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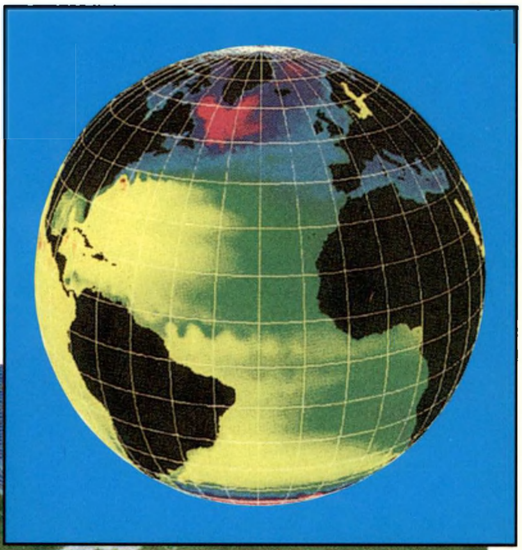
# The Science Base of EuroGOOS



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***Cover picture***

***Large image:*** "A water perspective of Europe", courtesy of Swedish Meteorological and Hydrological Institute. The white lines show the watershed boundaries between the different catchment areas flowing into the regional seas of Europe.

***Inset image:*** Height of the sea surface in the north Atlantic and Arctic simulated by the OCCAM global ocean model, courtesy of David Webb, James Rennell Division, Southampton Oceanography Centre.

# The Science Base of EuroGOOS



edited by D Prandle and N C Flemming

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# Executive Summary

**The role of the SAWG as specified in 'The Strategy for EuroGOOS' (Woods, et al., 1996) is to:**

- **Provide best available scientific advice on the design and implementation of observing systems.**
- **Ensure requisite models are developed and tested.**
- **Analyse limits to predictability and the associated role of data assimilation.**
- **Alert EuroGOOS to new scientifically-led opportunities and, conversely, to scientific shortcomings, and needs for research.**

**The Science Plan involves three phases with the following foci:**

1. **To 1999, assess performance and limitations of existing operational oceanographic systems, with a primary focus on physical parameters in shelf seas.**

2. **To 2002, add water chemistry, nutrient exchange, oxygen to above forecast systems; specify operational modelling criteria for the North Atlantic and Arctic, experiment with global coupled ocean-atmosphere models.**

3. **To 2006, incorporate scientific criteria for climate monitoring observing systems based on science provided by WOCE and CLIVAR, add to shelf sea forecasts SPM, ecosystems and aspects of fisheries recruitment, combine Atlantic and shelf models to investigate interdecadal variability.**

**Activities in subsequent phases need to be addressed from the outset with subsequent accelerated effort. Although it is important to recognise that EuroGOOS is not a scientific research programme, EuroGOOS needs the active and continuous participation of scientists and science will be amongst the major beneficiaries from its success. The existence of a routine marine observing system with a high standard of quality control will provide a sound basis for a new generation of scientific experiments.**

**This first edition of the Science Plan entitled 'The Science Base of EuroGOOS' focuses on phase (1), revised editions will be published progressively addressing subsequent phases.**

EuroGOOS aims to exploit the extensive European investment in marine science to provide a new range of global and regional services. These services will: improve the efficiency of marine and coastal industries, enhance environmental management and ensure the sustainable use of resources. The SAWG was established to advise on the scientific base which underpins EuroGOOS and thereby to identify related options and priorities for developing operational oceanography in Europe and on the global scale. This includes extending predictability based on present knowledge and parallel developments via advances in technology and scientific understanding.

Here operational oceanography is defined as the activity of routinely making, disseminating, and interpreting measurements of the seas, oceans and atmosphere to provide forecasts, nowcasts and hindcasts. Existing operational forecasting systems in European waters provide real-time and near real-time products describing wind field, wave height spectra, sea surface temperature, salinity, floating sea ice, chlorophyll, tides, surface currents, and storm surges. Movements of oil slicks and algal blooms are also predicted on an emergency operational basis. During 1997 operational models with data assimilation were implemented for the Atlantic.

The variables and parameters measured and modelled in each region differ and likewise the range of forecasts required differ. Thus, modelling and monitoring approaches will differ in each case reflecting their intrinsic variability and end-use concerns e.g. surface ice in the Arctic, or eutrophication in the Mediterranean. However there are many generic issues including: scientific understanding, numerical methodology appropriate to ever-increasing computing capacity, sensor development, the design and functioning of monitoring networks (including associated communication and data processing), protocols and methodology for linking models to models and models with observations (assimilation).

Scientific issues of concern to the SAWG in developing operational oceanography include:

- defining the scientific problems which need to be solved in order to improve forecasts at the oceanic and shelf-seas scales,
- improving the design of observation systems and sampling strategies;
- defining the scientific criteria for data management and delivery (specifying quality assurance and quality control standards);
- analysing the most effective methods for utilising remote sensing;
- advising on all aspects of numerical modelling, data assimilation, and model validation;
- outlining the need for new technology, instrumentation, and measuring systems.

European applications of operational oceanography are most likely to develop via the Regional programmes in the Arctic, Baltic, Black Sea, NW Shelf Seas, Mediterranean and Atlantic. The SAWG will aim to identify both existing and likely future obstacles to development and to overcome these by an integrated European approach. Additionally, via the connections of EuroGOOS with the EU, GOOS and related international programmes such as the IGBP, GCOS, GTOS and WMO, global efforts can be concentrated and co-ordinated for optimum benefits to people and the environment. The knowledge gained from WOCE-AIMS and CLIVAR will be an essential input to the design of operational systems at the oceanic and global scales.

The existing capability in real-time operational ocean forecast modelling at National Meteorological Centres and operational Oceanographic Institutes should be built upon. Links with 'non-real-time' models running at other agencies and institutes should be developed (e.g. ecological models). The need for a wider, coverage of reliable, quality controlled, co-located observations of physical quantities (elevation/ T,S / current profile / wave spectrum/surface fluxes) for assimilation into, and verification of, existing and planned models should be assessed. The existing communications infrastructure and protocols for meteorology should be taken advantage of, for distribution of observations and model data. The concept of quality assurance needs to be recognised at every stage of monitoring, modelling and forecasting.

# Introduction

**The purpose of this report is to outline the scientific base underpinning operational oceanography and thereby to advise EuroGOOS on the options and priorities for developments within Europe and on the global scale. This includes the extension of the predictability of forecasts, based on present knowledge and probable improvements in technology and new scientific understanding.**

EuroGOOS is concerned with modelling and forecasting both physical variables and biogeochemical variables, although present services are mostly concerned with physical variables. One of the objectives of SAWG is to extend the range of variables which can be measured and predicted. Also to increase the geographical coverage and scale of forecasts.

This report presents many recommendations. To assist EuroGOOS Members to select those which are of the highest priority, those recommendations closest to the wider interests of EuroGOOS and GOOS are identified. Likewise items considered of highest priority are highlighted at the end of the report.

EuroGOOS is the European Association for the Global Ocean Observing System (See Box 1). Details of the structure and plans for the development and implementation of GOOS are published in the report "GOOS 1998, Prospectus" issued by the Intergovernmental Oceanographic Commission (IOC 1998).

The majority of recommendations refer to actions which can be carried out in the next 5 years, and will produce benefits on that time scale. Some of the actions refer to the timescale 5 to 10 years into the future, subsequent editions of the Science Plan will address these future actions more fully.

The long term objectives of EuroGOOS are set out in the Strategy for EuroGOOS (EuroGOOS Publication 1, 1996). The immediate proposed actions for EuroGOOS are described in the Plan for EuroGOOS (EuroGOOS Publication No. 3,1997).

**Box 1**

## EuroGOOS

EuroGOOS is the Association of national agencies for European scale marine forecasting in GOOS. It exists to maximise the benefits for Europe from operational oceanography within the framework of GOOS.

GOOS is a scientifically designed system to provide forecasts, predictions, and descriptions of the state of the ocean and the marine environment to meet socio-economic requirements.

The Global Ocean Observing System (GOOS) is sponsored by 4 United Nations Agencies (IOC/UNESCO, WMO, UNEP, FAO) and the International Council of Scientific Unions (ICSU).

### The Goals of EuroGOOS are:

**Goal 1:** Building on the success of the last 50 years of European investment in marine science, to exploit this knowledge and technology to provide a new range of global and regional services.

**Goal 2:** To create new operational marine services, develop new business, and create jobs; to use operational marine forecasting to improve the efficiency of marine and coastal industries, and improve environmental management and the use of resources.

**Goal 3:** To develop a global system using a collaborative scientific approach to planetary environmental management. European collaboration will permit Europe to wield influence on a global scale.

The Terms of Reference for the Science Advisory WG were agreed in March 1996 (EuroGOOS Document EG95.26) and are attached as Annexe 1. The primary objective is "The WG shall prepare (....a report...) which defines the scientific basis for EuroGOOS, bearing in mind the stipulations of the MoU, and with particular attention to the limits of predictability, sampling design, required accuracy and precision of observations, numerical modelling techniques, data assimilation, and sensitivity trials of models."

The Science Advisory WG (SAWG) has held six meetings to identify its objectives, and to define and draft this Report. Schedule of meetings in Annexe 2.

The Membership of SAWG is shown in Annexe 3.

The SAWG provides advice to EuroGOOS on the existing limits of predictability in the ocean, and promotes initiatives to extend predictability. The work needed to achieve this includes basic scientific understanding, modelling systems, monitoring networks, and data management. EuroGOOS promotes links with WOCE-AIMS, EuroCLIVAR, JGOFS, GLOBEC, and LOICZ in order to benefit from the scientific and technical advances produced by those experiments, and to identify the ways in which operational services can benefit science in future. Where necessary SAWG provides links within EuroGOOS to the Technology Plan WG (TPWG), the Regional Test Case Task Teams (RTCTTs), and Pilot Projects; and externally to GOOS, and other marine research and operational programmes in Europe. The SAWG will promote training, convene workshops and commission reviews in furtherance of these objectives.

**In summary, the Mission of the SAWG is to:**

- identify the scientific problems which must be solved to improve the performance of operational systems.
- advise on the scientific base for implementing and developing EuroGOOS
- analyse the actions needed to extend the limits of predictability
- improve the design of observation systems and sampling strategies
- advise on the scientific criteria for data management and delivery
- specify quality assurance and quality control standards
- analyse the most effective methods for utilising remote sensing.
- advise on all aspects of numerical modelling, data assimilation, and model validation.
- outline the need for new technology, instrumentation, and measuring systems to meet scientific objectives.
- advise on training requirements and capacity building.

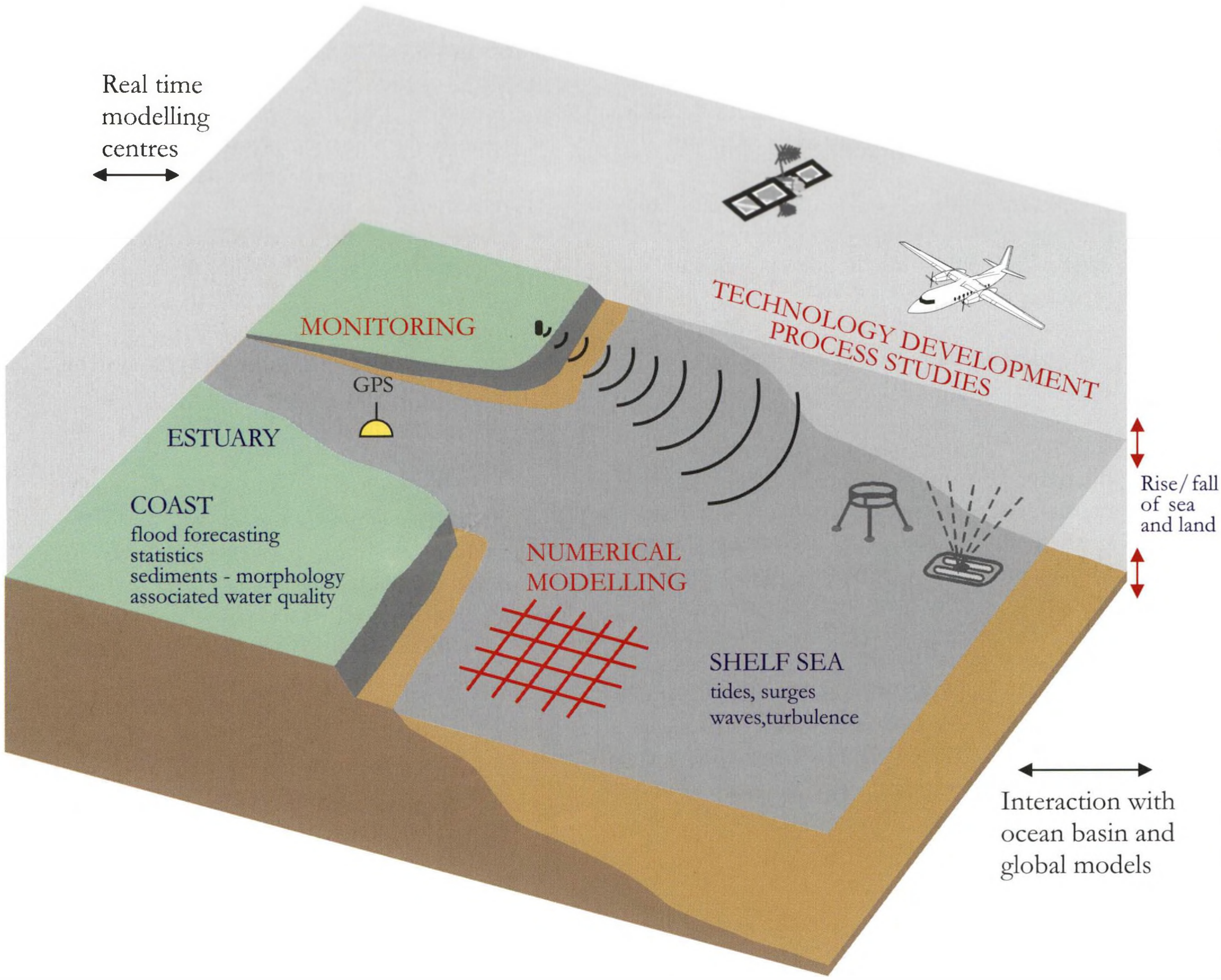


**Figure 1. Schematic of operational oceanography - marine forecasting**

*Source: Proudman Oceanographic Laboratory*

# Operational oceanography

## Scope

**Operational oceanography is the activity of routinely making, disseminating, and interpreting measurements of the seas, oceans and atmosphere so as to:**

- **provide continuous forecasts of the future condition of the sea for as far ahead as possible - forecasting**
- **provide the most useful accurate description of the present state of the sea including living resources - nowcasting**
- **assemble climatic long term data sets which will provide data for description of past states, and time series showing trends and changes - hindcasting**

Operational oceanography proceeds usually, but not always, by the rapid transmission of observational data to computer models, with dissemination of the results to the user community in time for them to make decisions based on the information. Some data types, especially those describing biological, chemical, and sedimentary processes cannot be measured or predicted on this timescale, and are routinely measured for processing through laboratory analysis, followed by distribution of information products.

The modes of operational oceanography are conventionally divided into three time-frames:

### Forecasting

This includes real-time numerical prediction of processes such as storm surges, wave spectra, sea ice occurrence, and toxic algal blooms, as well as climatic statistical forecasts, and seasonal and inter-annual variability of biological and chemical components. Forecasts may extend forward for hours, days, months, or even years and decades on a climatic or statistical basis.

