Sections 5.8, 5.9 and 5.14 | Section 4.11 Table 11 Section 5.3.1 |
| S3-MR-830 | Timeliness | Sentinel-3 Visible, Near Infrared, Short- Wave Infrared, and Thermal Infrared radiances (L1b products) and Altimeter L2 (IGDR type) products shall be available to users in NRT. | RD-52, RD- 54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6 | Section 4.12 |
| S3-MR-840 | Timeliness | Sentinel-3 products for GMES Services shall be made available according to the timeliness requirements described in Table 17 and Table 18. | RD-52, RD- 54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6 | Pg. iv, Para.2, Bullet 4 Section 2 Section 2.1.1, Para. 2 Section 5.4, Para. 2 |
| S3-MR-850 | Spectral sampling | Sentinel-3 OLC instrument Visible, Near Infrared, radiances shall include as a minimum the band spectral characteristics set out in Table 15 taking into account optional bands as follows: A channel at 1.02 microns to improve the existing MERIS atmospheric and aerosol correction capabilities, Additional channels in the O2A spectral region for improved cloud top pressure (height) and water vapour retrieval. | RD-182, Section 5.8 and 5.9 | Section 4.8 Table 8 Section 5.3.2 Table 15 |

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| | | • Other bands may be considered for fluorescence measurement (e.g. 673nm) and to improve land and ocean geophysical retrievals, provided the instrument complexity is not increased. | | |
|-----------|----------------------|---|--|--|
| S3-MR-860 | Spectral sampling | Sentinel-3 SLST instrument Visible, Near Infrared, radiances shall include as a minimum the band spectral characteristics set out in Table 16. | RD-52, RD- 23, Section 5.8 and 5.9 | Section 4.9 Section 5.3.3 Table 16 |
| S3-MR-870 | Spectral sampling | Sentinel-3 SLST and OLC shall use at least one common band for instrument pixel co-registration in overlapping swath regions. | Section 5.8 | Table 11 Table 15 Table 16 Pg. 44, Para. 3 |
| S3-MR-880 | Spectral sampling | Sentinel-3 active fire detection and characterisation capability requires a channel at \sim 3.7 µm and one other at 11 or 12 µm providing continuity to ENVISAT AATSR measurements. <i>Note: These channels shall not drive the mission design or development.</i> | RD-47, RD- 48, RD-49 | Section 4.11 Table 11 Pg. 35, Para. 4 |
| S3-MR-890 | Spectral sampling | For continuity of the SST and ocean colour data sets generated by Sentinel-3, all channels shall have as similar a spectral shape as practicable to those on ENVISAT MERIS and AATSR. | RD-52 | Pg. iv, Para. 1 Bullet 3 and 4 Pg. 25, Para. 3 Section 5.3.4 |
| S3-MR-900 | Spectral sampling | The spectral shape of Sentinel-3 channels shall be known before flight to 5% of their peak response at any wavelength. | RD-182 | Pg. iv, Para. 1 Bullet 3 and 4 Pg. 25, Para. 3 Section 5.3.4 |
| S3-MR-910 | Spectral sampling | The peak out of band response for each of the channels shall be characterised. | RD-23 | Pg. iv, Para. 1 Bullet 3 and 4 Pg. 25, Para. 3 |

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| | | | | Section 5.3.4 |
|-----------|---------------------------|--|------------------------------------|---|
| S3-MR-920 | Spectral sampling | Following ENVISAT MERIS, the OLC instrument shall have the capability to change its band position, band width and gain throughout its lifetime. | RD-182 | Pg. iv, Para. 3 Bullet 2 Pg. 22, Para. 4 Pg. 24, Para. 4 |
| S3-MR-930 | Spectral sampling | The desired spectral resolution for the OLC instrument shall be at least 1.25 nm (MERIS baseline). | RD-182 | Pg. iv, Para. 3 Bullet 2 Pg. 22, Para. 4 Pg. 24, Para. 4 |
| S3-MR-940 | Dynamic range | Sentinel-3 TIR channels shall have a dynamic range optimised for SST retrieval but also allow the retrieval of IST, LWST, LST and cloud top temperature (at least equivalent to ENVISAT AATSR instruments). | RD-52, RD- 23 | Pg. iv, Para. 3 Bullet 2 Table 17 Pg. 25, Para. 2 and 4 Section 4.5.2, Para. 2 |
| S3-MR-950 | Dynamic range | Sentinel-3 VIS channels shall have a dynamic range at least equivalent to ENVISAT MERIS and AATSR instruments. | RD-182, Section 5.9 and 5.19 | Pg. iv, Para. 3 Bullet 2 Section 5.3.2 |
| S3-MR-960 | Radiometric Saturation | Sentinel-3 channels used for snow, cloud and fire monitoring shall not saturate for these targets although this is not a driving requirement. The saturation limit over fire is 750 K (goal). <i>Note: fire measurements are a secondary</i> <i>mission objective and shall not drive the</i> <i>system design S3-OB-6.</i> | Section 5.19 | Pg. 34, Para. 2 Pg. 35, Para 3 Pg. 35, Para 4 (<650 K is wrong) |
| S3-MR-970 | Radiometric Saturation | Sentinel-3 OLC instrument VIS measurements shall be optimised to measure the ocean colour over the open- ocean and coastal zones but shall not (as a | Section 5.9 and 5.19 | Pg. 34, Para. 2 Pg. 42, Para. 1 |

