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SP 035:333:88

Chemical Variability in Ocean Frontal Areas

Results of a Workshop Conducted 19 - 22 September 1983

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CHEMICAL VARIABILITY IN OCEAN FRONTAL AREAS

Results of a Workshop conducted 19–22 September 1983
at the National Space Technology Laboratories, NSTL, Mississippi

Sponsored by the

Naval Ocean Research and Development Activity

Denis A. Wiesenburg and Dana R. Kester, Co-Chairmen

PREFACE

Between 19 and 22 September 1983, over 50 scientists met at the Naval Ocean Research and Development Activity (NORDA) to discuss issues related to the study of biological and chemical processes at oceanic fronts. A formal report of that meeting was planned, but never completed. That report would have been NORDA Report 78, and has been mentioned in some writings since the abstracts from that meeting have been cited by others. Although NORDA Report 78 was never issued, the abstracts from it have been cited often as:

Wiesenburg, D. A. and D. R. Kester. 1983. Chemical variability in ocean frontal areas – workshop results. NORDA Rep. 78. Nav. Ocean Res. and Dev. Act. NSTL, MS

In lieu of the publication of NORDA Report 78, this document has been printed to distribute the abstracts of the meeting. The abstracts are the revised abstracts submitted by attendees at the meeting and reflect the presentations made during the workshop. Included is a draft of the recommendations of the overall workshop. This draft of the meeting recommendations has not been reviewed and should be considered as preliminary. Also included is a list of the members of the four working groups and the names and addresses (during September 1983) of the workshop participants.

WORKSHOP SUMMARY AND RECOMMENDATIONS: CHEMICAL VARIABILITY IN OCEAN FRONTAL AREAS

The Need for an Interdisciplinary Approach

Investigating and understanding the chemical variability at fronts in the ocean is clearly an interdisciplinary problem. The general structure of waters at a front is often a consequence of physical factors such as very large horizontal current shear or the boundary between distinct water masses. Assessment of chemical variability must be made relative to a knowledge of the physical processes associated with the front. There are some examples of chemical fronts without an associated physical structure. Distributions of particulate matter and some metals such as iron across a continental shelf or within an estuary have shown large lateral gradients without corresponding gradients in salinity or other conservative water properties. Chemical fronts such as these in the absence of a physical front represent regions of very active chemical processes. Consequently, the integration of physical and chemical investigations is essential to identify frontal processes.

Biological factors are also important in studies of chemical variability at fronts. The special conditions prevailing at fronts, such as the slope of isopycnal surfaces, the interleaving and enhanced mixing of waters, can accelerate biological activity resulting in modification of chemical properties.

The relationship among nutrients, light intensity, and water column stability are of primary importance to biological activity at fronts. Fronts can be localized regions of upwelling in areas of the ocean that would not otherwise have the high levels of biological production and associated chemical activity of an upwelling system.

One recommendation of the workshop is that the investigation of chemical variability at fronts should be conducted on an interdisciplinary basis. While it is possible to gain some information about the physical, chemical or biological aspects of a front with strictly disciplinary methods, a much greater and more rapid increase in understanding frontal processes can be realized through an integrated, multidisciplinary approach to the problem.

Specific Processes for Investigation

The understanding of chemical variability at fronts will be enhanced through investigations of particular processes in frontal regions. Some of these processes include:

1. *Chemical fluxes at fronts* -

The transport of chemicals at fronts is an important indication of the physics, chemistry and biology occurring in these systems. There are three components of the chemical fluxes at fronts which should be identified: the cross-front flux, the along-front flux, and the vertical flux. Investigation of these fluxes will involve determinations of concentration gradients and transport velocities; it will also involve the assessment of mass budgets and the behavior of particulate phases.

2. *Non-conservative processes at fronts* -

The comparison between conservative properties, which are modified only by mixing and boundary exchange processes, and chemicals which participate in biological, photochemical and solid-solution phase exchange processes provides a means of identifying important *in situ* processes. There is likely to be an intimate relationship between primary productivity and chemical processes at fronts. Recognition of the inherent time scales associated with fronts is an important factor in identifying those chemical processes which will be of primary importance. If the residence time of waters within a frontal system is on the order of hours or tens of hours, one may exclude many chemical processes with rates that are not within this time range. Those reactions that have time scales similar to that of the front, such as redox reactions, phytoplankton growth and reproduction, and particulate scavenging, are prime candidates for producing and enhancing chemical variability at fronts.

3. *Far field effects of fronts* -

The localized effects of fronts on chemical distributions is evident, but there is the possibility that frontal systems play a major role in the larger scale chemical balance of the ocean. The frequency and extent of fronts in the ocean and the relative rates of processes in and removed from frontal systems will determine the overall importance of fronts in the chemistry of the ocean. It will be useful to make comparative investigations of the rates of processes in fronts and in non-frontal areas.

4. *Fronts as steady state or transient decay systems* -

Two different models could be used to characterize the chemical and biological interactions occurring at fronts. One would consider that the frontal system is a biological chemostat in which the fluxes of nutrients and photic energy maintains a steady state of biological activity. This may be the Eulerian view of biology and chemistry at a front. Alternatively, one may consider that organisms and chemicals are swept into a frontal system where rate processes are accelerated and then the products of this interaction fade away from the front. This Lagrangian view corresponds to perturbation and relaxation of the chemical and biological properties that have interacted with the front. It is likely that both of these models will be useful in characterizing chemical processes at fronts.

Methods of Investigation

A variety of techniques can be identified to investigate chemical variability at fronts. Some of these methods have been used by oceanographers for many years, some have been developed recently and are continuing to be refined, and others appear to be within the range of current technology, but have not yet been implemented.

Remote sensing imagery from satellites is presently emerging as an extremely valuable tool for obtaining information on near-surface ocean variability. A great wealth of information is available with lateral scales on the order of a kilometer and times scales on the order of a day. Thermal infrared sensors have been especially useful in defining the physical structure of surface fronts. Sensors in the visible range of the spectrum provide information based on pigments and particles that is more directly related to chemical and biological processes. Remote sensing should be a component of a comprehensive investigation of a frontal system, but it will have to be augmented by conventional shipboard measurements in order to investigate specific chemical and biological processes, and to extend the study of the front to depth in the ocean.

Moored and drifting sampling and measurement systems should be very useful in studies of fronts. These systems can include the measurements of currents, temperature, salinity, oxygen, particles, and particulate fluxes. These remote measuring devices should probably be deployed in conjunction with shipboard experiments, because of the relatively short time scales of frontal processes. Shipboard measurements and experiments will be required for many of the chemical and biological investigations of fronts. An important modification from traditional oceanographic studies, however, will be to use high resolution temporal and spatial sampling. Automated methods for chemical and biological measurements may be necessary to achieve the required data density. Sampling methods such as vertical and underway pumping or use of the controllable batfish platform are particularly well-suited for investigation of fronts.

