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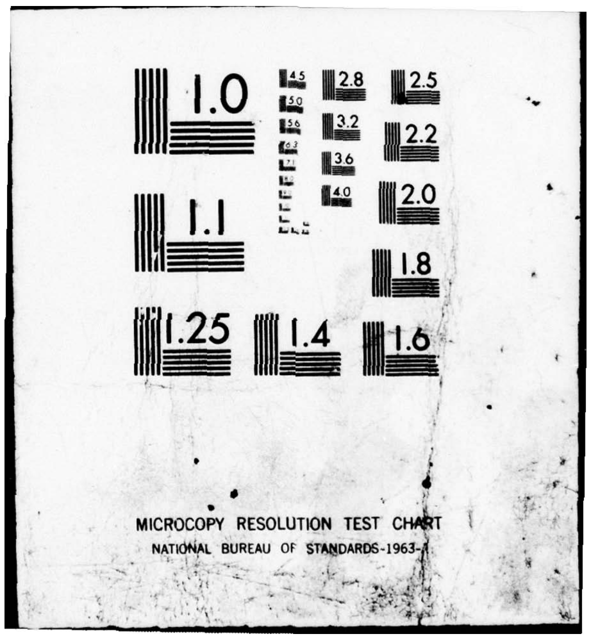
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This report presents a summary of work sponsored by the Physical Oceanography Program (Code 481), Office of Naval Research, Ocean Science and Technology Detachment, covering the FY 79 period. It includes a brief description of (1) the status of research for each of eleven different areas of physical oceanography, (2) each of the four multi-investigator, multi-institutional, and multidisciplinary projects which ONR 481 jointly sponsors, (3) each of the 79 individual projects which ONR 481 sponsors, and (4) all referred journal articles appearing during FY 1979.

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PHYSICAL OCEANOGRAPHY PROGRAM

(ONR Code 481)

REPORT FOR FY 1979

CDR Robert G. Kirk, USN	Program Director
Dr. Louis Goodman	Scientific Officer
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OCEAN SCIENCE & TECHNOLOGY DIVISION

OFFICE OF NAVAL RESEARCH DETACHMENT

NSTL STATION, MISSISSIPPI 39529

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SECTION I--INTRODUCTION

Once again, the Physical Oceanography Program (Code 481) of ONR's Ocean Science and Technology Detachment presents a report of our current science effort: a compilation of those research efforts currently being funded by Code 481, written by the individual Principal Investigators. It represents how we view our program objectives in terms of science, and is a measure of our program effectiveness.

The objective of the Physical Oceanography Program is to improve our understanding of those open-ocean physical processes which are of fundamental scientific importance and which impact on present or potential Naval operations. It is a mission-oriented program, and it assumes that such an improved understanding will better enable the Navy to use the ocean environment to its own advantage.

It must be emphasized that, even though the Code 481 program is mission oriented, research efforts must be, first and foremost, of fundamental scientific importance and results of these efforts must appear in the open and refereed scientific literature.

Code 481 maintains a balanced effort across the field of physical oceanography covering descriptive, analytic, and modeling; upper ocean, volume, and bottom boundary layer; and to developing new tools such as remote sensing and synoptic instrumentation--in other words, all those aspects which may be of use to the Navy. Over the last few years, the program has focused more on upper ocean questions which we consider to have high Navy priority, as well as being some of the most interesting, and toughest, scientifically. In a world of finite resources, in order to be able to adequately support the higher program priorities, we are generally staying away from near shore, equatorial, and Southern Hemisphere support. We intend to maintain a viable, sea-going, scientifically sound program in chosen priority fields, rather than sub-critical support spread across the board.

We appreciate the effort of all the P.I.'s whose work make this volume possible and who continually help us with advice, briefing materials, and tutoring. A special thanks to the authors of the scientific area summaries and project summaries which help to give perspective to the view of the individual investigations.

SECTION II---AREA SUMMARIES

The Bottom Boundary Layer

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The past years have seen accelerated investigation of the oceans' bottom boundary layer. With this activity has come recognition of this layer's importance to oceanic mixing, both vertically and horizontally of properties such as heat, salt, chemical tracers, and sediment. Bottom boundary layers are also a major source for finestructure and microstructure found within the interior water column.

On a flat abyssal plain, bottom boundary layer structure as indicated by signatures in the density, sound velocity, temperature, salinity and particle distributions, is dominated by $\sim$ 10 km long patchiness. These patches have a vertical scale of 10-50 m. Immediately above this layer, often other mixed layers are found. It is now apparent that these layers have come along their respective constant density surfaces from other bottom mixed layers. Similarities exist among planetary boundary layers: As an example, a benthic front, similar to fronts seen in the atmosphere and ocean surface mixed layer, has been recently found.

In the presence of topography, such as seamounts, ridges, and continental rises, less is known. Evidence exists that mixed layers formed at topography separate from the topography and are carried into the interior fluid. The horizontal scales of $\sim$ 1 km for these mixed structures is shorter than those formed on abyssal plains.

Details of bottom generated turbulence, and resultant response of the sediment, will be investigated by the ambitious HEBBLE project (Williams, Wimbush). Understanding of bottom turbulence will benefit also from progress made by the fluid dynamics turbulence community; coherent, describable, structures are now recognized as fundamental to practically all turbulent flows.

The measurement of fluctuating velocity fields is in itself a difficult instrumental problem; the job of distinguishing from these measurements the wave motions and the turbulence is yet more difficult with information about the fluctuations alone. An important distinguishing property of turbulence is its capability to mix dynamically passive contaminants such as decaying tracers. The distribution of tritium in the Western Boundary Undercurrent is direct evidence of the southward penetration of fluid that lay near the ocean surface more recently than 20 years ago (Rhines and Jenkins). The presence of radon, with a half life of four days, in mixed layers seen above the bottom in GEOSECS profiles, is also direct evidence of the recent boundary origin of these layers. Cooperation with geochemists will be important in the future for understanding ocean mixing both at the bottom boundary layer and in the interior water column.

Important questions still remain unanswered. No detailed studies have as yet been undertaken in the neighborhood of rough topography such as seamounts. From signatures in temperature, salinity, and particulate matter distributions made downstream of such features, their importance to oceanic mixing has been inferred. The fate and evolution of the mixed layers formed at the bottom boundary layer as they are carried into the interior water column is also not well understood.

For more details concerning the bottom boundary layer see the sections of Armi, Rhines, Williams, and Wimbush.

DESCRIPTIVE PHYSICAL OCEANOGRAPHY

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Descriptive studies of the circulation of the world ocean are being pursued now more vigorously and on larger scales than at any time in the past, though the number of investigators is small. We have at hand the general nature of abyssal thermohaline flow, some principal features of the near-surface flow, and the concepts of geostrophy and western boundary currents as a framework, and investigators in descriptive oceanography are implementing these in studies at various depths in all of the world's oceans except the Arctic. In particular, the mid-depth circulation--the range between 1000 m and 3000 m is being addressed. Earlier studies had usually dealt with the near-surface or the abyssal flows, and the mid-depth flow had appeared only in calculations of total top-to-bottom transport.

The North Atlantic Ocean has received the greatest amount of attention. McCartney is dealing with the density structure, mixing, and overturn, leading to the formation of North Atlantic Deep Water within the Labrador Sea, along the axis of the subarctic gyre. Joyce is examining the front-like transition between the Mediterranean Outflow Water and the surrounding colder and less saline water in the vicinity of the Mid-Atlantic Ridge. The relation of the flow and mixing processes at mid-depth (1000-1500 m) to the Ridge (about 3000 m), when determined, may bear upon circulation problems in many other areas.

Worthington is pursuing the seasonal and year-to-year variation of the strength of the Gulf Stream in terms of mixed-layer depth changes resulting from summer-winter and winter-winter heat differences. He has presented evidence that the Gulf Stream is stronger in late winter than in summer and strongest after a severe winter. He hopes to apply this concept to the other major currents of the world. Broks is making direct current measurements in the waters that flow into the Caribbean and form the Florida Current in their outflow, and finds a quasi-geostrophically balanced inflow with substantial variations of both tidal and nontidal time-scales.

A program of moored arrays (carried out by Fofonoff, Schmitz, and Luyten) is studying the general circulation of the North Atlantic over a wide time- and space-scale. This group, working with investigators, is capable of measuring currents and temperature at fixed positions and depths over long periods of time. Its record in the recent programs is excellent. Immediate plans are to measure the Gulf Stream for a year, in the area where it divides into a northward flow (the North Atlantic Current) and a southwestward flow (the Gulf Stream Return Current).

In the Indian Ocean, Warren is studying the overall deep circulation, in particular the dynamics of the deep western boundary currents. He has found such deep equatorward currents just east of Madagascar, in the Madagascar Basin, and just east of the Ninetyeast Ridge, the western edge of the West Australia Basin. Reid is studying the circulation at shallower depths (2000-2500 m), in particular the intrusion of the upper part of the saline layer that has come into the Indian Ocean south of Africa from the Atlantic Ocean.

The Antarctic circulation, and its exchange with the basins just to the north, particularly the Argentine Basin, are being investigated by Reid. In addition, he has demonstrated in the Atlantic and Pacific that the large anticyclonic gyres of subtropical zones shift poleward at greater depths.

We are limited in our progress by at least two difficulties. The first, obviously, is that this is a complex field of study, not yielding itself usefully to the sort of simplifications commonly used to make the theoretical and numerical models tractable. Finding out what is going on in the ocean, rather than what might go on under certain assumptions, is a difficult job. The other major limitation is the small quantity of first-rate data in some of the critical areas. These holidays in the data bank are being filled in carefully and well, but the rate of progress is slow. Only a few of the institutions have the capability now of doing this work with sufficient accuracy, and the number of research vessels capable of doing deep-sea work in the critical areas of the open ocean in high latitudes and in winter is small and appears to be decreasing. Lack of ships could become the most severe limitation in the study of worldwide subsurface circulation.

The present lines of investigation seem well worth pursuing. Distribution of characteristics, geostrophic shear, and direct measurements of flow seem to be the most powerful techniques, and they have not yet been fully exploited. If the present rate of data collection continues, and the number of ships and investigators remains the same, our understanding of deep and abyssal flow will grow steadily but slowly.

INTERNAL WAVES

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We are still working on the problems of where does internal wave energy come from, where does it go, and what does it do? Progress has been marginally forward on some aspects, somewhat backward in others.

Where Does Internal Wave Energy Come From?

The concept of internal waves as a viscosity against which the large-scale flow must work, thus energizing the internal wave field and dissipating the large-scale flow, has now been tested in several cases in the ocean and shown to be not nearly as strong (i.e., not as important) as predicted theoretically.

Meanwhile, two opposing views of internal wave generation by interacting pairs of surface waves have been presented: one, which yields a substantial energy flux to internal waves, supposes that the surface waves and the internal waves remain phase-locked during the growth process, while the other view, which yields only a small energy flux to the internal waves, supposes a quite random picture of the phase relations. These ideas are not yet tested experimentally.

We may discover that the internal wave field is exceedingly eclectic, that in fact it is both capable and willing to accept energy from a large variety of sources, such as wind stress, surface waves, mixed-layer turbulence, bottom roughness, current shear, etc. Which is prominent in any instance would probably depend on their relative strengths and on the character of the energy deficits in the internal wave field, which in turn must depend on the kinds of dissipative processes at work and on the energy redistributive processes (non-linear interactions) within the field.

Where Does Internal Wave Energy Go, and What Does it Do?

The abstract idea of a "breaking" internal wave may have outlived its usefulness. It is difficult to reconcile even a breaking surface wave with a particular wave component in the spectrum, and even more difficult for an internal wave spectrum; the picture of internal surf rolling over and crashing (albeit slowly) against an isopycnal surface is quite inapplicable.

Instabilities due to shear are likely mechanisms to dissipate internal wave energy and produce mixing in the vertical - this is a conversion of internal wave energy into potential energy of the mean state - but such instabilities probably occur at localized regions in space that are defined by the random superposition of shears provided by the many wave components present. In this case, it is not a "wave" breaking but rather a flow instability that simply affects the waves present.

The tendency for a wave component to overturn when the particle velocity exceeds the phase velocity does contribute to the breakdown of an internal wave field, but probably not very often. However, this effect can enhance the tendency for a shear instability to occur. It therefore may be that just as the internal wave field is eclectic in its sources, it is unpredjudiced in its sinks.

Whatever the sink mechanism, the consequence is vertical mixing. Based on recent measurements, the amount of mixing does not seem to be very large although it may be the major vertical mixing that is taking place. (The rest of the required mixing for a global heat balance could be due to horizontal mixing along sloping surfaces, thus giving a virtual vertical mixing.)

What are the Outstanding Problems?

ONR-supported investigators are working on the problems outlined above, especially the source and sink descriptions. Since upper-ocean internal waves are closely-coupled to direct atmospheric forcing, the simultaneous description of the internal wave and the atmospheric fluctuations is a difficult but productive area; MILE and JASIN results are contributing to this understanding.

Joint internal-wave and fine/microstructure work is needed to understand both subjects more fully, but such experiments are awkward to design and delicate to perform.

In general, the greatest need in internal wave research now is acquisition of quality data from situations that will provide clues as to the interplay of the various possible sources and sinks; this inherently demands broad experimental programs that monitor the relevant source processes and study concurrently the small-scale processes affected by the internal waves.

LARGE-SCALE AIR-SEA INTERACTION

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In response to energy received from, or through the atmosphere, complex patterns of circulation and density develop in the ocean, transporting the water and its properties from place to place. In physical oceanography, one seeks to understand these circulation and density patterns in terms of physical and dynamical principles. Oceanographic investigators in large-scale air-sea interaction attempt to identify and understand oceanic features which are directly attributable to atmospheric forcing, and which have horizontal dimensions comparable to the size of entire ocean basins.

In recent years, considerable advances have been made through large-scale air-sea interaction studies, both in the tropics and middle latitudes. Among the most significant advances, many of which were supported by ONR, are the following. A new theory for the formation of El Niño involving the ocean's dynamic response to remote atmospheric forcing was established and later confirmed through numerical model simulation and advanced statistical data analysis. Theoretical and numerical model studies of equatorial ocean basins have helped to identify mechanisms important for the development of the Somali Current and have clearly demonstrated the general importance of remote changes in atmospheric forcing in the tropics brought about by the propagation of equatorial waves. In middle latitudes, the large-scale thermal structure of the central North Pacific Ocean has been observed continuously for nearly four years by a ships-of-opportunity program and theoretical investigations with the data are beginning to provide answers to important questions about the dynamics of the observed variability. Preliminary results indicate that, in contrast to the situation in equatorial regions where, due to the propagation of equatorial waves, remote atmospheric forcing is crucial, in mid-latitudes, local atmospheric forcing seems to be the more important mechanism. The oceanographic importance of air-sea exchanges of heat, moisture and momentum due to synoptic weather disturbances has recently been reemphasized in a number of mid-latitude studies. In addition, the possible importance of such disturbances for the generation of persistent or low-frequency (weeks-months) temperature fluctuations has also been identified.

As a result of the above studies, the following admittedly simplified, general picture of large-scale air-sea interaction emerges. Oceanic variability in tropical and equatorial latitudes can sometimes be explained solely in terms of local atmospheric forcing, but the existence and propagation of equatorial waves, along the equator and poleward along the eastern coasts, make remote atmospheric forcing an important mechanism also. In such a case, atmospheric events over one part of the ocean can produce an oceanic response a considerable distance away. Oceanic variability in middle latitudes seem to be more strongly controlled by local atmospheric forcing, particularly that due to synoptic disturbances. The ocean's response is not uniquely determined by the atmospheric forcing, however, because the response also depends on the state of the ocean at the time the forcing occurs. These results of large-scale air-sea interaction studies have an important bearing on the kind of monitoring and prediction system that could be effective in a given region.

In spite of the above progress in understanding the effects of large-scale air-sea interaction, a number of important questions must be addressed in the near future. Because of the demonstrated importance of local atmospheric forcing in middle latitudes, and the particular importance of forcing by synoptic weather disturbances, more attention should be given to the effects of such disturbances in the future. There are at least two major problems involved in such an endeavor. The first problem is the formidable difficulty in taking oceanographic and meteorological observations during high wind and sea conditions. The second problem is the large number of observations, in space and time, which are needed to adequately describe synoptic scale disturbances and their three-dimensional effect on the ocean. Effective and economical methods of obtaining the required observations should be developed, however, if we are to continue to make progress in understanding the effects of large-scale air-sea interaction.

MESOSCALE EDDIES

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The term "mesoscale eddies" is commonly used to designate oceanic motions which generally occur throughout the water column from sea surface to bottom and are characterized by horizontal spatial scales from tens to hundreds of kilometers and time scales from tens to hundreds of days. These motions constitute the internal "weather phenomenon" within the oceans and are, in fact, often referred to as "synoptic scale" motions in analogy to their dynamical counterpart in the atmosphere. The very low frequency end of the spectrum is designated the secular scale. Mesoscale eddies are known to be very energetic and at any moment a significant part of the flow in the world ocean is dominated by eddy currents of various synoptic types including intense current meandering, associated ring structures, and mid-ocean eddies. Properties of the eddy field, viz, synoptic type, characteristic scales and amplitudes and higher order statistical quantities (Reynolds stress, heat transport) vary geographically, influenced by environmental factors such as boundaries, topography and strong currents. This geographical variation can occur over short distances, i.e., the field is spatially statistically inhomogeneous and energy levels can vary by an order of magnitude in a few hundred kilometers. Relatively strong energy levels and a smooth flat sea bottom tend to inhibit the variation with depth of the horizontal velocity.

The eddy phenomenon is diverse and there is a range of dynamics and a variety of causes, most of which are not known, for various eddy types and for various regions of the ocean. The origin of mid-ocean eddies has not been established but direct production in the open ocean by atmospheric forcing or local energy conversions (instability mechanisms) is unlikely. Strong current regions (e.g., the Gulf Stream and its recirculation) which spawn rings also produce eddy energy by subtler processes of conversion from mean kinetic and potential energy (baroclinic and/or barotropic instability). Such source regions export eddy energy to the mid-ocean. Topography is thought to affect transmission and also to provide the possibility of primary production. Knowledge of the eddy field is of obvious dynamical importance in its own right where it is the dominant flow. Eddy/mean field interactions also occur which can directly or indirectly be fundamental to the general circulation. Synoptic details of the mesoscale eddy field are of importance for studies related to the forecasting of ocean currents and the influence of the mesoscale on acoustic phenomenon, dispersion mechanisms and biological processes. Statistics of the mesoscale eddies are necessary for studies related to the general ocean circulation, to climate and its variability, and to the influence of ocean currents on geochemical and nutrient distributions. To achieve an understanding of mesoscale eddies, to summarize our knowledge and to apply it requires special purpose (numerical) models. Most of our knowledge of the mesoscale phenomenon has been gained in recent years through dedicated and intensive experiments, novel model construction, and the re-examination of historical data in the light of new insights. Although progress has been excellent much more remains unknown than the known and a continued research effort now is essential and should reasonably be expected to provide significant advances.

New experiments and observational results in the North Atlantic are beginning to provide a description of the population and distribution of rings and of the kinematics of their motions and interactions (Gulf Stream Experiment). European scientists are observing the kinematic properties of the eastern North Atlantic (NEADS), NORPAX studies have documented mesoscale (and secular scale) phenomenon in the North Pacific; the Antarctic Circumpolar Current is emerging as a production region (ISOS). The largest recent experimental effort has, however, been carried out within the POLYMODE (US-USSR) program in the western North Atlantic. The field program including intensive local dynamical synoptic and extensive statistical geographical components is essentially concluded. Long time series, synoptic maps of a block of ocean for over a year (new small strong baroclinic features were discovered) and other dynamically and statistically interesting measurements were and are being obtained. New instrumentation included an Absolute (acoustic) Velocity Profiler, and long lived SOFAR floats tracked by moored Autonomous Listening Stations which now extend the region in which floats can work.

A major task for the present and the near future is the analysis, interpretation, and synthesis of this new data set. Models, used in the design of the experiment will be further developed during their use in the interpretive phase. The construction of numerical models with sufficiently high horizontal resolution to resolve mesoscale eddies is a major accomplishment of the past few years; present progress is occuring in the areas of theory and analysis of numerically simulated flows, model-model intercomparisons, model-data intercomparisons, and the incorporation of additional important processes (topography, forcing functions, boundary conditions). The interpretation of these new results should serve not only to reveal their specific dynamical information content but also to provide generally a basis for the design of future mesoscale eddy experiments and monitoring initiatives.

Important future research activities include a synthesis of the scientific results from the intensively studied North Atlantic regions with the information available from elsewhere in the worlds-ocean in order to provide an overall assessment of the phenomenon and to guide the direction of mesoscale research. New results should be applied in a timely fashion to relevant problems involving dispersion and transport. Mesoscale studies should be made an intrinsic part of or added on to regional studies or studies predominantly directed toward other phenomenon (equatorial studies, near surface layer studies, general circulation studies). A continuing search for new synoptic types and exploratory studies of important new regions (such as the Gulf Steam extension) can now be carried out relatively efficiently by our new technology. Further development of special instruments is essential; scientific results of significance can be expected if efforts are successful in utilizing satellite, acoustic tomographical, and near surface current measurement techniques for mesoscale motions. By the mid 1980's a major mesoscale experimental program should be undertaken in the energetic and interactive region of the greater Gulf Steam and recirculation system. In the next few years regional open ocean models and eddy-resolving gyre-scale general circulation models (e.g., of the North Atlantic) should be operating with known mesoscale processes, partially verified, and providing the basis for mesoscale eddy parameterizations in larger models.

Small Scale Mixing Processes

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The processes that mix the ocean tend to smooth the variability produced at the sea surface by interactions with the atmosphere. These processes act over a 10^{10} range of scales (up to 10^4 km for ocean basins to about 1 mm for the diffusive cut-off of salinity fluctuations). Oceanographers loosely consider the small scale range to encompass vertical dimensions from a few tens of meters to the diffusive cut-off (with corresponding horizontal scales of to about 10 km). Since physical processes tend to vary logarithmically rather than linearly this 10^7 range of scales encompasses a large fraction of the spectrum of ocean physics.

Any attempt to model the large energy-containing processes requires a suitable parameterization of the smaller ones. The present excitement in mixing work comes from the ability to make observations of at least the signatures of mixing processes. From these measurements, estimates of fluxes can be compared with the requirements of the large scale balances. However, the measurements are difficult and must be interpreted without any comprehensive theoretical understanding of turbulent mixing, especially in stratified fluids.

The programs described by the following abstracts span the full range of the small scale processes. The measurement tools that have been developed over the past decade have all been brought to a state where they can take part in joint field programs focussed on specific processes or regions. These include the mixed layer (M.I.L.E.), the Gulf Stream (F.A.M.E.), the Equatorial Undercurrent (GARP), island mixing (F.A.M.E.) and mesoscale eddies (Polymode). Some significant results have come from these programs and more are expected.

Most of the instrumentation work consists of obtaining an adequate understanding of the behavior of the individual sensors and data systems so that the scientific results are not contaminated by incorrect or ambiguous data. This is slow, difficult work and promises to require several more years for some of the systems.

The newer developments are the advent of expendable sensors, particularly the expendable velocity profiler, and horizontal mapping techniques for microstructure as well as finestructure. These will require more effort to bring to the same stage as the existing systems.

Further advances require continued work in present directions, leading to integration of sensors onto the same platform so that the relationships among variables such as shear and microstructure can be examined. Ultimately these must be investigated in 3 dimensions as a function of time. It appears that such observations are a prerequisite to the development of a sound theoretical base.

The basic technology exists to solve most of the current problems in the field. The rate of progress is presently limited by the number of competent investigators and the levels of funding. Incremental increases in funding can produce some acceleration but a major thrust cannot be had without the time necessary to train new investigators.

OCEAN SURFACE FRONTS

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In some ocean regions, abrupt changes of temperature, salinity, and velocity occur more in one horizontal direction than in the other. These oceanic frontal areas are observed to exist in a large variety of temporal, vertical, and horizontal scales and at all depths in the ocean. On the ocean surface, frontal regions are clearly visible from satellite sensors. Ocean surface waves, acoustic propagation, and currents change abruptly across these areas. Because there is great promise that the temporal and spatial evolution and variability of the frontal regions can be measured by satellite, it is of some import and intense scientific curiosity to understand how their structure is rooted in deeper water columns. From the experience of measuring and modeling atmospheric fronts, we believe that some ocean surface fronts occur because the relative advection or convergence of surface water masses is much larger than their mixing or diffusion; however the job of measuring the flow rates and diffusion rates which may be responsible for frontal formation and/or decay and understanding the principal hydrodynamical processes presents a difficult problem. The modeling of fronts is difficult because relative advective processes make the theoretical problem non-linear; the circulation measurement problem is difficult because fronts do not stay well-fixed in space or time, and fixed, moored sensors cannot be used effectively to measure frontal structures.

Best understood are fronts between fresh water of continental run-off and salty ocean water because these are two-dimensional (or two layer) phenomena, and they have been crudely modeled. Also, fronts associated with upwelling area were studied and modeled in the CUEA Program during the past ten years, and the Gulf Stream frontal phenomenon between the Yucatan Straits and the Grand Banks has been of considerable interest and study over the past twenty years.

In these well-studied areas, fronts are primarily described by hydrography, and in some limited areas the space and time evolution of the surface features can be followed. However, progress in understanding and modeling and prediction of fronts is severely hampered because ocean current, fine structure, and turbulence or "mixing" processes have not been described adequately. These are the most essential elements to the formation and decay of fronts.

The most significant advances in measurements of turbulence and dissipation have come from free-falling microprofiles. For frontal studies, these need to be adapted so rapid surveys can be made in the horizontal direction. Most significant advances in measurement of upper ocean currents are acoustic doppler velocimeters, and these need to be adapted to vertical profiling modes, and coupled with the

Global Positioning System, they can be used for measurement of horizontal currents from a moving ship.

As in other areas of research, oceanographers are planning frontal experiments where "turbulence," fine-structure, currents, and hydrography can be measured at the same time. Such complete descriptive studies will be a strong impetus for modeling and predicting ocean fronts.

REMOTE SENSING AND SATELLITE OCEANOGRAPHY

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The past twelve months represent a watershed in ocean remote sensing. Although several years will be needed to realize their full impact, the launchings of three new satellite systems by NASA in 1978 are beginning to provide oceanographers with a wide range of new data. TIROS-N begins a new generation of infrared sensors for sea surface temperature mapping. NIMBUS-7, the last of this series of meteorological research satellites, carries a scanner dedicated to ocean color measurement. SEASAT-1 carried four very different microwave-based sensors.

The data from these new systems is only very slowly becoming available. Funding levels for processing, analyzing and interpreting these data are miniscule compared with the costs of designing, launching and operating these satellite systems. A relative handful of oceanographers are actively involved in remote sensing, while most are waiting for the often promised potential to be translated into concrete demonstrations of useful capability.

The last few years have seen increasing reliance on satellite infrared scanner data to observe sea surface temperature variations across major ocean currents, fronts and eddies. Surface-based radar scattering experiments are beginning to show conclusive surface current measurement capabilities. A few papers are beginning to appear which provide at least partial evidence that satellite radar altimetry can measure the surface slope across strong currents such as the Gulf Stream. High resolution visible imagery from LANDSAT satellites has been exploited to give new insights into internal wave generation through tidal current interaction with bottom topography.

The prospects for the future in satellite oceanography are dependent on how the ocean research community uses those three satellites launched last year. No new missions have been approved by NASA or any other agency. SEASAT ceased working after providing three months of near-flawless data. NIMBUS-7 will hopefully continue successful operation for another two years. Several years will follow then in which only infrared-type data will be available from operational meteorological satellites.

The gestation period from approval of a new satellite mission until its launch is generally four years or more. Approval for new starts to remedy this situation will call for a consensus in the oceanographic community which focuses on one or two remote sensing approaches with the greatest demonstrated capability. Many physical oceanographers believe that radar altimetry should have top priority in any move toward a new mission. The relative merit of this versus other ocean remote sensing methods should be settled using data which has already been collected and is stored on the ground waiting to be analyzed.

NUMERICAL MODELING IN OCEANOGRAPHY

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There are two general categories of numerical ocean modeling within the ONR basic research (6.1) community. The first of these is numerical modeling (or analytic work) for understanding of oceanic processes and phenomena that have a potential impact on Naval operations. Objectives of this type of modeling include: (a) Examining and/or suggesting hypotheses to be tested in field experiments; (b) Evaluating or even developing observing strategies to be used in the field; and (c) Simulating events or phenomena observed during the field experiment. Examples of successful programs involving numerical modeling and observational field experiments include the coastal upwelling and El Nino studies. More recently the NORPAX project has involved all three of these objectives.

The ability to simulate phenomena observed in the ocean leads naturally into the second category of numerical modeling that will eventually contribute to oceanic prediction in support of fleet requirements. Until quite recently this category of numerical modeling based on real initial data and real forcing has been lacking, and this has contributed to our inability to predict the oceanic environment. It is obvious that an understanding of the oceanic phenomena is not the only prerequisite for developing an oceanic forecast model. One must also have the observations and analysis techniques required to define the initial oceanic conditions, as well as the forcing, on the proper space and time scales. In some cases a natural by-product of the second category of numerical modeling is the specification of the proper space and time scales of particular oceanic phenomena. The responsibility for developing and testing of oceanic prediction models for operational application has now been assigned to the numerical modeling group at the Naval Ocean Research and Development Activity (NORDA). This NORDA group should help bridge the technology gap between the basic research in ocean modeling and the Navy's need to predict the oceanic environment. The decade of the 1980's promises to be a period of increasing interest and activity in ocean prediction comparable to the expansion in numerical weather prediction during the past 10 years.

According to present policy, ONR Code 481 sponsors "numerical modeling only to the extent that it is integrated with and needed by the go-to-sea research efforts". That is, the modeling efforts that are "close to the data" are likely to be the most beneficial. Nevertheless, model studies utilizing idealized conditions and forcing can contribute to a well-conceived sea-going program. One new area of modeling is in the developing of coupled atmosphere-ocean models. Although the present efforts are primarily motivated by the interest in climate, ONR should consider encouraging short-term forecasting with these coupled models. Such models could be used to understand the role of synoptic and shorter time scale forcing of the near-surface layers of the ocean and at depth, as well as the feedback through the atmospheric boundary layer to storms. In some ocean areas with adequate initial data, it is possible that the predictability of the atmospheric forcing will be the limiting factor in ocean prediction. The success in developing atmospheric models to forecast 1-2 weeks rather than 1-2 days thus may impact on ocean forecasting. A coupled atmosphere-ocean model may be necessary to satisfy the requirements in both media.

ONR Code 481 should consider adopting a corollary policy statement: "Observational programs that are based on and supported by analytical studies and numerical modeling have a higher expectation of success and thus will receive a higher priority for funding." No major field program should go to sea without a well-defined hypothesis based on physical principles. Only after demonstrating that the historical observations are inadequate to test the physical hypothesis should a new field experiment be started. It should then be clear what calculations are to be made with the new data, and what statistical, analytical or numerical model tests are to be performed. Consistent with the above-stated need for oceanic forecasting, whenever possible the research plan should include the measurements needed to carry out numerical simulations and verifications. This will result in a combined observational and modeling program that promises to get the maximum benefit from the field experiment.

UPPER OCEAN MIXED LAYER

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Several years ago computational models of the mixed layer and upper ocean had been developed to a point where the paucity of relevent field observations limited further improvement. This imbalance has not been rectified, but in the past several years the experimentalists have been gaining ground and observational techniques and measurements have improved to the point that progress can be rapid. As upper ocean processes are seen more clearly their complexity becomes more evident. It becomes more and more evident that the combination of many techniques will be required to master this complexity. Still required are some advances in instrumentation and data analysis techniques, especially the capability of truly combining the various measurements, and the ability to use these techniques under the adverse conditions of the big storms that produce radical changes in the upper ocean.

Some of the exciting questions for the next few years are: (1) What is the relative importance of the various processes carrying momentum and mass through the mixed layer? (2) What is the role of surface waves? (3) How are momentum and mass exchanged at the interface between mixed layer and thermocline? (4) Do internal waves have an important dynamical effect? (5) What is the efficiency of turbulent processes, i.e. how much of the energy available for mixing is dissipated to heat without accomplishing any mixing? Many other questions are unsettled. Answers will be different as the atmospheric exitation changes from storm conditions when active mixing penetrates into stratified depths to lighter conditions when the lower parts of the mixed layer restratify and active mixing takes place only near the surface. The dynamics of the mixed layer are quite different in the summer dirunal cycle from those in a winter storm.

