

MERSEA  
data and products  
for GMES

HALO  
report

Draft

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## 1 Introduction

The report gives an overview on data requirements and production of the MERSEA integrated project. Prepared for the HALO<sup>1</sup> specific support action, the overview intends to meet the need for a description of MERSEA's data flow and dissemination relevant to GMES<sup>2</sup> activities.

The report provides a summarised inventory of MERSEA's main data needs, which are satellite and in-situ observation of the ocean and the near sea surface atmosphere. MERSEA's numerical ocean models as well as the existing infra structure for data provision and exchange between the MERSEA partners will be introduced. Knowing existing models and data architecture will be a starting point for supporting further developments of links to other GMES integrated projects.

MERSEA (Marine Environment and Security for the European Area) is funded under FP6 (Thematic Priority Space/GMES) and runs for four years (2004-2008). MERSEA aims to develop a European system for operational monitoring and forecasting on global and regional scales of the ocean physics, bio-geochemistry and ecosystems. The prediction time scales of interest extend from days to months. The integrated system will be the Ocean component of the future GMES system.

A preliminary eighteen-month project, MERSEA Strand 1 project, was funded under FP5 (Sustainable development), with the objective to analyse the existing European capabilities for development, implementation and operational use of marine modelling and data assimilation systems, space borne observations and in-situ observing networks and systems. Many of the Strand 1 participants are also part of the MERSEA Integrated Project. Results of the Strand 1 project are a major contribution to the report since they describe the current status of development.

Many strong links exist between atmosphere, ocean and land integrated projects due to coupling in the Earth-System. Examples of interactions concerning the oceans are:

- Wind stress, heat fluxes and precipitation force the ocean dynamics.
- High resolution ocean modelling (SST) is a prerequisite for seasonal atmospheric forecasting.
- Biochemical ocean observations and modelling is necessary for understanding the global carbon cycle.

Within the overall architecture of the Land – Ocean and Atmosphere GMES system, the main present link of the ocean and marine application service (MERSEA) is towards the atmosphere community, essentially with the standard outputs of Numerical

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<sup>1</sup> HALO is a GMES specific support action (SSA), which will be responsible for the harmonized coordination of the interaction between the atmosphere, land and ocean integrated projects of the GMES backbone. The objective of HALO is to enable an efficient and coherent data exchange between the relevant IP's of GMES. HALO will provide agreed recommendations for the data architecture of GMES in its operational phase starting in 2008.

<sup>2</sup> GMES is a joint initiative of the European Commission and the European Space Agency, designed to establish a European capacity for the provision and use of operational information for Global Monitoring of Environment and Security. Besides the ocean theme, GMES's thematic priorities are land & vegetation, atmosphere, water resources, natural risks and security.

Weather predictions services. The future MERSEA system will benefit from the enhanced capabilities to be provided by GEMS (aerosols, Carbon cycle variables). As far as the Land connection, the main requirement is for river output in support of coastal modelling and monitoring.

The information sources used for preparing this report are the MERSEA proposal (Annex I - Description of work), a draft report on observational requirements of the MERSEA Strand 1 project and the draft GODAE implementation plan. Further, web based documentation and user support documents, web sites of MERSEA, ICO, WMO and space agencies have been consulted. Finally, personal communication with scientist involved in the MERSEA activities during study visits to IFREMER (Brest), to the FOAM team at UK Met-office and to the Environmental Systems Science Centre at Reading University has been an important input.

The report starts in chapter 3 with a general overview of the MERSEA project. Chapter 3 introduces to the observation of ocean with focus on in-situ measurements and chapter 4 covers the satellite observations. Chapter 5 presents MERSEA models. Chapter 6 and 7 contain a summary of their data needs and product output. Technical issues of the data exchange within MERSEA are discussed in chapter 8.

## 2 Overview of MERSEA objectives

MERSEA aims to develop a European system for operational monitoring and forecasting on global and regional scales of the ocean physics, bio-geochemistry and ecosystems. The prediction time scales of interest extend from days to months. This integrated system will be the Ocean component of the future GMES system.

At the core of the system is the collection, validation and assimilation of remote sensed and in-situ data into ocean circulation models that allow for the self consistent merging of the data types, interpolation in time and space for uniform coverage, nowcasting (i.e. data synthesis in real-time), forecasting, and hindcasting, and delivery of information products. The project will develop Marine Applications addressing the needs of both intermediate and end-users, whether institutional or from the private sector, with the objective to :

- Improve the safety and efficiency of maritime transport and naval operations
- Enable the sustainable exploitation and management of ocean resources (offshore oil and gas industry, fisheries)
- More efficiently mitigate the effects of environmental hazards and pollution crisis (oil spills, harmful algal blooms)
- Improve contribution to ocean climate variability studies and seasonal climate prediction and its effects on coastal populations
- Improve national security and reduce public health risks
- Advance marine research with the aim to better understand the global climate, the ocean and its ecosystems.

The project will lead to a single high-resolution global ocean forecasting system shared by European partners together with a co-ordinated network of regional systems for European waters, which will provide the platform required for coastal forecasting systems. During the project the main pre-operational systems will be transitioned towards operational status and three of the centres will converge on a single ocean model framework suitable for both the deep ocean and shelf-seas.

### 2.1 Ocean observing systems

GMES requires high quality and reliable information from fully validated global data sets, both remote sensed and in-situ. Remotely sensed data from satellites deliver near real-time, long-term, synoptic, high resolution, global estimates of key parameters (e.g. sea surface topography, sea surface temperature, ocean colour, sea ice, winds). However, since they can sense only surface parameters, they must be complemented by in-situ data, which are much more sparsely and irregularly distributed in time and space. The in-situ data are indispensable for calibration of the satellite data, validation of the models, assimilation into the models and improving the assimilation of the satellite data.

One of the objectives of MERSEA will thus be to develop further the European capacity in global ocean remote sensing data processing and distribution. A remote

sensing work-package will ensure the availability in real time of state-of-the-art remotely sensed global products optimised for supporting operational oceanography. Near real time and delayed mode products will be delivered over the period 2004-2008. In parallel, processing systems will be improved through R&D activities and consolidated to become fully operational by 2008.

The in-situ observing system has been revolutionised in the past few years by the ARGO program which is seeding the global ocean with thousands of autonomous profiling floats reporting temperature and salinity to 2000 m depth on a real-time basis. These data are essential for the modelling and assimilation within MERSEA. GMES should contribute to the ARGO array to provide MERSEA with global, real-time upper ocean salinity and temperature information. The MERSEA project will integrate the collection, quality control and dissemination of relevant in-situ data for the MERSEA system at the European level.

Routinely provided biogeochemical data are desperately needed by the modelling and forecasting system planned under MERSEA. This gap will be filled by the MERSEA activity of operating and demonstrating real-time multidisciplinary moorings in representative ocean regions ("provinces"). A profound need exists for the collection of multi-disciplinary in-situ data, since satellites cannot provide the required information (chlorophyll estimates are possible but only in the near-surface layer and need constant validation, while e.g. oxygen and nutrients cannot at present be observed from space), and no observing system exists for such type of information. Gliders and floats with multidisciplinary sensors are innovative tools to fill this gap, and MERSEA will demonstrate their value in operational systems.

## 2.2 Modelling and assimilation

The state of the art for the optimum combination of multi-sensor data sets is through assimilation into numerical models, which take explicitly into account the physics and dynamics which control the temporal evolution of the ocean. Systems such as FOAM, MERCATOR, MFS and DIADEM/TOPAZ for instance, have demonstrated over several years the ability to monitor and forecast global ocean and European seas through routine assimilation of near-real-time satellite and in-situ observations into 3D ocean models.

These modelling systems must now be further upgraded, consolidated, more fully validated to ensure their reliability and transitioned to a state of readiness for fully operational monitoring during GMES.

Advances in computer power and numerical methods make it possible now to run global high resolution models of ocean circulation. A resolution of the order of  $1/12^\circ$  (in latitude and longitude, equivalent to a grid scale of order 9 km) is already feasible, and necessary to reproduce adequately the physics of ocean processes. The challenge MERSEA will address is to implement a system assimilating data into such a model and to run it as a real-time sustainable service.

Forcing fields (wind action, surface heat and moisture fluxes) obtained from numerical weather forecasting are essential to determine and forecast the ocean response. But as they are presently provided, they present several draw-backs : the parameterisations are simplified and not optimised for oceanic applications ; and available satellite data (scatterometer) are not used to their full resolution. MERSEA

intents to improve the forcing fields and to provide operational products in support of the monitoring system.

While global models are necessary to provide the extensive coverage expected from GMES, higher resolution coverage is required for regional and local applications. On the regional level, operational models are run by national agencies (usually Meteorological Offices) to provide analyses and forecasts of sea state, storm surges, and sea-ice or icebergs, to forecast the drift of oil spills and to assist in search and rescue operations.

Also most operational 3D-ocean regional models currently use only climatological lateral boundary conditions for temperature and salinity and do not assimilate observational data. The key scientific and technical improvements to the regional models that will be achieved within MERSEA include the use of appropriate boundary data (nesting) from larger area models (e.g. the global model), increases in model resolution, assimilation of available local data sets and high resolution remotely sensed data, improvements in the modelling of the region of the shelf break and assessment of improvements in predictive skill. Finally, some of the pre-operational systems will transition towards pre-operational daily forecasts.

Monitoring of the ocean environment for GMES requires not only physical but also **ecosystem** models. Although significant advances have been made in recent years, understanding and modelling the complex processes in ecosystems requires much research and more appropriate data. MERSEA will contribute to progress by developing modelling and assimilation methods (in particular for ocean colour implementing them in pre-operational systems and assessing the results by intercomparison with observations. In cooperation with proposed research projects, MERSEA plans to incorporate the latest research results, observations, and parameters into its operational models.

### 2.3 Marine applications

Some of the most significant marine services, in terms of safety at sea and risk prevention, are provided by NWP1 centres in the form of wind, wave, storm surges, and sea-ice forecasts. These centres also provide assistance and support in case of accidents and disasters (search and rescue, oil spill forecasts).

The quality and skill of these analyses and forecasts (particularly of freak waves and sea-ice) could be improved by the use of high resolution information on ocean currents and temperatures, which are presently not taken into proper account.

MERSEA proposes to contribute to the development of enhanced marine services through the provision of high resolution currents in support of marine safety. MERSEA will also develop products for final users such as the offshore oil and gas industry, forecasting of sea ice and iceberg drifts, and improved sea state (surface wave) forecasts notably by better incorporation of wave-current interaction modelling. These applications require research and development of high quality products and close interaction with the service providers to establish the information systems and interfaces that will deliver to them the necessary products in the appropriate formats and in a timely manner.

