Sentinel-1 Product Definition

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CHANGE RECORD

From issue 1.0 to 2.5, the Sentinel-1 Product Definition was maintained by a consortium led by MDA under the reference S1-RS-MDA-52-7440.

The S-1 IPF and associated documentation is then maintained by the S-1 Mission Performance Center. From the issue 2.6 the Sentinel-1 Product Definition is maintained by The S-1 Mission Performance Center which is a consortium led by CLS.

ISSUE	DATE	PAGE(S)	DESCRIPTION
1/0	Oct. 27, 2008	All	First Issue
1/1	Jan. 16, 2009	All	First Issue, First Revision. Updated for major SRR RIDs: SRR-002: Added S1-TN-ARE-PL-0007 as applicable document SRR-008: Corrected EW and WV mode definition in Table 3-1 SRR-010: Reorganized Sections 3.2 and 3.3 SRR-011: Added Tables 4-1 and 4-3 as product tree SRR-013: Described applications for all L1 product types SRR-014: Added annotation product description SRR-016: Clarified term “derived” in section 4 SRR-023: Improved SLC IW product description in section 4.1.2 SRR-029: Corrected GRD product description in section 4.2 SRR-034: Corrected GCD/ORD product description in sections 4.3 and 4.4 SRR-035: Clarified approach for generating GCD/ORD products from GRD products. SRR-039: Attached spreadsheet with product characteristics calculation SRR-041: Added missing product characteristics in section 5. SRR-042/SRR-396: Added range DTAR graphs and clarified bits per pixel definition. SRR-045/SRR-062: Added oversampling

ISSUE	DATE	PAGE(S)	DESCRIPTION
			calculation to spreadsheet. SRR-050: Separated GRD/GCD/ORD product characteristics tables. Added sub-type with large ENL. SRR-054: Added graph plotting incidence angle vs orbit position. SRR-066: Removed ENL options leading to non-squared resolutions for IW/EW. SRR-070: Clarified DEM used and DEM accuracy impact on ORD product characteristics. SRR-393: Removed Figure 4-1 image SRR-398: Clarified number of bits per pixel for SLC products SRR-400: Added reference to S1-TN-SLR-SY-0003 for location accuracy details SRR-404: Removed sentence about products satisfying Nyquist criterion. SRR-406: Changed geoid to ellipsoid in definition of absolute location accuracy in section A2.9 SRR-462: Clarified that the application of the scaling LUT is optional and configurable. Updated for medium and minor SRR RIDs: SRR-003, SRR-004, SRR-006, SRR-007, SRR-009, SRR-012, SRR-015, SRR-017, SRR-018, SRR-019, SRR-020, SRR-021, SRR-022, SRR-024, SRR-026, SRR-027, SRR-030, SRR-031, SRR-032, SRR-033, SRR-036, SRR-037, SRR-038, SRR-040, SRR-043, SRR-044, SRR-046, SRR-047, SRR-048, SRR-049, SRR-051, SRR-052,SRR-053, SRR-055, SRR-056, SRR-057, SRR-058, SRR-059, SRR-060, SRR-063, SRR-064,SRR-067,

ISSUE	DATE	PAGE(S)	DESCRIPTION
			SRR-068,SRR-071, SRR-072,
			SRR-073, SRR-074, SRR-075,
			SRR-076, SRR-078 SRR-391,
			SRR-394, SRR-395, SRR-399,
			SRR-403, SRR-405, SRR-444,
			SRR-461.
2/0	June 24, 2009	All	Second Issue.
			Added L2 OSW and OWI product definitions.
			Added L1 WV BRW product definition.
			Updated GRD product definition for new resolution classes.
			Updated for major SRR RID:
			SRR-014: Added annotation products.
			Updated for medium and minor SRR RIDs:
			SRR-017, SRR-048, SRR-074.
			Updated for medium and minor Post-SRR RIDs:PostSRR-1, PostSRR-2, PostSRR-3,
			PostSRR-4, PostSRR-5, PostSRR-7,
			PostSRR-8, PostSRR-9, PostSRR-10,
			PostSRR-12, PostSRR-13, PostSRR-14,
			PostSRR-15, PostSRR-16, PostSRR-17,
			PostSRR-20, PostSRR-21, PostSRR-22,
			PostSRR-23.
2/1	July 16, 2010	All	Second Issue, First Revision.
			Updated for Change Request #2:
			Removed GEC/GTC content and added slicing section.
			Updated for major PDR L1 RIDs:
			PD-1: Detailed change record for versions released after SRR.
			PD-5: Updated BRW Product characteristics.
			PD-6: Added TBC for GRD resolution class used as basis for BRW Product.

ISSUE	DATE	PAGE(S)	DESCRIPTION
			PD-8: Added complete product tree (L1 and L2). PD-9, PD-11: Revised L2 product definition tables. PD-12, PD-13: Added note that all L2 auxiliary files come from the PDGS or external sources. PD-14: Added L2 characteristics definition to Appendix A in line with product definition tables. Updated for medium and minor PDR L1 RIDs: PD-2, PD-3, PD-4, PD-7, PD-10, PD-15, PD-16, PD-21.

ISSUE	DATE	PAGE(S)	DESCRIPTION
2/2	Oct. 27, 2010		Second Issue, Second Revision.
			Updated for major PDR L2 / Delta PDR L1 RIDs:
		Section 6.3	S1IPFPDR-161: Removed concatenated L1 products from list of possible inputs to L2 Processor.
		Section 5.4	S1IPFPDR-180: Clarified that annotation products for L2 products are based on the internal L1 SLC product used for L2 processing.
		Section 6.1	S1IPFPDR-182: OWI algorithm input is a GRD product.
		Section 5.5	S1IPFPDR-190: Added reference to Product Specification for L1 product concatenation strategy. Mentioned blackfill in L1 imagery due to SWST changes and explained that its amount varies with the segment length.
		Section 2.2	S1IPFPDR-325: Updated name of reference document “Mission Requirements Document for the European Radar Observatory Sentinel-1”.
			Updated for medium and minor PDR L2 / Delta PDR L1 RIDs:
			S1IPFPDR-160, S1IPFPDR-162, S1IPFPDR-163, S1IPFPDR-178, S1IPFPDR-179, S1IPFPDR-181, S1IPFPDR-183, S1IPFPDR-185, S1IPFPDR-187, S1IPFPDR-188, S1IPFPDR-189, S1IPFPDR-301, S1IPFPDR-302, S1IPFPDR-303, S1IPFPDR-304, S1IPFPDR-305, S1IPFPDR-306, S1IPFPDR-307, S1IPFPDR-308, S1IPFPDR-309 (except point 2), S1IPFPDR-329, S1IPFPDR-330, S1IPFPDR-332.
			Updated for PDR L2 actions:
		Section 8	PDRL2-A8: Clarified that OSW/OWI/RVL grids are in ground range.
		Section 8	PDRL2-A10: Updated L2 product volumes to match Product Specification release 2/1 and to match L1 product lengths used in section 7.

ISSUE	DATE	PAGE(S)	DESCRIPTION
2/3	Mar. 21, 2011		Second Issue, Third Revision
		Sections 5.1 and 7	Updated L1 product characteristics in line with version 1/5 of GMES Sentinel-1 SAR Performance Analysis document.
		Section 7	Added Quick-Look characteristics.
		All	Removed browse products (descoped).
		All	Removed auxiliary Doppler calibration file.
		All	Removed auxiliary bathymetry and coast line files, which are now internal to the IPF.
			Updated for major Delta PDR L2 RIDs:
		Section 9.1	S1IPFDPDRL2-42: Clarified digital elevation models supported by the IPF.
			Updated for minor Delta PDR L2 RIDs:
		Section 10	S1IPFDPDRL2-41
2/4	Aug. 22, 2012		Second Issue, Fourth Revision
		Sections 7.2.1, 7.3.1	Updated TOP SLC azimuth pixel spacing (SENIPF-5152)
		Section 7.3	Updated EW ground coverage (SENIPF-5134)
		Table 5-1, Section 7	Updated ENL for all GRD products (SENIPF-5107)
			Updated for minor CDR RIDs:
			IPFCDR-1, IPFCDR-2, IPFCDR-5
			IPFCDR-3: changed RID resolution to remove the OWI component from the WV OCN product, and to mention that the wind information is present in the OSW component.
2/5	Mar. 28, 2014		Second Issue, Fifth Revision
		Section 8.1.1	Update OSW size from 4 to 5 or 6 range cells (SENIPF-5357)
		Sections 7.2 and 7.3, Appendix C	Update the TOPS antenna steering rates and the affected product characteristics. (SENIPF-5666)

ISSUE	DATE	PAGE(S)	DESCRIPTION
2/6	June 18, 2014	Table 8-1, Table 8-2, Table 8-3, Table 8-4	Changed parameters values, descriptions (related to MPCS-430, MPCS-543, IPF-3)
		Table 8-1, Table 8-2, Table 8-3, Table 8-4	Deleted Doppler Spectral reference (related to MPCS-507, MPCS-533, IPF-3)
		A 2.2.4	Deleted Doppler Spectral Width section (related to MPCS-507, MPCS-533, IPF-3)
2/7	March 25, 2016		Update of the L2 Product Definition for OCN products
		Table 8-1	Main Product characteristics for SM OCN: OSW specific (Spectral Grid Resolution) and RVL Specific (RVL Spatial Resolution and Grid Dimension)
			Product performance parameters (partition number)
			Processing parameters – OSW specific (Azimuth Look Bandwidth and Number of pixels used in spectral Estimation [range, azimuth])
			Data Size & Volume (number of Lines in Spectra and of Pixels per Line)
			Update of Notes in the table
		Table 8-2	Main Product characteristics for IW OCN: RVL Specific (RVL Spatial Resolution and Grid Dimension)
			Update of Notes in the table
		Table 8-3	Main Product characteristics for EW OCN: RVL Specific (RVL Spatial Resolution and Grid Dimension)
			Update of Notes in the table
		Table 8-4	Main Product characteristics: OSW specific
			Product performance parameters (partition number)
			Processing parameters – OSW specific
			Data Size & Volume
			Update of Notes in the table
		Appendix	New section: A.2.4: Radial surface velocity

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ACRONYMS AND ABBREVIATIONS

A/D	Analog to Digital Converter
ACE	Altimeter Corrected Elevations (Digital Elevation Model)
ADC	A/D Converter
ASAR	Advanced Synthetic Aperture Radar
BAQ	Block Adaptive Quantization
CFI	Customer-Furnished Information
CNR	Clutter to Noise Ratio
dB	Decibel(s)
DC	Doppler centroid
DCE	Doppler Centroid Estimation
DEM	Digital Elevation Model
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Centre)
DTAR	Distributed Target Ambiguity Ratio
DTED	Digital Terrain Elevation Data
EADS	European Aeronautic Defence and Space Company
ECMWF	European Centre for Medium-Range Weather Forecasts
ECR	Earth Centred Rotating (Coordinates)
EGM	Extended Graphics Memory
ENL	Equivalent Number of Looks
ENVISAT	ENVIronmental SATellite
ERS	European Remote Sensing Satellite
ESA	European Space Agency
EW	Extra Wide Swath Mode
FR	Full Resolution
GETASSE	Global Earth Topography And Sea Surface Elevation (Digital Elevation Model)
GHz	Gigahertz
GLOBE	Global Land One-km Base Elevation
GMES	Global Monitoring for Environment and Security
GRD	Ground Range, Multi-look, Detected
H	Horizontal
Hz	Hertz

HH	Horizontal polarisation on transmit, Horizontal polarisation on receive
HR	High Resolution
HV	Horizontal polarisation on transmit, Vertical polarisation on receive
I and Q	In-phase and Quadrature (channels)
ID	Identifier
IFREMER	Institut français de recherche pour l'exploitation de la mer (French Research Institute for Exploitation of the Sea)
IPF	Instrument Processing Facility
IRF	Inpulse Response Function
IRW	Impulse Response Width
ISLR	Integrated Side Lobe Ratio
IW	Interferometric Wide Swath Mode
L1	Level 1
L2	Level 2
LUT	Look-up Table
km	kilometre
kW	kiloWatt
m	metre
MB	Megabyte - Unit of data volume equal to 2^{20} bytes
MDA	MacDonald, Dettwiler and Associates Ltd.
MERSEA	Marine Environment and Security for the European Area
MHz	MegaHertz
MR	Medium Resolution
MSS	Mean Sea Surface
MTF	Modulation Transfer Function
N/A	Not Applicable
NRCS	Normalized Radar Cross-Section
NESZ	Noise Equivalent Sigma Zero
Net CDF	Network Common Data Forum
NGA	National Geospatial-Intelligence Agency
NRT	Near-Real-Time
NWP	Numerical Weather Prediction
OCN	Ocean (product)
OSI SAF	Ocean and Sea Ice Satellite Application Facility

OSV	Orbit State Vectors
OSW	Ocean Swell Spectra (component of OCN product)
OWI	Ocean Wind Field (component of OCN product)
PDGS	Payload Data Ground Segment
PDR	Preliminary Design Review
PRF	Pulse Repetition Frequency
PSLR	Peak Side Lobe Ratio
PTAR	Point Target Ambiguity Ratio
RF	Radio Frequency
RFC	Radio Frequency Compatibility
Rx	Receive
RVL	Radial Velocity (component of OCN product)
SAR	Synthetic Aperture Radar
ScanSAR	Scanning SAR
SLC	Single-Look Complex
SM	Stripmap Mode
SNR	Signal to Noise Ratio
SOW	Statement of Work
SRTM	Shuttle Radar Topography Mission
SWST	Sampling Window Start Time
T/R	Transmit/Receive
TA	Target Motion Analysis (module)
TBC	To Be Confirmed
TBD	To Be Determined
TOPSAR	Terrain Observation with Progressive Scans SAR
TRIM	Terrain Resource Information Management
Tx	Transmit
UTC	Universal Time Coordinated
V	Vertical
VH	Vertical polarisation on transmit, Horizontal polarisation on receive
VV	Vertical polarisation on transmit, Vertical polarisation on receive
WGS84	World Geodetic System (1984)
WV	Wave Mode

1 INTRODUCTION

1.1 Purpose

In the frame of the Global Monitoring for Environment and Security (GMES) program the European Space Agency (ESA) is undertaking the development of the Sentinel-1, a European polar orbit satellite system for the continuation of Synthetic Aperture Radar (SAR) operational applications in C-Band.

This document defines the complete Sentinel-1 product family generated by the Sentinel-1 Instrument Processing Facility (IPF).The document also provides a brief overview of the Sentinel-1 instrument, the operational modes and their characteristic parameters, and the auxiliary data used for the generation of the products and the applications which may use Sentinel-1 products.

1.2 Scope

This document includes:

- A description of the complete family of Sentinel-1 Level 1 and Level 2 products.
- A definition of the main system, processing and image quality characteristics of each type of product (Note that the detailed derivation of these product characteristics presented in Section 7 is included in Appendix C).
- The list of auxiliary data required for the generation of the proposed product family.

The scope of this document is to describe products generated by the Sentinel-1 IPF. The Level 0 products (i.e. the products that contain the acquired raw data) used to produce the Level 1 products presented in this document are described in [R-8].

This document also focuses on the overall characteristics of the Sentinel-1 products. Descriptions of the Sentinel-1 detailed product format and metadata contents are provided in the Sentinel-1 Product Specification [R-6].

1.3 Document Structure

This document is structured as follows:

- **Section 1** introduces the purpose, scope and structure of the document.
- **Section 2** lists the applicable and reference documents.

- **Section 3** provides an overview of the Sentinel-1 instrument and acquisition modes.
- **Section 4** presents the Sentinel-1 product family tree.
- **Section 5** introduces the L1 product types and provides an overview of the L1 product characteristics.
- **Section 6** introduces the L2 product types and provides an overview of the L2 product characteristics.
- **Section 7** contains the detailed L1 product definitions.
- **Section 8** contains the detailed L2 product definitions.
- **Section 9** contains an overview of the auxiliary data required for the generation of the Sentinel-1 L1 product family.
- **Section 10** contains an overview of the auxiliary data required for the generation of the Sentinel-1 L2 product family.
- **Appendix A** provides definitions for the product characteristics and image quality parameters used in the product definition tables.
- **Appendix B** contains graphs describing in more detail SAR performance of the Sentinel-1 Level 1 products.
- **Appendix C** provides the detailed derivation of the product characteristics.
- **Appendix D** contains notes on some Product Definition related issues, specifically the derivation of the (predicted) ENL and the Doppler Centroid Estimation.

2 DOCUMENTS

2.1 Applicable Documents

A-1	GMES-DFPR-EOPG-SW-07-00006	Sentinel-1 Product Definitions & Instrument Processing Facility Development Statement of Work, Issue/Revision 4/1, 23-05-2008.
A-2	CCN No.2	Contract Change Notice N. 2, Changes in ESRIN Contract No. 21722/08/I-LG, June 21, 2010.
A-3	S1-TN-ARE-PL-0001	GMES Sentinel-1 SAR Performance Analysis, Version 1/5, Sep. 24, 2010, Aresys.
A-4	S1-RS-MDA-52-7452	Sentinel-1 IPF System Requirements Document, Issue/Revision 2/2, Apr. 20, 2012. MacDonald Dettwiler.

2.2 Reference Documents

R-1	ES-RS-ESA-SY-0007	Mission Requirements Document for the European Radar Observatory Sentinel-1, Issue 1/4, ESA, July 11, 2005.
R-2	S1-RS-ESA-SY-0001	GMES Sentinel-1 System Requirements Document, Issue 3/2, March 4, -2009, ESA.
R-3	S1-DD-ASD-PL-0001	Sentinel-1 SAR Instrument Technical Description, Issue 5, Jan 25, 2010, EADS Astrium.
R-4	S1-RP-ASD-PL-0003	Instrument Calibration and Performance Analysis and Budgets, Issue 2, Jul. 31, 2008, Astrium
R-5		Digital Processing of Synthetic Aperture Radar Data, 2005 Artech House, Inc, Ian G. Cumming and Frank H. Wong.
R-6	S1-RS-MDA-52-7441	Sentinel-1 Product Specification, Issue/Revision 2/5, August 2012. MacDonald Dettwiler.
R-7		Aerospace Avionics Systems, 1993 Academic Press Inc. George M. Siouris.

R-8	GM-ID-ACS-T8-0106	Sentinel-1 L0 Product Format Specification, Issue/Revision 1/1, Apr. 20, 2010, ACS.
R-9	S1-RS-MDA-52-7443	Sentinel-1 IPF Auxiliary Product Specification, Issue/Revision 2/5, August 2012. MacDonald Dettwiler.
R-10		Rogers, W. E., “An investigation into sources of error in low frequency energy5 predictions”, Tech. Rep. Formal Report 7320-02-10035, Oceanography division, Naval Research Laboratory, Stennis Space Center, MS, 2002
R-11		Bidlot, J., S. Abdalla, and P. Janssen (2005), “A revised formulation for ocean wave dissipation in CY25R1”, Tech. Rep. Memorandum R60.9/JB/0516, Research Department, ECMWF, Reading, U. K.
R-12		Tolman, H. L. (2002), Validation of WAVEWATCH-III version 1.15, Tech. Rep. 213, NOAA/NWS/NCEP/MMAB.
R-13		Lotfi A., Lefevre M., Hauser D., Chapron B., Collard F., “The impact of using the upgraded processing of ASAR Level 2 wave products in the assimilation system”, Proc. Envisat Symposium, 22-26 April 2007, Montreux
R-14		Barstow S., Mørk G., Lønseth L., Schølberg P., Machado U., Athanassoulis G., Belibassakis K., Gerostathis Th., Spaan G., “WORLDWAVES – Fusion of data from many sources in a user friendly software package for timely calculation of wave statistics in global coastal waters”, Proc. of ISOPE 2003, May 2003, Hawaii
R-15		Ardhuin F., A. D. Jenkins, D. Hauser, A. Reiers, B. Chapron, “Waves and Operational Oceanography: Toward a Coherent Description of the Upper Ocean”, Eos, Vol.86, No.4, 25 January 2005
R-16		Ryder P., “GMES Fast Track Marine Core Services – Strategic Implementation Plan”, Final Version, 24 April 2007

3 SENTINEL-1 MISSION AND SAR SYSTEM OVERVIEW

3.1 Mission Overview

The Sentinel-1 SAR mission is part of the GMES system, which is designed to provide an independent and operational information capacity to the European Union to warrant environment and security policies and to support sustainable economic growth. In particular, the mission will provide timely and high quality remote sensing data to support monitoring the open ocean and the changes to marine and coastal environmental conditions.

Sentinel-1 mission requirements are based on applications and services developed in the frame of the GMES Service Element based on ERS and ENVISAT data and, while taking full benefit of the heritage from these pre-cursor missions, are optimised to enhance performance and operational capabilities.

The Sentinel-1 Ground Segment covers the complete supply chain required to monitor and control the space and ground segment, to perform mission planning according to defined operational scenarios, to acquire, process and distribute Sentinel-1 products.

The mission objectives are defined in the Sentinel-1 Mission Requirements Document [R-1].

3.2 Sentinel-1 Main Payload and Platform Characteristics

The Synthetic Aperture Radar (SAR) instrument is the main instrument carried by the Sentinel-1 spacecraft. It operates in the C-Band with horizontal and vertical polarisations. The instrument is based on a deployable planar phased array antenna carrying Transmit/Receive Modules. The antenna features both azimuth and elevation beam steering facilities, allowing SAR data acquisition in four different modes (as described in Section 3.3), according to the needs of the particular application. Table 3-1 summarises the characteristics of the platform and SAR instrument. More details about the instrument can be found in [R-3].

Table 3-1 Sentinel-1 System Parameters

System Parameter	Value
Radar Carrier Frequency	5.405 GHz
RF Peak Power	4.141 kW
Incidence Angle Range	20°-46°

System Parameter	Value
Look direction	Right
Antenna Length	12.3 m
Azimuth Beam Width	0.23°
Azimuth Beam Steering Range	-0.9° to +0.9°
Antenna width	0.82 m
Elevation Beam Width	3.43°
Elevation Beam Steering Range	-13.0° to +12.3°
Maximum Range Bandwidth	100 MHz
Pulse Repetition Frequency (PRF) Range	1000 Hz - 3000 Hz
Polarisation Options	Single (HH, VV) Dual (HH+HV, VV+VH)
Attitude Steering	Zero-Doppler Steering and Roll Steering

Section 3.2.1 introduces the acquisition modes; Section 3.2.2 describes the polarisation capabilities of the instrument and Section 3.2.3 presents the attitude steering capabilities of the platform.

3.2.1 Sentinel-1 Acquisition Modes Overview

The Sentinel-1 SAR can be operated in one of four nominal acquisition modes (see Figure 3-1):

1. Stripmap Mode (**SM**)
2. Interferometric Wide Swath Mode (**IW**)
3. Extra Wide Swath Mode (**EW**)
4. Wave Mode (**WV**)

The SAR instrument is capable of operating with duty cycles of 25 minutes per orbit in the SM, IW or EW acquisition modes.

An overview of the Sentinel-1 acquisition modes is presented in Section 3.3.

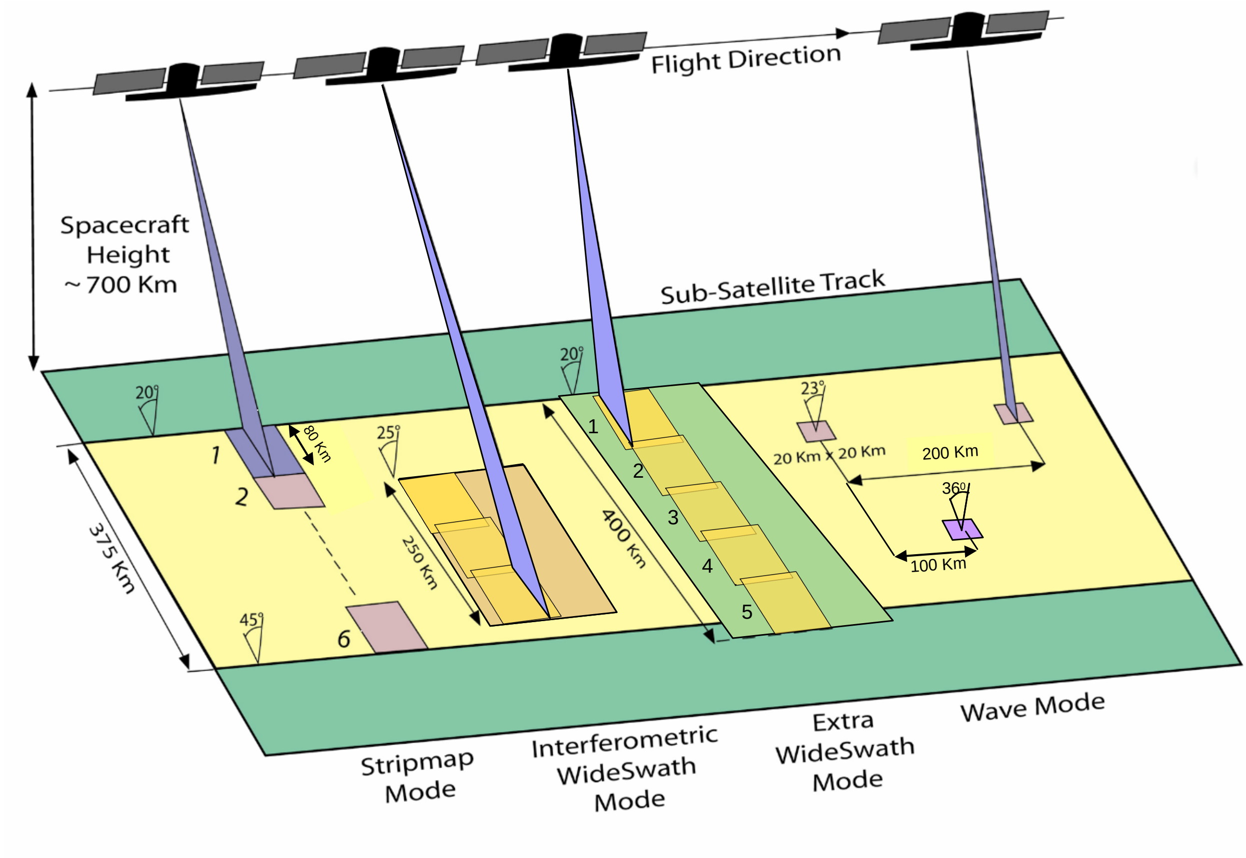

Figure 3-1 Sentinel-1 Acquisition Modes

3.2.2 SAR Instrument Polarisation Capabilities

The Sentinel-1 instrument is able to transmit horizontal (H) or vertical (V) linear polarisations. The instrument is able to receive, on two separate receiving channels, both H and V signals simultaneously.

Single co-polarisation products are obtained by operating the radar with the same (H or V) polarisation on both transmit and receive. Dual-polarisation products are obtained by operating the radar with one (H or V) polarisation on transmit and both simultaneously on receive.

Dual-polarisation products are provided in the form of two images each corresponding to a different polarisation channel (HH, VV, HV or VH). The images have the same product characteristics and are co-registered.

For the SM, IW and EW modes, data can be acquired in either single co-polarisation (HH or VV) or dual polarisation (HH+HV or VV+VH). For WV mode, only single co-polarisation data acquisition is supported (HH or VV only).

Complex-valued dual polarisation products contain the inter-channel phase information which enables complex-valued polarimetry to be performed. Dual-polarisation SAR allows the user to measure the polarisation properties of the terrain in addition to the backscatter that can be measured from a single polarisation. Ground targets have distinctive polarisation signatures in the same way that they have distinctive spectral signatures. For example, volume scatterers have different polarisation properties than surface scatterers. Dual-polarisation products therefore provide improved classification of point targets and distributed target areas.

3.2.3 Attitude Steering Capabilities

The spacecraft attitude is the relative orientation of a spacecraft-fixed frame with respect to a certain flight frame of reference. The attitude can be defined by a sequence of three rotations described by the Euler angles, yaw, pitch and roll (for attitude angles definition, see for example [R-7]; for definitions of Sentinel-1 reference frames see [R-2]).

During data acquisition activities, the attitude of the Sentinel-1 spacecraft is controlled in order to satisfy specific purposes, ultimately leading to increased image quality and efficient satellite operation activities.

The Sentinel-1 attitude steering has two main components, Zero-Doppler Attitude Steering (which has both a yaw and a pitch component) and Roll Steering. These modes of operation will be described in the next two sections.

3.2.3.1 Zero-Doppler Attitude Steering

The Sentinel-1 spacecraft nominal mode of operation is the Zero-Doppler Attitude Steering Mode.

The Zero-Doppler Attitude Steering law - implemented for the first time on the TerraSAR-X spacecraft - represents a significant improvement over the classical yaw-steering law designed for previous SAR missions like ERS-1/2, ENVISAT or RADARSAT-2.

Due to the Earth's rotation, the Doppler centroid, which is the Doppler frequency associated with the centre of the illuminating beam on the ground, varies over the orbit; it also varies over range due to Sentinel-1's orbit inclination being different from 90º (see Sentinel-1 orbit characteristics in [R-2]). Uncompensated variations of the Doppler centroid may cause significant, undesirable radiometric variations in the image. For cases of large Doppler centroid errors, focusing and geo-location quality may also be affected.

Similar to the yaw-steering law, the zero-Doppler steering law is a technique aimed at compensating the Doppler shift induced by Earth's rotation. Unlike the yaw-steering law, which is designed to reduce the Doppler centroid to zero at the mid range of the swath, the Zero-Doppler Attitude Steering Law is designed to reduce the Doppler centroid to a theoretical 0 Hz, independent of the range position of interest. This is achieved by combining the yaw-steering with an additional pitch-steering. In this way, residual errors are only due to pointing inaccuracy, orbit variation errors, variations in terrain height or implementation approximations.

The Zero-Doppler Attitude Steering law has a number of notable advantages with bearing on the Sentinel-1 Level 1 products and potential applications quality. The low residual Doppler centroid and the reduced variation of the Doppler centroid over range allow:

- More accurate Doppler centroid estimation and therefore more precise azimuth antenna pattern compensation
- Potential reduction of scalloping in the images produced from ScanSAR-type modes (IW and EW). Note that the Terrain Observation with Progressive Scans SAR (TOPSAR) imaging technique already avoids scalloping, independently of the Zero-Doppler Attitude Steering law.
- Optimized overlap of the azimuth spectra of SAR image pairs for cross-track interferometry
- Reduced susceptibility to range dependent interferometric phase bias caused by a misregistration between the interferometric images

3.2.3.2 Roll Steering

The Roll Steering Mode is a new type of attitude control implemented for the first time on the Sentinel-1 spacecraft. The Roll Steering Mode is a continuous manoeuvre around the orbit (similar to the yaw steering in azimuth) that compensates for the altitude variations, in order to minimize the updates of the PRF and sampling window position around the orbit. This allows the instrument to operate with a small fixed set of antenna beams, and simplifies the instrument operation significantly (see [R-3]).

The roll steering law defines the roll angle (or equivalently, the off-nadir angle of pointing) of the antenna mechanical boresight versus time. The off-nadir angle is defined as a linear function of the satellite altitude. This results in a variation around the orbit of the off-nadir angle of up to approximately $\pm$ 0.8 degrees with respect to the off-nadir angle at the reference altitude, which is 711.7 km (see Table 3-3, Table 3-5, Table 3-7 and Table 3-9 for angle ranges specific for each beam).

Due to this variation, parameters dependent on the off-nadir angle (and implicitly on the incidence angle) will also exhibit (small) variations around the orbit. In particular, the ground range resolution will vary by a maximum of ± 5% with respect to the reference incidence angle and around the orbit, maximum variation taking place at near range (~ 19 degrees) (see also the ground resolution plots in Appendix B). The ground range coverage is also affected by the incidence angle variation, but only marginally.

Figure 3-2 shows the type of variation of the off-nadir angle along the orbit, versus the orbit time and versus the altitude over the reference ellipsoid (this particular example is for a predicted orbit of 1st January 2011). The top graph illustrates the variation of the off-nadir angle with respect to orbit time while the bottom graph illustrates the variation of the off-nadir angle with respect to orbit altitude.