Taking the MILE (Mixed Layer Experiment) expedition as an example of the state of the art of upper ocean measurement, we see that current meters can be installed very near the surface in deep water with excellent data recovery, although effects of mooring motions still handicap analysis. Reliable temperature and salinity profiles can be produced and measurements of even the smallest scale gradients of temperature can be performed under moderate storm conditions. Measurements of horizontal temperature structure were demonstrated in lighter winds. In other experiments vertical shears in the currents have been measured. These measurements have revealed in the phenomena a degree of complexity which is not unexpected, but which will require true combination rather than mere coordination of measurements. For example, on the most naive level it is obvious that internal waves distort temperature profiles so much that bookkeeping cannot be done on heat content and vertical mixing without careful attention to sorting out internal wave effects. On a more fundamental level it is not clear what the significance of energy transport by the internal waves is to the mixed layer dynamics. Another example is the relation between moored current and temperature measurements and profiling measurements of vertical structure. The relationship between current shear and mixing events cannot be fully unraveled by either because the moored data, being taken at discrete levels, does not have the required vertical resolution in defining the vertical structure, and the profiling measurements, even if they incorporate shear profiles, cannot have the temporal sampling required to sort out the various phenomena. The degree of horizontal variation revealed by towed and surveying instruments presents even more difficulties in achieving an adequate description of upper layer phenomena. How can we find out what is happening in the ocean over a substantial area with a reasonable amount of effort in the face of this variability?

Some of the advances in technique to be hoped for in the next few years in order to achieve a knowledge of the phenomena in the upper ocean sufficient to trigger the next level of advance in theory and modeling are: (1) Moorings with less motion on which current meters with minimal sensitivity to the motion are mounted. The VMCMs used in MILE seem to be a real advance. (2) Rapid surveying tools used from a moving ship, measuring temperature, salinity and current structure. Maintenance of calibration is especially important. (3) Unattended profiling instruments and instruments hardened for rough-weather deployment. These are especially needed to get the big-storm data we lack so completely now.

At least as important as these individual developments is the effective combination of them. Given the horizontal variability and internal wave distortion of measurements, can data from moored and profiling instruments ever be combined to give us a true picture of instabilities in the flow in the upper ocean? If rapid surveying techniques are developed the data handling problems will be increased an order-of-magnitude from present single-instrument, single-spot procedures. As understanding of upper ocean processes is gained, can it be used to simplify their description? One way this question might be put is, how many parameters are required to describe the upper layer, parameters such as the characteristics of the internal wave field, a simplified description of the density structure, the shear field, radiation, turbulence field, and what others.

One particular problem that needs attacking is the quantitative observation of Langmuir cells, vertical circulations in the mixed layer generated by the combination of wind and waves. If they are as strong as some have suggested, their vertical circulation could dominate energy and mass transport through the mixed layer, perhaps especially in heavy weather; we just don't know.

Western Boundary Currents

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Strong ocean currents, such as the Gulf Stream, are usually found near western boundaries. A similar current off the coast of Somalia and Arabia has surface speeds about twice those found in the Gulf Stream. Surface currents are well known to be modulated by the tides; in some passages between islands in the Carribean Sea, the flow which eventually becomes the Gulf Stream is modulated very strongly by tides -- not only at the surface, but all the way to the bottom.

A major hindrance to our understanding of these currents has been that observations are needed simultaneously on very long scales -- hundreds to thousands of miles -- while at the same time the observations need to be long in time. There are important physical processes happening on scales of hours, days, weeks, months, and years. Unfortunately the small-scale motions have large amplitudes; to resolve all the important scales involved is an observational challenge.

Recently there have been new kinds of data available from a remarkable variety of sources. Multiple-ship sweeps across an ocean, taking XBT data, have provided pictures of time and space scales never before obtained simultaneously. Satellites give rapid coverage over long spatial scales, although there are awkward gaps in the data; there are limited numbers of satellites and the infra-red images are obstructed by clouds. The availability of the airborne XBT has meant that rapid coverage can be obtained in special areas. The satellite altimetry data is very exciting, although it is of limited scope now. From the GEOS III altimeter and (to a limited extent) from the SEASAT, recognizable ocean features -- especially the Gulf Stream -- can be found. Traditional current-meter moorings can now remain in the ocean a year or longer.

To the historical accumulation of the monthly summary, The Gulf Stream, are now added detailed weekly maps of position by various agencies (NOAA, USCG,NavOceanO). These show positions of strong surface currents in the Gulf of Mexico, along The U.S. East Coast, and extending beyond Cape Hatteras to ~50°W longitude, nearly half-way across the Atlantic. Their value is great, for a variety of purposes -- but it will only be after the historical data have been accumulated that careful analyses will allow the predictable parts of the variations to be separated reliably from the random features. The observations and theory have to go hand in hand.

Advances are being made in the analyses of the way currents interact with bottom topography -- especially as the interactions affect the density distribution. In the Gulf Stream the historical records have allowed calculations of both time and space scales to investigate a special class of waves (topographic Rossby waves) that seem to control Gulf Stream meanders -- in which bottom topography and the rotation of the earth are important effects. For four successive years a large eddy off the coast of Somalia has been observed and is thought to be a regular, time-dependent, feature rather than a random feature as are many mid-ocean eddies. A large gyre in the western Gulf of Mexico is being studied, as it has many aspects of a western boundary current; it is thought to be the result of forcing by the large-scale wind field.

SECTION III---LARGE PROJECT SUMMARIES

Project Title: "INDEX: An Oceanographic Contribution to International Programs (FGGE/MONEX and IOC/CINCWIO) in the Monsoon Region of the Indian Ocean"

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Scientific Objectives

The purpose of the INDEX experiment has been to explore the ocean's complex interactive role with the Indian summer monsoon. As revised by Dr. John Swallow, of IOS, Wormley, in the meeting of the Indian Ocean Panel of SCOR Working Group 47 at UNESCO, Paris, 25-27 September 1978, the general objectives of the program during FGGE are as follow:

1. The development of the structure of the upper layers of the Arabian Sea during the advance of the monsoon.
2. The onset of the Somali Current, particularly the evolution and vertical structure of the different inflows and outflows.
3. The variation in time and space of the eddies off East Africa, and the relationship between the regions of upwelling, the eddies, and the main boundary current.
4. The vertical distribution of current through the whole water column along the equator in the western Indian Ocean, with particular emphasis on its zonal and temporal variation in the upper thousand meters.

Specific Objectives

Certain individual objectives of likely participants in the proposed observational program have been identified.

1. To study the large and mesoscale features of the sea surface temperature field of the whole Arabian Sea during the southwest monsoon, using remote sensing techniques, and to investigate the use of satellite altimetry in mapping the upwelling and eddy field of the Arabian Sea. (O. Brown, U. of Miami)
2. To study the heat budget in the upper 1500 m of the Arabian Sea, in the region 11^{o}-15^{o}N, 72^{o}E. (J.S. Sastry, NIO, Goa)
3. To study the seasonal and interannual variations in the offshore vertical distribution of temperature and other properties along the coast of East Africa. (J. Bruce, WHOI)
4. To observe the annual and interannual variations of coastal currents and temperature field off Kenya and Somalia, using nearshore temperature recorders. (D. Johnson, W. Duing, U. of Miami)
5. To observe the northern part of the Somali Current before the onset of the monsoon (Feb.-Mar.), during the onset (Apr.-May) and again in June-July at the peak of the southwest monsoon. (W. Duing, F. Schott, U. of Miami)

6. To make deep velocity transects across the Somali Current between $2^{\circ}S$ and $3^{\circ}N$ in April and May. (A. Leetmaa, NOAA, Miami)

7. To study the onset and structure of the Somali Current, the offshore eddies and equatorial phenomena in the presence of the western boundary. (R. Molinari, A. Leetmaa, NOAA, Miami)

8. To contribute to mapping the Somali Current and offshore eddies between $4^{\circ}S$ and $7^{\circ}N$ during the growth of the current in May-June, and again in late June when it is almost fully developed. (J. Swallow, IOS, Wormley)

9. To study the distribution of nutrients and plankton off the coast of Somalia in three phases of the monsoon, in conjunction with the physical studies in item 5 above. (L. Codispoti, U. of Oregon, S. Smith, Brookhaven Nat. Lab)

10. To study the seasonal variations in physical properties, currents and nutrients in the neighborhood of the North Kenya Banks, within 50 miles of the coast between $3^{\circ}S$ and $2^{\circ}S$. (D. Johnson, U. Miami)

11. To observe the vertical distribution of current and temperature in a section across the equator at longitude $62^{\circ}E$ in Jan.-Feb., when the equatorial undercurrent may be present. (R. Frassetto, Venice, Italy)

12. To observe the vertical distribution of current and water properties, and their temporal variation, in the equatorial region at longitude $62^{\circ}E$, where the eastward equatorial surface jet may be expected in May-June. Meandering of the jet, and the possible westward progression of its deceleration region, using satellite-tracked drifting buoys. (M. Fieux, MNHN, Paris)

13. To observe the zonal and temporal variation of the current in the upper 1000 meters near the equator, with particular emphasis on the observed westward jets and their modification by the western boundary. (J. Luyten, WHOI)

14. To make observations of the structure and development of the near surface mixed layer at the equator. (I. Jones, RANRL)

15. To verify by means of deep hydrographic stations, that deep water moves into the equatorial Indian Ocean along a track east of $90^{\circ}E$. (D. Rochford, CSIRO, Australia)

Proposed Observational Program

1. Already started and continuing through 1979, two XBT sections will be occupied. The section from the Persian Gulf towards the Cape, made by tankers of opportunity, will be extended southwards if possible, from $2^{\circ}S$ to $12^{\circ}S$. (J. Bruce, WHOI)

2. The section between Bombay and Mombasa is being occupied by Indian naval vessels (Admiral Fraser, Hydrographer of Indian Navy, and H. Stommel, WHOI). Two runs have been made in 1978 and it is expected that this will be intensified in 1979. Additional bathythermographic observations of opportunity will be welcomed via IGOSS, and it is expected that all oceanographic vessels will make hourly BT observations on passages in the Indian Ocean.

3. Three water temperature recorders were placed in shallow water off the coast of Somalia in July 1978, and three current meter moorings are already in place offshore. These instruments will be recovered during 1979 (W. Duing, D. Johnson). Several more moored instruments will be set.

4. A satellite receiving station will be set up in the Kenya Marine Fisheries Research Laboratory at Mombasa, where an oceanographic operations base is being developed. High-resolution pictures of sea surface temperature will be received in real time, up to four times per day (Brown, Evans, U. Miami).

5. Month-by-month narrative of ship observations in 1979.

Support

The American components of this international program are supported jointly by the Office of Naval Research, the National Science Foundation, and the National Aeronautics and Space Administration. Foreign INDEX participants are supported for the most part by their own governments.

JOINT AIR-SEA INTERACTION PROJECT (JASIN)

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Background

JASIN is a United Kingdom-initiated program and a U.K. contribution to the Global Atmospheric Research Project (GARP). Proposed by the Royal Meteorological Society in 1966, there were field trials in 1970, 1972, and 1977, all devoted to preliminary exploration of scientific and engineering aspects of the major joint experiment which took place from mid-July to mid-September 1978 northwest of Scotland in an area bounded approximately by 57°-60.4°N, 9°-14.5°W.

The U.K. Royal Society is the lead agency, Professor Henry Charnock (University of Southampton) is the Project Director, and Dr. Raymond Pollard (Institute of Oceanographic Sciences, Wormley) is the Scientific Coordinator. The Project Office at Wormley is aided by a grant from the Air-Sea Interaction Panel of the NATO Science Committee.

Objectives (from: Pollard, Bull. AMS, 59, 1310-1318, 1978)

1. To observe and distinguish between the physical processes causing mixing in the atmospheric and oceanic boundary layers and relate them to mean properties of the layers.
2. To examine and quantify aspects of the momentum and heat budgets in the atmospheric and oceanic boundary layers and the fluxes across and between them.

Although the meteorological aspects of JASIN involve both large and small-scale processes, many of the oceanographic efforts are on scales smaller than some tens of kilometers in the horizontal, and time scales less than a day. The goals and methods overlap those of MILE, held a year earlier in the North Pacific. The advantage of JASIN is a greater concentration of ships, aircraft, and people during a longer and larger field experiment; the disadvantage is the additional complexity of the experiment and the post-experiment analysis and interactions.

Current Status and Plans

1. The field experiment took place with almost 100 percent of the planned participation and experimentation actually occurring. In addition to the basic plans (Pollard, 1978), there were two multi-ship experiments involving 3-4 ships towing instruments around a stationary array of 3-4 CTD'ing ships and a vertical array of current meters.

2. Weather conditions were not as severe as hoped, but there were several periods of winds in excess of 10 $m\,s^{-1}$ including one period of sustained winds over 12 $m\,s^{-1}$ reaching a maximum of 18 $m\,s^{-1}$ and a stress of 5 dyne cm^{-2} (0.5 Pascal).
3. Participants are now involved in the production and distribution of cruise and data reports and in the preliminary stages of scientific analyses. Subject and Event Coordinators are being identified to enhance the analysis effort.
4. A Data Display Meeting will be held at Woods Hole Oceanographic Institution during 21-25 May 1979 for the purposes of data intercomparison, initial scientific discussions, and preparation of a post-experiment report documenting the field phase of the project.
5. Early results are appearing in JASIN News, a limited-distribution document issued by the Project Office in Wormley primarily for purposes of communication between participants.
6. Tentative coordination plans include a science workshop in 1980, probably to be held in Europe. Although some individual scientific results may begin to appear in 1979, the major findings are expected in 1980-81.

Support

The U.S. contributions to JASIN are funded mainly by ONR Code 480 and the National Science Foundation, Division of Ocean Sciences.

TITLE: NORPAX (The North Pacific Experiment)

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NORPAX is a multi-institutional research effort designed to investigate the dynamics and energetics of large-scale fluctuations in the upper ocean and to study the connection between these fluctuations and changes in climate over North America. It is expected that NORPAX results will assist in the forecasting of upper ocean thermal structure. Such results may also enhance our ability to predict atmospheric climate.

At the present time most of the NORPAX activities can be subdivided into three general groups: the Anomaly Dynamics Study (ADS), the Equatorial Dynamics Study (EDS), and the Atmospheric Climate Study (ACS).

The Anomaly Dynamics Study deals with the several processes responsible for the development of large-scale upper ocean thermal anomalies. Because of its obvious relevance to acoustic propagation as well as climate, ONR has chosen to focus its support on this part of NORPAX.

Beginning with a working hypothesis that Ekman pumping is the most important anomaly generating mechanism, ADS investigators designed a major field program to test this hypothesis. Since the time scales of variability for the anomalies range from a few months to a few years it was decided that the field program should cover, as a minimum, a five year time span, 1976-1981. Since the space scales for the anomalies are on the order of thousands of kilometers the experiment area had to cover a major fraction of the North Pacific. For various logistical and scientific reasons the principal ADS experiment area was chosen as roughly 30°N to 50°N and 130°W to 170°E.

The ADS field experiment consists of the measurements of surface currents using satellite tracked drifting buoys, the measurement of the thermal structure down to 500m using XBT's and AXBT's, measurement of density field over limited time and space intervals, the calibration of existing U.S. Navy FNWC wind stress fields and the computation of surface heat fluxes from standard ships' weather reports.

By chance the first year of the ADS field experiment happened to span the unusually severe winter of 1976-77. XBT data taken during that time indicates that vertical mixing, surface heat flux and north/south advection were more effective anomaly generating mechanisms than Ekman pumping. For some as yet not clearly understood reason, there was weak mixing below the traditional "mixed layer" and down to 300m or more. The Ekman pumping mechanism did seem to have a significant influence on the temperature structure at the deepest part of the XBT data but this could not be definitely distinguished from mixing without accompanying salinity profiles.

For lighter wind conditions, such as occur during the spring and summer, Ekman pumping appears to explain much of the vertical movement of the thermocline. This is not generally true, however, in the vicinity of major frontal zones where the advective mechanism must play a more important role.

During high wind stress periods the satellite tracked drifter data indicates that the surface currents are slab-like and run approximately 30° to the right of the wind direction. During light winds the surface currents are only weakly coupled to the stress. To test the vertical structure of the surface currents the most recent deployment of buoys has been drogued at various depths down to 200m.

A 10 level, primitive equation ocean circulation numerical model has been used in an attempt to simulate the observed response of the ADS area to the severe winter of 1976-77. In the most recent runs the model was initialized using TRANSPAC (the ADS ship-of-opportunity program) XBT data and forced using FNWC winds and computed heat fluxes. After a period of four months the pattern of the simulated anomalies compared well with those observed but the amplitude of the model response was too high. A more elaborate, more realistic mixed layer model is now being imbedded in the general circulation model.

One intriguing result obtained from TRANSPAC XBT maps and drifter tracks is the possibility of major near surface mesoscale eddy features which are either generated by or trapped by bathymetric features such as seamounts or ridges. The data are as yet too scarce to definitely establish this as fact but there may be a field of quasi-permanent eddies spread across the North Pacific and other oceans.

The NORPAX Equatorial Dynamics Study (EDS) focuses on the banded east-west current system that exists in the low-latitude Pacific. The goal of the study is to establish the design for an efficient and relatively inexpensive observing system capable of long-term monitoring of the interannual fluctuations in the current system. These fluctuations are driven by fluctuations in the Trade Winds. The current fluctuations are responsible for major changes in tropical sea surface temperature which, in turn, affect the tropical atmosphere. EDS has just launched a major 16 month tropical field experiment in the mid-Pacific between Hawaii and Tahiti. Most of this experiment is being funded by NSF-IDOE but ONR is assisting with the making of regular AXBT sections through the area. Data from frequent Navy AXBT flights performed during the winter of 1977-78 showed major differences in the east/west transport of the equatorial current system over a longitudinal extent of only 8°. The present EDS field experiment coincides with the period of the GARP World Weather Experiment.

A third component of NORPAX, the Atmospheric Climate Study (ACS), is designed to investigate ocean/atmosphere interaction on climatic time scales. Scientists working in this area use large historical data bases to develop statistical/phenomenological models of the response of the atmospheric circulation to sea surface temperature anomalies. Using these techniques NORPAX scientists were able to forecast the general patterns of surface temperatures in the U.S. during the winters of 1976-77 and 1977-78.

At the present time, NORPAX consists of about 30 Co-Principal Investigators working at 15 educational institutions and government laboratories. The main sources of support are the Office of Naval Research and the National Science Foundation's Office of the International Decade of Ocean Exploration (IDOE). In addition to these sources some individual NORPAX investigators are subsidized by the Naval Ocean Research and Development Activity (NORDA), the U.S. Navy Fleet Numerical Weather Central (FNWC), the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA). Foreign NORPAX Participants from Germany, France, England and Japan are supported mostly by their own governments.

POLYMODE

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POLYMODE is an international cooperative scientific investigation of low-frequency, medium scale motions in the sea.

By early 1970s, eddies, oceanic mesoscale variabilities with horizontal scales of the order of 100 kilometers and time scales of the order of 60 days, had emerged as the dominant factor in the medium frequency processes in the ocean. The basic long range goal of eddy science is to understand the dynamics of eddies and their role in the large scale circulation of the oceans. As a major mechanism in the energetic processes of the ocean, eddies may have strong influences in the areas of meteorology, distribution of chemical properties in the ocean, and marine biology.

POLYMODE builds upon results from two previous large scale intensive eddy experiments conducted in this decade. Limited POLYMODE experimentation began in 1975. The intensive field work phase was from mid-1977 to mid-1978, with some additional work continuing to the fall of 1979.

US efforts in POLYMODE are being coordinated with USSR scientists under a bilateral agreement, as well as with related work being done by oceanographers from Canada, the United Kingdom, France, and the Federal Republic of Germany. The Canadian and European work is coordinated through SCOR Working Group 34.

The US work is funded by the Office of Naval Research and the National Science Foundation (Office of the International Decade of Ocean Exploration). The National Oceanic and Atmospheric Administration of the Department of Commerce administers the US/USSR bilateral agreement. During the field work phase of the program, liaison was maintained with the Office of the Oceanographer of the Navy.

The experimental program of POLYMODE is divided into two areas: statistical-geographical exploration, and local dynamics. These areas are complementary, and were carried out simultaneously with some overlap in space.

The statistical-geographical experiments were aimed towards determination of the geographic occurrence and variability of eddies in the North Atlantic Ocean. Arrays of moorings were set for extended periods by the US on either side of Mid-Atlantic Ridge and in the North Equatorial Current, by the USSR on the Hatteras Abyssal Plain, by Canada in the Gulf Stream Extension region, and by a UK/France/FRG group in the northeastern basin of the Atlantic. The final US array in these experiments will be recovered in October, 1979. The USSR one-year array was recovered in September, 1978.

Data from these arrays, when combined with data from earlier experiments, have provided a picture of the geographic distribution and variability with depth of eddy energy, as well as information on the time variability of eddy statistics for periods of a year or more.

The local dynamics work was designed to closely examine one or more eddies over a shorter time in one location, and to provide a quantitative picture of the physical processes involved and the dynamics of an eddy. The intensive US experiment was deployed from May to July, 1978 on the Hatteras Abyssal Plain in conjunction with the USSR statistical/synoptic array already there. An array of SOFAR floats was deployed, and has continued to provide data from this region. The mooring array will be recovered in May, 1979. During the intensive phase repeated density surveys were carried out.

POLYMODE has reached the end of its major field work phase. Data analysis has begun for most elements of the experimental program. It is anticipated that 1980 will see the first published papers of results from the main field program.

Several distinct types of eddies have been identified, perhaps characteristic of different regions of the ocean. During the Local Dynamics Experiment, a small, very compact and intense eddy restricted to levels below the main thermocline was seen.

The US/USSR synoptic XBT surveys have provided a unique picture of the evolution of the eddy field of a large area of ocean over a period of more than a year. They show high eddy activity, some interaction between eddies, and a generally westward movement of the eddy fields.

Theoretical efforts in POLYMODE have included modelling of eddy processes. Now that considerable field data is becoming available from the main field program, efforts are underway to compare modelling results with field observations.

SECTION IV---INDIVIDUAL PROJECTS BY INSTITUTION

Applied Science Associates, Inc.

Brown, G. S.: Electromagnetic Scattering Studies Related to Oceanographic Remote Sensing

University of British Columbia

Burling, R. W. and Pond, S.: Measurement and Parameterization of Air-Sea Fluxes at High Wind Speeds: Adaptation of Bulk Parameterizations to Allow Flux Computations from Climatological and Synoptic Data

Emery, W. J. and Dugan, J. P.: XBT Swath Analysis: A Study of Spatial Variability

Mysak, L. A.: Studies of Mesoscale Waves and Currents over Steep Topography

Osborn, T. R.: Studies of Microstructure

University of California, Berkeley

Watson, K. M.: Transfer of Energy among Modes within the Oceanic Internal Wave Field

Catholic University of America

Ling, S. C. and Kao, T. W.: Study of the Mechanics of Momentum, Water Droplets, Moisture, and Heat Transfer at the Sea-Air Interface under High Sea States

University of Delaware

Garvine, R. W.: Theoretical Model of Oceanic Front Evolution

Florida State University

O'Brien, J. J.: Research in Mesoscale Atmosphere and Ocean Interaction Ocean Forecasting

Sturges, W.: Response of the Ocean to Time-Dependent Wind Forcing

Weatherly, G. L. and Blumsack, S. L.: Studies of the Oceanic Bottom Boundary Layer

Harvard University

Robinson, A. R.: Dynamics of Oceanic Motions

University of Hawaii

Magaard, L.: Analytical Modeling of the Large-Scale Temperature Fluctuations in the North Pacific

Lamont-Doherty Geological Observatory

Gordon, A. L.: Sea Level and Sea Level Temperature Expression of Ocean Transients as Viewed from Satellite

Institute of Oceanographic Sciences

Gould, W. J.: XBT Sections in the Northeast and South Atlantic

Gould, W.J. and Webb, D.C.: Development of a Towed, Two Component Surface Current Sensor

Massachusetts Institute of Technology

Eriksen, C. C.: Equatorial Dynamics

Mollo-Christensen, E.: Oceanographic Uses of Satellite Information

Wunsch, C., Acoustic Tomography and Internal Waves

University of Miami

Brown, O.T.: Satellite Remote Sensing of Large-Scale Oceanic Transient Events

Duing, W.: Transient Processes in Ocean Currents

Schott, F.: Analysis of Ocean Currents

National Oceanic and Atmospheric Administration

Halpern, D.: Variability of Wind-Generated Upper Ocean Currents during MILE and JASIN

Naval Ocean Research and Development Activity

La Violette, P. E.: Definition of Ocean Surface Current Boundaries Using Synthetic Aperture Radar over the Tail of the Grand Bank

Naval Ocean Systems Center

Lovett, J. R.: Evaluate Second Generation Expendable Environmental Sensors XSVTD and XCTD

Naval Postgraduate School

Elsberry, R. L. and Garwood, Jr., R. W.: Oceanic Thermal Response to Atmospheric Forcing

Haney, R. L.: Numerical Studies of the Dynamics of Large Scale Ocean Anomalies

University of North Carolina

Bane, Jr., J. M. and Brooks, D. A.: Observations of Topographic Rossby Waves and Gulf Stream Meanders along the Continental Slope

Nova

Brooks, I.: Studies of Flow through Passages of the Lesser Antilles

McCreary, Jr., J. P. and Moore, D. W.: Studies of Equatorial Dynamics

Spillane, M.: Tidal Forcing of Baroclinic Waves

State University of New York at Buffalo

Shaw, R. P.: Topographic Wave Trapping

Oregon State University

Caldwell, D. R.: Mixed-Layer Microstructure

de Szoeke, R. A.: Dynamics of the Ocean Surface Mixed Layer

Paulson, C. A.: Air-Sea Interaction

University of Rhode Island

Wimbush, M.: The Relation of Sediment Movement to Benthic Current Flow

Scripps Institution of Oceanography

Bernstein, R. L.: Satellite Remote Sensing Facility

Cox, C. S.: Internal Wave Transport Processes

Cutchin, D. L.: NORPAX Program Administrator

Davis, R. E.: Upper Ocean Dynamics

Gibson, C. H.: Towed Microstructure Measurements in the Upper Ocean: MILE experiment, US/USSR Turbulence Intercomparison

Knox, R. A.: Observations and Analyses of Indian Ocean Equatorial Currents

Lange, R. E.: Small Scale Oceanic Features

Pinkel, R.: Dynamics of the Upper Ocean Internal Wave Field

Regier, L. A.: The Optimization of Acoustic Backscatter Techniques to Measure Current Profiles from Moving Vessels

Reid, J. L.: World Ocean Circulation: Weddell Sea and Atlantic-Indian Basin, Deep Pacific Ocean, Atlantic Ocean

Stewart, R. H.: Radio Measurements of the Sea Surface

White, W. B. and Bernstein, R. L.: Study of the Dynamics of Large-Scale Thermal Variability in the Upper Waters of the Mid-Latitude North Pacific

The Sippican Corporation

Hudson, A. and Reed, E.: Feasibility Study for Improving the AN/SSQ-36: The Navy's Airborne Expendable Bathythermograph (AXBT)

University of Southern California

Browand, F. K.: Turbulent Decay: Laminar-Turbulent Interface

Maxworthy, T.: Turbulent Decay: Dynamics of Rotating and Non-Rotating

Stanford University

Howard, H. T. and Peterson, A. M.: Radio Measurements of the Surface

Peterson, A. M. and Vesecky, J. F.: Ocean Wave Measurement by Analysis of Radar Images of the Ocean

Texas A&M University

Ichiye, T.: Entrainment Processes at Ocean Fronts

Reid, R. O.: Theoretical Studies in Ocean Dynamics

Spence, T. W.: The Dynamics of Cyclonic Gulf Stream Rings

Vastano, A. C.: Cyclonic Ring Experiment

University of Washington

Gregg, M. C.: Small Scale Mixing Processes

Katsaros, K. B.: Air Sea Interaction Processes

Roden, G. I.: Oceanic Fronts of the North Pacific Ocean

Woods Hole Oceanographic Institution

Armi, L.: Benthic Boundary Layer Experiment

Armi, L.: Norwegian Sea Overflow Intrusion Experiment

Briscoe, M. G.: Internal Waves and Upper-Ocean Variability

Bruce, J. G. and Warren, B. A.: Temperature Measurements with XBTs in the Northwestern Indian Ocean

Bryden, H. L.: Mediterranean Outflow Measurements

Fofonoff, N. P.: Gulf Stream Extension Mooring Array

Fofonoff, N. P., Schmitz, Jr., W. J., and Luyten, J. R.: Moored Array Program

Hogg, N. G.: Island Trapped Waves

Joyce, T. M.: Internal Wave and Mediterranean Water Front Studies

Luyten, J. R.: Equatorial Jets in the Indian Ocean (INDEX)

McCartney, M. S.: Pycnostadal Analyses of the Upper Water Masses and Circulation of the World's Oceans.

Rhines, P. B.: Western-Boundary Undercurrent

Richardson, P. L.: Cyclonic Gulf Stream Rings

Sanford, T. B.: Oceanic Variability and Dynamics

Schmitz, Jr., W. J.: Low-Frequency, Large-Scale Ocean Circulation

Schmitz, Jr., W. J. and Hogg, N. G.: Currents in the Charlie-Gibbs Fracture Zone

Warren, B. A.: Large-Scale Circulation

Williams, 3rd, A. J.: Velocity Structure of the High Energy Benthic Boundary Layer

Worthington, V.: Water Mass Formation and Gulf Stream Variations

SECTION V---INDIVIDUAL PROJECT SUMMARIES

Summaries of individual research projects are given on the following pages, alphabetical according to the name of the senior prinicipal investigator.

Benthic Boundary Layer Experiment

Laurence Armi

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(617) 548-1400 Ext. 2535

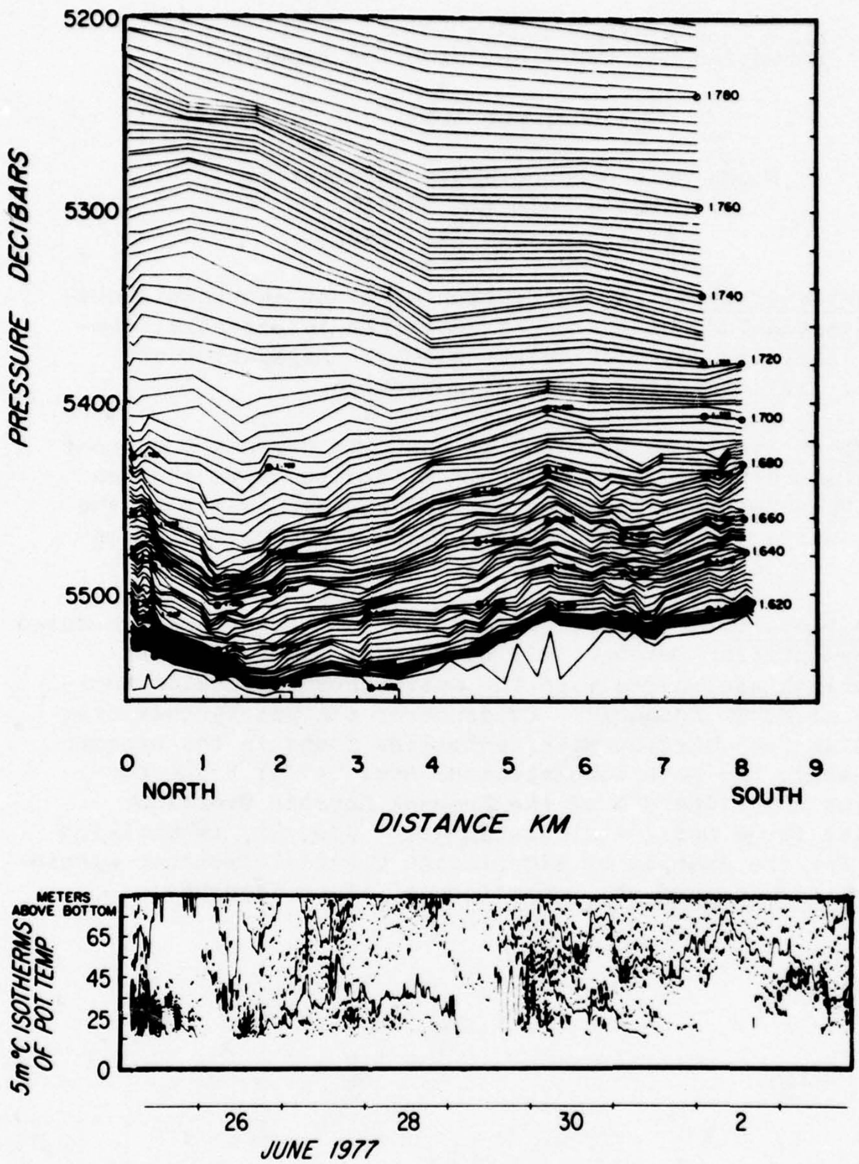
Long-range Objectives. A description and maybe some understanding of deep ocean turbulence and mixing processes. Primary focus has been on the bottom boundary layer as a source of turbulence capable of cross-isopycnal mixing. The products of bottom boundary layer mixing, when coupled with horizontal along-isopycnal advection and diffusion, may be the dominant source of deep ocean microstructure and the primary large scale mechanism responsible for vertical mixing in the deep ocean.

Project Objectives. A detailed description and understanding of bottom mixed layer structures and dynamics.

Status of project and accomplishments. The field exploration of the benthic boundary layer on the Hatteras Abyssal Plain has been successfully completed. A temporal description was provided by an array of current meters and temperature sensors spanning the bottom mixed layer. A spatial description at the current meter array was obtained using a towed yo-yo-ing CTD nephelometer profiler in conjunction with real time acoustic navigation.

