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A benefit–cost analysis of a regional Global Ocean Observing System: Seawatch Europe

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The Global Ocean Observing System (GOOS) is a joint effort of the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the World Meteorological Organisation (WMO) and the United Nations Environmental Programme (UNEP). GOOS will provide long-term ocean data based on a globally coordinated strategy. These data will be used for climate forecasting. The Seawatch Europe project of the European Marine environment programme (EUROMAR) is an on-line monitoring and surveillance system of the North Sea and is a regional component of GOOS. Seawatch forecasts and environmental data are distributed to public authorities, aquaculture/fish farming, commercial fishing, tourist industry, research institutes, navy and coastguards. The Seawatch system is now operative in Norway and Thailand. It is at present installed in Spain, and Indonesia Seawatch has aroused considerable interest in Sweden, The Netherlands, Greece, Italy, Mexico, China, Korea and the USA. In this paper some of the results of a benefit–cost analysis of the Seawatch System are discussed. So far the main revenues occur in the oil and gas exploitation, commercial fisheries and fish farming, tourism, meteorological forecasting,
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In 1988 a major algal bloom originated off southern Norway and quickly spread along the coast to the western part of the country. The bloom caused serious mortality among both wild fish stocks and fish farms. Unlike previous toxic blooms, this one was detected early by buoys of the new Seawatch system. A warning was issued. As a result, many fish farms towed their net enclosures to sites predicted to be safe from the bloom. In retrospect it was estimated that this response saved $30 million worth of farmed fish (salmon and trout). The cost of the preparedness and warning activities was only 7% of this amount, or $2.1 million. This is the annual running cost of a ten-buoy Seawatch unit.

China reported the loss of approximately $700 million as the result of a bloom of poisonous algae in 1992. Fish farms there tend to be land-based, using salt-water pumped from the sea. Given an accurate forecast of an algal bloom, farmers could shut down these pumps for as much as a week. This is enough time for the peak of a typical bloom to pass. Thus there appears to be a huge opportunity to reduce losses in Chinese fish farms, but it requires high-quality data on the development of the bloom and the sea conditions that support it. Such data are provided by Seawatch, the world's only complete off-the-shelf marine environmental monitoring and forecasting system.

The Earth from space appears as a sparkling gem against the empty blackness of the universe. Sunlight reflects the uniqueness of the planet in bright blues and whites, the colours of solid, fluid, and gaseous water, the *conditio sine qua non* for life. For billions of years the lithosphere, hydrosphere, atmosphere, and biosphere have evolved while maintaining a complex and intricate dynamic balance. The atmosphere regulates the temperature of the Earth's surface and has done so throughout geological time. The history of life on Earth, as deduced from the geological record, demonstrates the extraordinary complexity of the biosphere, as well as its tendency, on occasions, to collapse catastrophically. Each time this has happened a new system developed. Yet the community present at the time of the collapse never returns.

The present balance of the biosphere may now be perturbed by the proliferation of life's most ambitious form and by the demands it places on the entire natural system. We do not fully understand the long-term effects of our own activities, including the large-scale burning of fossil fuels, generations of novel chemical wastes, clearing of vast tracts of vegetation, overgrazing and overfishing, and the global dispersal of previously local species. The growing concern about the global impact of human activities comes into sharpest focus when we recognize that the oceans, which cover 70% of the earth's surface, are at risk. The vastness of our oceans and regional seas is so deeply embedded in our minds that it has led us to believe that these areas are immune to our actions. Actually we are used to consider the sea as a threat to mankind, not the other way round. The intensive exploitation of ocean resources, and the by-products of industrial development, all put enormous pressure on what is an increasingly fragile environment.

It is widely recognized that the world's oceans play a major role in global environmental change. To really understand the complicated processes in the sea and to predict their outcome over time scales of months, years, or even decades, experts need to observe and describe them in detail. Sophisticated numerical models of the marine environment are vital for predicting changes. Satellites can provide some of the synoptic data needed, particularly from large areas of ocean that have previously remained unobserved. However, these measurements need to be validated and complemented by reliable *in situ*, ground-based, information. This demands that full advantage can be taken of technological advances in sensors, platforms, measuring systems and telemetry, and also that internationally co-ordinated, cost-effective programmes ensure easy access to the data by all users. Clearly it is urgent to establish the criteria for making the necessary choices among the many possible courses of action, and to implement the laws and create the institutions required to affect these choices. We must be able to correct mistakes caused by man's ignorance. Among other things this means controlling the discharge of sewage effluents, industrial wastes, radioactive wastes, and accidental spills of oil and chemicals.

Global Ocean Observing System, GOOS

Some 150 years of scientific and technological progress have made available tools capable of unlocking the ocean's secrets. These include observation tools in space and in the sea as well as scientific computational models, which have been developed and tested in major international research programmes such as the Tropical Ocean Global Atmosphere (TOGA) study, the World Ocean Circulation Experiment (WOCE), the Joint Global Ocean Flux Study (JGOFS), and the Climate Variability and Predictability (CLIVAR) programme. Today, we know how to *observe* and *understand* the ocean and tomorrow we will be capable of *forecasting* its evolution. This approach was confirmed during the United Nations Conference on the Environment and De-

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crises management etc. It is calculated that in the North Sea, a delay of 105 minutes in startup of the productional of a well will cover the costs of Seawatch. The global potential for the Seawatch System in the Exclusive Economic Zone is an estimated 50 units of ten buoys with a running cost of $100 million per year. A strong point of the Seawatch system is that it is commercially off-the-shelf technology. Seawatch is, however, still competing with academic and governmental institutions for funds when viewed as either a research venture or an operational programme. It is important for public authorities at the national and international level to participate in Seawatch and help to steer it towards the potential it was designed to fulfil namely a building stone of GOOS.

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velopment (UNCED). This meeting took place in Rio de Janeiro in 1992. UNCED recognized the ocean as a key element of the global environment of a Global Climate Observing System (GCOS).

The Global Ocean Observing System (GOOS) is a joint effort of the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the World Meteorological Organisation (WMO), the International Council of Scientific Unions (ICSU) and the United Nations Environment Programme (UNEP). GOOS will provide long-term ocean data based on a globally coordinated strategy. These data will be used for climate forecasting. GOOS will be based on the results of research programmes, which identify strategies and model needs and new technologies. The system will be built as far as possible on present global, regional and national systems through an integrating process. GOOS will consist of a number of modules to address specific objectives such as: (1) Climate Assessment and Prediction; (2) Marine Living Resources; (3) Coastal Zone Management and Development; (4) Health of the Ocean; (5) Marine Meteorological and Oceanographic Operational Services. It will provide a reliable description of the state of the ocean, which will be regularly updated and will serve as an input to a wide range of operations, such as coastal protection, marine resource exploitation, safety, monitoring the marine environment, and pollution control. GOOS will be developed in phases. A pilot experiment is planned for 1997–2007.

To put the costs of a regional GOOS system, such as Seawatch, in context it is useful to look at estimates of the total cost of GOOS, even though GOOS has not yet advanced to the point where its costs are known with any precision. Globally, expenditures on oceanography and marine technology total \$5 to 10 billion annually. It is thought that a fully operational GOOS may require an additional expenditure that is approximately the same as current world-wide expenditures for meteorology, or \$1 to 2 billion annually.[1] N C Flemming has made a rough breakdown of how the costs may be attributed to GOOS components[2]. Much research still needs to be done to refine that estimate. The scale of ocean eddies (analogous to atmospheric cyclones) suggests that ocean models may need a resolution ten times finer in horizontal dimensions, and possibly in the temporal dimension, than current atmospheric models. Flemming suggests a need for a thousand times more powerful computer to run the models and, more importantly, a denser field of observations to support the models. It is not yet known whether simplifying assumptions can be made, nor is it known what the data needs are.

