GLOBAL MONITORING FOR ENVIRONMENT AND SECURITY

THE COPERNICUS POD SERVICE

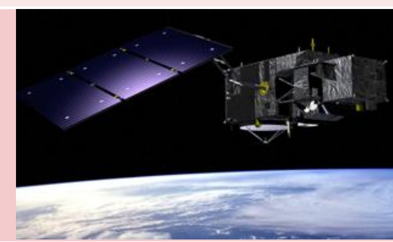
COSPAR 2018, 16th July; PASADENA, USA

Jaime Fernández Sánchez / GMV
Heike Peter / POSITIM
Pierre Féménias / ESA-ESRIN

COPERNICUS

- **Copernicus** (http://www.copernicus.eu)
  - European Programme for the establishment of a European capacity for Earth Observation:
    - coordinated and managed by EU
    - implemented ESA, EUMETSAT, ECMWF, EU Agencies and Mercator Océan
  - Funding: **4.3 Billons** (2014-2020)
  - Planned for 20 years!
- ESA's Sentinels missions (http://sentinel.esa.int)
  - **Sentinel-1, -2, -3**, -4, -5p, -5, and 6.
  - Several units of each mission (**A/B**, C/D …)

SENTINELS – 1, -2 AND -3

	SENTINEL-1	SENTINEL-2	SENTINEL-3
Altitude	639 km	786 km	814.5 km
Inclination	98.18 deg	98.58 deg	98.65 deg
Mass	2300 kg	1140 kg	1250 kg
Function	Imaging C-band and Synthetic Aperture radars (SAR)	Multi-Spectral Instrument (MSI) from the visible to the shortwave infrared	Radar Altimeter
Launch	S1A: 03/04/2014 S1B: 07/04/2016	S2A: 22/06/2015 S2B: 07/03/2017	S3A: 16/02/2016 S3B: 25/04/2018
POD instruments	2 dual freq. GPS receivers (RUAG)	2 dual freq. GPS receivers (RUAG)	2 dual freq. GPS receivers (RUAG) 1 DORIS receiver 1 LRR
Representation			

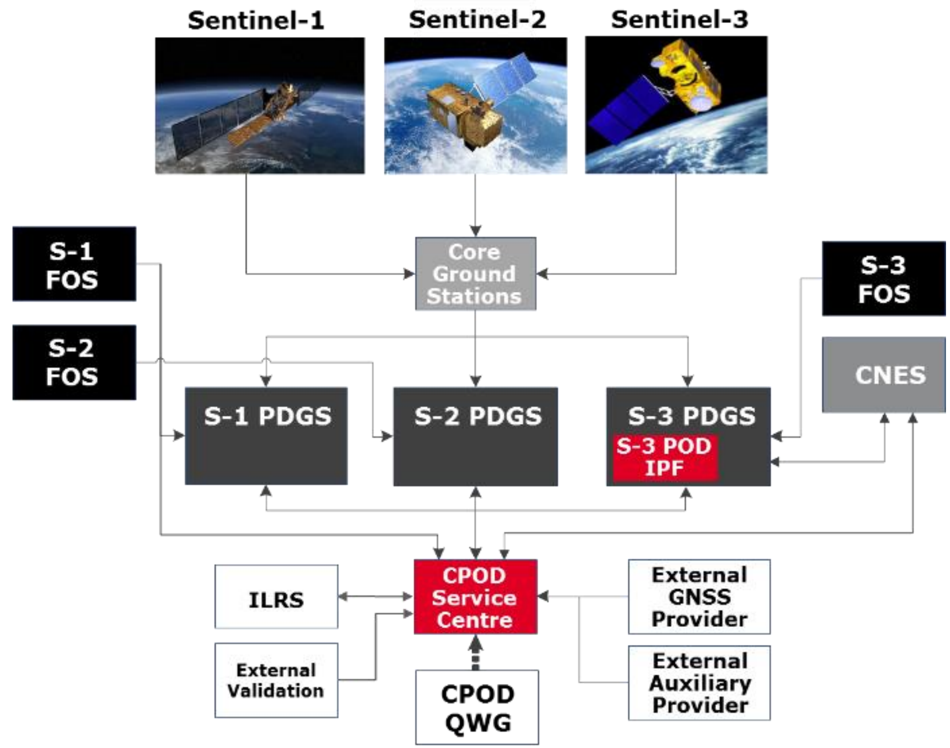
POD REQUIREMENTS

- Categories:
  - NRT – Near Real Time: Between 30 minutes and 3 hours
  - STC – Short Time Critical: The following day
  - NTC – Non Time Critical: Few weeks later
- Criteria:
  - S-1 & S-2: 2D / 3D RMS
  - S-3: radial RMS

Mission	Category	Latency	Orbit Accuracy (RMS)
S-1	NRT	180 min.	10 cm (2D)
	NTC	20 days	**5 cm (3D)**
S-2	NRT (predicted)	90 min. before ANX	3 m (2D)
	NRT	**30 min.**	1 m (3D)
S-3	NRT (S3PODIPF)	**30 min.**	10 cm radial (target of 8 cm)
	STC	1.5 days	4 cm radial (target of 3 cm)
	NTC	25 days	**3 cm radial (target of 2 cm)**

COPERNICUS POD SERVICE

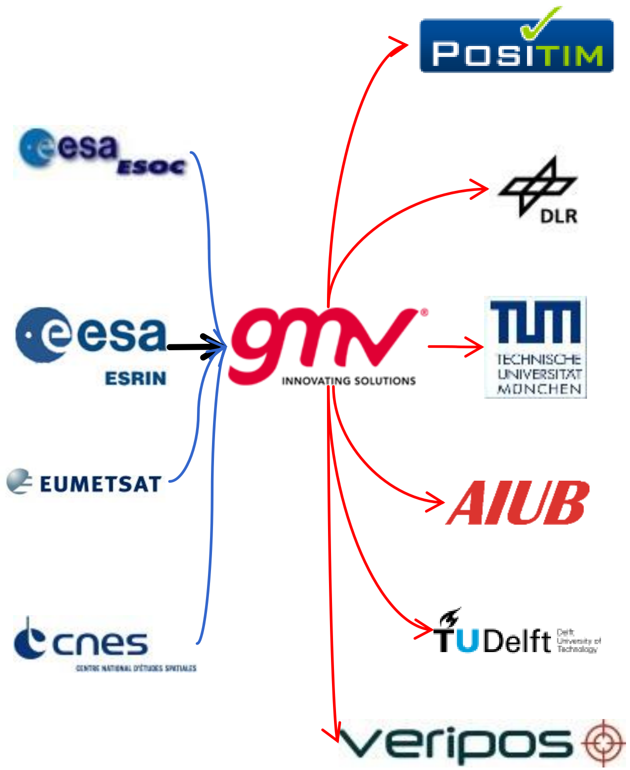
- **Payload Data Ground Segment (PDGS):**
  - Processing the scientific data
  - Provider of GPS and attitude data to the CPOD Service
  - User of the orbits and platform files from the CPOD Service
- **Sentinels Flight Operations Segment (FOS):**
  - Orbits, manoeuvre and satellite mass evolution
  - ESA/ESOC for S1 and S2; EUMETSAT for S3
- **Centre National d'Études Spatiales (CNES):**
  - S-3 orbital and attitude products, DORIS data
- **ILRS - SLR data provider:**
  - International Laser Ranging Service –ILRS- centres
- **External Validation:**
  - AIUB, CLS, CNES, DLR, ESOC, EUMETSAT, TU Delft, TUM, (NASA)
  - provision of independent orbital products
- **External GNSS data Provider (EGP):**
  - VERIPOS; provider of high accurate GPS orbits and clocks products
  - ***magicGNSS***: in-house back-up GPS provider
- **External Auxiliary providers:**
  - Atmospheric gravity models, EOPS and leap seconds, etc.
- **CPOD Quality Working Group (CPOD QWG):**
  - Monitoring the quality of CPOD products
  - Definition of enhancements (algorithms, standards, etc.)



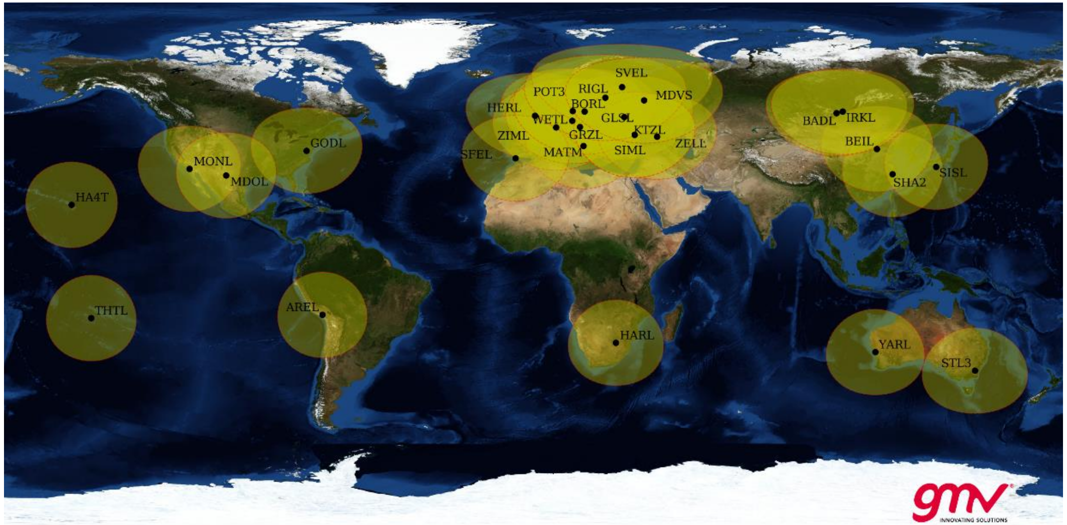
S-3 PDGS

Marine Centre (EUMETSAT)
Land Centre (ESA)