Studies of seasonal forecasting are also proposed in this project because of the very high stakes involved. NWP centres produce such forecasts operationally using rather

low resolution ocean models or products that do not incorporate, as MERSEA proposes to do, all available data from ocean observing systems.

Research projects, such as DEMETER, have shown that significant skill can be achieved in seasonal prediction in the tropics (particularly precipitation), if high resolution sea surface temperature fields are used to initialise the forecasts. MERSEA proposes to investigate and develop the methods required to incorporate high resolution ocean products into these forecasts, and to evaluate the improvement in predictive skill.

## 2.4 Specific Objectives

In view of the state of the art, as briefly reviewed above, MERSEA has identified the following key specific objectives:

- Develop the systems needed, and use them, to provide real-time, high quality, validated, merged products from satellite data for surface height, surface temperature, ocean colour, sea-ice and surface velocity.
- Implement and assess the value of moorings and gliders for bio-geochemical data. Initiate routine provision of real-time data from specific research vessels. Make cost-effective contributions to the in-situ system for the Mediterranean and the global Argo system. Collect in-situ data and make them available in real-time through a unique server.
- Implement and test a high resolution global ocean model with assimilation of remote sensed and in-situ data ; develop a deep ocean model for use in shelf seas and evaluate its performance on NW European shelf; evaluate methods for nesting of models ; develop and assess biogeochemical models ;
- Progressively implement a co-ordinated ocean and sea-ice monitoring and forecasting system for the global ocean and European seas, assimilating in-situ and satellite data and providing high resolution forecasts on a daily or weekly basis for physical and bio-geochemical variables.
- Make systematic assessments of the performance of the analyses and forecasts of the physical and bio-geochemical variables.
- Assess the value of boundary data for regional forecasts and implement data assimilation methodologies for regional seas and test their impact.
- Develop an information management system that will deliver both real-time and delayed mode information to users, allowing them to exploit multiple data sets from many different sources with user-friendly internet-based interfaces. Provide full documentation and meta-data.
- Develop and demonstrate applications in support of the safety of marine operations including improved wave-forecasting, and forecasts for ship routing, the offshore oil and gas industry, oil spill drift.
- Implement research results and perform specific experiments to improve now-casting (analysis) and forecasting for ecosystems and seasonal weather forecasting.



- Help to organize appropriate teams and agencies to establish the proper framework for the ocean component of GMES by 2008.

### 3 Observation of the ocean state

#### 3.1 Variables to be measured

Observation of the oceans and coastal zones aim to measure geophysical and biogeochemical properties of ocean water and the ocean-atmosphere interface. Within MERSEA, the data is used for assimilation into the models and for validation purposes. Meteorological data provides the atmospheric forcing, which controls the ocean circulation and its geophysical and biogeochemical state.

The GCOS<sup>3</sup> Implementation plan identifies the following essential climate variables for the ocean:

- Surface: Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean colour (for biological activity), Carbon dioxide, partial pressure.
- Sub-surface: Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton.

#### 3.2 Ocean surface meteorology

Over the oceans the WMO's global observation system WWW (World weather watch) relies on ships, moored and drifting buoys and stationary platforms. Many of them provide both oceanographic (**SST**) and atmospheric data. Observations made by ships recruited under the WMO Voluntary Observing Ship Programme (VOS), comprise much the same variables as at surface land stations, namely pressure, temperature, wind, humidity and cloud cover. Additionally, sea surface temperature and wave properties are recorded. The number of observing ships is about 7,000 world wide. About 40% are at sea at any given time. The operational drifting buoy programme comprised about 750 drifting buoys providing 6,000 sea surface temperature and surface air pressure reports per day.

#### 3.3 Oceanographic observation programs

Ocean observation programmes, from space or in situ, are coordinated by a number of international agencies and programmes, whose structure is complex, with many joint responsibilities and sponsorship. Some of the main ones are listed here.

The Global Ocean Observing System (**GOOS**) is a permanent system for observation, modelling and analysis of marine and ocean variables to support operational services world wide. GOOS belongs to the Global Climate Observing System (**GCOS**), which was established in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users.

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<sup>3</sup> Global Climate Observing System

Other parts of GCOS are the the Global Atmosphere Watch (**GAW**) and the Global Terrestrial Observing System (**GTOS**) as well as World Weather Watch (**WWW**).

GOOS comprises existing observation systems, pilot projects (e.g. Argo, GODAE) and regional implementation as EuroGOOS or MedGOOS for the Mediterranean. The Argo programme is a new method of collecting information from the upper ocean using a fleet of robotic floats. The Global Ocean Data Assimilation Experiment (**GODAE**) aims to develop a global observation, modelling and data assimilation system for the Ocean. GODAE builds on experience gathered in the Tropical Ocean-Global Atmosphere (**TOGA**) and the World Ocean Circulation Experiment (**WOCE**).

### 3.3.1 *Global in-situ observational programmes*

Global programmes in GOOS are:

- **DBCP** : Data Buoy Co-operation Panel. Drifting and moored data buoys, ice floats, and sub surface floats are now generally accepted as a very cost-effective means for obtaining meteorological and oceanographic data from remote ocean areas. As such, they form an essential component of marine observing systems established as part of WWW, WCRP, GOOS and GCOS.
- **SOOP** : Ship-of-Opportunity Programme SOOP is directed primarily towards the continued operational maintenance and co-ordination of the ship of opportunity network operating mainly XBT but other types of measurements as well (e.g. TSG, XCTD, CTD, ADCP, pCO<sub>2</sub>, phytoplankton concentration).
- **GLOSS**: Global Sea Level Observing System. GLOSS aims at the establishment of high quality global and regional sea level networks for application to climate, oceanographic and coastal sea level research.
- **TIP** : Tropical Moored Buoys Implementation Panel. TIP is responsible for development, co-ordination, and implementation of moored buoy programs in the tropical ocean regions as part of an integrated approach to observing the climate system (ENSO) to address the research needs of CLIVAR and the operational strategies of GOOS and GCOS.
  - **TAO** : Tropical Atmosphere Ocean project
  - **TRITON** : Triangle Trans-Ocean buoy Network
  - **PIRATA** : Pilot Research Moored Array in the Tropical Atlantic
- **CPR** : Continuous Plankton Recorder Programme
- **GCRMN** : Global Coral Reef Monitoring Network
- **VOS**: Voluntary Observing Ships for observation of marine meteorology
- **ASAP**: Automated Shipboard Aeronautical Programme

Within Europe, several research and development programmes contributing to the development and implementation of operational oceanography and observation of ocean parameters have been funded in recent years by the European Commission and the ESA.



### 3.3.2 *Argo programme*

Argo is a new method of collecting information from the upper ocean using a fleet of robotic floats : temperature and salinity profiles from 2000 m to the surface, every ten days, nominally. Argo data complement other in-situ observations (many restricted to shipping routes) and data from earth-observing satellites. The main Argo data uses are in operational ocean and climate monitoring and forecasting and in oceanographic and climate research.

The sub-surface drift enables the currents that transport heat and water to be estimated across entire ocean basins. The 3000 float Argo array (spaced about 300 km apart) will deliver 100,000 profiles per year. Argo deployments began in 2000 by mid 2004 the array is over 40% complete. Completion is expected by 2006.

Argo is a major contributor to the WCRP's Climate Variability and Predictability Experiment (CLIVAR) project and to the Global Ocean Data Assimilation Experiment (GODAE). The Argo array is part of the Global Climate Observing System/Global Ocean Observing System GCOS/ GOOS).

### 3.3.3 *GODAE*

The Global Ocean Data Assimilation Experiment (GODAE) aims to develop a global system of observations, communications, modeling and assimilation, that will deliver regular, comprehensive information on the state of the oceans in a way that will promote and engender wide utility and availability of this resource for maximum benefit to the community. Achieving global coverage by assimilation in-situ and remote sensing data from various observation networks (Argo, SOOP etc) is a main motivation of GODAE.

GODAE objectives are:

1. Apply state-of-the art ocean models and assimilation methods to produce short-range open-ocean forecasts, boundary conditions to extend predictability of coastal and regional subsystems, and initial conditions for climate forecast models.
2. Provide global ocean analyses for developing improved understanding of the oceans, improved assessments of the predictability of ocean variability, and as a basis for improving the design and effectiveness of a global ocean observing system.

MERSEA, as a European GODAE centre, serves GODAE goals. The projects GHRSSST-PP (GODAE high-resolution sea surface temperature pilot project) has been established to give international focus and coordination to the development of a new generation of global, multi-sensor (Satellites and in-situ), high-resolution (~6 hours and 10 km), SST products. The most promising way to achieve the GHRSSST -PP aim is to combine observations from complementary infrared (IR) and passive microwave (PM) satellite sensors on polar -orbiting and geostationary platforms together with quality controlled in-situ observations from ships and buoys. The imminent advent of AATSR, MODIS, GLI and SEVIRI, key infrared satellite sensors for improving SST data quality, as well as new satellite microwave radiometers such as TRMM TMI and AMSR, makes this an appropriate time to develop and demonstrate the benefits of such an approach.

## 4 Satellite missions for ocean observations

Since the ocean is opaque to electromagnetic radiation, space based instruments only observe the properties of the ocean surface. Sea level (altimetry), ocean surface characteristics (waves, ice and oil spills), sea surface temperature and salinity as well as ocean colour and surface wind can be inferred from satellite data.

Satellites provide global coverage of the ocean. The radiation received by the instruments is altered due to the ocean surface properties and the atmosphere above. Special design of the instrument, multi sensors and good knowledge of the atmospheric state are needed for a correct retrieval of the targeted ocean properties.

One can distinguish the following active MW instruments useful for ocean observations:

- **Radar Altimeters** measure dynamic anomalies in the ocean surface height, as well as ocean significant wave height due to the time delay of emitted radiation
- **Scatterometers** measure ocean surface wave height and wind speed and direction due to the measurement of the backscatter coefficient
- **Synthetic aperture radars** measure ocean surface wave spectra and surface properties (sea ice, oil spill etc.)

The sea level anomalies in the open ocean provide the pressure gradients causing large scale ocean circulation. They are caused by circulation itself and the ocean temperature. The roughness or waves structure of the ocean surface are mainly caused by the winds near the ocean surface. Therefore wind data, which in return force the ocean surface current, can be indirectly inferred by the ocean surface properties. Ocean ice cover or oil spills change the surface structure as well. Ocean colour reflects the turbidity of the water and therefore the content of plankton and algae.