Several new capabilities can be identified that would be useful in the study of fronts as well as other problems in the ocean. Controllable or programmable remote vehicles with sensors for temperature, salinity, oxygen, fluorescence and light scattering could greatly enhance the resolution of ship related measurements. The development of new sensors for chemical measurements in the sea will contribute additional capabilities for high resolution for a wide range of chemical parameters when combined with a suitable sampling system.

The Future

It was evident from the discussion of this workshop that rapid progress could be made in understanding chemical variability and processes at fronts, if a coordinated plan of research is pursued. Investigations of fronts by scientists working individually will contribute to further knowledge of frontal processes. But the scope of the work to be done is multidisciplinary and extensive; this is a problem that would benefit greatly from a long-range, multi-investigator, coordinated study. The major components of such an investigation would include: (1) satellite and aircraft remote sensing, (2) physical characterization of the frontal system and its exchange processess, (3) measurements of chemical gradients and rates for substances participating in biological, photochemical, and solid phase processes, and (4) determination of the abundance and rates of biological activity associated with a front. It is likely that there is a wide range of frontal systems in the ocean that need to be distinguished. A coordinated investigation would provide the greatest advancement of knowledge for a given investment of resources. [illegible] Marine biology Chemical Oceanography [illegible] [illegible] Salinity [illegible]

Chemical Variability in Ocean Frontal Areas

Presented at a workshop held 19-22 September 1983
Organized by the Naval Ocean Research and Development Activity

ABSTRACTS

OPTICAL VARIABILITY AND BIOLOGICAL ACTIVITY ACROSS THE ALBORAN FRONT AS MONITORED BY CZCS

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A major experiment was conducted in the Alboran Sea in October 1982, in which the optical water properties and surface chlorophyll were correlated with satellite imagery. Atlantic water inflowing at the Straits of Gibraltar forms a large anticyclonic warm core gyre in the center of the Alboran Sea. Upwelling of Mediterranean water occurs to the north of the inflowing jet and coastal waters are located along the Spanish Coast. Differences in the optical properties, surface chlorophyll, and surface temperature of these water types were observed in the Coastal Zone Color Scanner and NOAA-6 satellites.

A time sequence of satellite imagery illustrates the daily and weekly movements of the spacial frontal variability of these water masses. A cyclic pulse of coastal water from the Gulf de Cadiz through the north side of the Straits is observed as optical and chlorophyll fronts propagating along the northern boundary of the inflowing jet.

SHORT TERM VARIATIONS IN CHEMICAL AND BIOLOGICAL PROPERTIES IN AN UPWELLING FRONT OFF PT. CONCEPTION, CALIFORNIA (OPUS II)

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Oceanic fronts that occur between upwelled water and the ambient surface waters are well known for the strong horizontal gradients in chemical and biological variables. The OPUS (Organization of Persistent Upwelling Systems) program was initiated several years ago to observe the cause and effect of upwelling in an area where upwelling was well known and regular: the Pt. Conception/Pt. Arguello area off southern California. In this paper we present some of the initial results of a multi-platform observational program that took place during April-May 1983 (OPUS II).

The results of the cruises show a sequence of at least three upwelling events centered in the Pt. Conception/Arguello area. Prior to upwelling events, surface fronts were weak with little horizontal variation in physical, chemical or biological properties. With the onset of upwelling favorable winds (from the northwest) the situation changed rapidly with strong horizontal gradients in temperature (0.5°C/km), salinity (0.1 ppt/km), the nutrients (i.e., nitrate gradients of 5 μM/km observed) and chlorophyll (1 μg/L/km). The chlorophyll gradients increased with time as phytoplankton growth rates increased.

The distribution of chemical and biological variables was highly correlated with the physical structure as indicated by density distributions.

PHAEOCYSTIS POUCHETTI AND THE PRODUCTION OF DIMETHYLSULFIDE IN THE SOUTHEAST BERING SEA

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During the spring of 1981 we conducted an investigation into the relationship between biological activity and production of dimethylsulfide (DMS) as part of the PROBES (Processes and Resources of the Bering Sea) program. This area has been shown to have several discrete frontal zones caused by a combination of both physical and biological factors. Our previous work in the Atlantic had shown a strong increase in the surface water concentration of DMS in the area of the Ushant front. This fact, coupled with a strong correlation between DMS and chlorophyll, prompted us to investigate the biochemical factors influencing DMS production.

This study showed that DMS is strongly correlated with chlorophyll, but not with light intensity, nutrients or productivity (as measured by C-14 uptake). When the data is subdivided according to the frontal domain from which the sample is taken, an extremely strong correlation is found for the oceanic (stations with depths greater than 1000 m) and outer (stations with depths between 100-200 m) domains, but not for the middle (stations with depths less than 100 m) domain. Phytoplankton cell counts made for species identification showed that *Phaeocystis pouchetti* was present in samples from the oceanic and outer domains but largely absent from the middle domain. The correlation-coefficient between DMS and *Phaeocystis pouchetti* is greater than 0.9 when Phaeocystis pouchetti accounts for 30% or more of the total cell count.

ARAGONITE AND CALCITE FLUXES IN THE KUROSHIO CURRENT AND ADJACENT WATERS ALONG 165 EAST

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Free-drifting sediment traps were deployed at 7 stations between 16 and 50 degrees north along 165 degrees east in the western Pacific Ocean. Gravimetric analysis of the materials from one-day collections has been carried out for samples from 100, 400, 900, and 2100 meters. In the area of the Kuroshio Current(34-35 degrees north) there was a marked shoaling of the isotherms in the upper 1.5 kilometers. Here fluxes of aragonite and calcite were especially high at all depths and the proportions of these biogenically-produced materials were markedly different than any detected to the north or south. It is hypothesized that the fluxes of biogenic materials as well as other components synthesized, scavenged and/or released by the biosphere are different in major frontal areas such as the Kuroshio.

SCALES OF CHLOROPHYLL-A VARIATIONS IN A FRONTAL ZONE OFF THE GEORGIA COAST

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The Georgia coast is a zone of relatively high freshwater runoff, the mixture of which forms a frontal zone extending 20-30 km offshore. The resulting density structure is irregular due to complex bottom bathymetry and shoreline. We have measured the relationship of chlorophyll-a near the surface to the density structure from data acquired by alongshore and offshore transects of 20-30 km in length with space intervals of 30-35 meters.