CPOD SERVICE – MEMBERS



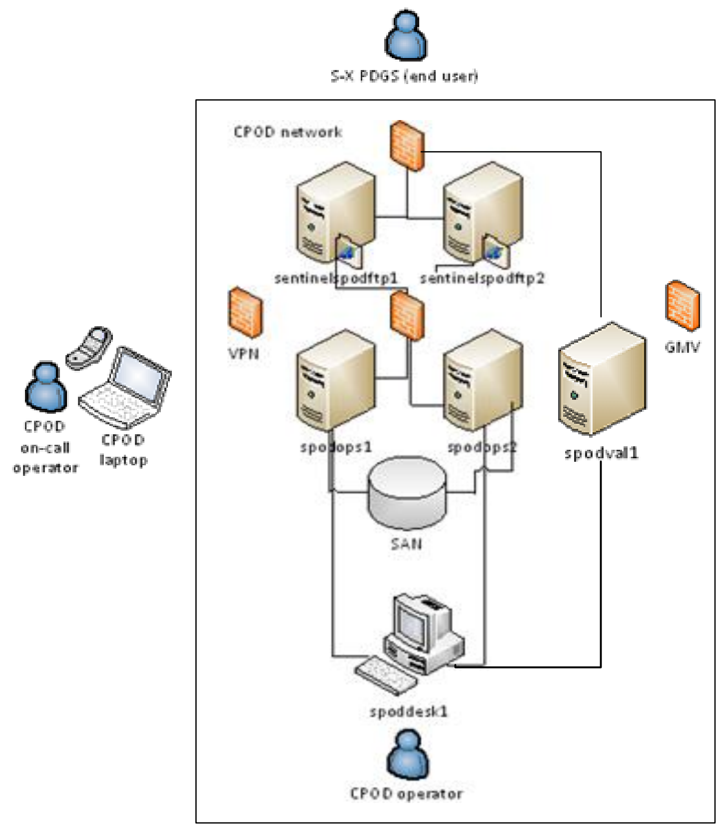
ILRS FOR SENTINEL-3



- ILRS supports Sentinel-3 mission through a network of 29 ILRS stations
  - Only a subset of the ILRS network is allowed to track Sentinel-3 to avoid damaging a visual instrument on-board the satellite
- CPOD generates the Sentinel-3 orbit predictions for supporting ILRS tracking
- The SLR observations provided by ILRS are used for the quality control of the orbits

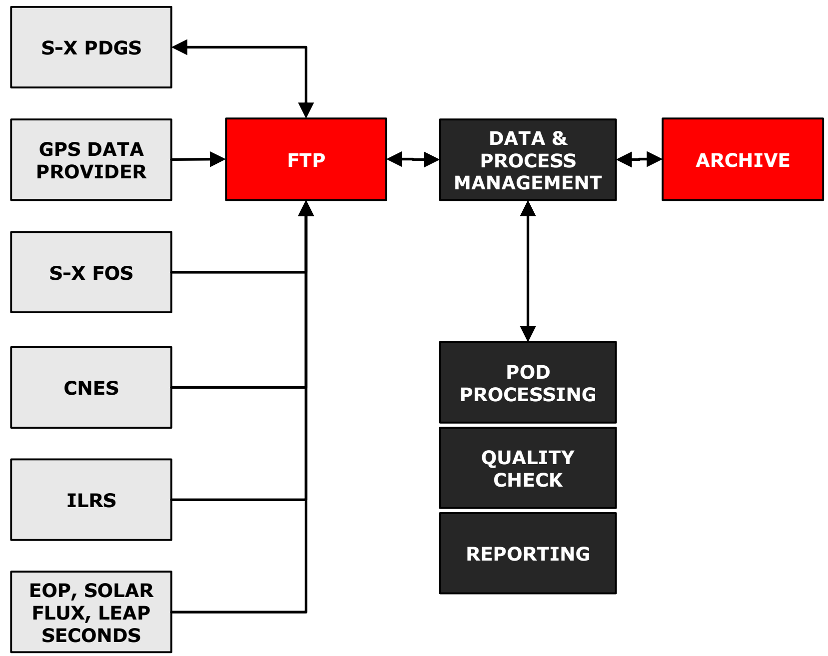
CPOD SERVICE - ARCHITECTURE

- The **operational** environment consists of the following elements:
  - A **redundant ftp** service
  - A **redundant firewall**
  - **Two operational processing servers** process the received data independently, one is the nominal and other act as hot redundant server
  - A **validation processing server**, processing the same data, but with pre-operational SW and configuration
  - Data stored into a **Storage Area Network** (**SAN**) system mounted in RAID 5 to ensure the required low risk levels.
  - Operator **workstations** for upgrades of the system
  - **VPN** service for remote call-in operations



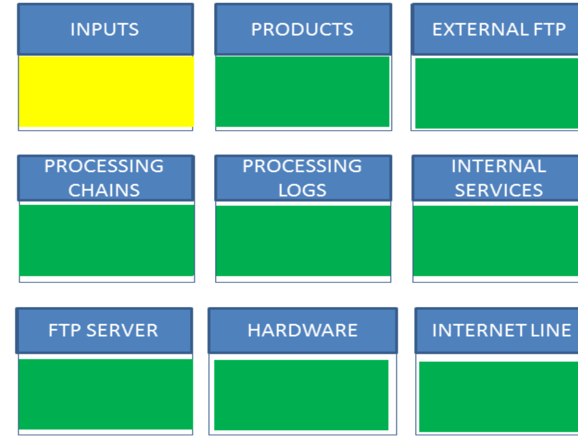
CPOD SERVICE - ARCHITECTURE

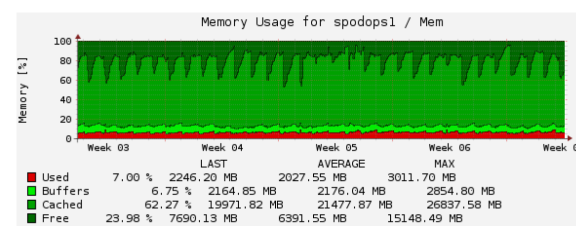
- **Functional components**:
  - **Storage, Reception and Dissemination**: It is composed by an **FTP** (for the reception and dissemination of inputs/producs) and an local **archive** to save all inputs and products generated since the beginning of the mission.
  - **Data & Process Management**: Manages the incoming and outgoing data and the processes that manipulate the data as part of the POD process → crontab + NAPEOS sequence
  - **POD Processing:** The POD SW is NAPEOS.
  - **Quality Check**: Verification on the resulting POD products by means of different orbit comparisons and residuals monitoring.
  - **Reporting**: Generation of periodic reports (PDF) with processing and accuracy information.



CPOD SERVICE - ARCHITECTURE

- **NAGIOS**: System monitoring tool:
  - Control of the **timeliness** and **availability** of inputs and outputs into the FTP server and external FTPs
  - Control of the **processing chains**’ status
  - Control of **internal network** and FTP status
  - Control of **hardware devices**: servers, FTPs, networks lines, firewalls, …
  - Accessible via **Internet**
  - Graphical information of the history of each particular service controlled can be displayed
- **Operations**:
  - 7x24 manned basic operations (anomalies handling, HW replacement, system monitoring)
  - 5x8 engineering
  - on-call POD engineers over weekend
- **Service Level Agreement (SLA):**
  - The CPOD Service has a SLA with ESA to guarantee an agreed service level.





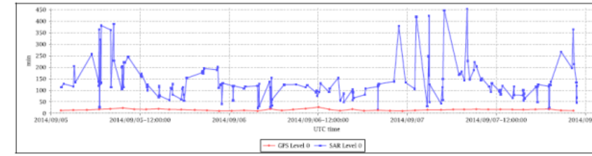
CPOD SERVICE - ARCHITECTURE

- **Reporting**:
  - Automatic generation of **periodic** reports every daily, weekly and cyclic.
  - Quarterly generation of a **Regular Service Review** (RSR) document with a complete evaluation of the quality of service.

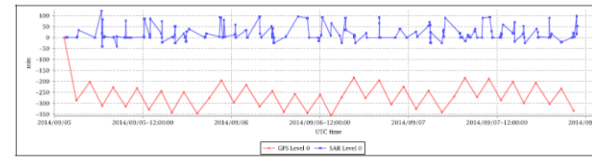
POD Inputs Availability:

Graphics:

Timeliness of inputs.



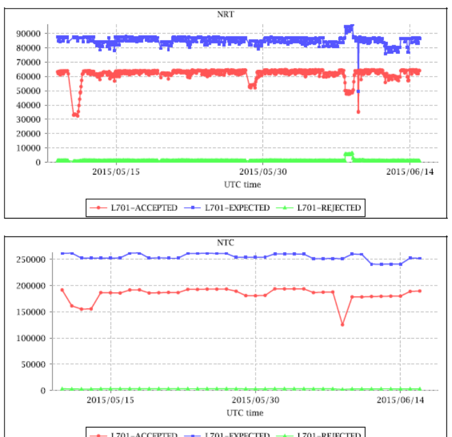
Gaps between inputs.



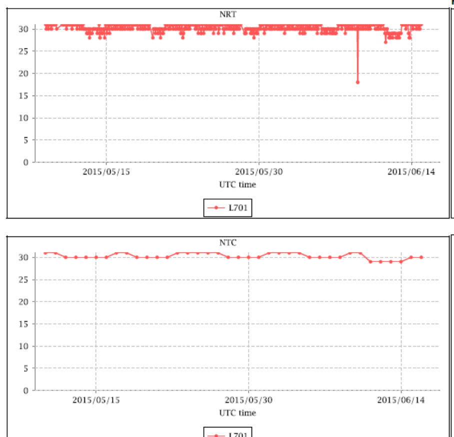
GNSS sensor performance metrics:

Graphics:

Number of observations (accepted/rejected/expected) per receiver.



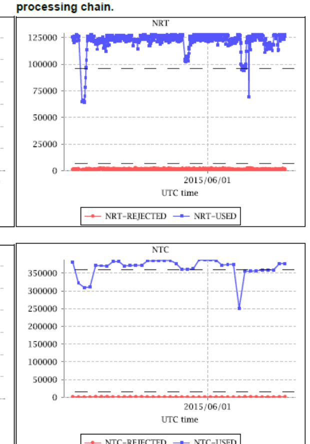
Number of GNSS satellites tracked per receiver.



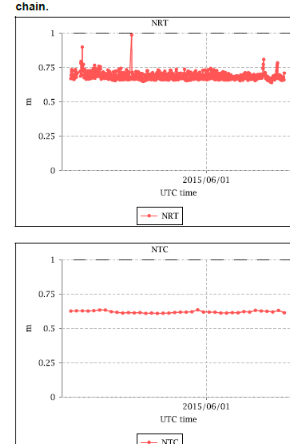
POD Processing Metrics:

Graphics:

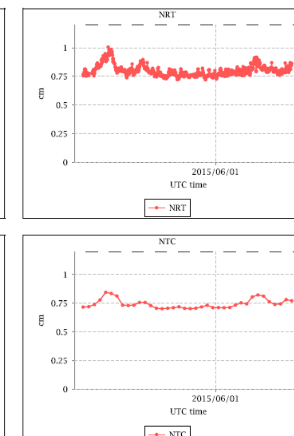
Number of observations (used/rejected) per processing chain.



