DOCUMENT

Sentinel-1 User Handbook

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Reference	**GMES-S1OP-EOPG-TN-13-0001**
Issue	**Draft**
Revision	**0**
Date of Issue	**1st September 2013**
Status	**For External Use**
Document Type	**User Handbook**
Distribution	**Open**

Source **https://sentinel.esa.int/**

European Space Agency
Agence spatiale européenne

APPROVAL

Title Sentinel -1 User Handbook	
Issue 1	**Revision** 0
Author SUHET	**Date** 1/09/2013
Approved by **Pierre Potin**	**Date** 1/09/2013

CHANGE LOG

Reason for change	Issue	Revision	Date

CHANGE RECORD

Issue	Revision		
Reason for change	**Date**	**Pages**	**Paragraph(s)**

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1 SENTINEL-1 MISSION GUIDE

The SENTINEL-1 mission comprises a constellation of two polar-orbiting satellites, operating day and night performing C-band synthetic aperture radar imaging, enabling them to acquire imagery regardless of the weather.

SENTINEL-1 will work in a pre-programmed operation mode to avoid conflicts and to produce a consistent long-term data archive built for applications based on long time series.

SENTINEL-1 is the first of the five missions that ESA is developing for the Copernicus initiative.

The first SENTINEL-1 satellite (SENTINEL-1A) is planned for launch on a SOYUZ rocket from Europe's Spaceport in French Guiana in early 2014 followed by the second (SENTINEL-1B) in 2016.

The SENTINEL-1 Mission Guide provides a high-level description of the mission objectives, satellite description and Ground Segment. It also introduces the related heritage missions, thematic areas, orbit characteristics and coverage, instrument payload and data products.

Figure 1: SENTINEL-1

1.1 Overview

The SENTINEL-1 mission is the European Radar Observatory for the Copernicus joint initiative of the European Commission (EC) and the European Space Agency (ESA). Copernicus, previously known as GMES, is a European initiative for the implementation of information services dealing with environment and security. It is based on observation data received from Earth Observation satellites and ground-based information.

The SENTINEL-1 mission includes C-band imaging operating in four exclusive imaging modes with different resolution (down to 5 m) and coverage (up to 400 km). It provides dual polarisation capability, very short revisit times and rapid product delivery. For each observation, precise measurements of spacecraft position and attitude are available.

Synthetic Aperture Radar (SAR) has the advantage of operating at wavelengths not impeded by cloud cover or a lack of illumination and can acquire data over a site during day or night time under all weather conditions. SENTINEL-1, with its C-SAR instrument, can offer reliable, repeated wide area monitoring.

The mission is composed of a constellation of two satellites, SENTINEL-1A and SENTINEL-1B, sharing the same orbital plane.

SENTINEL-1 is designed to work in a pre-programmed, conflict-free operation mode, imaging all global landmasses, coastal zones and shipping routes at high resolution and covering the global ocean with vignettes. This ensures the reliability of service required by operational services and a consistent long term data archive built for applications based on long time series.

1.1.1 Heritage

SENTINEL-1 continues the C-band SAR Earth Observation of ESA's ERS-1, ERS-2 and ENVISAT, and Canada's ADARSAT-1 and RADARSAT-2.

ERS-1 and ERS-2

Figure 1: ERS-2 Satellite

The European Remote Sensing (ERS) satellites have achieved several milestones in Earth Observation. Launched in July 1991, ERS-1 introduced reliable and stable radar from space with its Active Microwave Instrument (AMI). ERS-2, launched in April 1995, shared the same orbital plane with ERS-1 allowing for a tandem mission in 1995 and 1996, where interferometric data was collected one day apart. ERS-1 was in operation until March 2000 while ERS-2 far exceeded its expected lifespan, acquiring images until 2011.

ENVISAT

Figure 2: ENVISAT Satellite

ENVISAT provided 10 years of SAR data mapping from March 2002 to May 2012, five years longer than its designed mission duration. With 10 instruments aboard and at 8 tons, ENVISAT is the largest civilian Earth Observation mission put into space. ENVISAT added new capabilities over ERS with its Advanced Synthetic Aperture Radar (ASAR) sensor including wide swaths, dual polarisation and simultaneous acquisitions from its MERIS sensor.

SENTINEL-1 provides enhancements over previous missions in the form of reliability, revisit time, geographical coverage and rapid data dissemination. SENTINEL-1 continues the C-band SAR Earth Observation of ESA's ERS-1, ERS-2 and ENVISAT, and Canada's RADARSAT-1 and RADARSAT-2.

1.1.2 Thematic Area

The mission will benefit numerous services. For example, services that relate to:

- monitoring of Arctic sea-ice extent
- routine sea-ice mapping
- surveillance of the marine environment, including oil-spill monitoring
- ship detection for maritime security
- monitoring land-surface for motion risks

- mapping for forest, water and soil management
- mapping to support humanitarian aid and crisis situations.

SENTINEL-1 will be the primary source of data for information on the oceans and the Arctic. The mission's ability to provide observation in all weather, and in day or night time conditions, makes it ideal for maritime and Arctic monitoring.

SENTINEL-1 dual polarimetric products will benefit users interested in agriculture, forestry and land cover classification. The enhanced interferometric capabilities will benefit users involved in activities like geohazard monitoring, mining, geology and city planning through subsidence risk assessment.

SENTINEL security users will be able to monitor major shipping routes to detect illegal activities, gather prosecution evidence in case of illegal discharges, detect unexpected building in remote areas, monitor deforestation and support search and rescue activities.

The rapid data dissemination and short revisit cycles of SENTINEL-1 together with its interferometric capabilities will also benefit emergency response users, such as the United Nations International Charter on Space and Major Disasters, in emergency situations such as floods, earthquakes, volcanic eruptions and landslides.

1.1.3 Mission Summary

The spacecraft carries a single C-SAR payload, deployable solar array and large data storage. The mission is expected to provide data quickly in the event of disaster monitoring.

The satellite has an operational lifespan of seven years with consumables for 12 years.

Planned Launch

SENTINEL-1A - scheduled for 1st quarter 2014

SENTINEL-1B - scheduled for 18 months after S-1A

Launched with a SOYUZ rocket from Guiana Space Centre in French Guiana.

Mission Objectives

- Land monitoring of forests, water, soil and agriculture
- Emergency mapping support in the event of natural disasters
- Marine monitoring of the maritime environment
- Sea ice observations and iceberg monitoring
- Production of high resolution ice charts
- Forecasting ice conditions at sea
- Mapping oil spills
- Sea vessel detection

- Climate change monitoring.

Mission Orbit

- Sun-synchronous, near-polar, circular orbit
- 693 km orbit height
- 98.18° inclination
- 12 day repeat cycle at Equator with one satellite, 175 orbits/cycle.

Satellite platform

- 3-axis stabilized, yaw/pitch/roll steering (zero Doppler)
- 0.01º attitude accuracy (each axis)
- Right looking flight attitude
- 10 m orbit knowledge (each axis, 3σ) using GPS
- Spacecraft availability: 0.998
- Launch mass: 2 300 kg (incl. 130 kg fuel)
- Solar array power: 5 900 W
- Battery capacity: 324 Ah
- Science data storage capability: 1 410 Gb
- Communication links: X-band data downlink and optical data link through EDRS for payload data at 520 Mbit/s; S-band 64 kbps uplink and 128 kbps / 2 Mbps downlink for TM/TC.

Instrument Payload

C-band Synthetic Aperture Radar

- Centre frequency: 5.405 GHz
- Polarisation: VV+VH,HH+HV,HH,VV
- Incidence angle: 20º - 45º
- Radiometric accuracy: 1 dB (3σ)
- NESZ: -22 dB
- DTAR: -22 dB
- PTAR: -25 dB.

Modes, Swatch Widths and Resolution

- Strip Map Mode: 80 km swath, 5 x 5 m spatial resolution

- Interferometric Wide Swath: 250 km swath, 5 x 20 m spatial resolution
- Extra-Wide Swath Mode: 400 km swath, 20 x 40 m spatial resolution
- Wave-Mode: 20 x 20 km, 5 x 5 m spatial resolution.

Data Products

- Level-0 Raw
- Level-1 Single Look Complex
- Level-1 Ground Range Detected
- Level-2 Ocean.

1.2 Mission Objectives

The mission provides an independent operational capability for continuous radar mapping of the Earth.

The SENTINEL-1 mission is designed to provide enhanced revisit frequency, coverage, timeliness and reliability for operational services and applications requiring long time series.

The mission will provide an operational interferometry capability through stringent requirements placed on attitude accuracy, attitude and orbit knowledge, and data-take timing accuracy.

The constellation will cover the entire world's land masses on a bi-weekly basis, sea-ice zones, Europe's coastal zones and shipping routes on a daily basis and open ocean continuously by wave imagettes.

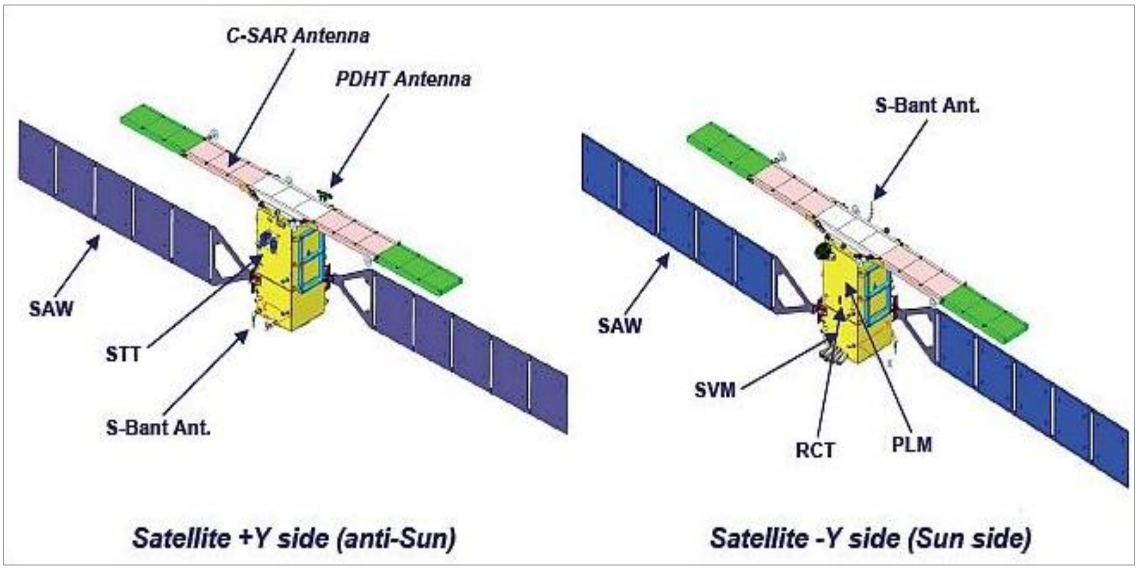
The SENTINEL-1 SAR instrument and short revisit time will greatly advance users' capabilities and provide data routinely and systematically for maritime and land monitoring, emergency response, climate change and security.

Each SENTINEL-1 satellite is expected to transmit Earth observation data for at least 7 years and have fuel on-board for 12 years.

The SENTINEL-1 Mission Requirements Document (MRD) describe all mission specific requirements in detail.

1.3 Satellite Description

The satellite has been created by an industrial consortium led by Thales Alenia Space Italy as prime contractor, with Astrium Germany being responsible for the CSAR payload, incorporating the central radar electronics sub-system developed by Astrium UK.



The spacecraft is a three-axis, stabilised satellite, characterised by sun, star, gyro and magnetic field sensors, a set of four reaction wheels dedicated to orbit and attitude control and three torque rods as actuators to provide steering capabilities on each axis. The satellite is equipped with two solar array wings capable of producing 5 900 W (at end of life) to be stored in a modular battery.

The satellite is based on the PRIMA (Piattaforma Italiana Multi Applicativa) bus, building on the experience gained from RADARSAT-2 and COSMO-SKYMED, which use the same bus. The bus provides highly accurate pointing knowledge (better than 0.004°) on each axis, high pointing accuracy (about 0.01° on each axis) and real-time orbit determination together with a dedicated propulsion system for precise orbit control.

The reference orbit will be maintained within an Earth-fixed orbital tube of a diameter of 100 m (RMS) during normal operation.

The satellite platform provides features for the management of the attitude and orbit control systems, data handling, propulsion, power, thermal control, spacecraft autonomy and failure detection identification and recovery, and communication with the ground.

The total mass of the spacecraft at launch is approximately 2 300 kg.

1.3.1 Orbit

SENTINEL-1 will be in a near-polar, sun-synchronous orbit with a 12 day repeat cycle and 175 orbits per cycle for a single satellite. Both SENTINEL-1A and SENTINEL-1B share the same orbit plane with a 180° orbital phasing difference. With both satellites operating, the repeat cycle is 6 days.

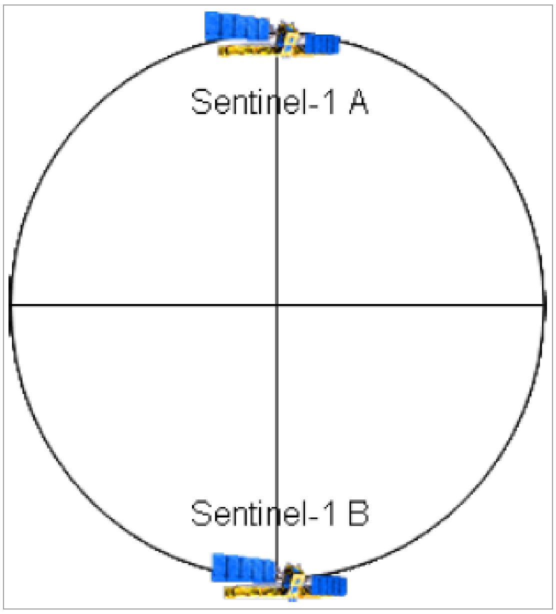


Figure 1: SENTINEL-1 Constellation

In particular for interferometry, SENTINEL-1 requires stringent orbit control. Satellite positioning along the orbit must be accurate, with pointing and timing/synchronisation between interferometric pairs. Orbit positioning control for SENTINEL-1 is defined using an orbital Earth fixed "tube", 50 m (RMS) wide in radius, around a nominal operational path. The satellite is kept inside this "tube" for most of its operational lifetime.

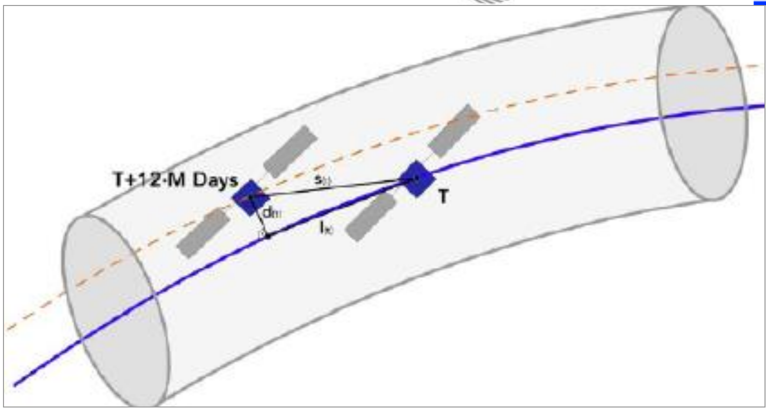


Figure 2: SENTINEL-1 Orbit Tube

1.3.2 Geographical Coverage

A single SENTINEL-1 satellite will be able to map the entire world once every 12 days. The two-satellite constellation offers a 6 day exact repeat cycle. The constellation will have a repeat frequency (ascending/descending) of 3 days at the equator, less than 1 day at the Arctic and is expected to provide coverage over Europe, Canada and main shipping routes in 1-3 days, regardless of weather conditions. Radar data will be delivered to Copernicus services within an hour of acquisition.

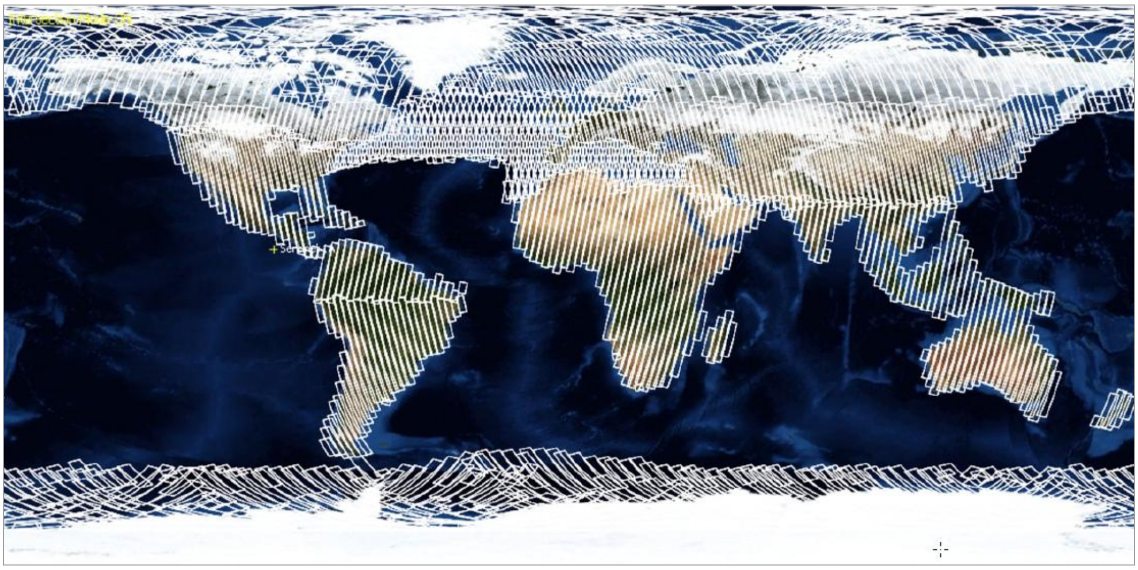


Figure 2: SENTINEL-1 Coverage

The following simulation shows one day of SENTINEL-1A acquisitions using the Interferometric Wide swath mode over land with a 250 km swath width.

1.4 Ground Segment

The ground segment is composed of the core ground segment, the collaborative ground segment and the Copernicus contributing missions' ground segments.

The Core ground segment monitors and controls the Sentinel spacecraft, ensures the measurement data acquisition, processing, archiving and dissemination to the final users. In addition, it is responsible for performing conflict-free mission planning according to a pre-defined operational scenario, and it ensures the quality of the data products and the performance of the space borne sensors by continuous monitoring, calibration and validation activities, guaranteeing the overall performance of the mission.

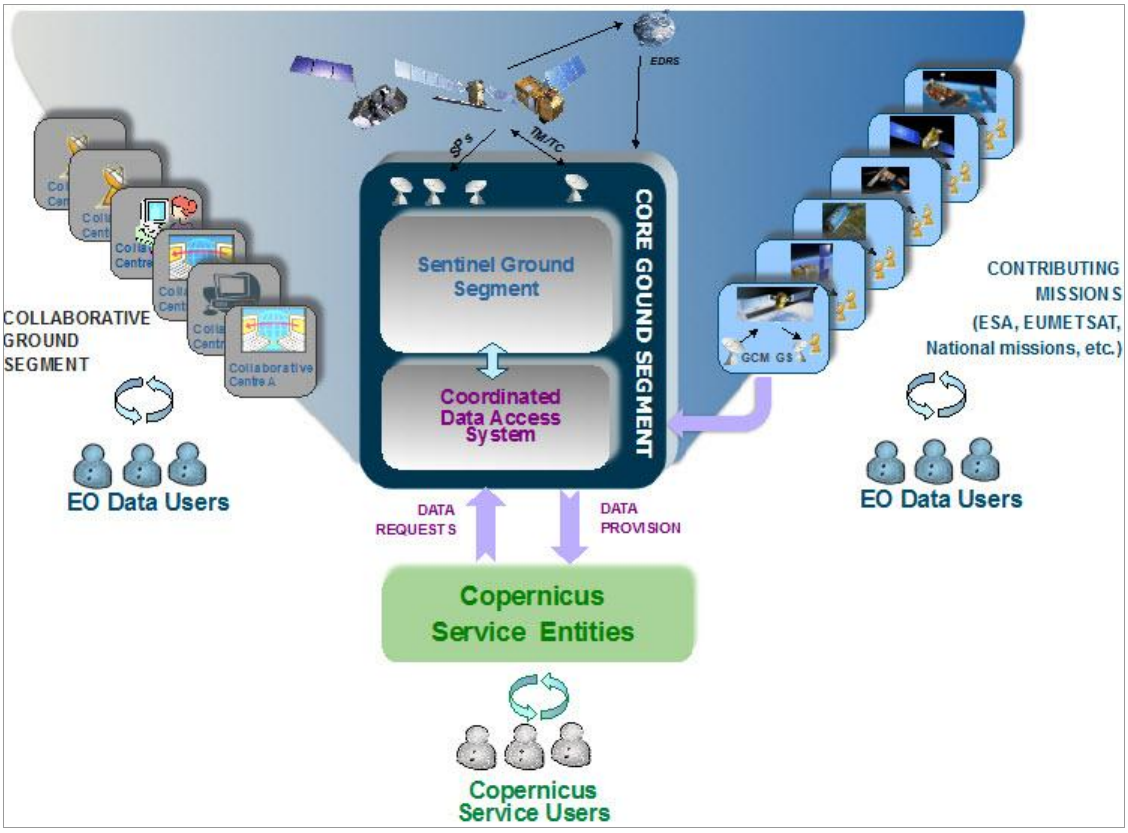


Figure 1: Copernicus Ground Segment Architecture

The Copernicus Ground Segment is complemented by the Sentinel Collaborative Ground Segment, which was introduced with the aim of exploiting the Sentinel missions even further. This entails additional elements for specialised solutions in different technological areas such as data acquisition, complementary production and dissemination, innovative tools and applications, and complementary support to calibration & validation activities.

