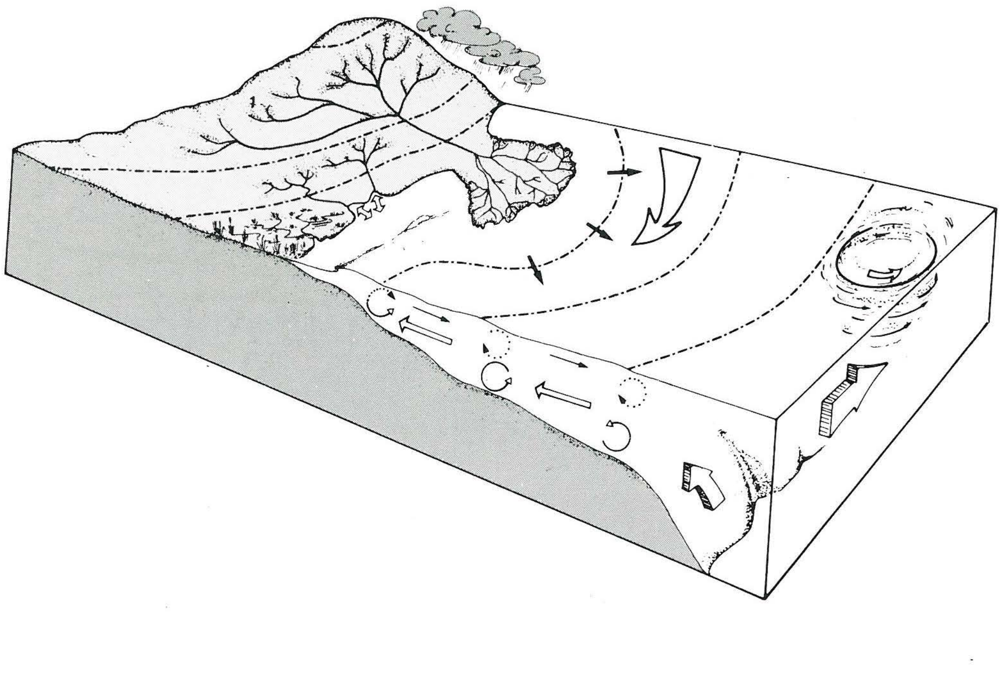
# GLOBAL CHANGE
IGBP

## REPORT No. 14



# Coastal Ocean Fluxes and Resources

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
of the International Council of Scientific Unions (ICSU)

Stockholm, 1990

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# COASTAL OCEAN FLUXES AND RESOURCES

Edited By P. Holligan

Report of a CP2 *Ad Hoc* Workshop
Tokyo, Japan, 19-22 September 1989

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
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Cover diagram:
Terrestrial and Marine Components of the Coastal Zone (G.C. Ray 1989)

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# 1. INTRODUCTION

The oceans have a fundamental role in the regulation of the global environment through physical and biogeochemical properties that largely determine the levels of carbon dioxide and, to a lesser extent, other greenhouse gases in the atmosphere. Furthermore, oceanic emissions of biogenic, volatile organic sulphur compounds (mainly dimethylsulphide, DMS) are thought to affect cloud formation and global albedo. Since climate itself and also climate-related fluxes of nutrients from the land (air and water transport, weathering processes, decay of terrestrial vegetation, etc.) affect marine productivity, there are important feedback loops between climate and ocean biogeochemistry. The elucidation and prediction of these processes under conditions of significant anthropogenic changes to the trace gas composition of the atmosphere has been the primary focus of IGBP Coordinating Panel 2 (CP2) dealing with Marine Biosphere-Atmosphere Interactions. Global change and the coastal oceans were the main subjects for discussion at an *ad hoc* meeting of CP2 held in Tokyo on 19-22 September, 1989. This report is the product of that meeting. It was not possible to discuss all aspects of the topic in detail so that additional material has been used, as appropriate, to provide a more comprehensive basis for future planning work.

# 2. MARINE BIOSPHERE INITIATIVES AND THE IGBP

## 2.1 Biogeochemical Cycles and Physical Climate Linkages

The main driving force for biogeochemical exchanges within the ocean-atmosphere system is phytoplankton photosynthesis in the surface, sunlit layers of the ocean. Plant cells utilize light energy, $CO_2$ and inorganic nutrients to produce a wide range of organic compounds, as well as biominerals such as calcite and opal, which directly or indirectly are the main source of biogenic materials exchanged between the atmosphere, deep ocean water and marine sediments. The physical processes that govern the availability of light and nutrients for phytoplankton are, in turn, affected by climate change. It is now well established that changes in total productivity and in the global distribution of phytoplankton (Mix, 1989) have been associated with glacial to interglacial fluctuations in levels of atmospheric $CO_2$ and in global temperature. Such changes are thought to be driven by variations in ocean circulation and temperature, and in the various mixing processes that determine light and nutrient levels in the euphotic zone (note that atmospheric properties such as cloud cover and transport of nutrients in the form of dust and aerosol particles from land masses are also important in this respect).

For predictive purposes the relationships between global climate, ocean productivity and atmosphere-ocean exchange of $CO_2$ are rather poorly understood. The ocean carbon cycle is the main focus of the Joint Global Ocean Flux Study (JGOFS), an established IGBP project. Looking to the late 1990s, a proposed study of the euphotic zone -- the Global Ocean Euphotic Zone Study (GOEZS) -- will form an important link between biogeochemical research (JGOFS) and climate-related ocean research (e.g., the World Ocean Circulation Experiment, WOCE) with emphasis on the important boundaries at the air-sea interface and at the seasonal thermocline. The project will build upon the findings of JGOFS and WOCE and it will have strong field, remote sensing and modelling components.

### 2.2 Ocean Carbon Cycle

The JGOFS was established by the Scientific Committee on Ocean Research (SCOR) in 1987/88 and became a Core Project of the IGBP in 1989. The research planning has been summarized in the JGOFS science plan (SCOR, 1990). The first pilot experiment of the JGOFS was in the North Atlantic Ocean in 1989/90 and included participation of ships and scientists from six countries. The main objective was to evaluate the rate and control of biogeochemical fluxes of carbon during the seasonal bloom in a region that is known to be a net sink for $CO_2$. The results of the experiment are still being analyzed, and further field programmes in both the North Atlantic and North Pacific are planned for 1991. As yet there are no firm plans for ocean margin experiments within the JGOFS.

### 2.3 Coastal and Estuarine Systems

The coastal oceans, extending from the land to the continental rise (see cover figure), represent less than 10% of the total ocean area (Walsh, 1988). However, they exhibit rates of biological productivity per unit area that are, on average, 2-3 times higher than in oceanic waters and act as important transformation and depository zones for dissolved and particulate carbon



delivered via river water and the atmosphere from land masses (Table 1). The effects of changes in sea level, as glacial-interglacial cycles cause alternating emergence and submergence of the continental shelves, on the fate of organic matter in the coastal oceans are not well understood.

Whether the coastal oceans represent a significant sink for anthropogenic $CO_2$ (Walsh, 1988) remains uncertain although geochemical models indicate (Smith and MacKenzie, 1987) a net heterotropic condition. The need to resolve this problem was recognised at an early stage of planning by CP2. The continuing urbanisation of coastal plains, where more than 50% of the world's people live, and heavy exploitation by man of the natural resources of the coastal oceans are thought to be significantly affecting exchanges of carbon dioxide and emissions of other trace gases to the atmosphere, with further alterations expected to accompany warming of the climate and any further rise of sea level.

Also of grave concern is pollution and physical disturbance of coastal ecosystems. Heavy metals, hydrocarbons, organic residues, radioactive wastes and other contaminants in estuarine and coastal waters and sediments are a threat to the health of a wide range of marine organisms (Kullenberg, 1986; Salomons et al., 1988) and, in turn, limit their exploitation by man. Coastal engineering practices cause extensive loss of habitat. Bulk inputs to the sea of nitrogen and phosphorus are associated with increased frequency of phytoplankton blooms which adversely affect natural fisheries and mariculture through the production of toxic substances and the deoxygenation of bottom water.

## 3. DEFINITION AND GLOBAL SIGNIFICANCE OF THE COASTAL OCEAN

### 3.1 Physical and Biological Features

The coastal oceans are considered in general terms to include the land margin affected by salt water (salt marshes, lagoons, mangroves, estuaries to the limits of tidal influence and penetration of salt wedges, coastal strip affected by sea-level rise, storms, salt spray, etc.), the continental shelves (Figure 1) and the continental slope. They lie largely within the Exclusive Economic

Zones (EEZ) of maritime nations. Several distinct hydrographic boundaries are usually observed within the coastal oceans, which mark transitions between different types of benthic and pelagic communities and act as barriers to lateral exchanges of energy and nutrients between the terrestrial and ocean environments.

One classification of such boundaries is shown in Figure 2. The horizontal gradients in temperature and salinity represent density changes so that water tends to move parallel with, rather than across the fronts. In recent work the nomenclature of estuarine, tidal and shelf break fronts (Figure 3) has been widely applied. Understanding exchange across such fronts is an important part of studies on the dynamics of the coastal ocean and, in this sense, it is necessary to extend the ocean and land margins of the coastal regions at least by spatial scales appropriate to the physical properties such as mesoscale eddies in the ocean and storm surges at the land margin. An offshore shelf region between the tidal and shelf break fronts is also defined, representing a relatively broad region on some continental shelves that is distinct from oceanic and estuarine regimes.