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| | | goal requirement) saturate over bright targets such as clouds and land surfaces, | | | |
| | | throughout its spectral range. | | | |
| S3-MR-980 | Radiometric stability | Sentinel-3 SST measurements shall have a long-term radiometric stability goal of 0.1 K/decade (≤ 0.2 K/decade threshold) for a 5 x 5° latitude longitude area. | RD-23, 58 | RD- | Section 5.3.3 Table 17 |
| S3-MR-990 | Radiometric accuracy | Sentinel-3 infrared channels shall have a radiometric accuracy goal of 0.1 K over a range of 270-320 K traceable to international reference standards. | RD-23 | | Table 17 |
| S3-MR-1000 | Relative radiometric accuracy | Sentinel-3 infrared channels shall have a relative radiometric accuracy of <0.08 K (threshold) with a goal of 0.05 K over a range of 210-350 K expressed as NE Δ T traceable to international reference standards. | RD-23 | | Table 17 |
| S3-MR-1010 | Absolute radiometric accuracy | Sentinel-3 VIS reflectance's at TOA shall have an absolute radiometric accuracy goal of <2 % with reference to the sun for the 400-900 nm waveband and <5% with reference to the sun for wavebands > 900 nm traceable to international reference standards. | RD-182, Section and 5.19 | 5.9 | Section 5.3.2, Bullet 2 (the new requirement qualifies the original requirement as for MERIS) |
| S3-MR-1020 | Relative radiometric accuracy | Sentinel-3 OLC instrument VIS reflectance's at TOA shall have a relative radiometric accuracy threshold of 0.2 % (goal) traceable to international reference standards. | Section and 5.19 | 5.9 | Section 5.3.2, Bullet 3 |
| S3-MR-1030 | Signal to noise | Sentinel-3 OLC instrument VIS channels shall have a high signal to noise specification building on and improving | RD-182 | | Pg. iv, Para. 3 Bullet 2 Pg. 42, Para. 1 Table 15 |

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| | | on MERIS heritage. | | |
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| S3-MR-1040 | Polarization | Sentinel-3 OLC instrument VIS channels shall have a known polarisation error less than 1 %. | RD-182 | Pg. iv, Para. 3 Bullet 2 Section 5.3.2, Bullet 7 |
| S3-MR-1050 | Polarisation | For the SLST instrument, the difference in responsivity between any two orthogonal polarisations shall not be more than 4% for the TIR channels. | RD-23 | Pg. iv, Para. 3 Bullet 2 |
| S3-MR-1060 | Polarisation | For the SLST instrument VIS and SWIR channels, the responsivity variation with plane of polarisation shall be known to better than 7% with a goal of 5%. | RD-23 | Pg. iv, Para. 3 Bullet 2 |
| S3-MR-1070 | Characterisation | For the SLST instrument, the responsivity variation with plane of polarisation shall be known to better than 0.5% for all channels. | RD-23 | Pg. iv, Para. 3 Bullet 2 |
| S3-MR-1080 | Geo-location accuracy | Sentinel-3 shall be designed to ensure geo-location accuracy better than 1.0 rms. of the spatial resolution of the sensor for optical measurements over land and coastal zones and without the need for any Ground Control Points. | Section 5.20 | Pg. 32, Para. 2 Section 5.3.2 Bullet 6 |
| S3-MR-1090 | Geo-location accuracy | Improved geo-location accuracy is possible when using ground control points and Sentinel-3 shall be designed to ensure a geo-location accuracy of better than 0.5 rms. of the spatial resolution of the optical sensor when using ground control points. | Section 5.20 | Pg. 32, Para. 2 Section 5.3.2 Bullet 6 |
| S3-MR-1100 | Inter-channel co-registration | The inter-channel spatial co-registration for Sentinel-3 visible measurements shall be < 0.5 of the spatial resolution of the | Section 5.95.20, Section | Section 5.3.2 Pg. 34, Para. 2 Pg. 42, Para. 1 |