The Copernicus contributing mission ground segments, with their own specific control functions, data reception, data processing, data dissemination and data archiving facilities, deliver essential data complementary to the Sentinels missions.

1.4.1 Collaborative Ground Segment

The SENTINEL Collaborative Ground Segment is intended to allow complementary access to SENTINEL data and/or to specific data products or distribution channels. It is composed of elements funded by third parties (i.e. from outside the ESA/EU Copernicus programme) and provides the framework for international cooperation. The collaborative elements are expected to bring specialised solutions to further enhance the SENTINEL missions' exploitation in various areas.

- Data acquisition and (quasi-) real time production. This is when local ground stations are configured to receive SENTINEL data directly during the satellite overpass (and supported as long as this does not conflict with the systematic operations of the Copernicus ground segment).
- Complementary products and algorithms definitions. These "collaborative data products" may include specific tailoring for regional coverage or specific applications. These types of products might extend the SENTINEL core product chains.
- Data dissemination and access, supporting redistribution of SENTINEL core products by establishing additional pick-up points (e.g. mirror sites).
- Development of innovative tools and applications.
- Complementary support to calibration/validation activities.

1.4.1.1 Collaborative Categories

Sentinel Mission Data Acquisition and (NRT) production

- Local/Regional stations complementing theCore X-band and Ka-band station network with the potential following activities
- (NRT) data processing and distribution for Sentinel-1 and/or Sentinel-2
- Elaboration of (NRT) products tailored to particular coverage / region, particular services, etc.

Sentinel Collaborative Data Products

Definition, specification, generation of data products in complement to the set of products provided by the Core ground segment, potentially including:

- Higher level products than produced by the Core Ground segment
- Product / algorithms tailored to a particular coverage or region, services or user community
- Generation of local / regional data sets with correction, projection, calibration, merging etc. different to the standardized one offered by the GSC Core Ground Segment

Note: These activities are mainly foreseen for collaborative entities interested in specific ESA support such as provision of dedicated access link to core products, advertising, host processing, mutual cal/val support, access to collaborative product through GSC catalogue, etc.

Sentinel Data Product Dissemination and Access

Particular regional or thematic data access nodes and mechanisms, potentially including:

- Redistribution services of Sentinels products, systematically received from the Core Ground Segment, becoming additional pick-up points (e.g. mirror sites)
- Regional online data servers and data pick-up points for specific user communities, etc

Innovative Tools and Applications

Development of particular innovative tools or 'Apps' by and for the general public.

Sentinel Complementary Calibration/Validation activities

Complementary support to calibration and validation activities.

1.4.1.1.1 Sentinel Mission Data Acquisition and (NRT) Production

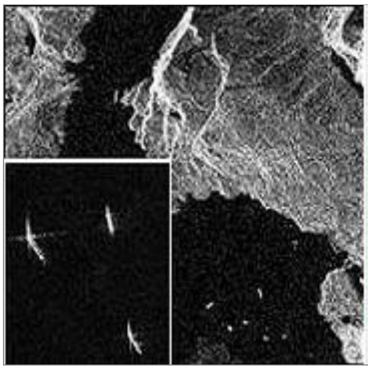
Sentinels data acquisition and Quasi Real Time production (Local Stations)

It can provide a regional (within the station coverage) quasi real-time (10-15 min from sensing) data service via Sentinels Collaborative (Local) Stations.

As far as no conflicts arise with the systematic space and ground segment operations, ESA will support operations in terms of mission planning (acquisition scheduling including all auxiliary information) over the local geographical area of interest and provision of satellite-to-ground interface information.

Only a limited number of Collaborative stations can be supported, as the systematic downlink scenario to Core stations may exclude certain real time downlinks. It is envisaged that only a very limited number of Collaborative stations outside Europe (Asia, South East Asia, Southern parts of North America and South America) a priori not in overlap with core receiving stations can be supported. In principle there is no limitation on the number of collaborative ground stations with similar visibility of the core stations (collaborative stations may "listen" the Sentinel data transmission to Core stations).

Ship Detection **Oil Spill Monitoring**



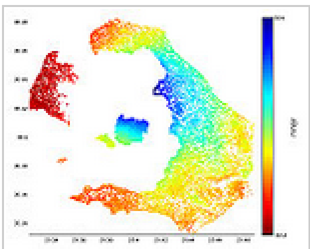
1.4.1.1.2 Sentinel Collaborative Data Products

Complementary collaborative data products and algorithms definition.

Collaborative ground segments may offer product types (or product formats) in addition to those offered by the CSC core ground segment functions and to complement the Copernicus Service products. Potential products of interest for collaboration maybe e.g.:

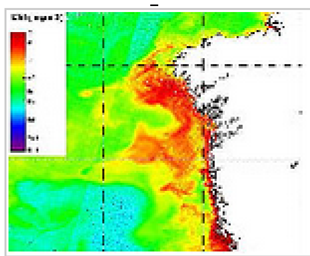
- Product algorithms tailored to a particular coverage or region
- Product algorithms tailored to specific services, like the generation ofessential Climate Variables
- Generation of local / regional data sets with correction, projection, calibration, merging etc. different to the standardised one offered by the CSC Core Ground Segment

Volcano Monitoring
Sentinel-1



Landslide risk monitoring
Sentinel-1

Sentinel-3 - complementary Level-2
Alternative Algorithm

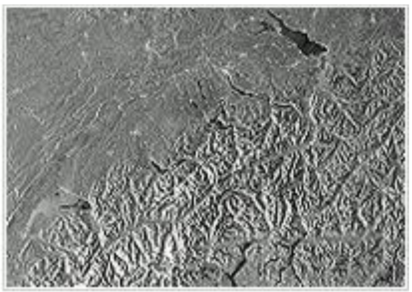


National Entities, EU agencies or even Copernicus core services, may at their own funds, provide such products.

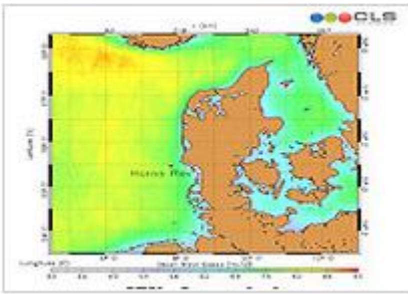
These entities may develop products of interest for specific user communities beyond the GMES Services (e.g. science) and establish operational distribution. Such activities could ensure continuity of initiatives exploiting data from previous missions.

Operational generation of collaborative products maybe supported by implementation and operation of specific data flow interfaces with the Core Ground Segment.

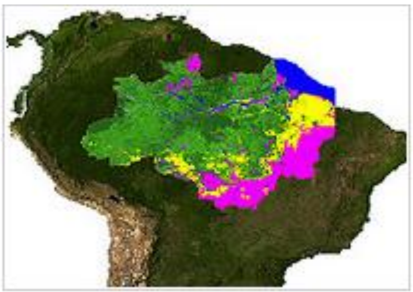
Octorectified
Sentinel-1



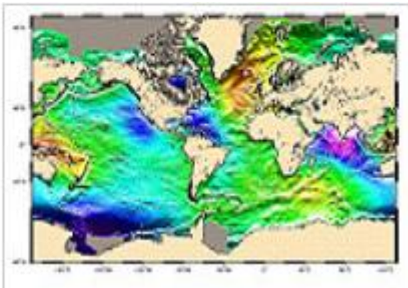
Wind statistics
Sentinel-1 regional



Deforestation monitoring REDD
Sentinel 1,2 & 3

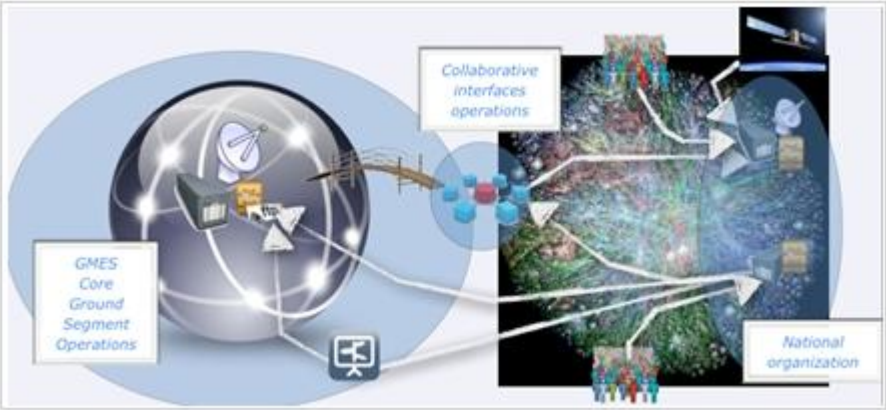


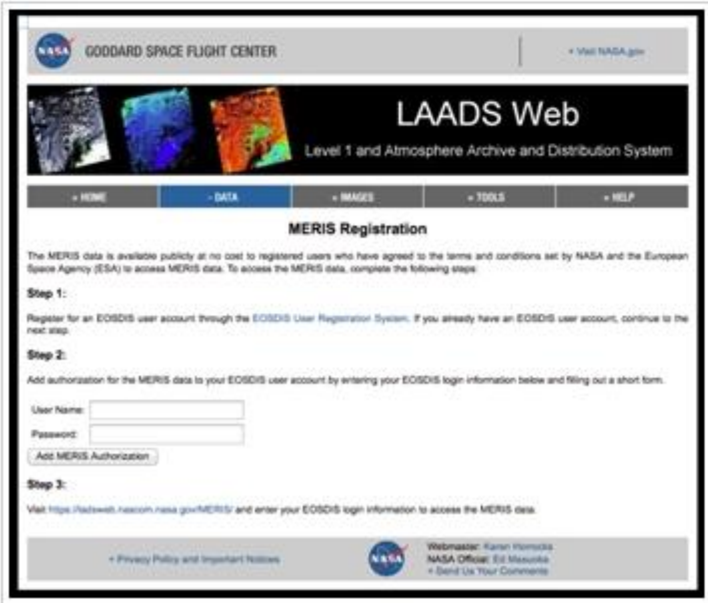
Sea surface height
Sentinel-3 altimetry



1.4.1.1.3 Sentinel Data Product Dissemination and Access

Particular regional or thematic data access nodes and mechanism may be offered, such as redistribution services of Sentinels core products, systematically received from the Core Ground segment, becoming additional pick-up points (e.g. mirror sites), at national or regional level.

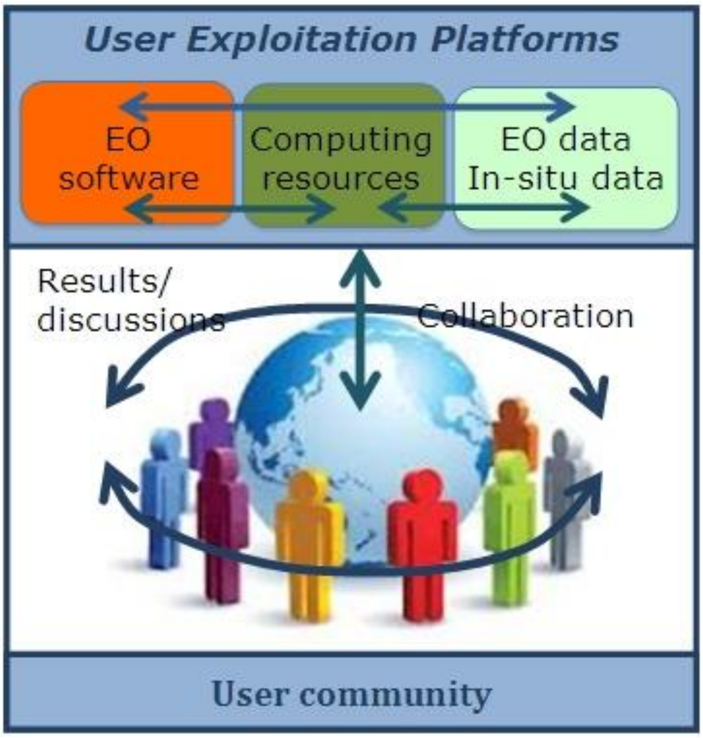




1.4.1.1.4 Innovative Tools and Applications

The free and open data policy and data access concept for the Sentinel missions may lead to the development of particular yet unforeseen "Apps" (Application software) by and for the general public.

Such developments are not only possible but encouraged. Their availability will be advertised within the Core ground segment. In some cases, according to available operational resources and budget, processing capability through hosting processing (eg. User Exploitation Platform) may be provided.

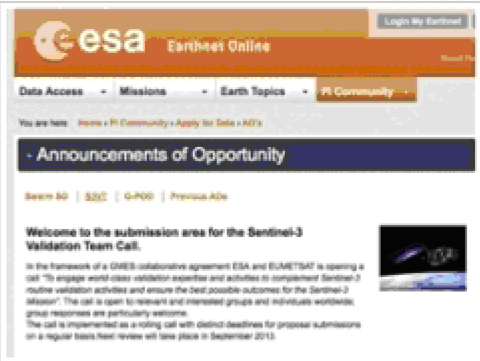


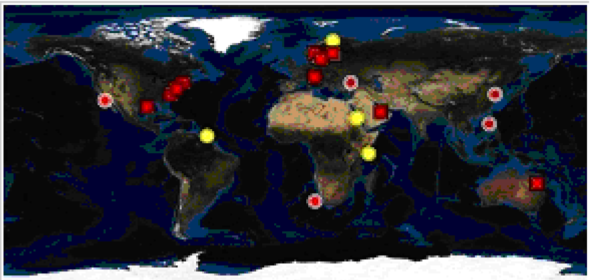
Such collaborative modes will be particularly encouraged wherever decrease of dissemination data volume will be demonstrated.

1.4.1.1.5 Sentinel complimentary Calibration/Validation activities

The goal of this collaboration category is to engage world-class expertise and activities (including access to in-situ infrastructure and data), through mutual benefit collaboration, that complement the implementation of the Sentinel validation activities during Commissioning and routine phases.

In this framework, access to Cal-Val infrastructure and data by collaborative partners may also be envisaged.





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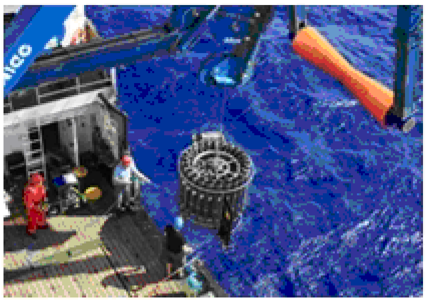
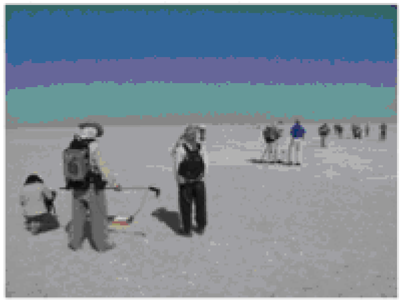




Validation campaigns

1.4.1.2 Agreement Process

Implementation of a collaborative GS with ESA Member States is based on three main steps:

1. Definition of process and collection of collaboration proposals

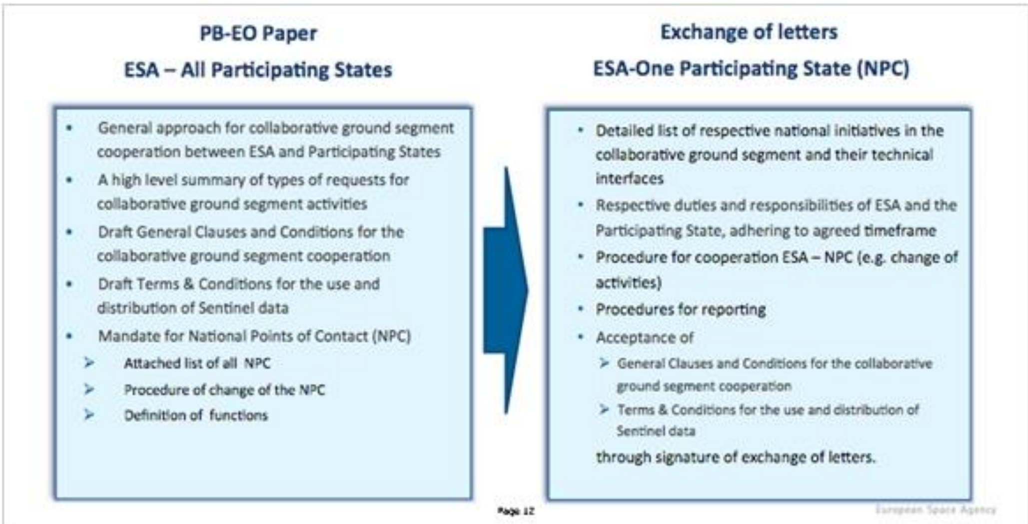
- Requirements collection: release of questionnaire to ESA Member States
- Enables ESA to make a preliminary assessment of the planned initiatives

2. Proposal feasibility analysis

- Execution of simulation scenarios, identification of potential conflicts
- Proposal refinement with collaborative partner

3. Formalisation of collaboration

- Document the technical operational interfaces
- Integrate, verify and validate the derived implementation
- Sign formal agreement (exchange of letters based on PBEO framework paper)



Interface to EU (non-ESA) Member States and international cooperation partners is led by the EU in close coordination with ESA for technical aspects. In these cases, for technical matters, a similar process (as with ESA Member States) is planned:

- Collection of collaboration proposals and requirements
- Proposal technical feasibility analysis
- Implementation of collaborative interfaces

- International agreement to be formalised via EU/ESA jointly

The collaborative ground segment types of activities are similar to the ones with ESA Member States with special focus on:

- Access to Sentinels data
- Set up of mirror sites for redistribution of Sentinel core data
- Complementary external support Validation activities

1.4.1.3 Existing/Planned Collaborative GS

Under construction.

1.4.2 Core Ground Segment

The Sentinel Core Ground Segment allows all Sentinel data to be systematically acquired, processed and distributed. It includes elements for monitoring and controlling the Sentinel satellites and for downloading, processing and disseminating the data to the users. It also has mechanisms for monitoring and controlling the quality of the data products, as well as for data archiving. The infrastructure is 'distributed', meaning that various centre's are in different locations but linked together and coordinated. Despite the complexity of the system, users are offered a single virtual access point for locating and downloading the products.

The main facilities of the Sentinel Core Ground Segment are:

- The Flight Operations Segment (FOS) - responsible for all flight operations of the Sentinel satellites, including monitoring and control, the execution of all platform activities and commanding of the payload schedules.
- The Core Ground Stations - where the Sentinel data are downlinked and products are generated in near-real time. A network of X-band ground stations allows the downlink of all Sentinel data. These are complemented by the utilisation of the European Data Rely Satellite (EDRS) for additional downlink of Sentinel data to EDRS ground stations.
- The Processing and Archiving Centre's (PACs) - where systematic non-time-critical data processing is performed. All data products are archived for online access by users. A network of PACs supports all the processing and archiving of Sentinels data.
- The Mission Performance Centre's (MPCs) - responsible for calibration, validation, quality control and end-to-end system performance assessment. The MPCs include expert teams for specific calibration/validation, off-line quality control and algorithm correction and evolution activities.
- The Sentinel Precise Orbit Determination (POD) facility - makes use of the GNSS receiver data on the Sentinels to deliver the orbital information needed to generate the data products.

- The Copernicus Space Component Wide Area Network (CSC WAN) - allows all products and auxiliary data to be carried across the various ground segment facilities and provides disseminated data products to the end users.

All Sentinel data are systematically processed up to the designated level and according to different timelines, ranging from near-real time to non-time-critical, available typically within 3-24 hours of being sensed by the satellite.

1.4.3 Flight Operations Segment (FOS)

The Flight Operation Segment (FOS) is responsible for command and control of the satellite and is operated from ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany.

Figure 1: ESA's European Space Operations Centre

The FOS consists of the Ground Station and Communications Network, Flight Operations Control Centre and a General Purpose Communication Network.

The FOS provides the capability to monitor and control the satellite during all mission phases including the Flight Dynamics System facility responsible for orbit determination and prediction, and for the generation of attitude and orbit control telecommands.

The main functions of the FOS include:

Mission planning

Long term planning of spacecraft and payload activities, covering the complete orbit cycle and repeating indefinitely. Short term planning, nominally every 2 weeks, in the form of updated mission schedules.

Spacecraft status monitoring

Processing housekeeping telemetry, providing information about the status of all spacecraft subsystems and attitude.

Spacecraft control

Taking control actions by means of telecommands, based on the spacecraft monitoring and following the mission plan.

Orbit determination and control

Using tracking data and implementing orbit manoeuvres, ensuring required orbital conditions are achieved.

