MERIS – A New Generation of Ocean-Colour Sensor onboard Envisat

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ESA has developed a multidisciplinary Earth-observation instrument that focuses on biological ocean observations. This Medium Resolution Imaging Spectrometer (MERIS) will provide a remote-sensing capability for observing, inter alia, oceanic biology and marine water quality through observations of water colour. MERIS, which will be the first spaceborne wide-field imaging spectrometer, is a nadir-looking sensor operated in a push-broom mode. The instrument measures the solar reflected radiation in fifteen spectral bands in the visible and near-infrared parts of the spectrum. Of particular interest is the ability to programme the position and width of the spectral bands in flight. This allows a large set of applications, making the instrument concept also attractive for future Earth Watch missions. ESA will produce a set of validated data products, such as chlorophyll concentration, water vapour and global vegetation index, which will be available at two spatial resolutions (300 m and 1200 m).

Introduction

In mid-2001, ESA will launch the Medium Resolution Imaging Spectrometer (MERIS) onboard its polar-orbiting Envisat Earth-observation satellite. MERIS, initially primarily dedicated to ocean-colour observations, has had the scope of its objectives broadened during development to include atmospheric and land-surface related studies. This has been possible due to the great flexibility that sensor and ground segment provide.

MERIS will have a high spectral and radiometric resolution and dual spatial resolution, within a global mission covering open ocean and coastal-zone waters and a regional mission covering land surfaces. One of the instrument's most outstanding features is the programmability of its spectral bands in terms of width and position.

MERIS's global mission will make a major contribution to scientific projects that seek to understand the role of the oceans and ocean productivity in the climate system, through its observations of water colour, and will further increase our ability to forecast change through modelling. Secondary objectives of the mission will be directed to the understanding of atmospheric parameters associated with clouds, water vapour and aerosols, in addition to land-surface parameters, in particular vegetation processes.

With all of the above-mentioned features, MERIS is considered to be a remote-sensing tool with great potential to contribute to climate studies and global-change observations by addressing environmental features in a multidisciplinary way. This article introduces the MERIS end-to-end mission concept (Fig. 1), based upon the scientific requirements and mission objectives.

In advance of launch, the ground segment is being designed and algorithms are being developed for the interpretation of MERIS's observations, and dedicated studies are establishing the means for validating its data products. This effort is being undertaken in close co-operation with the European Expert Support Laboratories, whose scientists are the main providers of the retrieval algorithms. Wherever possible, the underlying physical models are being validated based on experience acquired before Envisat's launch, using data provided by airborne or shipborne campaigns and in-situ measurements at specially equipped campaign sites.

Scientific rationale

With the advent of large-scale optical imaging spaceborne sensors in the seventies, a tool was found that enabled the observation and monitoring of the Earth's surface in a qualitative, but synoptic fashion. The biggest asset of these sensors, of which the Advanced Very High Resolution Radiometer (AVHRR) is the most prominent example, was their large coverage swath and high repeat rate, enabling the timely observation of changing large-scale phenomena. With the end-of-life of the US Coastal-Zone Color Scanner mission (CZCS) in 1986, the scientific oceanographic community demanded a new spaceborne ocean-colour observing system that would allow more accurate determination of oceanic constituents, such as chlorophyll, suspended matter and decayed organic material, thereby providing

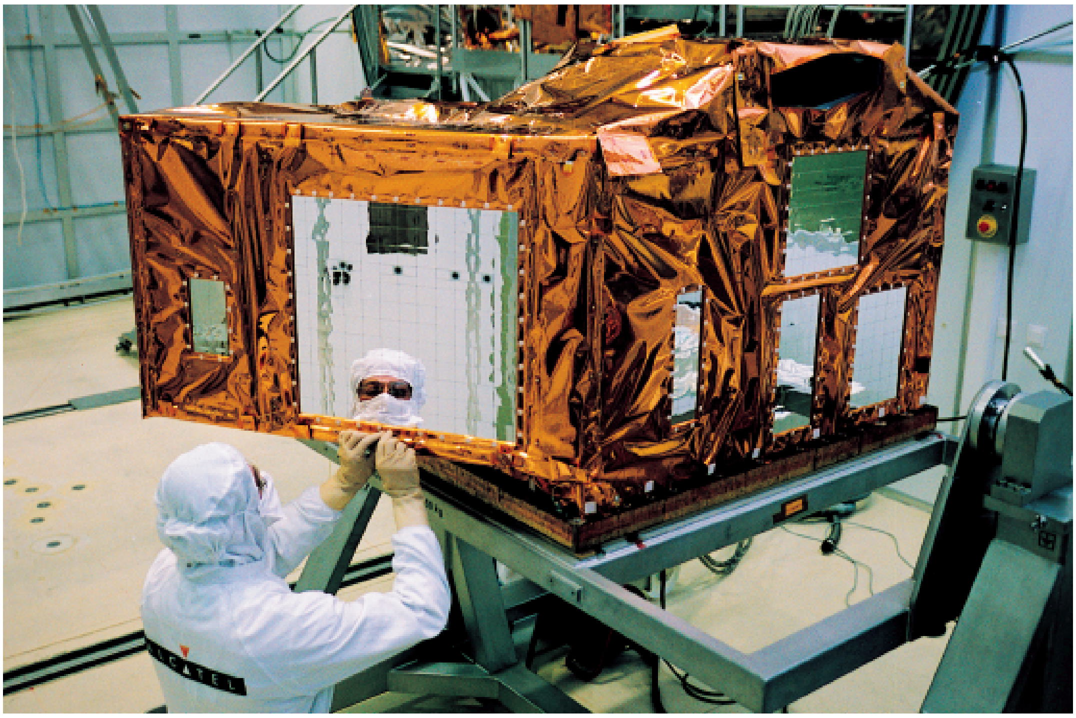


Figure 1. The MERIS flight model during integration at Alcatel Space Industries in Cannes (F)

vital information about the water's quality and its productivity.

