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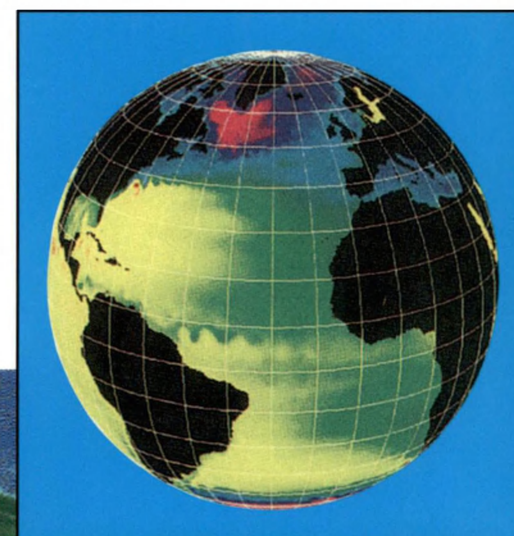
The EuroGOOS Technology Plan Working Group Report



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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 EuroGOOS Technology Plan Working Group Report

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edited by C Tziavos and N C Flemming

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5.	The EuroGOOS brochure, 1997	
6.	The Science Base of EuroGOOS	ISBN 0-90417530-8
7.	Proceedings of the Hague Conference, 1997, Elsevier	ISBN 0-444-82892-3
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Contents

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Introduction

EuroGOOS is the European association of national agencies dedicated to the development of operational oceanography and marine forecasting in Europe. EuroGOOS was founded in 1994 as part of the Global Ocean Observing System (GOOS) and the membership is listed in Annexe 2.

The EuroGOOS Technology Plan is being published just after the GOOS 1998 Prospectus (IOC 1998) published by the Intergovernmental Oceanographic Commission, GOOS Project Office. During 1999 delegates to IOC will formally increase their commitment to GOOS, and already components of GOOS are taking shape in the GOOS Initial Observing System. The regional programmes of North East Asian Region GOOS (NEAR-GOOS) and EuroGOOS are both well advanced in implementation at the regional and coastal scales, and new Regions of GOOS are being formed in the Mediterranean (MedGOOS), the Caribbean and Gulf of Mexico (Inter-American Seas, IAS-GOOS), and other regions. The use of new technology, and the efficient deployment of existing technology, are key elements in the design of GOOS, and for this reason EuroGOOS has analysed those devices which seem to have the greatest promise in routine operations and long-term monitoring.

EuroGOOS bases its plans on the premise that operational forecasting depends upon obtaining a scientifically planned stream of observational data in real time, or near real time, which are transmitted to modelling centres, assimilated into numerical models, and used to produce simulations and forecasts of the state of the ocean and coastal seas. The necessary temporal and spatial resolution and geographical coverage of the observations required cannot be obtained by a simple extension of the observational methods presently used, which are designed mostly for research experiments. For example, it is not reasonable to imagine obtaining more closely spaced temperature profiles every day by using a greatly increased number of ships and an order of magnitude more XBTs, or CTDs.

For each kind of measurement needed the Technology Plan WG of EuroGOOS has considered the technologies available which are most likely to produce a reliable, accurate, long-term data stream with the absolute minimum of personnel needed to go to sea. Sometimes this can be achieved by a more efficient application of existing technology such as satellite remote sensing; in other cases we suggest a greatly extended use of an unmanned technology which is only just becoming available, such as long range coastal radar, or acoustic tomography.

We have tried to consider all the technologies which have emerged as important in the studies and exercises of the other components of EuroGOOS. There are regional Task Teams in EuroGOOS responsible for promoting operational oceanography in each of the sea areas: Arctic, Baltic, North West Shelf, Mediterranean, and Atlantic. Some of the requirements are outlined in the abbreviated EuroGOOS Plan, (1997, Publication No. 3). Additionally, EuroGOOS has conducted a survey of the instruments and systems presently being used by its Member agencies, and this has been published as the EuroGOOS Marine Technology Survey (1998, Publication No. 4). The First EuroGOOS Conference was held in the Hague in 1996, and the proceedings were published in 1997 (Publication No. 7). The Proceedings contain many papers on aspects of technology suitable for continuous operational systems and services. In 1998 EuroGOOS published the report of its first Atlantic Workshop (EuroGOOS Publication 9) which includes discussion of the technologies needed on the oceanic and global scales. The TPWG Plan does not seek to be exhaustive or complete in its description of available or potential technologies, but provides an introduction, stresses the benefits of each system, and gives references. We accept that some interesting technologies are not yet fully proven. Trials are needed. Reference to trade name, brand name, or commercial organisation does not consitutte any endorsement by EuroGOOS.

Europe is surrounded by shallow shelf seas and enclosed seas, as well as the open oceans of the Arctic and Atlantic. The benefits of operational forecasting will be obtained most rapidly by improved observation and modelling of the adjacent seas. The present report therefore concentrates upon physical observations in the shelf seas of Europe, and the Mediterranean, with some consideration of the Atlantic basin. There is little consideration of the special techniques used to work under Arctic ice, and no serious consideration of the technology needed for in situ measurements of full water column depth properties on a totally global scale. We have not yet considered the technologies which would be most efficient in the Southern Ocean.

At present most operational modelling is confined to hydrodynamic modelling, predicting the future state of sea ice, sea level, currents, wind, waves, and upper ocean temperature, and salinity. Operational climate forecasting models are already used, especially for the tropical Pacific. Already some measurements of chlorophyll, optical properties, suspended sediments, and nutrient parameters are measured and modelled for special purposes routinely.

Recent surveys by EuroGOOS of data requirements show that off-line processing of ecosystem data and analysis of pollution and water quality data is gradually evolving towards operational data quality control and modelling. There is therefore a very high priority to develop and improve sensors which can measure biogeochemical variables reliably for long periods untended. EuroGOOS has identified an ideal target of at least one month of untended operation for all such instruments even at the time of year which is worst for biological fouling in coastal and shelf seas. Much longer periods of untended duration are needed in the open ocean, up to several years.

The acceptability of a technological system is always determined by its cost and efficiency. In an ideal world the present report would contain at least an outline analysis of the capital costs, running costs, reliability, breakdown rate and repair costs, for each system. In practice this is impossible because of the delays in obtaining financial data, commercial confidentiality, rapid changes in precise specifications and prices, etc. We have tried to identify those technologies which provide the greatest number of measurements, the highest resolution, cover the greatest area or depth profile, last the longest with the least maintenance, and can be deployed and operated with a small number of ships and people. There are many recommendations in each section, and these will be taken up wherever possible by various subsidiary bodies of EuroGOOS.

The Editors thank all contributors to this report. Parts of each section were initially written by different authors, and then circulated for criticism by all participants at several meetings of the TPWG. Sections should not therefore be interpreted as the work of single authors.

Satellites technology

Summary of recommendations

Some satellite issues, especially those involving sensor development and mission design, are so large and of such broad interest that they are inappropriate for EuroGOOS to consider alone and are best handled in conjunction with other international programmes and agencies. They tend to involve timescales of at least 10 years. EuroGOOS should focus on the additional work required to generate operational activities, especially improving existing or imminent satellite systems in which progress can be made on the medium term, say 1-5 years. This is reflected in two main recommendations:

1. Set up joint EuroGOOS/EuroCLIVAR (and EuroGLOBEC) working group on oceanographic satellite issues
2. Propose Concerted Action to EU for co-ordination of Operational Marine Requirements for EO-derived data and information (OMAR) and use recommendations from study to influence planning of EU and spacecraft operators

In addition there are some short-term actions which could be undertaken with little difficulty. Two possibilities are:

3. Identify existing sources of satellite data relevant to operational oceanography, collate and publicise through EuroGOOS WWW pages. Seek reinstatement of ATSR near real-time service at Tromsø
4. Encourage development of systems to allow easier access to data sets by end users

Introduction: Requirements for this technology

Satellites offer the only way of systematically observing large areas of ocean over long periods of time and with the ability to resolve down to small scales. Although often thought of in global or basin-scale terms satellite data can be used very effectively in regional programmes, especially in conjunction with airborne and land-based remote sensing and with subsurface measurement systems. Most of the parameters which can already be measured from space are among those identified as of high priority for EuroGOOS (see Technology Survey and regional project outlines in EuroGOOS Summary Plan). In addition to monitoring applications (e.g. detection of climate change, studies of extreme events, basis for design of coastal installations) satellite data are needed both in near real time for forcing ocean forecast models and for independent verification of model performance. Real time data can also be used to design more efficient survey patterns, including those needed for rapid environmental assessment.

Present status

Satellite remote sensing has seen great progress in the last 20 years and it is possible to measure SST, winds, waves, sea level (sea surface topography), and sea ice extent to accuracies approaching or similar to those measured at the surface. Imaging radar has yielded fascinating glimpses of a wealth of ocean features manifested through their effects on surface roughness. Recently new ocean colour sensors have been launched which are likely to expand the user community significantly. The scientific community has, after initial scepticism, become convinced of the value of such data and they are used extensively in studying the physics of the oceans over a wide range of time and space scales, its interaction with biology, and the response to changes in atmospheric forcing. Considerable effort has also been made by CEO and others to promote a wider take-up of the data, e.g. in fisheries, marine pollution, ice monitoring by means of demonstrator projects. Some of the data are available in near real-time; most missions have infrastructures for systematic processing, archival and distribution of data. Some commercial organisations provide an operational service, e.g. wave climate atlases based on satellite data.

Principal shortcomings and need for improvements

Continuity

Whilst some EO missions are flown as part of an operational system, e.g. the AVHRR on NOAA meteorological satellites, the majority are not and fall into the categories of experimental programmes (one-offs, where failure after a few months is still regarded as a success by the research community) or pre-operational (which aim to provide continuity but no standby replacements are provided). The result has been guaranteed SST data, several years of altimeter data due to satellites exceeding design lifetimes, and intermittent series of ocean colour data. There is concern over a possible future lack of scatterometer data. Uncertainties over future availability of data discourage operational users from investing effort.

Timely delivery of data

Experience in the research community has shown that users grow frustrated by delays in receiving data and may seek other sources. It may then be difficult to restore confidence even when problems have been solved. The issue is even more serious in operational activities where data become useless for some purposes unless received by a certain cutoff, e.g. for forecasting or ship survey planning.

Data policy

Some satellite operators have data policies which inhibit the growth of the user sector. The pressure to exploit remote sensing satellites commercially should not be allowed to frighten off potential users. Particular attention should be given to ensuring data for demonstrator projects is provided free.

Key EuroGOOS decisions

The need for satellite data is stated throughout EuroGOOS documents, including especially the Strategy (Chapters 4 and 5) the Science Plan (pp. 27&28), and the Plan. The Science Plan highlights the following desired improvements: the ability to estimate the sea-ice thickness and more accurate ice extent and type algorithms. Particular mention is made of making the most effective use of satellite data, its integration with airborne remote sensing and in situ data, assimilation, and the estimation of new variables. All the EuroGOOS projects require satellite data but with varying emphases.

Links to GOOS, WOCE, CLIVAR, HELCOM, OSPARCOM, LOICZ, EUROMAR, etc.

There are considerable overlaps between the interests of EuroGOOS and the above. Satellites are so important to WOCE, for example, that the observational phase was extended by 2 years to accommodate the delayed launch of Topex/Poseidon. Common issues should be pursued in concert with other programmes such as WCRP, IGBP and their component programmes, and with CEO and CEOS. This will avoid unnecessary duplication. Themes include: identifying requirements for new sensors and algorithms, increasing the NRT data delivery capability of planned missions, making existing datasets available in more easily accessible form. EuroGOOS should focus on those processes relevant to operational oceanography. Assimilation of remotely-sensed data is clearly of great importance and EuroGOOS should ensure that this is actively pursued within the GODAE initiative, as well as within its own projects. GLOSS has a need for precision altimeter data.

Description of the technology: problem to be solved

To ensure fuller exploitation of existing satellite datasets for operational oceanographic purposes and provide operational user perspective on design of future ocean satellite missions.

Work needed

- Establish what is already being achieved through CEOS and other organisations, identify common and distinct elements, and where appropriate join forces

- Improve timeliness of data delivery taking into account trade-offs between delivery time and accuracy

- Develop techniques for better use of satellite data (including combining data from different sensors and with in situ, assimilation into models, validation of models) as a generic underpinning activity for all EuroGOOS projects

- Identify new key parameters to be measured from space

- Conduct underpinning research into potential estimation, contribute to the design of new sensors, assist with mission planning

Resources available in EuroGOOS - or other agencies in Europe

Make use of Concerted Action to bring together some key parties who can carry out the study, establishing priorities and proposing feasible implementation strategies. If the proposal is unsuccessful the study could still be carried forward perhaps with funding from ESA or EUMETSAT.

End-product or deliverable which can be achieved within a stated timescale

Final recommendations from Concerted Action within 1 year of start.

Publicise access information to key WWW sites (initial list by end of March 1998, then maintain in updated form) with brief explanation of what is available.

Set up inter-programme committee or working group on satellite oceanography issues (within 1 year).

Actions already initiated

Concerted Action proposal submitted in October, now under consideration.

Wider programme of CEO.

Shared costs actions such as OMEGA (funded), Med. Forecast System (submitted), CleanSeas (funded), TRANSPOSE (submitted), ICAMS (funding approved), GEONET 4D (funded) which involve the use of satellite data for monitoring the ocean.

Action Recommended

1. There are considerable overlaps between the interests of several European research programmes and EuroGOOS. It is important to integrate their concerns and user expertise to promote the fullest possible use of satellite data. These programmes have tended not to set up dedicated working groups for satellite data - probably a mistake. In order to provide a specific user focus we recommend an inter-programme working group consisting of EuroGOOS/EuroCLIVAR, EuroGLOBEC reps and involving scientists, commercial organisations, CEO and ESA.

2. Propose Concerted Action to EU for co-ordination of Operational Marine Requirements (OMAR) for EO-derived data and information and use recommendations from study to influence planning of EC and spacecraft operators

Two recommendations for short-term action:

3. Identify existing sources of satellite data relevant to operational oceanography, collate and publicise through EuroGOOS WWW pages. Ensure that existing capabilities for delivering real-time data are preserved, in particular seek reinstatement of ATSR service at Tromso.

4. Encourage development of systems to allow easier access to datasets by end users

Suggested Agencies or individuals who could co-ordinate the actions

OMAR Consortium

Earth Observation Sciences, UK (Neil McIntrye, Mary James)
CEDRE, France (Alain Febvre)
CETEMAR, France (Enrique Gonzales Pino)
CSIC, Spain (Jordi Font)
GEOS, UK (Robin Stephens)
MeteoMer, France (Hafedh Hajji)

Nansen Centre, Norway (Lasse Pettersson, Stein Sandven)
SOC, UK (Trevor Guymer)
SOS, UK (Gordon Jolly)
ESA/ESTEC (Johnny Johannessen)

Joint EuroGOOS/EuroCLIVAR, Euro-GLOBEC WG on satellite oceanography issues.

Meetings, travel, workshops

Three OMAR workshops (1st - User requirements assessment; 2nd - EO Applicability; 3rd - Recommendations and Prioritisation).

EuroGOOS representative at CEOS meetings.

New interprogramme committee on oceanographic satellites.

Communications

It would be useful to include on the EuroGOOS Web pages the addresses of Web sites through which NRT satellite data are available and to summarise the status of satellite programmes.