Passive MW imagers as SSM/I (NOAA) can be used to provide wind speed (no direction) and to detect ocean sea ice. All active and passive MW imagers are carried onboard polar orbiting satellites, which cover the whole earth in 1 -2 day.

Sea Surface Temperature can be directly measured by means of the emitted IR and MW radiation. IR (e.g. ATSR) and MW (e.g. SSM/I) radiometers are carried on polar orbiting satellites. IR measurements from VIS and IR images (e.g. SERVI) on operational meteorological geostationary platforms (MSG, GOES) allow higher temporal resolution but lower spatial resolution and limited coverage. IR radiometers can only measure SST in cloud free conditions.

Ocean colour measurements use the imagers operating in the visible range in order to detect chlorophyll content, which is an indicator of biological production in the ocean. Specific radiometers design and atmospheric correction is required since only a small part of the received signals comes from the ocean, the main part comes from the atmosphere.

HF-radars (high frequency) are a new technique for land based remote sensing of the sea surface from the land, negating the need for expensive ship time, and enabling



measurements to be taken during difficult weather conditions. Deployed at the coast, they can measure the sea surface up to 70 km offshore.

Several satellite missions are dedicated to specific aspects of ocean observation; some environmental satellites carry instruments especially designed for ocean observations ; other instruments measure both ocean, atmosphere or land properties. Almost all ocean satellite data are obtained from polar orbiting platforms.

Jason-1 (2) and TOPEX/Poseidon (NASA & CNES) are satellites specialised in altimetry measurement by radar. Quikscat (NASA) has only Scatterometer for Ocean wind retrieval onboard. ESA's Envisat and ERS-2/1 carry, among other instruments, Radar altimeter, Scatterometer and Synthetic Aperture Radiometers (SAR). Modis on AQUA and Terra (NASA) and MERIS (Envisat) can be used for ocean colour and SST retrieval as well as for aerosol retrieval.

Environmental satellites and operational meteorological satellites carry sensors capable to observe SST by means of IR or MW radiation. Passive MW instruments such as SSM/I (NOAA) can be used to detected sea ice and to determine ocean winds.

Altimeter measurements need precise data of the earth gravitation field, which will be provided by special gravity missions. New developments like the SMOS will allow retrievals of Sea Surface Salinity.

A list of currently operating satellite instruments is given in Table 1. The following sub paragraphs briefly describe important missions or instrument and supply a schematic of the schedule of present and future missions.



SATELLITE SENSOR	SPACECRAFT	TEMPORAL COVERAGE	SPATIAL COVERAGE & RESOLUTION	MEASUREMENT OF OCEAN PROPERTIES
SeaWiFS VIS Imager	SeaStar	Daily (cloud limited)	Global 1 km	<b>Ocean Colour</b>
Vegetation VIS Imager	Spot	Daily (cloud limited)	Global 1 km	<b>Ocean Colour</b>
MODIS VIS IR Imager	Aqua & Terra	Daily (cloud limited)	Global 250 m to 1 km	<b>Ocean Colour, SST</b>
MERIS VIS IR Imager	Envisat	Daily (cloud limited)	Global 4 km	<b>Ocean Colour, SST</b>
AVHRR VIS IR Imager	NOAA	Daily (cloud limited)	N. Atlantic & Mediterra. 1 km	<b>SST</b>
ATSR IR imager	ERS-2	3rd Day (cloud limited)	Global 1 km	<b>SST</b>
AATSR IR imager	Envisat	3rd Day (cloud limited)	Global 0.5 km	<b>SST</b>
TMI MW-imager	TRMM	Daily	35N-35S 2-30 km	<b>SST</b>
SERVI VIS-IR imager	Meteosat 2nd Generation	15 Min	Earth disk, no poles 4 km	<b>SST</b>
AMSR (-E) MW-imager	Aqua Adeaos-II	Daily	25 km	<b>SST , sea ic</b>
RA Radar Altimeter	ERS-2	7 days	1 km	<b>Sea Level, Significant wave height</b>
RA-2 Radar Altimeter	Envisat	7 days	1 km	<b>Sea Level, Significant wave height</b>
Poseidon-2 Radar Altimeter	Jason-1	10 days	1 km	<b>Sea Level, Significant wave height</b>
Poseidon Radar Altimeter	TOPEX/Poseidon	10 days	1 km	<b>Sea Level, Significant wave height</b>
ASAR SAR instrument	Envisat	Daily	Global with 5*5 km every 100 km	<b>Wind speed &amp; direction, oil spill , sea ice</b>
SAR (AMI) SAR instrument	ERS-2	Daily	Global with 5*5 km every 300 km	<b>Wind speed &amp; direction, oil spill , sea ice</b>
Seawinds Scatterometer	Quikscat Adeos-II	Daily	Global, 50 km	<b>Wind speed &amp; direction, oil spill , sea ice</b>
WS (AMI) Scatterometer	ERS-2	Daily	Global, 100 km	<b>Wind speed &amp; direction, oil spill , sea ice</b>
SSM/I passive MW instrument	DSPM F series	Daily	Global 25 km	<b>Wind speed Sea Ice,</b>
Coriolis passive MW instrument	Windsat	Daily	Global 25 km	<b>Wind speed Sea Ice,</b>
PR MW radar	TRMM	Daily	35N-35S 2-30 km	<b>Precipitation</b>

**Table 1 Current satellite instrument for observing the ocean**

#### 4.1 Missions and instruments for ocean wind and wave observation

**WS (Wind Scatterometer)** onboard ERS-2. The purpose of the WS is to obtain information on wind speed and direction at the sea surface. It operates by recording the change in radar reflectivity of the sea due to the perturbation of small ripples by the wind close to the surface. This is possible because the radar backscatter returned to the satellite is modified by wind-driven ripples on the ocean surface and, since the energy in these ripples increases with wind velocity, backscatter increases with wind velocity

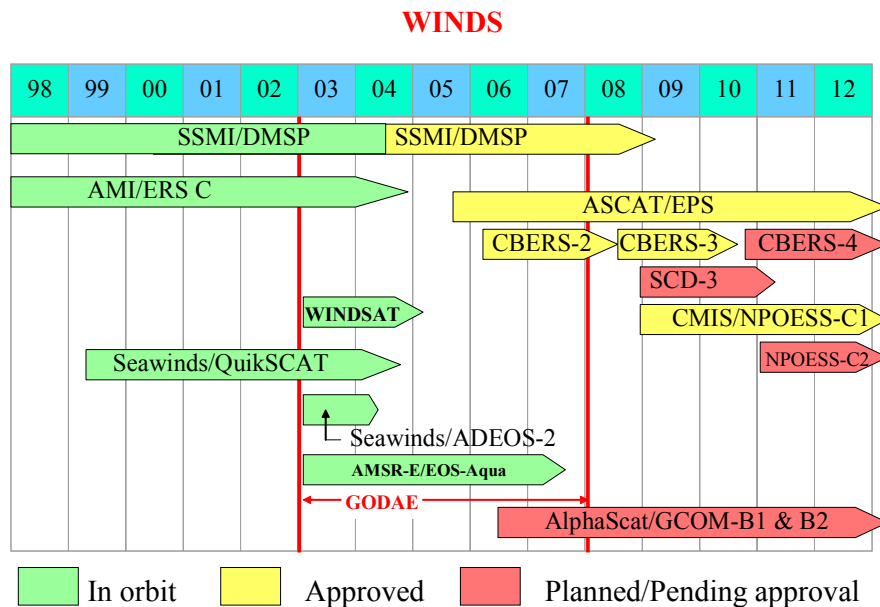
**SeaWinds** onboard Quikscat uses a rotating dish antenna with two spot beams that sweep in a circular pattern. The antenna radiates microwave pulses at a frequency of 13.4 gigahertz across broad regions on Earth's surface. The instrument will collect data over ocean, land, and ice in a continuous, 1,800-kilometer-wide band, making approximately 400,000 measurements and covering 90% of Earth's surface in one day.

**WINDSAT** is a joint IPO/DoD/NASA risk reduction demonstration project intended to measure ocean surface wind speed and wind direction from space using a passive polarimetric radiometer. The WindSat/Coriolis mission will measure the ocean surface wind field at a horizontal resolution of 25 km using a 1.9-m diameter reflector that is almost three times as large as the antenna on the DMSP Special Sensor Microwave Imager (SSMIS).

**SAR (Synthetic Aperture Radar)** on ERS-2 builds together with the Scatterometer WS the AMI (Active Microwave Instrument). SAR provides two-dimensional spectra of ocean surface waves. For this function the SAR records regularly spaced samples within the image swath. The images are transformed into directional spectra providing information about wavelength and direction of wave systems. SAR images can also show the effects of other phenomena, such as internal waves, slicks, small scale variations in wind and modulations due to surface currents and the presence of sea ice.

**ASAR (Advanced Synthetic Aperture Radar)** on Envisat operates at C-band, ASAR ensures continuity with the image mode (SAR) and the wave mode of the ERS-1/2 SAR (AMI). ASAR provides a swath coverage of over 400-km wide using ScanSAR techniques.

**SSM/I (Special Sensor Microwave Imager)** is a seven-channel, four frequency, linearly-polarized, passive microwave radiometric system which measures atmospheric, ocean and terrain microwave brightness temperatures at 19.35, 22.235, 37.0 and 85.5 GHz. The first satellite equipped with a SSM/I instrument was F8, launched in 1987, aboard the Defense Meteorological Satellite Program (DMSP). SSM/I instruments on the F-13, F-14 and F-15 satellites are currently assimilated actively in operations. Its data can be used to retrieve Ocean winds and sea ice.



**Figure 1** Schedule of satellite missions for ocean surface winds (from draft GODAE implementation plan <http://www.bom.gov.au/bmrc/ocean/GODAE/Planning/IP/Plan.htm>).

#### 4.2 Missions and instruments for altimetry and gravimetry

**TOPEX/Poseidon** by NASA and CNES (France). TOPEX/Poseidon builds on the outcomes of previous missions GEOS-3 (Geodynamics Experimental Ocean Satellite, 1975), Seasat (Sea Satellite, 1978), and Geosat (Geodetic Satellite, 1985), which proved validity and precision of a satellite altimeter in measuring the sea surface height from space over time. A challenge of TOPEX/Poseidon was to improve an accuracy in measurement using a state-of-the-art dual-frequency radar altimeter and three independent precision orbit determination systems. The satellite orbits the Earth at altitude of 1336 km. The satellite takes measurements of height of the ocean at the same points every 10 days using the two altimeters.

