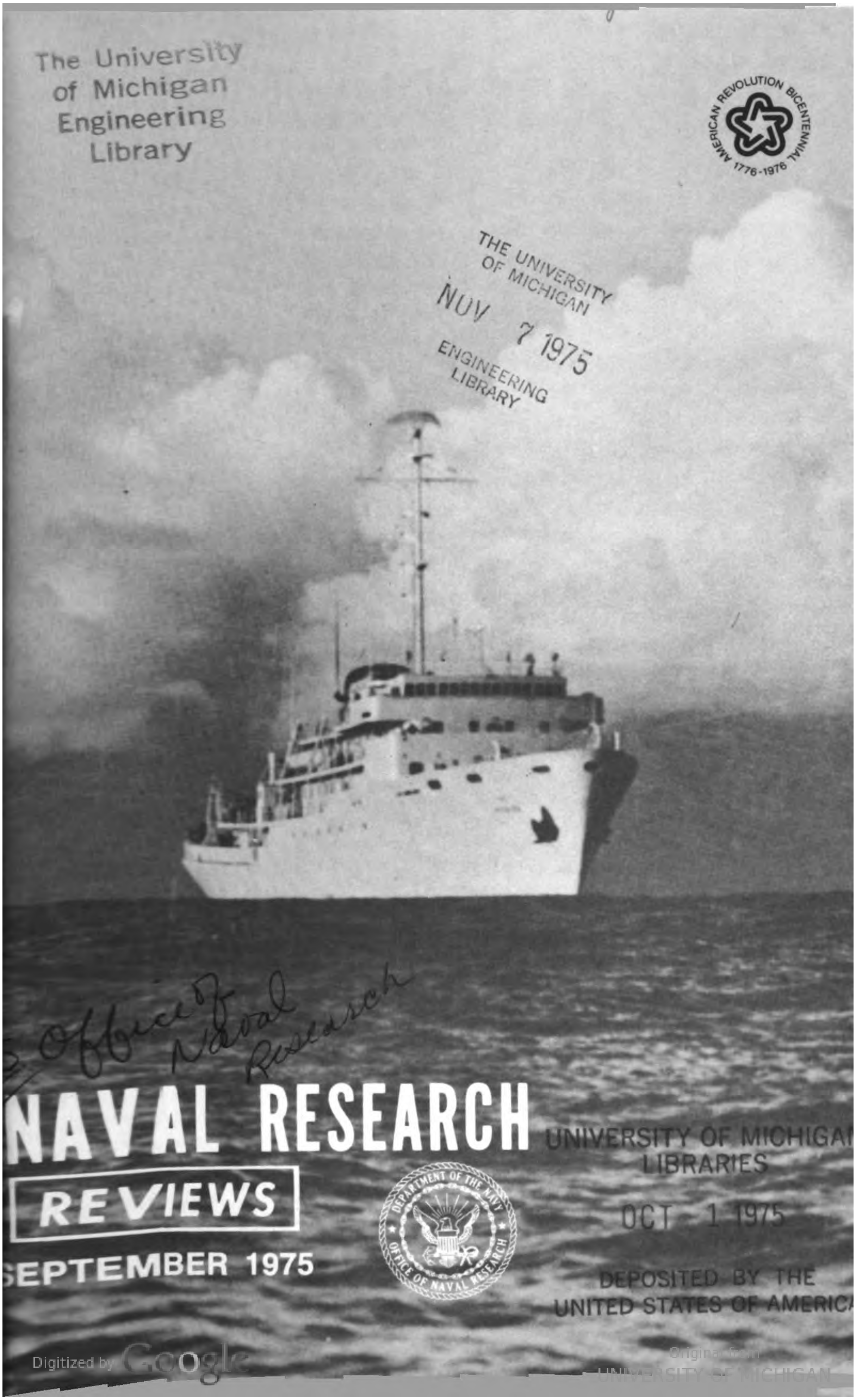

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PROFILES IN SCIENCE

Dr. Richard W. James

Dr. Richard W. James has pioneered in the development of oceanographic prediction. His system of optimum track ship routing has saved the Navy millions of dollars. He is co-author of the book "Observing and Forecasting Ocean Waves," the first text on spectra wave forecasting. Dr. James and his associates introduced the first synoptic oceanographic broadcasts to the Fleet portraying ocean-wide wave or thermal conditions on daily charts. A technique he developed for computing wind drift currents has been adopted by the U.S. Coast Guard in their Search and Rescue operations. Most recently he has developed a practical system of forecasting sonar ranges aboard aircraft carriers. The success of this development is attested to by numerous letters and messages from the operating Fleet. He has also assisted other nations in establishing oceanographic support to ASW and is known internationally for his many accomplishments in the development of oceanographic prediction methods.

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Naval Oceanographic Office

D. Jean Keen

When the Navy, in 1830, authorized a modest Depot of Charts and Instruments to service the fledgling U.S. Fleet and merchant marine, it established the rootstock that would someday produce the Navy Hydrographic Office-HYDRO (1866); Naval Observatory (1866); National Oceanographic Data Center-NODC (1961); Naval Oceanographic Office-NAVOCEANO (1962); National Oceanographic Instrumentation Center-NOIC (1969), and the Defense Mapping Agency Hydrographic Center-DMAHC (1972). NAVOCEANO, in the direct line of descent, is the former Hydrographic Office renamed. The Data and Instrumentation Centers have been absorbed by the National Oceanographic and Atmospheric Administration (NOAA) within the Department of Commerce.

Directed from its headquarters in Suitland, Maryland, the NAVOCEANO of 1975 is an organization of 1240 military and civilian men and women whose purpose is to enhance the Fleet's capability over, on, and in the sea by gaining and exploiting new knowledge about the ocean and its boundaries, surface and bottom, toward strategic and tactical ends. Nine ships and three aircraft are employed full-time in carrying out these responsibilities, and NAVOCEANO also manages three other ships that support its oceanographic R&D tasks as well as those conducted at the laboratories of the Naval Material Command.

From the days of the leadline to our current use of precision echo-sounding sonar arrays, measuring the depth to the ocean bottom and charting its configuration have been of continuing and vital interest to maritime nations. The U.S. provides for the safe navigation of its mariners by statute, placing responsibility for surveying and charting home waters on the National Ocean Survey (formerly the Coast and Geodetic Survey), and for open ocean and foreign coastal waters on the Department of Defense. From 1837, when the first U.S. nautical chart was published by the Navy, until 1972, NAVOCEANO was the DoD's sole agent for the task.

Surveying the sea floor remains a major NAVOCEANO responsibility, though the charts and other navigational aids that result are now printed by the Defense Mapping Agency, Hydrographic Center (DMAHC). Six large survey ships, one aircraft, and about one-third of NAVOCEANO's personnel and resources are directly engaged in the three types of hydrographic surveys — bathymetric, gravimetric and geomagnetic — and the geodetic support these surveys require. The hydrographic ships operate world-wide; four in the deep ocean and two in foreign coastal waters. The deep ocean surveys acquire geophysical

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data to support our strategic forces: precise bathymetry that permits navigating by undersea features, and gravity measurements from which deflection of the vertical is computed. These gravity measurements are essential for correcting inertial guidance systems and determining the shape of the geoid (Figure 1).

Figure 1 — Hydrographic survey ship USNS Wilkes, one of the modern path finders of the seas

Two 4000-ton ships, each carrying a helicopter and four survey launches, are devoted exclusively to coastal surveys, one operating in the Atlantic and the other in the Pacific. The small launches survey close to shore where shoals might jeopardize the larger ship. Shore-side geodetic control stations set up to establish datum and provide precise positioning are supported by helicopter and landing craft (Figure 2).

The aircraft, an RP-3D Orion, collects world wide marine magnetic intensity data used to correct the magnetic compasses of mariners and aerial travelers everywhere, and to assess the magnetic background noise against which magnetic devices for detecting submarines must operate. Project MAGNET, now working with its third aircraft, has surveyed over three million track miles of ocean since its beginning in 1953 (Figure 3).

Research and development support of NAVOCEANO's hydrographic survey mission is concerned mostly with improvements to equipment and methods. Operational evaluation of a new coastal survey system,

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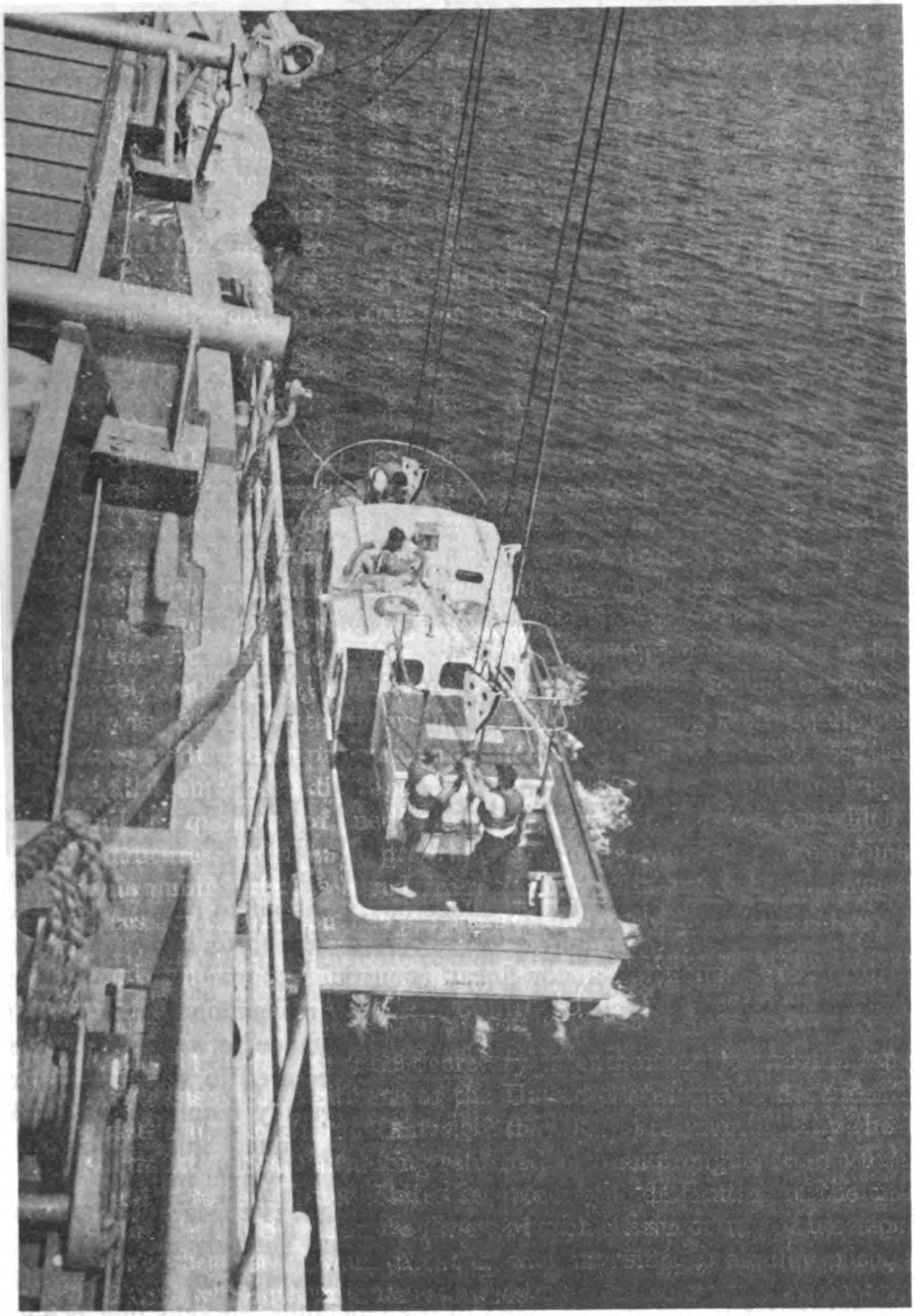

Figure 2 — Coastal survey launch being readied for work.

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Figure 3 – Project MAGNET's RP-3D aircraft "Roadrunner" has logged over four million miles of marine magnetic surveys and circled the globe four times

HYSURCH (HYdrographic SURveying and CHarting), began early this year (1975), and engineering development of an airborne laser/photographic system for measuring bathymetry very close to shore, where even small boats find it dangerous, is about to commence. The laser-calibrated photography gives accurate data up to 15 fathoms. On the deep ocean side, a non-linear acoustic reconnaissance sonar in development is expected to illumine major navigational hazards out to 15-20 nm. This will permit widening the distance between ship tracks with a corresponsing decrease in the time required to survey a given area. Complete bathymetric surveys now normally require 6 nm track spacings. In these days of petrodollars and limited ship availability, such an advantage would be worth more than its weight in gold.

The rest of NAVOCEANO, more than half, is engaged in Oceanographic Survey and Research. The strategic submarine force, anti-submarine forces and the surveillance community are the principal beneficiaries of the several types of oceanographic surveys that NAVOCEANO conducts.