Cross-correlations of density and chlorophyll-a reveal predominant spatial scales at 6-8 km and 1 km. Chlorophyll-a spectra from Denman show a break in slope near 1-km wave numbers. At scales greater than this, the spectra slope is approximately - 5/3. Our data show no break in slope which suggest that "diffusive" mechanisms are responsible for chlorophyll-a variability at scales greater than 1 km.

We are hypothesizing that the major scale size of 6-8 km is correlated with the scale of the undulating bottom topography. We will try to show that the interaction of the M2 tide with the complex bottom topography can result in a residual circulation pattern that accounts for this scale of chlorophyll-a variation.

REDUCED GAS GEOCHEMISTRY AT OCEAN FRONTAL AREAS

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Upper water column (<400 m) profiles of reduced gases (methane and nitrous oxide), suspended matter, biological indicators, and hydrographic parameters were obtained from 9 stations in the Eastern Tropical North Pacific ocean and 15 stations in the northwestern Equatorial Atlantic ocean aboard cruises of the USNS Desteiguer and USNS Hayes. The reduced gas distributions from these stations will be related to ocean frontal systems in the equatorial regions. Both methane and nitrous oxide displayed subsurface maxima, containing up to 3 times near-surface concentrations associated with the upper part of the thermocline. Both the Atlantic and Pacific data indicated the methane distribution was largely controlled by physical oceanographic processes, but is also apparently affected by in situ biological production. Maximum concentrations of methane corresponded most closely with the pycnocline at most of the stations studied. Methane and nitrous oxide maxima were correlated closely with fronts between tropical current systems in both oceans. Microbial activity associated with suspended particulates, possibly recycled by repetitive zooplankton grazing, is believed most likely responsible for the excess methane.

DISTRIBUTION OF NUTRIENTS IN WARM CORE GULF STREAM RINGS

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The periphery of Gulf Stream rings may be viewed as a circular frontal boundary separating the core region from the waters outside the ring. The physical, chemical, and biological characteristics of warm core Gulf Stream rings in the Slope Water region off the northeast coast of the United States were studied during a series of cruises from April through October 1982. The horizontal and vertical distributions of nutrients (nitrate, nitrite, phosphate and silica) in the water column were measured during radial transects across several warm core rings (WCR 82-B, 82-E and 82-H). The nutrient distributions in a warm core ring differ markedly from the surrounding Slope Water. The core of a warm core ring retains the chemical and physical characteristics of its source water, the Sargasso Sea, during its lifetime; the depth of the main thermocline and the nutrient maxima decreases as the ring ages. The radial symmetry of nutrient distributions in a warm core ring and interaction of entrainment features from the Slope Water with the frontal region of a warm core ring were investigated.

THE BERING AND WEDDELL SEAS' ICE-EDGE ZONES IN WINTER

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Extremely sharp vertical and horizontal fronts were observed near the marginal ice zone in the central and southeastern Bering Sea shelf in February and March, 1983. Oxygen, pH and total alkalinity profiles were obtained along several cross-sections. The results indicate that at depths shallower than 75 m, the water column was homogeneous, near freezing, and has high oxygen and pH values but low CO_2 concentration. Between 75 and about 200 m the structure was essentially two-layered with a cool, fresh, high-oxygen and high-pH layer overlying a warm, saline layer with lower oxygen and pH. The degree of oxygen saturation in the surface layer, however, was lower than the bottom layer. The transition from one layer to two layers occurred within as little as 10 miles, and the pycnocline in the two-layer structure was as thin as 10 m.

The wintertime Bering Sea results will be compared with the summer data, and with the Weddell Sea data collected in the austral winter of 1981.

HORIZONTAL TRANSPORT ALONG THE NORTH ALEUTIAN SHELF AS DETERMINED FROM THE DISTRIBUTION OF DISSOLVED METHANE

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As part of an interdisciplinary study of sediment and water transport along the North Aleutian Shelf dissolved methane was used as a quantitative tracer of mean circulation along the coastal zone. The coastal zone is unstratified by tidal mixing and is separated from the seasonally stratified waters of the Bering Sea Shelf by a front at approximately 50 m. Salinity, temperature, and dissolved methane all show gradients across the front.

The major source of methane to the coastal zone is Port Moller, an embayment along the North Aleutian Shelf. Methane, primarily associated with the freshwater runoff to the estuary, is transported to the coastal zone by tidal pumping. While the concentration of dissolved methane at the entrance to Port Moller is seasonably variable, it averages about a factor of 10 above the ambient coastal levels regardless of season. By fitting the distribution of dissolved methane to a 2-D advection-diffusion model, we estimated a mean velocity toward the east of 3–5 cm s^{-1} (depth < 50 m), which was independent of season. The trajectory and mean velocity were confirmed by moored current meters deployed during the experiment. Tidal and sub-tidal perturbations to the velocity field are not resolved by the model, hence the implied mean velocities represent averages applicable to the time scale of the methane tracer, which in this case was about one month.

The source strength of dissolved methane from Port Moller is sufficiently strong to permit the methane to be traced for 150-200 km along the North Aleutian Shelf in late summer and fall. Cross frontal transport of dissolved methane, on the other hand, appeared to be weak as the major sink for methane was air-sea exchange.

FRONTS IN RELATION TO CHEMICAL VARIABILITY IN THE PERUVIAN UPWELLING REGION

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At least three types of fronts appear to effect chemical distributions near 15°S in the Peruvian upwelling region. A front between equatorial waters and subantarctic waters exists near 15°S. The subantarctic waters have lower nutrient and higher oxygen concentrations than the more dominant equatorial waters, and intrusions of this southern water can cause marked variations in the composition of upwelling waters. We found the southern waters to be more important in July - October than during March - May.

Off Peru, the fronts that appear to mark the boundary of the coastal upwelling system are associated with high ammonium values just below the euphotic zone, and with intensification of the secondary nitrite maximum found in the oxygen deficient waters that occur between 100-400 m. We speculate that the local maxima in ammonium and nitrite found near these fronts are a consequence of enhanced sinking of organic material in the vicinity of these fronts.

Finally, significant chemical gradients appear to arise from trapped coastal waves with several day periods. We may be taking some liberties in describing these resulting gradients as fronts, but significant chemical variability is associated with the passage of these waves, and at times they appear to be correlated with intensified horizontal gradients in chemical properties. Some of the changes that we observed within the oxygen minimum zone off Peru during the passage of these waves may significantly change nitrogen pathways and turnover rates.