Analysis of this data has shown the occurrence of intrusive layers of low stability and large scale patchiness with a scale of ∿ 7-10 km (top figure). Similar temporal variability is also found in the moored array records. The observed intrusive layers are seen in the bottom figure to be connected with active bottom boundary layers.

Recent results of this project are discussed in Armi (1978, 1979), (Armi, 1978. Mixing in the deep ocean — the importance of boundaries, Oceanus, 21 (1), 14-19), and Armi and D'Asaro (in preparation).



Isotherms of potential temperature: spaced at 2 m°C intervals from an acoustically navigated yo-yo-ing CTD (top) and spaced at 5 m°C intervals from a moored array (bottom).

Norwegian Sea Overflow Intrusion Experiment

Laurence Armi

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(617) 548-1400 Ext. 2325

Long-range Objectives. A description of along isopycnal horizontal advection and diffusion of anomalies in potential temperature, salinity and particulate matter. Separation of effects of diffusion from those of advection.

Project Objectives: Measurement of the time dependent current and temperature variability of Denmark Straits Norwegian Sea Overflow Water where it becomes part of the deep water of the North Atlantic. Description of the space and time scales associated with deep water intrusions.

Status of Project. Five bottom instrument moorings are scheduled for deployment from October 1979 to October 1980. Four of these moorings are shared with the Gulf Stream Extension Mooring Array of N. P. Fofonoff. Evidence of the patchy character of Norwegian Sea Overflow Water anomalies found in the western North Atlantic has been demonstrated, Armi (1978). The persistence of the signature of the Denmark Straits Overflow source over large horizontal distances, $\sim$ 2000 km, is striking evidence for the absence of significant vertical exchange within the basin interior and the importance of along isopycnal exchange.

1. a. Observations of Topographic Rossby Waves and Gulf Stream Meanders along the Continental Slope.

John M. Bane, Jr.
Curriculum in Marine Sciences
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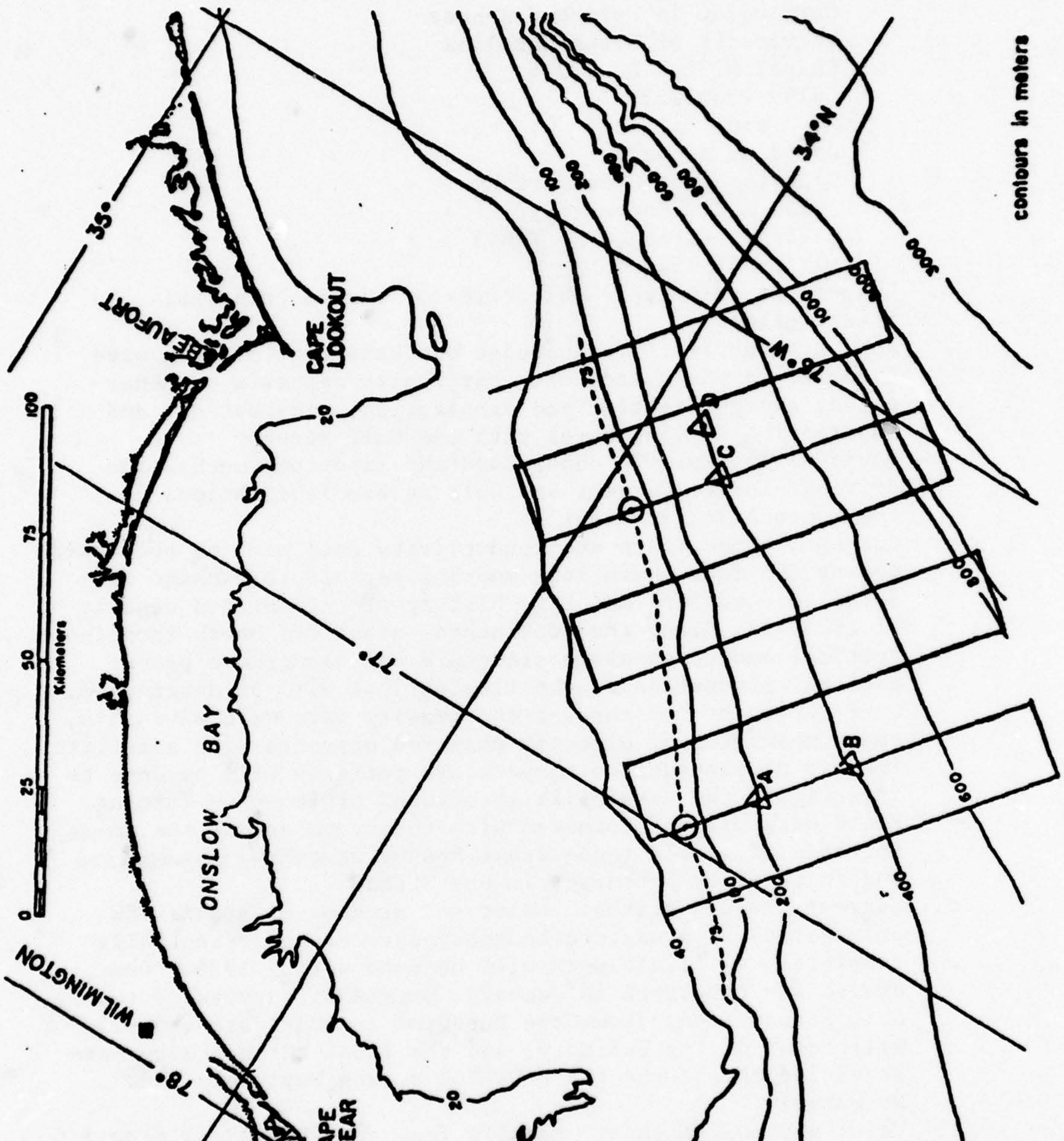
Chapel Hill, NC 27514
(919)-933-1253
and
David A. Brooks
Department of Oceanography
Texas A & M University
College Station, TX 77843
(713)-845-1546

b. Long-range scientific objectives of the co-principal investigators.
John M. Bane Jr.: To increase our knowledge of long wave dynamics in the ocean, with particular emphasis on generation, energy transfer and propagation, dissipation, and interaction of long waves with the Gulf Stream.
David A. Brooks: To understand the important mechanisms driving Florida Current and Gulf Stream fluctuations in the South Atlantic Bight.

c. Current, temperature and conductivity data will be collected during two four-month long mooring periods to examine the detailed structure and time history of current and density fluctuations along the continental slope off North Carolina. Vertical and cross-slope structure and alongshore propagational properties of the fluctuations will be determined. Correlation of the current and density data with wind data, and comparision of directly measured currents with satellite imagery of sea-surface temperature patterns will be done to investigate the possibilities of wind or lee-wave forcing. Field data will be compared with theory to assess the importance of stable topographic Rossby wave(TRW) propagation and instability processes in the Stream.

d. Current project status: Numerical studies of stable TRW propagation in a western boundary current are essentially complete. All field work will be done during 1979. One cruise was completed in January, four AXBT surveys of the Gulf Stream front from Cape Hatteras to Charleston, S.C., will occur during February, and the final three cruises are scheduled aboard the R/V ENDEAVOR during May, July and November.

e. Major accomplishments: Results from the TRW models provided information on the sturcture of the stable modes in the Gulf Stream, which aided in the design of the mooring array for the field studies. The four moorings were successfully deployed during the first cruise aboard the ENDEAVOR, 14-19 January 1979. Four XBT and two STD sections through the Gulf Stream front were made, also.



Experiment area showing mooring locations (triangles) and ship/aircraft tracks for hydrographic measurements. (Circles are locations of current meter moorings that are part of a North Carolina State University shelf circulation study.)

TITLE: Scripps Institution of Oceanography
Satellite Remote Sensing Facility

INVESTIGATOR: Robert L. Bernstein NR083-005
Scripps Institution of Oceangraphy, A-030
La Jolla, California 92093
714-452-4233

LONG-RANGE SCIENTIFIC OBJECTIVE: Application of satellite remote sensing information to improve description and understanding of ocean circulation and processes.

PROJECT OBJECTIVES: To provide a facility, open and accessible to research oceanographers, that enables investigators to easily obtain and interactively process the full range of available ocean remote sensing data from satellites. The facility includes a 5 meter diameter tracking antenna to provide real-time support of experiments in the Northeastern Pacific Ocean.

CURRENT PROJECT STATUS: All equipment is on order, to be delivered in June. The facility should be available for use in August 1979.

INTERNAL WAVES AND UPPER-OCEAN VARIABILITY

Melbourne G. Briscoe

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543
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Long-Range Objectives

Understanding of the role played by internal gravity waves in the transfers of energy, momentum, heat and mass vertically and horizontally in the ocean. Determination of the sources and sinks of internal wave energy, and the relation of internal waves to larger-scale (especially fronts and eddies) and smaller-scale (especially finestructure) ocean processes. How are upper-ocean internal waves related to other variability there, and to the deeper-ocean variability?

Project Objectives

Present work is devoted to an analysis of the energy balance of internal waves in the upper ocean via field work during the international Joint Air-Sea Interaction project (JASIN). The experiment, in cooperation with other U. S. and foreign investigators, monitored the fluctuations of atmospheric and upper-ocean generating mechanisms for internal waves, the changing spectra of the internal waves themselves, and the finestructure field associated with energy losses from internal waves. Together with theoretical and numerical analyses, we expect to obtain a description of upper-ocean internal-wave space-time variability as well as the main objective of estimating the energy balances.

Future work will include a long-term monitoring experiment on upper-ocean internal waves and an assessment of the contribution that horizontal hydrographic variability in the upper ocean makes to the internal wave variability.

Status of Project and Accomplishments

JASIN occurred during July-September 1978. The field experiment was successful and a full complement of data under various atmospheric and hydrographic conditions was obtained. The cooperative work with other shipboard scientists and other ships went smoothly.

Data reports are in production on the currents, the hydrography, and the meteorology. An international meeting at Woods Hole 21-25 May 1979 will be the first post-field phase JASIN data summary and workshop; we are the hosts and co-organizers (along with Dr. R. T. Pollard from I.O.S., Wormley, England).

STUDIES OF FLOW THROUGH PASSAGES OF THE LESSER ANTILLES

Principal Investigator: Irving Brooks
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Ocean Sciences Center
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Dania, Florida 33004
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Long-Range Scientific Objectives

To understand the formation processes and evolution of western boundary currents.

Project Objectives. The majority of the mass transport which leaves the Caribbean to eventually form the Florida Current is believed to enter the Caribbean through the passages of the Lesser Antilles. The currents previously observed in these passages have been shown to be large in magnitude but highly tidal in behavior. The goal of this project is to monitor the velocity field and associated mass transport in the St. Lucia Passage to determine tidal and non-tidal characteristics.

Current Status of Project. During the summer of 1977, an experimental program was conducted in the St. Lucia Passage. This program consisted of a dropsonde experiment together with moored current meters. A strict schedule was determined for the dropsonde experiment so that M_2, S_2, K_1 and O_1 tidal components could be studied. The dropsonde data set has revealed much insight into the flow regime. Analysis of the current meter data is now in progress.

Accomplishments

The M_2 tide dominated everywhere; its amplitude was as large as the mean and its phase was relatively constant across the passage. Thus total transport through the passage was M_2 dominated also. The predominant non-tidal variability was centered around periods of about four and twelve days. Average transport through the St. Lucia Passage was 1.7×10^6 m^3/sec varying from a high of 7×10^6 m^3/sec to a low of -3×10^6 m^3/sec.

The northern part of the passage accounted for almost the entire net average transport. There is a subsurface velocity maximum, centered at about 250 meters, in the northern part of the passage, and a weak countercurrent in the deep part of the passage. Isotachs of the average downstream velocity field deepened toward the north. The average cross-stream velocity field showed a relatively strong northward component near the surface and a weak southward component with depth.

Contours of kinetic energy in the mean velocity field generally follow the downstream velocity isotachs. Throughout the section, the kinetic energy of the fluctuations from this mean are as large as the mean, except near the surface. The influence of the tides is felt everywhere and not only on a vertically averaged basis. Near the surface, vertical gradients of kinetic energy are large. With increasing depth, the horizontal gradients become larger than the vertical gradients.

Temperature and salinity profiles were taken at each station. Near the surface (less than 50 m) very low salinity water was almost always detected, presumably from South American river discharges (Amazon or Orinoco). This water was only found in the surface region where the average cross-stream velocity was toward the north. The great majority of water in the passage was North Atlantic Central Water. Near the bottom of the deep central stations, Antarctic Intermediate Water and North Atlantic Deep Water were detected.

The average density field indicates geostrophic flow into the Caribbean. However, the isopycnals show no indication of the subsurface velocity maximum observed at the northern part of the section.

TURBULENT DECAY
Subtitled - Laminar-Turbulent Interface

Principal Investigator: F. K. Browand
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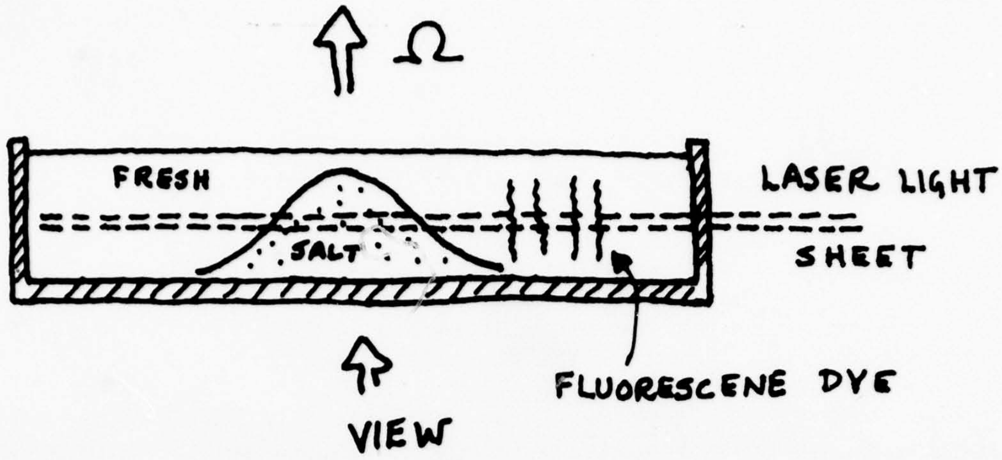
Department of Aerospace Engineering
Los Angeles, California 90007
(213) 741-2035

The long range objective is to contribute to a fundamental understanding of turbulent flows, and to apply this understanding to oceanic mixing processes. This is accomplished by means of laboratory experiments designed to identify the important mixing processes at various scales. These laboratory experiments focus on individual mechanisms and provide detailed information useful to the working oceanographer.

We have previously made a series of measurements of turbulence produced by shear at the boundary between two layers of different density. A paper on this subject has been submitted for publication. The work will continue in a larger facility completed recently with the following objectives: i) to observe mixing at more realistic Reynolds numbers; ii) to determine the spanwise (cross flow) extent of these large scale features.

On a somewhat larger scale, a simple two layer model of an ocean eddy has been produced in a rotating container. An initial release of slightly heavy fluid into uniform ambient produces a geostrophically balanced equilibrium state. This condition may be unstable, and develop waves which ultimately pinch off to form smaller geostrophic eddys. This process is visualized by using fluorescent dye and a laser light sheet. Figure 1 is a sequence illustrating the instability and the formation of three smaller eddys.



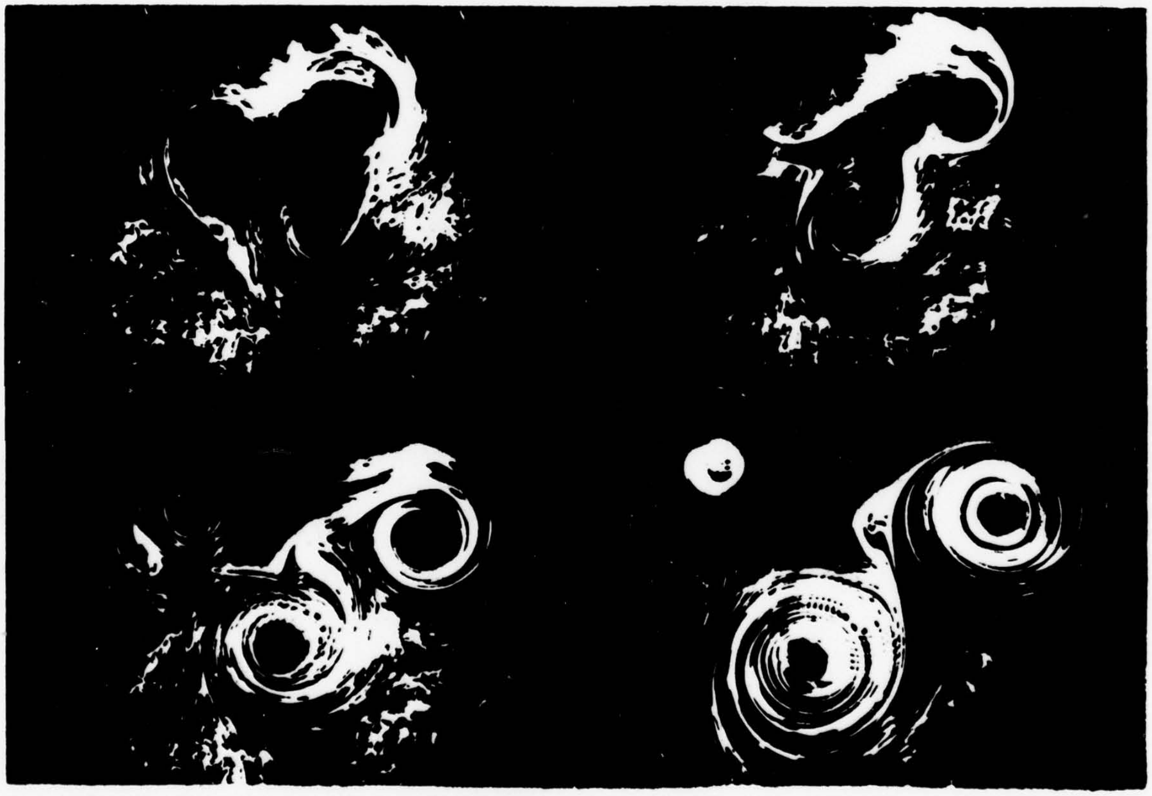


Figure 1. Instability of Geostrophically Balanced Two Layer Flow. Development of Smaller Eddys.

PROJECT TITLE: Electromagnetic Scattering Studies Related To Oceanographic Remote Sensing

INVESTIGATOR & AFFILIATION: Dr. Gary S. Brown
Applied Science Associates, Inc.
105 E. Chatham St.
Apex, North Carolina 27502
(919) 362-9311

LONG RANGE OBJECTIVES: Determine through the use of active microwave techniques means for remotely sensing oceanographic surface characteristics which are important to the understanding of ocean surface wave generation and propagation.

PROJECT OBJECTIVE: Determine the correlation between ocean frontal activity and changes in the mean waveform and backscattered power as recorded by a spaceborne, short pulse, radar altimeter. Determine the impact of ocean wave generation nonlinearities upon theoretical models for electromagnetic scattering from the ocean surface.

CURRENT STATUS: This project was initiated on 1 March, 1979.

MAJOR ACCOMPLISHMENTS: None to date since the project has just started.

SATELLITE REMOTE SENSING OF LARGE-SCALE OCEANIC TRANSIENT EVENTS

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Telephone: (305) 350-7491

LONG-RANGE SCIENTIFIC OBJECTIVES

Develop quantitative methods for the interpretation of satellite-sensed sea surface temperatures and wind stress. In particular, apply these types of synoptically sensed data to the problems of western boundary current spinup, equatorial current meandering, and large-scale mixed layer heat budgets.

PROJECT OBJECTIVES

Develop simple algorithms suitable for mini-computer use which will extract, calibrate and map raw satellite data and insert it into an accessible data base.

Validation of high resolution two-dimensional time series of satellite data fields in the Atlantic and Indian Oceans.

Study the large-scale thermal response of the Western Indian Ocean to the Southwest Monsoon. Specifically, determine the role of large-scale vs. local wind forcing on the initial spinup.

Study the genesis of the surface thermal signature of the "Great Whirl", the large-scale anticlonic eddy southeast of Socotra, during Somali Current spin-up. Identify principal mechanisms responsible for large-scale cooling in the interior of the Western Indian Ocean. Investigate the causes of the variability of the Somali Current separation latitude.

CURRENT STATUS

Satellite data processing is presently carried out in several stages:

1. Scanning Radiometer (SR) data from Indian Ocean is being routinely processed and analysis is underway.
2. Polar orbital navigation model (based on orbital emphemeris) is operational.
3. NOAA/VHRR/AVHRR infrared and visible data from the Arabian Sea is being received in Mombasa and archived on magnetic tape.
4. High precision, landmark driven navigation model for VHRR/AVHRR imagery is operational.

MAJOR ACCOMPLISHMENTS

1. Atlantic Ocean: observation of long wave forcing of equatorial thermal field in the Eastern Atlantic.
2. Indian Ocean: identification of bimodal structure of the Somali Current.
3. Indian Ocean: monsoon induced large scale cooling of Western Indian Ocean.
4. Indian Ocean: study of interannual variability in the Arabian Sea surface temperature field.
5. Atlantic Ocean: fine structure mapping of Gulf Stream instabilities by ship and satellite.

TEMPERATURE MEASUREMENTS WITH XBTs IN THE NORTHWESTERN INDIAN OCEAN (an INDEX proposal)

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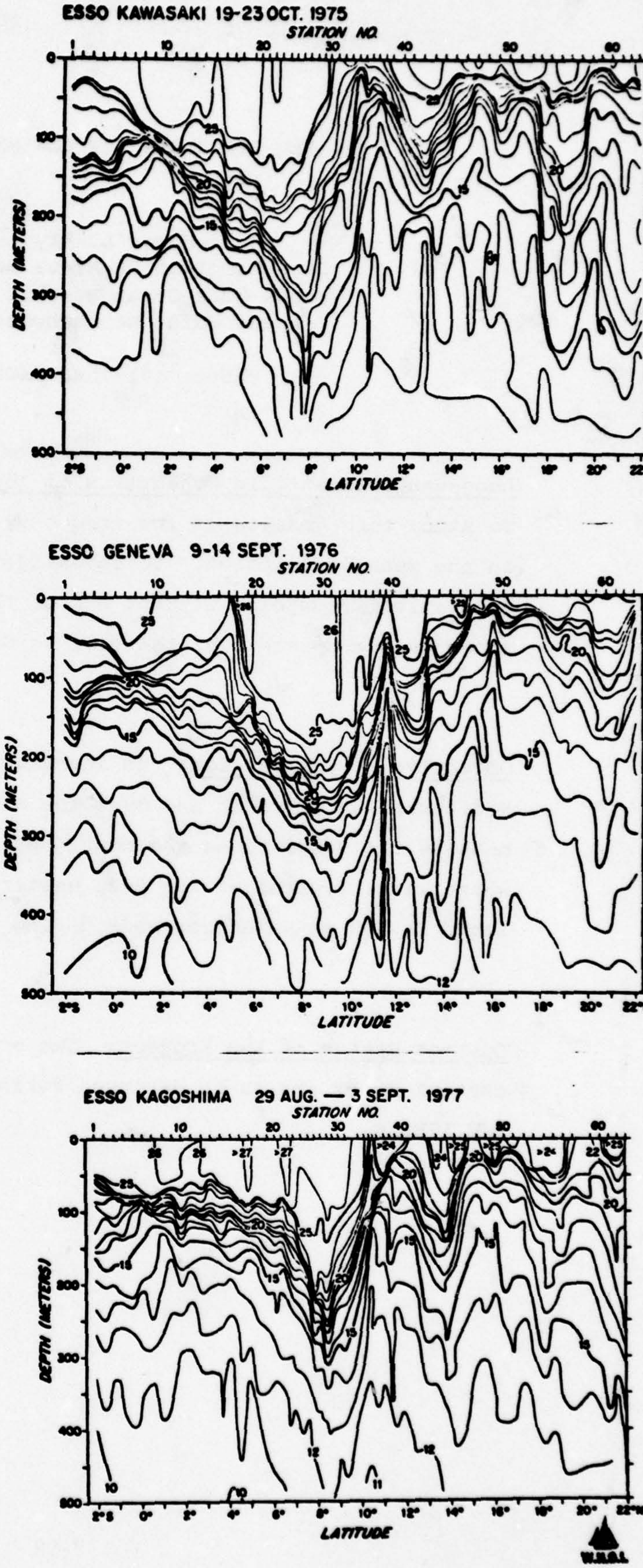
The long-range scientific objectives of the proposed program are to attempt to understand the circulation dynamics of the western Indian Ocean, particularly as it responds to the strong monsoonal winds. We hope to determine the time variations and horizontal scale of the eddy circulation associated with the commencement of the dominant southwest monsoon, the variation during an entire season and also from year to year, whether certain preferred modes exist in the current patterns, the decline of the flow upon cessation of the monsoon winds, the changes in the heat content of the mixed layer, the variations in the region of strong upwelling off the Somali and Arabian coasts, and the changes occurring in the near-equatorial dynamic topograpy as a result of the Somali circulation.

It is felt that studies in this region might be important to the Navy because we are now obtaining considerable information about the unusually strong horizontal temperature gradients which develop during northern summer off the Somali and Arabian coasts within a relatively short period (two to three months for full strength). Variation in acoustic propagation patterns in this area would be quite large. Also the surface currents associated with these gradients are on the order of about twice that found in the Gulf Stream.

The objective of the project is to monitor the changes in thermal structure in the eddy field in the northwestern Indian Ocean by means of XBT observations from tankers and a survey during August and September 1980 from USNS WILKES. The program is associated with INDEX (Indian Ocean Experiment) which will result in numerous observations during a multiple ship survey of the commencement stage of the southwest monsoon 1980. The observational program is planned to enable the measurements to compliment each other as the monsoon season and Somali eddy develop.

Starting in October 1975 we now have completed 21 round trips from the Exxon tankers with another presently in progress. A total of 12 trips are planned for 1979 with special attention to the development of the southwest monsoon.

Major accomplishments are: (1) the prime eddy has been observed for four successive years, forming in the northern Somali Basin (~8°N to 10°N) in late May, reaching full development by September and decaying over the next four or more months. Each year a smaller eddy is formed off Socotra to the northeast of the prime eddy. On occasion (1976 monsoon) a southern eddy (south of about 5°N) forms along the coast resulting in upwelling at 5°N as well as at 9°N to 10°N (associated with the prime eddy). (2) We have also observed that the eddy circulation appears to strongly modify the sea surface dynamic height at the equator by cooling the mixed layer. Such a signal might be responsible for a variation of the equatorial undercurrent.



Temperature (°C) sections along the tanker sea lane from XBTs for three successive southwest monsoons: 1975, 1976, and 1977. The large Somali prime eddy is clearly discernable (4°N to 12°N), particularly toward the middle or end of the southwest monsoon.

MEDITERRANEAN OUTFLOW MEASUREMENTS

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Long-Range Scientific Objectives of the Principal Investigator: To study the dynamics of low-frequency motions and their effects on the mean circulation. To investigate the dynamics of the Antarctic Circumpolar Current and of the flow of deep Mediterranean water up and over the sill at Gibraltar.

Objective of the Project: To investigate the flow of deep Mediterranean water up and over the sill at Gibraltar. To measure the currents on the continental slope north of Morocco where water typical of the deep western Mediterranean basin was found in CTD measurements made during 1975.

Current Status of the Project: Two moorings each with one current meter are to be deployed during August, 1979 from R/V ISELIN.

MEASUREMENT AND PARAMETERIZATION OF AIR-SEA FLUXES AT HIGH WIND SPEEDS: ADAPTATION OF BULK PARAMETERIZATIONS TO ALLOW FLUX COMPUTATIONS FROM CLIMATOLOGICAL AND SYNOPTIC DATA

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The long-range objective is to understand the nature, mechanisms and consequences of air-sea processes. Knowledge of the transfers is of importance to meteorological and oceanological forecasting. Momentum transfer is important for waves and currents and the mixing of the upper layer. The total energy flux determines the formation and breakdown of the seasonal thermocline. The forecasting of these phenomena is important in many practical ways, e.g. navigation, operations, submarine detection, ship motions, etc. Oceanic and atmospheric turbulence are important in diffusion of materials, wake detection and radio transmission scatter.

The objectives are: (1) to measure and parameterize fluxes of momentum, sensible heat and latent heat (moisture) up to high enough wind speeds to allow good calculations of these fluxes over the ocean; (2) to see if a wider range of data may be used by comparing fluxes calculated from data reduced to climatological form (wind roses and averages of air-sea temperature and humidity differences) and synoptic form (surface pressure maps and air-sea temperature and humidity differences averaged over various periods) with fluxes calculated using bulk aerodynamic formulae.

Many data allowing momentum and sensible heat flux estimates by both Reynolds flux and dissipation methods in winds up to 20 ms^{-1} have been collected on the Bedford Institute Stable Platform located about 10 miles off Halifax, Nova Scotia. The Reynolds flux and dissipation methods give the same results on average for both momentum and sensible heat fluxes. A comparison for momentum based on 192 one hour runs is shown in Pond, et al. (1979). Data allowing dissipation estimates of the stress and sensible heat flux have also been obtained on the CCGS Quadra at ocean weather station PAPA in winds up to about 25 ms^{-1}. Drag coefficients based on dissipation estimates from the ship and the Bedford platform are in good agreement on average; based on over 1500 runs C_D is constant on average up to about 10 ms^{-1} and then increases with wind speed reaching about 1.5 times the constant low speed value at 20 ms^{-1}. Data from which dissipation estimates of the moisture flux can also be made were obtained during JASIN and are being examined.

Following the investigation of the use of climatological and synoptic type data to calculate fluxes reported in Fissel, Pond and Miyake (1977) for which station P data were used, further work using data from 10 Atlantic weather ships and station N in the Pacific is in progress to see how the results based on the P data may be generalized.

MIXED-LAYER MICROSTRUCTURE

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Oregon State University
Corvallis, Oregon 97331

LONG RANGE OBJECTIVE

To develop an understanding of the physical processes by which heat and mass are transferred vertically in natural waters.

PROJECT OBJECTIVE

The extension of our knowledge of vertical transport processes affecting the surface mixed layer, through observations of temperature and salinity "microstructure."

CURRENT STATUS

In August-September 1977 a month-long cruise as part of the MILE experiment resulted in 381 microstructure profiles at station P. Analysis of this data base has resulted in the following publications and manuscripts: (1) "Temperature Microstructure Profiles at Ocean Station P: Preliminary Results from the MILE Experiment" (OSU Reference 77-22); (2) "Catastrophic Events in a Surface Mixed Layer" (Nature, v. 276 p. 601, 1978); (3) "High-Frequency Internal Waves at Ocean Station P" submitted to JGR December 15, 1978); (4) "The Redistribution of Plankton by Storms" (submitted to Science December 15, 1978). Two other manuscripts have been prepared and are nearly ready for publication: (1) "Scaling of the Cut-Off Wavenumber of Vertical Temperature Gradient Spectra" (to be submitted to JGR, March 1979); (2) "Universiality of Vertical Temperature Gradient Spectra" (to be submitted to Jour. Fluid Mech., April 1979). In addition, a calibration facility for measuring the temporal response of thermistors has been constructed, and response calibrations pertinent to the MILE experiment will be completed in March 1979. Progress is continuing on an analysis of the distribution of magnitude of turbulence before, during, and after a storm. Because of the large data set, most of the remainder of 1979 will be devoted to this study.

MAJOR ACCOMPLISHMENTS

Microstructure measurements of a temporal sampling density for greater than that achieved before were obtained under adverse weather conditions. These measurements reveal: (1) Relatively infrequent but large-scale mixing events can dominate heat transport during a large storm; (2) A relation exists between the Cox number, buoyancy frequency, and cut-off wavenumber; (3) Vertical temperature gradient spectra have a universal form which resembles but differs significantly from the Batchelor spectrum; (4) High-frequency internal waves are dominated by low-order modes; (5) Vertical distributions of plankton in the upper waters are radically altered by a storm.

INTERNAL WAVE TRANSPORT PROCESSES

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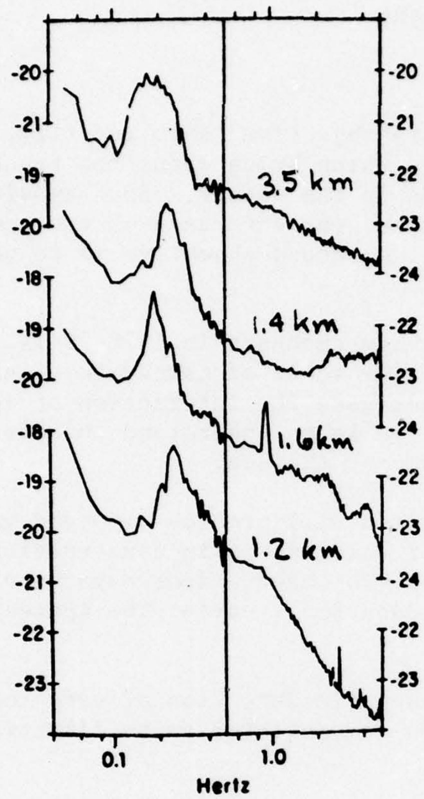
Long Range Objectives. My primary objective is to identify, locate, and measure the small scale processes which bring about the transfer of heat, momentum, and material substances in the oceans. Such knowledge is necessary to understand dissipative processes, the structure of the ocean, and rates of change of oceanic properties. A second objective is to understand electrodynamic processes in the ocean.