Underwater acoustic measurements — bottom reflectivity and reverberation, ambient noise and propagation loss – are important features of this program, as are profiles of the ocean's physical properties, temperature, salinity and sound velocity. With the imminence of suspended sonar

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arrays and moored deep water mines, a critical need has arisen to know more about the vertical current structure in various parts of the ocean, top to bottom. Recent surveys have been measuring the current profile as well, using bottom-moored arrays of self-contained current meters which can be implanted and left unattended for upwards of a year. These arrays have six to a dozen meters each and are often over two miles long; the geometry of the implantment of course varies with the problem at hand.

Nearshore surveys obtain the data for mine laying, mine sweeping, and counter-measures. The fact that visibility, acoustics, magnetics and pressure are the principal measurements required has given rise to the acronym "VAMP." VAMP Surveys are now conducted entirely in foreign waters on the host countries' vessels and with their active participation and support. Yet another type of survey acquires Oceanographic Data in Submarine Trial Areas, (ODISTA). ODISTA Surveys rely on the Teleprobe, a remotely steered, video-monitored underwater sled with side scanning sonar and cameras, to reveal any untoward or hazardous bottom features and other obstructions in the trial areas. Oceanographic measurements are also included in ODISTA surveys, but they are obtained by more conventional means.

Altogether, about 25% of NAVOCEANO is directly involved in the collection, processing and interpretation of oceanographic survey data, its disposition in data banks, and its presentation in brochures, handbooks, charts or other material that responds to fleet-generated requirements.

Eventhough hydrography has been an integral factor in NAVOCEANO's life since 1834, the first oceanography survey did not take place until 1947, and its Research, Development, Test and Evaluation Mission (RDT&E) is even more recent. The first certified R&D program was established in 1960, and NAVOCEANO's official mission was changed to reflect the new program in 1962. As happens in any organization charged with a continuing support responsibility, what would now be called R&D had been conducted over the years with operational funds to seek improvements in collection and analysis capabilities.

The initial R&D work was in the area of oceanographic prediction and was spear-headed by a group of meteorologists who had been weather forecasters in World War II. For many of these meteorologists their introduction to the marine environment was predicting wave conditions in the English channel and the surf on the Normandy beaches for the eventual D-Day. After waves came ice forecasting because ships supplying the DEWLINE (a post-WWII Distant Early Warning Line of interconnected radar stations across northern Canada) were suffering continual and considerable ice damage. For this the meteorologists turned again to that most successful tool of their trade, sets of synoptic observations, to obtain the big picture of the *now* situation from which

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to extrapolate future conditions. The impossibility of acquiring enough synoptic data from ground stations led to the use of aircraft for ice reconnaissance; aircraft have remained important factors in oceanographic research and surveys ever since.

Then in the late 1950's new developments in submarine detection systems, airborne and shipboard, were found to be strongly and often severely, limited in performance by characteristics of the medium. Predicting the nature and distribution of the most important of these, the vertical temperatre profile, became the forecasters' next project. The dimensions of the problem, in terms of concept, potential applicability and present state-of-the-art, not to mention logistical difficulties, all pointed to a major undertaking, much of which would explore new ground.

The venture became the ASW Environmental Prediction System, ASWEPS, progenitor of the Fleet's present-day oceanographic forecasting services. ASWEPS implemented a synoptically reporting network for bathythermograph (BT) observations; pioneered synoptic analysis of sea surface temperatures, layer depths, currents, and sonar ranges; provided the impetus and developmental support for the now-popular Salinity/Temperature/Depth reports and Shipboard, Expendable Bathythermographys; innovated ASW shipboard forecasting and tactical assists; established oceanographic forecaster training programs for officers and achieved billet allocations for oceanographic specialists on ASW staffs ashore and afloat. When the program ended, oceanographic prediction was in the Fleet to stay.

The R&D performed today addresses a much broader range of subject matter and is interlocked with current survey practice. The types of problems attacked can be generalized into seven major categories: underwater acoustics, tactical applications, sea ice phenomenology, geology and geophysics, ocean dynamics, observational techniques, and instrumentation (Figure 4).

Until recently, underwater acoustic research centered on measuring and modeling volume reverberation at long range active sonar frequencies. Preliminary models under this program are now part of the sonar operating doctrine, and many of the measurement techniques developed have become standard survey procedure. Volume reverberation research is shifting emphasis from the mid to the very high (torpedo) frequency range sensitivity, and the overall effort is becoming subordinate to development of low frequency geoacoustic models of bottom propagation, reverberation and reflectivity. Aircraft and explosive measurement techniques are used extensively in both approaches.

The Integrated Carrier ASW Prediction System, ICAPS, exemplifies the concept of Tactical Applications. ICAPS is a software package that is added to the repertoire of existing shipboard computers and operates

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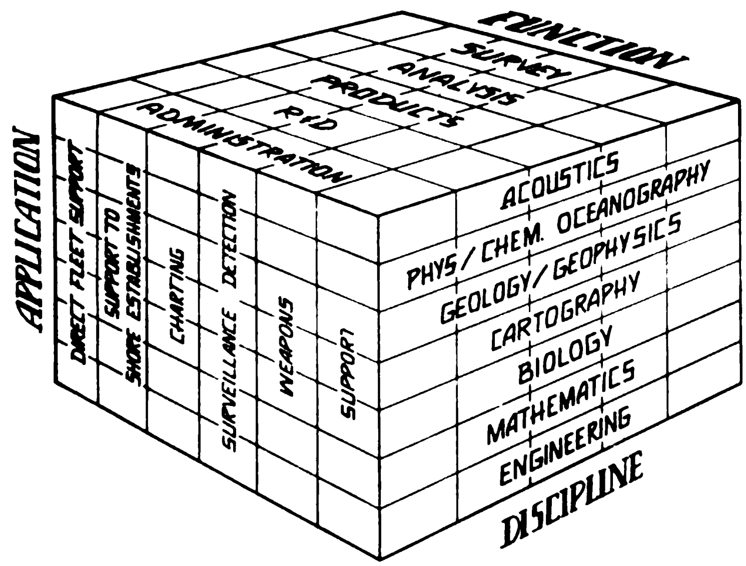

Figure 4 – NAVOCEANO – Programmatic Summary

on *in situ* oceanographic observations in near-realtime. Propagation loss curves and detection ranges can be computed for any desired combinations of operational parameters.

Over the last five years the thrust of the Arctic research project has shifted from a basically synoptic-statistical approach to forecasting sea ice features to one of modeling the dynamics of the Arctic weather and current regimes. While synoptic observations remain critically important, satellite imagery and laser profilers are replacing the MARK-I eyeball (Figure 5). Operationally, NAVOCEANO supports every submarine under ice transit with presail planning guidance and enroute forecasts of the subsurface topography, ice thickness, and probability of occurrence and duration of polynyas.

There is a wide variety of R&D projects in geology, geochemistry and geophysics—from designing environmental filters to improve submarine detection with the Magnetic Anomaly Detector (MAD) gear on ASW aircraft, to removing pollution products from fresh water with manganese-impregnated acrylic fibers. Basic research includes studies of "hot spots" in the earth's crust and contributions to further refinement of plate tectonics theory, mapping climatological regimes from sediment analysis, and investigations of the acoustic reflective properties of sub-bottom strata.

In physical oceanography, the research emphasis has always been on waves and currents. There is a progression from theoretical wave research on momentum transfer at the air-sea boundary to numerical

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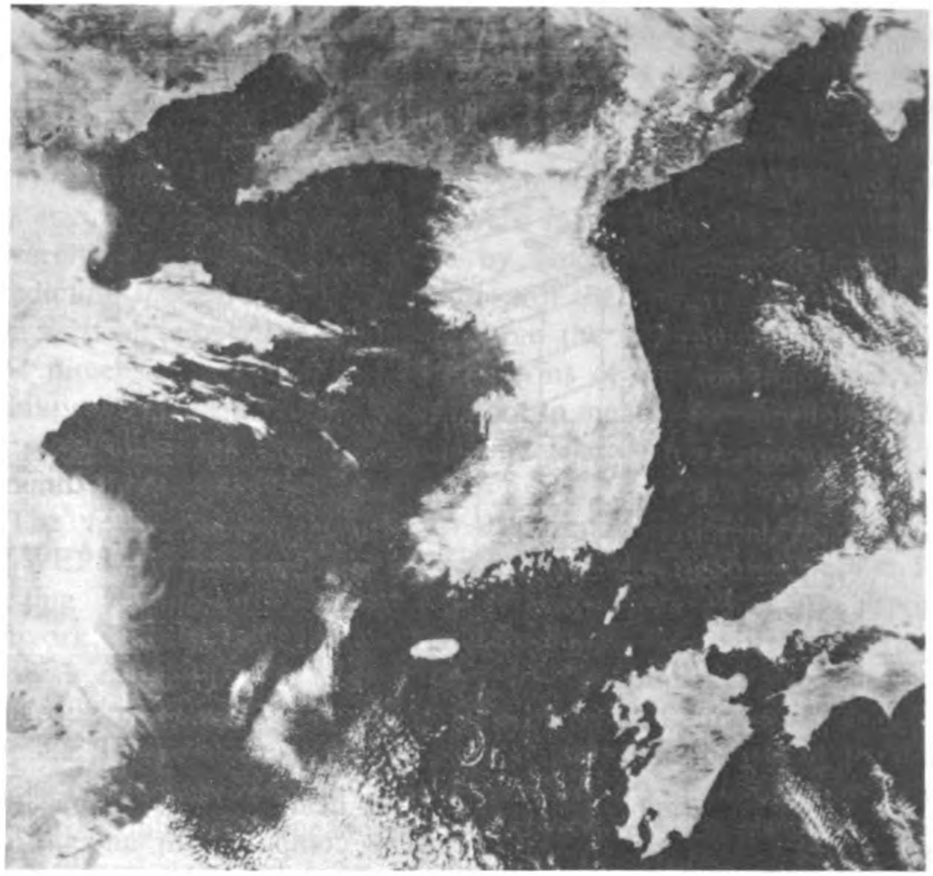

Figure 5 — Visual imagery from meteorological satellite with patterns of light reflected from the land and shallow bottom in the river deltas

models for forecasting the total wave spectrum. Present and future studies of the circulation are stressing dynamic modeling. Large, deep-water arrays are now used to obtain subsurface current measurements.

NAVOCEANO's two oceanographic aircraft are constantly on the go, with more outside requests for their services than they can possibly handle. Last year, in addition to supporting in-house surveys and R&D tasks, they flew for GATE, NORPAX, MODE and LRAPP. Bringing them to their present level of capability has been a very important aspect of R&D in observational techniques.

Recent work pertains to the uses of satellite data for forecasting and analysis of dynamic variables and processes. Most of the engineering research experties at NAVOCEANO is presently engaged in tasks supporting hydrography, rather than oceanography. This is a relatively new trend, which partially reflects the fact that previous developments—such as a telemetering solid state current meter—have moved off the laboratory bench and are heading for the production line.

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The goal of NAVOCEANO's programs, remains as always, Fleet Support. When results benefit the marine community at large, so much the better, but the true objective, first and foremost, is to support the Fleet. Resident representatives at major and type command headquarters help insure that this aim stays clearly in focus.

Sea Ice Classification Utilizing Dual-Frequency Passive Microwave Techniques

During December 1973, the Naval Oceanographic Office (NAVOCEANO) and the Naval Research Laboratory (NRL) conducted a joint remote sensing experiment over the sea ice fields off Scoresby Sound on the east coast of Greenland using NAVOCEANO's RP3-A BIRDSEYE aircraft, laser profiler and infrared scanner, and NRL's 19.34 and 31.0 GHz nadir-looking radiometers. The objectives of this mission were: (1) to develop interpretational skills of sea ice passive microwave data, (2) to expand, if possible, the two category capability of passive microwave sensors over sea ice, (3) to compare two frequencies (19 and 31 GHz) to determine which may be more useful in a scanning radiometer now under development at NRL, and (4) to determine the value of multi-frequency study of sea ice as compared to single frequency.

Since no photography or *in situ* ground truth were possible for this mission, it was necessary to rely on the interpretations of the laser and infrared (IR) data to evaluate the performance of the microwave radiometers. Fortunately, excellent laser and IR data were collected, and a confident description of the ice overflown was possible.

Using two frequencies, passive microwave appears capable of distinguishing between five distinct ice type/ice forms: (1) open water/new ice, (2) smooth first-year ice, (3) ridged first-year ice, (4) multi-year ice, and (5) a higher brightness temperature form of multi-year ice, interpreted as second-year ice. By plotting average brightness temperature of the two frequencies versus the temperature difference of the two frequencies, it appears possible to generally describe the ice fields, in terms of the five categories listed above, regardless of weather conditions.

(Continued on Page 23)

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Investigations of Acoustic Losses at the Ocean Bottom

Part I – The Measurement of Bottom Loss

John A. Frank

Sound reflected from the ocean bottom suffers a loss in intensity due to the "bounce" or reflection from the water-sediment interface and from subbottom interfaces.[1-12] This loss, usually referred to as bottom loss, is defined simply as 10 log I_r/I_i, where I_r is the intensity of the bottom reflected signals and I_i is the intensity of the wave incident at the sea floor interface.