Attitude determination and control

Using processed attitude sensor data from spacecraft monitoring and by commanded updates of control parameters through the on-board attitude control system.

On-board software maintenance

Integrating software images received from the spacecraft manufacturer (pre-launch and post-launch) into the telecommand process.

Communications

Communicating (TM/TC) with one satellite at a time.

1.4.4 Payload Data Ground Segment (PDGS)

The Payload Data Ground Segment (PDGS) is responsible for exploitation of the instrument data. The PDGS is operated from ESA's Centre for Earth Observation also known as the European Space Research Institute (ESRIN) in Frascati, Italy. The PDGS operationally generates the user products and distributes raw Level-0 products, processed Level-1 products and derived Level-2 products.

The PDGS includes the facilities responsible for mission control (mission planning, production planning), quality control (calibration, validation, quality monitoring, instrument performance assessment), precise orbit determination, user services interface and acquisition, processing and archiving.

Real-time sensed data as well as data played back from on-board saved data are downlinked directly to ground or via the European Data Relay Satellite (EDRS), received, down-converted, demodulated and transferred to the processing facilities for systematic generation and archiving of Level-0 and Level-1/2 data products.

The PDGS is expected to receive and process 2.4 TBytes of compressed raw data per day for the two satellites in addition to data from all other ESA missions. SAR Level-0 data are processed to produce Level-1 and Level-2 products applying all the necessary processing algorithms and formatting techniques.

The PDGS is distributed over several core centres including Core Ground Stations (CGS), Processing and Archiving Centres (PAC), Mission Performance Centres (MPC) and Precise Orbit Determination (POD) facilities.

Core Ground Stations

The network of X-band Core Ground Stations located in Matera, Italy, Maspalomas, Spain and Svalbard, Norway, are responsible for data acquisition and near real-time processing.

Processing and Archiving Centres

PACs perform long-term data archiving, data access and systematic non-time-critical data processing. Archiving and long-term preservation of data is ensured for all Level-0 data and for a set of configurable systematic higher level products.

Mission Performance Centres

MPCs are responsible for calibration, validation, quality control and end-to-end system performance assessment. The MPCs include expert teams for specific cal/val, off-line quality control and algorithm correction activities.

Precise Orbit Determination

POD facilities make use of the GNSS receiver data on-board the SENTINEL satellites to deliver the orbital information needed for generation of mission products.

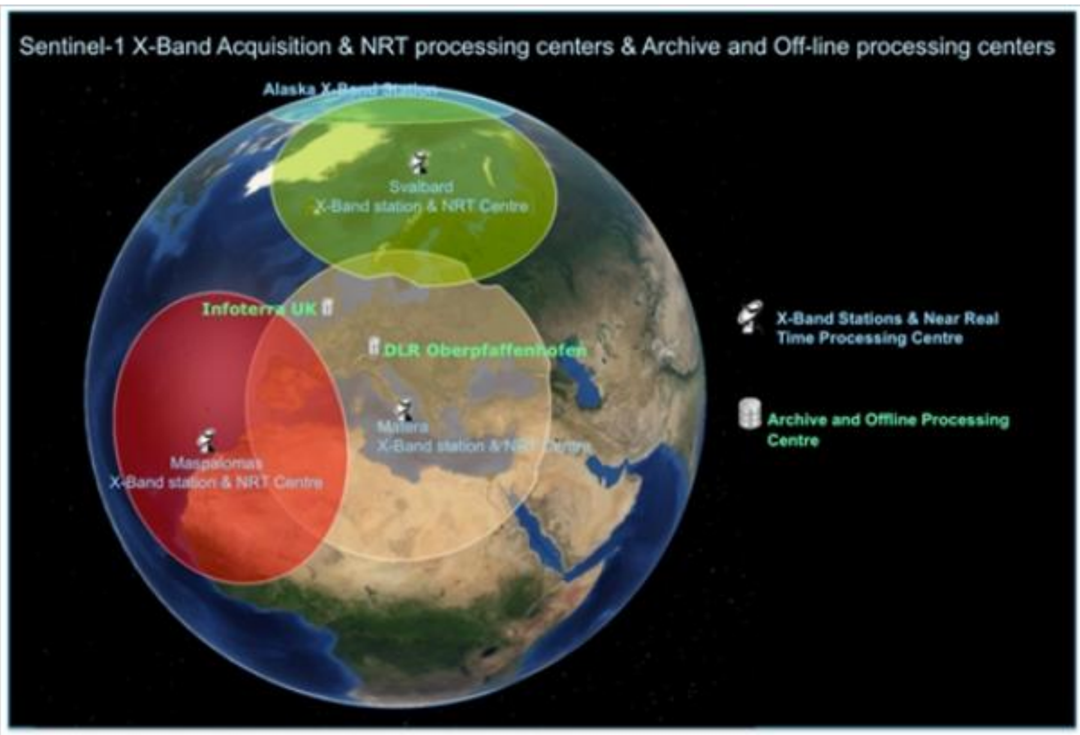


Figure 1: Sentinel-1 receiving stations and offline processing and archiving centers

Coordination between the centres is provided through the Payload Data Management Centre (PDMC) at ESRIN in Frascati, Italy.

SENTINEL-1 products are provided to the user through online access. Near real-time dissemination is allocated to the receiving stations and less time-critical data dissemination is allocated to the assembly, processing and archiving centres.

1.5 Observation Scenario

SENTINEL-1 SAR observation scenario implements a baseline pre-defined mission observation scenario, making optimum use of the SAR duty cycle within the technical constraints of the overall system. This scenario aims at fulfilling, during the routine exploitation phase, in order of priority and to the fullest extent, the observation requirements of the GMES services for use by member states. In addition, on a best effort basis and with lower priority, a secondary objective is to satisfy other SAR user communities, ensuring continuity of ERS/ENVISAT, considering requirements from the scientific community, as well as from international partners and cooperation activities.

The elaboration of a pre-defined observation plan necessitates solving, *a priori*, the potential conflict among users (e.g. different SAR operation modes or polarisation schemes required over same geographical area).

During the ramp-up exploitation phase, the SENTINEL-1 observation plan will gradually evolve in line with the increasing operational capacity. Accordingly, the observations and volume of data available to SENTINEL-1 operational users will gradually increase during this period.

Within the predefined observation plan, the SENTINEL-1 mission shall ensure observations fulfilling the following two main categories of services:

- Monitoring services related to oceans, seas and sea-ice. These services require quasi real-time or near real-time data, typically in less than 3 hours, and in some cases in less than 10 minutes. Quasi real-time services or services requiring data within 1 hour from sensing require reception by local stations. Most of these monitoring types of services require systematic or very frequent (e.g. daily) observations.

- Services/applications over land. These services or applications cover a wide range of different thematic domains. They generally do not require data in quasi real-time and few of them require data within 3 hours (near real–time) from sensing. Related data are mostly planned to be recorded on-board and downloaded to the core ground station network. Products not required in near real-time will be available within 24 hours from sensing.

The high level SENTINEL-1 observation strategy during full operations capacity is based on:

- optimum use of SAR duty cycle (25 min/orbit), taking into account the various constraints (e.g. limitation in the number of X-band RF switches, mode transition times, maximum downlink time per orbit and maximum consecutive downlink time)

- optimum use of single and dual polarisation acquisitions, in line with the available downlink capacity

- Wave Mode (WV) continuously operated over open oceans, with lower priority versus the high rate modes

- Interferometric Wide swath (IW) and Extra Wide swath (EW) modes operated over pre-defined geographical areas:
    - over land: pre-defined mode is IW
    - over seas and polar areas, and ocean relevant areas, pre-defined mode is either IW or EW.

In exceptional cases only, emergency observation requests may alter the pre-defined observation scenario, possibly requiring use of the Stripmap (SM) mode.

Over land, it is planned to systematically make use of the same SAR polarisation scheme over a given area, to guarantee data in the same conditions for routine operational services and to allow frequent InSAR. Depending on the area, the selection is either vertical or horizontal, the choice being made according to the main application behind.

The figure below shows an example of the IW and EW acquisitions over Europe for a 12 day period.

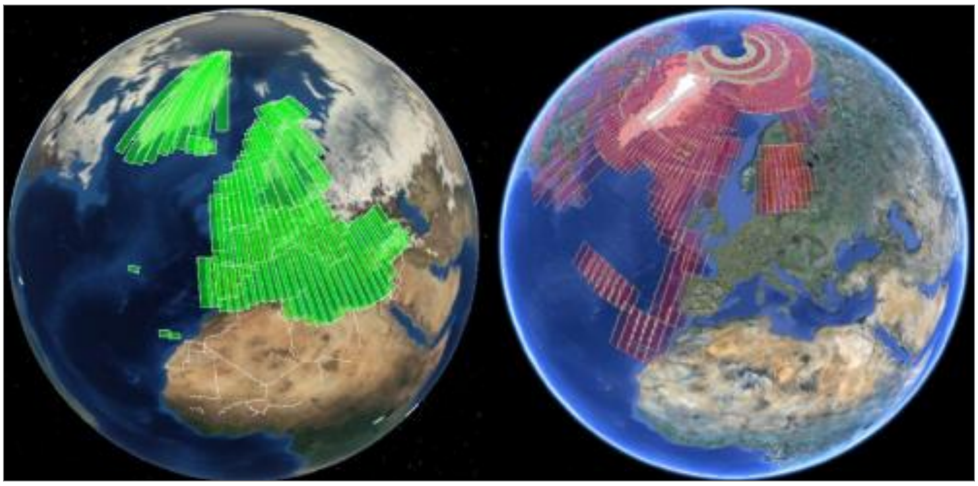


Figure1: Left: Europe and European waters – IW mode, ascending orbits over a 12-day repeat cycle (January)
Right: Europe and European waters – EW mode, descending orbits over a 12-day repeat cycle (January)

Please see the Sentinel High Level Operations Plan for specific details about which modes will systematically acquire data over specific regions to meet the requirements of the priority applications.

1.6 Data Distribution Policy

To promote full utilisation of SENTINEL data, increased scientific research, growth in EO markets and job creation, SENTINEL data is provided on an open and free basis by ESA and the European Commission based on the following principles:

- Anyone can access acquired SENTINEL data. In particular, no distinction is made between public, commercial and scientific uses, or between European or non-European users.
- Licenses for the use of SENTINEL data are available free of charge.

- SENTINEL data will be made available to users via 'generic' online access, free of charge, subject to a user registration process and acceptance of generic terms and conditions.
- Additional access modes and delivery of additional products will be tailored to specific user needs and will be subject to tailored conditions.
- In the event that security restrictions apply, affecting the availability or timeliness of SENTINEL data, specific operational procedures will be activated.

Large scale on-line distribution of the SENTINEL data will be possible within the technical limitations of the system (in particular the dissemination network) and depends on operational funding levels.

Open and free access to the data will maximise the beneficial utilisation of SENTINEL data for the widest range of applications and intends to stimulate the uptake of information based on Earth Observation data for end users.

All SENTINEL-1 SAR data acquired are systematically processed to create predefined product types and are available globally, regionally and locally, within a defined timescale.

Global products will be systematically generated for all acquired data. They include Level-0, detected Level-1 and Level-2 ocean products. These products are made available within 1 hour of observation over NRT areas with a subscription and, in every case, within 24 hours of observation.

Regional products are systematically generated for a subset of the total acquired data, over well-defined regions or areas. Level-1 SLC products are made available within 1 hour of observation over specific NRT areas and systematically over specified areas within 24 hours of observation. The systematic processing approach allows the systematic generation of a pre-defined set of Level-1 products after acquisition (either in NRT or within 24 hours), with no ordering required for each product to be generated.

For critical GMES and national services requiring data in quasi real-time, notably maritime surveillance, data are transmitted by the satellite in real-time for reception by local collaborative ground stations supporting these services. This requires that SENTINEL-1 is inside the coverage of these collaborative ground stations.

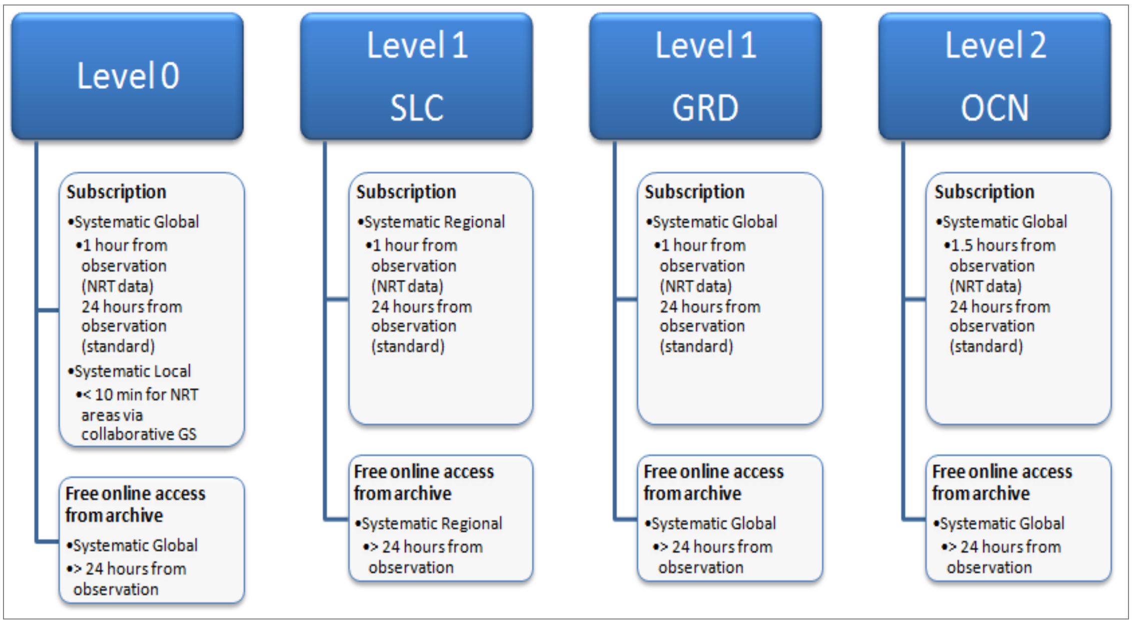


Figure 1: Operational Product Availability for Each Level

In addition to systematic and routine production, rush processing with high priority at the ground receiving stations, will support emergency/security related observation requests. These observations will be minimised to within the strict necessary duration to avoid overriding the pre-defined observation scenario.

1.6.1 Operations Ramp-Up Phase

The operations ramp-up phase refers to the period starting at the completion of the first spacecraft launch and commissioning, and continues until the the Full Operational Capacity (FOC) is reached with the constellation.

The operations phase is based on a ramp-up approach in terms of exploitation capacity that will gradually increase over time. This exploitation capacity ramp-up will start during the commissioning phase of the first SENTINEL satellite and will reach the routine exploitation capacity with the two-satellite constellation approximately 2 years after the launch of the first SENTINEL-1. The ramp up will continue after that period, further increasing the capacity of the production.

This ramp-up phase approach is based on a gradual SENTINEL-1 ground segment system deployment and mission resources exploitation, defined in order to:

- complete the ground segment commissioning started during the Space Segment Commissioning Phase
- complete the operational user product quality verification/calibration/validation
- gradually increase the exploitation capacity in line with the SENTINEL-1 data user needs to reach routine exploitation with the two-satellite constellation.

This ramp-up allows adaptation of the SENTINEL-1 exploitation capacity to the increasing needs of users (GMES services, national use, science use, etc.) while optimising the available resources (e.g. deployment of receiving stations in line with available operational budget). Factors such as the huge volume of data systematically generated by the mission (potentially up to 2 TBytes of data per day) are also taken into account in the definition of the ramp-up scenarios.

1.7 Instrument Payload

SENTINEL-1 carries a single C-band synthetic aperture radar instrument operating at a centre frequency of 5.405 GHz. It includes a right-looking active phased array antenna providing fast scanning in elevation and azimuth, data storage capacity of 1 410 Gb and 520 Mbit/s X-band downlink capacity.

The C-SAR Instrument supports operation in dual polarisation (HH+HV, VV+VH) implemented through one transmit chain (switchable to H or V) and two parallel receive chains for H and V polarisation. Dual polarisation data is useful for land cover classification and sea-ice applications.

SENTINEL-1 operates in four exclusive acquisition modes:

- Stripmap (SM)
- Interferometric Wide swath (IW)
- Extra-Wide swath (EW)
- Wave mode (WV).

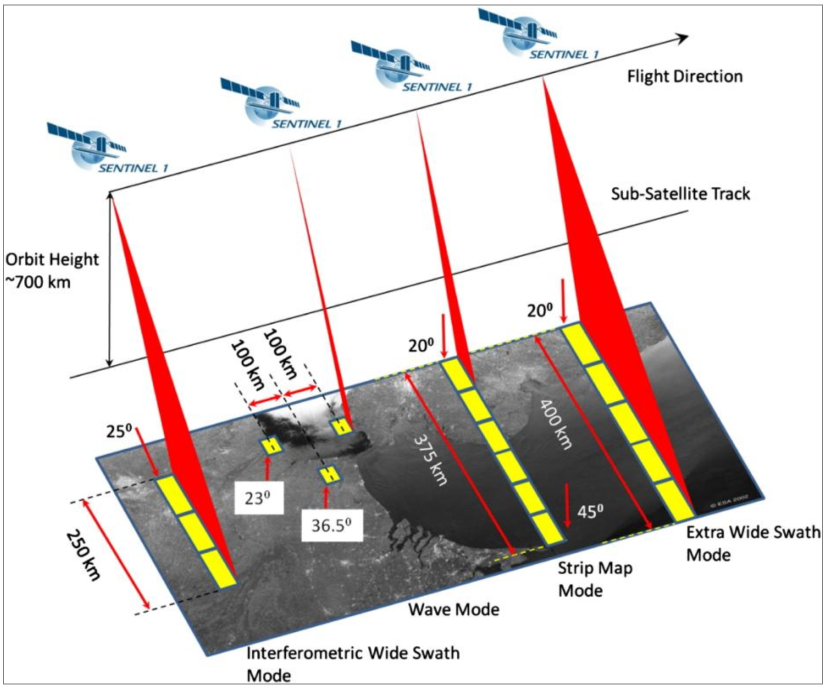


Figure 1: SENTINEL-1 Modes

The primary conflict-free modes are IW over land and WV over open ocean.

Stripmap Mode

Stripmap imaging mode is provided for continuity with ERS and ENVISAT missions. Stripmap provides coverage with a 5 m by 5 m resolution over a narrow swath width of 80 km. One of six imaging swaths can be selected by changing the beam incidence angle and the elevation beamwidth.

Interferometric Wide Swath Mode

The Interferometric Wide swath (IW) mode allows combining a large swath width (250 km) with a moderate geometric resolution (5 m by 20 m). The IW mode images three sub-swaths using Terrain Observation with Progressive Scans SAR (TOPSAR). With the TOPSAR technique, in addition to steering the beam in range as in SCANSAR, the beam is also electronically steered from backward to forward in the azimuth direction for each burst, avoiding scalloping and resulting in a higher quality image. Interferometry is ensured by sufficient overlap of the Doppler spectrum (in the azimuth domain) and the wave number spectrum (in the elevation domain). The TOPSAR technique ensures homogeneous image quality throughout the swath.

The IW mode is the default acquisition mode over land.

Extra Wide Swath Mode

The Extra Wide swath imaging mode is intended for maritime, ice and polar zone operational services where wide coverage and short revisit times are demanded. The EW mode works similarly to the IW mode employing a TOPSAR technique using five sub-swaths instead of three, resulting in a lower resolution (20 m by 40 m). The EW mode can also be used for interferometry as with the IW mode.

Wave Mode

SENTINEL-1 Wave mode, in conjunction with global ocean wave models, can help determine the direction, wavelength and heights of waves on the open oceans.

Wave mode acquisitions are composed of stripmap imagettes of 20 km by 20 km, acquired alternately on two different incidence angles. Wave imagettes are acquired every 100 km, with imagettes on the same incidence angle separated by 200 km.

1.7.1 Resolution and Swath

Spatial resolutions depend on the acquisition mode and the level of processing.

- Level-1 SLC
- Level-1 GRD
- Level-2 OCN

Mode	Incidence Angle	Resolution	Swath Width	Polarization (H = Horizontal V = Vertical)
Stripmap	20 - 45	5 x 5 m	80 km	HH+HV, VH+VV, HH, VV
Interferometric Wide swath	29 - 46	5 x 20 m	250 km	HH+HV, VH+VV, HH, VV
Extra Wide swath	19 - 47	20 x 40 m	400 km	HH+HV, VH+VV, HH, VV
Wave	22 - 35 35 - 38	5 x 5 m	20 x 20 km	HH, VV

The SENTINEL-1 constellation offers an improvement in revisit time over ERS-1/2 and ENVISAT ASAR and a continuity of wide area coverage as with ENVISAT ASAR, but achieving higher resolution and potentially global dual polarisation coverage over landmasses.

1.8 Data Products

SENTINEL data products are made available systematically and free of charge to all data users including the general public, scientific and commercial users. Radar data will be delivered within an hour of reception for Near Real-Time (NRT) emergency response, within three hours for NRT priority areas and within 24 hours for systematically archived data.

All data products are distributed in the SENTINEL Standard Archive Format for Europe (SAFE) format.