### Nowcasting

Observations are analysed in numerical models and the model is used to create the best estimates of fields at the present time, without forecast. Typically daily or monthly descriptions of sea ice, sea surface temperature, or wind-wave data.

### Hindcasting

Observational data are assimilated into a model to compile sets of historic fields and distributions (typically monthly or annually) of variables such as sea surface elevation, water temperature, salinity, nutrients, radio-nuclides, metals, fish stock assessments, etc.

### Monitoring systems

The aim of monitoring and forecasting networks is to distribute data products in real-time. Rapid availability of outputs satisfies all timescales of use, and provides early warning of instrument malfunction. However, some parameters require prolonged laboratory analysis, and data availability may then be delayed.

Lists of variables which need to be measured for various purposes have been obtained from user surveys, surveys of technology, instrument deployments, and models presently in use, and from the requirements of the Regional Task Teams.

There is need for long time series which can build into historical data sets, and which help to reveal long term trends and variability. Not all variables need to be measured in real time. The concept of real-time varies from hours to decades depending upon the rate of change of the phenomenon being observed.

To identify the discrete variables required by an observing system, it is relevant to describe the processes which we need to monitor (Box 2).

## Models

There needs to be a hierarchy of models starting from the deep ocean models (Global / Atlantic / Mediterranean) providing boundary conditions for shelf-wide models which in turn provide boundary conditions to high-resolution local models (e.g. southern N Sea or English Channel).

**Box 2**

### Processes which need to be analysed, understood, and predicted (examples)

#### 0-2 week timescale

- storm surges
- pollution spills and dispersal
- algal blooms, harmful
- sea ice

#### 1- month

- mesoscale phenomena, eddies, meanders, effect on productivity
- erosion, sediment transport

#### Seasonal

- freshwater budget, heat storage
- circulation changes
- biology

#### Interannual

- climate variability, physical, biological, fish stocks
- anthropogenic changes
- deep water formation, oceanic ventilation and convection

#### Related forcing, boundary conditions

- tidal constituents, wind, heat flux, inflows, overflows, outflows, precipitation, river inputs, sediment sources

### Summary of methods for observations*

#### Existing real time observing systems

- meteorological network.
- meteorological buoys at shelf edge
- some ferry routes, fixed sensors in the Baltic, XBT in Mediterranean
- telemetering buoys in shallow water, met., phys., chem., biol.
- waves, wave spectrum
- remote sensing parameters
- sea level gauges, some are real time
- CTD profiles from local observers, e.g. Norway
- drifting buoys, EGOS, surface, ice, water properties

#### Techniques which could be made operational

- drifting buoys, current meters, surface parameters
- profiling floats (PROVOR, PALACE)
- VOS, towed instruments (undulating), dropped (XBT, XCTD, using GTS), ADCP
- surface moorings, deep water, for oceanographic variables

#### Innovative approaches

- subsurface moorings, current meter, profiling CTD, IES
- acoustic remote sensing, tomography, acoustic thermometry, etc.
- transports, moored geostrophy, acoustics
- new biological sensors, chemical sensors, time series, profiles
- autonomous untethered vehicles (AUVs)
- variable buoyancy undulating drifters
- HF radar
- CASI and airborne LIDAR

* For a general discussion of the possible future development of technological systems in EuroGOOS see the EuroGOOS Technology Plan (Document 13).

## Existing forecasting systems

**Existing forecasting systems in European waters provide real time and near real time products describing wind field, wave height spectra, sea surface temperature, salinity, floating sea ice, chlorophyll, tides, surface currents, and storm surges. There are a number of operational pollution monitoring systems measuring chemical variables in near real time, but not incorporated into real time models. Movements of oil slicks and algal blooms are also predicted on an emergency operational basis.**

Sea state forecasting (using spectral wave models) is well established and in widespread operational use. A range of wave models (both second and third generation) is applied both globally and regionally. For coastal waters the SWAN model is available (public domain) and has been adopted by the US Navy ONR as the best tool for transforming forecasts of sea state from offshore up to the surf zone.

For shelf seas, depth-averaged hydrodynamic models of storm surge elevations and currents are also well established in operational use. 3D current profile models are also available. The principal shortcoming, which is already being addressed by research and development, is the inability of present operational models to cope with conditions on the shelf edge. Research is needed on this problem.

Deep ocean global forecast models, including data assimilation, are becoming available for operational use - an example is the one degree global FOAM (Forecasting Ocean Atmosphere Model) model at the UK Meteorological Office. Present operational real-time models are not eddy resolving, but future developments will include nested eddy resolving regional models, and more sophisticated data assimilation techniques to capture mesoscale features of the ocean circulation. Such projects include GODAE, MERCATOR, DIADEM and are summarised in the EuroGOOS Atlantic Workshop report (Publication 9, 1998).

European companies are providing contract services to make similar products available in south east Asia, the Caribbean, and other areas on a global scale. Existing services are necessarily based on past scientific research and development phases which may have taken as much as 5 to 10 years.

The SAWG can influence and improve the development of new modelling and forecast systems by helping to improve the design of models and observing strategies which support existing systems, and by examining how additional variables can be added to the systems. These developments should be aimed at increasing resolution of the output (if required), increasing accuracy, increasing the limits of predictability, and increasing the range of variables which can be measured and processed.

Studies by the North West Shelf TT, the Ferry Box WG, and the Technology Survey of the TPWG indicate that the variables of interest can be classified approximately as shown in Box 3.

## Surface waves

In order to provide practical wave forecasts needed by industry there is a strong need for improvement of the quality of forecast winds in the medium range, up to 5-10 days.

Extended range (10 day to 30 day) forecasts from NWP (Numerical Weather Prediction) models may be prepared using ensemble forecasting techniques. These have not yet been applied in forecasting the sea state or the meteorologically induced circulation on shelf seas, and development of appropriate techniques would be required. This would allow probabilistic forecasts to be made, in addition to the deterministic forecasts made at present.

The following paragraphs are based on the work of SAWG combined with reports submitted to J-GOOS by Komen and Smith (1997).

| **Box 3** | |
|---|---|
| Variables which can be measured operationally in real time and assimilated into models with a useful level of resolution and predictive skill:<br><br>• Sea surface temperature<br>• Current velocity and direction<br>• Instantaneous, hourly, and mean sea level<br>• Wave height<br>• Wave period<br>• Wave spectrum<br>• Wind speed and direction<br>• Atmospheric pressure<br>• Upper ocean and shelf seas temperature profiles<br>• Sea ice | Variables which can be measured routinely in real time or near real time, but which are not usually assimilated in models:<br><br>• Chlorophyll, fluorescence<br>• Suspended sediments<br>• Nitrate<br>• Sea surface salinity<br>• Salinity profile<br>• Oxygen |

Wave modelling is directly dependent on the prescription of wind-induced sea-surface stress provided by atmospheric models. However, the friction that the atmospheric model used to compute the surface winds might be different from the wave-drag computed from these winds, with related inconsistent momentum fluxes. Ideally, a two-way coupling should be incorporated between the atmosphere and the waves. This should take into account also the effects of density stratification caused by air/sea temperature difference. It appears that these stability effects also determine the level of gustiness of the winds, which has an effect on the wave growth.

The wind input term of the WAM model is based on the quasi-linear theory, which extends Miles' description of shear flow instability. It is in fair agreement with observations. The problem of turbulent flow in the coupled air/sea system is only partially understood. It is desirable to try to extend the theory. A few items deserve special attention. What is the correct scaling velocity: is it u*, U10 or something else? How do stability and density stratification affect wave growth? How should gustiness be described and parameterised? How should the roughness of the very short waves be treated? What is the best turbulence closure in an oscillating boundary layer? What happens in the case of adverse wind? What is the effect of swell on wave growth?

For the wave-wave interaction the so-called discrete interaction approximation is made. Wave growth comes out well, but transfer rates differ from the exact ones.

With respect to deep water dissipation much work remains to be done. The challenge remains to work out the statistics and hydrodynamics of different whitecapping dissipation theories and to find experimental ways of distinguishing between them.

Further study is also required concerning the interaction of waves and currents. In coastal waters, resolution of the coastline can determine the effective fetch in the wave model. The ability to resolve mesoscale features in the modelled wind field is also important.

In general, computer-limited resolution limits the quality of the predictions. Grid nesting may sometimes help, but here also more research is needed. The ability to make high resolution models operational will depend to a large extent on the availability and architecture of large computers.

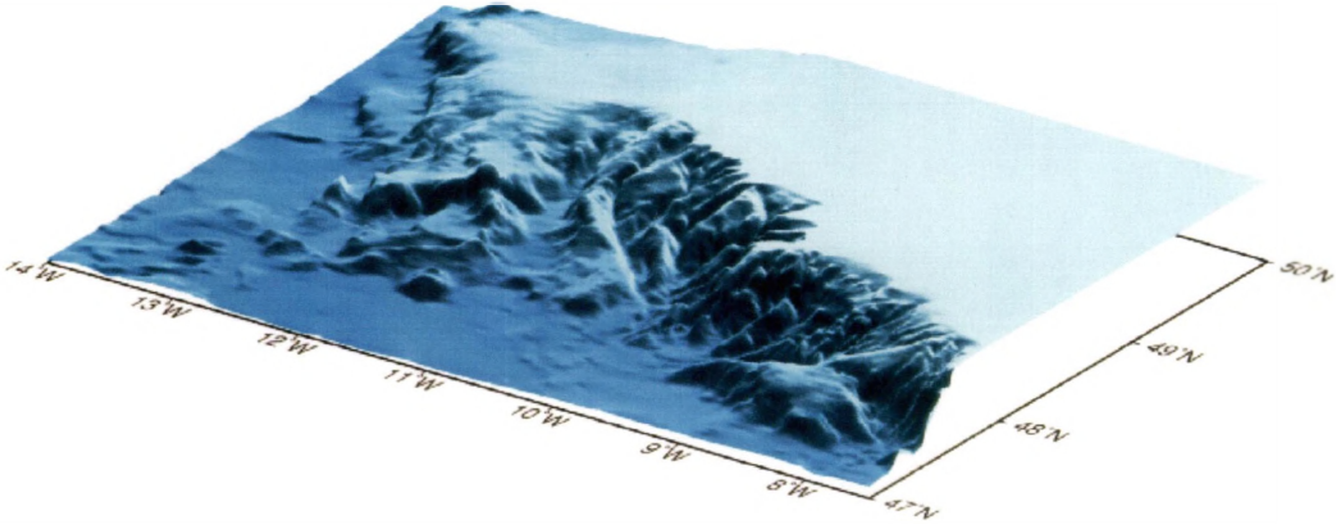


**Figure 2. Bathymetry of the OMEX-1 Study Area - Goban Spur**
*Illuminated view of the shelf edge in the area being studied by the Ocean Margin Exchange (OMEX) project (vertical exaggeration 35:1). Source: British Oceanographic Data Centre*

## Storm surge forecasting improvements

Storm surges are usually divided into two categories, those associated with tropical cyclones and those associated with mid-latitude storms. The development of understanding and predictive capabilities has differed for these two types of storm surge forcing. One of the factors leading to this differential development has been the relatively poor skill of numerical weather prediction systems in low latitudes compared with that at midlatitudes. Another is that of pure circumstance: one of the areas that is impacted by mid-latitude storm surges is the North Sea. The coastal regions of the various countries bordering the North Sea, like Britain and The Netherlands, are mostly very sensitive to water level changes because of the degree of commercial and industrial development and the tendency for denser population of the low lying coastal regions. This in turn has fostered considerable research and development in the area of storm surge monitoring, modelling and prediction, far greater than in any other region of the world.

Three-dimensional storm surge models are now becoming the norm, partly because integrations are no longer limited by available computing resources, and partly because three dimensional models give a more accurate and richer description of the circulation associated with surges. The parameterisation of bottom friction is more realistic if the near bottom velocity is used rather than the depth mean, and it is possible (though not always with significant impact) to capture non-linear surge-astronomical tide and surge-surface wave interactions.

Limitations in our knowledge of bathymetry can be a significant source of error in surge models. In most cases the domain of interest is not bounded so it is necessary to find suitable representations for the open boundaries. The boundary conditions should allow energy to propagate out of the domain "freely" and not excite free modes of oscillation related to the location of the boundaries. Ideally, of course, we would also like to propagate energy into the domain from the far field when appropriate. The specification of such conditions remains a significant problem, the rule of thumb being make the boundaries as far away from the region of interest as possible.

### The role for observations

The discussion above highlights several key areas:

1) Meteorological observations are critical for determination of the past forcing and for initialising atmospheric model predictions, be they from a complex numerical weather prediction system or, as is most often the case for the tropics, from a simple representation of the storm/cyclone (for cyclones it is usual to represent the atmosphere in terms of just a few parameters for the intensity, maximum winds, radius and path);
2) It is important to have accurate, high-resolution bathymetric data; and
3) It is useful to have sea level measurement sites located near or at the open boundaries to help determine appropriate boundary conditions, and at locations within the domain to tune and validate the model.

## Sea ice, improvements in observations and forecasts

Sections of the following paragraphs have been adapted from a report by Cattle and Allison to J-GOOS IV (1997). Cattle represents the UK Met Office in EuroGOOS.

### Sea ice and climate

Sea ice is important for climate both as a potentially sensitive indicator of high latitude atmospheric and oceanic change, and because changes in sea ice distribution feedback to the climate system through the ocean-atmosphere heat budget and the vertical salt flux to the ocean. Interactive sea ice models, albeit often highly simplified ones, are an essential component of coupled general circulation climate models. Model predictions demonstrate a marked reduction in both Arctic and Antarctic sea ice extent with global warming (IPCC, 1990, 1995). Given their predicted high sensitivity, monitoring of sea ice extents, thickness and concentration is seen as an important activity for searching for indicators of the onset of climate change.

### Sea ice and operational forecasting

A number of centres produce detailed operational analyses of sea ice characteristics, either regionally or globally for one or both hemispheres which meet a variety of operational needs, but principally for shipping. In the context of operational forecasting, Numerical Weather Prediction (NWP) models also require information on global sea ice extents as a component of the fields of analysed sea surface temperature which provide the bottom boundary condition for these models. For example the UK Met Office utilises NOAA/NESDIS joint Ice Centre charts to determine the NWP ice edge, which is updated in the model on a weekly basis. Satellite data provide an essential input to the derivation of these analyses. Sea ice information is also required as a component of operational ocean modelling systems. For example, the US Fleet Oceanography Center suite of oceanographic models and products (Clancy and Sadler, 1992) includes PIPS, the Polar Ice Prediction System (Preller, 1985, Preller and Posey, 1989) which enables numerical analysis and forecasts of ice extents, both hemispherically and for detailed regional areas (e.g. Preller et al., 1989) to be carried out in an oceanographic context. In the UK, the Met Office is developing FOAM, the Forecast Ocean-Atmosphere Model System (Foreman et al., 1994) which will provide operational analyses and forecasts out to five days of the global ocean. The FOAM system includes a sea ice component coupled to a global ocean model. Production of sea ice analyses within both of these systems requires not only sea ice data (FOAM will access Canadian sea ice concentration analyses for this purpose), but also techniques to update the model analysis fields via appropriate methods of data assimilation. Sea ice also affects the surface wave field, so that operational wave prediction models also need to take into account its presence on the ocean surface.