RMS of pseudorange residuals per processing chain.



RMS of phase residuals per processing chain.



CPOD SERVICE – POD SW

Software	
Name and version	**NAPEOS**
Arc cut	
Arc lengths	32 hours
Handle of Manoeuvers	Manoeuvres are calibrated in the POD process
Handle of Data gaps	Yes
Reference System	
Polar motion and UT1	IERS C04 08
Pole model	IERS 2010 Conventions
Precession/Nutation	IERS 2010 Conventions
Satellite Reference	
Mass and centre of gravity	Variable with input from FOS
Attitude Model	Quaternions
GPS antenna reference point (X,Y,Z)	Documentation
GPS antenna orientation (Euler angles, Z,Y,X)	Documentation
Gravity	
Gravity field (static)	EIGEN.GRGS.RL03.v2 (120x120)
Gravity field (time varying)	drift/annual/semi-annual piece wise linear terms up to degree/order 50
Solid Earth tides	applied (IERS 2010)
Ocean tides	EOT11a (50x50, 106 tidal constituents)
Atmospheric gravity	AGRA (20x20)
Atmospheric tides	Ray-Ponte 2003
Earth pole tide	IERS 2010
Ocean pole tide	IERS 2010
Third bodies	Sun, Moon, Planets DE405

Surface forces and empiricals	
Radiation Pressure model	Box-wing model
Earth radiation	Albedo and Infra-red applied
Atmospheric density model	msise90
Radiation pressure coefficient	1 per arc (loosely constrained to 1.0).
Drag coefficients	10 coefficients per day (loosely constrained to 1.0). 15 coefficients for 32 hours.
1/rev empirical	2 sets per day: in along-track and cross-track direction (with sin/cos signals)
Other empiricals	n/a
GPS measurements	
Relativity	applied (IERS 2010)
Sampling	10 sec
Observations	iono-free linear combinations of phase and pseudo-range measurements
Weight	0.8 m (pseudo-range) / 10 mm (carrier-phase)
Elevation angle cut-off	7 degrees
Down-weighting law	none
Antenna phase-centre wind-up correction	applied
Antenna phase-centre variation	applied
GPS parameters	
Receiver clocks	per epoch, every 10 sec
Receiver ambiguities	estimated (float)
GPS orbits	fixed (IGS finals)
GPS clocks	fixed (IGS finals)

CPOD QWG

- The following centres provides routinely orbital products for orbital validation

	AIUB	CLS	CNES	CPOD	DLR	EUM	ESOC	TUD	TUM
SW	Bernese	GINS / DYNAMO	ZOOM	NAPEOS	GHOST	NAPEOS	NAPEOS	GHOST / GIPSY	Bernese
Process	Kinematic / Red. Dynamic	Red. Dynamic	Red. Dynamic	Red. Dynamic	Kinematic / Red. Dynamic	Red. Dynamic	Red. Dynamic	Red. Dynamic	Kinematic / Red. Dynamic
Sentinels	S1, S2, S3	S3	S3	S1, S2, S3	S1, S2, S3	S3	S1, S2, S3	S1, S2, S3	S1, S2, S3
Data	GPS	DORIS	GPS+ DORIS	GPS (DORIS)	GPS	GPS	GPS (DORIS)	GPS	GPS

(DORIS): Capability to process GPS+DORIS, but not done operationally

- CPOD generates also a combined solution as a weighted mean, which is the same scheme used by IGS with the GPS combined orbits
  - Advantage: A common reference when there is no other techniques (e.g. DORIS, SLR)
  - Limitations: favour similar solutions using same approach (e.g. dynamic vs. kinematic)

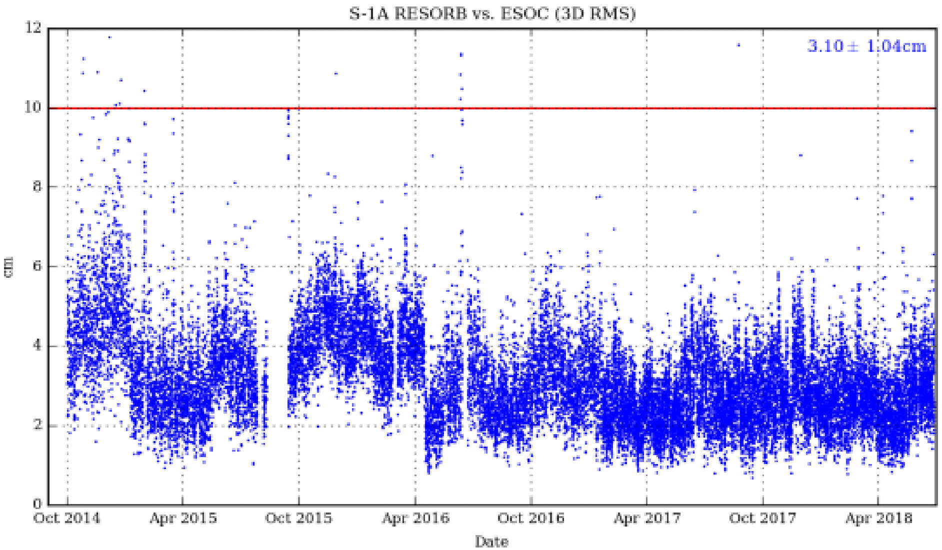
ORBITAL QUALITY CONTROL

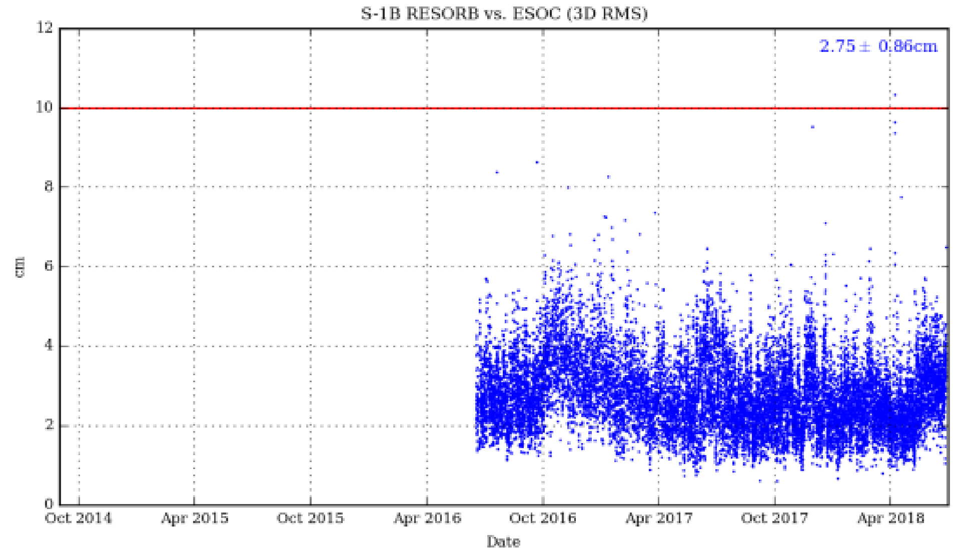
- **Routinely** for all Sentinels: comparison against ESOC solution to assess fulfilment of requirements:
  - Same POD SW: NAPEOS but different versions and set-up
  - Different GPS orbits and clocks
- **Routinely** for S-3:
  - Comparison against CNES solutions:
    - Different POD SW: NAPEOS – ZOOM
    - Different tracking: CPOD (GPS), CNES (GPS, GPS+DORIS)
    - Different GPS orbits and clocks
  - SLR Residuals analysis

ORBITAL QUALITY CONTROL

- **Periodically** (every four months) – Regular Service Review (RSR):
  - Participation of: AIUB, CLS, CNES, CPOD, DLR, EUM, ESOC, TUD, TUM
  - Generation of combined solutions
  - Different comparisons:
    - CPOD vs. all
    - COMB vs. all
    - All vs. all (cross-comparisons)
  - S3: SLR residuals analysis

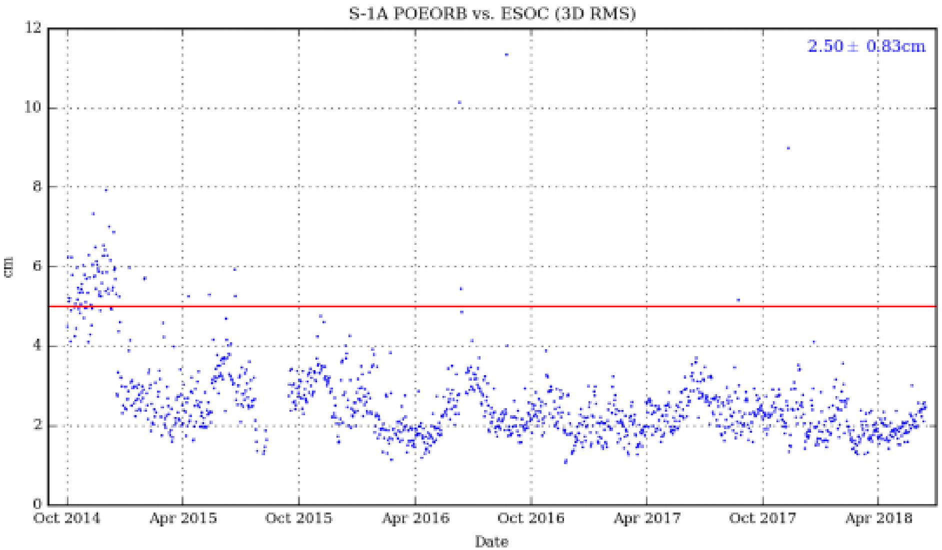
RESULTS – SENTINEL-1 NRT

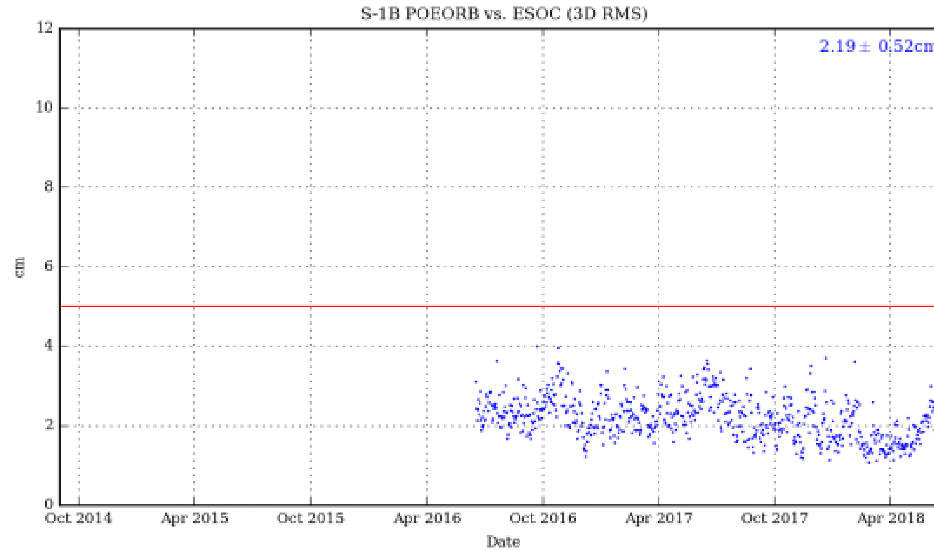




- S-1A (left): Improvement during first year thanks to implementation of IERS 2010
- Mean performance ~ 2.7 – 3.1 cm in 3D RMS (requirement: 10 cm 2D RMS)