Objectives of current work. Primary emphasis in 1978-79 is to describe the processes which bring about the fine scale of temperature, salinity and density in the ocean and to investigate the interaction of internal waves with shear flows. Another objective is to understand the distribution of internal wave energy in the volume of the sea.

Current status. An instrument which will provide repeated vertical profiles of the three components of water velocity is in construction. A closely spaced array of stations at which CTD observations have been repeatedly carried out has provided useful data for study of the space-time history of oceanic fine structure.

Major accomplishments. Electromagnetic detection of very low frequency sound waves in the ocean has been demonstrated to be effective.



Spectra of one horizontal component of the electric field measured at the sea floor. The depths of observation sites are shown on each trace. The ordinate is the logarithm (base 10) of the electric field intensity in $(V/m)^2/Hz$. The prominent peak on each spectrum near 0.2 Hz has been associated with the nonlinear interference of sea surface wave trains traveling in opposite directions. In water more than 1.9 km deep, the pressure disturbance so generated can be considered an infrasonic wave.

Title: NORPAX Program Administrator

Investigator: Dr. David L. Cutchin
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The goal of the NORPAX administration office is to provide overall program administration for the NORPAX project which encompasses more than 35 scientists at approximately 15 institutions and government agencies. This administrative function involves proposal coordination and review, long-range planning, funding agency interface and day-to-day program administration. It serves as a central point of contact and public relations to the outside world concerning the NORPAX program.

Accomplishments:

1. A Quarterly Report is issued to provide participating scientists, funding agencies and other interested parties a vehicle for keeping abreast of current accomplishments and direction of this multi-institutional program.

2. A mainland coordination base is being provided for the NORPAX/FGGE equatorial experiment between Hawaii and Tahiti. Planning for the experiment started in the spring of 1978 and the field phase will go for 16 months beginning in February of 1979. Dr. Cutchin's responsibilities include, among other things, the integration of a large number of non-NORPAX piggyback projects. There are now about 10 of these projects funded for a total of $1 million.

3. Organized and conducted meeting of the NORPAX Co-Principal Investigators and guests. The 1978 meeting was the best attended of all Co-Principal Investigator meetings to date.

4. Shepherded NORPAX P.I.'s through NSF and ONR proposal reviews. The NSF review was also a comprehensive review of the long-term accomplishments of NORPAX and its plans for phasing out by 1982.

5. Prepared and delivered a number of presentations about NORPAX and its plans and accomplishments. Examples are presentations for the Naval Research Board of the National Research Council, groups of foreign naval officers attending the ASW school in San Diego, the crews of the Royal Air Force planes which are flying AXBT sections for the NORPAX tropical experiment, and the FGGE Panel of the U.S. Committee for GARP.

UPPER OCEAN DYNAMICS

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The objective of this study is integration of observation and theory into a description of the momentum budget of the upper ocean. On the observational side, this entails developing instruments and techniques for detecting and identifying dynamical entities such as internal waves, vertically propagating inertial motions and wind driven currents. On the theoretical side the aim is to use the observations to develop an ability to predict quantities like the vertical structure of wind driven currents or the variability of the internal-inertial wave climate under varying conditions.

Instrument intercomparisons in the MILE experiment and laboratory testing have shown that the biaxial propeller vector measuring current meter developed for this study has provided an accurate moored instrument for use in the upper ocean. These instruments were again deployed in JASIN. The MILE and JASIN data is under analysis. Completion of this analysis will result in two descriptions of upper ocean response to wind forcing, of the vertical structure of the velocity, and of the nature of the inertial and internal wave motion observed in these experiments. Plans have begun to expand this description of the upper ocean by investigating the variability of the response to forcing and of the internal wave climate in a year long mooring deployment in cooperation with Mel Brisco of WHOI and David Halpern of P.M.E.L.

Upper ocean variability, in regions where wind forcing is less dominant and internal processes lead to rapid horizontal variability, demand observational techniques other than fixed position moorings. An Ametek-Straza Doppler ship's log has been improved and now has the capability of making useful velocity measurements to depths of nearly 100 m with a depth resolution on the order of 10 m. In combination with accurate navigation this will be used in the Frontal Program Pilot Study to investigate the dynamically active Pacific subtropical frontal region.

Dynamics of the Ocean Surface Mixed Layer

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Long-Range Objectives

- To examine and model the processes of air-sea exchange of heat, momentum and mechanical energy.

- To examine the horizontal distributions of heat and salt in the upper ocean in terms of models of these processes.

- To examine the processes of formation and decay of fronts in the upper ocean.

- To examine the interaction of the upper ocean with deeper processes, such as eddies.

- To participate in the design and interpretation of field experiments contributing to the above goals.

Project Objectives

- Theoretical study of a model of instabilities of an oceanic density front to determine the dynamical time and space scales of fluctuations.

- Completion of MILE data analysis: description of mixed layer response to atmospheric forcing; description of internal wave state in upper ocean.

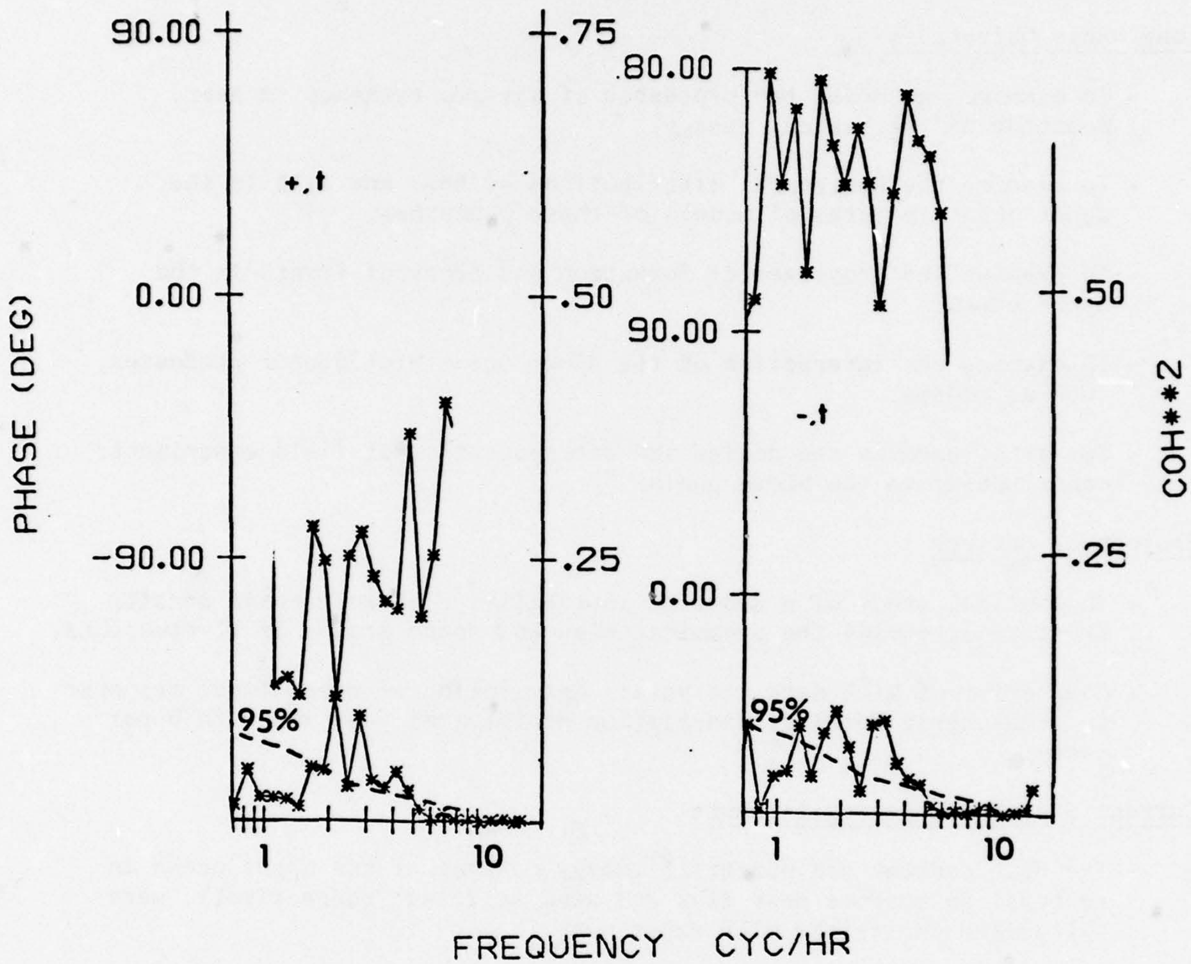
Current Status and Accomplishments

- The heat content and potential energy content of the upper ocean in response to surface heat flux and wind stirring, respectively, were calculated during the MILE experiment.

- The spectral phase and coherence structure of the internal waves observed in the MILE current meter-thermistor array was examined. A band of strong vertical coherence in temperature (or displacement at high frequency (1-5 cph) cut-off was discovered. Coherence is seen also between horizontal velocity at shallow levels and temperature (displacement) at deeper levels with phase relationships that suggest standing wave modes in this frequency range (see Figure).

- A numerical model of frontal dynamics is being implemented.

- A two-dimensional mixed layer model which demonstrates tendency towards frontal formation has been re-formulated.



High-frequency internal waves during MILE. Coherence-squared and phase spectra are shown between anti-clockwise (left) and clockwise (right) rotary components of velocity at a shallow level (11m) with temperature at a deeper level (32m) somewhat below the mixed layer. A band of statistically significant (95%) coherence between 2-5 cph is found in the region of a strong cut-off in the temperature (or displacement) spectra. The hypothesis of vertically standing modes requires that the (+,T) phase and (-,T) phase sum to zero, which the reader may judge for himself.

Transient Processes in Ocean Currents

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Long range objectives:

Develop a better understanding of the kinematics, dynamics and transient behavior of well-defined, intensive ocean currents and, furthermore, of the role of intensive ocean currents in air-sea feedback systems and in oceanic heat budgets.

Project objectives:

Conclude GATE effort, continue ongoing fieldwork in the Indian Ocean (since 1976) and prepare for major international field effort in the Western Indian Ocean for Spring/Summer of 1979.

Current Status and Major Accomplishments:

GATE: The P.I. serves as guest-editor to Deep Sea Research. Approximately 25 papers are on hand (2 papers co-authored by the P.I.) and about 18 were found suitable for publication in a supplement issue for Deep Sea Research. Publication of this volume is scheduled for 1979.

A study entitled "Intercomparison Between Cloud Level and Surface Winds for the GATE Area" is in press. The results of this comparison were rather disappointing concerning expectations on the ability to derive surface wind-stress from cloud level motion. It was found that cloud-level-to-surface transformations are highly variable in space and time, and yield surface winds which correlate poorly with observed winds.

INDEX: A heat budget study for the Arabian Sea suggests that the main contributors to Arabian Sea summer cooling are upwelling and cross-equatorial advection of cold water by the Somali Current. Exploration of details of these mechanisms are planned during a major field experiment in 1979. Long term moorings of current and temperature recorders along the coast off Somalia (both in shallow and in deep water) were continued during the past year and will be maintained until July 1979 to embed shipboard observations and remotely sensed sea surface temperatures in a continuum of time series.

OCEANIC THERMAL RESPONSE TO ATMOSPHERIC FORCING

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The long-range scientific objective of this research is to improve our understanding of the response of the oceanic planetary boundary layer (OPBL) to atmospheric forcing. Specific methods used in this study include advancement of higher-order turbulence closure techniques, preparation and study of atmospheric forcing fields, and time integration of realistic upper-ocean thermal (and salinity) structures, together with comparative analyses with verifying ocean data fields.

The objectives for this year have three primary components: (1) analysis and modeling of the mixed layer experiment (MILE) results, (2) coupling an OPBL model with an ocean general circulation model, and (3) initial study/modeling of boundary layer interactions with large-scale surface density fronts. A preliminary one-dimensional numerical simulation of the mixed layer evolution during MILE has been conducted. The results for layer depth and temperature compare favorably with CTD observations, and may prove useful in diagnosing significant vertical mixing events from the actually observed thermal structure changes that include a strong tidal-period internal wave signal. The coupling of the Haney OGCM and the Garwood OPBL model is progressing. In order to rigorously test the coupling scheme, a very demanding (both dynamically and numerically) first problem has been undertaken: the unsteady two-dimensional upper-ocean response to a tropical cyclone. If the coupled system can realistically simulate this problem, it can be successfully used for many other problems, including frontal studies.

Other accomplishments this year include a study (Elsberry and Garwood, 1978) of how sea-surface temperature anomalies may be generated by both anomalous storm strength in the fall and by anomalous timing of storm incidents during the spring. From this, it has become clear that the frequently very rapid winter-to-summer transition of the OPBL may play a crucial role in the development of certain kinds of persistent upper-ocean temperature anomalies.

Expanding upon the cooling-season study of Elsberry and Camp (1978), Elsberry and Raney (1978) presented statistics for the observed ocean response to atmospheric forcing during the heating season. Again the role of synoptic-scale surface forcing is clear from both the statistics and from the model simulations (see Fig. 1).

A workshop on the ocean thermal structure response to hurricanes was convened at the Naval Postgraduate School in April 1978. The purpose of this was to document the state of the art in numerical modeling of this phenomenon and to assess the quantity and quality of the observational data base.

A comprehensive review of recent sea-air interaction and mixed layer modeling literature was completed. The results were summarized in a U.S. report to the IUGG (Garwood, 1979). Part of this review included a new study of the theoretical differences of alternative mixed layer entrainment models.

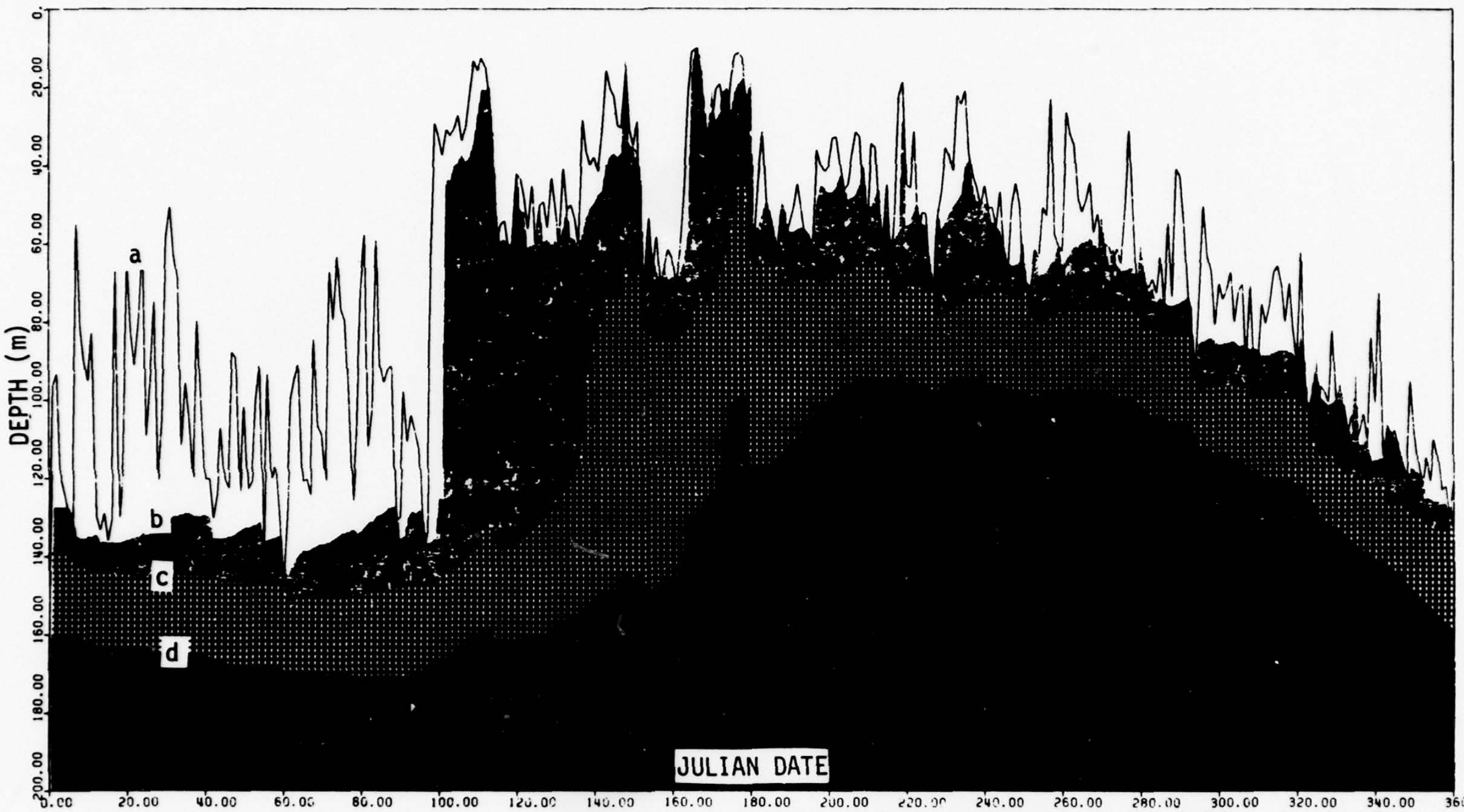

Fig. 1 Model simulation of the mixed layer evolution at Ocean Station P for 1959: depth of (a) the turbulent boundary layer showing synoptic-scale variability; depth at which temperature is (b) 0.2 C, (c) 1.0 C, and (d) 2.5 C less than mixed layer temperature. Notice the rapid winter-summer transition on about day 100.

XBT SWATH ANALYSIS: A STUDY OF SPATIAL VARIABILITY

Co-Principal Investigators

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Long-Range Scientific Objectives of this Investigator*

Through the study of new and existing data develop an understanding of the spatial and temporal variations in the thermohaline structure of the ocean. To achieve this understanding I would like to promote the collection of data with spatial character such as multi-ship surveys, satellite thermal IR, ship of opportunity XBT sampling and air XBT surveys.

Objectives of this Project:

To use the existing six multi-ship XBT swaths to better describe the mesoscale features, such as fronts and eddies, observed in these surveys. To develop a suite of statistical techniques that would better quantify mesoscale features and further facilitate the interpretation of single XBT sections. To evaluate where and when future multi-ship or air XBT surveys should be made.

Current Status:

Vertical temperature sections from all ships are being used in conjunction with horizontal plots of surface and sub-surface isotherms to evaluate which mesoscale features can be identified as closed eddies. Using the isotherm deflection, normalized by the standard deviation, criteria have been established to identify those features which are significant above the noise level. Comparison is being made between the six multi-ship swaths and similar XBT surveys collected as part of the Polymode program.

Auto- and cross-correlations have been computed for all six surveys and will be used, along with a histogram technique, to identify the predominant length scale for each swath. Mesoscale thermal features are considered as individual events and are not necessarily periodic. Vertical correlations between various isotherms will determine how representative surface temperature is of sub-surface thermal features.

Major Accomplishments:

A paper based on a Pacific multi-ship survey has been accepted for publication in the Journal of the Acoustic Society of America. In this paper XBT casts are extrapolated to the bottom, and a three-dimensional picture of sound velocity is created using mean temperature-salinity curves to produce density from the temperature data. Numerical acoustic propagation experiments in this structure demonstrate the effect of mesoscale features on the propagation of sound in the deep sound channel.

A census of four of the six surveys indicates that most of the mesoscale features, identifiable in vertical sections, are not closed eddies.

Equatorial Dynamics

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The ultimate objective of our work is to understand the dynamics of equatorial oceans, particularly the response of the equatorial oceans to wind forcing. It is recognized that while the physics of each ocean is roughly the same, the forcing in each is quite different. We would like to obtain descriptions of long time scale variability so that we can build realistic physical models which will predict the behavior of equatorial oceans.

The project objective is to measure currents and temperatures in coherent arrays within the equatorial waveguide over a long period of time so that we can test ideas of equatorial confinement, zonal energy flux, and vertical transfer to momentum. A variety of spatial and temporal scales are involved in equatorial response to wind forcing; we wish to identify them and find physical models which relate the various processes properly.

Currently we are making 16-month moored instrument observations in the western Indian Ocean and 24-month observations in the western Pacific Ocean (Gilbert Islands). Earlier observations in the Indian Ocean indicate the presence of equatorially trapped waves. Our present measurement programs are designed to further describe the wave field and allow examination of long period motion (months and longer).

With the Indian Ocean data we have been able to demonstrate for the first time the existence of equatorially trapped inertial gravity, mixed Rossby-gravity and Kelvin waves over a large frequency band (periods from a couple of days to roughly a month). The waves have broad bandwidth; for any given frequency there are many waves of different wavelength with significant energy. The field of equatorial waves has an energy spectrum similar to internal waves at mid-latitude. With further measurements, we will look for a "universal" equatorial wave spectrum. Preliminary work indicates that one exists.

Gulf Stream Extension Mooring Array

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The long-range objective is measurement of the time-dependent current and temperature variability throughout the Gulf Stream System to provide estimates of the mean and eddy momentum and kinetic energy distributions. These are required to describe and understand the energetics of the System.

A moored current meter array of 10 moorings is planned to be deployed jointly with the Bedford Institute of Oceanography for one year starting October, 1979 in the region southeast of the Grand Banks bounded by latitudes 35° to 40°N and longitudes 42° to 47°W. The array will be set to explore the area of separation of the Stream into the Atlantic Current flowing north and a branch flowing southeast and west into the Sargasso Sea. It is expected that the region will contain strong variable currents at all levels from surface to bottom. The array is exploratory with spacing between moorings ranging from 100 to 250 km. Velocity and/or temperature will be measured at 500, 800, 1500 and 4000 m depth. Four of the moorings will be instrumented to obtain near bottom measurements (5000 m) in a cooperative experiment (L. Armi) to study Norwegian Seawater intrusion in the bottom layer.

NR 083-400

Moored Array Program

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The overall objectives of the moored array program are to explore and describe the velocity and associated temperature, salinity fields in the oceans over a broad range of time and space scales; to interpret the data in terms of theoritical and conceptual models; and to improve and develop instruments and platforms needed to obtain the data desired.

Research is carried out jointly with investigators from within the moored array program and with scientists associated with other programs, departments and institutions. Each scientist utilizing moored array program resources will describe his personal research elsewhere in this report. The principal investigators listed above are responsible for the technical quality of the observations made, and for encouraging the best possible cooperative experiments. With respect to technical quality: (a) mooring recovery is nearly 100%, (b) current meter data return is near 90%, (c) all commitments made in the last few years have been successfully completed, including innovative efforts such as a tri-mooring, the first large-scale sediment trap moorings, and one-year deployments. It is felt that the results of experiments utilizing our capability are playing a fundamental role in forming the observational base for contemporary oceanography.

"Theoretical Model of Oceanic Front Evolution"

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The long range scientific objective of the principal investigator is to develop understanding and predictive capability for oceanic frontal dynamics. Both theoretical modeling and field observations are used to this end.

The objective of the current project is to develop a model of the time and space evolution of an established upper ocean density front subject to perturbation. An analytic model has been completed which treats the linear case of small amplitude, sinusoidal displacements of the frontal system. The basic state of the system is similar to Stommel's model of the Gulf Stream frontal zone with uniform potential vorticity; however, finite cross-stream flow is permitted. The analysis shows the system to be stable for all perturbation wavelengths if the basic state has zero cross-stream flow. However, finite cross-stream flow generally makes the system unstable with disturbance amplitudes growing in time.

A numerical model is being developed to treat the same phenomenon, but where finite amplitude disturbances are present. It is hoped that this model will yield information on the growth of frontal meanders and of eddy generation.

"Towed microstructure measurements in the upper ocean: MILE experiment, US/USSR turbulence intercomparison"

Carl H. Gibson, Associate Professor of Engineering Physics and Oceanography, Scripps Institution of Oceanography, La Jolla, Calif. 92093 (714) 452-3184

Analysis of the data from both expeditions reveals a complex layered structure in the temperature, density and salinity fields produced by interacting internal waves, shear and turbulence. Most of the mixing, vertical diffusion and dissipation appears to be concentrated in patches which occupy a rather small volume fraction of most layers, but which dominate the average flux and dissipation rates. Turbulence in the patches appears to be rapidly damped out by buoyancy to produce a small scale internal wave-like motion, but temperature microstructure produced by the turbulence persists as fossil temperature turbulence. Universal similarity scales for the diffusive range of fossil scalar turbulence using the buoyancy frequency N as an effective rate of strain parameter rather than the Batchelor turbulence rate of strain parameter γ are shown in the table. Many observed temperature gradient spectra in the ocean converge to the same diffusive cutoff peak when normalized by the buoyancy length, time and scalar scales, suggesting fossil temperature turbulence.

	Buoyancy Scales	Turbulence Scales
Length	$(D/N)^{\frac{1}{2}}$	$(D/\gamma)^{\frac{1}{2}}$
Time	N^{-1}	γ^{-1}
Scalar	$(\chi/N)^{\frac{1}{2}}$	$(\chi/\gamma)^{\frac{1}{2}}$
	χ = dissipation rate of scalar variance	D = scalar diffusivity

Others have peak wavenumbers intermediate between the fossil value of about $0.3(N/D)^{\frac{1}{2}}$ and $0.3\,(\gamma_0/D)^{\frac{1}{2}}$ for active turbulence at the point of fossilization, where it can be shown that $\gamma_0 \cong (40C/Pr)^{\frac{1}{2}} N$, C is the Cox number and Pr is the Prandtl number, suggesting partial fossilization.

Horizontal profiling over several kilometers and vertical profiling over several meters appears to be necessary to adequately characterize the microstructure in any density layer.

a. Sea Level and Sea Level Temperature Expression of Ocean Transients as Viewed from Satellite.

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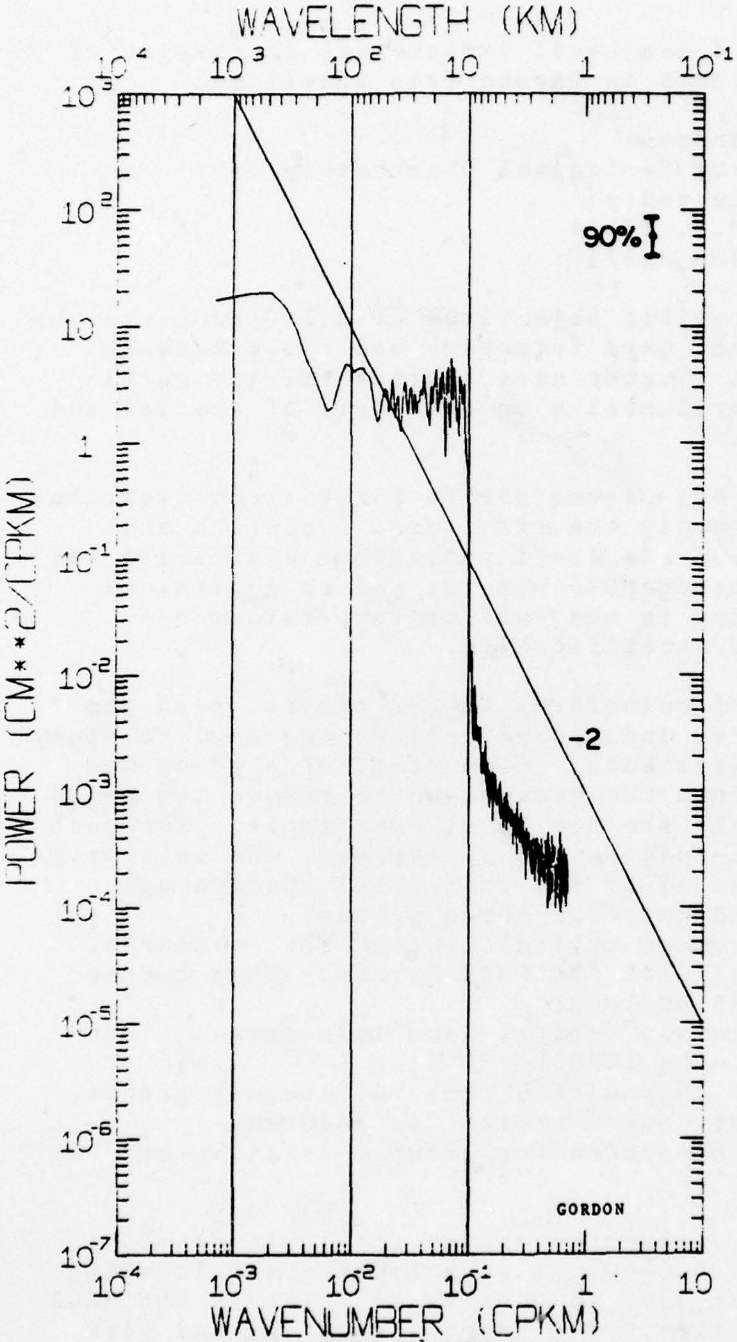
b. General scientific objectives of A.L.Gordon are the study of water mass formation and the processes that transport water mass characteristics vertically and horizontally on a variety of spatial and time scales.

c. The project objectives are to first study distribution and secondly the structure, evolution and translation of sea level variations associated with transient geostrophic events, and to determine their relation to sea surface temperature and thermohaline stratification.

d. Six groups of coincident GEOS-3 orbits, each composed of three individual orbits, are used to study sea level transients. Each orbit of a group was subtracted from the group mean to remove the geoid and leave only the sea level transients. For each difference a spectra was determined, and an average spectra composed of all individual spectra was made. We did this for three groups:
a) longest common orbital line on the equatorial (Sargasso) side of the Gulf Stream. This turned out to be 735 km long;
b) longest common orbital line in general. This turned out to be 1080 km:
c) a special composite of the two longest groups, whose longest common orbital is 1430 km.
The composite spectra for group C is given as figure 1.

e. An increase of spectra energy (following a -2 slope) up to 500-600 km wave lengths and leveling off at longer wave lengths is most likely the MODE mesoscale eddies. The trough at 200 km and peak near 100 km may be part of the suspected instrumental nearly white noise, clearly seen at less than 100 km, but its persistence in the GEOS-3 records and its spectral width suggest further evaluation.



6 SPECTRA: GROUPS 18, 19
2048 POINTS=1430 km
10 km CUTOFF

(1) 5

PROJECT TITLE

XBT sections in the Northeast and South Atlantic

PRINCIPAL INVESTIGATOR

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Surrey GU8 5UB

LONG RANGE SCIENTIFIC OBJECTIONS OF P.I.

Investigation of mesoscale motions in the N.E. Atlantic

OBJECTIVE OF PROJECTS

T-7 XBT probes supplied by ONR have been deployed on ship tracks in the N.E. Atlantic and more recently in the South Atlantic ocean. The objective has been to collect XBT information capable of revealing the mesoscale structure in previously sparsely covered ocean areas.

STATUS OF PROJECT

In addition to the XBT tracks previously collected by this project in the N.E. Atlantic (North and East of 33^{O}N and 30^{O}W) we have recently received data from three log tracks penetrating into the S. Atlantic. The first two were made by HMS Endurance on passage from the UK to South America and were made by alternating UK T-4 probes with the ONR funded T-7s'. The total length of these two tracks is 11,500 km and they reveal great detail in the equatorial regions. The third track was made by RRS Discovery between Recife and Cape Town early in 1979 and reveals eddy activity close to the Walfis Ridge. The remaining probes are to be deployed in the Antartic and Indian oceans during 1979. A final data summary will be prepared.

Project

Development of a towed, two component surface current sensor.

Principle Investigators

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Long range scientific objectives of PIs

Investigation of mesoscale dynamics of Eastern N. Atlantic

Development of oceanographic instrumentation.

Project objective

The project aims to build a near surface towed body incorporating two velocity component, heading and temperature sensors the outputs of which when processed in the deck control unit and combined with satellite navigation information will yield values of near surface currents over the periods between satellite positions.

Current status

This project was a joint development effort between the UK Institute of Oceanographic Sciences and the Woods Hole Oceanographic Institution. Fabrication of the towed sensor package and a shipboard data logger was completed in July 1978 by Mr. D. Bitterman and given its initial trials aboard the RRS Shackleton and R/V Atlantis during and after the JASIN experiment. Presently this data is being reduced and analyzed in order to evaluate the performance of the system. These are two main goals in this year's work. First the capability of providing a real time display of the surface currents is being incorporated into the system to make it more practical for the user. Secondly, an effort is being made to get it into the field as an integral part of several field experiments to determine its usefulness as a scientific tool.

SMALL SCALE MIXING PROCESSES

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Long-Range Scientific Objectives of the Principal Investigator

My long-range scientific objectives are to develop a quantitative understanding of the dissipative processes in the ocean and their role in the large-scale, time-averaged budgets of heat, salt, and momentum. To achieve this understanding it is necessary to observe microscale fluctuations of temperature, salinity, and velocity to scales less than a centimeter and to relate the dissipative structures found to the fine scale variability occurring over scales of from a meter to about 10 kilometers. Since these same variables also determine the velocity of sound, some of the processes and structures observed are major factors causing acoustic fluctuations in frequency bands of practical importance to the Navy.