Ice cover on the ocean is usually expressed as a fraction of the ocean covered by ice (C, tenths of concentration) but it is the fraction of surface area covered by leads or other open water features, (1-C), that is the more important parameter within the ice-covered oceans. During winter, the average surface heat budget and ice mass balance are highly sensitive to this fraction, as most heat loss from the ocean surface occurs through areas of open water or very thin ice. But the total heat loss is not a linear function of open water fraction: the largest changes with ice concentration occur in the concentration range 0.8 - 1.0, while there is little change in total heat loss with further decrease in concentration below about 0.5. Thus in winter, ice concentration affects the temperature of the atmospheric boundary layer and the depth of the oceanic mixed layer. During summer the ice concentration has a significant effect on area average surface albedo and on the melting rate of floes due to solar radiation absorbed in the open water.

### Measurement of sea ice

Sea ice thickness is not presently amenable to direct measurement by satellite remote sensing, and satellite-borne sensors capable of accurately estimating sea ice thickness remain five or more years in the future. Satellite microwave radar polarimetry has demonstrated some capability to measure ice in the 0-50 cm thickness range. Other than on the space shuttle, this technology is not expected to be available on a space platform until the European Space Agency's ENVISAT mission.

In the Arctic, measurements of ice thickness have been made from submarines equipped with ULS, on an opportunistic basis. The WCRP ACSYS Arctic Ice Thickness Project, based on moored ULS, was launched in 1988 and underwent rapid progress with significant increase in ULS deployments in 1991 and a further increase in 1992. Altogether 19 ULS moorings were deployed by 1993 and some 15 are currently operational, though the distribution is very much confined to the peripheries of the Arctic basin and the region and the Fram Strait and the East Greenland Coast. Experiments with AUVs and upward looking sonar may solve this problem.

### Measurement of pack ice velocity

Ice motion in response to wind and currents plays a major role in determining the ice thickness distribution and ice edge location. Ice thickness and motion combined determine the transport of ice mass, and therefore of latent heat, salt, and fresh water. Ice velocity data are also necessary to verify sea ice models, and since ice motion provides the mechanical forcing for the ice-covered ocean, can be used to drive ocean models.

The large scale motion of sea ice can be observed using data buoys deployed on ice floes and tracked using the ARGOS location and data relay system on NOAA series satellites. Most of the data buoys also report sea level air pressure and some, temperature. In the Arctic, this is carried out through the International Arctic Buoy programme, which has good coverage over the central pack.

### Concluding remarks on sea ice

This section attempts to summarise the current situation with regard to sea ice observations and modelling for climate and large scale operational forecasting. A number of aspects of sea ice modelling and observational studies are being addressed by the WCRP ACSYS programme for the Arctic and are planned to be addressed by SCAR ASPECT for the Antarctic, but in a research context. Key issues are (i) the need for greater sophistication in the sea ice models used for both climate and operations, including the specification of surface forcing, particularly from NWP models which currently do not include representation of open water (leads) in the ice, and (ii) the need to maintain and develop the current network for sustained observations, and particularly to develop the buoy network in the Antarctic sea ice zone. Satellite data are of high relevance to monitoring of high latitudes and some algorithm improvement is required in particular for ice concentration and ice type is required. Measurement of global fields of ice/snow thickness remains problematical. An important advance would be the capability to remotely-sense sea ice/snow thickness from space.

## Ocean basin scale processes

Ocean basin scale prediction can be considered as long-term, that is seasonal to decadal, or short term, that is days to weeks. Both types of prediction have value.

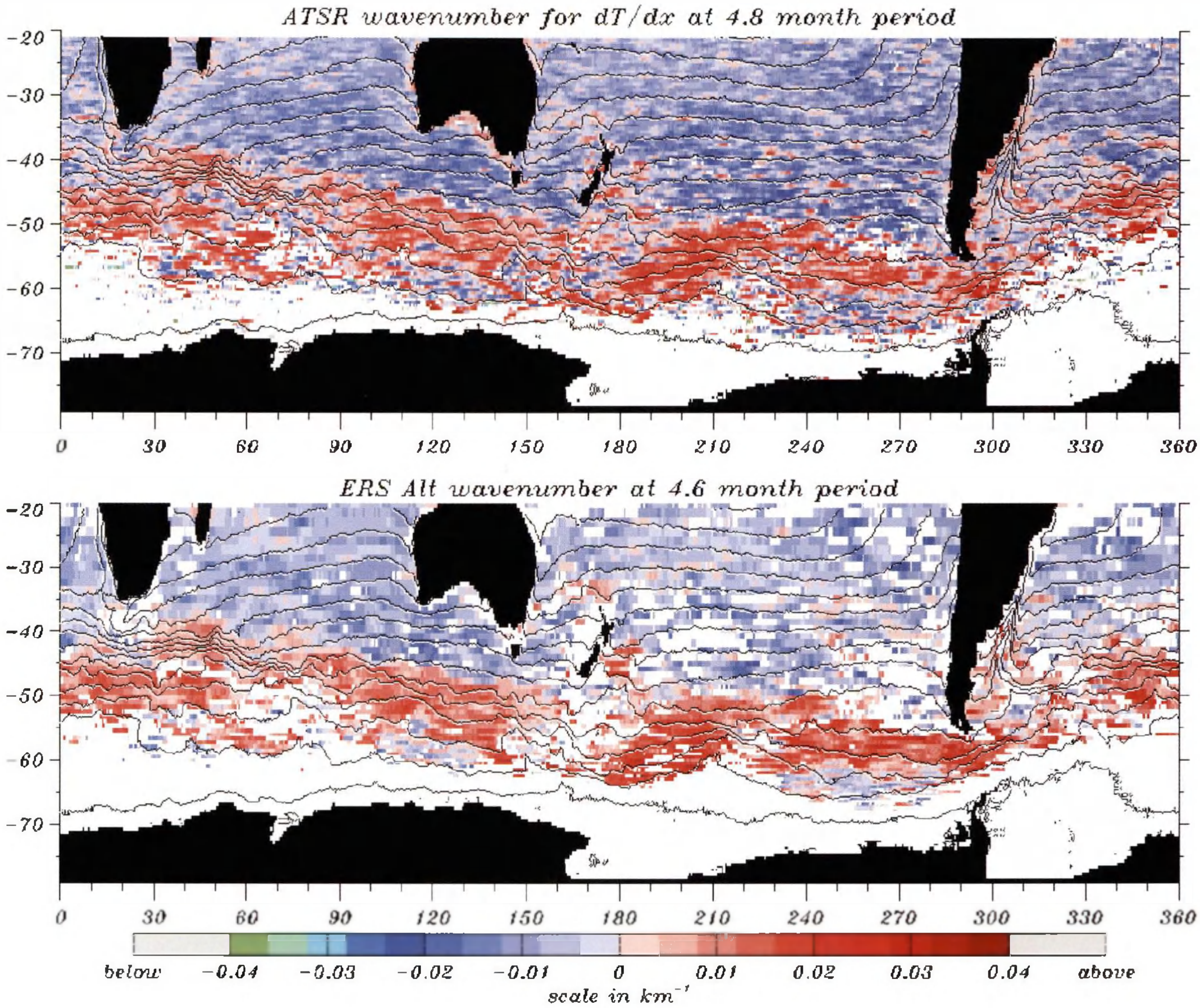


**Figure 3. Global ATSR/ERS satellite data**
*Zonal wavenumbers for waves seen in sea surface temperature gradients at a period of 4.8 months (top), and in sea surface slopes (bottom). Red colouring corresponds to eastward wave propagation and blue to westwards propagation. White regions are those in which the wave coherence is not significant at the 95% level. Contours are mean sea surface temperature at intervals of 2 degrees. Eastward propagation can clearly be seen in the Antarctic Circumpolar Current, as well as in narrower eastward currents such as the South Atlantic Current and the Tasman Front.*
*Source: J M Vassie*

In addition to its Regional Task Teams for the European regional seas, EuroGOOS has an Atlantic Task Team which has the objective of promoting operational modelling at the Atlantic scale, and promoting the participation of European agencies in global prototypes for operational systems such as GODAE and ARGO. The Atlantic Task Team has held two meetings, one at Toulouse in September 1997, and a workshop at Southampton October 1997. The Workshop proceedings have been published as EuroGOOS Publication No.9. Another meeting will be held during 1998.

Scientific design and operational criteria are required to meet the following objectives:

- provision of oceanic boundary conditions for operational shelf seas models,
- forecasts of shelf edge and slope processes, needed by deep offshore oil and gas producers,
- prediction of shelf edge and slope conditions relevant to fish stock migration,
- modelling and forecasting the dispersion and transport of oceanic contaminants and pollutants,
- monitoring and predicting fluctuations in the Gulf Stream and North Atlantic Current, including possibly predictable decadal variability,
- monitoring and modelling the formation of Atlantic bottom water, the ventilation, convection, and deep water formation, the multi-annual and decadal changes of the state of the Atlantic Oscillation,
- assessment of oceanic and benthic biochemical parameters,
- modelling and predicting oceanic and global carbon transports and greenhouse gases,
- forecasting surface and near surface sea state for oceanic shipping,
- forecasts of upper ocean conditions for fisheries management,
- monitoring and forecast of sea ice and icebergs,
- improved marine meteorology.

This section considers topics which are not covered by the other sections on surface phenomena such as wind waves and sea ice. During the World Ocean Circulation Experiment (WOCE) the research ships occupied 8500 full ocean depth hydrographic sections in the North Atlantic between 1990 and 1997. About 6000 XBT profiles were obtained each year, which provide sufficient data on the upper ocean thermal structure to document seasonal changes, and to initialise predictive models such as FOAM and MERCATOR. Central to WOCE was the TOPEX-POSEIDON altimeter satellite giving spatial and temporal information on the sea surface slopes.

During 1996-97 large numbers of profiling ALACE (P-ALACE) floats were deployed in the North Atlantic, and it seems certain that a future operational system would have to utilise large numbers of such floats. Within the plans for GODAE and ARGO it is assumed that upper ocean thermal structure is provided by PALACE/PROVOR floats. Each float provides the equivalent of 200 CTD profiles to subthermocline depths at a cost of about $100 per profile. The best sensors are capable of maintaining stability of +/- 0.005 in salinity over a year.

During MAST II the DYNAMO model intercomparison exercise compared 3 different numerical models of the North Atlantic, based on the different principles of vertical gridding using either fixed levels, isopycnic surfaces, or proportional terrain-following vertical intervals. All three models were successful in simulating the North Atlantic with a considerable degree of realism, and the differences between them were revealing both as to model performance and the processes in the real ocean.

Assessing the seasonal variability of basin-wide models would provide valuable inputs into designing a monitoring and observing strategy for collecting data sets to assimilate into forecasting models. Resources could be concentrated into those areas which are most variable.

The importance of long-term multi-year and decadal variability in the Atlantic, and its effect on European climate and regional migration of fish stocks can hardly be over-estimated. During recent years analysis of historical data sets, and the conduct of repeated sections across the North Atlantic, have revealed remarkably large changes in the thermocline and in the deep ocean. The clearest signal is in the subtropical North Atlantic where intermediate and upper deep waters are warming at a rate as large as 1°C per century. Inventories of North Atlantic water masses will be needed over approximately decadal time periods because the signatures of these changes provide a sensitive testbed for ocean-atmosphere models of the climate system, and help to explain the causes of long-term climate change.

Another decadal process which requires further research in order to evaluate its usefulness as a predictive tool is the apparent propagation of sea surface temperature anomalies along the path of the Gulf Stream with quasi-decadal periodicity. The propagation is much slower than the near surface currents, and the full mechanism is not yet understood. (Sutton and Allen, 1997).

Data assimilation strategies are a major area of research in ocean modelling, and the general issues of data assimilation are dealt with later in this report.

### Limitations of existing systems and future trends

The following notes on limiting factors are based on a report by Johannes Guddal (DNMI) compiled for J-GOOS III, (1997). Several EuroGOOS Members contributed to the report.

i) Lack of international infrastructure for operational oceanographic data gathering, transmission, and products, (e.g. as adopted in World Weather Watch), and consequently lack of common standards.

ii) Lack of clear right or duty to collect and transmit real-time data.

iii) Lack of "open boundary" conditions needed for limited-area numerical models.

iv) Lack of appropriate forcing data fields (winds, air pressure, etc.) for numerical models.

v) Lack of geographical coverage of measured data on the global scale, but also regionally, and in sub-surface in particular.

vi) Lack of proper design of a services structure, using, for example, multiple data inputs such as wind, waves, and currents, to generate predictions of oil spill movements.

vii) Imbalance between monitoring (measurement) technology and capacity for postprocessing data and subsequent real time use of numerical models.

viii) Lack of "fitness for purpose" awareness in the design and setup of services.

The most obvious trends within operational services are:

ix) Increased end user influence; both with regard to specific "fitness for purpose" requirements, and via communication with larger user constituencies, such as international associations dealing with shipping, coastal engineering, vessel traffic services etc.

x) Enhanced environmental legislation and maritime jurisdiction, usually followed by increased demand for ocean environmental information.

xi) Gradual introduction of international standard procedures for quality assurance of services and products.

# Operational oceanography

## Assimilation: linking models and observations

**Assimilation is the transfer of information of a limited set of observed parameters, that are directly or indirectly related to the model state, to update the model state, the model forcing and/or model coefficients.**

### Background

Information about numerous physical processes can be provided by numerical models and observed data. Both can be considered as components in a framework to gather and to generate specific user-information. A considerable step ahead can be made by exploiting the complementary character of models and observations: the generic, dynamically continuous character of process knowledge embedded in models versus the specific, quantitative character of observed data. By means of data assimilation, model information and observed information can be integrated in an optimal way, taking into account the uncertainties or errors in the model and the observations,

- to validate and calibrate the models,
- to determine the best representations of parameter fields for use as initial conditions in forecast runs, etc.

That data assimilation indeed plays an important role is illustrated by the fact that in numerical weather prediction it is acknowledged that further improvement of the forecasts is best realised by improving the assimilation of observations, not by improving the quality of the atmospheric models.

Wunsch (1996) notes that ocean modellers have paid little attention to working with real data. This is attributed to both the initial need to understand the models *per se* and the paucity of available data. However he notes the rapid change in the latter, with new technologies already providing useful data sets complemented by a range of emerging technologies to widen the scope for model initialisation, forcing and verification. However it is recognised that models will always be dependent on 'indirect' observations and that the temporal and spatial extent and resolution of observations will always be less than that of the models.

### Basic principles

The advantage of model-based assimilation techniques (e.g., Kalman filtering and adjoint modelling) is that the system dynamics is included in this transfer in such a way that the updated model state is consistent with the model. However, in practical applications the consistency between the assumed and actual properties of the uncertainties with which both the model as well as the observations are corrupted (either in deterministic or in statistical sense), is a major factor in determining the effectiveness of the assimilation. The latter aspect strongly emphasises the need for validation of the models as well as the data that are to be assimilated (re-analysis, accuracy assessment, standardised QC procedures, error characteristics). A useful summary of present activity is provided by Stammer, et al., 1998.

### Applicability & experience

There is an extensive experience with assimilation of wind, wave and water level data. Techniques for assimilating sea surface temperature distributions are developing continuously.