Knowledge about the zones defined in Figure 2 and the plant and animal communities they support is extremely variable at a global level. Some regions, such as the North Sea, have been extensively studied for up to 100 years by several nations, whereas others in the tropics remain largely undescribed.

One general feature of the coastal ocean is its variable but relatively high energetic state due to mixing and advection caused by ocean currents, upwelling tides, wind, and freshwater buoyancy. In particular, ocean dynamics and the topography of the continental shelf are important features in determining high and low energy shelf systems which, in turn, define the spatial extent and boundary properties of the regions shown in Figure 2. The flushing time for water on continental shelves is generally less than one year.

From a geochemical standpoint, the coastal ocean may be considered as a continuum of buffer zones between the land and the open ocean into which inputs of materials, including fresh water, occur largely from the land via rivers and the atmosphere, and inputs of energy and momentum largely from the ocean. Such a system is complex, especially when interactions with the atmosphere are also considered, and subject to considerable variability in boundary conditions. For this reason, an understanding of the properties of the



coastal oceans is critical to improving knowledge about coupling between the terrestrial and marine biospheres, especially as the rates of exchange of matter and *in situ* biological productivity are typically high.

Within JGOFS the significance of the ocean margins has been clearly recognised in relation to fluxes of carbon to deep water and oceanic sediments (U.S. JGOFS Planning Report No. 6, 1987). However, the present research programme (SCOR, 1990) includes no specific plans for studies of the ocean margins. This problem appears more tractable as part of a coastal ocean study which takes into account the terrestrial-to-ocean transfer of matter.

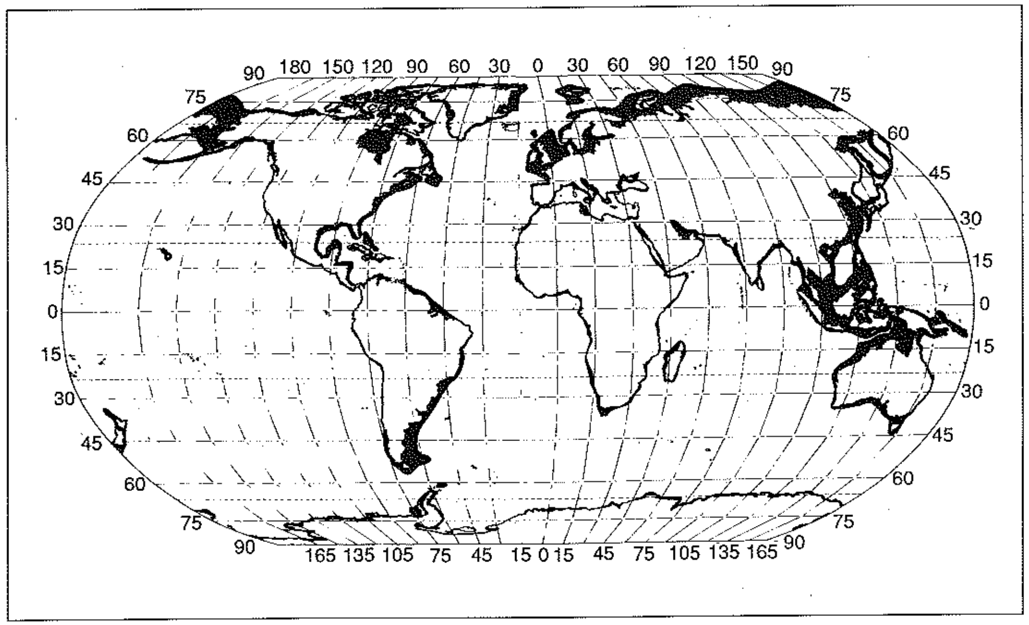



Figure 1
Continental shelves (< 200 m water depth) of the world (from Postma and Zijlstra, 1988)

### 3.2 Global Biogeochemical Perspective

The physical and biological diversity of the coastal oceans, combined with their extended land and ocean boundaries (Figure 1), makes it more difficult to formulate a coherent global strategy to study this zone than is the case for either the land or open ocean. However, a number of general considerations clearly demonstrate their overall importance as part of the earth system:

a) The coastal oceans represent regions of biogeochemical interaction between land and ocean, and are characterised by active fluxes, transformation and accumulation of organic and inorganic matter. They are sensitive and responsive to global environmental change and include ecosystems of critical value to the sustainability of the global biosphere.

b) The largely unknown fate of large inputs of dissolved and particulate terrestrial carbon (Table 1), together with high rates of *in situ* productivity suggest that an accurate picture of the global carbon cycle cannot be established without better information on the coastal oceans.

c) The coastal zone is a significant source of other greenhouse gases such as $N_2O$ and possibly $CH_4$, and also of dimethylsulphide (DMS) which contributes to acid deposition and the formation of cloud condensation nuclei.

d) The coastal oceans contain valuable living and non-living (e.g., minerals, tidal energy) resources that are likely to be affected in various ways by global change (Bardach, 1989).

e) The susceptibility of the coastal oceans to exploitation by man, and sensitivity to changes in climate and sea level have led to an urgent need for improved scientific guidelines and policies relating to a wide variety of management issues, in particular concerning ecosystems at the land-sea boundary (mangrove, saltmarsh, reefs, mudflats, etc.).

f) There are urgent socio-economic and demographic requirements for reliable predictions of environmental change, especially for low-lying and heavily populated coastal areas, in relation to variations in climate and sea level (Carter, 1989).



Table 1. Recent estimates of global marine inputs and burial of organic carbon and calcium carbonate carbon

| | | | |
|---|---|---|---|
| <u>Inputs of organic carbon:</u> | | $10^{12}$ g C $yr^{-1}$ | |
| Phytoplankton production | - particulate | 40,000[5] | |
| | - dissolved (~10%) | 5,000 | |
| Rivers | - particulate | 150 (degraded)[3] | |
| | | 81 (labile)[3] | |
| | - dissolved | 200[4] | |
| Atmosphere | | 24-72[2] | |
| <u>Burial of organic carbon*:</u> | | | |
| Shelf deltaic sediments | | 130(104)[1] | |
| Shelf carbonate sediments | | 7 | 27(22)[1]-100(40)[6] |
| High productivity (upwelling) ocean sediments | | 14 | |
| Low productivity ocean sediments | | 6 | |
| <u>Burial of calcium carbonate carbon:</u> | | | |
| Shelf waters | | 89-156[1] | |
| Ocean waters | | 170(150)[6] | |

**References:**

1. Berner (1982)
2. Duce in Unesco (1989)
3. Ittekot (1988)
4. Meybeck (1982)
5. McCarthy et al. (1986/87)
6. Whitfield and Watson (1983)

* Estimates of final burial after decomposition within sediment layers are given in parentheses. A similar value for total marine burial of organic carbon is given by Smith and Mackenzie (1987) but with a higher proportion attributable to ocean sediments.

### 3.3 Resources and Human Activities

Although the scientific basis for managing and sustaining living resources, and for controlling environmental degradation (habitat loss, decrease in biodiversity, etc.) is generally determined by regional criteria, a more general approach to establishing reliable methods for observing and measuring change, to setting acceptable chemical and biological limits of change, and to determining how to prevent irreversible losses of resources and damage to the environment needs to be adopted.

In addition to the discharge of effluents into rivers, the impacts of human activities on the coastal zone include the dumping of wastes, mineral extraction and other procedures that disturb bottom sediments, coastal engineering and various aspects of marine transportation. In some regions, health hazards associated with recreational pursuits are an important issue.

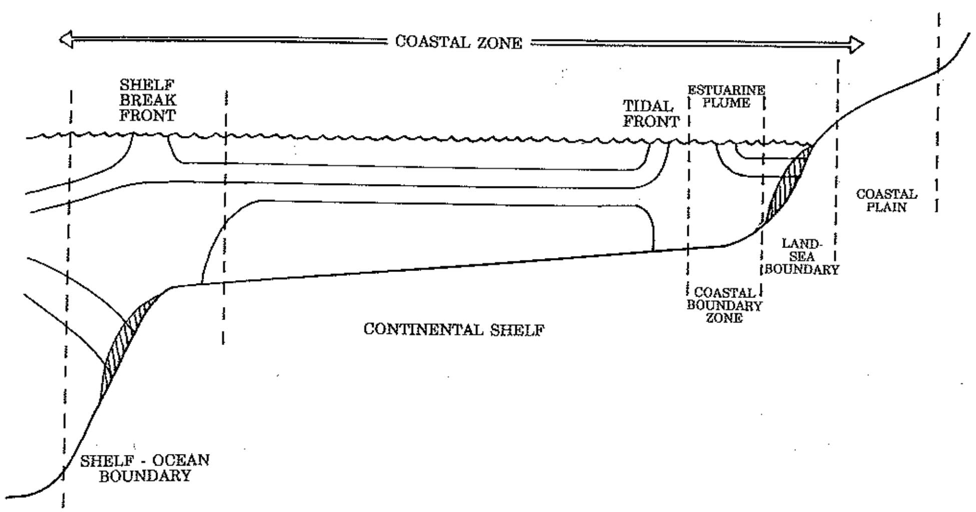



Figure 2
Diagrammatic hydrographic section across a representative coastal ocean.