Costs

Budget for OMAR project + post in EuroGOOS office to co-ordinate satellite issues (1/2 person) + funds to enable participation in committees and working groups (~ 15 KECU per year).

Funding sources

EU (CEO), ESA, NATO (?), EUMETSAT.

Collaborating Agencies

WCRP, IGBP, ESA, EU, key commercial organisations.

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Airborne remote sensing in the coastal zone

The UK Environment Agency plays a central role in licensing all kinds of water discharge into the sea and estuaries, and improving the environment. The UK experience with coastal airborne remote sensing will be used as a model to suggest European-scale actions. It is essential that the Environment Agency maintains an effective, holistic environmental monitoring and assessment programme and that it tests environmental compliance with prescribed standards and targets. Techniques such as Remote Sensing form an integral part of the monitoring programme by providing a synoptic overview of the environment. The coastline cannot be viewed in isolation from the adjacent land. Data from instruments such as the Compact Airborne Spectrographic Imager (CASI), Thermal scanners (I.R.) and laser scanners (LiDAR), provide wide scale information about environmental processes and states.

The CASI is a flexible remote sensing tool which can provide data for varied environmental applications. CASI is able to add value to traditional monitoring techniques by providing large-scale, homogeneous coverage via easily repeatable measurements. The homogeneity of coverage allows traditional, point-based measurements to be interpolated and extrapolated over wide areas. This use of the CASI reflects a progression in measurement techniques from point-based to line-based to the integrated techniques which are presently in use. These techniques incorporate large area coverage and integration of various instruments to provide, for example, land cover mapping, chlorophyll-a and suspended solids maps, plume maps and intertidal classifications, elevation models (LiDAR) and surface temperature.

Overview of the CASI

The Compact Airborne Spectrographic Imager (CASI) is used in order to generate multi spectral, remotely-sensed imagery of intertidal, marine and riverine environments. The CASI is an imaging device, which, once installed on an aircraft, provides multi spectral digital data for environmental monitoring and analysis at short notice. This high availability enables the CASI to be deployed anywhere within flying distance in order to obtain time-critical imagery of events such as oil spills or algal blooms. Environmental events such as these are transient in nature and difficult or impossible to predict. The timeliness of the CASI makes it ideal for obtaining data about these transient and rapidly changing events. The flexibility of the system also makes it possible to redirect or stop flights at short notice if weather conditions make acquisition of good quality data impossible. This prevents the costly acquisition and processing of data which cannot be used.

The CASI sensor produces imagery covering the visible and near infra red wavelengths (288 spectral bands between 430-900 nm). This has to be used in conjunction with a thermal sensor in order to obtain data in the mid and far infra red wavelengths. Imagery produced by the CASI consists of up to 512 pixels across the swath and the spatial resolution (area represented by one pixel) can be varied from ten metres down to less than a metre by adjusting the altitude of the aircraft and the CASI imaging lens.

This imaging system provides flexibility and resolution which are not available with current satellite-based imaging systems. By selecting preferred spectral bands, it is possible to obtain data which are tailored to suit the user's application. Also, by simply specifying the height of the aircraft, the data resolution and area of coverage can be adjusted as desired. Finally, in certain weather conditions, the CASI can avoid cloud-cover problems suffered by satellites by simply flying below the cloud base. The imagery can be geometrically corrected using data from a vertical gyroscope and Global Positioning System (GPS) receivers which are mounted on the aircraft. These corrections compensate for variations in the aircraft attitude during image formation. Radiometric correction can be performed through the use of pre-flight calibration constants and by using an Incident Light Sensor to measure the down welling radiance at the aircraft. This radiometric correction can be used to calibrate the imagery in terms of spectral reflectance values, rather than absolute radiance values and enhances the ability to make useful comparisons between data obtained at different times.

Overview of LiDAR

LiDAR (Light Detection And Ranging) systems are based upon laser range finders, used for many years for accurate, line of sight distance measurements. A laser pulse is fired at a target and the time the pulse takes to hit the target and return is measured. A fixed laser system installed in an aircraft, whose position is very precisely calculated using post-processed GPS, can measure the distance to the ground directly under the flight path. By scanning the laser, perpendicular to the line of flight, the system can survey a swath 600 m wide, beneath the flight path. The systems have recently been refined, with the addition of dedicated computing packages that maximise information derived from the data. By tuning the wavelength of the laser, bathymetric surveys are possible. The laser can even selectively excite compounds at the target to detect pollution such as oil or chlorophyll.

The technique will be used within the Environment Agency for flood defence mapping, long term climate change monitoring and Coastal zone mapping. At present there are no accurate maps of the UK coastline below the five-metre contour. Without these maps we will not be able to manage the effects of climate change and sea level rise.

The need

When built into a routine monitoring program with ground truth data, a unique data set can be collected. These data form the essential prerequisite of any coastal zone management system. It adds the spatial dimension so often ignored. Point sampling presents many problems, the main one being to try and relate its position with respect to the dynamics of a complex environment.

With the costs of field surveys being one of the major limiting factors, we must develop practical remote sensing as the cost-effective solution to the data requirement dilemma. Without monitoring data it is not possible to manage the environment in any meaningful manner. Lack of knowledge is no defence. We require data for:

- Coastal zone mapping.
- Climate change monitoring and managed retreat.
- Identification of water bodies, coastal plumes and their movement.
- Survey planning.
- Production of models based on total coverage both spatial and temporal.
- Quantification of Suspended Solids and Chloropyll-a including area affected.
- Outfall dispersion plumes and Dye tracing.
- Stratification.
- Intertidal and Salt marsh classification and change monitoring.
- Coastal geomorphology, erosion accretion.
- Land classification to identify and quantify pressure from the coastal zone.

EuroGOOS actions

EuroGOOS should examine the techniques of airborne CASI and LiDAR as used at present by a range of coastal agencies in Europe, promote collaboration, standardisation of techniques, exchange of data where relevant, and the integration of CASI and LiDAR data into real time or near real time data streams for use in operational modelling.

Shore stations: Tide gauges

Summary of recommendations

- Make all tide gauge stations in EuroGOOS member states operational i.e. data are collected in real time.
- Maintain strong working relations with SeaNet.
- Establish a common European reference level for tide gauges.
- Develop and improve techniques to use remotely sensed sea level observations operationally.
- Establish a EuroGOOS calibration and quality control manual for sea level data.
- Establish close relations to GLOSS and EOSS.

Introduction

Measurements of sea level is a vital component of an oceanographic observation program for many reasons ranging from immediate operational requirements of ships navigation and storm surge to long term monitoring and prediction of global sea level changes due to climate variations.

European waters are well covered with sea level measuring sites of which the most strategic placed stations constitute an integral part of the global network operated by Global Sea Level Observing System (GLOSS) under the Intergovernmental Oceanographic Commission (IOC). SeaNet (1998) provides a tabulation of tide gauges installed in the North Sea Region.

Key EuroGOOS decisions

The importance of high-quality water level data have been clearly stated in all EuroGOOS documents especially in relation to storm surge warnings, data assimilation and forcing parameters for numerical models.

Links to GOOS, WOCE, CLIVAR, HELCOM, LOICZ, EUROMAR, etc.

All the major marine research and monitoring programmes include a water level observation component, which normally consists of selected stations from the GLOSS network supplemented with project specified stations. There is, therefore a considerable overlap between EuroGOOS and the above mentioned programmes and EuroGOOS can benefit from a co-operation with these programmes in:

- continued operation of non-GLOSS stations
- establishment of new stations
- data exchange
- use the GLOSS data centre as a common data centre for storage of long time series

Description of the technology

Measuring techniques

There are two basic parameters which may be monitored, both having scientific as well as instrumental advantages:

- the surface level itself
- the pressure at some fixed point on the seabed

Traditionally, the sea surface has been measured by means of a float arrangement mounted above a well which damps out short-period wave motions. This procedure is simple, well proven and has no inherent drift. However, there are problems of non-linear responses of stilling wells to waves and currents (Bernoulli effect), which can produce errors in the measurement of the water level. Alternative methods for sensing the sea surface include acoustic and electromagnetic gauges. These avoid the problems associated with moving floats and wires, but will still be subject to errors if mounted over stilling wells. Despite these reservations, the stilling well arrangement, if properly designed, remains a robust and reliable system for many applications.

An alternative is to measure near-shore seabed pressure and to convert this to sea level by means of the hydrostatic relationship between pressure, water density and gravitational acceleration. Seabed pressure includes atmospheric pressure, which must be corrected for, either by separate measurement or by differential transducers vented to the atmosphere as in some bubbler gauges. With pressure systems, care is necessary to ensure that datum level remains constant and sea water density variations must be monitored at suitable intervals for the best accuracy.

The use of remotely sensed data from various satellite missions plays a substantial role in monitoring of the sea level. This measuring technique offers a variety of advantages:

- Improved recovery of ocean tides i.e. monitoring of sea level in open ocean areas.
- Improved analysis of seasonal sea level changes
- Improved sea level forecasting and storm surge warning

In order to be operational tide gauges shall record automatically in computer-format and data shall be transmitted to a regional database in real time. Sampling of sea level averaged over a few minutes (to avoid aliasing), at intervals of 15 minutes is recommended.

Reference level

All tide gauge stations must measure sea level relative to a fixed and local tide gauge bench mark, which is connected to a number of auxiliary bench marks. These guard against the movement or destruction of the main tide gauge bench mark. The tide gauge bench mark shall be controlled at regular intervals.

Another fundamental development is the ability to connect all network tide gauge bench marks into a Global Vertical Datum System, which will eventually allow the vertical crustal movements to be distinguished from sea level trends. Similarly, it may eventually be possible to relate all the bench marks to a reference geoid, which will allow computation of absolute pressure gradients between stations and to relate these to permanent currents.

Tide gauges measure only the relative motion between the sea surface and the land, and since land can rise or subside, the problems of relative motion must be solved by more sophisticated technology if sea level data are to be properly interpreted and used. The development of new geodetic techniques based on Very Long Baseline Interferometry (VLBI), the Global Positioning System (GPS) and absolute gravity measurements has created the opportunity to link a network of tide gauges to a highly accurate global reference system. By distinguishing sea level changes from land rise or subsidence, this global reference system will ultimately provide the first measure of absolute sea level changes.

Actions already initiated

Many of the practical and scientific questions in relation to retrieval of high quality water level data are addressed by the GLOSS program. On a European scale the EU COST 40 Action European Sea Level Observing System (EOSS) has recently been established.

The SeaNet project has been funded by DGXII and includes standardisation of sea level data in the North Sea region.

Recommendations

It is recommended to:

- Make all tide gauge stations in EuroGOOS member states operational i.e. data are collected in real time.
- Establish a common European reference level.
- Develop and improve techniques to use remotely sensed sea level observations operationally (in co-operation with the Satellite Technology Project, see this report page 5).
- Establish a EuroGOOS calibration and quality control manual for sea level data.
- Establish close relations to GLOSS and EOSS.

Meetings, travels and workshops

It could be valuable to arrange a workshop together with representatives from GLOSS, EOS, WOCE, CLIVAR, HELCOM etc. in order to:

- Define the optimal European network of water level stations taking into account operational as well as research aspects.
- Co-ordinate calibration and quality assurance procedures.

- Establish formats and procedures for real-time data exchange.
- Evaluate the benefits of a common data centre.
- Define and agree upon a common European reference level.
- Establish procedures for the use of remotely sensed data.

Communications

Facilities for rapid (real-time) exchange must be secured.

Costs

The expenses related to making all tide gauge station in EuroGOOS member countries operational must be a national responsibility and the same goes for the levelling of the tide gauges relative to a agreed common European reference level. Costs are unknown.

Development and improvement of techniques to use remotely sensed sea level observations operationally are already included in existing research projects. Costs of further development and implementation is unknown.

The cost of the proposed workshop amounts to around 25.000 ECU.

Funding agencies

EU.

Collaborating agencies

GLOSS, EOSS, WOCE, ESA.

References

"The Strategy for EuroGOOS" (publication no.1).

"The EuroGOOS Plan" (publication no.3).

Global Sea Level Observing System (GLOSS) Implementation Plan.

Shore stations: Coastal radar

Summary of recommendations

Foster closer co-operation and communication between groups who are developing and using oceanographic coastal radar systems, and between the users and modellers who will assimilate the data into forecast models.

Establish potential market, and encourage manufacturers to plan for supply as standard products.

Plan integrated systems with nested coverage to optimise assimilation into forecast models, also with nested grid nodes, for operationally and scientifically important areas. Consider Framework 5 proposal.

Support work on data product assimilation into numerical models.

Introduction

The four types of coastal radar (MIROS microwave, X-band, HF SWR and HF sky-wave) can all provide surface currents, but with different spatial coverages and resolutions. They can also measure wave spectra, and surface winds. Two HF radars with intersecting areas of coverage are required to obtain surface current speed and direction, and wave direction. HF radars with fine directional resolution require linear antenna arrays typically from 85 to 225m (say, 16 elements spaced $\lambda/2$ apart) long perpendicular to the boresight direction.

The HF radar techniques provide time series maps of sea surface parameters, and are particularly suitable for data assimilation into numerical forecast/hindcast models.

All techniques have been implemented and validated. GEOS and SOC/POL routinely operate transportable OSCR HF Radars for surface current mapping during site surveys, and a number of MIROS systems are permanently installed on Norwegian offshore installations. Electronics and software for X-band systems are available from manufacturers, and several systems are in use by research organisations. However, the OSCR systems in current use have become obsolete and are difficult to support, and no manufacturer offers new HF radar systems on a production basis. Viable, more technically advanced HF systems exist within research organisations.

Key EuroGOOS decisions

Establish and confirm the need for coastal radar systems within the EuroGOOS framework.

Links to GOOS, WOCE, EUROMAR, etc.

Chair of WMO/IOC Working Group on Operational Services of the Global Ocean Observing System is member of EuroROSE consortium. EuroROSE consortium MAST III application (Reference number PL 971607).

MAST II project SCAWVEX (Surface Current and Wave Variability Experiment, MAST2-CT94-00103).

MAST III project PROMISE (Pre-operational modelling in the seas of Europe).

Description of the technologies

There are four distinct types of coastal radar which are used for measurements of physical properties of the sea surface. These, with their respective ranges, are:

- MIROS (Microwave Ocean Sensor) Wave/current Radar - approx 500m.
- X-Band Marine Radar - up to 10km.
- HF SWR (Surface Wave Radar) Systems - normally up to 40km, Long Range versions to 180km.
- HF skywave radar - over-the-horizon by ionospheric reflection, typically 1,500km.

In each case, the dominant radar scatterers are surface gravity waves whose wavelength is half the radar wavelength (the so-called Bragg resonant condition). The penetration depth into the sea surface of a 20MHz radar is about 1.5m.

MIROS

MIROS transmits 5.8GHz (microwave) pulses in a 30° sector, from an elevation of about 50m, into a footprint 7.5m in range (50ns pulse length), at a range of about 500m from the radar. The Doppler shift of the return pulse from the capillary waves is modulated by the gravity wave velocity integrated over the illuminated area. A time series of wave velocity is Fourier analysed to produce a wave power spectral estimate in that direction. Six beams covering a full 180° provides the total wave power spectrum from all directions.

