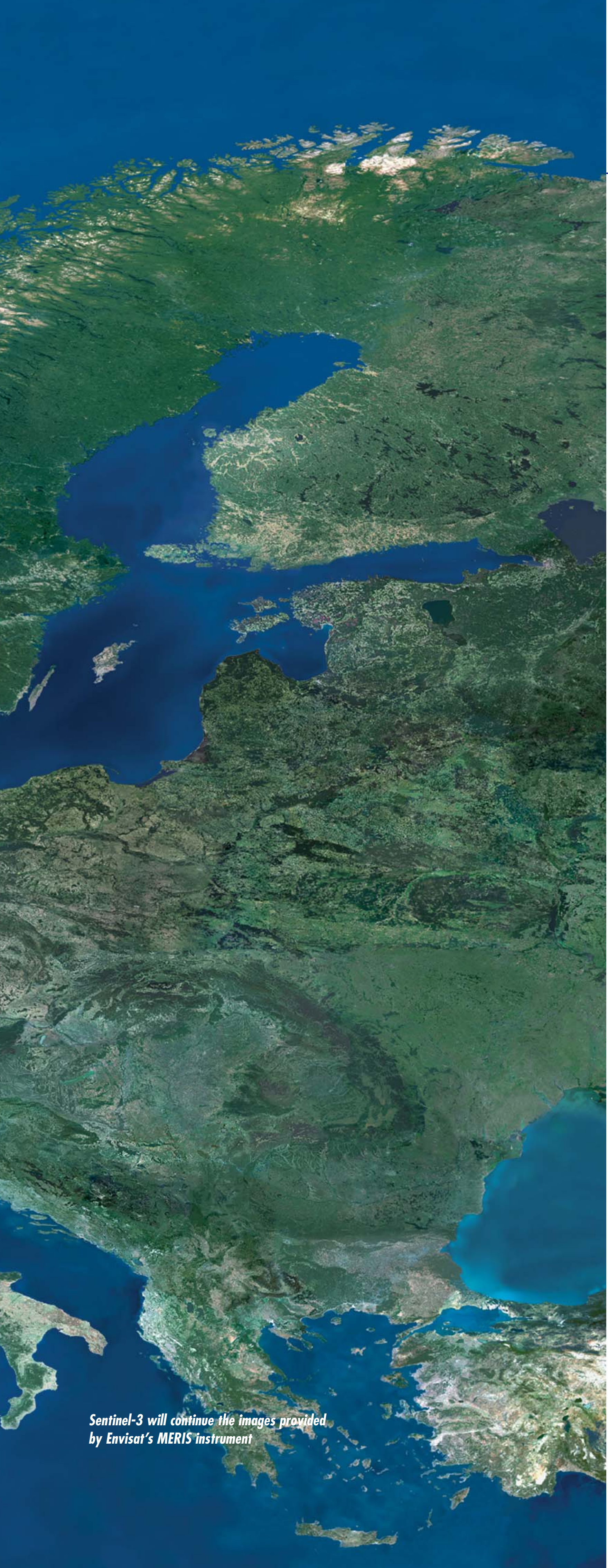
Sentinel-3

The Ocean and Medium-Resolution Land Mission for GMES Operational Services



Sentinel-3 will continue the images provided by Envisat's MERIS instrument

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The ESA Sentinels will be the first series of operational satellites to meet the Earth observation needs of the European Union-ESA Global Monitoring for Environment and Security (GMES) programme. The pair of Sentinel-3 satellites will provide global, frequent and near-realtime ocean, ice and land monitoring. It continues Envisat's altimetry, the multispectral, medium-resolution visible and infrared ocean and land-surface observations of ERS, Envisat and Spot, and includes enhancements to meet the operational revisit requirements and to facilitate new products and evolution of services. The first launch is expected in 2011/2012.

What Users Need

The pair of Sentinel-3 satellites will routinely monitor ocean and land surfaces to generate valuable information for the European Union (EU) and its Member States as part of the Global Monitoring for Environment and Security (GMES) programme (*www.gmes.info*). The EU Marine Core Service (MCS) and the Land Monitoring Core Service (LMCS), together with the ESA GMES Service Element (GSE), have been consolidating those services where continuity and success depends on operational data flowing from the Sentinels.