The advent of low- and mid-frequency sonar systems which utilize the bottom-reflected path has created an increasing need to understand the effect of the ocean bottom on sound propagation. In particular, knowledge of the reflecting properties of the ocean bottom is important to sonar design and performance prediction studies. As a consequence of this need, the Naval Oceanographic Office has been conducting bottom reflection loss research studies and broad measurement programs for many years. These investigations and measurements have been devoted to developing an understanding of the complex bottom reflection mechanism over a relatively broad frequency range and to developing appropriate prediction models and charts.

During a typical measurement two ships are used (see Figure 1). One ship remains stationary and lowers a hydrophone into the water, while a second ship deploys 1.8-lb explosive charges as it proceeds along a

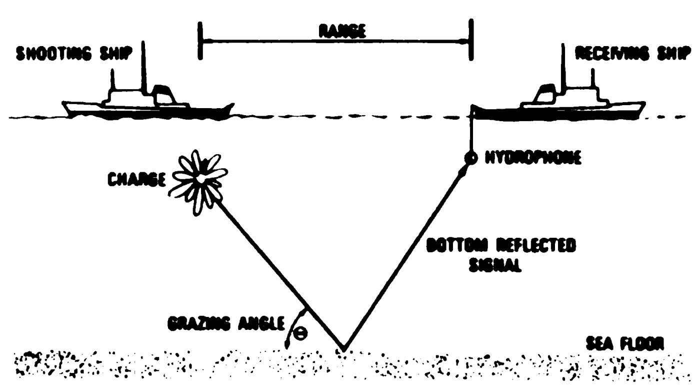

Figure 1 – Experimental geometry for two ship bottom loss measurement (Other paths between charge and hydrophone are not shown. The travel times for these other paths differ from the bottom returns.)

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track away from the source ship. The explosive signals are recorded at the receiving ship on magnetic tape and processed through a bank of one-third octave band filters. After filtering, the received level is determined by measurement of the peak amplitude or the total energy of the signal. In either case, knowledge of the explosive source level and transmission loss due to geometric spreading and absorption is required to compute bottom loss. The average source level of the explosive charges is obtained by measuring the level of selected direct signals over short ranges and then by processing as described above. Geometrical spreading and absorption losses in the water column are computed based on the source-receiver geometry and a measured sound speed profile. The bottom loss is then generally computed over a range of bottom grazing angles, from about 5 to 90 degrees, and frequencies.

Interpretation of Bottom Loss Data

A striking feature of the ocean bottom is its variability of topography. Geologists generally divide submarine topography into three divisions—continental margins, the ocean-basin floor and the mid-ocean ridge.[13] Within these divisions are physiographic provinces displaying clearly defined surface morphologies, sediment types, and sub-surface stratifications. It is natural to attempt to relate these physiographic provinces to analogous acoustic provinces since bottom reflectivity depends on surface morphology, acoustic impedance contrasts between layers, and thickness and shape of sub-surface layers. An example of 2 kHz bottom loss data over three different physiographic provinces as a function of grazing angle is shown in Figure 2. It is evident in this example that bottom loss increases with increasing bottom roughness.

An initial approach which may be taken toward understanding world-wide bottom loss data is the identification of large areas of the ocean

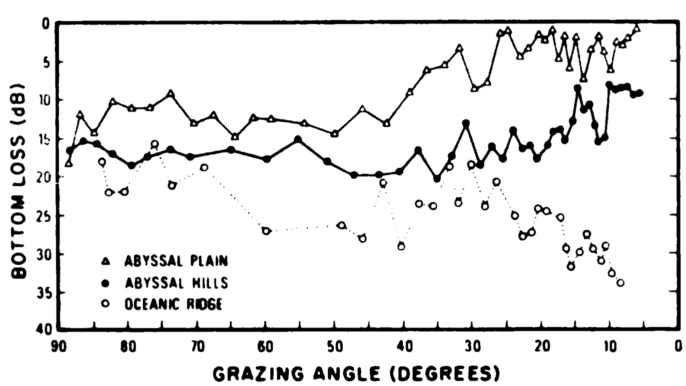

Figure 2 — Acoustic bottom loss over three characteristic provinces versus bottom grazing angle. Frequency = 2.0 kHz.

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floor displaying relatively uniform bottom loss. To the extent that such acoustic domains coincide with physiographic provinces, knowledge of the submarine geology should permit prediction of the corresponding acoustic characteristics. In keeping with this approach a statistical study of world-wide bottom loss data was conducted to test for significant correlations with parameters which characterize physiographic provinces. At high frequencies (1 to 6 kHz) the result was a successful separation of the data into geographic in which differences among areas could be qualtatively attributed to measured differences in the macroscopic relief of the ocean bottom. At low frequencies (approximately 100 Hz and lower) a similar separation of the data was not found to be statistically significant. Instead, the losses over most geographic areas were approximately described by a single curve as a function of grazing angle.

In some areas at grazing angles below 20 degrees, apparent negative losses were observed. Upon closer inspection of some of these cases, a large low frequency arrival was observed in addition to the reflected arrival. Unlike sub-bottom reflected arrivals this additional arrival was not observed at grazing angles above 20 degrees. The frequency content and the measured travel time behavior of the arrival suggested that the energy had traveled via a shallow refracted sediment path (see Figure 3). As evidence, theoretical arrival times computed on the assumption of a constant gradient sediment sound velocity structure were found to be in good agreement with the observed data.

The refracted arrival has been recognized, isolated, and shown to be related to the sub-bottom sound velocity structure. The total reflection/refraction process at low frequencies, however, is not yet understood

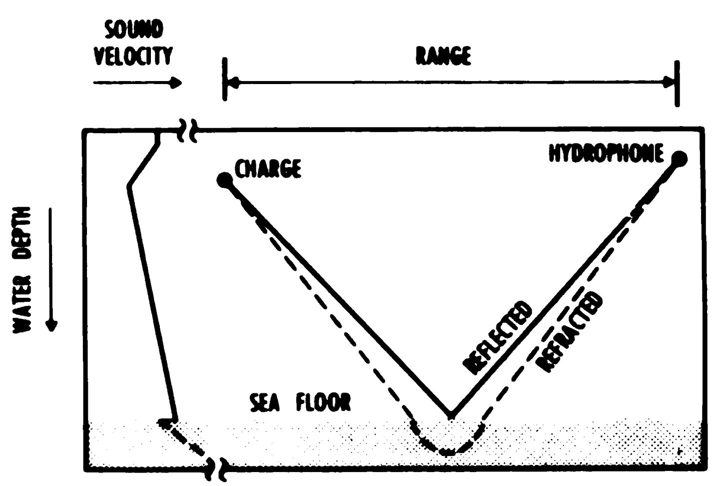

Figure 3 — Reflected bottom path and shallow bottom refracted path shown for a given combined water-sediment sound velocity profile

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well enough to either rigorously relate bottom loss to physical properties of the sediments, or to account for the occurrence of the apparent negative losses. Further analysis using digital deconvolution processing which makes possible the study of the reflection and refraction processes separately promises to add further insight.

Part II — Digital Deconvolution Processing

Ronald L. Dicus

The methods of world-wide data collection and analysis described in the previous section might be referred to as the macroscopic approach. A microscopic approach is also desirable since each acoustic shot contains more information than is available from one-third octave filtering alone. It prompts us, therefore, to take a closer look at this additional information to gain more detailed insight into the acoustic-bottom interaction process. In this approach the detailed shape and magnitude of the received waveform is studied on a shot by shot basis. The power and utility of the large scale digital computer promises to make this approach a fruitful one.

Much of the ocean bottom throughout the world is stratified by layers of sediments which may differ in density, mineral content, particle size, porosity, and degree of compaction. The varying physical properties of the sediments generate differences in the acoustic reflection coefficient, sound velocity and attenuation. Each time acoustic energy intersects the boundary between two dissimilar sediment layers, part of its energy is reflected and part is transmitted. Thus, the acoustic signal returned to the receiver shows a positive or negative pulse for each significant sediment layer boundary encountered by the incident energy. An examination of the position in time and the magnitude of these pulses provides information which is related to the geophysical properties of the bottom.

Explosive charges commonly used as acoustic sources generate signals which are not well suited for direct interpretation of bottom returned signals. This is because the source signal consists of a shock pulse followed by a number of pulses (called bubble pulses) produced by the oscillating gas globe in the water. As a consequence, this signal produces a number of pulses on reflection from a sediment boundary rather than one. In addition, the pulses are not sharp spike-shaped features but instead are spread-out, unsymmetrical peaks. When the reflection/refraction process is from a system of closely spaced layers, the width and multiplicity of the source signal peaks prevents resolution of the layers.

One solution to the source signature (waveform) problem is digital deconvolution processing.[14,15] This is a method in which the bottom

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returned signals are processed on a digital computer and converted to the output corresponding to an ideal impulsive source. The processed trace called the impulse response or the deconvolved trace appears with bubble pulses removed and shock pulses converted to ideal spikes. This technique permits the separate measurement of energy reflected from different layers, whereas without such processing the energy reflected from one layer may overlap the energy reflected from other layers. An example of a measured source signal is shown as the unprocessed trace in Figure 4. The deconvolved trace shown in the figure is the effective source signal after processing and is a good representation of an ideal spike signal. Bottom-returned signals corresponding to both of these source signals are shown in Figure 5. The processed traces in figure 5b exhibit greater resolution and simplification compared with the unprocessed traces in Figure 5a.

Deconvolution may be accomplished by a series of mathematical operations using the bottom reflected signal and an accurate replica of the acoustic source signal. For this purpose the replica may be measured directly as the first signal arriving at the hydrophone ahead of the bottom reflected signal. Direct measurement of the source signal is, however, subject to difficulties. In the usual case of a shallow receiving hydrophone the direct signal propagates within a surface channel which may severely distort the waveform rendering it unusable for deconvolution processing. A deeper hydrophone below the surface channel may be used, but at long ranges corresponding to low bottom grazing angles, the direct signal may still be noisy, distorted or complicated by surface arrivals.

To overcome the problems of direct signal measurement, deconvolution methods using a synthetic direct signal have been developed.[16,17]

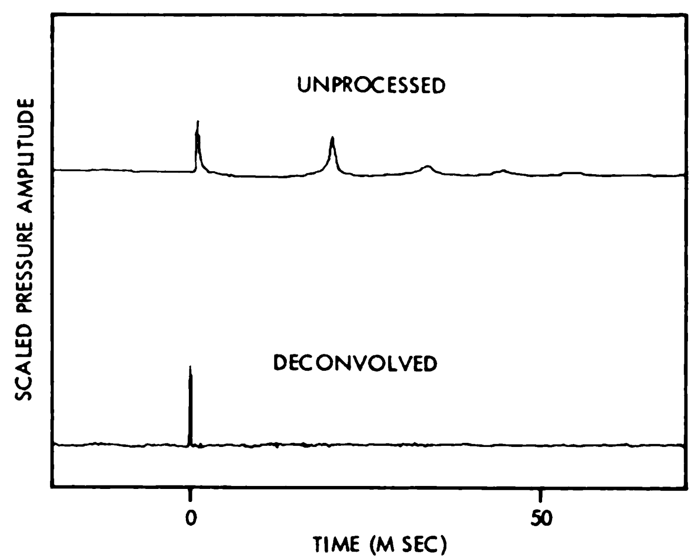

Figure 4 — Acoustic source signal before and after deconvolution processing

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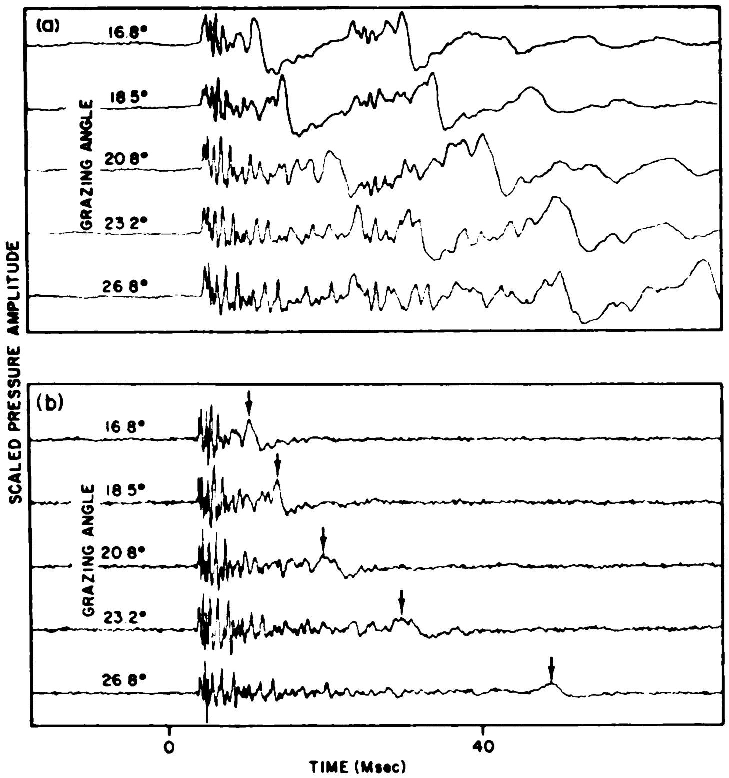

Figure 5 — Ocean bottom returned signals at several grazing angles (a) before processing and (b) after deconvolution processing. Refracted arrivals are indicated by vertical arrows.