Radial surface current vectors in each beam are obtained by mixing two 500ns microwave pulses (footprint 75m wide in range) with a frequency difference of 10MHz. The current measurement principle is then the same as an HF radar (see below). The six radial vectors are resolved into a single current speed and direction.

This system is primarily designed for use from offshore fixed or floating structures, but it has been used from coastal sites. Near the coast, the wind and current field can no longer be assumed homogeneous in space.

X-Band Marine Radar

Gravity waves cause "sea clutter" in marine radar displays, which is normally regarded as noise for ship detection purposes. However, by selecting an area of the image, and taking a time sequence of images, it is possible to perform a 3-dimensional Fourier transform on this time sequence of spatial images. The resulting 3-dimensional power spectrum can be integrated over k-number, using the dispersion relation, to obtain a 2-dimensional spectrum in frequency and direction. Thus, wave height, period and direction parameters can be calculated from the spectral estimates. In fact, the absolute energy is not known, and must be obtained by another method (for example, calibration of the radar echo intensity), in order to obtain wave height.

By measuring the displacement of the k-number spectrum from the theoretical dispersion relation, the current velocity integrated over the image area can also be obtained.

HF SWR

An HF antenna transmits a "groundwave" signal (typically 8 to 10MHz, 25 to 27MHz or 49 to 51MHz) which is back-scattered from the sea surface and detected by a receiver antenna array. Spatially distributed cells on the sea surface are selected by a variety of techniques:

- steered transmit and receive beams.
- floodlight transmit and steered receive beam.
- direction-finding receive antenna.

Within each cell, the frequency spectrum of the received signal can yield:

- radial current vector from the Doppler displacement of the two Bragg resonant lines and the dispersion relation for the appropriate sea wave length.
- wave spectrum from the 2nd order component of the spectrum.
- wind speed and direction.

Radial current is calculated from the difference between the actual frequency shift and the shift expected from the theoretical dispersion relation between wave frequency and wave length for the appropriate water wave length (half the radar wavelength).

By using two intersecting beams, current velocity and wave direction, as well as the other parameters, can be determined on a grid of points.

Range and spatial resolution are frequency dependent. Typical values are:

Operating frequency	Range	Spatial resolution
10MHz	180km	5x5km
27MHz	40km	1x1km
50MHz	10km	250x250m

HF Over-the-Horizon Radar

Instead of ground-wave propagation, the sea surface can be illuminated by reflecting the signal from the ionosphere. This enables longer ranges to be achieved, at the expense of reliable propagation (due to the variable reflective properties of the ionosphere), and hence up-time. Spatial resolutions of 10 to 15km are possible, at ranges of typically 1,500km.

Radial current components are obtained from one radar. Two intersecting beams from separate sites are required to determine current vectors on a grid of points.

Actions already initiated

The EuroROSE consortium has submitted a MAST III application (Reference number PL 971607) to fund a 2 year study to assimilate X-band and HF radar products into now- and fore-cast models. Two of the consortium members have been involved in the MAST project SCAWVEX (Surface Current and Wave Variability Experiment, MAST2-CT94-00103).

Three of the consortium are participants in the MAST III project PROMISE (Pre-operational modelling in the seas of Europe). This has been supported.

GEOS have a joint proposal with GEC-Marconi Research Centre under consideration by NWAG for a feasibility study for Long Range HFSWR systems to cover the west of Shetlands area. GEC-Marconi Research Centre currently operate a single Long Range HFSWR system covering the Thames Estuary from Foulness to a range of 80km (limited only by permissible transmitted power).

Action Recommended

- Maintain a circulation list of all organisations who are active in the development and operation of coastal radars for oceanographic measurements.
- Organise workshops involving these members to encourage and stimulate the exchange of ideas and operational experience.
- Direct potential funding sources to this body.

Meetings, Travel Workshops

The EuroROSE consortium could hold open interim workshops pending approval of their MAST III proposal. Funding is approved and the project started in July 1998, and there will be regular meetings for the consortium members, and dissemination symposia.

Communications

A central focus for collecting information, specifications and references on the technologies and their applications would assist the achievement of the recommended actions. This could be channelled to:

GEOS
email: archer@geos.com
direct tel: +44 1793 746446
fax: +44 1793 706604

GEOS Limited
Hargreaves Road
Swindon SN2 5AZ
UK
Tel: +44 1793 725766
Fax: +44 1793 706604
http://www.geos.co.uk

Selected summary data should be made available on the EuroGOOS Website.

Funding sources

MAST III.
North West Approaches Group (UKCS offshore industry consortium).
Framework 5.

Collaborating Agencies

GKSS, Hamburg (Dr Heinz Günther; guenther@gkss.de)
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OCN BV, Netherlands (Frans van Dongen)
Southampton Oceanography Centre, UK
Proudman Oceanographic Laboratory, UK.

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Moored buoys

Summary of Recommendations

Fixed buoy moorings carrying surface and sub-surface instrument packages are an essential long term observing system for EuroGOOS.

Although the design of platforms and moorings is a mature technology, there are still many different commercial designs and "in-house" designs, effectively preventing economies of scale, and the concentrated acquisition of experience in installation, maintenance, and continuous operations.

The limiting factor to wide use of moored buoys with multi-sensor sub-surface arrays of instrumentation is the short operational life of sensors, other than the main current, wave and temperature measurements.

Introduction

Instruments mounted on moored buoys have provided a standard source of oceanographic data for many decades. Recent improvement in communications via satellite links, improved power supplies, use of solar panels, reduced power consumption, miniaturisation of instruments and data packages, and improved sensors, have greatly extended the potential for the use of oceanographic buoys. See also sections in this report on Drifting Buoys, Sub-Surface Profiling Drifting Buoys (Floats), and Fixed profiling systems and Pop-up Systems.

Moored buoys provide continuous observations of marine meteorological conditions in remote deep water locations, ground truth data for satellite measurements, sub-surface water column data, the platform for complex suites of sensors in coastal waters, and the communications package for sea bed instruments. While the technology of mooring design and buoyancy platform is mature, instrument packages and communications are evolving rapidly.

Basic references for operational moored buoy networks are provided by the WMO, Marine Meteorological Services (MMS), Operational Newsletter (e.g. WMO, 1998) (ref: http://www.wmo.ch/web/ddbs/opnews.html) , and the joint WMO-IOC Data Buoy Co-operational Panel (DBCP, Meindl, 1996). The MMS Operational Newsletter lists the co-ordinates, communications system, and parameters measured for about 100 moored buoys, with most measurements restricted to wind direction and peak wind speed, air temperature, air pressure, SST, wave period, height, and spectra, and occasionally sub-surface sea temperature. Relatively few buoys carry sub-surface instrument packages. SeaNet provides an inventory of North Sea buoys with their sensor packages.

Moored ocean buoys offer the only means of obtaining real-time, continuous, frequent, and accurate observations of marine conditions from some deep-water location. Often, the first indications that forecasters have of rapid intensification or change in movement of storms come from buoys. In United States (US) coastal and offshore waters, approximately 50 per cent of all marine advisory warnings or actions are instigated by buoy reports or reports from automated platforms in coastal areas.

Examples of major moored buoy operational programmes include the Pacific tropical TAO array, the Atlantic PIRATA project, the US NOAA coastal and shelf buoys, the UK Met Office and Météo-France chain of met buoys on the outer European shelf, the French coastal buoy chain, German Mermaid buoys, and chains of Oceanor buoys off Norway, India and Thailand.

Description of the technology

Buoy installations range from full ocean depth such as in the tropical Pacific (TAO array), 1000-2000 metre depth on the shelf edge (UK Met Office, Oceanor), to shallow installations in 50m or less on the continental shelf and in estuaries (MAREL, MERMAID). Mooring design is a complex art which has evolved over several decades, and the particular choice of mooring is determined by water depth, current strength and stratification, wind and wave forces, variation in sea surface elevation, corrosion, and risk of vandalism, collision, or damage from fisheries. In European waters numerous instrumented buoys have been installed in coastal waters and estuaries, in the North Sea and off the coast of Norway to support the offshore hydrocarbons industry, on the western shelf and slope to measure meteorological conditions in the Atlantic, and a deep water buoy programme is being developed in the Mediterranean to support the Mediterranean Forecasting System (Poseidon).

The Tropical Atmosphere-Ocean (TAO) Array consists of approximately 70 deep-ocean moorings spanning the equatorial Pacific Ocean between 8N and 8S from 95W to 137E. It is a major component of the global climate monitoring system, and is supported by an international consortium, involving co-operation between the United States, France, Japan, Korea and Taiwan. The purpose of the array is to provide high quality, in-situ, real-time data in the equatorial Pacific Ocean for short-term climate studies, most notably those relating to the El Niño Southern Oscillation (ENSO) phenomenon. TAO measurements consist primarily of surface winds, sea surface temperature, upper ocean temperature and currents, air temperature and relative humidity. Data are telemetered in real time via Service Argos, and a subset of these data is placed on the Global Telecommunications System (GTS) for distribution to operational centres for assimilation into weather and climate forecast models. A major step forward in long-term support for the array was the commissioning in FY96 of the NOAA ship Kalimimoana, a research vessel dedicated to servicing TAO moorings between 95W and 165E. Also in FY 96 new Next Generation ATLAS moorings were introduced into the array.

A historical overview of the development of the Tropical Ocean Global Atmosphere (TOGA) observing system has been made. Specific plans for new measurement programs were advanced: for a Pilot Research Moored Array in the Tropical Atlantic (PIRATA) in collaboration with Brazil and France, for a moored ATLAS array as part of the South China Sea Monsoon Experiment (SCSMEX) in collaboration with Taiwan, and for the Triangle Trans Ocean Buoy Network (TRITON) in collaboration with Japan.

The TAO project provides interactive access to TAO data, display software and graphics via the World Wide Web and the workstation-based TAO Display Software. The TAO software features a point-and-click interface and a data subscription service providing remote users with automated daily updates to real time and historical TAO data, and is actively used at nearly 50 research institutions throughout the world. Time series of data from individual instruments on the TAO moorings have been made available on the World Wide Web. The TAO Project Office has also established a TOGA COARE moored data centre, with Web access to nearly all moored time series collected during the COARE experiment. More information on TAO can be obtained via a World Wide Web site: [http://www.pmel.noaa.gov/toga-tao/home.html].

The estimated variables and parameters measured by EuroGOOS Member agencies (status January 1998) are described in The EuroGOOS Marine Technology Survey (EuroGOOS Publ. No 4, EG97.14). Table 20b "indicates that the most commonly used operational platform is the moored buoy, and hence, probably, that most sensors are installed on moored buoys." The Survey identified Surface (11 from 42) and Subsurface (2 from 42) Moored Buoys. A detailed catalogue of buoy moorings in the North Sea area is provided by SeaNet (1998), listing the oceanographic and meteorological parameters measured by each buoy.

The trend towards remote sensing of physical parameters either by satellite, aircraft or coastal radars has increased the need for Surface Moored Buoys as Ground Truth data sources. The mean time between maintenance of such a buoy is estimated to be between 12 times per year for sensitive parameters, e.g. analytical systems for nutrient analyses up to 4 years for simple physical sensors, e.g. for meteorology. The quality/reliability of the data and the maintenance-free period is mainly influenced by biofouling which depends on the sea area, sea temperature and the season.

The shape of the buoy's hull depends mainly on the combination of planned location (sea conditions) and field of operation. Typical shapes of Surface Moored Buoys are wave followers, spar buoys or disc boys.

Among the several monitoring stations in Europe being operated by national monitoring agencies and private enterprises the German network "MARNET" contains sensors/ analysers for biological-chemical parameters. This is achieved by the MERMAID system, an automatic remotely controlled marine observation system for estuaries and coastal waters. Prototype development and testing was carried out within an EUREKA/EUROMAR project. The MERMAID system is in operational mode now on different "MARNET" stations. Further developments are carried out on the German MERMAID buoy, a disc shaped Surface Moored Buoy with approximately. 12 m diameter and 12 m height. (see fig.) This type of buoy is used on two MARNET stations.

Mermaid Marine Environmental Data Buoy

Antifouling

The main problem for moored buoys is the biofouling problem which at the time being prevents the unattended measurement of many parameters, e.g. optical measurements, nutrient determination and with some systems even the exact measurement of salinity for a period of more than 1-2 months (in temperate climate, in tropical areas much less). Apart from antifouling coatings of the buoy body itself which may contaminate e.g. heavy metals determinations, the main problem is prevention of biofouling on the sensors. At the time being only few systems have the possibilities for effective antifouling measures (e.g. closed flow-through systems) which are not suitable for all parameters. Therefore there is a strong need for the development of sensor-specific antifouling measures.

Energy consumption

The mean time between maintenance should be increased, by using energy management systems which optimise the consumption and by improvement of subsystems with low-energy supply demands.

The Marel system

The MAREL program attempts to develop automated monitoring station for classical water analysis, able to work autonomously and during long periods without servicing on the sensors and the measurement stations. Measurements (parameters, frequency, water levels, etc.) must be adapted both to the exact questions addressed and to local conditions of the environment.

The general architecture of the MAREL monitoring system, includes an innovative measuring device, a telecommunication link using Internet protocols, and a land-based management station for collection, processing and dissemination of qualified data. Water samples are pumped through a sampling pipe at different levels in the sea water column and are analysed by sensors located in a measuring cell on the floating structure. This technical solution allows a continuous cleaning of sensors in order to secure measurement quality.

The main parameters measured with high frequency are water temperature, salinity, turbidity, pH, dissolved oxygen, nitrates and chlorophyll in the sea water, and added parameters as hydrological (current, wave) and meteorological (air temperature and pressure, wind) ones.

Data are released in near real time for users through the Internet.

The automated monitoring approach allows high frequency measurements, and then gives the opportunity to detect fast variations and to have a rather continuous observation of the water. Offshore, the monitoring can give a good help to study the evolution of the water quality in the long term independently of the river and bay influence.

The data transmission system is also standardised, using the telephone and GSM network, VHF or satellites if necessary. A land-based management station automatically receives via the transmission system and stores data from the monitoring stations, keeps them available for the users via Internet and may also receive alarm messages from monitoring stations.

Marel Buoy

Action required

- Harmonise an open Interface-Policy (e.g. on basis of FIESTA). At the time being four interfaces are used most widely: a) analogue signals, b) serial digital signals (RS232, RS485), c) parallel digital signals and d) bus systems (CANBUS, BITBUS, IEEE 488 etc.). Developments in the near future should use one of these interfaces. However, since it seems impossible to standardise the software protocols to one common standard for every application, the manufacturers of equipment should be encouraged to reveal software protocol to enable the development of software protocol converters. Consult with SeaNet.

- Generate a common Quality Assurance (QA) of data. Whereas QA procedures (protocols) for many meteorological and oceanographic sensors exist and are agreed upon in the community there is a deficit for biological-chemical parameters, e.g. chlorophyll (by fluorescence measurements), turbidity/optical attenuation and nutrients. For these parameters common QA procedures should be developed in order to be able to compare the data. In addition a QA handbook for data generation and data exchange should be developed taking into consideration the results of the "SEANET Data Interface Group".

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Drifting buoys

Summary of Recommendations

Drifting buoy technology is mature in the design of the buoys and the communications, but the instrumental suite is limited almost entirely to sea surface temperature and marine meteorology. EuroGOOS Members should examine the possibility of including other sensors on drifting buoys in the Atlantic, provided that sensor durability is adequate at an acceptable cost. The Atlantic Task Team and the Science Advisory Working Group should specify whether the data would be an important addition to model inputs. Negotiations for the addition of extra sensors should be conducted with EGOS when the EuroGOOS objectives have been established. If more sensors and variables are added to drifting buoys it may be advantageous to use an interactive communications system which permits responsive management of the device.