**Jason-1** is a follow-on to the highly successful TOPEX/POSEIDON mission that measured ocean-surface topography to an accuracy of 4.2 cm. TOPEX/POSEIDON enabled scientists to forecast the 1997-1998 El Niño and has improved understanding of ocean circulation and its effect on global climate. Jason-1 altimeter data will be part of a suite of data provided by other JPL-managed ocean missions. Objectives of the Jason are to extend ocean surface topography measurements into the 21st century, to provide a 5-year view of global ocean surface topography. Jason data will help to increase understanding of ocean circulation, to improve forecasting of climate events and to measure global sea-level change. Jason -1 will be followed by **Jason 2** in 2008.

**GOCE** by ESA. The Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) mission will measure high-accuracy gravity gradients and provide global models of the Earth's gravity field and of the geoid. The geoid (the surface of equal gravitational potential of a hypothetical ocean at rest) serves as the classical reference



for all topographical features on the planet. The accuracy of its determination is important for surveying and geodesy, and in studies of Earth interior processes, ocean circulation, ice motion and sea-level change.

**OSTM** by NASA, Proposed Launch: 2005, OSTM - Ocean Surface Topography Mission, is a follow-on to Jason-1. It will take oceanographic studies of sea surface height into an operational mode for continued climate forecasting research and science and industrial applications.

**GRACE** by NASA (Launched 2002) The Gravity Recovery and Climate Experiment (GRACE) consists of two spacecraft flying in tandem that will measure Earth's gravitational field very precisely. These measurements will enable a better understanding of ocean surface currents and ocean heat transport. The mission will be able to measure changes in sea-floor pressure and show how the mass of the oceans change. It will also measure and monitor ice sheets and changes in the storage of water and snow on the continents.

**SSALTO/DUACS** (SSALTO/Developing Use of Altimetry for Climate Studies) is a multi mission altimeter data processing system and service operated by CLS (France). Jason-1, TOPEX/Poseidon and ERS-2 data are processed. It serves in near-real time the main operational oceanography and climate forecasting centres in Europe and worldwide. Ssalto/Duacs near-real time data are used, in particular, by GODAE, Mercator and MERSEA.

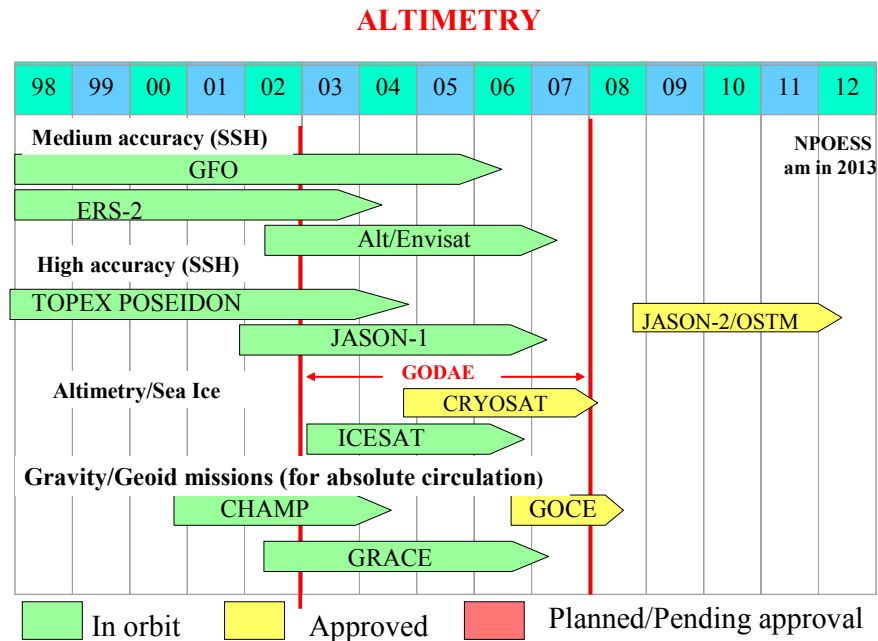


Figure 2 Schedule of missions for ocean surface topography (from draft GODAE implementation plan <http://www.bom.gov.au/bmrc/ocean/GODAE/Planning/IP/Plan.htm>).

#### 4.3 Missions and instruments for sea surface temperature, salinity and ocean colour

**AVHRR (Advanced Very High Resolution Radiometer)** is onboard NOAA Satellites. AVHRR is a radiation-detection imager that can be used for remotely determining cloud cover and the land and sea surface temperature. This scanning radiometer uses 6 detectors that collect different bands of radiation wavelengths in the VIS to IR range. The first AVHRR was a 4-channel radiometer, first carried on TIROS-N (launched October 1978). This was subsequently improved to a 5-channel instrument (AVHRR/2) that was initially carried on NOAA-7 (launched June 1981). The latest instrument version is AVHRR/3, with 6 channels, first carried on NOAA-15 launched in May 1998. AVHRR SST data and in-situ observations are the data source for the Reynolds SST product.

**AMSR-E (Advanced Microwave Scanning Radiometer for EOS)** onboard Aqua is a twelve-channel, six-frequency, total power passive-microwave radiometer system. The spatial resolution of the individual measurements varies from 5.4 km at 89.0 GHz to 56 km at 6.9 GHz. AMSR-E Measures precipitation rate, cloud water, water vapor, sea surface winds, sea surface temperature, ice, snow, and soil moisture in all weather conditions.

**ATSR (Along-Track Scanning Radiometer and Microwave Sounder)** consists of two instruments, an Infra-Red Radiometer (IRR) and a Microwave Sounder (MWS). On board ERS-1 the IRR is a four-channel infra-red radiometer used for measuring sea-surface temperatures (SST) and cloud-top temperatures, whereas on board ERS-2 the IRR is equipped with additional visible channels for vegetation monitoring. The MWS is a two channel passive radiometer.

**AATSR (Advanced Along Track Scanning Radiometer)** is to establish continuity of the ATSR-1 and ATSR-2 data sets of precise sea surface temperature (SST), thereby ensuring the production of a unique 10 year near-continuous data set at the levels of accuracy required (0.3 K or better) for climate research and for the community of operational as well as scientific users

**SERVI** onboard MSG-1 (Meteosat 2<sup>nd</sup> Generation, geostationary) and MSG-2 (2005). The Earth's radiation enters the instrument at every revolution through a 50 cm x 80 cm aperture. The nominal repeat cycle of 15 min was the driver in selecting the number of detectors per channel and the spin rate (100 rpm). The 1 km resolution of the High Resolution Visible (HRV) channel is achieved by using 9 broad-band detection elements. The other channels are sampled at 3 km resolution by using 3 narrow-band detection elements per channel.

**SMOS** by ESA: The Soil Moisture and Ocean Salinity Mission is the second Earth Explorer Opportunity mission scheduled for launch in early 2007. Its overall objectives are to provide global observations of two crucial variables for modelling the weather and climate, Soil Moisture and Ocean Salinity. It will also monitor the vegetation water content, snow cover and ice structure.

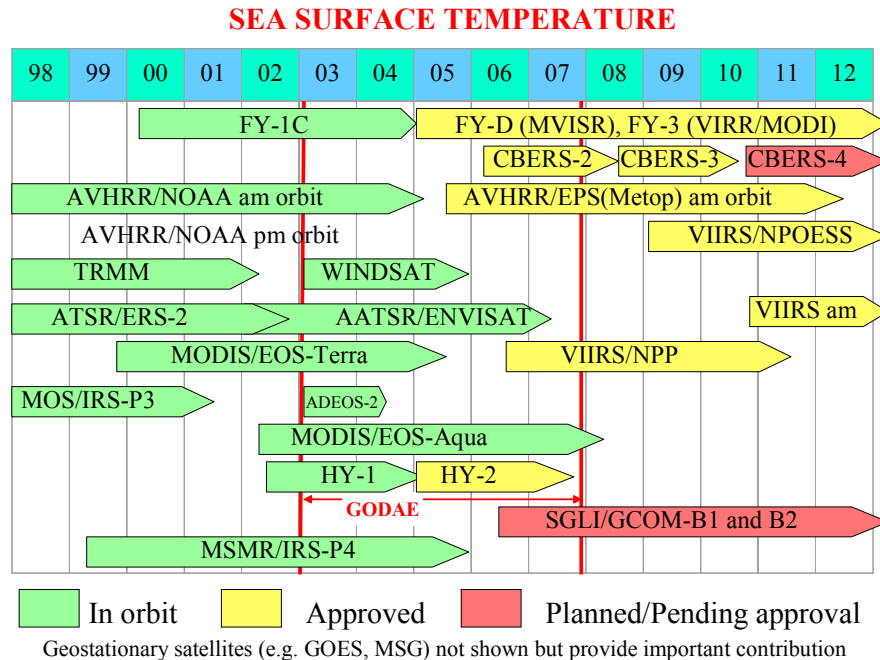
**MODIS (or Moderate Resolution Imaging Spectroradiometer)** is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and



Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths.

**MERIS** (MEdium Resolution Imaging Spectrometer Instrument) on Envisat. The primary mission of MERIS is the measurement of sea colour in the oceans and in coastal areas. Knowledge of the sea colour can be converted into a measurement of chlorophyll pigment concentration, suspended sediment concentration and of aerosol loads over the marine domain. MERIS is, also capable of retrieving cloud top height, water vapour total column, and aerosol load over land. These measurements constitute MERIS secondary mission.

**SeaWifs** (NASA). The purpose of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project is to provide quantitative data on global ocean bio-optical properties to the Earth science community. Subtle changes in ocean color signify various types and quantities of marine phytoplankton (microscopic marine plants), the knowledge of which has both scientific and practical applications. The SeaWiFS Project will develop and operate a research data system that will process, calibrate, validate, archive and distribute data received from an Earth-orbiting ocean color sensor.



**Figure 3 Sampling capabilities and performance of in-situ and satellite temperature sensors (from draft GODAE implementation plan <http://www.bom.gov.au/bmrc/ocean/GODAE/Planning/IP/Plan.htm>).**

## 5 MERSEA modelling activities

### 5.1 The MERSEA Strand 1 assessment

One of the core objectives of the MERSEA Strand 1 project was to analyse the strengths and weaknesses of the existing marine observational network in providing an adequate flow of data operational ocean forecasting systems. Some of the conclusions from the project are excerpted, adapted and reproduced here, since the systems that were evaluated are also at the basis of the future GMES / MERSEA ocean component.