Each mode can potentially produce products at SAR Level-0, Level-1 SLC, Level-1 GRD, and Level-2 OCN.

Data products are available in single polarisation (VV or HH) for Wave mode and dual polarisation (VV+VH or HH+HV) and single polarisation (HH or VV) for SM, IW and EW modes.

Level-0

The SAR Level-0 products consist of the sequence of Flexible Dynamic Block Adaptive Quantization (FDBAQ) compressed unfocused SAR raw data. For the data to be usable, it will need to be decompressed and processed using focusing software.

Level-1

Level-1 data are the generally available products intended for most data users. Level-1 products are produced as Single Look Complex (SLC) and Ground Range Detected (GRD).

Level-1 Single Look Complex (SLC) products consist of focused SAR data geo-referenced using orbit and attitude data from the satellite and provided in zero-Doppler slant-range geometry. The products include a single look in each dimension using the full TX signal bandwidth and consist of complex samples preserving the phase information.

Level-1 Ground Range Detected (GRD) products consist of focused SAR data that has been detected, multi-looked and projected to ground range using an Earth ellipsoid model. Phase information is lost. The resulting product has approximately square resolution pixels and square pixel spacing with reduced speckle at the cost of reduced geometric resolution.

GRD products can be in one of three resolutions:

- Full Resolution (FR)
- High Resolution (HR)
- Medium Resolution (MR).

The resolution is dependent upon the amount of multi-looking performed. Level-1 GRD products are available in MR and HR for IW and EW modes, MR for WV mode and MR, HR and FR for SM mode.

Level-2

Level-2 OCN products include components for Ocean Swell spectra (OSW) providing continuity with ERS and ASAR WV and two new components: Ocean Wind Fields (OWI) and Surface Radial Velocities (RVL).

The OSW is a two-dimensional ocean surface swell spectrum and includes an estimate of the wind speed and direction per swell spectrum. The OSW is generated from Stripmap and Wave modes only. For Stripmap mode, there are multiple spectra derived from internally generated Level-1 SLC images. For Wave mode, there is one spectrum per vignette.

The OWI is a ground range gridded estimate of the surface wind speed and direction at 10 m above the surface derived from internally generated Level-1 GRD images of SM, IW or EW modes.

The RVL is a ground range gridded difference between the measured Level-2 Doppler grid and the Level-1 calculated geometrical Doppler.

2 SENTINEL-1 USER GUIDE

The SENTINEL-1 User Guide provides a high level description of the available instrument modes and products. It also covers an introduction to relevant application areas, information on data distribution, product formatting and software tools available from ESA.

For an in-depth description of the mission's products and algorithms as well as details on the SAR instrument and its performance, please refer to the **SENTINEL-1 Technical Guide**. The detailed information available in the Technical Guide is focused upon users such as academics and industrial software engineers who have previous experience of similar EO missions and in-depth experience of data manipulation and management.

2.1 Overview

SENTINEL-1 is an imaging radar mission providing continuous all-weather, day-and-night imagery at C-band. The SENTINEL-1 constellation provides high reliability, improved revisit time, geographical coverage and rapid data dissemination to support operational applications in the priority areas of marine monitoring, land monitoring and emergency services.

SENTINEL-1 potentially images all global landmasses, coastal zones and shipping routes in European waters in high resolution and covers the global oceans at regular intervals. Having a primary operational mode over land and another over open ocean allows for a pre-programmed conflict-free operation. The main operational mode features a wide swath (250 km) with high geometric (typically 20 m Level-1 product resolution) and radiometric resolutions, suitable for most applications.

The SENTINEL-1 Synthetic Aperture Radar (SAR) instrument may acquire data in four exclusive modes:

Stripmap (SM) - A standard SAR stripmap imaging mode where the ground swath is illuminated with a continuous sequence of pulses, while the antenna beam is pointing to a fixed azimuth and elevation angle.

Interferometric Wide swath (IW) - Data is acquired in three swaths using the Terrain Observation with Progressive Scanning SAR (TOPSAR) imaging technique. In IW mode, bursts are synchronised from pass to pass to ensure the alignment of interferometric pairs. IW is SENTINEL-1's primary operational mode over land.

Extra Wide swath (EW) - Data is acquired in five swaths using the TOPSAR imaging technique. EW mode provides very large swath coverage at the expense of spatial resolution.

Wave (WV) - Data is acquired in small stripmap scenes called "vignettes", situated at regular intervals of 100 km along track. The vignettes are acquired by alternating, acquiring one vignette at a near range incidence angle while the next vignette is acquired at a far range incidence angle. WV is SENTINEL-1's operational mode over open ocean.

SENTINEL-1 data products distributed by ESA include:

Raw Level-0 data (for specific usage)

Processed Level-1 Single Look Complex (SLC) data comprising complex imagery with amplitude and phase (systematic distribution limited to specific relevant areas)

Ground Range Detected (GRD) Level-1 data with multi-looked intensity only (systematically distributed)

Level-2 Ocean (OCN) data for retrieved geophysical parameters of the ocean (systematically distributed).

2.1.1 Geophysical Measurements

SENTINEL-1's C-band SAR active sensor can observe the Earth's surface at any time of the day or night, regardless of weather and environmental conditions. SAR has the advantage of operating at wavelengths not impeded by cloud cover or lack of illumination.

Unlike passive optical sensors that require the sun's illumination, an active SAR instrument transmits its own microwave signal to illuminate the Earth's surface at an angle. SAR actively transmits microwave signals towards the Earth and receives a portion of transmitted energy as backscatter from the ground. The returned backscatter echo of the scene is received by the instrument's antenna a short time later at a slightly different location, as the satellite travels along its orbit. The brightness amplitude of the returned signal, along with its phase information, is recorded to construct an image of the scene.

The SAR instrument provides radar backscatter measurements influenced by the terrain structure and surface roughness. Generally, the more roughness or structure on the ground, the greater the backscatter. Rough surfaces will scatter the energy and return a significant amount back to the antenna resulting in a bright feature. Flat surfaces reflect the signal away resulting in a dark feature. Likewise, more structurally complex targets such as forests will appear brighter as signal interaction with the leaves, branches and trunks will result in a higher proportion of the signal being transmitted back to the sensor.

The dielectric constant of the materials on the ground also play a factor in the measurements. In the microwave region of the spectrum, most natural materials have a dielectric constant in the range of 3 to 8 when dry, whereas water has a dielectric constant of approximately 80. The dielectric constant indicates the reflectivity and conductivity of materials. Therefore, the presence of moisture in soil and vegetation results in significant reflectivity.

These properties make SAR very suitable for various applications, including geology and geomorphology, soil moisture, land cover, oceanography and maritime applications and in particular for applications exploiting SAR's polarimetric and interferometric properties.

2.1.2 Polarimetry

SENTINEL-1 can collect several different images from the same series of pulses by using its antenna to receive specific polarisations simultaneously. The SENTINEL-1 SAR is a dual polarisation radar. It can transmit a signal and receive in both horizontal (H) and vertical (V) polarisation. Dual polarisation SAR products containing complex value and inter-channel phase information allow for measurement of the polarisation properties of terrain in addition to the backscatter that can be measured from a single polarisation.

Targets on the ground have distinctive polarisation signatures reflecting different polarisations with different intensities and converting one polarisation into another. For example, volume scatterers have different polarisation properties than surface scatterers. Polarimetric decompositions allow the separation of different scattering contributions and can be used to extract information about the scattering process, providing improved classification of point targets and distributed target areas.

The following RADARSAT-2 image of Flevoland in the Netherlands shows the difference in intensities from VH (left) and VV (centre). The composite RGB (colour) image on the right was created using the VV channel for red, VH channel for green and the ratio |VV| / |VH| for blue.

Figure 1: Intensities from different polarimetric channels (image courtesy of MDA and CSA)

Applications of polarimetry include:

- agriculture: crop type identification, crop condition monitoring, soil moisture measurement
- forestry: biomass estimation, species identification and fire scar mapping
- hydrology: monitoring wetlands and snow cover
- oceanography: sea ice identification, coastal wind field measurement, oil spill detection
- security: ship detection and classification.

With SENTINEL-1, dual polarisation acquisitions are potentially collected over land worldwide as well as over priority coastal zones, making the applications of such data routine and global.

For an introduction to polarimetric concepts, please see the Radar Polarimetry chapter of the Fundamentals of Remote Sensing tutorial from the Canadian Centre for Remote Sensing (CCRS). For an in-depth theory course on polarimetry, please see the ESA POLSARPRO Polarimetry Tutorial.

2.1.3 Interferometry

A SAR signal contains amplitude and phase information. Amplitude is the strength of the radar response and phase is the fraction of one complete sine wave cycle (a single SAR wavelength). The phase of the SAR image is determined primarily by the distance between the satellite antenna and the ground targets.

Interferometric SAR (InSAR) exploits the phase difference between two complex radar SAR observations of the same area, taken from slightly different sensor positions, and extracts distance information about the Earth's terrain.

By combining the phase of these two images after coregistration, an interferogram can be generated where phase is highly correlated to the terrain topography and deformation patterns can be mapped. If the phase shift related to topography is removed from the interferograms, the difference between the resulting products will show surface deformation patterns occurred between the two acquisition dates. This methodology is called Differential Interferometry (DInSAR).

The following interferogram of Bam, Iran shows the terrain deformation following a M6.6 earthquake on December 26th 2003, which killed 26,271 people and injured an additional 30,000. The images were acquired from ENVISAT ASAR on December 3rd 2003 and February 11th 2004 with a baseline (spatial separation between satellite orbits) of 14 m. The coloured fringes map the deformation of the surface of the Earth in the direction of the view from the satellite in units of the radar wavelength (2.8 cm) between colour cycles.

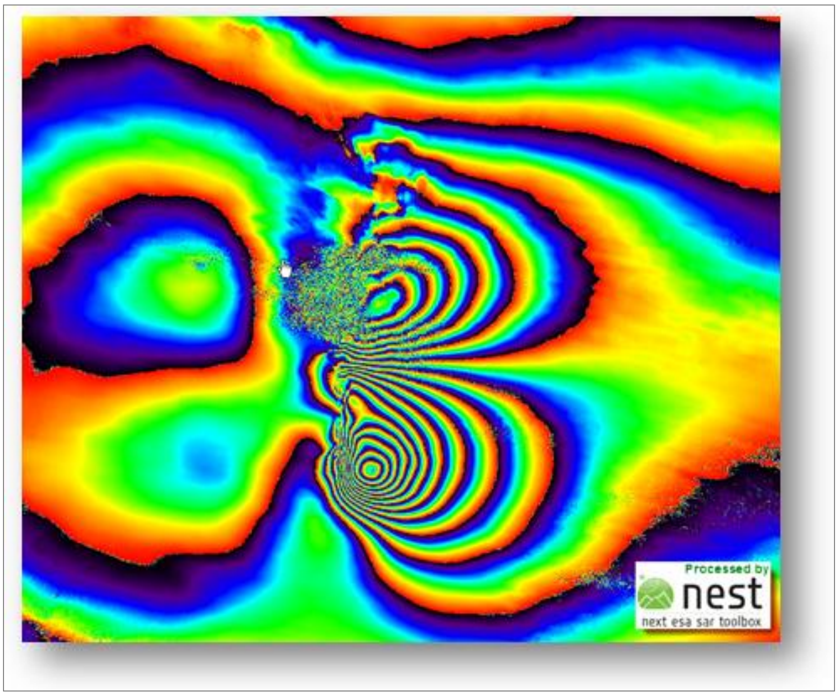


Figure 1: ENVISAT Interferogram of Bam, Iran

Persistent Scatterer Interferometry (PSI) is a branch of interferometry that exploits point scatterers, with strong radar backscatter, over a long time period (years) to provide a phase history of the point target over time. Persistent scatterers can be small, usually manmade, features that remain very correlated over time.

Conventional DInSAR can have limitations with respect to discrimination between the effects of displacement and atmospheric signature. PSI techniques can overcome such limitations by relaxing usual baseline and temporal constraints and maximising the number of useable interferograms, which can then be used to calculate mean trends over time from a large history of interferograms. Only the targets with sufficiently high coherence are considered, resulting in reduced pixel density.

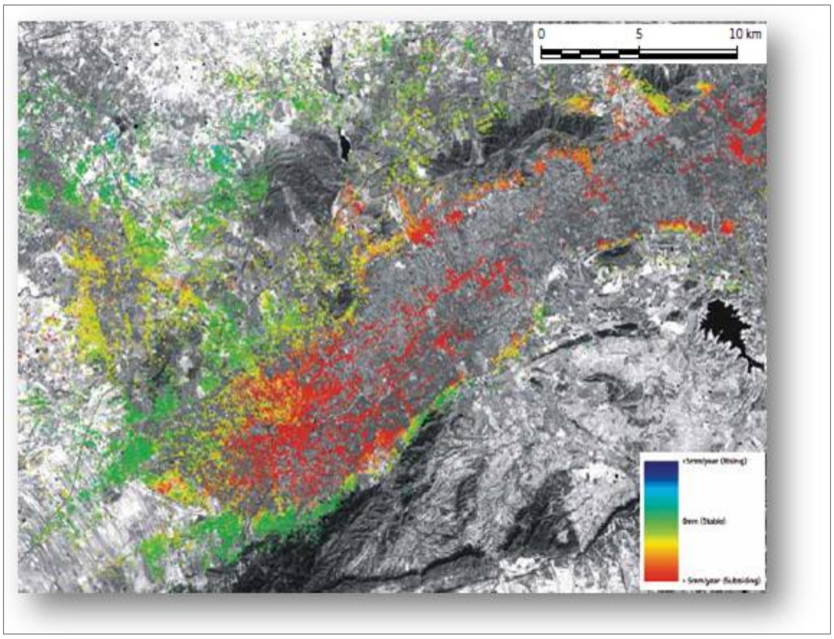


Figure 2: Terrain Deformation Map of Murcia, Spain Using the PSI Technique. The Maximum Subsidence (Red) is About 5 cm per Year. (image courtesy of Altamira Information TerraFirma project)

Applications of InSAR include:

- geophysical monitoring of natural hazards: earthquakes, volcanoes and landslides
- time-series analysis of surface deformation: subsidence and structural stability
- glacier motion analysis
- digital elevation mapping.

ESA's Next Generation User Services for Earth Observation (ngEO) can be used to search for suitable interferometric datasets, taking baseline, Doppler centroid and burst synchronisation criteria into account.

For an introduction to interferometric concepts, please see ESA's InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation (ESA TM-19).

2.2 Applications

SENTINEL-1 provides data feeding services for applications in the Copernicus priority areas of maritime monitoring, land monitoring and emergency management.

2.2.1 Maritime Monitoring

Ice Monitoring

High-resolution ice charting services supply ice classification and iceberg data to national coast guards, navies and shipping companies, to assist in assuring safe year-round navigation in the ice-covered Arctic and sub-Arctic zones. For sea-ice, information on ice concentration, extent, type, thickness and drift velocity can be determined. The location, size and drift of icebergs can also be collected. SENTINEL-1 dual polarisation data can significantly improve ice classification and discrimination.

Through the detection of changes in the Arctic sea-ice extent, SENTINEL-1 can be used to assess environmental impacts on coastal areas and transportation.

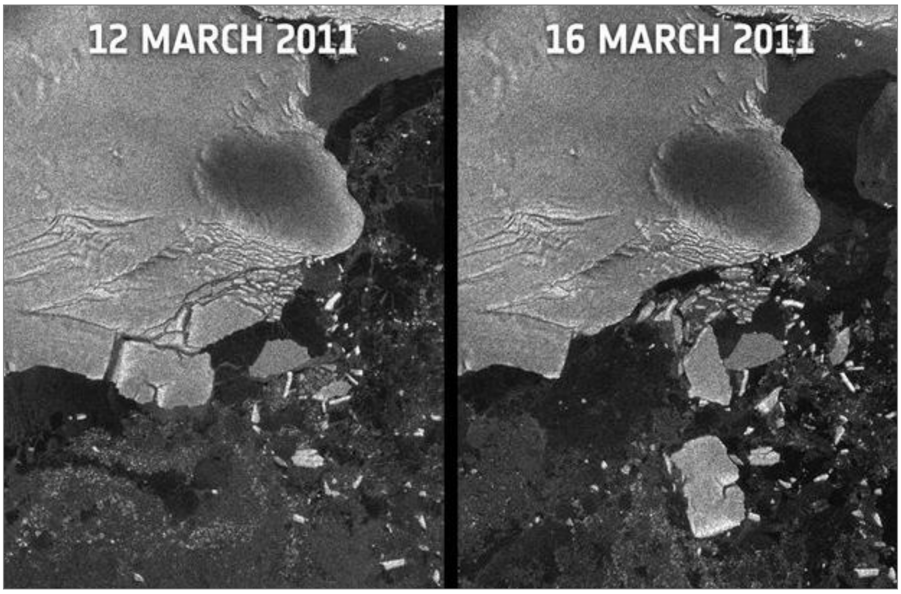


Figure 1: ASAR Image on March 12th and March 16th 2011 of the Sulzberger Ice Shelf in Antarctica (newly formed icebergs can clearly be seen in the second image).

Ship Monitoring

SENTINEL-1 uses wide area coverage with improved revisit times and is able to potentially detect smaller ships than ENVISAT ASAR. The mission's ability to observe in all weather and in day or night time, makes it ideal for precise cueing and location of ship activities at sea, allowing for more efficient and cost-effective use of other security assets, such as patrol aircraft and ships. Data relevant to ship detection are transmitted by the satellite in real-time for reception by local collaborative ground stations supporting European and national services.

Figure 2: ASAR Image Showing the Ships for the International Fleet Review Assembling in the Solent Between the Isle of Wight and Portsmouth on June 26th 2005.

Oil Pollution Monitoring

Oil detection applications are used for gathering evidence of illegal discharges, analysing the spread of oil spills and prospecting for oil reserves by highlighting naturally occurring seepage. Oil slicks are distinctly visible in SAR imagery as characteristically dark features. Most oil slicks are caused by ships emptying bilge before entering port. Detections can be correlated with Automatic Identification System (AIS) or Long-Range Identification and Tracking (LRIT) information broadcasts from ships to determine sources and prosecute offenders. Data relevant to oil spill monitoring are transmitted by the satellite in real-time for reception by local collaborative ground stations supporting European and national services.

Likewise, detection of naturally occurring oil seepage from the ocean floor can provide clues for oil prospecting.

Figure 3: ASAR Image on May 2nd 2010 Showing the Deepwater Horizon Oil Spill in the Gulf of Mexico Near theDelta National Wildlife Refuge.

<u>**Marine Winds**</u>

SAR is sensitive to spatially varying surface roughness patterns caused by winds on the ocean surface. SENTINEL-1 ocean products, in conjunction with global ocean wave models, help determine the direction, wavelength and heights of waves on the open oceans and assist in weather prediction, ship transportation and wave energy applications.

Wind field estimates also play an important part in oil spill monitoring to help discriminate look-alikes from actual spills.

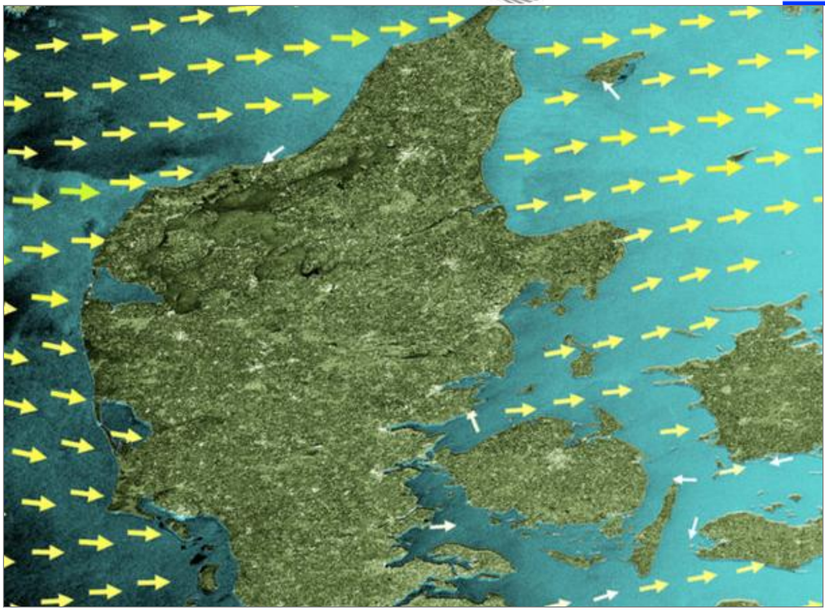


Figure 4: Wind Field Observations Derived from an ASAR Image Over Denmark and the North Sea on September 30th 2009 (the wind speed values range from 0 to 20 m/s represented by the the size and colour of the arrows).

Furthermore, SENTINEL-1 will provide data on the interactions between ocean waves and currents allowing the visualisation of large-scale ocean currents, cold/warm water masses, coastal water currents, and internal waves.

2.2.2 Land Monitoring

Forestry

SENTINEL-1 can play an important role in sustainable forest management with clear-cut and partial-cut detection, forest type classification, biomass estimation and disturbance detection. For climate change, mapping of forest fire scars can be an important part of mapping the carbon history of a forest and plays a critical role in the estimation of carbon emissions.

