

DIVIDENDS FROM INVESTING IN OCEAN OBSERVATIONS: A EUROPEAN PERSPECTIVE

Nicholas C FLEMMING

Southampton Oceanography Centre, Empress Dock, Southampton, SO14 3ZH, UK

ABSTRACT - *An ocean observing system to provide the data for climate research, modelling, and forecasting must be designed to high standards of accuracy and continuity. The observations are maintained for many years to develop the criteria for climate forecasting, and hence, in the meantime many of the data can and should be used for short and medium term purposes. When combined with other observations, usually of a local or regional nature, the combined data set provides the full suite of marine and coastal observations needed to serve a wide range of socio-economic and environmental objectives. The diagnostic and forecasting models on different scales are interfaced or nested to produce different analyses and products. The short and medium term systems provide an economic and social return which helps to cover the cost of the long term system. Although there are insufficient economic data to conduct a strictly controlled cost-benefit analysis at present, the effect of this strategy is, in economic terms, to ensure that the net discounted value of benefits minus costs never goes too heavily into deficit, and it may even be possible to maximise short and medium term returns so as to justify the whole system. In practice, expenditure and incomes for the various parts of the system to not occur in the same places, or agencies, and so a national or regional view is required, to maximise the net benefits in terms of public good.*

1 - INTRODUCTION

The European component of the Global Ocean Observing System (EuroGOOS) was set up in 1994 and now includes 30 Government Agencies from 16 European countries. Between 3 and 5% of input to the European GNP (EU) is generated directly by marine-based industries and services (Woods *et al.* 1996, p.21). The value added directly by these activities is of the order of \$140-230bn/yr. The industries and services are subject to uncertainty, loss of efficiency, and direct costs and damage caused by the unpredictable forces of the marine environment such as storms, sea level surges, waves, erosion, transport and resuspension of pollutants, shifts in fish stock migration, and toxic algal blooms. The temperature and salinity of the north Atlantic determines the weather and climate of Europe, Russia, and the Mediterranean. Europe has a great need to understand, monitor and predict the state of its coastal seas, the Mediterranean, and the adjacent oceans, Atlantic and Arctic. The monitoring and forecasting of the North Atlantic Oscillation, the fluctuations of the Gulf Stream, convection and deep water formation, and Arctic sea ice formation, are particularly important at the oceanic scale (Broecker 1991; Parrilla *et al.* 1994; Schott *et al.* 1994; DYNAMO 1997; Sutton and Allen 1997; Le Provost and Flemming 1998; EuroCLIVAR 1998; Wood *et al.* 1999; Shindell *et al.* 1999).

This paper will not consider the technical design of an ocean observing system, and will concentrate on the broad economic and social arguments as to why the system is needed, how it should be paid for, and how the costs and benefits can be measured.

Improvement of the short- to medium-term prediction services for maritime conditions would improve the value of maritime industries and services by a few percent. If we accept 1% as a most conservative estimate, the value added to the GNP of the EU by a prediction system is of the order of \$1.4-2.3bn/yr (Woods *et al.* 1996). This is a minimum which should be exceeded by a factor of 2-3. In addition there are the longer term benefits of climate prediction, and its impact on agriculture, energy generation, water supply management, land use and other social activities, which would be of the same order. More recent economic studies under way now are suggesting the methods for quantifying in comparable ways the benefits from short term commercial activities, through specific short and medium term public good benefits, to long term public good, environmental, and climate scale risks and benefits.

Europe possesses the wealth, institutions, and expertise to benefit strongly from operational oceanography on a European, Mediterranean, and North Atlantic-Arctic scale. The same institutions permit Europe to contribute to and participate in the Global Ocean Observing System (GOOS), (IOC 1998, p.114). European agencies recognise their obligation to contribute resources and skills pro rata to the global observing system, and it is also important to Europe that the global infrastructure is designed so as to guarantee the required data products and benefits needed by Europe. Most of the countries with EuroGOOS Members attended the 4th meeting of the Intergovernmental GOOS Committee (I-GOOS-IV) in June 1999 (IOC 1999), and the GOOS Commitments meeting in July 1999.

European national marine research institutes, operational establishments (fisheries agencies, meteorological offices, environmental protection agencies), and trans-national agencies and bodies (ESA, ICES, EUMETSAT, ESF, CEC, ECMWF, Eureka EUROMAR, and the pollution and dumping Conventions) in combination possess most of the scientific research basis, expertise, engineering ability, and data processing ability needed to install and manage operational oceanography on a European scale, and to benefit substantially from global operational oceanography. However, prior to 1994 there was no declared objective, and no mechanism, to co-ordinate the collaboration between these bodies. It is the objective of EuroGOOS to promote this co-ordination.

2 - BACKGROUND

Europe is a continent of peninsulae and archipelagos. It could legitimately be called the water continent. The only comparable areas of the globe so dominated by coastal seas, enclosed seas, islands, straits, and large areas of continental shelf, are northern Canada and South East Asia. Northern Canada, in spite of boasting the longest national coastline in the world, has a low population density, and small economic significance apart from some prospects of offshore oil. South East Asia is an area of important economic growth and high population, but no country in that region is yet a major player in global marine science or marine technology.

The continental shelf and slope adds 63% to the land area of Europe, and the next highest ratio is North America with an added area of 57% for its associated Arctic continental shelf and slope. On a standard classification of "Continentality" Europe rates lowest of continents with the greatest length of coast in relation to its land area, 62% of its regions close to the sea, and a mean distance of land from the ocean of only 340km.

Europe is therefore dependent upon and influenced by marine conditions more than any other developed continental region. Changes in mean sea level, changes in storm conditions and coastal erosion, have a greater impact on shelf-seas and oceanic fisheries, tourism, land use, shipping and

ports, and offshore oil than in other continents. Concern about possible global sea level rise and its combination with regional earth movements is of high priority, as evidenced by the activity of the European component of the Global Sea Level Observing System (GLOSS). The Mediterranean is an almost closed basin with unique circulation which requires a relatively high resolution observation and modelling scheme (Golnaraghi *et al.* 1996; Jeftic *et al.* 1992; Jeftic *et al.* 1996). The Mediterranean Forecasting System proposed by EuroGOOS in collaboration with the Mediterranean GOOS organisation (MedGOOS) emphasises regional nested modelling and forecasting (Pinaridi and Flemming (1998). This modelling is important both for the Mediterranean coastal states, and to provide accurate assessment of the Mediterranean outflow of dense water into the Atlantic. The Baltic region has a highly developed set of collaborative structures, with a sophisticated programme of linked hydrodynamic models, interfacing with biological productivity models.