The MERSEA Strand 1 models can be divided in the core models having global or ocean wide coverage and regional or local models with basin wide coverage.

The MERSEA core models are:

- Mercator (France, Mercator - group)
- FOAM (Forecasting Ocean Assimilation Model, UK met-office)
- TOPAZ (Towards an operational Prediction system for the Atlantic and European Coastal Zones, Norway)
- MFS (Mediterranean Forecast System, Italy)

The core models prognostics variables are at present geophysical parameters (currents, temperature, salinity and mixed layer depth). The TOPAZ model has already a biogeochemical module that allows to forecast nutrients and chlorophyll. A brief description of the four core models is given in the Annex.

Regional or local models cover smaller areas. Their hydrodynamic core is accompanied by range of modules simulating ecological dynamics, sedimentation, ice formation, storm surges, waves or oil drifts.

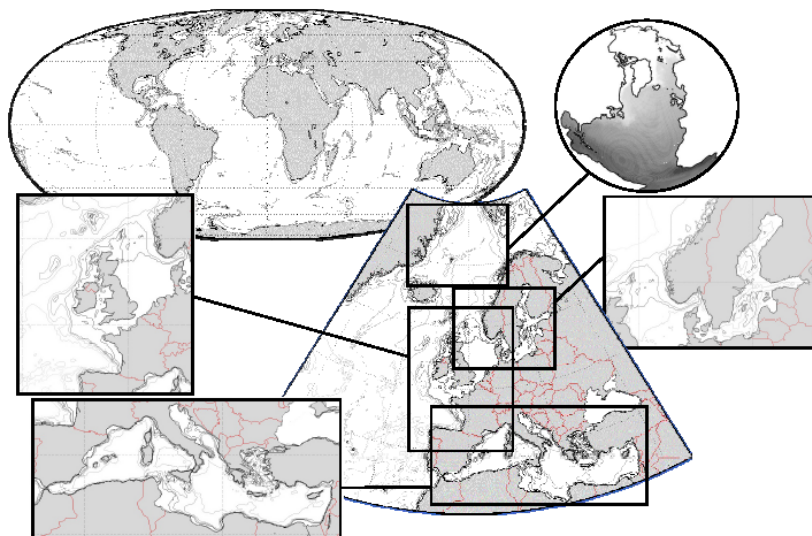
- POLCOMS (Proudman Oceanographic Laboratory Coastal-Ocean Modelling System)
- NORWECOM
- BOOS (Baltic Operational Oceanographic System)
- Poseidon (only MERSEA Strand 1 project )

Beside the ocean models there is the ECMWF wave model WAM, which operates in a global mode and in several local versions.



SYSTEM	TARGETED AREA	KEY INPUT	KEY OUTPUT
MERCATOR	Global, North Atlantic, Mediterranean	Atmospheric forcing data. Remote sensing SLA, SST and ocean color., and Argo profiling floats.	Ocean currents, temperature, salinity, mixed layer depth
TOPAZ	North Atlantic/ Nordic Seas	Atmospheric forcing data. Remote sensing SLA, SST and ocean color. From spring 2002 also satellite sea ice, and Argo profiling floats.	Ocean currents, temperature, salinity, nutrients, chlorophyll a mixed layer depth
FOAM	North Atlantic	Atmospheric forcing data. Remote sensing SLA, SST and sea ice, and Argo profiling floats, VOS XBTs.	Ocean currents, temperature, salinity, mixed layer depth
MFS	Mediterranean	Remote sensing SLA and SST, VOS XBTs, Buoy and Argo profiler data	Ocean circulation forecasts at basin scale and selected coastal areas.
POLCOMS NORWECOM BOOS POSEIDON	North Atlantic Northern European shelf seas, Baltic, Greek Seas, Adriatic Sea, etc.	Atmospheric forcing data, tides, buoy data information, river run-off, satellite SST, SSI and wind, boundary conditions from SYS 1 to SYS 4.	Sea level, storm surges, T; S; currents, sea ice, drift (oil, objects), transports of pollution, dispersion
WAM	North Atlantic and adjacent seas	Meteorological forcing, wave buoy information, satellite SAR, scatterometer and altimeter data	Wind wave, swell, significant wave height, wave spectra, wave-period

**Table 2 Overview of MERSEA Models Strand 1**



**Figure 4 Domains of the MERSEA models**

## 5.2 Development of the MERSEA operational model system

The targeted operational MERSEA ocean forecast system will be designed and implemented in progressive steps, with regular upgrades and convergence of existing model systems. In parallel with those evolutions, current systems will be operated in real-time to deliver products suited to the intermediate users and to the applications. They will also provide the metrics necessary for the scientific evaluation of the outputs, and the boundary conditions for the regional systems.

The implementation will be based on existing operational or pre-operational systems and lead to the:

- Global MERSEA model (based on MERCATOR)
- Arctic/Atlantic model (based on TOPAZ)
- North East Atlantic and shelves high resolution model (based on FOAM – POLCOMS),
- Mediterranean high resolution model (based on MFSTEP)
- Baltic high resolution model (based on BOOS)

The common MERSEA operational system will be build around the OPA (acronym for Océan Parallélisé) circulation model, which is already the core of the MERCATOR system. OPA is considered to be a flexible tool for studying the ocean and its interactions with the other components of the Earth climate system (atmosphere, sea-ice, chemical tracers). MFS for the Mediterranean is transitioning to OPA as part of the MFSTEP project. The UK Met Office intends to participate in the development of OPA into a European ocean model framework (EOMF) and aims to transition its ocean forecasting systems to this framework with assistance from MERSEA.

In the pre-operational phase 2006, all models will include ecosystems model, will be fully nested and ready for production.

The final global model MERCATOR will have multivariate assimilation and included sea ice and ecosystem models (without assimilation). The resolution of the physical model will be  $1/12^\circ$  and that of the ecological model  $1/4^\circ$ .

The Arctic model run by Met.no will finally have a horizontal resolution of 9-18 km. SSH, SST, ice data (Cryosat ice thickness data), Argo and ocean colour data will by assimilated by means of an Ensemble Kalman Filter.

North East Atlantic model ( $1/32^\circ$ ) will include assimilation. The model will be fully nested in the global MERSEA system. The POLCOMS system for NE Atlantic shelf uses a 12 km grid and no assimilation. Both will be run daily with an ecosystem model included.

The Mediterranean model ( $1/12^\circ$ ) assimilates sea level surface temperature and profile data using the ROOI scheme on weekly basis and will be adapted to overall MERSEA operation with full operational implementation of nesting.

The Baltic model will have increased resolution and will be fully nested in the East North East Atlantic model. It will be run twice daily.



### 5.3 Development of ecological modelling in MERSEA

Ecological modelling is still very much a domain of active research and development, with limited operational forecasting skill. In contrast to the geophysical models, biogeochemical modelling and data assimilation is presently less developed. MERSEAs activities related to the ecological modelling are in the following research areas:

- Further development of ecological models and assimilation schemes
- Retrieval of ocean colour from remote sensing
- Validation of ecological models with in situ biogeochemical observations (including CO<sub>2</sub>) provided by other projects (CARBOOCEAN)

Research efforts related to the carbon cycle concentrate on the ecological models pursuing two lines of research: (i) global or basin scale bio-geochemical modelling, using simplified models with few compartments aiming mostly at carbon cycle monitoring, and (ii) ecosystem modelling in the coastal seas. The latter is motivated by socio-economic needs, and the existence of local monitoring systems.

MERSEA has no operational commitment towards the ocean carbon cycle before 2008 because the quality of the biogeochemical modules has not been sufficiently validated. The biogeochemical models will include both the biological and the solubility pump for dissolved inorganic carbon and air-sea gas exchange.

The core models in MERSEA with global or basin wide coverage will implement biogeochemical modules in the coming years<sup>4</sup>:

- (a) the TOPAZ system already runs an ecosystem component routinely on a weekly basis and plans to assimilate ocean colour data from Oct 2005
- (b) the Mercator system plans to run an ecosystem component in delayed mode from Oct 2005 and on a weekly basis with assimilation of ocean colour data from April 2007
- (c) the MFSTEP (Mediterranean) system plans to run an ecosystem component on a daily basis in demonstration mode from April 2007
- (d) the NE Atlantic system for MERSEA operated by the Met Office is not committed to running an ecosystem component until April 2008<sup>5</sup>.

MERSEA starts to develop near real time global ocean colour products from SeaWiFS Meris or Modis - Instruments. MERSEA work package 2 will be providing ocean colour products from October 2006. In combination with the operational physical model, their assimilation in the emerging ecosystem model will give a more

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<sup>4</sup> Information provided by Mike Bell, UK met-office

<sup>5</sup> However, at the Met Office the ERSEM ecosystem model coupled to the POLCOMS system for the NW European shelf has been spun-up near to real-time and will probably be maintained near to real-time. Most of the work in the MetOffice on ecosystem models will be done in collaboration with the NERC CASIX and QUEST projects. (e.g. assimilation of ocean colour data into an NPZD model containing total alkalinity (TALK) and dissolved inorganic carbon (DIC) components coupled to FOAM is being developed in collaboration with the CASIX project).



realistic description of the standing stocks of surface chlorophyll and phytoplankton biomass.

Atmospheric aerosol fields provided by GEMS subproject on aerosol could be valuable data about iron intake, which controls biological production in the oceans. More detailed river input data is needed by MERSEA ecological models as well.



## 6 MERSEA data needs

The data requirements of the ocean models in MERSEA can be discriminated in the following five main groups:

1. Forcing meteorological fields
2. In-situ ocean observation for data assimilation and model validation
3. Satellite observation for data assimilation and model validation
4. Boundary data
5. Land sea mask and bathymetric data bases.

### 6.1 Forcing meteorological fields from NWP

The main atmospheric forcing is the wind stress, which drives the flow of the ocean surface currents. Heat and moisture heat fluxes influence temperature and salinity, which are key variables in the ocean models. Precipitation data is needed for the fresh water input at the ocean surface, which alters the water density.

The meteorological forcing of the core model is provided by analysis and forecast of ECMWF and UK met office global numerical weather prediction models. MERCATOR, which will become MERSEA global operational model is driven by ECMWF data. The regional and local models use either ECMWF or data of HIRLAM.

In General, the resolution of the ocean models is higher than that of the current operational global NWP models, which leads to the request of higher resolution meteorological data for the purpose of ocean modelling. The fluxes provided by the NWP models may lack the required accuracy due to simplified parameterisation within the models. Both problems will be tackled within MERSEA by blending NWP fields with additional or higher resolution satellite data for ocean winds (Scatterometer) and or related to heat fluxes (SST data). The satellite information may already be assimilated in the NWP fields but with a lower horizontal resolution.