The rough estimates for GOOS do not include all of the costs of local and regional oceanography. In particular, planners recognize that models of much higher resolution – and much denser observation sets – will be developed to meet particular needs in coastal zone and other limited areas. These local and regional observation systems will benefit from the availability of GOOS. In turn, GOOS will draw data from the local and regional systems, so that planning for the compatibility of data sets will be mutually advantageous. It is expected that some of the costs of local systems will be supported by local users. GOOS will also incur joint costs in some other areas, especially satellites. Satellites will be used for meteorology and terrestrial observation, as well as oceanographic observation. Communications satellites that carry GOOS data will have many other users as well, and are considered as 'sunk' costs.

[1]This estimate is based on the cost of global meteorological forecasting and known satellite costs. At present the global annual costs of all aspects of marine research and marine technology development is, according to Flemming[2] some \$10 billion.

[2]OECD, *Oceanography*, OCED, The Megascience Forum, OECD, Paris, 1994.

EUROMAR's Seawatch

The European Marine environment project (EUROMAR) of the European Research Coordination Agency (EUREKA) aims at the development of marketable advanced technology for environmental surveillance. EUROMAR was launched in June 1986 and has stimulated cooperation between the European industry and science in developing marine instrumentation, methods and operating systems. Jointly the 13 EUROMAR countries are improving the productivity and competitiveness of the European marine industry and are putting this industry on today's and tomorrow's world market. The approach is a bottom-up one. So far, EUROMAR has launched more than 20 projects of which five are completed, with a total investment of ECU120 million (some $250 million).

The Seawatch project of EUROMAR is an on-line monitoring and surveillance system of the North Sea and is a regional component of GOOS. The technological objective of Seawatch Europe is to integrate the various results of the EUROMAR programme within the areas of marine surveillance technology and information technology into an international operational monitoring system for, among others, the North Sea. By this, the project implements the best available technology and develops an innovative operational marine environmental network. Major technical issues for the Seawatch system are: network structure, standardisation, innovative sensor technology, data transmission, data processing facilities and storage, integrated use of monitoring technology and operational modelling technology, and comprehensive user facilities. A number of aspects are covered to some extent by ongoing EUROMAR projects such as FIESTA for standardisation, OPMOD for hydrographic modelling and transport processes in shallow waters, VISIMAR for video displays of marine environmental data and MERMAID for a remote-controlled, automatic measuring and sampling device for the determination of micropollutants such as heavy metals and synthetic organic compounds. Other aspects are dealt with by the Seawatch partners. Seawatch is recognized by the IOC and the Organisation for Economic Cooperation and Development (OECD) as a regional GOOS system. As such it is an important building-stone for GOOS.

The Seawatch Europe project aims at covering areas subjected to transboundary pollution transport. The project comprises an international system of automatic oceanographic stations with real-time data transmission to shore-based receiving stations, data handling and analysis systems for information synthesis and a user friendly information system for internationally presenting the environmental data to various users. Each participant in Seawatch is provided with environmental data from other participating countries on an operational basis. For the industrial partners, Seawatch serves as a pilot project for innovative technologies and a 'marketing tool' for extensive data sets from the marine environment. The data and information collected are offered to European environmental agencies, research institutes and private industries. In doing so it strengthens the growing demand of a quality oriented market. The users of Seawatch forecasts are public authorities, fish farmers, the aquaculture and commercial fishing industry, research institutes, the navy and coastguards, and the tourist industry.

Seawatch was developed to provide an operational marine environmental surveillance and information system for the management of

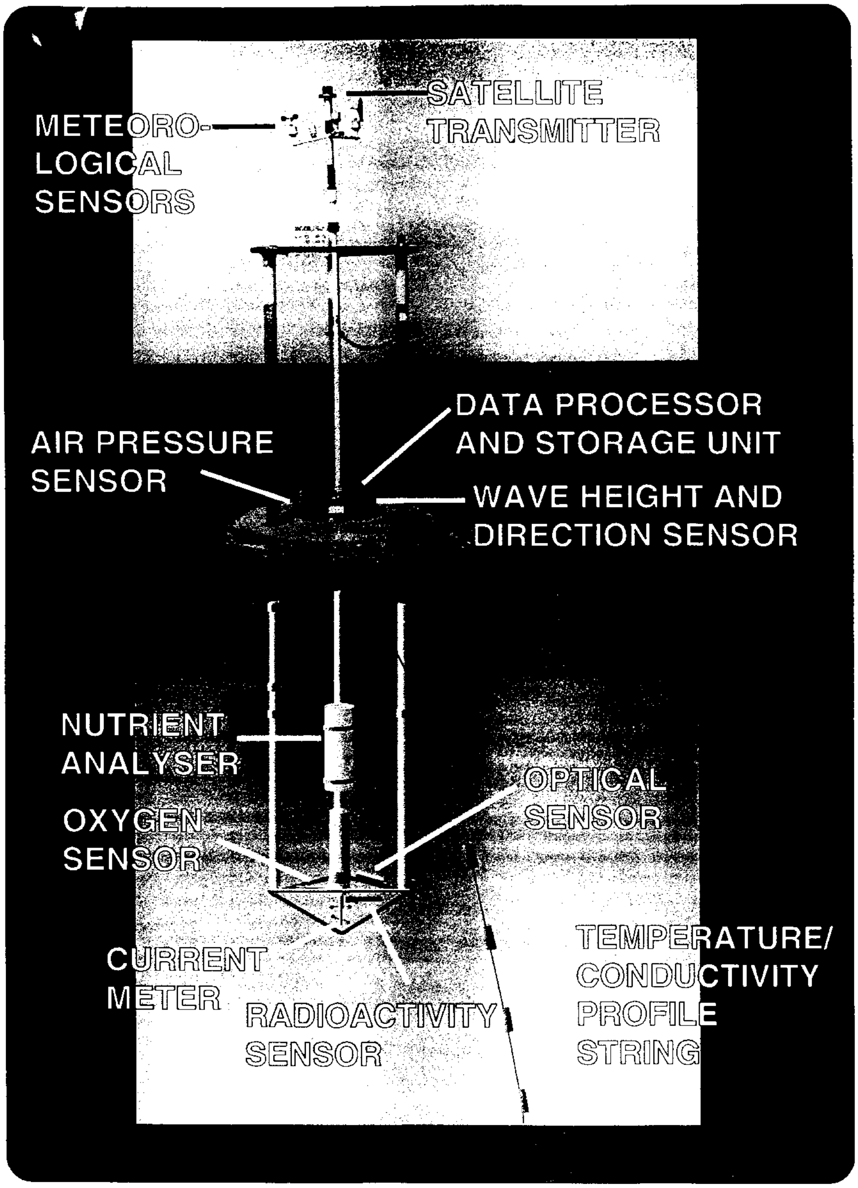

Figure 1. The Tobis buoy of the Seawatch system. At present some 20 environmental parameters are measured in real-time.