In accordance with its dependence upon the ocean and shelf seas Europe has developed a network of over 300 marine research institutes and university departments within the EU, and a strong fleet of ocean going research vessels. Within the EU there are 9 civilian research vessels in the size range 80-120m length; 16 in the range 60-79m length; and 11 in the range 40-59m. During the last 5 years a range of CEC programmes (MAST, Environment, Climate, EPOCH, Framework 5, etc.) have generated added value on the European scale above the excellent work carried out at the national level. European laboratories and scientists have also participated strongly in the global ocean programmes such as World Ocean Circulation Experiment (WOCE), Tropical Ocean Global Atmosphere (TOGA) Experiment, and Joint Global Ocean Fluxes Study (JGOFS). The launch and operation of the satellites ERS-1, ERS-2, and Topex-Poseidon have made major contributions to oceanographic science. In 1999 the EU Commission launched the Fifth Framework programme (FP5) which outlines the priorities for investment in research for the next 4 years (EU-CEC 1998). Within this programme large budget categories are provided for research and technological development in sectors such as coastal management, operational marine modelling, coastal ecosystems modelling, marine water quality management, coastal erosion, climate modelling, marine forecasting, and marine technology. Infrastructure categories exist for funding such items as data bases, communications systems, distributed networks.

Europe exploits a vast range of marine and coastal resources. European states have substantial offshore oil and gas reserves and producing fields off the coast of Norway, in the Barents Sea, the North Sea, west of the Shetlands in the Atlantic, the Irish Sea, the Channel (La Manche) and the Mediterranean. Large quantities of gas are piped under the Mediterranean from Tunisia and Algeria, and a pipeline has been constructed across the Straits of Gibraltar. Offshore oil and gas drilling is increasing in water depth to 3000m (Offshore 1998). European fisheries require intensive monitoring and precise management to prevent over-fishing and destruction of stocks. Millions of tonnes of sand and gravel are dredged from European waters each year for concrete and ballast, while extensive dredging operations are also carried out for navigational channels and pipeline entrenching and protection. European coastal seas and estuaries are amongst the busiest navigational routes in the world, while the pressure on estuarine resources in terms of waste disposal, fisheries, shell-fisheries, aquaculture, recreation, and navigation requires extremely careful control and management. Expensive collisions, groundings, and oil spills have been reduced by rigorous traffic separation schemes, but major accidents in the last two years show that the problem is not perfectly resolved. Inland and semi-enclosed seas such as the Baltic, North Sea, Mediterranean, Adriatic and Black Sea are used intensively, and require continuous environmental monitoring and management. A significant proportion of European tourism consists of a north-south movement to the coasts of the Mediterranean. In all these activities there is a great benefit to be obtained from better operational monitoring, modelling, and prediction of the marine environment.

Most European coastal states have developed operational oceanographic data gathering and forecasting at the shelf seas level, often with collaboration between adjacent states. Existing operational services provide monitoring and short term forecasts of conditions such as storm surges of sea level, wave spectra, currents, floating sea ice, icing conditions, plankton or algal blooms, sea surface temperature, dissolved oxygen, coastal and estuarine pollutants, radionuclides and movement of oil slicks. Many of these services are accessible through the internet (See Table 1).

Existing marine forecast systems have limited spatial extent and give short-term forecasts, but they provide immediate commercial and social benefits, and essential experience in testing instrumentation, communications, data analysis, and data product delivery to customers. On the scale of the European shelf and regional seas there are advantages in pooling resources to join the forecasting systems together, and to use the best practices available as standards. This process is particularly advanced in the Baltic region. Operational models of the Atlantic are already in use, with more advanced models under development, in both France and the UK.

The northward transport of heat in the Atlantic surface currents depends upon the rate of formation of cold bottom water which sinks at the interface between the Arctic and Atlantic Oceans (Pollard 1994; Wadhams *et al* 1996; Johannessen *et al.* 1995; Johannessen *et al.* 1997; Bjørge *et al.* 1997; Prandle and Flemming 1998, p.23; EuroCLIVAR 1998). Records from ice cores and ocean sediments show that this circulation has varied dramatically in the past, and that significant changes could occur which would result in the climate of Europe becoming similar to present day Labrador. More normal fluctuations show that there are decadal variations in mean temperature of the upper Atlantic Ocean which cause variations in currents, fisheries migrations, and continental weather (Glantz 1992; Dickson *et al.* 1994; Dickson *et al.* 1996). These decadal fluctuations have an effect on the global climate, and influence global fluctuations on a timescale longer than the ENSO period of 2-5 years. By monitoring and predicting the northward heat transport in the North Atlantic Europe would be making a contribution to global climate prediction, and acting in its own interests.

The ability to monitor and predict North Atlantic changes on the multi-year timescale would provide the boundary conditions for models of the shelf seas, and hence permit prediction of conditions in the coastal areas. In addition to the Atlantic variability it is important to understand the variability of Arctic sea ice, and the variability of the ocean waters under the ice. European countries will benefit greatly from a programme of remote sensing of the Atlantic and Arctic Oceans, combined with in situ instrumentation. The ocean scale models should be run so as to provide seasonal, inter-annual and multi-year predictions. In 1997 EuroGOOS held a joint workshop with participants from the USA to analyse requirements for operational modelling of the Atlantic (Le Provost and Flemming 1998). EuroGOOS Member Agencies are prominent in the planning of the Atlantic ARGO Pilot Experiment, jointly with the USA.

European countries have policies on aid and assistance to developing countries, and agreements for joint programmes and collaboration or partnership on projects. GOOS is a natural vehicle for collaboration in capacity building. As a general structure for EuroGOOS is set up, the common or collective view on the involvement of developing countries is an important element. EuroGOOS actively collaborates with the other GOOS Regions, especially with Mediterranean GOOS (MedGOOS) (Drago 1998), and Africa GOOS, and Black Sea GOOS.

The cost of EuroGOOS can only be justified by considering the economic and social benefits which arise from operational oceanography. One of the benefits is scientific research, since scientists will be able to conduct research starting from a basis of a much more complete description of the environment in which they work. Given the descriptions and monitoring provided by GOOS they will be able to postulate and test more complex and fundamental hypotheses than at present.