Introduction

In April 1997 there were 1222 drifting sea surface buoys reporting data automatically to be processed at the Argos global Processing Centre in Toulouse, France, and Landover Maryland USA, for distribution in real time or deferred mode. These buoys are operated by 19 countries (Australia, Brazil, Canada, China, Finland, France, Germany, Iceland, India, Italy, Japan, Korea, Netherlands, New Zealand, Norway, South Africa, Spain, UK, and USA). Of these 1222 buoys about 53% transmit data in real time via the Global Telecommunication System (GTS).

Most of the buoys measure at least sea surface temperature, and approximately 250 measure air pressure. A few drifting buoys measure sea surface salinity and wind speed. Approximately 7% of all drifting buoys have no sensors, and are used as Lagrangian tracers only. Maps produced by Canadian MEDS (GOOS, IOC-INF 1997, p.49) show that data are reported from almost every 30 degree by 30 degree square of the world ocean, and from most 10 degree squares. The Southern Ocean is poorly covered, and there are gaps in the central Pacific and Atlantic. The North Atlantic is best covered.

Quality control guidelines for buoy data as proposed by the Data Buoy Co-operation Panel (DBCP) have been formally incorporated as part of the World Weather Watch (WWW). In Europe the centres responsible for drifting buoy data quality control are ECMWF, UK Met Office, and Météo France. The Responsible National Oceanographic Data Centre (RNODC) for buoy data is in Canada. More information on drifting buoy data generally can be obtained from the DBCP www site:
dbcp.nos.noaa.gov/dbcp/contents.html

In 1989 a regional action group for European collaboration on drifting buoys in the Atlantic was set up as the European Group on Ocean Stations (EGOS, North Atlantic). EGOS is co-ordinated by the Norwegian Institute for Water research (NIVA) Bergen, and publishes a monthly data report. Monitoring statistics on the buoys are tabulated by the UK Met Office, and buoy trajectories are prepared by the Danish Met. Institute. There are typically 20-30 buoys deployed by EGOS at any one time, almost all of them north of 45 degrees north in the Atlantic. They tend to drift eastwards, and therefore the ocean has to be re-seeded on a routine basis with buoys which are dropped in the centre or western Atlantic.

Key EuroGOOS decisions

EuroGOOS Members require a constant source of real time data on the conditions of the open Atlantic surface and upper ocean waters for modelling and forecasting, in addition to climate research. Upper ocean profiling floats provide data at intervals of weeks, so that surface buoys are likely to remain important with a higher frequency of reporting observations. The key EuroGOOS decision is the extent to which it will be possible or scientifically valuable to add sub-surface sensors to the surface buoys, and to what extent this investment would be justified by the additional information. In principle such additions could be tested and implemented through discussions with EGOS.

Links to GOOS, WOCE, CLIVAR etc.

Drifting buoys were a major component of WOCE and the technology was greatly improved during WOCE. A EuroGOOS strategy to plan for an enhanced system of surface buoy deployment of additional sensors would need to be evaluated as part of the Atlantic Pilot Project.

Description of technologies

The design of surface drifting buoys, drogued and non-drogued, has become a mature technology as a result of the experience from major global programmes such as WOCE. To minimise wind drift or effects on the buoy of waves and near surface wind driven currents the shape of the buoy is designed to minimise wave rectification, and the drag area ratio of the system should be high. A drogue consisting of a fabric cylinder perforated with holes in the side is often used, and is known as a "holey sock drogue". The typical holey sock drogue is 7.5m long and 1.5m in diameter, suspended approximately 20m below the surface. The usual communication method for measurements and position is by Systeme Argos.

Actions already initiated

EuroGOOS has made one presentation to an EGOS meeting, and is in correspondence with the EGOS Office.

Action recommended

Any plans to increase use of surface drifting buoys should arise from the needs of the Atlantic Pilot Project, and additional or extended sensors should be considered in the context of the EuroGOOS Panel on Sensors and Biofouling.

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Sub-surface and profiling drifting buoys

Summary of recommendations

Profiling floats should be considered as a cost-effective means of obtaining routine upper ocean temperature and salinity profiles and of tracking subsurface water movements in the open ocean. Remaining obstacles to wide-spread deployment are hardware, tracking and data retrieval costs and sensor stability. Such floats could also be used to carry a wide range of physical, biological and chemical sensors. EuroGOOS should support implementation of the ARGO project and development of floats.

Introduction

Since the mid-sixties, freely-drifting sub-surface floats at a prescribed depth have been used to track water masses, providing a Lagrangian description of the oceanic circulation. Early versions were tracked by attendant ships but from the 1970s onwards low frequency acoustic signals were used to position these deep floats (SOFAR and RAFOS).

During the last decade, multicycle floats that drift with the water mass, pop-up to the surface, are positioned and transmit data via satellite and then return to the prescribed depth were developed and extensively used in the WOCE Project. This made this technology available for global studies. The ALACE float is solely positioned by Systeme ARGOS each time it surfaces. The profiling version (P-ALACE) also measures a temperature and salinity profile during its ascent and transmits it to the satellite. MARVOR floats have acoustic positioning during their submerged trajectories. These floats have been extensively deployed in 1996 and 1997 as part of the Atlantic ACCE component of WOCE. Activities are in progress in Europe to develop a profiling float (PROVOR), on the basis of MARVOR technology.

Profiling floats are potential routine collectors of upper ocean (down to 2000m) in situ data over very large sections of ocean basins. They have the advantage of being able to produce data from remote and hostile areas.

Key EuroGOOS decisions

The Lagrangian profilers are clearly positioned within the EuroGOOS strategic sector 4. They are one of the major means cited to meet the requirements for in situ TS data for GODAE and more generally for data to be assimilated in forecasting models. EuroGOOS must evaluate and plan its role in the ARGO project.

Links to GOOS, WOCE, CLIVAR, HELCOM, LOICZ, EUROMAR, etc.

WOCE has been the major project which used this technique intensively. ALACE and MARVOR were developed in this framework. CLIVAR relies for a large part on the capability to profile salinity and temperature repeatedly and for long periods.

The OOSDP cited this technique in the enabling technology (OOSDP - Final Report - March 1995, pp 168-169)

Description of the technology

The example of PROVOR, the only European instrument already in series production, is described here first.

PROVOR is a lagrangian profiler based on the technology developed in the MARVOR, with the following characteristics:

- As MARVOR, PROVOR doesn't need any ballasting operation and the operating pressure can be decided just before deployment.
- The float executes identical programmed cycles of descent, drift at depth at a given pressure for a few days, descent to the start of profile depth, raising, transmit data through ARGOS system.
- T (Temperature) or CT (Conductivity, Temperature) measurements are carried out during the descent and/or the ascent phases.
- The float is not located at depth. It is located only at the surface during the ARGOS data transmission phase.

- The float is able to synchronise the beginning of the raising profile in order to get synoptic CTD profiles from floats which are not deployed at the same time in an area.
- The number of cycles is comprised between 50 and 100, depending upon the number of points which are kept for each profile.
- The float can profile between the surface and 2000 m.
- The CTD measurements are carried out every 10 seconds and the data are processed before transmission to reduce the amount of information and keep only some points, as a function of the desired accuracy, using a method which is used to reduce the data of XBT casts.
- The characteristics of the sensors are:

Pressure:	Range : 2000 dbar Accuracy : +/- 5 dbar Resolution : 1 dbar
Temperature:	Range : -2 to 35 °C Accuracy : +/- 0.05 °C Resolution : 0.01 °C
Conductivity:	Range : 0 to 70 mS/cm Accuracy : +/- 0.05 mS/cm Resolution : 0.01 mS/cm

These characteristics concern the entire measurement system, including the sensors and all the necessary electronics and data processing to provide data which can be directly used by the final user.

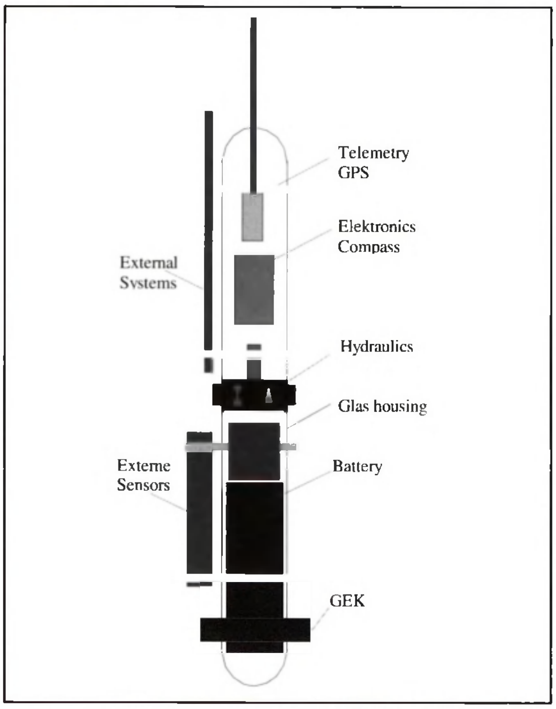
- The speed of the profiler during the ascent phase to the surface is about 10 cm/sec.
- PROVOR-T: sensors provided by SEASCAN
- PROVOR-CT : sensors provided by FSI or SEA-BIRD.
- The first sea experiments were conducted in 1998 and the floats are now (1999) produced by series.

Figure 1. *Two temperature PROVOR profilers on board LA THALASSA before launching. One profiler is linked to a reference CTD for metrological comparisons (photo S.Le Reste - IFREMER).*

The APG Autonomous Profiling system has been under development by co-operation between the Institute of Applied Physics in Kiel, the Baltic Sea Research Institute in Warnemünde and the firm 4H JENA engineering GmbH in Jena, Germany since 1996, and is a EUROMAR project. User trials have been carried out, with further trials scheduled for 1999, and work is now on the design of a production version. The EUROMAR project will finish during 1999.

The Autonomous Profiling Equipment Carrier realises different measuring tasks and programs:

- free drifting Lagrangian current follower in the depth range up to 2000 m.
- for floating or vertical profiling in lower water depth 0 - 20 ... 100m.
- for profiling use in water depth 0 - 2000 m.



The APG System

The production of a defined depth profile can be realised by mooring or free drifting. The advanced processing is done by a computer menu on Windows. The pressure housing of the APG is produced using glass technology. A cage of V4A rods is over the glass housing for mechanical protection and to carry the external devices and measuring systems as well as the additional buoyancy system. The APG was developed for external measuring equipment according to the user requirements. A GEK-system (geomagnetic electro kinematograph) can be installed for the calculation of the trajectory during the free drifting mission.

The transmission of the measuring values is made by GSM-network, acoustic modem, satellite or data radio with added GPS. The reading from the APG can also be done via serial interface with a PC or Laptop. The operation time is up to two years.

The bi-directional data transmission transmits the measuring values but also the return of new measuring programs to change the procedure of the APG. The data management, the intelligent controlling and the bi-directional communication allows a very flexible use.

First tests of the APG with the redesigned system were done in Greece. Three APGs were prepared for different tasks. Further experiments were done with the "Institute for Oceanography" in Warnemünde on the "Darsser Schwelle" in the Baltic Sea. Co-operative field experiments in the southern of the Canary Islands and on the shelf line of the African continent were done in co-operation with the “Alfred-Wegener-Institut” and the ICCM. Three moorings have been done at Spitzbergen with the Institute of Oceanography in Hamburg. Different measuring tasks were realised in the Mediterranean Sea at Sardinia with the Institute of Oceanography in Kiel with support of IMC. A mooring was done in Norway with the aid of the Institute of Oceanography in Bergen.

Actions already initiated

MARVOR floats are used through EUROFLOAT and ESOP 2 projects which were funded by MAST III

Action Recommended

The length of the operational life duration of these equipments and the global amount of provided data show that they can be ranked in the operational category; however, some improvements have to be taken into account:

- The cost-effectiveness relies on the life duration (determined by the life duration of the critical components such as pressure housing, antenna or hydraulic parts). Production costs need to be reduced but without sacrificing reliability.
- Sensor packages to measure chemical and biochemical variables remain to be developed and evaluated for operational use. These packages are to be designed to meet the limitations of the float in weight, space and energy. A generic theme for all these developments is biofouling prevention which must preserve the sensors' characteristics and have very low energy consumption. That concerns the salinity sensors in particular.
- Low cost and higher data rate positioning and data retrieval systems need to be used, on the basis of the new low-Earth-orbit satellites facilities.
- EuroGOOS should promote development and improvement of profiling floats through the conduct of trials in the context of the Atlantic Pilot Project and the ARGO project.

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Ship-borne instrument packages

Summary of recommendations

As has been shown in the EuroGOOS working-document EG95.25 ("The potential use of European ferries for operational oceanographic observations") there are more than 300 ferry boats routinely operating within the coastal waters of Europe with frequencies varying between once a week to several times daily. In addition to these rather regional routes the long distance traffic from Europe across the major oceans to other continents contributes too, though on a less frequent basis. By developing and installing an operational ship-borne instrument package ("Ferry Box" for the ferries or "Blue Box" for other ships of opportunity, in analogy to the "black box" of a commercial airplane) several parameters and properties of the surface waters en route could be monitored without any additional plattform costs thus contributing to GOOS-Module 1 "Climate Monitoring, Assessment and Prediction" and GOOS-Module 3 "Monitoring of Coastal Waters". It is therefore recommended to develop, install and operate ship-borne instrument packages within the EuroGOOS community by using several approaches in parallel.

Introduction

Measuring and collecting data of surface water properties from a ship underway is not a new approach but has been performed for many years mainly on board of research vessels. Typical sensors and instruments that have been applied for such measurements are temperature sensors or thermo-salinographs using water which was pumped either from the ship´s own operational system or which was supplied to the instrument by an inlet system specially designed and dedicated for scientific purposes. But because of the operational scheme of research vessels the general monitoring information of such en route records is low because of the normally single passage through an area of interest without periodic repetitions.

The strong advantage of ferry boats in this aspect is based on their repetitive and routine coverage of well defined sections of coastal waters. Therefore they can provide high frequency time series of certain surface water parameters and a continous update of the most recent background in case of a sudden regional emergency within these coastal waters. These data sets are well structured for assimilation in water quality and ecosystem models.

EuroGOOS decisions

The EuroGOOS secretariat and the TPWG have already at a very early date started to discuss the possibilities of ferry boat instrumentation and operation for routine monitoring of coastal waters thus improving the technology capabilities and the operational conditions for GOOS Module 3 "Monitoring of the Coastal Zone environment and its changes". This early discussion has led to the establishment of a "Ferry Box Project" and accordingly to a "Ferry Box Working Group" as part and subgroup of the TPWG.

This working group has meanwhile met several times, in Dublin (Nov. 95), in Southampton (Apr. 96), in Le Hague (Oct. 96) and in Toulouse (Sept. 97), Brighton (March 98), Southamapton (Feb. 99). During the Toulouse meeting of the working group 17 participants from 8 European countries took part in the discussion which among several technological aspects underlined the need for further joint European action. It was decided that the Ferry Box Project (Project No.: EuroGOOS P96.04) will with a timescale of 2 years work on the "engineering feasibility and design study for a system of multi-sensor operational real time marine data gathering from ferry ships".