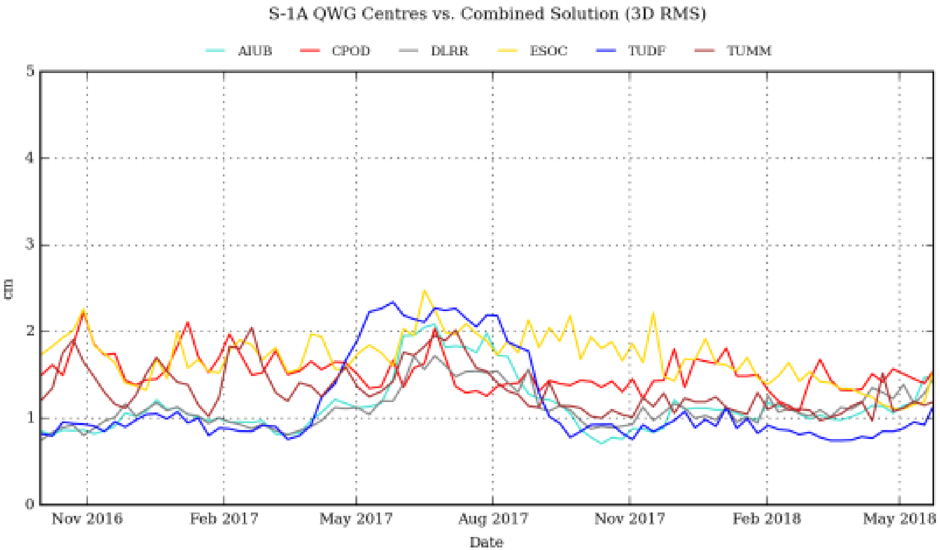
RESULTS – SENTINEL-1 NTC

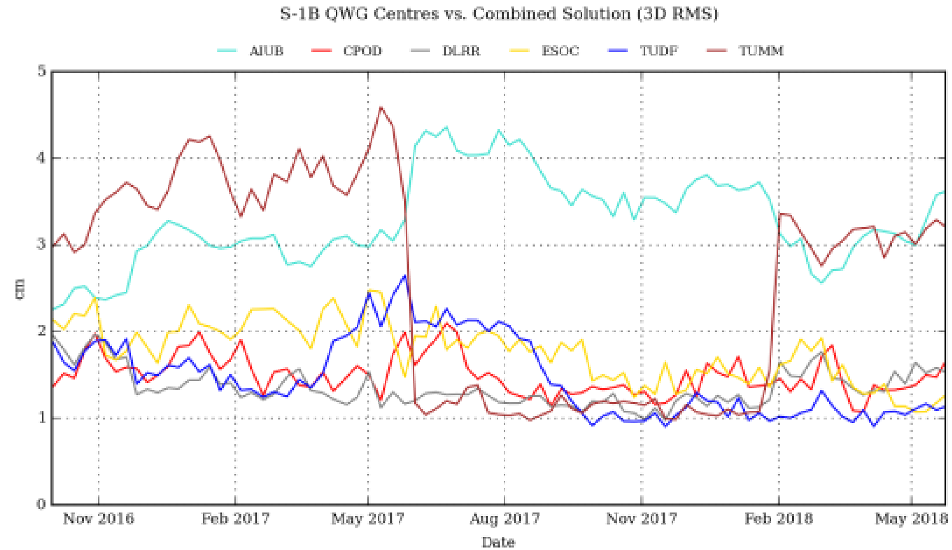




- S-1A (left): Improvement during first year thanks to implementation of IERS 2010
- Mean performance ~ 2.2 – 2.5 cm in 3D RMS (requirement: 5 cm 3D RMS)
- Main difference with NRT is the source of GPS orbits and clocks: NTC is IGS finals

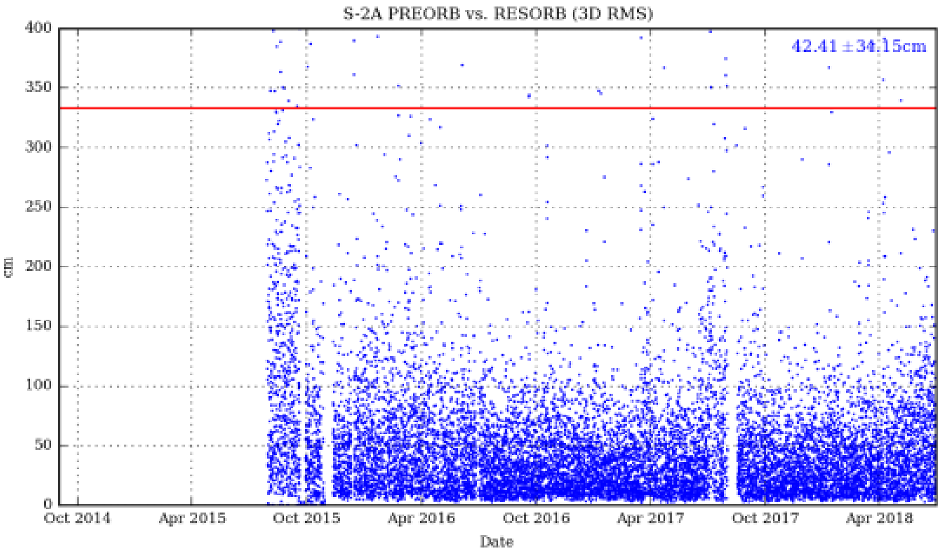
RESULTS – SENTINEL-1 COMB

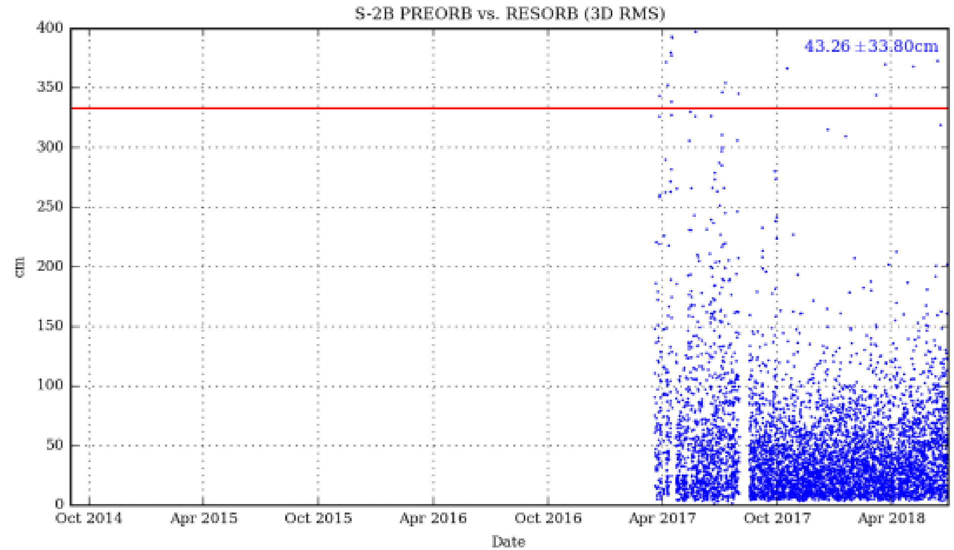




- Differences wrt. a combine solutions. Plots show smoothed differences
- Big jumps are due to configuration changes every ~four months
- Big differences (in particular with S-1B):
  - Incorrect location of center of phase + CoG. In total around 4 cm wrong.
  - However changing the configuration will impact the InSAR processing.