regional seas. It consists of the following modules: data acquisition; data storage; analysis and presentation; environmental modelling and forecasting; distribution of data; forecasts and user relevant information. The data acquisition module includes a network of moored marine environmental data collection buoys. The Seawatch buoy is a vertical stabilised automatic buoy. The buoy (Figure 1) is presently equipped to collect the following parameters: air pressure, air temperature, wind speed and direction, wave parameters, sea current, vertical temperature and salinity profile, oxygen saturation, nutrient contents, particle or algae concentrations and radioactivity. As the buoy is made to be very flexible, suitable new sensors could be included as they become operational. The buoys also include data logging equipment, on-board processing (data analysis, quality control) and a data transmission system. The data are transmitted through a two-way satellite communication system (Argos or Inmarsat) to a shore station. In this way

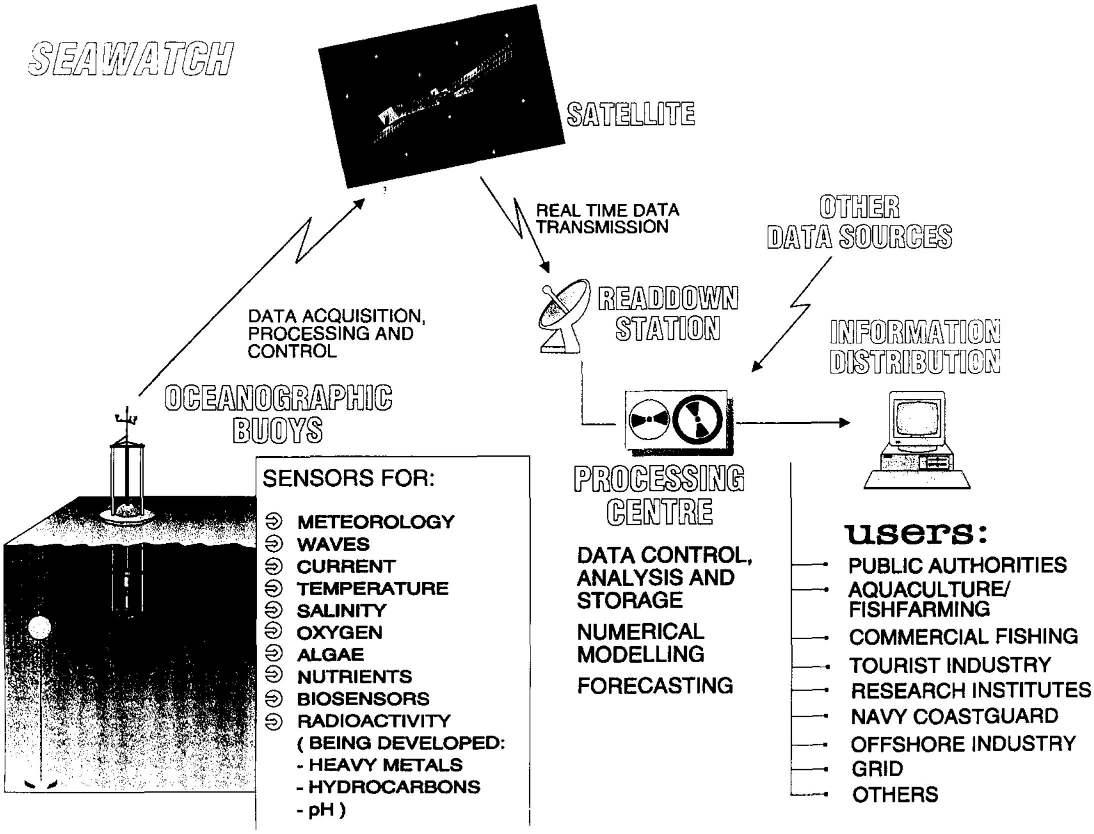

Figure 2. The Seawatch system consists of a real-time measuring system in the sea, and a land based processing and product distribution centre. The Seawatch system is the world's only state of the art off-the-shelf monitoring system.

environmental sea data from the remotest of waters and anywhere in the world can be received at the operation centre only hours after they have been collected (Figure 2).

In the shore station the data is further checked, analyzed, distributed and stored. The buoy data are integrated with information from other sources as input to various numerical models, such as current, transport and oil slick models. Results from these models are combined with information from the buoy network to generate user-tailored forecasts. One important aspect of the system is the use of the data with operational forecasting models for ocean currents, pollution transport and impact assessments. All data and results from the various models, are collected in a processing centre where the results are quality checked, and then used for monitoring and forecasting purposes. This centre could be compared with processing centres in weather bureaus.

The fourth part of the system is the computer-based system for distribution of relevant environmental information to interested parties. By using an ordinary PC, equipped with the necessary software, i.e. Ocean Info system, various users can achieve the required data or relevant information in a very easy and user friendly way. Measured and simulated data are presented to the users in a geographic information system using digitized geographical maps that will be continuously updated with relevant information. One should mention, however, that observations from traditional oceanographic research programs, remote sensed data and from local observers scattered along the coast can and should be integrated in a Seawatch system.

Seawatch provides marine environmental information quickly, thus giving us the opportunity to make informed decisions when crises occur. The Seawatch forecasts and environmental data are distributed to users whose livelihood depends on reliable information from the marine environment, such as: public authorities, aquaculture/fish farming, commercial fishing, tourist industry, research institutes, navy and coastguards. The Seawatch system is now operative in Norway and Thailand, will be installed in Spain and Indonesia, and has aroused considerable interest in coastal states (Sweden, The Netherlands, Greece, Italy, Mexico, China, Korea, USA etc) all over the world.

A strong point of the Seawatch system is that it is commercially off-the-shelf technology. It can be applied anywhere in the world as a complete system or, based on local needs, as a stripped down version. It is a highly adaptable platform for placing a range of instruments *in situ* and extracting data in *real time*. For the seas of India, it has been estimated that the cost of purchase and operation of 12 Seawatch buoys will be approximately the same as that of a medium size oceanographic research vessel. There is no doubt that the 12 buoys will collect many times more data than one ship alone would be able to. For Eastern Africa a nine buoys system might be adequate. Last, but not least, the implementation of a Seawatch system also includes training and technology transfer in relevant aspects, such as buoy operation, buoy maintenance, software use and training in forecasting related aspects. Therefore, Seawatch could become instrumental in Capacity Building activities in developing countries, and by this, allowing for the development of a truly global GOOS.

Benefit–cost analyses

A benefit–cost analyses (BCA) is an arithmetic method for valuing a stream of benefits and costs from public (or private) investment in terms of their present economic value. Around the turn of the last century it was developed by the US Army Corps of Engineers. They used it to determine whether harbors should be dredged and, if so, to what depth.[3] During World War II both the United Kingdom and the United States developed a variety of research methods for deploying military resources. These were later incorporated into benefit–cost analysis and applied to a wide range of public projects. BCA employs the fact that a unit of currency (eg an ECU or US $) received today has a higher economic value than a similar one spent in the future. The discount rate is used to deflated monetary amounts received or spent in the future to a single present value, the net value. The longer the delay between the start of the cost stream and the onset of the benefit stream, the greater the sensitivity to the discount rate. For example, if a project costs $10 million per year and produces benefits of $20 million per year, you cannot say whether it is worthwhile until you know when each cash flow begins. If the costs and benefits begin immediately, the discounted present value of costs and benefits at 10% annually, is $100 million and $200 million respectively. In this situation the net gain is $100 million.[4] If, however, the costs begin today while the benefits begin 10 years later, then the present value of costs and benefits at 10% annually is 100 million and 77 million respectively.[5] So, the net loss is $23 million. As a

[3]In the United States the Army Corps of engineers is responsible for navigational civil works, even when there is no relationship to national defense.