Description of the Technology

A ship-borne instrument package for routine operational monitoring of surface water parameters from ships of opportunity in general or ferry boats in particular consists of the instrument system itself and in addition necessarily of several auxiliary or subsystems as described by the following key topics:

- **instrument package:** sensors with electronics, front end µP-logic, bus system.
- **data aquisition and storage system.**
- **data telemetry.**
- **auxiliary subsystems:** seawater inlet/ supply system, debubbling system, filtration system (removal of suspended particulate matter), back-up sampling system, seawater discharge system.

Several sensors and instruments are presently available in the field as possible candidates for routine operation though it should be kept in mind that operational monitoring over longer periods of several days up to several weeks with unattended sensors requires careful selection criteria. Among these sensors and instruments are sea water temperature, electric conductivity, light attenuation, light scattering, oxygen concentration, spectral fluorescence, nutrient concentrations.

The technological task to be accomplished in the development of a ship-borne monitoring system for GOOS is the integration of some or all of these sensors and instruments in one autonomous operational instrument package which performs data sampling, data evaluation, data storage and data telemetry under way without any interference by an operator.

Though the hardware systems, especially the sensors and instruments, might differ widely according to the various commercial manufacturers on the market it has to be assured that the collected data are compatible with regard to their monitoring evaluation. This requires intensive collaboration among developers, manufacturers, operating agencies and end users within the EuroGOOS scope. This requires further inter-european standardisation and calibration with the advantage that European industries might be able to define world wide accepted standards for this type of operational equipment.

Actions already initiated and recommended

Extensive experience has been acquired in recent years by installing instrument packages on Finnish vessels in the Baltic, and trials are underway on ferries on the German coast, and between Southampton and the Isle of Wight.

Besides the already ongoing activities within the Ferry Box Working Group which are aimed at defining the technology and its incorporation into a working system there are several actions to be performed in parallel for the near future:

- Hardware activities based on national funding.
- Inter-European collaboration, either national funded or as Eureka project.
- Concerted Action with participants of several countries and EU funding.
- Consider a Shared Cost project in Framework 5.

An important aspect for the development of ship-borne instrument packages and their routine operation within GOOS module 3 "Monitoring of the Coastal Zone environment and its changes" are the costs and the time scales associated with the development. Both, the costs as well as the time scales, depend directly on the simplicity or complexity of the intended system which, in its simpiest version and for the purpose of demonstration only, could consist of just a few sensors but with all required auxiliary and subsystems.

Towed undulating vehicles

Sampling of large ecosystems at increasingly finer temporal and spatial scales can be prohibitively expensive. The problem of adequate sampling prompted Sir Alistair Hardy (1896-1985) to devise an instrument that could be deployed from ships of opportunity and the resulting samples preserved by non-scientists for late laboratory analysis. The instrument he developed was the towed continuous plankton recorder (CPR).

In Canada the Batfish undulating vehicle with instrument sensor package was developed in the early 1970s at the Bedford Institute of Oceanography. The developers of the CPR, the Institute of Marine Environmental Research (now the Plymouth Marine Laboratory Centre for Coastal Marine Sciences) produced an undulating oceanographic recorder in the 1970s. In a parallel development, the UK's Institute of Oceanographic Sciences (now the Southampton Oceanography Centre) produced the larger SeaSoar vehicle which is deployed from research ships capable of deploying large sensor suites at speeds of 10 knots down to 500 metres. The data are passed to the towing vessel in real time by the tow cable.

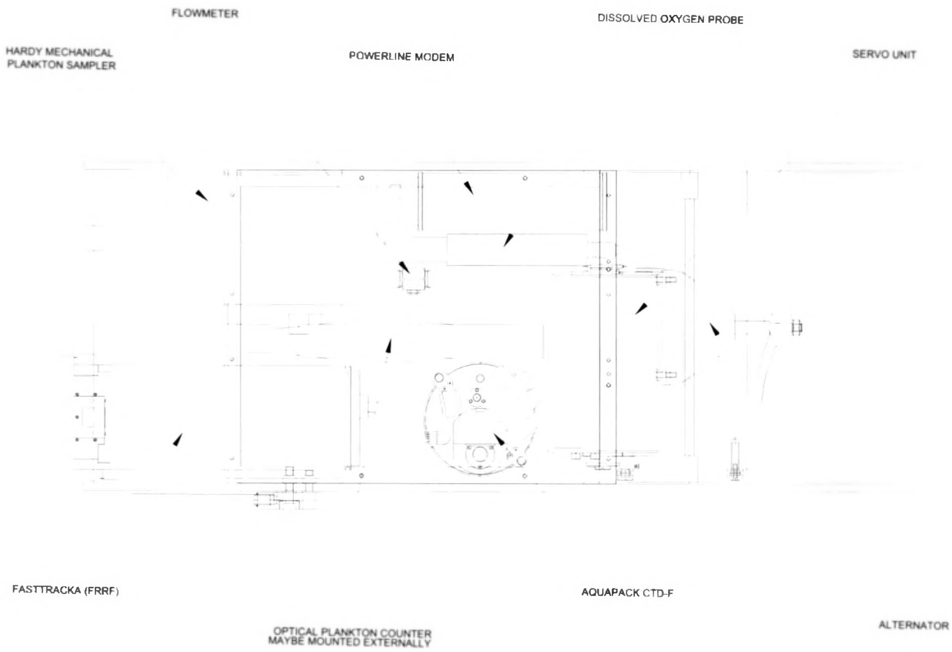
An undulating vehicle, with its full payload, must be able to generate sufficient hydrodynamic forces to overcome the drag on the tow cable and vehicle when diving; and the tow cable, vehicle and payload weight and drag on the tow cable reverse catenary when climbing. Paying out more and more cable to meet a stated depth requirement is only part of the story. When specifying a vehicle/payload/ cable system consideration must be given to not only the maximum depth required but also the aperture through which the fully laden vehicle must undulate and at what ship's speed. With a great length of cable paid out it is highly unlikely that the vehicle would be capable of generating sufficient lift to raise its own weight (including payload), together with that of the tow cable, to the surface. In summary, the vehicle, payload, tow cable/ fairing, ship's speed, maximum depth and the undulation aperture required form a highly constrained system with often little flexibility in the design solution.

Today there are perhaps 10 - 20 commercially available towed undulating vehicles. The range of depth capabilities is from a few 10s of metres to 600 metres. Most are towed at speeds from 4 - 15 knots, although a few can be towed at speeds up to 20 - 25 knots. The maximum payload available is less than $1m^3$ the penalty of the larger payload is the associated weight, (in air); 150Kg for the largest in comparison to 7Kg of the smallest vehicle. Costs of the vehicle range from 16 - 80 KECU. However, the costs of fairing and winch required for the larger systems can be twice or more than the cost of the vehicles. The following table provides a short summary of some of the available systems.

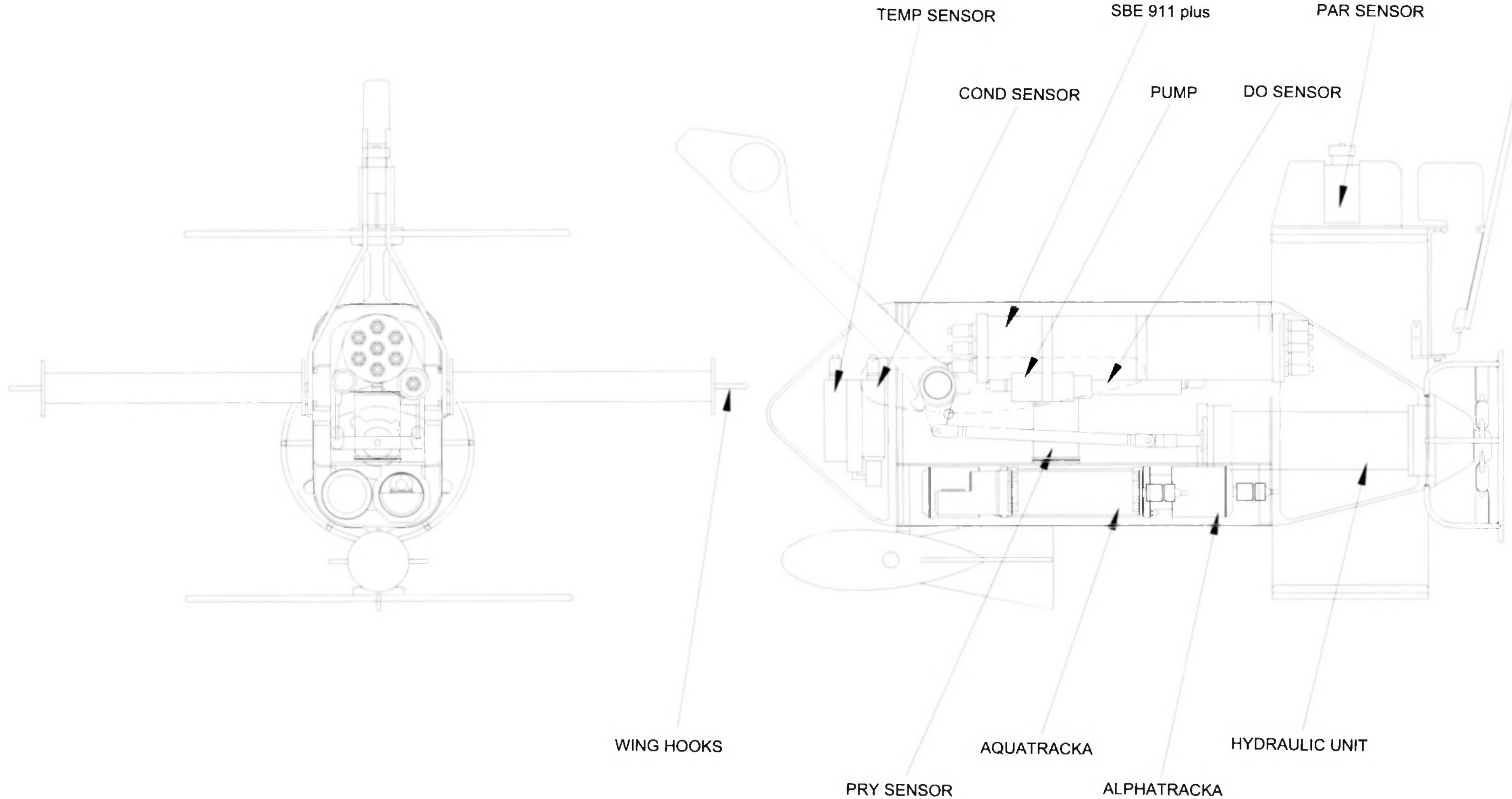
Most of the modern systems display Pitch and Roll GPS and the cable tension. Bottom avoidance, or perhaps should be more aptly named Bottom Warning systems are, or can be, included within the system. The sensor payload 20 - 60Kg, can accommodate a full range of the oceanographic equipment; C, T, Fluorimeters, Transmissometers, Nephelometer, Nutrient Sensors, Continuous Plankton Recorder, Optical Plankton Recorder, pH, DO_2 and REDOX. Indeed providing the instrument is not more than 1m in length, any recording package could be accommodated within the payload. To illustrate this point some typical system layouts are enclosed.

In the foreseeable future there is a European Programme to develop a robust ruggedised towed undulator independent of ship's power supply for deployment from ships of opportunity in support of existing long term data gathering programmes and those of the future such as EURO GOOS. It is difficult to see the market drive to develop large deep diving towed undulators as the development costs are significant and the market relatively small. The future development, if any, will be in the vehicles undulating to 100 - 200 metres with the aim to produce less expensive vehicles with greater payloads. However, the hydrodynamics of vehicles requires compromise; a long sleek shape for stability and minimum drag, but width is required to mount the instruments. The future thrust will not be in designing new vehicles but into reducing the size and power requirements of the instrument to be deployed.

Top view of a towed vehicle



Chelsea Instruments NuShuttle Towed Vehicle



ESTIMATED WEIGHT IN AIR : 200Kg
ESTIMATED WEIGHT IN WATER : 140Kg

Chelsea Instruments SeaSoar MkII Towed Vehicle

MODEL	DEPTH RANGE m	TOW SPEED (kts)	PAYLOAD AREA m^3	WEIGHT IN AIR (kg)	CARGO WEIGHT (kg)	DIVE SPEED m/s	CABLE TYPE ϕ / cond	CABLE LENGTH (m)	P & R	B A	G P S	C T
Guildline Minibat	60	up to 10	.75x.13x.13	7	?	?	8 / 7c	100	X	X	X	X
WS Oceans U Tow	100	4 to 20+	.63x.41x.18	40	60	1	N/S	N/S	✓	X	X	X
Chelsea Instruments NuShuttle	80	5 to 15	.61x.5x.2	72	70	2	8.2 / 7c	500	✓	✓	✓	✓
NuShuttle	150	5 to 15	.61x.5x.2	72	70	2	8.2 / 7c	350 / 150F	✓	✓	✓	✓
with Faired Cable												
Chelsea Instruments AquaShuttle	80	5 to 25	.55x.33x.2	66	50	.6	8.2 / 7c	500	✓	✓	✓	✓
AquaShuttle	120	5 to 25	.55x.33x.2	66	50	.6	8.2 / 7c	350 / 150F	✓	✓	✓	✓
with Faired Cable												
MacCartney Scanfish MKI	100	2 - 10	.75x1x.13	34	25	?	8.2 / 7c	200	X	✓	✓	✓
MacCartney Scanfish MK II	600	2 - 10	.8x1.6x.14	50	40	?	6.2 / Coax	2000	X	✓	✓	✓
Guildline 'Batfish' Series 8800	300	3 - 10	?	80	23	1	8.1 / 7c	400	X	X	✓	✓
Guildline 'Batfish' Series 8800	400	3 - 10	?	80	23	1	8.1 / 7c	600F	X	X	✓	✓
with Fairing												
Chelsea Instruments SeaSoar	100	4.5 - 12	1.2x.25x.45	150	?	1		500	✓	X	✓	✓
SeaSoar with Fairing	500	4.5 - 12	1.2x.25x.45	150	?	3		1000 / 750F	✓	X	✓	✓

P&R - Pitch and Roll option BA - Bottom Avoidance option GPS - Global Positioning System Input Option CT - Cable Tension Input Option

Acoustic Tomography and acoustic thermometry

Summary of recommendations

Acoustic remote sensing of the ocean interior on scales of tens to thousands of kilometres shows promise for monitoring the flow through passages/straits, for quantifying climatic changes in deep water mass structures and heat contents, and for routinely providing integral constraints in assimilation procedures. Since the technique has been proven to work in practice in a variety of settings, it is time to identify key regions where routine acoustics networks can contribute uniquely and where they can be gradually installed. Such sites include the Strait of Gibraltar, the interior of the Mediterranean and the source regions for the thermohaline circulation in the northern North Atlantic.

Introduction

Acoustic techniques like tomography and thermometry rely on transmitters and receivers installed in fixed places, either moored autonomously or cabled to shore. Problems in the moored mode are energy storage, time keeping, and data transmittal. All of these are not an issue when cabled instruments are used, but the logistics and engineering of laying a cable are not trivial. These are all technical issues which can be solved and which should be addressed in the next years. Once installed, tomography-like techniques will be able to provide continuous operational large-scale integrals of flows (i.e. transports) and stratification (e.g. heat content). In key regions, the transports would provide boundary conditions for basin budgets or model simulations, while the temperature integrals can be indicators of large-scale water mass changes and provide long-range constraints in models.