For wave models, techniques to assimilate co-located observations of wave height and windspeed (e.g. from satellite borne radar altimeters) are well developed and in operational use in global models. Data from *in situ* buoys are not as widely used for assimilation, except in some regional wave models, because of the sparse coverage. Techniques to assimilate spectral observations are being developed, but are not in widespread operational use. Spectral observations from satellite borne SAR are available but need costly processing before use. *In situ* observations of the wave energy spectrum are sparse. There are few co-located measurements of 'offshore' and 'onshore' wave conditions.

For shelf seas models a range of techniques for assimilating tidal elevation data are available; some more developed than others. These are not in widespread operational use. In UK waters the main tide gauges are located in ports, on the coast. There are few, if any, real time *in situ* observations of sea surface elevation in open water. There are few real-time observations of surface currents or of current profiles available.

Global and regional sea surface temperature (SST) analyses are already carried out for use by operational numerical weather prediction (NWP) models. For use in shelf seas models the detail of how the SST influences temperatures at depth needs further study, (i.e. is the water mass well mixed or stratified) and the ability to assimilate temperature soundings in shelf seas models needs to be developed.

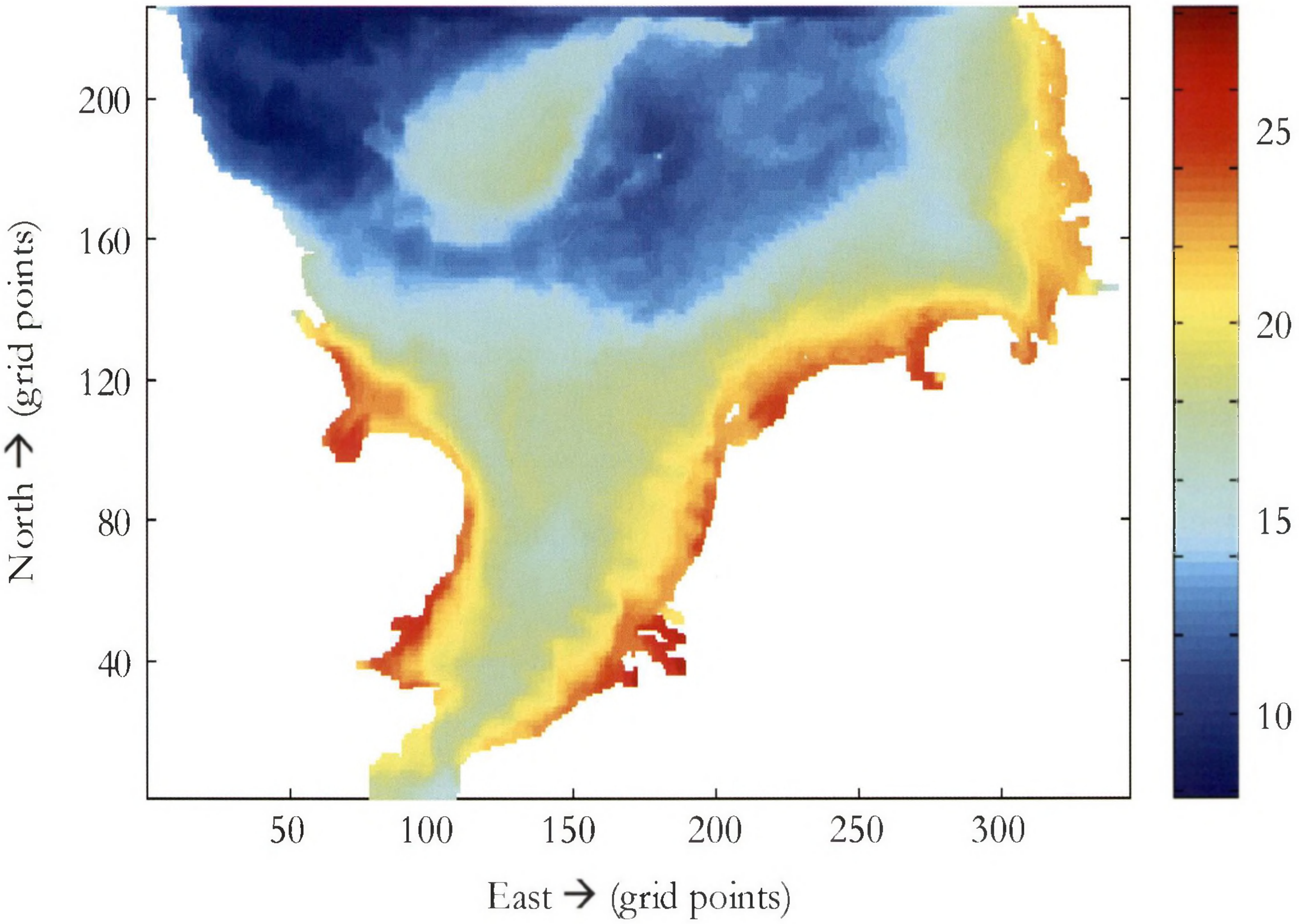


**Figure 4 North Sea bottom temperature**

*Summer distribution of computed sea-bed temperature (°C), in which the Flamborough front is clearly visible. Source: Proudman Oceanographic Laboratory*

Assimilation of transport data (velocity profiles, suspended matter and/or salinity) and ecological data is in progress. Problems that have to be dealt with are, a.o., the local character (velocities) and the indirect relation with the modelled state *(e.g., RS* reflection images that need to be transferred to concentrations, derivation of the forcing wind field or the bathymetry from wave data). One of the key issues is to determine the temporal and the spatial scales and resolution allowing the extraction of meaningful information from the differences between the modelled and the observed parameters.

The potential of data assimilation has to be exploited by focusing on the conditions that have to be met to optimise the process of 'generating information', starting from the notion of the complementarity of models and observations. This points at the use of assimilation techniques already in the design phase of monitoring networks and measurement campaigns (what parameters must be observed, the required accuracy, etc.) In this way, data assimilation directly contributes to the EuroGOOS objectives.

In much the same way, data assimilation techniques can be used in setting up integrated models. The level of detail at which various modules should be coupled (what parameters must be transferred, what is the required accuracy?) can partly be deduced from both sensitivity analyses and actual assimilation experiments.

### Evaluation and validation of models

Over the last few years, the amount of field data is rapidly growing, especially RS data, (atmosphere), imaging spectrometer observations of water quality parameters and suspended matter, wave information that can be related to the bathymetry and morphodynamic changes in the coastal zone. RS data have contributed significantly because of the high spatial correlation of the data (patterns), despite its low temporal coverage and sometimes limited accuracy, as opposed to *in situ* data. Here also, this complementarity of *in situ* and RS data must be exploited, both in the assimilation process and in the pre-operationalisation of observation systems: there is a need to identify what kind of parameters need to be measured in advance.

## Summary and recommendations

Given models and observations, data assimilation (being the interface between them) is the third essential component of information systems,

Assessment of models and observations should be made to identify their role in integrated (information) systems and to address questions like cost-effectiveness.

A prerequisite for assimilation of observational data is the availability of digital, well-documented, easily accessible data, which have been screened by (standardised) QC procedures.

**Box 4**

## Assimilation Applications

### Wind waves

Recently considerable progress has been made in data assimilation of wave observations in wave models. The presently operational, simple wave data-assimilation schemes based on optimum interpolation (Lionello, 1992; see also Foreman et al., 1994) are being extended to include more wave parameters. Recent progress was made by Young and Glowacki (1996) and by Voorrips et al. (1997) who extended the O/I approach and successfully assimilated two-dimensional spectra obtained from directional buoys and the SAR. In addition, so-called four-dimensional methods should be further developed. A promising method is based on use of the adjoint of the WAM model (de las Heras and Janssen, 1992; Hersbach, 1997). Kalman filtering approaches should also be considered, however. It is important that corrections made to wave estimates are consistently introduced in the forcing wind fields. Therefore, future models should attempt to incorporate two-way coupling between atmosphere and waves. Without this the greatest impact of wave data-assimilation occurs for swell. Once the coupling has been realised, one may also expect a beneficial impact on wind sea forecasting.

### Water level

In the Northwestern shelves area a great number of water level stations are in operation. A few of these situated at strategic locations can be selected for comparison of model forecasted water level and the actually measured level. Water level is often a convenient integrator of other effects with spatial smoothing.

### Sea surface temperature

Model sea surface temperature patterns can be validated through comparison with remotely sensed data. Single point values can be compared with observations from fixed monitoring stations and drifting buoys. For the fixed monitoring stations, time series of temperature (and other parameters such as salinity, oxygen, nutrients etc.) can be obtained for comparison. Present techniques are limited by the availability and accuracy of data from remote sensing and by its restriction to the surface layer.

### Transports

The quality of the calculated transports as well as the vertical distribution of temperature, salinity etc. through well defined sections can be validated by performing oceanographic measurements on a dense net of stations along the section from a research vessel equipped with a hull mounted ADCP. Inter-cruise validation can be obtained by a few fixed oceanographic stations on the section. The fixed station should be equipped with current meters (ADCPs,) and temperature-salinity sensors and there should be real-time communication to the stations.

### Drift

One important aspect of using model prognoses is the ability to predict drift patterns of for instance oil, lost cargo etc. Validation of the quality of predicted drift patterns can be done in two ways.

- using satellite tracked surface drifters (which can also measure other parameters such as temperature and salinity)
- experiments with tracers, for instance rhodamine B. Experiments with use of tracers can also check the model's ability to simulate the diffusion of the substance.

# Extending predictability

## *Assessing forecast systems, quality assurance, data management*

### General scientific assessment

**The SAWG will provide analyses of factors which limit predictability and thereby insight into developments necessary to extend the range (length of forward prediction), scope (additional parameters), accuracy and reliability.**

Such analyses may conveniently be considered under three headings; Models, Observational Networks and Instrumentation.

### Models

The diversity of marine systems makes it unlikely that a single integrated model will evolve as for weather forecasting in national meteorological agencies. However, rationalisation of modules within tailored modelling systems is a common goal together with standardisation of prescribed inputs such as bathymetry, tidal boundary conditions etc. Such enhanced rationalisation will enable the essential characteristics of various types of models to be elucidated including the inherent limits to predictability.

### Range of models

- EuroGOOS has compiled a catalogue of existing operational, or nearly operational models (see Fig. 5). This catalogue, together with its report (Document 4) should be used as the starting point for a general assessment and validation of models, followed by a pooling of expertise, and estimation of the best way to progress to the next generation of operational models.

- Adoption of standardised modules can allow individual modelling groups to concentrate on more specialised sub-modules. However, there is a continuing need for a wide range of types of models with different characteristics and associated advantages. Modelling has not evolved to the point where prescribed versions can be readily adopted. While individual organisations may concentrate on local and specialised models, there is a strong need for large scale models to provide the boundary conditions at the shelf edge. The oceanic inputs can be ignored for short term forecasts, but are important to gain longer predictions.

### Observational Networks

Almost all existing monitoring networks (e.g. tide gauges, wave buoys) have evolved to address specific end-user requirements using instrumentation technology prevailing at the outset with occasional up-grading. The design of new, comprehensive networks exploiting synergistic aspects of a range of instruments/platforms integrally linked to modelling requirements/capabilities is a prospect as exciting as it is daunting. Likewise specialist skills and systems are required to network such observational data in real-time. The specific challenge to scientists is to develop first the perception, thence the implementation frameworks to exploit the new opportunities created by an integrated European approach.

The peculiar inter-relationship between model output and observational data used for both initialisation/updating and validation requires development of concepts and related methodologies for assimilation, quality assurance and model validation.

### Instrumentation

Extending the scope of operational oceanography, especially in relation to biological and chemical parameters, will be closely related to the development of new instrumentation. Lead-times between proof-of-concept laboratory tests and availability of commercial marine packages have traditionally been of order of a decade or two.

**Figure 5. EuroGOOS catalogue of existing operational, or nearly operational models** **Source: J Davies, UK Met Office**

| Centre | Model Name | Model Type | Area | Oper. Date | Predicted Variables | Horiz. Res (km) | Vert Layers | Atmos. Force | Nested | Assim. Var |
|---|---|---|---|---|---|---|---|---|---|---|
| Met. O. (UK) | FOAM | OGCM | Global | 1997 | v,s,T,I | 100 | 20 | v,solar+ | X | T,h,s |
| | Global Wave | Wave | Global | 1987 | wh,sh,ws | 90 | N/A | v | X | wh |
| | Europ Wave | Wave | At,Med,Blt | 1987 | wh,sh,ws | 25 | N/A | v | Yes | X |
| | SURGE | Tide/Surge | Eur.Shelf | 1992 | v,h | 12 | 1 | v,P | Yes | X |
| | UKOPMOD | Tide/Surge | Eur.Shelf | 1996 | v,h | 12 | 6-50 | v,P | X | X |
| KNMI (NL) | NEDWAM | Wave | N.Sea | 1998 | wh,sh,ws | 32 | N/A | v | Possib. | wh,ws |
| | NAT. GID. | Statistical | N.Sea | 1996 | v,wh,sh,ws | N/A | N/A | v,wh,sh+ | N/A | X |
| Delft H. (?) | Delft 3D | OGCM | Shelf,est,riv | 1998 | v,h,wh,s,biol+ | Any | Any | v,P,heat+ | Yes | X |
| | Delft 2D | OGCM | Shelf,est,riv | 1994 | v,h,wh,s,biol+ | Any | Any | v,P,heat+ | Yes | X |
| | TRISU. 3D | Tide/Surge | Shelf,est,riv | 1984 | v,h,s,T | Any | Any | v,s,heat+ | Yes | dissolv. |
| | DELWAQ | Water qual. | Shelf,est,riv | 1984 | dissolv. | Any | Any | T,dissolv. | Yes | h |
| | DELPAR | Dispersion | Shelf,est | 1990 | s,T,dissolv. | Any | Any | v | Yes | dissolv. |
| | DCSM | Tide/Surge | Eur.Shelf | 1986 | v,h | 9 | 1 | v,P | Yes | h |
| | MARS | Dispersion | N.Sea,Chan | ? | dissolv. | Any | Any | v,T | Yes | X |
| | PREMO | Tide | N.Sea,I.Sea | 1991 | h | 8 | 1 | X | X | h |
| | RESTWAQ | Dispersion | S.N.Sea | 1999 | dissolv. | 3.2 | 1 | v | Yes | ws |
| | PHIDIAS | Wave | N.Sea | 1992 | wh,sh,ws | Any | N/A | v | Yes | dissolv. |
| | DELFTNN | Tide/Wave | N.Sea | 1994 | v,h,ws | N/A | N/A | Yes | N/A | Yes |
| MUMM (B) | MU-STORM | Tide/Surge | N.Sea | 1981 | v,h | 8-70 | 1 | P,v | Yes | X |
| | MU-WAVE | Wave | N.Sea | 1991 | wh,wh,ws | 5-50 | N/A | v | Yes | X |
| | MU-SLICK | Dispersion | N.Sea/other | 1987 | spill position | N/A | N/A | v | Yes | X |
| RWS (?) | Neural Net | Tide | S.N.Sea | 1993 | h,sh | N/A | N/A | X | X | X |
| | Ar1-9ax-E10 | Wave | S.N.Sea | 1986 | h,sh | N/A | N/A | v | X | X |
| EDS (?) | WAQUA | Tide/Wave | Eur.Shelf | 1989 | v,h | 16 | 1 | v,P | X | h |
| NIOZ (?) | WAQUA | Tide/Surge | Wadden | 1985 | v,h,dissolv. | 0.5 | >1 | X | ? | X |
| IFREMER (?) | ELISE | Ecology | Channel | 1999 | T,s,chem,biol | 3km | 2 | v,P,T+ | X | X |
| SHOM (?) | SOAP | OGCM | NE.Atlantic | 2001 | v,T,s,h | 15 | ? | v | X | h |
| CNR (?) | MEDGCM | OGCM | Med | 2000 | v,T,s | 10-20 | 31 | v,T | X | T |
| OCN (?) | MAESTRO | Tide/Wave | Any | 1998 | v,wh,sh,ws | N/A | N/A | v | X | X |
| Met. Eir (?) | WAM | Wave | Eur.Shelf | 1997 | wh,sh,ws | 25 | N/A | v | Yes | X |
| BSH (D) | OP BSH | OGCM/Tide | N.Sea/Baltic | 1983 | v,h,P,s,T,d,I | 2-20 | 10 | v,P,T+ | Yes | X |

v = velocity (vector) s = salinity I = ice dissolv. = dissolved and other substances
h = surface elevation T = temperature wh = wave height
P = pressure ws = wave spectrum sh = swell height + = more also

The development of Satellite Remote Sensing will dictate the rate of development of operational oceanography for many parameters and this, likewise has a planning cycle of order of a decade. Thus the longer-term development of operational oceanography will be governed by the foresight of scientists and technologists in prioritising areas of investment.