Land cover maps can be used to support forest management and the monitoring of illegal timber harvesting worldwide.

Agriculture

Monitoring of crop conditions, soil properties and mapping tillage activities, help to assess land use, predict harvests, monitor seasonal changes and assist in implementing policy for sustainable development. SENTINEL-1 will also be used for monitoring the changes of agricultural production and productivity of pastures caused by drought and monitoring the decline of land productivity and soil degradation due to excessive cultivation and pasturage and improper irrigation.

Agricultural maps enable provision of independent and objective estimates of the extent of cultivation in a given country or growing season, which can be used to support efforts to ensure food security in vulnerable areas.

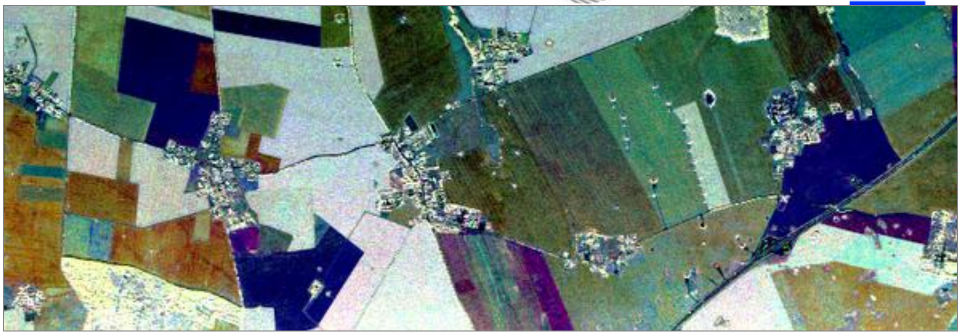


Figure 1: Colour Composite of Three SAR Images Taken Over the AGRISAR Test Site Within a Period of 2½ Weeks at the Beginning of the Growing Season (the different colours reflect the crop type and change in crop condition during this short time period).

Urban Deformation Mapping

Interferometric SAR can detect surface movements with an accuracy of a few millimetres per year and can provide an accurate tool for monitoring of land subsidence, structural damage and underground construction to improve safety and reduce economic loss.

2.2.3 Emergency Management

Flood Monitoring

Over 75% of natural disasters that occur worldwide involve flooding. SAR's inherent capability to observe during cloud cover and SENTINEL-1's frequent revisits makes it ideal for flood monitoring. It can be used to assess the extent of flooded areas and the impact on human, economic and environmental loss.

Furthermore, high-resolution digital elevation models (DEMs) generated through SENTINEL-1's interferometric modes can be used to conduct run-off and inundation analysis in areas previously lacking elevation data.

Earthquake Analysis

InSAR provides the unique ability to produce medium and high-resolution maps of earthquake deformations. Through the persistent monitoring of earthquake-prone areas, active fault lines can be discovered and potential risks can be studied. The Interferometric Wide swath mode will make it easier to monitor very large scale earthquakes.

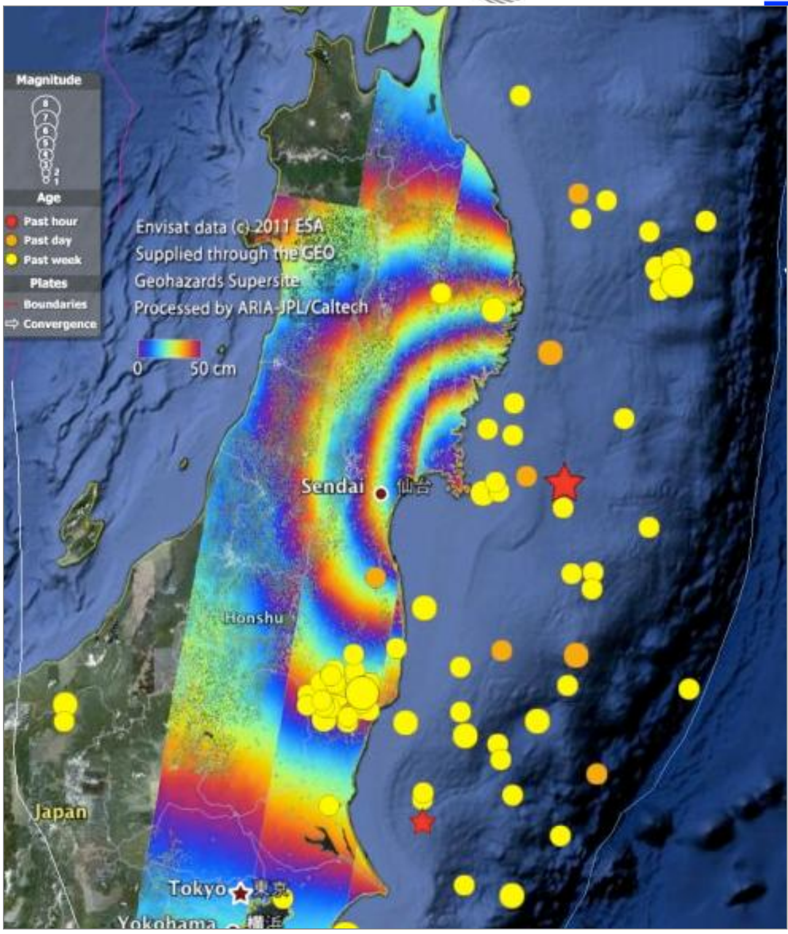


Figure 1: ASAR coseismic interferogram of the 2011 Tohoku-oki earthquake in Japan processed by JPL/Caltech ARIA project using ROI_PAC. One color cycle represents 50 cm of motion in the radar line of sight.

<u>Landslide and Volcano Monitoring</u>

SAR interferometry can locate areas prone to landslides and monitor surface deformation to provide early warning of potential disasters and monitoring of critical infrastructure. Pre-eruption uplift and post eruption volcanic shrinkage can be monitored with similar interferometric techniques and can complement in-situ networks from volcano observatories. InSAR monitoring can help detect first signs of increasing levels of volcanic activity, preceding earthquakes and other precursors that may signal eruptions.

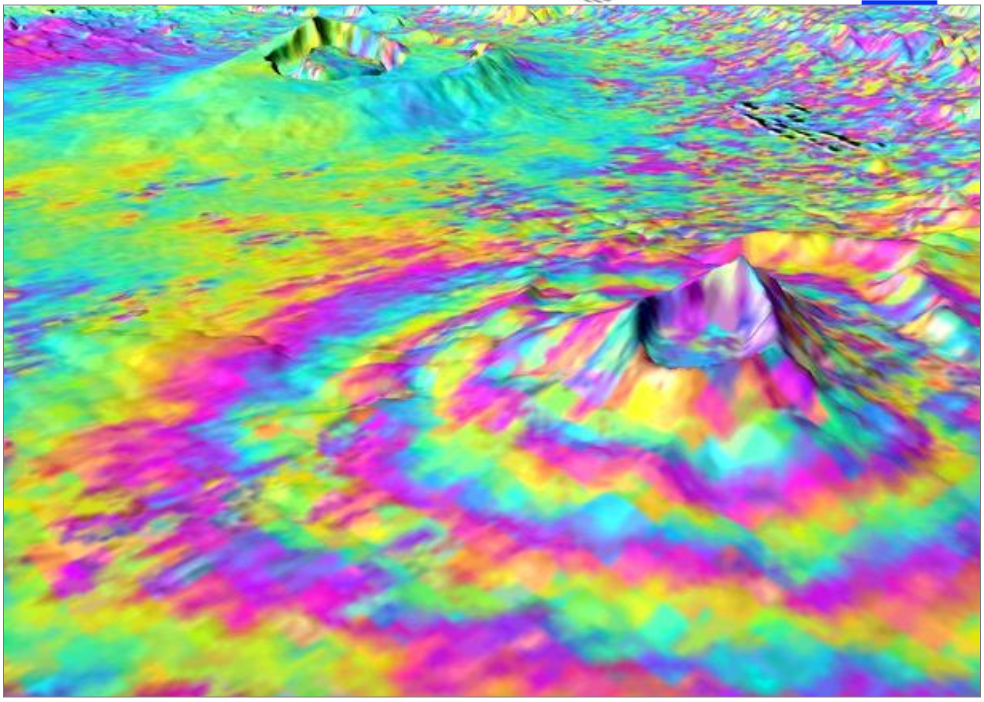


Figure 2: ASAR interferogram image over the Kenyan section of the Great Rift Valley shows small surface displacements that are not visible to the naked eye of the Longonot Volcano. Interferogram images appear as rainbow-coloured interference patterns. A complete set of coloured bands, called 'fringes', represents ground movement relative to the spacecraft of half a wavelength, which is 2.8 cm in the case of ENVISAT's ASAR.

2.2.4 Mapping Applications to Sentinel-1 Modes

Each application can best be served by specific SENTINEL-1 acquisition modes and product types as shown in the table below. Note that Stripmap mode is used in exceptional cases only, to support emergency management actions. The Interferometric Wide swath mode is the primary operation mode for most applications over land.

Application	Mode			
	SM	IW	EW	WV
Arctic and sea-ice		X	X	
Open ocean ship surveillance		X	X	
Oil pollution monitoring		X	X	
Marine winds				X
Forestry		X		
Agriculture		X		
Urban deformation mapping		X		
Flood monitoring	X	X		
Earthquake analysis	X	X		
Landslide and volcano monitoring	X	X		

Table 1: Typical applications mapped to modes

2.3 Acquisition Modes

SENTINEL-1 potentially operates in four exclusive acquisition modes:

- Stripmap (SM)
- Interferometric Wide swath (IW)
- Extra-Wide swath (EW)
- Wave (WV).

The SENTINEL-1 C-band SAR instrument supports operation in single polarisation (HH or VV) and dual polarisation (HH+HV or VV+VH), implemented through one transmit chain (switchable to H or V) and two parallel receive chains for H and V polarisation.

SM, IW and EW are available in single (HH or VV) or dual polarisation (HH+HV or VV+VH). WV is single polarisation only (HH or VV).

The primary conflict-free modes are IW, with VV+VH polarisation over land, and WV, with VV polarisation, over open ocean. EW mode is primarily used for wide area coastal monitoring including ship traffic, oil spill and sea-ice monitoring. SM mode will only be used on request for extraordinary events such as emergency management.

Having the Interferometric Wide swath mode as the one main operational mode satisfies most currently known service requirements, avoids conflicts and preserves revisit performance, simplifies mission planning, decreases operational costs and builds up a consistent long-term archive.

For each mode, it will be possible to produce products at SAR Level-0, Level-1 SLC, Level-1 GRD and Level-2 OCN.

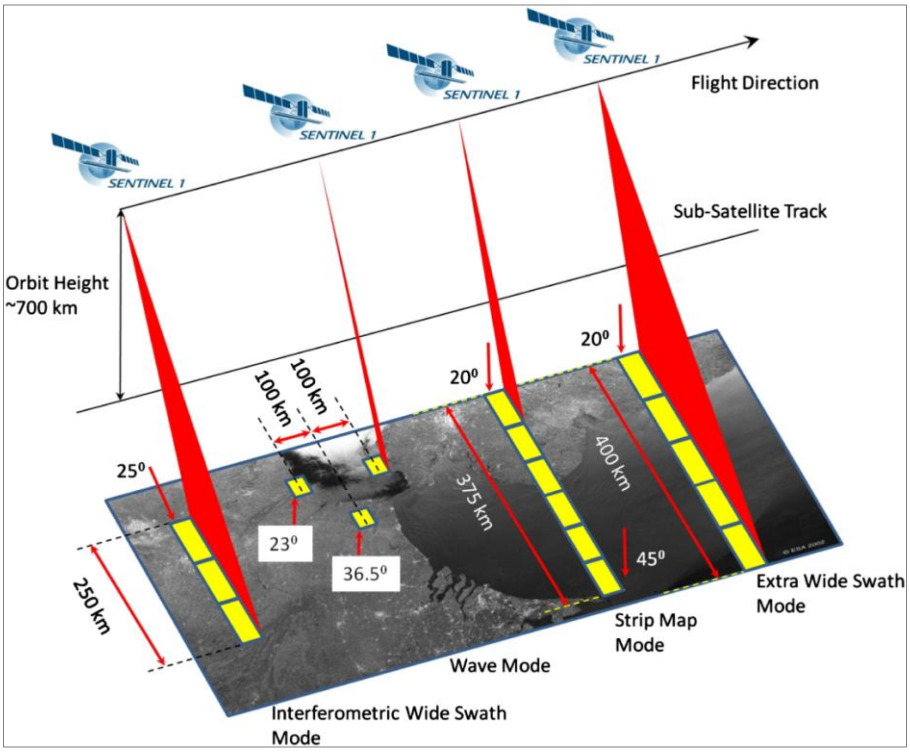


Figure 1: SENTINEL-1 Product Modes

2.3.1 Stripmap

Stripmap mode acquires data with an 80 km swath at 5 m by 5 m spatial resolution (single look). The ground swath is illuminated by a continuous sequence of pulses while the antenna beam is pointing to a fixed azimuth angle and an approximately fixed off-nadir angle. SM images have continuous along track image quality at an approximately constant incidence angle.

The following table shows the main characteristics of Stripmap mode.

Characteristic	Value
Swath width	80 km
Incidence angle range	18.3° - 46.8°
Elevation beams	6
Azimuth and range looks	Single
Polarisation options	Dual HH+HV, VV+VH Single HH, VV
Maximum Noise Equivalent Sigma Zero (NESZ)	-22 dB
Radiometric stability	0.5 dB (3σ)
Radiometric accuracy	1 dB (3σ)
Phase error	5°

Table 1: Characteristics of Stripmap mode

Stripmap imaging mode can operate with one of six predefined elevation beams, each at a different incidence angle. The table below shows the incidence and off-nadir angles for Stripmap beams.

The incidence angle is the angle between the incident SAR beam and the axis perpendicular to the local geodetic ground surface.

The off-nadir angle is the look angle between the satellite's nadir position and the SAR beam.

Beam	S1	S2	S3	S4	S5	S6
Off-nadir angles at min orbit altitude	17.93-23.53	21.00-26.33	26.18-30.99	30.87-35.15	35.07-38.85	37.53-41.01
Incidence angles at min orbit altitude	19.99-26.31	23.45-29.50	29.33-34.85	34.71-39.72	39.62-44.12	42.53-46.73
Off-nadir angles at max orbit altitude	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 at max orbit altitude	18.32-24.55	21.78-27.76	27.64-33.13	33.00-38.02	37.89-42.43	40.79-45.04

Table 2: Angles for Stripmap mode beams

Stripmap mode is used in exceptional cases only, to support emergency management actions.

2.3.2 Interferometric Wide Swath

The Interferometric Wide swath mode is the main acquisition mode over land and satisfies the majority of service requirements. It acquires data with a 250 km swath at 5 m by 20 m spatial resolution (single look). IW mode captures three sub-swaths using Terrain Observation with Progressive Scans SAR (TOPSAR). With the TOPSAR technique, in addition to steering the beam in range as in ScanSAR, the beam is also electronically steered from backward to forward in the azimuth direction for each burst, avoiding scalloping and resulting in homogeneous image quality throughout the swath [1].

TOPSAR mode is intended to replace the conventional ScanSAR mode, achieving the same coverage and resolution as ScanSAR, but with a nearly uniform SNR (Signal-to-Noise Ratio) and DTAR (Distributed Target Ambiguity Ratio).

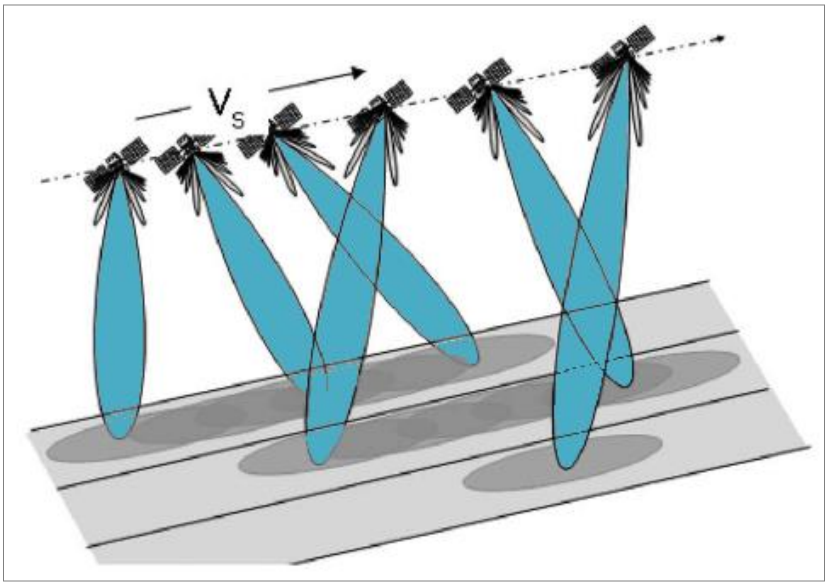


Figure 1: TOPSAR Sub-Swath Acquisition

Azimuth resolution is reduced compared to SM due to the shorter target illumination time of the burst. Using the sweeping azimuth pattern, each target is seen under the same antenna pattern, independently from its azimuth position in the burst image. By shrinking the azimuth antenna pattern, as seen by a target on the ground, scalloping effects on the image can be reduced. Bursts are synchronised from pass to pass to ensure the alignment of interferometric pairs.

IW SLC products contain one image per sub-swath and one per polarisation channel, for a total of three (single polarisation) or six (dual polarisation) images in an IW product.

Each sub-swath image consists of a series of bursts, where each burst has been 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 ENVISAT ASAR Wide ScanSAR SLC products.

Due to the one natural azimuth look inherent in the data, the imaged ground area of adjacent bursts will only marginally overlap in azimuth by just enough to provide contiguous coverage of the ground. The images for all bursts in all sub-swaths are resampled to a common pixel spacing grid in range and azimuth while preserving the phase information.

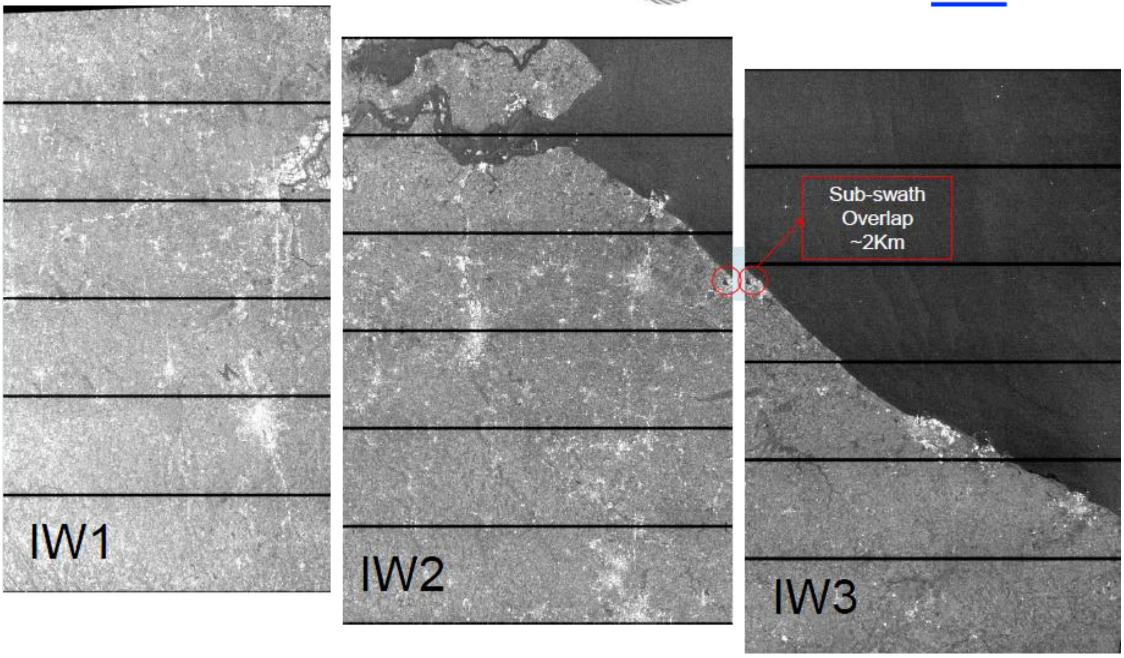


Figure 2: IW Sub-Swaths with Minimal Overlap

After de-bursting and merging the sub-swaths, a wide area product can be created. The TOPSAR technique greatly reduces scalloping effects over conventional ScanSAR.