FACTORS INFLUENCING THE DEGREE OF SATURATION OF THE SURFACE AND INTERMEDIATE WATERS OF THE NORTH PACIFIC OCEAN WITH RESPECT TO ARAGONITE

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New data for the solubility of aragonite in seawater were used to determine the degree of saturation of the surface and intermediate waters of the North Pacific with respect to aragonite. The saturation state of these waters is largely dependent upon the carbonate ion concentration which is primarily a function of physical mixing and biological processes. Large gradients in the saturation state occur normal to the Subarctic Front in the north-south direction and across the Subtropical Gyre in the east-west direction. These gradients are primarily due to the extensive ventilation and lateral mixing that occur in the intermediate waters of the western North Pacific.

A set of dissolution experiments using freshly collected pteropods exposed to seawater collected from the upper kilometer of the water column (depths = 100 m and 400 m) was carried out with samples from the North Pacific Ocean. Significant pH increases relative to the controls were noted in all cases and led us to the conclusion that the water from both depths was undersaturated with respect to aragonite. In these experiments pH changes between 0.04 and 0.08 units were observed when the $CaCO_3$ samples (1.2 - 14 mg) were exposed to 10 mL of seawater for 27 hours. The results of these experiments with freshly collected aragonitic particles appear to substantiate the saturation calculations.

AN INEXPENSIVE MOORED WATER SAMPLER FOR INVESTIGATING CHEMICAL VARIABILITY

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Study of small and mesoscale variations in the chemical properties of sea water has been inhibited by the expense of taking time series data. With the exception of observations taken close to shore, collection of time series data on chemical variability has required considerable amounts of expensive shiptime.

We have developed an inexpensive sampling device that can collect twenty pairs of chemical or biological samples and which can be moored like a current meter. This sampler is controlled by a quartz timer that activates twenty pairs of syringes equipped with filters, one-way valves, and an appropriate preservative for the variables of interest. Sampling intervals can be varied over the hr week time scale.

Preliminary tests of this sampler have been successful, and it is currently being used to monitor chemical and biological variability off Monhegan Island, Maine. With some companion hardware, the samplers can function as their own time release mechanism and we are testing a mooring system that can be used for repeated deployments.

An array of these sampling devices could provide truly synoptic "pictures" of chemical fields in a frontal region.

NUTRIENT VARIABILITY ACROSS AN OCEANIC FRONTAL ZONE IN THE EASTERN SCOTIA SEA

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Autoanalyzer analyses for NO^{3-}, NO^{2-}, NH^{4+}, PO^{4-}, and $Si(OH)_4$ were run at sea on samples collected by CTD rosette multisampler from the surface to 200 m in the eastern Scotia Sea in January and February of 1981. Five longitudinal sections of 12-49 stations each, spaced at intervals of 10 minutes of longitude, were made between 50°W and 33°W. Within this study area, Drake Passage Water meets Weddell Sea Water in a zone of confluence. Using profiles of silicate and nitrogen species as function of density and the ratios of nitrogen to phosphate and silicate to nitrogen, we will compare the confluence of the two water masses with that determined from its thermohaline characteristics by Foster and Middleton (in press) and from its tritium signature by Michel (in press). East of about 45°W, the confluence is a zone of eddy-like structures that mix Weddell Sea Water with Drake Passage Water. Ratios of N:P and Si:N allow the two end members to be located as far east as 33°W. The interaction between mixing processes and biological regeneration and uptake on the patterns of N, P and Si observed across the zone of confluence will be emphasized.

THE EXCHANGES OF HEAT AND SALT ACROSS THE ICELAND-FAEROE OCEAN FRONT

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Hydrographic surveys conducted during the fall, 1980, north of the Faeroe Islands, reveal complex temperature and salinity variability, in both across and along front directions. Finescale interleaving, driven perhaps by double-diffusive convection, is present. Along-front current shear appears to be associated with the entrainment of anomalous "globs" of water which may be subsequently advected away. A small eddy or along-front "fold" further complicates the picture; satellite imagery and previous investigations suggest that such features are ubiquitous in the region.

Such convolutions in the frontal structure coupled with the effects of intruding tongues of anomalous water are likely to have a pronounced effect on the overall exchanges of material across the front. Estimates of the exchanges of heat and salt are made for the region studied.

EFFECTS OF FRONTAL EXCHANGE PROCESSES IN THE ANTARCTIC CIRCUMPOLAR CURRENT AT DRAKE PASSAGE

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The Antarctic Circumpolar Current in Drake Passage consists of four water mass zones separated by three fronts. Ordered from South America to Antaractic, these are designated as: Subantarctic Zone, Subantarctic Front, Polar Frontal Zone, Polar Front, Antaractic Zone, Continental Water Boundary, and Continental Zone. The time development of the circulation and dynamics of these regions are investigated using year-long velocity and temperature records obtained from twenty-two moorings deployed in Drake Passage during 1979. The primary tools for this analysis are weekly-averaged, objectively-derived maps of the stream function at 500 m and 2500 m and weekly-averaged, interpretative temperature maps at 500 m. These maps have sufficient temporal and spatial resolution to determine variability in the positions of the Subantarctic and Polar Fronts and to determine through- and across-passage development of meanders and rings, including their propagation speeds and residence time in Drake Passage. The effect of this mesoscale variability on the exchange of mass, heat and vorticity across the Antarctic Circumpolar Current is considered. Speculations regarding the effects of low frequency frontal variability on biological processes are also presented.

SOME CHEMICAL IMPLICATIONS OF PHYTOPLANKTON DISTRIBUTIONS IN FRONTAL SYSTEMS ON THE N.W. EUROPEAN SHELF

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The general characteristics of phytoplankton populations associated with tidal and shelf-break fronts to the southwest of the British Isles are described in terms of the spatial/temporal distributions of chlorophyll a, particulate carbon and nitrogen, and the major taxonomic groups. Problems of sampling are considered in relation to in vivo fluorescence properties of the algae, internal waves, and other physical phenomena shown by satellite data on sea surface temperature and ocean colour.

Various aspects of the cycling of carbon and nitrogen in the frontal regions are discussed, with particular emphasis on calcite production by coccolithophores, the transport of nitrogen through the seasonal thermocline by dinoflagellates, and remineralisation by bacteria.

