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EXECUTIVE SUMMARY

The objectives for a series of satellites comprising the GMES Sentinel-3 mission encompass the commitment to consistent, long-term collection of remotely sensed marine and land data, of uniform quality, for operational ocean state analysis, forecasting and service provision, in the context of Global Monitoring for Environment and Security (GMES). A comprehensive measurement system facilitating global ocean and land observations is required to provide input data for advanced numerical forecasting models. For the remote sensing variables the following set of observational requirements have been established:

- Sea surface topography (SSH) and, significant wave height (SWH) over the global ocean to an accuracy and precision exceeding that of Envisat RA-2.
- Sea surface temperature (SST) determined globally to an equivalent accuracy and precision as that presently achieved by A/ATSR (i.e. <0.3 K), at a spatial resolution of 1 km.
- Visible and Thermal Infrared radiances ("Ocean Colour") for oceanic and coastal waters, determined to an equivalent level of accuracy and precision as MERIS data with complete Earth coverage in 2 to 3 days, and co-registered with SST measurements.
- Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances ("Land Colour") for land surface, with complete Earth coverage in 1 to 2 days, with products equivalent to those derived from MERIS, A/ATSR and Spot VGT, together with those from their combination.

Essential operational requirements of the Sentinel-3 mission concept are:

- High inclination polar orbit, to achieve near-complete global coverage.
- Optical instrumentation requires a sun-synchronous orbit with a descending node equatorial crossing time to complement existing platform observations, and to mitigate sun glint, morning haze and cloud-cover impact.
- Complete global coverage from optical instrumentation every 1 to 3 days.
- Near-real-time data processing and delivery of all processed products for operational users.
- Continuous flow of data of at least the same quality as delivered by Envisat, for a programme duration of 20 years.
- Launch of 1st satellite in 2012 timeframe (with a series of platform to meet observational requirements and requirements for robust, continuous operational data provision).

The GMES Sentinel-3 system shall incorporate the following essential components:

- An advanced Radar Altimeter concept (with Envisat RA-2, Jason-2 and CryoSat minimum baseline altimeter performance).
- Multi-channel optical imager (VIS, IR) either as one instrument or separate for ocean and land colour and surface temperature operational applications (with equivalent Envisat A/ATSR and MERIS minimum baseline performance).
- Appropriate system components for high-accuracy atmospheric water vapour, aerosol, and ionospheric corrections (with appropriate on-board redundancy).
- Appropriate system components for accurate/precise orbit determination (i.e. 3-d position), and on-orbit pointing knowledge (with appropriate on-board redundancy).

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1. Introduction

The definition of the GMES Sentinel-3 mission is based on the requirements of the joint European Commission (EC) and European Space Agency (ESA) Global Monitoring for Environment and Security (GMES) initiative which was started in 2001 (RD1; RD3; RD4). The purpose of GMES is to ensure that Europe will in the future have autonomous access to the best, up-to-date information on the global environment, with which to define, implement and assess its policies on Environment and Security (see: www.gmes.info). GMES will also serve other sectors such as regional development, external relations, agriculture and transport.

The concept of the GMES Sentinel-3 mission was drafted in 2001 in the framework of ESA's Ocean Earth Watch mission. This mission concept has been the first ESA programme to address the needs of operational and long-term remote sensing data exploitation for both public services and the private sector. The Earth Watch concept is complemented by the science driven Earth Explorer missions with the emphasis on advancing understanding of Earth system processes (RD2).

The successful evolution of the concept of operational oceanography over the last 5-10 years has led to the development of a critical mass in ocean forecasting capabilities as well as the establishment of successful operational services. The longevity and success of scientific satellite missions such as ERS and T/P has stimulated the steady development of global ocean models to the point at which data assimilation capabilities facilitate the transition from "traditional oceanography" to "operational oceanography". EU 5th (Strand 1) and 6th (Strand 2) Framework Programme projects like "Mediterranean Forecasting System (MFS)" and "Marine Environment and Security in the European Area" (MERSEA), respectively, have provided the essential developments for this transition. Continuity and consistency in these kinds of space-based measurements is critical to the realisation, maturation and maintenance of a fully operational ocean observing system. Furthermore, the justification for expenditure on European operational ocean observations from space depends on the integration of the resulting data into a wide range of models and processing channels with both global and regional scale applications (RD9).

The basic set of variables which are considered to be essential for a spaceborne ocean observing systems has not changed since the first draft of this document, however, the requirements from different user communities and operational entities have been further consolidated and refined. This document outlines the information requirements expressed by the operational forecasting entities, operational service providers and the associated user communities and their translation into mission requirements.

Two decades after the ocean-science dedicated SEASAT mission, ERS-2/Envisat, Geosat Follow-on (GFO), Topex-Poseidon (T/P) and Jason are acknowledged as integral components of the Integrated Global Observing Strategy (IGOS). The "Oceans Theme" IGOS Partnership (RD5) offers a comprehensive framework for bringing together remotely sensed and *in-situ* ocean observations from both operational and research programmes under the international coordination of the Global Ocean Observing System ([*]GOOS) (RD6) and regional initiatives

[*] GOOS is being implemented by national and international services, and is sponsored by the Intergovernmental Oceanographic Commission (IOC); the World Meteorological Organisation (WMO); the United Nations Environment Programme (UNEP); and the International Council of Scientific Unions (ICSU)

such as EuroGOOS (RD7). But many of the data sets required for a consistent, routine, comprehensive description of the ocean state are not presently acquired by operational meteorology satellites. Examples include; sea-surface height/topography (SSH), significant wave height (SWH), ocean Chlorophyll (Chl), yellow substance (YS) and suspended sediment, sea-ice thickness, and sea-ice surface temperature (SST). Thus, the present combined satellite ocean remote sensing component of IGOS builds on the strategies of existing programmes and attempts to build a consistent time series of fundamental ocean measurements of SSH, SWH, surface wind speed, sea-surface temperature (SST), and ocean colour (OC) to complement and extend the other data available from operational meteorological and *in-situ* sensors.

In considering the justification for, and timeliness and benefits of an ocean-focused Earth Watch mission, we must take into account the needs of the following targeted, broad user communities:

Atmospheric Weather Forecasting: Satellite ocean observation data will improve existing predictive capability by providing a better understanding of global ocean processes that govern weather patterns. A network of global ocean (satellite and in-situ) observations is required to provide the data input for specifying boundary conditions in advanced numerical weather forecasting models. Operational availability of ocean observations is a prerequisite to data assimilation and ultimately consistent, improved predictions of atmospheric and oceanic conditions.

Coastal Zones Monitoring: Demands for information on the state of coastal waters are growing in response to population pressure. Thus, there is a requirement for environmental monitoring of phenomena such as harmful algal blooms (HAB) and habitat assessment in addition to weather and ocean nowcasting and forecasting. The characteristics of the coastal phenomena and the importance of the area for aquaculture, sea-defences, and tourism each justify the observation of coast related parameters with enhanced accuracy and resolution.

Open Ocean and Ice Monitoring: The health and state of the oceans can only be assessed with the aid of globally comprehensive, integrated observations. With such data it will be possible to increase the predictability of characteristics such as sea-state, ice formation, and ocean circulation, and the impact of physical conditions on ocean biogeochemistry. The open ocean also provides important boundary conditions for coastal regions.

Global Land Monitoring Applications: Sentinel-3 will provide daily coverage of the Earth, facilitating global fast revisit observation of the land surface. These data will allow the study of parameters such as regional and continental-scale land cover, vegetation state or vegetation productivity, and fire location, intensity and effects (such as burnt scar area). Sentinel-3 compliments other missions that provide higher resolution but longer revisit times, with a suite of channels that include infrared bands.

Environmental Policy and Law: Through international negotiations, governments have agreed to numerous conventions which, although not in all cases explicitly stated, embody the requirements for measuring various ocean parameters globally in a concerted, systematic way. The Kyoto Protocol, the Framework Climate Convention, the European Water Framework Directive, the Biodiversity Convention, the EU Marine Strategy, and other such agreements all make it obligatory for states to monitor and manage the exploitation of the marine, coastal and land environment.

Maritime Safety and Security: At National and EU level, recognition of the importance of solving problems associated with the pollution consequences of shipping accidents, passenger vessel safety, and, more recently, with potential terrorist actions, has led to the formation of institutions responsible for coordinating legislation. At EU level the European Maritime Safety Agency (EMSA) was set up in 2002 to provide technical and scientific assistance to the European Commission and Member States on matters relating to the proper implementation of European Union legislation on maritime safety and pollution by ships. This includes actions aimed at improving safety at sea for oil tankers and passenger ships, as well as bulk carriers, container ships and fishing vessels. This makes monitoring of ocean conditions for security at sea a high priority.

Global and Climatic Change: Many of the products requested by the communities indicated above will be of interest to the scientists studying global and climatic change. Operational missions are the only way to provide the long term, consistent quality data-bases required to study the regulating effect which ocean processes exert on climate. Improved analysis of climatological data sets will also support and enhance operational forecasting applications.

The scope of this document is to outline the objectives and from it the derived scientific and mission requirements of a first GMES Sentinel-3 mission planned for launch in the 2011-2012 timeframe. This *Mission Requirements Document* is intended to provide guidelines for the technical implementation of the mission. It has been divided into several chapters including an introduction; a guiding definition of operational oceanography; the operational and scientific background and context for the mission; the users, user service requirements for the mission; the observation and data product requirements; and the derived instrument requirements.

2. Mission Background and Justification

2.1. Operational Satellite Oceanography

2.1.1. Defining Operational Oceanography

Operational oceanography, as defined by the European Global Ocean Observing System EuroGOOS and GODAE (RD7, RD8, RD9), is the routine measurement, dissemination, and interpretation of quantitative data on the marine environment in order to:

- Provide a useful and accurate description of the present state of the marine environment including living resources
- Facilitate forecasts of future marine conditions with as long a lead time as possible
- Assemble uniform, consistent, long-term climatic data set that provides an accurate description of past states, trends and changes.

Figure 1 summarises an operational data flow model as portrayed in this document. Operational oceanography exists via the acquisition, downlink, and rapid dissemination of global satellite observation data to computerised data assembly centres, where the satellite data are assimilated in conjunction with other in-situ data sources into numerical forecast models (RD9). Some models are run continuously in near-real time, hence the data delivery timeliness requirement. In addition to producing ocean state estimates or analysed fields (e.g. flow fields), hindcasts and forecasts, the outputs from the numerical models are used to generate secondary value-added data products for special applications, often at regional or local level. All data products and forecasts shall be distributed in a timely manner to government agencies, commercial users, service providers and appropriate regulatory authorities.

A key aspect of operational oceanography is that the model data assimilation framework for marine analysis and forecasting provides an essential foundation for value adding services that require these and other routine products as an input. In order to sustain or further develop marine services of this kind, it is necessary to develop an increased capacity to deliver data in a timely and routine operational manner. The following fundamental aspects will enable an increase in European capacity:

- Deployment of a European global ocean observing satellite with near-real time data transfer capabilities
- Operational data processing, data management and unrestricted data distribution
- Robust and validated satellite products
- Sustained, consistent, reliable and accurate long-term measurement capability.

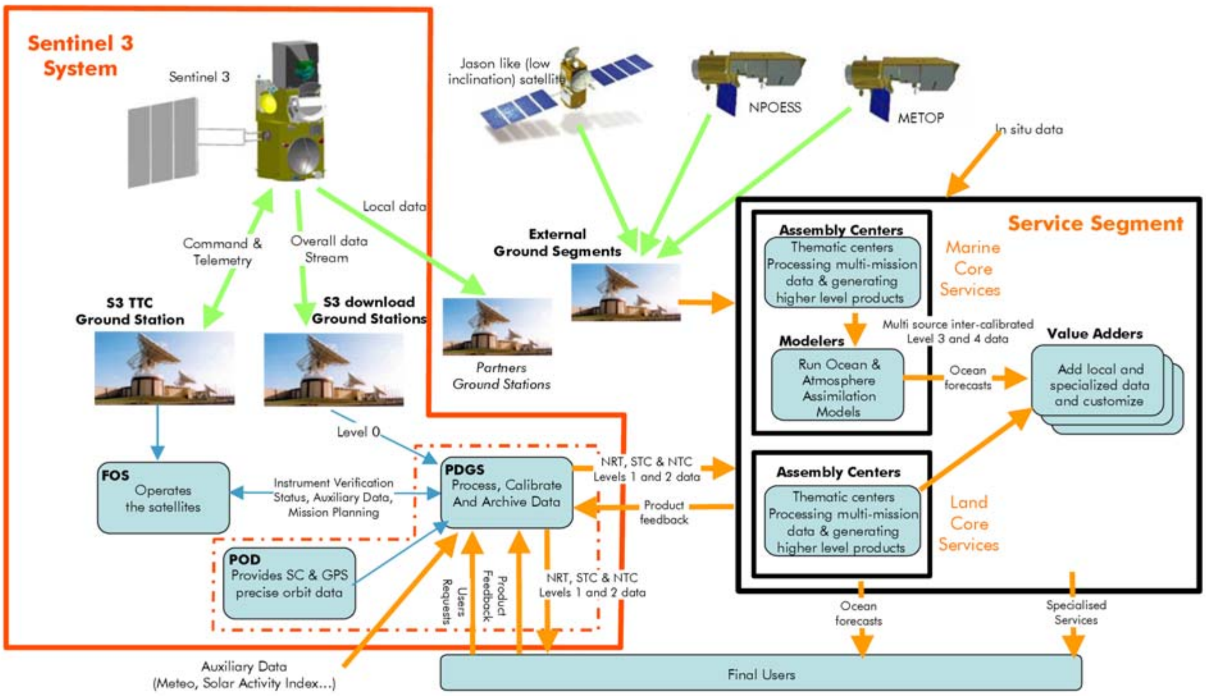

Figure 1: Schematic diagram showing data distribution for an operational ocean forecasting system

2.1.2. Establishing Operational Services

By definition, operational oceanography already exists at local levels (see: www.eurogoos.org). Routine forecasts are conducted and provided for: wind speed and direction over the sea; wave height, direction and spectrum; surface currents, tides, storm surges, sea-surface temperature, and floating ice. The development of an integrated satellite observing system for the purpose of global marine observations has meant therefore, that there are significant advantages to be gained from routine assimilation of global data products. All parts of the coupled climate system can be analysed and forecast simultaneously with a greater degree of accuracy and lead-time than ever before. Global data products from satellite or in-situ system will be insufficient for certain times or areas due to technical failures or simple cloud cover. Therefore quality and routinely delivery of products has to be ensured by an effective combination of satellite and in-situ data with operational model systems.

It is essential that these services at local level are further consolidated and brought to a European perspective. For GMES, ESA has initiated a framework programme to prototype potential services and providers and applications. In the first stage from 2001-2004 twelve projects called GMES Service Elements (GSE) (earth.esa.int/gmes) were initiated, including two initiatives "Coastwatch" (www.coastwatch.info) and "ROSES" (Real-Time Ocean Services for Environment and Security: roses.cls.fr) that are providing marine services of direct relevance here. These initial GSE Projects, however, have since 2005 been consolidated into ten service portfolios. These include, for instance, the consolidation of ROSES and Coastwatch into a single consolidated set of Marine and Coastal environmental information services called MarCoast (see: www.gmes-marcoast.com). Together, these portfolios comprise a representative cross-section of the GMES initial services by the GMES Advisory Council. In addition, key elements of these services form a foundation for the Fast Track or GMES Pilot Services currently being initiated by the European Commission.

In addition, new by-products of Sentinel-3 data have been identified that are of value to industry and government agencies, but to be of greater practical value regular, sustained, uninterrupted, near-real-time data access is first required. These include: indicators of marine pollution and contamination; movement of oil slicks; prediction of water quality; concentrations of nutrients; primary productivity; surface and sub-surface currents; temperature and salinity profiles; sediment transport; and erosion. These higher level products must be developed and made regularly available such that they benefit the widest possible range of industries, services, and regulatory authorities.

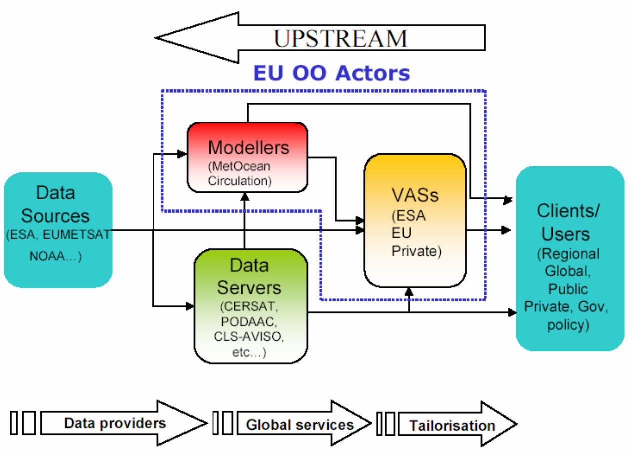

Figure 2: An illustration showing the Actors in Operational Oceanography and their interdependent relationships.