A synthetic direct signal can be constructed from analytic mathematical functions, or by various transformations on a single measured direct signal. In any method employed, the bubble pulse time (time from the shock pulse peak to the first bubble pulse peak) for each shot must be determined. The bubble pulse time depends on the depth at which the explosive detonates, and this varies from shot to shot. Precise determination of bubble pulse times may be accomplished using computer techniques recently developed at NAVOCEANO. Results of the synthetic deconvolution work indicate that bubble pulses in deconvolved traces can be reduced below the noise level, and that the error in energy measurement rarely exceeds one decibel when averaged over bandwidths of 100 Hz.

Digital filters offer exciting possibilities for unraveling ghosted traces.[18,19] Ghosted traces are bottom-reflected paths that also reflect from the water surface. This results in multiple images which are time delayed and superimposed. With traditional processing, a correction term is added to the bottom loss to approximate the effects of the ghosts. This results in errors which may be important at low frequencies and low grazing angles. Digital filters, on the other hand, can properly remove the ghosts yielding the correct bottom loss and uncovering returns

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otherwise masked by the ghosts. An example of a deghosted trace is shown in Figure 6.

Deconvolved bottom returns make it possible to partition the energy associated with different mechanisms. For example, the refracted arrival discussed in Part I of this article can be separated from the other arrivals (see Figure 5). This suggests the possibility of measuring its energy at different frequencies as a function of the refracted path length. The path length may be computed from an assumed model of the sound velocity variation within the sediments. Parameters in this model are determined by the time of arrival behavior of the refracted return. This approach to the development of a method for the in situ measurement of sound attenuation in sediments at low frequencies is in progress at NAVOCEANO. An accurate determination of the attenuation coefficient in sediments is, of course, a prerequisite to the ultimate goal of developing a rigorous bottom loss model.

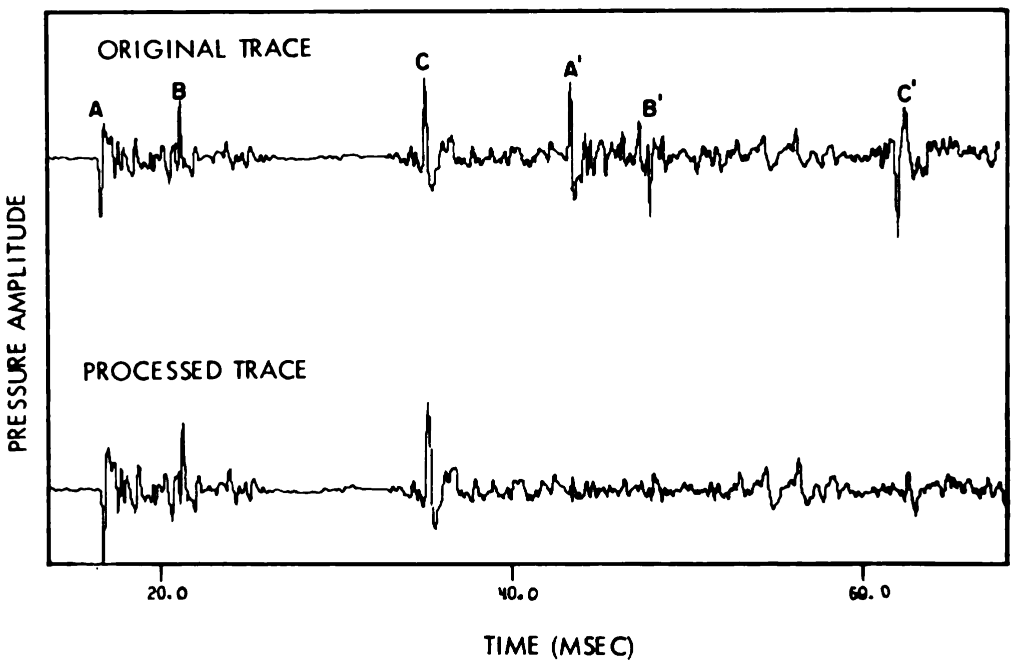

Figure 6 — Ocean bottom returned signal with water surface reflections before and after digital deghosting. Arrivals A', B' and C, are the water surface reflections corresponding to arrivals A, B and C.

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Ocean Wave Measurements for Ocean-Wide Wave Predictions

P. S. DeLeonibus

Modern wave forecasting traces its genesis to the Normandy invasion of World War II, where a quantitative relationship between wind velocity fields over the ocean and resulting "sea" (waves under the direct action of the wind) and "swell" (waves moving into a region of weaker winds or calm) was developed. A conceptional break came with application of time series analysis to observations of ocean waves and realization that for a great many applications, only the spectrum over a relatively narrow band of ocean surface wave periods need to considered. Thus, wave periods ranging from a few seconds to a very few tens of seconds cover many operational requirements normally associated with adverse effects of waves at sea. During the 1950's to mid-1960's, a spectrum approach gradually found its way into operational usage, and a second conceptual break occurred with development of an empircal spectrum based on measured waves followed by development of a computerized approach to wave forecasting for an entire ocean.

Why has it taken so long to advance to the present state considering the impact of the sea on civilization? An over-simplified answer might be associated with the problem of measuring and recording ocean wave heights and surface winds over an area of just a few miles. In modern times, we did have a theory on wave measurement, a very plausible but incorrect one, published by the English physicist Jeffreys in 1924. His theory related air flow separation over ocean wave crests to a "sheltering coefficient." The difficulty arose, in part, from not testing this theory over the open ocean with field experiments. In the following we give a brief account of instrumental approaches to field experiments designed to test wave forecast theory and methods associated with Pierson, Miles, Phillips, and Hasselmann,* as described by Kinsman.

Wave Measurements

Figure 1 illustrates three wave measurement approaches used at NAVOCEANO. Figure 1A illustrates airborne measurements made with a downward-pointing laser that provides a continuous profile of sea surface wave height. Figures 1B and 1C illustrate the corresponging trace when waves are observed moving past a deep-anchored ship or fixed tower. The most convenient way to display properties of such

*See Kinsman, Blair, "Wind Waves." Prentice-Hall, Englewood-Cliffs New Jersey, 1965.

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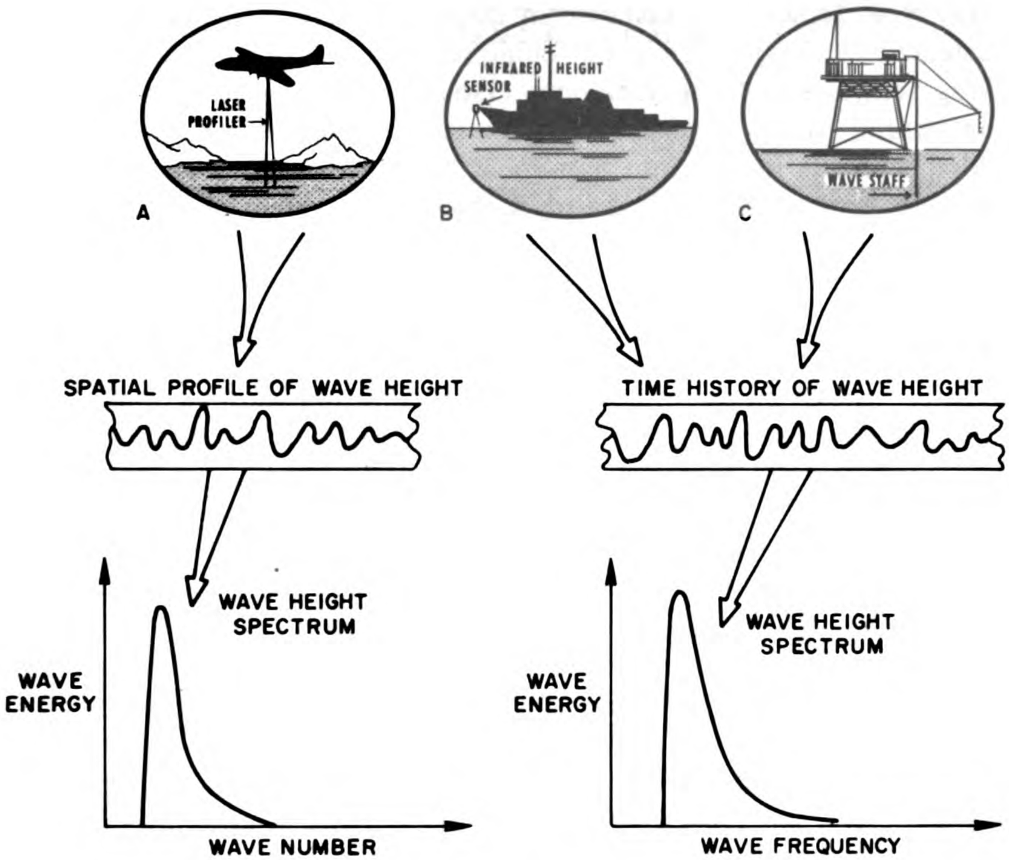

Figure 1 – Wave observations at NAVOCEANO are made with airborne laser (A); shipborne infrared sensor (B) and resistance wire wave staff (C). spectrum analysis illustrates the narrow band characteristics of ocean surface gravity waves. Note the sharp spectral peak.

records is by spectrum analysis. Figure 1 illustrates a one dimensional wave number spectrum (aircraft) and a one dimensional frequency spectrum (fixed platforms). A numerical expression for directional spreading of such spectra came from results of SWOP (Stereo Wave Observation Project),—a two aircraft photography experiment in which NAVOCEANO participated. Most experimental testing is done with one dimensional spectra owing to the enormous difficulty in measuring directional spectra. Fortunately, ocean surface wave spectra are narrow-band (compared to many other geophysical processes), and yield two extremely useful parameters: significant wave height (average height of the one third highest waves) and the wave frequency (or period) at the peak of the spectrum. As stated above, the rationale for such wave measurements is to compare wave observations with wave predictions from a theoretical model so that forecasts can be prepared for a whole ocean. For example, in 1965 a NAVOCEANO aircraft equipped with a downward pointed radar executed one of the first definitive field experiments by flying seaward over a constant wind field from Atlantic

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City, New Jersey to a distance of 200 miles. The experiment was repeated in 1969 with an aircraft equipped with the current laser system flying seaward of Cape Henlopen, Delaware. Both these experiments contributed to development of wave forecast theory and in addition, added valuable insight into non-linear properties of wave growth. For example, suppose we profiled a sea surface wave system which developed under action of strong, steady offshore winds (Figure 2A). We might have expected spectral wave components to grow smoothly and steadily with increasing distance from shore (Figure 2B). We observe, however, the overshoot-undershoot growth associated with non-linear energy transfer whose mechanism is not completely understood. Similar behavior was observed in a NAVOCEANO experiment from a fixed tower where waves were observed as a function of time.