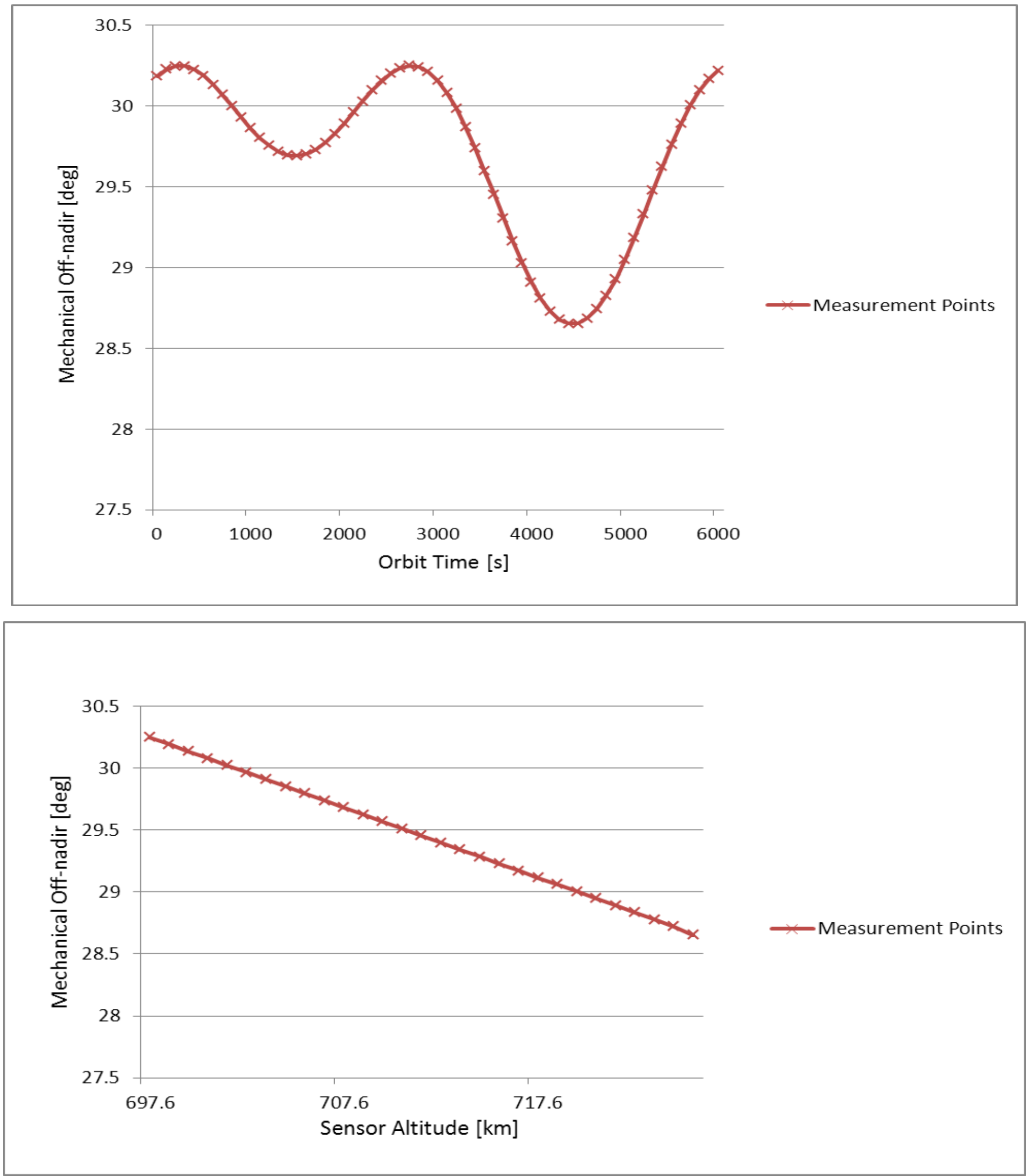

Figure 3-2 Roll steering Variation of the Mechanical Off-nadir Angle along the Orbit

3.3 Sentinel-1 Acquisition Modes

This section provides a brief description of each Sentinel-1 acquisition mode.

3.3.1 Stripmap Mode (SM)

The Sentinel-1 SM mode is a standard SAR stripmap imaging mode (as shown in Figure 3-1), where the ground swath is illuminated with a continuous sequence of pulses while the antenna beam is pointing to a fixed azimuth angle and an approximately fixed off-nadir angle (The off-nadir angle is subject to small variations according to the roll steering law, as described in Section 3.2.3.2). This results in an image strip with continuous along-track image quality at an approximately constant incidence angle. SM can operate with one of 6 predefined elevation beams, each characterised by a different incidence angle coverage. The main parameters characterising this mode are summarized in Table 3-2. Note that the resolution values specified in the table correspond to the 1-look Ground Range Multi-Look Detected (GRD) product approximate resolution (see Section 5.2.2 for the GRD product definition).

Table 3-2 Sentinel-1 SM Mode Characteristics

Parameter	Value
Minimum Ground Swath Width	80 km
Incidence Angle Range	18.3°-46.8°
Number of Elevation Beams	6
Azimuth resolution	5.0 m
Ground Range Resolution	5.0 m
Polarisation Options	Single (HH or VV) or Dual (HH+HV or VV+VH)

Table 3-3 provides the precise incidence and off-nadir angle ranges corresponding to the minimum and maximum orbit height satellite positions, which are ~698 km and respectively ~726 km. (Off-nadir angles - and implicitly incidence angles - vary with position of the satellite in orbit according to the roll steering law as described in Section 3.2.3.2.)

Table 3-3 Incidence and Off-Nadir Angles for Stripmap Beams

<table>
<tr><th colspan="2">Beam</th><th>S1</th><th>S2</th><th>S3</th><th>S4</th><th>S5</th><th>S6</th></tr>
<tr><td rowspan="2">Minimum Orbit Altitude</td><td>Off Nadir Angles [°]</td><td>17.93-23.53</td><td>21.00-26.33</td><td>26.18-30.99</td><td>30.87-35.15</td><td>35.07-38.85</td><td>37.53-41.01</td></tr>
<tr><td>Incidence Angles [°]</td><td>19.99-26.31</td><td>23.45-29.50</td><td>29.33-34.85</td><td>34.71-39.72</td><td>39.62-44.12</td><td>42.53-46.73</td></tr>
</table>

Beam		S1	S2	S3	S4	S5	S6
Maximum Orbit Altitude	Off Nadir Angles [°]	16.45-21.96	19.51-24.77	24.67-29.45	29.34-33.63	33.53-37.34	35.98-39.51
	Incidence Angles [°]	18.32-24.55	21.78-27.76	27.64-33.13	33.00-38.02	37.89-42.43	40.79-45.04

3.3.2 Interferometric Wide Swath Mode (IW)

The Sentinel-1 IW mode acquires data of wide swaths (composed of 3 sub-swaths), at the expense of resolution, using the TOPSAR imaging technique. The TOPSAR imaging is a form of ScanSAR imaging (the antenna beam is switched cyclically among the three sub-swaths, as shown in Figure 3-1) where, for each burst, the beam is electronically steered from backward to forward in the azimuth direction, as shown in Figure 3-3. This leads to uniform NESZ and ambiguity levels within the scan bursts, resulting in a higher quality image.

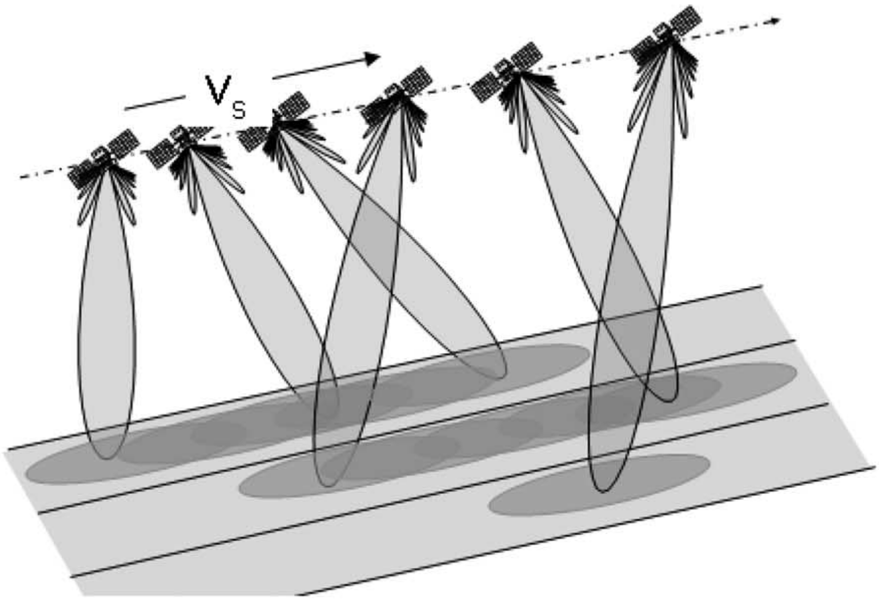

Figure 3-3 TOPSAR Imaging Mode

Another key feature of the IW mode is that bursts are synchronised from pass to pass to ensure the alignment of interferometric pairs.

The IW mode is a TOPSAR single sweep mode; the radar beam switching has been chosen to provide one azimuth look per beam for all points. Table 3-4 presents the main parameters characterising this mode. Note that the resolution values specified in the table correspond to the 1-look Ground Range Multi-Look Detected (GRD) product approximate resolution (see Section 5.2.2 for the GRD product definition).

Table 3-4 Sentinel-1 IW Mode Characteristics

Parameter	Value
Minimum Ground Swath Width	250 km
Incidence Angle Range	29.1°-46.0°
Number of Sub-swath	3
Azimuth Steering Angle	± 0.6°
Azimuth Resolution	20 m
Ground Range Resolution	5 m
Polarisation Options	Single (HH or VV) or Dual (HH+HV or VV+VH)

Table 3-5 provides the precise incidence and off-nadir angle ranges corresponding to the minimum and maximum orbit height satellite positions, which are ~698 km and respectively ~726 km. (Off-nadir angles - and implicitly incidence angles - vary with position of the satellite in orbit according to the roll steering law as described in Section 3.2.3.2.).

Table 3-5 Incidence and Off-Nadir Angles for Interferometric Wide Swath Beams

Beam		IW1	IW2	IW3
Minimum Orbit Altitude	Off Nadir Angles [°]	27.53-32.48	32.38-36.96	36.87-40.40
	Incidence Angles [°]	30.86-36.59	36.47-41.85	41.75-46.00
Maximum Orbit Altitude	Off Nadir Angles [°]	26.00-30.96	30.86-35.43	35.35-38.88
	Incidence Angles [°]	29.16-34.89	34.77-40.15	40.04-44.28

3.3.3 Extra-Wide Swath Mode (EW)

The EW mode (as shown in Figure 3-1) also uses the TOPSAR imaging technique (see Figure 3-3). The EW mode provides a very large swath coverage (obtained from imaging 5 sub-swaths) at the expense of a further reduction in resolution.

As the IW mode, the EW mode is a TOPSAR single sweep mode. Table 3-6 presents the main parameters characterising this mode. Note that the resolution values specified in the table correspond to the 1-look Ground Range Multi-Look Detected (GRD) product approximate resolution (see Section 5.2.2 for the GRD product definition).

Table 3-6 Sentinel-1 EW Mode Characteristics

Parameter	Value
Minimum Ground Swath Width	410 km
Incidence Angle Range	18.9°-47.0°
Number of Sub-swath	5
Azimuth Steering Angle	± 0.8°
Azimuth Resolution	40 m
Ground Range Resolution	20 m
Polarisation Options	Single (HH or VV) or Dual (HH+HV or VV+VH)

Table 3-7 provides the precise incidence and off-nadir angle ranges corresponding to the minimum and maximum orbit height satellite positions, which are ~698 km and respectively ~726 km. (Off-nadir angles - and implicitly incidence angles - vary with position of the satellite in orbit according to the roll steering law as described in Section 3.2.3.2).

Table 3-7 Incidence and Off-Nadir Angles for Extra Wide Swath Beams

Beam		EW1	EW2	EW3	EW4	EW6
Minimum Orbit Altitude	Off Nadir Angles [°]	17.94-26.07	26.02-30.66	30.61-35.10	35.06-38.66	38.63-41.20
	Incidence Angles [°]	20.00-29.20	29.15-34.47	34.41-39.66	39.60-43.89	43.86-46.97
Maximum Orbit Altitude	Off Nadir Angles [°]	16.36-24.49	24.44-29.08	29.03-33.52	33.48-37.08	37.05-39.62
	Incidence Angles [°]	18.22-27.57	27.38-33.42	32.65-38.05	37.84-42.53	42.08-45.16

3.3.4 Wave Mode (WV)

The WV mode (as shown in Figure 3-1 acquires small stripmap scenes (also called “vignettes”), situated at regular intervals of 100 km along track (between the centre of consecutive vignettes), similar to the ERS and ENVISAT ASAR wave imaging modes. This sub-sampling allows generating low data volume.

The vignettes are acquired in ‘leap frog’ mode, i.e. one vignette is acquired at a near range incidence angle while the next vignette is acquired at a far range incidence angle, as illustrated in Figure 3-1.

The WV mode, which allows sampling of low-volume data from vast areas, was specifically designed for ocean applications (see Section 5.6 for examples of applications).

Table 3-8 presents the key Sentinel-1 WV mode characteristics. Note that the resolution values specified in the table correspond to the 1-look Ground Range Multi-Look Detected (GRD) product approximate resolution (see Section 5.2.2 for the GRD product definition).

Table 3-8 Sentinel-1 WV Mode Characteristics

Parameter	Value
Vignette ground coverage	20 km x 20 km
Along Track Distance between Centre of Consecutive Vignettes	100 km
Incidence Angle Range	21.6 – 25.1 and 34.8 – 38.0
Number of elevation beams	2
Azimuth Resolution	5.0 m
Ground Range Resolution	5.0 m
Polarisation Options	Single (HH or VV)

Table 3-9 provides the precise incidence and off-nadir angle ranges corresponding to the minimum and maximum orbit height satellite positions, which are ~698 km and respectively ~726 km. (Off-nadir angles - and implicitly incidence angles - vary with position of the satellite in orbit according to the roll steering law as described in Section 3.2.3.2).

Table 3-9 Incidence and Off-Nadir Angles for Wave Mode Beams

Beam		WV1	WV2
Minimum Orbit Altitude	Off Nadir Angles [°]	21.03-22.40	32.56-33.62
	Incidence Angles [°]	23.47-25.03	36.67-37.92
Maximum Orbit Altitude	Off Nadir Angles [°]	19.43-20.79	30.96-32.02
	Incidence Angles [°]	21.68-23.22	34.88-36.13

4 SENTINEL-1 PRODUCT FAMILY TREE

The Sentinel-1 product family tree is presented in Figure 4-1. The acronyms in this figure are described in Sections 5.1 and 6.1 for Level 1 and Level 2 respectively.

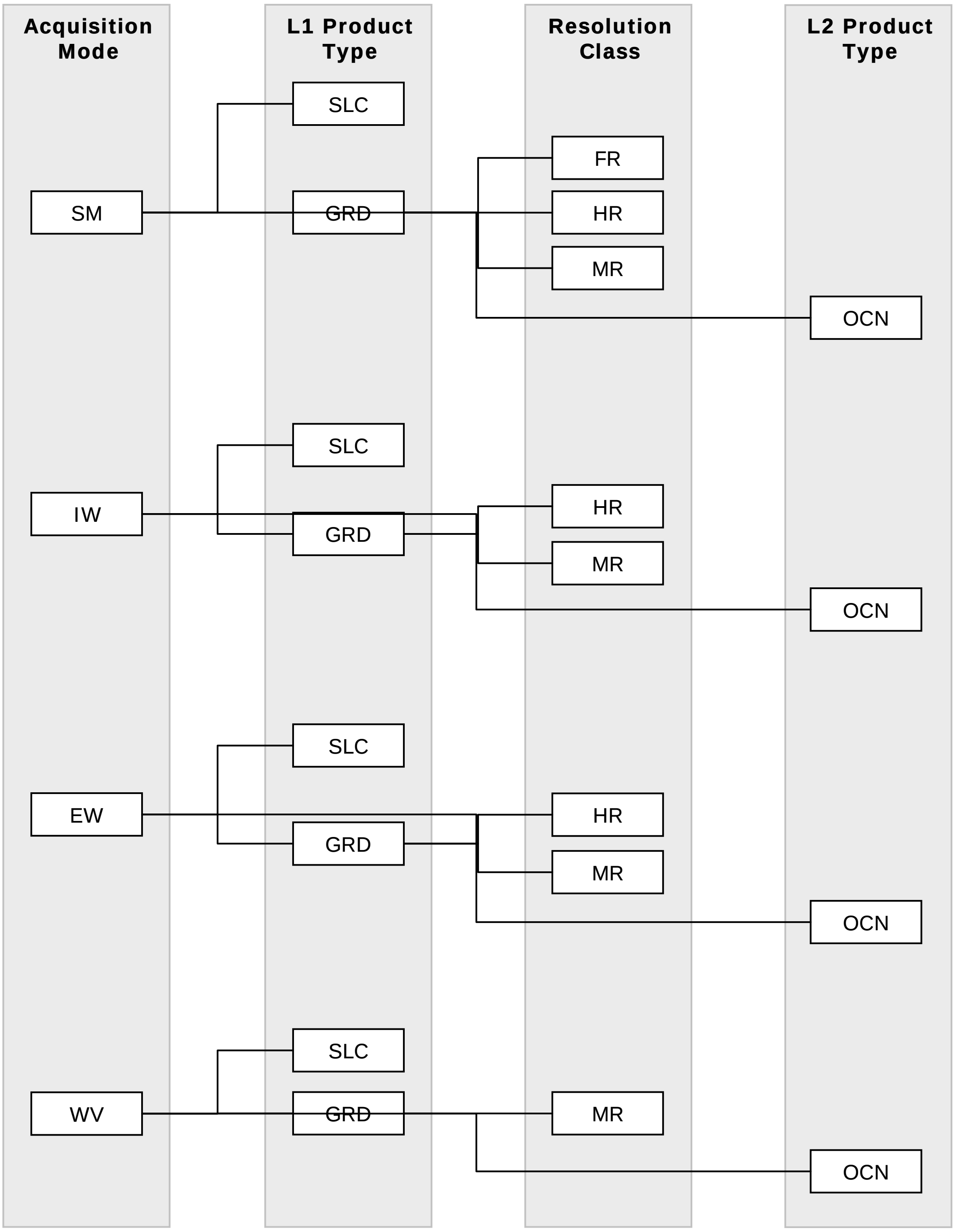

Figure 4-1 Sentinel-1 Product Family Tree

5 LEVEL 1 PRODUCTS OVERVIEW

This section presents an overview of the Sentinel-1 Level 1 products and their properties. A detailed definition of each product in the family is provided in Section 7.

Section 5.1 summarizes the Level 1 product family and the main properties of each product in the family. Section 5.2 briefly describes each product type. Section 5.3 introduces the annotation products. Section 5.4 describes the slicing scenario and how it impacts L1 products characteristics. Section 5.5 describes the radiometric corrections applied by the IPF during processing. Finally, Section 5.6 describes Sentinel-1 applications and presents a mapping of these applications to modes and product types.

5.1 Products Summary

For the Sentinel-1 acquisition modes discussed in Section 3.3, the following types of L1 products are defined:

a) Slant Range, **S**ingle-**L**ook **C**omplex (**SLC**)

b) **G**round **R**ange, Multi-Look, **D**etected (**GRD**)

The detected products can be further classified according to their resolution into:

- **F**ull **R**esolution (**FR**) products
- **H**igh **R**esolution (**HR**) products
- **M**edium **R**esolution (**MR**) products

Resolution classes are characterised by the acquisition mode employed as well as by the level of multi-looking performed during processing.

The SLC products, being single-look products, have the resolution largely determined by the acquisition mode; therefore further classification according to resolution class does not apply for SLC products.

The resolution classes are consistent between the modes in the sense that two products of two different modes but in the same resolution class will have approximately the same key properties (as reflected in Table 5-1).

Table 5-1 presents all the valid combinations of acquisition modes, product types and resolution classes for the standard Level 1 products together with their main properties.

Table 5-1 Level 1 Product Family Summary

Acq. Mode	Product Type	Resolution Class	Resolution [1, 2] [Rng x Azi] [3] [m]	Pixel Spacing [2] [Rng x Azi] [m]	No. Looks [Rng x Azi]	ENL[4]
SM	SLC		1.7 x 4.3 to 3.6 x 4.9	1.5 x 3.6 to 3.1 x 4.1	1 x 1	1
	GRD	FR	9 **x** 9	3.5 x 3.5	2 x 2	3.7
		HR	23 x 23	10 x10	6 x 6	29.7
		MR	84 x 84	40 x 40	22 x 22	398.4
IW	SLC		2.7 x 22 to 3.5 x 22	2.3 x 14.1	1	1
	GRD	HR	20 x 22	10 x 10	5 x 1	4.4
		MR	88 x 87	40 x 40	22 x 5	81.8
EW	SLC		7.9 x 43 to 15 x 43	5.9 x 19.9	1 x 1	1
	GRD	HR	50 x 50	25 x 25	3 x 1	2.7
		MR	93 x 87	40 x 40	6 x 2	10.7
WV	SLC		2.0 x 4.8 and 3.1 x 4.8	1.7 x 4.1 and 2.7 x 4.1	1 x 1	1
	GRD	MR	52 x 51	25 x 25	13 x 13	123.7

Notes:

(1) For GRD Products, the resolution corresponds to the mid range value at mid orbit altitude, averaged over all swaths.

(2) For SLC SM/IW/EW products, the resolution and pixel spacing are provided from lowest to highest incidence angle. For SLC WV products, the resolution and pixel spacing are provided for beams WV1 and WV2.

(3) For SLC products, the range coordinate is in slant range. All the other products are in ground range.

(4) For GRD IW/EW products, the equivalent number of looks corresponds to an average over all swaths.

5.2 Product Type Descriptions

The main distinguishing characteristics of the Sentinel-1 Level 1 product types are the data type and the coordinate system of the image (see Table 5-2). Note that all Sentinel-1 Level 1 products are geo-referenced. Also note that all Sentinel-1 Level 1 products are time tagged with the zero Doppler time at the centre of the swath and that the geo-referencing is corrected for the azimuth bi-static bias by taking into account the pulse travel time delta between the centre of the swath and the range of each geo-referenced point.

Table 5-2 Sentinel-1 Level 1 Product Types

Mnemonic	Data Type	Coordinate System
SLC	Complex	Slant Range x Azimuth
GRD	Detected	Ground Range x Azimuth

Note that for products of any type generated from SM, IW or EW data, the focused image can be as long as the complete acquisition segment/strip. To ensure the homogeneity of the scene, SAR parameters that vary with the satellite position in orbit (like azimuth FM rate, Doppler Centroid Frequency, terrain height) are periodically updated to ensure the homogeneity of the scene. (See also in Section 5.5.1 the reference to the antenna elevation beam pattern correction.)

Similarly, products generated from WV data can contain any number of vignettes, potentially up to an entire orbit’s worth.

Sections 5.2.1 and 5.2.2 give brief descriptions of each Sentinel-1 Level 1 product type.

5.2.1 Slant Range, Single-Look, Complex Products (SLC)

SLC products are images in the slant range by azimuth imaging plane, in the image plane of satellite data acquisition. Each image pixel is represented by a complex (I and Q) magnitude value and therefore contains both amplitude and phase information. The processing for all SLC products results in a single look in each dimension using the full available signal bandwidth. The imagery is geo-referenced using orbit and attitude data from the satellite. SLC images are produced in a zero Doppler geometry. This convention is common with the standard slant range products available from other SAR sensors e.g. ERS-1/2, ENVISAT/ASAR, RADARSAT-1/2, TerraSAR-X.

In addition to the general SLC properties discussed above, some acquisition mode-specific properties are discussed in the sections below.

5.2.1.1 SM SLC Product

The SM SLC Products contain one image per polarisation channel (i.e. one or two images).

The SM SLC image is sampled at the natural pixel spacing. This means, the pixel spacing is determined, in azimuth by the pulse repetition frequency (PRF), and in range by the radar range sampling frequency.

The detailed definition of the SM SLC product is provided in Section 7.1.1.

5.2.1.2 IW SLC Product

The IW SLC product contains one image per sub-swath, per polarisation channel, for a total of three or six images. Each sub-swath image consists of a series of bursts, where each burst was processed as a separate SLC image. The individually focused complex burst images are included, in azimuth-time order, into a single sub-swath image, with black-fill demarcation in between, similar to the ENVISAT ASAR ScanSAR SLC product. This image format is described in further detail in the Sentinel-1 Product Specification [R-6].

Due to the one natural azimuth look inherent in the data, the imaged ground area of adjacent bursts will only marginally overlap in azimuth - just enough to provide contiguous coverage of the ground.

Unlike SM and WV SLC products, which are sampled at the natural pixel spacing, the images for all bursts in all sub-swaths of an IW SLC product are re-sampled to a common pixel spacing grid in range and azimuth. The resampling to a common grid eliminates the need of further interpolation in case, in later processing stages, the bursts are merged to create a contiguous ground range, detected image (see Section 5.2.2).

The detailed definition of the IW SLC product is provided in Section 7.2.1.

5.2.1.3 EW SLC Product

The EW SLC products contain one image per sub-swath, per polarisation channel, for a total of five or ten images.

Each TOPSAR EW burst in a sub-swath is processed as a separate SLC image, and included in a sub-swath image exactly as in the IW case. Like the IW mode, EW is a one natural azimuth look mode, and therefore the EW and IW images have similar properties.

As for the IW SLC products, the images for all bursts in all sub-swaths of an EW SLC product are re-sampled to a common pixel spacing grid in range and azimuth.

The detailed definition of the EW SLC product is provided in Section 7.3.1.

5.2.1.4 WV SLC Product

WV acquisitions consist of several vignettes, with each vignette processed as a separate image. Thus, each WV product contains multiple images, all corresponding to the single-polarisation in which the data has been acquired (VV or HH).

As the SM SLC product, the WV SLC product is sampled at the natural pixel spacing.

The detailed definition of the WV SLC product is provided in Section 7.4.1.

5.2.2 Ground Range, Multi-Look, Detected Products (GRD)

GRD products lie in the ground range by azimuth surface, with image coordinates oriented along ground range and flight direction. The standard GRD products are detected, multi-look products, with approximately square resolution cells and square pixel spacing. Multi-looking is a processing property that results in images with reduced speckle, but also with reduced resolution: the more looks the less speckle noise and the lower the resolution (see also definitions A1.3.1 to A.1.3.5).

For each mode, a number of resolution classes are defined, as described in Section 5.1; the resolution, pixel spacing and multi-look characteristics of the standard GRD products are provided in Table 5-1.

To convert from imaging slant range coordinates to ground range coordinates, a slant to ground projection is performed onto an ellipsoid (typically the WGS84 ellipsoid) corrected using terrain height, which varies in azimuth and is constant in range.

GRD images are produced in a zero Doppler geometry. The principle of generating GRD products is the same for all acquisition modes. However, for the TOPSAR modes, the multi-looking is performed on each burst individually, while for the SM mode multi-looking is performed on entire blocks of azimuth data.

For the IW and EW GRD products, as opposed to the SLC products, all the bursts in all sub-swaths are seamlessly merged to form a single, contiguous, ground range, detected image. Therefore, the IW and EW GRD products, like the SM products, contain one image per polarisation channel (i.e. either one or two images).

The definitions of the GRD products for the SM, IW, EW and WV acquisition modes are provided in Sections 7.1.2, 7.2.2, 7.3.2 and 7.4.2 respectively.

5.3 Annotation Products

An annotation product is a product created from one of the standard products described above. It is identical to the product it is based on, except that it does not include the full resolution image(s), but only the lower resolution quick-look image(s) if there is one in the base product. If generated, the annotation product is produced in addition to the original product. For L2 products, the annotation product is based on the internal L1 SLC product used as input to the L2 Processor.

Annotation products are intended for PDGS internal quality assurance, calibration and validation purposes only. They are not meant to be distributed to GMES services end-users.

5.4 Slicing Impact on L1 Products

L1 products may be generated by the Sentinel-1 IPF using one of the following processing options:

- Processing a L0 segment of data and generating a single L1 product that covers the segment
- Dividing the L0 segment of data to process into multiple slices (where slices are overlapping subsets, in the azimuth direction, of the full segment) and processing each slice separately. These slices are processed such that the multiple L1 slice products generated can be recombined into a single, continuous L1 product after all the slices have been processed. The rationale for the slicing scenario is to enable the processing of a segment of data in parallel to increase the processor throughput for SM, IW and EW acquisition modes.

Figure 5-1 depicts how the data is split in the slicing scenario, and how this affects the extents of the L1 products generated by the IPF.

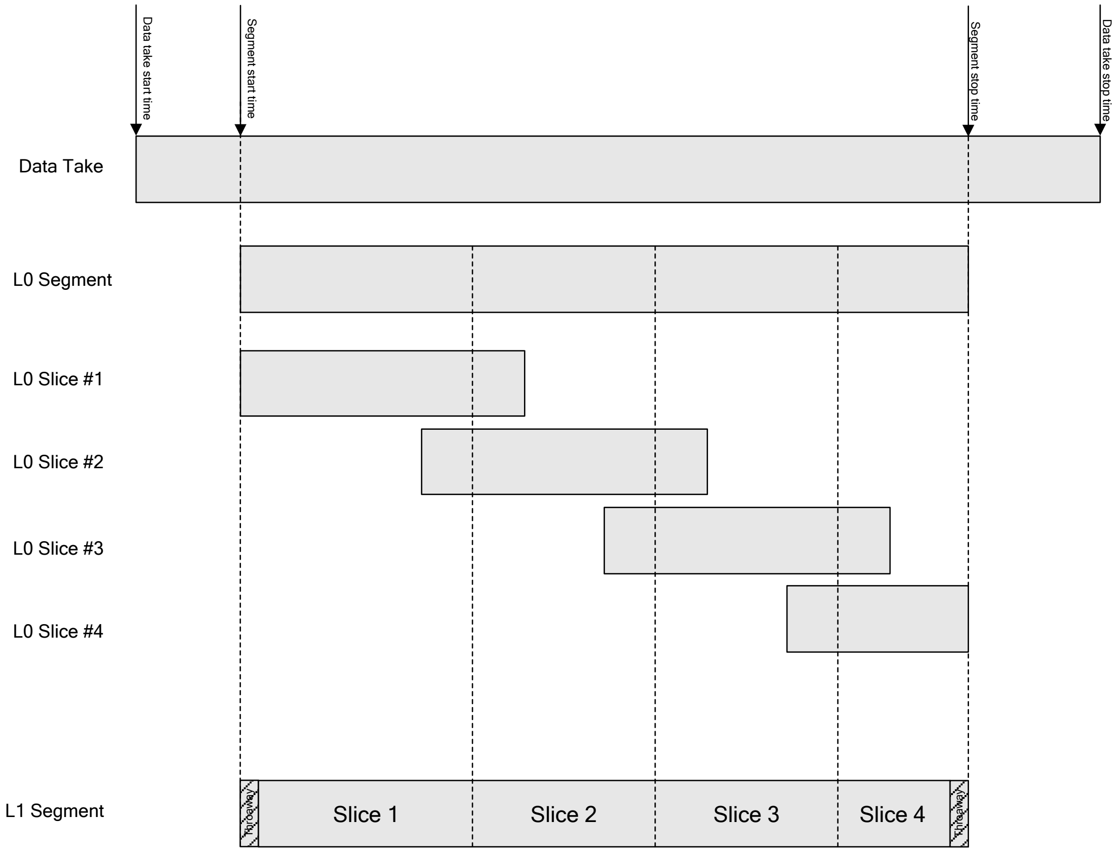

Figure 5-1 Data splitting for slicing scenario

As a result of these two processing options, the L1 products generated by the IPF for a given L0 segment of data may be either:

- An individual scene product, which is a single L1 product that covers the complete L0 segment of data (non-slicing scenario); or
- A set of L1 slice products that collectively cover the same L0 segment of data (slicing scenario before concatenation of all L1 slices was performed). These L1 products are continuous in terms of coverage (no overlap or gap between them) and in terms of radiometry and phase. As a result, it is possible to assemble them into a single L1 product that covers the segment of data. The assembly strategy for L1 slice products is described in [R-6].

L1 product characteristics described in Sections 5 and 7 are not affected by slicing in the sense that an L1 individual scene product and a set of L1 slice products generated from the same L0 segment of data have the same characteristics (collectively for the L1 slice products).

The amount of blackfill at near and far range of the L1 imagery, due to SWST changes, varies with the segment length. The longer the segment the more blackfill is present, generally. As a result, a L1 slice product which is part of a longer segment generally contains more blackfill than a non-slice product that covers the same extent as the single slice.

5.5 Radiometric Corrections

This section gives a brief description of the radiometric corrections performed by the IPF. Section 5.5.1 lists the standard radiometric corrections applied to all Level 1 products. Sections 5.5.2 and Section 5.5.3 present the following additional radiometric corrections: Thermal Noise Correction and Application-specific Output Image Scaling.

5.5.1 Standard Corrections

The SAR processor incorporates several corrections designed to compensate for variations in the radar sensor and its ability to provide repeatable measurements over periods of time. The SAR processor also compensates for variations in signal intensity due to either the antenna beam patterns or the propagation of spherical electromagnetic waves. For all products, the following corrections are applied by default during SAR processing:

- Raw signal I and Q channel bias correction
- Transmitted power and receiver (instrument) gain and other parameters and offset corrections
- Antenna elevation beam pattern correction
- Antenna azimuth beam pattern correction
- Range spreading loss compensation
- Inter-channel (phase and gain) correction, applied to dual-polarisation products. This correction is implicitly built into the extracted replicas, but it is applied as a separate processing step when using the nominal coefficients.