Objectives of the Project

There are two phases of the project. One is to assess the levels of small scale, i.e. centimeter, mixing in the upper ocean and the other is to study the evolution of intrusive water bodies. The intrusions have vertical scales of from 1 m to tens of meters and horizontal scales up to tens of kilometers. They appear to be major factors in the heat and salt fluxes of the ocean and in short range sound speed anomalies.

Status

Many parts of the analysis of microstructure and towed body data taken during MILE have been completed. To complete the microstructure work the dynamic response of thermistors is being extensively tested. Measurements taken simultaneously with Sanford's shear profiles during Polymode are partially analyzed.

Major Accomplishments

1) A new method for measuring the vertical velocity of internal waves was developed.
2) Strong evidence for mixing adjacent to the island of Bermuda was found associated with nearly adiabatic step-like features.
3) The dominant microstructure activity in the Gulf stream was found to be associated with double diffusivity activity on the boundaries of thermohaline intrusions. Gradient flux mixing was relatively weak - implying moderate-to-low levels of turbulent mixing.
4) Algorithms for estimating the rms noise in N^2, Ri, dynamic topography and maps on density surfaces were developed.

Variability of Wind-Generated Upper Ocean Currents during MILE and JASIN

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Long-range scientific objectives

Parameterization of wind-generated physical processes occurring in the upper ocean.

Project objectives

(1) Coherence between wind and upper ocean currents at frequencies less than 2 cph and horizontal scales of 10 km - 100 km. (2) Studies of local Ekman dynamics. (3) Wind-generated deepening of the mixed layer via dynamic instabilities. (4) Wind-generated high frequency internal waves. (5) Reliability and accuracy of upper ocean current measurements.

Current status

(1) MILE: data processing completed; paper describing the current meter intercomparison will be ready for submission in March; involved in a collaborative effort to describe the response of the current and temperature fields to a intense storm. (2) JASIN: data processing in progress and should be completed before the May meeting at WHOI.

Significant accomplishments:

(1) The 'MILE intercomparison of current meters' paper was summarized at the Fall AGU and will be submitted in March for publication. (2) A summary of moored current measurements in the upper ocean will be published in Instruments and Methods in Air-Sea Interaction, Plenum Press. (3) Of possible interest to ONR but at no-cost to ONR, a paper describing the variability of mixed layer currents in the Atlantic North Equatorial Countercurrent has been completed.

NUMERICAL STUDIES OF THE DYNAMICS OF LARGE SCALE OCEAN ANOMALIES

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The long-range scientific objective of my research is to improve our understanding of the large scale thermal variability in the upper layers of the ocean and to develop a dynamical, numerical model capable of simulating that variability with proven skill. It is expected that this improved understanding and modeling skill will increase the Navy's capability to predict environmental factors which are required to meet various operational needs.

The objective of this project is to continually develop and improve a numerical model of the North Pacific Ocean and to use the model to identify processes responsible for the formation and evolution of large-scale, low-frequency thermal anomalies in the open ocean. An improved version of Haney's (1974, J. Phys. Oceanogr.) ten-level primitive equation model is being used to investigate the ocean's response, over several months, to prescribed changes (anomalies) in initial conditions and atmospheric forcing. The anomalies in the oceanic initial conditions are obtained from the NORPAX-ADS monitoring program (TRANSPAC), and the anomalies in the atmospheric forcing are obtained from other NORPAX investigators.

Model studies in which the anomalous atmospheric forcing is represented entirely by monthly mean wind anomalies has been published (Haney, Shiver and Hunt, 1978, J. Phys. Oceanogr.). The results suggest that horizontal advection of mean temperature by anomalous surface (Ekman) currents is an important anomaly generating mechanism in the upper layers of the midlatitude North Pacific Ocean. New simulations for the fall and winter of 1976-1977 suggest that, in addition to the horizontal advection of mean temperature by anomalous surface Ekman currents, anomalies in the surface heat flux and in wind generated vertical mixing are also important. An explicit prognostic formulation of the well mixed surface layer (Garwood, 1977, J. Phys. Oceanogr.) is presently being imbedded into the ocean circulation model in order to examine the effects of surface generated vertical mixing more realistically.

The major accomplishments during the past two years are (a) the successful simulation of large-scale anomalies starting with observed data from the ocean, and (b) the identification, by model simulation, of important mechanisms for the generation of large-scale thermal anomalies in the upper layers of the ocean.

Island Trapped Waves

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This project is an outgrowth of a program to study mixing processes near boundaries and is a part of a long term investigation of the effects of bottom relief on water motions. The particular objects of this study are to observe trapped wave motions near Bermuda using current meter moorings and to understand the trapping mechanism in terms of simplified analytic and numerical models.

A three mooring array with Bermuda at the center of a large triangle was deployed for nine months in 1975. The resulting time series exhibit significant horizontal coherence at a number of discrete frequencies corresponding to periods ranging from 6.2 hr to 384 hr. At periods longer than inertial the estimated phases are consistent with wave motions traveling clockwise around the island. Shorter period results are ambiguous but indicate that both directions of travel are possible.

We have investigated the mechanism for trapping energy near a circular island with sloping sides. At periods greater than inertial perfect trapping is possible and the waves must propagate clockwise. At shorter periods the trapping is not perfect but energy leaks away at a rate which depends on the particular wave mode as well as other environmental parameters. Waves can travel in both directions

A second array of three current meters was deployed for 14 months in 1977-78 at locations much closer to the island with the object of studying the dynamics of the trapping mechanism. Analysis of the observations is just beginning.

RADIO MEASUREMENTS OF THE SEA SURFACE

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This is a joint venture between a group at Stanford and Dr. R.H. Stewart of Scripps. The long range scientific objective is the measurement of currents, current shear, wind speed and direction and sea state using remote sensing, i.e., radar techniques. A central feature of the joint work is the comparison of radar results with simultaneous oceanographic measurements with the goal of providing independent ship or shore based radar instrumentation to measure the above parameters.

We have completed an experiment which will produce comparisons of shore based radar with simultaneous spar buoy and pitch and roll buoy observations in the radar cell. Several publications discussing ocean surface current and directional spectra and a Ph.D. dissertation are presently in preparation.

Using much of the same equipment, we participated in the JASIN experiment in the summer of 1978. The radar was installed on board the Woods Hole vessel Atlantis II for daily operation and comparison with the Scripps pitch and roll buoy and numerous other investigators' current, wind and spectra measurements. The radar and buoy performed well during the experiment, including periods of moderately heavy seas. The antenna measurements indicate that the patterns were not seriously influenced by the ship structure, and on-board processing indicates that the radar data quality is quite good.

A paper describing the results and oceanographic interpretations of the Galveston Island synthetic aperture experiment has been submitted for publication. We plan to spend most of the coming year analyzing the data from the JASIN experiment. It is expected that the combination of Pescadero and JASIN results will produce a nearly complete understanding of what HF radar can and cannot do in oceanography.

FEASIBILITY STUDY FOR IMPROVING THE AN/SSQ-36

THE NAVY'S AIRBORNE EXPENDABLE BATHYTHERMOGRAPH (AXBT)

The Sippican Corporation
Mr. Alan Hudson
Marion, MA 02738
617-748-1160

Naval Air Development Center
Mr. Edgar Reed
Code 6013
Warminster, MA 18974
215-441-3249

A cooperative program is underway to study the feasibility of improving the current Navy AXBT, specifically by replacing the thermal sensor with a new probe which combines the depth capability of the Sippican T-7 probe with the fine grain structure of the T-11 probe. (The AXBT is an aircraft-launched expendable bathythermograph. A temperature profile is obtained via an RF link with with the aircraft. Within the probe temperature is converted to frequency. Thus, by sensing the release of the probe and knowing the drop rate, a frequency versus time data can be obtained and converted in the aircraft to temperature versus depth.)

In addition, depth accuracy errors in the current designs due to the effects of sea state and surface current shears will be eliminated by designing a sea-keeping spool into this system.

A comparison of the features of the current and improved AXBT's is as noted:

	Current	Improved
Depth Range (M)	305	760
Thermal Time Constant	1 sec (max)	.1 sec (max)
Sea-keeping Spool	None	Yes

Sippican is developing electronics to interface with a modified T-11 probe to convert the temperature data into frequency compatible with the present AXBT specification. In addition, a deployment system is being developed which will be accurate even in adverse sea state and high shear current conditions. These designs are being integrated into a complete AXBT system for production cost/benefit trade-offs.

NADC provides design constraint data and testing for P-3 flight/deployment conditions.

The ultimate objective of this program is to make available to the scientific community and the Navy a synoptic thermal measurement capability in which the capability of the T-7 and T-11 ship XBT's are mated with the capability of the Navy P-3 aircraft for rapid coverage of relatively large oceanic areas.

Title: Entrainment Processes at Ocean Fronts

Principal Investigator: Takashi Ichiye
Institutional Affiliation: Texas A&M University
Mailing Address: Dept. of Oceanography, Texas A&M University
College Station, Texas 77843
Telephone No.: (713) 845-6661

Long-range scientific objectives

(1) Dynamics of meso-scale phenomena contributing to oceanic general circulation
(2) Momentum, energy and water mass exchange processes of meso-scales

Objective of the project

To study entrainment processes along the edge of the western boundary current like the Kuroshio and the Gulf Stream.

Current status of the project

(1) The XBT and CTD data over Izu-Bonin Ridge were obtained during Cruise KH-78-4 on board R/V Hakuhomaru through Dr. T. Sugimoto (Sept. 18 - Oct. 7, 1978) of Tohoku University, now a visiting faculty here. The isobaths of 5°C followed the bottom topography between two islands at about 34°N showing an abrupt change in the Kuroshio path and surprisingly close agreement of surface flows measured with GEK (Fig. 1). Further analysis is going on.
(2) Closely spaced XBT and CTD stations will be taken in May this year on board R/V Soyo Maru by Scientists from Tohoku University and Tohoku Fisheries Research Institute along the front of the Kuroshio east of Japan for studying frontal entrainment of cold and fresh water into the Kuroshio (Fig. 2).

Major accomplishment

Waves of infra-inertial frequencies propagating along the coast are studied for a system consisting of a barotropic shelf and a two-layer deep ocean (Fig. 3). For a flatbottom shelf (A), there are two modes of non-divergent waves: the modified Kelvin waves and the barotropic-baroclinic (Bt - Bl) shelf waves. Both propagate in the direction with the coast on the right but approximate speed is $(g'h)^{\frac{1}{2}}$ for the former and fL for the latter, where g' is the reduced gravity, h is the upper layer depth and L is the shelf width.

The amplitude of the sea level on the shelf is almost linear with a distance from the coast for small wave lengths but it increases for the former or decreases from the coast for the latter. Thus the latter waves may have caused frequently the abnormal mean sea levels along the Pacific and Japan Sea coasts of Japan. For a exponential depth shelf (B) there is no baroclinic Kelvin waves (to be presented at AGU Spring Meeting in 1979).

Fig. 1
The 5^{O}C Isobaths
from HK-4-78
(Sept. 18-Oct. 7)

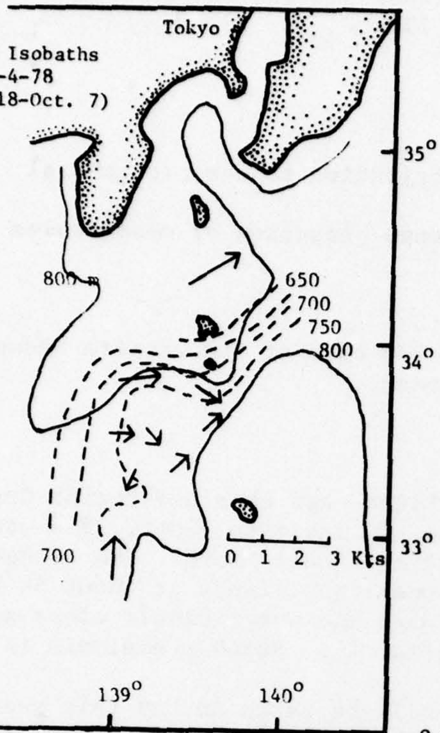


Fig. 2 Experimental
Design in May, 1979

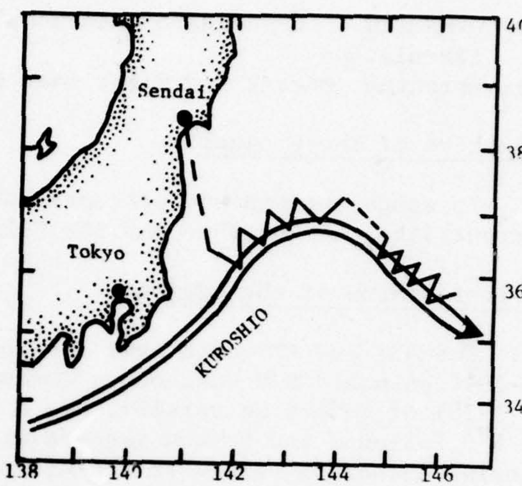
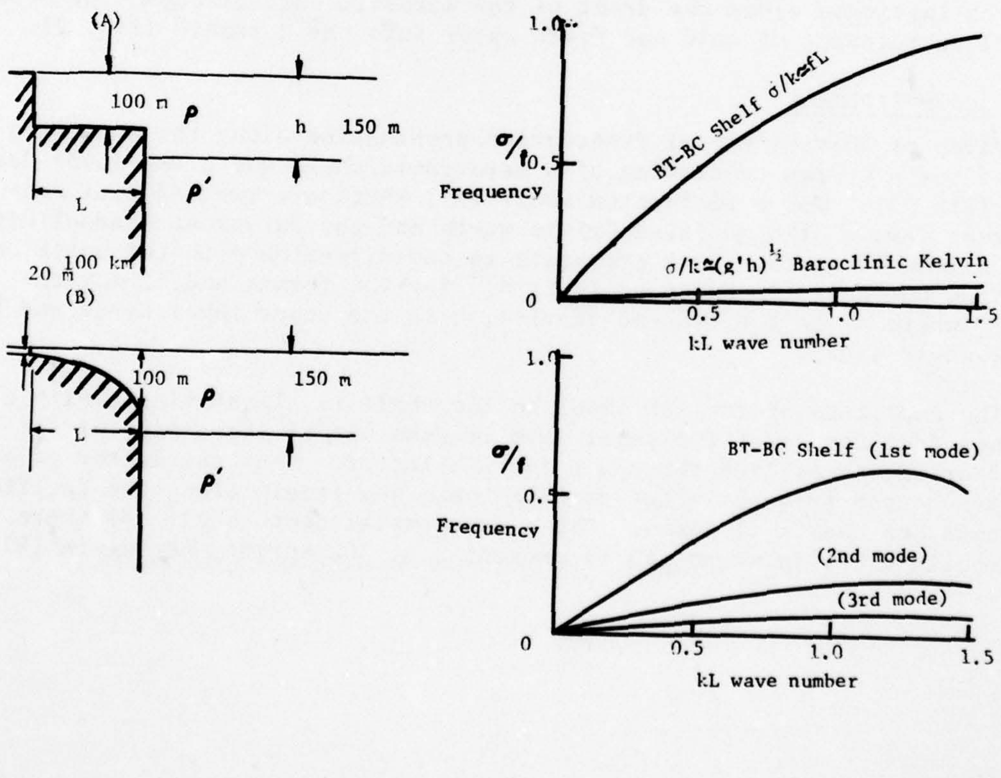


Fig. 3 Shelf-Open Sea geometry and frequency curves



INTERNAL WAVE AND MEDITERRANEAN WATER FRONT STUDIES

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My long-term research interests involve the experimental study of both internal gravity waves and small-scale mixing in the ocean and the formulation of simple mathematical models to aid in the interpretation of experimental results.

In the recent past ONR has sponsored two field experiments for me: a moored current meter array for internal-wave studies and a cruise south of the Azores in which a CTD was used to study a front-like transition in the Mediterranean Water near the mid-Atlantic Ridge.

Studies of internal wave variability and mean-flow interaction during the internal wave experiment (IWEX) and from long time series data in POLYMODE are soon to be published. Further work on vertical propagation of internal waves is in progress.

The effect of the mid-Atlantic Ridge upon the salinity distribution of the Mediterranean Water is being studied. An advective-diffusive numerical model has been run including effects of barotropic guiding of a large-scale gyre by bottom topography. A CTD section across the ridge axis is presented together with a discussion of the Mediterranean Water front and the horizontal structure of intrusions at this boundary. An attempt is made to relate this transition to large-scale structure of the geostrophic velocity field near the ridge.

AIR SEA INTERACTION PROCESSES

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Scientific Objectives: The goals of this work have through the various phases been focused on explaining the interactive relationships between atmospheric boundary layer structure and characteristics of the upper ocean. In particular, we are lately concerned with the interpretation of manifestations of such interaction, at the interface, which are observable remotely from aircraft and satellites.

Present Work:

A. Participation in the Joint Air Sea Interaction Experiment (JASIN): Between July 15 and September 10, 1978 we participated in the international JASIN experiment taking place in the North Atlantic, west of Scotland. Our purpose was to collect data on sea surface temperatures and short and longwave radiation fluxes from one ship and from the NCAR Electra instrumented aircraft.

These data were successfully collected, and the ship data is presently being analyzed. The Electra data is being processed at NCAR until March 1979, when we will receive our first tapes. From these data we will in the present year accomplish the following:

1. We will produce time series of the up- and downwelling streams of short and longwave radiation at the ship in the northwest corner of the meteorological triangle.

2. By analyzing satellite cloud pictures (D.S.M.P. and NOAA 5) in conjunction with our ship and aircraft data and in cooperation with Professor Raschke and students in Köln, we will also provide daily areal averages of the radiative fluxes for the JASIN area.

3. We will analyze the aircraft sea surface temperatures over JASIN to produce maps of sea surface temperatures, where temporal and spatial changes will be interpreted in relation to the radiative and atmospheric forcing as well as the upper ocean dynamics.

B. Continued Work with MSMAST Data: Data obtained at our Lake Washington field site during 1977 is still being analyzed for the following relationships:

1. ΔT versus u_*: This project concerns evaluation of the temperature deviation of the surface water from lower strata (ΔT) when wind stress (u_*) is acting. Analysis is nearing completion.

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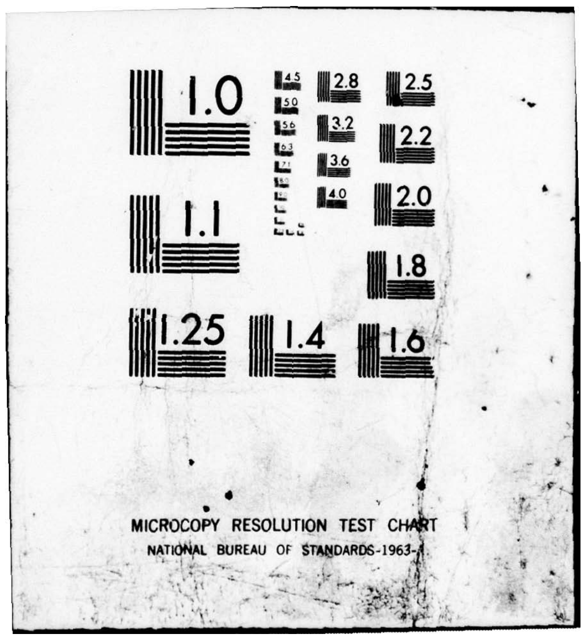
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2. Turbulence over surface waves: This analysis is being done in conjunction with Dr. Søren Larsen of Risø, Denmark, who obtained high frequency turbulence measurements immediately over the waves, while we were recording wave information and other data in August 1977. We expect to finish the joint analysis in 1980, when K. B. Katsaros expects to spend 3 months at Risø.

3. Eddy diffusivity in waves: A method was found for estimating turbulent diffusivity under waves. This was first explored with a NATO-sponsored student in our summer course in 1976. Some additional data will be obtained in the spring of 1979.

C. Effects of Surfactant Films on the Near Surface Thermal Structure and on High Frequency Surface Waves:

1. A laboratory study of the modifying effects of monolayers on turbulent free convection is planned for one week in March 1979 together with Dr. William Garrett of the Naval Research Laboratory, Washington, D.C.

2. Dr. Ferren MacIntyre of the Graduate School of Oceanography, Rhode Island University plans to photograph the dilation of a surface film as high frequency waves penetrate at our Lake Washington research mast in the spring of 1979, while we obtain wave spectra.

II. Future Plans:

A. Continued JASIN Analysis: In 1980-81 we expect to be synthesizing the various components of related JASIN data to begin to understand:

1. Evolution of sea surface temperature patterns in terms of local atmospheric turbulent heat losses and radiative gain or losses, and horizontal advection and vertical mixing.

2. The radiation fluxes, short and longwave, in terms of cloud structure for eventual parameterization. This work will be done with Professor Raschke and students. We hope to bring Johannes Schmetz of the University of Köln to the University of Washington as a post-doctoral research associate for 6 months.

B. Wind Stress Variations across Ocean Thermal Fronts: We are just giving thought to a study of wind stress variations across the gulf stream boundaries in the spring of 1980. Contrasts in roughness have been observed both in visible light and by microwave radiometers as well as by thermal scanners. Cooperation with Dr. LaViolette of NORDA is planned.

SMALL SCALE OCEANIC FEATURES

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Long Range Objectives: An understanding of the levels of oceanic mixing in the vertical, and advection and mixing in the horizontal is sought. The variability (temporal and spatial) of physical and biological properties of the ocean is desired, to understand the propagation of heat, mass, momentum and biota, and their interrelationships with each other and with larger scale motions of the ocean.

Project Objectives: An investigation of the fine and microstructure in the temperature and velocity fields has been investigated in the MILE experiment through the use of a large, free-fall vehicle, during and after the passage of a storm. The nature of the entraining layer at the base of the mixed-layer will be investigated for the effects of stirring and suppression by buoyancy forces to determine the mixing efficiency, and downward propagation of energy of such events. Concommitantly, the use of a slow-fall XBT has been examined and will continue to be evaluated for possible use as an expendable fine to microstructure survey tool.

Status of Project and Accomplishments: Twenty-six successful drops were made in the MILE experiment, under conditions ranging from 40 knot winds to calm seas and clear skies. This data is presently under analysis. A persistent and sometimes turbulent shear layer was observed at the base of the mixed layer, and was relatively thin--from 1 to 3 meters thick. Deeper within the thermocline, the levels of velocity structures were immeasureably small. Due to the catastrophic loss of the free-fall vehicle in a shakedown cruise in preparation for the POLYMODE Local Dynamics Experiment, the effort for developing an expendable fine structure profiler was vigorously pursued, with successful results. Both data sets are now under the final phases of analysis. Concommitantly, with Eric Shulenberger, a towed CTD/video sampler for looking at patchiness of biota is being evaluated as a possible step-up in the technology of sampling physical and biological structures of small scales.

OBSERVATIONS AND ANALYSES OF INDIAN OCEAN EQUATORIAL CURRENTS

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One of my scientific interests, the one which lies behind this project, is the time-dependent circulation in the equatorial oceans. The principal feature which distinguishes the equatorial region from midlatitudes is the rapidity of baroclinic adjustment to variable wind stress via equatorially trapped waves (Moore and Philander, 1977).

This project has had as its objectives the observation of selected aspects of the time-dependent equatorial circulation in the Indian Ocean, and, during the past year, some theoretical studies of interactions between equatorial waves and mean flows. The observational effort has been to maintain moored current meters at the equator north of the Seychelles long enough to assess the importance of seasonal (monsoon-driven) fluctuations at intermediate depths (500 m). Such fluctuations dominate the near-surface record (Knox, 1976). The field work has ended and the data are now being analyzed. An example of data gathered already, although too short to address monsoon phenomena, contains some interesting higher frequency information. Spectra (not shown) indicate that energy in the meridional component (v) exceeds that in the zonal component (u) at periods between 100 and 1000 hrs; this argues for dominance of modes with latitudinally symmetric v-fields, of which the gravest is the Yanai wave. Similar results at similar depths have been obtained in the Atlantic by Weisberg, Miller and Knauss (1975) and discussed by Weisberg, Horigan and Colin (1979).

The theoretical work, largely due to M. McPhaden, a graduate student, has utilized a simple two-layer equatorial β-plane model with various prescribed, geostrophically balanced mean zonal flows in the upper layer. A linear stability analysis reveals neutral oscillations corresponding to what would be the classical free modes in an ocean without mean flows. The mean flow induces changes in the mode frequencies and structure; the principal effect is to distort u, while hardly changing v or the pressure (sea level) field. Thus measurements of zonal velocity as a function of latitude, not presently available in sufficient detail, would provide a much more sensitive test of the importance of wave-mean flow interactions than would island sea level records, which have been used to identify equatorial modes (Wunsch and Gill, 1975). This stability analysis is now in press (McPhaden and Knox, 1979). McPhaden is now investigating a steady model which includes both dissipation and friction, in order to study the role of these processes in the near-equatorial circulation. We expect this work to lead, for example, to a consistent description of the "breakdown" of the Ekman layer as the equator is approached, i.e., of the transition from midlatitude dynamics (frictional effects confined to a thin surface layer) to equatorial dynamics (friction important at depth).

DEFINITION OF OCEAN SURFACE CURRENT BOUNDARIES USING SYNTHETIC APERTURE RADAR OVER THE TAIL OF THE GRAND BANK

Principal Investigator - Paul E. La Violette

Naval Ocean Research and Development Activity
NSTL Station, Mississippi 39529
601 688-4864

Interest: The long-range scientific objectives of this experiment are to explore and exploit the use of remote sensing instruments for oceanographic purposes with special emphasis on specialized radars such as synthetic aperture (SAR) and side-looking (SLAR) radars.

Experiment Purpose: The main purpose of the present experiment is to show (a) that surface currents modify or create conditions which modify the amplitude and/or orientation of local waves to form surface patterns with definable boundaries and (b) that the diffuse return of aircraft and satellite SAR's and SLAR's can delineate these patterns and boundaries. If successful, the results of the experiment will show that ocean roughness patterns in imagery derived from specialized radar data can be used as an all-weather tool to derive the oceans surface circulatory.

Experiment Plans: The region of study for the experiment is an area off the coast of Newfoundland called the Tail of the Grand Banks. Satellite, aircraft and ship data will be collected in the area during two phases of the experiment. The first phase called "Baseline," occurred two weeks in late June 1978; the second phase, called "New Look," will occur in May 1979. To provide continuity between the two phases, satellite data will be collected for selected seasonal months.

SEASAT A, the satellite that was to provide satellite SAR data during New Look became inoperative in October 1978. Therefore, during New Look, SAR data will be collected by aircraft using the ERIM SAR aboard SURSAT's Convair 580.

Major Accomplishments: Completion of Baseline. All data collected successfully and are now being analyzed. This analysis is aimed at preparations for New Look rather than research publication. The one paper containing material on the experiment: "Oceanographic Implications of Features in NOAA Satellite Visible Imagery," by P.E. La Violette, S. Peteherych and J.F.R. Gower is in the review process now for a special issue of Boundary-Layer Meteorology. Although SEASAT failed prior to New Look, sufficient SAR data were collected during its short lifetime to be of use in the experiment analysis.

STUDY OF THE MECHANICS OF MOMENTUM, WATER DROPLETS, MOISTURE, AND HEAT TRANSFER AT THE SEA-AIR INTERFACE UNDER HIGH SEA STATES

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Our long range objective is to study the extremely complex problem of sea-air interface through a step by step plan of theoretical analyses, controlled laboratory studies, and field experiments. These steps will be repeated until a satisfactory analytical model is obtained. Particularly we are interested in the production of water droplets by whitecaps and sea sprays, because the evaporation of droplets creates a strong latent heat sink which in turn enhances the vertical transport of moisture and heat from the ocean. In addition, we are interested in the mechanics of the wind on the breaking waves, because wind drag on waves produces a surface drift which in turn causes wave breaking, air entrainment, and turbulence. The turbulence in turn enhances the transport of heat through the sea surface layer.

Our first objective is to understand the complex mechanics of the atmospheric surface layer and then the mechanics of the sea surface layer. From this knowledge we eventually hope to treat the two layers as one coupled system. Ultimately, the theory will be used to obtain the global fluxes from the ocean by satellite.

Currently we have succeeded in developing a realistic analytical model that will account for the inter-coupling effect of the wind, temperature, water droplet, and humidity fields. We have also developed an accurate water droplet size-concentration detecting system for application over the ocean. The system was successfully applied during the 1978 Joint Air-Sea Interaction Project, JASIN, which involved three extensive cruises over the North Atlantic Ocean. Complete sets of soundings for wind, temperature, humidity, and droplet size concentration were successfully collected, covering a wide range of sea states including data taken near the eye of severe storms.

Our major accomplishments can be briefly summarized as follows:

1. Developed an accurate droplet size-concentration detecting system.
2. Discovered that the droplets produced by breaking waves have a universal normalized size distribution.
3. Proven that 30-200μ water droplets are a major source of moisture for the atmosphere. Their latent heat sink promotes transfer of heat from the ocean.
4. Developed a realistic model for the atmospheric surface layer, from which accurate estimate for the vertical fluxes of heat and moisture can be made.
5. Extensive results from JASIN project are being prepared for publication.

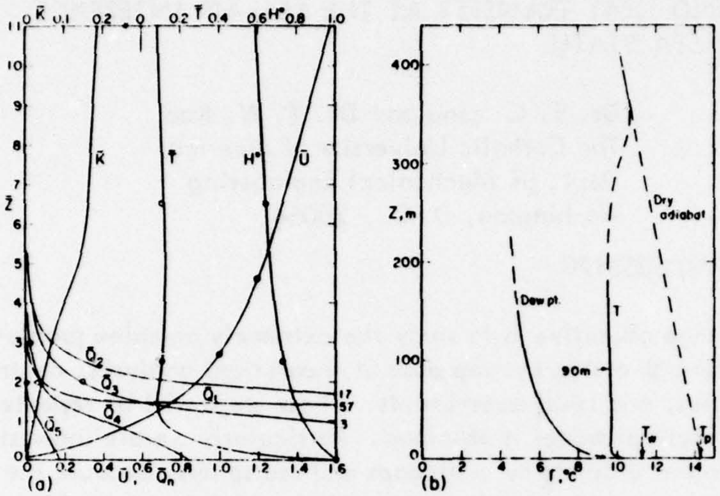

Fig. 1. Figure 1(a) is an analytical simulation of a sounding (b) obtained during passage of a storm, 1977 JASIN experiment. Where z is the elevation above the mean wave trough, and $\bar{z}$ is z normalized by the mean wave height $\epsilon = 4.5$ m; $\bar{U}$ is the wind speed normalized by the 10m wind $U_{10} = 12.5$ m/s; $\bar{K}$ is the eddy diffusivity normalized by U_{10} and ϵ ; $\bar{T}$ is the normalized temperature $(T - T_o)/|T_w - T_o|$, where T_o is the air temperature at 90m, and T_w the sea surface temperature; T_p is the potential temperature of upper air; H^* is the relative humidity; and $\bar{Q}_n = Q_n U_{10}/q_{s2}$ are the normalized droplet concentrations for n droplet size groups of 10, 40, 80, 140, and 300μ, respectively, where q_{s2} is the surface flux of 40μ droplets. Note that in spite of the fact that the upper air is warmer than the sea there exists a surface layer of air which is cooler than the sea due to the latent heat of water droplets. Note also that the concentration of water droplets is highly stratified. From these results the vertical fluxes of heat and moisture from the ocean can be obtained with good accuracy. The vertical water mass flux and latent heat flux were found to be 2.9×10^{-5} g/cm^{2}s and 1.7×10^{-2} cal/cm^{2}s, respectively.