WINTER-SEASON FRONTS AND EDDIES IN THE KOREA STRAIT AND SEA OF JAPAN

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The Sea of Japan is divided into two sectors, a warm sector in the south and east, influenced by the Tsushima Current, and a cold sector in the north and west, influenced by winter cooling and melting of ice. The Korea Strait provides warm, saline water in winter an a mixture of warm, saline and warm, low-salinity waters during summer and fall. The cold-air outbreaks of the winter monsoon season provide intermittently clear sky areas, extreme cooling, and mixed-layer deepening. High-resolution data from the NOAA-series satellites verify the speculation by Yoon and Suginohara (1977) that the Sea of Japan is filled with mesoscale vortices. The mesoscale turbulence observed in the SST field is nearly isotropic in the north, but is organized around the branching of the Tsushima Current and major fronts in the south. Transport of coastal water through the Korea Strait and along the northwest wall of the East Korea Warm Current has been observed by satellite- and aircraft-acquired imagery. Color aerial photography and LANDSAT data have shown plumes and boluses of turbid coastal waters detached from the Korean coast and transported offshore toward the Polar Front. Synoptic sea-surface flow patterns indicate that any massive pollution of Korea or Japanese coastal waters will, by convergence along a major oceanic front, eventually reach international fishing grounds in the Sea of Japan and North Pacific. Frequent cloud-free conditions, turbidity gradients, and the strong SST gradients along the east coast of South Korea make satellite remote sensing particularly useful for oceanographic studies of these seas.

PHYTOPLANKTON PRODUCTIVITY RELATED TO THE BERING SEA FRONTS

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The southeastern Bering Sea contains three fronts between which two different food webs occur. The outer shelf domain between the 200 m and 100 m isobaths contains a well developed pelagic food web while the middle shelf domain between the 100 m and 50 m isobaths contains a well developed benthic food web. The spring phytoplankton bloom first develops inshore of the structural front near the 50 m isobath. The bloom develops next in the middle shelf front and finally forms in both the outer and middle sheld domains. Oceanic copepods do not penetrate in large numbers past the middle shelf front into the middle shelf domain; they graze most of the diatoms in the outer shelf domain leaving a phytoplankton community numerically dominated by the haptophyte Phaeocystis pouchetti. The middle shelf domain euphotic zone contains diatoms for several weeks longer than the outer shelf domain after which the diatoms sink to the bottom. Small copepods distributed across the shelf do not exert sufficient grazing pressure to significantly reduce diatom numbers in the middle shelf domain. Enhanced phytoplankton productivity occurs in the shelf break front during the spring and early summer.

DISTRIBUTION OF NITRATE, CHLOROPHYLL FLOURESCENCE, AND PRIMARY PRODUCTIVITY ACROSS A THERMAL FRONT IN THE SANTA BARBARA CHANNEL

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A persistent thermal front is present in the eastern end of the Santa Barbara Channel. The front is the boundary between the warm California Counter Current and cold water whose source is either upwelling in the channel and Pt. Conception region, or the California Current. Two cruises were conducted in May and August of 1982 to study the nutrient and biological structure of this front. The front was located on each cruise by mapping the surface temperature distribution. The ship was then anchored in the frontal zone for the remainder of each cruise. Vertical profiles were made continuously at the anchor station using a submersible pump to sample the water column. Temperature, chlorophyll fluorescence, and nitrate were determined at one minute intervals on the effluent from the pump. Large oscillations were apparent in the temperature, nitrate, and chlorophyll fluorescence data. These oscillations, which were of tidal period, had the superficial appearance of internal waves (tides) with a 40 m vertical amplitude. Careful inspection of the data has shown them to be due to horizontal oscillations of the front, however. The frontal zone was characterized by extremely sharp boundaries. The horizontal temperature change was as high as 1.5°C across the front, which had an estimated width of 100 m. Discrete samples were analyzed for DCMU enhanced fluorescence indices, primary productivity and phytoplankton species. Strong correlations were found between these measurements and the physical and chemical environment.

UPPER OCEAN MESCOSCALE FRONTS, WITH EMPHASIS ON THE NORTHWEST ATLANTIC AND WARMCORE RINGS

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Varieties of Upper Ocean Fronts and the physical mechanisms for their formation are briefly reviewed. These fronts range from small scale river plumes to gyre scale sub-tropical and polar fronts. One key to uncovering the existence and dynamics of oceanic fronts is the observationalist's ability to synopticly map the relevant dynamical quantities. As fronts can evolve on time scales of a day, this can be a difficult task. New instrumentation must be developed and employed in order to make new advances in this field of frontal research. Some recent examples are drawn from our study of Gulf Stream warm-core rings, where we made use of an acoustic doppler current profiler. This relatively new tool allowed us to discover a highly non-linear mesoscale front in the center of a ring where none was expected.

NEAR-INTERNAL WAVE INTERACTION WITH GEOSTROPHIC SHEAR

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Near-inertial internal waves propagating in geostrophic fronts interact with the vorticity associated with the alongfront jet. These waves stall at critical-depths where the effective Coriolis frequency, which is equal to the planetary value of the Coriolis frequency plus half the geostrophic vorticity, becomes equal to the waves' intrinsic frequency. Consistent with conservation of action-flux, the wave amplifies, and its vertical wavelength shrinks at the critical-depth. Both these changes increase the shear and the likelihood of internal wave-breaking. Amplification of near-inertial waves in negative vorticity regions has been observed on the warm side of the North Pacific Subtropical Front, in a warm-core ring and on the edge of a cyclonic flow over the Caryn Seamount. Enhanced breaking could lead to higher eddy diffusivities and greater mixing at the base of negative vorticity flows. Dissipation levels 1000 times higher than usually observed in the pycnocline have been found at the base of the core of a warm-core ring.

MICROBIAL ACTIVITY AND BIOMASS IN A WARM-CORE RING

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A warm-core ring separated from the Loop Current in the Gulf of Mexico and drifted west across the Gulf. It was sampled in December 1982, along with a control station 270 km north of the ring and beyond its influence, for ATP biomass, respiration, microbial growth rate, optical transmission, and various physical parameters. The ring was warmer, had a slightly higher salinity, and a more gradual density profile down to 1,000 m, at which depth the ring and the control station were indistinguishable. Optical transmission data revealed that the control station had a much greater particulate burden than the ring did, although the ATP biomass was greater in the ring, particularly in the mixed layer. In spite of the elevated ATP concentrations, the growth rate in the ring was about half that observed for the control station, indicating a large, but relatively inactive microbial population. This difference in microbial activity could reflect the previous history of the ring, i.e. conditions in the loop current itself, or a depletion of critical nutrients by virtue of the isolated nature of the ring. The latter condition is most easily envisioned for the ring and undoubtedly occurs. However, the initial speculation, that the history of the water mass is important in governing its biological functions, can also be supported by our data for the control station.

