II. BIOPROCESSES

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A. Introduction

Remote sensing of the hydrosphere is a technical discipline which has developed to a point where it can now contribute to the solution of important scientific and environmental problems. There is neither a lack of problems nor a lack of measurement requirements and possible applications of present or projected remote sensing capability. This is particularly true in physical, chemical, and biological investigations of large water bodies which are invariably limited by lack of data. In choosing our recommendations of first-order problems to which remote sensing should be applied we have been guided by the following criteria:

(a) The importance of the problem as indicated by present level of scientific and engineering effort being expended in improving our understanding of its causes and of developing methods for controlling its consequences

(b) The unique capability of remote sensing to provide synoptic large spatial scale and short temporal scale data as compared to conventional ship-based sampling procedures

(c) The parameters available for measurement using present and projected remote sensing techniques

(d) The demonstrated need for these measurements in ongoing and planned investigations.

We recommend two classes of problems be considered which are related in certain respects but distinct in emphasis: (1) eutrophication and (2) location and characterization of fronts.

B. Eutrophication

1. Statement of the Problem

(a) Why It Is Important Scientifically and Politically

Artificially accelerated eutrophication in natural waters is a manifestation of man's age-old practice of disposing of his wastes in the most convenient river, lake, or ocean. This process, which is often referred to as cultural eutrophication, can result from the perturbation of the environment which (1) stimulates the production of algae without a concomitant increase in cropping or other loss processes, (2) stimulates certain nuisance algae to outcompete other more desirable algae, or (3) suppresses natural grazing processes. The result of extreme cultural eutrophication is an accumulation of algae which are classed as undesirable because they result in a disruption of the normal food web. The herbivores do not accept them as suitable food substitutes for the algae which have been displaced, and with advanced eutrophication the water body usually loses important finfish and shell fish populations. The resultant accumulation of algae depletes nutrients from the water, the algae become light limited, and subsequently decompose. The decaying algae are an aesthetic problem on beaches, they affect the taste and odor qualities of the water supply, and when in high populations, the bacterially mediated decomposition can result in reduced oxygen concentrations and widespread fish mortality.

Cases of cultural eutrophication have been thoroughly documented for polluted natural waters, and corrective measures have successfully reversed the development of eutrophication in some instances, primarily small freshwater lakes. However, the remedial measures for the eutrophication of large water bodies are extremely costly and the projected degree of their effectiveness is still a matter of debate. It is these problems that are currently of major importance.

The first biological indication of cultural eutrophication is a change in either biomass or the species composition of the algae, the organisms at the base of the aquatic food web. Oceanographers and limnologists are often unable to recognize such changes in the biota until they have reached fairly dramatic levels. Consequently the scientist usually becomes aware of a developed eutropic condition or a large population bloom (such as red tides or the unusual dinoflagellate dominance and dissolved oxygen depletion in the New York Bight during the summer of 1976) after it has developed. At the heart of this problem is our inability to synoptically monitor large areas for quantity and quality of algal biomass.

(b) Consumers of Results

Information regarding eutrophication in both marine and fresh waters is of great use to scientists interested in factors which regulate both biological productivity and community structure. Surveillance of the Great Lakes is currently being carried out by a joint U.S.-Canadian effort and large-scale control programs are being designed. Investigations of coastal water eutrophication in the New York Bight by the MESA program of NOAA and in the Chesapeake Bay by EPA are currently underway. NASA remote sensing data can complement these efforts and add significantly to the available data. This information is needed in order to make decisions regarding the management of pollutant inputs, fishery resources, and recreational uses of the natural waters. Academic scientists who are interested in understanding the process of eutrophication would also be major users of these large data sets of environmental parameters which influence productivity.

2. <u>What Needs To Be Measured?</u>

(a) Limitation of Existing Conventional Techniques

The parameters which must be measured are the amount of biomass in the water column, its species composition, its rate of production, numerous environmental factors which regulate productivity (light, temperature, salinity, and nutrients), and, most importantly, the time and space scales of the variability in these features. All of the above can be measured from stationary ships, and in most instances the analytical precision is adequate.