## 4. IMPLICATIONS OF GLOBAL CHANGE

### 4.1 Coupling of Terrestrial and Ocean Biospheres

The coastal oceans are characterised by extensive recycling of external inputs of organic carbon and of nutrients (Jansson, 1988). For this reason, rate measurements of productivity are not necessarily useful indicators of net exchanges of materials with coastal sediments, the oceans or the atmosphere. The influxes of organic matter from land as dissolved and particulate organic carbon (DOC and POC) exceed the total quantity of organic carbon buried in marine sediments (Table 1), so that the coastal oceans can be considered as a heterotrophic system with respiration exceeding photosynthesis (Smith and Mackenzie, 1987). However, some regions may exhibit net autotrophy with both terrestrial and marine organic matter exported to the ocean. This distinction is important in establishing how the present coastal ocean behaves as a source/sink for atmospheric $CO_2$ and in predicting how global change will affect the carbon cycle. Another point to emphasize is the crucial role of large river systems, especially in tropical regions, in the transport of carbon from the land to the sea.

With respect to fluxes of methane and nitrous oxide to the atmosphere, the marine biosphere is generally considered to be a minor source compared to terrestrial ecosystems. Rates of production of the two gases are relatively high for salt marshes and estuaries where the inputs of organic matter to anoxic sediments are also high, but the areal extent of these ecosystems is small.

The situation for DMS is rather different because the coastal ocean is an important source (Andreae, 1986) and because much of the oceanic DMS may be oxidised and re-deposited as sulphate over the sea with little or no influence on the land. By contrast, the DMS from coastal waters, in contributing to cloud condensation nuclei (Charlson et al., 1987) and to the acidity of rainfall, and to the transfer of sulphur from sea to land, potentially affects the terrestrial biosphere in various ways.

The coastal ocean directly influences the climate of adjacent land areas through exchanges of heat and water with the marine atmosphere. These processes are seasonally variable as the land becomes hotter or colder than the sea, and are affected significantly by ocean currents that interact with the continental shelf waters. Thermal fronts in shelf seas also modify local climate.

## 4.2 Change in the Coastal Ocean

Climate change (temperature, precipitation and wind), and any sea level rise, will modify coastal ocean ecosystems both directly as important environmental parameters and indirectly via effects on the terrestrial and oceanic biospheres. The magnitude of the impacts are difficult to predict, but the most important are likely to be the influences of increased temperature at higher latitudes on species distributions, of precipitation on the inflow of freshwater and on coastal circulation, of wind on upwelling and nutrient supply, of sea-level rise on the growth and survival of reef and littoral communities, and of a combination of precipitation and sea-level rise on turbidity. In each case, gradual changes in climate as opposed to episodic events, are likely to have rather different effects. Biological productivity will be most affected by changes in nutrients and turbidity, although these may be somewhat ephemeral as new balances between the land and the open ocean are reached. Changes in the form of biological production are possible, in particular a relative increase in the rate of calcification compared to photosynthetic carbon fixation, as higher water temperatures favour greater diversity of calcifying organisms and as sea-level rises create new space over reefs and along shores. Differential responses of pelagic and benthic communities could also occur, especially if changes in inputs of particulate organic matter affect the coupling of water column and sediment processes.

Temperature effects on the degradation of organic matter and on the release of volatile compounds to the atmosphere also need to be considered. It is possible that warming of coastal sediments in the arctic might lead to large releases of methane presently in the form of low temperature methane clathrate, and at mid-latitudes submerged glacial peat deposits may be degraded more rapidly with enhanced methane production. Increases in the temperature of coastal waters, together with changes in sea level and precipitation, will modify the physical mixing processes (seasonal stratification, frontal stability) that affect the growth of the biota, especially in cold-water ecosystems.

Man has already caused changes in many estuaries and nearshore low salinity waters through the release of heavy metals, hydrocarbons and other toxic substances and large additions of nitrogen and phosphorus mainly from



agricultural fertilisers. Only for a few regions have these changes been quantitatively documented, and much of the biological evidence for toxicity or increases in productivity is fragmentary and statistically not meaningful. Thus, unambiguous conclusions about the anthropogenic effects are difficult to establish except in cases of habitat destruction and of severe pollution in harbours and on beaches. Bioassays for ecotoxicological effects have an increasingly important role in environmental impact studies for this reason, particularly for pollutants that are not easy to detect by routine chemical methods and for investigations of the additive effects of toxic compounds.

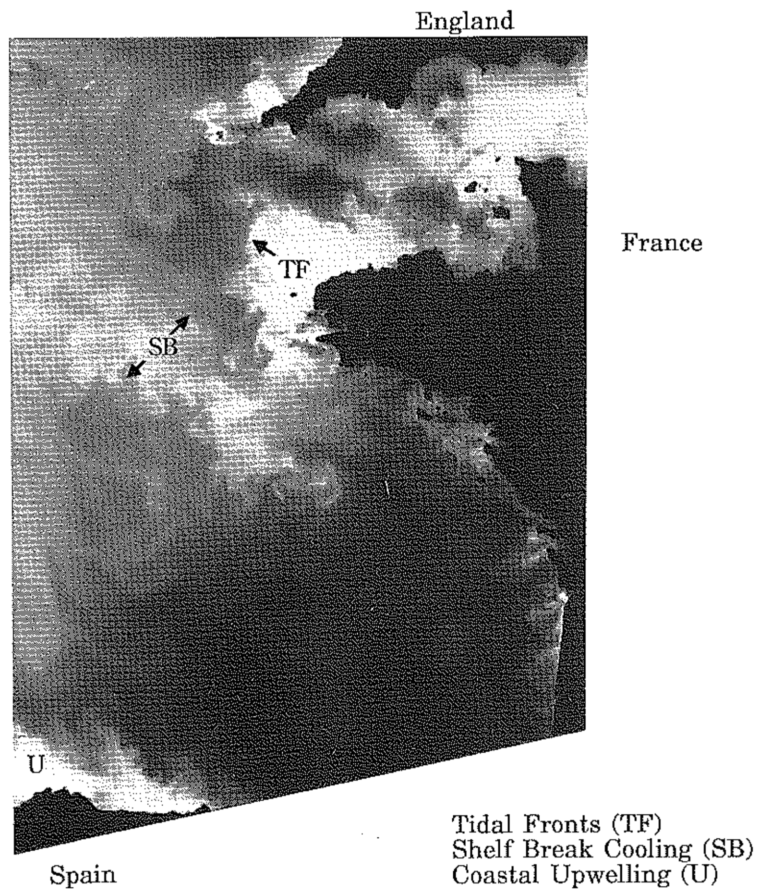



Figure 3
Satellite (NOAA) sea-surface temperature image of part of the northwest European Shelf, 18 August 1981, showing tidal and shelf break fronts and coastal upwelling.

Alteration of marine food chains is also difficult to detect and ascribe to particular causes. There are many reports of increased frequency of phytoplankton blooms in coastal waters and of shifts in population structure from large-celled diatoms to small flagellates linked to eutrophication of coastal waters. In cases of toxic organisms or of bottom anoxia related to the sedimentation of organic matter, effects on natural communities of organisms (including commercially valuable species) can be severe. Avoidance of the phytoplankton by herbivores is likely to be an important factor in bloom formation.

In a biogeochemical context there is increasing evidence that both eutrophication and anoxia lead to higher emissions of biogenic gases to the atmosphere either as a result of the growth of particular phytoplankton species (for example, flagellates that produce DMS) or due to increased metabolic activity in the water column and sediments ($N_2O$ and $H_2S$ production). Nitrous oxide is a product of both denitrification and nitrification, with anthropogenic nitrate being a substrate in anoxic estuarine muds and ammonia a substrate in productive coastal waters, respectively.

### 4.3 Climate Feedback

In the preceding sections only the immediate effects of climate change and of chemical modification of coastal waters have been considered. A variety of feedback effects could also occur, although these are difficult to assess in terms of the coastal ocean alone, since in general the more extensive ocean and terrestrial biospheres have a greater impact on the atmosphere and climate. However, it is important to note that the effects of expected global change on the coastal ocean suggest positive feedback in terms of $N_2O$ and $CH_4$ emissions. The situation for $CO_2$ is difficult to assess without better knowledge of the fate of terrestrial organic matter in the sea.

DMS emissions may also increase due to hydrographic conditions (increased N/P to Si ratios coupled with a tendency for greater stratification of the water column) favouring the growth of flagellates (as opposed to diatoms) which are known to be strong sources of sulphur compounds. A cloudier climate that might result from higher DMS fluxes and increased temperatures would tend to reduce photosynthetic carbon fixation, but the overall implications for the carbon cycle are uncertain.



Our understanding of geochemical feedback on climate is very crude. However, it is important to identify such interactions in order to design new observational experiments and predictive models.

## 5. POSSIBLE OBJECTIVES OF A COASTAL OCEAN FLUXES AND RESOURCE STUDY

- To describe quantitatively the physical, chemical and biological properties of the coastal ocean that affect global climate through modification of the biogeochemical coupling between terrestrial and oceanic ecosystems and through direct exchange of biogenic trace gases with the atmosphere.

- To develop and apply objective methods for measuring and predicting change in the coastal ocean ecosystems caused by variations in global climate and by human activities so that rational policies for maintaining the biological diversity and productivity, and the inhabitability of the coastal zone can be developed and maintained.