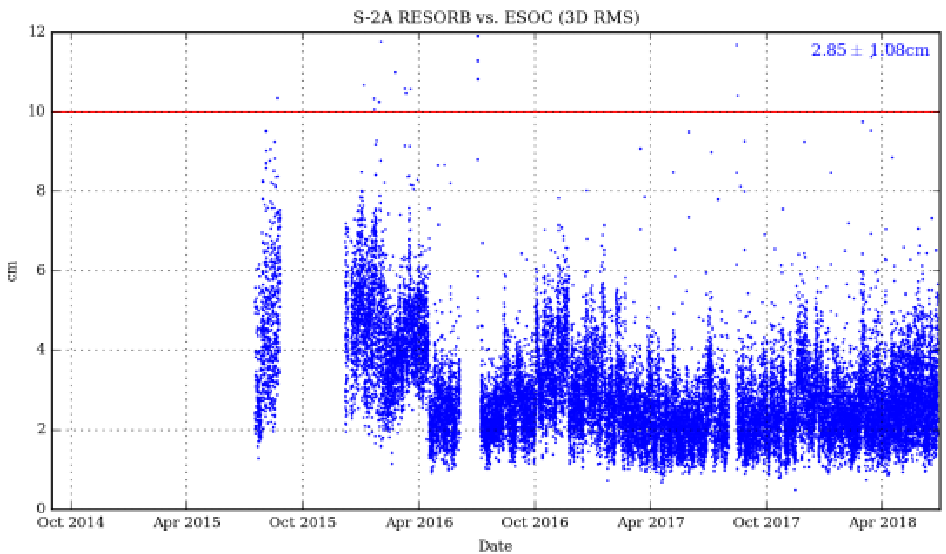
RESULTS – SENTINEL-2 PRE

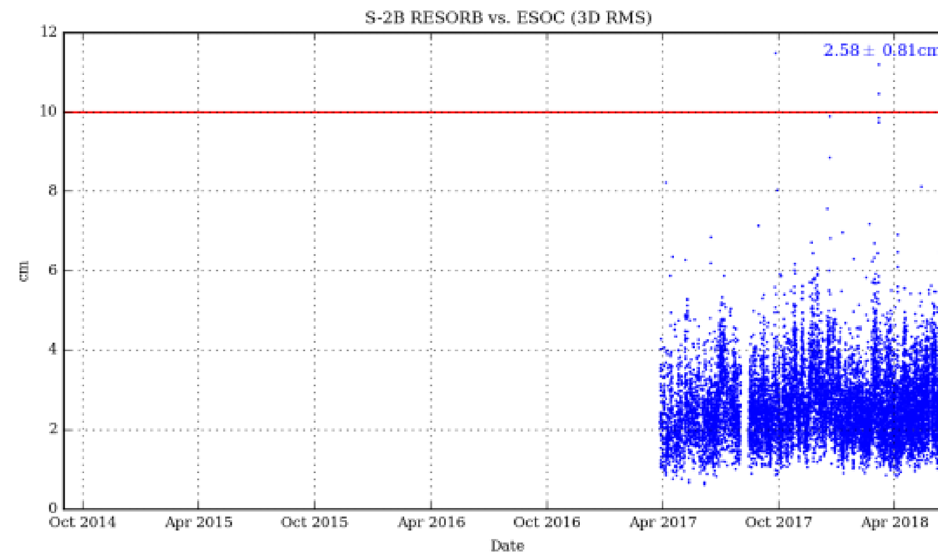




- Predictions to three orbits (~ 5 hours): Uncertainty in drag
- Mean performance ~ < 45 cm in 3D RMS (requirement: 330 cm 3D RMS)

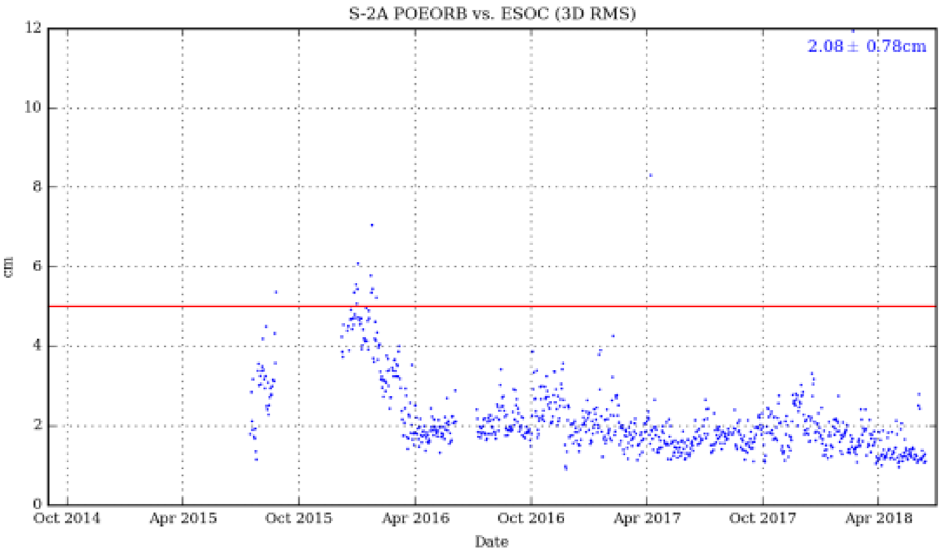
RESULTS – SENTINEL-2 NRT

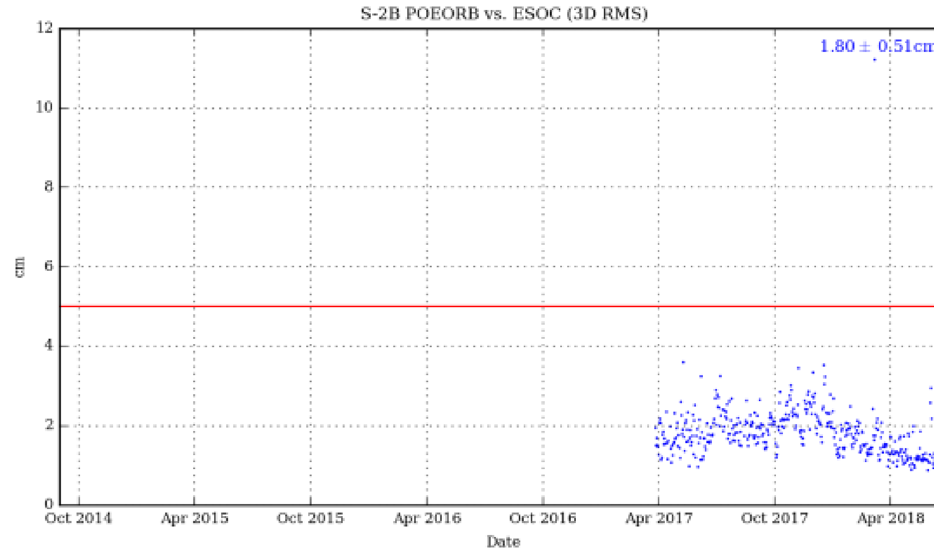




- Mean performance ~ 2.6 – 2.8 cm in 3D RMS (requirement: 100 cm 3D RMS)

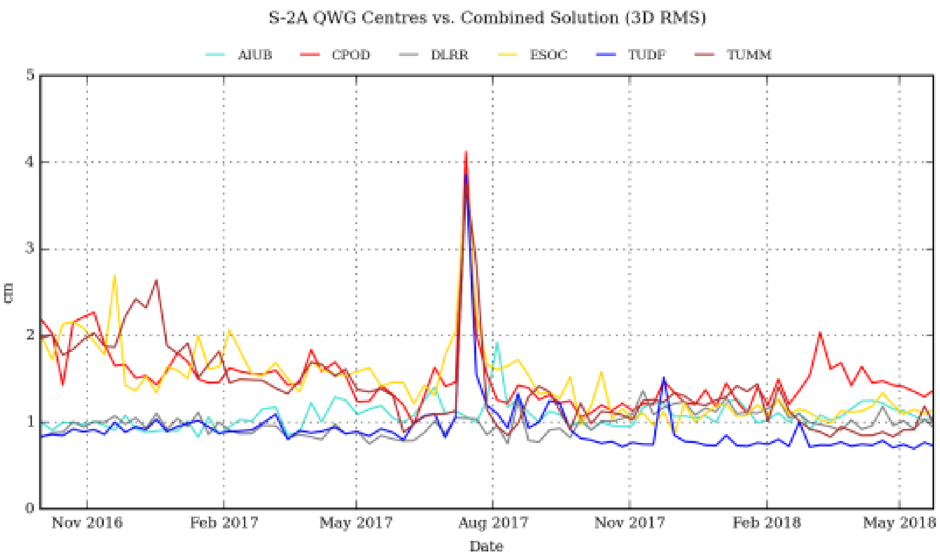
RESULTS – SENTINEL-2 NTC

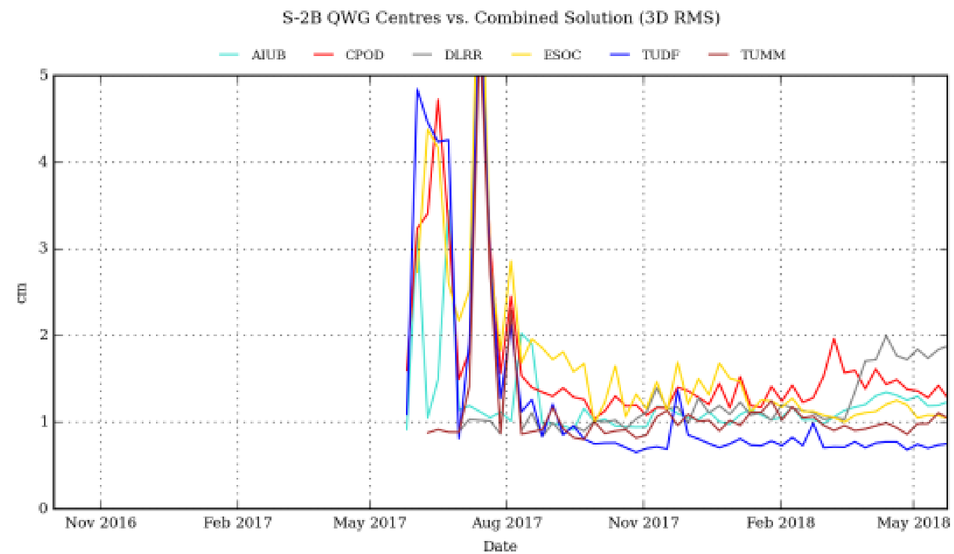




- Mean performance ~ 1.8 – 2.1 cm in 3D RMS (no requirement)
- Main difference with NRT is the source of GPS orbits and clocks: NTC is IGS finals