[4]For this simple case, discounting is straightforward. The usual formula calculates the present value, PV, of a stream of payments in year i, ai, over n years at an interest rate r:
PV = Summation [for i = 1 to n] {ai (1 / (1+r)i)}.
When the payments are perpetual and constant, the result is that PV = a/r. For example, if a = $10 million and r = 10%, or 0.1, then PV = $100 million. The easiest way to make this intuitive is to think of the reverse transaction a bank deposit of $100 million earning 10% interest will pay $10 million per year in perpetuity. Thus $100 million today, and $10 million per year forever, are equivalent.

[5]Perpertual annual payments of $20 million are worth $200 million on the day they begin. If that is 10 years hence, then an additional discount factor of (1 / (1+r)10), or 0.386, reduces their present value to $77 million.

rule lower discount rates make a project more attractive, while a longer delay makes it less attractive. Therefore, the choice of a discount rate is a critical element in the analysis of any long-term (science) project. Most of the nuances and subtleties involved in BCA arise from the difficulties of reliably estimating future costs and benefits, and include the difficulties of *ex ante* estimations of economic value and the attribution of economic values for goods and services that are public, i.e. available to all without exclusion. The remaining difficulties with the technique have to do with the shortcomings of the net present value as a social welfare measure, the problems of determining the appropriate boundaries of a project within a larger programme of research, and the attribution of benefit and costs to a source when they involve substantial complementary investments in development and commercialisation. Nevertheless, many public policies significantly affect the overall economy or wellbeing of the general public. A benefit–cost assessment is an important step in public policy decision making.

With regard to scientific research projects, however, the major problem to applying BCA arises from the difficulty in anticipating the outcome of research that is inherently exploratory. Moreover, the economic benefits of most scientific research are uncertain and we have little, if any at all, prior knowledge of the distribution of the economic returns they might generate. Historical experience with scientific research indicates that major benefits have often been unanticipated. Yet, those who wish to encourage governments to commit resources to scientific research point out, correctly, that retrospective evaluations of science and technology projects tend to show very high social returns. This is true for both public and private expenditures. In part, this is evidence that the projects that survive to be evaluated in retrospect are good ones. Weak projects are weeded out early. The screening mechanisms used to select projects — including the peer review process, self selection (as researchers choose careers), and budgetary scrutiny — appear to be working reasonably well.

We do not know what effects BCA for the Megascience project selection will have on public welfare. It may increase, decrease, or leave unchanged the overall social welfare generated by the projects selected. So far, there are very few examples of benefit–cost analyses of megascience projects. Another paper prepared for the Megascience Forum[6] reviews what examples can be found, and enumerates the considerable barriers that must be overcome when benefit–cost analysis is applied to megascience projects. Some of those barriers are particularly troublesome in the case of Seawatch Europe.

Costs of Seawatch

Costs of Seawatch Europe/Thailand

While Seawatch Europe was partly developed within EUROMAR, the cost of Seawatch includes large 'sunk' costs, which do not have to be incurred again if the system is expanded or cloned. Therefore the costs that have been incurred to date in building Seawatch Europe, are not necessarily the most relevant numbers for a benefit–cost analysis whose purpose is to help inform future policy decisions. It goes without saying that research and development continues to be a large part of the Seawatch budget and the sensors and other components of the system

[6] M Brown, *Cost/Benefit Analysis of Large-Scale Science and Technology Projects: Some Methodological Issues*, Megascience Forum, OECD, Paris, 1995.

continue to be improved. If we want to describe the cost of Seawatch Europe there are two ways to ask the question. The first one is: What did it cost to create it? The second one is: What would it cost to do it again?

The last question can be answered if we look at the cost of Seawatch Thailand, a nine-buoy operational system. Of course, every deployment of the system will occur under unique conditions and will present its own challenges. As we are only interested in the approximate costs, a comparison between Europe and Thailand is instructive. Based on this we think that for a Seawatch 'planning unit' consisting of ten instrumented buoys and the associated data systems, the annual costs are between $2 and 3 million. To answer the first question precisely is probably not possible as some of the development costs of the instruments are 'joint costs'. Those instruments can also be used in another, non-Seawatch context. Based on Oceanor's annual reports a rough estimate of these costs is some $10 to 20 million.

Global potential of Seawatch

If the Seawatch concept is successful and is widely deployed, how large might it grow and what would it cost? For the purpose of this thought experiment, we will try to imagine a Seawatch system that covers all shelf seas, coastal zones, archipelagos, key straits and topographical choke points. It can be considered complete when it covers these areas to a resolution that is technically and economically justifiable.[7] We shall assume away the various political barriers to the global deployment of Seawatch (or any *in situ* system). For example, in the Mediterranean there are governments that will only consider participating in a joint venture if certain other governments do not participate. Some developed countries may insist on building their own system for coastal zone observation. Such obstacles make improbable the idea of a global system bearing the label 'Seawatch'; nonetheless this thought experiment is illustrative in that it puts Seawatch on the same scale as GOOS for the purposes of comparison.

An assessment of sampling needs[8] estimated that GOOS might require more than 100 moored instrument arrays for deep ocean observation. For shelf seas the same table contains a '?' with the footnote: "The question marks indicate complete uncertainty". By looking at Seawatch, we can at least put some bounds on this complete uncertainty. If we think in terms of ten-buoy planning units, the Gulf of Thailand contains one such unit; the Baltic/North/Norwegian Seas contain one unit and ought to have another to provide more complete coverage. The number of opportunities for productively deploying similar systems is certainly greater than ten. On the other hand, it is unlikely to exceed 200, since 200 units would cover all of the earth's wet surface with the same density of buoys that now exists within Seawatch Europe; fewer than 100 such units would cover all of the EEZ (roughly corresponding to all of the shelf seas and continental shelves). Let us use 50 units as an illustrative estimate, being 500 Seawatch buoys[9] worldwide with a running cost-figure of $100–150 million per year. When we adjust this estimate for economies of scale in data management, modelling, instrument manufacture, maintenance, etc. we conclude that a fully deployed 500-buoy global Seawatch network would cost some $100 million annually. This projected cost-figure commensurates with the guesstimate made by Flemming[2] for other components of GOOS.

[7]Alternatively, we could consider deploying Seawatch throughout the EEZ. In practice, there is not much difference between these two approaches.

[8]*Op cit*, Ref 2, p 94, Table 1.

[9]Oceanor reports that in making plans and proposals to various countries, it has so far examined on the order of 200 potental sites for Seawatch buoys.

Benefits of Seawatch

Marine structural design criteria

Seawatch's ability to collect time-series that allow the estimation of extreme events (waves, currents, algal blooms etc) for the purpose of engineering design is one of the most straightforward benefits. In low-lying coastal areas coastal design criteria are important when engineering solutions are considered for protective measures such as the UK Thames Barrier and the multibillion dollar Dutch Delta works. The Netherlands obviously has the most experience with this, and has its own coastal monitoring system, including three fixed platforms at sea. As the sea level rises the question of whether barriers are adequate must be constantly reconsidered. Since Seawatch buoys do not measure the water level directly, their ability to forecast maximum storm surges is limited.