For MCS, operational oceanography services are being developed within the MERSEA 6th Framework Programme (*w3.mersea.eu.org*) and through the ESA GSE Marcoast (*gmes-marcoast.com*) and Polarview (*www.polarview.org*) projects. The MCS will deliver regular, systematic products on sea-surface topography and sea-state and ecosystem characteristics over the oceans and the European regional and shelf seas. The information from Sentinel-3 will be assimilated into models in near-realtime to provide routinely the best-available estimate of the state of the oceans, together with forecasts (from days to weeks) and reanalyses ('hindcasts' of ocean state over long time-series in the past). The fast-track component of the MCS focuses on ocean dynamics and primary ecosystem characteristics, but also covers sea-ice monitoring and oil-spill detection.

GMES/Sentinel-3 Initial Services

Sentinel-3 will deliver routine operational services to policy-makers and marine and land service users:

Marine and Coastal Environment
Sea-surface topography
Mesoscale circulation
Water quality
Sea-surface temperature
Wave height and wind speed
Sediment load and transport
Eutrophication (excessive plant growth in water bodies)

Polar Environment
Sea-ice thickness
Ice surface temperature

Maritime Security
Ocean-current forecasting
Water transparency
Wind and wave height

Global Change Ocean
Global sea-level rise
Global ocean warming
Ocean carbon dioxide flux

Land Cover & Land-Use Change
Land-use mapping
Vegetation indices

Forest Monitoring
Forest cover mapping

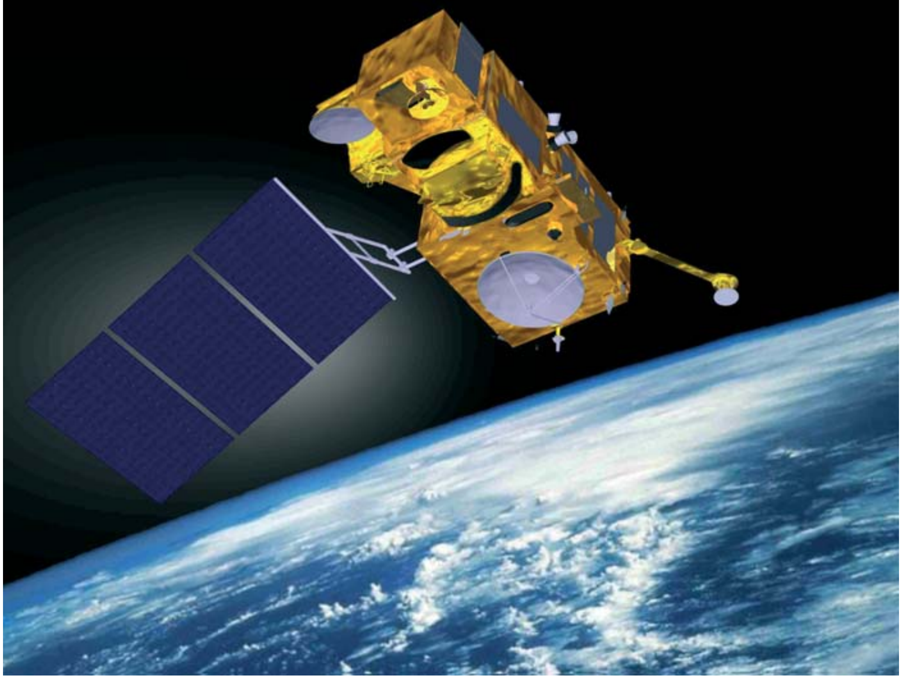
Food Security Early Warning
Regional land-cover mapping
Drought monitoring

Humanitarian Aid
Land-use mapping

Air Pollution (local to regional scales)
Aerosol concentration

Risk Management (flood and fires)
Burned scar mapping
Fire detection

Global Change Land
Forest-cover change mapping
Soil degradation mapping



The Land Monitoring Core Service is being developed through the Geoland 6th Framework Programme (*www.gmes-geoland.info*) and ESA GSE projects such as Forest Monitoring (*www.gmes-forest.info*), Global Monitoring for Food Security (*www.gmfs.info*), and the disaster mitigation and humanitarian relief RESPOND (*www.respond-int.org*) service.