Driven by the concerns about our environment and the pressing need for a new ocean-colour observing system, ESA, supported by its international scientific advisors, began the development of a spaceborne large-scale optical system with the primary objective of providing quantitative ocean-colour measurements, but having enough flexibility to also serve applications in atmospheric and land-surface science.

Mission objectives

Based on the above rationale, mission objectives were derived driving the development of the MERIS instrument and its mission.

Ocean mission

The principal contributions of MERIS data to the study of the upper layers of the ocean will be:

- the measurement of photosynthetic potential by detection of phytoplankton (algae)
- the detection of yellow matter (dissolved organic material)
- the detection of suspended matter (re-suspended or river-borne sediments).

Apart from the above three major observable features, it should also be possible to detect special plankton blooms, for example red tides through their absorption feature near 520 nm. In addition, investigations of water quality, the monitoring of extended pollution areas and topographic observations (such as coastal erosion) should also be possible.

Atmospheric mission

The radiation balance of the Earth/atmosphere system is dominated by water vapour, carbon dioxide and clouds, as well as being very dependent on the presence of aerosols. However, the global monitoring of cloud properties and their processes is not yet sufficiently accurate. MERIS is intended to help redress this balance by providing data on cloud-top height and optical thickness, water-vapour column content, as well as aerosol properties.

Land mission

Questions related to global change include the role of terrestrial surfaces in climate dynamics and bio-geochemical cycles. Spatial and temporal models of the biosphere are currently being developed to study the mechanics of such complex systems in order to predict their behaviour under changing environmental conditions. These models are based on physical and biophysical relationships, which need to be validated on a regular basis using data from spaceborne sensors. Repetitive, accurate physical measurements are necessary to quantify surface processes and to improve the understanding of vegetation seasonal dynamics and responses to environmental stress.

Scientific requirements

In order to achieve these mission goals, the different radiometric and geometric requirements imposed by the various objectives have to be satisfied. With the help of the ESA Science Advisory Group for MERIS, these requirements have been refined, taking into account the constraints imposed by a polar-orbiting platform and the technical capabilities of an imaging spectrometer.

Geometric requirements
The MERIS data are of interest both for global observations and for detailed examinations for regional applications, and operation at two spatial resolutions has therefore been selected. Full-resolution (FR) data with 300 m on-ground resolution at the sub-satellite point will be mainly required in coastal zones and over land. Reduced-resolution (RR) data with 1200 m on-ground resolution at the sub-satellite point are intended for large-scale studies. Oceanographic and atmospheric investigations require global Earth coverage within three days.

Spectral requirements
MERIS is designed to acquire 15 spectral bands in the 390 - 1040 nm region of the electromagnetic spectrum. The band position, bandwidth and gain are in-flight programmable. The spectral bandwidth can be varied between 1.25 and 30 nm, depending on the width of a spectral feature to be observed and the amount of energy needed within a given band to perform an adequate observation. Over open ocean, an average bandwidth of 10 nm is required for bands located in the visible part of the spectrum. Driven by the need to resolve other spectral features such as the oxygen absorption band occurring at 760 nm, a spectral bandwidth lower than 10 nm is required. In accordance with the mission goals and priorities for this instrument, a set of 15 spectral bands has been derived for oceanographic and interdisciplinary applications (Table 1). These spectral bands are used as the reference set for prototyping the ground-segment algorithms. Preliminary results seem to advocate a fine tuning of some of the bands to optimise product quality. If confirmed, this fine-tuning can be performed using the instrument's programmability.

The spatial, spectral and radiometric programmability of MERIS is justified by the different scales of the various targets to be observed and the diversity of their spectral and radiometric properties. The advantage of the programmability lies not only in being able to select the width and position of a particular spectral band, but also in being able to tune the dynamic range and adapt it to different target observations, which may become of higher priority during the lifetime of the MERIS mission.

Table 1. The 15 spectral bands of MERIS

Band Nr.	Band Center (nm)	Bandwidth (nm)	Potential Applications
1	412.5	10	Yellow substance, turbidity
2	442.5	10	Chlorophyll absorption maximum
3	490	10	Chlorophyll, other pigments
4	510	10	Turbidity, suspended sediment, red tides
5	560	10	Chlorophyll reference, suspended sediment
6	620	10	Suspended sediment
7	665	10	Chlorophyll absorption
8	681.25	7.5	Chlorophyll fluorescence
9	705	10	Atmospheric correction, red edge
10	753.75	7.5	Oxygen absorption reference
11	760	2.5	Oxygen absorption R-branch
12	775	15	Aerosols, vegetation
13	865	20	Aerosols correction over ocean
14	890	10	Water vapour absorption reference
15	900	10	Water vapour absorption, vegetation

Radiometric requirements
The radiometric performance is one of the most crucial requirement for MERIS because the signals coming from the ocean are weak and thus most difficult to detect and quantify. Even though the radiometrically most challenging target to be observed is the open ocean, MERIS also has to have a large dynamic range to cover these low-level signals as well as signals emanating from bright targets such as clouds and land surfaces, throughout its spectral range. This imposes demanding radiometric performance requirements.