As a long-term perspective sustained operational observing systems including a strong space segment will ultimately lead to improved long range forecasts based on new technology and new understanding of the marine environment. This will be of great benefit in managing the seas and oceans, and in predicting changes and variability of climate.

2.2. Background

The technical maturity of existing ocean satellite observing systems and systems being implemented on currently planned ESA Earth Explorer missions is both consistent with, and adequate for present-day implementation of an operational GMES Sentinel-3 mission.

Sampling capabilities in oceanography have evolved greatly over the last twenty years. Satellite-based remote sensing of sea-surface temperature, surface winds and ocean colour (plus the future possibility to observe surface salinity) has made oceanography a truly global science. In-situ sampling systems, compatible with remote sensing, have also been developed as contributions to two of the global change programmes, namely the World Ocean Circulation Experiment (WOCE) and the Tropical Ocean Global Atmosphere (TOGA), each components of the World Climate Research Programme (WCRP). Likewise, during this period, numerical models of ocean circulation have advanced rapidly, and are now being coupled to atmospheric and ecosystem models, keeping pace with the increasing speed and capacity of supercomputing technology. The operational global observing system of the future is presently being established by capitalising on the observing systems of today, many of which were developed for research purposes at academic institutions. The present development of the European Union (EU) Marine Core Fast Track Service has at its heart an operational ocean model forecasting capability that will be used to provide state of the art ocean state analyses combining satellite and in-situ observations with modelled 3d ocean tracer properties. This capability is fundamental to delivering robust, routine downstream value-adding services.

The GMES Sentinel-3 mission has strong economic and social value, as has been pointed out in 1997 during initial considerations for an Earth Watch ocean concept (RD10), in further assessments of the need for operational remote sensing (RD11), and also in recent assessments of the socio-economic benefits of GMES (RD45). Many activities pursued at sea and along the coast would be much more efficient, or would do less damage, if better information were available on a daily basis. Accidents could be avoided; catastrophic oil spills could be reduced or managed more effectively; biological stocks could be better protected; coastal erosion could be controlled at lower cost; ships' voyages would be more efficient; oil and gas would be produced more efficiently; public health could be improved; and scientists could perform better quality research, etc. On the same basis, though on longer time scales, improved knowledge and forecast skills of the ocean climate (and the coupled ocean-atmosphere climate) would provide benefits to the management of agriculture, fresh water and power generation. In RD45 the socio-economic impact and the value of the industries and services, and the benefits of having better marine forecasts have been accurately evaluated. These benefits accrue to producers, customers, and the European community at large.

The value accrued from GMES Sentinel-3 implementation will not only be economic. It is assumed that the natural environment (including the air, forests, rivers, ocean, soil, etc.) represents capital and is performing valuable functions (such as keeping drinking water clean, providing the right balance of oxygen and carbon dioxide in the atmosphere, etc.) which would otherwise have to be paid for. If the value of these services were properly evaluated and included in everyday financial calculations, a different way of treating and valuing the environment would develop. This argument can be applied to the marine environment as well as to the land. It is essential therefore, to understand the role of the sea better in order to protect its true value.

A combination of forecast techniques incorporating ENSO analysis, the Pacific Decadal Oscillation and the North Atlantic Oscillation (NAO), would provide benefits measured in hundreds of millions of dollars per year for each of several management sectors related to fresh water reservoirs, agriculture, oil and gas storage, agriculture and tourism (RD5, RD23). Medium term to multi-year forecasting in the European region does not have the advantage of a clearly dominant signal like the ENSO cycle, but analysis of Atlantic and Arctic processes is beginning to reveal several potential mechanisms and cycles in addition to the NAO, which may make useful forecasts feasible. If this is the case, improved boundary conditions for shelf-sea models and the climate forecasts for the whole continent, could have user values of an equivalent order of magnitude to those derived for the USA.

The sum total of benefits estimated by EuroGOOS Euro Global Ocean Observing System) for the European region has been estimated to be of the order of 2-5 BEuro per year (RD8). This figure includes mainly Commercial, Economic and Social benefits.

2.3. Justification

In consideration of the justification for (and timeliness of) an ocean- and land-focused mission the following points need to be taken into account:

2.3.1. Human Need for Ocean Observations

In weather forecasting, satellite ocean observation data will improve predictive capability by providing a better understanding of global ocean processes that govern weather patterns. A network of global ocean observations is required to provide more realistic boundary conditions for advanced numerical weather forecasting models. Operational availability of ocean observations is a prerequisite to consistent, improved predictions of atmospheric and oceanic conditions, thereby enabling safer use of the sea and the exploitation of the economically important regions such as the 200 km exclusion zone. More accurate weather forecasting in turn helps protect people from the impacts of extreme weather events such as hurricanes, storm surges and flooding.

The health of the oceans can only be assessed with the aid of globally comprehensive integrated observations. With such data it will be possible to increase the predictability of phenomena such as sea-state, ice formation, coastal erosion and harmful algal blooms. This facilitates more efficient management of food sources from the ocean and of input of waste products into the oceanic and coastal waters: to reduce the possibility of accidents and associated risks of major pollution incidents. Further, they will enable more effective mineral prospecting and offshore platform operations. Lastly, as the ocean exerts a major control upon climate, observation-based prediction over longer periods will help advance understanding and forecasting of climate change.

2.3.2. Economic Importance of the Oceans

The state of the ocean influences climate via carbon sequestration or uptake, and via the energy and water cycles. Consequently it affects agriculture as well as water and energy supplies. The state of the ocean also affects the intensity of hurricanes and tropical cyclones, which cause hundreds of millions of dollars in property damage and alter the economic fortunes of businesses in the affected areas. European weather is similarly dependent on the state of the Atlantic Ocean.

The El Niño/La Niña phenomenon of the tropical Pacific has a widespread impact on the economics of crop production in the tropics and mid-latitudes. World-wide trade, 90% of which goes by sea, is expected to double over the next decade, requiring improved now-casting and forecasting services in order to ensure safe navigation and cost-effective operations. As the oil and gas industry operates in ever-deeper waters it demands improved marine nowcasts and forecasts.

Demands for information on the state of coastal waters are growing in response to population pressure, an increase in the runoff of waste products and fertilisers from land, and in response to the increased use of coastal seas for recreational activities, fishing, and aquaculture. Thus, there is a requirement for environmental monitoring and habitat assessment in addition to weather and ocean nowcasting and forecasting. Concerns such as the health of coral reefs or the destruction of mangroves must all be addressed.

In coastal seas, an increasing number of well-instrumented, local-area, observation grids are being set up to meet these various demands. However, it is increasingly apparent that, to exploit information provided by these local grids, a better understanding of transfers with the open ocean is essential because conditions far away from coasts frequently influence coastal conditions.

2.3.3. Environmental Policy and Law

Through international negotiations, national governments have agreed to numerous conventions which, although not in all cases explicitly stated, embody the requirements for measuring various ocean parameters globally in a concerted, systematic way. The list of relevant conventions is growing and presently includes:

- United Nations Convention on the Law of the Sea (UNCLOS);
- United Nations Framework Convention on Climate Change (UNFCC);
- Biodiversity Convention; Agenda 21 (agreed at the United Nations Conference on Environment and Development in Rio in 1992);
- Global Plan of Action for the Protection of the Marine Environment from Land-Based Activities;
- London Dumping Convention;
- Agreement on Highly Migratory and Straddling Stocks.

Governments need coherent information and improved understanding of the ocean to meet their obligations under these Conventions. The Conventions identify requirements and needs which can only be satisfied by the concerted action of a large number of countries. The UNFCCC, at its fourth meeting in Buenos Aires in November 1998, called for increased sampling of the ocean, especially to fill present data gaps, as essential for monitoring climate change.

2.3.4. Land Services

The domain of GMES operational land services is less mature than that for the oceans. Nevertheless, the development programmes mentioned above, and the operational use of the SPOT payload VEGETATION (VGT) during the last years, has allowed the development of global operational land services. These services provide routine information for global land monitoring (agriculture and forestry), and for applications such as: low resolution mapping, regional and continental scale land cover mapping and, fundamentally, for global land productivity, agriculture or vegetation status and determination of biophysical vegetation parameters. These parameters, which are needed for climate modelling, carbon fluxes, crop yield estimations, and land degradation, may change rapidly with time. Thus, the regular daily revisit and large number of bands including thermal infrared, provided by Sentinel-3 become strong assets that compensate its moderate resolution.

2.3.5. Realisation of an Operational Observing System

The operational global observing system of the future will be built initially by capitalising on the observing systems of today (RD12, RD13), many of which were developed for research purposes. As research continues, there will be further improvements to the system as can be demonstrated with the MERSEA project (RD21, RD22) for a global ocean modelling system. Indeed, experience from these kinds of projects has confirmed that the full involvement of academic institutions and scientists is essential for the establishment of the GOOS, since the technology and research available at such institutions is needed to guide its development. Commercial communications expertise and other user community expertise are also required for technical reasons and to refine present observing systems for optimum effectiveness.

These developments and the new GMES context demonstrate the need for a global ocean observing system and that technically the time is opportune for an ESA contribution of a dedicated operational oceanography and land-surface mission.

3. User Information Requirements

3.1. Identifying the needs and characterisation of Users

As an example of the general classes of GMES Users, Figure 2 identifies the primary classes of Actors (i.e. composition) involved in Operational Oceanography, enclosed within the blue dotted line, and the interactions amongst them (after RD26). Each of the elements can be considered as components of a system transforming data to information between the data sources and the clients (or end product user). This figure also highlights the dependency of Value Adding Servers (such as companies or GMES projects) on model outputs and data servers.

The discussion are mostly based on a recent requirement analysis study (RD26) where previous results (RD19, RD20, RD25) on the various requirements and objectives of different users are sorted, consolidated and condensed for a "Roadmap towards an Operational Oceanography Mission". User requirements were collected and consolidated from a cross-section of Actors in the following categories:

- Private Sector (i.e. Small to Medium-sized Enterprises – SME's; and large Industrial companies)
- EU Projects (including GMES FP5 and FP6 projects)
- Existing operational forecast model systems (met-ocean and ocean forecasting systems)
- ESA GMES Services Element (GSE); Earth Observation Market Development (EOMD); and Data User Programme (DUE) Studies
- EU GMES Marine Core Service (MCS) and Land Monitoring Core Service (LMCS)

For each of the contacted organisations, summary descriptions of their activities; services/products offered; value adding process; customers; partners; and their Earth Observation (EO) data product requirements, have been catalogued. Appendices A-G list the major sources of information and provide links to their respective web sites, where available.

To simplify the discussion in the following chapters, these identified end users are split into the following broad categories:

- Operational users;
- Institutional national and regional organisations delegated to undertake specified activities;
- Research organisations, including those compiling and managing earth science data and those conducting direct research and investigation (e.g. physical oceanography, climate system modelling etc).
- GMES Service Providers (ESA and EU)

3.2. Operational users

3.2.1. Offshore oil and gas operators

In the medium term, the evolution of this industry will be dominated by an increasing reliance on new deep water fields such as offshore Angola, the new UK-Faroes licence areas, the Deepwater Gulf of Mexico and the Eastern Brazilian coast. Timely and accurate ocean environment forecasts and nowcasts constitute a vital contribution to the cost effective extraction of oil and gas in these regions. The management of operations requires information to support decisions on scheduling, production levels etc. Requirements include wind and wave forecasts (and nowcasts), and information on the distribution and structure of surface currents and the variation of current with depth.

In addition, Arctic operations (and activities in the Northern Caspian) require sea ice forecasts and nowcasts for safety measures and shipping route planning. Regions experiencing stress forces generated by intense internal waves require forecasts of expected internal wave regimes. As an example of the potential impact of the latter, several major oil companies have ceased development activity in the Andaman Sea area due to the difficulties associated with handling the harsh internal wave conditions.

In response to changes in the operating and production licences, offshore operators are increasingly being required to implement some form of environmental protection system. This may include the real time detection of oil discharges and the systematic monitoring of water quality and sea surface temperature in the surrounding environment to ensure timely detection of any operational impacts.

3.2.2. Oilfield logistics support

Due to the wide range of different support operations, the span of information necessary to ensure activities are properly planned and managed is very wide. For example, helicopter operators require sea surface temperature maps to prepare flight plans (flights can overfly only regions where the temperature is sufficiently high to ensure crew survival in the event of a forced landing), while the environmental management system operators require ocean colour and sea surface temperature data (as well as other data) to identify and monitor accidental discharges.

Offline environmental information is also necessary for example in planning operations or deciding where to locate infrastructure. Wind/wave/current climatologies are essential and ocean colour and sea surface temperature data are needed to conduct assessments of potential environmental impacts and to establish baseline environmental audits prior to actually initiating operations.

3.2.3. Offshore and coastal engineering operators

Marine engineering operations such as rig movement and platform installation require wind, wave and in particular current forecasts for the short term planning of operations as well as offline information on climatologies for use in the optimised design of coastal and offshore structures and the planning of installation and transport operations. Towing, lifting and installation operations are particularly vulnerable to long wavelength swell conditions (both period and propagation direction are important). Dredging operators require information on local water quality as well as wind, wave and current forecasts to ensure the safety of operations and to detect any accidental discharge arising from operations (e.g. for certain classes of mud, dredging operators must ensure no dispersion of the material into the surrounding environment).

3.2.4. Marine survey operations

Seismic survey and acoustic seabed mapping operators require wind and wave climatologies to support the planning of operations while, the fragile nature of the equipment deployed, means that such companies require timely and accurate wind, wave and current forecasts to ensure safe operation, especially in shallow waters. In addition, the increasing use of autonomous underwater vehicles (which use acoustic communication and ranging systems) requires more accurate knowledge of ocean conditions including sediment and organic matter concentrations, temperature and salinity structures, the local internal wave environment and ambient noise due to wind/wave and current conditions. Arctic operations require small scale knowledge of a range of sea ice conditions including iceberg location, "grease" ice formation and sea surface temperature to ensure that the icing of equipment, such as hydrophone arrays, does not reach a level that would endanger the mother ship.

3.2.5. Meteorological/Oceanographic institutes

Public meteorological and/or oceanographic institutes are usually responsible for the provision of forecast and nowcast services covering marine areas under national responsibility. This activity is supported by a range of forecasting models which can be local, regional or global in scope. In Europe, such agencies generally run at least a regional atmospheric model to support meteorological forecasting.

The operation of such models requires the regular assimilation of a range of observations to ensure forecast accuracy. In terms of oceanographic data, meteorological models assimilate bulk sea surface temperature and sea ice extent as boundary conditions and also sea surface wind vectors to ensure the accurate location of depressions. Ocean forecasting requires sea-surface temperature, sea-surface height, current vectors, sea-surface wind vectors as well as wave height, period and propagation direction. Salinity measurements and vertical profile data from moorings, drifters and floats are also assimilated where available. Where such models are used for storm surge forecasting, near-shore sea-surface height measurements are also required.

3.2.6. Naval operations support

The support of naval operations encompasses a wide range of operational responsibilities and requires correspondingly large amounts of information of different types all of which must be collected, analysed and disseminated. Routine environmental parameters provided to fleets include wind and wave forecasts as well as ocean forecasts (sea surface temperatures, current structure (both large scale and mesoscale), internal wave regimes, and water clarity and salinity structure)

All these parameters are required to support day to day operational decisions by ship commanders and by the managers responsible for the operation of specific systems (e.g. radar, sonar, mine countermeasures etc). Sea ice conditions are also important in arctic operations both for safety and to predict the operational performance of surveillance systems. In addition, atmospheric parameters such as visibility and total column amounts of atmospheric water vapour are important in predicting the behaviour of particular surveillance and targeting systems.

To support littoral operations, additional information such as oil-slick distribution, water depth/sea surface height, bioluminescence and sediment loading, are required to support decisions on whether to initiate a particular operation and if so, how.

3.2.7. Shipping operators and marine safety

Maritime transport is of fundamental importance to Europe and the rest of the world. As noted by the European Maritime Safety Agency EMSA (http://www.emsa.eu.int) over 90% of European Union external trade goes by the sea and more than 1 billion tonnes of freight a year are loaded and unloaded in EU ports. This means that shipping is the most important mode of transport in terms of volume. Furthermore, as a result of its geography, its history and the effects of globalisation, maritime transport will continue to be the most important transport mode in developing EU trade for the foreseeable future. Shipping operators require wind and wave forecasts to avoid regions where conditions are liable to slow progress or endanger the ship or the crew. In addition, oceanic and meteorological data are used to identify the course to steer to ensure a ship can obtain maximum profit from prevailing conditions. Sea ice maps are of importance to ships operating in the polar environment. For shipping operators moving or towing large structures, additional information on wave period and propagation direction is required.

3.2.8. Fisheries operators

The masters of fishing boats require reliable wind and wave forecasts to support decisions as to when and how to deploy nets and lines. In addition, to help identify fishing zones, SST and Ocean Colour maps are currently provided by companies such as the Orbital Imaging Corporation. The location of upwelling zones (related to high nutrient concentrations hence high fish population) through temperature, nutrient concentration or low surface wind signatures, is expected to enhance the quality of such information services.