Note that the radiometric homogeneity of long acquisition images can potentially be affected by variations in the terrain height. To address this issue, the elevation beam pattern correction accounts for terrain height variations in both range and azimuth directions.

The azimuth antenna beam pattern removal accuracy depends on the accuracy of the antenna beam pointing determination. As explained in Section 3.2.3.1, this precision in the determination of the antenna beam pointing is greatly improved by the zero-Doppler steering capability of the Sentinel-1 platform.

5.5.2 Thermal Noise Removal

Unlike quantization noise, thermal noise is independent of the signal power. Consequently, as a result of the range varying radiometric corrections applied during SAR processing, the thermal noise contribution is reshaped in a range varying fashion, affecting in this way the quality of the image (especially in areas of low backscatter like calm seas, lakes etc). The Sentinel-1 SAR processor provides the capability to estimate and to remove the thermal noise contribution, improving in this way the quality of the detected Level 1 images. This correction is applied only to detected products. Thermal noise removal is optional and configurable. The thermal noise is provided in the product annotations to give the user the possibility to re-apply it to products where it was removed.

5.5.3 Application-Specific Output Image Scaling

The final step in producing an output image is the adjustment of the output scaling. The application of this scaling is optional and configurable. The purpose of this scaling is to:

- Optimize the radiometric scaling of the main feature of interest (while optimizing the available dynamic range in the output product),
- Compensate for changes in the radar backscatter with changing incidence angles (for the main feature of interest to the user).

To achieve these objectives, adequate Application Look-Up Tables (LUTs) are used to apply a range dependent gain function (and possibly a fixed offset) to the processed data prior to generation of the final image output.

The Application LUT applied depends on configuration parameters. Examples of application LUTs include:

- Point Target Application LUTs - suited to applications involving scattering from bright points targets. Typically these LUTs provide poor quantization over area of very low backscatter.
- The Sea, Land, Mixed and Ice LUTs - suited to the thematic applications they describe in which low backscatter features are expected. Typically, bright targets will saturate. Values vary with incidence angle.
- General application LUT – typically very bright targets will be saturated.

The application-specific scaling that has been applied by the processor is reported in the product annotations, hence the user has all the information necessary to convert the pixel integer values back to the original digital numbers.

5.6 Applications for Level 1 Products

The Sentinel-1 products are defined to serve a number of activities within the GMES Services Element. These activities, the specific information that can be extracted from the SAR images, as well as the services that could exploit this information are described in Table 5-3 (see also [R-1]).

Table 5-3 Sentinel-1 Applications

Activities/ Applications	SAR-enabled Capability	Objectives/Services
Monitoring the European Marine Environment	• Oil-spill pollution detection • Ship detection	• Gather prosecution evidence in case of illegal discharges • Support effective survey aircraft deployment and cleaning operations • Monitor activities by flag state vessels in third party waters • Monitor major shipping routes to detect illegal activities
Monitoring the Arctic Environment and Sea-Ice Zones	• Perform ice type classification • Perform sea-ice mapping • Detect changes in Arctic sea ice extent • Detect ice-infested areas along the major transport routes	• Assess environmental impact of changes in extent and properties of the Arctic ice • support transport operations
Monitoring and Assessing Land Surface-Motion Risks	• High accuracy (up to millimetre-size) detection of ground level displacements using interferometry • In particular, detection of urban subsidence, landslides and other terrain displacement to be encountered in earthquake zones, coastline zones and flood plains	• provide a Pan-European ground motion hazard information service to facilitate saving lives, improving safety and reducing economic loss • Regular measurements of subsidence over all major urban areas • Regular surveillance of transport infrastructure
Open Ocean Surveillance	• Ocean Surface Currents • Ocean Wave / Spectra • Ocean Surface Winds	• Produce wind-wave numerical forecast models (from WV mode data)
Forest Monitoring	• Detect changes in forest growth and land cover patterns • Provide forest type classification • Forest Monitoring for Climatic Change	• Forest Monitoring for Sustainable Forest Management • Forest Monitoring for Environmental Issues and Nature Protection
Water Management and Soil Protection	• ability to delineate between water and land boundaries due to the sensitivity of SAR to surface roughness • soil-moisture measurements • wetland mapping and discrimination	• Support Soil protection initiatives • Support geo-information needs of the environmental community

Activities/ Applications	SAR-enabled Capability	Objectives/Services
Forest Fire Flood Management	• Identify areas burned by forest fires, flooded areas (and areas affected by other hazards) • Identify change patterns/trends in the areas affected by various natural hazards	• Assess impact in terms of human, economic and environmental loss. • Support the organizations and institutions mandated for the management of natural hazards, throughout the prevention, anticipation, response and post-response phases • Monitoring for seasonal mapping of the areas burnt by forest fires • Perform flood risk analysis for flood risk mapping and potential loss assessment, based on historical data • Real-time awareness service for flash flood anticipation.
Food Security and Crop Monitoring	• Backscattered type classification • Monitoring of actual rainfall and vegetation growth changes (based on long-term Earth observation time-series) • Crop/vegetation classification	• Monitoring of global food security and related environmental processes • Assist stakeholders and various organizations to better implement their policies towards sustainable development • Assist agro-meteorological modeling and forecasts • monitoring and forecasts, mainly aiming at delivering detailed information on actual acreage during the agricultural season for major crop types at planting date, during the crop growth, and at harvest time,
Global Mapping for the Humanitarian Community	• Backscattered type classification • Identification of slow (e.g. famine) onset crisis areas (based on long-term Earth observation time-series) • Identification of fast (e.g. earthquake) onset crisis areas • Mapping, cartography and other SAR satellite image-derived information	• Increase the effectiveness of the humanitarian community through the appropriate and reliable application of geographical information. • Better deployment of development aid training and in-field support • Support to forecasting and alert services

Each application is best served by specific acquisition modes and product types. The mapping of applications to acquisition modes and product types are provided in Table 5-4.

Table 5-4 Mapping of Applications to Modes and Product Types

Applications	Acquisition Mode			Product Type	
	SM	IW / EW (wide coverage)	WV	SLC (Interferometry)	GRD
Monitoring the European Marine Environment		✓			✓
Monitoring the Arctic Environment and Sea-Ice Zones		✓		✓	✓
Monitoring and Assessing Land Surface-Motion Risks	✓	✓		✓	
Open Ocean Surveillance	✓	✓	✓		✓
Forest Monitoring	✓	✓		✓	✓
Water Management and Soil Protection	✓	✓		✓	✓
Forest Fire and Flood Management	✓	✓			✓
Food Security and Crop Monitoring	✓	✓			✓
Global Mapping for the Humanitarian Community	✓	✓			✓

6 LEVEL 2 PRODUCTS OVERVIEW

This section presents an overview of the Sentinel-1 Level 2 products and their properties. Section 6.1 summarizes the Level 2 product family and the main properties of each product in the family. Section 6.2 briefly describes each product type. Section 6.3 describes how the slicing scenario impacts L2 products characteristics. Finally, Sections 6.4, 6.4.2 and 6.4.3 describe Sentinel-1 Level 2 applications that can make use of Ocean Swell Spectra, Ocean Wind Field and Radial Surface Velocity information respectively.

6.1 Products Summary

For the Sentinel-1 acquisition modes discussed in Section 3.3, one type of L2 product is defined: OCeaN (OCN). The OCN product may contain the following components:

a) **O**cean **SW**ell spectra (**OSW**)

b) **O**cean **WI**nd field (**OWI**)

c) **R**adial Surface **V**e**L**ocity (**RVL**)

Table 6-1 presents all the valid combinations of acquisition modes, product type and component types for the Level 2 products as well as the type of the corresponding input Level 1 product.

Table 6-1 Level 2 Product Family Summary

Acq. Mode	Product Type	Component Type	Input Level 1 Product Type
SM	OCN	OSW	SLC
		OWI	GRD
		RVL	SLC
IW	OCN	OWI	GRD
		RVL	SLC
EW	OCN	OWI	GRD
		RVL	SLC
WV	OCN	OSW	SLC
		RVL	

6.2 Product Type Descriptions

6.2.1 Ocean Products (OCN)

Sections 6.2.1.1, 6.2.1.2 and 6.2.1.3 give a brief description of the component types that compose a Sentinel-1 L2 OCN product.

6.2.1.1 Ocean Swell Spectra Component (OSW)

The OSW component of the OCN product is a two-dimensional ocean surface swell spectra estimated from a Level 1 SLC image by inversion of the corresponding image cross-spectra. The cross spectra are computed by performing multi-looking in azimuth followed by co- and cross-spectra estimation among the detected individual look images. The OSW swell spectra is computed for each SLC vignette for WV mode, or for sub-images extracted from an SLC image for SM mode.

The OSW component is given on log-polar grid for the wavenumber and direction. The spatial and spectral resolutions depend on the mode of the SAR instrument. Because of the nature of SAR ocean imaging, the actual spectral resolution also depends on the direction of wave propagation relative to azimuth and the sea state.

The OSW component contains one estimate of the wind speed and direction per ocean swell spectrum, as well as parameters derived from the ocean swell spectra (integrated wave parameters for the five most energetic partitions) and from the vignette (image statistics). The OSW component also contains a quality cross-spectra per ocean wave spectra.

The spatial coverage of the OSW component is equal to the spatial coverage of the corresponding L1 WV SLC vignette or L1 SM SLC sub-image, limited to ocean areas.

The OSW component cannot be generated from TOPSAR data, since individual looks with sufficient time separation are required. The obtained inter look time separation within one burst is too short due to the progressive scanning (i.e. short dwell time). Individual looks from neighbouring bursts require significant spatial overlap, which is not achieved in full resolution with the standard IW and EW configurations of the TOPSAR mode.

6.2.1.2 Ocean Wind Field Component (OWI)

The OWI component of the OCN product is a gridded estimate of the surface wind speed and direction at a height of 10 m above the ocean surface. The spatial resolution of the SAR wind speed is lower than the resolution of the original L1 product and depends on the level of uncorrelated speckle noise. SAR wind speed and direction will be provided at the same resolution even if a priori wind direction from SAR-observed wind streaks or from a Numerical Weather Prediction (NWP) model has lower resolution. The spatial resolution of the wind estimate is 1 km for all modes except WV mode for which it is 20 km. In practice, the wind estimate can have a spatial resolution as fine as 500 m, depending on the effective signal to noise ratio, compared with a spatial resolution of 25 km for scatterometer wind products. Such high-resolution products could be of major benefit for coastal monitoring applications.

It is important to note that SAR wind retrieval geophysical model functions are designed to retrieve the equivalent neutral stability wind speed at a height of 10 m above the ocean surface. The model responds to changes in roughness at the ocean surface, but cannot respond directly to changes in wind speed due to atmospheric stratification. The equivalent neutral stability wind speed is defined as the mean wind speed that would be observed if there was neutral atmospheric stratification.

For WV, the wind information comes from the ECMWF atmospheric model and is reported in the OSW component, while for SM and TOPS it is derived from the L1 data and reported in the OWI component.

6.2.1.3 Radial Surface Velocity Component (RVL)

The RVL component of the OCN product is calculated based on the difference between the measured L2 Doppler grid and the geometrical Doppler calculated by the L1 processor. The measured L2 Doppler grid accounts for the antenna mispointing Doppler by including the antenna error matrix in the antenna model synthesis. The formula used to calculate the radial velocity, U_r [m/s] from the corrected Doppler frequency, f_{dc} [Hz] is given as:

$$U_r = \frac{\pi f_{dc}}{k_{rad}}$$

The variance of the radial velocity as a function of the variance of the Doppler frequency is then easily given from the same formula as:

$$\left\langle (U_r)^2 \right\rangle = \frac{\pi \left\langle (f_{dc})^2 \right\rangle}{k_{rad}}$$

The L2 Doppler is computed on a grid similar to the OWI component grid and provides an estimate of the Doppler frequency and the Doppler spectral width. The uncertainties of the estimates are also provided for both the Doppler and radial velocity.

The Doppler frequency and the Doppler spectral width are estimated based on fitting the azimuth spectral profile of the data to the antenna model taking into account additive noise, aliasing, and side band effects. The Doppler frequency provided in the product is the pure Doppler frequency estimated from the SLC data without correcting for geometry and mispointing errors.

The radial velocity can be used, in combination with the estimated wind field, to retrieve the radial component of the surface current field. However, this is not provided as part of the L2 processing.

6.3 Slicing Impact on L2 Products

L2 products may be generated from an L1 product covering a segment of data (non-slicing scenario). In this case, L2 products correspond to the segment and are called L2 individual scene products.

L2 products may also be generated from an L1 slice product that covers a single slice (slicing scenario before concatenation of L1 slices was performed). In this case, L2 products correspond to a single slice and are called L2 slice products. The L2 slices are not processed in a way that would allow easy concatenation between them; in other words the grids are not aligned between L2 slices. Note that having assembled L2 products covering the complete segment is not necessary for L2 applications.

L2 product characteristics described in Sections 6 and 8 are not affected by slicing in the sense that an L2 individual scene product (non-slicing scenario) and a set of L2 slice products (slicing scenario without concatenation of L1 slice products) generated from the same segment of data have the same approximate characteristics (collectively for the L2 slice products).

6.4 Applications for L2 OCN Products

6.4.1 OSW Component

6.4.1.1 Applications

The following applications can benefit from the OSW component of Sentinel-1 OCN products:

a) **Numerical Weather Prediction Models and Wave Forecasting**: Since ocean swell systems are observed to propagate over long distances, their energy should be conserved or weakly dissipated. However, limited quantitative information is available on this topic leading to relatively poor prediction of swell systems [R-10]. Numerical wave models that neither account specifically for swell dissipation, nor assimilate wave measurements, invariably overestimate significant wave heights in the tropics [R-11], [R-12]. The OSW component can be used to assess the performance of swell prediction in global numerical wave models, and thus help improve the models. The OSW component can be used to assess the performance of swell prediction in global NWP models, and can thus help to improve the models. Another related application is the assimilation of OSW components into operational numerical wave prediction models such as Wave Prediction Model (WAM). Impact studies have been conducted and validation shows a positive impact in swell dominated areas [R-13].

b) **Wave Climate**: The OSW component can provide input to a global database of high-quality wave information. In combination with existing software packages (e.g., statistical and wave propagation tools) that utilize the wave database, wave climate statistics and/or time series of wave height, period and direction can be provided at any coastal or offshore site worldwide. Such tools exist already in the market [R-14].

c) **Earth Observation System**: Earth observation systems rely extensively on satellite remote sensing techniques for ocean surface winds, sea surface temperature, sea level, ocean colour, and sea ice, which all again are highly affected by ocean waves. The mutual coupling between different ocean parameters and how they are manifested in satellite measurements, require precise modelling and measurements of all key ocean parameters. Since ocean waves can be viewed as the “gearbox” between atmosphere and ocean, a detailed understanding and knowledge of waves can significantly improve the parameterisation of air-sea fluxes and surface processes [R-15].

6.4.1.2 GMES services

The following GMES services are expected to benefit from the OSW component of Sentinel-1 OCN products:

a) **Marine and coastal environmental information services:** The objective of the GMES marine core services is to streamline consistent European capacities for forecasting, monitoring and reporting on the ocean state, and to foster derived applications (downstream GMES services) on specific environmental and safety issues, for both the global ocean and the regional European seas. Considering the applications above, the GMES services that benefit from the OSW component indirectly through these applications are related to:

  - Exploitation and management of ocean resources (e.g. offshore oil and gas industry, fisheries);
  - Safety and efficiency of maritime transport, shipping, and naval operations;
  - Marine research (e.g. understanding of the oceans and their ecosystems, of ocean climate variability);
  - Seasonal climate prediction;
  - Coastal management and planning (e.g. coastal flooding and erosion).

b) The OSW component is a natural part of the open ocean (sea-state) application areas of Sentinel-1 in relation to the Marine Core Services [R-16].

6.4.1.3 Basic User Requirements

The two main users of the OSW component are the meteorological community and the oceanographic service providers. The meteorological community requires *systematic*, *near-real time* access to the products acquired *globally* over the *open ocean*. The preferable Sentinel-1 mode of operation for these users is the Wave Mode.

The oceanographic service providers require both systematic and on-demand products from global (open ocean) and local (coastline) coverage. The preferable Sentinel-1 mode of operation is the Stripmap mode over coastline (on-demand) and Wave Mode over open ocean areas (systematic).

6.4.2 OWI Component

6.4.2.1 Applications

The following applications can benefit from the OWI component of Sentinel-1 OCN products:

a) **Numerical Weather Prediction Models Forecast**: It is well known that wind is poorly represented at very high resolution in numerical models. The OWI component can be used to assess the performance of wind prediction in coastal areas where NWP models have difficulties accounting for complex orographic effects. Another related application is the assimilation of OWI components into NWP models.

b) **Wind Climate**: The OWI component can provide input to a global database of high-quality wind information. Wind climate statistics and/or time series of wind speed and direction can be provided at any coastal or offshore site worldwide.

6.4.2.2 GMES Services

The following GMES services are expected to benefit from the OWI component of Sentinel-1 OCN products:

a) **Marine and coastal environmental information services:** The objective of the GMES marine core services is to streamline consistent European capacities for forecasting, monitoring and reporting on the ocean state, and to foster derived applications (downstream GMES services) on specific environmental and safety issues, for both the global ocean and the regional European seas. Considering the applications above, the GMES services that benefit from the OWI component indirectly through these applications are related to:

- Oil spill detection from SAR images since the SAR-derived wind is a key parameter to help discriminate look-alikes from actual spills. This is currently used in CLEANSEANET operational oil spill service provided by EMSA; the wind retrieval is an external product used for oil spill monitoring since the synoptic view on the wind map helps to actually search for the oil spills. In existing operational environment such as with EMSA, the L2 product is generated just before starting the oil analysis since the L2 are not produced in the same software that L1 processing.
- Exploitation and management of ocean resources (e.g. offshore oil and gas industry, fisheries);
- Safety and efficiency of maritime transport, shipping, and naval operations;
- Marine research (e.g. understanding of the oceans and their ecosystems, of ocean climate variability);

- Seasonal climate prediction;
- Coastal management and planning (e.g. coastal flooding and erosion).

b) The OWI component is a natural part of the open ocean (sea-state) surveillance defined as one of the application areas of Sentinal-1 in relation to the Marine Core Services [R-16].

Note that Met centers or GMES services are only interested in L2 products, whereas experts are interested in L1 products to work on algorithms or provide L2 to end users. But we know from experience that operational processing in ground segments should be driven by experts to provide fast response to the many issues that can arise at any time of the mission on the L1 products that will not necessarily be easily detected on L1 but clearly modify the quality of L2. This is particularly the case with the incidence angle annotation and absolute calibration.

6.4.3 RVL Component

The applications for the RVL component of Sentinel-1 OCN products are similar to those for the OWI component (refer to Section 6.4.2.1).

The GMES services expected to benefit from the RVL component are similar to those for the OWI component (refer to Section 6.4.2.2).

The RVL component can be used in combination with the OWI component to extract the radial surface current field.

7 LEVEL 1 PRODUCTS DEFINITION

This section provides the detailed characteristics of the standard Sentinel-1 Level 1 products for each image mode. Descriptions of the terms used in the product definition tables are given in Appendix A1.

The Level 1 products are identified by a combination of up to three mnemonics, each corresponding to the following acquisition mode or product characteristics:

- The acquisition mode, as defined in Section 3.3 (SM, IW, EW or WV).
- The product type, as defined in Section 5.2 (SLC or GRD).
- The resolution class, as defined in Section 5.1 (FR, HR or MR).

If one of the mnemonics is not applicable, for instance the resolution class for SLC products, it will be omitted. For example, the identifier IW_GRD_HR corresponds to a high resolution multi-look GRD product generated from data acquired in IW mode.

The image quality values currently included in the tables (resolution, ISLR, PSLR ambiguity ratios, NESZ, radiometric accuracy, location accuracy) are to be understood in the theoretical sense. The pixel localisation accuracy values are currently the predicted values, which are based on the calibration and performance budgets presented in [R-4].

The actual image quality characteristics will be derived from measurement performed on real data images, during the commissioning phase.

The number of lines and the data volumes in the tables are provided as examples only. Actual products have a variable number of lines and a variable volume.

The resolutions in the tables correspond to an average over the minimum and maximum orbits, and to the following swath range positions:

- near range, for azimuth resolution
- mid range, for ground range resolution
- any, for slant range resolution (it does not vary with the range position within a swath).

7.1 Stripmap L1 Products Definition

7.1.1 Stripmap SLC Product Definition

Table 7-1 Stripmap SLC Product

Product ID	SM_SLC					
Product Type	Stripmap, Slant-Range, Single Look, Complex					
Main Product Characteristics						
Pixel Value	Complex					
Coordinate System	Slant Range					
Bits Per Pixel	16 I and 16 Q					
Polarisation Options	Single (HH or VV) or Dual (HH+HV or VV+VH)					
Beam ID	S1	S2	S3	S4	S5	S6
Ground Range Coverage [km]	80.1					
Slant Range Resolution [m]	1.7	2	2.5	3	3.3	3.6
Azimuth Resolution [m]	4.3	4.9	3.6	4.8	3.9	4.9
Slant Range Pixel Spacing [m]	1.5	1.8	2.2	2.6	2.9	3.1
Azimuth Pixel Spacing [m]	3.6	4.2	3.5	4.1	3.6	4.1
Incidence angle [°]	22.3	25.6	31.2	36.4	41	43.8
Equivalent Number of Looks (ENL)	1					
Radiometric Resolution	3					
Product Performance Parameters						
Range PSLR [dB]	< -21.2					
Azimuth PSLR [dB]	< -21.2					
Range ISLR [dB]	< -16.1					
Azimuth ISLR [dB]	< -16.1					
Distributed Target Ambiguity Ratios [dB]	< -22.3					
Point Target Ambiguity Ratios [dB]	< -32.2					
NESZ [dB]	< -22.2					
Channel Co-registration Accuracy [pixels]	< 0.25					
Absolute Radiometric Accuracy [dB] (3 sigma)	1					
Relative Radiometric Accuracy [dB] (3 sigma)	0.1					
Absolute Location Accuracy [m] (NRT)	2.5					
SAR Processing Parameters						
Number of Looks (range x azimuth)	1 x 1					
Look overlap (range x azimuth)	N/A					
Range Look Bandwidth [Hz]	87.6	74.2	59.4	50.6	44.9	42.2
Azimuth Look Bandwidth [Hz]	1586	1405	1904	1429	1886	1398
Range Hamming Weighting Coefficient	0.75	0.75	0.75	0.75	0.75	0.75
Azimuth Hamming Weighting Coefficient	0.75	0.75	0.75	0.75	0.65	0.75

Data Size & Volume for a 25 Second Long (Approximately 170 km Azimuth Coverage) Product						
Approx # of Lines	46800	40400	48200	41300	47500	41600
Approx # of Pixels per Line	21500	20600	19600	19000	18600	18400
Max Data Volume (Single Polarisation) [MB]	3840	3176	3605	2995	3372	2921
Max Data Volume (Dual Polarisation) [MB]	7680	6352	7210	5990	6744	5842
Quick-Look Characteristics						
Bits Per Pixel	8					
Range Decimation Factor	39					
Azimuth Decimation Factor	24					
Range Averaging Factor	59					
Azimuth Averaging Factor	36					
Range Resolution [m]	66.8	78.8	98.5	115.6	130.3	138.6
Azimuth Resolution [m]	103.2	116.4	85.9	114.3	94.8	116.7
Range Pixel Spacing [m]	58	68.5	85.6	100.5	113.2	120.5
Azimuth Pixel Spacing [m]	87.4	101.4	84.9	98.9	85.9	98
Approx # of Lines	1950	1690	2010	1730	1980	1740
Approx # of Pixels per Line	560	530	510	490	480	480

7.1.2 Stripmap GRD Products Definition

Table 7-2 Stripmap GRD FR Product

Product ID	SM_GRD_FR					
Product Type	Stripmap, Ground Range, Multi-look, Detected, Full Resolution					
Main Product Characteristics						
Pixel Value	Magnitude Detected					
Coordinate System	Ground Range					
Bits Per Pixel	16					
Polarisation Options	Single (HH or VV) or Dual (HH+HV or VV+VH)					
Beam ID	S1	S2	S3	S4	S5	S6
Ground Range Coverage [km]	80.1					
Ground Range Resolution [m]	8.1	8.4	8.8	9	9.2	9.2
Azimuth Resolution [m]	8.1	8.7	8.8	8.9	8.9	9.1
Ground Range Pixel Spacing [m]	4					
Azimuth Pixel Spacing [m]	4					
Incidence angle [°]	22.3	25.6	31.2	36.4	41	43.8
Equivalent Number of Looks (ENL)	3.5	3.5	3.7	3.5	3.7	3.5
Radiometric Resolution	1.9	1.9	1.8	1.9	1.8	1.9

Product Performance Parameters						
Range PSLR [dB]	< -21.2					
Azimuth PSLR [dB]	< -21.2					
Range ISLR [dB]	< -16.1					
Azimuth ISLR [dB]	< -16.1					
Distributed Target Ambiguity Ratios [dB]	< -22.3					
Point Target Ambiguity Ratios [dB]	< -32.2					
NESZ [dB]	< -22.2					
Channel Co-registration Accuracy [pixels]	< 0.25					
Absolute Radiometric Accuracy [dB] (3 sigma)	1					
Relative Radiometric Accuracy [dB] (3 sigma)	0.1					
Absolute Location Accuracy [m] (NRT)	2.5					
SAR Processing Parameters						
Number of Looks (range x azimuth)	2 x 2					
Look overlap (range x azimuth)	0.200 x 0.200					
Range Look Bandwidth [Hz]	48.7	41.2	33	28.1	24.9	23.4
Azimuth Look Bandwidth [Hz]	881	781	1058	794	1048	777
Range Hamming Weighting Coefficient	0.75	0.75	0.75	0.75	0.75	0.75
Azimuth Hamming Weighting Coefficient	0.7	0.75	0.52	0.7	0.52	0.7
Data Size & Volume for a 25 Second Long (Approximately 170 km Azimuth Coverage) Product						
Approx # of Lines	48700					
Approx # of Pixels per Line	22900					
Max Data Volume (Single Polarisation) [MB]	2128					
Max Data Volume (Dual Polarisation) [MB]	4256					
Quick-Look Characteristics						
Bits Per Pixel	8					
Range Decimation Factor	40					
Azimuth Decimation Factor	40					
Range Averaging Factor	60					
Azimuth Averaging Factor	60					
Range Resolution [m]	325	336.5	350.6	359.9	366.5	369.9
Azimuth Resolution [m]	322.3	349.3	351.8	357.2	354.6	364.6
Range Pixel Spacing [m]	140					
Azimuth Pixel Spacing [m]	140					
Approx # of Lines	1220					
Approx # of Pixels per Line	580					

Table 7-3 Stripmap GRD HR Product

Product ID	SM_GRD_HR					
Product Type	Stripmap, Ground Range, Multi-look, Detected, High Resolution					
Main Product Characteristics						
Pixel Value	Magnitude Detected					
Coordinate System	Ground Range					
Bits Per Pixel	16					
Polarisation Options	Single (HH or VV) or Dual (HH+HV or VV+VH)					
Beam ID	S1	S2	S3	S4	S5	S6
Ground Range Coverage [km]	80.1					
Ground Range Resolution [m]	21.4	22.2	23.1	23.7	24.2	24.4
Azimuth Resolution [m]	21.3	23	23.2	23.6	23.4	24.1
Ground Range Pixel Spacing [m]	10					
Azimuth Pixel Spacing [m]	10					
Incidence angle [°]	22.3	25.6	31.2	36.4	41	43.8
Equivalent Number of Looks (ENL)	26.8	26.3	29.7	26.8	29.7	26.8
Radiometric Resolution	0.8	0.8	0.7	0.8	0.7	0.8
Product Performance Parameters						
Range PSLR [dB]	< -21.2					
Azimuth PSLR [dB]	< -21.2					
Range ISLR [dB]	< -16.1					
Azimuth ISLR [dB]	< -16.1					
Distributed Target Ambiguity Ratios [dB]	< -22.3					
Point Target Ambiguity Ratios [dB]	< -32.2					
NESZ [dB]	< -22.2					
Channel Co-registration Accuracy [pixels]	< 0.25					
Absolute Radiometric Accuracy [dB] (3 sigma)	1					
Relative Radiometric Accuracy [dB] (3 sigma)	0.1					
Absolute Location Accuracy [m] (NRT)	2.5					
SAR Processing Parameters						
Number of Looks (range x azimuth)	6 x 6					
Look overlap (range x azimuth)	0.250 x 0.250					
Range Look Bandwidth [Hz]	18.4	15.6	12.5	10.7	9.5	8.9
Azimuth Look Bandwidth [Hz]	334	296	401	301	397	294
Range Hamming Weighting Coefficient	0.75	0.75	0.75	0.75	0.75	0.75
Azimuth Hamming Weighting Coefficient	0.7	0.75	0.52	0.7	0.52	0.7
Data Size & Volume for a 25 Second Long (Approximately 170 km Azimuth Coverage) Product						
Approx # of Lines	17100					
Approx # of Pixels per Line	8100					
Max Data Volume (Single Polarisation) [MB]	265					
Max Data Volume (Dual Polarisation) [MB]	530					

Quick-Look Characteristics						
Bits Per Pixel	8					
Range Decimation Factor	16					
Azimuth Decimation Factor	16					
Range Averaging Factor	24					
Azimuth Averaging Factor	24					
Range Resolution [m]	343	355.2	370	379.9	386.8	390.4
Azimuth Resolution [m]	340.3	368.7	371.3	377	374.3	384.8
Range Pixel Spacing [m]	160					
Azimuth Pixel Spacing [m]	160					
Approx # of Lines	1070					
Approx # of Pixels per Line	510					

Table 7-4 Stripmap GRD MR Product

Product ID	SM_GRD_MR					
Product Type	Stripmap, Ground Range, Multi-look, Detected, Medium Resolution					
Main Product Characteristics						
Pixel Value	Magnitude Detected					
Coordinate System	Ground Range					
Bits Per Pixel	16					
Polarisation Options	Single (HH or VV) or Dual (HH+HV or VV+VH)					
Beam ID	S1	S2	S3	S4	S5	S6
Ground Range Coverage [km]	80.1					
Ground Range Resolution [m]	78	80.7	84.1	86.4	87.9	88.7
Azimuth Resolution [m]	77.3	83.8	84.4	85.7	85.1	87.5
Ground Range Pixel Spacing [m]	40					
Azimuth Pixel Spacing [m]	40					
Incidence angle [°]	22.3	25.6	31.2	36.4	41	43.8
Equivalent Number of Looks (ENL)	358.3	350.5	398.4	358.3	398.4	358.3
Radiometric Resolution	0.2	0.2	0.2	0.2	0.2	0.2

Product Performance Parameters						
Range PSLR [dB]	< -21.2					
Azimuth PSLR [dB]	< -21.2					
Range ISLR [dB]	< -16.1					
Azimuth ISLR [dB]	< -16.1					
Distributed Target Ambiguity Ratios [dB]	< -22.3					
Point Target Ambiguity Ratios [dB]	< -32.2					
NESZ [dB]	< -22.2					
Channel Co-registration Accuracy [pixels]	< 0.25					
Absolute Radiometric Accuracy [dB] (3 sigma)	1					
Relative Radiometric Accuracy [dB] (3 sigma)	0.1					
Absolute Location Accuracy [m] (NRT)	2.5					
SAR Processing Parameters						
Number of Looks (range x azimuth)	22 x 22					
Look overlap (range x azimuth)	0.225 x 0.225					
Range Look Bandwidth [Hz]	5.1	4.3	3.4	2.9	2.6	2.4
Azimuth Look Bandwidth [Hz]	92	81	110	83	109	81
Range Hamming Weighting Coefficient	0.75	0.75	0.75	0.75	0.75	0.75
Azimuth Hamming Weighting Coefficient	0.7	0.75	0.52	0.7	0.52	0.7
Data Size & Volume for a 25 Second Long (Approximately 170 km Azimuth Coverage) Product						
Approx # of Lines	4300					
Approx # of Pixels per Line	2100					
Max Data Volume (Single Polarisation) [MB]	18					
Max Data Volume (Dual Polarisation) [MB]	36					
Quick-Look Characteristics						
Bits Per Pixel	8					
Range Decimation Factor	4					
Azimuth Decimation Factor	4					
Range Averaging Factor	6					
Azimuth Averaging Factor	6					
Range Resolution [m]	311.9	323	336.4	345.5	351.7	355
Azimuth Resolution [m]	309.4	335.3	337.6	342.8	340.3	349.9
Range Pixel Spacing [m]	160					
Azimuth Pixel Spacing [m]	160					
Approx # of Lines	1080					
Approx # of Pixels per Line	530					