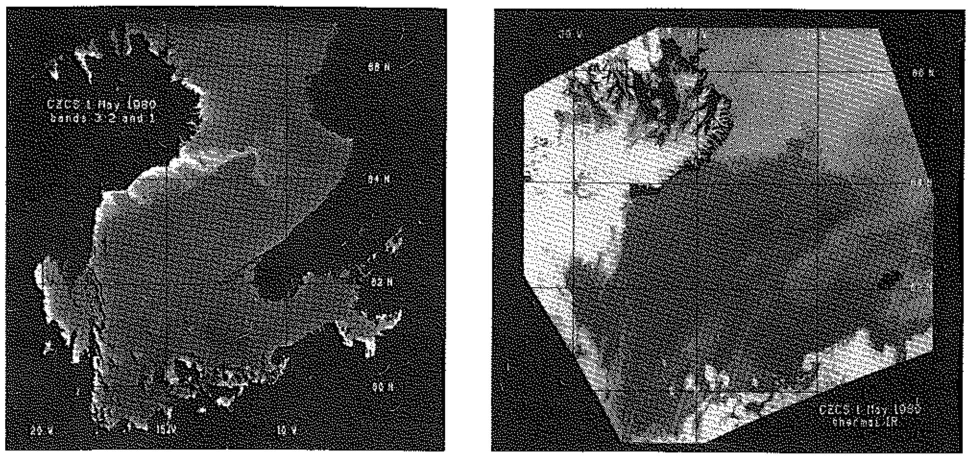
- To determine the direction and significance of feedback effects between global climate and coastal ocean ecosystems that are the result of chemical modification of the atmosphere and of coastal waters by man.

## 6. RESEARCH PRIORITIES

In this section the conclusions of the workshop are briefly summarized. Most topics could only be discussed briefly; in particular, little attention was given to the large river systems which, from case studies (e.g., Milliman and Qingming, 1985), are known to play a very important role in the transport of terrestrial materials and of mankind's byproducts from land to the oceans.

The fluxes from land, effects of sea-level variations, and influence of man on water quality are most extreme at the land-sea margin. By contrast, the input to the coastal ocean of energy, momentum and nutrients, and output from the coastal ocean of organic carbon (including terrestrial matter) are largely determined by physical processes at the shelf break. Any thorough study of the coastal ocean must depend on a balanced account of the influence of these inner and outer boundaries (Figure 4). The latter is of particular significance to the JGOFS, for which an accurate assessment of carbon transport from the shelf to the slope and deep ocean is required.

One general difficulty is the problem of scaling-up from site-specific studies of the coastal ocean to a global perspective, and the knowledge that global change will not be a uniform process. The effects of man are quite different along the coastlines of industrialised countries compared to non-industrialised countries; warming will be greatest at high latitudes; and sea-level changes will be locally variable depending on the relative importance of thermal expansion, continuing isostatic effects and subsidence of sediments. These points must be taken into consideration when selecting sites for long-term observations.



a) Colour composite

b) Surface temperature
Light = cool
Dark = warm water

Figure 4
Satellite (CZCS) colour composite and sea-surface temperature images of the south Iceland continental shelf, 1 May 1980, showing entrainment of riverine suspended matter into an ocean frontal boundary.



There is a need to maintain a global perspective from the outset in order to achieve a properly balanced scientific programme. A focus on the carbon cycle is the main link with other IGBP projects, which would set important constraints on the planning of an interdisciplinary study of the coastal ocean. Some system for classifying coastal oceans (Fricker and Forbes, 1988), incorporating information on the influence of ocean circulation on river sediment and freshwater discharge, on shelf topography and on seasonality related to latitude (US JGOFS Planning Report No. 6, 1987) is required in order both to extrapolate from local or regional studies and to identify gaps in our knowledge.

## 6.1 Dynamics and Biogeochemical Fluxes

Determining the effects of global change on the coastal oceans depends on basic knowledge of the dynamics of the natural ecosystems. There are two priorities: physical processes that dictate rates of transport between the land, coastal ocean, open ocean and atmosphere, and biogeochemical processes that determine the main sources and sinks and the rates of turnover of carbon and other elements. A palaeoecological perspective is also necessary, particularly concerning differences in the fate of terrestrial organic carbon under conditions of high (present) and low (glacial times) sea level.

In relation to the problem of sustaining of natural resources under given methods of harvesting, it is necessary to recognise the importance of environmental factors that influence recruitment and standing stocks of marine organisms as well as the causes of natural variability in fisheries. In this context, the proposed coastal study will complement the work of fishery biologists seeking to predict the success of species in commercially important foodwebs. The main needs and priorities are:

*Physical dynamics*

Diverse physical phenomena in the coastal ocean have a profound influence on biological productivity, including wind-induced mixing events, onshore intrusions, frontal zone dynamics, coastal and shelf-break upwelling, etc. (Brink, 1987). These physical processes are characterised by both onshore-offshore and a longshore gradients in water properties with considerable seasonal and interannual variability. They influence nutrient availability to the primary producers and the transport of material through, and its recycling within, the various zones of the coastal ocean (Figure 5). Consequently, further study of physical processes is essential to improving our understanding of coastal zone dynamics, its capacity for biological production, and the effects of variability and change in climate. To obtain this knowledge, the following physical processes need to be further evaluated.

1. Definition of mesoscale variability, taking into account topographic effects and transient atmospheric forcing.

2. Elucidation of surface mixed-layer properties, including ventilation of the pycnocline.

3. Studies of seasonal variability, including baroclinic motions and the dynamics of upwelling events, and buoyancy driven circulation related to inputs and alongshore flows of freshwater.

4. Studies of slope and boundary currents and their importance for the transport of biogenic materials.

5. Estimation of the rates of exchange across boundaries that define the coastal ocean, taking into account episodic exchange events (filaments, rings, etc.), entrainment effects and atmospheric forcing, including interactions with coastal orography and terrestrial processes.

*Biological dynamics*

The ecosystems of the coastal ocean include, e.g., marsh, mangrove, lagoonal, reef, littoral, estuarine, and offshore communities. In offshore deeper waters the food chain is phytoplankton-based whereas nearshore the primary producers include sea grasses, macroalgae and benthic microalgae. In mid- to high-latitudes, saltmarsh ecosystems are a conspicuous feature of the land-sea margin; in the warmer, low latitudes mangrove communities dominate. Shallower reaches of the coastal ocean as well as mixed waters (banks, shoals) are characterized by tight pelagic-benthic coupling; seaward along the onshore-offshore gradient, pelagic processes are progressively more important and strongly influenced by upwelling (Barber and Smith, 1981) and oceanic eddies (Figure 5). These various coastal-ocean habitats are characterised by a diversity of foodweb structures.



Many habitats function as recruitment (spawning) grounds and/or nurseries for migratory finfish and also for commercially important invertebrates (shrimp, etc.). Sheltered nearshore waters are increasingly being transformed into aquacultural farming areas.

While much is already known about the diversity of coastal ocean ecosystems, this information needs to be reviewed to identify gaps in our knowledge and to design quantitative investigations of the pathways and efficiency of organic-matter transformation. The following are high priority tasks:

1. Quantitative comparisons of the structure, function, and energetics of the main types of ecosystem in coastal oceans.

2. Measurement of fluxes of biogenic materials through the marine food chain, including the development of improved methods as required.

3. Investigation of biological processes that assimilate and degrade oceanic and terrestrially-derived dissolved and particulate organic carbon, with special attention to pelagic-benthic coupling.

4. Development of ecosystem models in order to explore and predict ecological and biogeochemical responses to environmental change in the coastal zone.

*Biogeochemical fluxes*

The air-sea exchange of gases, the land-sea transfer of nutrients, detritus (Mann, 1988) and other particulate material, the fluxes of materials between sediments and the overlying water column, and the inputs of energy and nutrients from the open ocean are all important boundary processes that determine the biogeochemical properties of the coastal ocean. Associated chemical transformations contribute to the productivity of coastal waters, and also link the oceans through coupled and feedback interactions to atmospheric and terrestrial processes on both a regional and global scale. The essential details of the sensitivity, and responsiveness of the coastal-ocean ecosystems to changes in the atmosphere and on land are largely unknown. However, there is now sufficient evidence, and suitable methodology that such linkages can be quantitatively evaluated. High priority studies include:

1. Measurements of the temporal and spatial distributions of properties that determine air-sea exchange of gases: the $CO_2$ system ($pCO_2$, alkalinity, pH, total $CO_2$); $CH_4$; $N_2O$; DMS, and other sulphur compounds such as $CS_2$ and $H_2S$. A more exact analysis of the relationship between wind strength and air-sea transfer velocity is of high priority for atmospheric studies.

2. Measurements of the distributions of POC and DOC in the water column and sediments, giving particular attention to the processes that determine gradients across freshwater-saltwater interfaces where flocculation occurs, across shelf-break fronts where exchange with the open ocean occurs, and between the water column and bottom sediments.

3. Determination of the carbon isotope ($^{14}C/^{13}C/^{12}C$) content and chemical nature of organic matter in shelf and slope sediments to establish sources and age of this material and to identify the main sites of export of organic carbon from the coastal sea to the ocean, and the rates of slope deposition in these regions.

4. Development of improved models for estimating biogeochemical fluxes incorporating information on processes such as air-sea exchanges, water-particle exchanges, and aerobic and anaerobic degradation processes in sediments (Heinrichs and Reeburgh, 1987).

*Living resources*

The coastal ocean represents less than 10% of the total oceanic area, but provides 87% of the total marine catch of finfish (Sharp in Postma and Zijlstra, 1988) and most of the shellfish catch. Increased utilization and conversion of nearshore embayments for aquaculture is further evidence of the remarkable natural and potential productivity of coastal oceans. The sensitivity of coastal ecosystems to changes in water quality, to the frequency of noxious phytoplankton blooms, and to environmental stress require studies directed to evaluating and protecting living resources. Priority should be given to:

1. Investigations of the processes that determine recruitment (feeding, predation, migration, etc.) and stock size of fish, shellfish and other commercially important organisms.
2. Identification of the causes of natural variability in stock size.