In modeling the wave structure of the sea surface we have to deal not only with non-linearities of wave generation but also with severe non-linearities associated with the turbulent wind field in the boundary layer over the sea. The wind and wave picture is complicated by background waves which always exist on the open ocean surface. This wave background may seriously influence the manner in which energy is extracted from winds above waves during wave generation. To attack this problem, momentum flux and turbulent wind spectra, obtained from fast-response anemometers, were used to measure the horizontal and vertical wind velocity at an open-ocean tower to document dependence of drag coefficient on both wave-background and atmospheric stability. Such studies are necessary because observational limitations force us to make use of parameters which can be related to more routine observations of atmospheric pressure, air, and sea temperatures and wind reports from ships. Figure 3 compares dependence of drag coefficients on mean horizontal wind velocity. The drag coefficient is a normalized momentum flux and is one way to represent the stresses acting on the sea surface. These stresses are associated with turbulent fluctuations of the wind field over the ocean, and it is of utmost importance that we document

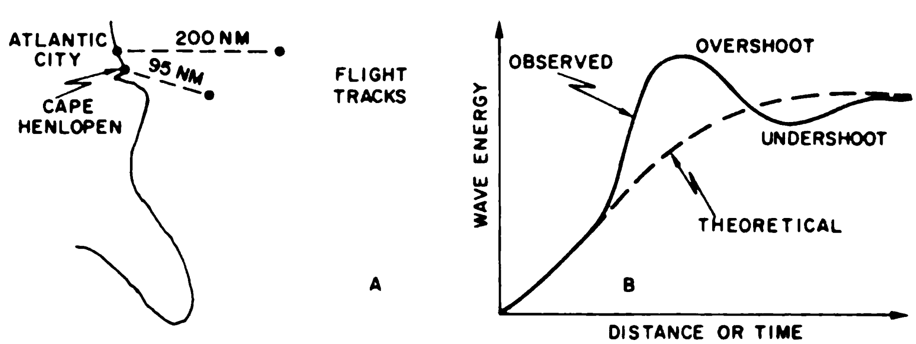

Figure 2 — Airborne wave observations made over flight tracks (A) displayed overshoot and undershoot growth associated with non-linear effects (B)

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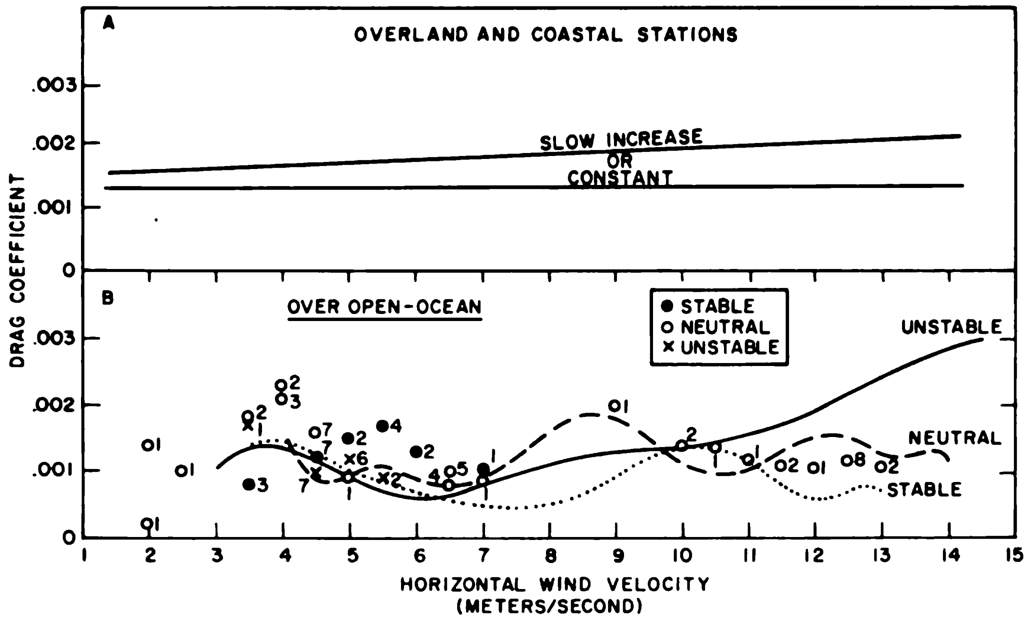

Figure 3 — Comparison of Drag Coefficients observed overland and coastal stations (A) to observations over the open-ocean (B)

their behavior at low, moderate, and high wind velocities. If we can do this, we can "parameterize" effects of turbulence in the lower atmosphere above the sea in terms of more routine observations of atmosphric pressure fields, air and sea temperatures, and ship reports of wind speed and direction.

Figure 3A illustrates drag coefficient observations taken at over land and coastal stations under "neutral" atmospheric stability. Neutral stability implies that wind turbulence was associated solely with mechanical action of wind with no increase or decrease of turbulent energy from buoyancy effects. Contrast the smooth behavior of Figure 3A to oscillations observed in Figure 3B by NAVOCEANO at an open-ocean tower. These oscillations are associated with *both* the existing wave background and atmospheric stratification. Unstable implies an increase in turbulent activity while stable implies a tendency to dampen turbulent activity. Figure 3B suggests a differential interplay between generating waves, existing waves, and atmospheric stability, and illustrates some of the difficulty in developing a realistic wind field model for use over the open sea.

The Navy's numerical wave prediction scheme became operational at the beginning of 1975, as a result of joint efforts by NAVOCEANO, Fleet Numerical Weather Central, Monterey, California, and Prof. Willard J. Pierson, City University of New York (formerly New York University). Figure 4 illustrates the type of world grid required to generate automated wave forecasts on a hemispheric basis, and numerical values of the directional spectrum are forecast twice daily over a network

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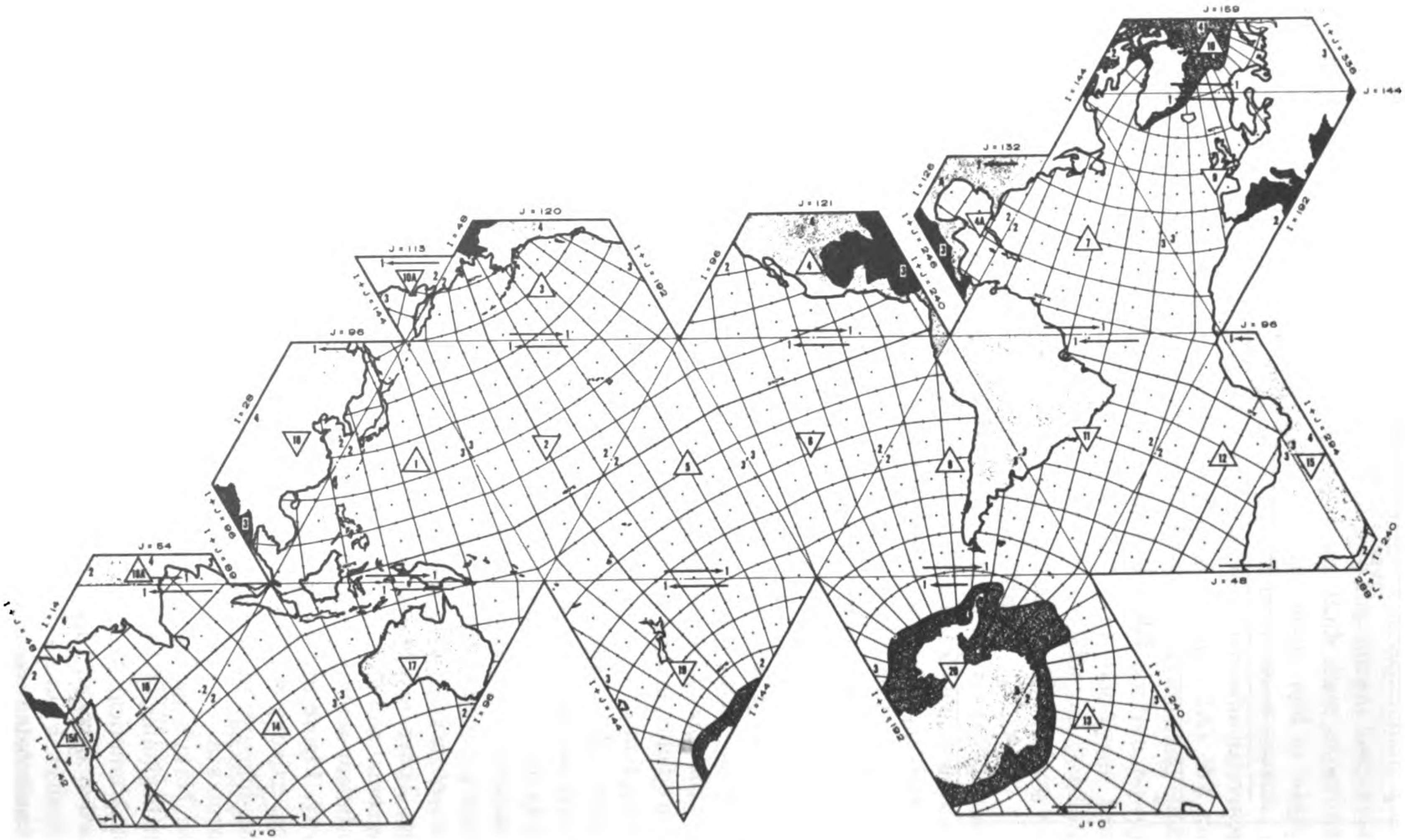

Figure 4 — The Icosahedral-Gnomonic Projection of the world Ocean for wave studies

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of grid points. These are summarized in facsimile charts of significant wave height and wave directions for operational use by the fleet.

An enormously valuable feature of the wave spectrum approach are the wave spectrum climatologies prepared from past wind data. Such wave climatologies have been used in study of aircraft carrier motions and development of response amplitude operators for calculating ship-bending stresses. In progress on NAVOCEANO's computer is a wave project to generate one-year wave climatologies for the North Atlantic and the North Pacific from past wind data. North Atlantic wave spectra will be used in recovery of space shuttle boosters; North Pacific spectra in interpretation of SKYLAB data.

As new wave generation theory is developed, NAVOCEANO stands ready to conduct open-ocean wave measurements. Eventually, wave forecasts will be provided on a global basis, particularly when data become available from new families of satellites equipped with remote sensors to scan the sea surface in remote parts of the southern hemisphere.

(Continued from Page 9)

Another value of the multi-frequency aspect of passive microwave study is the elimination of possible ambiguities or erroneous interpretations which can occur using only a single frequency. For example, open water/new ice to a 31 GHz radiometer has a brightness temperature of about 148°K and first-year ice to the same radiometer has a brightness temperature of about 240°K. Should a combination of these two ice forms be in the beam spot of the radiometer, some average temperature between the two will be recorded and could conceivably be within the temperature range of multi-year ice, namely 170° to 190°K. However, using a dual-frequency system (19 and 31 GHz) and comparing the difference in brightness temperatures (19 minus 31 GHz), the difference value will be negative (about −0.8°K) since the brightness temperature of open water/new ice is lower for the 19 GHz radiometer (140°K as compared to 148°K for the 31 GHz radiometer) than that measured by the 31 GHz radiometer.

Conversely, if the ice within the beam spot is in fact multi-year ice, the difference in temperatures will yield a positive value (about 30°K) since the 19 GHz radiometer yields a temperature approximately 30°K higher than that the 31 GHz radiometer.

This concept of dual-frequency microwave study should be applied to imaging radiometer systems. At this time, the Naval Research Laboratory is developing a dual channel imaging system which has a unique capability which allows interchangeability of radiometers of various frequencies. This versatility will allow study of the relationships which exist between the frequencies for various ice types. A study of this type should expand the multi-frequency capabilities of passive microwave study of sea ice. Hence, this remote sensing system has the potential to be a valuable tool in future Arctic programs.

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Synoptic Oceanography

Richard W. James

The oceans are conservative in nature; with few exceptions the dark, silent waters below 600-1000 meters change slowly in space and even slower in time. Above this depth, however, in what may be called the layer of surface disturbances, considerable variations may occur in the nature, movement, and properties of the water. Unfortunately, it is in this complex oceanic troposphere that the Navy attempts to perform its mission. The air-sea interface itself is in a constant state of fluctuation and can, in many different ways, degrade the performance of ships, weapons and sensors.

It is evident from past experience that a truly all-environment system does not exist. Every system designed to operate in the ocean continues to be degraded to a varying degree by problems of an environmental nature. Deep ocean conditions are sufficiently stable so that survey data can meet most operational requirements. For the upper ocean levels, single surveys are not adequate, and repeated measurements are needed to provide the data required for tactical decisions. This, in essence, is synoptic oceanography—to chart a property of the oceans the same way as the meteorologist maps the weather—showing properties such as waves, ice, currents, or the thermal structure as it exists over an area at a given time.

History of Synoptic Oceanography

Early efforts in oceanography were directed toward large-scale sampling of the oceans either through surface measurements along a ship's track, or by stopping at intervals and taking deep sea measurements. These endeavors provide considerable information about the nature of the seas and form a valuable data base for modern research.

With increasing research, however, it became evident that the oceans were not static and that surveys had to be repeated periodically in order to establish seasonal and short term variations. In order to obtain a degree of synopticity, multiple ship surveys were organized, as in OPERATION CABOT in 1950, during which several ships surveyed the Gulf Stream simultaneously.

A higher degree of synopticity was obtained with the introduction of aerial reconnaissance for survey purposes. An aircraft equipped with remote sensing instruments, or specially trained observers to make visual reports, could survey an area about thirty times as large as that covered

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by a ship in the same time period. Aircraft were first utilized for large-scale synoptic measurements by the Naval Oceanographic Office in 1952 when Patrol squadrons flying out of Kodiak, Alaska and Argentia, Newfoundland flew ice reconnaissance missions over the Arctic. Thule and other air force bases were being established, and the Navy had the responsibility to transport large quantities of material to the Arctic. Large convoys were formed, led by icebreakers assisted by reconnaissance planes reporting on the ice conditions which lay ahead of their track (Figure 1).

An extensive ice forecasting program was established by NAVOCEANO with field units providing analyses and 48 hour forecasts of ice conditions to the ships via radio facsimile broadcasts. Longer range ice predictions were prepared at NAVOCEANO, and special numerical codes were devised to permit transmission of detailed ice data in the most concise form possible.