- Open ocean
In the upper layer of the open ocean, the chlorophyll concentration varies from less than 0.03 mg.m^{-3} in oligotrophic waters, up to about 30 mg.m^{-3} in eutrophic situations. Ocean colour responds to this variation, which spans over three orders of magnitude, in a non-linear manner. The goal with MERIS is to discriminate 30 classes of pigment concentrations within the three orders of magnitude. These classes should be of equal logarithmic width. This requirement translates into a radiometric sensitivity of 2 x 10^{-4} for NEΔR (noise equivalent spectral reflectance at sea level) being set for MERIS.

- Coastal waters
For the detection of several water substances, commonly used techniques like simple colour ratios which are applied successfully for open oceans, are not sufficient. The similarity of the spectral scattering and absorption coefficients for all optically active water substances poses problems in finding an adequate procedure for their detection. Here the Sun-stimulated chlorophyll fluorescence at a wavelength of 681.25 nm can improve the detection of pigment concentration. The fluorescence signal is small, but is detectable from space. The spectral resolution should ideally be better than 10 nm and the radiometric resolution better than 0.03 W (m^{-2} sr^{-1} nm^{-1}) for the discrimination of a 1 mg.m^{-3} pigment concentration.

Outstanding radiometric accuracy is imperative for the atmospheric correction, which is of critical importance since, over ocean, typically

90% of the signal reaching the sensor originates from the atmosphere. MERIS is designed to achieve this by having spectral bands positioned such that quantification of the atmosphere's influence is possible. Moreover, MERIS is required to have a sensitivity to the polarisation of the incoming light scattered from the atmosphere lower than 1%.

Instrument operation

Measurement principle

MERIS is an imaging spectrometer that measures reflected solar radiation in the visible and near-infrared parts of the spectrum. It is a nadir-looking sensor operated in a pushbroom mode. Image acquisition is performed with a line of detectors scanning the two-dimensional scene. The motion of the satellite provides the along-track dimension. This imaging mode permits a much longer dwell time compared to classical scanners. The spectrum of every single ground pixel is recorded thanks to the use of a two-dimensional detector. The swath width is imaged over the detector line, the spectrum over the detector column. The instrument has the ability to transmit 15 spectral bands. As a unique feature, the spectral bands can be changed in width and position by ground command. The global Earth coverage within three days required by oceanographic and atmospheric investigations is ensured thanks to the large instrument swath of 1150 km.

Operating concept

MERIS is designed to acquire data whenever illumination conditions are suitable. Instrument operation is restricted to the day zone of the orbit where the Sun's incidence angle is less than 80° at the subsatellite point (Fig. 2). Calibration will be carried out, on average, once every two weeks, when the spacecraft flies over the south orbital pole and the Sun illuminates the instrument's onboard calibration device. For the rest of the orbit, MERIS will be in non-observation mode.

The MERIS instrument is designed to serve both global and regional applications. It will acquire reduced-resolution (RR – 1200 m) data continuously over the Sun-illuminated part of the orbit, with data recorded on-board and dumped once per orbit (every 100 min) via X- or Ka-band links to high-latitude ground stations. This data will be processed systematically for all orbits.

In addition to the RR data, MERIS will deliver full-resolution (FR – 300 m) data in the same 15 spectral bands. This FR data will be transmitted via a Data Relay Satellite (DRS) or an X-band ground receiving station when in view of the satellite. Envisat also has a Solid-State Recorder (SSR) which can be used to record FR data when outside DRS coverage or ground-station visibility. The combined usage of DRS, ground station and SSR will ensure that every part of the globe can be accessed with FR data.

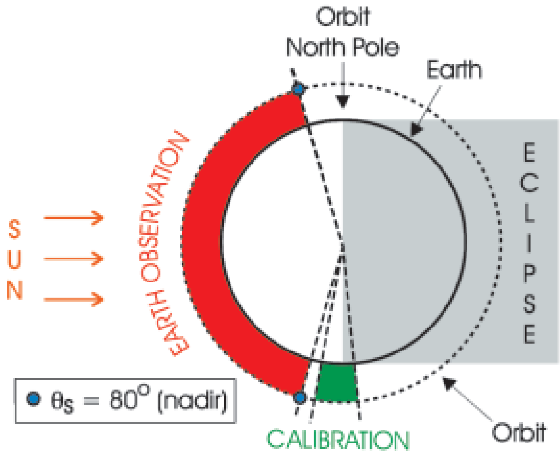


Figure 2. MERIS operation profile

Instrument design and performance

Figure 3 shows the mechanical layout of MERIS. The instrument consists of five identical cameras sharing the large field of view of 68.5° (Fig. 3). These cameras are arranged in a fan-shaped configuration in which their fields of view overlap slightly. The modular design ensures high optical image quality over the large field of view. The output of each camera is processed separately in an analogue and digital processing unit (Fig. 4).