EVALUATE SECOND GENERATION EXPENDABLE ENVIRONMENTAL SENSORS XSVTD and XCTD

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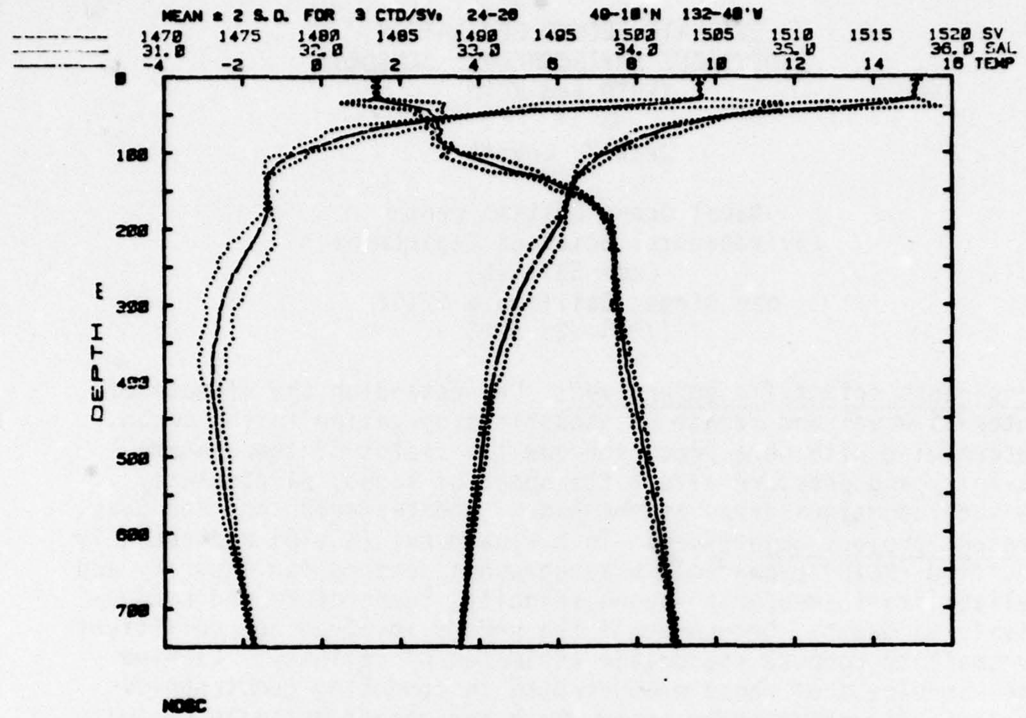
Long-range scientific objectives: Understanding the effects of internal waves and fronts on acoustic propagation in the ocean. Determining with more precision how the fields of temperature, salinity and pressure affect the speed of sound, particularly in such anomalous areas as the Black, Mediterranean and Red Seas.
Present project objectives: To evaluate new (XSVTD) and recently modified (XCTD) expendable oceanographic sensors for accuracy and reliability in measuring sound velocity, temperature and conductivity vs depth. Determine if the errors involved are sufficiently small to compute reasonable estimates of salinity. Examine the usefulness of these measurements in computing geostrophic currents for those ocean areas where one cannot estimate salinity reliably from temperature measurements alone. Analyze the ability of these new expendables to measure or compute sound velocity more accurately than the standard XBT for antisubmarine warfare purposes.
Current status: The analysis of the XSVTD in comparison with a Grundy (Plessey) model 9041 CTD/SV is nearing completion.
Major accomplishments: 1. Developed an improved depth equation for the XSVTD. 2. Demonstrated the presence of aliased 60 Hz noise in the temperature data from the new Sippican deck recorder (the manufacturer is correcting the problem). 3. The simultaneous measurement of sound velocity allows one to detect erroneous temperature measurements that would be visually acceptable in a standard XBT. 4. These temperature errors are almost invariably positive, the unknowing acceptance of which may bias any overall data set. 5. The initial drop rate may not conform to the standard depth vs time equation, producing false near surface temperature, sound velocity and salinity gradients.


MEAN ± 2 S.D. FOR 3 CTD/SVs 24-28
48-18'N 132-48'W
1470 1475 1480 1485 1490 1495 1500 1505 1510 1515 1520 SV
31.0 32.0 33.0 34.0 35.0 36.0 SAL
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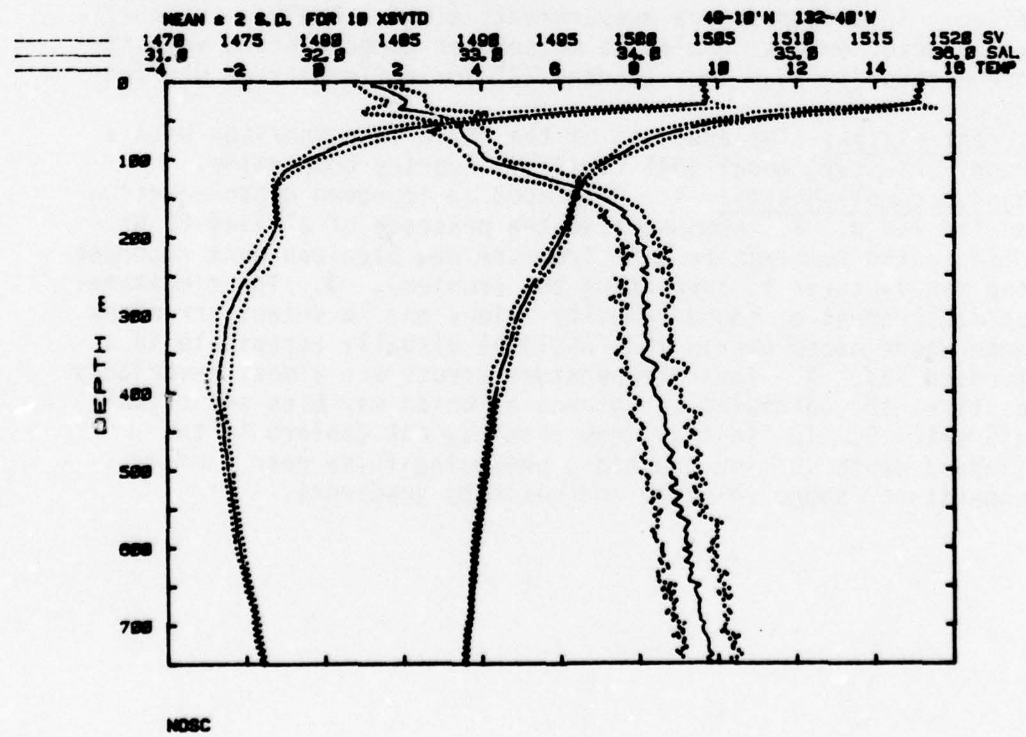
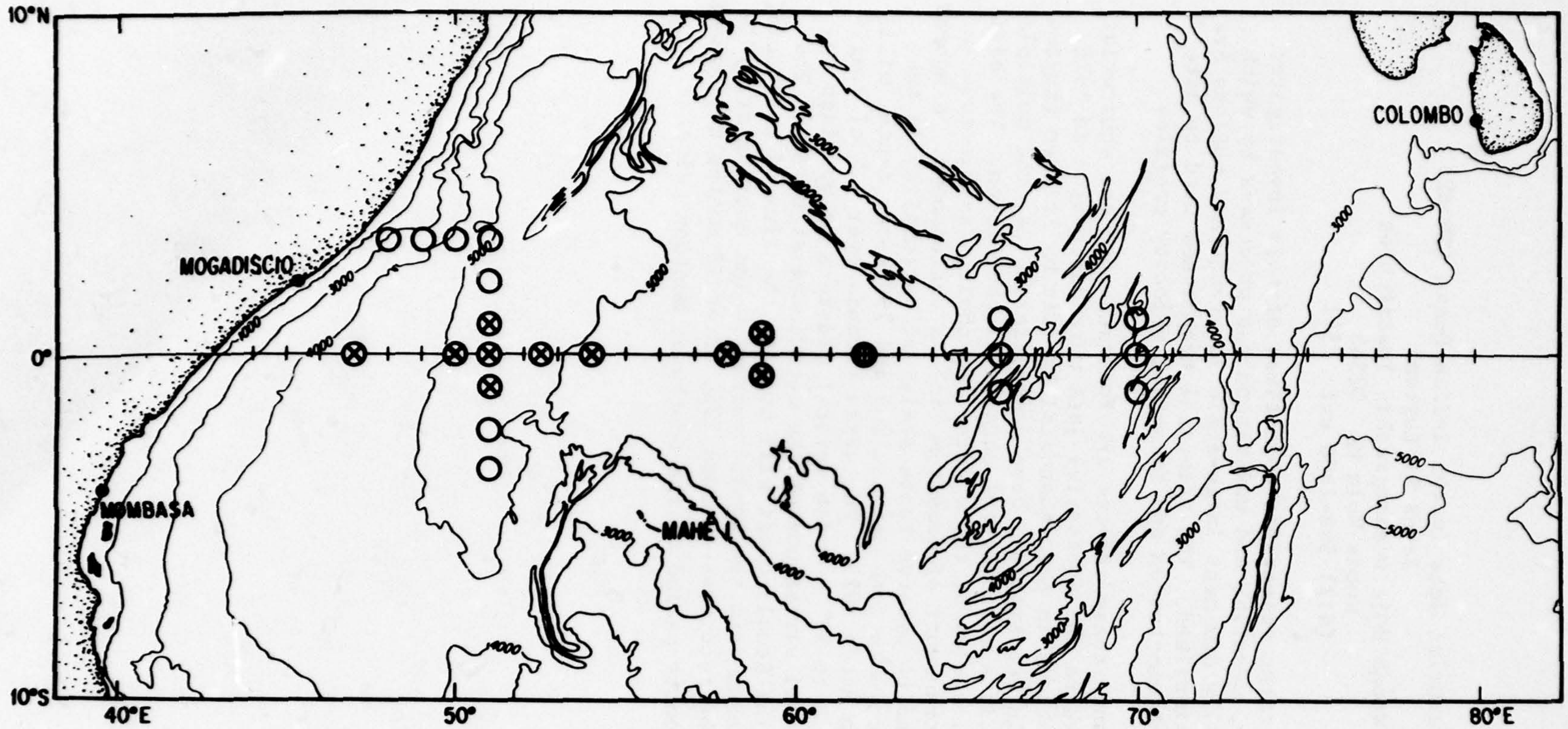

MEAN ± 2 S.D. FOR 18 XSVTD
48-18'N 132-48'W
1470 1475 1480 1485 1490 1495 1500 1505 1510 1515 1520 SV
31.0 32.0 33.0 34.0 35.0 36.0 SAL
-4 -2 0 2 4 6 8 10 12 14 16 TEMP
DEPTH m
0
100
200
300
400
500
600
700
NOSC

Equatorial Jets in the Indian Ocean (INDEX)

James R. Luyten
Woods Hole Oceanographic Institution
Woods Hole MA 02543
(617) 548-1400 ext. 2541

The long range scientific objectives of this investigator are to observe, describe and understand the processes by which the energetically dominant large-scale low-frequency motions are excited and maintained. The principal techniques used to date are moored instrumentation and free-fall velocity profiles.

At present, these efforts are focussed upon the equatorial Indian Ocean where the equatorial jets were discovered in 1976. Recent observations in the equatorial Pacific by Eriksen (Luyten and Eriksen, in preparation) have demonstrated that the multiple jet structure is a more general equatorial phenomenon. The basic zonal temporal scales of these jets, and their possible role in the vertical transport of momentum, are as yet unknown. A moored array, designed to observe these scales of variability in the most energetic subsurface jets at 200 and 750 meter depth, will be deployed in March 1979. The array extends over 12° of longitude from 47° E to 59° E, with several clusters of moorings to examine the zonal variations of the meridional structure. The mooring near the Somali coast will monitor the flux of equatorial mass and momentum into the Somali current. The mooring array is scheduled to be recovered in June 1980 after 15 months deployment, spanning the onset period of the Southwest Monsoon twice.



INDEX - 79 EXPERIMENT

○ WHITE HORSE PROFILING SITE

× WHOI MOORING - CURRENT METERS AT 200, 500, 750 METERS

▯ FRENCH MOORING - CURRENT METERS AT 200, 300, 500, 750 METERS

W.H.O.I.
LUYTEN

Analytical Modeling of the Large-Scale Temperature Fluctuations in the North Pacific

Lorenz Magaard, Principal Investigator

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Honolulu, Hawaii 96822
Telephone (808) 948-7509

Long-range scientific objectives of the Principal Investigator: Development of theoretical models for fields of large-scale and meso-scale waves and turbulence in the ocean with application to field data (mainly from the North and Equatorial Pacific) in order to understand and predict fluctuations of temperature, sound velocity and currents in the ocean, especially in the upper ocean.

Objective of the project: Analysis of temperature data (XBT and hydrographic data, time series of monthly mean values up to 20 years) from various parts of the North Pacific by means of model fitting (cross spectral fit). Development of models, especially baroclinic Rossby wave models in case of non-vanishing mean shear flow. Study of generation of observed processes (from the temperature analysis), especially by local meteorological forcing. This project is part of NORPAX.

Current status of the project: The development of baroclinic Rossby wave models has been completed. We are presently applying these models to the TRANSPAC data which are being collected under the NORPAX program in the area 30°N to 50°N, 170°E to 150°W. The application of our theory of local meteorological forcing to oceanic and meteorological data from an area between Hawaii and California has almost been completed. A study of the refraction of baroclinic Rossby waves in the North Pacific is in progress.

Major accomplishments: We have found that, for time scales between about 1 and 10 years and lengths scales between about 1000 and 3000 km, first order baroclinic Rossby waves appear to dominate the internal temperature fluctuations in those parts of the North Pacific between 20°N and 50°N where the mean current is negligible. For the area of the North Pacific Current, we have determined the shear modes of velocity and temperature. Our Rossby wave model, which is now fitted to the TRANSPAC data, is composed of these shear modes. First results indicate that Rossby shear modes play a significant role in the North Pacific Current.

TURBULENT DECAY

Subtitled - Dynamics of Rotating and Non-Rotating Intrusions and Internal Solitary Waves

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University of Southern California
Department of Aerospace Engineering
Los Angeles, California 90007
(213) 741-6240

The long range objective is to understand the role played by internal solitary waves, intrusive motions and double diffusion in the dynamics of the world's oceans; to determine various mechanisms, whereby, internal solitary waves can be generated in a stratified fluid, how these solitary waves interact, promote mixing and transfer energy to various scales of motion and how they are related to the dynamics of intrusions.

We have completed a series of experiments on the effect of doubly diffusive processes on the motion of intrusions formed by both the collapse of a finite volume of fluid and the continuous injection of fluid into a fluid of different density and species-diffusivity. The results will be written up for a journal paper before the end of the current contract period.

It is anticipated that the following experiments will be carried out in the two-layer water channel: 1) a survey of the channel with the mixer removed; ii) the mean density distribution, integral density thickness, mixedness function and spectral characteristics of the density fluctuations will be determined within the decaying mixed region. The data will be compared to similar measurements taken in the ocean (Schedvin, Gibson and Deaton (1978), Gargett (1978), Eriksen (1978) and Gregg (1977)). No major journal publication on this work is anticipated until 1980, we will, however, report results at appropriate meetings and in the form of short notes as events warrant.

The Internal Solitary Waves Produced by Tidal Flow over Submarine Topography: A paper on this subject is in press with the Journal of Geophysical Research. We plan to extend the measurements to include variations in the shape of the topography, the form of the ambient stratification, and the propagation of the resultant waves into a region of varying depth.

PYCNOSTADAL ANALYSES OF THE UPPER WATER MASSES AND CIRCULATION OF THE WORLD'S OCEANS

Michael S. McCartney
(617) 548-1400, ext. 2797

Long-Range Scientific Objectives:

The principal investigator plans to study the circulation of the upper 1500 meters of the world's subtropical and subpolar gyres. The main data analysis technique is pycnostadal analysis. The goal is to deduce source regions for the dominant modes of the main thermocline waters. Theoretical studies of the interplay between the formation process and circulation dynamics will be undertaken.

Present Project Objectives:

Complete the documentation of a subpolar mode water family in the North Atlantic and relate it to the North Atlantic circulation, to define the circulation paths for Labrador Sea water, and to examine the possible mechanisms of coupling between the mode water convective formation process and the upper water circulation dynamics.

Current Status:

Distributions of pycnostads in the North Atlantic have revealed a family of subarctic mode waters. The patterns suggest a cyclonically turning circulation, with the modes being progressively cooled along the cyclonic path. The final mode is identical to Labrador Sea water, and is traced as a pycnostad east and south from the Labrador Sea, as shown in the accompanying figure. Papers documenting these distributions are in preparation.

Major Accomplishments:

A new perspective is emerging on the origins of the main thermocline and intermediate waters of the world's subtropical gyres. A single process has been found to be responsible for the dominant large volume central waters of these gyres. This is vertical convection on the poleward side of the gyres in a relatively restricted area, which gives, through its vertical homogenization, a narrowly defined temperature-salinity correlation over a large depth range--a pycnostad. These pycnostads recirculate in the gyres following the geostrophically balanced large-scale circulation, with little further alteration of characteristics. Thus the subpolar region's role in defining the water masses of the subtropical main thermoclines is being demonstrated. Pycnostads have been shown to be a useful circulation path indication for the difficult main thermocline level of the world's oceans.

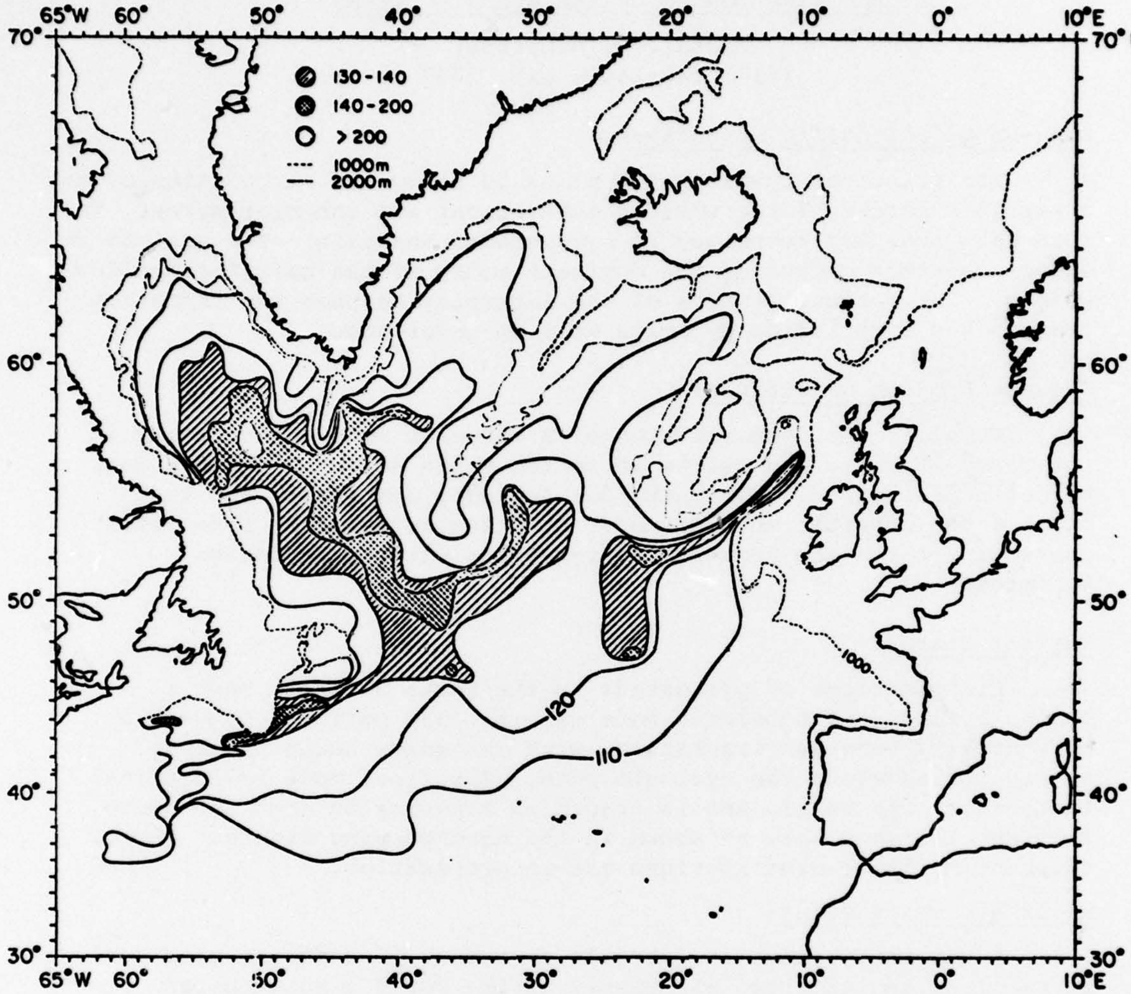

Figure 3. Pycnostadal strength: Brunt-Väisälä period at the deep maximum between 3° and 4°C, defining the Labrador Sea water. The convective formation region is central near 52°N. High strength tongues extend eastward into the Irminger Sea, and across the mid-ocean ridge to the southeast Iceland channel and the Rockall channel off Ireland. A last flow path is indicated westward past 50°W south of the Grand Banks of Newfoundland.

STUDIES OF EQUATORIAL DYNAMICS

Principal Investigator: Julian P. McCreary, Jr.
(with Dennis W. Moore)
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8000 North Ocean Drive
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(305) 587-6660 ext. 288

I am interested in modelling low frequency (periods greater than the local inertial period) and larger scale (wavelength greater than the local Rossby radius of deformation). The equatorial region is particularly intriguing because of the existence of obvious signals (e.g., the steady Undercurrent, vertically propagating signals, the strong seasonal response of currents, stacked equatorial jets). Recent observations also suggest that the atmosphere and ocean are strongly coupled there; changes in equatorial ocean circulation patterns may act to alter the atmospheric circulation. In the next decade I hope to extend my modelling efforts to isolate the important dynamics of some of these phenomena.

In the past year I have extended Lighthill's linear analytic ocean model to allow for a viscid deeper ocean. As a result the present model (unlike Lighthill's model) has non-trivial steady solutions. In particular the model has a realistic equatorial current structure, with an Undercurrent and meridional circulation which fit the "classical" pattern. The dynamics of the model are simple. Easterly winds generate an eastward baroclinic pressure force; it is this pressure force which drives the Undercurrent.

A major objective of the present research is to see if a similar ocean model (with essentially the same dynamics) can also generate a steady coastal Undercurrent (like that observed off the coast of California). Finally, if the winds have a seasonal component, is it possible to generate poleward surface flows which flow against the direction of the winds (like the Davidson Current). Does the Coastal Undercurrent migrate vertically throughout the seasons? Is it possible to generate a banded set of alongshore currents seaward from the coast? At the present point in time there are no major accomplishments to report; the model is in an initial stage of development.

OCEANOGRAPHIC USES OF SATELLITE INFORMATION
NR 083-157

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Cambridge, Massachusetts 02139

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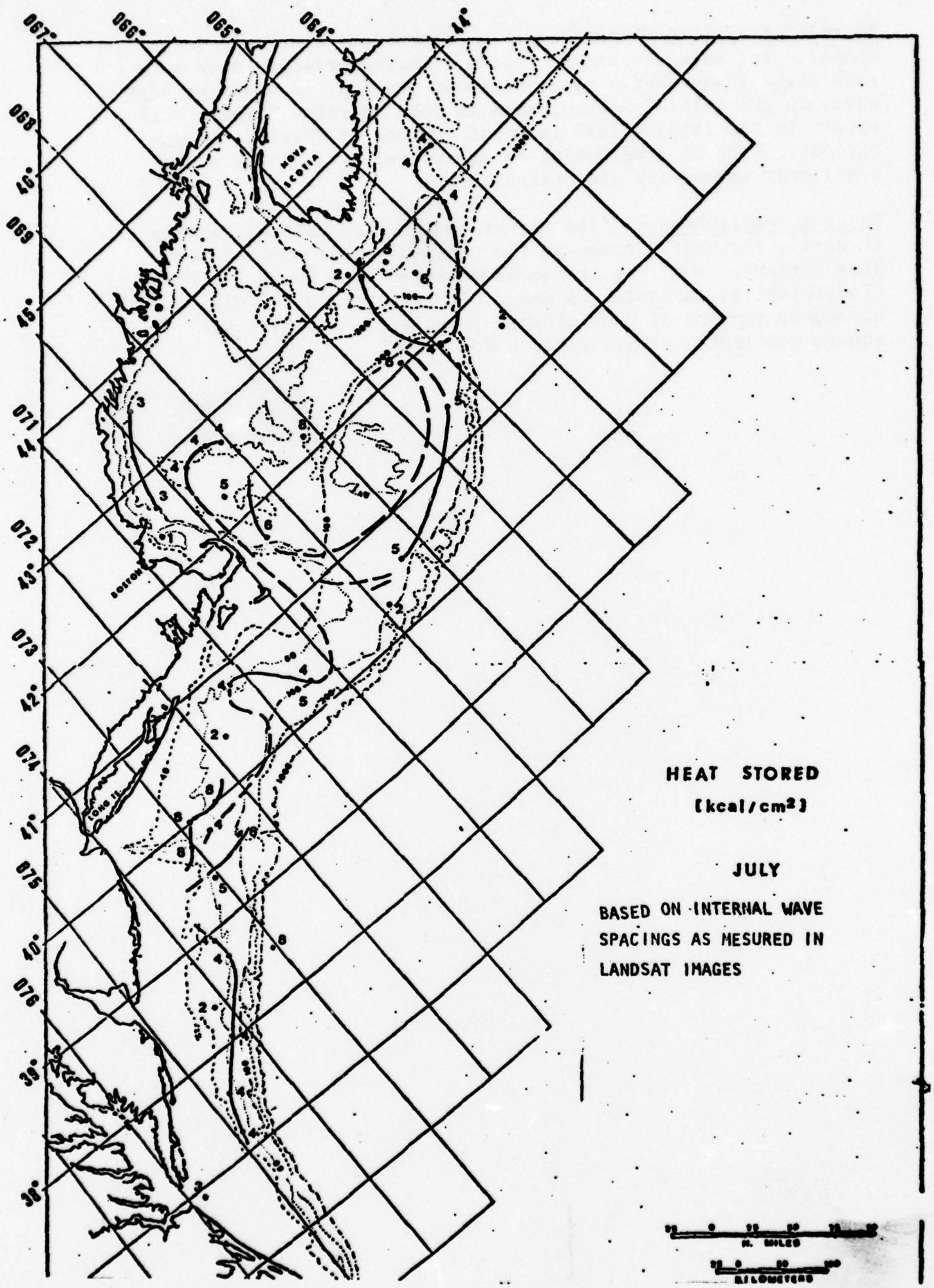
Long Range Scientific Objectives of Principal Investigator: Description of the dynamics of nonlinear wave phenomena, with a view towards their role as internal characteristics, such as topographic waves in currents, their propagation properties, and their effect on exchange and mixing processes. Description of some of the features of random waves and turbulence in terms of fields of wave packets. Uses of observations of waves to infer other properties and variables in the ocean.

The Objectives of the Project: To assess the utilization of satellite information in oceanography. To investigate the propagation characteristics of internal waves and interpret observations of these. To generate examples of use of remote sensing information in oceanography and make suggestions for the better use of satellite information. As part of the effort, we are preparing to process the current meter data from the Equatorial Atlantic, obtained by Institut fur Meeresforschung, Kiel, and USSR ships during the GATE experiment, to determine what one can learn about propagation and dispersion of internal waves in the area.

The Current State of the Project: Mr. Mascarenhas, Jr. has completed his Master's thesis on the calculation of heat storage in the seasonal upper mixed layer from LANDSAT data. A short note on the method has been accepted by "Science" magazine, and should appear soon. Another manuscript is in preparation, giving the results. We are looking for more data on surface signs of internal waves, to find out how to organize a routine program of observation of heat storage in the seasonal upper mixed layer. We are also processing the GATE current meter data, the software is largely up, and we have clarified some format problems in reading tape, and should be ready to produce soon. As a digresive activity, I discovered when asked to give some talks at the NATO Symposium in Norway in April 1978, that few investigators knew about the disturbance generated upstream of probe supports in a boundary layer. Since the errors induced by ignoring such effect can render air-sea interaction observations rather misleading, I wrote a paper on the effects and used the results from wind tunnel tests of the R/V FLIP. The paper will appear in the March 1979 issue of

Journal of Applied Meteorology. A request has been made for SEASAT data, so as to see if internal characteristics show surface signs in synthetic aperture radar imagery. A paper on edge waves in the Gulf of Mexico, seen in GOES infrared images, will appear in the January 1979 issue of Journal of Physical Oceanography. Work is progressing on equatorial ocean large scale non-linear waves with discontinuities.

Major Accomplishments: The use of sea surface LANDSAT imagery to derive the heat storage in the seasonal upper mixed layer. This variable, now that it can be measured, may be an important climatological variable. A chart of heat storage in July is appended; isoline of heat storage in kilogram calories per square centimeter of sea surface are shown.


HEAT STORED
[kcal/cm2]
JULY
BASED ON INTERNAL WAVE
SPACINGS AS MESURED IN
LANDSAT IMAGES
NOVA SCOTIA
BOSTON
LONG IS.

STUDIES OF MESOSCALE WAVES AND
CURRENTS OVER STEEP TOPOGRAPHY

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Institute of Oceanography
University of British Columbia
Vancouver, B.C. V6T 1W5
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Long-range Objectives:

To understand the generation, interaction and dissipation of topographic Rossby waves, eddies and large-scale shear flows over and near steep topography.

Present Objectives:

1. To develop a theory for the atmospheric generation of trench waves, with applications to the Japan and Peru trenches.

2. To investigate the reflection and scattering of baroclinic Rossby waves by ridges and seamounts.

3. To apply certain known baroclinic and barotropic stability models of coastal flows in an attempt to understand the low-frequency variability of the Somali Current.

Current status of the project:

The project began in February 1973.

Research in Mesoscale Atmosphere and Ocean Interaction
Ocean Forecasting

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Long-range Scientific Objectives

The long-term scientific objectives of this investigator encompass the utilization of numerical models of physically realistic upper ocean circulation to demonstrate our understanding of physical processes in the ocean.

Objective

We wish to discover once and for all in a five-year research project whether or not we can actually construct a useful model of the circulation of the ocean in a limited region (1000 km square) on the time scales of several days to a few months. The project will sort out the various basic research problems which need to be solved to integrate with some measureable success a baroclinic ocean of 1000 km square embedded in a coarse grid (x = 200 km) climatological model the size of an ocean basin. At the present time the project is developing a complete model of a baroclinic ocean front to investigate its stability to wind events.

Current Status of Research and Progress

Final coding of the El Niño model is being completed by Kindle. A multi-dimensional model of ocean circulation with emphasis on bottom-trapped Rossby modes is under development by Suginohara. A review of errors in ocean models has been prepared. Two Ph.D. students, Roisin and Camerlengo are starting work on the upper ocean frontal models.

Major Accomplishments

A linear model on an equatorial β-plane has been integrated over a 120 day period in a basin that approximates the tropical Atlantic ocean. An increase in the westward wind stress of 0.025 N m^{-2} in the western Atlantic excites an equatorially trapped Kelvin wave that propagates eastward along the equator, moves poleward at the eastern boundary, and produces upwelling throughout the Gulf of Guinea. Non-linearities are shown to have the effect of amplifying the effects of the Kelvin wave and prolonging the upwelling event. It is shown that local winds cannot account for the seasonal upwelling in the Gulf of Guinea. A new paper on open boundary conditions has been accepted for publication in *J. Comp. Physics*.

STUDIES OF MICROSTRUCTURE

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Long-range scientific objectives: To understand the role of turbulence in determining the circulation and the distribution of salt and heat in the ocean.

Project objectives:

(1) Studies of Oceanic Energy Dissipation.

The objective is to relate estimates of the energy dissipation from our free-fall measurements of small-scale (1-50 cm) velocity fluctuations to the mean fields of velocity and density.

(2) Horizontal Profiling of Ocean Turbulence.

Work is beginning on a system to produce horizontal transects through the ocean to study the distribution and occurrence of turbulence.

Current status:

(1) Energy dissipation studies - Three major cruises have been made with the instrumentation. Results from one are published, results from a second are in press, and the results from the third are in the final stages of preparation. A new instrument is being built to replace the one which is now worn out. Development of the velocity probe has simplified construction, improved the response characteristics and the calibration procedure.

(2) Work is also underway toward explaining the dynamic response of temperature sensors as well as temperature sensors heated for anemometry purposes. Addition of heated sensor to our vehicles will allow us to determine if and when oceanic turbulence is isotropic.

(3) Measurements have now been taken in the Pacific Equatorial Undercurrent to complement those in the Atlantic Equatorial Undercurrent.

(4) Cruises to a variety of oceanic regimes are now in the planning stages including fronts, rings, the shelf break as well as the open ocean.

(5) Data collected along the Equatorial Atlantic have been analyzed for information about the spatial extent and the relation of the temperature microstructure to the local dissipation rate.

(6) A paper has been written relating the local dissipation rate to the cross isopycnal diffusion of buoyancy.

Major accomplishments:

(1) Development of a useful velocity sensor and support systems for measuring oceanic velocity microstructure.

(2) Measurement of dissipation rates associated with the Atlantic Equatorial Undercurrent and their relation to the energetics of the region.

(3) Measurements of dissipation rates near the Azores which showed high dissipation rates at the base of the thermocline, as well as providing statistics for the upper 800 m of the ocean.

(4) Measurements of velocity microstructure in a variety of oceanic environments as a part of the Fine and Microstructure Experiment (F.A.M.E.).

(5) Theoretical explanation and measurements for thermistor response (Deep-Sea Research, October 1977).

(6) Theoretical explanation for the high and low frequency behaviour of hot film probes as well as the low frequency behaviour of heated thermistors.

AIR-SEA INTERACTION
Dr. Clayton A. Paulson
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Long-Range Objective

- To gain a better understanding of physical processes in the upper ocean and their relation to atmospheric and oceanic forcing.

Objectives

- To determine characteristics of internal waves in the upper ocean.

- To investigate mechanisms of mixing in the upper ocean.

Current Status

Measurements were made with a towed thermistor chain during the Mixed Layer Experiment (MILE). The observations have been analyzed to show the characteristics of internal waves in the upper ocean. The investigation of small-scale temperature fluctuations will be continued.

Measurements were also made with the towed thermistor chain in the upper 70 m during JASIN. The 84 hours of data collected are under analysis. We will construct cross-sections of the temperature field, compute spectra and investigate the characteristics of internal waves and mixing. The analyses will be related to complementary towed and moored observations.