Country	Member Institution	Homepage	Operational Products	Oceanographic databases	Reports and Publications	Cruises	Links
Belgium	GHER	http://modb.oce.ulg.ac.be/GHER/		MODB			
	MUMM	http://alpha2.mumm.ac.be/~wwwusr/	Sea Level, Waves, Storm Forecast, Oil slick prediction		MNZ pollutants	+	
Denmark	DMI	http://www.dmi.dk/dmi/index.html	Sea Weather, Currents, Tides, Water level		Press releases, Articles, Technical reports		
	RDANH	http://www.fomfrv.dk/	Surface measurements		Index		
Finland	FIMR	http://www2.fimr.fi/	Plankton, SST, SSS, N, P, Ice	Algaline	Algaline reports, Library	+	+
France	IFREMER	http://www.ifremer.fr/francais/	MAREL floats	SISMER, CERSAT	Catalogue	+	+
	Meteo France	http://www.meteo.fr/	Sea Weather		Guide marine, Library index		
Germany	BSH	http://www.bsh.de/	Ice, Water level, Tides, Currents, SST, Bathing Water, Waves, Magnetic Variation	DOD, MUDAB, Oil Survey	Library, Nautic Publications, Charts, J.Hydrography, Environm.reports, Press releases	+	+
Greece	IMBC	http://www.imbc.gr/		Thalassalink, Aquaculture/Environment	Bibliogr.Services		+
Ireland	Marine Institute	http://www.marine.ie/		EDMED, Biotoxins	Newsletter	+	+
Italy	ENEA	http://estaxp.santateresa.enea.it/www/index.html	SST/SSS since 1909	MEDB, UMIC, SIAM, Malacofauna, Caulerpa	Library, Article search, Seagrassbed Atlas	+	
Netherlands	KNMI	http://www.knmi.nl/	Sea Weather, Tides		News and Library		
	RIKZ	http://www.minvenw.nl/nws/rikz/engrikz.html	Water level/quality, Currents, Waves, Wind, SST, Tides, Storm warning	NetCoast, Wadden Sea	Publications, News	+	
Norway	IMR	http://www.imr.no/andre.html	Coastal SSS, SST, SST from Liners, SST daily (1 station)		Index		
Poland	IMGW	http://www.imgw.gdynia.pl/				+	
	IO-PAS	http://www.iopan.gda.pl/		RBDO	Oceanologia, Library, Publications		+
Spain	PE	http://www.ieo.es/	Waves, Storm surge and Sea level		Index		+
Sweden	SMHI	http://www.smhi.se/	Algae, Oxygen, Marine Weather	BALTEX, SHARK	Annual/Quarterly reports, Algae reports, Others	+	
UK	EA	http://www.environment-agency.gov.uk/	Environment Information		Index		
	Met Office	http://www.met-office.gov.uk/	Marine Weather and Services				+
	NERC	http://www.nerc.ac.uk/	GEBDO	BODC, GLOSS, UKMED	UKDMap	+	+

Table 1. EuroGOOS links to free Internet Resources of Members. This table shows the websites already operational amongst the EuroGOOS Members, providing real time access to operational observations and marine data bases (compiled by Johanne Fischer, EuroGOOS Secretariat)

There are therefore several fundamental assumptions in the design of EuroGOOS activities, and its justification as a worthwhile investment.

- The maximum benefit of operational oceanography can be developed if we include regional and sub-regional components.
- Effectiveness depends strongly on the ability to obtain data fast and run real time models.
- Models need to be nested and interfaced on different scales, and representing different variables.
- Europe must play a proportionate role in the global observing system
- The missing factors which EuroGOOS can provide are to promote the transition from research mode to operational mode, and to promote focused collaboration on agreed objectives.
- Present scientific knowledge enables us to start designing a fully operational system, but continuing research is needed to exploit the full possibilities in terms of resolution, forecast horizon, and variables.
- New technology is needed to enable more data to be obtained routinely without increased personnel and ship requirements.

These considerations, and others, lead EuroGOOS to develop a simple model of the components of investment which will always be needed. Fig. 1. shows the connections between these components. The way in which each sector of investment will be developed will change continuously, and the acronyms refer to currently active programmes in each sector.

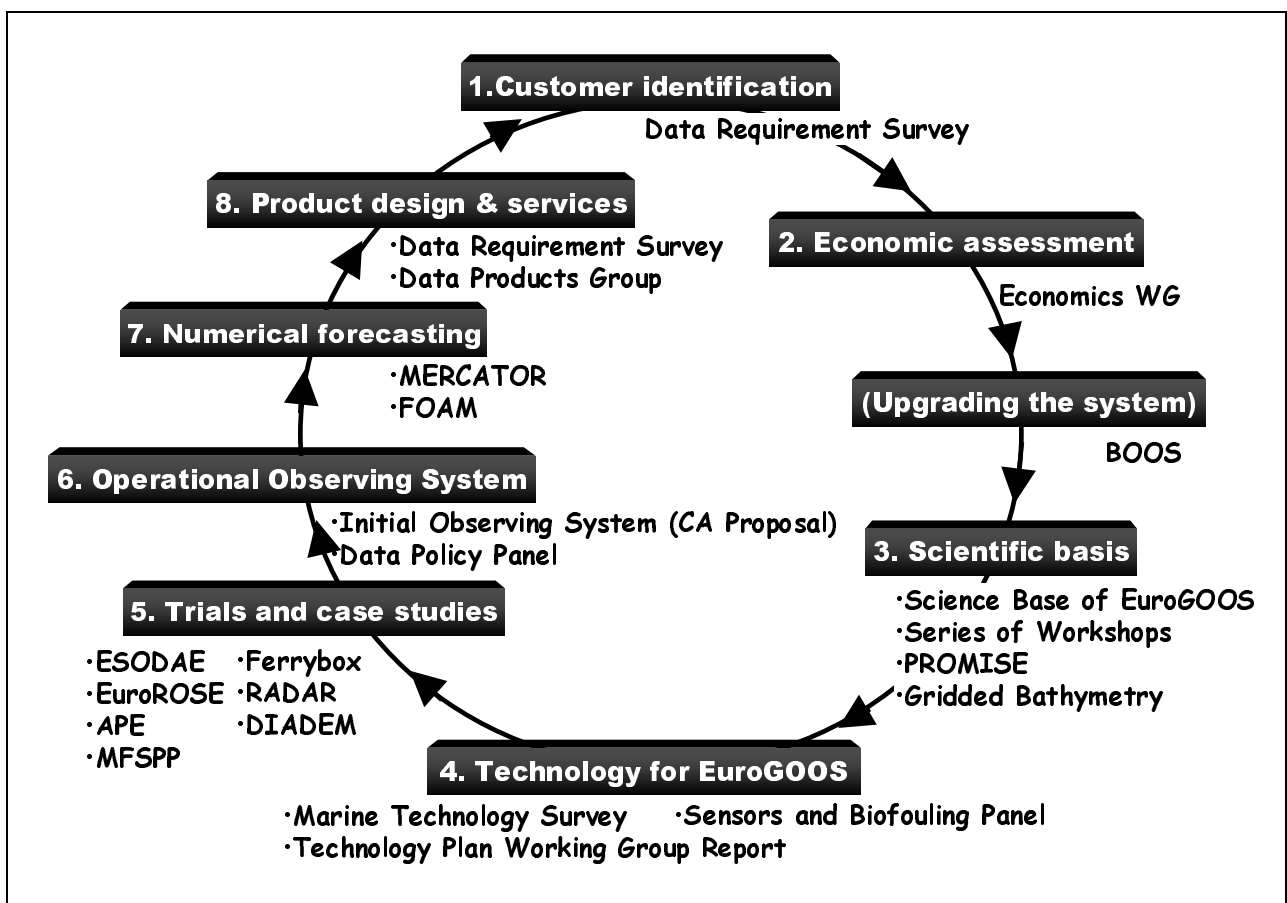


Fig. 1: EuroGOOS has identified 8 sectors of activity which are, on present assessment, needed on a long term basis to advance the development of operational marine observations in Europe, and globally, so as to provide data with proven needs and applications. The acronyms and notes under each sector show present projects within that Sector.