The ATP peak observed at 800-850 m (identified as AAIW) reveals a population approximately 10 times greater than was found either above or below this peak, but the growth rate within this ATP maximum is 1/4 that found above or below it. There was no apparent density discontinuity to retard the sinking of particles in this region, and the optical transmission data show no build-up of particles in the AAIW. One would thus expect that no difference would be noted above, across and below the AAIW unless the water parcel itself exerted some influence. It appears then, that in certain situations, vertical fluxes of nutrients may play less of a role that thought in regulating microbial functions. Some water masses, including rings, may have a distinct microbiological identity determined more by what has happened to the water rather than by what is going on around or above it.

THE PROBLEM OF INTEGRATING REMOTE SENSING AND CONVENTIONAL DATA IN THE STUDY OF OCEAN FRONTS

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The physical, chemical, and biological processes taking place at an ocean front are normally interrelated. Although those relationships are not linear, a thorough understanding of the processes taking place in any one discipline quite often requires a broad understanding of the processes occuring in the others. A synoptic view of the spatial and temporal events taking place in and about the region of the front is needed for such an understanding. To a limited degree, aircraft and satellite remote sensing techniques can provide these views. The limitations are imposed by the fact that remote sensors have no direct connection with the ocean. Data collection using these techniques is limited to the utilization of the electromagnetic radiation of the ocean. However, the data are informative; and when combined with a strong program of properly integrated data collection (i.e., remote sensed in situ data) and the imagination and skill of the investigator, they can be used to bring about a broad understanding of the ocean frontal processes.

Because of the interdisciplinary nature of such programs of study, better definitions of terms are needed. Such basic questions as what constitutes a "front" varies according to the discipline and needs of the users. Horizontal and vertical definitions are needed. For example, color fronts indicating biological/chemical changes may not, for a variety of reasons, appear to coincide with thermal fronts. Since color fronts may be below the surface, the slope angle of the front becomes important. Other problems of definition abound. It is hoped that one of the results of this symposium and workshop will be a set of definitions that cross disciplinary lines and permit investigators of one discipline to maximize for his own use the information disclosed by remote sensed and conventional data sets.

COASTAL ZONE COLOR SCANNER PIGMENT OBSERVATIONS IN COASTAL WATERS OFF LOUISIANA AND THEIR RELATIONSHIP TO BOTTOM WATER HYPOXIA

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Hypoxic bottom water (< 2.5 mg L^{-1}) was found along the inner shelf (< 50 m depth) of southwest Louisiana during May - August, 1982. Shipboard measurements suggested the probable mechanism for development to be the sinking of detritus from nutrient-driven surface phytoplankton blooms into a strongly vertically-stratified water column. Areas of high pigment concentration and surface temperature derived from the Nimbus-7 Coastal Zone Color Scanner (CZCS) were linked with the hypoxic bottom water zones. Bottom water oxygen concentration and CZCS-derived pigment concentration were significantly correlated. Shrimp and finfish were found to be absent when bottom oxygen concentration was less than 2.0 mg L^{-1}.

CHEMICAL MEASUREMENTS NEAR THE ICELAND-FAEROE RIDGE

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A suite of water samples was collected in a north-south transect across the Iceland-Faeroe Ridge in September, 1980. Both surface and deep samples were obtained. These samples were analyzed for dissolved copper, oxygen, nitrate, phosphate and silicate. Water at the Arctic Front, located directly over the Ridge, was enriched in copper with respect to adjacent North Atlantic water. Lobes of water with high copper concentrations protruded into the Norwegian Sea, where copper concentrations were generally depressed. An eddy-like feature north of the Arctic Front was identified in T–S diagrams and in the copper data. The copper concentration at the eddy's core was similar to those found at the Front.

Silica data exhibit an apparent upwelling on the north side of the Faeroe Ridge. A contour map of silica in the frontal region displays some similarity to the copper contours. Nitrate and phosphate data are notably lacking in frontal detail, but exhibit anomalies in the vicinity of the eddy.

OBSERVATIONS OF GULF STREAM FRONTAL UPWELLINGS

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In situ and satellite (Nimbus-7/CZCS) observations of pigment concentrations within Gulf Stream frontal upwellings are compared. The objectives are to check the satellite estimates of concentration versus shipboard measurements in order to determine the validity of the CZCS algorithms in these waters and to extend the areal coverage of the ship survey in order to improve the interpretation of the surface circulation associated with these upwellings. The comparison consists primarily of two data sets collected in the Georgia Bight, one on April 28, 1979 and the other on April 15-16, 1980.

The 1979 event was an upwelling induced by a Gulf Stream filament (a convoluted wave) where surface pigment levels exceeded 7 mg m^{-3}. The horizontal distribution of phytoplankton in this feature was anomalous to what is believed to be the usual pattern since the highest concentrations where found in the warm tongue and not the cold core where the upwelling was actually occurring. This filament is contrasted to one observed eleven days earlier which did have the 'normal' pattern (high concentrations confined to the cold core) and to another filament which had a surface distribution 'intermediate' to the other two. The explanation for the variation in phytoplankton patterns can be attributed to differences in the entrainment of phytoplankton into the warm filament tongue. All filaments observed thus far have this 'leakage' from the cold core which is advected around the warm tongue and distributed downstream along the front. The causes for variations in the rate of entrainment has not been precisely determined, but is probably due to differences in the lateral shears within the features and in the wind fields.

The 1980 event was an upwelling unlike that associated with a filament although two filaments were present in the vicinity of this event. The surface pigment pattern was approximately 5-10 km wide, extended nearly 200 km along the front and was offshore of the filaments, but clearly associated with the front. It is shown that the feature was connected to the subsurface chlorophyll maximum within the Gulf Stream and had a structure identical to what is expected along a current meander (a small amplitude frontal wave). Zones of frontal convergence and divergence along a wave occur because of changes in frontal curvature. This feature propagated downstream at a faster velocity than the two filaments.

The satellite data clearly indicate that upwellings are common along the front and that the primary productivity resulting from them make a major contribution to the total production of the southeastern continental shelf. It is also clear that shipboard sampling of these features must be complemented with satellite coverage because of the transience of these upwellings.

RADIOISOTOPE TRACERS AND OCEAN FRONTS

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The radium isotopes offer promise in measuring exchange across ocean fronts. ^{228}Ra with a half-life of 5.7 years may be used to study processes on a 1 - 20 year time scale while ^{224}Ra with a 3.64 day half-life gives resolution of 10 - 100 hours. Strong source functions in estuarine and coastal waters for these isotopes produce steep gradients off shore. Such gradients may be interpreted in terms of mixing and decay. In this paper I present some of the first measurements of ^{224}Ra in estuarine and coastal waters and discuss aspects of its geochemistry which confuse its use as a conservative tracer. The fact that ^{228}Ra and ^{224}Ra are isotopes in the same decay series places strong constraints on their source functions. Further work should lead to a resolution of the ^{224}Ra source function which in turn should lead us to a clearer understanding of the physical and chemical processes which regulate the distribution of other chemical species in these waters.