## 6.2 Effects of Chemical Modification

Man is continuing to introduce to the coastal oceans, through river and coastal discharges, the transport of aerosols in the atmosphere, dumping of wastes at sea, mariculture and various other practices, large quantities of dissolved and particulate materials that alter the chemical nature of the water (GESAMP, 1986, 1987; UNEP, 1990). Precise information about changes now occurring in water quality at regional and global scales is not available. Furthermore, the additional effects of freshwater management and of coastal engineering are not well understood.

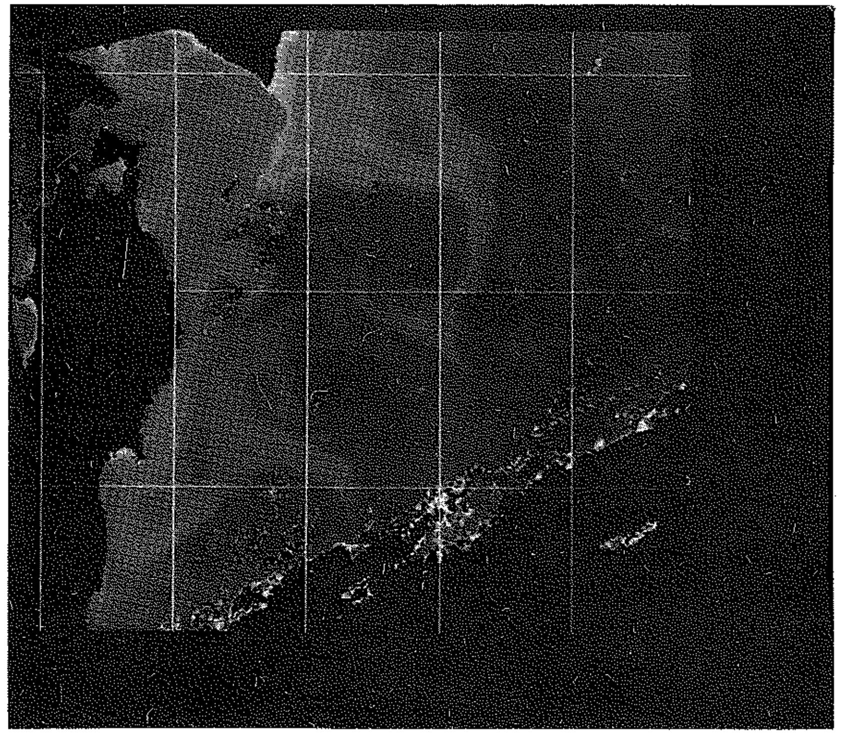


Figure 5
Satellite (CZCS) chlorophyll image of the coastal waters of northeastern Japan, 17 September 1981, showing chlorophyll-rich nearshore waters and a chlorophyll-poor, warm core eddy (centre of image).

Various physico-chemical and biological processes act to concentrate and transform contaminants. Boundary conditions, including persistent coastal eddies, haloclines, sea-surface films, the water-sediment interface, and the transition between oxic and anoxic sediments are particularly important in this respect and must be carefully considered in any flux estimates or mass balance calculations for materials being introduced into the coastal zone and in the design of monitoring programmes.

Distinct chemical and biological sinks are recognised for many compounds such as adsorption of metals onto particulate matter and the accumulation of organic residues within marine food chains. In some cases, there is considerable uncertainty about how much of what is added to estuaries actually reaches the open sea, reflecting a lack of knowledge of the processes controlling estuarine exchanges with sediments and the atmosphere.

The impacts of chemical modification on coastal ecosystems are extremely diverse, ranging from direct toxic effects on organisms to the development of large-scale phytoplankton blooms in response to bulk additions of nutrients. General consequences of most concern, as seen for example in the Baltic and N. Adriatic Seas, are the loss of diversity in pelagic, littoral and benthic communities, and the secondary effects of blooms which include the production of substances toxic to man and the depletion of oxygen, especially in bottom water, as organic matter decays.

In regions heavily affected by man distinct gradients in water quality and degree of biological impact now exist between contaminated estuarine and inshore waters and relatively pristine offshore waters. Examples of chemical changes and biological responses are illustrated in Figures 6 and 7. The existence of such gradients is indicative of the assimilative or "self-purification" capacity of the coastal ocean and offers some encouragement that, as observed for some freshwater lakes, rapid improvements in water quality can occur if appropriate control measures are taken. However, there are no grounds for complacency especially as contaminants accumulated and degraded only slowly in estuarine sediments can be re-mobilised when the sediments are disturbed. Also, there are good reasons for believing that water quality in many industrialised and heavily populated regions will continue to deteriorate further with serious effects on recreational uses of coastal waters and increasing risk to human health.



To deal effectively with the various environmental problems caused by chemical modification of coastal waters there is a need, especially in less-developed countries, for much better information on sources and sinks of contaminants and on the effects of seasonal (rainfall, thermal stratification) and episodic (storms) events on transport and transformation processes. On the whole, reliable sampling and analytical methods, as well as techniques for estimating fluxes, are available. The following research priorities were identified.

*Causes of phytoplankton blooms*

Increases in the frequency and intensity of phytoplankton blooms in coastal waters have been widely reported. The ecological and biogeochemical impacts of such events depend largely on the properties of the causative organisms. Some species produce substances toxic to marine organisms or to man, others inhibit grazing by zooplankton thereby disrupting the marine food chain. Many bloom-forming flagellates are strong sources of DMS, and in cases where the degradation of large quantities of algal matter lead to oxygen depletion enhanced production of $N_2O$ is likely. The indirect effects of coastal blooms, for example on pelagic-benthic coupling of energy transfer and on the production of calcifying organisms, is not well understood. Aspects of this problem that require particular attention include:

1. Elucidation of environmental factors that determine the occurrence and species composition of phytoplankton blooms, with respect in particular to increases in the abundance of flagellates (Figure 6) and implications for the microbial food web.

2. Causes of the spread of bloom-forming species to coastal regions in which they had not previously been recorded.

3. Development of systems to detect conditions for the initiation and spread of phytoplankton blooms and to provide warning of ecological and environmental impact.

*Impact on living resources and biogeochemical fluxes*

Coastal pollution affects the health of individual organisms (metabolic vigour, susceptibility to disease, reproductive capacity, etc.) as well as communities (species diversity, structure and energetics of the food chain) both directly through the introduction of toxic substances such as heavy metals, hydrocarbons and pesticides, and indirectly through the influence of changes in levels of nutrients and in turbidity (availability of light energy) on the growth of plants. Biogeochemical fluxes between the land, the ocean and the atmosphere are similarly altered as materials released by man are acted upon by physico-chemical and biological processes.

Not all the changes attributed to chemical modification of seawater are adverse -- for example, increased fish yields have been reported for eutrophic waters in Japan (Tatara, 1981) -- leading to the idea that the development of constructive policies within the framework of the assimilative capacity concept for managing both quantity and quality of wastes should be encouraged. However, predictions of ecological and biogeochemical responses are likely to be very uncertain for most situations so that retrospective evaluation procedures for setting realistic limits to chemical pollution should be an integral part of any research programme. Particular emphasis should be given to:

1. Acquiring reliable quantitative information on the short- and long-term fates of pollutants, including agricultural N and P, in estuaries and coastal waters that are significantly affected by change in land use and in industrialisation.

2. Determining trends in emissions of trace gases such as DMS, $N_2O$ and $CH_4$ for situations where inputs of organic matter are increasing through anthropogenic additions or through enhanced rates of plant growth.

3. Assessing and predicting the effects of declining water quality on the distributions and abundance of commercially important species of marine organisms.

4. Estimating rates of habitat loss and of reduction in biodiversity in response to physical disturbance of the coastal zone and to chemical pollution.

*Ecotoxicology*

Experimental studies of the effects of stress on marine organisms, including exposure to pollutants, hypoxia and anoxia, naturally-occurring toxins,



sub-optimal quantities and quality of food, habitat disturbance, and temperature changes, have been based largely on laboratory experimentation. Field investigations are concerned mainly with catastrophic situations, in particular oil spills, and with conditions of chronic pollution associated with point sources and accumulation zones which lead to high levels of mortality. However, it is widely recognised that sub-lethal, long-term exposure to low and intermediate levels of pollutants also causes significant adverse effects on communities and species that are difficult to recognise and quantify, especially when information about the chemical nature of the pollutant and its specific physiological impact is lacking. Decreases in fecundity, in the survival rates of larval stages, and in resistance to disease are particularly difficult to estimate for natural populations, especially in situations where two or more types of pollutants might cause additive effects. In general, there is an urgent need to apply and extend ecotoxicological techniques to field situations, with particular attention to:

1. Evaluation and intercalibration of ecological, physiological and cellular/histochemical methods for assessing the health of commercially valuable species of fish and shellfish and also of endangered marine species including mammals. Methods of extrapolation to the population/community level are also needed.

2. Development of sensitive bioassay methods to assess overall water and sediment quality (i.e., for two or more contaminants) and to detect pollutants that cannot be chemically determined or have not previously been recognised as toxic.

3. Development of objective methods for assessing retrospectively the ecological success/failure of pollution control measures.