7.2 Interferometric Wide Swath L1 Products Definition

7.2.1 Interferometric Wide Swath SLC Product Definition

Table 7-5 Interferometric Wide Swath SLC Product

Product ID	IW_SLC		
Product Type	Interferometric Wide Swath, Slant-Range, Single Look, Complex		
Main Product Characteristics			
Pixel Value	Complex		
Coordinate System	Slant Range		
Bits Per Pixel	16 I and 16 Q		
Polarisation Options	Single (HH or VV) or Dual (HH+HV or VV+VH)		
Beam ID	IW1	IW2	IW3
Ground Range Coverage [km]	251.8		
Slant Range Resolution [m]	2.7	3.1	3.5
Azimuth Resolution [m]	22.5	22.7	22.6
Slant Range Pixel Spacing [m]	2.3	2.3	2.3
Azimuth Pixel Spacing [m]	14.1	14.1	14.1
Incidence angle [°]	32.9	38.3	43.1
Equivalent Number of Looks (ENL)	1		
Radiometric Resolution	3		
Product Performance Parameters			
Range PSLR [dB]	< -21.2		
Azimuth PSLR [dB]	< -21.2		
Range ISLR [dB]	< -16.1		
Azimuth ISLR [dB]	< -16.1		
Distributed Target Ambiguity Ratios [dB]	< -22.5		
Point Target Ambiguity Ratios [dB]	< -27.2		
NESZ [dB]	< -23.7		
Channel Co-registration Accuracy [pixels]	< 0.25		
Absolute Radiometric Accuracy [dB] (3 sigma)	1		
Relative Radiometric Accuracy [dB] (3 sigma)	0.1		
Absolute Location Accuracy [m] (NRT)	7		

SAR Processing Parameters			
Number of Looks (range x azimuth)	1 x 1		
Look overlap (range x azimuth)	N/A		
Range Look Bandwidth [Hz]	56.5	48.3	42.8
Azimuth Look Bandwidth [Hz]	315	301	301
Range Hamming Weighting Coefficient	0.75	0.75	0.75
Azimuth Hamming Weighting Coefficient	0.7	0.75	0.75
Data Size & Volume for a 25 Second Long (Approximately 170 km Azimuth Coverage) Product			
Approx # of Lines	14600	14600	14600
Approx # of Pixels per Line	20800	24800	24100
Max Data Volume (Single Polarisation) [MB]	1160	1383	1344
Max Data Volume (Dual Polarisation) [MB]	2320	2766	2688
Quick-Look Characteristics			
Bits Per Pixel	8		
Range Decimation Factor	46		
Azimuth Decimation Factor	6		
Range Averaging Factor	69		
Azimuth Averaging Factor	9		
Range Resolution [m]	122.1	142.8	161.2
Azimuth Resolution [m]	136.96	137.02	136.91
Range Pixel Spacing [m]	106.1	106.1	106.1
Azimuth Pixel Spacing [m]	84.5	84.5	84.5
Approx # of Lines	2440	2440	2440
Approx # of Pixels per Line	460	540	530

7.2.2 Interferometric Wide Swath GRD Products Definition

Table 7-6 Interferometric Wide Swath GRD HR Product

Product ID	**IW_GRD_HR**		
Product Type	Interferometric Wide Swath, Ground-Range, Multi-Look, Detected, High Resolution		
Main Product Characteristics			
Pixel Value	Magnitude Detected		
Coordinate System	Ground Range		
Bits Per Pixel	16		
Polarisation Options	Single (HH or VV) or Dual(HH+HV or VV+VH)		
Beam ID	IW1	IW2	IW3
Ground Range Coverage [km]	251.8		
Ground Range Resolution [m]	20.4	20.3	20.5
Azimuth Resolution [m]	22.5	22.6	22.6
Ground Range Pixel Spacing [m]	10		
Azimuth Pixel Spacing [m]	10		
Incidence angle [°]	32.9	38.3	43.1
Equivalent Number of Looks (ENL)	4.4	4.4	4.3
Radiometric Resolution	1.7	1.7	1.7
Product Performance Parameters			
Range PSLR [dB]	< -21.2		
Azimuth PSLR [dB]	< -21.2		
Range ISLR [dB]	< -16.1		
Azimuth ISLR [dB]	< -16.1		
Distributed Target Ambiguity Ratios [dB]	< -22.5		
Point Target Ambiguity Ratios [dB]	< -27.2		
NESZ [dB]	< -23.7		
Channel Co-registration Accuracy [pixels]	< 0.25		
Absolute Radiometric Accuracy [dB] (3 sigma)	1		
Relative Radiometric Accuracy [dB] (3 sigma)	0.1		
Absolute Location Accuracy [m] (NRT)	7		
SAR Processing Parameters			
Number of Looks (range x azimuth)	5 x 1		
Look overlap (range x azimuth)	0.250 x 0.000		
Range Look Bandwidth [Hz]	14.1	12.1	10.7
Azimuth Look Bandwidth [Hz]	315	301	301
Range Hamming Weighting Coefficient	0.7	0.73	0.75
Azimuth Hamming Weighting Coefficient	0.7	0.75	0.75

Data Size & Volume for a 25 Second Long (Approximately 170 km Azimuth Coverage) Product			
Approx # of Lines	17100		
Approx # of Pixels per Line	25200		
Max Data Volume (Single Polarisation) [MB]	822		
Max Data Volume (Dual Polarisation) [MB]	1644		
Quick-Look Characteristics			
Bits Per Pixel	8		
Range Decimation Factor	50		
Azimuth Decimation Factor	49		
Range Averaging Factor	75		
Azimuth Averaging Factor	74		
Range Resolution [m]	1017.6	1016.3	1026.5
Azimuth Resolution [m]	1104.6	1109.6	1106.31060
Range Pixel Spacing [m]	500		
Azimuth Pixel Spacing [m]	490		
Approx # of Lines	350		
Approx # of Pixels per Line	510		

Table 7-7 Interferometric Wide Swath GRD MR Products

Product ID	IW_GRD_MR		
Product Type	Interferometric Wide Swath, Ground-Range, Multi-Look, Detected, Medium Resolution		
Main Product Characteristics			
Pixel Value	Magnitude Detected		
Coordinate System	Ground Range		
Bits Per Pixel	16		
Polarisation Options	Single (HH or VV) or Dual(HH+HV or VV+VH)		
Beam ID	IW1	IW2	IW3
Ground Range Coverage [km]	251.8		
Ground Range Resolution [m]	87.9	87.8	88.7
Azimuth Resolution [m]	90.2	90.6	90.3
Ground Range Pixel Spacing [m]	40		
Azimuth Pixel Spacing [m]	40		
Incidence angle [°]	32.9	38.3	43.1
Equivalent Number of Looks (ENL)	83.9	81.2	80.5
Radiometric Resolution	0.4	0.5	0.5

Product Performance Parameters			
Range PSLR [dB]	< -21.2		
Azimuth PSLR [dB]	< -21.2		
Range ISLR [dB]	< -16.1		
Azimuth ISLR [dB]	< -16.1		
Distributed Target Ambiguity Ratios [dB]	< -22.5		
Point Target Ambiguity Ratios [dB]	< -27.2		
NESZ [dB]	< -23.7		
Channel Co-registration Accuracy [pixels]	< 0.25		
Absolute Radiometric Accuracy [dB] (3 sigma)	1		
Relative Radiometric Accuracy [dB] (3 sigma)	0.1		
Absolute Location Accuracy [m] (NRT)	7		
SAR Processing Parameters			
Number of Looks (range x azimuth)	22 x 5		
Look overlap (range x azimuth)	0.225 x 0.250		
Range Look Bandwidth [Hz]	3.3	2.8	2.5
Azimuth Look Bandwidth [Hz]	79	75	75
Range Hamming Weighting Coefficient	0.7	0.73	0.75
Azimuth Hamming Weighting Coefficient	0.7	0.75	0.75
Data Size & Volume for a 25 Second Long (Approximately 170 km Azimuth Coverage) Product			
Approx # of Lines	4300		
Approx # of Pixels per Line	6300		
Max Data Volume (Single Polarisation) [MB]	52		
Max Data Volume (Dual Polarisation) [MB]	104		
Quick-Look Characteristics			
Bits Per Pixel	8		
Range Decimation Factor	12		
Azimuth Decimation Factor	12		
Range Averaging Factor	18		
Azimuth Averaging Factor	18		
Range Resolution [m]	1054.7	1053.4	1064
Azimuth Resolution [m]	1082	1087	1083.7
Range Pixel Spacing [m]	480		
Azimuth Pixel Spacing [m]	480		
Approx # of Lines	360		
Approx # of Pixels per Line	530		

7.3 Extra Wide Swath L1 Products Definition

7.3.1 Extra Wide Swath SLC Product Definition

Table 7-8 Extra Wide Swath SLC Product

Product ID	EW_SLC				
Product Type	Extra Wide Swath, Slant-Range, Single Look, Complex				
Main Product Characteristics					
Pixel Value	Complex				
Coordinate System	Slant Range				
Bits Per Pixel	16 I and 16 Q				
Polarisation Options	Single (HH or VV) or Dual (HH+HV or VV+VH)				
Beam ID	EW1	EW2	EW3	EW4	EW5
Ground Range Coverage [km]	410				
Slant Range Resolution [m]	7.9	9.9	11.6	13.3	14.4
Azimuth Resolution [m]	43.7	44.3	45.2	45.6	44.0
Slant Range Pixel Spacing [m]	5.9	5.9	5.9	5.9	5.9
Azimuth Pixel Spacing [m]	19.9	19.9	19.9	19.9	19.9
Incidence angle [°]	23.7	30.9	36.2	40.9	44.5
Equivalent Number of Looks (ENL)	1				
Radiometric Resolution	3				
Product Performance Parameters					
Range PSLR [dB]	< -21.2				
Azimuth PSLR [dB]	< -21.2				
Range ISLR [dB]	< -16.1				
Azimuth ISLR [dB]	< -16.1				
Distributed Target Ambiguity Ratios [dB]	< -23.1				
Point Target Ambiguity Ratios [dB]	< -27.4				
NESZ [dB]	< -23.1				
Channel Co-registration Accuracy [pixels]	< 0.25				
Absolute Radiometric Accuracy [dB] (3 sigma)	1				
Relative Radiometric Accuracy [dB] (3 sigma)	0.1				
Absolute Location Accuracy [m] (NRT)	Not Specified				
SAR Processing Parameters					
Number of Looks (range x azimuth)	1 x 1				
Look overlap (range x azimuth)	N/A				
Range Look Bandwidth [Hz]	22.2	15.1	12.9	11.3	10.4
Azimuth Look Bandwidth [Hz]	225	154	151	149	154
Range Hamming Weighting Coefficient	0.6	0.75	0.75	0.75	0.75
Azimuth Hamming Weighting Coefficient	0.5	0.75	0.75	0.75	0.75

Data Size & Volume for a 60 Second Long (Approximately 400 km Azimuth Coverage) Product					
Approx # of Lines	23700	23700	23700	23700	23600
Approx # of Pixels per Line	8600	7000	8700	8700	7500
Max Data Volume (Single Polarisation) [MB]	781	636	790	790	678
Max Data Volume (Dual Polarisation) [MB]	1562	1272	1580	1580	1356
Quick-Look Characteristics					
Bits Per Pixel	8				
Range Decimation Factor	16				
Azimuth Decimation Factor	4				
Range Averaging Factor	24				
Azimuth Averaging Factor	6				
Range Resolution [m]	126.4	158.9	186	212.4	230.7
Azimuth Resolution [m]	174.8	177.2	180.7	182.2	176.2
Range Pixel Spacing [m]	93.9	93.9	93.9	93.9	93.9
Azimuth Pixel Spacing [m]	79.6	79.6	79.6	79.6	79.6
Approx # of Lines	5930	5930	5930	5930	5900
Approx # of Pixels per Line	540	440	550	550	470

7.3.2 Extra Wide Swath GRD Products Definition

Table 7-9 Extra Wide Swath GRD HR Product

Product ID	**EW_GRD_HR**				
Product Type	Extra Wide Swath, Ground-Range, Multi-Look, Detected, High Resolution				
Main Product Characteristics					
Pixel Value	Magnitude Detected				
Coordinate System	Ground Range				
Bits Per Pixel	16				
Polarisation Options	Single (HH or VV) or Dual (HH+HV or VV+VH)				
Beam ID	EW1	EW2	EW3	EW4	EW5
Ground Range Coverage [km]	410				
Ground Range Resolution [m]	49.1	50.3	50.4	50.7	51.4
Azimuth Resolution [m]	51.5	51.1	51.34	51.1	51.5
Ground Range Pixel Spacing [m]	25				
Azimuth Pixel Spacing [m]	25				
Incidence angle [°]	23.7	30.9	36.2	40.9	44.5
Equivalent Number of Looks (ENL)	2.8	2.7	2.7	2.7	2.7
Radiometric Resolution	2	2.1	2.1	2.1	2.1

Product Performance Parameters					
Range PSLR [dB]	< -21.2				
Azimuth PSLR [dB]	< -28.3				
Range ISLR [dB]	< -16.1				
Azimuth ISLR [dB]	< -19.4				
Distributed Target Ambiguity Ratios [dB]	< -23.1				
Point Target Ambiguity Ratios [dB]	< -27.4				
NESZ [dB]	< -23.1				
Channel Co-registration Accuracy [pixels]	< 0.25				
Absolute Radiometric Accuracy [dB] (3 sigma)	1				
Relative Radiometric Accuracy [dB] (3 sigma)	0.1				
Absolute Location Accuracy [m] (NRT)	Not Specified				
SAR Processing Parameters					
Number of Looks (range x azimuth)	3 x 1	3 x 1	3 x 1	3 x 1	3 x 1
Look overlap (range x azimuth)	0.250 x 0.000				
Range Look Bandwidth [Hz]	8.9	6	5.2	4.5	4.2
Azimuth Look Bandwidth [Hz]	155	154	151	149	154
Range Hamming Weighting Coefficient	0.6	0.7	0.72	0.75	0.75
Azimuth Hamming Weighting Coefficient	0.6	0.61	0.62	0.63	0.6
Data Size & Volume for a 60 Second Long (Approximately 400 km Azimuth Coverage) Product					
Approx # of Lines	16400				
Approx # of Pixels per Line	16600				
Max Data Volume (Single Polarisation) [MB]	520				
Max Data Volume (Dual Polarisation) [MB]	1040				
Quick-Look Characteristics					
Bits Per Pixel	8				
Range Decimation Factor	32				
Azimuth Decimation Factor	33				
Range Averaging Factor	48				
Azimuth Averaging Factor	50				
Range Resolution [m]	1571.4	1610.1	1613.8	1623	1645.3
Azimuth Resolution [m]	1699.1	1684.8	1694.2	1686.8	1699.6
Range Pixel Spacing [m]	800				
Azimuth Pixel Spacing [m]	825				
Approx # of Lines	500				
Approx # of Pixels per Line	520				

Table 7-10 Extra Wide Swath GRD MR Product

Product ID	EW_GRD_MR				
Product Type	Extra Wide Swath, Ground-Range, Multi-Look, Detected, Medium Resolution				
Main Product Characteristics					
Pixel Value	Magnitude Detected				
Coordinate System	Ground Range				
Bits Per Pixel	16				
Polarisation Options	Single (HH or VV) or Dual (HH+HV or VV+VH)				
Beam ID	EW1	EW2	EW3	EW4	EW5
Ground Range Coverage [km]	410				
Ground Range Resolution [m]	90.8	93.1	93.3	93.8	95.1
Azimuth Resolution [m]	90.1	89.4	89.85	89.45	90.13
Ground Range Pixel Spacing [m]	40				
Azimuth Pixel Spacing [m]	40				
Incidence angle [°]	23.7	30.9	36.2	40.9	44.5
Equivalent Number of Looks (ENL)	15.2	9.7	9.6	9.5	9.6
Radiometric Resolution	1.0	1.2	1.2	1.2	1.2
Product Performance Parameters					
Range PSLR [dB]	< -21.2				
Azimuth PSLR [dB]	< -28.3				
Range ISLR [dB]	< -16.1				
Azimuth ISLR [dB]	< -19.4				
Distributed Target Ambiguity Ratios [dB]	< -23.1				
Point Target Ambiguity Ratios [dB]	< -27.4				
NESZ [dB]	< -23.1				
Channel Co-registration Accuracy [pixels]	< 0.25				
Absolute Radiometric Accuracy [dB] (3 sigma)	1				
Relative Radiometric Accuracy [dB] (3 sigma)	0.1				
Absolute Location Accuracy [m] (NRT)	Not Specified				
SAR Processing Parameters					
Number of Looks (range x azimuth)	6 x 3	6 x 2	6 x 2	6 x 2	6 x 2
Look overlap (range x azimuth)	0.275 x 0.250				
Range Look Bandwidth [Hz]	4.8	3.3	2.8	2.4	2.2
Azimuth Look Bandwidth [Hz]	88	88	86	85	88
Range Hamming Weighting Coefficient	0.6	0.7	0.72	0.75	0.75
Azimuth Hamming Weighting Coefficient	0.6	0.61	0.62	0.63	0.6
Data Size & Volume for a 60 Second Long (Approximately 400 km Azimuth Coverage) Product					
Approx # of Lines	10300				
Approx # of Pixels per Line	10400				
Max Data Volume (Single Polarisation) [MB]	205				
Max Data Volume (Dual Polarisation) [MB]	410				

Quick-Look Characteristics					
Bits Per Pixel	8				
Range Decimation Factor	20				
Azimuth Decimation Factor	21				
Range Averaging Factor	30				
Azimuth Averaging Factor	32				
Range Resolution [m]	1816.9	1861.7	1865.9	1876.6	1902.3
Azimuth Resolution [m]	1892.2	1876.26	1886.8	1878.5	1892.7
Range Pixel Spacing [m]	800				
Azimuth Pixel Spacing [m]	840				
Approx # of Lines	500				
Approx # of Pixels per Line	520				

7.4 Wave L1 Products Definition

7.4.1 Wave SLC Product Definition

Table 7-11 Wave SLC Product

Product ID	WV_SLC	
Product Type	Wave, Slant-Range, Single Look, Complex	
Main Product Characteristics		
Pixel Value	Complex	
Coordinate System	Slant Range	
Bits Per Pixel	16 I and 16 Q	
Polarisation Options	Single (HH or VV)	
Beam ID	WV1	WV2
Ground Range Coverage [km]	20	
Slant Range Resolution [m]	2	3.1
Azimuth Resolution [m]	4.8	4.8
Slant Range Pixel Spacing [m]	1.7	2.7
Azimuth Pixel Spacing [m]	4.1	4.1
Incidence angle [°]	23.4	36.4
Equivalent Number of Looks (ENL)	1	
Radiometric Resolution	3	
Product Performance Parameters		
Range PSLR [dB]	< -21.2	
Azimuth PSLR [dB]	< -21.2	
Range ISLR [dB]	< -16.1	
Azimuth ISLR [dB]	< -16.1	
Distributed Target Ambiguity Ratios [dB]	< -27.2	
Point Target Ambiguity Ratios [dB]	< -34.2	
NESZ [dB]	< -26.3	
Channel Co-registration Accuracy [pixels]	< 0.25	
Absolute Radiometric Accuracy [dB] (3 sigma)	1	
Relative Radiometric Accuracy [dB] (3 sigma)	0.1	
Absolute Location Accuracy [m] (NRT)	Not Specified	

SAR Processing Parameters		
Number of Looks (range x azimuth)	1 x 1	
Look overlap (range x azimuth)	N/A	
Range Look Bandwidth [Hz]	74.5	48.2
Azimuth Look Bandwidth [Hz]	1428	1429
Range Hamming Weighting Coefficient	0.75	0.75
Azimuth Hamming Weighting Coefficient	0.75	0.75
Data Size & Volume per Vignette		
Approx # of Lines	4900	4900
Approx # of Pixels per Line	5000	4700
Max Data Volume (Single Polarisation) [MB]	94	89

7.4.2 Wave GRD Product Definition

Table 7-12 Wave GRD MR Product

Product ID	WV_GRD_MR	
Product Type	Wave, Ground-Range, Multi-Look, Detected Medium Resolution	
Main Product Characteristics		
Pixel Value	Magnitude Detected	
Coordinate System	Ground Range	
Bits Per Pixel	16	
Polarisation Options	Single (HH or VV)	
Beam ID	WV1	WV2
Ground Range Coverage [km]	20	
Range Resolution [m]	50.8	52.4
Azimuth Resolution [m]	50.6	50.5
Ground Range Pixel Spacing [m]	25	
Azimuth Pixel Spacing [m]	25	
Incidence angle [°]	23.4	36.4
Equivalent Number of Looks (ENL)	123.7	123.7
Radiometric Resolution	0.4	0.4

Product Performance Parameters		
Range PSLR [dB]	< -21.2	
Azimuth PSLR [dB]	< -21.2	
Range ISLR [dB]	< -16.1	
Azimuth ISLR [dB]	< -16.1	
Distributed Target Ambiguity Ratios [dB]	< -27.2	
Point Target Ambiguity Ratios [dB]	< -34.2	
NESZ [dB]	< -26.3	
Channel Co-registration Accuracy [pixels]	< 0.25	
Absolute Radiometric Accuracy [dB] (3 sigma)	1	
Relative Radiometric Accuracy [dB] (3 sigma)	0.1	
Absolute Location Accuracy [m] (NRT)	Not Specified	
SAR Processing Parameters		
Number of Looks (range x azimuth)	13 x 13	
Look overlap (range x azimuth)	0.250 x 0.200	
Range Look Bandwidth [Hz]	7.4	4.8
Azimuth Look Bandwidth [Hz]	135	135
Range Hamming Weighting Coefficient	0.75	0.75
Azimuth Hamming Weighting Coefficient	0.75	0.75
Data Size & Volume per Vignette		
Approx # of Lines	800	
Approx # of Pixels per Line	800	
Max Data Volume per Channel [MB]	2	

8 LEVEL 2 PRODUCTS DEFINITION

This section provides the detailed characteristics of the Sentinel-1 L2 products for each image mode. Descriptions of the terms used in the product definition tables are given in Appendix A2.

The Level 2 products are identified by a combination of up to two mnemonics, each corresponding to the following acquisition mode or product type:

- The acquisition mode, as defined in Section 3.3 (SM, IW, EW or WV).
- The product type, as defined in Section 6.1 (OCN).

For example, the identifier SM_OCN corresponds to an OCN product generated from data acquired in SM mode.

The grid dimensions and data volumes in the tables are provided as examples only. Actual products have variable grid dimensions and a variable volume.

8.1 Stripmap L2 Products Definition

8.1.1 Stripmap OCN Product Definition

Table 8-1 Stripmap OCN Product

Product ID	**SM_OCN**					
Product Type	**Stripmap Ocean**					
Main Product Characteristics						
Coordinate System	Ground Range (OSW, OWI and RVL)					
Polarisation Options	Single or Dual Co-polarisation (HH or VV)					
Beam ID	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
Incidence angle [°]	22.3	25.6	31.2	36.4	41.0	43.8
Main Product Characteristics – OSW specific						
Ocean Swell Spectra [m^4]	60 wavenumber bins (rad/m, $\{2\pi/1000 \ldots 2\pi/30\}$) x 72 directional bins (degN, equidistantly {0, 5, 10, ….,355})					
Quality cross-spectra [m^2]	60 wavenumber bins (rad/m, $\{2\pi/1000 \ldots 2\pi/30\}$) x 72 directional bins (degN, equidistantly {0, 5, 10, ….,355}) for both real and imaginary part					
Ocean Swell Spectra Spatial Resolution [km x km]	20x20(1)					
Ocean Swell Spectra Spectral Resolution [m]	On average, between 30 and 220 m depending on wave direction relative to azimuth direction					
Ocean Swell Spectra Grid Dimension [azimuth cell x ground range cell]	8x5 or 8x4					
Main Product Characteristics – OWI specific						
Ocean Wind Field Spatial Resolution [km x km]	1x1(2)					
Ocean Wind Field Grid Dimension [azimuth cell x ground range cell]	170x80					
Main Product Characteristics – RVL specific						
Radial Surface Velocity Spatial Resolution [km x km]	1.5x1.7(2)					
Radial Surface Velocity Grid Dimension [azimuth cell x ground range cell]	117 x 47					
Product Performance Parameters						
Product Performance Parameters – OSW specific						
Number of Wave Partitions	5					
SAR Significant Waveheight [m]	>0, RMSe < 0.5, Bias < 0.1					
Dominant Wave Length [m]	$\in \{30.,1000.\}$, RMSe < 50, Bias < 10					
Dominant Wave Direction [degN]	$\in \{0,360\}$, RMSe < 40, Bias < 10					
Azimuth Cut-off Wavelength [m]	$\in \{15,800\}$, 210m < Mean < 260m					

Product ID	SM_OCN
Confidence Flag For Wave Direction Retrieval	0 or 1
Product Performance Parameters – OWI specific	
Wind Speed [m/s]	$\in \{0,25\}$, RMSe < 2.0
Wind Direction [degN]	$\in \{0,360\}$, RMSe < 30
Product Performance Parameters – RVL specific	
Radial Surface Velocity [m/s]	$\in \{-10,+10\}, RMS \in \{0.29,0.37\}$
Doppler frequency [Hz]	$\in \{0,60\}, RMS \in \{2,5\}$
Processing Parameters	
Processing Parameters – OSW specific	
Number of individual looks (range x azimuth)	1 x 3
Frequency separation of neighbouring looks [Hz]	$0.27\, f_{PRF}$
Range Look Bandwidth [Hz]	$0.78\, f_{sf}$
Azimuth Look Bandwidth [Hz]	$0.75\, f_{PRF}$
Number of Pixels Used in Spectral Estimation [range, azimuth]	256, 256
Low Pass Filter Width for Detrending of Image [m]	1000
Processing Parameters – OWI specific	
Geophysical scattering model function	CMOD-IFR2 NN or CMOD2-I3 NN
Polarization ratio model	Mouche et al (1)
Data Size & Volume for a 25s Long (approximately 170 km Azimuth Coverage) Product	
Data Size & Volume	
Number of Lines in Spectra	60
Number of Pixels per Line	72
Data Volume per Spectra [bytes]	17280
Total Data Volume of Ocean Swell Spectra Component [bytes]	1816000
Total Data Volume of Ocean Wind Field Component [bytes]	1197000
Total Data Volume of Radial Surface Velocity Component [bytes]	1007000
Total Data Volume of OCN Product [bytes]	4020000
Notes	
(1)	Product splits 170km x 80km SM image into 8x4 images of 20km x 20km for OSW estimation.
(2)	Product splits 170km x 80km SM image into 235x95 images of 0.75km x 0.85km for RVL estimation. Note that the spatial resolution is approximately twice the grid spacing in RVL

8.2 Interferometric Wide Swath L2 Products Definition

8.2.1 Interferometric Wide Swath OCN Product Definition

Table 8-2 Interferometric Wide Swath OCN Product

Product ID	**IW_OCN**		
Product Type	**Interferometric Wide Swath Ocean**		
Main Product Characteristics			
Coordinate System	Ground Range (OWI and RVL)		
Polarisation Options	Single or Dual Co-polarisation (HH or VV)		
Beam ID	IW1	IW2	IW3
Incidence angle [°]	32.9	38.4	43.1
Main Product Characteristics – OWI specific			
Ocean Wind Field Spatial Resolution [km x km]	1x1[(1)]		
Ocean Wind Field Grid Dimension [azimuth cell x ground range cell]	170 x 250		
Main Product Characteristics – RVL specific			
Radial Surface Velocity Spatial Resolution [km x km]	2x2[1)]		
Radial Surface Velocity Grid Dimension [azimuth cell x ground range cell]	85 x 125		
Product Performance Parameters			
Product Performance Parameters – OWI specific			
Wind Speed [m/s]	$\in \{0,25\}$, RMSe < 2.0		
Wind Direction [degN]	$\in \{0,360\}$, RMSe < 30		
Product Performance Parameters – RVL specific			
Radial Surface Velocity [m/s]	$\in \{-10,+10\}, RMS \in \{0.30,0.38\}$		
Doppler frequency [Hz]	$\in \{0,60\}, RMS \in \{2,5\}$		
Processing Parameters			
Processing Parameters – OWI specific			
Geophysical scattering model function	CMOD-IFR2 NN or CMOD2-I3 NN		
Polarization ratio model	Mouche et al (1)		
Data Volume for a 25s Long (approximately 170 km Azimuth Coverage) Product			
Data Volume			
Total Data Volume of Ocean Wind Field Component [bytes]	3740000		
Total Data Volume of Radial Surface Velocity Component [bytes]	3146000		
Total Data Volume of OCN Product [bytes]	6886000		
Notes			
(1)	Product splits 170km x 250km IW image into 170x250 images of 1km x 1km for OWI estimation. Product splits 170km x 250km IW image into 85x125 images of 2km x 2km for RVL estimation. Note that the spatial resolution is approximately twice the grid spacing in the RVL product.		

8.3 Extra Wide Swath L2 Products Definition

8.3.1 Extra Wide Swath OCN Product Definition

Table 8-3 Extra Wide Swath OCN Product

Product ID	**EW_OCN**				
Product Type	**Extra Wide Swath Ocean**				
Main Product Characteristics					
Coordinate System	Ground Range (OWI and RVL)				
Polarisation Options	Single Dual Co-polarisation (HH or VV)				
Beam ID	EW1	EW2	EW3	EW4	EW5
Incidence angle [°]	23.7	30.9	36.2	40.9	44.5
Main Product Characteristics – OWI specific					
Ocean Wind Field Spatial Resolution [km x km]	1x1(1)				
Ocean Wind Field Grid Dimension [azimuth cell x ground range cell]	400 x 400				
Main Product Characteristics – RVL specific					
Radial Surface Velocity Spatial Resolution [km x km]	4x4[1)]				
Radial Surface Velocity Grid Dimension [azimuth cell x ground range cell]	100 x 100				
Product Performance Parameters					
Product Performance Parameters – OWI specific					
Wind Speed [m/s]	$\in \{0,25\}$, RMSe < 2.0				
Wind Direction [degN]	$\in \{0,360\}$, RMSe < 30				
Product Performance Parameters – RVL specific					
Radial Surface Velocity [m/s]	$\in \{-10,+10\}, RMS \in \{0.30,0.38\}$				
Doppler frequency [Hz]	$\in \{0,60\}, RMS \in \{2,5\}$				
Processing Parameters					
Processing Parameters – OWI specific					
Geophysical scattering model function	CMOD-IFR2 NN or CMOD2-I3 NN				
Polarization ratio model	Mouche et al (1)				
Data Volume for a 60s Long (approximately 400 km Azimuth Coverage) Product					
Data Volume					
Total Data Volume of Ocean Wind Field Component [bytes]	14080000				
Total Data Volume of Radial Surface Velocity Component [bytes]	11842000				
Total Data Volume of OCN Product [bytes]	25922000				
Notes					
(1)	Product splits 400km x 400km EW image into 400x400 images of 1km x 1km for OWI estimation. Product splits 400km x 400km EW image into 100x100 images of 4km x 4km for RVL estimation. Note that the spatial resolution is approximately twice the grid spacing for the RVL product.				