### Model developments on a European scale

- Within a few years, it will be necessary to have a major operational ocean modelling centre in Europe (possibly in network form), and increased resources for regional marine modelling centres. Much of the work needed for European scale marine and ocean modelling could be done by nodes on a high-speed data network, but there will be a need for lead organisations, and dedicated large computers, with teams to operate them in operational mode.

- A future task of SAWG is to identify the scientific criteria for European and regional marine operational modelling centres.

- Experience in the use of models needs to be more widely shared

- EuroGOOS can provide a useful service by promoting the intercomparison and partial validation of models, which will assist Agencies to make choices.

- Europe has a high skill level in the development of ecosystem models, which are almost at the point of being used operationally.

- Data assimilation is a major area of new techniques and learning. New initiatives are needed, and EuroGOOS should work with other groups, such as EuroCLIVAR and ESF.

- EuroGOOS Members should participate in the Global Ocean Data Assimilation Experiment (GODAE).

- Different specialised tasks can be distributed on a nodal network.

- Statistical and climatic models are needed, and are useful for climate forecasting, as well as fisheries management.

Neural network techniques are showing promise in statistical forecasts, and EuroGOOS should collaborate with EuroCLIVAR to investigate the potential for their use operationally.

## Quality assurance

Increasingly the user of environmental data will access (on- or off-line) an information system incorporating both observational and numerically modelled data. Models can also be used, uniquely, for prognostic (what if?) and forecasting (prediction) purposes. An important characteristic of any model which any potential customer will need is quality assurance (QA). QA is multi-variable too, requiring validation and quality control (QC) throughout the whole operational system.

Numerical models simulating processes in the seas and ocean have been operational for a number of years, e.g. for tides, surges, waves. Models (3D) for temperature and currents are presently under evaluation for operational purposes. Further models of chemical, biological and sedimentological variables are in prospect as understanding of processes improve and as computer capacity increases. The important question that has to be addressed in each case is 'how good are they?'. In turn this begs the question of their purpose, and how fit they are for it.

Regular observations are likely to be the most expensive component of an operational system, and it is important to find out the minimum quantity and accuracy of observational data necessary to keep a model 'honest'. However the costs of maintaining the software, especially through frequent changes in computer technology should not be underestimated.

Part of the system QA must be validation, for which independent (i.e. not already assimilated) observational data will usually be needed with which to compare the model output data. Rarely can this test data ever be comprehensive, it will be limited to a small proportion of the output, sometimes from a special and expensive field experiment. New data coming on stream from implementations of GOOS and EuroGOOS may sometimes serve this purpose in future. Observational data whether for validation, assimilation or QC testing, will generally be inhomogeneous e.g. a mixture of *in situ* time series, along track ship data, lagrangian drift data and remotely sensed snapshots. The relative values of these to operational systems will vary (Voorrips et al, 1997).

In a validation exercise differences between observations and model output will arise from errors in either. Some of the questions that need to be addressed before a model passes from development to operational status include:

a) how close must the model output and the test observations be to be useful?
b) what are the sensitivities to initial conditions at this level of model accuracy?
c) do the assimilated data reduce output errors?
d) how rapidly do the errors build up as forecast period increases?
e) do the spatio-temporal patterns of errors give clues to inadequacies in the processes that are simulated?
f) what is the optimal set of observations for testing the model?
g) if the optimal set cannot be afforded what is the trade off in accuracy with the set that can be afforded?

Even with the great computer power available today, many fine scale processes have to be parameterised rather than be simulated directly, turbulence is the obvious example of this, but there are many others, such as highly irregular topography or complex patterns of floating sea ice. When non-linear processes are included there is the prospect of chaotic behaviour in the model even without errors in representing the turbulence. Numerical instabilities may arise from finite spatio-temporal and bit length limitations, and from discretisation of analytic functions in the algorithms. Software auditing is essential. The full error analysis of a complete system is therefore an important and non-trivial task.

There is a limit to generalisations about this QA process, because every model and application are different, and different criteria will apply. This has been addressed by Dick P Dee (1995), which includes a useful and recommended glossary of terms. As part of the formal procedure of model quality control in the area of industrial hazards a European Model Evaluation Group have proposed (5 May 1994) a protocol, supported by EC DGXII. Both these articles emphasise that QA involves QC of all stages in the system, the important role of validation and the uniqueness of each case. This suggests that there may not be much generic work that can be done on the topic, and that EuroGOOS may have to follow the example of MAST and proceed by Test Cases (e.g. Gerritsen and Proctor, 1995). The experience of meteorological agencies over many years must surely be relevant too.

## Data management

The technology and procedures of data management, quality control, data transmission, avoidance of data corruption, and speed of delivery are not matters on which SAWG can comment. SAWG is concerned to draw attention to the need for standards of performance in these sectors. Various standards and recommendations do exist for programmes such as WOCE, TOGA, JGOFS, LOICZ, and for operational procedures in IGOSS, DBCP. IOC has published a general manual of data management quality control (Unesco, 1993). Operational agencies already operating routine services have their own quality control, data management, and archiving rules.

The SeaNet programme is developing common formats for data acquisition, formatting, and transmission for fixed instrument stations in the North West Shelf region. The Mediterranean Forecasting System is similarly developing data management programmes. In recent years, all collaborative MAST research projects supported by DG XII have been obliged to include an explicit data management plan, with allocations of resources.

It is too early to be specific about general data management policy and standards in EuroGOOS, other than to say that adherence to standards will be an essential component of an efficient and reliable operational system. So far as possible the standards and procedures adopted will be compatible with pre-existing international standards, allowing EuroGOOS to transmit data into and out of the European area of interest with maximum efficiency.

Factors to be taken into account are shown in Box 5.

**Box 5**

**Evaluating systems and requirements**

Infrastructure for data exchange and transmission
Met systems, that is GTS
Oceanographic data and systems

**Requirements**

Identify using regional activities and the needs of the different monitoring programmes.
Which variables and processes are:
- Forecasted
- Nowcasted
- Hindcasted

**Data management**
- Data policy
- Property right, legal agreements
- Data quality control
- Verification, validation
- Documentation, meta-data

**Data exchange mechanisms**
- E-mail
- FTP
- WWW
- GTS
- Traditional methods
- Dedicated electronic links, fibre optics

## Comments & recommendations from this section

i) Data management must be conducted under international protocols such as those governing the transmission and availability of data to protect Safety of Life at Sea (SOLAS). Other data are measured and transmitted by WMO and IOC as part of IGOSS. There is no convention, treaty, or agreement on the general obligations to share, exchange, or transmit data from marine observations, c.f. Resolution 40 of WMO.

ii) In the absence of generally applicable or treaty-defined data policy protocols, EuroGOOS Member Agencies will share and exchange data sets between Members in the interests of creating European-wide models and model outputs. This does not preclude the development of downstream commercial data products.

iii) Some remote sensed products (Scatterometer wind speed, Altimeter, AVHRR/ATSR) can be provided in Fast Delivery Products (1 - 2 days delay) to standards which are acceptable for modelling. However, the delayed mode products are much more accurate. Further effort is needed to improve the accuracy and reduce latency of FDP.

iv) Data management requires a strict procedure for quality assurance, relevant to each variable. Once operational models are running routinely, the process of data assimilation acts as a filter to reject bad data, but this cannot be regarded as an adequate system on its own, especially if the proportion of bad data is high.

v) Operational agencies are not usually responsible for environmental data archiving. Long term data sets are needed for climate statistics, time series, and trend analysis. However, at the present stage, EuroGOOS SAWG is not in a position to specify an archiving policy.

vi) The EuroGOOS Pilot Projects being planned by Regional Seas Task Teams should include real time data management and exchange.

vii) EuroGOOS supports the programme of SeaNet to up-grade and standardise the data management, data transmission, and data quality control of fixed instruments in the North West Shelf area.

viii) Quality control and data validation procedures should be automated wherever possible.

ix) When operational oceanography is well established there will be a need for comprehensive manuals and procedures for all stages of data gathering, calibration, and management, probably in electronically accessible form. At present it is not possible to consider such standardisation.

# Extending predictability

## Requirements

### Adequacy of present forecasting ability and related limiting factors and constraints

**The variables and parameters measured and modelled in each region differ and likewise the range of forecasts required differ. In some areas requirements can be met, but not others. The cause for a forecast failing to meet demand (the adequacy of data or the quality of modelling) are considered.**

The following table shows a method of analysis which compares the types of product which have already been developed operationally in each region, and the causes of constraints in that region. The reasons for failing to meet requirements or ideal forecast differs between regions and parameters. The table is not complete. It illustrates a method.

**Table 1 Examples of technique for identifying functional limits of predictability**

| Parameters | Stage of development | Time range of prediction required | Constraints |
|---|---|---|---|
| Ice (Baltic) | Operational prediction (model) | 2 months | Atmospheric forecast |
| Ice (Baltic) | Operational (model) | 2-5 days | Atmospheric forecast + ice cover(?) |
| Ice (Arctic) | ~ nowcast (mapping of data) operational | - | Atmospheric forecast + PAR, rheology of ice - knowledge thickness |
| Waves (Baltic) | Operational | 2 days | Atmospheric forecast |
| Waves (NW Shelf) | Operational (UK, NL, DE, DK, NO...) | | |
| Waves (Mediterranean) | Operational ECMWF | 2-5 days | Grid resolution |
| Waves (Mediterranean) | Operational, Spain | 1-2 days | Atmospheric forecast |
| Waves (Atlantic) | Operational, ECMWF (UK) | 2-5 days | Atmospheric forecast |
| Sea level (Baltic) | Operational | | |
| Sea Level (NW Shelf) | | | |
| Sea level currents (NW Shelf) | Operational | | |
| Temperature (frontal structure) | Research everywhere | | |
| Currents | Research everywhere | | |
| Tides (Barents Sea) | | | |
| Tides (North Sea) | | | |
| Temperature, Salinity | | | |
| Chlorophyll (algal blooms) (NW shelf) | Operational | 2-10 days | |

### Improvements in oceanic density and current vertical structure forecasts

The ocean density and current structure depend, almost in equal proportion, upon air-sea interface momentum, water and heat fluxes and the internal non-linear dynamics of the flow field, e.g. the presence of mesoscale eddies. This in turn means that forecast skill heavily depends on the accuracy with which the oceanic initial condition is known. This puts a formidable constraint on our capability to predict the ocean density and current structure which will be partially solved only if both observations of the ocean interior and high resolution accurate atmospheric parameters are available. The increased predictability of the ocean interior physical state variables will affect our capability to predict physical climate fluctuations on seasonal, interannual and decadal time scales and the pelagic primary and secondary producers fluctuations, perhaps up to fish stocks. Coastal areas physical parameters predictions can strongly depend on our capability to predict the open ocean flow field and its interaction with the shallower areas.

This is the field where data assimilation tools have been traditionally developed and applied both operationally and in a research mode to improve the predictability time of the large scale and mesoscale flow field in the open ocean. Great attention should be focused in the future on the development of adequate multivariate data assimilation schemes, tailored to the oceanic observational network. This should involve a mixture of remote sensing and *in situ*, vertically resolved data since the majority of oceanic dynamical regimes involve stratified water conditions.

## Seasonal oceanic temperature structure forecasts

In recent years, the importance of El-Ninõ phenomenon and its atmospheric related aspects on the world-wide economy has fostered the development of seasonal oceanic operational forecasts with coupled ocean-atmosphere models. The system is based upon observations of VOS, XBT and TAO array data and global ocean models with data assimilation components. Forecasts have practical skill up to several months or a year. Data assimilation components mainly consider univariate input and normally univariate model update, even if experiments with multivariate output parameter updates show some success. The techniques are based on both time intermittent or continuous data assimilation schemes. This system is run operationally at NCEP and pre-operationally at ECMWF.

## Short-term open ocean mesoscale forecasts

The oceanic mesoscale is important for the development of the open ocean trophic chain, perhaps also in the coastal areas since important transfers cross the continental slope are carried out by the intermittent mesoscale eddy field. Furthermore, the mesoscale eddy field is essential to understand and predict sound propagation in the ocean interior for any kind of marine operations. A short term (few weeks) relocatable mesoscale forecast system has been developed in the past fifteen years which considers the design of appropriate observing networks, high resolution physical hydrodynamical models and application tools to determine primary production, sound and light propagation in the forecasted mesoscale field. Predictive skill has been shown to exist for maximum few weeks, depending on the dynamical regime.

## Implementation of SeaNet in collaboration with EuroGOOS

SeaNet is a European organisation concerned with monitoring networks on fixed structures in the North Sea region. The SeaNet organisation is a co-operation between the North Sea monitoring agencies with regular meetings to exchange mutual experiences in data communication and data collection. These meetings are used to identify, discuss and establish co-operation between the members involved in SeaNet. Users in the North Sea countries might require additional parameters or even additional stations; new instrument technology might provide new opportunities - one or more members can join forces to work out solutions. In the development of certain projects, co-operation is sought with, or benefits are taken from, international R&D programmes such as EC-MAST and EUROMAR, national R&D programmes, national developments and EuroGOOS developments.

The objectives of SeaNet are:

- a homogenous distribution of fixed monitoring sites,
- promotion of online data exchange between fixed monitoring networks,
- standardisation of data collection, processing methods and validation techniques,

- co-operation in the development of new measuring techniques and sensors, and testing of existing sensors,
- exchange of experience in data communications and data collection, particularly on fixed structures.