LMCS focuses on exhaustive high-resolution continental-scale land-cover/land-use mapping complemented by land-monitoring based on daily land-cover mapping, vegetation characteristics and fire monitoring at continental and global scales. The dynamics of vegetation characteristics require an update frequency of days to weeks, and comprehensive global observations with the best revisit frequency possible (especially to minimise the effects of clouds and high levels of aerosols).

LMCS will evolve in Europe to include vegetation monitoring linked to Common Agricultural Policy requirements such as reviewing and monitoring EU policies (water framework directive, biodiversity strategy, common agricultural, regional policies) and reporting obligations under international treaties such as the Kyoto Protocol.

Sentinel-3 will frequently revisit all sites. This is useful, for example, for crop yield monitoring and food security, and forest cover mapping and change monitoring. Parameters include land cover, leaf area index, fraction of absorbed photosynthetically active radiation, burnt areas, and land surface and active fire temperature. These global vegetation data, together with atmospheric corrections, such as aerosol optical depth, will provide critical input data for numerical weather forecasting, global climate models and in climate and greenhouse gas monitoring.

To meet user needs, Sentinel-3 will support the routine generation of a general suite of high-level geophysical products, with priority on:

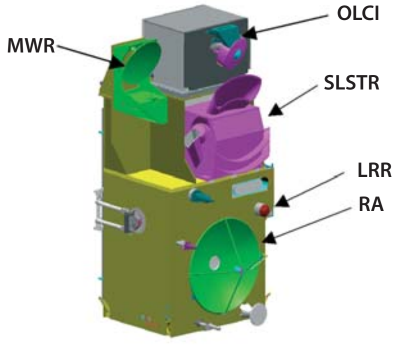
– ocean, ice, land and inland water surface topography;
– sea-surface temperature;
– ocean colour;
– land surface biophysical properties;
– land surface temperature.

These primary goals have driven the design towards a mission concept that can routinely and continuously (that is, operationally) deliver robust products with well-characterised accuracy and confidence limits. In turn, this will lead to improvements over previous missions and instruments, which, through their technology and data-processing, have guided the design of the Sentinel-3 system.

Mission Definition

The sea-surface topography mission has the primary objective of providing accurate, closely spaced altimetry measurements from a high-inclination orbit with a long repeat cycle, to complement the Jason ocean altimeter series. Monitoring mid-scale circulation and sea levels requires measurement of ocean topography. Measuring wave heights is essential for operational wave forecasting. Sea-ice measurements similar to those from CryoSat-2 (though from a slightly different orbit) will be made. The single-antenna radar altimeter, with aperture synthesis processing for increased along-track resolution, balances the needs for continuity and improved performance. It will extend observations to inland waters and coastal zones.

Accompanying the altimeter will be a Precise Orbit Determination (POD) system and microwave radiometer (MWR) for removing the errors added as the signals are delayed by water vapour in the atmosphere. The altimeter will track over a variety of surfaces: open ocean, coastal sea zones, sea ice and inland waters. The chosen mode will depend on the surface below, with changes pre-programmed in the satellite to avoid data loss.



Sentinel-3 in launch configuration

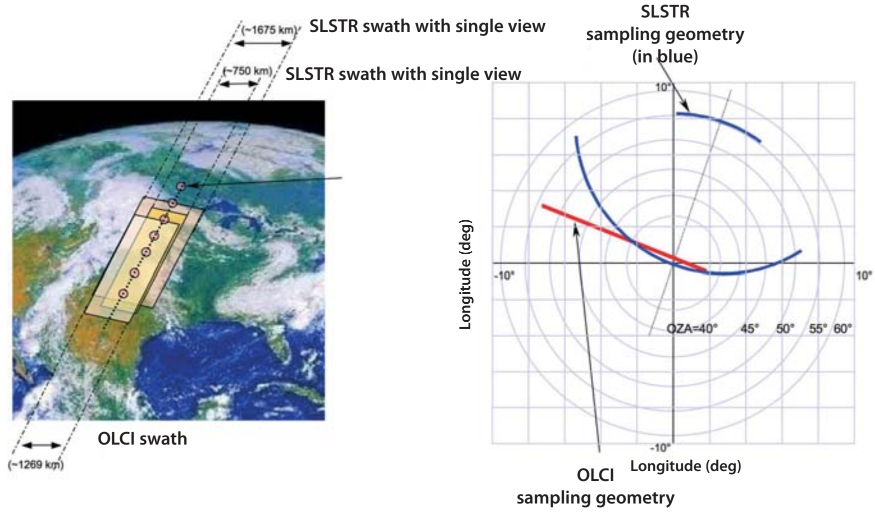
The Ocean and Land Colour Instrument (OLCI), based on Envisat's MERIS instrument, fulfils ocean colour and land-cover objectives. The Sea and Land Surface Temperature Radiometer (SLSTR), based on Envisat's Advanced Along Track Scanning Radiometer (AATSR), is designed for ocean and land-surface temperature observations. Unlike AATSR, SLSTR has a double-scanning mechanism, yielding a much wider swath stretching almost from horizon to horizon. The OLCI and SLSTR swaths will broadly overlap, yielding extra information.