RADON-222 SURFACE WATER EXCESSES: INDICATION OF RECENT CONTACT WITH SHELF OR SLOPE SEDIMENTS

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Several rings, including 81-D, 81-G, 82-B, and 82-H, have been surveyed in conjunction with the warm core rings program. Mixing processes in and around these rings were characterized using the radioisotopes radon-222 and radium-226. Normal open ocean radon profiles show deficiencies at the surface but approach equilibrium values at some depth in the mixed layer. In many cases, classical surface profiles were observed allowing an estimate of the intensity of air-sea gas exchange. However, a large number of typical surface profiles were noted throughout the ring and its boundary region: these profiles showed radon-222 concentrations in excess of their radium-226 equilibrium values. Substantial excess surface radon concentrations as high as 70% greater than their radium supported values can be seen in the upper 250 meters of ring center. Typical high radon concentrations reach 12 dpm/100 liters with the standard radium-226 supported value no higher than 10 dpm/100L. These surpluses appear to extend as deep as 600 meters in some cases.

The upper limit of radon-222 measured in both the Gulf Stream and Sargasso Sea was 10 dpm/100L. Radon-222 concentrations up to 36 dpm/100L are found in the shelf water adjacent to the rings while values as high as 25 dpm/100L are observed in the slope water bordering the rings. The shelf and slope waters provide the only logical source of excess radon-222. Near-surface radon surpluses disappear quickly due both to decay (3.8 day half-life) and escape to the atmosphere. The significant surpluses found in warm core rings indicate a recent penetration of shelf and slope waters into the ring center region. Using radon-222 surpluses as a clock, estimates of time elapsed, since movement of the waters off the shelf until incorporation into ring center, yield values on the order of one week.

OPTICAL AND PARTICULATE PROPERTIES AT OCEANIC FRONTS

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Distributional patterns of optical and particulate properties observed at various ocean fronts are presented. Characteristic optical properties of the water types associated with the fronts are examined to describe physical, optical and biological processes. These processes are closely related with the effects of the front. These processes are different on either side of the fronts and through these processes frontogenesis can be better understood. Fronts observed in coastal upwelling region have shown strong contrasts in optical and particulate properties in addition to variations in distributional patterns. The contrasts associated with fronts in the open ocean were smaller than those in coastal fronts and a higher accuracy of measurements is necessary to detect smaller signals.

TRANSIENT RESPONSES OF SEABIRDS TO FRONTS IN THE SOUTHEASTERN BERING SEA

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The evidence that fronts attract marine vertebrates (fish, snakes, birds, mammals) is largely anecdotal. Significant enhancement of numbers at a front relative to adjacent waters has been demonstrated only once to date. We measured seabird densities at three fronts in the southeastern Bering Sea: a shelf-break front, a middle shelf front associated with the 100 m isobath, and a shallow sea front near the 50 m isobath. The shelf-break and inner shelf fronts attracted birds. Counts were significantly higher at these fronts than in adjacent waters on 9 out of 31 crossings. There were no instances of significantly lower counts at these two fronts. The middle front marked a discontinuity in bird density. The average count was higher at the middle front than landward of the front in 88% of the 16 crossings. Counts on the seaward side were lower than at the front in half of the 16 crossings, higher in the other half. The effect of fronts on birds was transient. At a time scale of a day (individual crossings), 39 out of 63 crossings of the three fronts were significantly higher at the front, 2 were significantly lower. Levels of explained variance ranged from 0 to 99%. At the time scale of months (all counts combined), significant effects occurred only at the middle front. Explained variances ranged fron 0 to 14%. Favorable conditions evidently occur too infrequently to cause a permanent elevation in the density of birds. Maximum carbon flux at the inner shelf front was calculated at 65 mg-C m^{-2} day^{-1}. Maximum guano production was calculated 40 mg (dry) m^{-2} day^{-1}. Sinking rate of fresh guano under field conditions was 1 m min^{-1}.

SATELLITE OCEANOGRAPHY AND CHEMICAL FRONTS IN THE CALIFORNIA CURRENT AND COASTAL UPWELLING ZONE

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Chemical fronts are observed in the California Current and Coastal upwelling zone as sharp nutrient gradients associated with current boundaries, eddies, upwelling systems and dynamic features in the "mixed layer". Chemical fronts which form during upwelling play a major role in the biogeochemistry of this region. Development of upwelling systems is related to seasonal changes in atmospheric pressure and wind fields. Following the spring equinox the North Pacific subtropical high moves northward and strengthens while a thermal low develops in the interior of southern California. Mean monthly surface

wind stress reaches a maximum over the California Current and moves northward on a seasonal time scale. Typically cold, nitrate- and phosphate-rich waters upwell at the coast from depths of tens to hundreds of meters to form cyclonic and anticylonic systems in the coastal zone or flow seaward in a broad irregular band or as surface streams which extend several hundred kilometers or more across the California Current. These features are generally 2 to 5°C colder than the nutrient-poor oceanic surface water and are clearly visible in satellite infrared images. While existing coastal upwelling theory is unable to predict upwelling distributions or details of upwelling circulation, satellites show that this large scale redistribution of nutrients is important in determining the distribution and production of primary biomass. Nutrients and chlorophyll have been mapped by calibrating satellite images. When viewed together they show that phytoplankton pigments are concentrat along frontal boundaries. The growth of plant cells in these gradients may be explained by a "chemostat effect". The long range objective is to develop a prognostic biochemical model of oceanic fronts, which can be coupled to satellite remote sensing. Three dimensional mapping experiments are in progress to relate subsurface structure to satellite imagery. Discovery of a chlorophyll maximum associated with downwelling of the surface layer and its expression in satellite imagery has turned our attention to dynamic structures in the mixed layer as sites of nutrient renewal and primary production. An atmospherically coupled turbulent boundary layer model has been adopted as a frame work to interpret relationships between dynamic variability, nutrient entrainment, and production in the surface ocean.