Optical sub-assembly

The optics of each camera has an external window, a folding mirror, an off-axis catadioptric ground imager and a spectrometer. The window scrambles the incident light coming from the Earth, making the instrument less sensitive to changes in polarisation. The dispersive element of the spectrometer is a low-groove-density holographic grating. The aperture stop is located on the grating. The entrance pupil is located in front of the camera optics, making it a suitable position for the scrambling window.

Focal-plane sub-assembly

The camera's detectors are CCD arrays specifically developed for MERIS (Fig. 5). Thinned back-side-illuminated CCDs have been selected, which offer the required high responsivity in the blue part of the spectral range. The CCDs are operated in frame transfer mode. At the end of a fixed period (integration time), the charges are rapidly transferred to the store region allowing the acquisition of the next frame to start. Charges in the store region are subsequently transferred to the shift register.

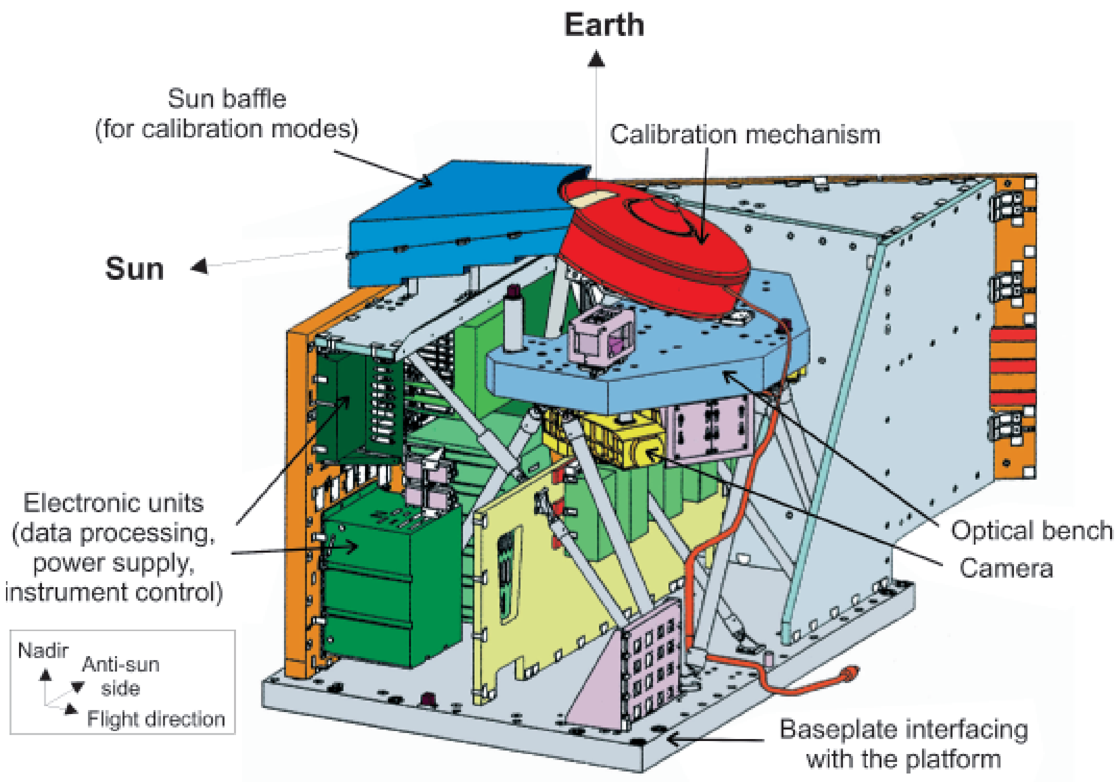


Figure 3. The MERIS mechanical layout, showing the locations of the various subsystems

