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Pollutant modification of atmospheric and oceanic processes and climate: some aspects of the problem

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PREFACE

GESAMP, the Joint Group of Experts on the Scientific Aspects of Marine Pollution, was established in 1969 and is today co-sponsored by the International Maritime Organization (IMO), Food and Agriculture Organization of the United Nations (FAO), United Nations Educational, Scientific and Cultural Organization (UNESCO), World Meteorological Organization (WMO), World Health Organizaton (WHO), International Atomic Energy Agency (IAEA), United Nations (UN) and United Nations Environment Programme (UNEP). According to its present terms of reference, the functions of GESAMP are:

- to provide advice relating to the scientific aspects of marine pollution[1/]; and
- to prepare periodic reviews of the state of the marine environment as regards marine pollution and to identify problem areas requiring special attention.

Since its beginning GESAMP involved a large number of experts as members of GESAMP or GESAMP Working Groups and produced, at the request of the sponsoring organizations, numerous studies, reviews and reports.

The first draft of the present report was prepared at the sixth session of the WMO-led GESAMP Working Group No. 14 on the Interchange of Pollutants between the Atmosphere and the Oceans held in Paris from 6 to 9 January 1986. The list of participants is given as Annex I.

The GESAMP at its sixteenth session (London, 17-21 March 1986) endorsed the report in principle and recommended that the working group should continue its work during the intersessional period. The work done by correspondence was completed in March 1988.

The report, which is available in English only, was subsequently revised and updated to incorporate comments made by GESAMP at its eighteenth session (Paris, 11-15 April 1988) which adopted the report and recommended that it be published in the GESAMP Reports and Studies Series.

Financial support for the work of Working Group No. 14 was provided by the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP) and the Intergovernmental Oceanographic Commission (IOC).

1/ GESAMP defined marine pollution as "introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea-water, and reduction of amenities."

CONTENTS

1. EXECUTIVE SUMMARY

The Sixth Session of the GESAMP Working Group on the Interchange of Pollutants between the Atmosphere and the Oceans stressed the impact of contaminants on climate. This included the effects of such "greenhouse" gases as CO_2 increasing temperature and aerosols decreasing temperature, as well as contaminants and processes at the air-sea interface that affect the interchange of energy and material which could affect climate regionally and even globally. The effect of oil films in retarding transfer of gases between the atmosphere and the sea and in damping capillary and larger gravity waves, and hence reducing wind mixing in the upper layer of the sea, is one example of such contaminants and affected processes.

Carbon dioxide is clearly increasing in the atmosphere at the rate of about 1 ppmv (parts per million by volume) per year, starting at 315 ppmv in 1958 when good records commenced. It is estimated that the near-surface global temperature will increase by 1.5° to 4.5°K with a doubling of the atmospheric CO_2.

The global cycle of carbon dioxide indicates that the terrestrial biosphere and the oceans each cycle about 10^2 Gt (1 gigaton = 10^{15} g) carbon per year between themselves and the atmosphere, in a two-way flux if the system is in a steady state. This equilibrium has been perturbed naturally in the last 10^4-10^5 years at least, as shown by the analysis of air trapped in bubbles of glacial ice cores. Since the start of the agricultural/industrial revolution, man has added another perturbation by burning fossil fuels and mobilizing CO_2 from the fixed carbon in the land biosphere. For the period around 1980, the release of CO_2 from fossil fuel combustion is about 5 GtC yr^{-1} and estimates of the release from biomass destruction, e.g., deforestation, ranges from 0 to 2 GtC yr^{-1}, depending on the technique of estimation. The major sink for man-mobilized CO_2 is the ocean which is estimated to accept about 2-3 GtC annually. The atmosphere retains about 2.5 GtC yr^{-1}; it is this residual CO_2 that contributes to the annual increase in atmospheric CO_2 concentration. The discrepancy between sources and sinks of man-made CO_2 is in the range of 0.5 to 1.5 GtC yr^{-1}, depending on the net biospheric input. Arguments are presented to show that the current input of CO_2 from the biosphere is no more that 1 GtC yr^{-1}, but uncertainty regarding the biomass contribution of CO_2 continues.

Some of the factors affecting the oceanic uptake of CO_2 from the atmosphere are presented. The gas transfer velocity is controlled mainly by the wind speed. The other variable that controls the CO_2 exchange flux is the partial pressure difference between the air and the sea. It is noted that there is a latitudinal variation in CO_2 flux, based on the observed CO_2 partial pressure distribution in the surface ocean. A net CO_2 flux of the order of 2 GtC yr^{-1} emanates from the sea in the equatorial region between 16°S and 16°N. To balance this contribution, there would have to be a net flux of about 4 GtC yr^{-1} from the atmosphere to the ocean north and south of this region.

Various models of the oceanic carbon cycle exist to estimate uptake of atmospheric CO_2 by the oceans. Diagnostic models have been developed in which the ocean is subdivided into a few well-mixed reservoirs connected by anthropogenic aerosols would have much influence on global ocean climate through direct intervention with solar energy. The interaction of aerosols and clouds, on the other hand, may have a more significant impact on climate. Recently, investigators have postulated that natural sources of sulphur over the oceans may play an important role in regulating the cloud-condensation nuclei and hence the albedo. Others conclude that the effects of aerosols will probably not overshadow the impact of greenhouse gases as the most important cause of climate change over the next century.