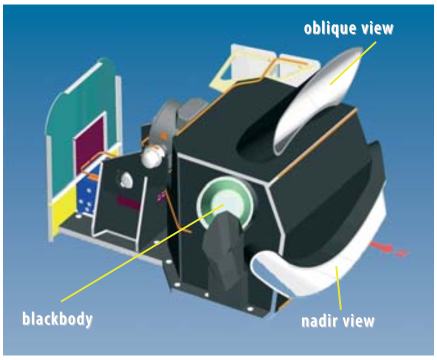
The Sun-synchronous orbit chosen is at 814 km altitude (14+7/27 revolutions per day) with a local equatorial crossing time of 10:00 a.m., as a compromise between the needs of the optical instrument and altimeter. The baseline of two satellites supports full imaging of the oceans within 2 days (even allowing for images spoiled by the Sun glinting off the water), while delivering global land coverage in just over a day at the equator and improving with latitude.

The continuous acquisitions of Sentinel-3 allow routine operations. An average of 103 Gbit of data will be downlinked once per orbit at 300 Mbit/s X-band to a single ground station with no blind orbits.

Four categories of products will be delivered: ocean colour, surface topography, surface temperature (land and sea) and land. The surface topography products will be delivered with three timeliness levels: NRT (Near-Real Time, 3 hours), STC (Standard Time Critical, 1–2 days) and NTC (Non-Time Critical, 1 month). Slower products allow more accurate processing and better quality. NRT products are ingested into numerical weather prediction and sea-state prediction models for quick, short-term forecasts. STC products are ingested into ocean models for accurate present state estimates and forecasts. NTC products are used in all high-precision climatological applications, such as sea-level estimates. The resulting analyses

OLCI is pointed eastwards, away from the Sun, to minimise Sun-glint off the sea. SLSTR has a symmetric double-scanning geometry, producing two swaths. The wide swath totally covers the OLCI swath for product synergy. The narrow-swath data, corrected with information from the wide swath, provides nadir-centred high-accuracy sea-surface temperature





SLSTR has a wide nadir view and a narrow oblique view

and forecast products and predictions from ocean and atmosphere adding data from other missions and *in situ* observations, are the key products delivered to users. They provide a robust basis for downstream value-added products and specialised user services.

Satellite Configuration

Though carrying five instruments, Sentinel-3 is of moderate size – about 1.3 t, 3.9 m high and compatible with small launchers like Vega (baseline) and Dnepr-ST3 (back-up). It is designed for a 7-year lifetime, with 90 kg of hydrazine propellant for 12 years of operations, including deorbiting at the end.

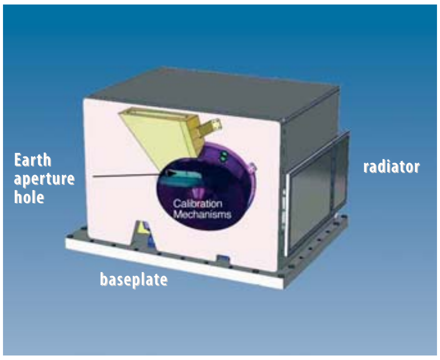
The layout is driven by the need to provide a large anti-Sun side to cool the optical instruments.

Optical instruments

The two optical instruments, OLCI and SLSTR, will provide a common quasi-simultaneous view of the Earth to help develop synergetic products.

The 150 kg OLCI benefits from MERIS heritage. The field-of-view is divided between five cameras on a common structure with the calibration assembly. Each camera has an optical grating to provide the minimum baseline of 16 spectral bands required by the mission together with the potential for optional bands for improved atmospheric corrections.