8.4 Wave L2 Products Definition

8.4.1 Wave OCN Product Definition

Table 8-4 Wave OCN Product

Product ID	**WV_OCN**	
Product Type	**Wave Ocean**	
Main Product Characteristics		
Coordinate System	Ground Range (OSW, OWI and RVL)	
Polarisation Options	Single (HH or VV)	
Beam ID	**WV1**	**WV2**
Incidence angle [°]	23	36.5
Main Product Characteristics – OSW specific		
Ocean Swell Spectra [m^4]	60 wavenumber bins (rad/m, { $2\pi/1000$ … $2\pi/30$) x 72 directional bins (degN, equidistantly {0, 5, 10, …,,355})	
Quality cross-spectra [m^2]	60 wavenumber bins (rad/m, { $2\pi/1000$ … $2\pi/30$) x 72 directional bins (degN, equidistantly {0, 5, 10, …,,355}) for both real and imaginary part	
Ocean Swell Spectra Spatial Resolution [km x km]	20x20	
Ocean Swell Spectra Spectral Resolution [m]	On average, between 30 and 220 m depending on wave direction relative to azimuth direction	
Ocean Swell Spectra Grid Dimension [cell]	1x1	
Main Product Characteristics – OWI specific		
Ocean Wind Field Spatial Resolution of [km x km]	20x20	
Ocean Wind Field Grid Dimension [azimuth cell x ground range cell]	1x1	
Main Product Characteristics – RVL specific		
Radial Surface Velocity Spatial resolution [km x km]	20x20	
Radial Surface Velocity Grid Dimension [azimuth cell x ground range cell]	1x1	
Product Performance Parameters		
Product Performance Parameters – OSW specific		
Number of Wave Partitions	5	
SAR Significant Waveheight [m]	>0, RMSe < 0.5, Bias < 0.1	
Dominant Wave Length [m]	$\in \{30..1000\}$, RMSe < 50, Bias < 10	
Dominant Wave Direction [degN]	$\in \{0,360\}$, RMSe < 40, Bias < 10	
Azimuth Cut-off Wavelength [m]	$\in \{15,800\}$, 210m < Mean < 260m	
Confidence Flag for Wave Direction Retrieval	0 or 1	
Product Performance Parameters – OWI specific		
Wind Speed [m/s]	$\in \{0,25\}$, RMSe < 2.0	
Wind Direction [degN]	$\in \{0,360\}$, RMSe < 30	

Product ID	**WV_OCN**	
Product Performance Parameters – RVL specific		
Radial Surface Velocity [m/s]	$\in \{-10,+10\}, RMS \approx 0.30$	$\in \{-10,+10\}, RMS \approx 0.34$
Doppler frequency [Hz]	$\in \{0,60\}, RMS \in \{2,5\}$	$\in \{0,40\}, RMS \in \{2,5\}$
Processing Parameters		
Processing Parameters – OSW specific		
Number of individual looks (range x azimuth)	1 x 3	
Frequency separation of neighbouring looks [Hz]	$0.27\, f_{PRF}$	
Range Look Bandwidth [Hz]	$0.78\, f_{sf}$	
Azimuth Look Bandwidth [Hz]	$0.75\, f_{PRF}$	
Number of Pixels Used in Spectral Estimation [range, azimuth]	256, 256	
Low Pass Filter Width for Detrending of Image [m]	1000	
Data Size & Volume for a 20 km Azimuth Coverage Product		
Data Size & Volume		
Number of Lines in Spectra	60	
Number of Pixels per Line	72	
Data Volume per Spectra [bytes]	17280	
Total Data Volume of Ocean Swell Spectra Component [bytes]	58000	
Total Data Volume of Ocean Wind Field Component [bytes]	90	
Total Data Volume of Radial Surface Velocity Component [bytes]	80	
Total Data Volume of OCN Product [bytes]	58170	

9 AUXILIARY DATA FOR L1 PROCESSING

In order to generate Sentinel-1 L1 products, the Sentinel-1 IPF SAR processor requires additional information not included in the data acquired from the satellite. This information is provided in auxiliary data files that originate either within the PDGS or from external sources.

The auxiliary data for Sentinel-1 L1 product processing can be grouped into the following categories:

- Digital Elevation Model
- L1 Processor Parameters
- Calibration Data
- Instrument Parameters
- Orbit and Attitude Information

9.1 Digital Elevation Model (DEM)

DEMs are optionally used by the IPF to derive height information used when processing L1 georeferenced products.

The IPF can use the following types of DEM:

- An internal coarse DEM (the National Geophysical Data Center TerrainBase Global DTM, which provides a global coverage with a 5 arcminute spacing), or
- A fine DEM provided externally.

The external DEMs supported by the IPF are those supported by the Earth Explorer CFI.

Version 4.2 of the Earth Observation CFI, currently used by the IPF, supports the Global Earth Topography And Sea Surface Elevation (GETASSE30) DEM, versions 1 and 2.

The GETASSE30 DEM is a composite of four other datasets: the SRTM30 data, the Altimeter Corrected Elevations (ACE) DEM, the Mean Sea Surface (MSS) data and the EGM96 ellipsoid. The resulting GETASSE30 DEM represents the earth topography and sea surface elevation with respect to the WGS84 ellipsoid at 30 arc second resolution.

9.2 L1 Processor Parameters

The L1 Processor Parameters auxiliary data contains various parameters required by the IPF for producing the L1 products with the desired properties, and the fine-tuning of the processor and the selection of specific processing options. The L1 processor parameters auxiliary data is described in Document R-9.

9.3 Calibration Data

The most important component of the Calibration Data is the set of antenna patterns. The antenna patterns are derived from pre-launch antenna measurements and after-launch antenna model verification activities. The beam-to-beam gain offsets are also derived through this process. The antenna patterns and beam-to-beam gain offsets are used by the SAR processor for radiometric calibration. Details of the Calibration Data are provided in [R-9].

9.4 Instrument Parameters

The Instrument Parameters auxiliary data includes mainly parameters either constant over the mission or requiring infrequent updates, and is described in [R-9].

9.5 Orbit and Attitude Information

High-accuracy Orbit State Vectors (OSV) and attitude quaternions are available within the Sentinel-1 downlink data and are provided on continuous basis and updated at a specific frequency. After the data acquisition, precise orbit and attitude determination data is reconstructed and made available to the IPF in the form of orbit files containing OSV auxiliary data and attitude files containing attitude quaternions auxiliary data. The IPF will use OSVs and attitude quaternions either from the orbit/attitude files or the downlink, depending on the IPF parameters used when processing a particular image.

Unlike the other auxiliary data described in the previous sections, which are static and change infrequently over the lifetime of the mission, the orbit state vector auxiliary data and the attitude quaternion auxiliary data will be updated frequently as new orbit state vectors and attitude quaternions are produced.

Details of the Orbit and Attitude Information are provided in [R-9].

10 AUXILIARY DATA FOR L2 PROCESSING

In order to generate Sentinel-1 L2 products, the Sentinel-1 IPF SAR processor requires additional information not included in the data acquired from the satellite. This information is provided in auxiliary data files that originate either within the PDGS of from external sources.

The auxiliary data for Sentinel-1 L2 product processing can be grouped into the following categories:

- ECMWF atmospheric model
- Simulated cross spectra data
- Sea ice data
- Wavewatch3 Stokes drift
- Excitation Coefficients Error Matrix
- L2 Processor parameters

10.1 ECMWF Atmospheric Model

Wind speed and direction at 10 m above the sea surface from the ECMWF atmospheric model is required with spatial and temporal resolution of 0.125 degrees every 3 hours. This is used for both OWI and OSW processing.

Details of the ECMWF Atmospheric Model are provided in Document [R-9].

10.2 Simulated Cross Spectra Data

The OSW processing algorithm requires simulated cross spectra look-up tables to predict the modulation transfer function (MTF) and to remove non-linear effects from the cross spectra. There is one look-up table for each swath and polarisation. The basic content of the look-up table is the simulated cross-spectrum for a given ocean swell spectrum, computed from the input wind speed, direction and inverse wave age, and an estimate of the MTF for the given wind field:

- Simulated Cross-Spectra are computed for a wide range of wind speeds and directions. The non-linear part of the cross-spectra is stored in the table.
- The real aperture MTF amplitude;
- The wind speed range array;
- The wind direction array;
- The inverse wave age array.

The Simulated Cross Spectra Data is described in Document [R-9].

10.3 Sea Ice Data

Sea ice data is used by the OWI algorithm. Wind inversion processing is not performed if sea ice coverage is greater than 10% in the imagette considered. This percentage is directly given by the sea ice edge product delivered by the Ocean and Sea Ice Satellite Application Facility (OSI SAF) at a spatial resolution of 10 km every day. The product is available on the OSI SAF sea ice FTP server (ftp://saf.met.no/prod/ice) in HDF5 and GRIB format and on the Marine Environment and Security for the European Area (MERSEA) server (http://www.mersea.eu.org).

Details of the Sea Ice Data are provided in Document [R-9].

10.4 Wavewatch3 Stokes Drift

The Wavewatch3 Stokes Drift file is used to interpret the RVL component of the OCN product for all imaging modes.

The stokes drift is a vector calculated as the third order moment of the wave spectra. This cannot be estimated from SAR wave spectra since the stokes drift is mostly dependent on wind sea which is not imaged by SAR. Therefore this information has to come from a model that has a good physical representation of the shorter waves. Stokes drift forecast files in NetCDF format generated by the operational Wavewatch3 model run at IFREMER will be used.

Details of the Wavewatch3 Stokes Drift are provided in Document [R-9].

10.5 Excitation Coefficients Error Matrix

The Excitation Coefficients Error Matrix is used by the RVL algorithm to derive the accurate Doppler estimation by synthesising a radiation beam pattern using an antenna model.

The Excitation Coefficients Error Matrix is a product of the Sentinel-1 RFC mode, which is a specific calibration mode meant to assess the instrument health and stability.

In particular, the RFC mode verifies the Tx and Rx excitation coefficients to ensure the validity of the radiation beam patterns generated by the instrument. This is done through the excitation coefficients error matrix product, which identifies changes in the excitation coefficients with respect to reference values (e.g. pre-launch reference).

One excitation coefficients error matrix product is defined for polarisation H and another one for polarisation V. Only the matrix matching the co-polarisation data is used by the IPF:

- in case of single polarisation HH or dual polarisation HH/HV only the matrix for polarisation H is used,
- in case of single polarisation VV or dual polarisation VV/VH only the matrix for polarisation V is used.

Details of the Excitation Coefficients Error Matrix are provided in Document [R-9].

10.6 L2 Processor Parameters

The L2 Processor Parameters auxiliary data contains various parameters required by the IPF for producing the L2 products with the desired properties, and the fine-tuning of the processor and the selection of specific processing options. The processor parameters auxiliary data is described in Document [R-9].

A PRODUCT DESCRIPTION TERMINOLOGY

This section explains the terms used in the product definition tables included in Section 7 and 8. As in the tables, the definitions have been grouped into four classes, separately for L1 and L2 products:

1. Main product characteristics
2. Product performance parameters
3. SAR processing parameters
4. Data size and volume

A1 Level 1 Product Description Terminology

A1.1 Main Product Characteristics

A1.1.1 Coordinate System

Products can be represented in the *slant range* coordinate system (SLC products) or in the *ground range* coordinate system (GRD products). See Section 4 for more information.

The slant range and ground range represented products are produced in 'zero-Doppler' orientation, i.e. with each row of pixels representing points along a line perpendicular to the sub-satellite track.

A1.1.2 Bits per Pixel

A pixel can be represented by either a pair of integers (representing the real and imaginary part (*I* and *Q*) of a complex number) or an unsigned integer (representing the magnitude of a complex number). Therefore the number of bits per pixel is:

- *(number of bits per integer)* (for each *I* and *Q*) for complex products
- *(number of bits per unsigned integer)* for detected products.

The number of bits per integer (signed or unsigned) is 16 or 8.

A1.1.3 Ground Range Coverage

The ground range coverage is the nominal range (across-track) dimension of the area on the ground surface represented in the image. The azimuth (or along-track) dimension of the image can be of any length and potentially as long as the acquisition segment. For some calculations in the product definition, however, the nominal length of each product has been defined to be equal to the ground range coverage.

A1.1.4 Resolution

The spatial resolution of an imaging system is a measure of its ability to distinguish between adjacent targets. The spatial resolution is defined as the Impulse Response Function width (IRW) measured at 3 dB (half of the intensity) below the peak value, in either range or azimuth direction.

The Impulse Response Function (IRF) (or the point target response) of a SAR system (sensor and processor) is the 2-D image of a point target in either slant range or ground range representation, neglecting effects of background clutter and thermal noise.

The intensity of the IRF is significant mainly along the range and azimuth directions and therefore, 1-D slices in range and azimuth, are used to characterize the 2-D IRF.

A1.1.5 Pixel Spacing

Pixel Spacing is the distance between adjacent pixels in an image measured in metres. This is the same as the pixel size. The pixel spacing may be different for range and azimuth. Range pixel spacing may be stated in slant range distance for SLC products or in ground range distance for GRD products.

Typically, for complex-valued images, the pixel spacing in each dimension of the image is similar in magnitude to the resolution in that dimension. For detected images, the pixel spacing in each dimension is similar in magnitude to half the resolution in that dimension. In order for the full information content of the image to be retained, the pixel spacing must meet the Nyquist criterion. To meet this criterion, the spatial sampling rate must exceed the bandwidth of the spatial frequency content in the image.

A1.1.6 Incidence Angle

The incidence angle is the angle between the incident SAR beam and the axis perpendicular to the local geodetic ground surface. The values provided in Section 7 are nominal in that they are calculated assuming that the local surface follows the ellipsoid, without any adjustment for the terrain height.

For Sentinel-1, the off-nadir angles, and implicitly the incidence angles, vary with position of the satellite in orbit due to the roll steering law (as described in Section 3.2.3.2). The incidence angle values specified in each product table represent, for each beam, the approximate incidence angle at mid swath and averaged over the orbit.

The precise off-nadir and incidence angle ranges corresponding to the minimum and maximum orbit height are shown in Table 3-3, Table 3-5, Table 3-7 and Table 3-9.

A1.1.7 Equivalent Number of (Independent) Looks (ENL)

The image speckle statistics for areas of distributed target are determined by the multi-looking used in image generation. The equivalent number of independent looks (ENL) for a given product type is intended to correspond to the number of equally-weighted, statistically independent looks which would produce the same speckle statistics as the processing used to generate the product.

For a distributed target (large enough to ensure statistical accuracy) in a perfectly homogeneous area of a SAR image generated using N_L equal, independent looks:

$$N_L = \frac{\mu^2}{\sigma^2}$$

where μ and σ are respectively the mean and the standard deviation of signal power over the distributed target. This ratio is therefore used to define the equivalent number of independent looks for the general case (non-independent looks):

$$ENL = \frac{\mu^2}{\sigma^2}$$

The ENL will normally be less than the total number of looks, N_L, because of partial overlapping of the looks and unequal weighting.

A1.1.8 Radiometric Resolution

The radiometric resolution is a measure of the ability to distinguish between uniform distributed targets with different backscattering coefficient. It is measured on a homogeneous distributed target, large enough to ensure statistical accuracy:

$$RR = 10\log_{10}\left(1 + \frac{1}{\sqrt{ENL}}\right)$$

A1.2 Product Performance Parameters

A1.2.1 Peak Side Lobe Ratio (PSLR)

The peak side lobe ratio is the worst-case measure of the SAR ability to identify a weak target from a nearby strong target. The PSLR is defined as the ratio of the peak intensity in the main-lobe of the IRF to the peak intensity of the most intense side-lobe over 10 times the 3dB-IRW in each azimuth and range direction.

A1.2.2 Integrated Side-Lobe Ratio (ISLR)

The ISLR characterizes the SAR ability to detect weak targets in the neighbourhood of strong targets. The ISLR is defined as the ratio of energy within the main-lobe of the IRF (defined as lying within a rectangle of size 2x and 2y centered on the peak, where x and y are the 3dB widths in range and azimuth) and the energy outside of this area integrated over a region bounded by sides 10 times longer.

A1.2.3 2D Distributed Target Ambiguity Ratio (2D-DTAR)

The unambiguous zone in defined, in the range direction by the nominal swath width and in the azimuth direction by the total processed Doppler bandwidth. An ambiguous zone is defined as a region outside the unambiguous zone.

The 2D Distributed Target Ambiguity Ratio (2D-DTAR) is the ratio of energy contribution from a distributed target in the unambiguous zone to the energy contribution from a distributed target located in the unambiguous zone.

The ratio is to be calculated using the Distributed Target Radar Cross Section Reference Model P’T/ΣPA, where:

P’T is the intensity of the radar response to a distributed target located within the unambiguous zone, and

ΣPA is the summed intensity of the radar responses to the respective distributed targets within the various ambiguous zones.

A1.2.4 Point Target Ambiguity Ratio (PTAR)

The Point Target Ambiguity Ratio is specified as the ratio PT / PA, where:

- PT is the peak intensity of the radar response to a point target located within unambiguous zone

- PA is the peak intensity of the radar response to a point target of the same radar cross-section as defined for PT but located within the worst ambiguous zone. The PTAR can be defined in both the range and azimuth directions.

A1.2.5 Noise Equivalent Sigma Zero (NESZ)

The Noise Equivalent Sigma Zero (NESZ) is a measure of the sensitivity of the radar to areas of low backscatter. The NESZ is defined as the backscatter coefficient σ_o (back-scattering cross section of a distributed target per unit area) of a distributed target within the product coverage for which the signal power level in the final image is equal to the noise power level (thermal noise only), i.e. an image SNR of 0 dB.

A1.2.6 Channel Co-registration Accuracy

The channel co-registration accuracy is a characteristic of the dual-polarisation products and it represents the difference between the location of the same point target in the two images, in either range or azimuth.

A1.2.7 Absolute Radiometric Accuracy

For a distributed target, the radiometric accuracy is defined as the 3σ deviation resulting from measurement of σ_0 of a homogeneous distributed target situated anywhere in the operating dynamic range of the system, anywhere in the swath, anywhere in time, and ignoring speckle.

For a point target, the radiometric accuracy is defined as the 3σ deviation of the measurement of the radar cross-section with respect to the true radar cross section, of a sufficiently bright target situated anywhere in the swath, anywhere in time.

The absolute radiometric accuracy accounts for all causes (including all errors from calibration devices, processing and channel imbalance in case of polarimetric products).

A1.2.8 Relative Radiometric Accuracy

The relative radiometric accuracy is the 3σ deviation that result form measuring the radar cross-section of equivalent targets at the same time at different locations within a product coverage. This includes stability effects within the time needed for the acquisition of the product.

A1.2.9 Absolute Location Accuracy

The pixel location accuracy is specified as the 3σ deviation in the estimate of the position of a point target of sufficiently large cross-section, the estimate being the point equidistant between the –3dB points of its detected impulse response measured in along-track and across-track directions.

If the pixel location error depends on location within the image, the worst-case location is applicable.

The values in the table assume that the Earth's surface follows the shape of the ellipsoid at a local specified elevation height. The use of ground truth data is not included.

A1.3 SAR Processing Parameters

A1.3.1 Number of Range Looks

The number of range looks is the number of distinct or overlapping coherently processed looks extracted from the pulse bandwidth which are combined after detection to form the image.

A1.3.2 Number of Azimuth Looks

The number of azimuth looks is the number of distinct or overlapping coherently processed looks extracted from the Doppler spectrum which are combined after detection to form the image.

A1.3.3 Look Overlap

The look overlap is specified as the ratio between the size of the overlap between any 2 nearby looks and the size of the look.

A1.3.4 Range Look Bandwidth

The range look bandwidth is the bandwidth of the segment of the total pulse bandwidth which is coherently processed for each individual range look.

A1.3.5 Azimuth Look Bandwidth

For Stripmap type modes, the azimuth look bandwidth is the processed Doppler bandwidth for each individual azimuth look.

For TOPSAR modes, this parameter is the Doppler bandwidth of the signal from any given target within the set of samples used for each look.

A1.3.6 Hamming Window Coefficient

In the SAR processor, both the range and azimuth spectrum of the data are weighted by a (generalized) Hamming window defined by the (beam-dependent) coefficient specified for each product table. The Hamming window is defined by

$$w(\alpha) = a - (1 - a) * \cos(\alpha), \quad \alpha \in [0, 2\pi]$$

where *a* is the Hamming window coefficient.

The weighting has opposite effects on resolution and side lobes level therefore the coefficient is chosen in such a way as to realize the desired trade-off between these IPF characteristics. Table A-1 lists the propertied of the Hamming windows applied in the Sentinel-1 SAR processor, as defined by the coefficient specified in the product tables:

Table A-1 Hamming Window Properties

Hamming Window Coefficient	IRW Broadening Factor	PSLR [dB]	ISLR [dB]
0.52	1.54	-36.22	-37.39
0.6	1.32	-31.6	-26.18
0.61	1.3	-30.34	-25.22
0.62	1.28	-29.26	-24.35
0.63	1.27	-28.33	-23.55
0.65	1.24	-26.79	-22.07
0.70	1.18	-24.07	-19.10
0.72	1.16	-23.27	-18.10
0.73	1.15	-22.55	-17.63
0.75	1.13	-21.22	-16.75

A1.4 Data Size and Volume

This section introduces the definitions of the number of lines, number of pixels and volume of an image.

A1.4.1 Number of Lines

The number of lines is calculated as follows:

Lines = (Image Azimuth Extent) / (Azimuth Pixel Spacing)

Note that for IW/EW, a small margin is included, to account for overlapping between bursts and interleaving blank lines.

The number of lines in the tables in Section 7 is approximate and corresponds to the specified azimuth dimension of the product (approximately equal to the ground range coverage). It is rounded up to the nearest hundred.

A1.4.2 Number of Pixels per Line

The number of pixels is calculated as:

PixelsPerLine = (Image Range Extent) / (Range Pixel Spacing)

For SLC products, *Image Range Extent* represents the slant range image extent.

The number of pixels in the tables in Section 7 is approximate and rounded up to the nearest hundred.

A1.4.3 Product Volume

The nominal product volume is calculated as follows:

*Volume = PixelsPerLine * Lines * BitsPerPixel*

The size of the annotations attached to the image is not included in the volume figure.

Where products may contain data for more than one polarisation, the value stated in the product definition table is given per polarisation channel.

A2 Level 2 Product Description Terminology

A2.1 Main Product Characteristics

A2.1.1 Coordinate System

The coordinate system for the two-dimensional wave spectrum in the OSW component is a log-polar grid.

Scalar parameters including the RVL and OWI estimates are given as geolocated measurements.

A2.1.2 Incidence Angle

The incidence angle for L2 products has the same meaning as for L1 products. Refer to Section A1.1.6.

A2.1.3 Spatial Resolution

The spatial resolution is the size of the area [km^2] on the ground from which the L2 product is derived.

For WV this is equal to the vignette size (20kmx20km).

For SM, the spatial resolution is the size of the nominal SM SLC (80kmx80km) divided 4x4 for a 20km x 20km resolution for the ocean swell spectra, and higher for the wind field and the radial surface velocity, typically 1km x 1km and 5km x 5km respectively.

For the EW and IW modes, the approach is similar to SM; the typical spatial resolution for the wind field and radial surface velocity is similar to the SM case.

A2.1.4 Ocean Swell Spectra Spectral Resolution

The spectral resolution of an ocean swell spectra cell is the shortest ocean wavelength [m] (or longest ocean wavenumber [rad/m]) that can be detected. For a SAR image, this depends on the sea state and the wave direction relative to azimuth. This parameter is a vector of wave lengths equal to the number of directional bins. In range, the theoretical limit is given by the range bandwidth, and does not depend on the sea state.

$$\lambda(\varphi) = \left(\lambda_c \cdot \cos(\varphi + \varphi_{track})\right) > \lambda_{\min}$$

where $\lambda_{\min} = 2\pi / k_{\max}$ is the shortest wavelength in the spectra. Here λ_c is the azimuth cut-off wavelength estimated from the SAR image spectra, and ϕ_{track} is the satellite track heading counter clockwise relative to North. This vector will be provided for each wave cell.

A2.1.5 Ocean Swell Spectra Grid Dimension

The ocean swell spectra grid dimension is the number of 2D SAR wave spectra cells in the range and azimuth direction. The spatial resolution in combination with the L1 image size defines the OSW grid dimensions.

A2.1.6 Ocean Wind Field Grid Dimension

The ocean wind field grid dimension is the number of SAR wind cells in the range and azimuth direction. The spatial resolution in combination with the L1 image size defines the ocean wind field grid dimensions.

A2.1.7 Radial Surface Velocity Grid Dimension

The radial velocity grid dimension is the number of radial surface velocity cells in the range and azimuth direction. The spatial resolution in combination with the L1 image size defines the radial surface velocity field grid dimensions.

A2.2 Product Performance Parameters

A2.2.1 Wind Speed

Wind speed is the ocean surface wind speed (at a height of 10 m above the ocean surface) given in [m/s] derived from the SAR (L1 product) data. The quality of the wind speed estimate depends on the NESZ and the calibration accuracy. This parameter is provided for each ocean wind field cell.

A2.2.2 Wind Direction

The wind direction is the direction of the wind at a height of 10 m above the ocean surface [degN, i.e. degrees clockwise from north], derived from the SAR data in combination with or provided by an external source (ECMWF wind direction). This parameter is provided for each ocean wind field cell.

A2.2.3 Doppler Frequency

The Doppler frequency [Hz] is estimated from the SLC data based on fitting the azimuth spectral profile of the data to the antenna model taking into account additive noise, aliasing, and side band effects. The Doppler frequency is used to retrieve an estimate of the radial surface velocity, after first removing the contribution to the Doppler from geometry and mispointing errors.

A2.2.4 Radial Surface Velocity

The radial surface velocity [m/s] is derived from the L2 Doppler grid using the difference of the L2 Doppler grid and the geometrical Doppler from L1. The radial surface velocity can be used to derive the radial component of the ocean surface current field. It is provided on the radial surface velocity grid.

A2.2.5 Number of Wave Partitions

The number of wave partitions is the number of independent wave systems the two-dimensional wave spectra (OSW) consist of. Typically this is a swell wave spectrum and wind sea wave spectrum. The default number of wave partitions is 5.

A2.2.6 SAR Significant Waveheight

The SAR significant waveheight is the significant waveheight computed from the OSW within the product [m] for the five most energetic wave partitions. This parameter is provided for each ocean swell spectra cell, and resampled into the ocean wind field grid.

A2.2.7 Dominant Wave Length

The dominant wave length is the dominant wavelength of the swell wave spectra [m] for the five most energetic wave partitions. This parameter will be provided for each ocean swell spectra cell and resampled into the ocean wind field grid.

A2.2.8 Dominant Wave Direction

The dominant wave direction is the dominant wave direction of the swell wave spectra [degN] for the five most energetic wave partitions. This parameter will be provided for each ocean swell spectra cell and resampled into the ocean wind field grid.

A2.2.9 Azimuth Cut-off Wavelength

The cut-off wavelength is the shortest wavelength in the azimuth direction [m] that is resolved in the ocean swell spectra. The azimuth cut-off wavelength is computed from the SAR imagette cross-spectra. The Spectral Resolution is derived from this parameter. The azimuth cut-off will increase with incidence angle because it is proportional to the range-to-velocity ratio. It also depends on the sea-state. This parameter is provided for each ocean swell spectra cell.

A2.2.10 Confidence Flag for Wave Direction Retrieval

The confidence flag for wave direction retrieval is the confidence of wave direction retrieval, for the five most energetic wave partitions [0, 1, 2, 3 or 4]. When this parameter is set to 0 the wave direction is resolved without 180 degree ambiguity, else it is set to 1. This parameter is provided for each ocean swell spectra cell, and resampled into the ocean wind field grid.

A2.2.11 Normalised Radar Cross Section

This is the normalized radar cross-section (NCRS) of the sub-image [dB]. The NRCS is used in the wind retrieval algorithm, and is also directly related to the dc-component of the image spectra. This parameter is provided for each wind field grid cell.

A2.2.12 Wave Age

The wave age is the ratio of wave velocity to wind velocity, and describes the saturation of the wave spectra [non-dimensional]. The wave age is an outcome of the OSW retrieval, and is provided on the wave grid cell.

A2.2.13 Signal-to-Noise Ratio

The signal-to-noise ratio is the spectral peak to noise ratio of the OSW product, and is used for setting the confidence of the wave retrieval. It is provided for the five most energetic partitions, and is given on the wave grid cell.

A2.2.14 Normalized Image Variance

The normalized image variance is the sub-image variance normalized with mean imagette intensity. It is provided on the wind grid cell.

A2.3 Processing Parameters

A2.3.1 Number of Individual Looks

The number of individual looks is the number of independent looks in range and azimuth extracted from the input SLC data by the OSW algorithm for the spectral estimation.

A2.3.2 Frequency Separation of Neighbouring Looks

The frequency separation between neighbouring, Δf looks gives the inter look separation time by the formula:

$$\tau = \frac{cR\Delta f}{f_{rad} V^2}$$

This is typically around 0.25 sec.

A2.3.3 Range Look Bandwidth

The range look bandwidth used during OSW processing is related to the instrument range sampling frequency (SF) as 0.78 $\times$SF.

A2.3.4 Azimuth Look Bandwidth

The azimuth look bandwidth used during the OSW processing refers to the individual look bandwidth. This is related to the instrument pulse repetition frequency (PRF) by default as 0.75 $\times$ PRF.

A2.3.5 Number of Pixels Used in Spectral Estimation

This is the number of pixels used in each periodogram, and thus specifies the spectral bin size of the Cartesian image spectrum. Default is 5012x512 pixels.

A2.3.6 Low Pass Filter Width for Detrending of Image

This is a filter that removes long wavelength non-wave features from the original input image in the spatial domain. Default is 1000m.

A2.3.7 Geophysical Scattering Model Function

The geophysical scattering model function is a model function (semi-empirical, empirical, or theoretical) that predicts the normalized radar cross-section for a given wind field and radar imaging parameters and geometry.

A2.3.8 Polarization Ratio Model

The polarization ratio model is a model function that relates the normalized radar cross-section of different polarizations. It is mainly used to convert the normalized radar cross-section of VV polarization into HH polarization.

A2.4 Data Size and Volume

This section introduces the definitions of the number of lines, number of pixels and volume of an L2 product.

A2.4.1 Number of Lines

This is the number of estimates in the azimuth direction.

A2.4.2 Number of Pixels per Line

This is the number of estimates in the range direction.

A2.4.3 Product Volume

The nominal product volume is calculated as follows:

*Volume = (PixelsPerLine(OSW) * Lines(OSW) * BitsPerPixel(OSW)) +*

*(PixelsPerLine(OWI) * Lines(OWI) * BitsPerPixel(OWI)) +*

*(PixelsPerLine(RVL) * Lines(RVL) * BitsPerPixel(RVL)) +*

The size of the annotations attached to the image is not included in the volume figure.

Where products may contain data for more than one polarisation, the value stated in the product definition table is given per polarisation channel.

B DETAILED SAR PERFORMANCE

In this appendix details of some of the main Sentinel-1 Level 1 SAR performance parameters are provided. In particular, for each acquisition mode, the graphs of the variation within each swath of the ground range resolution, range DTAR and NESZ are presented.

The ground range resolution graphs are provided for the SLC products as well as for all standard GRD products. They are based on the detailed derivation of the Level 1 product characteristics provided in Appendix C.

The range DTAR and NESZ performance are provided for the SLC products. For the GRD products, the range DTAR and NESZ performance are very similar. Minor differences area function of slightly different processing window coefficients and the GRD look overlap. Note that the current graphs correspond to the space segment SLC definition and are based on [A-3]. The actual graphs are TBD and will be included in a future version of this document.

Note that, in theory, the NESZ profiles present a slight dependency on polarisation through the (simulated) sub-array patterns used to compute the overall antenna pattern. However, the difference between co- and cross-polarisation is less than 0.1 dB on the main-lobe of the overall elevation pattern. This would cause the co- and cross polarisation NESZ plots to appear totally overlapped on the graphs. Therefore, for each beam, the NESZ profile for only one polarisation (the worst case) was represented.

When the actual measured embedded row patterns, both in elevation and azimuth, will be available, the graphs will be updated (TBD) if a more significant difference between polarizations is identified.

Due to the variation of the off-nadir angle (and implicitly incidence angle) induced by the roll steering law (as presented in Section 3.2.3.2) the parameters described in this appendix vary with respect to the position of the satellite along the orbit. To reflect this variation, two instances of each graph are provided: at minimum orbit altitude (~ 698 km) and at maximum orbit altitude (~ 726 km).