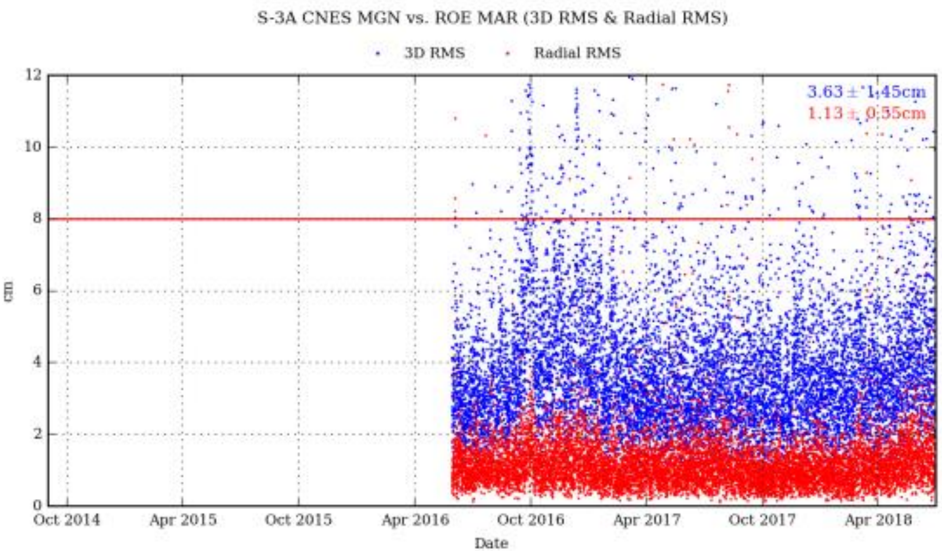
RESULTS – SENTINEL-2 COMB

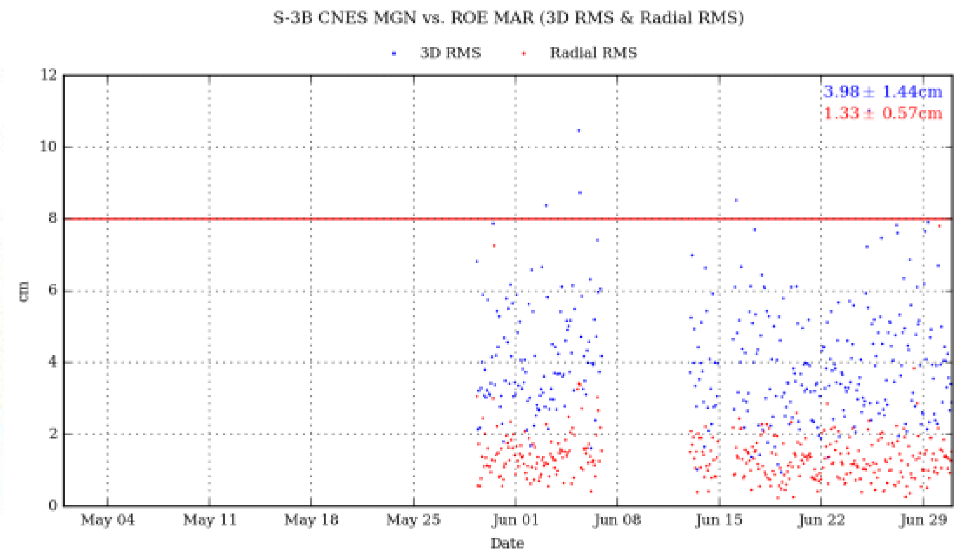




- Differences wrt. a combine solutions. Plots show smoothed differences
- Big jumps are due to data gaps

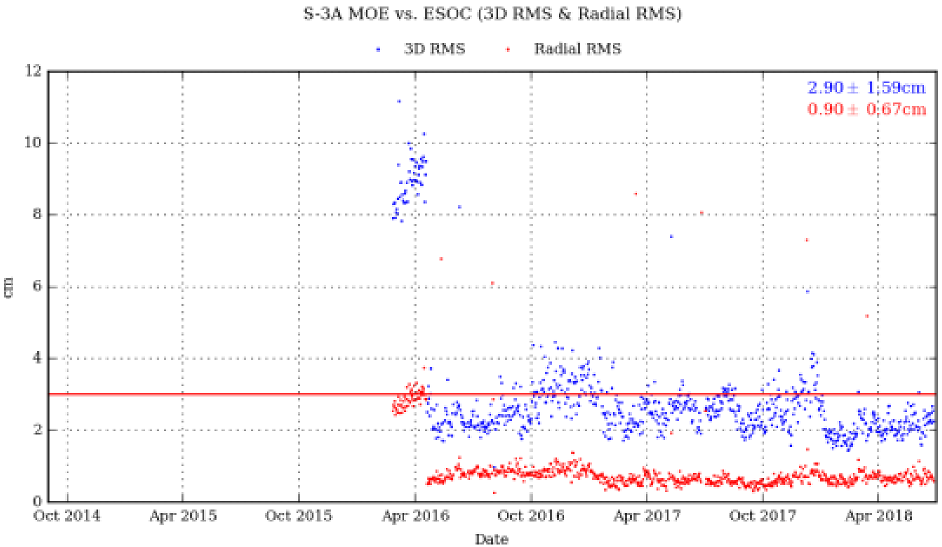
RESULTS – SENTINEL-3 NRT

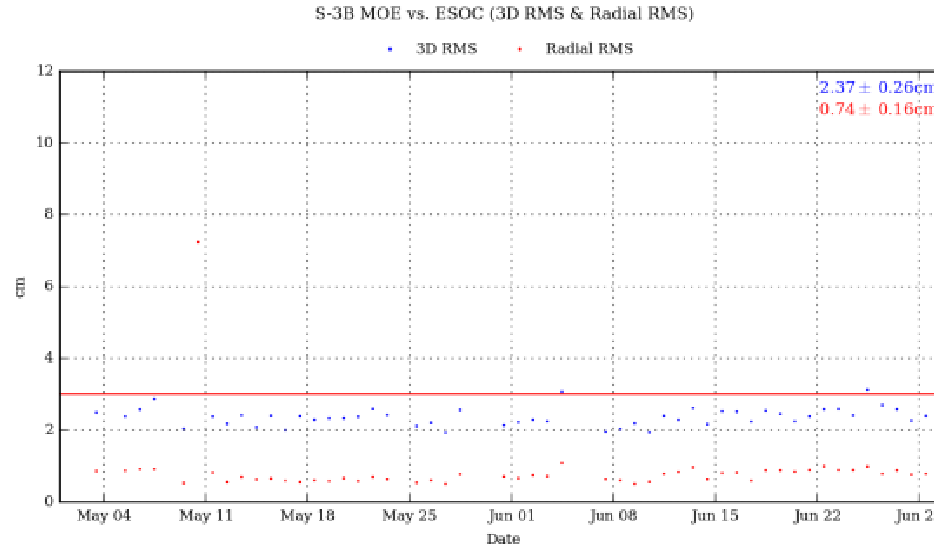




- Mean performance S3A ~ 3.6 cm in 3D RMS / **1.1 cm** in radial RMS (requirement: 8 cm radial RMS)
- Mean performance S3B during commissioning phase ~ 4.0 cm in 3D RMS / **1.3 cm** in radial RMS (requirement: 8 cm radial RMS) -> Performance should improve after the commissioning phase once the configuration is updated.

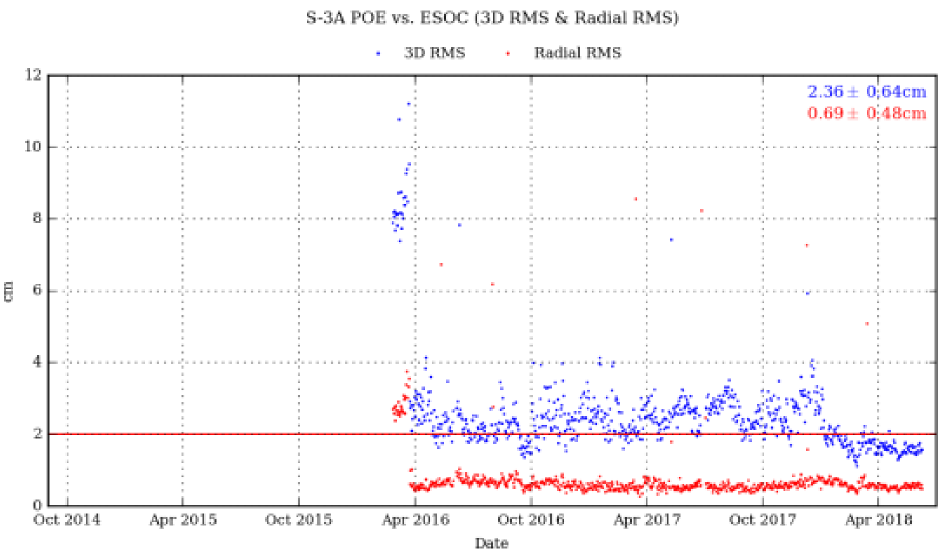
RESULTS – SENTINEL-3 STC

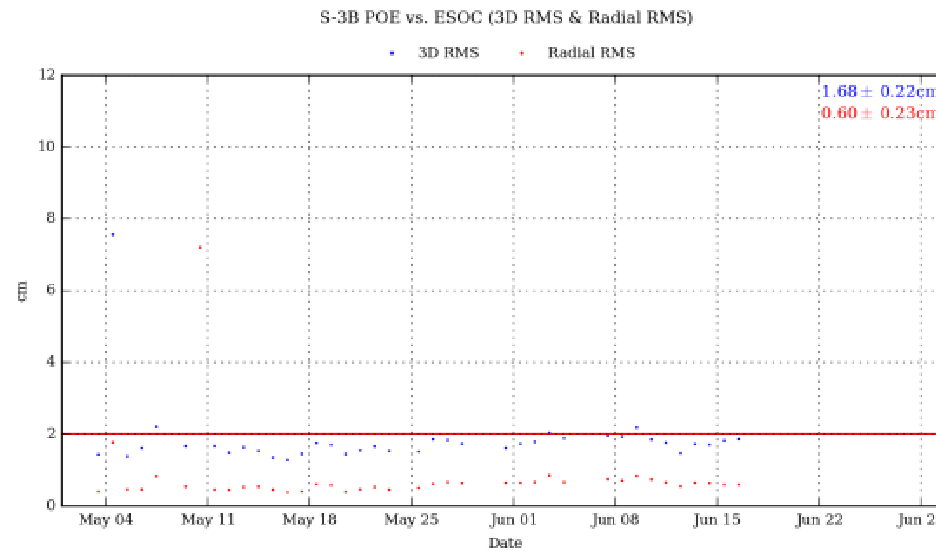




- Mean performance S3A ~ 2.9 cm in 3D RMS / **0.9 cm** in radial RMS (requirement: 3 cm radial RMS)
  - Anomaly at the beginning due to wrong configuration of location of GPS antenna. Corrected during the commissioning phase.
- Mean performance S3B during commissioning ~ 2.4 cm in 3D RMS / **0.7 cm** in radial RMS (requirement: 3 cm radial RMS)