Key EuroGOOS decisions

There is a need for 'remote sensing' systems for the ocean interior which can supplement the surface observations via satellites and which can routinely give high-accuracy data for the deep ocean. The "EuroGOOS Plan" (publication no.3) recognises this in the 'Global Pilot Project' section and this is also an element in the CLIVAR implementation plan. Acoustic tomography/thermometry techniques can fulfil this requirement and should therefore be pursued. "The Strategy for EuroGOOS" (publication no.1) cites as a medium-term objective to investigate the routine application of techniques at present experimental such as acoustic tomography. The "Science Base of EuroGOOS" (publication no.6) distinguishes a hierarchy of methods (from operational to innovative) which lists tomography and thermometry as worthwhile candidates. Tomography is already an element of the second phase of the planned EuroGOOS Mediterranean Forecasting System (see the "Strategy for EuroGOOS"). The CLIVAR implementation plan embraces 'end point' techniques like these, which can sense the ocean interior between two fixed instruments/moorings.

Description of the technology

At present, tomography is used in an individual mode by few specialised groups world-wide. Work is already underway as part of a MAST-3 project which aims at making the analysis of tomography data more routine and operational and at transferring some of the expertise to SMEs. New instruments are being developed in various places at this time, to improve the efficiency and other technical aspects of the equipment. A new expertise that needs to be established is the installation of cabled instruments. This should be addressed in the first round of post-MAST3 proposals. Using such support, within 5 years the first pilot permanent systems could be installed, e.g. in the Strait of Gibraltar. The experience from that could be used to achieve first fully operational systems within 10 years.

Actions already initiated

As pointed out above, a MAST-3 project (OCTOPUS) has been initiated which aims at advancing tomography to a more routine level. A pilot experiment in the Strait of Gibraltar with autonomous instruments has demonstrated that the technique is feasible and accurate.

Action Recommended

For each application planned, the availability of suitable types of sound sources should be explored. Depending on frequency, a considerable range of sources exists already, while new types are also under construction currently. For land-cabled applications, new or at least modified electronics packages need to be built, but these also could the follow the design of existing systems. The main challenge lies in the actual laying of cables to shore. Here work is required to find out where in Europe this expertise exists and how it can be used cost-effectively. Since this is hardly scientific work, an industrial collaboration seems to be the way to go. However, the efforts should be quality-controlled and co-ordinated with the overall goals in mind by a group experienced in acoustic tomography, of which there are two in the EU (IFREMER/Brest and IfM/Kiel).

Meetings, travel, workshops

No meetings are currently required, since the interested community will without doubt become active and start the work when the funding time frame is known. This could be as early as summer 1998.

Communications

The use of tomography in a routine mode could be improved by communicating first successes of pilot monitoring deployments. This will take another 4-5 years.

Costs

No costs other than implementing the technology itself, which would need to come from proposal funding.

Funding sources

The most likely funding source is the EC through the 5th framework program. Strong collaboration with industry and SMEs will be required for the implementation.

Collaborating Agencies

There are some groups at research laboratories in the US which should be involved, since they have greater experience from ATOC work. A suggestion is to collaborate with them in the framework of global GOOS or CLIVAR.

References

"The Strategy for EuroGOOS" (publication no.1).

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WWW page for the CANIGO Strait of Gibraltar pilot experiment:

http://www.ifm.uni-kiel.de/ro/canigo/gibraltar_1.html

Acoustic listening arrays, tracking

Summary of recommendations

- Request access be granted to the military acoustic arrays located in the Atlantic.
- Negotiate further utilisation of operational oceanographic techniques which have been limited to military use in the past.
- Establish a EuroGOOS Military Liaison policy.
- Undertake a cost benefit study into the value of having access to the acoustic listening arrays.

Introduction

The Atlantic contains a number of military fixed acoustic arrays from which valuable data on the state of the Atlantic could be collected either as ATOC or in conjunction with a planned programme of SOFAR type float deployments. The routine provision of this data would enhance the EuroGOOS planned capability to produce timely and accurate oceanographic forecast products for the region.

The Acoustic Thermometry of Ocean Climate (ATOC) experiment [1] brought to the attention of the civilian oceanographic community the potential to use the United States Navy's fixed seabed acoustic arrays, known then as the SOund SUrvelliance System (SOSUS), in climate studies. The ATOC experiment proposed to use the USN arrays located in the Pacific to assist in determining the presence and magnitude of seasonal and interannual temperature changes in that ocean. The new system is called the Integrated Undersea Surveillance System (IUSS).

In June 1993 Dr J Gould was invited by the Scientific Committee on Oceanic Research (SCOR) Working Group 96 (Global Acoustic Monitoring of the Ocean) to form a subgroup to investigate the need for an Atlantic ATOC programme. One of the conclusions of the report produced by the WG [2] was that an array of approximately 10 autonomous receivers in addition to any fixed USN/USAF receivers that may be available will be needed to resolve the known spatial scales of decadal thermal anomalies in the area

The mid 1990s saw a significant increase in the interest [3] in utilising military acoustic listening arrays. A proof of concept project entitled the National Oceanographic Environmental Monitoring System (NOEMS) was put before the Department of Defence (DOD) [4] by an industry and NGO partnership. The concept was to gain access to the recently abandoned Bermuda SOSUS array to provide a wide range of environmental data to the civilian community. The DOD at the time was looking at "dual use" of defence system technologies and as part of this review had already provided access to SOSUS data to a small group of federal agencies. This access showed the department the value of making data collected from SOSUS available to the wider scientific community. The navy subsequently agreed to provide equipment and the necessary access to the array to allow the partnership to pursue the proof of concept.

EuroGOOS needs to understand the Atlantic and be able to predict its state. This will enable it to produce the range of operational oceanographic products it has identified, in its published strategy [5] and plan [6], as being required by its potential European customer base.

Key EuroGOOS decisions

The decisions with respect to this topic are laid down in the strategic objectives sector 4. [5]

Overall Strategic Objective

To analyse existing technological systems available for operational oceanography, estimate the optimum technology needed to implement different phases of an operational forecasting service, identify gaps in technology, and foster the development and application of new technology to improve forecasting.

Medium Term Objective For EuroGOOS up to end 2002

To investigate the practical applications on a routine basis of techniques at present experimental, such as tomography, new sensors for chemical and biological variables, combinations of sensors and telecommunications, automatic data quality control and data assimilation, and the potential use of AUVs. **Explore the use of mid-water floats and acoustic tracking on a routine basis.**

Links to other programmes

WOCE
ATOC
NOEMS

The description of the technology

The technology relating to the arrays remains classified. However, the following references [1] and [4] describe the technology required to patch into the data from the arrays

Actions already initiated

The Director of WOCE has already requested access to the military acoustic arrays in the Atlantic.

Action already recommended

None

Meetings, travel and workshops

- The following meetings are suggested
- With the NATO MILOC committee
- With the national defence departments responsible for the military arrays
- The formation of a EuroGOOS Military Liaison Policy
- With relevant defence suppliers of the technology

Communications

None.

Costs

The main costs in developing this technology will be in the provision of the data recording, data analysis and the secure array interface capability. It is recommended that a cost benefit study be undertaken on the implementation of this technology by EuroGOOS. The experience gained with the setting up of the ATOC, NOEMs and Sea Sentinel projects should be used.

Funding Sources

None currently identified. However the proposed programme of meetings would need support.

Collaborating Agencies

NATO
ONR (Europe)

There are a number of defence contractors who work in the area of producing fixed array systems that it is recommended that EuroGOOS try and collaborate with. However, due to the sensitive nature of this subject it is not intended to list these at this stage.

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4] Cox, D (1996). National Oceanographic Environmental Monitoring System. Sea Technology November 1996 pp 51-52.

5] Woods, J D, H Dahlin, L Droppert, M Glass, S Vallerga and N C Flemming (1996) The Strategy for EuroGOOS. EuroGOOS Publication No. 1. Southampton Oceanography Centre, Southampton.

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Autonomous Underwater Vehicles

Autonomous underwater vehicles have been under development by the military and civilian research community since the 1970's. Busby compiled a comprehensive review of progress up until 1987, [1]. Over the last three years significant advances have been made, in particular, vehicles are now completing missions as well as acting as test-beds for technology development. AUVs are no longer engineering curiosities.

Major projects underway in several countries are now at the stage of demonstrating autonomous missions of real scientific and commercial utility. A survey of coastal fronts in Hero Strait, British Columbia was completed in June 1996 by the Massachusetts Institute of Technology's Odyssey II vehicle, [2]. Careful comparisons have been made of the temperature and salinity measurements from Odyssey with those from a conventional CTD [3], knowing the quality and limitations of measurements is an essential prerequisite for the use of AUVs in operational oceanography. In April 1996, in an operational task, a 175 km long fibre optic cable was laid under sea ice in the Canadian Arctic by ISE Research's Theseus AUV, [4]. Repeated magnetic and physical observations have been made by Woods Hole Oceanographic Institution's ABE vehicle in the region of the Juan de Fuca ridge in 1995 and 1996 [5,6] and trials off Florida by Florida Atlantic University's Ocean Explorer vehicle [7] have shown that it was possible to reduce the vehicle self noise and vibration to such an extent that meaningful turbulence measurements could be made.

As storing the energy to provide propulsion remains a problem for conventional AUVs, an unpowered glider, Slocum, has been developed by Webb Research Corporation. The vehicle obtains forward motion from control surfaces that utilise part of the energy obtained from a buoyancy change engine 'fuelled' from the temperature gradient in the ocean [8]. Slocum has already been used to survey the physical oceanography of the Sargasso Sea, completing 113 profiling cycles between October 1995 and June 1996, albeit using a powered buoyancy change engine [9].

Recent developments in high-capacity disk storage devices and in fibre-optic cable spooling and high data rate acoustic communications from underwater vehicles have led to AUVs carrying extensive and complex sensors including an advanced laser line scan imager [10] on Applied Remote Technology's XP21 vehicle and a swath bathymetry sounder for a survey of Oslo Fjord by HUGIN I, an AUV from a Norwegian government - private sector consortium [11]. The consortium are already marketing HUGIN services to the offshore oil and gas industry. The MARTIN AUV from Maridan has demonstrated the use of a sophisticated collision avoidance sonar and processing system in real time to navigate the vehicle through a series of obstacles [12]. This successful demonstration brings the concept of an AUV routinely navigating in confined waters one step closer. The UK Autosub vehicle has completed over 140 missions (up to November 1998) and the vehicle technology has been licensed to Chelsea Instruments Ltd. [13]

Transnational projects supported by the EU have helped to accelerate the development of AUVs within Europe and have greatly increased the cohesion and information interchange between national groups. A seven member, three nation consortium conceived, designed and built the Marius vehicle, which included several technological innovations in the areas of command and control [14]. Another major EU project undertook generic systems research for AUVs tackling issues in acoustic navigation, composites for pressure vessel and command and control, as well as exploring common science mission scenarios across a number of European laboratories [15]. AUVs have been also proposed as a key component of multi-institution, multi-platform underwater surveillance and monitoring systems [16] and initial feasibility trials have taken place involving moored and free swimming constituents communicating with each other and with scientists ashore using acoustic and radio communication [17].

Even with these tremendous achievements a number of issues still need further consideration before AUVs can become routine platforms for operational oceanography. These issues include:

- **reliability of hardware, software and mission definition**. The reliability of electronic hardware and even underwater connectors is now sufficiently high (or sufficiently well known) to enable mission duration of over a hundred hours to be performed with low probability of failure due to hardware problems. The latest generation of AUVs that utilise distributed network architecture and highly modular software have a high mean time between irrecoverable software crashes. Perhaps the area that currently limits reliability is in mission definition. Some vehicles use very simple mission scripting languages, but most use complex sequences of commands and parameters that cannot be formally verified. Research and development is required to apply formal methods to the design and implementation of AUV mission scripts.

- **on-board energy storage**. This is still the major limiting factor for long range AUVs. Even using low weight-to-displacement ratio pressure vessels, today's battery technology puts a practical/cost-effective limit of about 500 km on AUV endurance. Recent experiments with semi fuel cells, fuel cells and sea water batteries suggest that this barrier could be overcome by the year 2000, but several safety and operational questions would need to be tackled. Lithium ion secondary batteries would be an attractive option, if their cost was to decrease by an order of magnitude. This is not impossible given the interest of some automobile companies in developing cost-effective electric vehicles with significant range between recharging.

- **legal issues**. International maritime law does not, at present, acknowledge AUVs. Their status is uncertain. An working group of the International Research Ship Operators Meeting is attempting to address the issues of operating AUVs in coastal, EEZ and international waters. Allied to legal status is the third party liability of AUV operators. Liability insurance can be obtained for AUVs, but the author is not aware if contingent liability can be insured, that is, if an AUV is used in an operational context and fails, then it may be difficult to insure against the repercussions of that failure for the customer.

- **data telemetry**. Operational uses of AUVs will usually require data transmission in near real time. For distances of 10's of km then radio telemetry when the vehicle is on the surface is a proven solution. Acoustic communication should not be relied upon in an operational scenario unless a network of acoustic systems has been installed in the working area. Spooling bare optical fibre from an AUV has been demonstrated, while offering a very high communication bandwidth there is a significant cost and the range is probably limited to less that 200 km. The cost-effective option is probably to use the new generation of low earth orbiting satellites such as ORBCOM or STARSYS.

In summary, many of the aspects of the use of AUVs for operational oceanography have already been demonstrated over the population of AUVs designed and used by the research community. No one AUV yet has all the attributes that are necessary. Undoubtedly such an AUV could be constructed and could see service in the first few years of the next century. European industry, in association with European research institutions, is well placed to deliver a family of vehicles adapted to specific requirements.

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Fixed profiling instruments, pop-up systems

Summary of recommendations

Fixed ("eulerian") in situ CTD (or density) profiling observations, achieved through a network of either anchored or pop-up systems, are ideal to supply data for the ocean circulation numerical models, being a natural complement to surface satellite observations. As such, they are a key technology for the GOOS.

They offer unique advantages to the model designer and to the sea operator, which makes them important for identified application sectors of the GOOS ocean basin and climate module observations.

For other application sectors of the GOOS climate module, they must be considered as a potential complement to profiling drifting buoys, but are presently limited by (1) their relatively high "cost per profile", (2) the fact that their technology does not benefit from the experience gained through former large scale programs (WOCE).

We recommend the continued engineering development, field trials and, based on the experience of trials, the deployment of YoYo and pop-up devices in the prototype observing systems of GOOS.

Introduction

Moored profiling systems have been well known as a method to obtain upper-ocean time-series data since the '70s (van Leer et al., 1974, Eriksen et al., 1982). Recently there have been several efforts to extend the depth range of these instruments from 1000m (Provost et al., 1996) down to full ocean depth (Doherty et al., 1998). The main advantage of these instruments lies in the fact that with one set of sensors the predetermined depth range can be continuously sampled. This allows a better spatial resolution of the measurements compared to fixed instruments with a separation of about 50m. Additionally where multiple sensors are used the drift and the offsets of the individual sensors are unknown so that interpolated profiles from fixed sensor chains are questionable. Therefore employing a profiling instrument carrier will allow new insight into the study of mixing processes in the sea.