B1 SM Mode

This section provides the following graphs:

- Variation of the SM near and far range incidence angles along the orbit
- Ground range resolution of the SM_SLC, SM_GRD_FR, SM_GRD_HR and SM_GRD_MR products at minimum and maximum orbit altitude
- Range DTAR performance of the SM_SLC product
- NESZ performance of the SM_SLC product

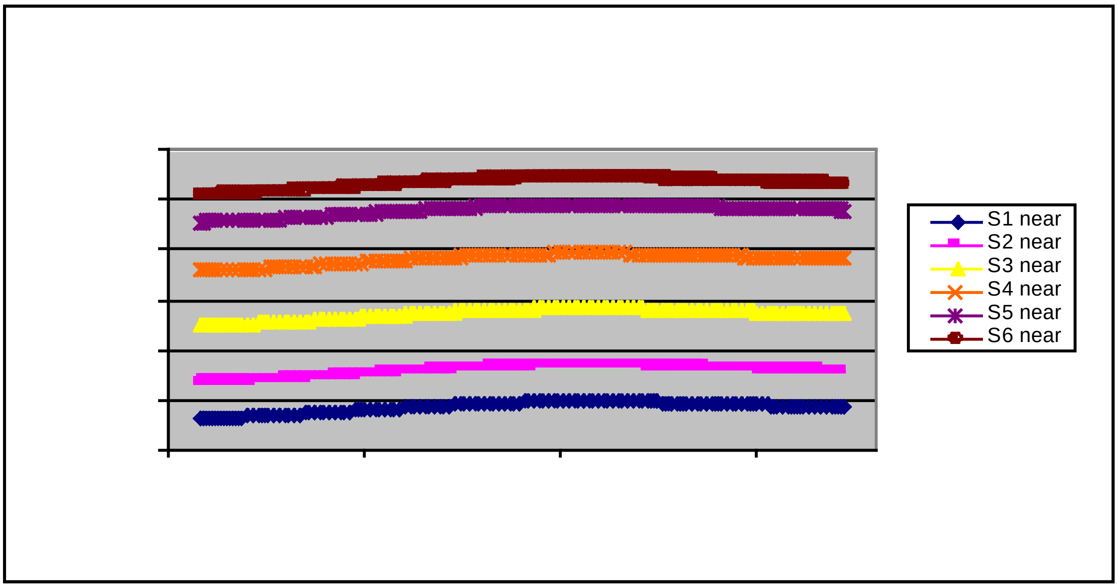

Figure B-1 Variation of the Near Range Incidence Angle along the Orbit for SM Mode

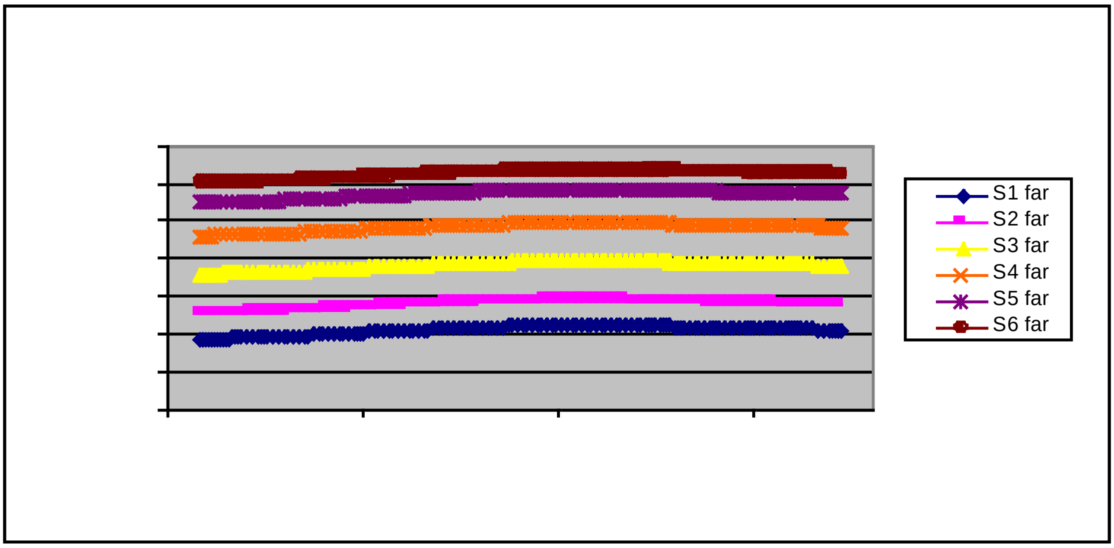

Figure B-2 Variation of the Far Range Incidence Angle along the Orbit for SM Mode

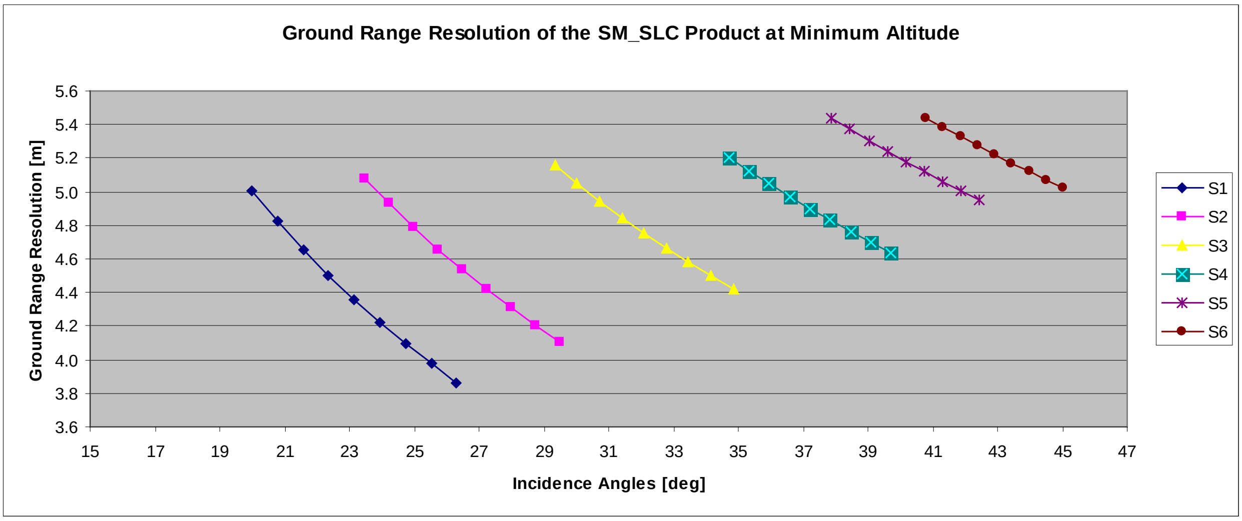

Figure B-3 Ground Range Resolution of the SM_SLC Product at Minimum Altitude

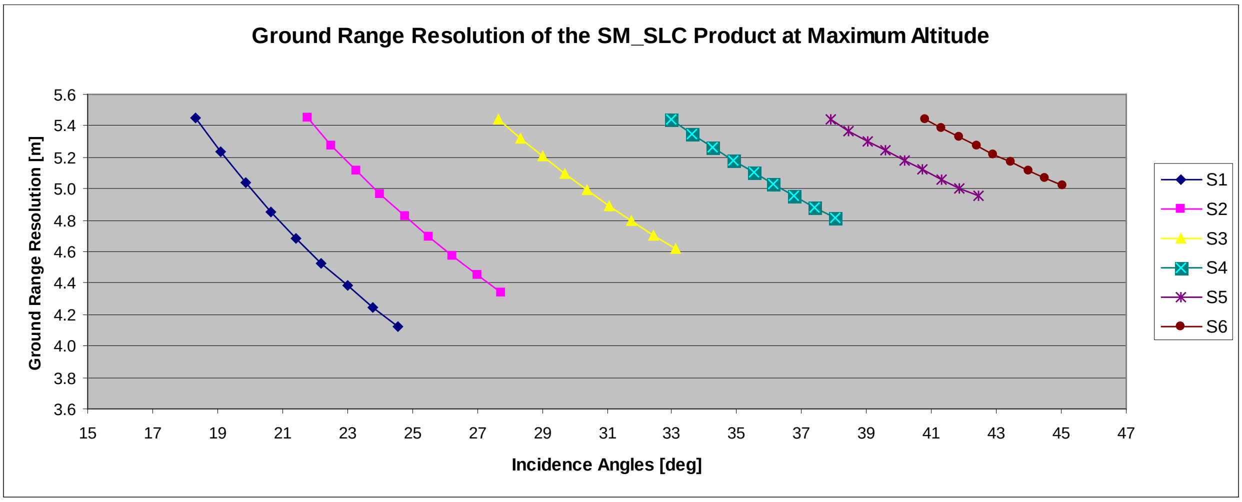

Figure B-4 Ground Range Resolution of the SM_SLC Product at Maximum Altitude

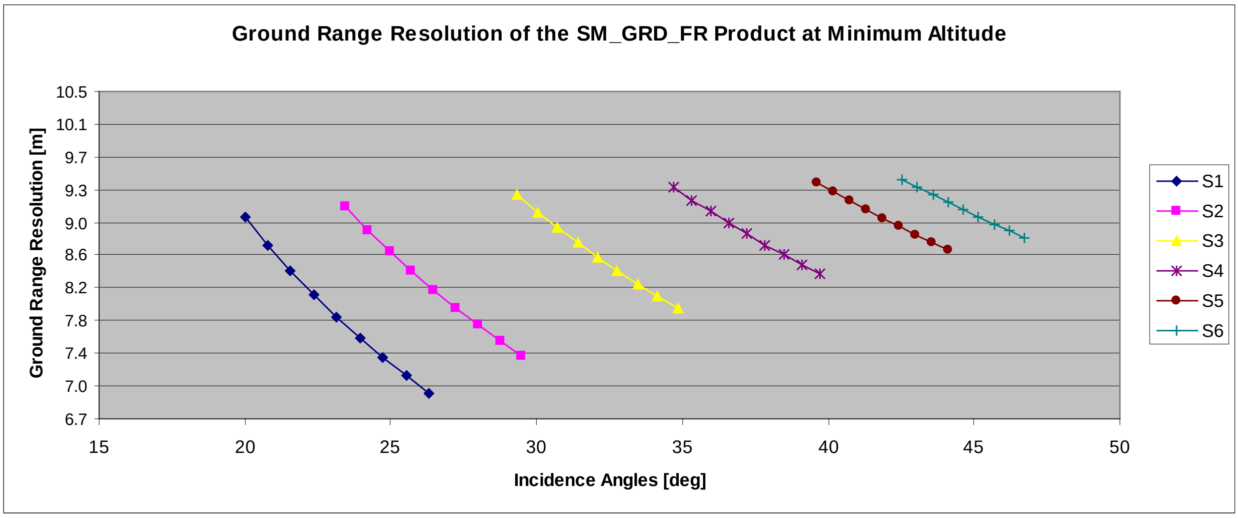

Figure B-5 Ground Range Resolution of the SM_GRD_FR Product at Minimum Altitude

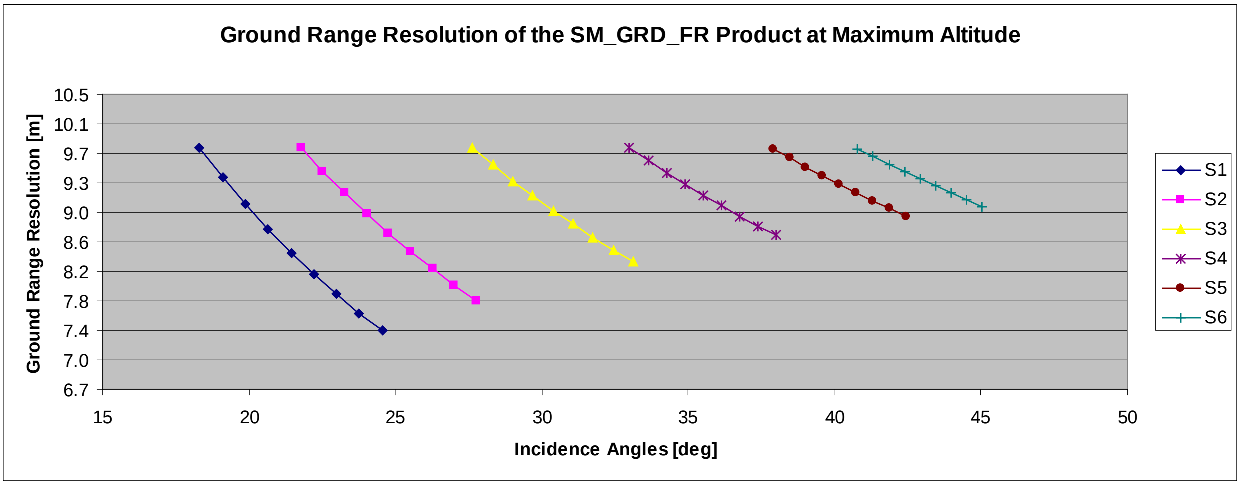

Figure B-6 Ground Range Resolution of the SM_GRD_FR Product at Maximum Altitude

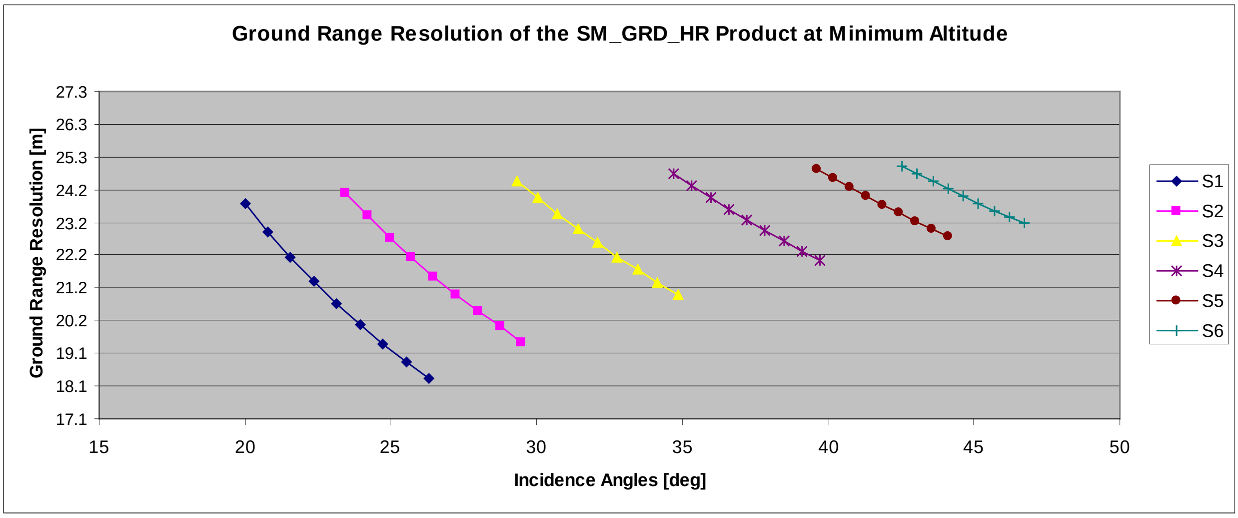

Figure B-7 Ground Range Resolution of the SM_GRD_HR Product at Minimum Altitude

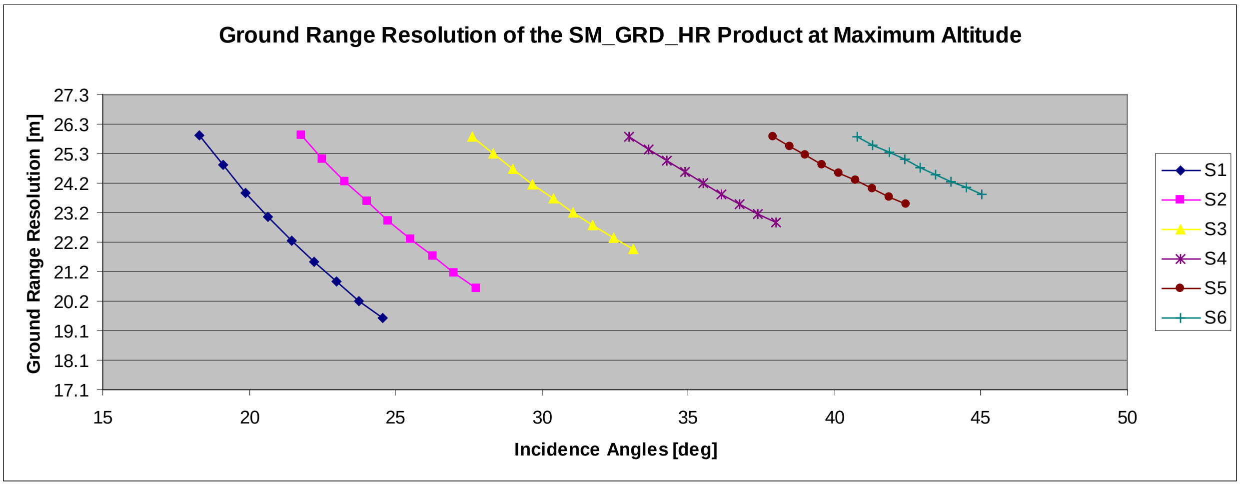

Figure B-8 Ground Range Resolution of the SM_GRD_HR Product at Maximum Altitude

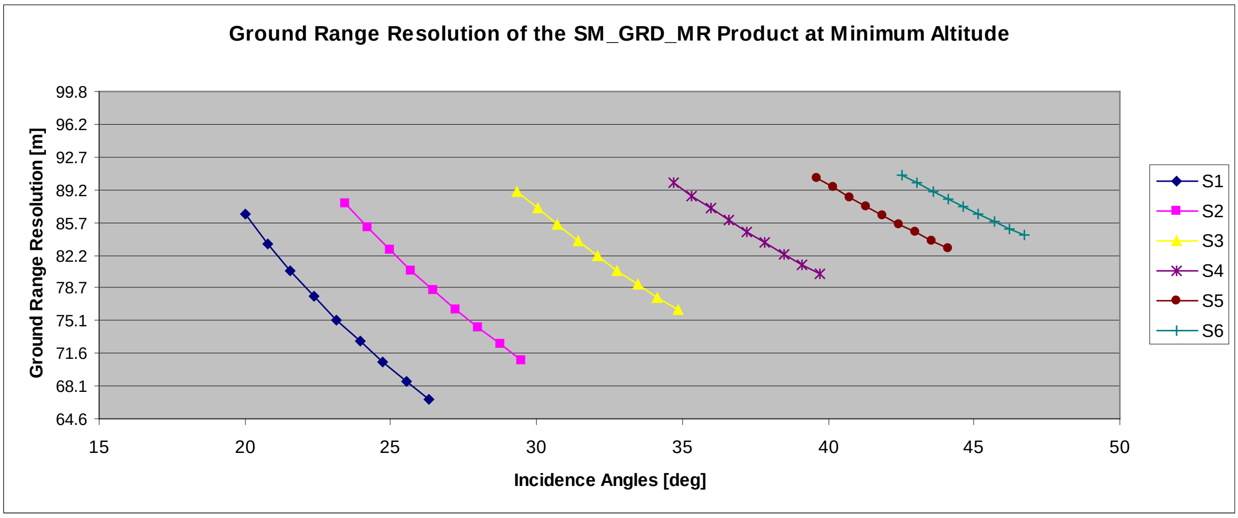

Figure B-9 Ground Range Resolution of the SM_GRD_MR Product at Minimum Altitude

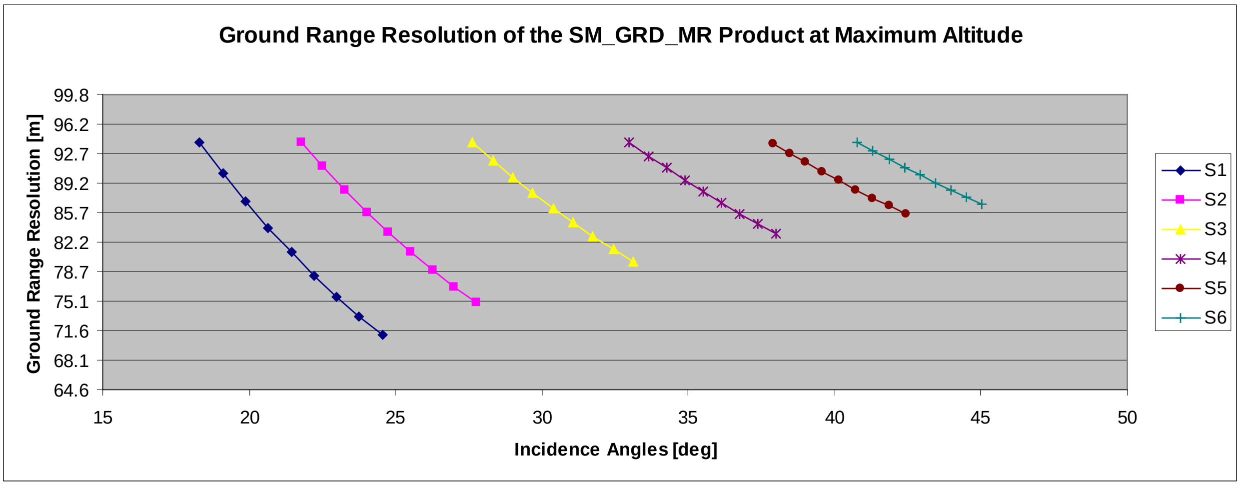

Figure B-10 Ground Range Resolution of the SM_GRD_MR Product at Maximum Altitude

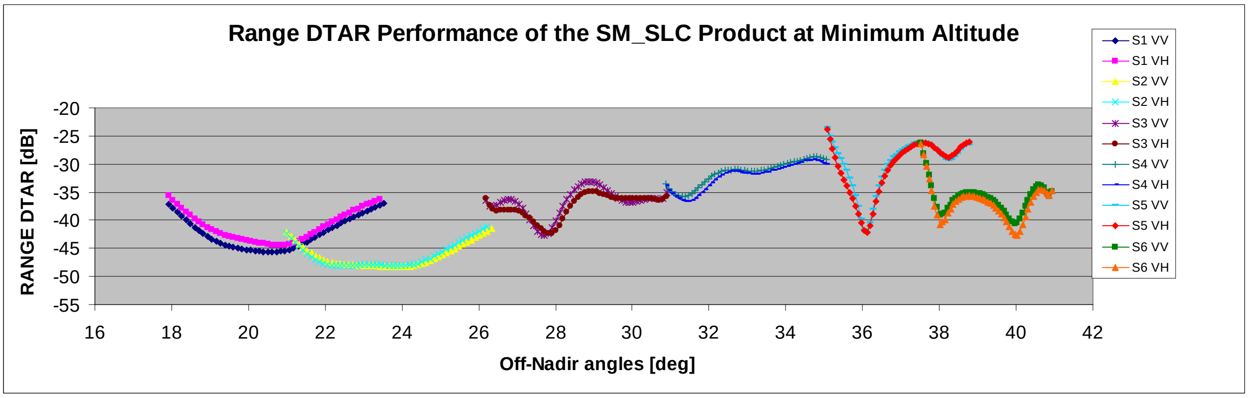

Figure B-11 Range-DTAR Performance of the SM_SLC Product at Minimum Altitude

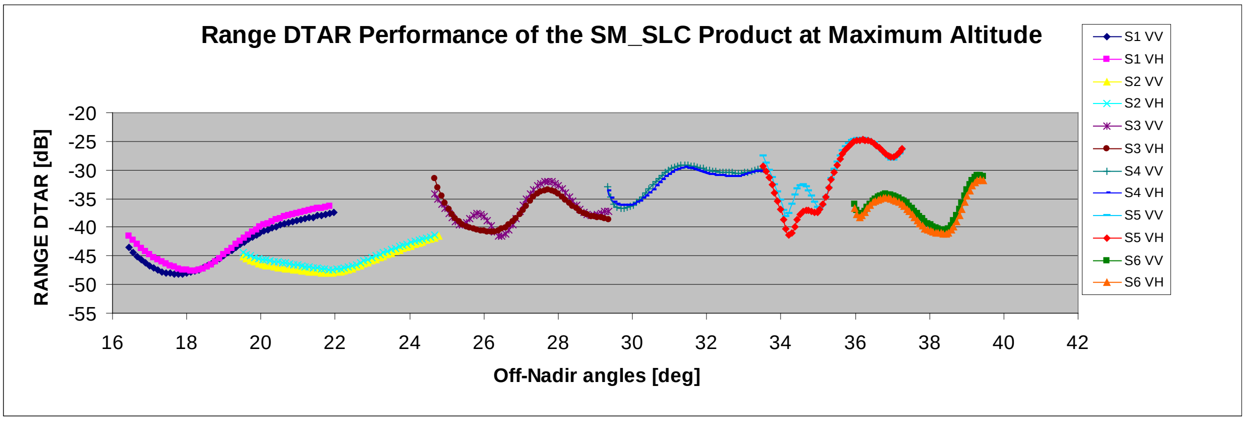

Figure B-12 Range-DTAR Performance of the SM_SLC Product at Maximum Altitude

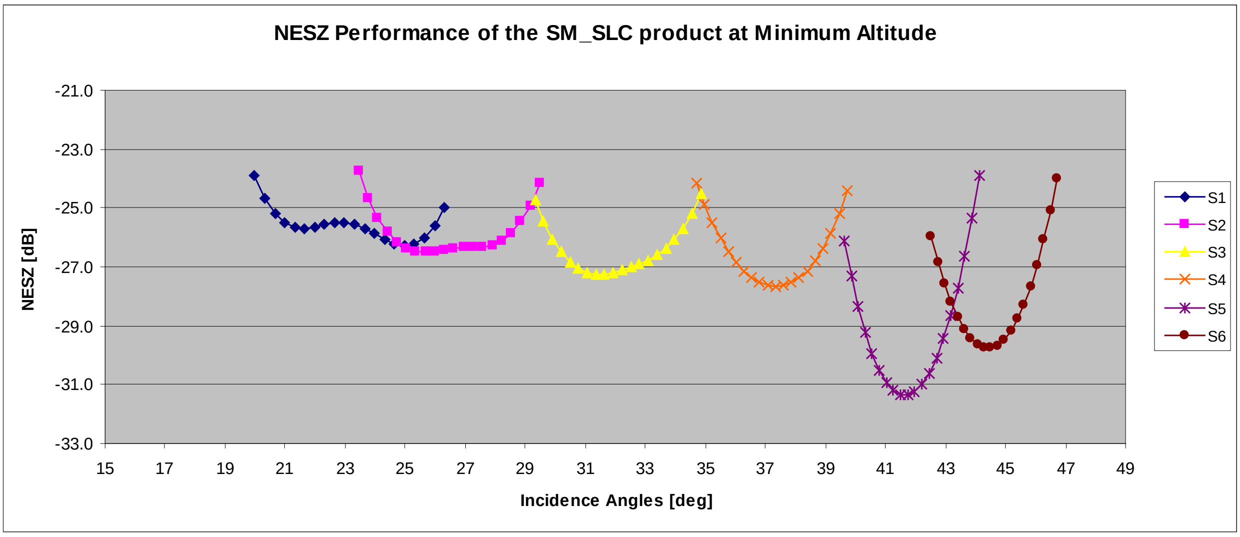

Figure B-13 NESZ Performance of the SM_SLC Product at Minimum Altitude

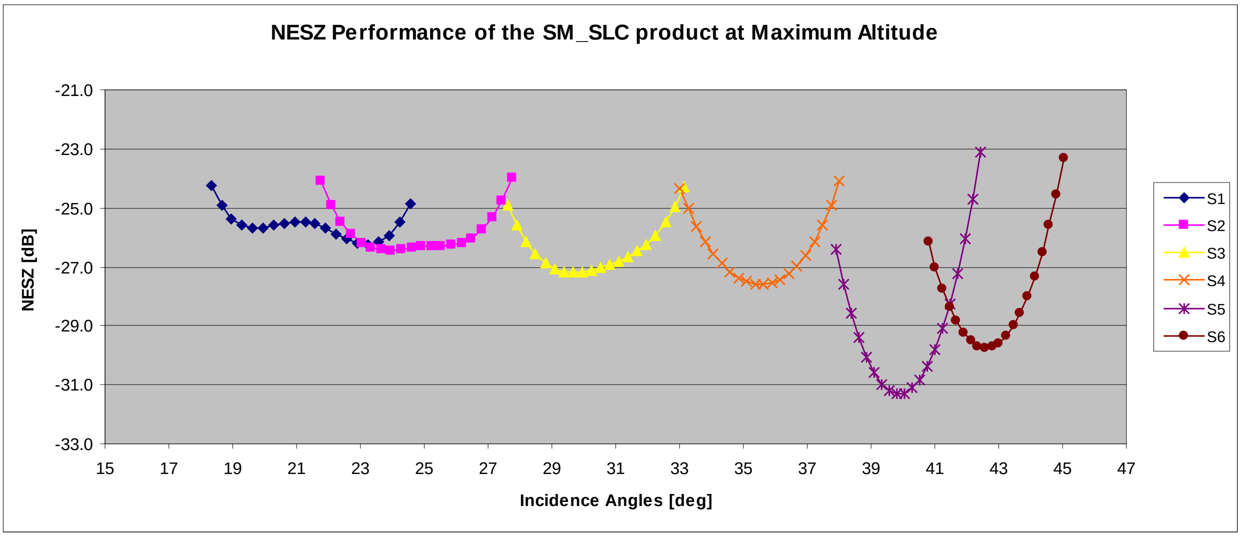

Figure B-14 NESZ Performance of the SM_SLC Product at Maximum Altitude

B2 IW Mode

This section provides the following graphs:

- Variation of the IW near and far range incidence angles along the orbit
- Ground range resolution of the IW_SLC, IW_GRD_HR and IW_GRD_MR products at minimum and maximum orbit altitude
- Range DTAR performance of the IW_SLC product, at minimum and maximum orbit altitude
- NESZ performance of the IW_SLC product, at minimum and maximum orbit altitude

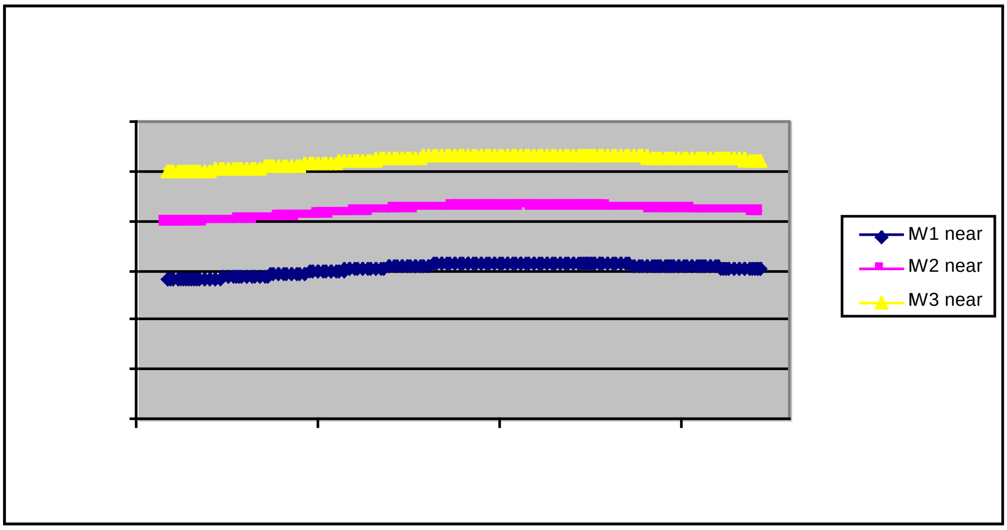

Figure B-15 Variation of the Near Range Incidence Angle along the Orbit for IW Mode

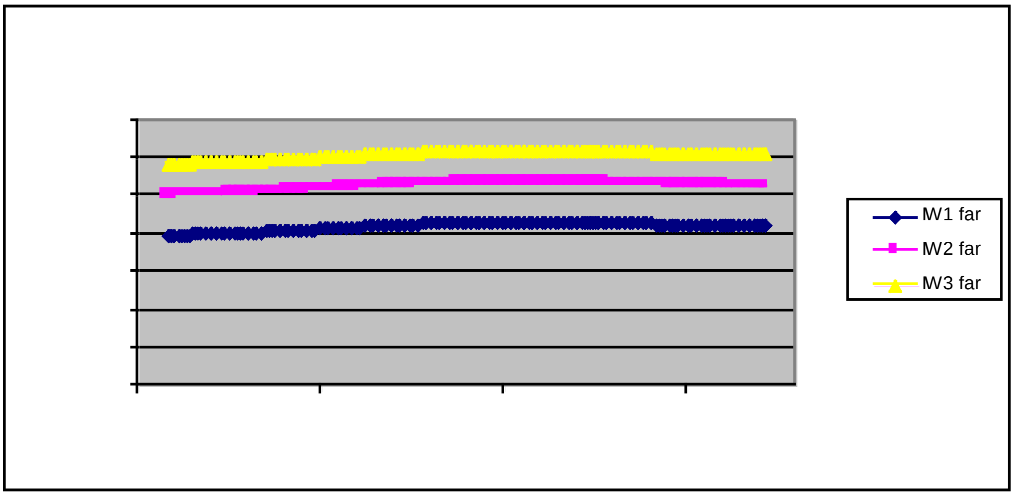

Figure B-16 Variation of the Far Range Incidence Angle along the Orbit for IW Mode