Knowledge of the properties of the surface microlayer is important for better understanding of the exchange processes between the atmosphere and the ocean. Surface films, both of natural and man-made origin, are always present, but vary in physical and chemical properties and concentration. Several areas of particular interest to air-sea exchange of substances were identified: modification by surface films of sea-surface reflectivity, emissivity and absorption both for the visible and microwave spectral regions; influence of surface films on the properties of breaking waves and the air-bubble size distribution and life-times; effect of natural films in biologically highly productive zones and of anthropogenic films in oil spill and municipal sewage disposal areas on the rate of exchange of CO_2 and other non-reactive gases between the atmosphere and the ocean; effect of electrification of surface films due to mechanical (wind, waves) perturbation on salt enrichment and changes of ionic ratios in aerosols; and the effect of surface films of lipid and petroleum origin, combined with bubble formation, in concentrating particulate contaminants at the sea surface and in sea-to-land aerial transport of such contaminants as chlorinated hydrocarbons, bacteria and viruses.

Space-based satellite imagery to detect petroleum slicks on the sea surface and to determine the extent of coverage by such slicks was considered. Oil slicks have been observed from space by thermal imagers, optical photography, and imaging synthetic aperture microwave radar. Such systems might be used to determine the frequency and distribution of pollutant slicks on a global/regional basis. False images for microwave radar and photography may arise, however, from natural slicks, wind and current attenuation of capillary wave scatterers, dense cloud shadows and unrippled water under calm conditions. Natural slicks, ship wakes and effluents, upwelling, or thermal variability of the sea surface may also confuse thermal infrared imagery. Therefore, space-based sensing of sea-surface oil slicks would be difficult, unless supported by extensive sea-truth investigations. It was considered important, nevertheless, to continue testing methodologies to improve the capability for monitoring sea-surface oil slicks with space-based remote sensing systems.

It was noted that recent in situ research, coupled with coastal-zone colour imagery from space, has demonstrated that space-based detection of the effect of phytoplankton on ocean colour is possible. Space-based sensing of changes of phytoplankton biomass may become important for monitoring effects of climatic change on oceanic primary productivity.

On the basis of its conclusions on the above-mentioned matters, the Working Group in 1981 proposed that the GESAMP definition of marine pollution* be amended by the following wording: "... and altering ocean-related physical processes especially pertinent to climate".

This proposal was discussed at length by GESAMP XII and it was agreed that the Working Group should prepare an explanatory statement on process modification by pollutants for consideration at the next session. At the fifteenth session, GESAMP re-affirmed its request to the Working Group and approved the following, inter alia, terms of reference: (i) to provide a continuing review of air-sea material interchange with emphasis on the pollutant modification of atmosphere and ocean-related processes, especially those pertinent to climate, and the energy balance of the oceans; (ii) to study certain properties of the ocean mixed layer and the surface microlayer, which are modified by pollutants, to clarify mechanisms of mass and energy transfer between the atmosphere and the oceans, and to assess the potential for the remote detection of pollutants as a result of these surface and near-surface effects.

It was decided later by the Working Group that, at the first stage of studying these problems, attention should be paid mainly to the role of the global ocean in the magnitude and variations of tropospheric carbon dioxide concentrations, the knowledge of which is indispensable for modelling and predicting any resulting climatic changes and anomalies.

The orientation of the activities of the Working Group toward pollutant modification of the atmosphere, ocean-related processes and climate requires that these activities should be connected with, and take into account the results of, other international programmes and projects, such as the World Climate Research Programme (WCRP) (WMO/ICSD, 1985), and its World Ocean Circulation Experiment (WOCE) and Tropical Ocean and Global Atmospheric Programme (TOGA), and others. Summaries of the activities within some of these programmes are given in Annex II.

3. MAIN PROCESSES AND SIGNIFICANCE OF THEIR CHANGES

The Working Group discussed the effect of contaminants in modification of processes in the atmosphere, at the air-sea interface and in the sea (see Annex III), in the context of weather and climate modification. It is clear that certain processes are modified by contaminants, but the significance of

* "Pollution means the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities."

TABLE I. MODIFICATION OF PROCESSES BY CONTAMINANTS

PROCESS	TROPOSPHERE	AIR-SEA INTERFACE	SEA
PHYSICAL	Soot and dust could alter the solar input and change the thermal characteristics of the troposphere. Cloud-condensation nuclei in the marine atmosphere modify the physics of clouds which may result in the modification of cloud formation patterns and the earth's albedo.	Organic films from petroleum hydrocarbons and/or detergents modify interfacial properties and exchange processes. Altered air-sea interfacial processes may influence the ocean-atmosphere exchange of gases (CO_2 and acid rain precursors) that are sources of acidity in coastal areas and seas, especially those affected by oil production and transportation.	Agricultural, forestry and construction silt runoff influences light penetration and possibly alters thermal structure in the euphotic zone. Estuarine areas and sites of municipal and industrial waste disposal would be of greatest concern.
CHEMICAL	Ozone is the source of the highly reactive radicals that control the chemistry of the troposphere. Changes in ozone can alter the concentrations of these radicals. Various atmospheric pollutants, e.g., nitrogen oxides and hydrocarbons, contribute to ozone through photo-oxidation processes.	Enrichment of organic films with petroleum hydrocarbons, organochlorines and metals occurs. This prevents ready transfer to the water column and enhances transfer to the atmosphere by bubble bursting. Exposure of substances in the surface film to the atmosphere and solar radiation promotes oxidation and photochemical processes.	Increased input of substances from man-made sources can change the minor element composition of seawater. Metal concentrations can be increased. Input of CO_2 can change the pH of seawater with certain consequences to chemical equilibria of ionic composition.
	Transfer of bacteria, viruses and fungus spores from the sea to the atmosphere and potential transport to	Pathological microorganisms could be concentrated in the surface film. Neustonic organisms can be	Dissolved constituents from municipal and industrial wastes, as well as from runoff, could be toxic to marine