PARAMETER GROUP	ATMOSPHERIC PARAMETERS
Surface wind stresses ( $\text{Nm}^{-2}$ )	Northward and eastward stress (X) components
Surface heat fluxes ( $\text{W m}^{-2}$ )	Net short-wave radiation (L), net long-wave radiation(L), latent heat flux (L), sensible heat flux(L), sublimation rate (I) surface melting flux (I), conductive heat flux through bottom of sea ice (I)
Surface mass fluxes ( $\text{kg m}^{-2} \text{s}^{-1}$ )	Precipitation (L), evaporation (L), snowfall rate (X)
Other surface parameters	Air temperature, SST, mean sea level pressure, sea ice concentration, atmospheric stability
Parameters at 2m height	Air temperature, dew point temperature
Parameters at 10m height	Wind speed components, air temperature, specific humidity

**Table 3 Forcing meteorological fields. The superscripts indicate which of the surface fluxes apply to the whole of a grid box (X) only the open water (Lfor leads), and only the sea-ice fraction (I).**

MODEL	MERCATOR	FOAM	TOPAZ	MFS	POLCOMS	BOOS	NORWECOM	WAM
NWP	ECMWF	UK met office	ECMWF	ECMWF	ECMWF/ UKMet office	DMI- HIRLAM	Met No	ECMWF

**Table 4 Source of meteorological forcing data for ocean modelling within MERSEA.**

## 6.2 In-situ ocean observation for data assimilation and model validation

In-situ data of the ocean are used for assimilation in the model and for validation purposes. Assimilated data have to be available in real or near real time and their quality has to be specified in terms of the observation error covariance. Data for validation purposes, and climatology data bases require strict delayed mode quality control.

The Coriolis Centre (IFREMER) acts as the main data centre for Ocean in-situ data within the MERSEA project. It receives data from various data providers, it performs real time quality control, and distributes the data to the MERSEA community.

The in-situ data are can be summarised in the following groups:

- Argo float data
  - Temperature and salinity profiles
- XBT data from SOOP and VOS
  - Temperature profiles
- Global Tropical Moored Buoy Network (TOA, TRITON, PIRATA)
  - Temperature and salinity profiles
- Regional moored buoy network (Mediterranean M3A, SMART in North Sea, Baltic Sea)
  - Temperature and salinity profiles
  - Biogeochemistry data
- Tide gauge data (GLOOS)
  - Sea level
- Drifters
  - Ocean surface currents, SST
- Research vessel and glider data
  - Temperature and salinity profiles
  - Biogeochemistry data
  - Currents

These data are used either for model initialization, validation, and for assimilation . In-situ observations of the Ocean biogeochemistry and ecosystems are too sparse to be assimilated..



MODEL	MER-CATOR	FOAM	TOPAZ	MFS	POL-COMS	BOOS	NORWE-COM
assimilated in-situ data	Argo SOOP / VOS XBT TIP Surface drifters	Argo SOOP/VOS XBT TIP	Argo	Argo SOOP/VOS XBT	None at present	Buoy Wave height T & S Tide gauge SOO/ferry box	None at present
Update	Weekly	Weekly	Weekly	weekly	-	within 3 hours	-

**Table 5 Assimilated in-situ data for ocean modelling within MERSEA Strand 1.**

### 6.3 Satellite observation for data assimilation, model validation and meteorological forcing

The radiance measured by the various satellite instruments does not penetrate the ocean but its interaction with the ocean surface can be used to infer its geophysical state. Satellite radiation measurements can be assimilated in geophysical models

either directly in the form of radiative quantities (brightness temperature) or in the form of retrieved products, which already present the geophysical parameters. The former approach is preferred in atmospheric models but requires the simulation of the link (radiative transfer, forward operator) between the radiation and the geophysical state (Atmosphere and Ocean surface) within the model. The latter approach is adopted within MERSEA. Dedicated satellite centres will provide retrieved products often by blending data from different satellite instruments and additional in-situ measurements. The products are then assimilated in the MERSEA models and will be used in MERSEA validation activities.

Satellite data is vital for ocean modelling since it provides global coverage of the Ocean surface. However, atmospheric clouds may constrain the coverage. Knowledge about atmospheric conditions and aerosol content is needed for a coherent retrieval.

Satellite products of following quantities are prepared for assimilation and/or validation:

- Sea Surface Topography data (Altimetry)
- Sea Surface Temperature
- Ocean waves (significant wave height and wave spectra)
- Sea Ice
- Ocean Colour (biological state and oil spills)

Satellite products of following quantities are used for providing or improving metrological fields from NWP:

- Surface Wind or Wind stress
- Latent and sensible heat flux data

- Air sea gas exchange coefficient

Improvement in those fields can be achieved by merging the NWP fields with satellite information to meet the special needs of the ocean models, mainly for higher horizontal resolution.

Within MERSEA CLS (Collecte Localisation Satellite, France) coordinates the work package devoted to remote sensed data (validation, merged products, distribution). CLS is also the Centre dedicated to altimetry products. Global altimeter data (along-track and mapped Sea Level Anomaly) from Jason-1, ENVISAT, GEOSAT Follow On and TOPEX data from the SSALTO/DUACS system will be prepared and distributed in near real time.

M-F/CMS (Météo-France/Centre de Météorologie Spatiale) is in charge of the work package related to the meteorological forcing (SST and fluxes). Together with Ifremer /CERSAT they will establish and test the methodology to merge NWP from ECMWF with Scatterometer data. This work is embedded in the Global Ocean Data Assimilation Experiment (GODAE) high-resolution sea surface temperature pilot project (GHRSSST-PP), which aims to develop of a new generation of global, multi-sensor, high-resolution SST products. The European Contribution will be the Medspiration project, which is supported by ESA.

The Joint Research Centre is the centre for Ocean colour retrieval data and Nansen Environmental and Remote Sensing Center (NERSC, Norway) leads the sea ice activities.

. ASSIMILATED REMOTE SENSING PRODUCTS	MERCATOR	FOAM	TOPAZ	MFS	BOOS	WAM
SST	Reynolds GHRSSST intended	Reynolds GHRSSST intended	Reynolds GHRSSST intended	Satellite SST	SST from AVHRR and ATSR	
Altimetry	SSALTO/DUACS maps Along track		SSALTO/DUACS maps	SSALTO/DUACS maps Along track	SSH from satellites and HF radar	
Ocean color			Tests with Seawifs data			
Sea ice			Passive MW (SSM/I)			
Wave					SWH	SWH SAR

**Table 6 Assimilated satellite data for ocean and wave modelling within MERSEA Strand 1.**



## 6.4 Un-accomplished data needs

The following list is a snapshot of current un-accomplished data needs and their purpose within the MERSEA project. The HALO activities may help to organise the provision of the data from other IPs under the GMES umbrella.

### 1. Data needs within MERSEA

- Biogeochemical in-situ measurements for
  - ecological model validation

### 2. Data needed from GEMS and NWP

- High resolution (<12 km, 3 to 6 hrs) wind stress and heat flux data ; in the coastal regions, local winds play a very significant role (orography), and higher spatial and temporal resolution is often needed.
- Aerosol data from GEMS for
  - deposition for ecological modelling (iron source)
  - short wave (UV, VIS) radiation input for ecological modelling
  - improved satellite retrievals (ocean colour)
- Improved precipitation data for
  - fresh water intake
- Improved cloud data for
  - short wave (UV, VIS) radiation input for ecological modelling
  - Satellite retrievals (ocean colour)

### 3. Further Data needs

- River discharge data (Water IP)
- High resolution sea land mask and bathymetric measurements especially in the Mediterranean
- Operational CO<sub>2</sub> flux data (biological and solubility pump)

## 7 MERSEA products

The MERSEA project goal is to develop a service to provide data, products and information to a wide class of intermediate and final users: operational agencies, service companies, policy makers, scientists, and the general public. To this end, the project has several research and development tasks devoted to improved and demonstration products, as well as special focus experiments in the more prospective fields of ecosystem modelling and seasonal forecasting.

MERSEA is going to provide products both in real time or delayed operational mode and for research studies. The products can be classified in the following groups:

- Output of the operational ocean model forecast
- Satellite products provided by the MERSEA satellite centres (see chapter 6.3)
- User oriented products
- European in-situ observation
- Output of special focus studies

The basic output of the models consists of two- and three-dimensional fields of ocean structure, denoted as Class 1 :

**Class 1:** Primary products, 2D and 3D gridded products, daily fields

- 2D fields
  - wind ( $T_x$ ,  $T_y$ )
  - total net heat fluxes including relaxation terms ( $Q_{tot}$ )
  - Water flux (E-P-R) including relaxation terms
  - Barotropic Stream Function (BSF)
  - Mixed Layer Depth (MLD) ( $MLD(t^\circ)$  for NAT and MED plus  $MLD(\rho)$  for NAT)
  - Sea Surface Height (SSH)
  - Mean Dynamic Topography (MDT)
- 3D fields
  - T, S, U, V

The MERSEA basic output fields will support activities in the domain of marine safety (oil spills, search and rescue, sea ice, marine pollution) and provide NWP services with high resolution data about the ocean.

*Oil spills and pollution, marine safety* : response to accidents is coordinated by National Weather Services under the WMO's Marine Pollution Emergency Response Support System (MPERSS). Specific ocean areas are under the responsibility of different NWS, which implement their own modelling and forecasting systems. Those systems have diverse characteristics and parameterization. Recent research has led to coupling with ocean circulation models for improved representation of currents and linkage with remote sensing detection of spills. Some of the MERSEA R&D tasks address improvements in the systems that can be brought about by the provision of



high resolution currents and sea surface temperature (oil spill fate prediction, wave forecasting, ship routing, sea ice).

*Short range and seasonal forecasting* : global high resolution SST products (and upper ocean heat content) can improve short range weather forecasting, in particular tropical cyclone evolution and tracking. A special focus experiment in the project deals specifically with the impact of ocean products on seasonal forecasting. From the Mersea basic model output one can derive higher level scientific fields, useful mainly for scientific research and model validation (transports, time series, sections, statistics, etc...). However, other users require specific products and information tailored to their needs, as for instance boundary conditions for coastal models.

Other examples of user oriented products include marine safety by improved forecasts of waves and sea-ice, ship routing, management of oil and chemical spills; search and rescue operations, and support to offshore industry operations.