The long-term objective is to realise a North Sea monitoring system based on fixed monitoring networks as a contribution to an integrated European marine monitoring and forecasting system

A survey has been carried out by SeaNet on the needs of information and opportunities of the fixed monitoring networks. For part of this the survey tools introduced by EuroGOOS were used, which would ease the logical link between EuroGOOS and SeaNet. The results from the SeaNet survey indicated that *in situ* measurements maintain their importance in the future, in spite of the growing importance of remote sensing and operational modelling. As a result from the SeaNet survey, three work groups have become active. They are: the Data Interface Group (DIG); the Current Temperature Salinity group (CTS) and the Automated measurements of Contaminants and Bio-effects group (ACB). As a contribution to the long-term objective of SeaNet, six monitoring agencies and four companies from Belgium, Denmark, Germany, Netherlands, Norway and Sweden decided to execute a SeaNet Data Interface (SNDI) project. The project comprises the definition, development and implementation of a data interface which will facilitate the data exchange between the national monitoring networks. The SNDI proposal has been submitted to the EC-MAST and has been evaluated positively. It is expected to start with the SNDI project in October 1998 which will last for 2½ years. Herewith, SeaNet will contribute to an improvement of the North Sea fixed monitoring infrastructure. It has become clear that the SeaNet initiative is very much welcomed. It offers new perspectives and opportunities in the field of fixed monitoring networks and operational oceanography and fits in well with the EuroGOOS initiative, to which all North Sea countries have agreed to contribute.

## Gridded bathymetry

In the European sea areas the historical background of many different hydrographic and mapping services means that bathymetric charts and data bases are not consistent. While this matter has the attention of IHO for navigation purposes, the fact remains that all published bathymetric information is derived and presented to meet specific purposes, with built in safety margins or biases. These biases, combined with unavoidable errors, make the data sets unsuitable for modern high-resolution modelling.

EuroGOOS Task Teams, and meetings of the SAWG have shown repeatedly that the deficiencies of available gridded bathymetry cause degradation of hydrodynamic models, tidal models, storm-surge models, estimates of sediment transport, and wave propagation and refraction models. Reports and publications submitted to J-GOOS by Komen and Smith (1997) describe some of the problems. Water depth is a critical parameter for 3-D storm surge models. Most 3D models use a bottom-following co-ordinate system to provide for better interpretation of topographic effects. Even so, limitations in our knowledge of bathymetry and practical limitations on our ability to represent the subtleties of changes in depth (some of which are extremely important) are a significant source of error for all surge models. There is also considerable uncertainty in the parameterisation of bottom drag, which also may depend on the bottom shape and roughness. Regarding wave shoaling models, an unsolved problem is the parameterisation of sub-resolution scale variations of bathymetry for refraction calculations.

A EuroGOOS Study Group aims to develop a proposal for deriving a high resolution gridded bathymetry for the NW Shelf seas to a depth of 200m, with possible extension at lower resolution part way down the shelf slope. The grid resolution will be 500m horizontally, with a vertical resolution of 1-2 metres, or a few percent of depth in deeper water. Agencies are participating from Norway, UK, Ireland, Germany, France, and Netherlands. Special attention will be given to the shallow coastal zone. Completion of the project will take about 3 years.

A second phase of the gridded bathymetry project will analyse the requirements for the Mediterranean.

## Observational networks

i) There are gaps in present observing schemes, both in terms of geographical coverage, and in terms of variables not yet measured. The precise definition of the gaps depends upon the products required, and the customer's objectives. EuroGOOS studies indicate gaps in:
- chemical data
- sediment data
- primary productivity, colour, plankton

ii) There are particular gaps in data coverage in shallow coastal waters.

iii) Long time series in the open ocean are essential to monitor decadal and multi-decade changes in surface and mid-waters (Dickson, 1997, Parrilla, 1994).

iv) To ensure continuous political effort to maintain oceanic observations it would be an advantage to use the justification of European Directives, or a Treaty or other Convention arising from the UNCED Rio Convention, or the Global Environment Facility. At present there is no Convention which requires states to observe or monitor the ocean.

### Observations and modelling system

i) European Directives on water quality are concerned directly with monitoring the biology and chemistry of sea water, but tend to ignore the physics - good physical modelling provides the underpinning for water quality models.

ii) New observing schemes and ecosystem models are needed for predicting harmful algal blooms and primary productivity. Co-ordination could sustain European leadership in related operational forecasting.

iii) The European development of observation and modelling in the Atlantic should contribute to the Global Ocean Data Assimilation Experiment (GODAE) which will have its operational phase from 2003-2006.

## Forecasts

Some generic points apply:

Operational oceanographic forecasting is integrally linked to meteorological forecasting. There are universal requirements for improvements in forecasting of: surface winds (and stress) and thermal exchange at the sea surface with a combination of direct measurements and dynamically linked ocean-atmosphere models.

- Short term forecasts are deterministic, and long term forecasts rely on statistical methods.
- Short term improvements depend critically upon improved monitoring and data delivery.

### Waves

- It is desirable to extend wave forecasts to 3-5 days if possible.
- Improvements in long term wave forecasting depend upon improved climatology.
- There is a need to improve the modelling of interactions between waves and bottom topography especially in shallow seas.
- Prediction of the height of maximum wave crest is a serious problem, and needs more study.
- In the Atlantic, forecasts of sea surface conditions 10-20 days ahead are desirable.

### Surges

- Sea level and surge forecasting is generally a well developed service.

## Comments from this section

i) The Task Team analyses show that there is a range of core variables which are common to all sea areas of Europe and the Atlantic, as shown by Table 3. There are then further ranges of variables which have been identified as important in only a subset of the sea areas. The conclusions are not surprising, but it is important to note that these lists are based on analysis within the working area by the Agencies directly responsible, and are not theoretical guesstimates.

ii) The Task Teams do have different processes to model and forecast in each region. This predicates a different approach, and different types of models. In brief, the determining characteristics which differentiate the regions are:

### Arctic

Year long sea ice, multi-year sea ice, permanent sea ice over oceanic depth water, very large river inflow, deep convection, interconnections with other ocean basins, exploited fish stocks, beginning of oil and gas exploration.

### Baltic

Shallow water, low salinity, minimal tidal influence, periodic inflow from the North Sea, high river inputs, intensive fisheries, large adjacent urbanisation and industrialisation.

### NW Shelf

Intense tidal currents and mixing, alternating seasonal periods of stratification and mixing, large sediment inputs, large sediment transport, frequent storms, forcing by large open boundary with the Atlantic, intensive fisheries, intensive maritime transport, urbanisation, waste disposal, oil and gas exploitation.

### Mediterranean

Minimal tide, oceanic type deep water thermohaline circulation, wind forcing of surface currents, very narrow continental shelf (mostly), intensive evaporation, low fresh water inputs, low primary productivity, urbanisation, waste disposal, local eutrophication.

### Atlantic

Full ocean scale processes, boundary currents, intermediate and deep water formation, convection, mesoscale eddies, fronts, decadal fluctuations, sea ice, tropical processes, shelf-edge processes, high regional primary productivity, exploited fish stocks, complex storm paths, very high waves in north, northward heat transport on a global scale.

# Extending Predictability

## New technology, instruments and measuring systems

**In considering the scientific base for EuroGOOS, the SAWG has revealed a range of technical issues which affect the ability to obtain the scientific data required. These issues are described with cross-referencing to the review of available and needed technology carried out by the TPWG.**

The following comments and recommendations have been extracted from other EuroGOOS documents, and the work of the SAWG itself.

### Comments and recommendations

i) Synergistic combinations of *in situ* airborne and remote sensing instrumentation will require optimisation in the design of monitoring systems.

ii) Long range HF radar can provide surface current and wave fields in real time up to 200km offshore. This technology is already being installed in limited areas to support offshore oil and gas production. It shows considerable promise as a technique for generating data which can be assimilated in real time, and could provide coverage at a scale which covers most European shelf seas, and much of the Mediterranean.

iii) Instrument packages and platforms need to be designed, wherever possible, to generate a data stream which permits production of a 1km square average value, rather than point values. The proposed Ferry Box project meets this requirement (ref. Document EG97.60).

iv) Major technological improvements are still needed in chemical sensors, especially in order to increase the period of use without fouling.

v) New acoustic systems are needed in biomass and fish stock assessment, and under Arctic ice.

vi) AUVs offer the possibility of intensive data gathering on space scales relevant to shelf-edge processes, and under ice.

vii) TAO-type buoys, similar to those used in the TOGA experiment, and currently in use for ENSO monitoring in the tropical Pacific, should provide a cost-effective way to monitor the tropical Atlantic, and the Mediterranean. Conditions in more northern latitudes may be too extreme, or would result in greatly increased costs.

viii) Moored buoys at present deployed for meteorological or physical oceanographic purposes, should be upgraded to include biological and biogeochemical sensors.

### Remote Sensing

Remote sensing systems are defined as including satellite observations, airborne observations, and some land-based systems such as horizontal HF radar. Satellites may be geo-stationary or low orbit. EuroGOOS objectives require significant input of remote sensed data. Remote sensed data provide coverage at global, regional, coastal, and bay/estuary scales. See GOOS 1998 pp53-56 for schedule of planned ocean satellite missions and instruments. Box 6 shows a summary of products.

### Ferry Box project

There are more than 800 ferry boats routinely operating within the coastal waters of Europe with frequencies varying between once a week to several times daily (EuroGOOS - document EG95.25 v.2/15.2.96 "The potential use of European ferries for operational oceanographic observations"). By developing and installing an operational autonomous ship-borne instrument package ("Ferry Box" or "Blue

Box" in analogy to the "black box" of a commercial aeroplane) an ensemble of important parameters and properties of the surface waters en route could be monitored frequently without any additional platform costs. Variables which may be measured include SST, SSS, oxygen, nitrate, sound velocity, fluorescence, light attenuation and light scattering.

Besides contributing to GOOS-Module 3 "Monitoring of Coastal Water Quality" such a RTD effort addresses the improvement of technologies for operational oceanography and operational marine forecasting, thus fitting to MAST III, Research Area C "Marine Technology", C.2.1 "Unmanned platforms and autonomous systems". The Ferry Box Project contributes simultaneously to the development of observational skills, the co-ordinated handling of data and information flows and integrated modelling. By these aspects it is definitely building and improving the European capacity in operational forecasting of the seas and oceans.

As the main area of interest is focussed on the coastal and shelf seas of Europe, according to the normal operational routes of ferries, the end-users of the produced forecasts are to be found among the various groups that are active in these zones, ranging from merchant ships traffic, fisheries, coastal protection to leisure activities and vacationers. The Mediterranean is included in the Ferry Box project.

It is therefore intended to develop, install and operate ship-borne instrument packages within the EuroGOOS community by using several approaches in parallel. The progress of the art which is accomplished by this RTD activity is based on the fact that in addition to the data gathered at strategic points in coastal areas by fixed stations or moored buoys the information along the transects of ferry ships will represent a significant step forward with regard to the spatial and temporal coverage of European adjacent seas.

## Box 6 RS measuring systems and types of products

### Coverage

Satellite: Global
Regional

Aircraft: Regional coastal area
Coastal zones or strips
Embayments, gulfs, estuaries

Land: Embayments
Straits
Fixed coastal sections out to several hundred km

Relevance of remote sensing to each of the GOOS/EuroGOOS Modules.

### Instrument types on different platforms

Satellites: Colour sensors
Thermal, AVHRR, ATSR
Altimeter
SAR
Scatterometer

Aircraft: Colour, CASI
Thermal
SAR
Air photo and LIDAR

Land based: Radar
Doppler radar

### Information provided by each type of instrument and data channel

Ocean colour: Algal phytoplankton, suspended solids, circulation features, gyres and currents. mixing zones, ocean fronts, ice, dispersion patterns, wave patterns, coastal classification, calibration data, monitoring change. (weather dependent)

Thermal: Sea surface temperature, circulation features, mixing zone, ocean fronts, ice, calibration data. (weather dependent).

Radar Altimetry: Sea surface elevation, dynamic topography, geostrophic currents, tidal elevation, storm surges, wave height. (weather independent)

SAR: Sea surface texture, wave spectrum, influence of bathymetry, sea ice, ice edge, oil slicks, ship's tracks. (weather independent).

Scatterometer: Sea surface winds (weather independent).

Importance of combining remote sensed data with *in situ* and water-column data.

### Advantages and constraints

Satellites: Some channels are cloud dependent, especially colour and thermal.
Low spatial resolution
Low repeat cycle, (unless in geo-stationary orbit.)
Fixed instrument configuration.
Certain data sets slow and expensive

Aircraft: Less weather dependent than satellites, work below the clouds
High resolution
Controllable, flexible, ground truthing.
Data can be used immediately.

Land based: High resolution
Limited number of system types and installations

### Applications of remote sensing

Meteorological systems, geostationary
Survey planning
Survey triggers
Holistic views
Inter-regional comparisons
Consistent sub-systems over large areas.
Input to modelling
Provides data from inaccessible regions

Remote sensed data can be used to:

Provide surface forcing for models
Model validation and subsequent development
Assimilation into forecasting models
Operational off-line, non real-time use

## Recommendations for steps necessary to extend predictability

### The way forward: new capabilities

- Importance of integration, satellite, aircraft, and ground truth, stacking.
- Large scale routine integration and assimilation into models
- Algorithm development, improved interpretation.
- New variables, ice thickness, salinity.
- Quantification of frequency of natural surface films
- Combining airborne and satellite data.
- Each EuroGOOS Task Team to identify and specify remote sensing requirements.
- Improved capability for a common framework of sensors, better compatibility.

Remote sensed data must be processed in hours to days, rather than weeks to months, if it is to be useful in operational oceanography.

1. Further develop multivariate data assimilation systems for the physical parameters and include them in near real time pre-operational systems (0-5 years). The multivariate input should include temperature, salinity, current profiles, sea surface height anomalies and sea surface temperatures from satellite and the model should be updated on all the dynamical model variables (usually three momentum components and density).

2. Extend the near-real time observing network to include more physical parameters, in particular current and salinity measurements (0-5 years).

3. Develop the observing system for upper ocean biochemical parameters in particular nutrients (0-5 years), water column optical parameters (0-5 years), primary production (0-5 years) and functional groups (5-10 years), small pelagic fishes (5-10 years. The system should be built upon remotely sensed data and *in situ* automatic monitoring systems.

4. Further develop marine ecosystem models, including the physical transport components and feedbacks, for the pelagic primary production (0-5 years) coupled to data assimilation tools for the biochemical parameters (5-10 years).

5. Develop complex water quality models, coupled to marine ecosystem models which include state of the art hydrodynamical models.

6. Develop new techniques of coupling marine pelagic primary producers forecasts to fish stock assessment tools (5-10 years).

# *Regional Test Cases and Pilot Projects*

**It is expected that the ocean circulation can be predicted further ahead than weather. This is the basis for climate prediction. Providing the theory and associated model validation of this hypothesis is the highest priority research target for physical oceanographers. The practical way ahead is to break the problem into two parts: local and global. The geography of the Task Teams reflects this, with the Arctic and Atlantic groups addressing near-global scales and the shelf-sea groups focusing on 'local' aspects.**

**The products of operational oceanography in Europe relate to regional sea areas. The modelling and monitoring approaches will differ in each case reflecting their intrinsic variability and end-use concerns e.g. surface ice in the Arctic, eutrophication in the Mediterranean.**

The following Regional Test Case Task Teams have been established in EuroGOOS:

Arctic
Baltic
North West Shelf Seas
Mediterranean
Atlantic/Global

Pilot Projects will address generic aspects such as the potential benefits of-. new models, enhanced computing power, higher resolution/accuracy monitoring networks, improved techniques for data assimilation and quality assurance. Observational System Sensitivity Experiments will be used to relate the enhancement in output data to investment in monitoring networks and to indicate the inter-dependence between, for example, the Baltic, North West Shelf Seas and the Atlantic.