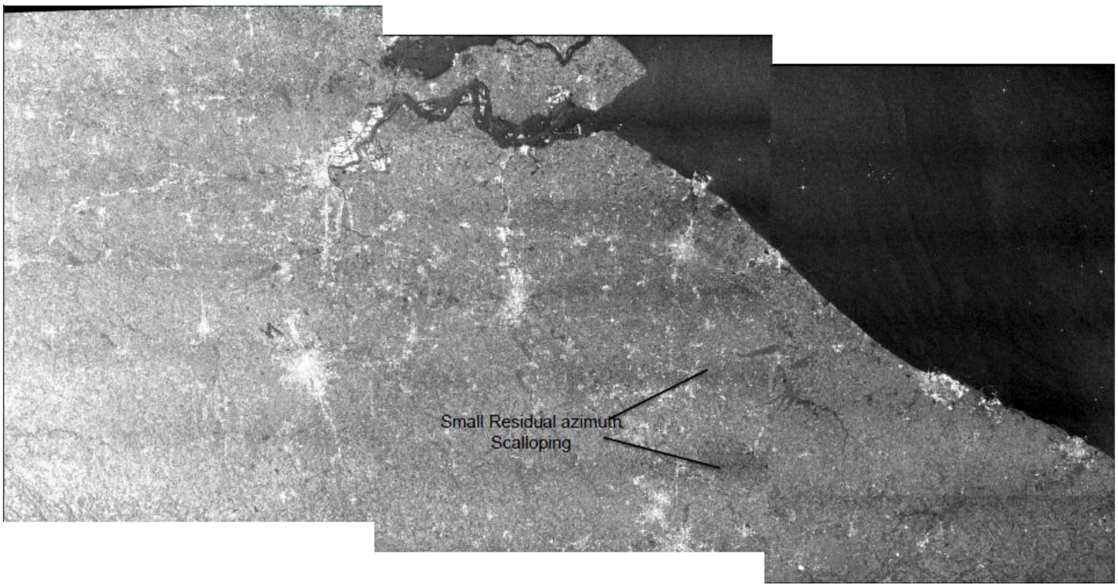


Figure 3: Resulting De-Burst and Merged IW Product

The table below shows the main characteristics of the Interferometric Wide swath mode.

Characteristic	Value
Swath width	250 km
Incidence angle range	29.1° - 46.0°
Sub-swaths	3
Azmiuth steering angle	± 0.6°
Azmiuth and range looks	Single
Polarisation options	Dual HH+HV, VV+VH Single HH, VV
Maximum Noise Equivalent Sigma Zero (NESZ)	-22 dB
Radiometric stability	0.5 dB (3σ)
Radiometric accuracy	1 dB (3σ)
Phase error	5°

Table 1: Characteristics of Interferometric Wide swath mode

The table below shows the incidence and off-nadir angles for Interferometric Wide swath mode beams.

Beam	IW1	IW2	IW3
Off-nadir angles at min orbit altitude	27.53-32.48	32.38-36.96	36.87-40.40
Incidence angles at min orbit altitude	30.86-36.59	36.47-41.85	41.75-46.00
Off-nadir angles at max orbit altitude	26.00-30.96	30.86-35.43	35.35-38.88
Incidence angles at max orbit altitude	29.16-34.89	34.77-40.15	40.04-44.28

Table 2: Angles for Interferometric Wide swath mode beams

[1] De Zan, F., & Guarnieri, A. M. (2006). TOPSAR: Terrain Observation by Progressive Scans. Geoscience and Remote Sensing, IEEE Transactions on, 44(9), 2352–2360. doi:10.1109/TGRS.2006.873853

2.3.3 Extra Wide Swath

Similar to the IW mode, the Extra Wide swath mode employs the TOPSAR technique to acquire data over a much wider area using five sub-swaths. EW mode acquires data over a 400 km swath at 20 m by 40 m spatial resolution.

EW SLC products contain one image per sub-swath and one per polarisation channel, for a total of five (single polarisation) or 10 (dual polarisation) images in an EW product.

The EW mode is aimed primarily for use over sea-ice, polar zones and certain maritime areas, in particular for ice, oil spill monitoring and security services. Like IW, EW mode can also be used for interferometry since it shares the same characteristics for burst synchronisation, baseline and Doppler stability.

The table below shows the main characteristics of the Extra Wide swath mode.

Characteristic	Value
Swath width	400 km
Incidence angle range	18.9° - 47.0°
Sub-swaths	5
Azmiuth steering angle	± 0.8°
Azmiuth and range looks	Single
Polarisation options	Dual HH+HV, VV+VH Single HH, VV
Maximum Noise Equivalent Sigma Zero (NESZ)	-22 dB
Radiometric stability	0.5 dB (3σ)
Radiometric accuracy	1 dB (3σ)
Phase error	5°

Table 1: Characteristics of Extra Wide swath mode

The table below shows the incidence and off-nadir angles for Extra Wide swath mode beams.

Beam	EW1	EW2	EW3	EW4	EW5
Off-nadir angles at min orbit altitude	17.94-26.07	26.02-30.66	30.61-35.10	35.06-38.66	38.63-41.20
Incidence angles at min orbit altitude	20.00-29.20	29.15-34.47	34.41-39.66	39.60-43.89	43.86-46.97
Off-nadir angles at max orbit altitude	16.36-24.49	24.44-29.08	29.03-33.52	33.48-37.08	37.05-39.62
Incidence angles at max orbit altitude	18.22-27.57	27.38-33.42	32.65-38.05	37.84-42.53	42.08-45.16

Table 2: Angles for Extra Wide swath mode beams

2.3.4 Wave

SENTINEL-1 Wave mode is similar to ERS and ENVISAT wave mode imaging but with improved resolution, larger vignettes and a new 'leap frog' acquisition pattern. WV acquisitions consist of several vignettes exclusively in either VV or HH polarisation, with each vignette processed as a separate image. WV mode products can contain any number of vignettes, potentially amounting to an entire data-take. Each vignette will be contained in an independent image within the product.

Wave mode acquires data in 20 km by 20 km vignettes, at 5 m by 5 m spatial resolution, every 100 km along the orbit, acquired alternately on two different incidence angles. Vignettes on the same incidence angle are separated by 200 km. Swaths alternate incidence angles between near range and far range (23° and 36.5° respectively).

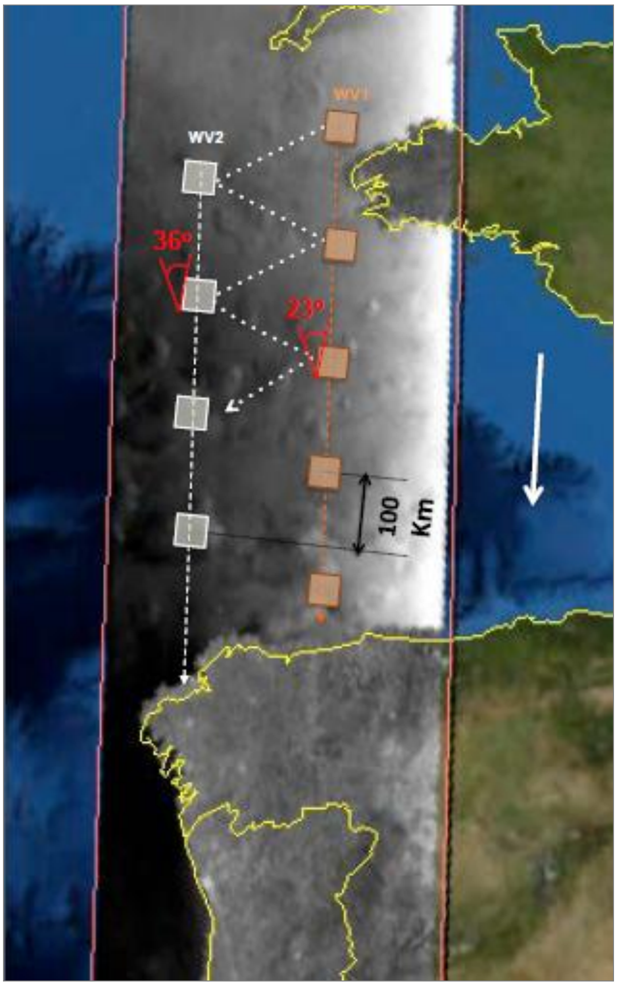


Figure 1: Alternating WV Mode Acquisitions

The Wave mode at VV polarisation is the default mode for acquiring data over open ocean. WV mode is acquired at the same bit rate as SM however, due to the small vignettes, single polarisation and sensing at 100 km intervals, the data volume is much lower. The table below shows the main characteristics of the Wave mode.

Characteristic	Value
Vignette ground coverage	20 km
Along track distance between vignettes	100 km
Incidence angle ranges	21.6° - 25.1° 34.8° - 38.0°

Elevation beams	2
Azmiuth and range looks	Single
Polarisation options	Single HH, VV
Maximum Noise Equivalent Sigma Zero (NESZ)	-22 dB
Radiometric stability	0.5 dB (3σ)
Radiometric accuracy	1 dB (3σ)
Phase error	5°

Table 1: Characteristics of Wave mode

The table below shows the incidence and off-nadir angles for Wave mode beams.

Beam	WV1	WV2
Off-nadir angles at min orbit altitude	21.03-22.40	32.56-33.62
Incidence angles at min orbit altitude	23.47-25.03	36.67-37.92
Off-nadir angles at max orbit altitude	19.43-20.79	30.96-32.02
Incidence angles at max orbit altitude	21.68-23.22	34.88-36.13

Table 2: Angles for Wave mode beams

2.4 Product Types and Processing Levels

SENTINEL-1 data products acquired in SM, IW and EW mode which are generated by the PDGS operationally are distributed at three levels of processing.

- Level-0
- Level-1
- Level-2.

Level-1 products can be one of two product types - either Single Look Complex (SLC) or Ground Range Detected (GRD). Level-2 Ocean (OCN) products can have different components available depending on the acquisition mode.

Products are designated based on their acquisition mode, product type and in the case of Level-1 GRD also its resolution.

All products are processed directly from the Level-0 product. Each mode can potentially generate Level-1 SLC, Level-1 GRD and Level-2 Ocean products. For WV mode, the Level-0 and Level-1 products are not distributed.

Level-2 OWS component is not available from the TOPSAR modes.

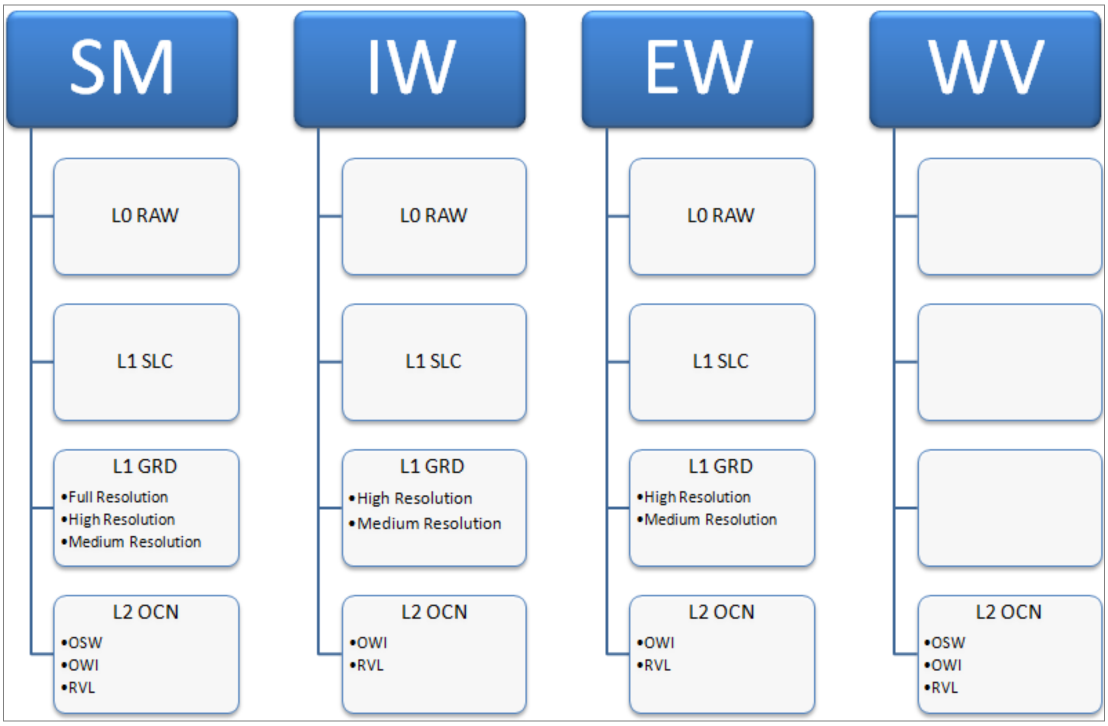


Figure 1: Product Levels From Modes

2.4.1 Level-0

The SAR Level-0 products consist of compressed and unfocused SAR raw data. Level-0 products are the basis from which all other high level products are produced.

Level-0 data is compressed using Flexible Dynamic Block Adaptive Quantization (FDBAQ) which provides a variable bit rate coding that increases the number of bits allocated to bright scatterers. For the data to be usable, it will need to be decompressed and processed using focusing software.

Level-0 data includes noise, internal calibration and echo source packets as well as orbit and attitude information.

Level-0 products are stored in the long term archives. They can be processed to generate any type of product during the mission lifetime and for 25 years after the end of the space segment operations.

Level-0 products are available to data users for only the SM, IW and EW modes.

2.4.2 Level-1

Level-1 focused data are the generally available products intended for most data users. The Level-0 product is transformed into a Level-1 product by the application of algorithms and calibration data to form a baseline engineering product from which higher levels are derived.

The processing involved to produce Level-1 data products includes pre-processing, Doppler centroid estimation, single look complex focusing, and image and post-processing for generation of the SLC and GRD products as well as mode specific processing for assembling of multi-swath products.

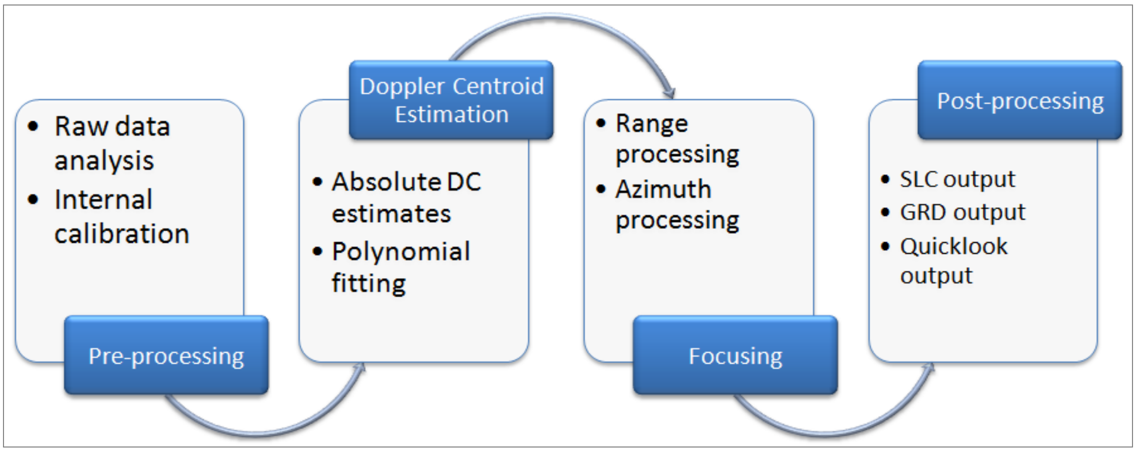


Figure 1: Level-1 Processing Flow

For converting digital pixel values to radiometrically calibrated backscatter, all the required information can be found in the product. A calibration vector is included as an annotation in the product allowing simple conversion of image intensity values into sigma or gamma nought values.

Level-1 products can be either Single Look Complex (SLC) or Ground Range Detected (GRD). Each acquisition mode can potentially generate Level-1 SLC and GRD products. GRD resolutions will depend on the mode and the level of multi-looking.

Single Look Complex

Level-1 Single Look Complex (SLC) products consist of focused SAR data, geo-referenced using orbit and attitude data from the satellite, and provided in slant-range geometry. Slant range is the natural radar range observation coordinate, defined as the line-of-sight from the radar to each reflecting object. The products are in zero-Doppler orientation where each row of pixels represents points along a line perpendicular to the sub-satellite track.

The products include a single look in each dimension using the full available signal bandwidth and complex samples (real and imaginary) preserving the phase information. The products have been geo-referenced using the orbit and attitude data from the satellite and have been corrected for azimuth bi-static delay, elevation antenna pattern and range spreading loss.

Stripmap SLCs contain one image for its single swath per polarisation band. IW, having three swaths, has three images in single polarisation and six images for dual polarisation. EW, having five swaths, has five images for single polarisation and ten images for dual polarisation.

For IW and EW, each sub-swath consists of a series of bursts. Each burst has been 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 Wide ScanSAR SLC products.

For IW, a focused burst has a duration of ~2.75 seconds and a burst overlap of approximately ~0.4 seconds. For EW, a focused burst has a duration of ~3.19 seconds with an overlap of ~0.1 seconds. The overlap slightly increases in range within a sub-swath. Unlike ASAR WSS which contains a large overlap between beams, for SENTINEL-1 TOPSAR products, the imaged ground area of adjacent bursts only marginally overlap in azimuth just enough to provide contiguous coverage of the ground. This is due to the one natural azimuth look inherent in the data.

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. Burst synchronisation is ensured for both IW and EW products.

The Swath Timing data set record in SLC products contains information about the bursts including dimensions, timing and location that can be used to merge the bursts and swaths together.

Ground Range Detected

Level-1 Ground Range Detected (GRD) products consist of focused SAR data that has been detected, multi-looked and projected to ground range using an Earth ellipsoid model such as WGS84. The ellipsoid projection of the GRD products is corrected using the terrain height specified in the product general annotation. The terrain height used varies in azimuth but is constant in range.

Ground range coordinates are the slant range coordinates projected onto the ellipsoid of the Earth. Pixel values represent detected magnitude. Phase information is lost. The resulting product has approximately square resolution pixels and square pixel spacing with reduced speckle at a cost of reduced geometric resolution.

In addition to the corrections applied to Level-1 SLC products, GRD products have thermal noise removed to improve the quality of the detected image.

For the IW and EW GRD products, multi-looking is performed on each burst individually. All bursts in all sub-swaths are then seamlessly merged to form a single, contiguous, ground range, detected image per polarisation channel.

2.4.3 Level-2

Level-2 consists of geolocated geophysical products derived from Level-1. Level-2 Ocean (OCN) products for wind, wave and currents applications may contain the following geophysical components derived from the SAR data:

- Ocean Wind field (OWI)
- Ocean Swell spectra (OSW)
- Surface Radial Velocity (RVL).

The availability of components depends on the acquisition mode. The metadata referring to OWI are derived from an internally processed GRD product, the metadata referring to RVL (and OSW, for SM and WV mode) are derived from an internally processed SLC product.

The OWI component is a ground range gridded estimate of the surface wind speed and direction at 10 m above the surface, derived from SM, IW or EW modes.

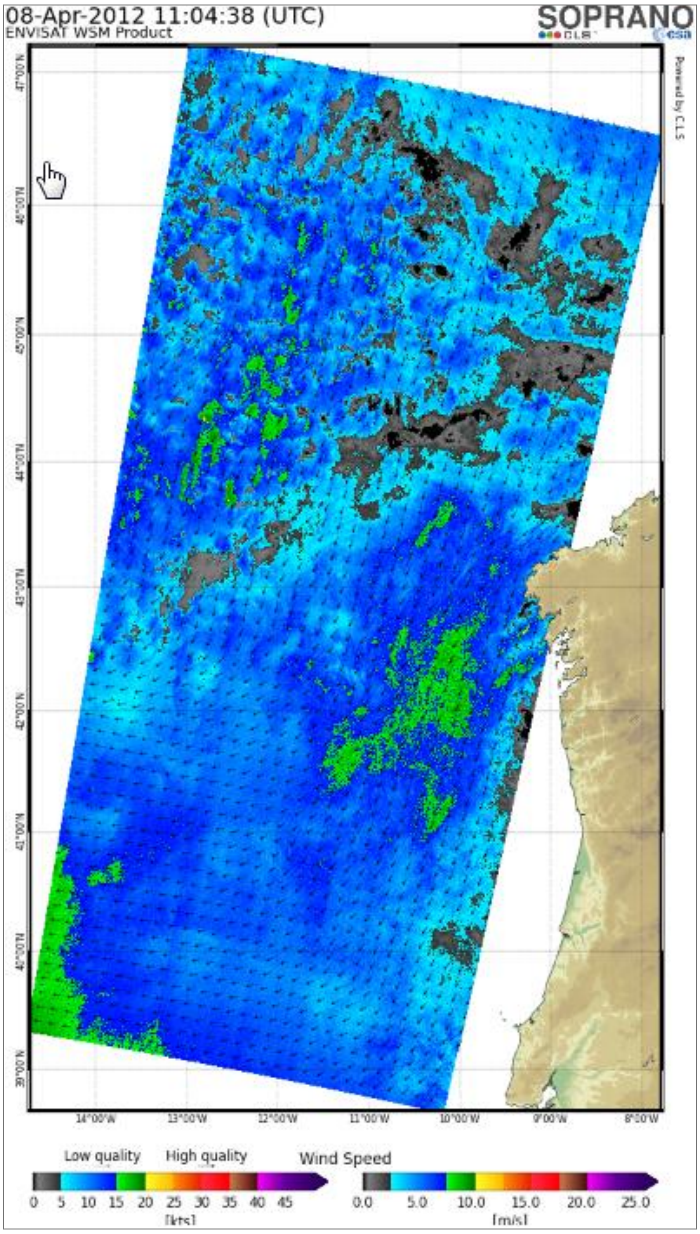


Figure 1: Wind Speed Plot (image courtesy of CLS SOPRANO)

The OSW component is a two-dimensional ocean surface swell spectrum and includes an estimate of wind speed and direction per swell spectrum. The OSW component provides continuity measurement of SAR swell spectra at C-band.