### 6.3 Effects of Changes in Sea level and Climate

Estimates of the rise in sea level over the next 100 years, corresponding to the period for an expected doubling of the pre-industrial concentration of atmospheric $CO_2$, are generally 6cm per 10 years (IPCC, 1990). The major causes will be thermal expansion of the surface ocean (the predicted global temperature increase is 0.3°C per 10 years (IPCC, 1990)), and the melting of alpine glaciers and small ice caps. However, regional variability is likely to be considerable due to the effects of subsidence related to natural consolidation of sediments and withdrawal of groundwater, and of continuing isostatic adjustments and various tectonic phenomena (Unesco, 1990). The main uncertainties are the behaviour of the Greenland and Antarctic ice sheets (for example, will melting of ice margins be offset by expected higher rates of snow accumulation as the climate warms?), and the degree and rate of warming of high latitude, mid-depth waters associated with sinking and downward entrainment of relatively dense surface waters. It is important to note that significant changes in the morphology and stability of Antarctic ice sheet are not expected over the century timescale.

The maximum predicted rate of increase in sea level is of the same order as that during the early part of the present interglacial period (~14 mm/yr between 16,000 and 6,000 years before present), and much more rapid than during the last six thousand years (~0.4 mm/yr) or recent estimates of the present rate of change (~2 mm/yr, Peltier and Tushingham, 1989). Examination of late glacial and early post-glacial shelf and slope sediment deposits are likely to provide important information as to how the land-sea margin responds to a relatively rapid rise in sea level.

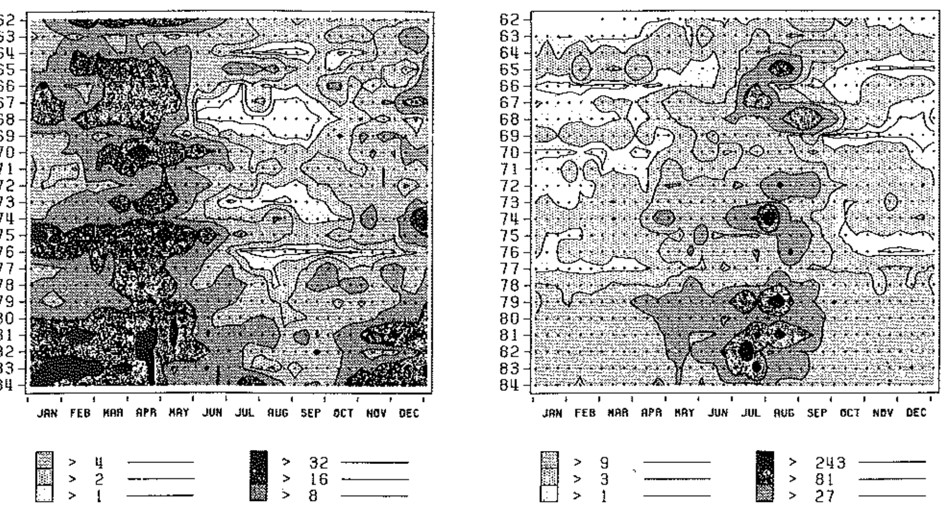



Figure 6
Changes in the annual abundance of nitrate (mmol N $m^{-3}$) and flagellates (phytoplankton mg C $m^{-3}$) at Helgoland Reede from 1962 to 1984 (from Radach et al., 1990).



The impact of sea-level rise of low-lying coastlines is complex, site specific in relation to geomorphology, sediment rock types, etc., and difficult to predict. Coastal plains tend to advance as the products of land weathering, reef and saltmarsh growth, and aeolian transport accumulate along the land-sea boundary, and can often accommodate a gradual rise in sea level without major topographical changes. By contrast, rather different responses are expected for urbanised coastal regions where subsidence is likely, and for deltas and large estuaries where inshore movements of the salt wedge have a strong influence on overall patterns of sediment deposition and transport.

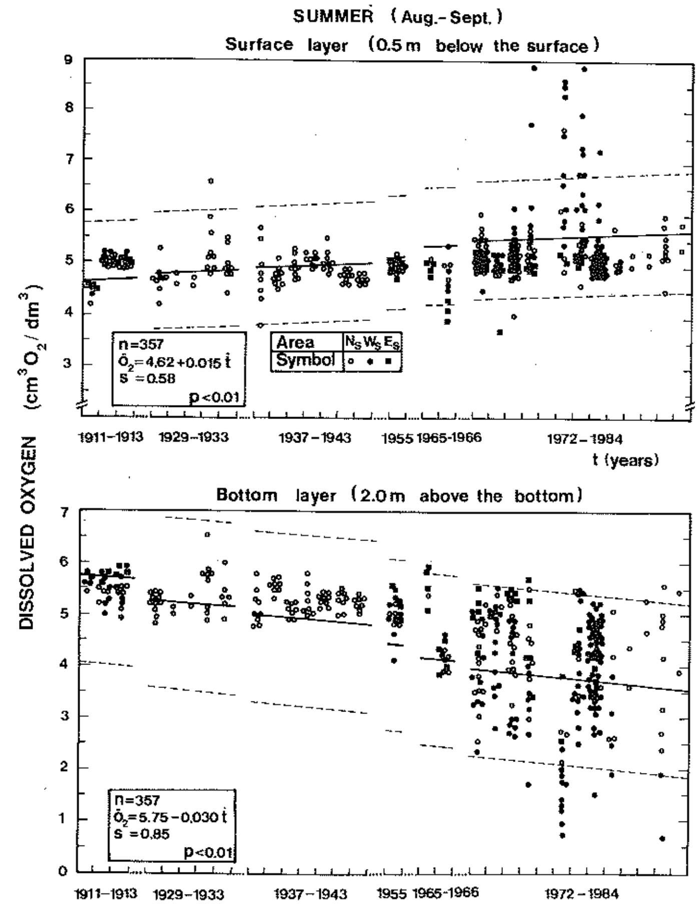



Figure 7
Changes in the oxygen content (ml $l^{-1}$) of the northern Adriatic Sea (April-May) from 1911 to 1984 (from Justić et al., 1987).

Another uncertain factor is the relative importance of episodic storm erosion, as opposed to an increase in mean sea level, in determining the dynamic properties of the land-sea boundary. Large-scale movements of sediment or significant geomorphological alterations occur mainly under the combined influence of large tides and waves. Whatever the mechanisms of change might be, the coastline could retreat up to 20 km inland over the next century in some regions. With associated modification of the stability and productivity of coastal and wetland ecosystems, the overall impact on human society would be severe.

Greenhouse warming due to increases of $CO_2$ and other trace gases in the atmosphere, which is the main cause of sea-level rise, will also affect the coastal zone through the direct influence of higher temperature and through related changes in climate. In particular, increases of storm frequency at mid-latitudes and of precipitation generally are expected. The rise in temperature will be most marked in polar regions and, through physiological and ecosystem responses, is likely to have a significant impact on the biogeography of marine organisms. Changes in the hydrological cycle and in temperature will alter land weathering processes and the delivery of materials to the ocean including freshwater, which largely controls buoyancy-driven circulation and exchange processes in shelf seas. Furthermore, the combination of sea-level rise, increased precipitation and adjustment of the partitioning of rainwater between surface runoff and groundwater replenishment will affect the degree to which saltwater penetrates coastal freshwater reservoirs.

Interactive effects related to sea level and climate changes are not only complex in themselves, but also difficult to distinguish from those due to man's activities (Section 6.2) and from natural variability in the dynamic state coastal ecosystems. Establishing causal relationships between climate and the biosphere is most difficult for feedback terms which concern the impact on climate changes in the biosphere. The dynamic properties of the land-sea margin and the coastal ocean appear to be important in determining exchanges of $CO_2$ with the atmosphere, so that realistic prediction of future levels of atmospheric $CO_2$ depend upon accurate estimates of carbon fluxes under present conditions.

The nature and causes of climate and sea level change will be largely investigated through the WCRP as well as other IGBP projects. Here it is sufficient to emphasise the requirement for the best possible data on future



sea level and climate conditions so that man can develop scientifically sound and socially acceptable policies for using the resources of the coastal ocean. From the perspective of the IGBP, future research should give priority to:

1. Evaluation of observations and predictions of sea level and climate change in relation to modification of the coastal environment (Hekstra, 1989), taking account of regional factors such as isostatic adjustment, subsidence, river discharges, exposure to wind and waves, and ice dynamics.

2. Observational and modelling studies of coastline geomorphology and nearshore sediment deposition and transport in relation to rises in sea level and the action of tides and waves. It will be important to identify threshold factors and episodic conditions that initiate active coastal erosion.

3. Determinations of changes in freshwater runoff and in the level of particulate and dissolved materials carried by rivers into shelf seas with respect to physical circulation and mixing processes and net fluxes from land to the ocean.

4. Investigations of the combined effects of changes in sediment stability and type, nutrient levels, turbidity, salinity and various physical factors (immersion, waves, currents, etc.) on marsh, littoral, benthic and pelagic ecosystems. Large-scale disturbance of riverine and deltaic sediments will have a great impact on the biota affected by the mobilisation of buried organic matter and, for some regions, pollutants. Subsequent oxidation processes could lead to extensive anoxia in deeper offshore waters.

5. Estimating the influence of resultant geomorphological, hydrological and ecological changes on biogeochemical fluxes between the land, sea and atmosphere, particularly with respect to variations in the burial and oxidation of terrestrial organic carbon in the sea and the emission of trace gases from the coastal margins. Special attention will need to be given to the transition zone between DMS-producing saltmarsh communities and $CH_4$-producing freshwater bogs under conditions of rising sea level.