Seawatch can play a much more important role in developing design criteria for off-shore oil and gas platforms, which must be able to withstand the sea for up to 50 years. This application does not require real time data. But it does require long time-series measured *in situ*. The Norwegian Petroleum Directorate for example requires a 1–2 year current measurement and a 10-year wave measurement prior to the development of a field. As most offshore platforms predate Seawatch their design criteria are not (yet) derived from Seawatch data. This will change when exploration extends to new areas. For example, on 1 January 1993, a Seawatch buoy at Nordkappbanken in the Barents Sea recorded a significant wave height of over 13.6 meter. The previous 100-year estimate was 12.5 meter. Further measurement will clarify whether this represents new information or whether it indicates a trend driven by climatic changes. Whichever is the case, it is likely to cause significant changes in the design of future platforms for the Barents Sea.

Offshore design criteria are important anywhere oil and gas reserves are developed. The benefits of improving these criteria, concern cost savings from both the avoidance of overdesigned structures, and reduced losses (including reduced loss of life) from the avoidance of underdesigned structures. Since the consequences of underdesign are so catastrophic, engineers tend to deal with uncertainty by overdesign.[10] Overdesign may add on the order of 10% to the development cost of a platform (the difference in cost between a platform that is just adequate to meet forecast environmental conditions and one that has a margin of safety to account for uncertainty in environmental conditions). The value of improved environmental design criteria is some fraction of that 10%. The exact amount depends on how much of an improvement is made.

Marine operations

In addition to providing time-series that contribute to structural design criteria, Seawatch buoys can provide data that helps optimize operations in real time. Many marine operations have limitations with respect to weather, current and waves. An important example is the tow-out of large platforms. By knowing when currents, winds, and waves are favourable — or at least do not exceed a prohibitive threshold — such operations can be concluded successfully in the earliest available window. More commonly, the benefits of now-casting and forecasting take the form of reduced standby for tug-boats, crane vessels, diving

[10] Errors of underdesign do occur, however. Some Ekofish platforms had to be redesigned and reinforced due to an underestimate of wave height as well as an underestimate of sea-floor subsidence; costs were $1–2 billion.

vessels, and other resources sensitive to currents and waves.

Another example is the operation of sub-sea pipelines that are sensitive to the bottom temperature. Seawatch has been able to monitor the intrusion of deep cold water into the Norwegian trench, enabling pipeline operators to optimize the use of chemical additives that are used to prevent condensate/precipitate formation when the bottom temperature falls below a critical threshold. Such chemical injection costs on the order of $2–3 million annually.

Improved off-shore weather forecasts and sea-state forecasts are important for the operation of transportation systems such as:

- Merchant vessels need current, wind, and wave data to optimize routing for efficiency as well as safety reasons.
- Roll-on/roll-off ferries are particularly vulnerable to adverse sea conditions.
- Recreational boaters need adequate warning systems for sea conditions that threaten small boats.
- Coastal rescue operations need detailed information in real time.
- Many helicopters will not fly over water when the wave height would prevent rescue.

Unfortunately it is almost impossible to estimate the benefits in these areas. Offshore transport is a large consumer of weather forecasting and sea condition information. Yet the incremental contribution of Seawatch cannot be quantified.

Oil and gas exploitation

One way to estimate the value of improved information by a Seawatch system is to consider the effect of accelerated cash-flows. Offshore oil and gas production is extremely capital intensive. Most of the costs are spent before the revenues begin. As a consequence, start-up delays are very expensive. At an annual discount rate of 10%, a 1-year delay in bringing a well into production results in a 10% reduction in the present value of the stream of benefits from that well. Current revenues from oil and gas production in the Norwegian sector of the North Sea amount to $15 billion. Since Seawatch costs roughly $3 million, the 'break-even point' occurs at 1.75 hours. That is, if Seawatch can avoid, on average, a delay of 105 minutes in the start-up of oil and gas production, then it will have covered its costs of operation — even without considering all of the other categories of benefits that it produces. Seawatch data can affect oil and gas operations in a variety of ways,[11] but it seems reasonable to expect that the cumulative effect far exceeds a few hours worth of delay in the production stream.

Rough estimates of the benefits of GOOS have used a benchmark of 1% of the value added in all marine-based activities.[12] In the case of oil and gas operations in the North Sea, it is plausible to believe that Seawatch can produce benefits of this magnitude, implying benefits on the order of $150 million annually. Expanding Seawatch Europe to other North Sea sectors could double the benefits. Worldwide revenues from offshore oil and gas production total $150 billion annually. If similar efficiencies can be achieved in other regions, the potential benefits of a global Seawatch system may approach $1.5 billion.[13]

Commercial fisheries

The global catch (now approximately 100 billion kilos with a value of

[11]In the North Sea the full potential may not have been realized, since planning and design for platforms mostly occurred before Seawatch was operational. In frontier areas, the use of a Seawatch system from the beginning would likely result in a greater improvement in efficiency.

[12]*Op cit*, Ref 2.

[13]Of course, a global Seawatch system by itself would not produce all of the benefits that have been forecast for GOOS. In the case of oil and gas development, however, it is reasonable to assume that all of the benefits could be realized with Seawatch because (1) Seawatch is designed to operate in all of the areas where offshore development is possible, and (2) almost all of the oceanographic data series of interest to oil and gas development are available through the Seawatch system. One exception is marine life—the interaction between offshore development and fisheries, marine mammals, etc.

$100 billion) has not increased since 1988. The UN has estimated that 70% of the world's commercial stocks are fully fished, overfished, or already depleted. At present, the fishing effort is as a rule, gradually shifting to lower value species as the more desirable species become scarcer. There are many obstacles, both technical and social, to improved fisheries management. The most important long-term contribution that Seawatch can make is to contribute to a better understanding of the natural factors that affect fish stocks and their variability. Improved models of water movement, pollution transport, nutrient availability, algal blooming, and climate variation, all can help our understanding and management of fishery stocks. On the other hand, Seawatch can also improve the efficiency of fishing operations. Ocean fishing is a hazardous occupation, and improved weather and sea-state forecasting can save lives as well as improve productivity. By mapping temperature and salinity gradients, Seawatch may help find cod and other fish, thereby lowering the effort involved in the catch.

Fish farming

Basically the problem of fishery management is a failure of property rights. A fisherman does not own a fish until he catches it. There is also no economic incentive to care for the fish that he does not catch. Thus fishermen, and even whole nations, may engage in a race to catch the fish, unwilling to let go what may be caught by someone else tomorrow and leading to the collapse of fish stocks, the establishment of fishery zones, and in the worst case to fishery wars such as the Canadian–Spanish conflict in 1995.

As an alternative, aquaculture allows the development of true private property rights in the immature fish. No fish farm ever collapsed from overfishing, and if it did its more efficient neighbor would simply expand to replace it. Aquaculture is seen as the dominant form of fish production in the future.[14] On land the transition from 'hunter–gatherer' to farmer took place some 12 000 years ago. At sea a similar transition is just beginning. One of the benefits of high-yield aquaculture is that it allows so much land to return to a relatively wild state. Similarly, by meeting demand for fish, aquaculture may allow many ocean fisheries to return to an essentially wild state.

On the other hand, the technology of marine aquaculture as it exists today has some inherent limitations. Fish farms, just as the high-tech EU and US sponsored cattle farms, can have serious environmental impacts. These need to be monitored. Naturally, production has initially been concentrated in high-value species like shrimp and salmon. On land, the most desirable species for human consumption are herbivores. As a contrast the most desirable marine species are carnivores feeding on fishmeal produced from low-value wild stocks. The result is that, while aquaculture is producing real economic value-added, it does not, in its present form, promise to increase the gross productivity of the sea nor solve once and for all the problem of fishery management.