3 - TIMESCALES AND DISCOUNTED CASH FLOW

Figure 2 shows the timescales on which different types of forecasts influence different industries or activities. For example, storm forecasts are important on timescales of hours to days, while climate variability forecasts are valuable to agriculture or fisheries on timescales of months to years.

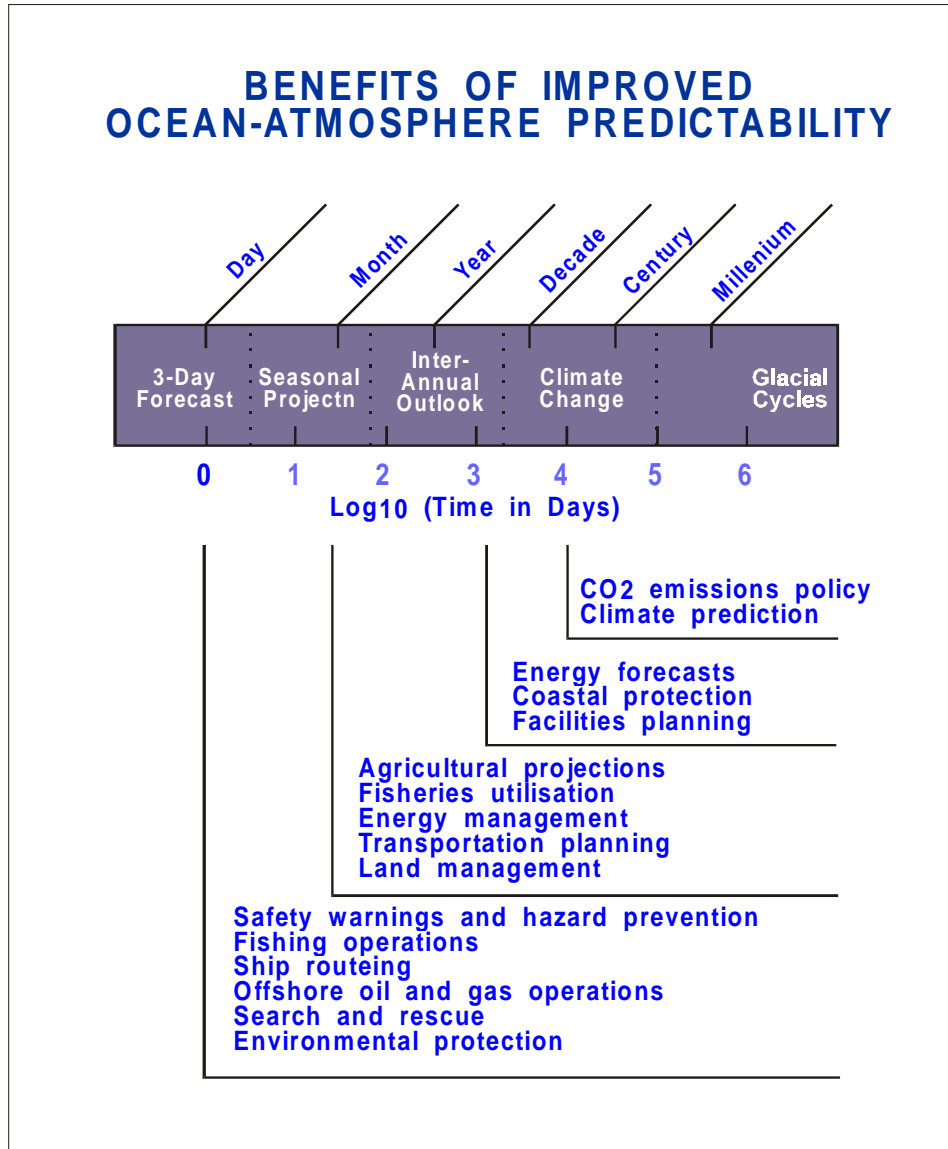


Fig. 2: In the early days of GOOS planning Dana Kester made this presentation of the timescale of different kinds of predictability, and the activities and services which would benefit. (Adapted from Dana Kester 1993). Each activity is linked to a timescale of prediction which is most relevant to it in terms of needs and benefits.

The short term beneficiaries in Fig. 2 tend to obtain their benefits either in immediate cash profit, or visible reduction in damage, in an easily understandable way. A commercial company or a local government authority can easily justify spending money on a wave forecast which protects an offshore oil platform, or a storm surge forecast which provides the warning to raise the gates of the Thames Barrage to prevent London flooding. Concrete proof of the justification of investment is obtained within a few months or years. As the timescale extends, through the seasonal to the multi-year cycle of the ENSO forecasts (Sassone and Weiher 1997; Epstein 1999) to long term energy planning or global sea level rise, the uncertainty becomes progressively greater, and the risk is

spread over the whole community. The ENSO cycle is a rewarding target for forecast because the multi-year signal is so strong, and the impacts so immediate on a timescale less than 1 year. In more general terms, we are planning responses to enormous disasters which may not happen. The introduction of the need to estimate risk and probability of damage or benefit of a certain scale, makes calculations of benefit more difficult (Brown 1997).

At the longest timescale, decades to hundreds of years, the economic calculations become inter-generational. (Economist 1999). Climate forecasting models for global warming are beginning to consider timescales of the order of 100-200 years, and the economics of calculating mitigating action must be analysed. Most studies of the costs and benefits of investing in response to climate variability, natural disasters, or climate changes, assume that the financial discount rate should be set at a level of the order of 7% after inflation. This rate of discount rapidly reduces the incentive to invest in protection or knowledge of risk in regard to future profits or possible disasters. At 7% discount a million dollars in ten years time is worth only half that now, and over 100 years discounted it is worth only 1000 dollars. This rate of discount, applied over more than a few years, encourages people to spend or invest the money elsewhere, and hope that the accrued profit will enable them to fix the problem later, if it occurs. For certain kinds of very large but uncertain future risks, such as global warming, sea level rise, or catastrophic shifts in agricultural productivity, the high discount rate produces a lack of action which seems morally and politically wrong. Common sense indicates that it cannot be wise to do nothing for so long. Studies edited by Portney and Weyant (Economist 1999) suggest that over short time spans, within the life of an individual or a single commercial venture, we estimate the discount rate in proportion to other actions which we could take, and benefits which we will receive, or lose personally, with some certainty. Over longer timescales the probability of continuity is greatly reduced, the benefits from some presumed investment at 7% interest are much less certain, and the weight which should be given to the needs of future generation is higher. In these circumstances, the rate of discount which should be applied should be reduced, possibly as low as 1%. This makes it more justifiable, on purely economic grounds, to invest in precautionary research and mitigating preparation for long term climate-related problems.