## 7. UNDERLYING NEEDS

### 7.1 Selection of Study Sites

The choice of sites for new initiatives on coastal-ocean research within a global plan must first take account of present national and regional efforts in general, of existent international programmes dealing in particular with living resources and pollution issues (see Unesco publications), and of human and economic needs which identify regions needing special attention. Other considerations are the need for a system of classification for continental shelves (see Walsh, 1988) as a basis of extrapolating from limited information, and differences in the relative sensitivity of coastal ecosystems to the impacts of human activity and climate change.

Although coastal oceans are recognised to be variable in a descriptive sense with respect to morphology, vegetation type at the land-sea margin, tidal energy dissipation (Miller, 1966), freshwater inputs (Milliman and Meade, 1983) and influence of the ocean, no formal classification has been attempted. Until this is done, global estimates of fluxes of energy and matter between the continents and the oceans will inevitably be somewhat subjective and based largely on a few site-specific studies.

In terms of the influence of man, broad latitudinal differences can be distinguished. Tropical coastal waters are now being strongly affected by land-use changes (Eisma, 1988), which give rise to large fluxes of particulate and dissolved material in rivers and flood waters, and by aquaculture developments, which introduce nutrients and locally alter the structure of the marine food chain. At mid-latitudes, especially in the Northern Hemisphere, industrialisation and use of agricultural fertilisers have led to progressive deterioration of water quality since the early part of this century. By contrast, in polar regions, the coastal ocean is still relatively unaffected by man (with the exception of oil spills) and the main concern is the future impact of climate and sea-level changes on fragile ecosystems with short growth seasons.

The impacts of climate change are also expected to be regionally variable especially with respect to increases in temperature (greatest at high latitudes) and to precipitation and freshwater run-off (generally greater due to increased evaporation but certain regions will become drier). Sea-level rise will be a global phenomenon with local variations, but some regions will be much more



adversely affected than others depending on interactions with coastal topography, the responses of marginal ecosystems, the nature of land-use practices, and the dynamics of sediment deposition and transport processes.

With these points in mind, six priorities are recognised.

1. Indonesian coastal waters, extending from the Gulf of Carpentaria north into the South China Sea, where the shelf is generally broad, tides are locally strong, the freshwater inputs and sediment loads of the rivers very high, and pressure on the coastal zone due to human activity extreme. There is also a special interest in the exchange of surface waters (and associated materials) between the Indian and Pacific Ocean through this region.

2. Mid-latitude shelf waters which have been heavily exploited for their natural resources and also exposed to industrial and agricultural wastes for a relatively long period. North West Europe provides the best documented cases of change (the Baltic, Adriatic, and North Seas), and is a region where the various problems of international co-operation, of detecting ecological change, and of developing appropriate ecosystem management policies have received considerable attention. It is important that this work continues and that active steps are taken to pass on the relevant expertise to less-developed countries.

3. Coastal waters surrounding the Arctic Ocean for which there is both a lack of basic information on dynamic properties and a recognition that the natural ecosystems are likely to be very sensitive to climate change.

4. Coastal upwelling systems which are important for their fisheries and in terms of the carbon cycle, and will be affected by climate change (Bakun, 1990).

5. Large river deltas which are the dominant sites for freshwater and sediment transfer from land to ocean and are being strongly modified by freshwater management schemes (Milliman et al., 1989).

6. Enclosed seas (e.g., Black and Caspian Seas).

## 7.2 Global Observation and Remote Sensing

Observing the coastal ocean is not a trivial problem due to its geographically narrow and extended domain (Figure 1), and to the constant state of change characteristic of a dynamic boundary zone. These properties necessitate a unique approach to observing the coastal ocean, which can take account of strong local signals (e.g., water advection), seasonal variability in all properties, natural long-term changes in sea level, populations, etc., as well as superimposed anthropogenic effects. Strategies for responding to change in the coastal ocean will depend on objective assessments of the scales of forcing processes, on recognising whether ecological effects are direct or indirect and on knowing the relative magnitude and direction of response to climatic and anthropogenic forcing.

In most parts of the coastal ocean, the scales and nature of natural variability are not well known and, with the exception of measurements of certain basic properties such as sea level and temperature, there have been few studies to determine the rate and cause of change. One reason is that, at a national level, support for long-term observations is often difficult to obtain. Additional problems are the maintenance of consistent sampling methods and of a high level of data quality, and the construction of a broad regional focus to the observations to allow intercomparison with other time-series of observational data.

Attempts to understand the physical climate and biogeochemical cycles of the coastal ocean on a global scale will require synoptic observations over one or more decades with sufficient spatial and temporal resolution to resolve the dominant frequencies and wave numbers of variability. This objective is only attainable through remote sensing, using particular advanced satellite sensors now in orbit or planned for the 1990s. The technological challenges remain large, not the least of which is both to reduce sensibly and to apply an unprecedented volume of data.

For the coastal ocean, vigorous parameterization of small-scale physical and biological processes will depend on critical field observations and experiments and on models of the surface mixed layer, as well as on remote sensing. Iterative coupling between these three approaches is essential and satellite observations alone will not provide adequate answers.



*Exchanges between land and coastal ocean*

Ocean colour sensors (SPOT/MOS/SeaWiFS) capable of detecting suspended and dissolved matter in coastal and oceanic waters will have an increasingly important role in studies of land discharges to coastal waters.

*Exchanges with the open ocean*

Studies of various physical processes, such as mesoscale eddy activity and exchange across the shelf break, are in their infancy in terms of remote sensing. Satellite altimeter measurements (TOPEX/Poseidon) coupled with ocean colour and sea-surface temperature observations are likely to provide a much more rigorous framework for research in this area.

*Biological productivity*

The now-defunct CZCS has revolutionised the way biological oceanographers view primary production in the oceans. Synoptic descriptions of phytoplankton abundance in shelf waters can be obtained although problems of quantitative interpretation related to the presence of variable amounts of dissolved and suspended matter need to be further resolved before the next sensors (MOS, SeaWiFS) are operational.

*Air - Sea Fluxes*

Biogeochemical exchanges between the atmosphere and sea depend on relevant inputs (light, $CO_2$, nutrients) and outputs (volatile substances) of phytoplankton growth and on physical properties (wind, temperature, transfer coefficients, etc.). The combined applications of passive and active sensors in the visible and microwave bands will open the way to much new research in this area, in particular combining studies of wind stress and sea state and of biological productivity. The use of satellite data for investigations of aeolian transport of dust from the continents to the sea will also be important in this context.

## 7.3 Long-Term Monitoring

Various sets of measurements of surface hydrographic and biological properties exist, some dating to the beginning of this century or even earlier. In addition, there are records of fishing activities, of sea-level change and of relevant climatic factors that extend back in time much further, and overlap with information on other types of change from sediments particularly for anoxic basins in which annual patterns of sedimentation are preserved (e.g., Soutar and Isaacs, 1974). The levels and objectives of interpretation of this information have been extremely variable, depending on the circumstances under which it was collected and the interests of the investigator.

There is increasing awareness of certain general restraints that must be placed on interpretation (for example, recognition of different timescales of variability) but also that such records do hold valuable information on regional (e.g., Dickson et al., 1988) or even global change. Re-evaluating and upgrading long time series of observations in the context of the IGBP is therefore required, especially to make objective comparisons of the timing and nature of climatic and environmental change in different parts of the coastal ocean. A comprehensive list of the sources and nature of this information should be prepared.

With regard to the future, the need to continue long-term records such as the Continuous Plankton Recorder Survey (Colebrook, 1986) and to acquire additional types of information relating to biological change is a high priority. New instrumentation and technology have opened up many new approaches to this problem based on moored, towed and submersible platforms. Automated methods for chemical analyses are becoming available, as are approaches to investigating biological responses over varying time and space scales (e.g., at different trophic levels in the food chain) to particular environmental triggers.

### 7.4 Documentation of Change in the Coastal Ocean

Although there are a number of well known examples of changes occurring in coastal seas over decadal or longer time periods (e.g., Figures 6 and 7), our knowledge at the global level of the effects of human activities or of natural variations in climate is very imprecise. Furthermore, the unequivocal interpretation of biological changes is often impossible due to a lack of knowledge of the structure and dynamics of coastal marine ecosystems so that, for management purposes, attempts to predict future trends or to set objective limits to disturbance of the marine environment are often controversial.

With recent technical advances in remote sensing and *in situ* monitoring systems, the major limitations to studying changes in coastal oceans appear to



be resources for the acquisition and interpretation of appropriate data especially for tropical regions, where the changes are most rapid and extensive. It will not be possible to develop sound management policies without reliable information on the types, scales and significance of changes in particular for biological and chemical parameters, although important progress has been made within Unesco programmes (UNEP, 1990).

The main requirement for the future is a global observation network based on remote sensing, moored *in situ* sensors, and regional surveys. New sensors will be needed for water quality studies and for validation of remote-sensing studies. The assimilation of such data into simulation and predictive models will require robust archiving and analysis methods, perhaps based on Geographic Information Systems, which have been successfully applied in other fields of environmental science.