This effort expanded as the number of ships required in the Arctic increased due to the establishment of Distant Early Warning (DEWLINE) sites across Canada and Northern Alaska. An ice observational

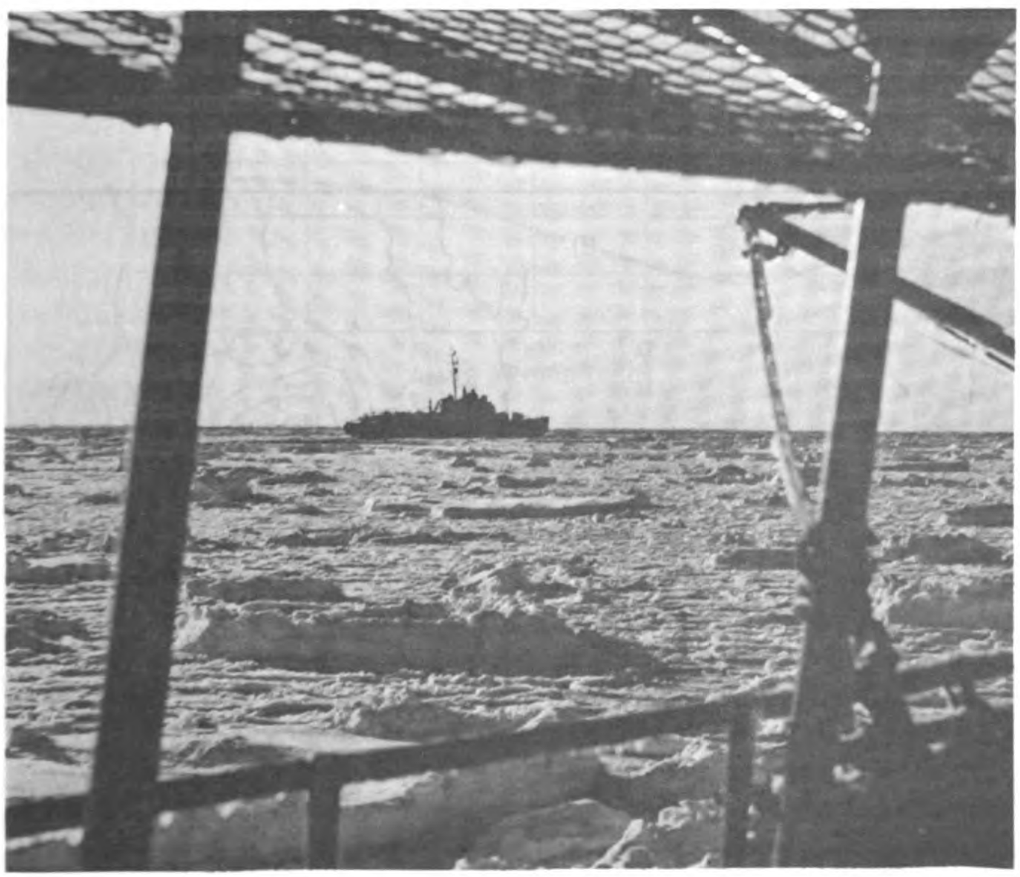

Figure 1 – The USS EDISTO in pack ice off the Greenland coast

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network was established to obtain data from all possible sources from which to generate a quasi-synoptic picture of ice conditions in the operating areas. Ships transiting the Arctic seas, land stations, Navy reconnaissance aircraft and other planes near by were tasked to transmit observations to NAVOCEANO. Sufficient data were generated on which a reliable ice program could be based, providing a complete spectrum of support from daily synoptic ice charts to seasonal forcasts.

During this same time period, the Naval Oceanographic Office also experimented with synoptic wave charts. Up to this time wave forecasts were made for specific points to support an amphibious landing or at-sea replenishment. The idea that characteristic wave patterns could be associated with various storm systems was new and the possibility of a chart showing wave conditions over the entire North Atlantic at a given time offered many potential applications to Fleet operations (Figure 2).

These charts were based on the wave conditions reported every six hours by ships at sea and supplemented, where necessary, by computations of sea and swell using wave generation and decay models. A second type of chart, the prognostic wave chart, propagates today's swell to the next day and combines it with newly generated waves as derived from the 24 hour wind predictions.

Both charts were declared operational in 1956, and their preparation and dissemination became the responsibility of the Naval Weather Service. More sophisticated wave models providing spectra information

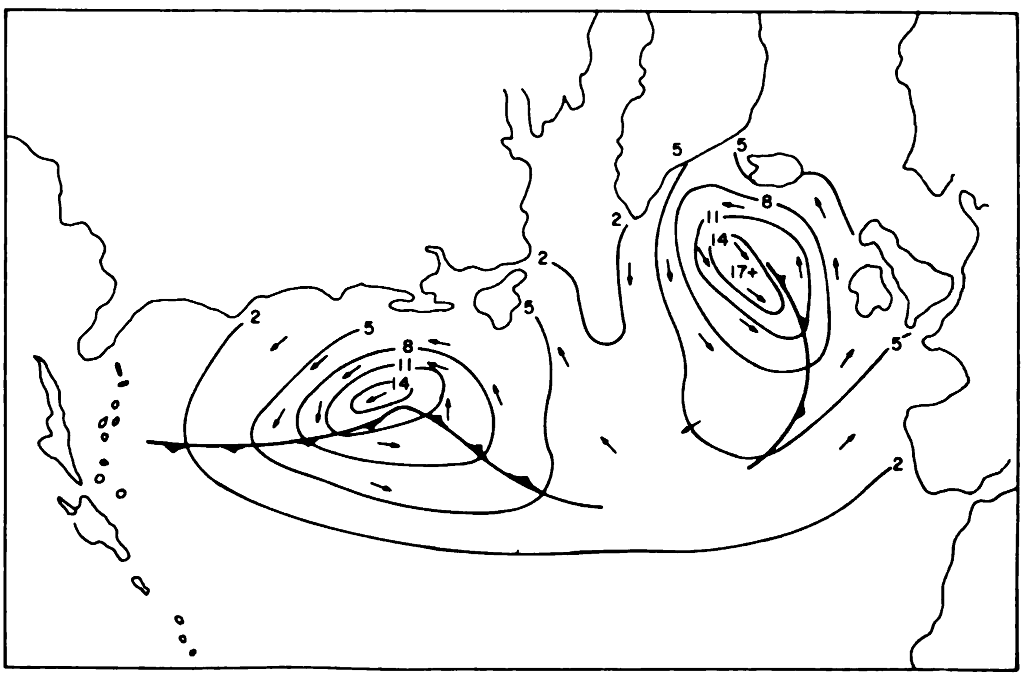

Figure 2 — Synoptic wave chart. Height in feet, arrows indicate direction of predominant waves

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and using automated techniques have been developed over the years as described elsewhere in this issue.*

One of the first applications of wave charts was in connection with ship movements. In October 1956, the Naval Oceanographic Office initiated an experimental ship routing program, utilizing ships of Military Sealift Command (MSC) for test purposes. Ship performance nomographs relating ship speed to wave height, length, and heading (Figure 3) were constructed from analysis of ship logs. An iterative procedure was utilized; where the ships progress along any of a series of possible tracks was calculated for each day's travel as a function of the wave conditions expected that day.

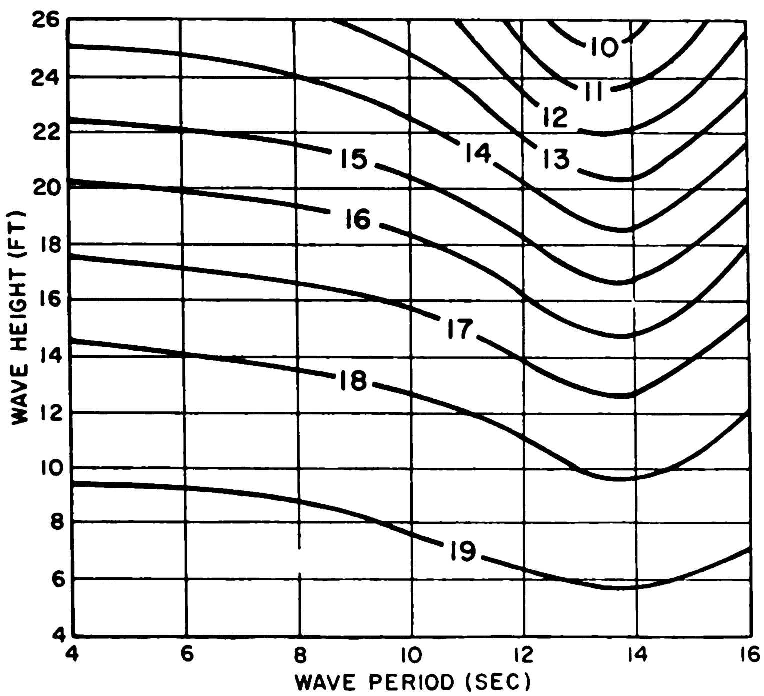

Figure 3 – Ship speed (KTS) in head waves as function of wave height and period – (P2-SE2-R1)

Initial routings were made for 32 MSC ships on trans-oceanic crossings, including the first refugee ship bringing Hungarians to this country following the Soviet take-over of that country. The routed ships arrived up to 33 hours earlier than non-routed control ships and demonstrated that ship routing could improve the cost effectiveness and efficiency of MSC. The Navy immediately requested that all Naval ships, including combattants, be routed when making trans-oceanic crossings. Responsibility for ship routing was turned over to Naval Weather Service in 1959, following a transitional phase in which the routing officers were

* P. Deleonibus, "Ocean Wave Measurements for Ocean-Wide Wave Predictions"

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trained on-the-job at NAVOCEANO. In 1969 these groups prepared some 3,700 weather routings for MSC and Naval ships on trans-oceanic transits.

During the late 1950's, NAVOCEANO applied synoptic techniques to the environmental support of ASW operations. At that time the Navy operated on the one-BT-of-the-day concept wherein one ship of a task group would take a bathythermograph (BT) which then would often be the basis for range calculations and tactical decisions for the day. A synoptic observations network was established, placing equipment on a number of MSC ships to obtain temperature vs. depth observations. All Naval ships were requested to make BT drops at six hour intervals, and various means for making continuous measurements of sea surface temperature were developed.

On the basis of these data, transmitted daily to NAVOCEANO, the first synoptic analyses of the oceanic thermal structure were drawn. In line with the dependence of sonar ranges upon the depth of isothermal water, the first chart attempted was the mixed layer depth. This was followed by the sea surface temperature chart since there were 10 times more surface data available than sub-surface from the standard weather reports of merchant ships.

Much was learned from these early charts concerning the reaction of the ocean to storms, the mixing of the upper layer due to turbulence, the cold up-welling following a hurricane's passage over an area, and the complexity of advection patterns. This aspect has become increasingly important with the detailed surface thermal data now available from satellite imagery. Using a combination of data and assumed models, synoptic charts were prepared describing sea surface temperatures, layer depth, depth and strength of sound channels and vertical thermal gradients. All of these charts, plus other special experimental displays, were transmitted to the Fleet via radio facsimile. In addition, NAVOCEANO ocean forecasters participated in some 50 ASW exercises during an eight year period to study how best to apply this new form of environmental information. In 1965 the responsibility for operational thermal analyses was given to Naval Weather Service and the latest forms of these products are computerized, northern hemisphere analyses prepared daily at Fleet Numerical Weather Central, Monterey. In addition, a number of acoustic products have been added.

During the above period, emphasis was placed on improving the capability of aircraft to obtain synoptic oceanographic data. An airborne radiation thermometer (ART) was developed under NAVOCEANO contract patterned after an original design by Woods Hole Oceanographic Institution. This instrument permitted continuous measurement of sea surface temperatures along a flight path. Later, the Navy developed an airborne expendable BT so an aircraft could, witin hours, obtain a detailed three-dimensional picture of the thermal field in a planned

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ASWEX area. This gave a better estimate of the sonar conditions that could be expected during an exercise, and thus permit more exact planning for the evaluation of a particular sensor or tactic.

Several new techniques were used to measure ice characteristics. Lasers were found to be ideal for recording surface profiles of ice roughness; multi-frequency side-looking radar to map ice features over a broad area, and of ice development (Figure 4). Much of the motivation for these new sensors was the change of emphasis from ice support for conventional shipping to the need for ice information for submarine under-ice cruises and the proposed use of surface effect vehicles in the Arctic. Similar developments were made for airborne measurements of waves.

True synopticity was obtained in oceanographic measurements with the establishment of environmental satellites in polar orbits. The Defense Meteorological Satellite Program (DMSP), for instance, has two satellites that circle the globe in 90 minutes, cover almost the entire earth's surface four times daily and transmit scanning radiometer data in infrared and visual ranges to land or ship-based receivers. From this imagery one can interpret discontinuities in the surface thermal field, obtain absolute surface temperature values, or locate ice characteristics such as pack boundaries, concentration, and water openings to a resolution of less than a mile. Measurement of wave conditions is possible and will be operational in future satellites. In the Arctic and Antarctic, particularly, the satellite has revolutionized observational techniques since ship access is limited, and aircraft reconnissance for the more inaccessible regions is a logistic problem.