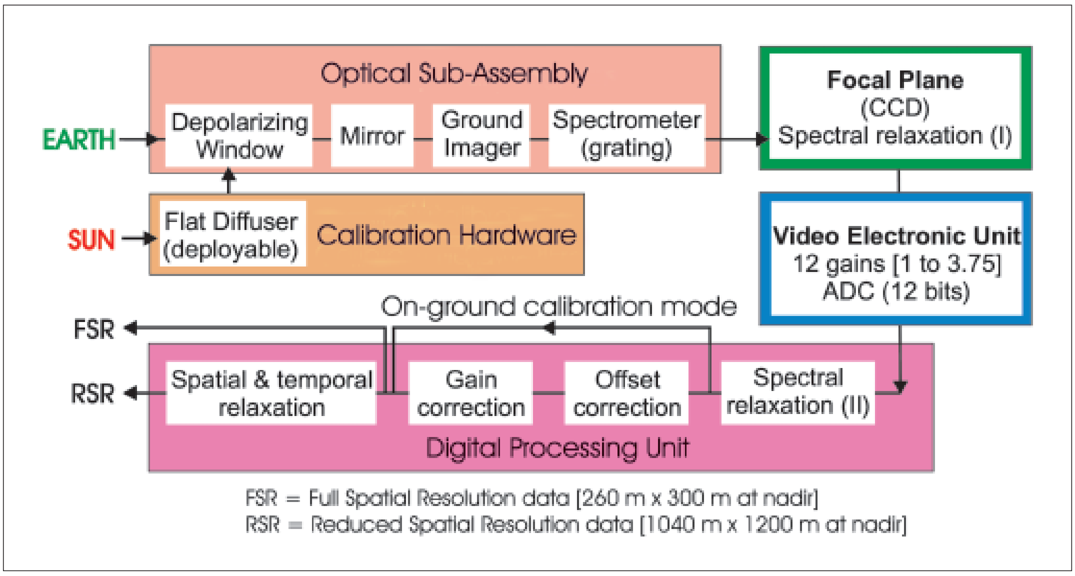


Figure 4. MERIS functional block diagram

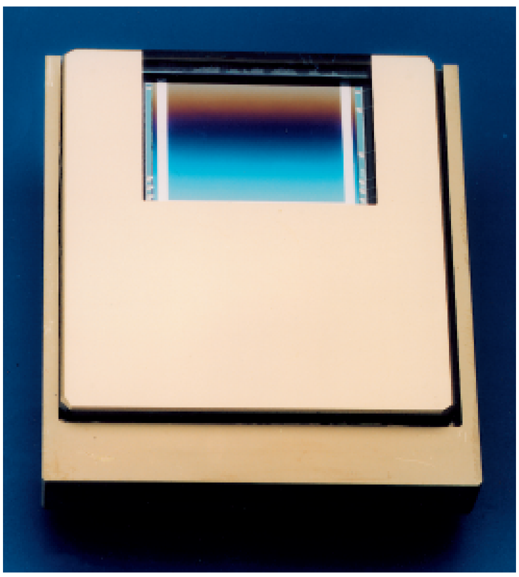


Figure 5. The MERIS CCD

The spectral range of MERIS is 390 to 1040 nm, with a spectral sampling interval of 1.25 nm. 530 rows are required to cover this range, including a margin of 10 rows for spectral alignment. The camera swath is imaged over 740 pixels along the CCD line. Included on either side of the line are dark reference pixels, which are covered by the aluminium shield. These pixels are used for offset compensation to ensure the stringent signal stability required along the orbit and between calibrations. The CCDs are operated at –22.5°C to reduce the dark current.

A special coating has been developed for the CCD surface. This coating features a wedge along the CCD column to reduce internal stray light to an acceptable level.

The CCDs play an important role in the programming of the spectral bands. Thanks to its large storage capacity, several lines can be accumulated in the shift register before clocking out the pixels. The selected bandwidth is obtained by summing the correct number of lines. The CCD lines that fall outside the 15 spectral bands are dumped at shift-register level.

Processing chain

Signals read out from the CCD pass through several processing steps in order to achieve the required image quality. Analogue electronics perform pre-amplification of the signal, correlated double sampling and gain adjustment before digitisation of the video signal on 12 bits. The signal amplification is done by selecting one of the 12 fixed gains defined in the range 1 to 3.75. The amplification gain is selected separately for each spectral band to minimise the noise contribution of the processing chain. Thus, the saturation level of any band can be optimised for the purposes of that band. For instance, a spectral band used only for ocean applications can saturate over clouds, leaving the full 12-bit digitisation for the useful dynamic range of the oceanic signal.

The digital output of the Video Electronic Unit is subsequently processed by the Digital Processing Unit in three major steps:
– completion of spectral relaxation up to the required bandwidth
– subtraction of the offset and correction for gain non-uniformity
– reduction of the spatial resolution of the data to 1200 m for the global mission summation of four adjacent pixels across-track over four consecutive frames.

The offset and gain corrections are based on coefficients computed during the calibration sequences. These coefficients are stored on-board as well as being sent to the ground. The instrument design offers the flexibility to have these corrections applied either onboard or on the ground. In the latter case, offset and gain correction are bypassed in the onboard processing flow and performed on the ground.

Performances

Verification of the instrument's performance is based on an extensive testing programme at camera and instrument level (Table 2). Of particular importance is the large signal-to-noise ratio in the blue part of the spectrum, which permits the required Noise Equivalent Difference in Reflectance at sea level to be met.

Instrument calibration

To meet the stringent accuracy requirements, the data need to be corrected for any non-uniformities and distortions introduced in the overall measurement system, as well as being converted into radiance values. Four in-flight calibration sequences are defined:
– dark calibration
– radiometric gain calibration
– diffuser ageing characterisation
– wavelength referencing.

During the dark calibration, the signal is recorded with the Earth and Sun aperture closed. In the gain calibration mode, a white diffuser plate, Sun-illuminated, is inserted at the cross-over point of the fields of view of the five cameras. The diffuser provides a reflectance standard across the entire spectral range and field of view.

Geometric Image Quality	
Field of View	68.5° centred about nadir
Swath width	1150 km
Localisation accuracy	< 2 km (without the use of landmarks)
Spatial resolution	RR: 1040 m x 1200 m (nadir) FR: 260 m x 300 m (nadir)
Band to band registration	< 0.1 FR pixel
Spectrometric Image Quality	
Spectral range	390 nm – 1040 nm
Spectral sampling interval	1.25 nm
Spectral resolution	1.8 nm
Band transmission capability	15 bands programmable in position and width
Band width	Programmable from 1.25 nm up to 30 nm
Band center knowledge	< 0.6 nm
Radiometric Image Quality	
Radiometric accuracy	< 2% in reflectance (i.e. relative to the sun irradiance)
Dynamic range	Up to bright clouds (100 % reflectance)
Signal to noise ratio	1650 (@ 412.5 nm) for typical ocean signal
Polarisation sensivity	< 0.3% over the full spectral range
Orbital signal stability	< 0.05%
Interface Budgets	
Mass	200 kg
Power	175 W
Data rate	RR: 1.60 Mbit/s FR: 24.0 Mbit/s

Table 2. MERIS performance summary

The calibration diffuser will be exposed to the Sun for a total cumulative period of about 1 h during MERIS's lifetime. Some limited degradation due to UV/VUV radiation and particle exposure may be expected even though ground testing has demonstrated remarkable diffuser stability over the instrument's spectral range. A second white diffuser is therefore implemented to evaluate changes in BRDF of the gain calibration diffuser. This diffuser will be used infrequently and will thus not degrade at the same rate as the first diffuser. Diffuser ageing will be monitored by comparing the data acquired with both diffusers.