Aquaculture is a promising technology and it has been expanding rapidly. Worldwide, the output from aquaculture is growing at 7% annually, with 85% of output coming from Asia. One of the benefits of aquaculture is that it provides the opportunity and incentive to advance science and technology in this field. Genetic engineering, using both traditional selection and modern molecular biology, might improve the stocks. Feed conversion can be raised and alternative sources of feed

[14] "As much as we may yearn for the traditional model of fishing, the development of technology, in the presence of finite stocks, is driving us in the direction of privatization, away from a common property resource." S F Singer, *Fisheries Management: Another Option,* Rethinking Fisheries Management Proceedings of the Tenth Annual Conference, Center for Ocean Management Studies, J G Sutinen and L C Hanson (eds), University of Rhode Island, June 1986.

can be found. Its ultimate potential is difficult to judge.

It is important to acknowledge that lower prices are the mechanism by which aquaculture produces most of its benefits.[15] Seawatch Europe has made a number of contributions to salmon farming in Norway. Ninety percent of salmon grow-out operations are insured with three companies that sell insurance for both equipment and for fish stocks. All three companies provide funding to Seawatch and require that their clients participate in the monitoring and alert network maintained by Oceanor. Data from the Seawatch buoys are supplemented with data collected by the farmers themselves. Losses are reduced by improved warning of storms, forecasts of water temperature changes, and monitoring pollution. Feeding schedules can be adjusted based on water temperatures and conditions, conserving feed as well as reducing mortality.

The main benefit of Seawatch, however, is the ability to monitor algal blooms. Farmers can take preventive action (which may involve moving the cages or harvesting the stock before it is affected) if a toxic bloom develops. In 1993, Norway produced 170 000 tons of farmed salmon. The market value was some $500 million. The insurance companies pay Oceanor approximately $150 000 annually for the services provided to clients. Losses (paid by insurance companies) due to toxic algae were only $100 000 in 1993 but averaged around $8 million annually in the preceding three years. In 1991 annual losses due to storm damage (equipment and escaped stock) were estimated at $12 million annually; a single severe storm 1 January 1992 caused $14 million in losses. Accurate tracking of blooms can also help avoid unnecessary preventive action by providing reassurance to farmers who will not be affected. In this regard, the value of Seawatch should increase with the planned upgrade of the light attenuation sensor, which will allow the system to distinguish (without manual sampling, as is done now) between toxic and non-toxic blooms. A sharper distinction between alarms and false alarms will enable fish farmers to respond efficiently and effectively.

The interannual variability of storms and algal blooms makes it impossible to perform a statistical assessment of the effect of Seawatch. Based on their experience with particular incidents, salmon farmers and their insurers believe that the Seawatch system is very effective in avoiding both storm damage and algal poisoning. The benefits of Seawatch are greater in the case of algal blooms because there are fewer alternative sources of information. When we assume a loss-reduction benefit of let us say 25% for algal blooms, and 1% for storm damage.[16] Then the revenues of Seawatch are some $2 million and $0.1 million respectively. The total of $2.1 million annually alone is by itself almost enough to justify a Seawatch system on the Norwegian coast. Due to the nature of aquaculture, and as the threats that it faces varies from region to region, the global potential is difficult to estimate. But algal blooms are a threat in many ways where fish farming is developing, and the threats from coastal pollution, oil spills, and radioactivity can also be addressed by the Seawatch system. In 1992, it was reported that shrimp farming losses in China were approximately $700 million, mainly due to red tides.[17]

The total worldwide fisheries catch is roughly 100 billion kilos, with a value of $100 billion dollars. Aquaculture production is about 20 billion kilos, of which about half is from salt water species. The value of aquaculture production varies a great deal, but we will assume that on

[15]The traditional fishing industry often regards lower prices as a cost, because of the losses experienced within the industry. From a social point of view, however, the lower prices produce benefits to consumers that outweigh the losses to high-cost producers. Moreover, lower prices can produce environmental benefits. For example, the growth of salmon farming in Chile, Norway, and Scotland has lowered the market price for fresh and frozen salmon in the United States by 25%. One result is a reduction of fishing pressure on the salmon fisheries of the Pacific Northwest and western Canada, which are seriously depleted. Inevitably, the perception of the North American industry will be that lower prices are just one more problem they have to face in addition to the depletion of wild stocks. From a broader social perspective, however, the effect of lower prices is to conserve the wild stocks, providing an additional benefit.

[16]Anecdotal evidence from fish farmers and insurers suggests higher savings, but such anecdotes need to be discounted until more experience is accumulated.

[17]Oceanor memorandum by Per-Erik Sxres, 15 March 1995. Many Chinese shrimp farms are land-based, and used pumped salt water. Bloom forecasts would allow the planned suspension of pumping to exclude contaminated water.

average the 10 billion kilos of marine production is worth $20 billion.[18] We assume that the rate of loss from storm damage and natural (algal) and man-made pollution is similar to the rate of loss in Norway, about 4% annually, or $800 million dollars. If we assume that Seawatch could reduce losses by 10% overall, this amounts to $80 million dollars annually at current levels of production.

Tourism

International tourism produced receipts of $300 billion in 1990.[19] When domestic tourism and travel are added, the total exceeds $2 trillion. A major share of this total is related to coastal tourism. The Mediterranean alone is estimated to account for 36% or more of international tourism. It goes without saying that, even without tourism the world's population is highly concentrated in the coastal zone. But tourism is particularly sensitive to water quality. In 1990, one-fifth of Mediterranean beaches were so polluted that they were closed to bathing.[20] Pollution around Athens caused Athenians to drive 70 km to find a clean beach. Countries with a significant tourist industry will find it increasingly important to monitor water quality and to determine the factors that influence it. France conducts some 20 000 tests of water quality each summer to ensure that coastal waters are safe for bathers.[21] In many of these areas Seawatch would be an important supplement to coastal data collection.

Meteorological forecasting

On land, a dense array of meteorological observation stations forms a global network that is increasingly integrated. Unfortunately, this dense network stops at the water's edge. One reason for this is that the demand for data is greater on land: more people live there, of course, and airports in particular have a great demand for accurate and current met data.

But offshore activities also demand accurate and current data. And some of the most important meteorological events — hurricanes and typhoons, storm surges, polar lows, monsoons, etc — develop at sea or from the interaction of the atmosphere with land/sea/ice surfaces, so that offshore data is critical to forecasting these events. Traditionally marine meteorological data for use in weather forecasting have been collected by observation ship staying in fixed positions. The cost of operating such ships has shown an increasing trend. Accordingly, the numbers of ships have been reduced. Norway operates one ship at a cost of $2 million a year, capital costs not included. For this cost, six Seawatch buoys could be operated and the amount of data available for forecast improvement would increase significantly.

The second and more important reason that met observations are much denser on land is that meteorological stations on land are far cheaper than those at sea. Very few meteorological platforms are available on the ocean, and those are often very expensive to build and maintain. When viewed as a network of weather observation stations at sea, Seawatch represents a dramatic reduction in the cost of expanding the land-based met network. Generating an accurate estimate of the social benefits of a weather forecasting station is nearly impossible, despite the fact that we build them all the time and that the benefits of the met system are unquestioned. We can approach the problem in a different way, however. If we suppose that the social benefits of a

[18]Farm product tends to be more valuable per ton than the wild catch, simply beause farmers choose to produce the higher-valued species.
[19]M K Tolba, *Saving Our Planet: Challenges and Hopes*, Chapman and Hall, London, 1992, p 170.
[20]D Hinrichson, *Our Common Seas—Coasts in Crises*. Earthscan Publications, 1990.
[21]OECD, *The State of the Environment*, Organization for Economic Cooperation and Development, Paris, 1991.

marginal land-based weather station is sufficient to justify its cost, we can ask whether the cost of a Seawatch buoy is anywhere close to the cost of its land-based counterpart.