OLCI is an autonomous instrument with simple interfaces to the satellite, thus allowing easy integration and minimising development risks.



OLCI contains five cameras to continue the work of Envisat's MERIS

The 90 kg visible/infrared SLSTR measures sea- and land-surface temperatures, following the AATSR concept. Its rotary scan mirror mechanism produces the wide swath of 750 km. It features ~1 km resolution at nadir for thermal-infrared channels and 500 m for visible and shortwave infrared channels. Like AATSR, it offers dual views – inclined forward and near-vertical nadir – to provide robust atmospheric correction over the swath. The nadir and forward views are generated by separate scanners, allowing a wider swath than possible with the single conical scan of the original ATSR design.

The channel selection (1.6, 3.7, 10.8 and 12 µm in the infrared and 0.55, 0.66 and 0.85 µm in the visible) include the Envisat/AATSR and ERS/ATSR-2 channels for continuity. Additional channels at 1.378 and 2.25 µm improve cloud detection, besides being used for new products.

The instrument includes onboard radiometric sources for accurate and stable in-flight calibration. The infrared detectors are cooled to 80K by active coolers.

Topography package

The topography payload consists of the Synthetic Aperture Radar Altimeter (SRAL), MWR and POD (a satnav receiver supplemented by a laser retro-reflector). They will determine very accurately the height of the Earth surface, and in particular the sea surface, relative to a precise reference frame.

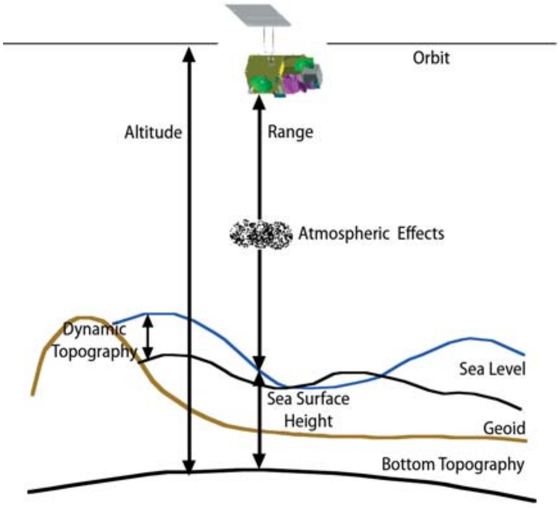
The radar altimeter determines the distance to the surface by bouncing microwave pulses off the surface. The time taken is derived very precisely by ground processing of the data. However, the propagation speed through the atmosphere is variable. The ionosphere and the troposphere add delays dependent on the density of electrons in the ionosphere, and the density of gases and the moisture content in the troposphere. The MWR determines the amount of water contained in the path of the radar pulses. The altimeter transmits pulses alternatively at two frequencies. Comparing their relative delay, the frequency-dependent part introduced by the ionosphere can then be found. The influence of gas density in the troposphere is less variable and can be determined sufficiently accurately using meteorological data and models.

Sentinel's own height will be measured with cm-accuracy by the geodetic-quality satnav receiver and laser retro-reflector.

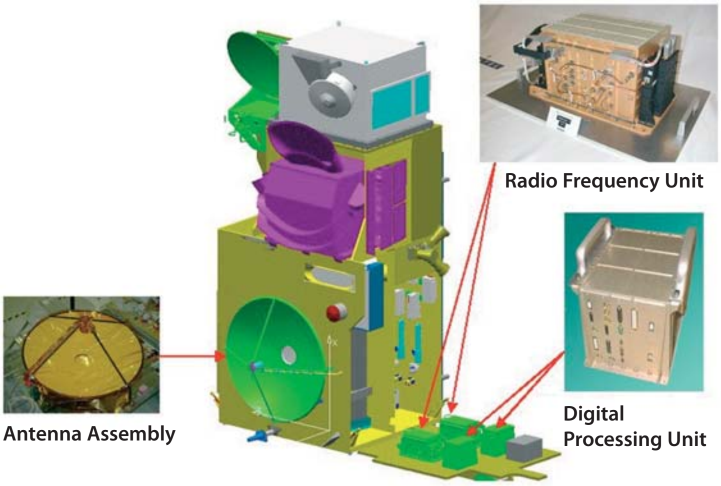
The 60 kg SRAL is a dual-frequency, nadir-looking microwave radar employing technologies from the CryoSat and Jason altimeter missions. The main range measurements are performed at 13.575 GHz Ku-band, while a second frequency at 5.41 GHz C-band allows compensation for ionospheric effects.