Wavelength calibration will be achieved by using another diffuser featuring well-known absorption peaks. MERIS spectral bands will be reprogrammed to sample the absorption features adequately. From this calibration, the spectral position of any spectral band can be derived. Use of the solar Fraunhofer absorption lines as an alternative when observing the Sun-illuminated white diffuser is also envisaged.

Following extensive environmental tests, Spectralon™ has been selected for the diffuser plates. Diffusers manufactured with this material offer both the requisite uniformity over the field of view and remarkable stability. A diffuser plate doped with a rare Earth oxide is used for the wavelength calibration.

The calibration hardware is implemented on a selection disc (Fig. 6). A stepper motor allows the selection of five disc positions, as the instrument mission requirements dictate. The calibration mechanism also supports the diaphragm introduced into the field of view to minimise stray light when observing the Earth.

Data processing

The MERIS products will be available with different time scales – with both near-real-time and consolidated processing – and with different spatial scales depending on the geographical location – global (1200 m) and regional (300 m) products – and with different levels of processing (1b & 2).

Near-real-time and consolidated processing

The Near Real Time (NRT) services will provide data 3 h after acquisition. Consolidation is a gradual process by which more accurate external (auxiliary) data become available over time. The consolidated data products will therefore typically be available within about three weeks. The formats of the NRT and consolidated data products are the same, but the quality of the auxiliary data used in the processing of the consolidated product is improved.

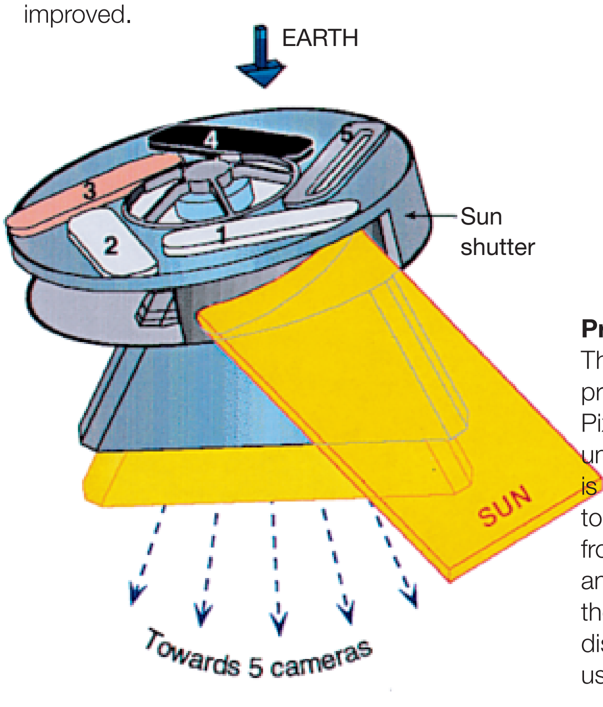


Figure 6. The MERIS calibration mechanism supporting three diffusers - for gain calibration (1), for diffuser ageing monitoring (2) and wavelength calibration (3) - the Earth shutter (4) and the Earth diaphragm (5)

Global and regional products

MERIS products will be available in FR and RR resolution. The RR data will be acquired globally for the entire daytime orbit and processed systematically for all orbits. The FR data will be available mainly over land and coastal zones, representing the regional mission for which data will be processed only on user request.

Data product levels

ESA has defined the following data product levels for MERIS (Table 3):

- *Level-0 Product:* This raw format data will not generally be made available to the users.
- *Level-1b Products:* These consist of calibrated top-of-atmosphere radiances in 15 VIS/NIR spectral bands, geolocated and resampled on a regular grid. Annotations will include surface identification (land, sea and clouds), localisation (latitude, longitude, altitude, or bathymetry), viewing and solar geometries, as well as meteorological data (ECMWF).
- *Level-2 Products:* These are called ‘distributed’ products because the geophysical quantities found in the data sets vary depending on the surface being measured. They will contain both geophysical parameters and surface radiances/ reflectances, depending on the surface products group – ocean colour products, land products and cloud products.
- *Browse Product:* This will be processed systematically to a 4.8 km resolution for the entire daytime orbital segment. It will consist of an RGB colour product, where the three MERIS bands have been chosen for the best visualisation of the land, sea, ice and cloud features. The browse will enable the user to choose the position of a scene of interest. User tools will be provided to allow the selection and ordering of scenes of 1150 km x 1150 km for RR products, and of 575 km x 575 km or 296 km x 296 km for FR products located anywhere along- and across-track in the acquired data sets. Users will be able to order multiple scenes to acquire a complete (daytime) orbit.