### 7.5 Predictive Progress/Ecosystem Models

Predictive models for the coastal zone that incorporate the effects of global change depend on accurate parameterisation of biological processes with respect both to the physical and chemical environment and to the biogeochemical cycling of carbon and other key elements. A focus on organic carbon is appropriate for several reasons: the coastal oceans are a major sink for carbon (Berner, 1982; Smith and MacKenzie, 1987) and therefore a critical element of the global marine carbon cycle; potential feedback effects on climate due to variations in the emission of trace gases such as $N_2O$ and DMS are linked to carbon through organic assimilation and dissimilation reactions; and the transformation, fate and impact of contaminants in coastal waters are closely associated with the cycling of organic matter especially within nearshore sediments.

Certain problems need particular attention, including how to bring together models from different disciplines (geomorphology, hydrodynamics, biochemistry, ecotoxicology, etc.) and how to incorporate into models processes which operate over very different scales. For example, environmental changes occur gradually over many years, whereas the impacts of such changes on populations of organisms involves the short term physiological responses of individuals. Extrapolation from one scale to another is full of uncertainty. Even physical processes are poorly understood, particularly concerning diffusion processes at the land and ocean boundaries in relation to fluxes of both dissolved and particulate matter.

### 7.6 Education, Scientific Training, and Technology Transfer

Identifying and responding to the impacts and economic problems of global change in the coastal zone in a way that takes account of the long-term needs of society will depend upon the improved education, training and availability of resources, with significant help being given to less-developed countries through aid programmes. The Unesco's COMAR project which places emphasis on the role of traditional knowledge and practices in sustaining living marine resources is an important step in this direction.

Another need will be the establishment of centres for training scientists in methods for monitoring change in the coastal oceans, in the efficient and non-damaging use of resources, in the control of coastal pollution (see the GESAMP reports 1986, 1987, and 1989), and in predicting the effects of climate and sea-level change. On account of the wide-ranging social implications, education of the public will also be necessary. Expert systems to provide scientifically-based advice to environmental managers will be required.

### 7.7 Scientific Management Policies

Decisions about the scale of change in the coastal zone that are acceptable to society, about the future regulation of marine practices, about management plans, and about responses to unexpected events will have to be made. There will be many choices, some concerning global or regional issues and international agreements, and others related to local issues for individual countries. The ability to make the best decisions will depend on a combination of sound scientific information, an understanding of both the short and long-term implications of different solutions, and good public awareness of the need to conserve the resources of the coastal zone. These are all difficult issues in which scientists must play an active and responsible role if the deleterious effects of human activities and of climate and sea-level change are to be kept to a minimum.



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# 9. APPENDICES

A. Acronyms

B. Related Research Programmes

C. List of *Ad Hoc* Workshop Participants

## A. ACRONYMS

| | |
|---|---|
| CCCO | Joint Committee on Climatic Changes and the Ocean (ICSU-IOC) |
| COMAR | Coastal Marine Project (Unesco) |
| COSPAR | Committee on Space Research (ICSU) |
| DMS | dimethylsulphide |
| DOC | dissolved organic carbon |
| EEZ | Exclusive Economic Zones |
| FAO | Food and Agriculture Organization |
| GEMS | Global Environmental Monitoring System (UNEP) |
| GEWEX | Global Energy and Water Cycle Experiment (WCRP) |
| GIPME | Global Investigation of Pollution in the Marine Environment |
| GOEZS | Global Ocean Euphotic Zone Study |
| IABO | International Association for Biological Oceanography (IUBS/ICSU) |
| IAHS | International Association of Hydrological Sciences (IUGG/ICSU) |
| IAMAP | International Association of Meteorology and Atmospheric Physics (IUGG/ICSU) |
| ICA | International Cartographic Association |
| ICACGP | Commission on Atmospheric Chemistry and Global Pollution (IUGG-IAMAP) |
| ICES | International Council for the Exploration of the Sea |
| ICSU | International Council of Scientific Unions |
| IGAC | International Global Atmospheric Chemistry Project (ICACGP/IGBP) |
| IGBP | International Geosphere-Biosphere Programme: A Study of Global Change |
| IGU | International Geographical Union |
| IHP | International Hydrological Programme (Unesco) |
| INTECOL | International Association for Ecology (IUBS/ICSU) |
| IOC | Intergovernmental Oceanographic Commission (Unesco) |
| IPCC | Intergovernmental Panel on Climate Change (WMO/UNEP) |
| ISCCP | International Satellite Cloud Climatology Project (WCRP) |
| ISSS | International Society of Soil Science |
| ISLSCP | International Satellite Land Surface Climatology Project |
| IUBS | International Union of Biological Sciences (ICSU) |
| IUGG | International Union of Geodesy and Geophysics (ICSU) |
| JGOFS | Joint Global Ocean Flux Study (SCOR/IGBP) |
| JSC | Joint Scientific Committee for WCRP |
| MAB | Man and the Biosphere |
| MOS | Marine Observational Satellite (Japan) |
| OSLR/ OSLNR | Ocean Science in Relation to Living/Non-Living Resources |
| POC | Particulate Organic Carbon |
| SCAR | Scientific Committee on Antarctic Research (ICSU) |
| SCOPE | Scientific Committee on Problems of the Environment (ICSU) |
| SCOR | Scientific Committee on Ocean Research |
| SeaWiFS | Sea-viewing Wide Field of View Sensor |
| SOTER | World Soils and Terrain Data Base |
| SPOT | Système pour l'Observation de la Terre (France) |
| TOGA | Tropical Oceans and Global Atmosphere Programme (WCRP) |
| TOPEX | Ocean Topography Experiment POSEIDON (USA/France) |
| UNEP | United Nations Environment Programme |
| Unesco | United Nations Educational, Scientific and Cultural Organization |
| WCDP | World Climate Data Programme |
| WCRP | World Climate Research Programme (WMO/ICSU) |
| WDDES | World Digital Database for Environmental Science |
| WMO | World Meteorological Organization |
| WOCE | World Ocean Circulation Experiment |



## B. RELATED RESEARCH PROGRAMMES

### a) Biosphere

| Programme | Status | Subject | Sponsor |
|---|---|---|---|
| 1. The Biogeochemical Cycles and their Interactions | Ongoing (1974-) | Biology Meterology Oceanography; Chemistry | SCOPE |
| 2. Bioindicators | Ongoing | Pollution of Environment; Biogeochemical Cycles | IUBS |
| 3. Man and the Biosphere (MAB) | Ongoing | Ecology | Unesco; IUBS INTECOL; SCOPE |
| 4. International Satellite Land Surface Climatology Project (ISLSCP) | Ongoing | Variations in Physical and Biological Land Surface Characteristics | COSPAR; IAMAP; UNEP; JSC of WMO-ICSU; IGBP |
| 5. International Recruitment Experiment | | Fisheries | Unesco/IOC |
| 6. Global Investigation of Pollution in the Marine Environment (GIPME) | | Pollution | IOC |
| 7. Ocean Science in Relation to Living/Non-Living Resources (OSLR/OSLNR) | | Natural Resources | IOC/FAO |

### b) Oceans, Atmosphere, Hydrology

| Programme | Status | Subject | Sponsor |
|---|---|---|---|
| 1. World Climate Research Programme (WCRP) | Ongoing | Meteorology; Oceanography | WMO; ICSU |
| 2. Tropical Oceans and Global Atmosphere (TOGA) | Ongoing (1985-94) | Meteorology; Oceanography | WCRP; IOC; SCOR |
| 3. World Ocean Circulation Experiment (WOCE) | Ongoing (1990-95) | Oceanography; Meteorology; Circulation; Air-Sea Interaction; Sea Ice | WCRP; CCCO IOC; SCOR |
| 4. International Hydrological Programme (IHP) | Ongoing (1975- ) | Hydrology | Unesco; WMO; UNEP; IAHS; IUGG |
| 5. Global Energy and Water Cycle Environment (GEWEX) | Proposed | Transport and Distribution of Water and Energy | WCRP |
| 6. Joint Global Ocean Flux Study (JGOFS) | Ongoing (1989- ) | Biogeochemical Fluxes | SCOR; IGBP |
| 7. International Satellite Cloud Climatology Project (ISCCP) | Ongoing (1983-) | Cloud Cover, Solar Radiation Fluxes | WCRP; IAMAP; COSPAR; SCAR |
| 8. International Global Atmospheric Chemistry Programme (IGAC) | Ongoing (1990- ) | Atmospheric Trace Constituents; Atmospheric Photochemistry; Aerosols | IAMAP; IUGG |
| 9. Interregional Project on Research and Training Leading to the Integrated Management of Coastal Systems (COMAR) | Ongoing | Coastal/Marine Ecological Processes | Unesco; IABO; IUBS |
| 10. Regional Seas Programme | | | UNEP |



### c) Monitoring and Data

| Programme | Status | Subject | Sponsor |
|---|---|---|---|
| 1. Global Environmental Monitoring System (GEMS) | Ongoing | Meteorology; Environmental Sciences; Ecology | UNEP; WMO; IOC; ICES; FAO, SCOPE |
| 2. World Digital Database for Environmental Science (WDDES) | Proposed | Hydrology; Bathymetry; Terrain; Coastline; etc. | ICA; IGU |
| 3. World Soils and Terrain Database (SOTER) | Proposed | Soils; Terrain | ISSS; UNEP |
| 4. World Climate Data Programme (WCDP) | Ongoing | Atmosphere - Ocean - Cryosphere - Terrestrial Earth Science Climate Data | WMO; UNEP |

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No. 1. The International Geosphere-Biosphere Programme: A Study of Global Change. Final Report of the *Ad Hoc* Planning Group, ICSU 21st General Assembly, Berne, Switzerland 14-19 September, 1986 (1986)

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