The special focus experiment "Predicting biogeochemical variability in European regional and shelf seas" conducts observations and experiments related to eutrophication, i.e. concentrations of (chlorophyll, nitrate, phosphate, silicate, ammonia, diatoms, flagellates, detritus, oxygen, primary production, suspended matter), transport and distribution of fish larvae, organic pollution.

## 8 Data transfer within MERSEA

One of the key integration activities in MERSEA is the design of a MERSEA Information Management system (MIM), corresponding to the needs of data exchanges within the project (input data, forcing fields, model outputs, etc...), provision of results and products to outside users, application centres or companies, project management and monitoring, and communication to a wide class of general public.

Data will be transferred between MERSEA's ocean model centres, satellite centres, in-situ data centres, external data providers and end users. Some of the Thematic Data Centres are already well established whereas the end users of the operational services will have to be specified in more detail.

The following main data streams will be the basis of the operational MERSEA system:

- Meteorological forcing fields from NWP centres to the Ocean model centres
- Satellite data from Satellite centres to the MERSEA Satellite Centres
- Satellite products from satellite centres to ocean model centres
- In-situ observations to the in-situ data centres
- In-situ observations in real time to the to the ocean model centres

Depending on data volumes, access times requirements and availability the data transfer (see Figure 5) will be managed by means of:

- Global Telecommunication System GTS (WMO)
- Standard ftp connections
- Internet using Live Access Servers based on the OPeNDAP Protocol

Part of the MIM design is to identify and implement the techniques most suited to the functional requirements of each link.

The GTS access allows receiving in real time meteorological observations, ocean observation by drifters, buoys and Argo floats, satellite data and forecasted ocean and atmospheric fields. Unlike the internet, GTS is a closed network open to the meteorological community. GTS access to MERSEA partners is provided by links to meteorological centres (Meteo France, UK met office etc.), which are participants in MERSEA. Data transferred via GTS have to be decoded in standardised formats (BUFR, GRIB, Ascii formats like BUOY), which are not very common outside the meteorological community. Paragraph 8.2 contains more detailed information about GTS.

Standard ftp connections using internet connection will provide the data exchange between centres which are not connected to GTS.

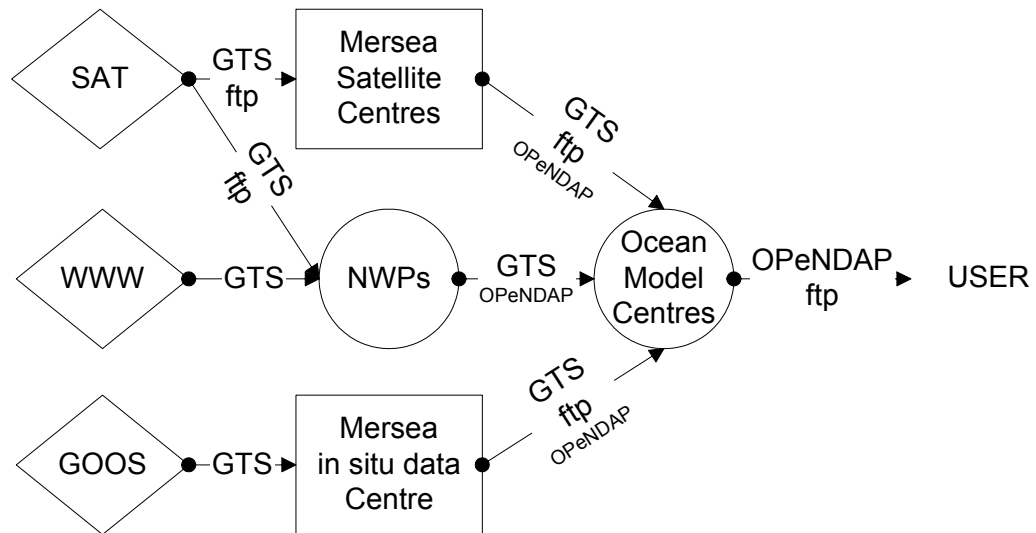
Data transfer via Internet using the Opendap protocol (dods) allows a flexible way to exchange data from various data centres. Data formats based on NetCDF are the most common way to decode gridded, profile and single observation data sets. Live Access Servers using OPeNDAP are widely used in the Ocean community. They provide a

good possibility to visualise gridded data from different sources. Horizontal map, cross section and time series are supported option for a compact visualisation of the data. Paragraph 8.1 contains more detailed information about OPeNDAP and Live Access Servers.

NetCDF has been chosen as a main data format between the MERSEA partners. NetCDF is used for in-situ data and for model output. Besides GRIB and BUFR, HDF formats are used for the exchange of field data. Paragraph contains 8.3 more detailed information about NetCDF and briefly introduced GRIB, BUFR and HDF.

GADS (Grid Access Data Service, developed at ESSC, Reading University) is an alternative protocol to OPeNDAP, which is based on web services using XML messages rather than URL as in the case of OPeNDAP. It provides improved visualisation possibilities (movie function) for gridded data sets and an easier way of meta data transfer. GADS allows great variability in format choice (GRIB, NetCDF etc.) and abstracts data from storage. GADS has been developed within the GODIVA project (Grid for Ocean Diagnostics, Interactive Visualisation, and Analysis) which contributes to GODAE.

It may become necessary to provide data base applications with improved features for the MERSEA 3D-space-time data. Performing statistical operation on the data like determination of threshold exceedance may be required by the end user community.



**Figure 5** Schematic of data flow in the MERSEA system. SAT stands for the satellite data providers (satellite agencies), WWW stand for WMO's World Weather Watch, which provides world wide meteorological observations. GOOS is the Global Ocean Observation System.

## 8.1 Live Access Servers using OPeNDAP

MERSEA choose the Opendap technology (cf. <http://www.opendap.org>) because it has been designed to minimize the barriers to sharing data over the Internet (supports server side subsetting of data and aggregation). It provides strong support for data

stored in NetCDF as well as for users of NetCDF enabled programs. The goal is to allow end users, whoever they may be, to access immediately whatever data they require in a form they can use, all while using applications they already possess and are familiar with. Opendap is a mechanism to facilitate access to data over the Internet network. Opendap client exists for many application packages (e.g. NCBrowse, Excel, Matlab, IDL, Ferret, GRADS, IDV, Las, Map Server). The data request functions use the http protocol, sending an enhanced URL to the server. Opendap also allows server-side function evaluation and advanced computational issues, as well as user traceability and user feedback (via logs analysis) for system improvements and end-users knowledge.

LAS (Live Access Server) is an Opendap data access highly configurable web server. Its default visualisation application is Ferret, an opensource software dedicated to gridded geo-referenced scientific data. Ferret is an Opendap client. Mercator offers access to its products via the LAS implemented in the MERSEA context. The MERSEA LAS federates four other MERSEA and Godae partners models : FOAM, the UK Met Office model, the NERSC Norwegian Topaz model, the INVG Italian Mediterranean MFS model, and HYCOM, the Miami model who has joined the European quartet in the GODAE context.

Whereas Opendap direct use requires from the user to have the knowledge and possession of a client software such as IDL or Matlab, LAS allows a not very well-informed user to visualise the data very easily. Some examples of what he can do with the LAS are given below :

- Map data with on-the-fly graphics,
- Request subsets of variables in a choice of different file formats,
- Compare (difference) variables from distributed locations (models intercomparison),
- Compute basic statistics (average or variance)

The special feature of the LAS consists in the facility for unify in a single vision access to multiple types of data from distributed data sources. The LAS can make requests to different remote Opendap servers. This enables to make comparisons or statistics upon several different data types. This is done in the MERSEA LAS where the LAS is inter-connected to 4 remote servers in US, UK, Norway, Italy and France.

Each satellite data center will provide its gridded data products in a Netcdf structure format using the same ocean convention such as COARDS/CF and will distribute them in an OPeNDAP catalogue and serve them with a LAS server. Use of OPeNDAP/LAS technology is a very effective means for exchanging and intercomparing large data sets from distributed sources. The remote sensing WWW site will thus allow us to select, zoom and intercompare (graphic overlay) the different remote sensing products using

## 8.2 Global Telecommunication Network

The GTS consists of an integrated network of point-to-point circuits, and multi-point circuits which interconnect meteorological telecommunication centres. The circuits of the GTS are composed of a combination of terrestrial and satellite telecommunication

links. They comprise point-to-point circuits, point-to-multi-point circuits for data distribution, multi-point-to-point circuits for data collection, as well as two-way multi-point circuits. Meteorological Telecommunication Centres are responsible for receiving data and relaying it selectively on GTS circuits. MERSEA groups rely on GTS access provided by Meteo France or UK-Metoffice.

Satellite-based data collection and/or data distribution systems are integrated in the GTS as an essential element of the global, regional and national levels of the GTS. Data collection systems operated via geostationary or near-polar orbiting meteorological/environmental satellites, including ARGOS, are widely used for the collection of observational data from Data Collection Platforms. Marine data are also collected through the International Maritime Mobile Service and through INMARSAT. International data distribution systems operated either via meteorological satellites such as the Meteorological Data Distribution (MDD) of METEOSAT, or via telecommunication satellites, such as RETIM or FAX-E via EUTELSAT are efficiently complementing the point-to-point GTS circuits.

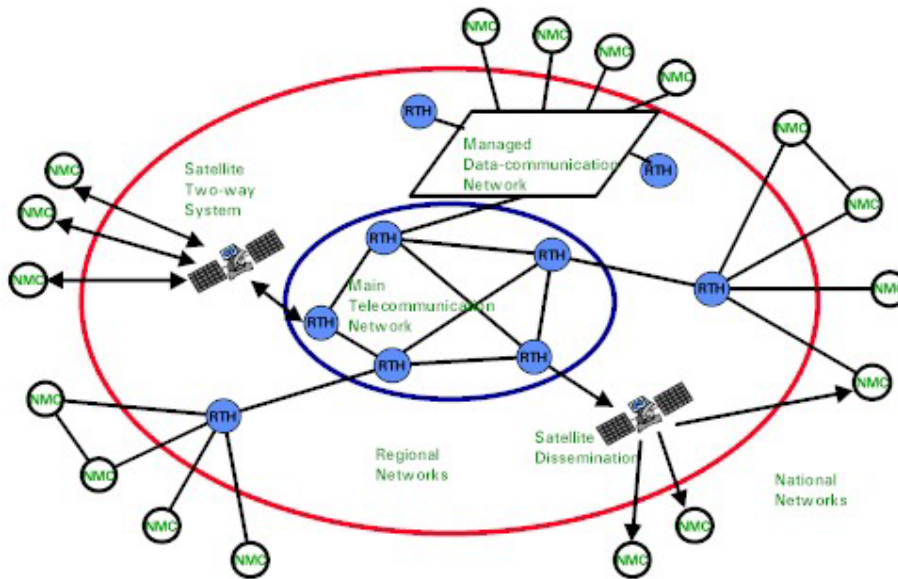


Figure 1 - Structure of the Global Telecommunication System

## Figure 6 Structure of GTS

### 8.3 NetCDF data format within MERSEA

NetCDF (network Common Data Form) is an interface for array-oriented data access and a library that provides an implementation of the interface. The NetCDF library also defines a machine-independent format for representing scientific data. Together, the interface, library, and format support the creation, access, and sharing of scientific data. The NetCDF software was developed at the Unidata Program Center in Boulder, Colorado.