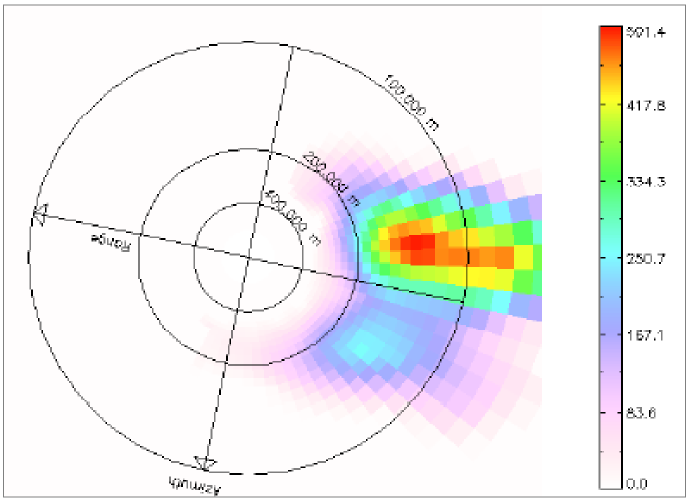


Figure 2: OSW Spectra (image courtesy of CLS SOPRANO)

The OSW is generated from Stripmap and Wave modes only and is not available from the TOPSAR IW and EW modes. For Stripmap mode, there are multiple spectra derived from the Level-1 SLC image. For Wave mode, there is one spectrum per vignette.

The RVL surface radial velocity component is a ground range gridded difference between the measured Level-2 Doppler grid and the Level-1 calculated geometrical Doppler. The RVL component provides continuity of the ASAR Doppler grid.

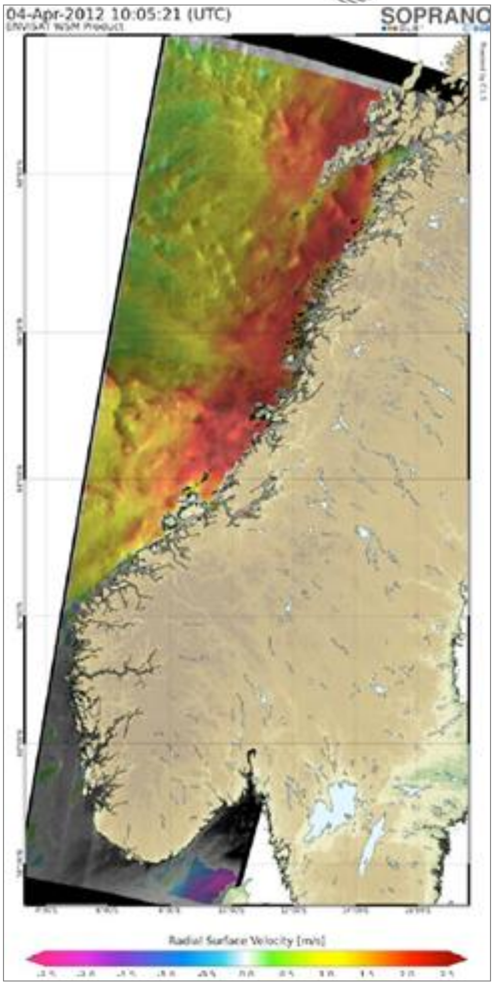


Figure 3: Surface Radial Velocity (image courtesy of CLS SOPRANO)

2.5 Resolutions

Spatial resolutions depend on the acquisition mode and the level of processing.

2.5.1 Level-1 Single Look Complex

Single Look Complex products have a resolution determined by the acquisition mode.

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.

Spatial resolution is a measure of the system's ability to distinguish between adjacent targets.

Pixel spacing is the distance between adjacent pixels in an image, measured in metres.

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.

Mode	Resolution rg x az	Pixel spacing rg x az	Number of looks	ENL
SM	1.7x4.3 m to 3.6x4.9 m	1.5x3.6 m to 3.1x4.1 m	1x1	1
IW	2.7x22 m to 3.5x22 m	2.3x17.4 m	1x1	1
EW	7.9x43 m to 15x43 m	5.9x34.7 m	1x1	1
WV	2.0x4.8 m and 3.1x4.8 m	1.7x4.1 m and 2.7x4.1 m	1x1	1

Table 1: Acquisition resolution Level-1 SLC

The SM and WV SLC products are sampled at the natural pixel spacing, meaning that pixel spacing is determined in azimuth by the pulse repetition frequency (PRF), and in range by the radar range sampling frequency.

IW and EW SLC products have all bursts in all sub-swaths re-sampled to a common pixel spacing grid in range and azimuth.

2.5.2 Level-1 Ground Range Detected

Level-1 GRD products can be in one of three resolutions:

- Full Resolution (FR) for SM mode
- High Resolution (HR) for SM, IW and EW modes
- Medium Resolution (MR) for SM, IW, EW and WV modes.

The resolution is dependent upon the amount of multi-looking performed. Level-1 GRD products come in MR and HR for IW and EW modes, MR for WV mode and MR, HR and FR for SM mode.

The resolution for a GRD product corresponds to the mid-range value at mid-orbit altitude, averaged over all swaths. The equivalent number of looks (ENL) for IW and EW GRD products corresponds to an average over all swaths.

Mode	Resolution rg x az	Pixel spacing rg x az	Number of looks	ENL
SM	9x9 m	4x4 m	2x2	3.9

Table 1: Full resolution Level-1 GRD

Mode	Resolution rg x az	Pixel spacing rg x az	Number of looks	ENL
SM	23x23 m	10x10 m	6x6	34.4
IW	20x22 m	10x10 m	5x1	4.9
EW	50x50 m	25x25 m	3x1	2.9

Table 2: High resolution Level-1 GRD

Mode	Resolution rg x az	Pixel spacing rg x az	Number of looks	ENL
SM	84x84 m	40x40 m	22x22	350-398
IW	88x87 m	40x40 m	22x5	105.7
EW	93x87 m	40x40 m	6x2	12.7
WV	52x51 m	25x25 m	13x13	123.7

Table 3: Medium resolution Level-1 GRD

2.5.3 Level-2 Ocean

For Level-2 OCN products, the swell spectra (OSW) are provided at a spatial resolution of 20 km by 20 km. The wind fields (OWI) and surface radial velocity (RVL) components have a spatial resolution of 1 km by 1 km.

2.6 Revisit and Coverage

The SENTINEL-1 constellation offers an improvement in revisit time over ERS-1/2 and ENVISAT ASAR, and a continuity of wide area coverage with ENVISAT ASAR, but achieving higher resolution and potentially global dual polarisation coverage over landmasses.

Each SENTINEL-1 satellite will be in a near-polar, sun-synchronous orbit, with a 12-day repeat cycle and 175 orbits per cycle. Both SENTINEL-1A and SENTINEL-1B share the same orbit plane with a 180° orbital phasing difference.

A single SENTINEL-1 satellite is potentially able to map the global landmasses in the Interferometric Wide swath mode once every 12 days. The two-satellite constellation offers a 6 day exact repeat cycle at the equator. Since the orbit track spacing varies with latitude, the revisit rate is significantly greater at higher latitudes than at the equator.

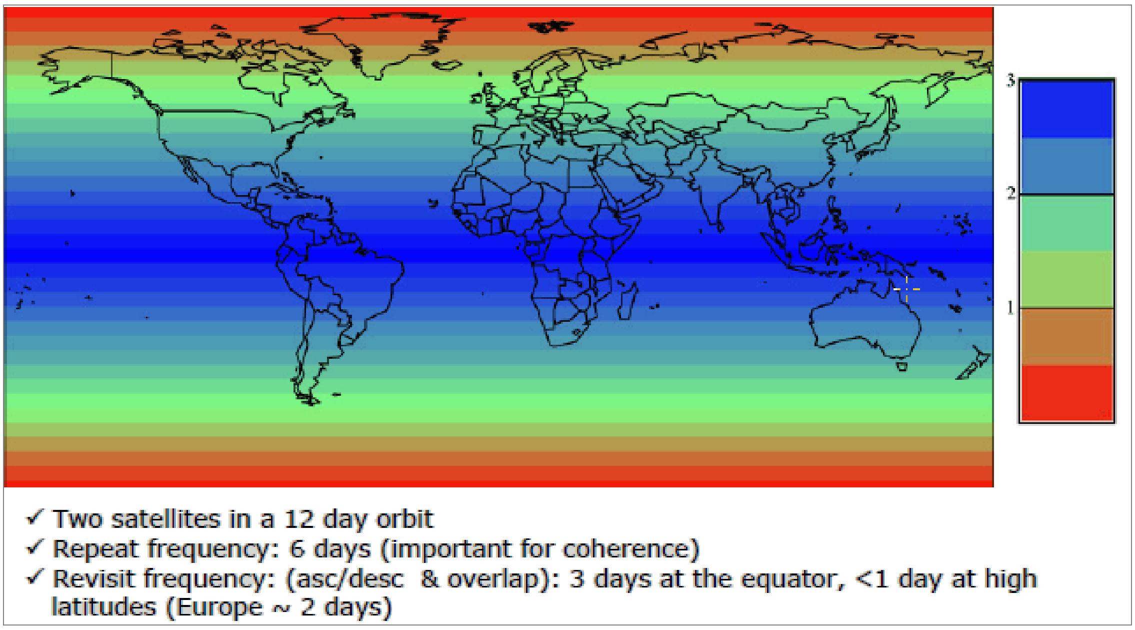


Figure 1: Revisit Frequency for S-1A and S-1B in Days per Revisit

Conflict-free operations, enabled by a main operational mode over land, allow exploitation of every data-take and creation of a consistent long term data archive for applications requiring long time series.

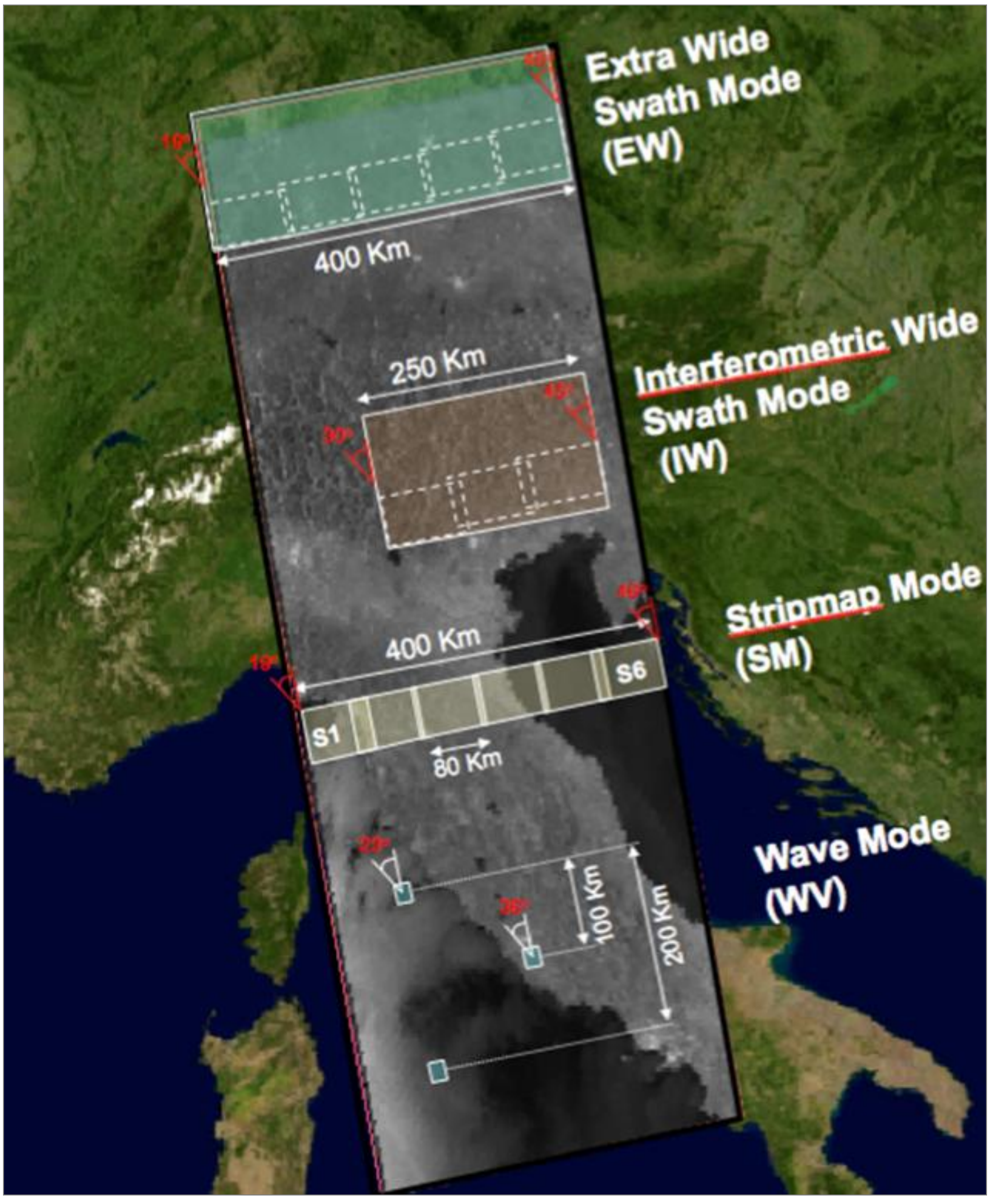


Figure 2: SENTINEL-1 Swath Coverage

Over land, IW mode will primarily be used for most services acquiring data at 5 m by 20 m spatial resolution over a 250 km wide area with selectable single or dual polarisation, allowing conflict-free high resolution coverage of dual polarisation and interferometric data potentially over all global landmasses. EW mode will be used over selected coastal and Arctic areas, primarily for ocean monitoring services covering a 400 km area with each data-take. SM mode will be used on request mainly for emergency management. Over open ocean, WV mode will be the main operational acquisition mode acquiring vignettes at regular intervals.

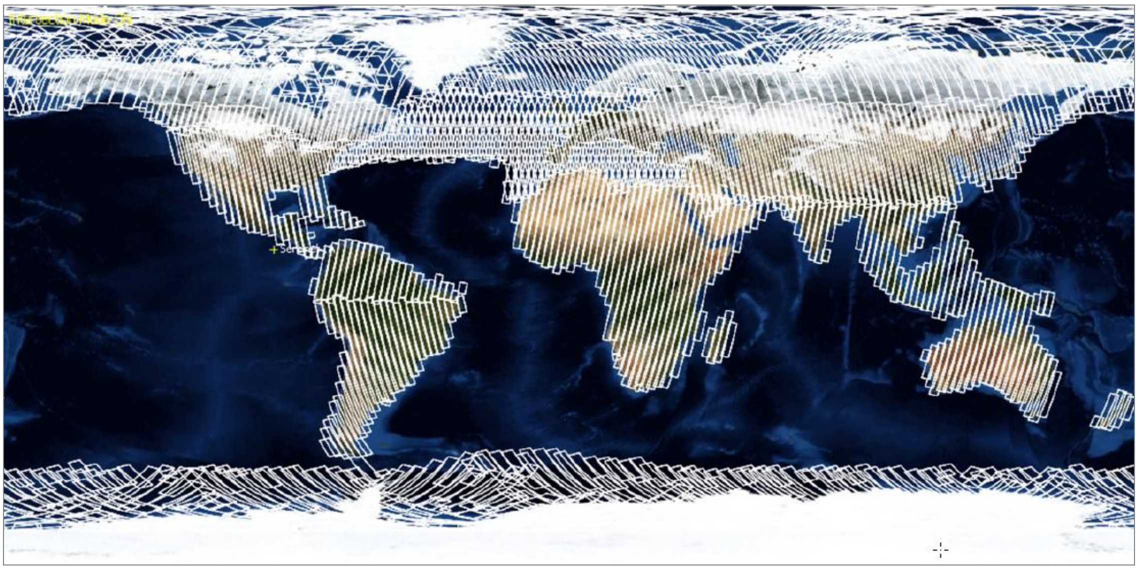


Figure 3: SENTINEL-1A IW Potential Coverage Over 12 Days

2.7 Naming Conventions

The top-level SENTINEL-1 product folder name is composed of upper-case alphanumeric characters separated by an underscore (_).

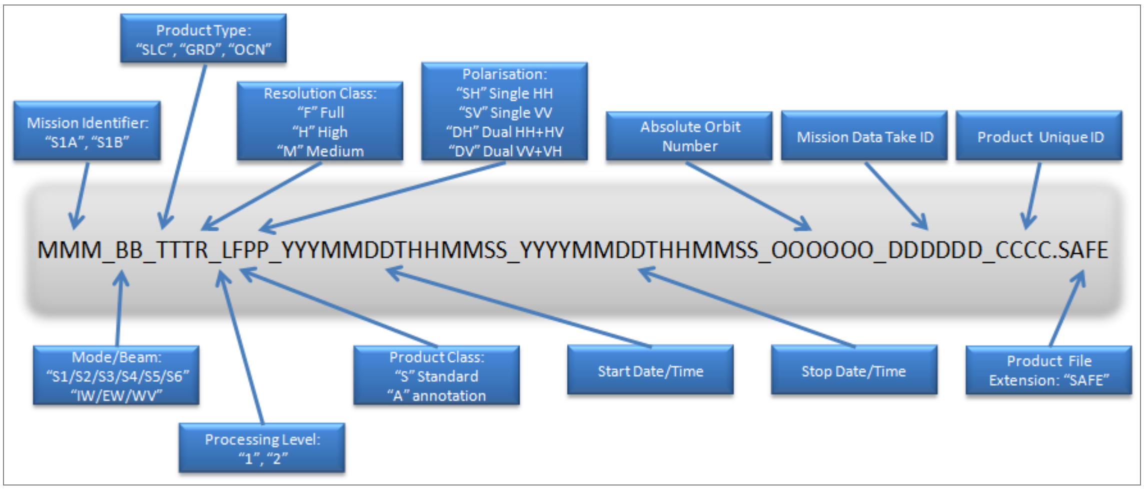


Figure 1: Product naming convention

The Mission Identifier (MMM) denotes the satellite and will be either S1A for the SENTINEL-1A instrument or S1B for the SENTINEL-1B instrument.

The Mode/Beam (BB) identifies the S1-S6 beams for SM products and IW, EW and WV for products from the respective modes.

Product Type (TTT) can be RAW, SLC, GRD or OCN.

Resolution Class (R) can be F (Full resolution), H (High resolution), M (Medium resolution), or _ (underscore: not applicable to the current product type). Resolution Class is used for SLC and OCN only.

The Processing Level (L) can be 0, 1 or 2.

The Product Class can be Standard (S) or Annotation (A). Annotation products are only used internally by the PDGS and are not distributed. Polarisation (PP) can be one of:

- SH (single HH polarisation)
- SV (single VV polarisation)
- DH (dual HH+HV polarisation)
- DV (dual VV+VH polarisation)

The product start and stop date and times are shown as 14 digits representing the date and time, separated by the character "T".

The absolute orbit number at product start time (OOOOOO) will be in the range 000001-999999.

The mission data-take identifier (DDDDDD) will be in the range 000001-FFFFFF.

The product unique identifier (CCCC) is a hexadecimal string generated by computing CRC-16 on the manifest file using CRC-CCITT.

The folder extension is always "SAFE".

Within a product folder, measurement datasets and annotation datasets follow a similar naming convention with lower case alphanumeric characters separated by an underscore (_).

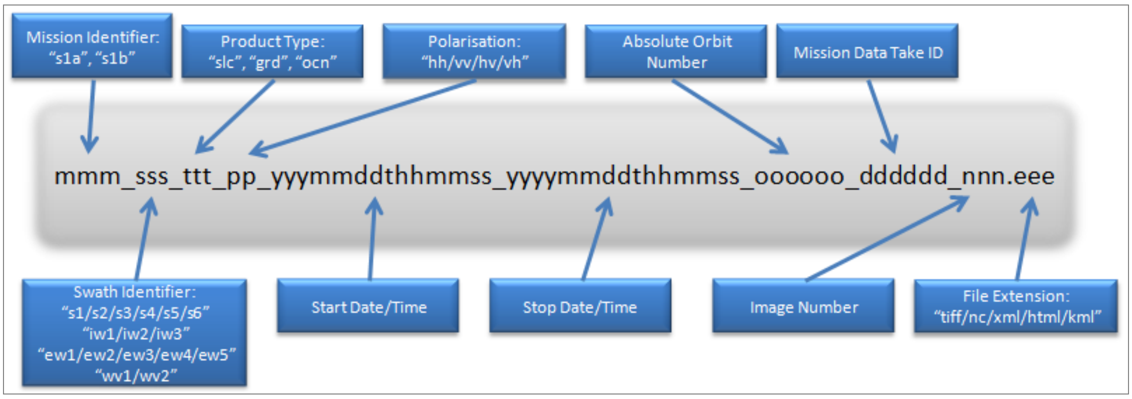


Figure 2: Dataset naming convention

The Mission Identifier (mmm) denotes the satellite and will be either s1a for the SENTINEL-1A instrument or s1b for the SENTINEL-1B instrument.