Fishing crews operating in polar ocean regions require additional information, in particular on the location of ice edge, iceberg reports, sea ice maps and SST maps (to determine local icing conditions). Managers involved in aquaculture require information on sea-surface temperature and water quality, especially the occurrence of algal bloom events and forecasts of their advection.

3.3. Institutional users

3.3.1. Transport agencies

Depending on the country, delegated responsibilities can include the provision of sea ice information for waters under government responsibility, wind, wave and current forecasting for sovereign waters, updating bathymetry maps, mapping sediment transport and monitoring storm surge/water depths. In general, oceanic and atmospheric data required for forecasting and nowcasting are obtained from the national oceanographic or meteorological institution although additional data may also be acquired and integrated into the information service. Sea ice data are obtained from airborne survey and satellite remote sensing while bathymetry charts are compiled using sonar surveys. These agencies may also operate Vessel Traffic Surveillance (VTS) systems for certain regions (e.g. the UK Coast Guard operate a VTS for the English Channel).

3.3.2. Coast Guard/Fisheries protection

Coast Guards are usually responsible for intercepting illegal incursions into sovereign waters, fisheries protection and search and rescue. In some cases, they may also be responsible for detecting illegal pollution activities and for monitoring water quality. Information requirements therefore include wind and wave forecasts to determine the likelihood of accidents, SST forecasts to estimate immersion survival times and (in combination with nutrient concentration measurements) to determine likely areas for illegal fishing. In addition, sea ice forecasts are required for countries bordering polar seas while the detection of vessels or pollution incidents through the systematic surveillance of the Exclusive Economic Zone must be conducted, usually by airborne surveys.

3.3.3. Coastal/environmental management agencies

The responsibilities of these agencies are complementary to those of the coast guard and cover the monitoring of coastal water quality, harmful algal bloom (HAB) detection, oil spill detection and notification, SST monitoring (e.g. for coral ecosystem protection) and civil protection applications such as coastal wind, wave and current monitoring and storm-surge forecasting and warning.

Information requirements are thus the systematic surveillance of the exclusive economic zone to detect oil spills and algal blooms, the regular and comprehensive sampling of water quality and the measurement of SST, the compilation of coastal meteo/oceanic conditions and the forecasting of storm surges in coastal waters. In general, the main requirement is to verify that conditions do not exceed pre-defined threshold levels (e.g. concentrations of certain chemicals are below legal levels). Additional responsibilities may include the monitoring of sediment transport levels and patterns and shore-side activities such as the monitoring of land cover change and beach erosion.

3.3.4. Port authorities

Port management is usually responsible for the provision of meteo/oceanic information from dedicated measurement stations for the immediate surroundings although this is often integrated with national or regional forecasts of environmental conditions. Depending on location, port authorities will be responsible for the provision of information on winds, waves and currents, sea-ice conditions and water depths (for approach channels). In addition, the port authorities themselves must regularly assess sediment transport in relation to the silting up of access channels and water quality for environmental impact assessment.

3.4. Research organisations

3.4.1. Ocean data centres

Most countries have designated national oceanographic data centres. Responsibilities vary amongst countries but often include the compilation and archiving of baseline regional and global geophysical variables to support analyses and research. Typical parameters include SST, SSH anomalies, temperature-salinity profiles, ocean primary productivities, wind and/or wave atlases, tide gauge measurements and bathymetry and sea-bed lithology measurements. Such centres often maintain dedicated in-situ data gathering capabilities and devote significant efforts to the development and operation of local and regional models.

3.4.2. Oceanographic researchers

The objectives of oceanographic research include advancing understanding and modelling of ocean processes and of air-sea interactions and the more precise characterisation of the role of the oceans in the various Earth system and climate cycles. As such, the range of information required is vast and cannot be sensibly characterised here. However, illustrative examples of on-going analyses include:

- the description and characterisation of the main features of ocean circulation, their dynamics and their interactions;
- the determination of intra-seasonal and intra-annual variability;
- the measurement of mesoscale and coastal variability associated with ocean current movements and the formation and propagation of eddies important in heat transport;
- the analysis of biochemical processes and their correlation with physical parameters;
- mean sea-level trend assessment.

The oceanographic research community is very keen to exploit satellite remote sensing data and sufficiently expert to specify information requirements in terms of satellite and instrument operating parameters.

3.4.3. Climate Users

Climate research has relied heavily on Earth Observation satellites for over a decade and the user community has a similar level of expertise as the oceanographic research community. Examples of current activities include the systematic long-term observation of ocean topography and sea-level using uniform altimetry products from inter-calibrated altimeter mission data referenced to accurate and precise geoid information. The analysis and modelling of the El Nino Southern Oscillation (ENSO), and North Atlantic Oscillation (NAO) dynamics, for example are of considerable interest to many nations and are addressed within several international collaboration efforts. In conjunction with altimetry, systematic measurements of sea-surface temperature (SST) data have been carefully assembled from ATSR, with which to robustly detect systematic climate-related changes in ocean heat storage on timescales up to and exceeding a decade (requiring 0.1K/decade accuracy). To ensure contingency of such valuable climate research data sets it is essential to aim for overlap in satellite operations with comparable instrumentation.

Developments in determination of the associated climate impacts of air-sea exchange processes require collocated observations of quantities contributing to the fluxes of momentum, heat, water vapour and greenhouse gases such as CO_2. Physical oceanography variables such as mixed-layer depth, sea-surface temperature, surface winds, and horizontal and vertical advection and mixing, play a critical role in the cycle of carbon and other biogeochemical tracers via their influences on the carbonate chemistry and biological processes in the ocean. Physical variability is a dominant driver of biogeochemical variability on diurnal, seasonal and inter-annual time scales, thus requiring higher resolution in coastal zones, where mesoscale circulation patterns dominate biogeochemical activity. Ocean uptake of, and transport of carbon and other biogeochemical tracers is generally regulated by the "solubility pump" (i.e. partial pressure pCO2 in surface waters), the "biological pump" (i.e. phytoplankton photosynthesis), and the dynamical state of the ocean. Quantification of the solubility pump requires knowledge of SST and wind speed (RD33) while quantification of the biological pump requires knowledge of the primary production, derived from estimates of near surface Chl a. In locations and instances where the biological pump dominates over the solubility pump, such as in coastal upwelling zones, specific knowledge of the limiting impact of Nitrate in surface seawater is required

(RD34). Determination of Nitrate relies on temporally and spatially coincident Chla and SST measurements.

Despite climate products requirements generally calling for 1 km or lower resolution, evidence from OCTS data on ADEOS-1 indicates that coverage of simultaneous, collocated Chl a and SST with a resolution finer than several hundred metres, is required to effectively capture the time-space variability in ocean characteristics which regular Carbon flux in the high-productivity coastal zones. Generally, simultaneous measurements of both sea surface temperature and ocean colour at 1 km resolution are required as essential parameters in order to estimate the distribution of pCO_2 and Nitrate (RD33; RD34) in the remainder of the global ocean.

Cryospheric elements of climate system research include the modelling of ice mass balance and the monitoring of changes in sea ice cover both as an element linking, for example, Pacific and Atlantic processes and also as part of albedo determination for radiation budget modelling. Current climate requirements also exist for ice surface temperature (IST) over the high-latitude oceans, for NWP model boundary conditions.

3.4.4. GOFC-GOLD

The Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) is a coordinated international effort working to provide ongoing space-based and in-situ observations of forests and other vegetation cover, for the sustainable management of terrestrial resources and to obtain an accurate, reliable, quantitative understanding of the terrestrial carbon budget (see: GOFC-GOLD Web Site). GOFC-GOLD has suggested a systematic program for coarse resolution (250 - 1000 m) land cover mapping on a five year cycle, combined with periodic mapping and monitoring of forested areas at fine resolution. Very large datasets from a wide range of sensors have to be acquired, assembled, processed, and analysed, by combining the data assets from Sentinel-3 and Sentinel-2, respectively.

3.5. ESA GMES Service Providers

The ESA GMES Service Element (GSE) focuses upon the delivery of policy-relevant services to end-users, primarily, but not exclusively, based on Earth Observation data sources. Several consolidated service portfolios at European level and Regional level, express data requirements relevant in the context of GMES Sentinel-3:

European Level:

- Marine and coastal environmental information services (MarCoast)
- Polar environment information services (PolarView)
- Land cover and Land use change information services (GSE-Land)

Regional level:

- Forest monitoring information services (GSE-FM)
- Flood and Fire risk management services (Risk-EOS)
- Food Security information services (GFMS)

In addition to these there are GSE services for Atmospheric Pollution, Maritime Security, and Humanitarian Aid which will benefit from the information provided by Sentinel-3.

3.6. EU GMES Core Services

The main relevant European Union efforts dedicated to GMES Marine Core Service (MCS) and Land Core Monitoring Service (LMCS) development are taking place within the sixth Framework Programme (FP6) managed by DG/ENT, European Commission. Activities financed under FP6 include Integrated Projects, Networks of Excellence, Strategic Targeted Research Projects (STREPs) and Specific Support Actions addressing various aspects of GMES. Examples include the MERSEA and GEOLAND FP6 Integrated Projects addressing the development and testing of new, so-called "fast track" oceanographic and land cover information services by 2008. Further details about these EU Projects and Services may be found at: www.gmes.info.

At programmatic level, the GMES Programme Office and the GMES Advisory Council help ensure that activities financed by different stakeholders and programmes are managed in the most efficient manner possible and respond to programmatic and political priorities. Meanwhile, at individual project level, workshops such as GMES Services Element Collocation meetings ensure that mechanisms are agreed for exchange of information and capabilities, such as to establish a common approach to the delivery of services to GMES user organisations identifiable via Service Level Agreements.

Table 1 (below) indicates a matrix indicating the general classes of GMES requirements together with the corresponding Services with those requirements relevant to Sentinel-3.

Table 1: Summary of GMES Services and Service Providers expressing Sentinel-3 data requirements.

Type of Service	GMES Service Provider*
Marine & Coastal Environment	GSE-MarCoast, EC MCS, FP6 MERSEA
Land Cover state & changes	GSE-Land, EC LMCS, FP6 GEOLAND
Atmospheric Pollution Management	GSE-PROMOTE
Risk Management (Fires & Flood)	Risk-EOS
Forest Monitoring	GSE-FM
Food Security	GSE-GMFS, EC MARS Food
Maritime Security (Transport, Coastal, Ice Monitoring)	GSE-MarCoast, GSE-PolarView, FP6 MERSEA
Humanitarian Aid	GSE-RESPOND, FP6 LIMES
Climate & Global Change Issues	Includes elements of most above services

*Follow links or see Appendices A-G for further details on listed services.

3.7. User Service Requirements

Using the grouping of end users as defined in the previous chapters their requirements have been identified based on surveys (RD26) and previous studies (RD19, RD20, RD25, RD44). Since it is beyond the scope of this document to explicitly list or summarise all individual requirements, a masterlist of sources is provided in Appendices B-H as a source for further requirements information. The following general requirement summaries are outlined to provide an overview of the general parameter requirements.

3.7.1. Operational Oceanography Users

Apart from naval operations support, most operational oceanography service providers and users rely heavily either on forecasting models operated by the national meteorological or oceanographic organisations, or the models currently operational under the EC Marine Core Service (MCS). The precise quantitative characterisation of the requirements to be satisfied by the information provided by these bodies is difficult as it is almost always used within a decision support system. It would therefore be necessary to evaluate the impact of different service performance levels on decision effectiveness and this is presently not feasible. Having noted this, however, there are certain requirement thresholds which must be exceeded for the information to have any value and certain characteristics which the information service must possess. These are summarised in Table 2 (below).

Table 2: Operational Oceanography User Requirements* (ranked by delivery requirement)

Parameter	Delivery Requirement	Revisit Time	Coverage Requirement	User
Wind-wave forecast	Near real time	3-6 hours	Regional-Global	MCS, MarCoast
Sea Surface Temperature	Near real time	6 -12 hours	Local, Regional and Global	MCS, FP6 MERSEA, MarCoast
Surface current vectors	Near real time	½ hour-6 hours	Local-Regional	MCS, MarCoast
Algal blooms	Near real time	1-3 days	Local-Regional	MCS, MERSEA, MarCoast
Temperature-salinity profile	3-6 hours	Daily	Regional	MCS, MERSEA, MarCoast
Water quality parameters	6 hours	1-3 days	Local	MCS, MERSEA, MarCoast
Sea Ice Extent and Thickness	24 hours	Daily	Regional	MCS, MERSEA, PolarView

* detailed requirements descriptions for individual applications are available in RD26.

Time scales of interest for forecasting range from 3-6 hours to 1-3 days. In contrast to, and distinct from, the meteorological and oceanographic institutes who provide regional data to support institutional requirements (see: Table 3), most operational users are interested in information only in the immediate vicinity of the site of their operations thus simplifying the discussion of scales or spatial resolution requirements.

Where exceeding a certain threshold situation triggers an alarm, typical requirements are the probability of detection of exceeding a threshold in excess of 95 % while probability of false alarm (i.e. a false indication of threshold violation) should be below 10 %. The majority of contracts for forecasting services specify a baseline level of forecast accuracy to be achieved, usually in the 70-80 % range.

3.7.2. Institutional Oceanographic Users

As institutional users want knowledge of similar phenomena, information requirements (Table 3) are often similar to those of the operational user community (the distinction is not always clear). The main difference compared with Table 2 lies in the coverage requirements.

Table 3: Institutional User Requirements (ranked by delivery requirement)

Parameter	Delivery Requirement	Revisit Time	Coverage Requirement	User
Wind-wave forecast	Near real time	3-6 hours	Regional-Global	NWP, EuroGOOS
Sea Surface Temperature	Near real time	6-12 hours	Regional-Global	GHRSST-PP, DUE Medspiration, NWP, EuroGOOS
Surface current vectors	Near real time	12 hours - daily	National waters-Regional	EuroGOOS
Algal blooms	Near real time	1-3 days	National waters-Regional	DUE GlobColour, EuroGOOS
Water quality parameters	6 hours	1-3 days	National waters	DUE GlobColour, EuroGOOS
Sea Ice Extent and Thickness	24 hours	1-3 days	Regional-Global	GlobICE, EuroGOOS

Operational end users tend to have stronger time constraints although acceptability thresholds are similar. Threshold alarm requirements are similar to those of the operational user community although there may be slightly stronger detection requirements (in excess of 97 – 98 %) with a correspondingly greater tolerance of false alarms.

In terms of ranking, a previous EuroGOOS survey of the institutional user community in Europe identified sea surface temperature and surface current data as being the two highest priority operational datasets.

3.7.3. Oceanographic Research Users

Research user requirements tend to focus on the quality of the information provided rather than on parameters such as delivery time, update frequency or format etc. These have largely been translated into the GMES Sentinel-3 Performance Requirements documented in the following sections. EuroGOOS statements on satellite observation requirements can be regarded as encompassing the needs of the oceanographic research community and these are also specified in more detail in the following chapter.

Major oceanographic research institutes each with their own state of the art ocean circulation model have grouped together in the EU FP6 MERSEA integrated project with the aim to pave the way for the transition from pure scientific analysis towards operational and routinely delivery and exploitation of ocean state parameters. Within MERSEA, four state of the art ocean models have been selected as a core set for the development of a general and global model system (Table 4) within which specific regional modelling and forecasting systems can be embedded at a later stage.

Within MERSEA Strand-1, the analysis has established a set of essential remote sensing measurements, *i.e.* the input data without which the model should not be considered reliable. Regarding satellite measurements the emerging key data requirements for the four MERSEA core data assimilation systems are similar and correspond closely with those previously identified for GODAE. These requirements are summarised in Table 4. It should be noted that although they are specific about the type of measurements needed, they are expressed qualitatively in respect of the sampling resolution and accuracy targets. These largely reflect the data already being used by the models, and for which continuity is required. There is continuous effort within MERSEA and other projects to exploit improved data products. It is to be expected that increasing model resolution for all models, will lead to a revision of satellite data requirements.

Table 4: MERSEA models: minimum EO data requirements

Model Parameter	**TOPAZ** (20-30 km)	**MERCATOR** (1/15°)	**FOAM** (1/9°)	**MFS** (1/15°)
Sea Surface Height	SSALTO/DUACS Gridded, weekly Sea-level anomalies	SSALTO/DUACS along-track data	SSALTO/DUACS along-track data	Along-track SLA Fields from available altimeters
Sea-Surface Temperature	1/4 ° resolution weekly data fields from CLS	Reynolds 1° resolution data (too coarse)	50 km resolution, AVHRR twice weekly, 5 km Atlantic data, in situ observations	Weekly from Satellite measurements.
Ocean Colour	Tested assimilation of SeaWifs data – positive impact	N/A	N/A	N/A
Sea Ice	Sea ice concentration, daily, 25 km resolution	N/A	Sea ice concentration from Canadian Met Centre (SSM/I)	N/A

3.7.4. Land Users

Within the framework of GMES a considerable number of established services and applications rely on the use of low/moderate resolution EO optical image data (Table 5). These services are mostly situated in the framework of global services and are directed primarily towards the support of policies addressing global change and sustainable development. Within the FP6 GEOLAND Integrated Project, for example, such data are largely focused on supplying generic information on bio-geophysical attributes of land surfaces from regional to global scale. Complementary EO Services and ESA DUE or DUP projects rely on the same class of optical image data.