The major limitations to conventional approaches are: (1) the measurements are not all available in real time, (2) even with multiple ship operations, the restricted spatial coverage limits the ability to generalize about the overall study area, and (3) no information is available on the behavior of the study area during the intervals between sampling periods. The scales of time which are important in eutrophication can be as small as days since the organisms replicate in periods of this length. But of equal importance is the longer term view which may range from a few to several years. Spatial scales of importance range from a few to hundreds of kilometers. The observations made from shipboard actually characterize only a small volume of water, and whereas we know that we can generalize from such observations to areas of hundreds of square kilometers in the open ocean, we are limited to areas of single kilometers or less in physically dynamic coastal regions of oceans and large lakes. Large-scale variability, even in the open waters of the Great Lakes, has also been observed during intensive lake-wide sampling (e.g., during the International Field Year investigations of Lake Ontario). To a large degree, the present limitations stem from the need for spending a large part of the day on station in order to properly characterize the properties mentioned above and the transit time between stations.

(b) Feasibility and Capability of Remote Sensing Techniques

Remotely sensed synoptic sea surface temperature, light penetration, surface currents, and quantity and quality of plant pigments at a daily frequency for study areas of interest would yield the data which, when combined with shipboard measurements of the other parameters of importance, would greatly improve the understanding of this problem which is otherwise difficult. We are now at the point where the development and verification of sound models for eutrophication are essential if we are to progress, and remote sensing is a key component in such an endeavor in large lakes and coastal waters.

3. Recommendations

Of prime importance in a NASA effort to apply remote sensing to the problem of eutrophication is a solid interfacing with other governmental agencies which are conducting scientific field programs which address this problem. Such interagency limnological and oceanographic investigations would provide the proper focus in addition to the shipboard observational and experimental capabilities. They must also have a strong modeling component which would greatly benefit from synoptic data which remote sensing can generate.

NASA should also support efforts to improve knowledge of optical physics in order to further develop the potential of both active and passive sensing systems. A program to assess the degree to which existing technology can provide accurate estimates of the depth of light penetration, the quantity and quality of plant pigments in waters of different depths, and in waters with different amounts of nonplant particulate material, and other variables is required.

C. Location and Characterization of Fronts

1. Statement of the Problem

(a) Why It Is Important Scientifically and Politically

Fronts are features characterized by sharp gradients in physical and biochemical variables in aquatic environments. The length scales of fronts range from 10^2 meters for some estuarine plume fronts to 10^6 meters for some continental shelf fronts. Fronts persist on the order of hours for some tidal fronts to years for the shelf break front in the Bering Sea. Factors which interact to cause frontogenesis are not well understood; therefore frontogenesis is currently an active research area in physical oceanography. Salinity gradients associated with shelf break fronts suggest that a balance between freshwater input from rivers along the northeast coast of North America and in the Bering Sea and offshore oceanic water is important in frontogenesis. The tides are known to be a primary source of energy for frontogenesis in shelf waters around the British Islands. The M2 internal tide has been strongly implicated in frontogenesis of the Nova Scotian shelf break front. All of the evidence to date suggests that fronts may be an important site for energy dissipation on continental shelves. Research in localized, readily available sites where regular physical dynamics occur is very important in attempts to understand the dynamics of the upper ocean.

Major fisheries along the east coast of the North American continent and in the Bering Sea are associated with continental shelf fronts. Enhanced dynamics of phytoplankton and zooplankton have been reported in fronts relative to dynamics in shelf waters not influenced by fronts. Distinct pelagic and benthic food webs appear to be associated with different regions along a cross-shelf transect through several fronts in the Bering Sea shelf waters. These food webs are coupled to the fronts which are stable features throughout the spring and summer. The fronts afford specific sites in which to investigate dynamics of significantly different food webs. Factors which control nutrient input to the photic zone in fronts are poorly understood, although the M2 internal tide may drive vertical advection of water in the Scotian shelf break front.