The Swath Identifier (sss) identifies the s1-s6 beams for SM mode, iw1-iw3 for IW mode, ew1-ew5 for EW more and wv1-wv2 for WV mode.

Product Type (ttt) can be slc, grd or ocn.

Polarisation (pp) can be one of:

- hh (single HH polarisation)
- vv (single VV polarisation)
- hv (single HV polarisation)
- vh (single VH polarisation).

The product start and stop date and times are shown by fourteen digits representing the date and time separated by the character "t".

The absolute orbit number at product start time (oooooo) will be in the range 000001-999999.

The mission data-take identifier (dddddd) will be in the range 000001-FFFFFF.

The image number (nnn) identifies each individual image. WV vignettes each have their own image number as do each swath and polarization image for SM, IW and EW.

The file extension denotes the data format of the file and could be tiff, nc, xml, html, kml, xsd or png.

For specific details on the SENTINEL-1 naming conventions as they apply to each processing level, please refer to the SENTINEL-1 Technical Guide:

- Level-0 Product Formatting
- Level-1 Product Formatting
- Level-2 Product Formatting

2.8 Data Formats

2.8.1 SAFE Specification

SENTINEL data products are distributed using a SENTINEL-specific variation of the Standard Archive Format for Europe (SAFE) format specification. The SAFE format has been designed to act as a common format for archiving and conveying data within ESA Earth Observation archiving facilities. SAFE was recommended for the harmonisation of the GMES missions by the GMES Product Harmonisation Study.

The SENTINEL-SAFE format wraps a folder containing image data in a binary data format and product metadata in XML. This flexibility allows the format to be scalable enough to represent all levels of SENTINEL products.

A SENTINEL product refers to a directory folder that contains a collection of information. It includes:

- a 'manifest.safe' file which holds the general product information in XML
- subfolders for measurement datasets containing image data in various binary formats
- a preview folder containing 'quicklooks' in PNG format, Google Earth overlays in KML format and HTML preview files
- an annotation folder containing the product metadata in XML as well as calibration data
- a support folder containing the XML schemes describing the product XML.

SAR Product Formatting

2.8.2 SAR Formats

Products from all processing levels (Level-0, Level-1 and Level-2) are delivered in SENTINEL-SAFE format. The data delivered is packaged as a file structure containing a manifest file in XML format listing general product metadata and subfolders for measurement data, annotations, previews and support files.

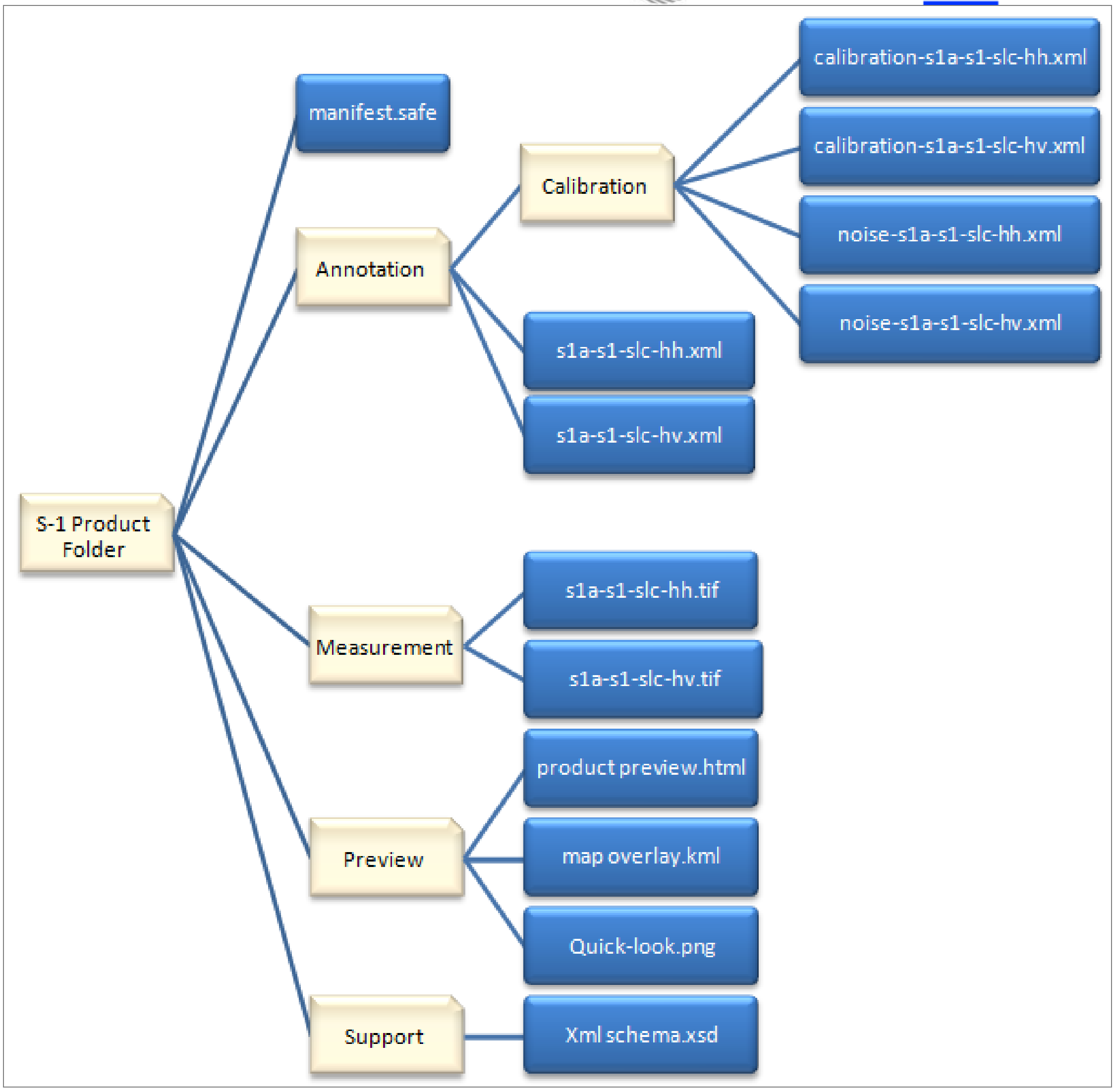


Figure 1: Product Folder File Structure for Level-1 Products

The manifest file is an XML file containing the mandatory product metadata common to all SENTINEL-1 products.

Annotated data sets contain metadata describing the properties and characteristics of the measurement data or how they were generated. For each band of data there is a product annotation data set that contains metadata describing the main characteristics corresponding to that band such as the state of the platform during acquisition, image properties, polarisation, Doppler information, swath merging and geographic location. Calibration annotations contain calibration information and the beta nought, sigma nought, gamma and digital number look-up tables that can be used for absolute product calibration. Noise data annotations contain the estimated thermal noise look-up tables. Annotated data sets are provided in XML format. Level-2 products do not contain annotation data sets as all product metadata is contained within the netCDF product file.

In the preview folder, quicklook data sets are power detected, averaged and decimated to produce a lower resolution version of the image. Single polarisation products are represented with a greyscale image. Dual polarisation products are represented by a single composite colour image in RGB with the red channel (R) representing the first polarisation, the green channel (G) represents the second polarisation and the blue channel (B) represents an average of the absolute values of the two polarisations. Level-2 OCN products do not contain quicklooks.

Representation data sets found in the support folder contain information about the format or syntax of the measurement and annotated data sets and can be used to validate and exploit these data. Representation data sets are provided as XML schemas.

Measurement data sets contain the binary information of the actual acquired or processed data. For Level-0 this is the instrument data, for Level-1 it is the processed images and for Level-2 it is the derived data. There is one measurement data set per polarisation and per swath. TOPSAR SLC products contain one complex measurement dataset in GeoTIFF format per swath per polarisation. Level-1 GRD products contain one detected measurement dataset in GeoTIFF format per polarisation.

Measurement data sets are provided in GeoTIFF format for Level-1 products and netCDF format for Level-2 products. The Level-2 OCN products in netCDF format include both the annotation and measurement datasets described as netCDF attributes, dimensions and variables in one self-describing, self-contained file.

For further details on the SENTINEL-1 product formats, refer to the SENTINEL-1 Technical Guide:

- Level-0 Product Formatting
- Level-1 Product Formatting
- Level-2 Product Formatting

2.8.3 Product Slices

The SENTINEL-1 SAR is capable of operating up to 25 minutes per orbit in any of the three high bit rate modes (SM, IW, EW). To avoid distributing huge unwieldy products to end users, the Level-0 and Level-1 products are segmented into 'slices' of defined length along a track. Product slices make the data more manageable for users and enable the ground segment to process slice data in parallel.

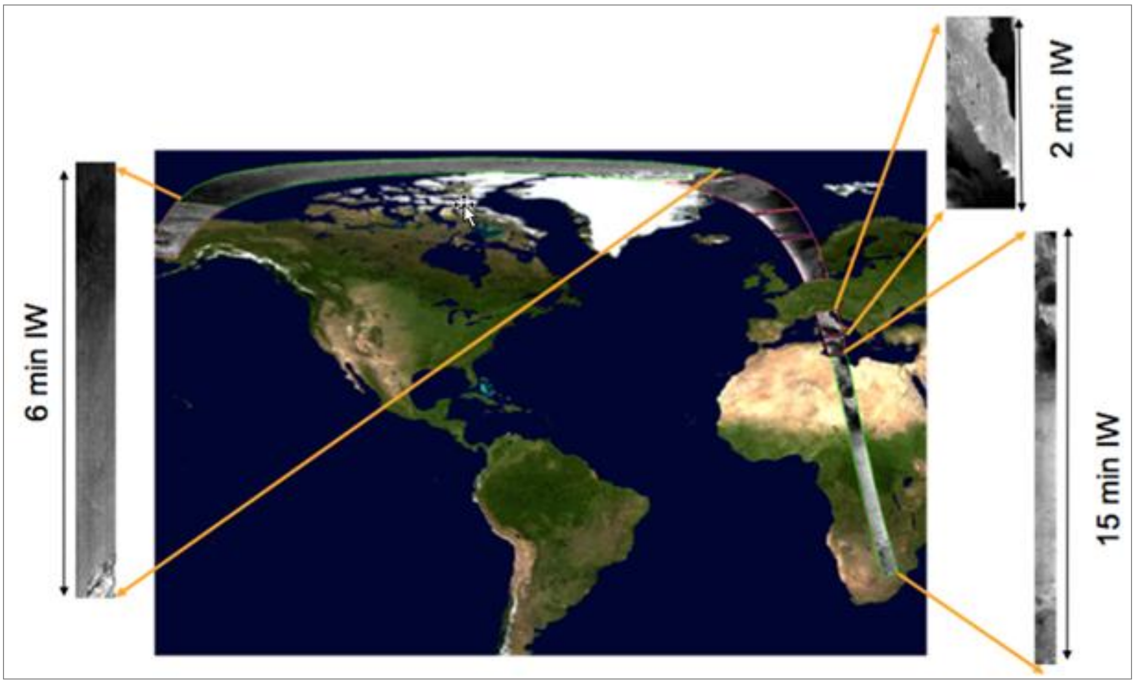


Figure 1: One Data-Take With Slices

Each product slice is a stand-alone product that can be processed independently. Slices are ~25 seconds in length for SM and IW and ~60 seconds for EW. Each GeoTIFF band within a product slice will be no larger than 2 GB. However, since a product could contain several bands for swaths and polarisations, the overall product size could be much larger.

WV data is not sliced and the full segment is processed into Level-2.

Assembling Sliced Products

Level-1 slice products are of seamless quality without any data gap or duplicated lines and with no geometric, radiometric or phase discontinuity. Sliced products may be seamlessly combined, including the metadata, into an assembled product. Product assembly follows specific rules for including, merging and concatenating the various components of the slice products.

Assembly is not performed by the Instrument Processing Facility for systematically archived data. Software such as ESA's NEST toolbox is needed to concatenate data slices together including annotations.

2.9 Software Tools

To work with SENTINEL-1 data products, users will require Earth Observation analysis software compatible with SENTINEL-1 products. ESA provides the open source toolboxes NEST and PolSARPro free of charge, for the exploitation of SENTINEL-1 data.

2.10 Definitions

Backscatter

Backscatter is the portion of the outgoing radar signal that the target redirects directly back towards the radar antenna. Backscattering is the process by which backscatter is formed. The scattering cross section in the direction toward the radar is called the backscattering cross section. The usual notation is the symbol σ (sigma). It is a measure of the reflective strength of a radar target. The normalised measure of the radar return from a distributed target is called the backscatter coefficient, or sigma nought, and is defined as per unit area on the ground. If the signal formed by backscatter is undesired, it is called clutter. Other portions of the incident radar energy may be reflected and scattered away from the radar or absorbed.

Beam

A focused pulse of energy. The antenna beam of a side-looking radar is directed perpendicular to the flight path and illuminates a swath parallel to the platform ground track. Due to the motion of the satellite, each target element is illuminated by the beam for a period of time, known as the integration time

Beam Mode

The SAR operating configuration defined by the swath width and resolution.

Beam Position

The area within the total possible swath that is actually illuminated while being governed by the characteristics of a specific beam mode.

Beta Nought

β° A radar brightness coefficient. The reflectivity per unit area in slant range which is dimensionless.

C-Band

A nominal frequency range, from 8 to 4 Ghz (3.75 to 7.5 cm wavelength) within the microwave (radar) portion of the electromagnetic spectrum. Imaging radars equipped with C-band are generally not hindered by atmospheric effects and are capable of 'seeing' through tropical clouds and rain showers. Its penetration capability with regard to vegetation canopies or soils is limited and is restricted to the top layers.

Calibration

Calibration is the process of quantitatively defining the system response to known controlled signal inputs.

Coherence

Coherence is the fixed relationship between waves in a beam of electromagnetic (EM) radiation. Two wave trains of EM radiation are coherent when they are in phase, that is, they vibrate in unison. In terms of the application to things like radar, the term coherence is also used to describe systems that preserve the phase of the received signal.

Complex Number

For radar systems, a complex number implies that the representation of a signal, or data file, needs both magnitude and phase measures. In the digital SAR context, a complex number is often represented by an equivalent pair of numbers, the real in-phase component (I) and the imaginary quadrature component (Q).

Data-take

A data-take is a continuous temporal segment of SAR acquisition without instrument mode change (due to on-board memory handling, a data-take can be downlinked in distinct moments and in different channels).

Detection (Radar)

Processing stage at which the strength of the signal is determined for each pixel value. Detection removes phase information from the data file. The preferred detection scheme uses a magnitude squared method, which is energy conserving, and has units of voltage squared per pixel.

Doppler Frequency

The Doppler frequency depends on the component of satellite velocity in the line-of-sight direction to the target. This direction changes with each satellite position along the flight path, so the Doppler frequency varies with azimuth time. For this reason, azimuth frequency is often referred to as Doppler frequency.

Horizontal Polarisation

Linear polarisation with the lone electric vector oriented in the horizontal direction in antenna co-ordinates.

Horizontal Transmit - Horizontal Receive Polarisation (HH)

A mode of radar polarisation where the microwaves of the electric field are oriented in the horizontal plane for both signal transmission and reception by means of a radar antenna.

Horizontal Transmit - Vertical Receive Polarisation (HV)

A mode of radar polarisation where the microwaves of the electric field are oriented in the horizontal plane for signal transmission, and where the vertically polarised electric field of the backscattered energy is received by the radar antenna.

Imaging Radar

Most imaging radars produce two-dimensional images. The two dimensions are range and azimuth.

Interferometry

A technique that uses the measured differences in the phase of the return signal between two satellite passes to detect slight changes on the Earth's surface. The combination of two radar measurements of the same point on the ground, taken at the same time, but from slightly different angles, to produce stereo images. Using the cosine rule from trigonometry to calculate the distance between the radar and the Earth's surface, these measurements can produce very accurate height maps, or maps of height changes. Mapping height changes provides information on earthquake damage, volcanic activity, landslides and glacier movement.

Level-0

Reconstructed unprocessed data at full space-time resolution with all available supplemental information to be used in subsequent processing (e.g. ephemeris, health and safety) appended. SAR Level-0 products may cover part of an acquisition segment (in case only part of a segment is down-linked at a certain ground station in the same pass) or a full acquisition segment. Level-0 products are generated at the receiving station immediately after acquisition.

Level-1

Reconstructed data at full resolution, time-referenced and annotated with ancillary information, including radiometric and geometric calibration coefficients, and geo-referencing parameters. Data may be radio-metrically corrected and calibrated in physical units at full instrument resolution, orthorectified and re-sampled to a specified grid.

Level-2

Derived geophysical parameters (e.g. sea surface temperature, leaf area index) at the same resolution and location as Level-1 source data.

Look Direction

The radar look direction defines the angle in the horizontal plane in which the radar antenna is pointing when transmitting a pulse and receiving the return signal from the ground or from an object. The look direction is an angular measurement (in degrees) and is usually made with respect to true north. In side-looking imaging radar, the look direction is often orthogonal (normal) to the flight trajectory (azimuth) of the platform carrying the radar and is synonymous with the range direction. The radar look direction is an important parameter when analysing features with a preferred orientation, for example fracture patterns in rock formations, regular street patterns or ocean waves, as these may be enhanced through choice of appropriate radar illumination direction.

Looks

Radar terminology refers to individual looks as groups of signal samples in a SAR processor that splits the full synthetic aperture into several sub-apertures, each representing an independent look of the identical scene. The resulting image formed by incoherent summing of these looks is characterised by reduced speckle and degraded spatial resolution. The SAR signal processor can use the full synthetic aperture and the complete signal data history in order to produce the highest possible resolution, albeit very speckled, single-look complex (SLC) SAR image product. Multiple looks may be generated by averaging over range and/or azimuth resolution cells. For an improvement in radiometric resolution using multiple looks there is an associated degradation in spatial resolution. Note that there is a difference between the number of looks physically implemented in a processor and the effective number of looks as determined by the statistics of the image data

Noise Equivalent Sigma Nought

A measure of the sensitivity of a given SAR. It describes the strength of the (additive) system noise in terms of the equivalent (average) power in the image domain that would result from an idealised distributed scatterer of the stated reflectivity. Smaller noise equivalent sigma nought values are better. Within physical limitations, smaller may be achieved by increasing the power of the radar transmitter, or by decreasing the noise figure of the electronics.

Polarisation

The process of confining the vibrations of the magnetic, or electric field, vector of light or other radiation to one plane. Orientation of the plane of the electric field relative to the Earth's surface.

Pulse Repetition Frequency (PRF)

Rate of recurrence of the pulses transmitted by a radar.

SAR Focusing

In a long synthetic aperture, SAR focusing involves the removal and compensation of path length differences from the antenna to the target on the ground. The main advantage of a focused synthetic aperture is that it increases its array length over those radar signals that can be processed and increases potential SAR resolution at any range. SAR focusing is a necessary process when the length of a synthetic array is a significant fraction of the range to ground being imaged, as the lines-of-sight (range) from a particular point on the ground to each individual element of the array differ in distance. These range differences, or path length differences, of the radar signals can affect image quality. In a focused SAR image these phase errors can be compensated for by applying a phase correction to the return signal at each synthetic aperture element. Focusing errors may be introduced by unknown or uncorrected platform motion. In an unfocused SAR image, the usable synthetic aperture length is limited.

Synthetic Aperture Radar (SAR)

A Synthetic Aperture Radar (SAR) is a coherent radar system that generates high-resolution remote sensing imagery. Signal processing uses magnitude and phase of the received signals over successive pulses from elements of a synthetic aperture to create an image. As the line of sight direction changes along the radar platform trajectory, a synthetic aperture is produced by signal processing that has the effect of lengthening the antenna. The achievable azimuth resolution of a SAR is approximately equal to one-half the length of the actual (real) antenna and does not depend on platform altitude (distance). High range resolution is achieved through pulse compression techniques. In order to map the ground surface the radar beam is directed to the side of the platform trajectory. With a sufficiently wide antenna beam width in the along track direction, an identical target or area may be illuminated a number of times without a change in the antenna look angle

Vertical Polarisation

Linear polarisation with the lone electric vector oriented in the vertical direction in antenna co-ordinates.

Vertical Transmit-Horizontal Receive Polarisation (VH)

A mode of radar polarisation where the microwaves of the electric field are oriented in the vertical plane for signal transmission and where the horizontally polarised electric field of the backscattered energy is received by the radar antenna.

Vertical Transmit-Vertical Receive Polarisation (VV)

A mode of radar polarisation where the microwaves of the electric field are oriented in the vertical plane for both signal transmission and reception by means of a radar antenna. In this case, the plane of the electric field of the microwave energy is designated by the letter V (vertical) for both transmit and receive events, i.e. VV; this transmit-receive polarity is also called like-polarised as opposed to cross-polarised (horizontal transmit - vertical receive, HV). The amount of radar backscatter received at a particular linear polarisation state from a particular ground surface or object depends, in part, on the scattering mechanism and depolarisation effects involved.

Zero Doppler Time

Zero Doppler time is the along track (azimuth) time at which a target on the ground would have a Doppler shift of zero with respect to the satellite (i.e. when the target was perpendicular to the flight path). It is also called the closest approach azimuth time. The SAR processor locates targets in the image at the zero-Doppler azimuth time.