The work of Costanza *et al.* (1997) and others also begins to show how the value of the natural environment, and hence the value of preserving it, may be estimated in economic terms over decades. Flemming (1997) and Brown (1997) and Sassone and Weiher (1997) have analysed different sectors of the marine industrial and service sectors to identify the applicability of economic techniques. Pugh and Skinner (1996) and IFREMER (1997) have analysed in some detail at the industry and service sector levels the economic value added by each marine activity in the UK and France respectively. Each activity could then be analysed in terms of its susceptibility to improvement or avoidance of loss by the application of improved ocean forecasting.

We can thus say that there are, at least in principle, economic methods for estimating the value of investing in ocean and climate forecasting on all timescales from hours to decades and even centuries (Ryder 1997; EuroGOOS, EG98-44 1998). Planning to invest on this longest timescale requires a strategy to reduce the risk of being wrong. Looking decades ahead, it may turn out that a major investment does not produce the results or benefits expected, or it turns out to have been unnecessary. Billions of dollars might be wasted. How can these risks be reduced?

The shorter term investments and forecasts carry much less risk of error than the long term ones, and require, by definition, a much shorter period of investment before the effectiveness and rate of return become proven. Mistakes are quickly corrected or abandoned. The overall investment risk of a long term ocean observing system can therefore be reduced if the same system, or components of it, can be designed to produce both short term and long term benefits.

For each component of an ocean observing system, say a particular suite of satellites, or a global array of measuring buoys, there will be a certain data stream which, in ideal terms, could be related to certain economic, social, or environmental benefits. In practice this calculation is not simple, since the same data may be incorporated with many other different data types, producing different benefits to different users. Let us assume that the single investment in a particular range of observations requires several years of deployment and investment, during which the benefits start to accrue, and after a certain period the cumulative return on the investment becomes positive. This is illustrated by any one of the curves in Fig.3. Each cash flow curve goes negative for a while, and then rises above the zero line, to show a cumulative profit.

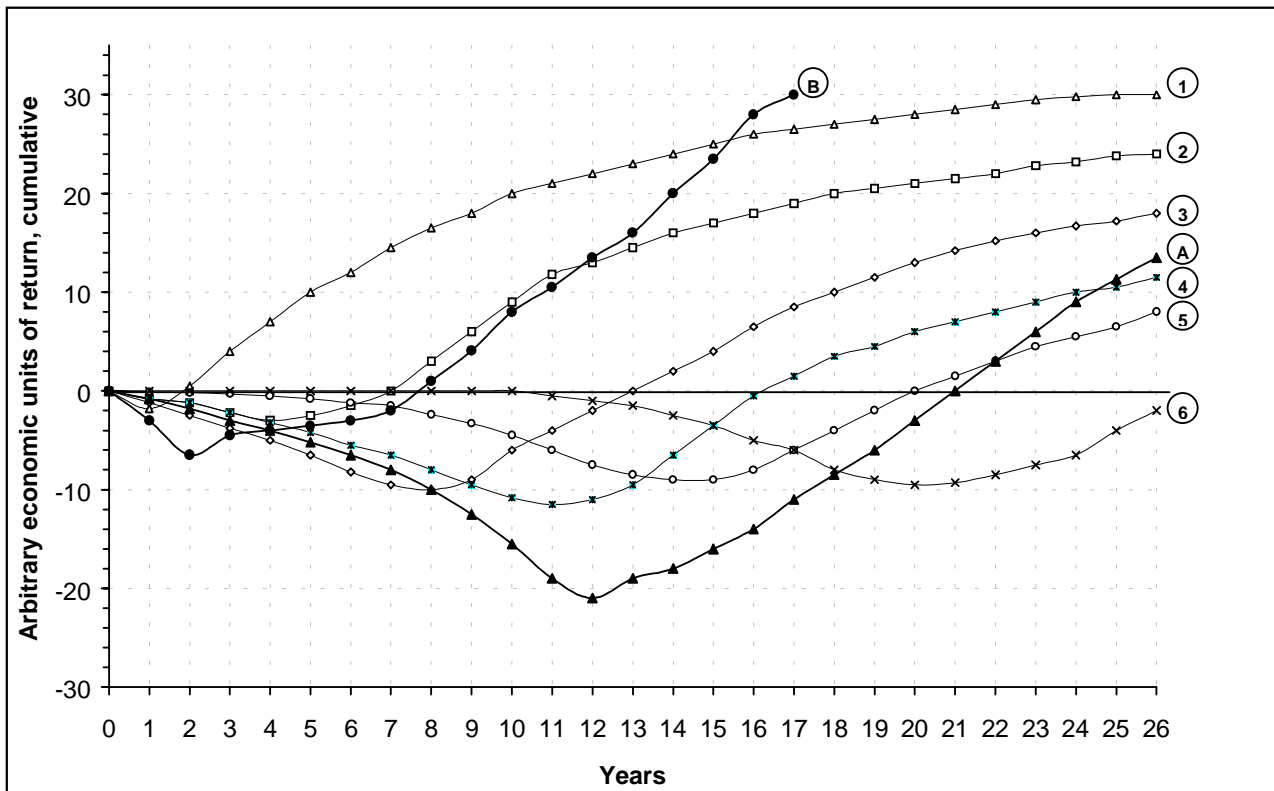


Fig. 3: The cumulative cash flow curve for 6 different hypothetical components of a global ocean observing system are shown, numbered (1) for the shortest term component to (6) for the longest term component. For each curve the investment causes the curve to go negative for a few years, and then to rise positively as returns are obtained. The scale of economic units on the y-axis is completely arbitrary. Curves 'A' and 'B' are described in the text.

Figure 3 shows in arbitrary and notional units the effect of combining short and long term components of an ocean observing system. Observing component 1 has a maximum cumulative deficit of 2 units, and shows a net economic benefit after 2 years. This would probably be some installation which improved weather forecasting or provides warnings against hazards on a timescale of days to weeks. By contrast, Observing component 4 has a negative cash flow for 10 years before it starts to show any return, and it is 16 years before the return is sufficient cumulatively to pay back the investment. Component 6 is so advanced that it cannot even be started within 10 years, and will require improved scientific knowledge and technology before it can be designed and implemented.