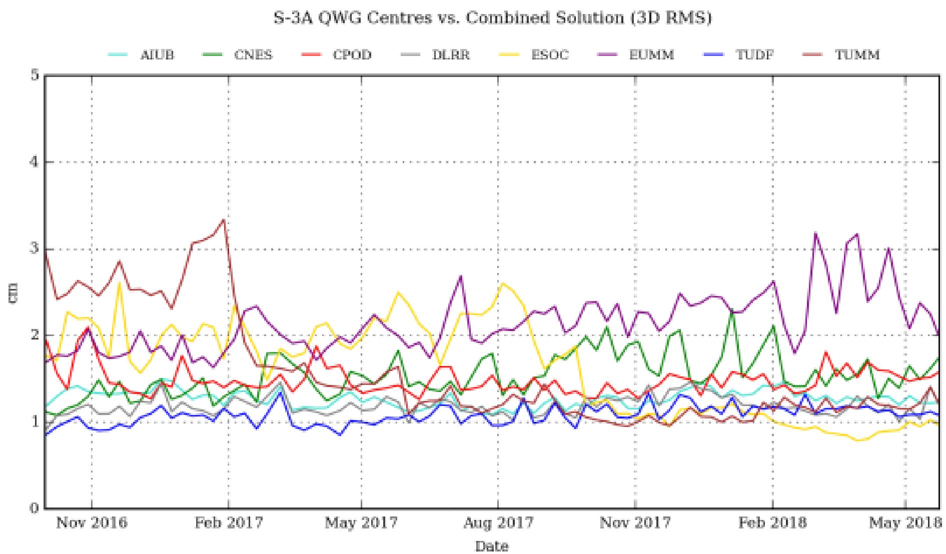
RESULTS – SENTINEL-3 NTC



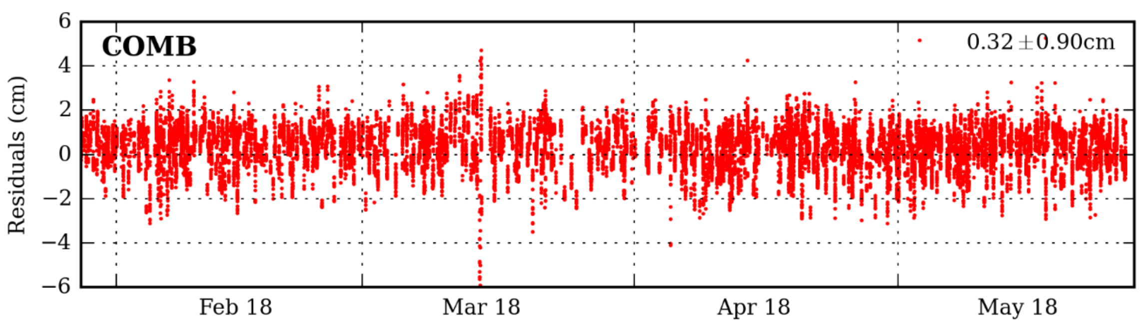


- Mean performance S3A NTC ~ 2.4 cm in 3D RMS / **0.7 cm** in radial RMS (requirement: 2 cm radial RMS)
  - Anomaly at the beginning due to wrong configuration of location of GPS antenna. Corrected during the commissioning phase.
- Mean performance S3B NTC ~ 1.7 cm in 3D RMS / **0.6 cm** in radial RMS (requirement: 2 cm radial RMS)

RESULTS – SENTINEL-3A COMB

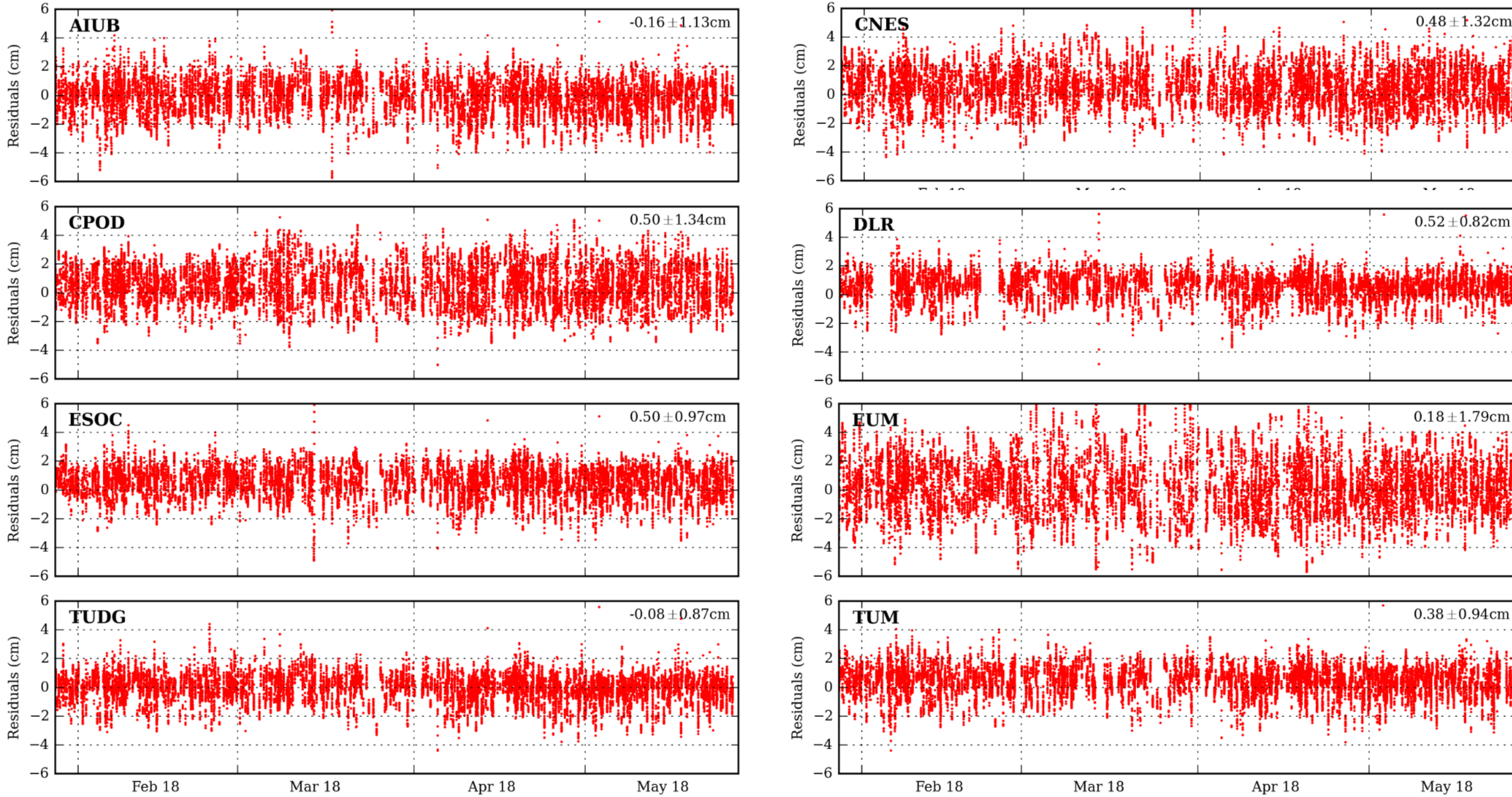


- Differences wrt. a combine solutions. Plots show smoothed differences

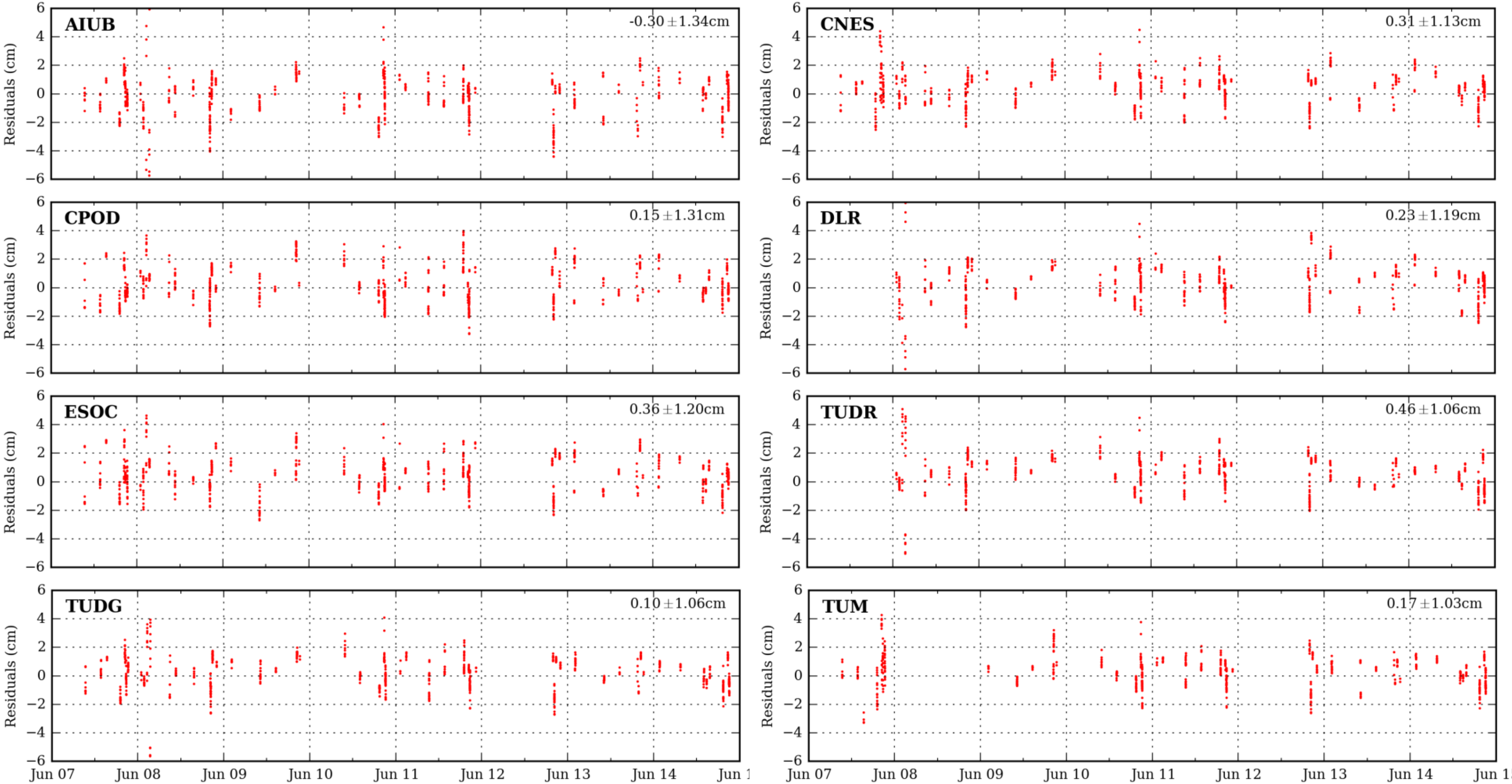


- SLR residuals of combined solution.
- Following slide shows the SLR residuals per solution.