The GSE Forest Monitoring (GSE FM) service was specifically established to address the policy related demands of the forestry and land use sector. Already consolidated services relate to information needs of environmental policies such as the United Nations Framework Convention on Climate Change (UNFCCC). In addition, forest monitoring services are under development to deliver information such as yearly carbon balance information, forest disturbance data, as well as products for practical forest and land use management. Together these services deliver products allowing governance within the forestry sector, as well as sustainability as a paramount consideration.

From an agricultural monitoring standpoint, the objective of key GMES services such as the GSE Global Monitoring for Food Security (GMFS) project is to improve the provision of operational and sustainable information services, derived at least partly from EO data, to assist food aid and food security decision makers from local to global level. Daily to weekly EO data products are generally required at continental or global scale (at sub-kilometre resolution) to complement existing regional information and early warning systems on food and agriculture.

Finally, in the context of risk management, the GSE Risk-EOS service focuses mainly on floods management and forest fires.

Table 5: Land User Requirements (ranked by delivery requirement)

Parameter	Delivery Requirement	Revisit Time	Coverage Requirement	User
Biophysical Parameters	Near real time	12-24 hours	Regional-Global	LCMS, GEOLAND, GMFS, GlobCarbon RESPOND
Vegetation Condition & Crop Monitoring	Daily	Daily	Global	GMFS, LCMS, GEOLAND,
Land cover mapping & Change Detection	Six-monthly	Daily	Regional-Global	GMFS, GSE-Land, GSE-FM, Risk-EOS, GlobCover GSE-RESPOND
Active Fire Monitoring & Effects Mapping	Near real time	Daily	Global	GOFC-GOLD, Risk EOS

4. Mission Objectives and Requirements

4.1. Measurement Priorities in the context of existing and planned missions

4.1.1. Ocean Measurement Priorities

The products and services delivered from numerical weather prediction centres as well as from the growing number of pre-operational and operational oceanographic monitoring and modelling systems all require access to integrated observations. The EuroGOOS Space Panel report (RD8), the EuroGOOS operational oceanography data requirements survey (RD7), the IGOS Ocean Theme report (RD5), the operations of EUMETSAT Satellite Application Facilities (i.e. CM-SAF, OSI-SAF), and the joint EC-ESA GMES initiative are fully compliant with this view. Similarly, the requirements for integrated observations are outlined in the plans for the Global Ocean Data Assimilation Experiment (GODAE) and the strategy for “Observing the Oceans in the 21st century” (RD13).

Capitalizing on the conclusions and recommendations from projects and initiatives such as SIREOC (RD25), the GHRSST Pilot Project (RD24; RD43) and GAMBLE (RD27), as well as the emerging preliminary results from MERSEA Strand-1 (RD21), and the WCRP Satellite Working Group Report on Space mission requirements (RD36) it is documented and commonly agreed that operational oceanography systems are significantly relying on routine and homogeneous availability of data derived from polar orbiting satellites. In the context of the main gaps in our knowledge, technology and tools that need to be filled, the following priorities are identified (not in any particular order of priority):

- A multi-satellite system for high resolution altimetry should be established and sustained indefinitely. Meanwhile, there is an urgent need to fly a high-inclination, near-polar orbiting altimeter mission to succeed ENVISAT. This mesoscale altimeter mission is needed to complement Jason-2 and to constrain in a satisfactory way the mesoscale variability and open ocean currents. Without this mission, the GMES ocean monitoring system (i.e. including Sentinel-3 + Sentinel-1) will not be adequate for several major applications (e.g. oil spill and pollution monitoring, search and rescue applications, boundary conditions for coastal models and their applications, etc).
- A long-term commitment is needed to provide high quality high resolution SST measurements from satellites, following the multi-sensor strategy proposed for the GHRSST-PP. This implies the need to maintain at least one sensor in orbit having measurement stability and accuracy equivalent to that of the ATSR series of sensors, as recommended in the IGOS Ocean Theme Team report (RD5).
- Measurement of wind vectors over the sea with 25 km resolution and global daily coverage must be made available in support of operational basin-scale ocean forecasting models to secure precise estimates of momentum forcing, turbulence parameterisation and heat and gas exchange fluxes at the ocean/atmosphere interface.
- An ocean colour sensor with the improved spatial resolution and flexibility of MERIS, but also near real time data delivery, is required in order to meet rather more stringent needs of biological monitoring in Case 2 coastal waters. For coastal applications there is a need to co-locate ocean colour observations with observations of sea surface temperature.

Taking into account the above priorities, the user information needs, and existing plans for the operational provision of scatterometer vector winds by the approved METOP series, the primary variables that are required to be measured by the Sentinel-3 GMES Sentinel-3 mission are:

- **Sea-Surface Height (SSH)**
- **Sea-Surface Temperature (SST)**
- **Ocean Colour (OC)**

4.1.2. Land Measurement Priorities

The continuity in optical instrument capabilities equivalent to those of presently operating space infrastructure (MERIS, MODIS, AATS/R, and Spot VGT) is critical to the continuity of existing GMES land and environment services. By 2010-2012, it is foreseen that all of these low-moderate resolution optical instruments will have reached the end of their operating lifetime, potentially leaving a gap in data streams for dedicated global land applications.

Taking into account the above priorities, and the secured future access to 1 km resolution METOP AVHRR data, what is required is a Sentinel-3 mission which can deliver multi-spectral data streams spanning the Visible and Infrared range, with a resolution commensurate with mapping fragmented landscapes at district and regional scale. Since Spot VGT 1km resolution is too limited for reliable land cover change detection, what is required is a broad swath sensor with resolution in the range 300 – 250 m. However, the challenge is to design a mission which can provide the daily global acquisition capability of VGT, in order to compensate for the cloud contamination. The result should be a system with the capability to deliver global cloud free land products at intervals of 1 week to 10 days.

The GMES relevant applications that are now operational or close to operational exploitation require guaranteed access to the following parameters:

- Vegetation health monitoring, carbon budget assessment, and climate modelling (i.e. biophysical parameters such as Leaf Area Index; Fractional Cover of Vegetation; and Fraction of Absorbed Photosynthetic Active Radiation);
- Food Security (i.e. crop management, crop yield estimation);
- Land Cover mapping & change detection (including deforestation and land degradation)
- Mapping and monitoring of active fires and burned surfaces (as input to climate change and atmospheric models)
- Surface water resource monitoring (i.e. rivers and lake levels).

Taking into account the above priorities, the user information needs, and secured provision of AVHRR on the METOP series, the primary variables that are required to be measured by the Sentinel-3 GMES Sentinel-3 mission are:

- **Land Colour (LC)**
- **Land-Surface Temperature (LST)**
- **Water Surface Level (River and Lakes)**

4.2. Ocean mission objectives

The request to ensure continuity for ocean altimetry after Envisat RA-2 and Jason 1 has been consistently expressed in several reports such as the *IGOS Ocean Theme Team* report, the *GAMBLE* project (RD27) and the *Roadmap for Operational Oceanography* Study Report (RD26; RD41). These projects provide a succinct summary of the future requirements and scenarios for the best possible implementation and exploitation of future altimeter instruments. The altimetry component of the GMES Sentinel-3 mission is considered as essential and is most demanding with respect to ensuring continuous, well-calibrated, long-term observations. In order to support the ongoing products derived from altimetry, there is a long term need for continuity of a polar-orbiting altimeter to enhance the temporal/spatial coverage of the global ocean. However, when considered single-handedly, the existing Jason-1 and planned -2 series of high precision altimeters (with an inclination of 66° and 10-day repeat orbit) do not meet the requirement for altimeter coverage of all of the high-latitude European shelf Seas. Their coverage is limited to the Atlantic region between the equator and 66° North and thus the region south of Iceland. In order to successfully resolve ocean mesoscale activity and tidal processes in shelf seas, the Jason sampling grid (300 km orbit track spacing at mid latitudes) must be supplemented by another altimeter acquiring intersecting ground tracks. For this reason it is acknowledged that GMES Sentinel-3 should provide complementary ocean altimeter coverage in a high inclination orbit, for optimal merging with Jason-2 (where this mission is assumed to have identical orbit parameters to Jason-1).

The high-inclination orbit of Sentinel-3 brings the added benefit of routine altimetric observations of marine and land ice in the Arctic and Antarctic high-latitude regions. GMES Sentinel-3 shall provide continuity to the high-resolution along track marine and land ice surface measurements of CryoSat, and shall result in the continued ability to derive sea-ice thickness and ice sheet topography from elevation profiles.

A combination of physical ocean data (dynamics) and biological data (colour) have led to new scientific insights with respect to circulation and its connection with biological productivity in the upper layer of the ocean, such as the occurrence of plankton blooms along internal waves. Although reliable correlations are yet to be established for the occurrence of algal blooms, the underlying processes of photosynthesis and phytoplankton productivity (derived from the combination of ocean colour and sea surface temperature data) are key inputs to carbon models. Also it must be borne in mind that information on sediments etc. is important for those concerned with inland waters and coastal zones (defined here as the area enclosed within a distance of 300 km from the coastline). Thus, the potential future need for simultaneous high accuracy observations of ocean colour with high accuracy sea surface temperature observations (for the accurate estimation of oceanic carbon fluxes) presents a direct challenge to Europe, namely to ensure the long term provision of collocated high accuracy ocean colour and high quality sea-surface temperature measurements.

It is recognised that selected sensor capabilities will extend naturally beyond independent measurement requirements stated above, and that additional requirements will be addressed with the instruments selected and embarked upon the GMES Sentinel-3. For instance, the GMES Sentinel-3 will also address terrestrial applications, particularly in the coastal hinterland, by way of its required consistency in capability to the Envisat MERIS and AATSR sensors. Further applications will arise in synergy with the other GMES Sentinel 1 (C-band SAR) and Sentinel 2 (High-resolution Visible Imager). Nevertheless, since these requirements do not drive the Mission Requirements they are not documented explicitly here, and instead are captured by the respective Mission Requirements Documents (RD31, RD32).

In addition to requirements on accuracy and spatial/temporal sampling the operational aspect of the GMES Sentinel-3 mission will have specific needs for fast delivery of data products. The inadequate delivery and processing facilities are the main reason why existing RS satellites are of limited use for operational services. This applies to data products of all instruments discussed in the following chapters.

4.3. Land mission objectives

As the GMES Sentinel-3 mission will provide global observation capability, land applications are also recognised as an important set of mission objectives. These objectives are to provide systematic access to global biophysical products at such as Land Surface Reflectance, Leaf Area Index (LAI), Fractional Coverage of Green Leaves (fCover), fraction of photosynthetically active radiation (fAPAR), Active Fires, Burnt Area, and Land Surface Temperature (LST) for GSE Land Services, Geoland and other linked GMES Land Monitoring Core Services (See: Appendix H).

On land, soil and canopy temperature are also among the main determinants of the rate of growth of vegetation and they govern seasonal start and termination of growth. Hydrologic processes such as evapotranspiration and snow and ice melt are highly sensitive to surface temperature fluctuation, which is also an important discriminating factor in classification of land surface types. Thus snow/cloud discrimination and Land Surface Temperature (LST) is fundamental to delivering effective land products, especially for the northern hemisphere during the winter season.

The requirements that land applications place on the mission concept design shall, in so far as possible, be optimised for consistency with existing MERIS and A-ATSR spectral bands, provided that they allow maintain continuity of global data products such as NDVI from SPOT VEGETATION (VGT), or MERIS Global Vegetation Index (MGVI) and MERIS Terrestrial Chlorophyll Index (MTCI). Further details of complementary, yet non-global, high resolution land requirements are covered in the Mission Requirement Document of the ESA GMES Sentinel-2 mission (RD31).

In addition to the variables listed above ice-surface temperature (IST) and snow and sea-ice extent and albedo are recognised as important variables of secondary priority. Though these should not override and drive the mission system design, the resulting mission concept shall be able to address such additional snow/ice parameters through the combination of a high-inclination orbit and appropriate instrument capabilities (i.e. altimeter with along-track sampling resolution, and optical instruments with appropriate spectral bands for day/night cloud/ice/snow/water discrimination).

4.4. Other mission objectives

4.4.1. Atmospheric Properties

All surface measurements performed by Sentinel-3 optical sensors require detailed attention to the effects of intervening atmospheric properties, such that robust, cloud-screened, calibrated and corrected radiances may be reported. By definition this requires careful retrievals of atmospheric properties such as cloud and aerosol concentrations, together with generation of appropriate accompanying error statistics.

Fundamentally, the precision and accuracy of the SST retrievals, and land surface parameters, are to a high degree dependent on precise quantitative knowledge of aerosol optical depth and cloud contamination. Experience with ATSR and A/ATSR dual-view measurements, shows that aerosol contamination is a particular hazard for climate-quality surface temperature retrievals. Recent results (RD46) indicate that this is particularly true in large areas of the world experiencing regular dust storms (e.g. Saharan dust over the Mediterranean and Atlantic Ocean). Aerosol effects of up to several Kelvins from such mineral dust storms require a high performance combination of dual view capability coupled with Visible and near-Infrared channels, in order to correct the absorption effects on the Thermal band retrievals of SST and LST.

Currently, there are well developed cloud and aerosol detection schemes available for operational use based on services developed under the ESA DUE GlobAerosol and GSE Promote/TEMIS Projects. The large-scale datasets that they currently produce using Envisat AATSR and MERIS are a vital component of the GMES air quality services as well research into climate forcing of aerosols (i.e. global dimming).

4.4.2. River and Lake Level Monitoring

Altimetric gauging of river and lake water levels is a secondary mission objective connected to requirements for water resources management and flood risk monitoring. Though currently not explicitly required by the GSE Respond or Risk-EOS projects, the river and lake level monitoring goal is of fundamental importance to understanding the role freshwater cycle in climate.

This secondary application foresees the need for altimetric elevation estimates of the surface of certain inland water bodies and large rivers. This requires the altimeter tracking to be sufficiently agile to make valid elevation measurements in highly variable topography, together with high along-track resolution.

This requirement shall not compromise the ability of the altimeter to meet the primary ocean and ice topographic mission objectives.

4.5. Measurement Heritage

4.5.1. SSH and elevation profiles

The development of altimetry has been steady and the benefits outstanding. There have been a quasi-continuous series of missions, starting with GEOSAT (1985), and followed by ERS-1/2 (1991 and 1995) and Topex-Poseidon (1992). Such missions have continued with GEOSAT Follow-On (1998), JASON-1 (2001) and Envisat RA-2 (2002). At present, only altimeter systems are capable of measuring sea-surface height (SSH), with which ocean circulation patterns and sea level are determined on a global scale. Altimeter systems also provide collocated measurements of significant wave height and scalar wind speed (at nadir), useful in their own right as assimilated or as independent validation data products for model-forecasted winds. On the user side, the Global Ocean Observing System "*requires global, near real-time, high accuracy and high resolution observations of sea surface topography*" from "*at least three (and preferably four) altimeter missions with one very accurate long term altimeter system*". In the near-term the future looks promising with a two-satellite altimeter system being maintained for the next several years with altimeters on JASON-1 and Envisat. GEOSAT-FO (GFO) is currently available as a third mission but with severe performance degradations. From 2009 onwards, the CryoSat Earth Explorer mission will provide for the first time (in addition to sea-surface topography) very accurate observations of marine ice surface topography ain ice-covered polar oceans with high-spatial resolution. The CryoSat altimeter concept, using synthetic aperture (Delay-Doppler) techniques for enhanced along-track resolution, could extend support operations in coastal waters (both ice-covered and ice free) and thus make significant advances with respect to conventional altimeters. Although without a microwave radiometer, CryoSat is also being prepared for studying its capability for near-real-time ocean data delivery using its conventional altimetry mode, in response to a GAMBLE Study recommendation (RD27).

4.5.2. SST

Since the late 1970's, Sea Surface Temperature (SST) measurements have been operationally available from the AVHRR imagers flown on the NOAA/TIROS meteorological satellites. Although AVHRR was not tailored to this mission, it is still providing valuable data. Significant improvements in performance were introduced in the early 1990's by the ATSR-class instruments on the ERS satellites to be followed by the second generation on Envisat. Routine high-quality SST observations from these polar orbiting instruments are also complemented by high temporal frequency SST data from instruments such as SEVIRI on the MSG geostationary platform, and low resolution all-weather, global data from the AMSR-E microwave sensor on EOS Aqua. The requirements formulated for the Global Ocean Observing System call for "continuation of the geostationary and low-earth-orbit meteorological satellites that produce merged sea-surface temperature data products" and for "continuity of the higher accuracy ATSR-class measurements". Though AVHRR continuity is assured by the METOP series, only ATSR-class measurements approach the accuracy required for climate modelling and climate change prediction/detection (i.e. a high absolute accuracy < 0.3 K combined with long-term radiometric stability of 0.1 K/decade). As atmospheric correction schemes are critical for accurate SST estimates, only an ATSR-type dual-view instrument can assure this quality in particular for times with high aerosol loadings in the atmosphere (i.e. Pinatubo volcano events)

In the ice covered hi-latitude oceans, under clear sky conditions, ice surface temperatures (IST) are also derived from thermal infrared sensors on polar-orbiting satellites such as AVHRR using 10.3 – 11.3 micron measurements. Ice surface temperatures (IST) are presently used as surface boundary conditions in both climate models and numerical weather forecasting models.