NetCDF data is:

- Self-Describing. A NetCDF file includes information about the data it contains.

- Architecture-independent. A NetCDF file is represented in a form that can be accessed by computers with different ways of storing integers, characters, and floating-point numbers.
- Direct-access. A small subset of a large dataset may be accessed efficiently, without first reading through all the preceding data.
- Appendable. Data can be appended to a NetCDF dataset along one dimension without copying the dataset or redefining its structure. The structure of a NetCDF dataset can be changed, though this sometimes causes the dataset to be copied.
- Sharable. One writer and multiple readers may simultaneously access the same NetCDF file.

MERSEA chose the NetCDF format (Unidata Network Common Data Form) + COARDS/CF conventions (Cooperative Ocean / Atmosphere Research Data Service (COARDS) - Climate Forecast (CF), see Conventions for the standardization of NetCDF files, NetCDF Climate and Forecast (CF) Metadata Convention, CF Conformance Requirements and Recommendations & CF standard name table).

As a file format for data exchange, NetCDF has plenty to recommend it: it is portable, binary, easily translatable to and from an equivalent ASCII format, and supported by a lot of freely available software for processing and graphics, including the NetCDF library itself, CDAT, Ferret and NCO. The COARDS NetCDF standard is widely used. It has conventions for identifying coordinate axes (longitude, latitude, vertical and time), and for specifying units and missing data values. CF is a standard for "use metadata", whose aim is to distinguish quantities (physical description, units, prior processing, etc.) and to locate the data in space-time and as a function of other independent variables (coordinates). This is the kind of metadata that is used at the time the data is processed and displayed; it can be distinguished from "discovery metadata", which is used in catalogues for identifying datasets. CF provides only rather basic discovery metadata, such as ways to record where and how the file was produced.

The CF conventions for climate and forecast metadata are designed to promote the processing and sharing of files created with the NetCDF Application Programmer Interface [NetCDF]. The conventions define metadata that provide a definitive description of what the data in each variable represents, and of the spatial and temporal properties of the data. This enables users of data from different sources to decide which quantities are comparable, and facilitates building applications with powerful extraction, regridding, and display capabilities.

The CF conventions generalize and extend the COARDS conventions [COARDS]. The extensions include metadata that provides a precise definition of each variable via specification of a standard name, describes the vertical locations corresponding to dimensionless vertical coordinate values, and provides the spatial coordinates of non-rectilinear gridded data. Since climate and forecast data are often not simply representative of points in space/time, other extensions provide for the description of coordinate intervals, multidimensional cells and climatological time coordinates, and indicate how a data value is representative of an interval or cell. This standard also relaxes the COARDS constraints on dimension order and specifies methods for reducing the size of datasets.



**HDF** (Hierarchical Data Format) from National Center for Supercomputing Applications, USA. HDF is a common data format for large sets of satellite data. HDF is a general purpose library and file format for storing scientific data. HDF can store two primary objects: datasets and groups. A dataset is essentially a multidimensional array of data elements, and a group is a structure for organizing objects in an HDF file. Using these two basic objects, one can create and store almost any kind of scientific data structure, such as images, arrays of vectors, and structured and unstructured grids.

**GRIB** (GRidded In Binary) from the World Meteorological Organization - WMO. GRIB is a WMO defined format for meteorological field data, or (more generally) any regularly spaced gridded data. Output of Numerical Weather prediction models (Forecasts and analysis) is typically coded in GRIB. Satellite data are often sometimes provided in GRIB too.

**BUFR** (Binary Universal Form for the Representation of meteorological data). BUFR is a WMO defined format for point data, which are irregularly spaced. In-situ observation data are stored in BUFR.

## 9 Links to documentations on the web

### Oceanographic Bodies and Programmes

- WMO web site on global observation system  
<http://www.wmo.ch/web/www/OSY/gos-components.html>
- IOC Intergovernmental Ocean Commission: <http://imo.unesco.org>

GOOS Global Ocean Observation system: <http://imo.unesco.org/GGOS>

ARGO <http://www.argo.ucsd.edu/>

GODAE <http://www.bom.gov.au/bmrc/ocean/GODAE/>

International Ocean Colour coordinating group <http://www.ioccg.org/index.html>

- SSALTO/DUACS  
[http://www.jason.oceanobs.com/html/donnees/duacs/welcome\\_fr.html](http://www.jason.oceanobs.com/html/donnees/duacs/welcome_fr.html)
- GODAE High Resolution Sea Surface Temperature Pilot Project/<http://www.ghrsst-pp.org/>

### MERSEA project

- <http://www.mERSEA.eu.org/>
- <http://www.mERSEA.eu.org/html/strand1/project.html>

### MERSEA Models

- MERCATOR ocean bulletins can be consulted at <http://www.mercator.com.fr>.
- FOAM <http://www.met-office.gov.uk/research/ocean/operational/foam/>
- MFS STEP <http://www.bo.ingv.it/mfstep/>
- TOPAZ <http://topaz.nersc.no/>

### Maritime IT

- Environmental Science System centre <http://www.nerc-essc.ac.uk/>
- OPeNDAP <http://opendap.org/>

### GMES

- GMES general information: <http://www.gmes.info/>
- GMES and ESA <http://earth.esa.int/gmes/>
- GMES cross - cutting assessment team <http://www.gmes-cca.co.uk>

## ANNEX

### Short Description of the MERSEA Core Models

Source: <http://www.MERSEA.eu.org/html/strand1/model.html>

FOAM (UK-Met office)

**Model heritage and coordinate system:**

- Hadley Centre Model
- Z coordinate / Rigid Lid, dynamical & thermodynamical sea-ice model,
- 5 months spin up & Kraus-Turner mixing.

**Model domain and resolution:**

- North Atlantic, Arctic ocean, Mediterranean Sea and Shelf Seas,
- (10° to 70°N, coast to coast),
- Horiz. 1/9° (12 km), Verti. 20 depth levels.

**Forcing:**

- 6 Hourly NWP-MetOffice forcing,
- Weak relaxation to Levitus SST and SSS,
- No relaxation to the Mediterranean outflow
- No river runoff,

**Data assimilation:**

- Data assimilation stopped in coastal areas from depth 300m towards the coast.
- Copper& Haines Optimal Interpolation,
- Assimilated once a week along-track SLA (Jason-1, GFO, Envisat),
- Assimilated once a day 2.5° gridded SST (ARGOS), T+S profiles at all depths,
- Gridded ice concentration,
- Mean SSH (sea surface height) from previous run.

MERCATOR (Mercator group, France)

**Model heritage and coordinate system:**

- OPA
- Z coordinate / Rigid Lid, simple thermodynamic & sea-ice model,
- 5 days spin up + TKE mixing.
- North Atlantic, Azores, and Mediterranean Sea,

**Model domain and resolution:**

- (10° to 70°N, coast to coast),
- Horiz. 1/15° (5-7 km), Verti. 43 depth levels.
- Extended to be MERSEAs global model

**Forcing:**

- Daily ECMWF forcing,
- Relaxation to Reynolds SST and Reynaud SSS,
- Relaxation to Medatlas (T,S) in Gulf of Cadiz below 500m,
- Monthly river runoff,

**Data assimilation:**

- Data assimilation stopped in coastal areas from depth 500m towards the coast.
- SOFA reduced order Optimal Interpolation,
- Assimilated once a week along-track SLA (Jason-1, GFO, ERS-2/Envisat),
- Mean SSH from Climatology

## MFS - Mediterranean Forecast System (ITALY)

**Model heritage and coordinate system:**

- Modular Ocean Model (MOM-1),
- Z coord./Rigid Lid, no ice model,
- 7 years spin up, constant vertical mixing and vertical adjustment.

**Model domain and resolution:**

- Mediterranean Sea,
- Horiz.  $1/8^\circ$ , Verti. 31 depth levels,
- Only Mediterranean basin, transport through Gibraltar parameterized.
- Several nested regional models at 5 km resolution
- Several Nested shelf models

**Forcing:**

- 6 hourly ECMWF forcings (bulk formulae momentum & heat),
- Relaxation to satellite night time Medatlas SST and SSS climatology,
- No river runoff

**Data assimilation:**

- Data assimilation stopped in coastal areas from depth 1000m towards the coast.
- SOFA reduced order Optimal Interpolation,
- Assimilated once a week along-track SLA (SSALTO/DUACS),
- Assimilated once a week  $1/8^\circ \times 1/8^\circ$  SST analysis mean maps,
- Assimilated once a week XBT thermal profiles to 500m,
- Mean SSH from previous run with 1993-1999 forcing.

## TOPAZ (Norway)

**Model heritage and coordinate system:**

- HYbrid Coordinate Ocean Model (HYCOM)
- hybrid coordinates / free surface, dynamic & thermodynamic sea ice model,
- 20 years spin up, KPP mixing.

**Model domain and resolution:**

- North Atlantic, Nordic seas and Arctic ocean,
- Horiz. from 20 to 30 km, Verti. 22 hybrid layers,
- Arctic and Atlantic till 60°S.

**Forcing:**

- 6 hourly ECMWF forcings (bulk formulae momentum & heat),
- Closed boundaries without relaxation, no mediterranean basin,
- Precipitation climatology + relaxation to Levitus SSS climatology (60 days),
- No river runoff,

**Data assimilation:**

- Data assimilation stopped in coastal areas from depth 300m towards the coast.
- Ensemble Kalman Filter (ENKF) assimilation method,
- Assimilated once a week SLA gridded maps (SSALTO/DUACS),
- Assimilated once a week SST from CLS AVHRR data,
- Maps of ice concentration,
- Mean SSH from OCCAM run.