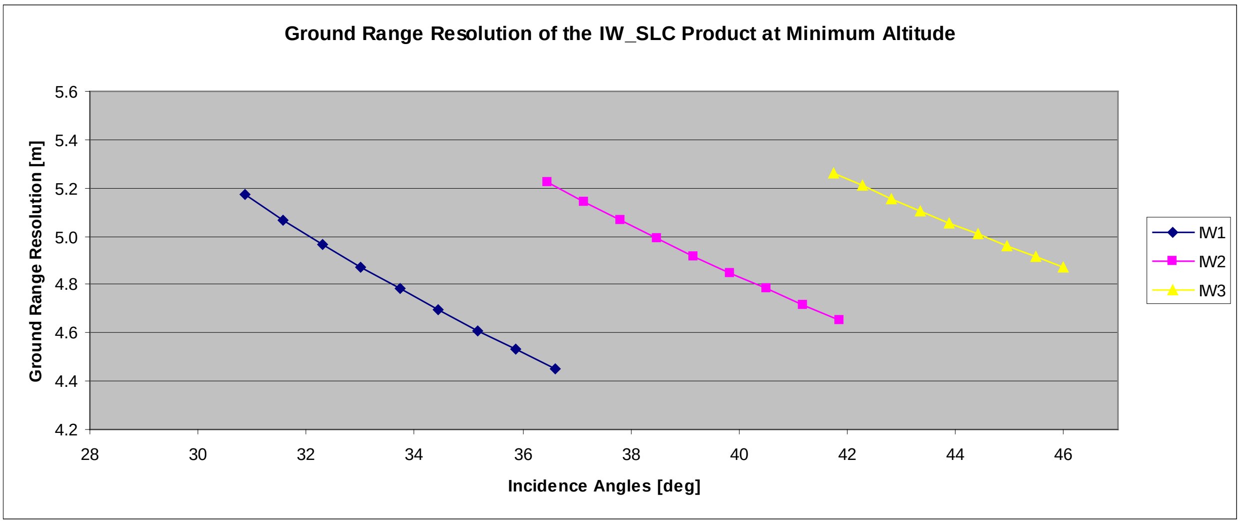

Figure B-17 Ground Range Resolution of the IW_SLC Product at Minimum Altitude

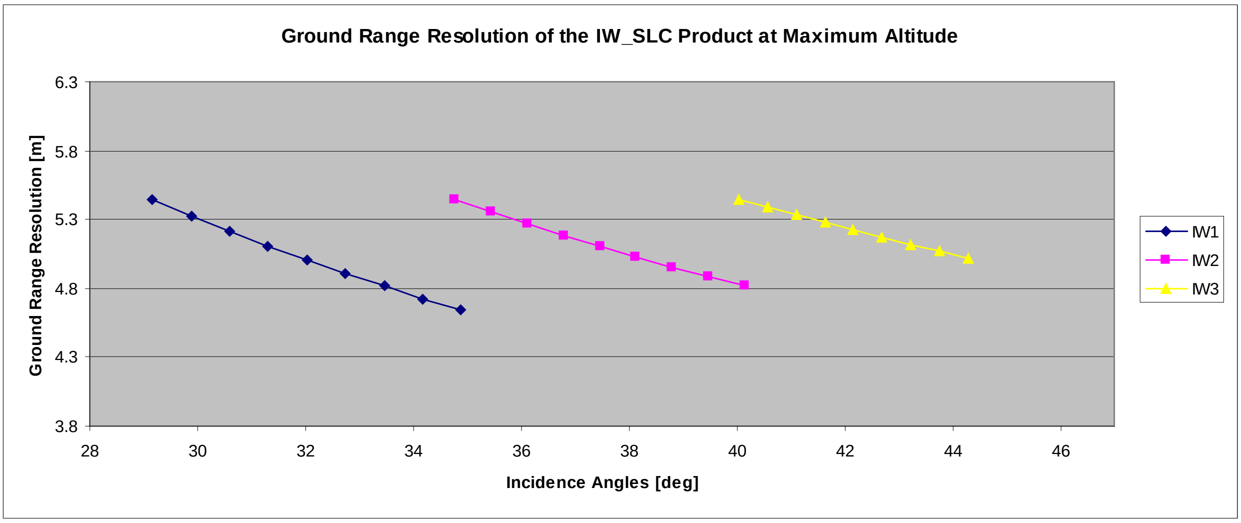

Figure B-18 Ground Range Resolution of the IW_SLC Product at Maximum Altitude

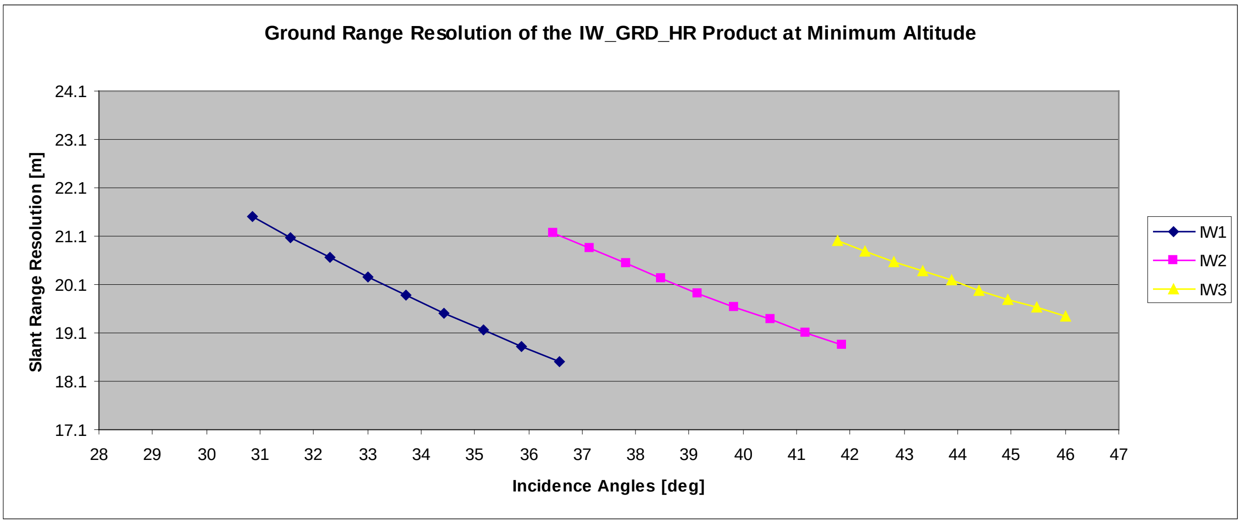

Figure B-19 Ground Range Resolution of the IW_GRD_HR Product at Minimum Altitude

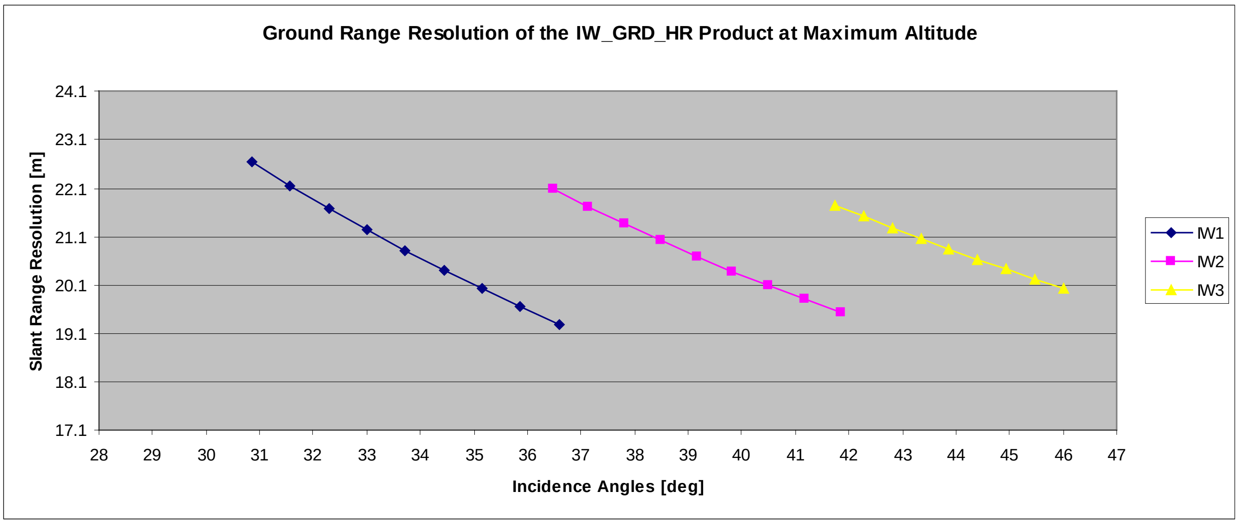

Figure B-20 Ground Range Resolution of the IW_GRD_HR Product at Maximum Altitude

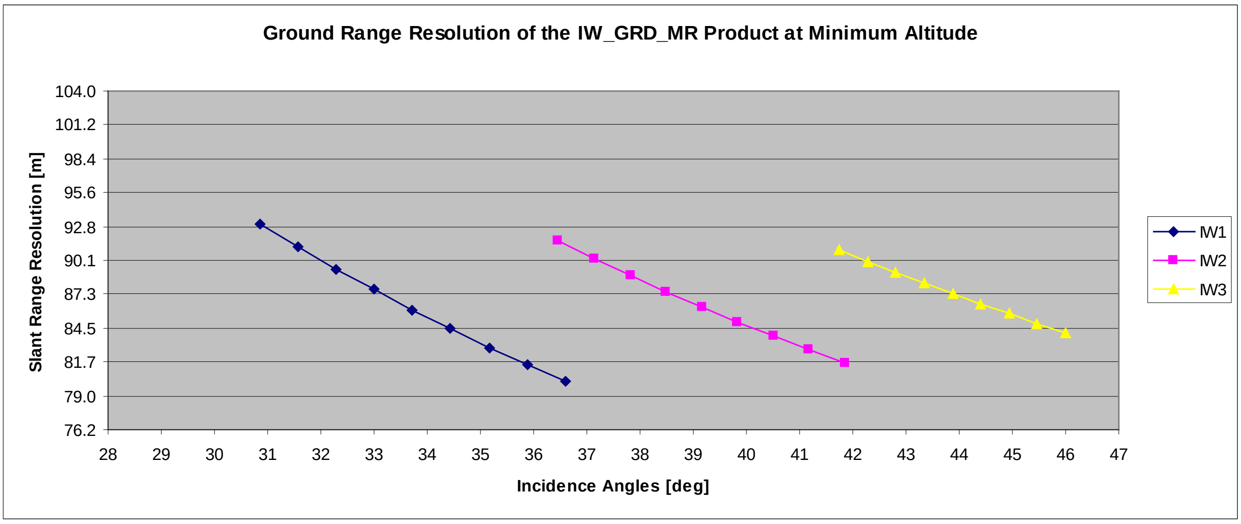

Figure B-21 Ground Range Resolution of the IW_GRD_MR Product at Minimum Altitude

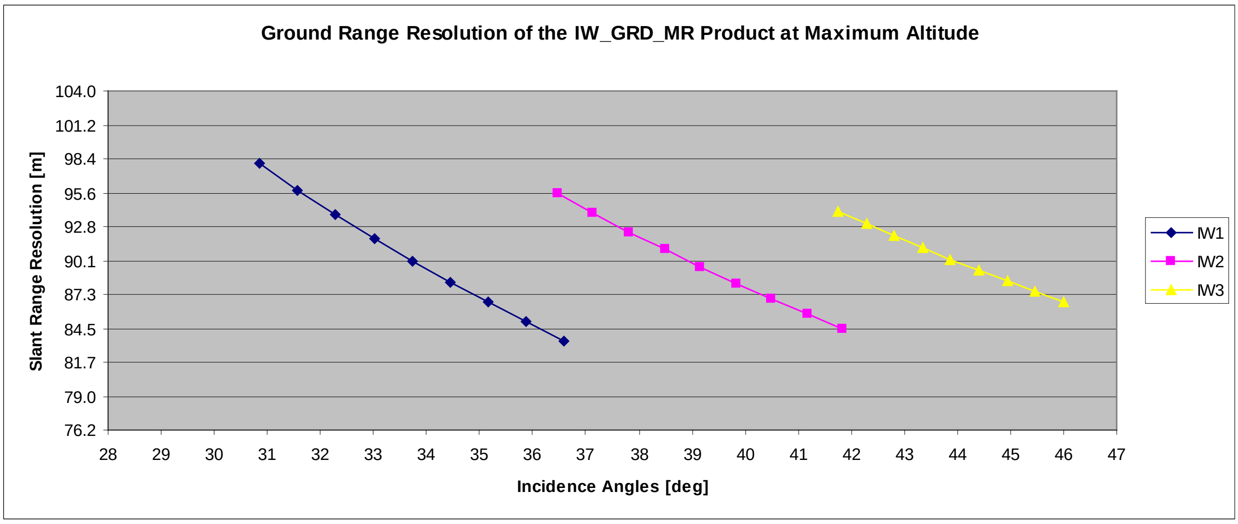

Figure B-22 Ground Range Resolution of the IW_GRD_MR Product at Maximum Altitude

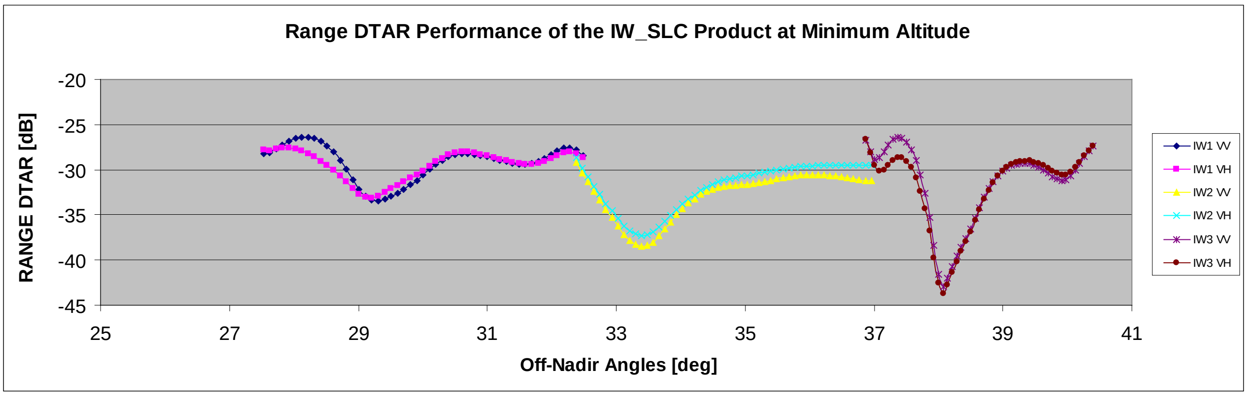

Figure B-23 Range DTAR Performance of the IW_SLC Product at Minimum Altitude

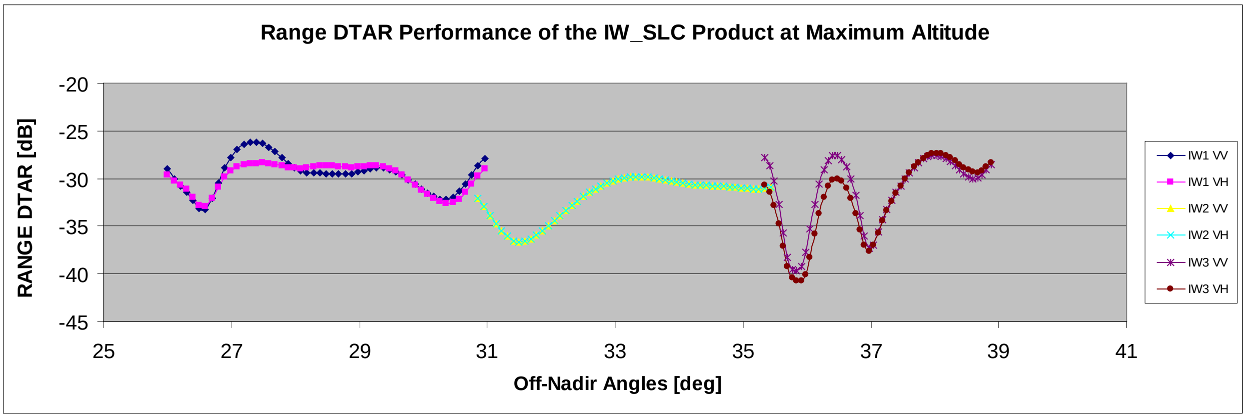

Figure B-24 Range DTAR Performance of the IW_SLC Product at Maximum Altitude

Figure B-25 NESZ Performance of the IW_SLC Product at Minimum Altitude

Figure B-26 NESZ Performance of the IW_SLC Product at Maximum Altitude

B3 EW Mode

This section provides the following graphs:

- Variation of the EW near and far range incidence angles along the orbit
- Ground range resolution of the EW_SLC, EW_GRD_HR and EW_GRD_MR products, at minimum and maximum orbit altitude
- Range DTAR performance of the EW_SLC product, at minimum and maximum orbit altitude
- NESZ performance of the EW_SLC product, at minimum and maximum orbit altitude

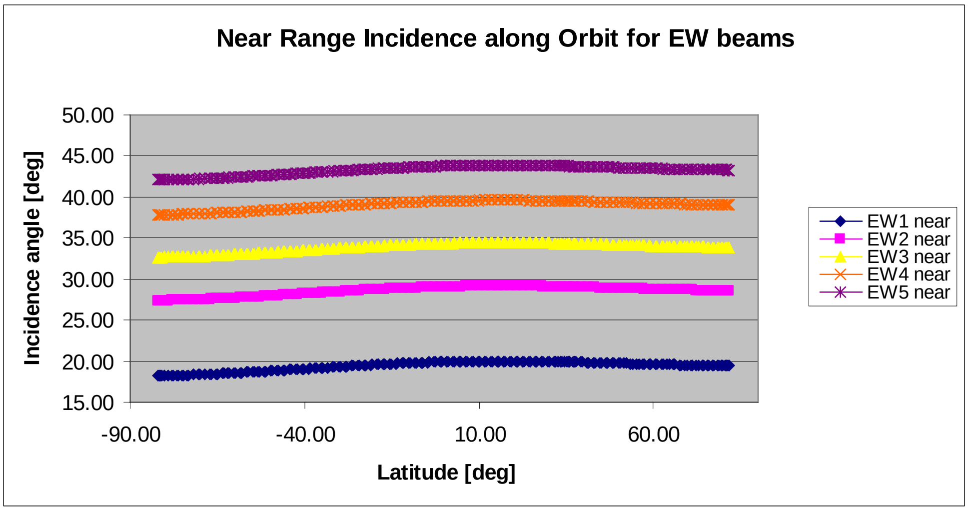

Figure B-27 Variation of the Near Range Incidence Angle along the Orbit for EW Mode

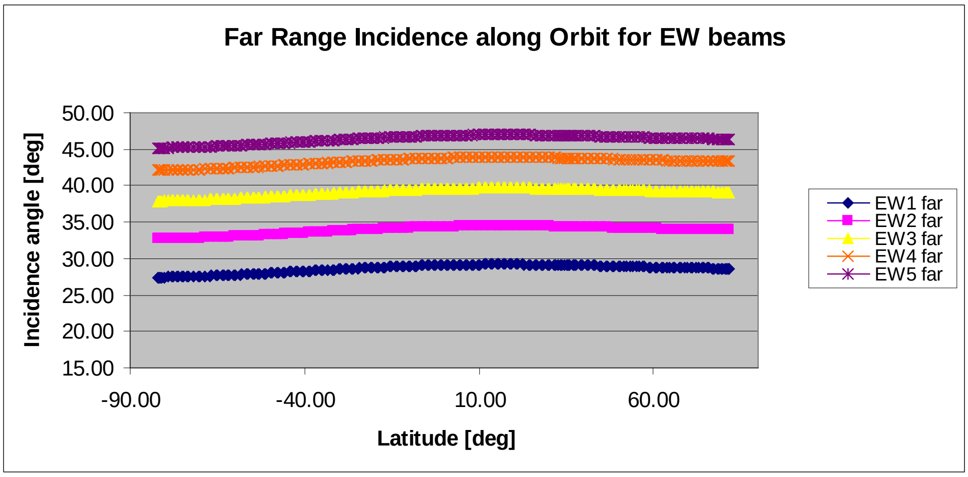

Figure B-28 Variation of the Far Range Incidence Angle along the Orbit for EW Mode