A fixed profiling instrument or a pop-up system is designed to generate time series of ocean parameters observations along one water column, - and to transmit the collected data to a processing centre via generally a radio link (Data collection satellite or direct link to shore).

Two types of fixed profiling instruments can be cited: (1) "YoYo" systems, when profiling the water column is obtained by moving up and down the sensors either along a rope (for deep sea operations) or at its extremity (for near shore operations). (2) chains of sensors, fixed below an anchored buoy.

In a pop-up system, the time series of profiles is generated by a set of free-flying lighter-than-water sensors-carrying probes, released sequentially from a sea bottom frame. Probes are generally expendable.

When a plurality of fixed instruments or systems are operated in a co-operative manner from a plurality of locations, it becomes possible to realise a 3D ("Eulerian") sampling of the water mass.

Interest for operational oceanography

YoYo instruments and pop-up systems operate in a systematic, automatic, non-manned way, ideally suitable for "operational" oceanography. The limitations of their use is due to technical feasibility factors which reduce the practical lifetime and increase the cost of operation, such as: (1) sensitivity of the sensors to fouling, (2) sensitivity of the mechanical parts (if any) to wear and sea corrosion and accidents (incl. trawlers and vandalism), (3) difficulty in establishing the data collection link.

Nevertheless, eulerian sampling instruments and/or systems offer the following unique advantages: (1) they can be operated in ocean currents, straits, capes, etc. where drifting buoys would be rapidly swept away, (2) they give to the ocean circulation model designer the possibility to clearly separate the time and the space components of a water mass motion, (3) they operate over the whole water column (except for the chains of sensors).

Description of the technology

Fixed profiling instruments

Several types of fixed profiling instruments have been proposed, either for deep sea or for near shore applications.

Fixed profiling instruments moving up and down along a deep sea anchor rope have been prototyped and experimented. Their design is mostly aimed to satisfy scientific investigation using heavy analysers and to operate as a stand alone station.

Fixed profiling instruments have also been proposed and experimented to cover near-shore applications. The sensors, mounted on a lighter than water container, are moved up and down by a winch stored on the sea bottom. Their limitation is mostly due to energy storage and sensor fouling problems.

An advanced system is the so called "Crawler" of the WHOI (Doherty et al.). The main advantage of this system is the high efficiency of the propulsion system. To achieve a similar performance with a buoyancy driven system calls for a special design of the pressure housing with the aim of a small overall volume or some sort of compressibility compensation. The draw back of the "Crawler" design is the close contact to the mooring line. There may arise problems with the transfer of disturbing motions of the line to the sensors or failure to complete a cycle due to biofouling on the mooring line. The advantage of buoyancy driven profilers is that they behave almost like free rising systems. The transfer of disturbances from the mooring line is negligible. This enables such systems to do high precision current measurements.

Due to the fact that all these systems are connected to the mooring line they lend themselves to the employment of inductive telemetry as a mean to communicate. Therefore an on-line transfer of in situ data is possible.

The cost effectiveness of such systems lies in the fact that a single device covers a large depth range. On the other hand it has to be proved that the reliability of such a technique is comparable to existing methods.

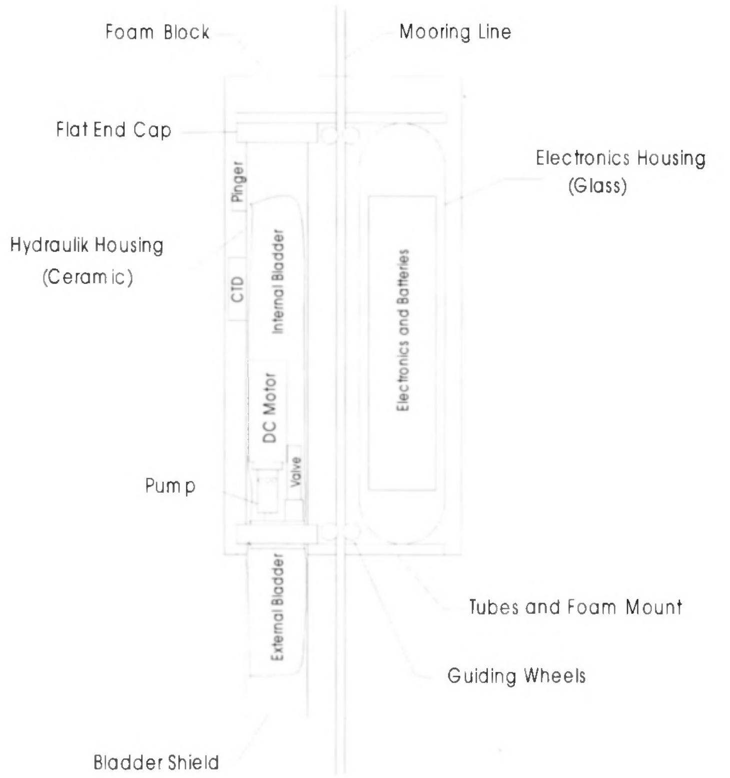
Currently there are groups in the US (Toole, Doherty, WHOI), France (Provost) and Germany (Waldmann, University of Bremen see figure, Budeus, Alfred Wegener Institute, Bremerhaven) engaged in pursuing deep sea profiling YoYo instruments. The first successful tests have been accomplished but it is still questionable which concept will survive over deployment times of 6 months and more.

The Externally Powered/Compressibility Compensated YoYo (EP/CC-YoYo) is a moored profiler designed for special applications. It is originally developed to monitor changes caused by winter convective events in the polar regions (Greenland Sea).

Basic demands were:

- deep profiles (typically 4000 m)
- many profiles (typically 360, i.e. 1 profile each day for 1 year)
- self contained vehicle (internal data storage to avoid problems with ice in arctic regions)
- measure C, T and p with precision high enough to indicate convective events in polar regions
- light construction for easy handling.

The design for the EP/CC-YoYo utilises the potential energy of weights (made from lead) for the power required to descend. The system is divided into two main parts: The vehicle moving down and up, and the control unit at the top of the mooring line, containing the weights and supplying them in preselected time intervals.



Deep Ocean YOYO-Profiler (MARUM, Bremen, 1998)

The control unit contains one weight for each profile (360 weights). Each weight amounts to 690g in air, of which about 470g are used to drive the downward movement of the vehicle. Such a weight is placed onto the vehicle at the time a cast shall start, and it is removed when it reaches the ocean bottom. The vehicle itself is balanced to possess some buoyancy and to ascend by itself, finally reaching the control unit again. The upward speed is much slower than the downward speed (0.7 to 1.0 m/s), and measurements are performed only during the downcast.

EP/CC-YoYos have already been moored in the Greenland Sea, demonstrating the principal functionality of the system and providing some experience about their performance. Somewhat more than 20 profiles show that the vehicles can be balanced correctly and that the planned speeds are reached. Refinements are necessary, however, to make the system fully operational.

Further developments should include:

- communication between vehicle and control unit to download data and allow for flexible time schedules
- communication between control unit and ship to access data without recovering the mooring
- tests about the behaviour of the EP/CC-YoYo in stronger currents.

Pop-up systems

A system concept (named EMMA) using free-flying lighter-than-water expendable probes, carrying sensors and RF transmission equipments, to be released sequentially from a frame stored on the sea bottom, has been proposed by the BrIO Company, to match the requirements of an operational in situ ocean observation network. Such a design minimises the technical limitations inherent to eulerian systems: (1) as the sensors are used only once, they can be protected during storage by a tight capsule, what eliminates any fouling problem, (2) as the tight capsule can be fulfilled with a calibration liquid, it is possible to make a calibration of the sensor chain just before pop-up, (3) the equipment does not include any part subject to wear, corrosion or vandalism, and uses commercial electronic parts subject to cost reductions.

Due to these features, the system should offer (1) a high quality and reliability of the measurements, (2) a long storage capability, (3) "operational" conditions of use. It can carry C & T but also optical sensors (for example, direct density via refractive index measurements). Its marginal cost per profile is estimated to be less than 2000 Euros in 2003 by quantities of several hundred buoys, and less than 1000 Euros with time and increased quantities.

Key EuroGOOS decisions

The Eulerian profilers are positioned within the EuroGOOS strategic sector 4, "Technology for EuroGOOS" (EuroGOOS Publication No. 1, p.58).

Links to GOOS, WOCE, CLIVAR

Profiling systems are important for global science programmes, as for operational oceanography.

Actions already initiated

EMMA/CTD: the development of a demonstration prototype making CTD measurements has been undertaken by IFREMER under BrIO licence. Appropriate resources have been engaged. First sea tests are scheduled for late 1999. Next actions to be defined after these demonstration tests, by the beginning of 2000. The German EPC-YoYo system is in the stage of advanced trials.

Action recommended

EMMA/Optical: the technical preliminary studies for integrating an optical refractive index measuring device developed by the Kiel and the Bremen University (Germany) into an EMMA vehicle should be encouraged and possibly funded. The significance of extended use of profiling and YoYo instruments should be studied in terms of the impact of the data on models and data assimilation.

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Data management technology

Objectives and Overall Requirements

The importance of data management for GOOS has been stressed in several documents and will be a main component of the EuroGOOS system. The objectives are :

- to organise the data circulation,
- to insure the quality and comparability of the data collected from different sources, for different community of users in data products,
- to offer fast delivery of oceanographic data and data products for scientific, forecasting, industrial and environmental needs,
- to safeguard the collected data and meta-data for the future.

On the long term, it aims at preparing long time series of qualified data for climatic and ecological studies which will constitute baseline studies for the assessment of environmental changes. The data archived will also be used to improve the climatological statistics and qualify the new data.

The data management requires :

- a common data management protocol,
- a data management structure equipped with hardware and software facilities,
- co-operation between countries and training in data processing, data qualification, archiving and communication.

Elements of these requirements exist in most of the European countries, however there are needs for development and progress. These requirements are discussed in the present document, which is based on previous GOOS documents and the data management systems developed for several international projects.

Organisation of the Data Circulation

Monitoring systems, operational observations, and oceanographic cruises result in wide numbers of measurements and generate a large suite of processed samples, analyses and products. The data flow has to assure the dissemination of all data acquired by the different groups among the EuroGOOS participants, selected users and public users, and their timelines. The data flow can be distinguished into three main categories: 1) the real time (or near real time NRT) data flow; 2) the delayed mode data flow; 3) the information (meta-data) flow. The policy to access these data and meta-data has to be defined with simple rules.

Real Time Data Flow organisation

The real time data flow will give access to observational data and forecasts :

- in-situ data collected by the operational system, fixed stations, drifters
- in-situ data collected by ship of opportunity
- remote sensing data (altimetry, SST, ocean colour, waves)
- meteorological forcing data
- analysed and forecast data produced by models

Delayed mode data circulation

The observational data, which have been compressed, reduced or decimated to allow fast transmission, should be replaced in the database by complete and fully validated delayed mode data when available. When several levels of processing are available, the archived data are normally the best available data set, that is the validated delayed mode data set rather than the real time data and the higher level of processing. However if this has not been transmitted, or for any other reason, it must be decided if several levels of processing have to be archived.

The long term archiving parameters which have been reviewed as having a high impact on the health of the ocean like dissolved oxygen, nutrients heavy metals and temperature have to be ensured. It is recommended to integrate these newly collected data sets in an historical database of the same type. Derived computed parameters like density and sound velocity which are currently used in the off shore industry have to be made accessible.

Information flow organisation

It is important to have a permanent visibility of the system and to make easily accessible general information (meta data) and catalogues namely :

1. methodological documentation including formats and instruments/sensors inventory.
2. ship schedule and cruise summary reports.
3. fixed stations and drifters inventory.
4. data sets inventory.
5. general EuroGOOS information and news.

Quality Assurance

Data Quality Assurance has to be ensured in the operational data management, at all stages of the data collection, processing and archiving.

- For data collected operationally, the validation cannot be made systematically by scientific laboratories. This will be made mostly automatically by the data management structure. However it is important to ensure that the procedure is:

    - In accordance the internationally agreed standards and well documented.
    - Intercompared.
    - Performed as soon as possible after the data collection.
    - Supervised by quality experts and regularly reviewed.

- As the data collection represents a high cost in time and money, it is very important to ensure that the collected data set is usable. Regular cross-checking including automatic and visual procedures, and comparison with other data sets, have to be performed, and the results of these checks transmitted to the data originators, for possible action on the data collection. The temptation of avoiding to ask the originator to change procedures, in order to spare susceptibilities, is a potential danger which has to be resisted.

The data processing and quality checks procedures are specified in the data management protocol for each data type. Basic data like temperature and salinity have internationally agreed standards, but this is not the case for heavy metals, toxic algae, and other biochemical parameters and these have to be developed. (See GOOS HOTO for example).

The execution of the defined tasks requires motivated and adequately trained personnel and appropriate facilities. The presence of skilled, multi-disciplinary groups, and of independent assessors from International Organisations will ensure the quality of the data products. EuroGOOS should work closely with SeaNet on these issues.

Common data management protocol

The data management protocol has to ensure comparability, coherence and communication. It covers several items.

Archiving specifications

Archiving specifications have to be defined for the common tools and products :

Catalogues:

- Cruises, ships, fixed stations, Lagrangian platforms.
- Instruments.
- In situ, remote sensing, atmospheric forcing, model data sets.

Documentation:

- Methods for data collection, data validation and archiving.
- Experimental reports.
- Technical manuals for software and user manuals.

Data dictionary:

- The key words used in the meta-data.

- The reference and observed parameters with common names, units, number of significative numbers and also control values for the quality checks.

- Data exchange formats, which take into account that real time data format and delayed mode have different constraints:

- Real time format must be compact.

- Delayed mode format must (according to international recommendations IOC/ICES) include environmental data on the condition of measurement (meta-data), be auto descriptive and independent from computer for the archiving.

Data Processing and Quality Checks

Data processing

Several levels of processing can be managed. Raw data may be transmitted in real time, and correction for instrumental errors or methods may be necessary. The methodological documentation has to be detailed and widely disseminated.

Quality checks

In conformity with the international UNESCO/IOC and ICES recommendations for data banking, quality checks (QC) have to be performed on the final data sets and meta-data. As a result, quality flags are added to allow direct use of the data without modifications. They include :

QC 0: Check of the format and completeness of information

QC 1: Check for date and location - check of the navigation - search for duplicates

QC 2: Check of the observations : they are adapted to each data type, but include at least broad range checks within sub-basin maximum and minimum values, detection of spikes, and comparison with local climatological values when available.

Data Products and Services

Continuous data and information services include:

- Updated catalogues and documentation, on WWW servers with hyperlinks between topical validation centres, archiving centres, modelling centres.
- Ftp anonymous servers are very efficient for exchange of data and documentation (manuals and annual reports).
- Forecasts on WWW.
- Observational data on request on ftp servers or electronic media.
- Analysed data, climatologies and gridded data products also on ftp servers or electronic media.

Operational data generated for real time applications is usually covered by an agreed data policy for real time exchange and use. EuroGOOS has established a Data Policy Panel to develop procedures in this context. The data of oceanographic programmes, after the confidentiality period, are normally released in the public domain through electronic data publishing like CDROM, for no more than the cost of reproduction and distribution.