4.5.3. Ocean Colour

Since the success of Coastal Zone Colour Scanner (CZCS) on Nimbus-7 a number of overlapping missions have been launched, that focus on ocean colour observations to serve climate research and coastal monitoring. SeaWIFS on SEASTAR, MOS on IRS-P3, MODIS on the EOS AQUA and TERRA spacecraft, and MERIS on Envisat are currently providing a wealth of valuable data upon which valuable operational services have been built. Beyond Envisat, only the VIIRS sensor, planned to fly on the NPOESS satellites, will provide ocean colour data. But, a potential future need for co-incident high accuracy observations of ocean colour with high accuracy sea surface temperature observations (for the accurate estimation of oceanic carbon fluxes, coastal and water quality management) presents a direct challenge to Europe, namely to ensure the long term provision of collocated high accuracy ocean colour (of MERIS class) and sea surface temperature measurements (of ATSR-class). A combination of physical ocean data (dynamics) and biological data (colour) have led to new scientific insights with respect to circulation in the upper layer of the ocean, such as the occurrence of algae blooms along internal waves. Although a reliable correlation is yet to be established for the occurrence of algal blooms, the underlying processes of photosynthesis and phytoplankton productivity could (derived by the combination of ocean colour and sea surface temperature data) be key inputs to carbon modelling. Also it must be borne in mind that information on suspended sediments, toxic algal blooms and yellow substance are important for those concerned with coastal zones and inland waters, and particularly in estuarine environments, thus desiring 250 m resolution.

4.5.4. Wind and Ocean Waves

In addition to standard ranging measurements and SSH products, altimeter data allow estimates of wind speed and significant wave height (SWH) through relatively well understood geophysical inversion algorithms based on peak backscattered power and the shape of the waveforms. SWH measurements have been shown to compare satisfactorily with collocated in situ buoy wave height estimates. Systematic bias is less than 0.1 metres and random bias on individual passes is ≈0.25 metres, but these accuracies are understood to decrease for very low and high wind conditions (RD27).Importantly, wind and wave estimates are also required for correction of the ranging uncertainty known as 'sea-state bias'. SSH is usually estimated from the centre point of the waveform leading edge, but estimates of sea surface height are affected by the skewness of the wave statistics, or non-Gaussian statistics of wave elevation and slope. Due to the non-linear processes that generate such ocean waves, the mean sea level is underestimated. This error is currently corrected in operational altimeters using an empirical dependence on the altimeter wind speed and significant wave height data.

Wind and ocean wave products are of scientific value and interest in marine forecasting, offshore platform design and operations, and ship routing. Though the spatio-temporal coverage of altimeter wind measurements makes them of limited value in numerical weather forecasting models, accurate measurements are extremely useful as independent validation of the accuracy of marine forecasts. Such products become of greater interest and practical value with multi-satellite measurements including scatterometers, combined with in-situ measurements. This provides improved time-space sampling for resolving temporal and spatial variability. The altimeter on GMES Sentinel-3 will contribute to this improved wind- and wave sampling.

4.6. Ocean Topography Requirements

Observation requirements for Sea Surface Heights (SSH) from the altimeter must support operational global ocean circulation structure and variability analysis, and research on improving an understanding of mesoscale variability and mean sea level trend analysis. Since spatial and temporal sampling are determined by the orbit, the orbit shall be optimised with respect to the planned altimeter-bearing missions, such as to be able to observe Kelvin and Rossby waves in the equatorial regions, and mesoscale eddies in mid-latitudes. Assuming a minimum of two altimeters, the principal SSH goals of GODAE are to capture global variability on the following scales:

- Large scale: 100 km resolution maps every 10 days to 1-2 cm accuracy
- Mesoscale: 25 km resolution maps every 7 days accurate to 2 cm

Both the above requirements rely on an optimal combination of the available multi-mission altimeter data to be able to achieve these goals.

The typical amplitude of mesoscale signals is 4 to 8 cm rms in the open ocean, and 20 to 40 cm rms in the high eddy energy regions (RD27). A 2 to 4 cm measurement noise (for a 1 second average; or 1 Hz sampling) is thus satisfactory but a smaller noise and/or improved along-track resolution may allow better estimation of the along-track sea level gradients (and thus cross-track velocity fields), or a more detailed analysis of eddy structure in the along-track direction.

4.7. Wind and Wave Requirements

Observation requirements shall support operational wave and wind-speed (derived from σ°) forecasting. This requires measurement of significant wave height and sigma naught (σ°) to certain degrees of precision and accuracy. The accuracy of Envisat RA-2 or Jason is considered an adequate baseline for this purpose. This would indicate a required threshold SWH accuracy of 20 cm or 4 % of SWH for 1 second averages in the 1 - 20 m valid domain. A goal of 5 cm or 1 % (whichever is greater) is expected based on further processing such as retracking (RD28).

The embedding of a microwave radiometer would allow collocated integrated water vapour measurements. These can be exploited for monitoring the atmospheric column contents of tropospheric water vapour to correct the altimeter height estimates, and to constrain numerical weather prediction models. Rain information may also be derived from combinations of the altimeter and radiometer data, and can be used for characterisation of the cloud liquid water path induced delay.

Table 6: Measurement Requirements for Altimetry (*)

Parameter	**Range**	**Fast Delivery** (<3hr)	**Climate Goal** (offline)
SSH	-	10 cm**	3.5 cm
Significant Wave Height	0.5 - 20 m	4% (= 8 cm @ 2 m)	1% (= 2 cm @ 2 m)
σ° Windspeed	-10 dB — +50 dB 0 — 20 m/s	±1.0 dB *rms*, 0.017 dB/s *stability**** 2.0 m/s	±0.5 dB rms, 0.017 dB/s *stability**** 1.5 m/s
Along track sampling	-	<10 km (open ocean) <300 m (over sea ice)	1 km (open ocean) <300 m (over sea ice)
Coverage	-	3-10 days (to be optimised with other Alt missions)	
Revisit time	-	2-3 days	

* Specified for 1-Hz averaged along-track samples.

** Note that sea-state bias remains a significant source of uncertainty that is instrument/frequency dependent. This could have a particular influence on any decision to change from the more traditional heritage Ku-band altimetry of the previous missions.

*** Stability computed using averages over 30 second intervals.

It is recognised that rigorous inter-satellite calibration and external calibration will be required to correct for calibration biases, and in order to maintain long-term uniform performance over a 20 year operational lifetime.

4.8. Ocean Colour Requirements

Observation requirements to support the operational and institutional information services, the oceanographic research community and European contributions to climate analysis must support the monitoring of marine ecosystems, coastal water quality, bio-geochemistry (carbon cycle) investigations, and research into the dynamics of the upper ocean and Earth radiative budget modelling. This requires observations of the concentration of the pigment Chlorophyll-a (*Chl*), total suspended material (*TSM*), the optical diffuse attenuation coefficient (*K*), and the photosynthetically active radiation (*PAR*). The latter are required to define the in-water light field that stimulates photosynthesis in ecosystem models. Open ocean models are rapidly developing towards assimilation of near-real time *Chl*, *K* and *PAR* for estimates of global primary productivity. In the shelf seas, water quality monitoring is a high priority, and *K* and *PAR* are required assimilation inputs to marine ecosystem models. Near real time *Chl* and *TSM* products are needed for marine environment management and for reporting on algal biomass distribution and evolution, harmful algal blooms (HAB), eutrophication, sediment distribution, concentration and transport.

Table 7: Geophysical parameters and accuracies for Ocean Colour (under clear daytime conditions)

Parameter	**Range**	**Accuracy Case 1 water**	**Accuracy Case 2 water**
Marine Reflectance [at 442 nm]	0.001 – 0.04	5 x 10^{-4}	5 x 10^{-4}
Water leaving radiance L_w (λ) (atmospherically corrected) [mW/cm^2/µm/Sr]	0.0 – 1.0	5%	5%
Photosynthetically available radiation, PAR [µmol quanta/m^2/s]	0 – 1400	5%	5%
Diffuse attenuation coefficient (or turbidity), K [m^{-1}]	0.001 – 0.1	5%	5%
Chlorophyll, Chl [mg/m^3]	0.001 – 150	threshold 30 % goal 10 %	threshold 70 % goal 10 %
Total Suspended Matter [g/m^3]	0.0 – 100	threshold 30 % goal 10 %	threshold 70 % goal 10 %
Coloured Dissolved Organic Material (CDOM) (a_{412} [m^{-1}])	0.01 – 2	threshold 50 % goal 10 %	threshold 70 % goal 10 %
Harmful Algae Bloom [mg/m^3] (same req. as Chlorophyll)	0.1 – 100	threshold 30 % goal 20 %	threshold 70 % goal 30 %

Sources: RD19, RD20 and references therein.

The instrument shall also be able to accomplish this task in both oceanic Case 1 and turbid Case 2 waters. Geophysical parameters ("Level 2 products") are derived from radiances in different spectral bands. The main parameters commonly exploited from existing sensors are summarized in Table 7 together with typical ranges and expected accuracies for operational applications. It is an objective to meet a product resolution goal of 30 classes of Chlorophyll and suspended matter, and 15 classes of dissolved organic matter in these typical Level 2 products.

Atmospheric correction for ocean colour data is very critical as only about 4% of the radiation originates from the water surface. A proper selection of channels in the near-infrared domain is essential for proper correction schemes. Atmospheric correction of both SST and Ocean Colour data requires aerosol/particulate measurements as well as water vapour measurements. At least 7 channels are necessary to cover the oceanographic and atmospheric correction measurement elements with sufficient accuracy in the open ocean (RD14) (i.e. Case 1 water). An extended baseline set of 15 channels similar to MERIS would ensure the presence of the signals to ensure sufficient atmospheric correction with which to retrieve the various products over case 2 waters (RD15). Recent studies have refined these channels sets (see Table 8) which could in practice meet most of the ocean colour, SST, and atmospheric correction requirements in one single instrument package (RD19, RD20). Additional channels in the red and infra-red may be exploited to observe turbid Case 2 waters, and to provide improved estimations of cloud cover.

Precise co-registration of SST and Ocean Colour pixel measurements can be useful for monitoring of coastal up-welling zones and for Carbon fluxes estimates.

Requirements on overpass time depend on the availability of alternative sources of Ocean Colour data. If data from such platforms are available, there will be a trade off to be performed between the probability of cloud cover probability and the optimal sampling time to assess diurnal variability and its impact on product quality.

Table 8: Measurement Requirements for Ocean Colour

Spectral Bands	Minimum of 15 bands from 400-1050 nm. The role of the bands for Case 1 (open ocean) and Case 2 (coastal) waters is: - 413 nm: *CDOM* discrimination in open ocean - 443, 490, 510, 560 nm: *Chl* retrieval from blue-green ratio algorithms - 560, 620, 665 nm + …: Retrieval of Case 2 water column properties using red-green algorithms - 665, 681, 709 nm + …: Use of fluorescence peak for *Chl* retrieval - 779, 870 nm for atmospheric correction - additional band required above 1000 nm to improve atmospheric correction over turbid water
Spatial Resolution	2-4 km (global monitoring) 0.2-0.5 km (coastal)
Revisit time	1 day (coastal) – 2-3 days (global)
Observation time	optimised to minimise sun-glint and cloud cover

4.9. Sea Surface Temperature Requirements

Sea-surface temperature data must satisfy the requirements of the operational and institutional communities and also the climate research community (see: Chapter 3.4.3). To support the climate change community, the strongest mission driver is the measurement precision and accuracy requirements which should support the capability to retrieve skin temperature changes to the order of 0.1-0.3° K. This requirement should be met even for occasional atmospheric events like higher aerosol loads due to volcanic eruptions. For coastal and regional applications the accuracy requirement are less stringent.

Table 9: User Product Requirements for SST

Application	Temperature accuracy [K]	Spatial resolution [km]	Revisit Time
Weather prediction	0.2 – 0.5	10 – 50	6 – 24 hrs
Climate monitoring	0.1	20 – 50	8 d
Ocean forecasting	0.2	1 – 10	6 – 24 hrs
Coastal/local	0.5	< 0.5	≤1 d

The spatial resolution of the existing AATSR instrument (RD23) is adequate for open ocean SST derivation, as is its geolocation accuracy: these capabilities should be maintained. As for all imaging systems the revisit time (i.e. time gap between two subsequent observations of an area not necessarily with the same observation geometry) and the coverage (i.e. elapsed time until orbit revolutions have covered the maximum observable area) are mainly driven by the swath width. A revisit time of 1 day is a goal which requires large swaths (> 2000 km) (e.g. equivalent to MODIS). Further, it should be noted that for both SST and Ocean Colour, the revisit time criteria does not take into account the problem of cloud cover and is not indicative of the actual revisit time (the merging of several missions is required to achieve an effective revisit time of 1 day – see GHSST-PP strategy (RD24). However as the main objective of the SST sensor on the GMES Sentinel-3 mission is to provide a stable, absolute reference for global SST measurements, the space/time coverage can take second priority for the climate requirement. It is assumed that SST observations of the GMES Sentinel-3 mission will be complemented by other IR and MW measurements to derive a combined SST product for long term climate applications.

Table 10: Sampling Requirements for SST

Spatial Resolution	1 km
Coverage:	global in 2-3 days at equator
Revisit time:	1 d (optimal) 2 - 3d (minimum) (at European shelf sea latitudes)
Observation time:	Local time around 10:00 optimal (but synergy with other EPS satellites is essential)

A reasonable compromise for revisit time is 2-3 days (i.e. similar to the requirements for Ocean Colour with an effort to optimise for European latitudes). This will result in swath widths of >1000 km, so performance degradation effects at swath edges will have to be considered.

4.10. Sea Ice Requirements

Sea-ice monitoring and forecasting is an essential part of operational oceanography at high latitudes. Ice parameters (ice edge location, ice motion, ice deformation and ice thickness) in combination with atmospheric-ocean parameters (temperature, wind, waves, currents, etc.) are of importance for all types of marine operations in and near ice-covered regions. This includes ice navigation, commercial shipping, offshore operations, such as oil and gas extraction, and fisheries, all of which require reliable monitoring and forecasting of sea ice. Observing sea ice and ocean parameters are also important for management of fishery resources and marine mammals. Long-term statistical information on key ice parameters (extent, thickness, types, etc) needs to be improved for certification and insurance of vessels and marine structures operating in polar waters.

It is an important objective of this mission to provide estimates of elevation/thickness of floating sea-ice, together with sea-ice extent and ice-surface temperature in high-latitude oceans. Whilst the latter can be accomplished under cloud-free conditions using the visible and infrared sensors, it is also feasible to use an altimeter to obtain high along-track resolution (< 300 m), ice surface elevation profile measurements with an instrument concept such as the SIRAL altimeter concept on CryoSat (RD35). This requires a beam-limited altimeter with resolution enhancement capability, and absolute calibration of sigma-naught (for discrimination between ice and water waveforms).

4.11. Land Requirements

An objective of the Sentinel-3 mission is to meet some basic global land requirements for land services, and climate and meteorological studies, where boundary conditions have to be prescribed as in the case of land surface component of General Circulation Models (GCMs) or forecasting models. Factors such as albedo, surface roughness, resistance to heat exchanges (sensible and latent) are important variables for such models, and which can be determined in connection with measurements that identify land cover characteristics. The seasonal and long-term variations of such variables are related to vegetation dynamics, and thus the capability to identify, through these variations, physical characteristics of land cover is a key to accurate prescription of these variables. Scales addressed in GCMs or forecasting models (typically about 100 km) require that land cover and its variability must be determined with a sampling of about 8 to 10 km: the basic spatial resolution needed for identification of land cover and the variability in vegetation indices such as NDVI is 1 km or better.

Additional GMES Services Element services to be sustained beyond continuity to SPOT VGT products and applications include meeting global monitoring requirements of, for example, the GEMS, GEOLAND, GLOBCARBON, GLOBCOVER, and GMFS studies in a large-scale to global 0.25 -1 km mode. The principal land product requirements are to provide a Normalised

Difference Vegetation Index (NDVI) or equivalent atmosphere-corrected MERIS Global Vegetation Index (MGVI), Fraction of Absorbed Photosynthetically Active Radiation (fAPAR), and Leaf Area Index (LAI) for characterisation of vegetation amount and coverage. To complement these products the MERIS Terrestrial Chlorophyll Index (MTCI) provides information on Chlorophyll content of vegetation and vegetation condition. Each of these products is required at a minimum resolution of 500m (250m goal) on a global scale every few days.