Based on the implementation of the so-called Automated Surface Observing System (ASOS) in the United States in 1992–1998, the total cost of an ASOS unit is an estimated $40 000. The per-buoy cost of a large Seawatch network is about $200 000. With a cost five times as great as comparable land-based stations, Seawatch buoys are not likely to be deployed as densely as the land-based network.[22] Given the current paucity of sea-based observations, however, it seems likely that the marginal benefit in terms of improving the scope and accuracy of the meteorological network is at least as great as land stations. Thus it is reasonable to estimate that a ten-buoy Seawatch system provides benefits of $400 000 or more, annually, to subscribing meteorological services and their users.

As a regional component of the GOOS system, Seawatch produces a continuous record of oceanographic data. For much of the ocean surface we now have only rare and expensive surveys conducted by ship, and satellite data that does not penetrate below the ocean surface and is difficult to interpret without 'ground-truth' information from *in situ* sensors. Thus the Seawatch buoys should work synergistically with satellites and with limited deep-ocean data, to provide a sufficient foundation for higher-resolution climate models.

Crisis response

One unique aspect of Seawatch is the inclusion of a highly accurate sensor for radioactivity.[23] It can, therefore, serve as an early warning system for detecting leaks from discarded nuclear reactors or weapons, from weapons tests, from nuclear ships, or from coastal nuclear power-plants. The buoys can (and have) detect unauthorized dumping of radioactive waste, and the transport models can help determine the source.

Seawatch data can also help forecast the behavior of oil spills. While the buoys do not (yet) have an oil sensor, the wind, wave, current, and temperature data, and accompanying numerical models, allow much more accurate predictions of how a spill will behave.

By supporting the development of detailed circulation models of the coastal zone, Seawatch can also help monitor the fate of continuous pollution from river mouths and coastal sources. There is broad international agreement that measures are needed to protect the ocean, and especially the coastal zone, from pollution. There is also broad agreement that these measures need to be cost-effectively designed. Policymakers cannot design such measures, nor enforce them, without accurate information about the sources and fates of pollutants.

Oceanographic research

Traditionally, oceanography has relied on measurements from research ships, but such ships can be expensive to operate. Many routine observations are made by merchant ships, but the need to avoid interference with commercial activities limits the scope of these measurements.

Mounting a major global survey involves enormous costs. The World Ocean Circulation Experiment (WOCE) will, between 1990 and 1997, require some 15 ship-years of sea time at a cost on the order of $100 to

[22]Estimates of the ultimate size of GOOS typically suggest that the technically optimal scale for oceanographic modelling is an order of magnitude denser than the scale for atmospheric modelling. Here we are only discussing Seawatch's contribution to meteorological forecasting, however, so that observation about the ocean does not apply. Due to topological simplicity, and the effectiveness of satellite observation over water, the technical need for *in situ* observations at sea is probably less dense than on land.

[23]Anecdotal evidence suggests that illegal dumpings of radiactive waste was discovered by Seawatch buoys in the Arctic.

$200 million to collect a global hydrography data set at 24 000 stations. An advantage of ships is that they can bring sophisticated laboratories, complete with trained personnel, to the measuring site. Samples can be taken and analyzed. Sensors and other equipment can be easily maintained and calibrated on board. However, in the future a survey that combined ships and buoys would be able to reduce costs and, more importantly, maintain continuous measurements not possible from ships alone.

Seawatch produces continuous real-time series of linked physical, chemical and biological data. One can watch the parameters change as a storm develops: winds shift and quicken, air pressure drops, waves develop, vertical mixing flattens the salinity and water temperature profiles, suspended bottom sediments increase turbidity. Similarly, one can watch over a longer term as an algal bloom develops: surface salinity may drop and surface temperature rise, nutrient loads increase, turbidity rises, oxygen rises and then falls. No other observation system gives so complete a picture of developments at sea without actually putting the observer at sea.

A strong point of the Seawatch system is that it can be applied anywhere in the world as a complete system or, based on local needs, as a stripped down version. It is a highly adaptable platform for placing a range of instruments *in situ* and extracting data in real time. For the seas of India, it has been estimated that the cost of purchase and operation of 12 Seawatch buoys will be approximately the same as that of a medium size oceanographic research vessel. There is no doubt that the 12 buoys will collect many times more data than one ship alone.

Seawatch Europe has already made a significant contribution to oceanographic research that may have important economic consequences. For many years nations around the Baltic have watched the deterioration of its health. Nitrate and phosphate runoff have accumulated, oxygen saturation has declined, salinity has declined, and long-term stratification has depleted the benthic fauna. Very expensive remedies were undertaken to reduce the pollution load entering the Sea. The Baltic Sea Joint Comprehensive Environmental Action Programme (1993–2012) is an 18 billion ECU programme to clean 132 hot spots in the Baltic catchment area. Part of this programme is, however, based on inadequate information as is demonstrated by the Seawatch buoys in the western Baltic. Most of the historic data are within the natural range as measured by the Anholt Buoy in the fall of 1994 (Figure 3).

In 1993 a rare event occurred that was well documented through the use of Seawatch buoys. Sustained westerly winds built up a water mass from the North Sea to a level that allowed it to recharge the Baltic. This saltier North Sea water was able to cross the shallow straits at the mouth of the Baltic, then flow along the bottom to the deeper basins. The last time the Baltic had been recharged by a large volume of ocean water was in 1976. In light of this new information, the dynamics of the Baltic ecosystem are being re-evaluated. While pollution is still a major concern, there is now a greater understanding of how pollution may interact with the natural cycles of Baltic recharge, so that interventions can be designed effectively.

Seawatch future

Traditionally, oceanographers and other marine environmental special-

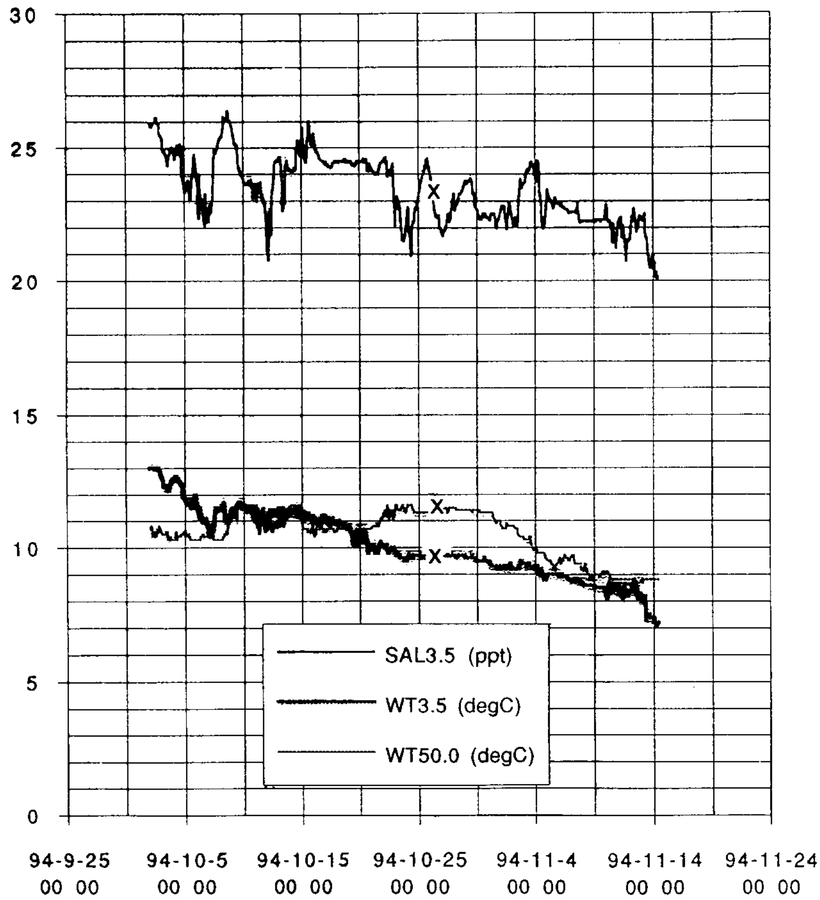

Figure 3. Salinity and temperature measurements at the Anholt Seawatch buoy in the western Baltic suggest that the variety of many historical data (x) collected by ships each 3 months, fall within the natural variability of the Baltic system.