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| | | sensor over the full spectral range (goal of | | |
| | | 0.3 of the spatial resolution of the sensor). | | |
| S3-MR-1110 | Inter-channel co-registration | The inter-channel spatial co-registration for Sentinel-3 SWIR and TIR measurements shall be sufficient to allow these channels to be co-registered with visible channels at higher spatial resolution data. | Section 5.9 | Section 5.3.2 Pg. 34, Para. 2 |
| S3-MR-1120 | Inter-channel temporal co- registration | The co-registration between Sentinel-3 optical images acquired at different times (e.g. from different spacecraft) shall be accurate to 1.0 rms. of the spatial resolution of the sensor. | Section 5.9 | |
| S3-MR-1130 | Inter-channel co-registration | Sentinel-3 OLC channels 442, 490, and 510 nm shall be closely co-registered to avoid errors in blue/green chlorophyll retrieval algorithms. | Section 5.20 | Pg. 42, Para. 1 |
| S3-MR-1140 | Inter-channel co-registration | Sentinel-3 OLC channels 620 and 665 shall be co-located and have as little difference as possible in the atmospheric paths to minimise errors in the atmospheric correction procedures. | Section 5.9 | Pg. 42, Para. 1 |
| S3-MR-1150 | Geo-location accuracy | Sentinel-3 shall be designed to ensure sufficient geo-location accuracy of topography measurements in the coastal and ice zones and for inland water (river and lake) monitoring applications. | Section 5.9 | Section 4.4.2 Section 5.1.2 |
| S3-MR-1160 | Calibration | The Sentinel-3 instrument payload shall be characterised and calibrated prior to launch as required to meet the instrument performance requirements specified for each instrument. | RD-52 | Pg. iv, Para. 3, Bullets 1 and 2 |

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| S3-MR-1170 | Validation | Sentinel-3 measurements on-orbit shall be validated to demonstrate conformance to GMES user requirements. Operational long-term validation and verification of all data products throughout the mission lifetime is required to monitor product uncertainty estimates. | RD-52, RD- 54 | Pg. 4, Bullet 3 Section 4.12 Section 4.4.1, Para. 2 |
| S3-MR-1180 | Service Da Products | Sentinel-3 shall provide data products required by GMES services. A non- exhaustive list of high-priority products from Sentinel-3 is provided in Table 17. A non-exhaustive list of additional products from Sentinel-3 is provided in Table 18 | RD-52, RD- 54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6 | Pg. iv, Para. 1, Bullet 4 Pg. iv, Para. 2, Bullet 4 Table 2 Table 3 Table 4 Table 5 Section 4 Table 6 Table 7 Table 8 Table 9 Table 11 Table 13 |
| S3-MR-1190 | Service Da Products | uncertainty estimates. | Table 3, Table 5, Table 6 | Pg.4, Para. 2 (data assimilation systems require uncertainty estimates for all data values) Section 4.1.2 Section 4.4.1, Para. 1 Pg. 20, Para. 1 (revision of data requirements required) Pg. 43, Para. 3 |
| S3-MR-1200 | Service Da Products | a Sentinel-3 shall provide River and Lake Hydrology (RLH) (e.g. lake area, lake | | Pg. iv, Para. 2 Bullet 4 Pg. 23, Para. 2, Bullet 5 |

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| | | | height differences from reference height, lake volume change) and River and Lake Altimetry (RLA, containing individual re- tracked radar echo waveforms) products shall be delivered to the hydrological services in a timely and operational manner. <i>Note: These products shall not drive the</i> mission design | RD-56, Table 3, Table 4, Table 5, Table 6 | Pg. 23, Para. 3 Bullet 3 Section 4.4.2 Section 5.1.2 Section 3.7.4 (floods) |
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| S3-MR-1210 | Service Products | Data | <i>mission design.</i> Sentinel-3 shall provide global coverage atmospheric aerosol products that minimise differences between retrieval algorithms over land and over ocean surfaces. Products shall make full use of S3 optical channels and dual view capability. <i>Note: These products shall not drive the</i> <i>mission design.</i> | 148, RD-52, | Section 4.4.1 Section 5.3.5 |
| S3-MR-1220 | Service Products | Data | Sentinel-3 shall provide data products in acceptable formats used by operational NOP and NWP systems (e.g., netCDF, L2P, BUFR). | RD-52, RD- 181, RD-56, Table 3, Table 5 | Pg. iv, Para. 2 Bullet 4 Section 4.1.2 |
| S3-MR-1230 | Service Products | Data | Sentinel-3 data Level-0 products shall be archived adhering to good data stewardship principles for use in long term climate monitoring studies. | RD-52, RD- 54, RD-181, RD-56, Table 3, Table 4, Table 5, Table 6 | Pg.3, Para. 2 Pg.6, Para. 4 Section 2.3.3 Bullet 2 Section 3.4.3 Table 13 (GCOS Systematic Observation Requirements for Satellite-Based Products for Climate) |

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| S3-MR-1240 Service Products | Data | Access to Sentinel-3 L1b altimeter high resolution echo waveform data shall be provided to users on request to allow necessary regional development of RLH, and coastal altimetry products including better validation and uncertainty estimation. | Section 3.3.3, 3.2.35.7 | Section 4.7, Para. 1 Section 4.4.2 (tracking) Section 5.1.2 |
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End of Sentinel-3 Mission Requirements Traceability Document.

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