A long term climate forecasting or global forecasting system based only on the requirement to develop long term observations and products might be analysed by summing the cash flow curves of observing system components 4, 5 and 6, in Fig. 3. The sum of these curves shows an increasing deficit for 12 years, with a maximum deficit of 21 units, followed by a decreasing cumulative deficit up to 21 years, and then a net benefit (Curve A). If observing systems 1, 2 and 3 are added to the whole pattern, cash flow dips to -7 units at 2 years, climbs back slowly to cumulative profit around year 7, and then climbs steadily to cumulative benefits by the 10th year, and 30 units in the date range of 15-20 years (Curve B). This example is a hypothetical and simple model, but it should be noted that systems 1-3 may include observations, instruments and communications devices which will also serve systems 4 or 5. There are differences in accuracy, resolution, stability of calibration, etc., between short term and long term requirements, but with good science and a little cunning it is often possible to make the same instruments perform both functions. Short term and real time data analysis often requires the omission of additional calibration information or checks, and the acceptance of coding errors and transmission faults. Given extra time, the same original observation can be re-calculated and calibrated to an additional order of magnitude of accuracy, and the sources of error can be checked and corrected, thus increasing the quantity of data.

The preceding analysis has omitted several factors which are essential in any economic estimate of the benefits of investment in a technological system. All benefits should be calculated as “value added”, that is the value generated less the inputs from other sectors, as if a process is part of the Gross National Product. If this computation is not performed, the summation of the gross value of many activities would add up to a many-fold multiple of the true value of the economy. Each calculation of the justification for investment must also be conducted by computing the discounted or net present value of the factors.

The benefits implied by the different sectoral curves in Fig. 3 describe activities which normally fall into different sectors of the economy, different industries, government or the commercial sector, offshore or coastal, or are the responsibility of different government regulatory agencies. The summing of the cash flow curves described in Fig. 3 only makes sense when viewed at a reasonably high level. At national level, a group of 5-8 government agencies with industry representatives working together can reconcile and accept the implied trade-offs, where one agency alone could not. At the regional or European level, this logic can be taken a stage further, and the contributions from different small geographical sea areas and national EEZs can be combined to provide the best possible and most economic distribution of instruments to provide the data for assimilation into regional models. The support of the marine research programme of Directorate General XII, the so-called MAST programme, from 1987 to 1999, has been important in developing the cohesion and integration between European countries in ocean research. During the last phase of MAST, that is MAST-3, a number of projects in operational oceanography have been supported and are running now. In the new European Research Programme, Framework 5, there is an even greater emphasis on operational oceanography and marine forecasting systems.

This section has shown the general feasibility of developing the economic justification for investment in ocean observations, and that the economic techniques can, at least potentially, cope with the range of commercial and public good sectors which benefit from ocean observations. Before considering individual observations, data requirements, and user communities, it is important to consider the methods needed to quantify the costs of operational ocean observing systems.

4 - THE COST MODEL FOR AN OPERATIONAL OCEAN OBSERVING SYSTEM

Civilian operational oceanography has existed in one form or another for a decade or more, and increasingly complex proposals are being developed now. It therefore seems embarrassing to have to admit that a thorough costing of the proposals, at either national or global level, has not been carried out. There is a genuine problem here of which we should not be ashamed. Various rough estimates have been made (e.g., IOC 1993; Flemming 1994; IOC 1998, p.30-33). The following discussion is based on consideration of the costs of a global operational observing system such as GOOS, but the same caveats apply to attempting an over-simple analysis of the costs of EuroGOOS. Since the European region tends to gain benefits from investing in an efficient global system, as well as from applications directly within the European sea areas, we can consider comments on the global system and European components as having equivalent force.

An attempt to sum the cost of global or regional ocean observations, or a complete operational observing system including modelling and forecasting, naturally involves summing a wide range of sub-costs, purchases of equipment, deployment costs, ship operations, maintenance and replacement of equipment, satellite launch costs, equipment planning and design costs, communications and data processing, modelling centres, computers, product delivery, and so on. Each component has a different proportion of capital investment, duration, and running costs. Aggregation of these costs requires that each component should be analysed to see whether there are multiple beneficiaries who should share the cost, hidden overheads, sunk costs, or might be developed anyway for other purposes. Table 2 summarises some of these factors.

Depending upon assumptions made in solving the ambiguities or questions in Table 2, the apparent cost of operational oceanography can be made to appear larger or smaller through an order of magnitude. Accounting procedures need to be agreed and transparent, at least at the national level, and preferably at the regional level.

This section does not provide answers to the problem of trying to predict the costs of operational oceanography, but it does illustrate that a sophisticated cost model will be required, fully taking into account standard procedures for coping with sunk costs, shared overheads, shared benefits, self-funded new technology, rented and leased equipment, etc. While such an approach may be justified, in practice agencies seem to be adopting a pragmatic step-by step process, committing to successive stages of ocean observation as each phase appears to provide benefits. This is consistent with an intuitive interpretation of the model presented in Fig. 3.

The costs of EuroGOOS and the benefits achieved may be balanced in various ways. If EuroGOOS Member agency activities were regarded as a pure public good, then a computation of the notional value of the benefits would be sufficient, and there would need to be no actual charging of customers or direct recovery of costs. If EuroGOOS Member activities were regarded as a commercial exercise, all the costs would have to be recovered from the sale of services and products. It is premature to make judgements on these factors, but already it is possible to see that parts of the infrastructure, parts of the remote sensing, deep ocean sampling, and long term climate predictions tend to have the characteristics of public good economics, while the short term coastal engineering, navigational, and fisheries predictions can probably be marketed as cash services. A full study of the costs and benefits of EuroGOOS Member activities would have to break down the services into a range of categories between these two extremes.

Table 2: List of factors which have to be taken into account in creating a cost and benefit model of an operational ocean observing system.