Present Synoptic Applications

One of the results of the synoptic studies was the realization that the oceans have many anomalous areas where the thermal structure changes rapidly horizontally and exhibits considerable variability in the shape of its vertical profile. Certain areas, such as the Gulf Stream, were already known for thermal peculiarities, but many other anomalous features have been identified; some transient in nature, some that drift over long distances, and some that are permanent and semi-stationary but so weak that they are difficult to locate.

The semi-stationary features are oceanic fronts and, in analogy to weather fronts, separate mediums of different physical properties. Unlike meteorological fronts, the ocean fronts do not move over long distances but fluctuate around a mean position. Figure 5 illustrates the variety of thermal profiles found in the vicinity of an ocean front; a task force proceeding along the indicated track would encounter *seven* distinct changes in the thermal structure in 24 hours. The significance of this is that the thermal anomalies generate acoustic anomalies so that sonar

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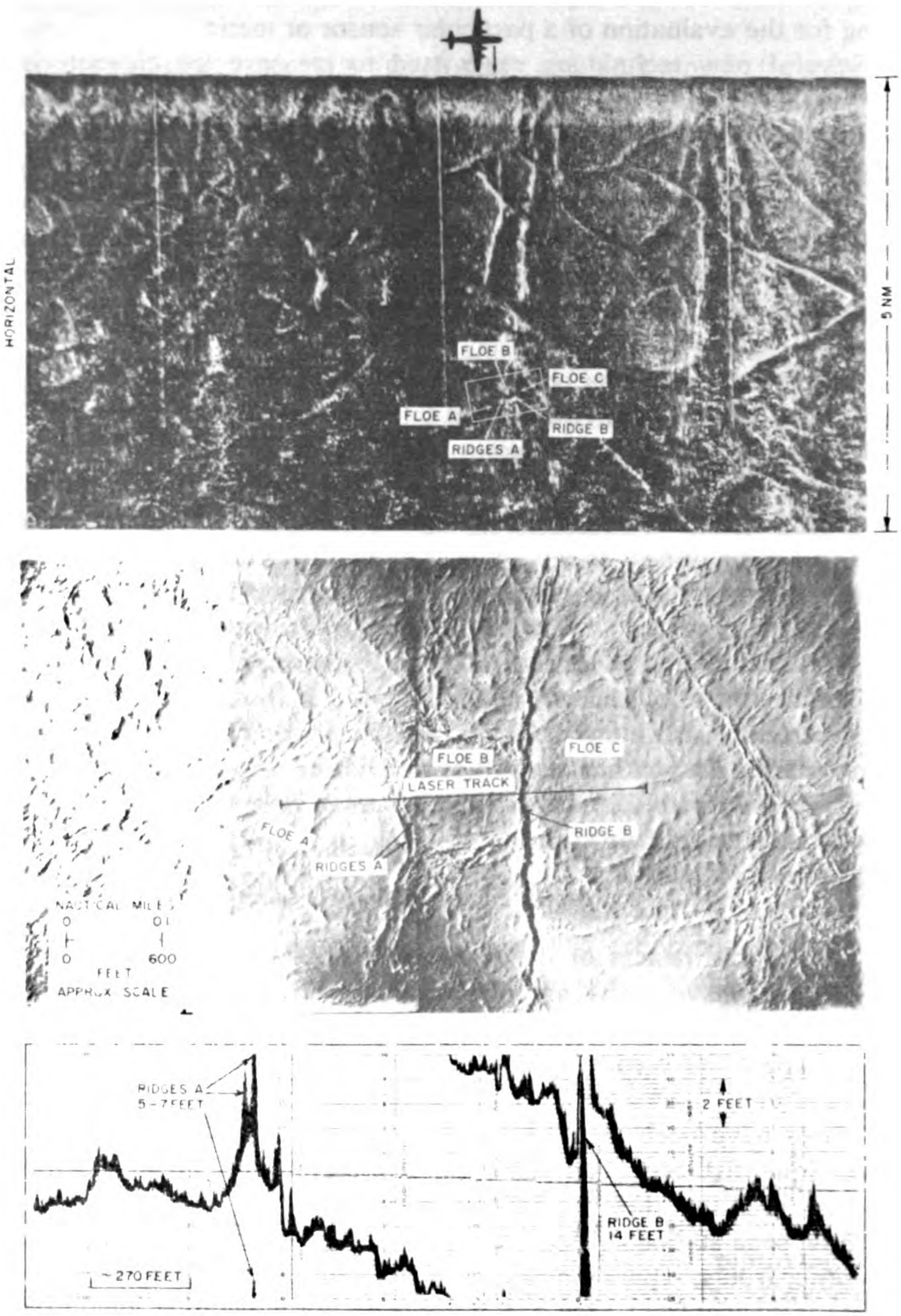

Figure 4 – Radar imagery (L-band 25 cm) V. CA-14 photography and laser profile.

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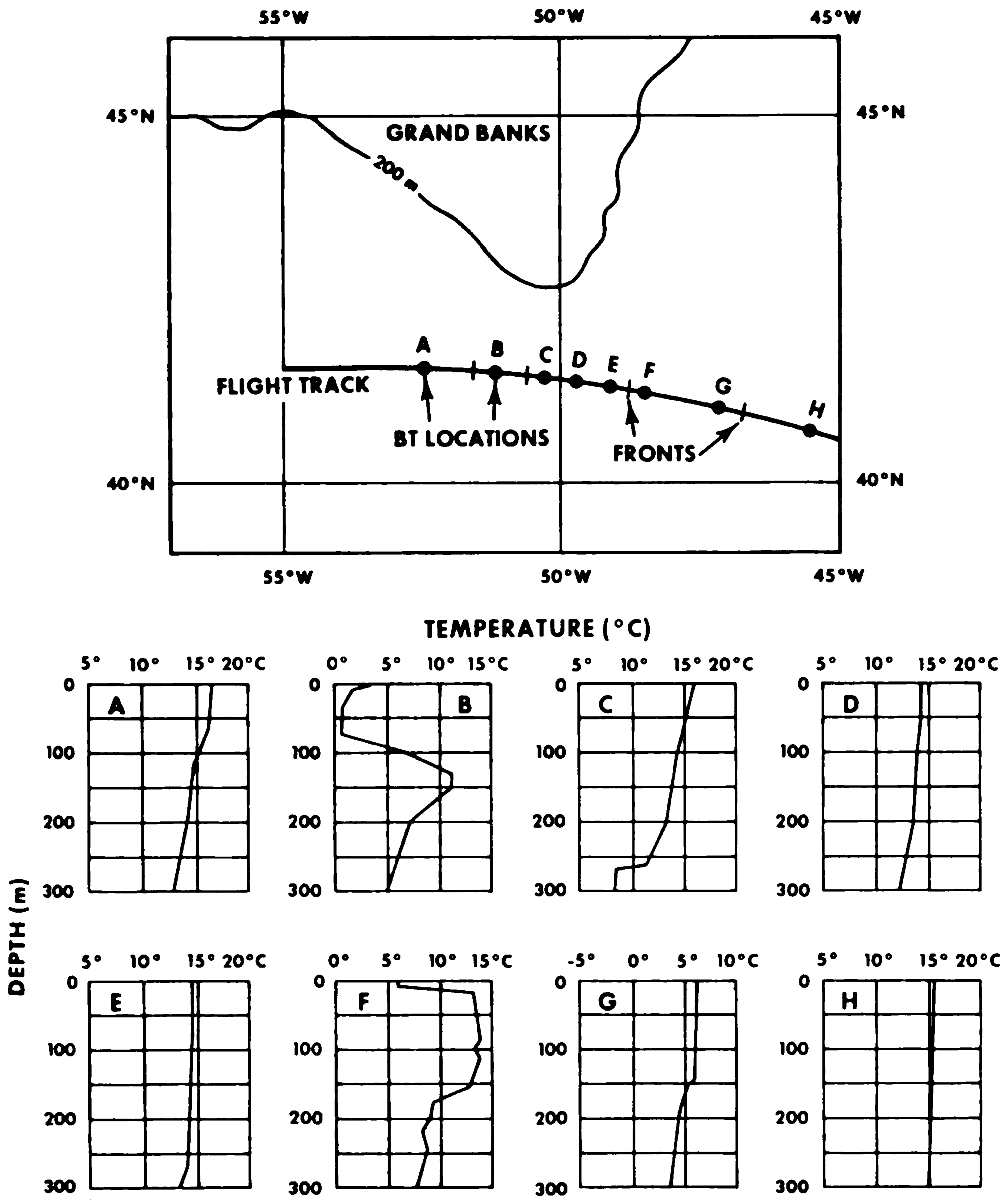

Figure 5 — Variability of thermal structure in vicinity of oceanic fronts

ranges, propagation modes, best sensor depths, sonobuoy field geometry and screen spacing would also change.

In addition, for cases where the submarine is on the opposite side of the front from the surveillance sensor, there are significant modifications to the sound as it propagates through the front. NAVOCEANO has conducted experiments to ascertain these effects by measuring the variability in signals received from explosive charges dropped across the fronts. Results show that submarines can utilize fronts to decrease the probability of being detected.

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When the meandering typical of most ocean fronts becomes too exaggerated, it has been observed that pools of warm or cold water (eddies) become trapped in a closed loop and break free of the main front. These spinning masses of water can be over 1000 m deep, up to 300 km in diameter, and may persist for months as they drift slowly in an alien watermass. Acting like giant lenses these eddies can produce anomalous refraction patterns for sound sources moving in their vicinity. Tests are currently being conducted to ascertain the degree to which this occurs, and its impact on ASW tactics and surveillance.

One unique approach has been to plant SOFAR floats at various depths within several eddies to track the feature and to act as a sound source within the eddy to measure propagation loss. Several floats placed in two eddies in October 1974 are still being tracked at this time.

Fronts and eddies occur in all parts of the world and, as found by many operating groups, complicate the ASW picture and generally reduce operating efficiencey. NAVOCEANO is presently mapping the location of these fronts and plans to issure technical notes concerning their effects on various aspects of ASW operations.

Another synoptic oceanographic project currently being developed at NAVOCEANO is the Integrated Carrier ASW Prediction System (ICAPS). This is an automated software package that provides the at-sea ASW commander with the means of rapidly calculating all of the sonar information required for his operational decisions. ICAPS complements the sonar forecasts received from shore in that the same acoustic models are used for both systems; but, where the latter looks at the big picture for a period of 1 to 8 days, ICAPS provides the more localized picture—what is happening right here, now, and in the immediate future. This difference stems from the fact that ICAPS utilizes BT's taken on-the-scene and can output the desired answers in minutes. Forecasts from Fleet Numerical Weather Central assimilate BT data from the entire Northern Hemisphere into a multi-layer oceanographic model that considers air-sea interface processes and ensures conformity to hydrodynamic principles.

Both systems are needed; one to provide the longer term, stable picture for any area desired, the other with the versatility to adapt in minutes to a changing situation, to permit more details to be known of the local situation, and to tailor the sonar output to any desired sonic frequency, target depth and sensor depth.

ICAPS is presently installed on six aircraft carriers and will eventually be operated from the Tactical Support Center (TSC) of all 12 CV carriers. There are two phases to ICAPS, the developmental and the operational. For developmental work a NOVA 800 computer is used to develop and test new programs. This versatile computer is also taken to sea to evaluate the system aboard various platforms. The operational

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system utilizes the 642B computer system in the Integrated Operational Intelligence Center (IOIC) and consists of four parts:

a. *Environmental.* This phase accepts the thermal profile from a locally observed BT, searches a historical data file for the appropriate deep thermal history to the bottom and, through a merge technique, outputs a surface-to-bottom temperature profile. This is combined with historical salinity data to generate a sound velocity profile to the bottom.

b. *Passive.* The velocity profile inputs to an acoustic model to permit computation of transmission loss between any combination of hydrophone and target depth desired for a given frequency. A lateral range curve can also be computed from the passive output for any selected type submarine operating at any depth (Figure 6).

c. *Active.* The active section calculates ranges for all active sonars for ship speeds of 6, 12, and 18 knots and assuming in-layer and below-layer targets. Information is also provided for best sensor depth, convergence zone, and bottom bounce ranges and the range at which the ship's sonar would be heard by a submarine.

d. *Applications.* The present tactical package provides optimum sonobuoy configuration on the basis of range input and selection of the number of sonobuoys to be used in a barrier.

Compared to the other areas of oceanography, synoptic oceanography is a newly emerging technique. One can be mislead by the profusion of oceanographic analyses available, and by the completeness of their neatly contoured isopleths, to assume that the situation is well in hand. In truth, the quantity of data used in most synoptic analyses is very insufficient, the quality of observations often questionable, and the physical models (to which we try to fit our analyses) either too research-oriented (requiring sophisticated data not easily observed), or too general for the applications required.