The following tables are extracted from the TT documents and project proposals. References are given to the original documents. The Technology Plan WG has conducted a survey of the instruments, numerical models and data transmission systems presently in use in Europe operationally, and this report (EuroGOOS Document 4) reveals the range of variables measured and predicted by different agencies, and by sea area.

Lists of variables which need to be measured in each RTT are shown in the following pages.

## Arctic

The following variables are taken from the proposals document for the Arctic Ocean System and the Global Environment:

| | |
|---|---|
| • Wind stress, atmospheric boundary conditions<br>• Temperature<br>• Salinity<br>• CFCs<br>• Ice albedo<br>• Ice thickness<br>• Ice fabric<br>• Polynyas, ice leads, brine pools<br>• River run-off inputs<br>• Precipitation<br>• Evaporation<br>• Bathymetry<br>• Currents<br>• Descending plumes<br>• Eddies and fronts<br>• Boundary currents<br>• Sea ice biota | • Ocean colour<br>• Primary production in ice<br>• Nutrients, nitrate, phosphate<br>• Oxygen<br>• Carbon flux in the water column<br>• Carbon dioxide<br>• Carbon-13<br>• Chlorophyll<br>• phytoplankton<br>• Particulate Organic Matter (POM)<br>• Micro-zooplankton<br>• Microbial activity<br>• Carbonate<br>• Alkalinity<br>• pH<br>• Sediment characteristics<br>• Geochemical traces |

## Baltic TT

The following table is taken from reports and tables concerning Baltic GOOS published in the EuroGOOS Plan, 1997, and supporting documents.

| | |
|---|---|
| • Wind stress<br>• Weather<br>• Sea ice<br>• Wave spectrum<br>• Temperature<br>• Salinity<br>• Sea level<br>• Turbidity<br>• Currents | • Current field<br>• Oxygen<br>• Nutrients, nitrate, phosphate<br>• Surface drift<br>• Primary productivity<br>• Chlorophyll<br>• Transport of fish larvae and eggs<br>• Fish reproduction volume |

## Atlantic

The following list of key variables was identified during the SAWG Meeting of 10 December 1996. The variables to be measured in the Atlantic region will also be determined by the observational strategy developed within GODAE.

| | |
|---|---|
| • Wind stress, heat fluxes and evaporation<br>• Waves, Hs, direction, spectrum, swell<br>• Sea level<br>• Surface temperature and salinity fields<br>• Temperature and salinity profiles<br>• Sound velocity field<br>• Sea Ice<br>• Bathymetry | • Ocean current field (especially near bottom currents)<br>• Nutrients, C02 content, light<br>• Biological productivity<br>• Biogeochemical fluxes and tracers<br>• Coastal pollution load<br>• Phytoplankton, Zooplankton, Nanoplankton, bacteria, virus levels and fish stocks |

## NW Shelf

This table is taken from the Minutes of the North West Shelf Task team meeting of June 1996 (Document EG96.13). Variables required to be measured and predicted, including those which can be measured now, and which may be measured in the near future.

| | |
|---|---|
| • Wind, stress<br>• Waves, Hs. direction, spectrum<br>• Swell<br>• Surface temperature field<br>• Surface salinity field<br>• Currents<br>• Water quality<br>• Temperature profiles<br>• Salinity profiles<br>• Sea level<br>• Tides<br>• Storm surges<br>• Sea ice | • Suspended sediments<br>• Bathymetry, changes in bathymetry<br>• Coastline, beaches, wetlands, marshes, creeks<br>• Nitrate<br>• Phosphate<br>• Nitrite<br>• Silicate<br>• Oxygen<br>• Sound velocity<br>• Light transmissivity<br>• Chlorophyll<br>• Fluorescence<br>• Bacteria, virus concentrations. (required, but difficult). |

## Mediterranean TT

The following variables are taken from the MFS documents:

| | |
|---|---|
| • Wind stress<br>• Heat flux<br>• Water fluxes<br>• Profile of the marine atmospheric boundary layer<br>• Sea surface temperature<br>• XBT upper ocean temperature profile<br>• XCTD, upper ocean temperature salinity profile<br>• Sea level, sea surface elevation, sea surface height anomalies<br>• Surface drift velocity<br>• Nitrate, nitrite<br>• Phosphate<br>• Chlorophyll<br>• Wave field, spectrum | • Ocean colour<br>• Precipitation<br>• Currents<br>• Bottom stress<br>• Relative humidity, evaporation<br>• Phytoplankton biomass<br>• Primary productivity<br>• Photosynthetically Available Radiation (PAR)<br>• Photosynthetic activity<br>• Zooplankton biomass<br>• Acoustic tomography, straits transports, stratification<br>• River inputs (from local authorities) |

## Comments from this section

i) The Task Team analyses show that there is a range of core variables which are common to all sea areas of Europe and the Atlantic, as shown by Table 3. There are then further ranges of variables which have been identified as important in only a subset of the sea areas. The conclusions are not surprising, but it is important to note that these lists are based on analysis within the working area by the Agencies directly responsible, and are not theoretical guesstimates.

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**Table 3** *The variable lists for each sea area are combined in this table to show those variables which are required by all 5 sea areas, and then with decreasing frequency down to one sea area. Variables are in alphabetical order within frequency band.*

| Variable | Arctic | Atlantic | NWSTT | Med. | Baltic |
|---|---|---|---|---|---|
| Chlorophyll | x | x | x | x | x |
| Currents | x | x | x | x | x |
| Salinity | x | x | x | x | x |
| Temperature, sea surface | x | x | x | x | x |
| Wind stress | x | x | x | x | x |
| Nitrate | x | | x | x | x |
| Sea level | | x | x | x | x |
| Wave spectrum | | x | x | x | x |
| Bathymetry | x | x | x | | |
| Evaporation | x | x | | x | |
| Oxygen | x | | x | | x |
| Phytoplankton | x | x | | x | |
| Sea Ice | | x | x | | x |
| Temperature profiles | | x | x | x | |
| Bacteria, virus concentrations | | x | x | | |
| Nitrite | | | x | x | |
| Nutrients, nitrate, phosphate | x | | | | x |
| Ocean colour | x | | | x | |
| Phosphate | | | x | x | |
| Precipitation | x | | | x | |
| Primary productivity | | | | x | x |
| River run-off inputs | x | | | x | |
| Salinity profiles, surface salinity | | x | x | | |
| Sound velocity | | x | x | | |
| Surface temperature field | | x | x | | |
| Waves, Hs. direction, spectrum | | x | x | | |
| Acoustic tomography, straits transports, stratification | | | | x | |
| Alkalinity | x | | | | |
| Biogeochemical fluxes and tracers | | x | | | |
| Biological productivity | | x | | | |
| Bottom stress | | | | x | |
| Boundary currents | x | | | | |
| Carbon dioxide | x | | | | |
| Carbon flux in the water column | x | | | | |
| Carbon-13 | x | | | | |
| Carbonate | x | | | | |
| CFCs | x | | | | |
| Changes in bathymetry | | | x | | |
| Coastal pollution load | | x | | | |
| Coastline, beaches, wetlands, marshes, creeks | | | x | | |
| Descending plumes | x | | | | |
| Eddies and fronts | x | | | | |
| Fish reproduction volume | | | | | x |
| Fluorescence | | | x | | |

| Variable | Arctic | Atlantic | NWSTT | Med. | Baltic |
| --- | --- | --- | --- | --- | --- |
| Geochemical traces | x | | | | |
| Heat absorption | | | | x | |
| Ice albedo | x | | | | |
| Ice fabric | x | | | | |
| Ice thickness | x | | | | |
| Light transmissivity | | | x | | |
| Micro-zooplankton | x | | | | |
| Microbial activity | x | | | | |
| Nutrients, C02 content, light | | x | | | |
| Ocean current field (especially near bottom currents) | | x | | | |
| Particulate Organic Matter (POM) | x | | | | |
| pH | x | | | | |
| Photosynthetic activity | | | | x | |
| Photosynthetically Available Radiation (PAR) | | | | x | |
| Phytoplankton biomass | | | | x | |
| Phytoplankton, Zooplankton, Nanoplankton, bacteria, virus levels and fish stocks | | x | | | |
| Polynyas, ice leads, brine pools | x | | | | |
| Primary production in ice | x | | | | |
| Profile of the marine atmospheric boundary layer | | | | x | |
| Relative humidity, evaporation | | | | x | |
| Sea ice biota | x | | | | |
| Sea level, sea surface elevation, sea surface height anomalies | | | | x | |
| Sediment characteristics | x | | | | |
| Silicate | | | x | | |
| Storm surges | | | x | | |
| Surface drift | | | | | x |
| Surface drift velocity | | | | x | |
| Suspended sediments | | | x | | |
| Swell | | | x | | |
| Tides | | | x | | |
| Transport of fish larvae and eggs | | | | | x |
| Turbidity | | | | | x |
| Water fluxes | | | | x | |
| Water quality | | | x | | |
| Weather | | | | | x |
| Wind stress, atmospheric boundary conditions | x | | | | |
| Wind stress, heat fluxes and evaporation | | x | | x | |
| XBT upper ocean temperature profile | | | | x | |
| XCTD, upper ocean temperature salinity profile | | | | x | |
| Zooplankton biomass | | | | x | |

# Conclusions, recommendations and SAWG actions

## Introduction

The previous chapters of this report have identified the scientific foundations which provide the basis for operational oceanographic modelling and services, and have listed numerous scientific problems and limitations which have to be tackled if operational oceanography is going to achieve its potential of applications and benefits. For the detailed individual recommendations, consult the final paragraphs of each section.

This chapter draws together and summarises the conclusions at a generic level, and provides recommendations to EuroGOOS indicating the future priorities and tasks of the Scientific Advisory Working Group. The recommendations are grouped in categories defined by the components of operational oceanography, as displayed in Figure 6.

## Components of operational oceanography

Figure 6 indicates the components involved in operational oceanography. The associated remit of the SAWG (Woods, et al 1996) is to: (i) advise on the design and implementation of observing systems - component C; (ii) ensure requisite models are developed and tested - component E; (iii) analyse limits to predictability and the associated role of data assimilation - component D; (iv) identify scientifically-led opportunities/shortcomings.

Figure 6 also indicates requisite future developments in operational oceanography, starting with speculative hypotheses testing model formulation through to pre-operational simulations and eventually operational forecasts. Associated developments involve advances from the initial short-term localised hindcasts of physical processes at coarse resolution through to long-term global forecasting of complete ecological systems with fine scale detail.

This report includes many detailed requirements relating to specific parameters or particular seas, the following list represents a generic synthesis of these ordered to correspond to the components A to H shown in Figure 6. Specific SAWG goals are numbered S1 to S9.

### Component A - Coupled models

The need for enhanced information from atmospheric models is a high priority item in Operational Forecasting. Accuracy and extent, in time ahead, of wind forecasts are the primary limiting factors for sea-state and surge forecasting. Likewise, sea surface heat exchange is clearly a determining factor in forecasting ocean mixed-layer depth and ice formation. In both cases the need for dynamically coupled ocean-atmosphere models is an essential element to improve 'atmospheric forcing'. Coupling of regional sea and ocean models is a pre-requisite for longer term simulations (especially hindcasting and nowcasting) in shelf seas. The coupling of oceanic and shelf seas models requires improved understanding of shelf edge and slope processes. Ocean basin modelling requires better understanding of the processes associated with fluctuations in the Gulf Stream and North Atlantic Current, the formation of Atlantic bottom water, ventilation, convection, and multi-annual changes in the state of the Atlantic Oscillation. Coupling with hydrological models, providing coastal fluxes for various contaminants, will eventually complete the 'water cycle' from rainfall to river to sea to ocean and back via evaporation.

S1: Develop science, and liaise with associated technology and infrastructure aspects, required to facilitate coupled ocean-atmosphere and coupled ocean-shelf sea models in operational mode.

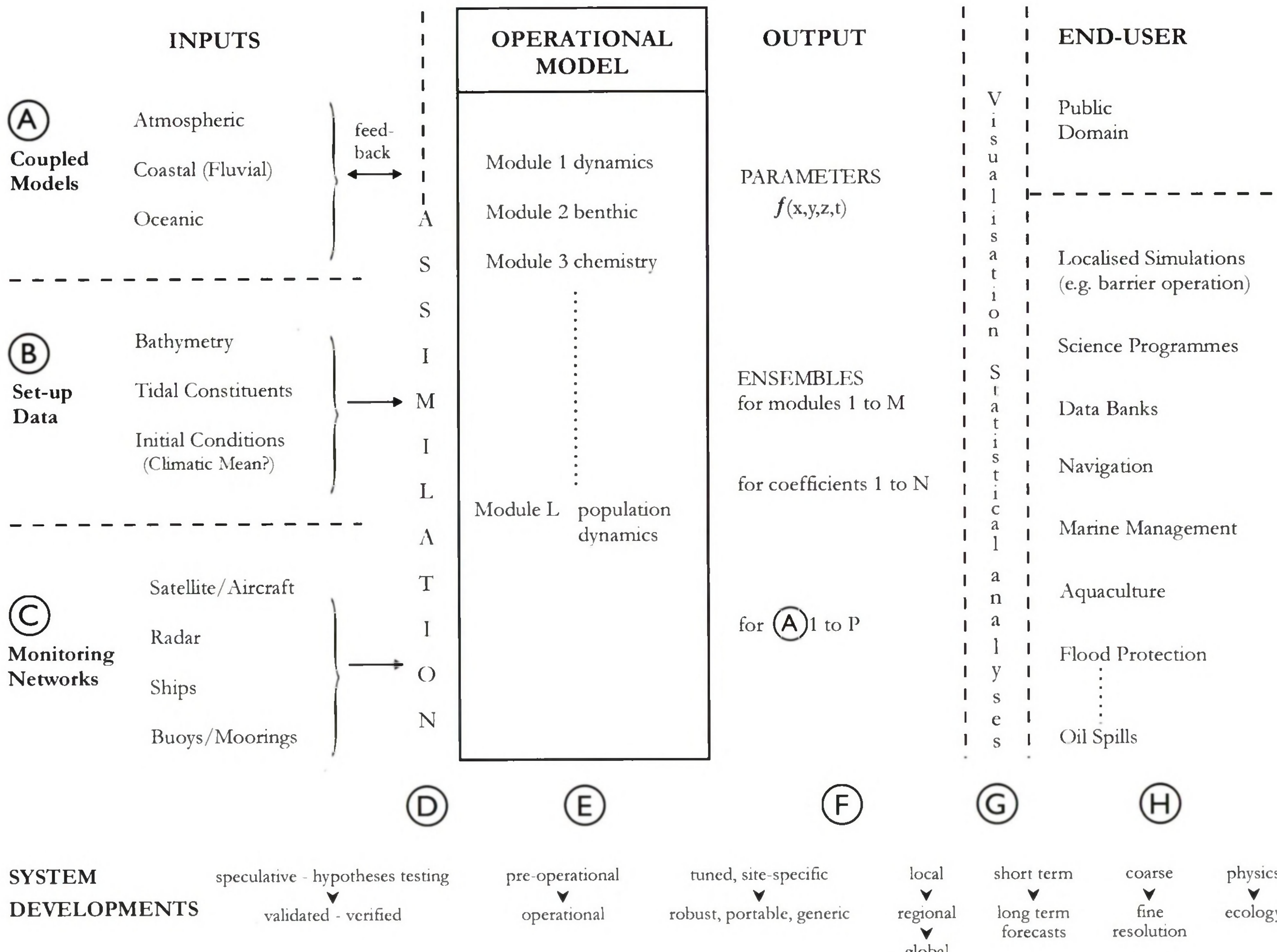


Figure 6. Components of Operational Oceanography (A) to (H) and future developments.