i)	Some systems needed for operational ocean observation already exist, and have been developed for other reasons, with the development costs written off. The running costs are paid by existing agencies. They may continue to serve their present objectives and ocean observing at small extra cost.
ii)	Some systems needed for ocean observation, including some satellite observing missions, will be developed for other objectives, but might suffer from serious omissions, gaps, or deficiencies in the absence of a specified ocean requirement which is built into the design and implementation. What should the ocean community pay for this extra specification? How should GOOS pay for dedicated operational ocean missions? A critical example is the potential opportunity to measure sea surface salinity from satellites, when the same sensor measures soil moisture on land. Who pays for operational missions?
iii)	Some systems needed by GCOS or GOOS, both satellite remote sensing and <i>in situ</i> observations, are partially effective already, but suffer from serious geographical lack of coverage. Who is responsible for implementing and paying for the extension of the geographical coverage to areas which are in nobody's immediate self-interest?
iv)	Some parameters are presently observed using technology which is too slow, too inaccurate, or too costly to fulfil the requirements of global ocean observations. New technology is being developed both in research laboratories and in commercial companies, but how do we assess now the perceived cost if this development or application of the instruments? The new instruments will greatly reduce the unit cost of operating components of the ocean observing system which would be more expensive if the technology had not been developed.
v)	If GOOS were not planned properly, or if there were no GOOS at all, many systems and satellites would be deployed in a manner which, in retrospect could be shown to be wasteful. There would be a hidden opportunity cost caused by the inefficient, redundant, or incomplete deployment of instruments in a way which failed to produce a potentially achievable benefit. The process of organising and managing GOOS, and placing instruments in more logical dispositions, would produce a greater benefit at possibly reduced cost.
vi)	As ocean observing and modelling develops the observing scheme could be reduced in intensity because diagnostic models and sensitivity trials would show that some observations were redundant. Such economies could not be achieved if ocean observations were not designed on a scientific basis.
vii)	Many of the infrastructural components in GOOS, telecommunications, data relay satellites, data bank software. etc., are probably best obtained through commercial purchase, leasing, or contract. Sound procurement practice should enable agencies to obtain very favourable terms.
viii)	A designed collaborative ocean observing system would result in shared compatible systems for data structures, data formats, quality control, model standards, data assimilation procedures, etc. This would avoid repeated re-invention of the same procedures at high cost and minimal compatibility.
ix)	Systems developed or installed purely for ocean observations may turn out to have many other applications and beneficiaries which were not expected.
x)	If the benefits of installing an additional component of GOOS can be brought on stream fairly quickly- say a few years- then the net cost of the system never runs extensively into deficit, and there is no large component of interest. This however requires that each additional component should be planned, costed, and implemented in such a way as to ensure that the marginal additional benefit is genuinely achieved.
xi)	From time to time the addition of a key component of GOOS or EuroGOOS will lead to a massive increase in efficiency, accuracy of products, or increase in forecast horizon, due to the increased ability to model a set of processes which was previously incomplete. The return from each additional component will not be linear, and analysis should be made to identify the essential clusters or aggregations of observations which exhibit this characteristic enhanced benefit.
xii)	Good design of an observing system should permit a minimal permanent deployment. Such a system could be designed so that, if necessary, the intensity of observation could be increased in key areas under pre-determined circumstances. This should lead to an increased quality of performance for the whole of GOOS at a cost below that of a relatively unplanned system.

5 - CUSTOMERS, USERS, BENEFITS AND DATA REQUIREMENTS

As shown in Fig. 1 the early sectors (1 & 2) of the design of EuroGOOS consist of identifying customers, whether government agencies, international bodies, or commercial companies, determining their requirements for different kinds of operational service, and assessing the economic and social value of the service, as generated by the applications of the data. Sector 8 consists of product design and interfacing services with the customer or user.

Surveys in France and the UK (IFREMER 1997; Pugh and Skinner 1996) have estimated the scale of different government marine activities, commercial operations, commercial services, living and mineral resources, and social activities such as tourism and enjoyment of parks and wildlife. These studies have not attempted to evaluate the more qualitative benefits such as impacts on public health, or the longer term effects of marine observations on climate, agriculture, and energy or water utilisation. One side effect of these studies is to provide a set of categories of activity in which the organisations are more or less intensive users of marine information and forecasts. Starting from this base, and using lists of members of trade associations, government departmental mailing lists, university departments, and exhibitors in various marine engineering and trade exhibitions, it is possible to construct mailing lists of many hundreds or thousands of potential beneficiaries from a marine observing and forecasting service at the national level.

EuroGOOS has designed a survey of customers for operational ocean data and their data requirements, which has been run in 6 countries (Fischer and Flemming 1999). The survey was conducted in Denmark, The Netherlands, UK, Italy, Spain, and Greece. This provides a reasonable balance between northern, temperate, Atlantic operators and southern, warm climate, Mediterranean operators. The survey identifies classes of hundreds of serious users of operational marine data and forecasts, and prioritises by frequency of requirement the variables which are most in demand, their geographical scale, accuracy, temporal and spatial resolution, product type (raw data, processed, statistics, forecast, hindcast, nowcast) and latency and medium of delivery. A side effect of such surveys is to build up a familiarity and working relation between the agencies planning new observing systems and their potential customers. Presentation of papers and reports on these themes at trade and industry conferences provides a very positive feedback.

There is a further range of additional benefits which are more difficult to quantify, but which all add value to the benefits from EuroGOOS. Firstly there are the long term benefits from improved climate prediction which are quantifiable, though reduced in value by discounting. These are being examined by GCOS, and there is no doubt that this will show increased benefits attributable to GOOS (GCOS 1994).

Then there are a host of rather intangible benefits which may be measurable in economic terms, but which at first sight are intractable to measurement in money. Econometric techniques have been developed in this field, but they have not yet been applied to marine and coastal activities. These benefits include the aspects of conserving biodiversity, protecting wildlife, preserving the aesthetic appearance of the coastal zone and wetlands, preserving ecological balance even when it is not shown to jeopardise fisheries or other living resources, and minimising the public sense of disturbance or insecurity which may be caused by climate change or rise in sea level. In its extreme form, this type of analysis computes the overall economic benefit from the existence of different natural environments (Costanza *et al.* 1997).

It is possible to summarise the categories of customer or user of operational ocean data, and the nature of the economic transaction, commercial or public good.

Table 3: List of applications sectors used by EuroGOOS in estimating the requirements of different end-users for marine observational data products and forecasts.

00. Transport (excluding military)	38. Desalination	75. Data services
01. Shipping operations	39. Phosphate	76. Data transmission, telecommunications
02. Hovercraft operations	40. Coal, subsea	77. Diving, including suppliers
03. Hydrofoil operations	41. Food from the sea	78. Inspection, maintenance, repair
04. Submersible/submarine operations/ROVs	42. Fisheries, catching	79. Insurance
05. Tunnel subsea operations	43. Fish farming	80. Metocean survey, mapping, hydrographic surveys
06. Barrage roads	44. Shellfisheries	81. Project management, non-defence, consultancy
07. Causeway	45. Shellfish, crustacea, farming	82. Remote sensing
08. Bridges, sea channels	46. Fishing gear	83. Salvage, towing
09. Navigational safety, lights etc. Electronic charts	47. Defence	84. Ship routing
10. Safety services, rescue, life preserving, fire	48. Military vessels, surface and submarine	85. Weather forecasting
11. Port operations	49. ASW, oceanographic applications	86. Equipment sales
12. Energy production	50. Underwater weapons	87. Marine electronics, instruments, radar, opto-electronics, etc.
13. Oil and gas production (Oil companies only)	51. Navigation, position fixing, etc.	88. Sonar
14. Oil and gas exploration and prospecting, and drilling services	52. Defence sales, equipment, components	89. Buoys
15. OTEC	53. Operations and efficiency, logistics, controls, computing	90. Tourism and recreation
16. Wave energy	54. Building, construction, and engineering	91. Basic and strategic research
17. Tidal energy	55. Coastal defences	92. Acoustics, electronics
18. Wind energy, offshore installation	56. Port construction	93. Civil engineering
19. Environmental protection/ preservation	57. Dredging	94. Climate change
20. Clean beaches	58. Land reclamation	95. Climate forecasting
21. Oil pollution control	59. Barrage construction	96. Coastal modelling
22. Non-oil pollution control	60. Tunnel construction	97. Data centre
23. Estuarine pollution	61. Outfalls/intakes	98. Environmental sciences
24. Health hazards	62. Consulting engineering	99. Estuarine modelling
25. Marine reserves	63. Components, hydraulics, motors, pumps, batteries, etc.	100. Fisheries
26. Species protection	64. Cables, manufacture and operations, laying	101. Marine biology
27. Environmental forecasts	65. Corrosion prevention, paint, antifouling, etc.	102. Marine weather forecasting
28. Flood protection	66. Heavy lifting, cranes, winches	103. Ocean modelling
29. Safe waste disposal	67. Marine propulsion, efficient ship, automatic ships, DP, props	104. Oceanography
30. Amenity evaluation	68. Offshore construction, platforms, etc.	105. Polar research
31. Environmental quality control	69. Pipelaying, trenching, burial	106. Remote sensing
32. Environmental data services	70. Ship-building, non-defence, all kinds	107. Shelf seas modelling
33. Mineral extraction	71. Services	108. Shipping/naval architecture
34. Aggregate, sand, gravel	72. Certification	109. Hinterland
35. Deep ocean, Mn, hydrothermal muds, crusts	73. Climate forecasting	110. Agriculture
36. Placer minerals, diamonds, tin, etc.	74. Data consultancy	111. Land use planning or zoning
37. Salts extraction, magnesia, bromine		112. Urban management
		113. Local government
		114. Wetlands management
		115. Public health