ists have undertaken ocean and coastal surveys by means of oceanographic vessels. Using these vessels, the scientists have taken water samples, deployed self recording instrumentation, taken biology samples (in water masses and at the bottom). These data have hence been analysed and reported in various ways, normally quite some time after the survey has been completed. These surveys have contributed significantly to the existing knowledge and understanding of the marine environment. In this way a wide variety of different parameters can be measured at one station at a time, since the vessels may carry advanced instrumentation and contain up-to-date laboratory facilities. The vessels to be used, are, however, expensive to get and to operate. This method is not operational, since data is collected only from one station at a time and/or delayed significantly before being reported.

Oceanographic academic and applied research have largely depended on data taken by ships. The Marine Research Institute in Bergen, Norway, dealing with applied fisheries research is at present operating five ships. The annual cost is $11 million, not including depreciation and capital costs. A well developed buoy network would significantly reduce the need for ship time. For the seas of India, it has been estimated that the cost of purchase and operation of 12 Seawatch buoys will be approximately the same as that of a medium-sized oceanographic research vessel. There is no doubt that the 12 buoys will collect many times more data than one ship alone. For Eastern Africa (South Africa, Mozambique, Madagascar, Tanzania and Kenya) a nine buoy Seawatch system might be adequate. This again demonstrates Seawatch's ability as a GOOS building stone.

Another method of getting data is by use of remote sensing, normally from satellites. The space sensors and the remote sensing techniques are capable of providing data coverage over a vast area in a short time. The space platforms can be separated into polar orbiting satellites and geostationary satellites. The geostationary satellites are able to monitor a portion of the globe continuously and make as many scans over the visible part of the globe as deemed necessary. However, in the context of oceanographic monitoring of a limited target area, the course group resolution of the products of the geostationary satellites limits the applicability of these satellite products, and thus mainly leaves the polar orbiting satellites for oceanographic usage. The data collected are for most sensors restricted to the surface layer of the ocean. The passive sensors, i.e. radiometers and passive microwave instruments, are also restricted by cloud coverage and other atmospheric disturbance of the signal.

The present usage of remote-sensor data for oceanographic applications are still mostly in the research stage. The algorithms for deriving oceanographic parameters of interest have to undergo further research. In addition, the processing methods have to be improved: today the processing time for the data is too slow. Since the oceanographic parameters normally come from polar orbiting satellites, the observation regularity is too sparse. The final and most important obstruction is, however, the fact that the satellites only cover the surface, while some of the most interesting features take place in the water masses beneath the sea. But even the surface data that satellites collect (wave direction and height; visible algal blooms, etc) need verification and calibration with *in situ* data. When properly combined in a computer model, there is considerable synergy between the overview provided by satellites and the fixed point measurements provided by buoys.

The only complete operational marine monitoring and information system available on the open market, integrating the features of the GOOS system, is the Seawatch system. It is clear that Seawatch Europe has passed an important test. It has been built, it is operational, and it is generating real economic benefits in excess of its costs. The strongest evidence for this is simply the observation that commercial customers in fish-farming and in offshore oil and gas operations are paying to participate in Seawatch and express enthusiasm about the value it has had in their operations.

The costs of Seawatch Europe are joint costs, producing a wide range of services that includes both commercial services and public goods. This combination, however, can be an uncomfortable one to manage, but generally is a healthy state of affairs. If Seawatch did not produce commercial services, the benefits would still be in the speculative realm and its fate would be uncertain. Moreover, the commercial clients impose a discipline on the enterprise, holding down costs, insisting on useful and accurate data delivered when needed.

If it is confined to supporting itself through the sale of commercial services, in Europe and elsewhere, Seawatch will be likely to survive. The technology appears to be cost-effective for those industries that need the data. And the North Sea contains enough industry — oil and gas, fishing, and commerce — to support such a network. It may also be replicated in other locations where commercial activity can justify it.

Potential sponsors among governments and international organizations may be tempted to let Seawatch be carried by its commercial clients.

This is particularly the case when national budgets are strained. In classifying goods as either public or private, we have glossed over an important distinction. Some public goods are strictly national goods: defense, for example. National governments are well situated to make a decision about whether it is in the interest of its citizens. International public goods are a little more difficult. National governments may evaluate them from a narrow perspective, and there may be 'free rider' problems to overcome. International organizations are not as well situated in terms of financing and authority to make decisions about what projects to fund; these necessarily must be sold to the national governments. In this respect Seawatch is like other megascience projects.

In addition, by its focus on the ocean, Seawatch is further handicapped. Each nation may be tempted to spend money instead on the particular problems of interest in its own coastal zone, rather than chip in to develop a system with a broader focus. Improved coastal forecasting information is expected to be of benefit to public and private, commercial and recreational activities in the coastal zone. The provision of improved coastal forecasting information is costly, and the question is whether the benefits of providing the information outweigh the costs.

A further problem is that Seawatch is competing with academic and governmental institutions. Meteorological offices, coastal zone management agencies and so forth may see it as competing for funds when viewed as an operational programme. When viewed as a research venture, it must compete for national funds that traditionally go to universities and to support scholarships. The agencies that allocate these funds may view their mission as national educational, and may be reluctant to support a foreign venture unless it appears to offer opportunities for students and professors. This again is a familiar problem with megascience programmes. It may be more difficult for Seawatch because one of its advantages is that it is less labour-intensive than the traditional means of doing oceanographic research. Thus it provides less employment for scientists and less training for students, but more of the other public goods. To the extent that national research agencies focus on the manpower aspect of their missions, they will undervalue Seawatch technology.

There is a danger, however, in going too far down this path. Seawatch may survive with commercial sponsorship, but it will not survive in the form that it was originally conceived. There will likely be a substantial loss of public benefits. To the extent that Seawatch must be sustained on a commercial basis, it will necessarily be responsive to the specific needs of its paying clients. That means that buoys will be located where they are needed, by oil drillers and fish farmers, but not necessarily where they can contribute the most to meteorological and oceanographic models and to science. Variables and sensors will be tuned to operational needs of the users and perhaps to regulatory requirements as well; they will not necessarily collect the most scientifically useful data. Time series may be truncated rather than long-term. Opportunities to build large-scale models will be limited. In addition Seawatch will feel continuing pressure to provide data on a proprietary basis, rather than share it with the broader community of users. For these reasons it is important for public authorities at the national and international level to participate in Seawatch and help to steer it towards the potential it was designed to fulfill.

Appendix

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