Data Management Structure

A distributed Data Management structure

It is noticeable that the existing meteorological forecasting system has retained national agencies and data centres after setting up European and global collaborative systems. Some duplication of the tasks ensures the safeguarding and better sharing of the responsibilities. An operational data management system for the ocean will similarly include distributed topical and regional data assimilation, modelling, and archiving centres. It is likely that the European countries which will contribute to the data collection in their economical areas, will participate also to the data management system. A partial duplication of the tasks will ensure quality and security.

Topical centres can have a specific responsibility for data validation, real-time processing and preparation of the forecasts and model outputs. The IODE network of designated National Oceanographic Data Centres can be developed to manage the delayed mode data, perform the final quality checks and to integrate the collected data set in larger historical data sets of the same type.

Software and Hardware Requirements

As the measurements should be routinely managed, and the dissemination of products carried out on a regular basis, hardware and software facilities have to be available, with performance and effectiveness in the procedures. They will include :

- Software development for data processing, quality checks, preparation of on line catalogues (WWW technology), preparation of data products and dissemination of data.
- Hardware properly dimensioned for running expert software and handling large volumes of data.
- Networking : the project implementation prerequisites good communication links, through electronic mail, WWW servers, and anonymous ftp disk for data dissemination.
- Electronic data publishing facilities : delayed mode data will be published on CDROM as a complementary tool for a wide distribution, with extraction and visualisation software.

State of the art and necessary progress

Oceanographic data management

It was reported by GOOS (UNESCO, 1996) that the present status of international data management including archiving and retrieval is inadequate to deal with the demands imposed by GOOS, and needs to be improved. See also the GOOS 1998 Prospectus for an outline of GOOS data management. The major requirement was that all data, either derived from research projects, regional monitoring activities, fishery research or classified military activity, need to be made available. It has been recognised further that methods and standards for archiving and exchange are in use only for physical oceanographic data, but are lacking for chemical oceanographic data. To encompass these problems, it has been recommended to be develop protocols for data receipt, verification and validation, in order to ensure that the GOOS data archive contains reliable data to assess the health of the ocean.

The pessimism of these assessments which apply to the global ocean data management, may be moderated for the European seas. In the frame of the UNESCO/IOC/IODE programme, several countries have established a National Oceanographic Data Centre (NODC) or a Designated National Agency (DNA) for national archiving and international exchange. Even if there is a often a gap between the official missions and the real state of the national data management, these centres do archive observational data and can be developed for the needs of EuroGOOS. Marine meteorological data are managed routinely in real time by the major European Meteorological Offices, and increasingly the Met Offices and Environmental Agencies collaborate to run operational marine models in real time.

In addition to the observational data archiving, gridded statistical climatologies of good quality have been produced for temperature and salinity, up to the monthly time scales, at large (basins) and small (coastal areas) space scales. Climatologies are also available for a limited number of bio-chemical parameters at large (global ocean) scale. They make use of advanced methods like variational interpolation and kriging, which have been successfully applied and intercompared. However the quality of these climatologies depends on the availability of observations and therefore on the geographical area. They have therefore to be updated when an important number of new data are released.

All the European countries have internet mailing facilities, but this is not yet the case for all the neighbouring countries. This is more crucial for the WWW server technology, the situation is improving very fast, and the centres already equipped can offer a site for web pages for those who do not have them yet.

Transfer of Knowledge

The development of National Information Systems and the management of the coastal data is a basic requirement of the system. The use of a common formatting system, and common quality control procedures has to be ensured. It needs to improve co-ordination, co-operation and exchange of information among data managers transfer of expertise and knowledge.

Expert systems for quality assurance have been developed by several data centres, with different versions depending on the hardware platforms. Some of these systems have been inter-compared to confirm that they provide identical control of data. Transferring methodology and software will ensure a comparable level of quality in the operations.

Priority has to be put on job training, through visits to the regional data centres. This exchange of visitors will help to avoid misunderstanding and usual communication difficulties, which can raise at any step of the project implementation, even with the best written specification manuals. More advanced regional centres must be encouraged to offer facilities for visiting scientists of other centres, and release their software tools and know-how.

Operational models, supercomputers, data assimilation

Summary

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' running at other agencies and institutes should be developed. 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.

We must establish user requirements for model forecast products, especially identifying viable commercial applications, or identifying a 'public good' to encourage funding from central Government agencies and elsewhere. This will allow further development of operational oceanography.

We must identify which requirements are needed in 'real time' and which are needed 'offline', possibly using the latest monthly or seasonal values of meteorological and physical oceanographic parameters.

Introduction

Numerical models are an essential tool for forecasting hydrodynamic and oceanographic variables, and for studying the complex interactions between motions and processes on all time and space scales.

Present status of real-time operational modelling

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, but not yet run operationally in real time as a viable commercial market has not yet been fully demonstrated. These models are valid only on the shelf, in waters of around 100m depth or less that are generally well mixed. Coupled wave-tide-surge models are available but need careful tuning and setting up to perform as well in all cases as the present operational surge models. For that reason operational use is not widespread at present.

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.

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. An ocean scale operational modelling programme under development is the French MERCATOR project.

Data assimilation and observations

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. For example, correlation scales need to be established, and the use of feature modelling could be explored further. Some of these issues will be addressed within the planned European Shelf Ocean Data Assimilation Experiment (ESODAE) project of the EuroGOOS NW Shelf task team.

Surface observations of meteorological parameters and fluxes are required, to compare with NWP model predicted surface fluxes.

Description of the technology

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). Surface fluxes from an appropriate resolution NWP model are required for each ocean model.

Experience in NWP has shown the need for a range of types of model, employed in a range of applications, to assist in identifying priorities for development of model formulation.

Model formulation

Trials of global coupled wave-atmosphere models have been run, particularly at ECMWF, demonstrating a small but positive impact. However coupled wave-atmosphere models are not in widespread operational use.

Coupled wave/tide/surge hydrodynamic shelf models are under development, and some Institutes have already implemented them operationally. The extension to coupled wave/baroclinic shelf models is also under development. However improvements in accuracy of surge residual predictions are most likely to come in the first instance from improved use of data assimilation, and also from the use of higher resolution (& more accurate) forcing NWP winds and pressures, and for the NW Shelf from including a deep ocean boundary forcing at the shelf edge.

Extended range (10 day to 30 day) forecasts from NWP 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, although this is some way into the future.

Running models/computer requirements

Real-time fully coupled complex models almost certainly require supercomputer processing capability, even if run at modest spatial resolution.

Supercomputers are replaced or upgraded every 3-4 years. They need full-time shift-working support for 'operational' use, and need to be fully utilised to justify the cost of overheads.

Offline non time-critical models can probably be run satisfactorily on available workstations.

Communication methods and protocols need to be discussed and agreed, probably based on existing Meteorological WMO standards.

Key EuroGOOS decisions

Previous EuroGOOS decisions have not reflected all the points discussed above. There has been some attempt to call for setting up a 'European Centre' for operational oceanography. The resources for this would need to be carefully itemised, including an allocation of costs. This approach could place the costs differently to an incremental approach building, for example, on existing National Meteorological Services and Operational Oceanographic Institutes.

Actions already initiated

The following planned programs are directly relevant to the development of operational ocean forecast models: GODAE; NW Shelf Task Team ESODAE proposal; Mediterranean Forecasting project (EuroGOOS); the Baltic - BOOS task team; the French MERCATOR project.

Meetings, travel, workshops

Many of the above points are being covered by EuroGOOS Task Team meetings under proposed concerted actions. These concerted action proposals should be strongly supported by EuroGOOS. For wave modelling, the WISE meeting for shallow water wave modelling has become established as the principal forum. At present this relies on funding from the attendees host institutes to cover travel and subsistence.

EuroGOOS could usefully help the development of operational ocean modelling by supporting studies of commercial application, hosting and arranging seminars which bring together customers (from industry and Government) and the operational agencies, to allow dialogue and the development of products. A clear statement of need for forecasts of particular variables will drive the operational implementation, as is already happening for currents on the shelf slope west of Shetland.

Communications

The development and use of operational ocean modelling could be improved by access to appropriate communications, sharing information, publications, surveys, and display of information on the EuroGOOS Website.

Costs

The major recommendation that could be funded by existing EuroGOOS agency commitments is the task of arranging seminars and communicating information. The cost of providing dedicated large supercomputer systems and telecommunications networks is beyond the resources of EuroGOOS alone - this is best addressed by building on, and sharing, existing real-time computing capacity at National Meteorological Centres or Oceanographic Institutes. The provision of a wider coverage of relevant observations in real time could be addressed in conjunction with the end-users of forecast products. Many already provide meteorological observations; this facility could be extended.

Funding sources

The best strategy for development of operational forecast products is to be close to the market - if agencies focus on delivering what 'industry' will pay for, and incidentally set an appropriate value for the product, then operational ocean forecast modelling will grow. If however the model products are developed in isolation from the end user, then the funding position will be precarious. The EEC may fund development of pre-operational models and techniques, but routine operational running requires a paying end-user.

Collaborating agencies

It would be useful for EuroGOOS to establish contact with the offshore industry panels and groups, for example NWAG.

References

EuroGOOS Publication No 3. The EuroGOOS Plan.

EuroGOOS Publication No 6. The Science Base of EuroGOOS.

EuroGOOS Survey of operational models.

Acronyms — Annexe 1

ACCE	Atlantic Circulation and Climate Experiment (WOCE)
ALACE	Autonomous Lagrangian Circulation Explorer
APG	An Autonomous Profiling system
ARGO	Array for Real-time Geostrophic Oceanography
ATLAS	Autonomous Temperature Line Acquisition System)
ATOC	Acoustic Thermometry of Ocean Climate experiment
ATSR	Along Track Scanning Radiometer
AUV	Autonomous Underwater Vehicle
AVHRR	Advanced Very High Resolution Radiometer
BITBUS	Bus interface system
CANBUS	Bus interface system
CANIGO	CANary Islands Azores Gibraltar Observations (MAST III)
CASI	Compact Airborne Spectrographic Imager
CEDRE	Centre de Documentation de Recherche et D'experimentations
CEO	Centre for Earth Observation (EU)
CEOS	Committee on Earth Observation Satellies
CLIVAR	Climate Variability and Predictability (of WCRP)
COARE	Coupled Ocean Atmosphere Response Experiment (TOGA-COARE)
CSIC	Consejo Superior de Investigaciones Científicas, Spain
CTD	Conductivity Temperature Depth
DBCP	Data Buoy Co-Operation Panel
DG	Directorate General
DOD	Department of Defense
ECMWF	European Centre for Medium Term Weather Forecasting
EEZ	Exclusive Economic Zone
ENSO	El Niño Southern Oscillation
EO	Earth Observation
EOS	Earth Observing System (NASA, USA)
EOSS	European Sea Level Observing System
ESA	European Space Agency
ESODAE	North West European Shelf Seas Ocean Data Assimilation and Forecast Experiment
ESTEC	European Space Research and Technology Centre
EU	European Union
EUMETSAT	European Meteorological Satellite organisation
EuroCLIVAR	European Climate Variability and Predictability
EuroGLOBEC	European Global Ocean Ecosystems Dynamics
EuroGOOS	European Global Ocean Observing System
EuroROSE	European Radar Ocean Sensing
EUROMAR	European Marine Research Programme within EUREKA
FIESTA	Euromar data interface standard
GEK	Geomagnetic Electro Kinematograph
GEONET 4D	Multimedia Geocentric Networked Environment
GLOSS	Global Sea Level Observing System (IOC)
GODAE	Global Ocean Data Assimilation Experiment
GOOS	Global Ocean Observing System
GPS	Global Positioning System
GTS	Global Telecommunication System
HELCOM	Helsinki Commission (Baltic Marine Environment Protection Commission)
HF	High Frequency

HFSWR	High Frequency Surface Wave Radar
HOTO	Health of the Ocean
IAS-GOOS	Inter-American Seas GOOS
ICAMS	Integrated Coastal Analysis and Monitoring System
ICCM	International Center for Culture and Management
ICSU	International Council of Scientific Unions
IEEE	Institute for Electronics and Electrical Engineering
IGARSS	International Geoscience and Remote Sensing Symposium
IGBP	International Geosphere-Biosphere Programme
IMC	Information Management Center
IOC	Intergovernmental Oceanographic Commission (Unesco)
IODE	International Oceanographic Data and Information Exchange (IOC)
ISE	International Submarine Engineering
IUSS	Integrated Undersea Surveillance System
JASA	Journal of the Acoustical Society of America
LOICZ	Land-Ocean Interactions in the Coastal Zone
LIDAR	Light Detecting and Ranging sensor
MAREL	Mesures Automatisées en Réseau pour l'Environnement Littoral
MARNET	Marine Buoy Network (German coast)
MARVOR	A multi-cycle RAFOS float
MAST	Marine Science and Technology (DG-XII CEC)
MEDS	Marine Environmental Data Service (Canada)
MERCATOR	French operational high-resolution global ocean prediction project
MERMAID	European Union shared cost action
MILOC	Military Oceanography
MIROS	Microwave Ocean Sensor
MMS	Marine Meteorological Services (of WMO)
MTS	Marine Technology Society
NGO	Non Governmental Organisation
NIVA	Norwegian Institute For Water Research
NOAA	National Oceanographic and Atmospheric Administration (USA)
NODC	National Oceanographic Data Centre (IODE)
NOEMS	National Oceanographic Environmental Monitoring System
NRT	Near Real-time
NWAG	North West Shelf Action Group
NWP	Numerical Weather Prediction
OCCAM	Ocean Circulation and Climate Advanced Modelling
OMAR	Operational Marine Requirements for EO-derived data and information
OMEGA	Object Metadata for European Geographic Analysis
ONR	Office of Naval Research
OOSDP	Ocean Observing System Development Panel
ORBCOM	Low earth orbiting satellite
OSCR	Ocean Surface Current Radar
OSPARCOM	Oslo and Paris Commission
PIRATA	Pilot Research Moored Array in the Tropical Atlantic
PROMISE	Pre-operational modelling in the seas of Europe
PROVOR	A Hydrographic Profiler
QA	Quality Assurance
RAFOS	Sound Fixing and Ranging Floats (a form of pop-up sub-surface float)
REDOX	Reduction/Oxidation
RF	Radio Frequency
RNODC	Responsible National Oceanographic Data Centre (IODE)
SAR	Synthetic Aperture Radar

SCAWVVEX	Surface Current and Wave Variability Experiment
SCOR	Scientific Committee on Oceanic Research
SCSMEX	South China Sea Monsoon Experiment
SEANET	Data interface group
SMEs	Small and Medium-sized Enterprises
SOC	Southampton Oceanography Centre
SOFAR	Sound Fixing and Ranging float
SOSUS	SOund SUrvelliance System
STARSYS	Low earth orbiting satellite
SWR	Surface Wave Radar
TOGA	Tropical Ocean Global Atmosphere Experiment
TOPEX/POSEIDON	Joint US/French Ocean Topography Experiment
UKCS	UK Continental Shelf
USAF	US Air Force
USN	US Navy
VLBI	Very Long Baseline Interferometry
WCRP	World Climate Research Programme (WMO, ICSU)
WERA	WEllen RAdar
WG	Working Group
WHOI	Woods Hole Oceanographic Institution (USA)
WISE	Shallow water wave modelling group
WMO	World Meteorological Organisation
WOCE	World Ocean Circulation Experiment
WWW	World Weather Watch (of WMO)
XBT	Expendable Bathythermograph

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