Processing architecture

The architecture of the MERIS Level-2 processing is shown schematically in Figure 7. Pixel identification is the process by which the underlying surface type (cloud, land and ocean) is determined. This is achieved using radiometry to separate bright targets (cloud, snow and ice) from land or ocean. The darker targets (land and ocean) are further classified according to their typical spectra and, finally, clouds are distinguished from the other bright targets using pressure (altitude) information retrieved

Table 3. MERIS products

	Processing level	Reduced Resolution Mode Scene Size [Mb] Coverage	Full Resolution Mode Scene Size [Mb] Coverage
Level 0	Annotated source packets	• 522 Mb per Orbit	3600 Mb for 20' per Orbit
Browse	RedGreenBlue	• 3.2 Mb per Orbit	N/A
Level 1b	Geolocated and calibrated TOA radiance + auxiliary data (meteo, geometry, altitude, bathymetry)	• 39 Mb per scene (1150kmx1150km) • 532 Mb per Orbit	157 Mb for 575kmx575km
Level 2	Geolocated oceanic, cloud, land and water vapour geophysical parameters + surface leaving reflectances+ auxiliary data	• 48.5 Mb per scene (1150kmx1150km) • 620 Mb per Orbit	187 Mb for 575kmx575km

from the bands situated in the spectral absorption features of oxygen (760 nm).

Once the surface type has been identified, surface-specific computing can start. Over water, computation starts with the identification of those areas affected by Sun glint (direct reflection of Sun on the water surface) and its partial correction in order to increase the coverage area of the ocean-colour products. This is followed by the identification of whitecaps and high inland lakes where the atmospheric correction quality will be reduced. Turbid waters are then screened and a special 'bright water' correction is applied to remove the marine signal contribution in the near-infrared (NIR) prior to entering the atmospheric correction, which is based on the assumption that the marine signal in the NIR is nil. The atmospheric-correction computations return water-leaving reflectances which are used for the estimation of the ocean-colour products (see below) and the aerosol optical thickness and type, which are then used in the computation of water-vapour content over oceans. Ocean-colour products are then computed using band ratios over the open ocean, while for the more complex coastal-water products all visible bands are used as inputs to a neural network.

Over clouds, the cloud optical thickness and albedo are derived directly using top-of-atmosphere radiances and the results of the cloud-top pressure computed earlier; a simple cloud type is computed based on cloud characteristics established by the International Satellite Cloud Climatology Project (ISCCP).

Over land, the MERIS Global Vegetation Index (MGVI) is computed using top-of-atmosphere reflectances. Atmospheric correction here consists only of removing molecular scattering and absorption, while the aerosol optical thickness and type are computed only above those targets identified as Dense Dark Vegetation (DDV), where it is assumed that the target has a well-determined reflectance.

Water vapour is computed over all surface types. The same algorithm is used over bright targets – land and Sun glint. Over the ocean, the aerosol contribution to the signal is corrected for.

Finally, all intermediate results are formatted according to the Envisat product specifications and the product confidence information computed using all of the results of the internal tests performed during the computation.

The data products

The variety of geophysical parameters that are to be measured by MERIS will support a host of applications in marine biology, land and atmospheric sciences, as outlined below.

Ocean products

Ocean colour is the key objective of the MERIS mission and therefore the ocean is the surface for which the largest number of products will be generated. In the open ocean (97% of the World's oceans), the concentration of phytoplankton (algae) is a key parameter for understanding the processes involved in the carbon cycle. In coastal areas, phytoplankton cohabit with suspended particulate and dissolved detritus matter (yellow substance) which will be derived by inverting a model of the optical properties of these complex water

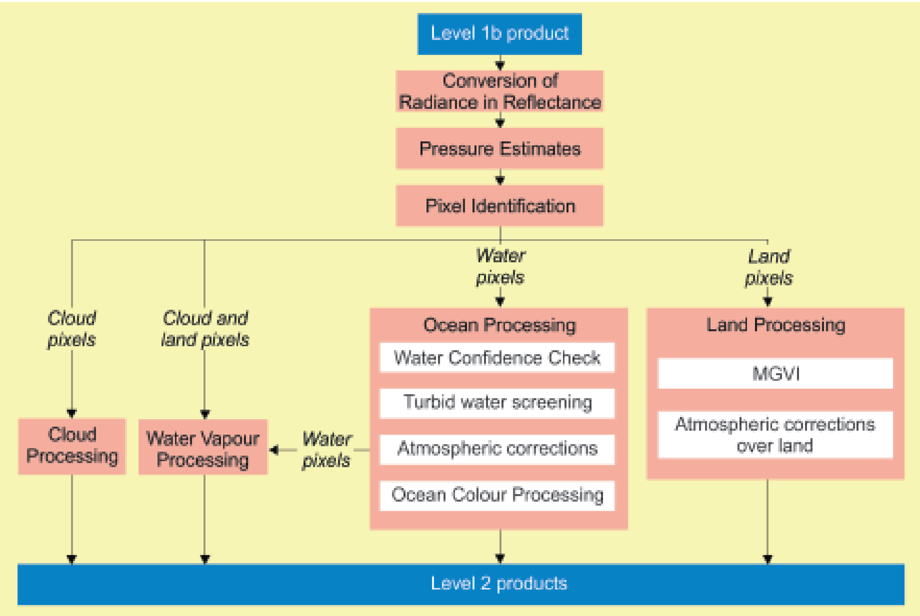


Figure 7. Level-2 product processing steps

bodies using a neural network. The Photosynthetically Active Radiation (PAR) – the amount of radiation available to the oceanic flora – will be provided to support studies of chlorophyll fluorescence. Desert dust, continental and maritime aerosol types and their optical thicknesses will be generated as a byproduct of the atmospheric correction.