A conventional pulse-limited, low-resolution mode employs autonomous closed-loop echo tracking, and is the primary operational mode for observing level homogeneous and smooth surfaces, like open oceans or central ice-sheet plateaux.

For more variable surfaces, SRAL has two extra features that can be used independently or in combination: the SAR mode, similar to that of the CryoSat SIRAL instrument, and the open-loop tracking mode. In the SAR mode, the horizontal resolution is increased along the ground track by sending out signals some 10 times more often. This will be used mainly over sea-ice and ice-sheet edges and inland water. Open-loop tracking will be used mainly over discontinuous surfaces (like land-sea transitions) or rapidly varying

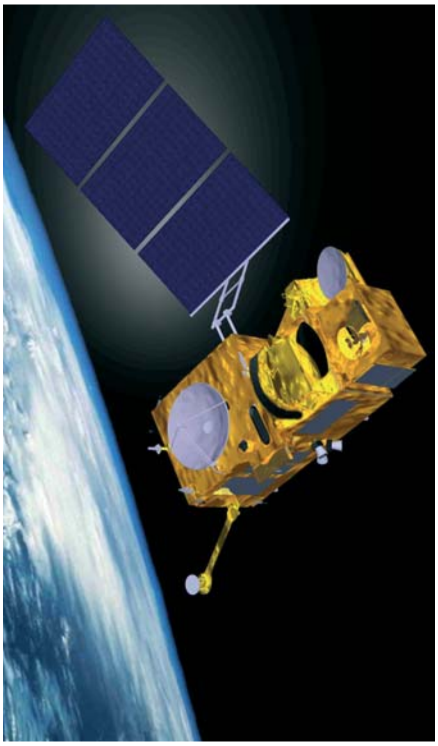


The measurement principle of the topography payload



Locations of the SRAL and MWR elements (green) on the satellite. SRAL is in the lower part and MWR in the upper part

topography like ice margins. In this mode, SRAL's tracking window is controlled based on *a priori* knowledge of the surface height, from existing high-resolution global digital elevation models, combined with knowledge of the location of the satellite from the satnav receiver. The main advantage is that the measurements are continuous, avoiding the data gaps typical of closed-loop tracking, which has problems in tracking the rapid topographic changes at coastal margins and in mountainous regions.



The 26 kg MWR measures the thermal radiation emitted by Earth. The received signal is proportional to the abundance of the atmospheric component emitting at the observed frequency and the sea-surface reflectivity. This information reveals the delay added to the altimeter pulses by moisture in the troposphere.

Each of the three channels addresses a different geophysical parameter. The 18.7 GHz channel, where the troposphere is transparent, is influenced mainly by sea-surface reflectivity. This allows separation of the atmospheric signal from the sea-surface contribution in the other two channels. The 23.8 GHz channel is used mainly to determine the delay of the altimeter pulse by tropospheric water vapour. The 36.5 GHz channel primarily addresses the delay from non-precipitating clouds. The observed signals are calibrated by comparison with a precisely known and very stable electronic reference source.

The POD equipment provides the satellite altitude to an accuracy of 2 cm. The 11 kg satnav receiver will operate with Global Positioning System satellites for the Sentinel-3 first generation and add Galileo for the following generations. The receiver can track up to 12 satellites at the same time.

The signals transmitted by the navigation satellites are also disturbed by the ionosphere. The effect is corrected by comparing two signals at different frequencies within 1160–1590 MHz.

The receiver produces an onboard height to within about 3 m, which is used to control SRAL's open-loop tracking and for Sentinel navigation. Ground processing yields the altitude to an accuracy of better than 8 cm within 3 hours for operational applications and 2 cm after some days of refinement.

Laser tracking stations will use the 1 kg retro-reflector to measure the distance to Sentinel-3 to within 2 cm. This will be done during the commissioning phase and regularly during the mission to check the other POD results.

Conclusion

GMES Sentinel-3 is a series of operational satellites that will guarantee access to an uninterrupted flow of robust global data products. Together with the other Sentinels, this mission will fulfil the monitoring needs of the GMES marine and land services and climate research communities for years to come.