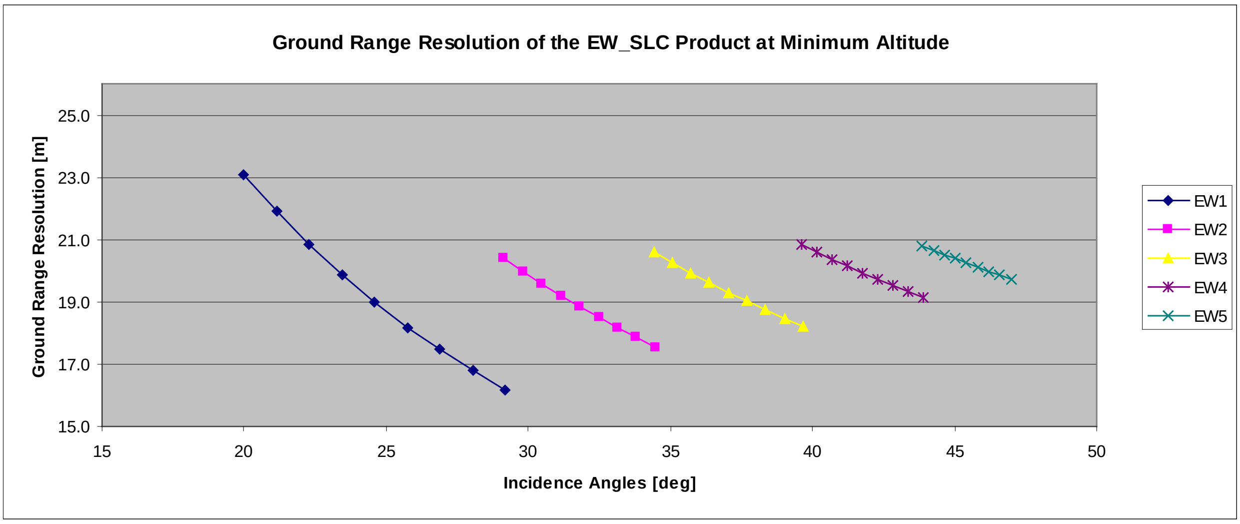

Figure B-29 Ground Range Resolution of the EW_SLC Product at Minimum Altitude

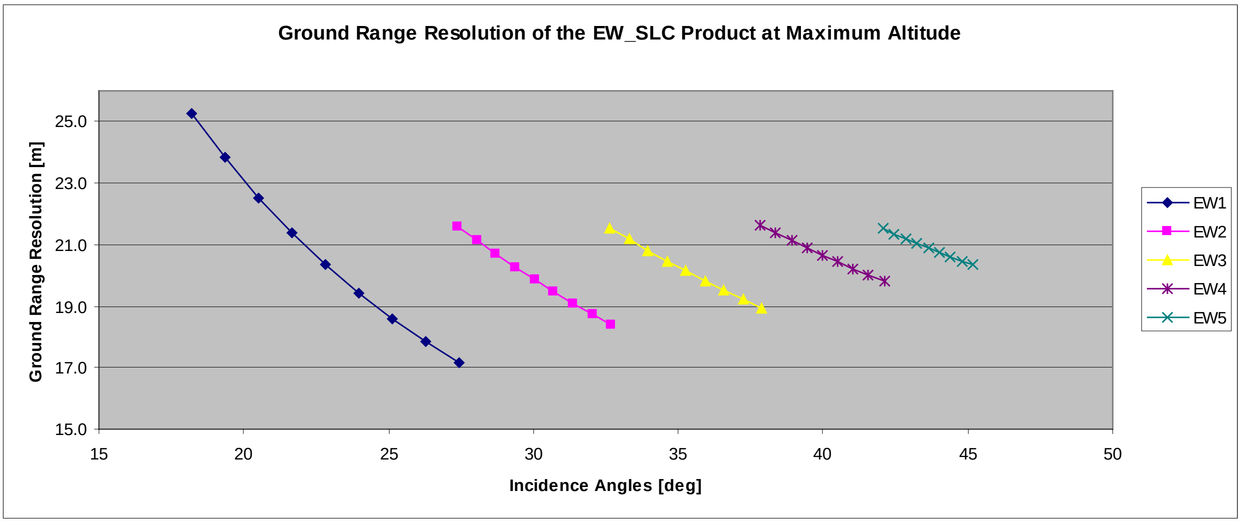

Figure B-30 Ground Range Resolution of the EW_SLC Product at Maximum Altitude

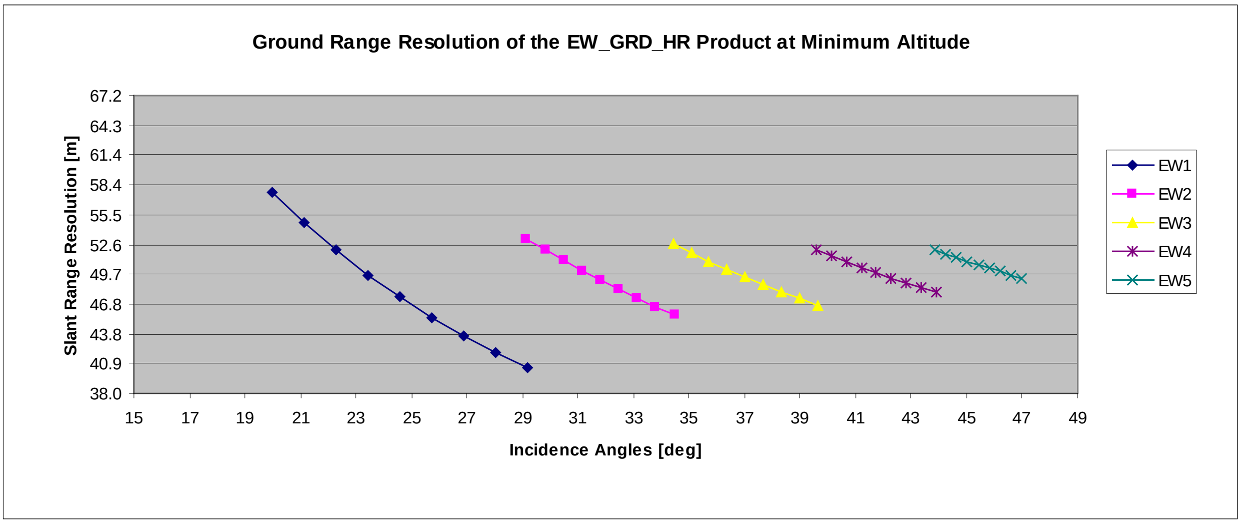

Figure B-31 Ground Range Resolution of the EW_GRD_HR Product at Minimum Altitude

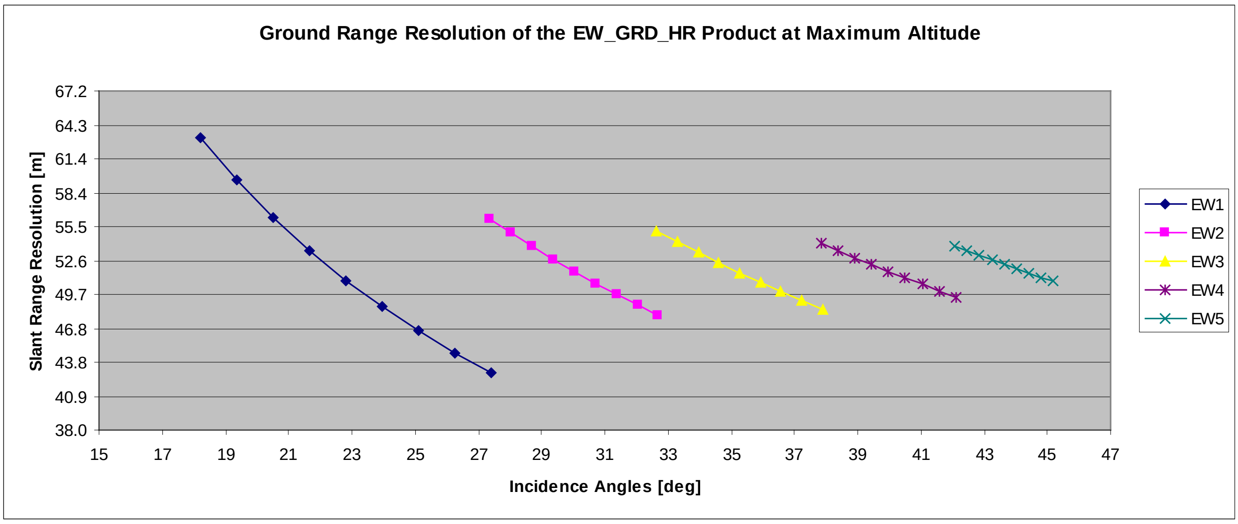

Figure B-32 Ground Range Resolution of the EW_GRD_HR Product at Maximum Altitude

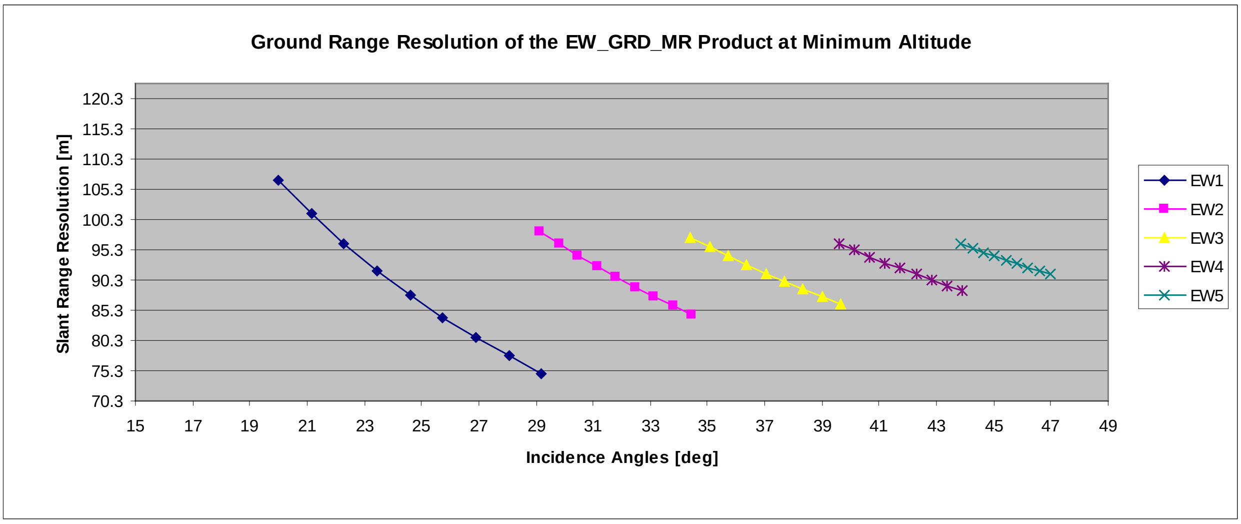

Figure B-33 Ground Range Resolution of the EW_GRD_MR Product at Minimum Altitude

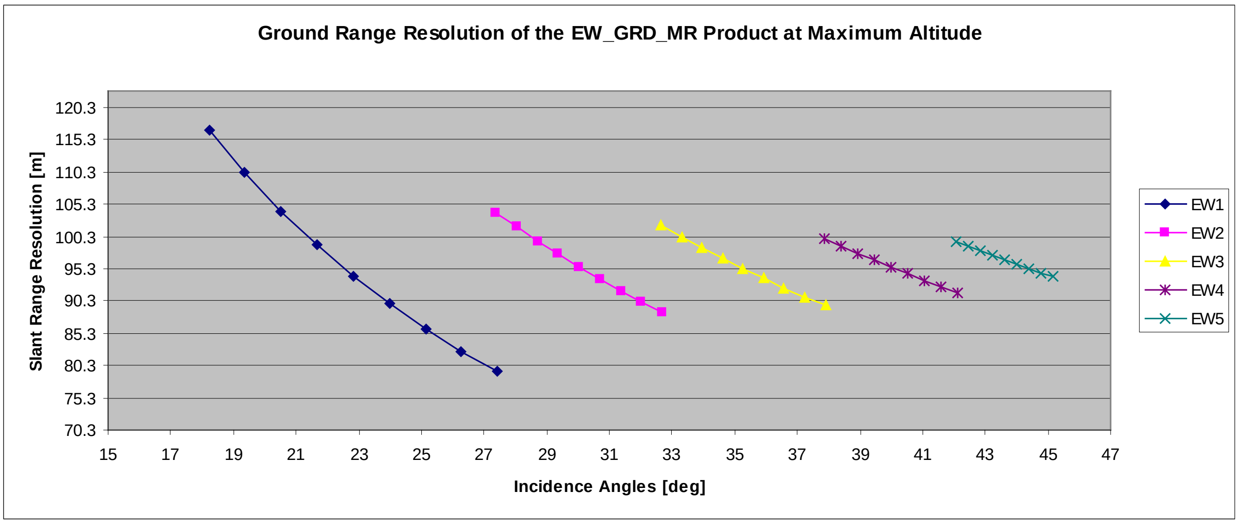

Figure B-34 Ground Range Resolution of the EW_GRD_MR Product at Maximum Altitude

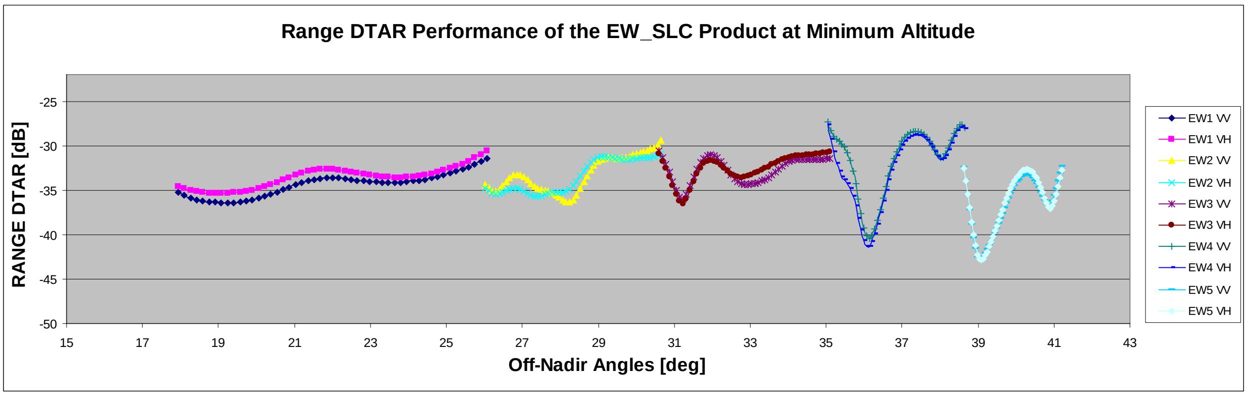

Figure B-35 Range-DTAR Performance of the EW_SLC Product at Minimum Altitude

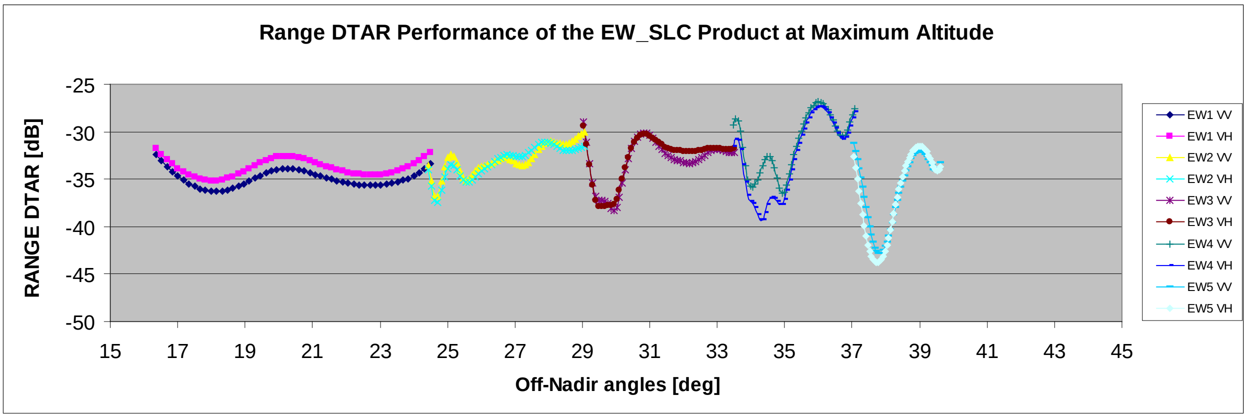

Figure B-36 Range-DTAR Performance of the EW_SLC Product at Maximum Altitude

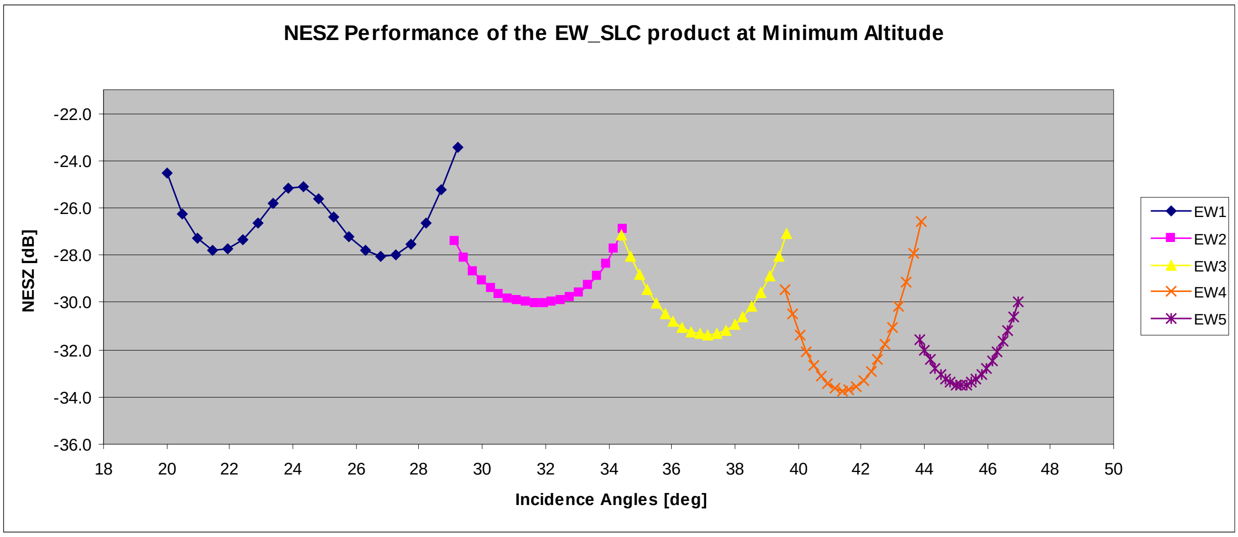

Figure B-37 NESZ Performance of the EW_SLC Product at Minimum Altitude

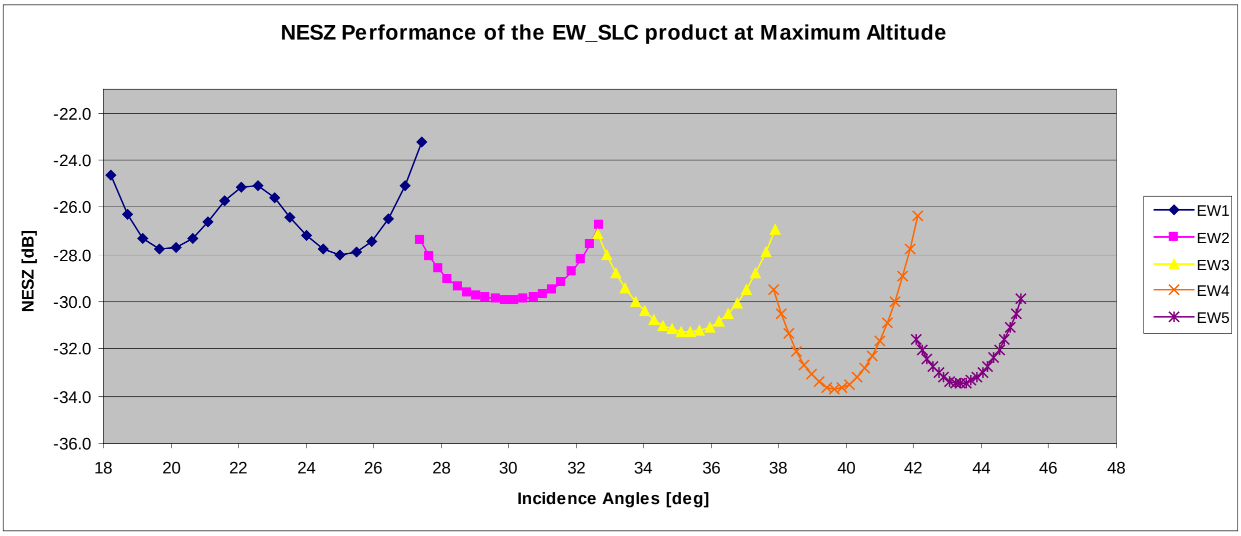

Figure B-38 NESZ Performance of the EW_SLC Product at Maximum Altitude

B4 WV Mode

This section provides the following graphs:

- Variation of the WV near and far range incidence angles along the orbit
- Ground range resolution of the WV_SLC and WV_GRD_MR products, at minimum and maximum orbit altitude
- Range DTAR performance of the WV_SLC product, at minimum and maximum orbit altitude
- NESZ performance of the WV_SLC product, at minimum and maximum orbit altitude

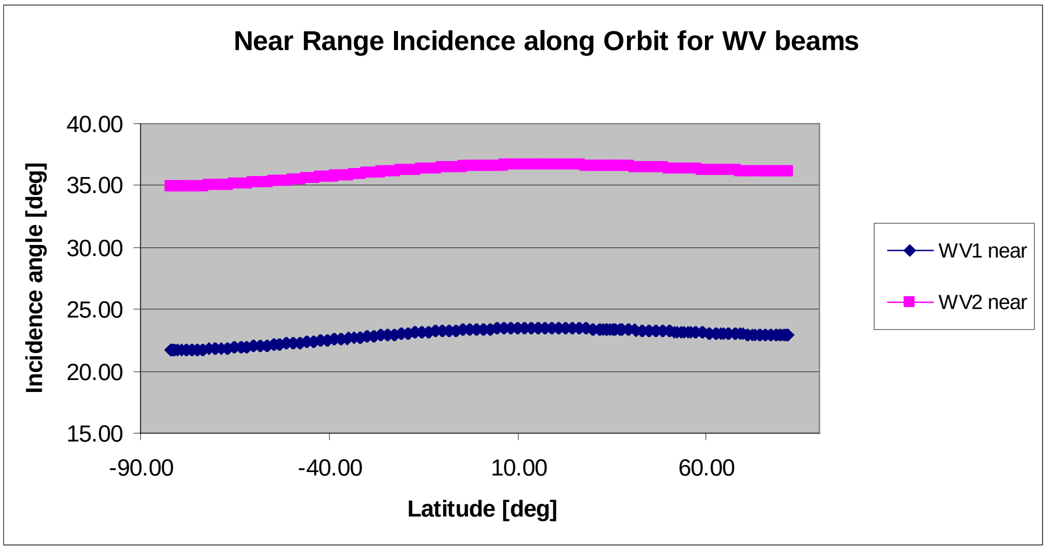

Figure B-39 Variation of the Near Range Incidence Angle along the Orbit for WV Mode

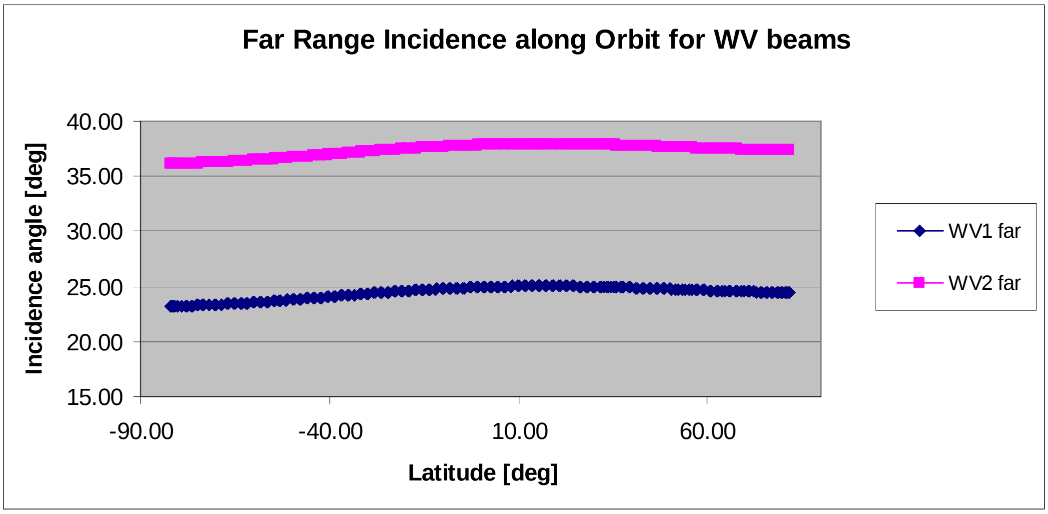

Figure B-40 Variation of the Far Range Incidence Angle along the Orbit for WV Mode

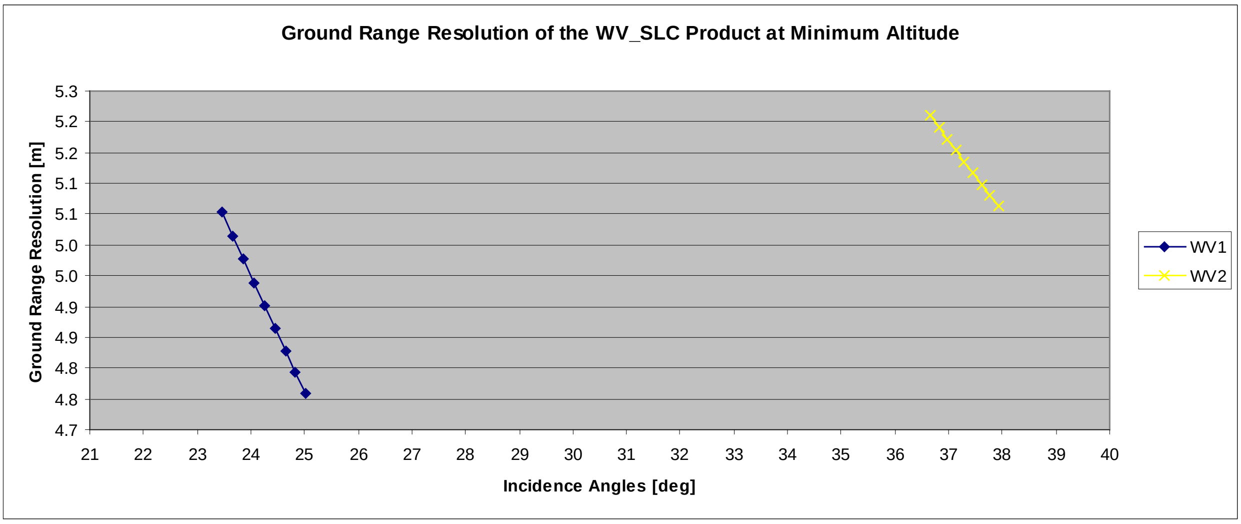

Figure B-41 Ground Range Resolution of the WV_SLC Product at Minimum Altitude

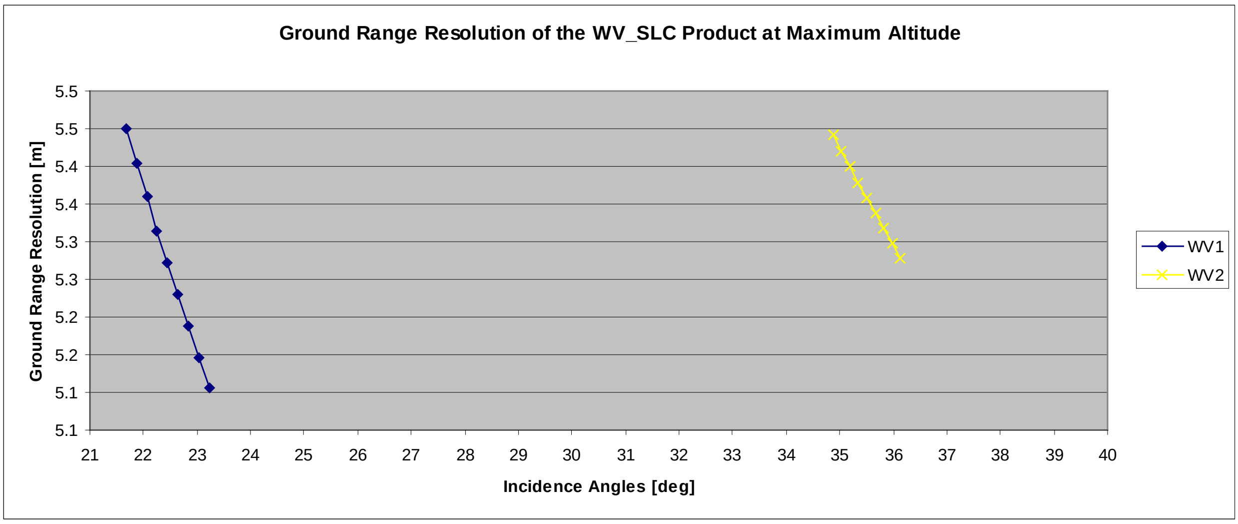

Figure B-42 Ground Range Resolution of the WV_SLC Product at Maximum Altitude

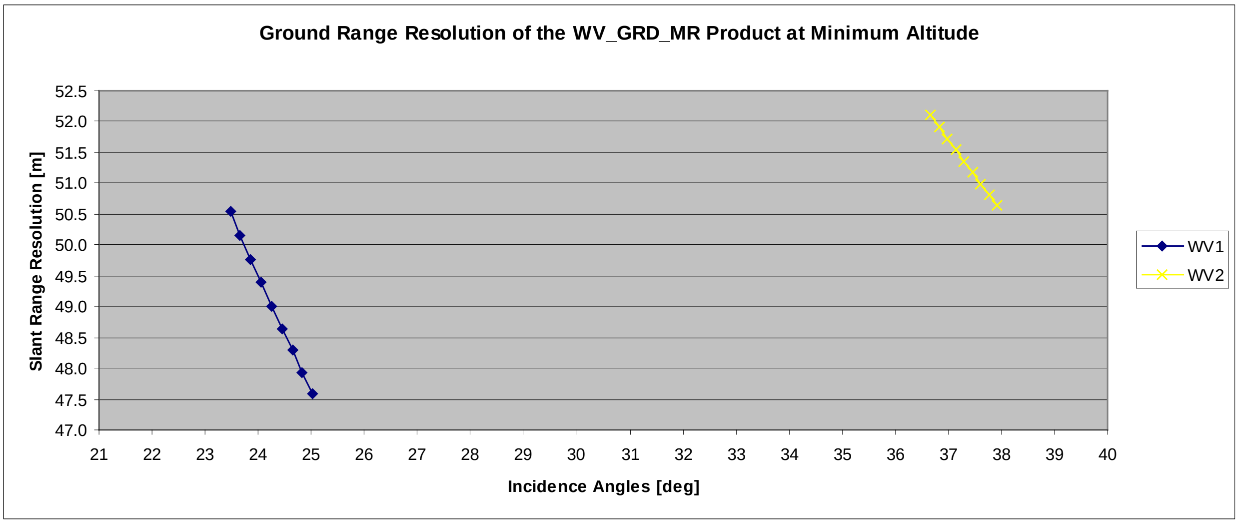

Figure B-43 Ground Range Resolution of the WV_GRD_MR Product at Minimum Altitude

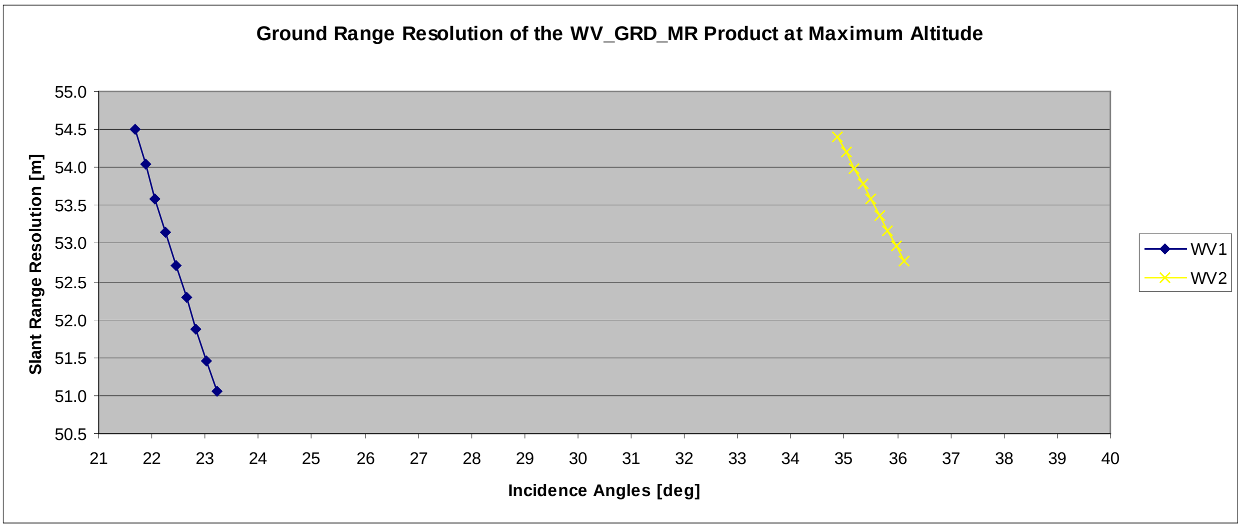

Figure B-44 Ground Range Resolution of the WV_GRD_MR Product at Maximum Altitude

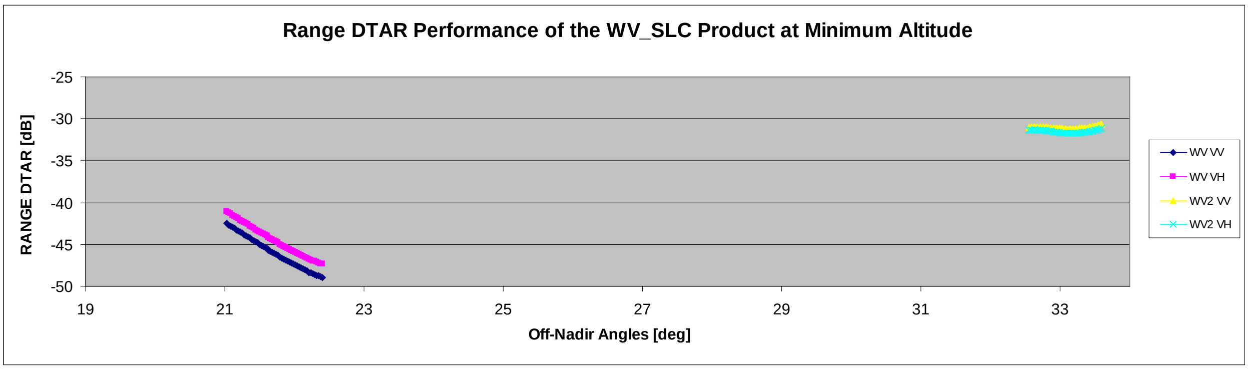

Figure B-45 Range DTAR Performance of the WV_SLC Product at Minimum Altitude

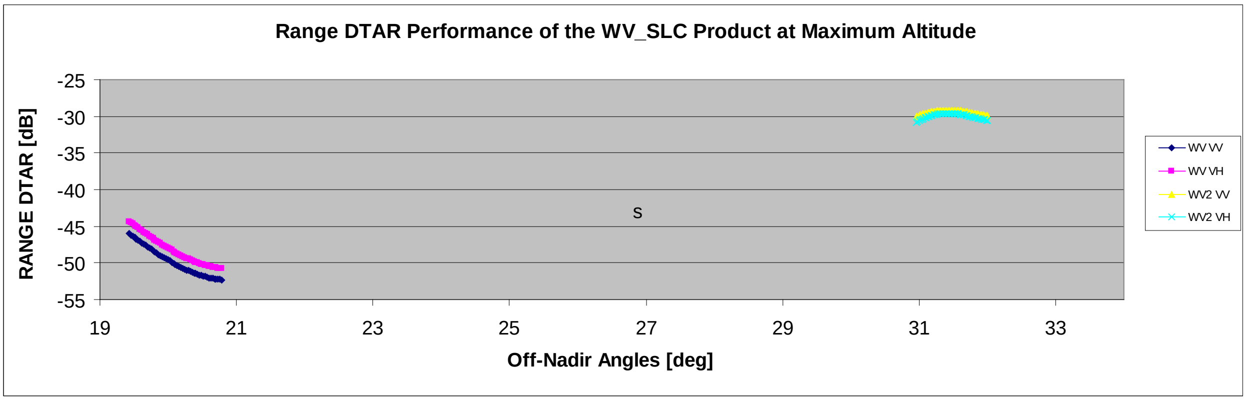

Figure B-46 Range DTAR Performance of the WV_SLC Product at Maximum Altitude

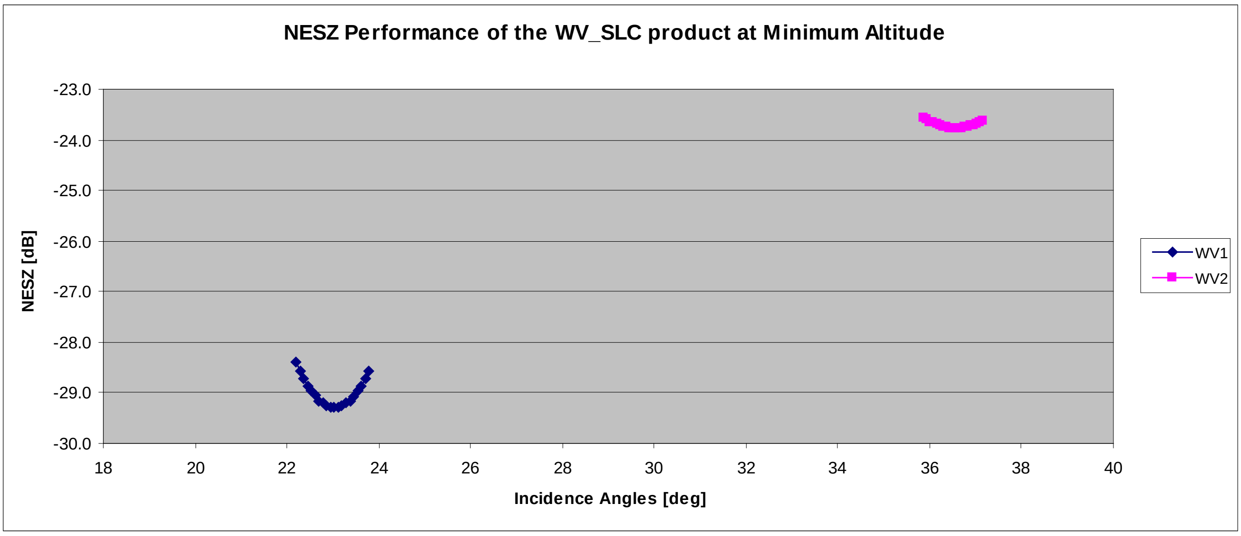

Figure B-47 NESZ Performance of the WV_SLC Product at Minimum Altitude

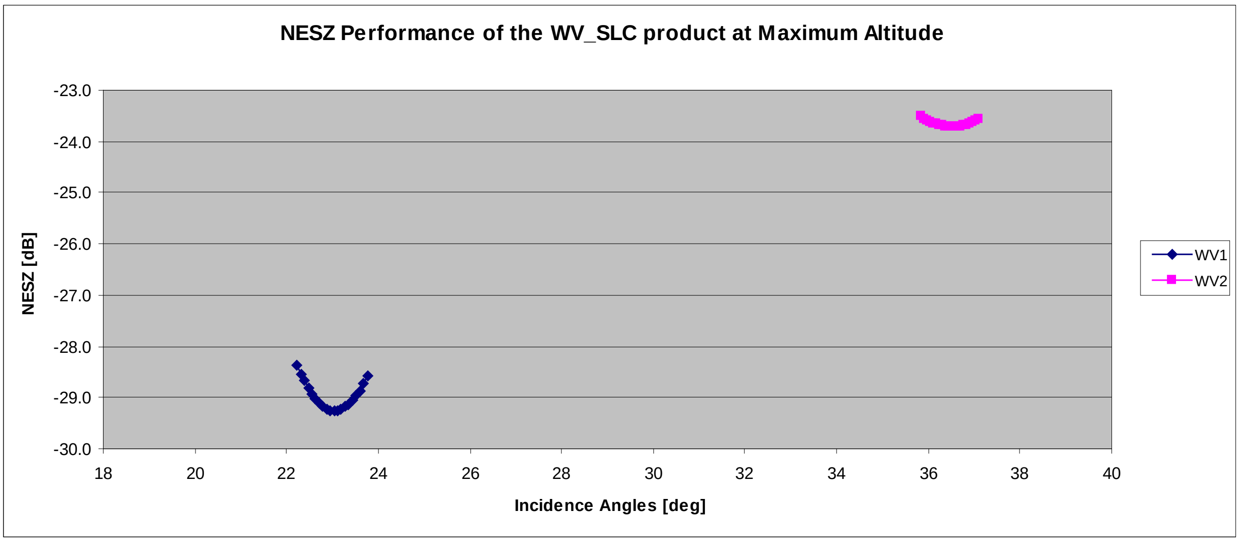

Figure B-48 NESZ Performance of the WV_SLC Product at Maximum Altitude

C DETAILED DERIVATION OF LEVEL 1 PRODUCT CHARACTERISTICS

The detailed derivation of the Level 1 product characteristics is provided in the Excel file S1-RS-MDA-52-7440_ProductDefinition_v2_4_AppendixC.xls.

D PRODUCT DEFINITION RELATED ISSUES

This appendix contains discussions relative to the derivation of the predicted ENL and the Doppler Centroid Frequency Estimation.

D1 Natural Looks, Processing Looks and ENL

The number of natural azimuth looks is one for all modes. For each GRD product, the number of processing looks and the overlap values were set in such a way as to achieve an approximately constant geometrical (range or azimuth) resolution between swaths and close to equal resolutions in the azimuth and range directions.

The ENL of the GRD products was estimated based on a one-dimensional simulation of 128 K samples of Gaussian complex noise weighted with the Hamming window corresponding to each mode and beam. The ENL is a function of the number of processing looks and the degree of correlation between them; when there is no overlapping, ENL is equivalent to the number of processing looks. The look correlation is affected by both the amount of overlapping between looks and the weighting applied to the looks. When weighting is used, the ENL is larger for a given overlap, because the overlapping portions of the looks are de-emphasized.

Figure D-1 presents this dependency for the 2 processing looks and the 3 distinct (azimuth) Hamming windows applied in the Sentinel-1 Stripmap case. From the figure, one can see that, if desired, one way to achieve constant ENL across swaths would be to use the same amount of overlap and the same amount of weighting (clearly the change in weighting would slightly affect the geometric resolution).

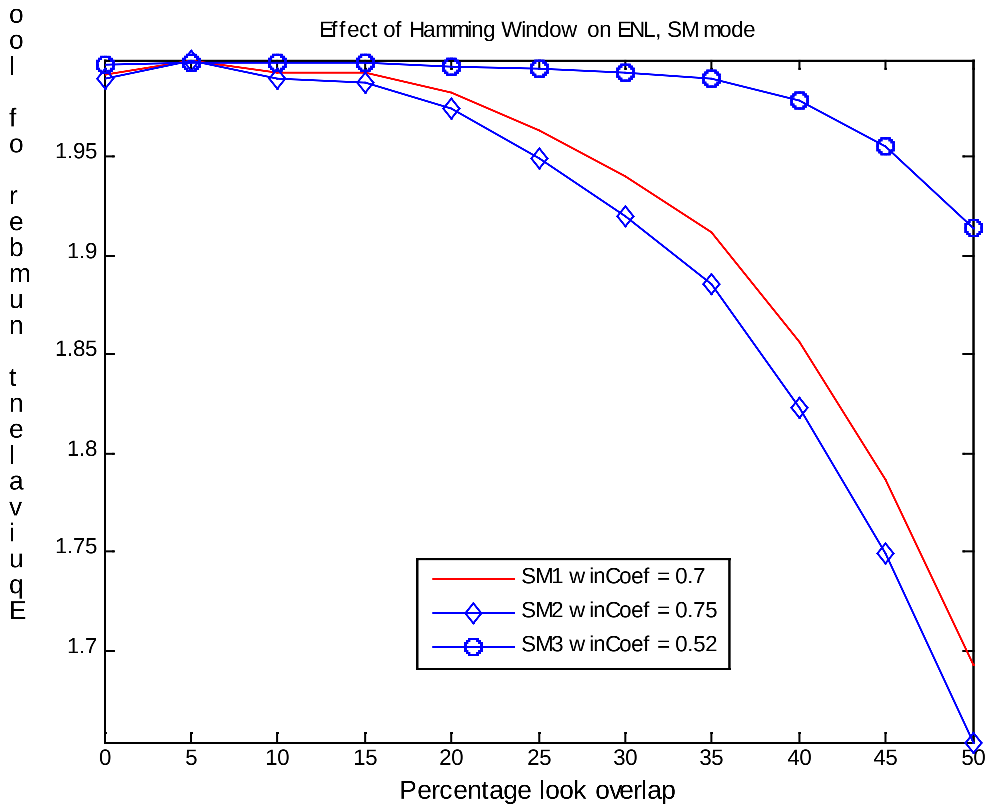

Figure D-1 Equivalent Number of Looks

For the TOPSAR modes, the azimuth multi-looking may be performed by a time-domain averaging (rather than by a (spectrum) look-summation). In this case the (averaged) data will have a different statistical distribution and therefore the ENL definition (as described in A1.2) no longer applies.

D2 Doppler Centroid Frequency Accuracy

Estimation of the Doppler centroid frequency, or simply Doppler centroid (DC), is an essential part of SAR processing. Poor estimates can affect radiometry, registration and focusing and raise the noise and ambiguity levels in the processed image (see [R-5]). For the TOPSAR modes in particular, due to the bursty nature of the (ScanSAR) data, periodic azimuth modulation of image amplitude (known as scalloping) can be caused by even relatively small DC errors.

The radiometric error due to a DC frequency error can be reduced by the process of multi-looking, which means that the products that are most sensitive (from the radiometric point of view) to DC frequency errors are SLC products.

The accuracy of the DC frequency estimation is relatively difficult to assess. Typically, this characteristic is assessed using indirect methods such as:

a) Analyzing the consistency and trends of the DC frequency estimations from data with the values calculated from geometry, over the same scenes. (This is made possible by the high measurement and beam pointing accuracy of Sentinel-1).

b) Analyzing the effect of intentionally introduced DC frequency errors on image characteristics like radiometry and ambiguity ratios.

The quality of the DC frequency estimation performed in either the RADARSAT-1/2 or the ENVISAT/ASAR MDA processors is considered very good with respect to the requirements of those systems. To address the more stringent Sentinel-1 DC accuracy requirements, the Sentinel-1 DC estimation scheme includes a refinement of the existing algorithms consisting of a filtering of un-reliable estimates based on scene-content (to supplement the already existing filtering based on statistical criteria).