A prototype conductivity sensor was installed on the towed chain during JASIN. We are evaluating the performance of the sensor and carrying out laboratory calibrations with a view toward having several conductivity sensors installed on the chain during an investigation of the Pacific subtropical front in early 1980.

We are analyzing observations made by W. V. Burt from four moorings during JASIN. Observations included wind speed and direction, air temperature, solar radiation and water temperatures from near the surface to a depth of 90 m. Characteristics of the surface meteorological field and oceanic internal waves will be investigated.

Accomplishments

- Found that the average spectrum of internal waves in the upper ocean during MILE is characterized by two slopes, a slope less than k^{-2} for wavelengths greater than 1 km and a slope greater than k^{-2} for wavelengths less than 1 km.

OCEAN WAVE MEASUREMENT BY ANALYSIS OF RADAR IMAGES OF THE OCEAN

Professor A.M. Peterson (Principle Investigator) (415) 497-3594
Dr. J. F. Vesecky (Associate Investigator) (415) 497-2669

Center for Radar Astronomy, Stanford Univ., Stanford, CA 94305

Long-Range Scientific Objective: Our overall, long-range objective is to discover and develop radar techniques which can make meaningful measurements of waves and currents over large ocean areas. Our intention is to demonstrate each technique as a useful research tool by applications to current problems in physical oceanography. These applications are made in collaboration with the oceanographic community. In pursuit of these goals we have employed radar wavelengths from centimeters (microwaves) to over a hundred meters (HF) with platforms on land and sea as well as aircraft and soon SEASAT-A. Our work has ranged from data collection hardware to data processing and interpretation.

Objective of this Project: Because radar techniques can gather wave data over large ocean areas at frequent time intervals, they are well suited to the study of problems in ocean wave generation, propagation and interaction with coasts and islands. High resolution ($\sim$10m) synthetic aperture radar (SAR) images of the ocean surface show great potential for studies involving such phenomena as ocean waves, current gradients, slicks, rainfall and internal waves. However, quantitative interpretation of SAR images in terms of ocean wave directional spectra $\Psi(k,\theta)$ is still very limited. Our objective is to i) investigate the basic radar wave-ocean wave interaction mechanism, ii) develop a mathematic model of the interaction and, iii) use this knowledge to construct and apply algorithms to quantitatively measure Ψ from SAR images. Applications involve SAR images and surface truth including data from the 1977 West Coast Wave and 1978 JASIN/SEASAT experiments. We collaborate closely with R.H. Stewart (SIO) and O.H. Shemdin (JPL).

Current Status of the Project: Our emphasis in the early stage of this research has been to compare estimates of Ψ, based on a very simple assumption, with surface truth measurements. This assumption is that SAR image density fluctuations are proportional to ocean surface height fluctuations. Such comparisons indicate that although estimates of Ψ based on this assumption show the dominant ocean wavelength and direction, the shape of $\Psi(k,\theta)$ in both k and θ differs significantly from ground truth measurements. These comparisons confirm that the radar wave - ocean wave interaction mechanism must be taken into account in order to make a useful estimate of Ψ from SAR images and suggest that the "tilt" mechanism is the one to consider first. We are now implementing a first order correction to our Ψ estimates based on this mechanism.

Robert Pinkel (714) 452-2056

University of California, San Diego
Marine Physical Laboratory
Scripps Institution of Oceanography
San Diego, California 92152

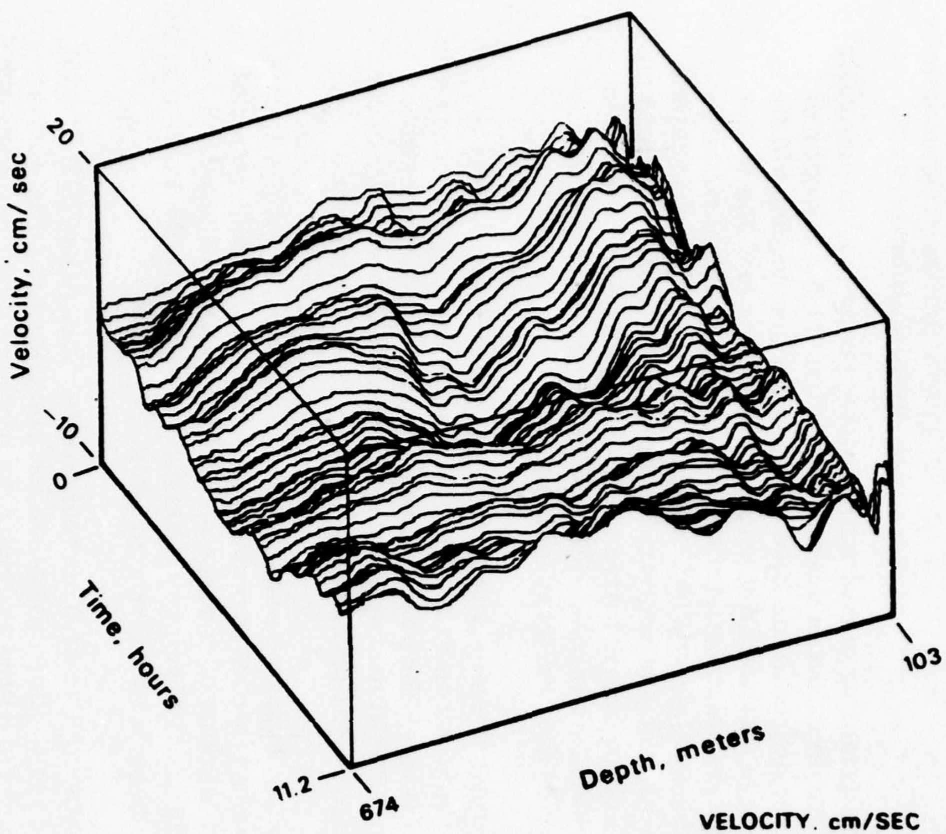
Better understanding of mid-scale oceanic processes, in particular the dynamics of the upper ocean internal wave field, is the objective of this program. The approach has been characterized by ongoing efforts to construct open ocean measurement arrays of sufficient size and sensor density to resolve the spectrum of the motions, as opposed to the more general (and ambiguous) practice of fitting parameters of a preconceived model to a more limited data set. Observations of the energy fluctuations in specific bands of the internal wave spectrum, in conjunction with wind and surface wave measurements, will be instrumental in pinpointing specific wave generation and decay mechanisms.

Doppler sonar is being developed to get the necessary array of measurements. Mounted on FLIP, the sonar transmits high frequency sound in a very narrow beam. The sound scatters primarily off zooplankton. From the Doppler shift of the returning sound the relative velocity of the scatterers - and the water they are drifting in - can be determined.

In 1978 a new high frequency sonar was constructed for use in this work. The sonar can operate between 65 and 90 kHz, at a peak power of 32 KW. In preliminary tests, a range of 1.6 km has been achieved. Range resolution is ~25 m. The velocity precision is approximately 1 cm/sec rms, after 30 seconds of pulse-to-pulse averaging.

It is our objective to have several sonars mounted on FLIP, looking in different directions. This system will be ready for scientific work at sea during early 1980. Initial testing of the prototype sonar has been completed. Construction is beginning on a duplicate system. Work has started on the design of signal conditioning hardware necessary to allow several sonars to operate simultaneously, without interfering with one another.

Analysis of preliminary data taken during 1977 has resulted in a number of interesting findings. The energy in the higher frequency internal waves appears to be modulated by 10-50% at 1-2 cycles per day. The cause of this modulation is not yet understood. Further work on the analysis of existing data is called for in conjunction with preparations for the coming cruise.



VELOCITY. cm/SEC
6 OCT 21:00 TO 7 OCT 08:46
ARRAY ANGLE 45° DOWN
75 kHz, PING LENGTH: 29 mSEC

Water velocity vs. range and time. These measurements were made from FLIP using Doppler sonar on 6-7 October 1978, in 4 km deep water off the coast of California. The sonar was mounted on the bottom of FLIP, with the beam directed 45° downward. Positive velocity is toward FLIP.

The Optimization of Acoustic Backscatter Techniques to Measure Current Profiles From Moving Vessels

Lloyd A. Regier
University of California, San Diego
La Jolla, CA 92093
714-452-4607

Long Range Objectives of Principal Investigator

To develop and utilize methods for observation of the spatial structure of oceanic processes in order to better understand their dynamics.

Objective of the Project

To optimize the use of acoustic Doppler backscatter networks from a moving vessel to provide vertical profiles of horizontal currents. This involves a modelling study of the contamination of observations by ships' motion and methods to reduce these errors.

Current Status of the Project

Construction has been started of a data-acquisition system to be used at sea to obtain acoustic measurements of current and to obtain data regarding the motional characteristics of surface vessels and the resulting contamination of Doppler measurement of currents. We will hopefully be ready for sea in May 1979 for a trans-equatorial cruise under the NORPAX program.

World Ocean Circulation: Weddell Sea and Atlantic-Indian Basin, Deep Pacific Ocean, Atlantic Ocean

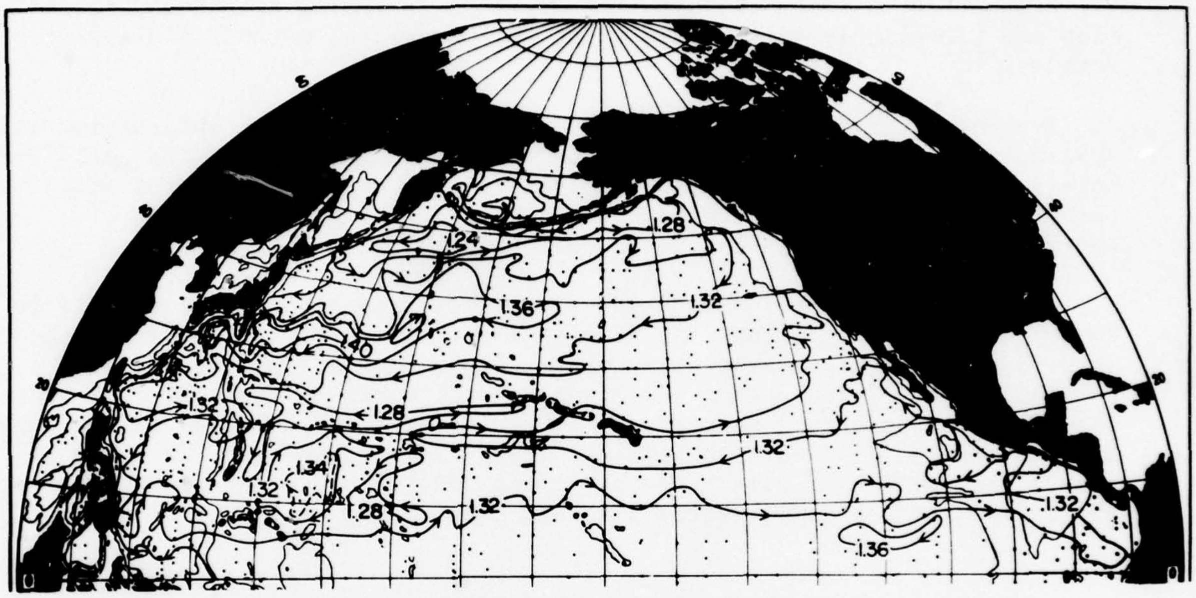
Joseph L. Reid, Professor of Oceanography
Scripps Institution of Oceanography, A-030, La Jolla, CA 92093
Telephone No. (714) 452-2055

(b) The long-range objective is an understanding of the formation and circulation of the water masses of the world ocean. By this I mean a description of the major circulation system of the entire world ocean that includes the flow at all depths and is internally consistent in that it will account at least qualitatively for the distribution of both the conservative and the non-conservative characteristics at all levels as consequences of what we know of the surface exchanges of heat and water and of the wind-driven and thermohaline circulation.

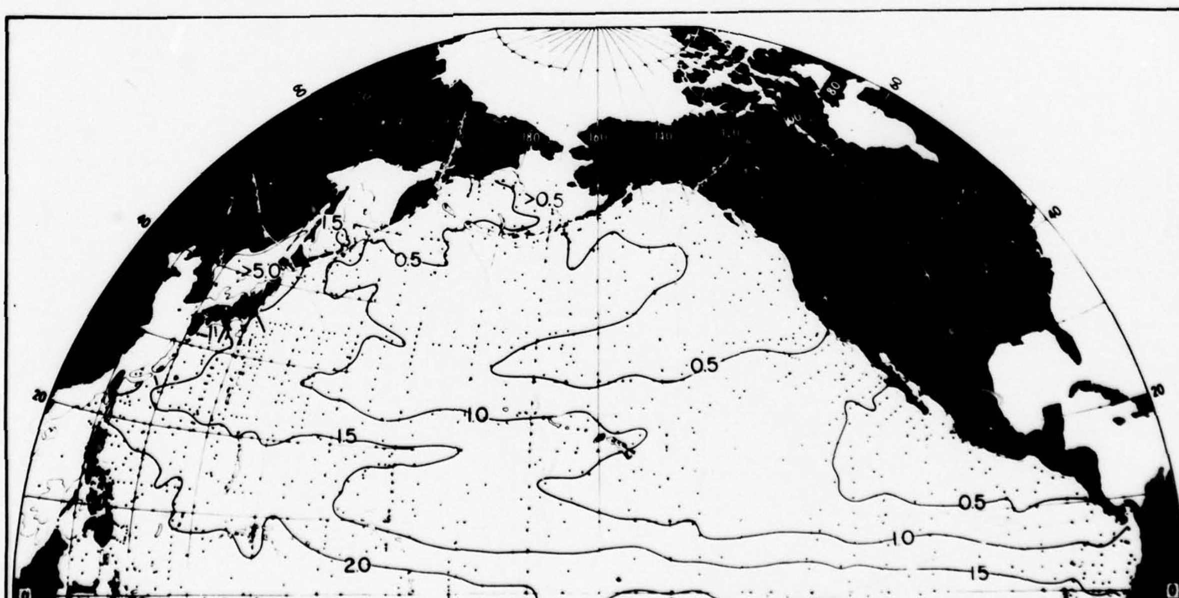
(c) During the next year we shall use the measurements made in November and December 1978 in the South Argentine Basin, with other data, to investigate the possibility that the deep circulation within the Argentine Basin is part of the cyclonic gyre of the Weddell Sea. We shall also continue studies of the deep circulation of the Pacific and the Atlantic.

(d) Selection of stations for study of the Weddell Sea and Atlantic-Indian Basin has been nearly completed, as has that for the Pacific and Atlantic. Indian Ocean selection for the area north of 60°S has been begun. Maps of the Antarctic area are in first-draft form and some for the Pacific are nearly complete. We expect to submit papers on the Argentine Basin/Atlantic-Indian Basin and the deep Pacific circulation during calendar 1979.

(e) Major accomplishments include: the work on the contribution of the Mediterranean outflow water to the Norwegian-Greenland Sea and its importance in the major thermohaline circulation of the World Ocean (Reid, in press); the mid-latitude westward flow at depths near 1000 m in both the North Atlantic and North Pacific oceans, as part of the return flow of the western boundary currents (Reid and Mantyla, 1978; Reid, 1978).



Geopotential anomaly at the 1000 db surface relative to the 3500 db surface, in dynamic meters. (Reid and Mantyla, 1978).



Concentration of dissolved oxygen (ml l^{-1}) along an isopycnal lying near 1000 m depth.

a. Theoretical Studies in Ocean Dynamics, Robert O. Reid, Department of Oceanography, Texas A&M University, College Station, TX 77843, Tel. 713/845-1443.

b. The long range objective of the principal investigator is to achieve an understanding of the basic mechanisms which control the evolution of transient phenomena in the sea via theory and numerical simulation.

c. Present focus is on the dynamics of rings including spin-down, translation and topographic interaction using both numerical methods and analytic methods.

d. A parametric study of ring behavior without topographic interaction is nearing completion. Work continues on the development of a depth parameterized model. A dissertation by Charles Abel entitled "Effects of turbulence on the estimation of horizontal velocity gradients from Lagrangian measurements" has been completed.

e. Results of numerical simulation of initially Gaussian rings with large Rossby number indicate that the ring spin-down is controlled primarily by friction rather than Rossby wave dispersion as in the linear case. In particular, it is found that the translational speed of the center of mass, the center of potential energy and the center of kinetic energy of the ring are all nearly identical, in contrast to the large difference in these speeds for the linear case. Thus, strong non-linearity, at least for initially Gaussian form, exerts a strong stabilizing effect.

a. Western-Boundary Undercurrent, Peter B. Rhines, Woods Hole Oceanographic Institution, Woods Hole, Mass. 02543, Tel. 548-1400, extension 2547.

b. The long-range objective of the principal investigator is to help to develop a modern dynamical picture of transient ocean currents and the mean circulation. The techniques used include theory, numerical experiments, and experiments at sea.

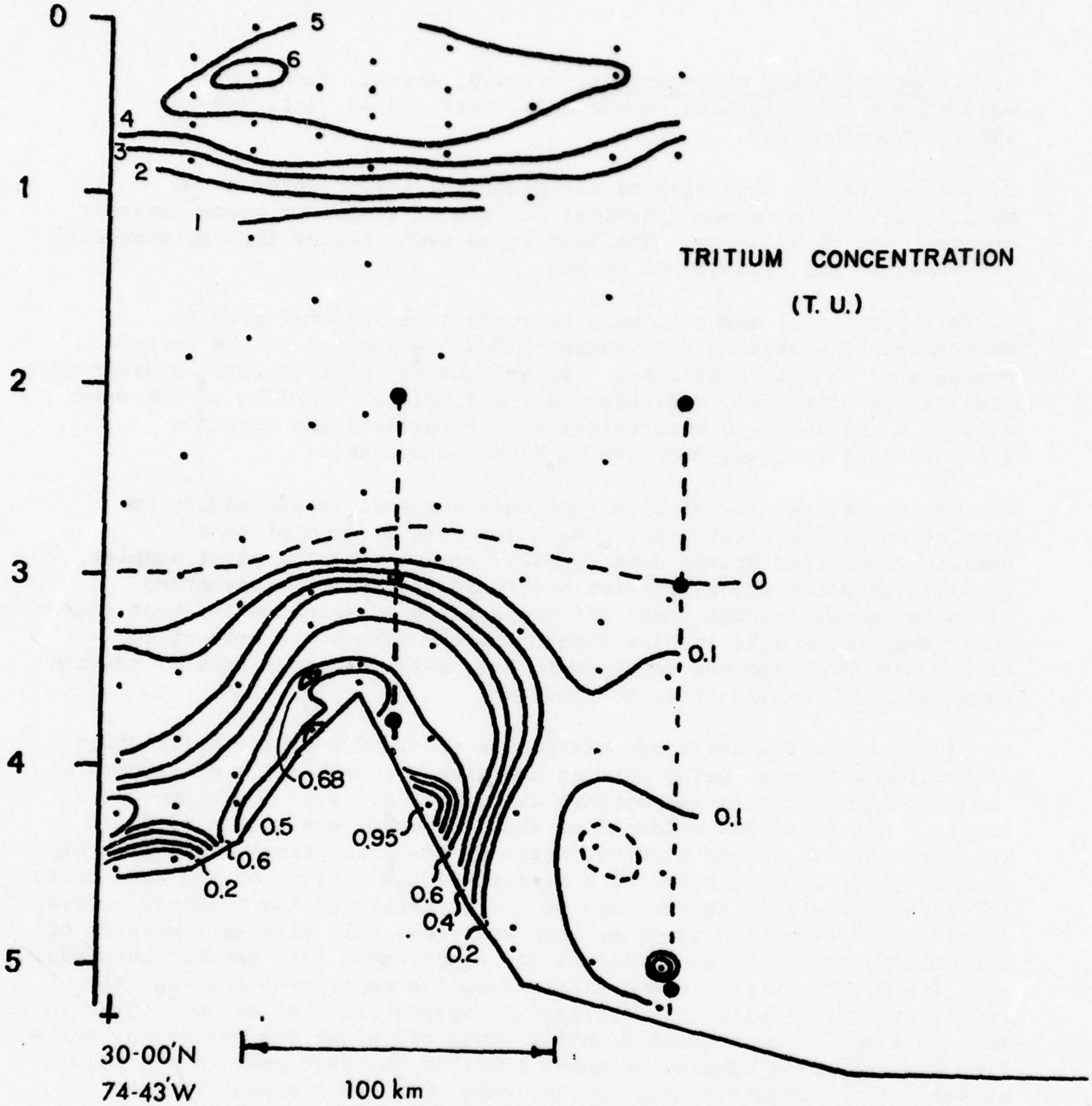
c. This project is meant to be a thorough observational program desscribing the abyssal circulation along one segment of the western boundary of the North Atlantic. Direct current measurements, hydrographic stations, geochemical, radiochemical, and optical sampling of the water column is involved. A theoretical effort involves the specific generation of boundary currents by midocean eddies.

d. The experiment is complete, and data analysis is proceeding to completion of the first phase, which involves section plots of quality controlled cruise data, quality analysis of the water samples, property-property plots, current-meter and thermistor time-series plots, spectra, current roses and the spectra of momentum and heat fluxes. The second phase will involve looking at the fine-scale properties of the ctd data, and the upper-ocean data set. Some analysis of tritium samples still remains to be carried out.

e. The most recent event of interest is the result of the first stage of tritium analysis, being carried out with Dr. Jenkins. A clear core of high tritium concentration appears along both sides of the Blake Outer Ridge. This is direct evidence of the southward penetration of fluid that lay near the ocean surface, north of the polar front, more recently than 20 years ago. It gives us a measure of the ability of the deep ocean to redistribute this tracer, and of the structure of the boundary current itself. The remaining samples, when analysed, will give us a measure of variability of the tritium, and of the penetration into the mid-Sargasso Sea.

The direct current measurements from the experiment show the flow to be intense, jet-like, and variable. Speeds reach 40 cm sec^{-1} just above the sea floor. The current actually shuts off every few months, at which time the isotherms subside by about 1 km. in the vertical. A mooring seaward of the Undercurrent, 100 km. away, exhibited a mean flow to the northwest, opposite to that of the Undercurrent.

The record from above the thermocline contributes to our knowledge of the wind-driven circulation, and of Gulf Stream rings. It shows a strong westward flow, plus a parade of intense rings, in the correct sense to feed the northward flowing Florida Current. The mean flow at this 600m level is also directly along the bottom contours, which may exert an influence even to the sea surface.



Tritium concentration in the Western Boundary Undercurrent (Rhines). The abyssal flow is directed out of the paper (southward) on the right (east) side of the Blake Outer Ridge, and conversely. The tritium is unmeasureably small above the Undercurrent, yet below the thermocline. In the upper ocean, direct injection of this bomb tracer yields high concentrations particularly the peak visible in the 18^{o} water.

CYCLONIC GULF STREAM RINGS

Philip L. Richardson
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(617) 548-1400, ext. 2546

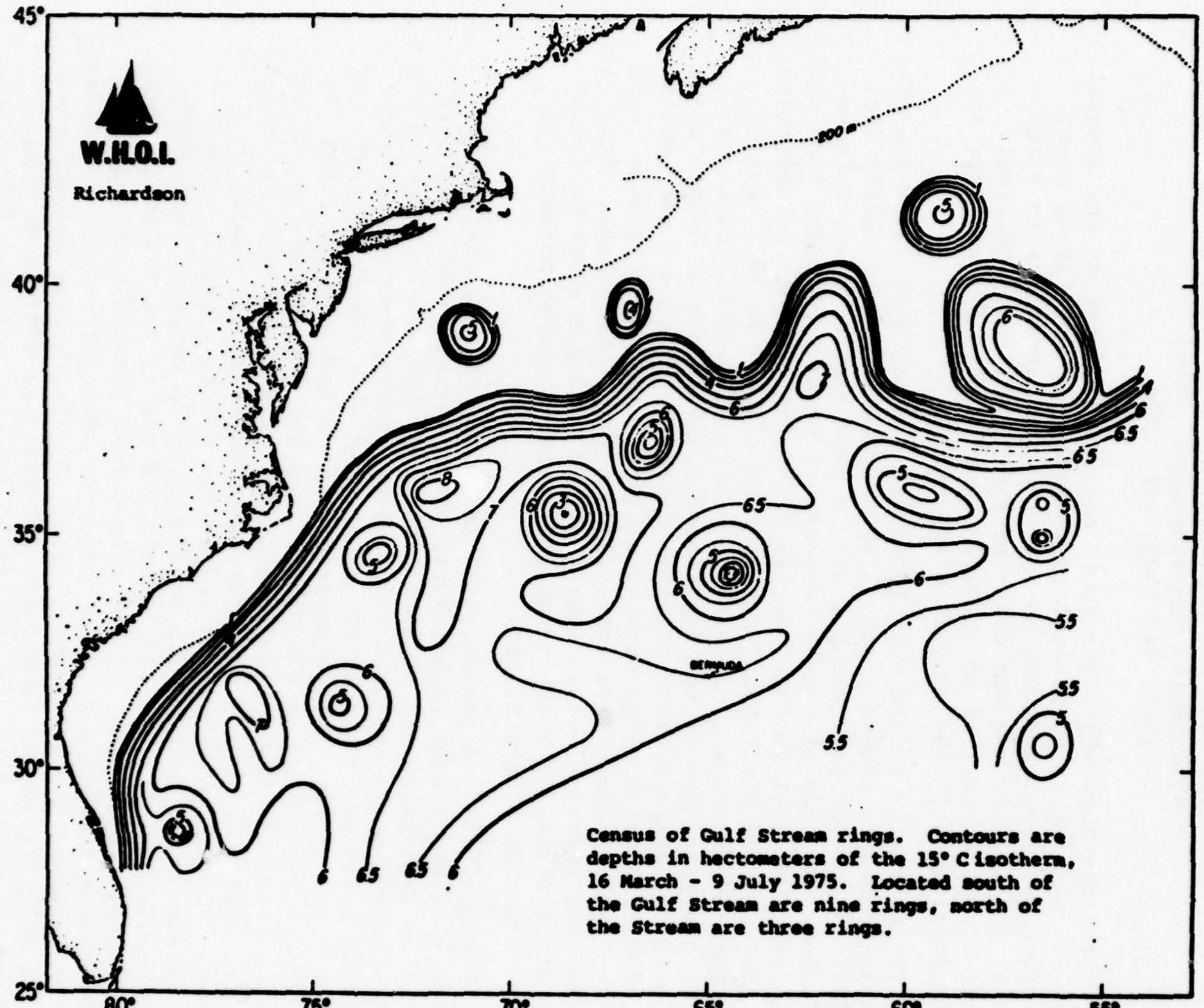
The long-range objective is to measure features of the general ocean circulation in an attempt to describe and understand them. The principal focus has been on the transport and velocity structure of the Gulf Stream and deep Western Boundary Undercurrent. A recent study consists of an investigation of Gulf Stream rings and their importance to the general circulation.

The objective of the Gulf Stream ring experiment is to describe the distribution, movement and decay of rings in the Sargasso Sea. In 1971 a ring was followed for over a year and the decay rate established. A study of 50,000 temperature records obtained from NODC and Fleet Numerical Weather Central (1970-76) was used to determine the distribution and typical movement of rings. In 1975 several shipboard XBT surveys plus satellite infrared images provided a nearly synoptic view of the distribution and number of Gulf Stream rings in the western North Atlantic (Richardson, Cheney and Worthington, 1978). Twelve rings were identified; nine were cyclonic (cold core) rings and three were anticyclonic (warm core) rings. This is the largest number of rings ever observed during a short period of time (four months). Evidence suggests that the mean movement of these rings was southwestward.

During 1976-77 I participated in an interdisciplinary Gulf Stream ring experiment with several other investigators; the data from this experiment are presently being analyzed. We measured the life history of two cyclonic rings using satellite-tracked, free-drifting buoys and a series of cruises and also the trajectories of twelve other rings. The movement of the rings was complicated and appears to be related to the Gulf Stream and strong topographic features such as the New England Seamounts. Rings that were not touching the Stream generally moved westward with typical speeds of 5 cm/sec. Rings that were attached to the Stream generally moved downstream in the Stream with speeds up to 75 cm/sec. Frequently rings coalesced with the Gulf Stream and one of the following three rings seemed to happen: 1) the ring turned into an open meander of the Stream and was lost; 2) the ring was advected rapidly downstream in the Stream and was presumably lost; 3) the ring became attached to the Gulf Stream and then split off again as a modified ring. Evidence suggests that one ring split into two pieces and that two separate rings collided.

<u>Reference</u>

Richardson, P. L., R. E. Cheney and L. V. Worthington, 1978. A census of Gulf Stream rings, spring 1975. <u>Journal of Geophysical Research</u>, **83**(C12), 6136-6144.



Census of Gulf Stream rings. Contours are depths in hectometers of the 15° C isotherm, 16 March - 9 July 1975. Located south of the Gulf Stream are nine rings, north of the Stream are three rings.

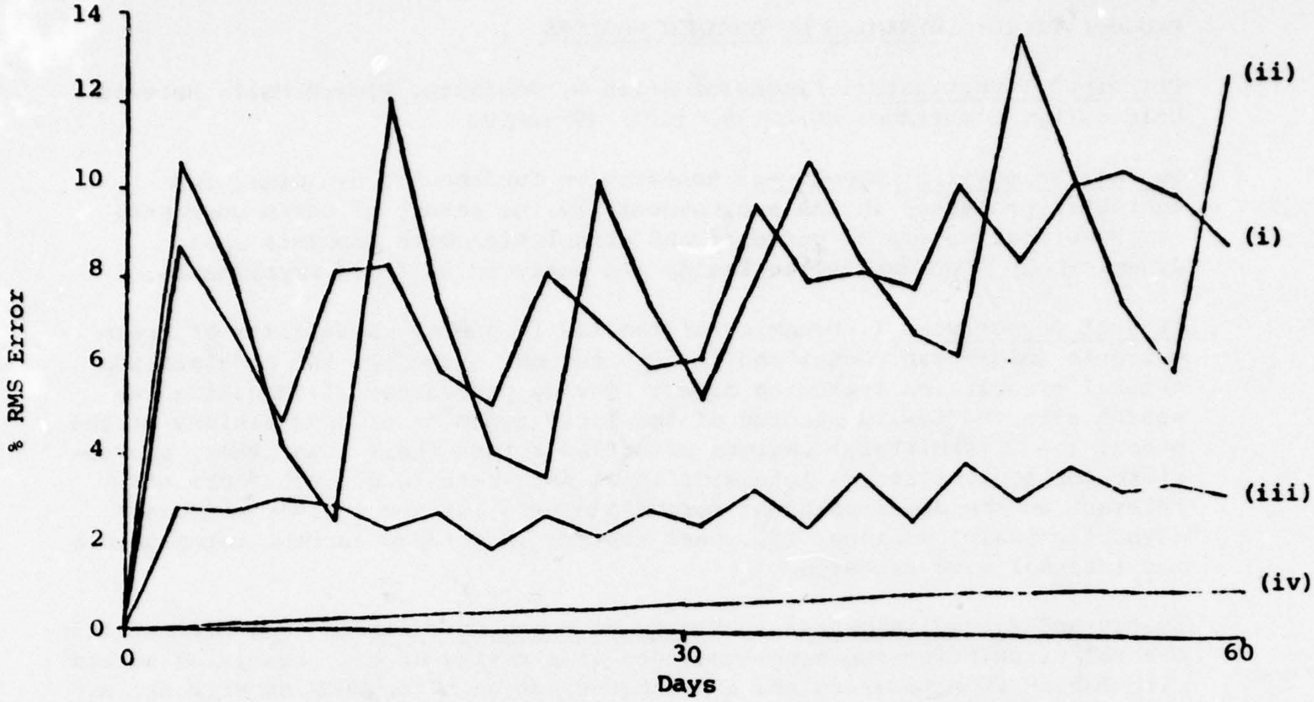
Project Title: DYNAMICS OF OCEANIC MOTIONS

Principal Investigator: Professor Allan R. Robinson, Pierce Hall, Harvard University, Cambridge, MA 02138, (617) 495-2819.

Overall Scientific Objectives: Research on fundamental dynamical and energetic processes in the sea, especially the theory of ocean currents; Numerical models of currents and circulation with emphasis upon dynamical/forecasting studies; Design and analysis of field experiments.

Project Objectives: I. Dynamics of the low frequency variability of ocean currents (mid-ocean eddies and intense current systems), the mid-latitude general circulation including direct forcing processes; II. Modeling research directed toward studies of the local dynamics of open regions of the ocean, i.e., (arbitrary) regions with flow across their boundaries, appropriate for application to intensive local data sets (e.g., POLYMODE) and relevant to the development of forecast models for the oceanic mesoscale (synoptic scale) motions; III. Near surface layer/deep current interactions and internal wave dynamics.