HPLC MEASURED CHLOROPHYLL AT OCEAN FRONTAL AREAS

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During a cruise on the USNS Hayes (1982) off of the southern coast of Brazil a frontal feature was found in the upper 200 meters some 100 kms offshore. Chlorophyll and phaeopigment concentrations were measured using standard fluorometric and HPLC methods. Comparison of the results of fluorometric and HPLC determination of chlorophylls showed that the fluorometric method underestimates (45%) total chlorophyll concentrations. This underestimation was variable among stations (12% to 84%) and is dependent upon the contribution by accessory chlorophylls (b & c) to total chlorophyll concentration. The frontal feature had higher mean integrated chlorophyll concentrations (0.127 mg m^{-3}) than the surrounding waters (0.050 mg m^{-3}). The highest mean integrated value (0.223 mg m^{-3}) was found just west of this frontal feature where a mixture of coastal and tropical water masses occurred. Another high chlorophyll area was found north of the feature overlying a steep thermal gradient at 1200 meters.

ESTIMATED APPARENT CROSS-FRONT EDDY DIFFUSIVITIES BASED ON SUSPENDED ALUMINUM DISTRIBUTIONS

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Distributions of suspended aluminum in the vicinity of a near-shore coastal front repeatedly showed dramatic exponential seaward declines in concentration. These systematic decreases in concentration were used in a one-dimensional horizontal transport model to estimate apparent cross-front eddy diffusion coefficients. Concentration gradients of a number of constituents measured across the front were used in conjunction with estimated apparent cross-front eddy-diffusion coefficients to calculate their seaward fluxes out of the near-shore zone. Where possible these fluxes were compared to their known fluxes into the near-shore zone from adjacent rivers and estuaries. Agreement between the two fluxes were often good. Significant differences between input and outputs were attributed to and consistent with periods when deviations from steady-state conditions were known to occur.

CHEMICAL VARIABILITY IN THE LOUISIANA COASTAL BOUNDARY LAYER: SPRING 1982

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Time series of current, temperature, and salinity were collected near the boarder between Texas and Louisiana in early 1982 when the Atchafalaya River was in flood. These data are complemented by data from four hydrographic cruises that measured temperature, salinity, dissolved oxygen, chlorophyll, nitrate, silicate, phosphate, and ammonia.

During the course of the spring flood, the following series of changes occurred. Inner-shelf currents increased toward the west. The salinity of the coastal boundary layer decreased by nearly 50%. The front separating this layer from the mid-shelf waters intensified accordingly. Chemical species within the boundary layer also underwent significant variations. Phosphate *distribution* was least affected by the front, whereas chlorophyll and silicate distributions mimicked the density distribution.

ONE DIMENSIONAL MODELS FOR PREDICTING NUTRIENT AND PLANKTON PRODUCTIVITY IN OCEAN FRONTS

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Can the enhanced abundance of phytoplankton observed in frontal regions be explained in terms of a one dimensional interactive model of light and nutrients? To answer this, I have treated a stabilized water column to steps of penetrative mixing which change the distribution of nutrients and temperature throughout that water column. The assumption is that enhanced productivity of frontal regions is due to nutrient replenishment, and hence becomes a region of high phytoplankton growth. The model agrues that as mixing deepens and the front is formed, the mean content of nutrients increases in the euphotic zone. Therefore, in combination with downwelling light, productivity is augmented. The model shows that the rate of change in temperature crossing the front will be different from the rate of increase in nutrients crossing the front. This change is largely due to the variation in the temperature and nutrient distribution in the parent stabilized water columns. By varying conditions in parent water column, one describes a seasonal sequence of nutrient temperature relationships and resulting productivity. The model is a prediction of the optimal mixing conditions that will satisfy the light and nutrient requirements.

VARIABILITY IN PRIMARY PRODUCTION IN RESPONSE TO DISTURBANCES OF THE LOOP CURRENT AND GULF STREAM FRONTS

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Meanders and eddies along the cyclonic Gulf Stream and Loop Current fronts cause nutrient-rich waters to episodically upwell and intrude onto the southeastern and southwest Florida continental shelves. This upwelling process is the major source of "new" nutrients for the outer southeastern continental shelf and may be an important source for the southwest Florida shelf as well. Phytoplankton "bloom" within upwelled waters in both regions, although the response appears to be more dramatic on the southeastern than on the southwest Florida shelf. Results from both regions are compared and discussed in relation to recent hypotheses concerning the possible importance of continental shelf primary production as a major biotic sink of the global CO_2 cycle.

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UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS None
2a SECURITY CLASSIFICATION AUTHORITY 2b DECLASSIFICATION/DOWNGRADING SCHEDULE	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
4 PERFORMING ORGANIZATION REPORT NUMBER(S) SP 035:333:88	5 MONITORING ORGANIZATION REPORT NUMBER(S) SP 035:333:88
6 NAME OF PEPFORMING ORGANIZATION Naval Ocean Research and Development Activity	7a NAME OF MONITORING ORGANIZATION Naval Ocean Research and Development Activity
6c ADDRESS (City, State, and ZIP Code) Ocean Science Directorate Stennis Space Center, Mississippi 39529-5004	7b ADDRESS (City, State, and ZIP Code) Ocean Science Directorate Stennis Space Center, Mississippi 39529-5004
8a NAME OF FUNDING/SPONSORING ORGANIZATION Naval Ocean Research and Development Activity 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code) Ocean Science Directorate Stennis Space Center, Mississippi 39529-5004	10 SOURCE OF FUNDING NOS PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT NO

11 TITLE (Include Security Classification)
Chemical Variability in Ocean Frontal Areas

12 PERSONAL AUTHOR(S)
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13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Yr., Mo., Day)	15 PAGE COUNT
Final	From ______ To ______	July 1988	25

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB GR	oceanic fronts, chemical fronts

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Between 19 and 22 September 1983, over 50 scientists met at the Naval Ocean Research and Development Activity (NORDA) to discuss issues related to the study of biological and chemical processes at oceanic fronts. A formal report of that meeting was planned, but never completed. That report would have been NORDA Report 78, and has been mentioned in some writings since the abstracts from that meeting have been cited by others. Although NORDA Report 78 was never issued, the abstracts from it have been cited often as:

Wiesenburg, D. A. and D. R. Kester. 1983. Chemical variability in ocean frontal areas – workshop results. NORDA Rep. 78. Nav. Ocean Res. and Dev. Act. NSTL, MS

In lieu of the publication of NORDA Report 78, this document has been printed to distribute the abstracts of the meeting. The abstracts are the revised abstracts submitted by attendees at the meeting and reflect the presentations made during the workshop. Included is a draft of the recommendations of the overall workshop. This draft of the meeting recommendations has not been reviewed and should be considered as preliminary. Also included is a list of the members of the four working groups and the names and addresses (during September 1983) of the workshop participants.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ■ DTIC USERS ☐	21 ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a NAME OF RESPONSIBLE INDIVIDUAL NORDA Classified Library	22b TELEPHONE NUMBER (Include Area Code) (601) 688-4868	22c OFFICE SYMBOL Code 125

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE

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