Table 11: Measurement Requirements for Land Colour

Spectral Bands	Minimum of 15 bands spanning spectral range from 443-1085 nm for Land surface and vegetation properties, and atmospheric corrections: - 0.443 µm (Blue): for MGVI, aerosol optical depth - 0.560 µm (Green): for Chl, NDVI - 0.665, 0.681, and 0.709 µm (Red): for Chl absorption peak, fAPAR, fCover - 0.753, 0.779 and 0.865 µm (NIR): Chl, fCover MGVI, MTCI, fAPAR - 1.61 µm (SWIR): cloud clearing, cloud/snow discrimination - 3.74 µm (Mid-Wave IR): for Active Fires - 10.85 and 12.0 µm (ThIR): for Land Surface Temperature, Active Fires - 865 µm common band requirement for OLC-SLST pixel co-registration - Additional SWIR bands required at 1.375 µm & 2.25 µm for cirrus cloud clearing and aerosol corrections
Spatial Resolution	0.25 - 0.5 km (global)
Revisit time	1 day (coastal) – 2-3 days (global)
Observation time	optimised to minimise sun-glint and cloud cover

For continuity in land applications the OLC and SLST instruments shall satisfy a resolution of between 0.25 and 0.5 km at nadir, and provide at a minimum continuity to channels allowing reproduction of MERIS and SPOT VGT land products. This requires continuity in existing MERIS and A/ATSR channels, together with additional channels to allow coregistration and improved cloud clearing. These channels should not saturate over land, snow or active fires.

Table 12 . Sampling requirements for Land Vegetation dynamics

Spatial Resolution	500 m threshold; 250 m goal (at nadir)
Coverage:	global in 2 days at equator
Revisit time:	1 d (optimal) 2-3d (minimum) (at Equatorial latitudes)
Observation time:	Local time around 10:00 optimal (but synergy with other satellites is essential)

The Fraction of Absorbed Photosynthetically Active Radiation (fAPAR) is also particularly useful in a number of applications ranging from crop yield forecasting and forestry, to environmental stress and sustainability monitoring with impacts in terms of food security, land degradation (e.g. desertification) and land cover mapping.

Leaf area index (LAI) measures the amount of leaf area in an ecosystem, which imposes important controls on processes such as photosynthesis, respiration, and rain interception. These processes couple vegetation to climate, and hence LAI is a key variable required to describe vegetation-atmosphere interaction in most land surface models.

Table 13 . Global Land Products under clear daytime conditions

Parameter	Range	Accuracy Goal	Accuracy Threshold	Frequency
MERIS Global Vegetation Index **(MGVI)** (or NDVI)	0 - 1	<5% at 0.3 km	<10% at 1 km	< 7 -10 d
MERIS Terrestrial Chlorophyll Index (**MTCI**)	0 - 3	<5% at 0.3 km	<10% at 1 km	< 7 -10 d
Fraction of Absorbed Photosynthetically Active Radiation, **fAPAR** [μmol quanta/m^2/s]	0 - 1	<5% at 0.3 km	<10% at 1 km	< 7 -10 d
Fraction of Vegetation Ground Cover (**fCover**)	0 - 1	<5% at 0.3km	< 10% at 1km	weekly
Leaf Area Index (**LAI**)	0 - 10	<5% at 0.3km	< 10% at 1km	weekly
Fire Radiative Power (**FRP**)	0 – 650 K	TBD at 1km	TBD at 1km	daily
Fire Disturbed Area	0 - 1	< 5% at 0.3 km	<10% at 1km	5 – 10 d
Land Surface Temperature **(LST)**	210 – 350 K	<1 K at 1km	At 1 km	daily

*Ref. GCOS Systematic Observation Requirements for Satellite-Based Products for Climate (RD42).

Land surface temperature (LST) derivation is only considered necessary on a best-effort basis. However, Global Terrestrial and Climate Observing System (GTOS/GCOS) GOFC-GOLD active fire detection and monitoring requirements (RD37) determine the need for supplemental products on active fire intensity, or fire radiative power, under cloud-free conditions. These general requirements were outlined in the Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCC and developed further within the GCOS Implementation Plan and its Supplementary Report on Systematic Observation Requirements for Satellite-based Products for Climate (RD42). In particular, these documents define Active Fires and Fire Radiative Power as important supplementary products to the Fire Disturbance Essential Climate Variable. In addition, the need for improved early warning, detection and monitoring of wild fires is included in each of the Disaster, Climate and Agriculture societal benefit areas of the GEOSS 10-year work plan.

Active fire detection and characterisation capability requires a 3.7 micron channel that does not saturate in the presence of fire (i.e. saturation limit of <650 K, and equivalent to NPOESS VIIRS fire channel), coupled with non-saturating thermal infrared band at 11 or 12 microns.

4.12. Product Delivery and Timeliness Requirements

The primary objective of the mission is to acquire data on a continuous basis with high frequency, and to deliver all products on a Near Real Time (NRT) basis in order to meet operational data assimilation requirements as stated in particular for altimetry in Section 4.6. The following characteristics should apply:

- NRT data processing and delivery (< 3 hours latency between acquisition and delivery) for all data products.
- Short- and Long-term Product calibration, validation and quality control procedures
- Higher level altimetric products (wind, wave etc.) should be available using the rapid-delivery orbit within 3 hours.
- Off-line altimeter products shall be processed and delivered as soon as a precise orbit becomes available (within a window of 2-3 days).

4.13. Synergy with external mission concepts

The specification for the altimetry component of the GMES Sentinel-3 mission is most affected by the availability of third-party missions. As many applications are gaining from a substantial increase in time and space sampling, a minimum set of 2-3 altimeter missions should be available. To allow the downscaling option for omitting the MWR or the dual altimeter frequencies, Jason 2 or a similar high precision altimetry mission has to be accessible during the life time of the GMES Sentinel-3 mission. Currently the planning for Jason 2 aims for a launch in 2008 and plans include an experimental wide swath instrument. If a SAR-mode for the altimeter on the GMES Sentinel-3 is implemented a major improvement for ocean mesoscale feature detection can be expected. The NOAA-Navy-NASA altimeter is planned for the NPOESS satellite series with a first launch no earlier than 2011.

With the loss of GLI (Global Land Imager) and POLDER (POLarisation and Directionality of the Earth's Reflectances) on ADEOS-2, this significantly reduces the number of operational ocean colour sensors (RD36). For optical imagers in the VIS/IR range, commitments have been made by several Agencies to fly sensors in the future. However, in the 2010 timeframe of the first GMES Sentinel-3 satellite, only S-GLI on the Japanese GCOM-W and VIIRS on the NASA-NOAA Preparatory mission will address the needs of the ocean biology and ocean carbon community, and the present status of GCOM is not certain. Given the position of EUMETSAT with respect to the requirement for purchasing AVHRR instruments for METOP, and the need for an operational European successor to AVHRR beyond METOP, it is necessary to develop a European operational instrument in this class.

In addition to synergy aspects with similar instrumentation on other satellites, the instrument and performance requirements of the GMES Sentinel-3 mission have considered the potential complementary with other satellite missions:

- a wind scatterometer is operationally provided by Eumetsat/ESA on the METOP series, starting with MetOp-1 in 2006.
- high resolution SAR observation will be covered by the GMES Sentinel 1 concept (RD32) as well as by future Radarsat satellites from CSA.
- Further passive microwave sensors will be covered with existing NOAA commitments (e.g. replacement instrument for cancelled NPOESS CMIS instrument).

5. Preliminary System Concept

This chapter attempts a first iteration on system requirements, derived from the consolidated user requirements in Chapter 3. This iteration is strongly based on the heritage and experience of existing instruments as well as on several technical feasibility studies (RD19, RD20, RD29). The aim is to define a minimum set of requirements and outline the potential of certain instrument classes.

5.1. Radar Altimeter System

5.1.1. Orbit selection

Although not a basic requirement, the orbit for the altimeter system could be sun-synchronous. The most preferred option would be to fly on the same repeat orbit as Envisat. This would allow continuation of the ERS/Envisat time series and also would allow us to benefit from the precise ERS/ENVISAT mean tracks, which are needed to extract the Sea Level Anomalies (SLA) from altimetry. The constraint of a repeat orbit for altimetry should be maintained. There is no preferred local equatorial crossing time (i.e. local time of ascending node LTAN). Errors of existing mean sea surfaces are about 3 cm rms (1 sec average) in the open ocean (and up to 5 cm rms in coastal areas); if a mean sea surface is used as a reference for a non-repeat orbit, the altimeter error budget will be significantly increased. ESA's GOCE mission will improve the situation but will not allow us to resolve the small scales of the geoid (below 100 km). Non-repeat orbit is thus a possible option but with a degraded accuracy for SLA products.

While SST, Ocean Colour and altimetry are quite complementary, there is no requirement for flying an altimeter on the same SST/Ocean Colour platform. The sampling characteristics of altimetry and optical imagers are quite different (swath versus along-track) and will not allow us to measure SSH, SST and Ocean Colour at the same position and time (except for along-track data). There is thus no particular advantage to fly on the same platform.

5.1.2. Measurement Concept, Modes of Operation and Parameters

It is proposed to deploy an altimeter capable of providing continuity to ERS, Envisat, and CryoSat altimeter measurements. It is also proposed to consider incorporating a high spatial resolution mode of the altimeter to ensure the continuation of the monitoring of sea-ice elevation in addition to the mesoscale characteristics of the ocean surface. CryoSat-type capability would also facilitate operation in coastal and inland waters and the gauging of the flow of large rivers, due to the greater along-track resolution. This concept was already considered during the Coastal Zones Earth Watch mission (studied in 1995/1996), recalled at the GMES meeting held in Lille in October 2000, and its feasibility will be demonstrated by CryoSat. Phase A studies will address the concepts feasible in the 2006 horizon.

The altimeter shall be capable of working in various modes of operation, which together will allow the main measurement objectives to be achieved. Its two modes of operation are as follows:

- Low resolution mode (LRM): employs conventional pulse-limited altimeter operation. The LRM mode is useful over open ocean surfaces where the topography is homogeneous over areas at least as large as the antenna footprint (~15km). The altimeter echoes have a predictable shape and the mean surface level of this area can be derived by an appropriate model fitting algorithm after averaging several echoes to smooth out the noise resulting from speckle
- High resolution sea-ice mode: this mode of the altimeter is designed to achieve high along-track resolution of order ~ 250 m over relatively flat surfaces. This property can be exploited to increase the number of independent measurements over a given area and is a prerequisite for sea ice thickness measurements and could be an interesting option for mesoscale ocean applications.

It is to be noted that there is no conflict amongst operational modes of the instrument as these modes are specified according to the target under the satellite path.

5.1.3. Tropospheric, Ionospheric and other Range Delay corrections

Wet/dry tropospheric, inverse barometer, tidal, electromagnetic (EM) bias, and ionospheric corrections have to be made to the altimeter range measurements to achieve the desired ranging accuracy (where *total height error* is typically expressed as the root sum squares of all independent contributions). Tentatively, threshold requirements for the uncertainty in single-pass wet and dry tropospheric delay corrections are 1.2 and 0.7 cm, respectively. The threshold accuracy for ionosphere correction is 0.5 cm, while the EM bias threshold accuracy is around 2.0 cm.

An optimal instrument configuration requires that the altimeter path delay correction due to the wet tropospheric component is estimated directly from the sigma naught information from the radar altimeter, from independent instrument data, or from atmospheric models. Given the continuous improvements of ECMWF wet tropospheric corrections, studies should be undertaken to quantify the degradation of results for an altimeter without a radiometer. Wet tropospheric and ionospheric corrections are associated to medium and large scale signals where high precision data from a Jason class altimeter could be exploited to assess the performance of independent sources of correction. However, as long as results from trade-off studies are not available the radiometer and the dual frequency altimeter are seen as the only option to achieve the desired accuracies in delay correction. Recent comparisons of ECWMF modelled wet-tropospheric corrections and radiometer corrections indicate that NWP analysis fields currently do not provide the spatial resolution to resolve mesoscale variability in the troposphere. Moreover, jumps or drifts occurring in NWP analysis products over the long-term preclude their use as correction data in long-term climate or sea-level change analyses (RD27).

The dry tropospheric and inverse barometer corrections are made without direct instrument information by use of ECMWF numerical analyses of the sea-level air pressure. Other than a twin-frequency altimeter option, a further means for obtaining ionospheric corrections can be derived from Doris data, if a Doris receiver were on board. CNES is also developing a service that will provide the integrated electron content operationally, for low Earth orbits (700 – 1300 km). This would make it possible to correct for ionospheric effects with neither Doris nor a second altimeter frequency. An even better alternative is the GPS-derived Global Ionosphere Map (GIM) correction, which in recent comparisons most closely represented the actual dual-frequency corrections, outperforming both Doris and the simple Bent model.

Corrections must be made for electromagnetic (EM) bias using knowledge of the sea-state (from SWH) and wind speed using recently improved semi-empirically-based schemes (RD24).

5.1.4. Altimeter Accuracy

The discussion on geophysical error estimates from the previous chapter is summarised in Table 14 indicating our best knowledge from recent altimetry missions such as Envisat and Jason-1. Geophysical corrections from ECMWF analysis fields are not available for fast delivery (NRT) products within a few hours after acquisition, but are expected to be available within two days for Intermediate Geophysical Data Record (IGDR) and Geophysical Data Record (GDR) processing.

For ocean altimetry the tracker bias shall be minimised by tuning performance of the tracking algorithm. Tracking bias over the ocean is proportional to the SWH, and shall not be higher than 1 cm, with a goal of 0.25 cm resulting from improvements in tracking algorithm performance, and use of dual-frequency measurements.

The requirements for measurements of SWH, wind and currents in section 4.7 demand for stable and accurate amplitude parameters. The threshold absolute accuracy of $\sigma°$ shall be better than 1 dB, with a resolution of better than 0.1 dB. The drift in $\sigma°$ should be characterised with an accuracy of better than 0.2 dB with a goal of 0.1 dB over a period of 1 year. The resulting derived wind-speed accuracy shall be better than 2 m s^{-1} for 1 sec. averages (for a range between 3 and 20 m/s). A goal of 1.5 m s^{-1} accuracy is expected from improved ground processing.

Table 14: Major error terms for altimeter height estimation*

	NRT (< 3hrs)		**IGDR (1-3 days)**		**GDR (<1 mo)**	
	Threshold [cm]	Goal [cm]	Threshold [cm]	Goal [cm]	Threshold [cm]	Goal [cm]
Range Noise	3.0	2.0	3.0	2.0	3.0	2.0
Sea state bias	5.0	3.0	3.0	2.0	2.0	1.4
Ionosphere	3.0	2.0	1.4	1.0	1.4	1.0
Dry troposphere	3.0	2.0	1.4	1.0	1.4	1.0
Wet troposphere	4.0	3.0	2.0	1.4	1.4	1.2**
RSS Range Error	**8.3**	**6.0**	**5.0**	**3.5**	**4.1**	**2.9**
Radial Orbit Error	10.0	8.0	4.0	3.0	3.0	2.0
RSS SSH Error	**13.0**	**10.0**	**6.5**	**4.6**	**5.1**	**3.5**

*Values derived from cal/val and performance analyses for RA-2 and Jason-1, assuming 1 Hz sampling, 1s along-track averages, 2m SWH and σ^o =11 dB (RD39).

** Goal assuming 3 frequency microwave radiometer.

5.2. Microwave Radiometer for Atmospheric Corrections

As discussed in previous chapters the additional microwave radiometer (MWR) is regarded mandatory for GMES Sentinel-3 to achieve the required accuracy in section 5.1.4 and Table 14.

5.2.1. Instrument Concept, Modes of Operation and Parameters

The baseline instrument concept should be based on the Envisat MWR with a minimum of two passive channels operating in Ka- and Q-band. The option for inclusion of a 3-frequency MWR will depend on the accommodation of a larger antenna. The MWR shall measure the amount of water vapour and liquid water content in the atmosphere, within a field of view centred immediately beneath the spacecraft track. This information provides the only means with which to make the wet tropospheric path delay correction for the radar altimeter on <100 km scales. The MWR measurements can also be employed for the determination of surface emissivity, and "soil moisture" over land and in support of studies on surface energy budget, atmosphere and ice characterisation (RD40).

5.2.2. Multi-channel Microwave Radiometer Tropospheric Delay Correction Accuracy

The path correction due to the wet tropospheric component can be estimated from the two (or optionally 3) brightness temperature measurements made by the MWR and from the sigma-naught information derived from the radar altimeter. Experience shows that this would give a residual inaccuracy of 1-2 cm. Thus, the requirement is a threshold correction accuracy of 2 cm with a goal of 1 cm rms.

Recent results from comparisons of performance of corrections using 3 vs. 2 frequency radiometers indicate a significant variance reduction on crossover range differences and on Sea Level Anomaly using the 3 frequency radiometer (RD47). Both are consistent with $1cm^2$ or 1% of total and global SLA variance reduction, and thus a significant improvement in the retrieved sea surface height. Locally the improvement can reach 10% of the SLA variance. The same study showed that on ENVISAT the variance reduction using a 2-channel radiometer correction (as opposed to a model-based wet Tropospheric correction) was about $5cm^2$. A three channel algorithm would provide an additional improvement of up to 20%. The better performance observed for the three channel algorithm is also stable in time (e.g: no seasonal signal).