Categories of information and benefit/customer

1. Short term environmental data to a commercial company enabling them to increase profits, improve operational efficiency, or avoid accidents. Cash sales, either direct or through a value-added organisation.
2. Medium to long term environmental data and statistics indicating design limits, extreme values such as wave run-up, highest storm surge, maximum ice thickness, etc. Required by both commercial companies, local government authorities, and regulatory authorities. Probably marketable for cash to many users. Some public good component.
3. Environmental management information. Real time and climatic statistical data describing natural marine environments, including ecological and fisheries information, contaminants and pollutants, public health warnings, facilitating management of estuaries and coastal zones. Regulatory authorities and enforcement of regulations. Mostly public good services.
4. Climate variability, seasonal, forecasts of rainfall, hurricane probability, long term temperature trends etc. Reducing uncertainty. Valuable for insurance risk assessment. Planning agriculture, fisheries, medium term water and energy requirements. Has commercial value, but very difficult to collect cash from the beneficiaries. Probably managed as public good information.
5. Long term ocean climate forecasting, atmospheric climate change, sea level change, changes in sea ice limits. Planetary management and even human survival. Almost entirely in the domain of politics, agency policies, environmental management, international environmental treaties and negotiations, and public good information.

These categories emphasise again the complexity of trying to estimate rigorously the total costs or total benefits of the ocean observing system. It is possible to see in general terms that some services would be paid for in cash by customers, but it may depend upon national budgetary policies as to whether data obtained at public expense are distributed at cost of reproduction, or whether agencies are compelled to price data to recover capital and running costs. If a pricing policy results in poor up-take of data or forecasts, the economic analysis of benefits is changed.

6 - CONCLUSIONS

1. An ocean observing system, with the necessary data analysis and product distribution, implemented at the global, ocean basin, and regional scales, generates positive dividends much greater than its costs for Europe (and probably everybody else), given the approximate calculations possible so far.
2. Europe has a positive incentive to support the development of the global ocean observing system, since the benefits from medium to long term understanding, prediction of climate variability, and climate change, depend upon global models. Europe is vulnerable to large scale climate changes in the circulation of the North Atlantic and adjacent Arctic Ocean.
3. The value of the beneficial return, however measured, from long term ocean climate observation and forecasting, must be discounted in economic terms to obtain a net present value. Ongoing economic studies indicate that the discount rate should be closer to 1% than the traditional 7% for inter-generational timescales, and thus it is more worth developing long term ocean observing programmes.
4. Europe is an archipelago continent, dependent to a high degree on marine transport and marine resources, while prone to a wide range of maritime hazards and the effects of climate

variability. It is therefore practical to develop marine observing systems at all scales from coastal to shelf scale to oceanic, in order to obtain short and medium term benefits from the system. The shorter timescale products and benefits provide an economic and social return which counterbalances the negative cash flow in the long term system for the first decade.

5. Existing European institutions and national facilities provide many of the components needed for a Europe-wide ocean observing system. On-going collaboration, promoted by EuroGOOS, is designed to maximise the benefits from the investment in these institutions.

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ACRONYMS

APE	Atlantic Pilot Experiment
ARGO	Array for Real-time Geostrophic Oceanography
ASW	Anti-Submarine Warfare
BOOS	Baltic Operational Oceanographic System
CEC	Commission of the European Communities
CEOS	Committee on Earth Observing Satellites
DIADEM	North Atlantic modelling project
EAG	EuroGOOS Action Group
ECMWF	European Centre for Medium Term Weather Forecasting
ENSO	El Niño Southern Oscillation
EPOCH	European Programme on Climatology and Natural Hazards
ERS	Earth Resources Satellite
ESA	European Space Agency
ESF	European Science Foundation
ESODAE	European Shelf Ocean Data Assimilation Experiment
EU	European Union
Eumetsat	European Meteorological Satellite Organization
EUREKA	European Research and Co-ordination Agency
EuroGOOS	European (component) Global Ocean Observing System
EUROMAR	European Marine Research Programme within EUREKA
EuroROSE	European Radar Ocean Sensing
FOAM	Forecasting Ocean Atmosphere Model
GCOS	Global Climate Observing System
GLOSS	Global Sea Level Observing System
GNP	Gross National Product
GOOS	Global Ocean Observing System
IACMST	Inter-Agency Committee on Marine Science and Technology (UK)
ICES	International Council for the Exploration of the Seas
ICSU	International Council of Scientific Unions
IGOSS	Integrated Global Ocean Services System
IOC	Intergovernmental Oceanographic Commission (UNESCO)
JGOFS	Joint Global Ocean Flux Study
MAST	Marine Science and Technology (DG-XII CEC)
MERCATOR	French operational high-resolution global ocean prediction project
MedGOOS	Mediterranean Global Ocean Observing System
MFSP	Mediterranean Forecasting System Pilot Project
MoU	Memorandum of Understanding
OECD	Organisation for European Co-operation and Development
OTEC	Ocean Thermal Energy Conversion
PROMISE	Pre-operational modelling in the seas of Europe
ROV	Remotely Operated Vehicle
TOGA	Tropical Oceans and the Global Atmosphere
TOPEX/POSEIDON	Joint US/French Ocean Topography Experiment
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
WMO	World Meteorological Organisation
WOCE	World Ocean Circulation Experiment