RESULTS – SENTINEL-3A SLR



RESULTS – SENTINEL-3B SLR

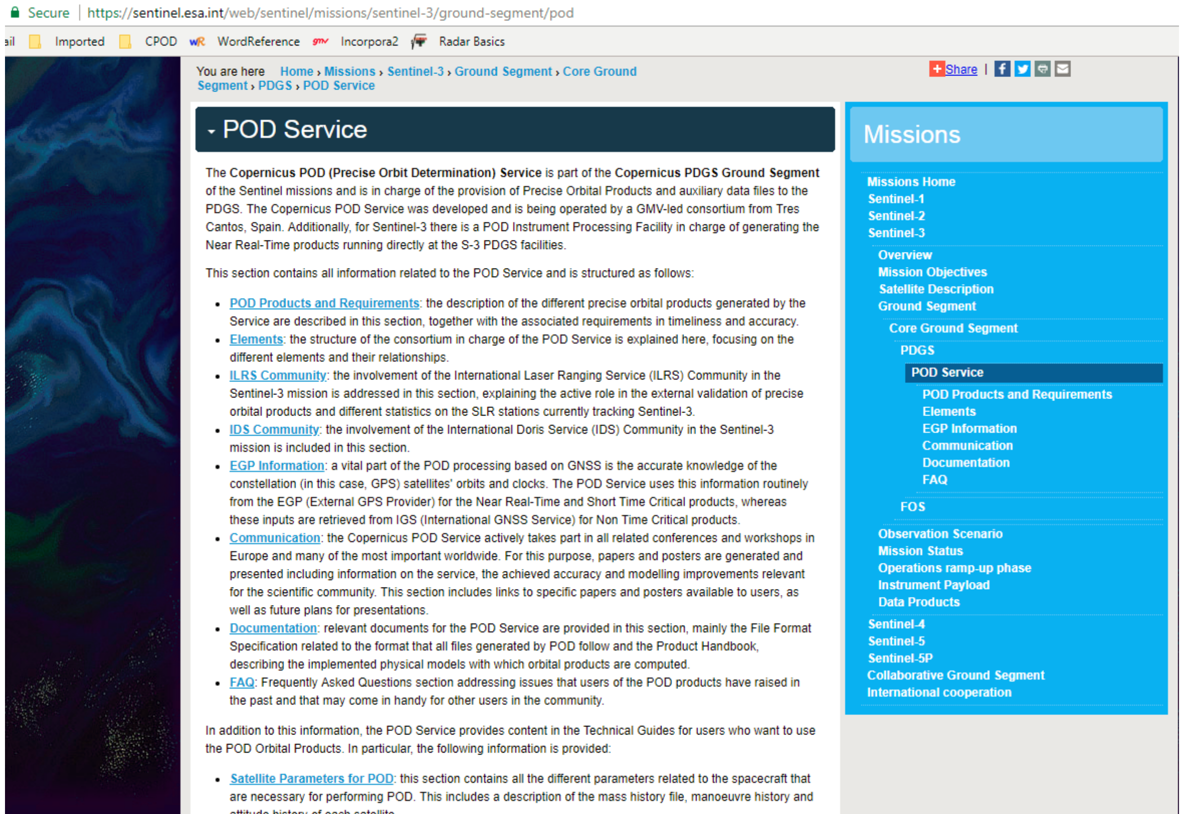


SUPPORT TO SCIENCE

- ESA Data Hub (https://scihub.copernicus.eu):
  - Rinex observation files: Format Rinex v3.03
  - Quaternions files (TBD): Format TBD
  - Operational orbits (TBD): Format EOF
- Sentinels On Line (https://sentinel.esa.int/web/sentinel/home)
  - Description of POD Service:
    - https://sentinel.esa.int/web/sentinel/missions/sentinel-3/ground-segment/pod
  - POD products:
    - Manoeuvre, mass history file, ANTEX, and description of satellite and receiver (TN)
    - S1: https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-1-sar/pod/satellite-parameters
    - S2: https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-2-msi/pod/satellite-parameters
    - S3: https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-3-altimetry/pod/satellite-parameters
- Applications:
  - SAR/InSAR / Altimetry / Orbit modelling / Gravity field modelling / Ionospheric research …

SUPPORT TO SCIENCE

Description of elements related with Copernicus POD



Secure | https://sentinel.esa.int/web/sentinel/missions/sentinel-3/ground-segment/pod

ail Imported CPOD WordReference Incorpora2 Radar Basics

You are here Home › Missions › Sentinel-3 › Ground Segment › Core Ground Segment › PDGS › POD Service

Share |

POD Service

The **Copernicus POD (Precise Orbit Determination) Service** is part of the **Copernicus PDGS Ground Segment** of the Sentinel missions and is in charge of the provision of Precise Orbital Products and auxiliary data files to the PDGS. The Copernicus POD Service was developed and is being operated by a GMV-led consortium from Tres Cantos, Spain. Additionally, for Sentinel-3 there is a POD Instrument Processing Facility in charge of generating the Near Real-Time products running directly at the S-3 PDGS facilities.

This section contains all information related to the POD Service and is structured as follows:

- POD Products and Requirements: the description of the different precise orbital products generated by the Service are described in this section, together with the associated requirements in timeliness and accuracy.
- Elements: the structure of the consortium in charge of the POD Service is explained here, focusing on the different elements and their relationships.
- ILRS Community: the involvement of the International Laser Ranging Service (ILRS) Community in the Sentinel-3 mission is addressed in this section, explaining the active role in the external validation of precise orbital products and different statistics on the SLR stations currently tracking Sentinel-3.
- IDS Community: the involvement of the International Doris Service (IDS) Community in the Sentinel-3 mission is included in this section.
- EGP Information: a vital part of the POD processing based on GNSS is the accurate knowledge of the constellation (in this case, GPS) satellites' orbits and clocks. The POD Service uses this information routinely from the EGP (External GPS Provider) for the Near Real-Time and Short Time Critical products, whereas these inputs are retrieved from IGS (International GNSS Service) for Non Time Critical products.
- Communication: the Copernicus POD Service actively takes part in all related conferences and workshops in Europe and many of the most important worldwide. For this purpose, papers and posters are generated and presented including information on the service, the achieved accuracy and modelling improvements relevant for the scientific community. This section includes links to specific papers and posters available to users, as well as future plans for presentations.
- Documentation: relevant documents for the POD Service are provided in this section, mainly the File Format Specification related to the format that all files generated by POD follow and the Product Handbook, describing the implemented physical models with which orbital products are computed.
- FAQ: Frequently Asked Questions section addressing issues that users of the POD products have raised in the past and that may come in handy for other users in the community.

In addition to this information, the POD Service provides content in the Technical Guides for users who want to use the POD Orbital Products. In particular, the following information is provided:

- Satellite Parameters for POD: this section contains all the different parameters related to the spacecraft that are necessary for performing POD. This includes a description of the mass history file, manoeuvre history and attitude history of each satellite.

Missions

- Missions Home
- Sentinel-1
- Sentinel-2
- Sentinel-3
  - Overview
  - Mission Objectives
  - Satellite Description
  - Ground Segment
    - Core Ground Segment
      - PDGS
        - POD Service
          - POD Products and Requirements
          - Elements
          - EGP Information
          - Communication
          - Documentation
          - FAQ
      - FOS
  - Observation Scenario
  - Mission Status
  - Operations ramp-up phase
  - Instrument Payload
  - Data Products
- Sentinel-4
- Sentinel-5
- Sentinel-5P
- Collaborative Ground Segment
- International cooperation

SUPPORT TO SCIENCE

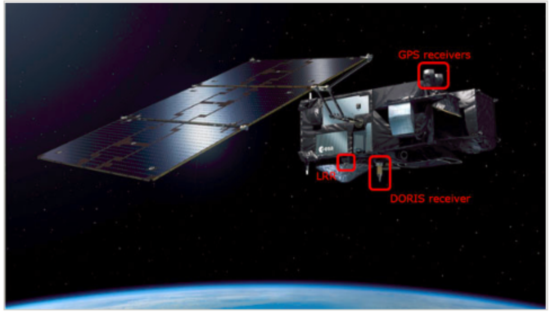
Inputs for POD per Sentinel mission

- Satellite Parameters for POD

The Sentinel-3 mission is supported by two identical spacecraft, Sentinel-3A and -3B, flying in the same orbital plane with a phase shift of ±140º (still to be decided by the European Commission to improve the scientific return).

An overall description of the satellite is available, explaining the main instruments and the geometry of the satellite.

Additionally, Sentinel-3 is equipped with a full Precise Orbit Determination Package consisting of 2 GPS receivers, one DORIS receiver and a Laser Retro Reflector (LRR) instrument for Satellite Laser Ranging.



Depiction of Sentinel-3A satellite showing the GPS receivers (image credit: ESA)

For Precise Orbit Determination processing it is of paramount importance to know in great detail the mass history of the satellite, the evolution of its centre of gravity, the manoeuvre history and the attitude information. Moreover, for GNSS based processing, the location and orientation of the antennae are required. In the case of the manoeuvre and mass history file (including the CG position), available hereafter, a historical record is kept since the launch of the satellite:

- Sentinel-3A Mass History file
- Sentinel-3A Manoeuvre History file

For Sentinel-3, the attitude information is provided as an official POD product. In all timeliness categories, ranging from Near Real-Time to Non Time Critical, Platform Data files containing the platform off nadir angles are computed. They shall be made available for public access with the rest of the official POD products.

For the convenience of users, another file combining information on manoeuvres and GNSS outages for the mission is provided below:

- Sentinel-3A Outage file

Please note that all of the files provided above contain a header that explains the format of their content.

The GPS Antenna absolute phase centre offset and variations (PCO/PCV) of both GPS receivers is located in this ANTEX file.

Technical Guides

CONCLUSIONS

- The Copernicus POD Service provides operationally orbital products to the Sentinel-1, -2 and -3 missions and subject to an Service Level Agreement
- It fulfil routinely all requirements in terms of accuracy (and also availability and timeliness)
- The CPOD Service, together with ESA and EUMETSAT, manages the Copernicus POD Quality Working Group (QWG) which gathers up to 9 centres in Europe.
- The CPOD Service, with inputs from the QWG, validates periodically the accuracy of the orbital products, using cross-comparisons, combined solutions and SLR residual analysis
- The CPOD Service is responsible for the generation of POD related inputs and products for its open scientific usage

THANK YOU FOR YOUR ATTENTION!

In case of questions concerning the **Copernicus products** please contact **eosupport@copernicus.esa.int**

Acknowledgements:

The Copernicus POD Service is financed under ESA contract no. 4000108273/13/1-NB, which is gratefully acknowledged.

The work performed in the frame of this contract is carried out with funding by the European Union. The views expressed herein can in no way be taken to reflect the official opinion of either the European Union or the European Space Agency.