The performance inter-comparison also showed that the 2 frequency results are more susceptible to biases from ocean-wave characteristics, sigma-naught anomalies (often encountered in coastal regions) and convective rain cells. Though globally, the 2 frequency radiometer results do not show a bias, regional effects can be significant. Thus, a 3 channel MWR is preferred over a 2 channel instrument, provided that accommodation of a larger antenna is feasible.

5.3. Optical Sensors

It has been demonstrated during early concept studies (RD19; RD20; RD26) that it is extremely challenging to meet the stringent sea-surface temperature and ocean colour product accuracy requirement when the instrument concept is designed specifically accommodate both MERIS and A/ATSR capabilities in one single Visible/Infrared optical instrument. Thus the design shall, in so far as possible, employ proven technology and heritage from the original Envisat sensors. Provided the requirement for substantially overlapping swaths and co-registered SST and Ocean Colour measurements can be met with sufficient accuracy, separate optical instrument concepts are favoured. Two separate instruments also ensure a high degree of redundancy in meeting the mission requirements for Ocean and Land services, respectively.

5.3.1. Orbit Selection

The orbit for the optical payload demands a sun-synchronous orbit which allows a 2-3 days revisit, bearing in mind the respective instrument swath widths. Sun glint and general illumination conditions for the VIS channels need to be carefully considered and sun-glint mitigated to the largest extent possible by choice of instrument pointing and final orbit configuration. Taking into account also the service provided by other operational meteorological satellites planned for the period of the GMES Sentinel-3 mission there are two main possibilities:

- To fly late in the afternoon, e.g. 15:00hrs LTAN. This provides the best alternative for diurnal cycle coverage with satellites flying a morning orbit, but it will degrade the performances of the imager (worst illumination angles and more clouds).
- To fly between 10:00 and 10:30 hrs LTDN. This provides still complementary local time coverage while optimising the viewing conditions for the imager.

The first solution does not allow the existing climate records from ERS and Envisat data products to be continued. The latter solution, however, is favoured as it allows to retain a sun-synchronous orbit configuration very close to that of Envisat, and would allow continuity in existing data records of climate significance.

5.3.2. Ocean and Land Colour (OLC) Imager

The OLC ground resolution requirement depends whether the data are acquired above open ocean, or coastal zones and land. Ocean Colour products require a spatial resolution at sub-satellite point of 1 km over Open Ocean, and Sea Ice and 0.25 km over coastal zones (Table 8), while land products require a resolution of 0.25 km globally. The coastal zone area is defined by the coastline and its extension outward into the ocean by 300 km (i.e. corresponding to a distance between the shelf limit of 150 km and of the Economic Exclusion Zone limit of 200 nautical miles). In addition, stringent sub-pixel co-registration of OLC and Sea and Land Surface Temperature (SLST) instrument products is required such that synergetic products may be developed, and such that the OLC products may benefit from improved atmospheric and aerosol corrections from the dual-view SLST instrument concept (see Section 5.3.3), as well as its complementary spectral bands for cloud detection, cloud properties and snow/cloud discrimination.

Further technical requirements for the OLC instrument can be summarised as follows:

- Low noise-equivalent radiances in all channels.
- Absolute radiometric accuracy threshold of 2%, with a goal of 1 %.
- Relative radiometric accuracy goal of 0.2 %.
- Precise internal calibration.
- Adequate dynamic range to accommodate both low oceanic signals in the case of clear atmospheres and higher signals in the presence of relatively high aerosol loading.
- Geolocation precision better than 0.5 pixels.
- Polarisation error less than 1 % for UV/VIS channels.

The instrument shall be optimised to measure the Ocean Colour over the open ocean and coastal zones, however, it shall not saturate over land targets. The spectral bands for the Ocean Colour are in the visible to near-infrared wavelength range and labelled O1 to O16 in Table 15 below. Because of the low radiance from ocean surfaces the signal to noise ratio (SNR) has to be high, in particular for the UV bands. To avoid errors in the blue/green chlorophyll algorithms, it is also necessary to similarly closely co-register channels O2, O3, and O4. To minimise errors in the atmospheric correction procedures, channels O6 and O7 shall be co-located and have as little difference as possible in the atmospheric paths. An additional channel at 1.02 microns has been added upon recommendations to improve the existing MERIS atmospheric and aerosol correction capabilities, and additional atmospheric correction bands may be considered.

Table 15: Minimum baseline band selection and performances for Ocean and Land Colour measurements

Channel	Centre Wavelength (nm)	Approx. Band (nm)	Band-width (nm)	Signal to Noise Ratio*	Application
O1	413	403-423	10	2006	Yellow substance and detrital pigments
O2	443	438-448	10	2087	Chl absorption max. / Vegetation
O3	490	485-495	10	1683	Chl, Other pigments
O4	510	505-515	10	1629	Chl, Sediment, Turbidity, Red tide
O5	560	555-565	10	1481	Chlorophyll reference
O6	620	615-625	10	1131	Sediment Loading
O7	665	660-670	10	1022	Chl, Sediment, Yellow Substance / Vegetation
O8	681	677.25-684.75	7.5	829	Chl fluorescence peak, red edge
O9	709	704-714	10	956	Chl fluorescence baseline
O10	754	750.25-757.75	7.5	673	O_2 absorption /Cloud/ Ocean colour
O11	761	759.125-762.875	3.75	407	O_2 absorption band/Aerosol corr.
O12	779	771.5-786.5	15	810	Atmos. / Aerosol corr.
O13	865	855-885	20	688	Aerosols, Clouds, Pixel co-registration
O14	885	885-895	10	417	Water vap. absorption ref.
O15	900	895-905	10	312	Water vap. Absorption / Vegetation
O16	1020	1000-1040	40	TBD	Atmos. / Aerosol corr.

*SNR threshold values assume a spatial sampling distance of 1.2 km and standard atmosphere over open ocean
**Ocean bands have a noise-equivalent differential radiance, NEΔρ goal of $< 5x10^{-3}$.

5.3.3. Sea and Land Surface Temperature (SLST) Sensor

An along-track view (bi-angular observation) is mandatory to make the atmospheric correction robust to changes in aerosol and water vapour loading. Ideally, the system should deliver high quality SST measurements over a wide swath (~1000km), as well as dual view over a narrower swath as a "*gold standard*" for all other SST measurements (over as broad a portion of the central swath as possible). The SST product requires a spatial resolution at sub-satellite point of 1 km for the ocean.

Table 16: Sea and Land Surface Temperature (SLST) instrument band selection

Channel	Centre wavelength (µm)	Bandwidth (nm)	Application
S1	0.555	20	Cloud screening
S2	0.659	20	NDVI,
S3	0.865	20	NDVI, Cloud flagging, , Pixel co-registration
S4	1.375	15	Cirrus detection over land
S5	1.61	60	Cloud clearing
S6	2.25	50	Vegetation State & Cloud Clearing
S7	3.74	380	SST, LST, Active Fire
S8	10.85	900	SST, LST, Active Fire
S9	12.0	1000	SST, LST

Channel selection for the SST instrument retains the mandatory SWIR and TIR channels based on ATSR heritage, whilst retaining the standard A/ATSR Visible channels for cloud screening and atmospheric corrections. Experience with SST retrieval from this sensor and technical feasibility studies allow specification of constraints on some radiometric performance parameters of the SST instrument (Table 17) which needs refinement during system definition.

Table 17: Radiometric accuracy requirements for SST measurements

	Threshold	Goal	Range
Resolution	0.06 K	0.025	210 – 350 K
Absolute Accuracy (related to 100% diffuse reflectance)	0.3 K	0.1 K	270 – 320 K
Relative Accuracy (expressed as $NE\Delta T$)*	0.08 K	0.05 K	210 – 350 K
Temporal stability	0.2 K / decade	0.1 K / decade	270 – 320 K

* Source: RD23

Current requirements to monitor SST for climate research are set at zero bias and an uncertainty of ± 0.3 K (1σ) for a 5 x 5° latitude longitude area, having a temporal stability of 0.1 K/decade. A potential secondary supplement could be a microwave SST sensor (e.g. AMSR type) to complement the infra-red sensor by providing global low resolution but all-weather (no cloud problems) SST measurements.

Dual-view SLST visible channels, accurately collocated with the SWIR and ThIR bands, will allow aerosol corrections to be co-estimated with SST retrievals. This requirement for continuation of the ATSR heritage visible channels provides the capability to fully meet the stringent SST requirements shown above. The utility of aerosol information derived from the overlapping dual-view channels also permits significant improvements to the accuracy of land surface temperature and vegetation products.

The use of common visible channels between OLC and SLST will allow coregistration of the individual pixel radiances derived from each respective instrument channel and will permit cross calibration between instruments. The resulting advantage is the benefit of having precise SLST dual-view atmospheric corrections for superior correction of OLC products as well as redundancy in the capability to generate high-quality Land surface products from SLST data.

5.3.4. Global Land surface capability

Continuity to typical sensor packages such as that onboard MERIS and SPOT VEGETATION would meet the basic land requirements for continuity in these data. These bands typically include relatively coarser spectral resolution with a blue band (overlapping Channel 2 in Table 15), a red band to capture the chlorophyll absorption peak at 665 nm, and accompanying Near Infrared and Short-wave infrared bands to characterise the fractional coverage of vegetation, canopy structural properties and the cloud discrimination. In so as far as is possible, these vegetation retrieval bands shall be optimised with respect to the existing baseline channels shown in Table 15 and Table 16.

The MGVI product identified in Section 4.10 provides quantitative information on the state of the plant cover over terrestrial areas and is based on 443, 681 and 865 nm. These are already captured by MERIS legacy bands 2, 8 and 13 in Table 15 . The additional MTCI product identified in Section 4.10 is also based on data in three red and NIR bands centred at 681, 709 and 754 nm, also already identified as part of the ocean colour channel package in Table 15. Importantly, daytime cirrus cloud detection over land have been observed to cause a significant adverse effect on the radiometry of the VNIR bands. Estimates from MODIS suggest at least 50% cirrus cloud contamination in the mid-latitudes and humid tropics, with >30% elsewhere. Effective corrections for cloud optical thickness are demonstrated to require the additional 1.375 and 2.25 μm channels in order for vegetation indices to be corrected or successfully flagged.

5.3.5. Atmospheric Corrections

The current principal limitation on ocean and land product performance is the quality of atmospheric corrections and flagging of atmospheric contamination. It has been demonstrated that by increasing the lever arm – or spectral separation between MERIS atmospheric correction channels – better atmospheric corrections are possible. For this reason, an OLC channel at 1.02 micron is added to the standard suite of MERIS channels to improve the quality of both ocean and land product retrievals. Furthermore, the SLST Visible channels provide additional capability to deliver cloud and aerosol products to complement those of OLC.

5.4. Precise Orbit Determination Package

Precise orbit determination is a prerequisite to success of the altimetry package on this mission. This assumes the inclusion of a precise 3-d positioning instrument which allows the possibility to reduce orbit errors (for the purpose of meeting the altimetry performance goals). For independent orbit determination to an accuracy demanded by the specified performance of the altimeter payload it will be necessary to carry a support payload like Doris or a geodetic quality GNSS receiver. Because of its significant contribution to precise orbit determination, and capability to provide a fail-safe back up solution in case of failure of other on-board orbit positioning systems, a laser retro-reflector is a minimum requirement.

The threshold performance for Near Real Time orbit determination is 10-20 cm, with a goal of 2 cm rms residual orbit accuracy after offline processing. For the high accuracy orbit to be useful in accompanyment to the altimetry data used in operational ocean models, the delivery timeliness requirement is 2-5 days.

5.5. Single or Multiple Platform Concepts

The mission requirements for Sentinel-3 may be met using either multiple satellite platforms with narrower-swath, lower risk instrument concepts, or alternatively by a single platform with wide-swath optical instruments. In the context of multiple platform concepts it is assumed that the proposed launch and replenishment scenario allows typical operational service availability requirements to be met.

6. Programmatics

6.1. General Aspects

The definition of the GMES Sentinel-3 mission shall take into account the following Programmatic constraints:

- Earth Watch GMES Sentinel missions are by definition designed to meet the demands of the GMES operational community. This forces the instrumentation and observables to be produced by the mission to be well known by the corresponding user communities. Therefore the instrumentation to be used based on already available or soon to be available technologies. Research instrumentation is dealt with under the “Earth Explorer” framework.
- To avoid duplication of efforts, the design of the mission shall take into account the commitments to research and operational data product developments already made by ESA and other agencies including Eumetsat, CNES, ISRO, NOAA, NASA and NASDA.
- The definition of the mission shall also take into consideration the level of European experience and maturity of technology in the area.

7. Reference Documents

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RD3: Towards an ESA Long-Term Plan for 2004-2013 (ESA/C(2004)30).

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List of Tables:

Abbreviations, Acronyms and Symbols

AATSR	Advanced Along Track Scanning Radiometer
AMSR	Advanced Microwave Scanning Radiometer
ATSR	Along Track Scanning Radiometer
DORIS	Doppler Orbit and Radio Positioning Integration by Satellite
ENSO	El Nino Southern Oscillation
ESA	European Space Agency
ESOC	European Space Operations Centre
ESTEC	European Space Research and Technology Centre
EuroGOOS	European Global Ocean Observing System
FOAM	Forecasting Ocean Assimilation Model
GHRSST	GODAE High Resolution SST Pilot Project
GMES	Global Monitoring and Environmental Security
GNSS	Global Navigation Satellite System
GOCE	Gravity Field and Steady-State Ocean Explorer Circulation
GOME	Global Ozone Monitoring Experiment
GOOS	Global Ocean Observing System
IGOS	Integrated Global Observing Strategy
IOC	Intragovernmental Oceanographic Commission
LMCS	Land Core Monitoring Service
LRM	Low Resolution Mode
LTAN	Local Time of Ascending Node
LTDN	Local Time of Descending Node
MARCOAST	Marine & Coastal Environmental Information Services
MERIS	Medium Resolution Imaging Specrometer
MERSEA	Marine Environment and Security for the European Area
MCS	Marine Core Service
MFS	Mediterranean Forecasting System
MODIS	Moderate Resolution Imaging Spectroradiometer
MWR	Microwave Radiometer
NAO	Northern Atlantic Oscillation
NASA	National Aeronautics and Space Administration (USA)
NOAA	National Oceanic and Atmospheric Administration (USA)
PRF	Pulse Repetition Frequency
SAR	Synthetic Aperture Radar
SIRAL	Sea Ice Radar Altimeter
SSH	Sea Surface Height
SST	Sea Surface Temperature
SWH	Significant Wave Height
T/P	Topex-Poseidon
TBD	To Be Determined
TOGA	Tropical Oceans Global Atmosphere
TOPAZ	Towards an Operational Prediction system for the Atlantic and European coastal Zones
VIIRS	Visible/Infrared Imager and Radiometer Suite
WCRP	World Climate Research Programme
WOCE	World Ocean Circulation Experiment

Appendix A: EU Actors in operational oceanography

Category	Actor/Company	Contact person
MetOcean Forecasting	BSH Model	Gerd Becker
	UK Met Office Model	Mike Bell
	Meteo-France Model	Herve Roquet
	ECMWF Model	Director
	Met-No Model	
Ocean Forecasting	FOAM Model	Mike Bell
	MERCATOR Model	Pierre Bahurel
	TOPAZ Model (NERSC)	Laurant Bartino
	MPI Model	Jochem Marotzke
	MFS Model (INGV)	Nadia Pinardi
	G-ECCO (IFM)	D. Stammer
	POSEIDON Model (NCMR)	L. Perivoliotis
ESA GMES	ROSES (ALCATEL)	Roberto Aloisi
	COASTWATCH (ACRI)	Phillipe Bardey
	NORTHERN VIEW (C-CORE)	Charles Randell
	ICEMON (NERSC)	Stein Sandven
	MARCOAST	Jerome Bruniquel
ESA DUP/DUE	TIDAL (ARGOSS)	Han Wensink
	MOCCASSIN (ARGOSS)	Cees de Valk
	MEDSPIRATION (SOC)	Ian Robinson
	FLOMON (SYNOPTICS)	Hans Van Leeuwen
	POWERS (MUMM)	K. Ruddick
	BABEL (ARGOSS)	
ESA EOMD	SAR-based oil spill and fishing vessel detection	KSAT- Lina Stainback
	EO Exploitation in the sector of Marine Information Systems, BMT Marine Information Systems	
	Integration of Envisat data into iceberg management	C-CORE
	Near real time sea-surface winds from SAR data	KSAT
EU	COASTMON	E. Svendsen
	DECLIMS & DISMAR	
	MERSEA Strand 1 (NERSC)	J. Johannessen
	MERSEA IP (Ifremer)	Y. Desaubiers
	NAOC, OCEANIDES	
	OROMA, REVAMP	
SMEs	Satellite Observing System (SOS)	David Cotton
	CLS	Pierre-Yves Le Traon
	OCEANOR	Jan-Petter Mathisen
	ARGOSS	Cees de Valk
	MeteoMer	Pierre Lasnier
	Starlab	Giulio Ruffini
	InfoSar	Christian Oliver
	NPA Group	Ren Capes
	Infoterra	Alexander Kaptein
	VEGA Group PLC	Phil Cartmel
	Systems Engineering & Assessment Ltd	Paul Phillips
	ACRI	
	BOOST	Vincent Kerbaol
	Plymouth Marine Applications	
Industrial companies	Qinetiq	Roger Robbinson
	Fugro Global Environmental & Ocean Sciences	Robin Stevens
	Telespazio	Alessandro Voli
	KSAT	Lina Stainback