The political significance of fronts is coupled with the tremendous biological productivity of fronts. Foreign fishing vessels are currently the primary vessels working fronts along the continental shelves of the United States. Management of U.S. coastal fisheries along the Atlantic coast and in the Bering Sea will be primarily focused on fronts in the near future.

(b) Consumers of Results

There are a number of investigations of frontal processes which would benefit now or in the next several years from application of NASA technology to location and characterization of mesoscale features of fronts. Some of these investigations include PROBES, a study of the Bering Sea funded by NSF Polar Sciences, DOE-funded investigations of the Gulf Stream front along the southeast Atlantic shelf, NMFS investigations of fronts near Georges Banks, and various smaller projects funded by NSF which are addressing front processes in the

New York Bight. NASA technology could be used to assist NMFS in monitoring the activity of fishing vessels in fronts along the continental shelves of the United States.

2. What Needs To Be Measured

(a) Limitations of Existing Conventional Techniques

Ships are the primary platforms which have been used in research on fronts, although some visible spectrum photography from light aircraft and satellites has been used to show spatial scales of fronts. Ships are obviously limited in the distance over which samples can be taken in short periods of time. This creates serious problems both in characterizing the spatial scales of large fronts and in obtaining even quasi-synoptic data sets. Large-scale motion associated with fronts is not very well known primarily as a consequence of limitations in shipboard data collection. Shelf break fronts appear to oscillate with the tides. Large-scale waves have been observed in shelf break fronts along the northeastern U.S. coast. Events of time scale 2 to 4 days appear to be important in frontolysis near canyons along the southeastern U.S. Atlantic coast. The temporal response of fronts to transient forcing events such as wind stress is largely unknown because ship scheduling is not responsive to the need to study transient events.

(b) Feasibility and Capability of Remote Sensing Techniques

Remote sensing of surface temperature, salinity, color, reflectance, and roughness would provide a set of data from which to obtain estimates of the spatial scales and near-surface dynamical features of fronts on all scales. The spatial resolution required for different variables depends on the nature of the front under investigation. For example, a resolution of 100 m would be adequate for characterizing the fronts in the Bering Sea or along the Atlantic coast of North America. Finer levels of resolution would be required for the study of plume fronts associated with the Mississippi or Columbia Rivers. The laser methods for measuring turbidity and chlorophyll now under development by NASA would allow finer resolution of features within fronts. Laser data would presumably be available more rapidly than would data collected by satellite, a consideration which is important when remote and surface data collection for real-time experiments is planned.

3. Recommendations

(1) NASA personnel should interact with investigators actively involved in frontal research so that information about front characteristics, data requirements, and actual and potential instrument capability can be exchanged in a timely manner.

(2) NASA should allocate resources to examine Coastal Zone Color Scanner (CZCS) data for evidence of fronts in locations where their existence is suspected based either on empirical or theoretical bases. This effort would determine the length scales of biologically active fronts on continental shelves

where large gradients in chlorophyll occur. Time series observations should be conducted for selected fronts to characterize the seasonal pattern of changes in frontal chlorophyll signature.

(3) NASA should interact with programs which are now addressing frontogenesis so that ground truth can be coupled with CZCS imagery in an attempt to elucidate forcing variable frequency and frontal response between periods when ships are on station. The input of NASA will be critical in attempts to understand the time scales of frontogenesis and frontolysis.

(4) NASA should continue the development of laser remote sensing instruments. Development should proceed in concert with field tests of the instruments in locations where frontal research is being performed. This would allow feedback between instrument development and application so that the laser methods are optimized for the variables of interest. When instrument reliability and performance are satisfactory, the instruments should be programmed into ongoing and planned research on fronts.