S2: Extend the parameter range of forecast models to include more chemical and biological processes - a major medium-long term goal. This goal requires the scientific ability to model and forecast the processes determining water quality, and the states of ecosystems.

### Component B - Set-up data

A high priority item is the provision of more accurate, finer resolution bathymetry - including descriptions of bottom features, sediment type and ultimately geochemistry. The provision from data archives of best-estimates spatially continuous climate-mean (or from specific observational campaigns) distributions is also a priority item for developing and testing simulation models.

S3: Liaise with European data centres in assembling 'assimilated' long term data archives (to include model hindcast data) to address questions such as ocean impact on climate and related decadal and long term trends.

### Component C - Monitoring networks

The challenge to optimise the provision of monitoring networks is especially urgent. Encouragement to make data from existing observational networks accessible in near-real time (with appropriate QC procedures) is a high priority. Satellite and sensor developments have lead times of decades and thus proponents of operational oceanography need to demonstrate, far in advance of implementation, the value of specific components of monitoring and how forecasts could be improved by data provided more frequently, at more places, more accurately, with finer resolution and over an extended parameter range. The concept of Observer System Sensitivity Experiments needs to be exploited on an international basis.

The optimum design of ocean and coastal monitoring and observing networks is complex, and poorly understood. A system designed from scratch would, in theory, have the minimum possible installation cost consistent with minimal life-time maintenance and replacement cost, while at the same time having the optimum combination of sensors on satellites, aircraft, ships, fixed stations, and within the water column, so as to produce the right data stream to condition the models and predictions required. The design would be based on a near perfect understanding of the processes involved. There are so many scientific and technological variable factors here that a series of complete trials and comparisons of possible combinations and variants is inconceivable, even if many of the trials were based on deleting components or data from a larger system. An additional factor is that there are huge sunk costs already written off in existing satellite missions, instruments and sensors which are commercially on the market, and observing programmes already under way, and it would be wasteful not to use most of these if possible. The observing system of the future is therefore strongly constrained by systems already in use and paid for, even if they are far from ideal.

Nevertheless, the investment in future components of the observing systems will be expensive, and the sampling strategy must therefore produce the greatest improvement possible in predictability. Since different deployments or combinations of equipments may produce radically different efficiency, the processes must be very well understood to achieve even a near-optimum design. This presents the Members of EuroGOOS with a major challenge to design and conduct appropriate OSSEs. The outcome of the major scientific experiments, WOCE-AIMS, CLIVAR, JGOFS and GODAE will be of great value in this respect.

Further European co-ordination, and appropriate delegation, of data processing of satellite data is required. The Regional Task Teams of EuroGOOS will address the issues of co-ordination of research vessel cruises, *in situ* deployments etc. The Ferry-Box programme will, consider co-ordination and expansion of 'ships of opportunity'. Pooling of resources and increased access to major facilities (flumes, radar etc.) is encouraged by various EU initiatives. Fuller exploitation of synergistic aspects of various instrument systems requires some imaginative collaboration between modellers and monitoring experts.

S4: Identification of critical technology development requirements needs to be addressed in co-operation with Regional Task Teams. Authoritative guidance is important to encourage the development of biological, chemical and sedimentary sensors.

S5: Formulate scientific strategy to optimise/assess the adequacy of observational networks and promote participation in relevant experiments. Recognising long lead times in technology development, implementation of satellite missions etc., clarify and quantify the potential forecasting benefits from elements of remote sensing including enhancement by synergistic *in situ* deployments.

## Component D - Assimilation

Expanding assimilation of model results with observational data is central to the development of operational oceanography. Techniques for routine assimilation with appropriate QC are urgently required. The underlying conceptual, mathematical and statistical aspects of assimilation need both developing and disseminating. The resulting enhanced awareness and understanding will encourage 'experimentalists' to design future instruments and networks to optimise the synergy of observations and models for operational forecasting.

Co-ordination in assimilation might be encouraged by new undergraduate, postgraduate and summer schools. The highly specialised nature of this topic makes it likely that such activities be focussed in a small number of European institutes.

S6: The broad question of analysing limits to predictability will be addressed in a series of workshops, with particular reference to availability of observational data and associated assimilation techniques. The first of workshop will be held in 1999.

## Components E and F - Modelling and model output

The characteristics of models used for existing operational forecasting have been described in detail. It is considered unlikely that one single model will emerge to serve all marine forecasting purposes (analogous to the meteorological models).

The basic requirement for readily-coupled modular structure is self evident. To incorporate more speculative inter-disciplinary simulations, a range of 'competing' modules is necessary, appropriate to a range of environments.

The operation of such models will require access to supercomputers and the software will require continuous maintenance. Specialist software is also required for Quality Control, visualisation and communication. Hence, given the integral link to the meteorological models, the location of a small number of European marine modelling centres coincident with the existing meteorological institutions seems appropriate. with an associated network of smaller centres addressing local applications.

End-user assessment is an essential element in operational oceanography, and feed-back for ensemble forecasts can provide indications of what modules are appropriate to particular conditions. Likewise, ensemble forecasts pertaining to a range of coefficient prescriptions or parameter settings can help provide vital confidence and sensitivity information.

S7: Formalised approaches for model validation and verification need to be developed, including procedures for Quality Control of modules and assemblage of a range of 'bench-test' observational data sets.

S8: Identify key scientific aspects required to extend the parameter range and accuracy of forecasts with particular emphasis on developing beyond existing physical parameters to incorporate chemistry, biology and ecology.

## Component G - Refined forecasts

There is considerable scope for added-value refined forecasts which might be provided directly by intermediate agencies e.g. a data centre extending and refining its existing databank or a specialist consultant modifying forecasts in a specific location utilising additional local observations or dedicated models.

## Component H - End-users

Existing operational oceanographic services have often been developed to meet specific end user requirements. EuroGOOS will enable planning of future developments to recognise longer term, wider scale, multi-user interests. EuroGOOS can accelerate the scope of such developments by exploiting the enormous advantages of international co-ordination in: developing and deploying instrumentation and associated platforms, near real-time processing and communication of observation and model data, accessing super-computers and in addressing underlying scientific questions.

S9: Identify new science needed to satisfy existing end-user requirements and scope for recent scientific successes to create new end-user opportunities.

# *Annexe 1* Science Advisory Working Group Terms of Reference and Objectives

### EuroGOOS Document EG95.26, 6.3.96

1. The purpose of the Science Advisory WG is to establish, and thence update, a scientific base to guide the EuroGOOS Plan.

2. The SAWG shall consist of a Chairman, appointed in the first case by the Officers after consultation with Members, and experts nominated by Members. The Chairman SAWG on subsequent occasions shall be elected by the Members after consultation with the Officers. Members of EuroGOOS may propose experts from their own staff to join the SAWG, or, if they wish, experts from other agencies in their own country whom they think would best represent the appropriate skills. Members may propose experts to the SAWG who are not themselves employed by Member Agencies.

3. The size of the WG may be limited if this is deemed necessary by the members of the WG, and the WG shall refer such a decision to the Chairman and Director of EuroGOOS for approval.

4. The term of appointment of the Chairman SAWG shall be for three years, with the option for re-appointment. Change of Chairmanship SAWG during an appointment period will proceed through the Director EuroGOOS.

5. Between Meetings of EuroGOOS Chairman SAWG shall report to Chairman EuroGOOS, and will work in collaboration with, and supported by, Director EuroGOOS.

6. Meetings of the WG should whenever possible be attended by a member of the Secretariat who will ensure that, so far as possible, proposed actions can be supported by the staff effort available from the Secretariat.

7. The SAWG shall draw on previous strategic science analyses conducted by EuroGOOS Members or any other relevant organisations in order to establish the appropriate applications for EuroGOOS. EuroGOOS is a vehicle for applying scientific research results to operational marine forecasting.

8. The activities of the SAWG shall be determined by Meetings of EuroGOOS, and Chairman SAWG shall prepare an outline of actions to be carried out between Meetings of EuroGOOS. If Chairman SAWG is not an Officer of EuroGOOS, he shall be invited to attend Officers Meetings when relevant. Between Meetings of EuroGOOS variations in the tasks of the Science Plan WG shall be agreed in advance by the Chairman EuroGOOS in consultation with the Officers.

9. The SAWG may operate through a programme meetings, workshops, publications, surveys, pilot studies and trials, including projects involving several Members. Activities approved between Meetings of EuroGOOS shall be reviewed for confirmation at the next Meeting of EuroGOOS.

10. All activities initiated by the SAWG shall be funded by the Member Agencies participating, or by obtaining outside grants or funding for the project.

11. If the SAWG wishes to enter jointly into an arrangement with another organisation, not being a Member of EuroGOOS, the proposed arrangement should be notified to the Director, and reported at the next Meeting.

12. These Terms of Reference can be modified only by decision of a Meeting of EuroGOOS.

**OBJECTIVES**

1. The WG shall prepare during 1996 a provisional Science Plan which defines the scientific basis for EuroGOOS, bearing in mind the stipulations of the MoU, and with particular attention to the limits of predictability, sampling design, required accuracy and precision of observations, numerical modelling techniques, data assimilation, and sensitivity trials of models.

2. The WG shall work mainly by correspondence, but may hold a 1-day meeting immediately prior to a meeting of EuroGOOS, and other meetings as required, at the cost of the Members concerned.

3. A preliminary summary of progress shall be presented at the October 1996 Meeting, and a draft Report at the December Annual Meeting 1996.

4. The WG should consult with the Technology Plan WG on matters of joint interest, especially the transfer of models from research mode to operational mode. The WG should consider different types of models or observing schemes needed in the different regional seas of Europe, and global models.

5. The Science Plan should address a 5-10 year framework, with special attention to the first 5 years.

6. The SAWG should identify developments in present scientific knowledge required to expand the reliability or predictive capabilities of GOOS or EuroGOOS, and liaise with groups and programmes conducting research into the relevant problems including: The EU Fourth Framework, MAST-3, environment and climate programmes, and other European CEC programmes.

7. The SAWG may stimulate proposals for Pilot Projects or Demonstration Projects to explore or prove scientific methodology or principles essential to the development of GOOS or EuroGOOS in conjunction with the Task Teams for Regional Test Cases.

8. These Objectives may be altered at the December Meeting 1996 to allow for further revision or extension of the Science Plan.

# *Annexe 2* Schedule of meetings of Science Advisory Working Group

| Date | Venue |
|---|---|
| 28 November 1995 | Dublin, Ireland |
| 6 March 1996 | Brighton, UK |
| 7 October 1996 | The Hague, The Netherlands |
| 10 December 1996 | Southampton, UK |
| 11 December 1997 | Athens, Greece |
| 11 March 1998 | Brighton, UK |

# *Annexe 3* Members participating in EuroGOOS Science Advisory Working Group meetings

S: Science Advisory WG nominated member, A: Alternate, G: Guest, O: Ex-Officio

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# Annexe 7 - Acronyms

| | |
|---|---|
| ACSYS | Arctic Climate System Study |
| ADCP | Acoustic Doppler Current Profiler |
| ALACE | Autonomous Lagrangian Circulation Explorer |
| ARGO | Array for Real-time Geostrophic Oceanography |
| ARGOS | Satellite-based system for environmental data telemetry and geopositioning |
| ATSR | Along Track Scanning Radiometer |
| AUV | Autonomous Underwater Vehicle |
| AVHRR | Advanced Very High Resolution Radiometer |
| CASI | Compact Airborne Spectral Interferometry |
| CLIVAR | Climate Variability and Predictability (of WCRP) |
| CTD | Conductivity Temperature Depth |
| DBCP | Data Buoy Co-Operation Panel |
| DYNAMO | Model intercomparison exercise |
| ECMWF | European Centre for Medium Term Weather Forecasting |
| EMaPS | European Marine and Polar Science |
| ENSO | El Niño Southern Oscillation |
| ENVISAT | Environmental Satellite Mission (of the European Space Agency) |
| ESF | European Science foundation |
| EU | European Union |
| EuroCLIVAR | European Climate Variability and Predictability |
| EuroGOOS | European Global Ocean Observing System |
| FAO | Food and Agriculture Organisation |
| FDP | Fast Delivery Products |
| FOAM | Forecasting Ocean Atmosphere Model |
| GCOS | Global Climate Observing System |
| GLOBEC | Global Ecosystem Experiment |
| GODAE | Global Ocean Data Assimilation Experiment |
| GOOS | Global Ocean Observing System |
| GTOS | Global Terrestrial Observing System |
| GTS | Global Telecommunication System |
| ICSU | International Council of Scientific Unions |
| IES | Inverted Echo Sounder |
| IGBP | International Geosphere-Biosphere Programme |
| IGOSS | Integrated Global Ocean Services System |
| IHO | International Health Organisation |
| IOC | Intergovernmental Oceanographic Commission |
| IPCC | Intergovernmental Panel on Climate Change |
| JGOFS | Joint Global Ocean Flux Study |
| LIDAR | Light Detecting and Ranging sensor |
| LOICZ | Land-Ocean Interactions in the Coastal Zone |
| MAST | Marine Science and Technology (DG-XII CEC) |
| MERCATOR | French operational high-resolution global ocean prediction project |
| MFS | Mediterranean Forecasting System |
| NCEP | National Centers for Environmental Prediction |
| NESDIS | National Environmental Satellite, Data and Information Service |
| NWP | Numerical Weather Prediction |
| NWSTT | North West Shelf Task Team (of EuroGOOS) |
| OCCAM | Ocean Circulation and Climate Advanced Modelling |
| ONR | Office of Naval Research |
| OOPC | Ocean Observations Panel for Climate |
| PALACE | Profiling Autonomous Lagrangian Circulation Explorer |
| POM | Princeton Ocean Model |
| RTT | Regional Task Team |
| SAR | Synthetic Aperture Radar |
| SAWG | Science Advisory Working Group (of EuroGOOS) |

| | |
|---|---|
| SOLAS | Safety Of Life At Sea |
| SPM | Single Point Mooring |
| TOGA | Tropical Ocean Global Atmosphere Experiment |
| TOPEX/POSEIDON | Joint US/French Ocean Topography Experiment |
| TPWG | Technology Plan Working Group (of EuroGOOS) |
| TT | Task Team |
| ULS | Upward Looking Sonar |
| UNEP | United Nations Environment Programme |
| VOS | Volunteer Observing Ship |
| WAM | Advanced Wave Modelling |
| WCRP | World Climate Research Programme |
| WMO | World Meteorological Organisation |
| WOCE | World Ocean Circulation Experiment |
| WOCE-AIMS | WOCE Analysis, Interpretation, Modelling and Synthesis |
| XBT | Expendable Bathythermograph |
| XCTD | Expendable Conductivity Temperature Depth sensor |

# Membership of EuroGOOS

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Institute of Marine Sciences, Turkey
Institute of Oceanology, Polish Academy of Sciences, Poland
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Nansen Environmental and Remote Sensing Center, Norway
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National Institute for Coastal and Marine Management (RIKZ), Rijkswaterstaat, Netherlands
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Polish Institute of Meteorology and Water Management, Maritime Branch, Poland
Puertos del Estado, Clima Marítimo, Spain
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