Appendix B: Sources of requirements for marine operations

Name	Project Leader	Brief Description	Date
COMKISS EU framework 4	University of Lund, Sweden,	Study of applications of EO data in 3 sectors of offshore shipping: Design, Unusual loads, fast ferries. http://www.satobsys.co.uk/Projects/Comkiss/	1998-2000
ESA Innovative Altimeter Study	Alcatel Space Industries, France	Specification for "Innovative" altimeter instrument for potential future deployment	2002-2004
ESA Innovative Altimeter Study	Alenia, Italy	As above	2002-2003
SEAROUTES EU framework 5	Technical University of Berlin, Germany	Advanced Decision Support for Ship routing based on Full-scale Ship-specific Responses as well as Improved Sea and Weather Forecasts including Synoptic, High Precision and Real time Satellite Data http://www.tu-berlin.de/fb10/MAT/searoutes/intro/	2002-2004
INMAREEU framework 5	CONS A.R. , Italy	To develop more efficient maritime transport services in an integrated inter-modal transport chain.	2004-2006
ICEMON ESA GSE	NERSC, Norway	To implement a coherent European operational oceanography system for the high latitudes, consisting of sea ice, meteorological and oceanographic services http://www.nersc.no/ICEMON/index.php	2003-2004
Northern View ESA GSE	C-CORE, Canada	To provide users with a 'one-stop-shop' for northern information, integrating EO and other information as needed http://www.northernview.org/	2003-2004
GAMBLE EU framework 5	Satellite Observing Systems, UK	Investigation of future requirements for satellite altimetry over the oceans. http://www.altimetrie.net	2002-2003
OSIMS EU framework 4	NERSC, No	Feasibility and cost benefits of using satellite data in operational ice monitoring, propose concepts for optimal use of satellite data in future sea ice monitoring and forecasting. http://www.nrsc.no/OSIMS/	1994-1998
SSALTO/DUACS	CLS, Fr	Operational system dedicated to the unification and the combination of altimeter data in near real time. Since early 2004, four missions have been routinely processed: Jason, ENVISAT, TOPEX/Poseidon, and GEOSAT Follow On. http://www-aviso.cls.fr/html/donnees/duacs/welcome_uk.html	operational
EMOFOR	NERSC, No CLS, Fr Fugro Geos, UK	European Space Agency project, whose main objective is to integrate Earth Observation data into numerical model used by the offshore industry. NERSC is responsible for the numerical models implementation, CLS provides satellite data and Fugro Geos is the product provider. http://www.eomd.esa.int/contracts/contract51.asp	1993-1995

Appendix C: Sources of requirements for security applications

Name	Project Leader	Brief Description	Date
ESA Innovative Altimeter Study	Alcatel Space, France	Specification for "Innovative" altimeter instrument for potential future deployment	2002-2004
SEAROUTES EU framework 5	Technical University of Berlin, Germany	Advanced Decision Support for Shiprouting based on Full-scale Ship-specific Responses as well as Improved Sea and Weather Forecasts including Synoptic, High Precision and Realtime Satellite Data. http://www.tu-berlin.de/fb10/MAT/searoutes/intro/	2002-2004
COMKISS EU framework 4	University of Lund, Sweden,	Study of applications of EO data in 3 sectors of offshore shipping: Design, Unusual loads, fast ferries. http://www.satobsys.co.uk/Projects/Comkiss/	1998-2000
MAESTRO	NL		
MERCATOR	Mercator-Ocean France	System of global and regional operational ocean model, assimilating EO data. http://www.mercator-ocean.fr/	operational
FOAM	UK Met. Office	FOAM produces real-time analyses and forecasts of the temperature, salinity and currents of the deep ocean for up to five days ahead for the UK Navy. http://www.met-office.gov.uk/research/ocean/operational/foam/	operational
GAMBLE EU framework 5	Satellite Observing Systems, UK	Investigation of future requirements for satellite altimetry over the oceans. http://www.altimetrie.net	2002-2003
MISEC	Satellite Observing Systems, UK	BNSC programme to test the integration of EO-based data and services into marine information products used for security. The resulting products can improve the operational effectiveness of maritime security activity. http://www.tenetdefence.com/misec/	2003-2004
CAMMEO	Satellite Observing Systems, UK	ESA EOMD project. Using NRT EO data to enhance forecasts for search and rescue and special operations.	2003-2004
GFO	Geosat Follow-On	http://gfo.bmpcoe.org/Gfo/default.htm	operational
NRL / Stennis	Naval Research Laboratory, US	NRL at Stennis Space Center generated user products from a number of ocean circulation models, and processed altimeter data. http://www7320.nrlssc.navy.mil/global_nlom32/skill.html	
IMPAST	JRC Ispra	IMPAST SAR based vessel detection, combined with vessel monitoring system (VMS) to monitor fishing. http://intelligence.jrc.cec.eu.int/marine/fish/IMPAST/IMPAST_index.html	2000 - 2003
DECLIMS	IPCS, JRC, ISPRA	FP5 project Detection and Classification of Marine Traffic from Space. Based on use of SAR. http://intelligence.jrc.cec.eu.int/marine/declims	2003-
Fishing Vessel Detection Services	Ksat / QinetiQ	To integrate a SAR based oil spill monitoring service into the North Sea Directorate and to develop the customer base for a SAR based vessel monitoring service. http://www.eomd.esa.int/contracts/contract54.asp	2002-
Remote Sensing Applications in Search and Rescue	ASA/Martec for Candian Coastguard, Rescue and Environmental Branch	Report on use of remote sensing data for search and rescue: http://www.rcc-net.org/rcc/rddocs/remote/remsenep.pdf	

Appendix D: Sources of requirements for coastal zone monitoring

Name	Project Leader	Brief Description	Date
COAST-DRIVE	HR Wallingford, UK	COASTDRIVE is an ESA Earth Observation Market Development Programme. As part of the project, HR Wallingford compiled a report on Data requirements of Coastal Zone Management.	2003
COAST-WATCH	EADS	ESA GMES programme addressing policy requirements of coastal zone management (http://www.coastwatch.info)	2002 - 2003
COASTMON	NERSC, Norway	Project supported by EC Environment and Climate Programme: To explore and test methods for use of synthetic aperture radar (SAR) and other new satellite data, in monitoring environmental/metocean conditions in regions close to harbours, to improve navigational safety, to aid coastal zone management (CZM), and to improve utilization of satellite observations in the user community http://www.nrsc.no/COASTMON/	Finished 1999
EUROSION	RIKZ, NL	EUROSION was commissioned by the EC General Directorate Environment. The objective is to provide a recommendations for policy-making and information management practices to address coastal erosion in Europe, after thorough assessment of knowledge gained from past experiences and of the current status and trends of European coasts http://www.eurosion.org	Finished 2004
EUCC	EUCC, NL	The EUCC "Coastal Union", has members from over 4 European Countries, and provides background and links to many ongoing, recent and past initiatives http://www.eucc.nl	
MARCOAST	AAS, F	MarCoast is an ESA GMES Services Services Element Study consortium comprising a core group of service providers delivering 6 core services in the areas of oil spill surveillance and water quality assessment and monitoring. http://gmes-marcoast.com	ongoing

Appendix E: Sources of requirements for ALGAL BLOOM MONITORING

Name	Project Leader	Brief Description	Date
ROSES	ALCATEL, France	GMES Service Element project. Delivering water quality monitoring services – in 2003-4 algae bloom and oil spill monitoring. http://www.gmes-roses.com/	2002-2004
COAST-WATCH	EADS	ESA GMES programme addressing policy requirements of coastal zone management (http://www.coastwach.info	2002 - 2004
Decide-HAB	NERSC, Norway	Web based HAB information site for North Sea, Skaggerak, and Kattegak. http://www.nersc.no/Projects/HAB	Operational service
Algeinfo	Institute for Marine Research, Norway	Web based HAB information site for Norwegian Coast, produced by the Institute of Marine Research (IMR) with the Directorate of Fisheries (FD), OCEANOR AS and the Norwegian Institute for Water Research (NIVA). http://algeinfo.imr.no/eng	Operational service
Alg@line / Baltic Sea portal	Institute of Marine Research, Helsinki, Finland	Web portal to marine environmental information for the Baltic Sea around Finland	Operational service
Algaware	SMHI, Sweden	Web page with algal bloom information for Baltic. http://www.smhi.se/weather/baws_ext/syd/ov_syd_eng.htm	Operational service
Moncoze Live Access Server	Meteorologisk Institut, Norway	Pilot system monitoring and modelling Norwegian Coastal environment. http://moncoze.met.no	Operational service
PML Image Browser	Plymouth Marine Laboratory, UK	Image browser (registration required), giving SST and parameters from SEAWIFS data (chlorophyll-A, rgb composite, water leaving radiance, aerosol radiance, optical depth (at 865 nm), in water pigment concentration, in water diffuse attenuation coefficient (at 490 nm). http://www.npm.ac.uk/rsdas/	Operational service
IFREMER Bay of Biscay browser	IFREMER, FR	Image Browser giving SST, Chlorophyll-A, suspended matter, solar irradiance. http://www.ifremer.fr/cersat/en/news/2002/Dec/biscay/overview.htm	Operational service
ADRISCOSM	GOS,ISAC Sez, Rome, Italy	Image browser, giving SST and ocean colour parameter from SeaWiFS data (chlorophyll, true colour images, case I/case 2 water maps). SST and chlorophyll data are available for the Adriatic (registration required). http://gos.ifa.rm.cnr.it/	Operational service
ECOMAR	JRC, IT	FP6 Programme. “Monitoring and Assessment of Marine Ecosystems:. Aims to develop tools for a better harmonization of coastal and marine monitoring, specifically to support role in the definition and implementation of a Community Marine Strategy. http://ies.jrc.cec.eu.int/Actions/ECOMAR	Finished Dec 2006
DISMAR	JRC, IT	FP5 Programme. “Data integration system for marine pollution and water quality.” http://www.nersc.no/Projects/dismar/	2002-2005
COAST	JRC, IT	FP5 Programme. “Coastal Monitoring and Management.”http://ies.jrc.cec.eu.int/Projects/COAST/	Finished 2003

Appendix F: Sources of requirements for OIL SPILL MONITORING

Name	Project Leader	Brief Description	Date
ROSES	ALCATEL, France	GMES Service Element project. Delivering water quality monitoring services – in 2003-4 algae bloom and oil spill monitoring. http://www.gmes-roses.com/	2002-2004
Northern View	C-CORE	ESA GMES programme addressing environmental policy requirements of the Northern Regions. http://www.northernview.org/gmes/	2002 - 2004
KSAT	KSAT, Norway	SAR analysis for oil spill monitoring, ERS-2, ENVISAT and RADARSAT. http://www/ksat.no	Operational service
Telespazio	Telespazio, Italy	SAR analysis for oil spill monitoring, ERS-2, ENVISAT. http://www.telespazio.it/vasco	Operational service
Oilwatch	QinetiQ	SAR analysis for oil spill monitoring. http://www.qinetiq.com/homepage/casestudies/2002/case_study52.html	Operational service
Ocean Monitoring Workstation	Satlantic, Canada	A suite of software which can analyse SAR images and provide estimates of vessel location, oil spill location and extent, and wind and wave fields. http://www.satlantic.com/default.asp?id=190&pagesize=1&sfield=content.id&search=257&mn=38.62.292.312.377	Application
Oil Spill and ship detection.	KSAT, QinetiQ	ESA EOMD project which aims integrate an Envisat based oil spill monitoring service into the portfolio of the North Sea Directorate (Market Owner), and to expand the customer base for SAR based fishing vessel monitoring services. http://www.eomd.esa.int/contracts/contract54.asp	Start up 2002
EO exploitation in Marine Information Systems	BMT, UK	ESA EOMD project which aimed to to integrate oil spill data from ERS SAR imagery into the marine information system which would then propagate forwards or backwards in time to provide an indication of where a large slick would be likely to beach or to identify the probable source of the slick. http://www.eomd.esa.int/contracts/contract86.asp	Start up 2000
CLEAN SEAS	SOS, UK	EC environment and climate programme "To evaluate the contribution that EO data in surveillance of marine pollution and establish how observations may be integrated to create a single information source'. http://www.satobsys.co.uk/CSeas/viewframe.html	1997-99
ISTOP	Canadian Space Agency	ISTOP (Integrated Satellite Tracking of Oil Polluters) using RADARSAT SAR for marine oil spill detection off Canada's east coast.	2002-03
OCEANIDES	JRC, IT	FP6 GMES wide ranging project looking at all aspects for requirements to establish a pan-European oil pollution monitoring and information reporting capability. http://intelligence.jrc.cec.eu.int/marine/oceanides/oceanides.html	2002-03

Appendix G: Sources of requirements for sustainable exploitation of the sea

Name	Project Leader	Brief Description	Date
WEMSAR	NERSC, Norway	EC Framework RTP programme. Use of (mainly) SAR, also scatterometry and altimetry to map wind energy resource for potential offshore wind farms.	2000-2003
IMPAST	JRC Ispra	The project aims to develop tools that will allow near real time access to space borne synthetic aperture radar (SAR) imagery and the integration and comparison of this information with the vessel monitoring system (VMS) position reports in order to improve and support control fishing activities. http://intelligence.jrc.cec.eu.int/marine/fish/IMPAST/IMPAST_index.html	2000-2003
UK/SADC Fish Resource Assessment Project	South Africa Development Community	High-resolution SST data used as input to ecosystem models. Outputs from these models were then used to characterise the potential pelagic fish resource http://ceos.cnes.fr:8100/cdrom-00b2/ceos1/casestud/malawi/malawi1.htm	1992-94
AlgeInfo	IMR Norway	Harmful Algal Bloom monitoring and warning system. Combines satellite data, circulation and ecosystem models and in-situ data. http://algeinfo.imr.no/eng	ongoing
ISOLE	Vitricoset, Italy	EC framework project aimed at evaluating the impact of mass tourism on marine environment by applying Earth Observation techniques http://www.vitrociset.it/eng/spazio/isole.htm	
EOFISS	EADS S & DE	An ESA EOMD project to establish prototype fishing support services http://www.eomd.esa.int/contracts/contract94.asp	2000-2001
ENVISEA	EADS S & DE	An ESA EOMD follow up project to EOFISS, to further develop the SEAMAPPER service. http://www.eomd.esa.int/contracts/contract105.asp	2001-2002
CATSAT	CLS	Fisheries service, based upon operational provision of SST, altimeter data and MERCATOR products http://www.catsat.com/	operational
Fishing Vessel Detection Services	QinetiQ	To promote a SAR based vessel monitoring service to fisheries monitoring centres. http://www.eomd.esa.int/contracts/contract90.asp	2002-
Fishing Vessel Detection Services	KSat / QinetiQ	To integrate a SAR based oil spill monitoring service into the North Sea Directorate and to develop the customer base for a SAR based vessel monitoring service. http://www.eomd.esa.int/contracts/contract54.asp	2002-

Appendix H: Sources of requirements for Land users

Name	Project Leader	Brief Description	Date
GOFC-GOLD	GTOS	Global Observation for Forest and Land Cover Dynamics GOFC-GOLD): http://www.fao.org/gtos/gofc-gold/	1999-
GEOLAND	EC/ESA	EU FP6: http://www.gmes-geoland.info/	
GlobCarbon	Marc Leroy/MEDIAS-France	ESA DUE: http://www.gofc-gold.uni-jena.de/sites/globcover.php	2005-
SAGE	Infoterra GmbH	ESA GSE: http://www.gmes-sage.info	2003-2005
CYCLOPES		FP5: http://www.avignon.inra.fr/cyclopes/	
ELDAS	KNMI	FP5: http://www.knmi.nl/samenw/eldas/	2002-
EWBMS	EARS, The Netherlands	EU DGXII: European Energy and Water Balance Monitoring System Project: http://www.ears.nl/EWBMS/E_frameset.htm	
GSE-Land	Infoterra GmbH	ESA GSE: http://www.gmes-gseland.info/	2006 -
GSE-Forest	GAF AG	ESA GSE: www.gmes-forest.info	2006 -
Risk-EOS	ASTRIUM	ESA-GSE: http://www.riskeos.com/	2006 -
GMFS	VITO	ESA-GSE: http://www.gmfs.info/	2006 -