Cloud products
Cloud-top pressure, optical thickness, albedo and type will be provided for climatological studies of the Earth's radiation budget.

Land products
The MERIS Global Vegetation Index (MGVI) is a measure of the presence of healthy live green vegetation, estimated from the fraction of absorbed photosynthetically active radiation. Surface pressure will be provided as an experimental product. Aerosol optical thickness and type will be provided for users to improve the atmospheric correction over land.

Water-vapour products
The concentration of water vapour found in the total atmospheric column will be computed over all surfaces. It is of particular interest over land where the traditional measurement means are limited and where MERIS can provide products with a resolution of up to 300 m.

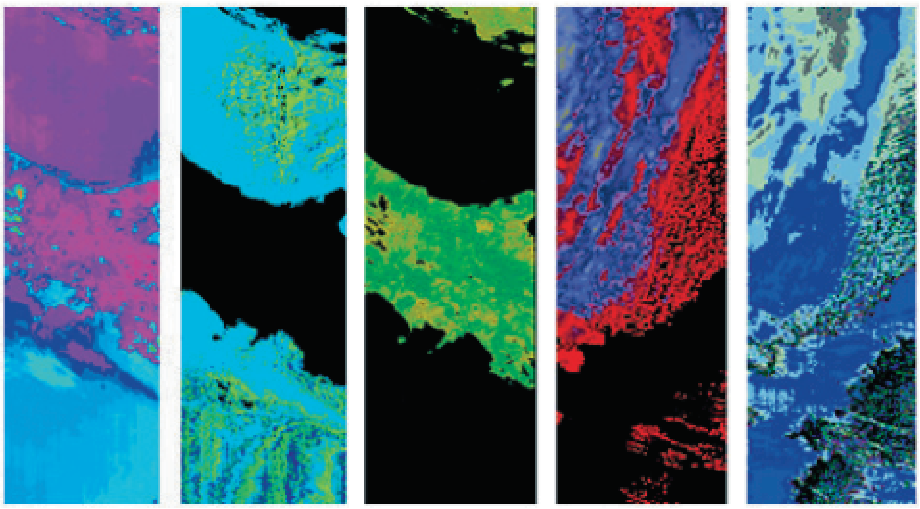
Breadboarding for modelled test-cases has enabled the accuracy of the products expected from MERIS to be estimated (Table 4). Typical images of the sort that will be acquired by MERIS are illustrated in Figure 8. They have been generated by the MERIS processor using reformatted MOS data.

Product validation
ESA has the responsibility to guarantee the quality of its data products. Consequently, a calibration/validation plan is being defined that includes in-flight calibration and campaigns in support of vicarious calibration and product validation. The plan forms the basis for developing scientific exploitation and application pilot projects related to MERIS, as already selected through the first Announcement of Opportunity for the exploitation of Envisat data.

Conclusions
The Medium Resolution Imaging Spectrometer (MERIS) belongs to a new generation of ocean-colour sensors that will provide a major improvement in our knowledge of such crucial processes as the contribution that the oceans make to the carbon cycle. The instrument has the unique capability of in-flight programmability of the position and width of the 15 spectral bands acquired in the visible and near-infrared parts of the spectrum. Data will be acquired with two spatial resolutions, 300 m and 1200 m, over a swath of 1150 km.

ESA will produce a set of validated data products from MERIS that will be available at various spatial resolutions, processing levels and within different time frames. These products and geophysical parameters have been identified as the most important, globally attainable parameters to be derived from MERIS. In addition to the Level-2 data, ESA will also provide the user with sufficient information to process the data to higher levels. The inherent flexibility of the MERIS instrument and the phased implementation plan will result in the development of a ground segment providing the most up-to-date products possible.

Acknowledgements
The MERIS instrument has been developed by an international team led by Alcatel Space Industries (F) under the Envisat prime contractorship of Dornier (D). The data-product algorithms have been developed under the leadership of ACRI (F).



TOA radiance @ 442.5 nm | Chlorophyll concentration | MERIS Global Vegetation Index | Cloud optical thickness | Water vapour

Figure 8. Images generated by the MERIS processor using reformatted data from the Modular Optoelectronic Scanner (MOS) on India's IRS-P3 satellite:
- TOA Radiance is a Level -1b product in band 2 acquired over the Adriatic Sea, central Italy and the Tyrenean Sea
- Chlorophyll concentration and MGVI illustrate the Level-2 distributed product concept over the same area as TOA Radiance
- Cloud optical thickness and water vapour computed using an image acquired over Germany

Products	Accuracy
Chlorophyll retrieval	30%
Sediment	30%
Yellow Substance	50%
Water Vapour	10% (over land)
Cloud Top Pressure	10%
Cloud Albedo	10%
Cloud Optical Thickness	30%
Aerosols Optical Thickness	20% (over ocean)
	50% (over land)
Surface Pressure	5% (over land)
Surface Reflectance	10%

Table 4. Estimated product accuracies