Status and Accomplishments: I. Theory of Ocean Currents and the Mid-Latitude General Circulation--we have concluded a) a review of eddy resolving general circulation EGCM modeling and a parameterization of an EGCM experiment, and b) studies of mesoscale mid-ocean eddy energy generation in and radiation from meander regions, and c) have estimated the response of a basin to simple wind forcing. We are continuing a study of stochastic surface forcing of the mesoscale by observed interactions. II. Regional/Forecast Modeling of Quasi-geostrophic Motions in the Open Ocean--we have applied a) the barotropic model and b) associated objective analysis routines to c) a simulated barotropic forecast error study based on MODE-I data and d) are completing the baroclinic model and its testing strategy. We will next carry out a simulated baroclinic forecast error study based on MODE-I and POLYMODE data e) and then perform dynamical/forecast experiments with the POLYMODE data set itself. III. Mixed Layer and Internal Wave Dynamics--we have finished a) a transient forcing study of the mixed layer, and are concluding b) a study of coupled near surface layer and deep quasigeostrophic motions, which is intended to serve as a guide for c) the construction of a numerical near surface layer model for coupling to the quasigeostrophic open ocean model. We are continuing studies of internal wave d) dissipation and generation mechanisms including e) critical layer effects.



(a) (b) (c)

Stream function field in a 500 x 500 km block of simulated ocean, a) initially, b) after two months, and c) after two months of forecasting. The eye can detect no difference between the actual and forecasted fields. The integrated normalized root mean square error (see graph (i) above) hovers around 10%. In this forecast new boundary data was supplied sequentially to each side of the square every fourth day (one side was "updated" each day). The graph compares other updating strategies:

(ii) all sides updated every fourth day
(iii) opposite sides updated every other day
(iv) all sides updated every day

OCEANIC FRONTS OF THE NORTH PACIFIC OCEAN

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Long-range scientific objective of investigator: To understand the dynamics of thermohaline and sound velocity fronts in the ocean so that meaningful predictions can be made of frontal variability.

Project objectives: To understand the mesoscale variability of fronts in the western Pacific and the dependence of the variability upon atmospheric forcing.

Current project status: An analysis was made of the variability of meridional thermohaline gradients with depth and longitude in the western Pacific, based on a dense network of STD stations. Mean and extreme values of the gradients were determined and vertical coherences of the gradients were computed. An analysis of the temporal variability of surface temperature fronts in the western Pacific, based on satellite data, and of the dependence of the frontal variability upon atmospheric forcing is in progress.

Major accomplishments: It was established that the shape of the power density spectra of meridional thermohaline and sound velocity gradients depends strongly upon depth. In the upper 150 m, the shape is irregular. Between 300 and 600 m, the spectra show a well defined peak between 1.5 and 3 cycles per 1000 km (c.p.1000 km) and a sharp decrease in power beyond 10 c.p.1000 km. Meridional gradients at the sea surface are coherent with those in the upper 150 m, and are incoherent with those below. This is relevant for remote sensing from space. Satellite imagery of surface thermohaline gradients can be used only to locate upper layer fronts. Fronts below pycnocline depth cannot be inferred from infrared or colorimetric measurements from space.

OCEANIC VARIABILITY AND DYNAMICS

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The long-range scientific objective of my research is to understand better the properties of ocean currents and waves, particularly the vertical structure of the velocity and density fields. We are studying low-frequency, mid-ocean eddies, the influence of the ocean bottom on currents, and the generation of internal waves and microstructure. Our principal observational tool has been the electromagnetic velocity profiler (EMVP) developed under this project. A subsidiary long-term goal is to exploit this technique to the point that it can have more widespread use.

During 1978 much progress was made on the publication of our profile observations and analyses, especially from the North Atlantic Fine and Microstructure Cruise (a.k.a. FAME). Hogg, Katz, and Sanford described the temperature and velocity finestructure around Bermuda. Gargett, Sanford, and Osborn reported velocity and dissipation measurements in a very energetic mixed layer. Johnson and Sanford argued from velocity profile data that Bermuda was an internal wave source (that it was also a sink is generally accepted). Sanford, Drever, and Dunlap published a detailed description of the EMVP. Richardson, Maillard, and Sanford described Gulf Stream genesis movement and structure. Lastly, we have developed and used extensively (150 probes) an expendable velocity profiler. Results from this program are very encouraging, and performance is expected to be about 1 cm/s r.m.s. at a vertical resolution of 10 m or less.

Low-Frequency, Large-Scale Ocean Circulation

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The principal aim of this project and of the principal investigator is to describe the properties of the low-frequency, large-scale ocean circulation, with particular emphasis on the relation between eddies and mean flow. A secondary objective is a comparison of the data base with results from numerical models.

Several exploratory long-term deployments of arrays of moored instruments in the North Atlantic have been completed in the past few years. Recent results have been published by Schmitz (1978), McCartney, Worthington and Schmitz (1978), Schmitz and Hogg (1978), and Schmitz and Dean (1978). Continued analysis of the data base and comparison with numerical models is in progress.

Major accomplishments are: (a) Eddy kinetic energy (K_E) levels have been shown to vary by orders of magnitude and to be related to the pattern of the general ocean circulation. Spatial coincidence of energetic eddies with the model equivalent Gulf Stream/recirculation regime is a basic property of eddy-resolving, gyre-scale numerical models. (b) The vertical distribution of K_E has been shown to be weakly depth dependent near the Gulf Stream along 55° W. In sharp contrast, the eddy field is essentially trapped to thermocline depths and above in the interior of the subtropical gyre. This type of dependence of vertical structure on energy level is one of the basic properties of local numerical models. (c) Spectral shape has also been found to be spatially inhomogeneous with the largest contribution by the temporal mesoscale (periods less than 100 days) in the thermocline near the Gulf Stream and by longer time scales in the thermocline towards the interior of the subtropical gyre. Spectral shape is generally dominated by the temporal mesoscale at depths well below the thermocline. The normalized vertical structure for the temporal mesoscale (only) is remarkably geographically homogeneous. (d) Weakly depth-dependent segments of the North Atlantic circulation have been discovered. (e) Preliminary comparison of the data base with gyre-scale, eddy-resolving numerical models suggests that existing runs are too barotropic in the interior of the model and too baroclinic near the Gulf Stream.

Currents in the Charlie-Gibbs Fracture Zone

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As part of a long term interest in abyssal flows and the influence of bottom relief upon them, three moorings were set in the Charlie-Gibbs Fracture Zone (CGFZ) for 9 months in 1975. CGFZ is a major east-west fault in the Mid-Atlantic Ridge at 53°N and is the deepest connection between the eastern and western basins. The objects of this experiment were to measure both the mean flow through CGFZ and the characteristics of the low frequency eddy field.

Along the north wall of the fracture zone there is observed a deep mean flow of order 2-3 cm/sec toward the west. There is also a more energetic eddy field which decreases in intensity toward the bottom at very low frequencies and away from the bottom at higher frequencies. Both mean flow and eddy field are strongly spatially dependent. Their characteristics have been reasonably well reproduced by analytic quasigeostrophic models which conserve potential vorticity and include the influence of small length scale bottom roughness.

One paper has been published summarizing the descriptive results and their relation to the overall general circulation of the area. Another, concerned with the dynamical interpretation, will be submitted shortly, thus completing the project.

a) TOPOGRAPHIC WAVE TRAPPING
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b) Long range scientific objectives are to understand wave phenomena in the oceans and to relate theoretical and numerical methods of analysis to the study of observed oceanographic phenomena.

c) The objective of this project is to obtain analytical solutions to two basic problems of topographic wave trapping. The first relates to topographic trapping of "edge" waves along a coastline; the second considers long waves trapped by bottom topography composed of constant and linearly varying depth segments.

d) The actual contract began December 1, 1979. Some research was carried out on these problems in anticipation of this date and two papers are in preparation, based on presentations at the International Symposium on Long Waves in the Oceans, Ottawa, June 1978 and the AGU Fall meeting, San Francisco, December 1978.

e) "Alternative Topographies for Edge Waves" presented at AGU Fall meeting, San Francisco, December 1978.

ANALYSIS OF OCEAN CURRENTS

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Long-Term Objectives

Improve understanding of kinematics and dynamics of mean and fluctuative processes at ocean boundaries and in the interior through application of model-fitting techniques to measurements of currents and hydrography.

Project Objectives

(1) Further tests and development of the "beta spiral" concept to determine absolute ocean currents from hydrographic station data.

(2) Continuation of fieldwork in the Indian Ocean to explore mean structure and fluctuations of Somali Current and relations to monsoon wind field.

(3) Estimation of horizontal fluctuative scales from moored current-meter array during FLEX '76 in the North Sea in relation to changing stratification.

Current Status and Accomplishments

Beta-Spiral Development: A comparative application of the method to different sets of hydrographic data from the same set of measurements - i.e., sigma theta, in-situ density, temperature, salinity - has been made and it was found that the effects of compressibility are quite important already in the upper part of the main thermocline. A 'depth tendency' in the results of the method - yielding lower currents at reference depth for deeper depth ranges of the stratification data than for shallow ranges for some ocean areas - could be linked to the effects of cross-isopycnal mixing.

Somali Current: In the starting pahse of our 1979 fieldwork, three current-meter moorings could be recovered off Somalia which were deployed in June 1978, and seven current-meter moorings, two wind-recording buoys and three temperature-pressure gauges were deployed. They will be retrieved in July 1979. The array is designed to serve four purposes: a) the study of the onset along the coast as the monsoon develops; b) measurements of vertical and off-shore structure when the current is developed; c) estimates on energy interactions between mean fields and fluc-uations; d) determination of wave-parameters of propagating low-frequency fluctuations. At present, low-frequency fluctuations are analyzed from a set of six-months-long current records obtained off Kenya in 1976.

Analysis of Near-Surface Fluctuative Scales from FLEX: In the Fladenground Experiment (FLEX) 1976, current-meter moorings with horizontal separations between 200m and 150km were deployed from March to June, i.e., from a totally unstratified situation to an almost two-layered density structure. The data have been analyzed and a determination of the changes of wave number frequency relationships of the fluctuations during different situations of stratification is being carried out in cooperation with I.F.M. Kiel, Germany. Also, a comparative study of horizontal mixing processes using moored current meters and dye measurements is in progress.

The Dynamics of Cyclonic Gulf Stream Rings

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The long-range scientific objective is to increase our understanding of meso-scale ocean phenomena and their role in the larger oceanic circulation.

This particular project has as its objective the interpretation of a set of observations from Gulf Stream cyclonic rings in terms of simple dynamic concepts of ring motion and spin-down. In addition, similarity of the ring's dynamics to other frontal-type phenomena is to be considered.

At this time, the ring data analysis is nearing completion, and a laboratory frontal study is soon to be started.

Some major accomplishments include:

1) the application of an XBT sampling array to determine the detailed azimuthal structure of Gulf Stream rings,

2) an analysis of the mean fields of a Gulf Stream ring, including density, velocity, and potential vorticity which may be interpreted in terms of a meridional circulation, details of which agree with drifter observations and water mass modification observations,

3) an analysis of the structure of non-axisymmetric perturbations on a Gulf Stream ring including a separation into azimuthal modes, the association of certain modes with ring movement, and an estimate of their energetics.

TIDAL FORCING OF BAROCLINIC WAVES

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Long-Range Scientific Objectives of the Principal Investigator

The long-range objectives of the investigator are an understanding of the time-dependent coupling of oceanic current/density fields with bottom topography.

Objectives of the Project. Current meter and transport measurements in the St. Lucia Passage consistently show intensification of the tidal fluctuations with depth. The primary goal of this project is a model for bottom-intensified baroclinic currents generated by the barotropic surface tide interacting with a sloping shelf surrounding an island. All baroclinic motions are generated on the shelf.

Project Status. A two-layer ocean with bottom topography confined to the lower layer was used. In the first model, the island/shelf geometry was assumed to be circular. The effect of the tides (whose wave lengths greatly exceeds the island/shelf dimensions) was modelled as a barotropic, spatially uniform, oscillating velocity field, away from the island/shelf. The principal azimuthal wave number which characterizes this forcing is one. The results of the circular island/shelf-geometry indicate no significant baroclinic effects for a wide range of stratification when the azimuthal wave number is one. The anticyclonic wave is forced at a higher amplitude than the cyclonic wave in all cases. Forcing with a non-uniform tidal flux to produce higher order azimuthal wave number motions does generate significant baroclinic motions. Bottom intensification occurs as the stratification increases, a result consistent with low frequency models. Present studies are focused on the generation of higher order waves by island/shelf geometric asymmetries. An elliptic island/shelf geometry is being used.

Major Accomplishments

Depending on the strength of stratification when interacting with bottom topography, barotropic tides can produce intensified barotropic motions, surface intensified currents or bottom intensified fluctuations. The baroclinic motions are not trapped to the shelf, but radiate outward, away from the island. The appearance of bottom intensified currents, driven by a spatially uniform tidal flux onto the island/shelf, can occur when asymmetries in the island/shelf geometry exists. It is the higher order azimuthal waves, generated by the asymmetries, that are bottom intensified.

RADIO MEASUREMENTS OF THE SEA SURFACE

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My long-range objective is to use radio waves of both dekameter and centimeter wavelengths to observe oceanic variables difficult to measure by conventional techniques.

This year we are using dekameter waves to measure precisely the velocity and direction of travel of typical ocean waves, From these we infer the velocity of currents near the sea surface, and their variation with depth, in order to study their relation to wind and wave height. Both wind and steep waves are known to produce currents in the upper few meters of the ocean, and they are one of the main sources of energy for stirring the waters near the surface. Yet there are few observations of their influence, primarily because of the difficulty of measuring currents very close to the surface under windy conditions.

Working closely with colleagues at Stanford University, we have used scattered radio signals at four frequencies to measure these currents in a series of experiments at Pescadero California and for two months in the North East Atlantic as part of the JASIN Experiment. At the same time, we measured wind and waves under a variety of weather conditions. Our first analyses of these observations show that the change in velocity with depth is related to wind speed, and is slightly larger than expected. Ultimately, we hope to compare our observations with similar ones made by others at JASIN to understand better how the surface mixed layer is formed.

Centimeter wavelength radio signals are used by new satellite instruments to study the sea surface from space. To help evaluate these new techniques, I have edited the papers presented at the Colloquium on Radio Oceanography held at Hamburg in 1976, and these have been published as volume 13 of Boundary-Layer Meteorology.

At the present time, I am evaluating the ability of the Synthetic-Aperture Radar to measure ocean waves, and the ability of the Scanning Multifrequency Microwave Radiometer to measure rainfall. Both instruments, carried on SEASAT-1, observed the JASIN experiment at the same time waves and rain were measured at the sea surface. I expect to analyse these observations with the goal of characterizing the performance of the satellite instruments under a range of surface conditions. Ultimately, I expect to use data from an identical radiometer on NIMBUS-7 to study rainfall over the oceans.

Response of the Ocean to Time-Dependent Wind Forcing

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I have been trying to understand the Panulirus data at Bermuda. The variability at periods near a year is large; peak-to-peak variation is ~2° at 800m. The amplitude in many different frequency bands varies with depth exactly as the vertical temperature gradient; thus the vertical amplitude of these motions is uniform vertically. This variability does not appear at the same frequencies as the wind curl that probably forces it. However, the wind curl has a large-scale horizontal wave-form; the mean ocean velocity advects this past Bermuda. That signal is modulated by the annual variability of curl. The resulting beat-frequency effect shifts the annual variability by ± .017 cycles per month, to periods near 10 months and near 15 months. From knowledge of the wind field, we deduce the mean flow at Bermuda to be ~4cm/s at mid-depth. Wunsch's inverse method finds the same. There is a resolvable but small vertical shear.

By frequency shifting the fluctuations back to 12 months, one can compute cross spectra between curl and temperature variations. The coherence is surprisingly high. The yearly peak in wind curl is fairly narrow... yet by smoothing over a frequency band about twice as wide as the wind curl, the coherency remains in excess of 0.7 for 5-band smoothing. The required 5-year variation in temperature, and in coherence with the wind data, can be calculated with only very skimpy confidence, but is borne out clearly in the coherence and phase calculations.

The temperatures at different depths are highly coherent and (almost) in phase; however, the small vertical difference in frequency shifting places the energy at slightly different frequencies at different depths. The temperature fluctuations in their original form therefore have vertical phase shifts of ~30° between 500m and 1200m in a 15-year record -- but this is caused, I suspect, by the vertical gradient in mean velocity.

This technique may allow additional estimates of the very low-frequency velocity in the ocean, that are independent of geostrophic calculations. The result also explains a portion of the observed low-frequency temperature fluctuations -- heretofore thought of as the red spectral background.

In the proposed western boundary current in the Gulf of Mexico, we find that the tide gauge records, when corrected for seasonal stored heat, are coherent with long-shore wind stress and with wind curl; along the Mexican coast the partial coherence suggests that the response to each forcing term is about equal. No baroclinic response was found in the interior, but we were looking at exactly 12 months. The work to examine a frequency-shifted version of the Gulf data is just beginning. Cruises to obtain sections across this current are scheduled in July and October 1979.

Recently a member of the geodesy/leveling group at NOS issued a remarkable statement. The long-shore slope of sea level along the Pacific coast, which had been reported as ~90 cm, now appears to be an order of magnitude smaller in the most recent re-leveling. The long-standing discrepancy between oceanic and geodetic leveling seems to have disappeared.

In October, a small workshop was held at FSU to discuss the present status of our understanding of circulation in the Gulf.

CYCLONIC RING EXPERIMENT

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LONG RANGE SCIENTIFIC OBJECTIVES The project goal is to produce an understanding of mesoscale features associated with strong current regimes. The research areas of interest are the description and analysis of cyclonic ring physical characteristics.

PROJECT OBJECTIVES The field experiment goals are the acquisition of physical data, hydrographic station and XBT processing, preparation of station and XBT sections, physical data report preparation and dissemination. Analyses include comparison of ring structures and energy distributions, entrainment and diffusion, transformation of water masses, volumetric water mass census, preparation of initial and verification data for numerical models and climatology of the North American Slope Water (NASW). Guidance for the Experiment is provided through membership in the Ring Steering Committee.

CURRENT PROJECT STATUS The project has completed and disseminated all four data reports for the primary ring experiment cruises. All hydrographic sections have been completed as well as all XBT sections. Analysis underway includes a water mass census (30%)*, transformation of tropospheric water masses (15%), a study of the Sargasso Sea background (10%) and a continuing examination of the climatology of the North American Slope Water region. The following two papers are in progress: 1) The Physical Oceanography of Two Rings Observed by the Cyclonic Ring Experiment. Part I: Physical Properties and 2) Part II: Water Mass Distribution and Transformation.

MAJOR ACCOMPLISHMENTS A paper: "Comparison of Cyclonic Ring Structures in the Northern Sargasso Sea" was published in J. Phys. Ocn., Vol. 8, No. 6, pp 997-1008.

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*percentage completion

LARGE-SCALE CIRCULATION

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Long-Range Scientific Objectives: To explore and interpret features of the large-scale ocean circulation and associated distribution of properties; including the pattern and rate of deep circulation in the world ocean, the structure, behavior, and dynamics of the major ocean currents, and effects of bottom topography on oceanic flow.

Present Project Objectives: Present objectives concern delineating the overall deep circulation of the Indian Ocean, and investigating the dynamics of deep western boundary currents.

Present Status: Profiles of temperature, salinity, potential density, and the concentrations of dissolved oxygen, silica, and phosphate on a transindian hydrographic section along Lat. 18°S (Madagascar - Australia, July - August 1976) have been finished and will be delivered in 1979 to a printer for production of color plates. Additional hydrographic stations will be made in March - April 1979 in the Central Basin of the Indian Ocean to clarify the sources and flow pattern of deep water there. The deep western boundary current of the eastern Indian Ocean (flowing northward along the Ninetyeast Ridge) has been analyzed in terms of a density-diffusive model for the structure of such currents; the agreement with observation was fairly good, about as good as obtained earlier for the deep western boundary current of the South Pacific. A general review of the deep circulation of the world ocean has also been written.

Transfer of Energy Among Modes
Within the Oceanic Internal Wave Field

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Professor Kenneth Watson has a continuing interest in studying the statistical mechanical properties of dynamical systems. This includes aspects of turbulence and transport phenomena in fluids.

The present project is directed toward the study of internal wave related turbulence in the ocean. Specific objectives are to understand the mechanism of energy transport within the internal wave field and related diffusion phenomena.

The project was initiated in December, 1977. The nonlinear hydrodynamic interaction of internal wave modes has been formulated and developed into a computer code. Two alternate formulations, one using two-time perturbation theory and one using the fluctuation dissipation theorem, have been developed to give transport equations. (Calculations of relaxation rates and energy transfer mechanisms have been made with each of those methods.) The three formulations appear to agree rather well. They also appear to be consistent with an "equilibrium" Garrett-Munk spectrum.

The hydrodynamic calculations indicate that a small distortion from the Garrett-Munk spectrum will rapidly decay, returning the spectrum to its Garrett-Munk form.

Project

Studies of the oceanic bottom boundary layer

Principle Investigators

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Long range scientific objectives

To gain insight into the physical processes determining the structure and variability of the bottom boundary layer.

Project Objective

The project aims to use analytical and numerical to model the tidally modulated turbulent Ekman layer formed in a stably stratified ocean over the continental rise and an array of vertically stacked rotors and thermistors to make measurements in such a bottom boundary layer.

Current Status

We are using analytical methods to describe the transient response of the bottom boundary layer to various types of tidal forcings. We are also testing various second order turbulence closure schemes to find one generally suitable for modeling a time-dependent buoyant bottom boundary layer. An existing instrument is being prepared for making long-term speed and temperature profile measurements in the HEBBLE Scotian Rise Program.

TITLE: STUDY OF THE DYNAMICS OF LARGE-SCALE THERMAL VARIABILITY IN THE UPPER WATERS OF THE MID-LATITUDE NORTH PACIFIC

PRINCIPAL INVESTIGATORS: W. B. WHITE, NR 083-005; R. L. BERNSTEIN, NR 083-005

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Approaching the 4th year of a five year XBT program to study the dynamics of large-scale thermal variability in the upper waters of the mid-latitude North Pacific, we are beginning to formulate some answers to questions raised before the inception of this study.

Concerning the questions of whether the main thermocline is displaced vertically by divergent action of the wind-driven surface currents, we find that for the two years of data that have been analyzed so far the main thermocline in winter, spring, and summer responds as it is supposed to do according to the theory. Important exceptions to this occur in the immediate vicinity of the Subarctic Front near 40°N and during the autumn season, when it appears as though deep mixing and/or barotropic advection are important to thermocline behavior. Estimates of the magnitude of these latter processes, using least-squares estimation theory in the explanation of the *change in T, S characteristics* of the water mass...(i.e., using CTD data from repeated hydrographic cruises in the area) finds the autumn season barotropic flow must have been 2-3 cm/sec and the vertical diffusion coefficient to have been 1-10 cm^2/sec in the main pycnocline from 300m - 800m depth.

Concerning the questions of why anomalous temperatures at ocean weather stations P (50°N, 145°W) and N (30°N, 140°W) of time scales 1-2 years tended to propagate from the sea surface downward at a rate of 100m/year is in the process of being understood. In the two years of analyzed XBT data, this same trend has been seen and dissected and is associated with a low frequency modulation of the anomalous atmospheric forcing in the autumn/winter period of each year. During these two years, the anomalous autumn/winters were colder than normal with mixed layer depths extending two times deeper than normal (250m depth) at 40°N, 160°W. From one winter to the next, the seasonal summer thermocline insulates the levels below 30m from further atmospheric influences; therefore, autumn/winter periods of similar anomalous atmospheric forcing have an integrated effect in the deeper waters that produces the observed cooling trend. It is still not clear how the cooling penetrates into the main thermocline below 250m.

Concerning the questions on the rate of mesoscale eddies and waves in the Kuroshio Extension in altering the mean background flow, it has been established that these waves are baroclinically unstable, with east/west tilting of the wave axis with depth that indicates a poleward eddy flux of heat in the upper 300m of ocean that rivals that extracted from this part of the ocean each winter by the atmosphere synoptic storm activity. We are presently working on the possibility of establishing the degree of barotropic instability in these waves.

Concerning the question on the partition of eddy energy in the Kuroshio Extension into that due to transient waves and that due to stationary waves, we find that west of 160°, between the coast of Japan and the Shatsky Rise, these two are of about equal value, but that east of there out to 180° the transient wave energy is very weak, dominated by that due to quasi-stationary waves that are apparently topographically controlled by such bathymetric features as the Shatsky Rise and the Emperor Seamounts.

This next year we should like to pursue the idea of augmenting the present TRANSPAC XBT program with an XCTD program and with bottom mounted current meters, both requiring cooperation with other principal investigators who would be willing to cooperate with us in further refining these studies.

Velocity Structure of the High Energy Benthic Boundary Layer

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My long-range objective in the study of BBL flows is to measure and understand the effect of the bottom topography on the transport of momentum from the flow to the sediment, and the converse effect of the large-scale flow structure on the generation of bedforms. My interest extends to the development of current sensors capable of measuring the turbulent fluctuations characteristic of these interactions and the data processing systems needed to compress the measurements into a comprehensible set of data.

The objective of the HEBBLE project is to study the intermittent high stress events responsible for sediment suspension and bedform modification in the high energy BBL environment of the Western Boundary Undercurrent. Correlations will be made of Reynolds stresses with optical and acoustic turbidity measurements, shear stresses at the sediment interface, and bottom photographs.

A deep sea acoustic current meter array has been tested on the North Bermuda Rise where vector velocities were monitored for six hours at heights of 25 cm, 50 cm, 1 m, and 2 m above the bottom. A high velocity was measured at an erosional site with an apparent roughness of 15 cm and a stress velocity of 22 cm/sec. Lower values were observed at depositional sites. Velocities at 2 m above the bottom varied from 60 cm/sec to 12 cm/sec.

THE RELATION OF SEDIMENT MOVEMENT TO BENTHIC CURRENT FLOW

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Long-Range Objectives. To develop as full an understanding as possible of: (1) the hydrodynamics of the frictional boundary layer at the bottom of the ocean; (2) the interaction of this layer with the sea-bed, in particular the relationship of hydrodynamic parameters to sediment transport and resulting bed forms.

Objectives of Current Project. The project is designed to investigate the relation between sediment movement and overlying current flow at a high energy deep-sea site.

The field program has three components:

(1) A site survey to locate a uniform region of bottom sediment with recognizable bedforms of less than one meter scale.

(2) The nearby installation of a specially designed apparatus (TRIFFID) containing on a fixed tripod frame:

(a) vector-averaging current meter (VACM), recording the current velocity at an elevation of 1 meter
(b) 16 mm camera to take time lapse motion pictures of the sediment in a 1x1.5m area
(c) 70 mm camera pair to take occasional stereo pictures of approximately the same patch of sea bed
(d) strobe light to illuminate the bottom
(e) acoustic release system for apparatus recovery

Above the tripod and attached to it is a string of four VACMs at elevations of 3, 10, 20, 60m.

(3) Obtaining relatively undisturbed samples of the sea bed in the vicinity of the apparatus.

In the analysis, data from these components is brought together to relate the observed changing bedform to the sediment composition and the overlying flow. It is hoped that this will result in a significant increase in understanding of the interaction of current and bottom sediment in the deep-sea environment.

Current Status. The camera system is being redesigned to give occasional high resolution stereo pictures of the sea bed. Two TRIFFID rigs will be built with this newly designed system.

One rig will be recovered from the Bermuda Rise in April. Then, after a testing cruise in July, another rig will be deployed on the Scotian Rise in a joint experiment to study the benthic boundary layer under the Western Boundary Undercurrent.

Accomplishments. 1976 experiments in the Florida Straits with the original version of the TRIFFID rig showed vigorous but episodic current induced northward sediment transport in the region. In contrast, a two-week deployment in 1977 near an abyssal furrow on the Bahama Outer Ridge showed very steady benthic current flow with no discernible disturbing influence on the bottom. In September 1978, the rig was deployed on the Eastern Scarp of the Bermuda Rise at the edge of a field of furrows which had been surveyed in detail. It is thought that the deep Gulf Stream Return Flow is actively eroding the sediments in this region, and it is hoped that when the rig is recovered in April it will bring with it an interesting record of this erosion process.

WATER MASS FORMATION AND GULF STREAM VARIATIONS

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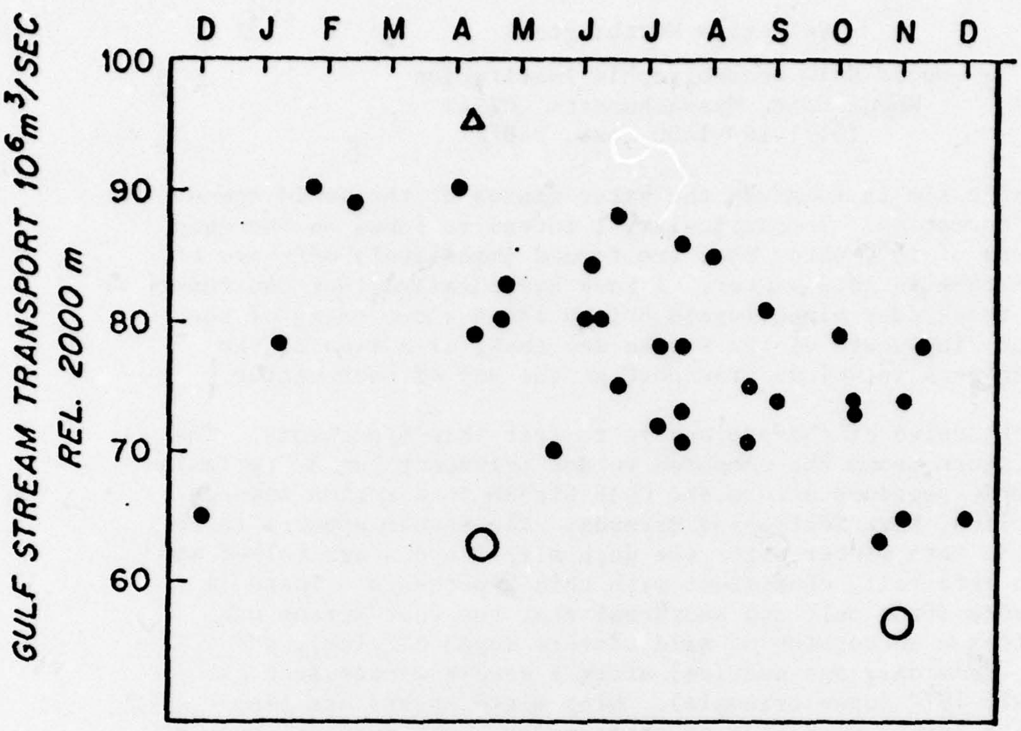
My scientific aim is to study the water masses of the world ocean and their formation. In particular, I intend to focus on the deep mixed layers of 18°C water that are formed immediately offshore of the Gulf Stream in late winter. I have hypothesised that the formation of these deep mixed layers brings about a deepening of the main thermocline south of the Stream and that, as a result, the Stream increases in volume transport at the end of each winter.

The main objective of the project is to test this hypothesis. The attached figure shows the computed volume transport for 32 reliable oceanographic sections across the Gulf Stream in a region between North Carolina, Nova Scotia and Bermuda. The Stream appears to be strongest in late winter after the deep mixed layers are formed and weakest in late fall, consistent with this hypothesis. There is also evidence (from only two sections) that the Gulf Stream was weakest after a succession of mild winters (open circles), and strongest (from only one section) after a severe winter such as that of 1976-1977 (open triangle). Deep mixed layers are also found on the equatorward side of other major ocean currents such as the Kuroshio, the Somali Current and the Antarctic Circumpolar Current; the hypothesis may also apply to these currents. Existing data are insufficient either to confirm or refute the hypothesis, and the exact mechanism by which the thermocline is deepened (if indeed it is) is not at all clear.

A modest start has been made in 1979 by means of oceanographic sections across the Gulf Stream on a "piggy-back" basis, and by examining the effect of past winters on the depth of the mixed layer and the thermocline in historical data.

The major accomplishments of this project are the published papers listed in the bibliography.



W.H.O.I.
Worthington

Computed geostrophic volume transports for sections in the Bermuda - Nova Scotia - Cape Hatteras triangle: •, 32 sections made between 1932 and 1968; O, sections made before and after the winter 1974-75; Δ, between Researcher stations 6 and 33 in April 1977. All transports are relative to 2,000 m and are plotted against month.

Acoustic Tomography and Internal Waves

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Long Range Objectives. The major present goal of this project is to learn to use acoustic methods to measure and understand the ocean. Involved is a complete understanding of long-range acoustic propagation in the deep sea, and the development of tools for determining the signal at a receiver at arbitrary distances from the source at any depth. To use this information, we must then solve the "inverse problem" in order to determine how the ocean has changed from one time period to another. A second goal of the present contract is a complete understanding of the deep ocean internal wave field, including its sources, sinks, propagation characteristics and influences and interaction with the mean flow.

Objectives of Present Contract. We are working with analytical acoustic ray-trace models to obtain a qualitative understanding of the acoustic "forward" problem. The model is being quantitatively compared to recently obtained acoustic arrival experiments in the western North Atlantic. We are designing a full test of tomography in late 1980 in that region. A study of the data resulting from an internal wave and mixing study in Hudson Canyon is being analyzed with a view toward understanding the dynamics of large canyons and the distortions which appear in the internal wave field under extreme conditions.

Current Status. One manuscript describing the acoustic modelling has been completed, and a second manuscript is in preparation. Comparison to the experimental data has begun. An analysis of the Hudson Canyon moored array is being written.

Major Accomplishment. The tomographic idea still appears feasible and is actually being demonstrated.

SECTION VI---BIBLIOGRAPHY

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