Synoptic measurement of the ocean is constantly being improved, particularly in the use of satellite sensors. Ocean buoys that can be implanted from the air and automatically record, date, and transmit on

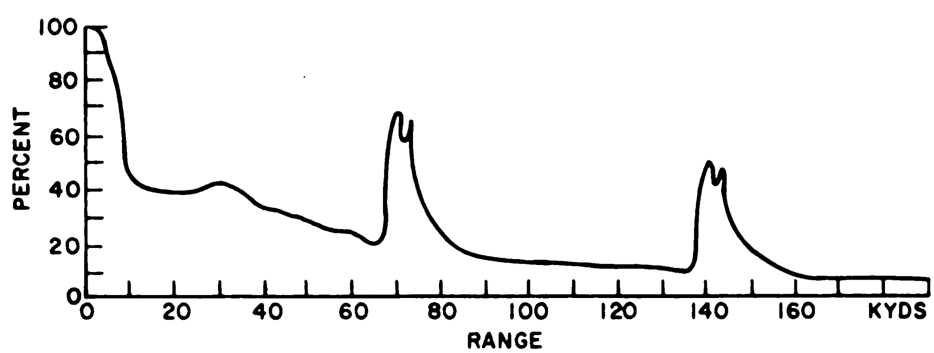

Figure 6 — ICAPS Probability of detection curve

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pre-determined schedule, are also feasible means of collecting information from remote areas. If past experience is any guide, however, the new data will generate as many questions as they answer concerning the true nature of the oceans.

Manganese-Fibers in Oceanography Public Health, and Environmental Engineering

Techniques developed at the Naval Oceanographic Office to extract radium isotopes from sea water for oceanographic studies may also be useful in purifying drinking water and treating industrial wastes.

Radioactive isotopes offer a unique means of studying ocean mixing. Surface waters receive radioisotopes such as carbon-14, cesium-137, strontium-90, and tritium from man-made and cosmic ray nuclear reactions in the atmosphere. Waters in contact with the ocean sediments receive radioisotopes such as radium-226, radium-228, and radon-222 by nuclear reactions in the sediments. This mechanism contributes radioisotopes to waters at the bottom of the ocean and to near shore waters.

After a water mass is tagged with radioisotopes by these processes, its motion and mixing may be monitored by measuring one or more of the radio-isotopes. These isotopes are in very low concentrations and their accurate analyses require considerable efforts in concentrating, purifying, and counting. To be useful in oceanographic investigations, many samples must be analyzed from each study area.

A fiberous material impregnated with oxides of manganese (Mn-fiber) will absorb radium isotopes from sea water. Instead of having to bring a 300-gallon sample of water from the bottom of the ocean to the ship for processing, the radium isotope may be concentrated *in situ* on the Mn-fiber in a special sampler. Many samples may be collected on the same cast with little effort. Analyses of the radium isotopes concentrated by the Mn-fiber are being used to study the rate of oceanic mixing through the main thermocline and near the sea floor.

Another use of the Mn-fiber is to purify drinking water contaminated by radium. In south Texas where some groundwaters are above the Public Health Service drinking water limit in radium, studies show the Mn-fiber to be effective in removing the radium at very low cost. The Naval Oceanographic Office is working with the Texas State Health Department in developing this new technology.

The Mn-fiber may also have many applications in removing other harmful metals from drinking waters as well as from industrial effluents.

Thus a material developed to study waters at the bottom of the ocean may have important applications in public health and industry.

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Bathymetry and Bathology

P. R. Vogt

Bathymetry, like so many other fields of science has rapidly progressed from description to analysis in recent decades. Bathymetry is actually four "sub-sciences." First, it is a technology to measure on board ship the water depth. This has been accomplished by echo-sounding since the 1920's, however, the sophisticated multi beam arrays now used at the Naval Oceanographic Office bear little resemblance to early echo sounders. The mere measurement of water depth is of little value unless the *place of measurement* is also known. The second major sub-science of bathymetry is therefore *navigation*. The satellite and inertial systems developed over the last two decades have produced significant improvements in accuracy. It is possible to end bathymetry at this point by simply printing numerical depth values on a chart; this is still done in areas where information is scarce. Usually, however, the bathymetrist is asked to create from these soundings a contour chart of ocean depth. Unless the soundings are closely spaced, the contours will only represent an educated guess of what water depths exist in the gaps between measurement points. Contouring, a tool of cartography, is then a third "sub-science," one that involves both an understanding of geologic processes that shape the ocean floors and, in recent years, an understanding of digital computers to interpolate, filter and contour the data.

The first three elements of bathymetry are primarily descriptive. Their final product is a contour chart. Such contour charts have many users, including the military services, lawyers, merchant marines, and groups interested in mineral resources. Perhaps the two primary applications are *hazard avoidance* and *navigation*. Shoal areas must be identified if they are to be avoided. There are still in the world oceans many uncharted shoals harzardous to surface shipping. A great number of dubious shoal soundings are printed on bathymetric charts so as to err on the safe side. With the deployment of increasingly costly, deeper diving submarines, such as the TRIDENT, more and more seamounts come within the depth range where collision is possible, while at the same time the penalty for such accidental grounding becomes astronomical.

A second major application of bathymetry is navigation. Hazard avoidance is an aspect of navigation; but if a vessel has depth-sounding equipment on board, it can, by comparing the soundings along a section of track with an accurate contour chart, establish where it passed through the contoured area. In actual practice a navigational "fix" can be obtained visually by plotting the supposed track on the chart and then adjusting the track so that observed soundings agree with contoured ones. Clearly

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the fix obtained from such a bathymetric chart is no better than the navigational accuracy of the survey vessel that produced the chart in the first place. Only since the successful deployment of navigational satellites about a decade ago have bathymetric charts and resulting fixes reduced errors to small fractions of a mile.

Having disgressed a bit on the subject of applications, we continue with the fourth and perhaps most interesting sub-science of bathymetry. This field might be called "bathology," for it goes beyond the task of making a chart by asking, "What do these cotours tell us about the physical processes operating on the sea-bottom? Do these charts help solve some of the broader problems of earth science?" As there are many other sources of information about the ocean floor than just its shape as defined by a shipboard echo sounder, it would be foolish to speculate on the meaning of a particular seamount using merely a contour depth chart. What are some of these other sources of information? First, the *gravity* and *magnetic* fields are readily measured by surface ship; and an extension of the echo-sounding principle is seismic reflection profiling, by which lower frequncy sonar energy is used to obtain echoes from below the ocean floor.

Second, the same measurements might be made from a submerged vehicle, such as a submarine or a towed instrument package (fish). Gravity and bathymetry have been measured from submarines. Bathymetry, magnetics, reflection profiling and even sea-floor photography have been accomplished from towed vehicles and, to some extent, from research supmersibles such as ALVIN. There are advantages of making measurements closer to the sea-floor. Signal strengths and resolution of finer details improve markedly, particularly as one approaches within a few hundred meters of the bottom. A third class of ocean floor information is obtained by actual sampling—dredging or coring from surface ships or submersibles, or deep drilling into the sub-sea floor.

At first glance it might appear that "bathology" is an academic subject which appears to follow bathymetry, and can therefore be separated conveniently from such operational requirements as locating navigation hazards and making the most probable contour charts. The error of this viewpoint is exposed by considering the "feedback" loop between geology and contouring. When a geologist is hired to make a contour chart from random ship tracks in a given area, his first steps are to search the scientific literature for additional constraints, and to inspect those fairly restricted areas that have been surveyed in detail. As a simple example, many of the spectacular mountains on land — like the Matterhorn—have been sculpted by glaciers in recent geological time. Such features have no counterpart on the ocean floor; indeed, bathymetric features 500 meters and larger in height are found from inspection of detailed charts rarely to exceed slopes of 20° or 30°. Such slopes are near

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the angle of repose for stony rubble, volcanic debris and lava flows. Although the geologically trained bathymetrist may in many cases be free to create Matterhorn-like peaks on his bathymetric chart, he would not be foolish enough to interpret his soundings that way. Computers, which have not been taught geology, might be foolish enough to do it; for this reason they are still no match for a geologist when it comes to contouring wide-spaced data. A better use of the computer is to first filter out the short wavelengths, and then produce an objective, repeatable *regional* contour chart. And, of course, for the small fraction of the world ocean that has been surveyed in detail, the contouring can be done wholly by machine, thus freeing the bathymetrist to spend more time thinking about what the data mean than how the numbers should be connected.

A second example of interpreting bathological data is illustrated schematically in Figure 1. There are infinite number of contour interpretations of depths collected along random tracks; not all are equally probable. In the mid-1960's continental drift, now known as a manifestation of plate tectonics, came to be established as virtual fact. It was found that the Mid-Oceanic Ridge, whose tectonic axis is the "crack" where new ocean crust forms, consists of sections or spreading centers offset by fracture zones – often deep valleys – whose traces turn out to describe the local motion between the two diverging plates. Since the crustal plates are fragements of a spherical shell, geometry requires the fracture zones to be arcs of small circles about a pole of plate/plate rotation. This knowledge, developed by analysis of existing bathymetric and other data, can be exploited to make more realistic bathymetric charts.

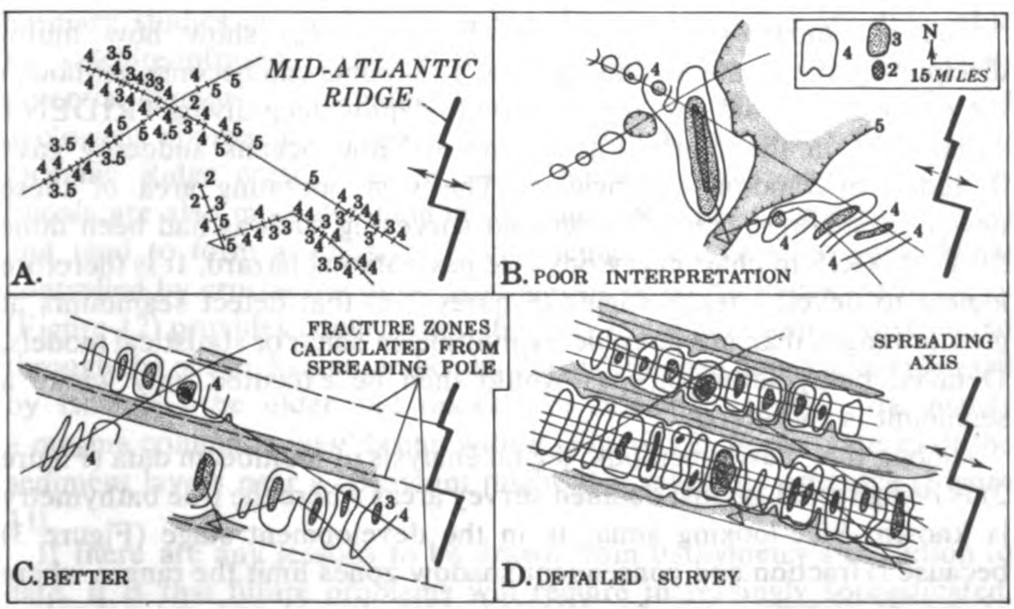

Figure 1 – Contours and continental draft

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We see, therefore that bathymetric charts require a "bathological" input, a knowledge fund that has been built up largely in the last two decades and largely because some areas *have* been charted and studied in detail. This vital feedback loop between routing bathymetric data collection and interpretation can be artifically impaired by arbitrary organizational barriers. Since operational requirements may change rapidly with military and geopolitical developments, a well-oiled product-generating machine (e.g., making bathymetric charts for the Fleet) must be able to respond to new problems quickly and efficiently; this requires R&D. Also, practical considerations require that separate "machines" be set up to respond to separate requirements; thus a magnetics group produces magnetic noise charts for MAD applications, an acoustics group makes bottom-loss charts for Fleet sonars, and a gravity group helps make vertical deflection charts for aiming missiles. It is impractical for each of these sizable operations to have their own research arms; however all these disciplines relate in some way to ocean floor geophysics. For this reason, interdisciplinary research groups exist that interact with the operational ones to pursue such interdisciplinary questions as: Can gravity anomalies be computed from the more easily measurable (by aircraft) magnetic anomalies? Can the new scientific understanding of plate tectonics and hot spots be exploited to make better bathymetric charts and, in general, to improve the prediction of desired geophysical variables in poorly or unsurveyed areas? How can seismic reflection, bathymetry, sediment cores and geological principles be used to improve bottom-loss contour charts? What other methods are there to find hazardous shoals without expensive, time-consuming detailed bathymetric surveys?

The accompanying illustrations (Figures 2-12) show how multidisciplinary the problem -finding shoal seamounts can become. Although the problem is an old one, the decision to deploy deep-diving TRIDENT submarines in the North Pacific and Atlantic oceans suddenly gave it added operational significance. The vast operating area of these newer submarines precludes detailed surveying such as had been done for POLARIS to chart every possible navigational hazard. It is therefore logical to develop technologies (Figures 2-6) that detect seamounts at greater ranges than are possible by multibeam sonar or statistical models. Detailed bathymetric surveys would then be executed only where a seamount is suspected.

Among the "new" methods, digital analysis of multibeam data (Figure 2) is being tested against detailed survey areas where the true bathymetry is known. Side-looking sonar is in the development stage (Figure 3) because refraction and consequent shadow zones limit the ranges where seamount summits can be detected. Density (ρ) and magnetization (J) contrasts between seamounts, and the surrounding ocean creates

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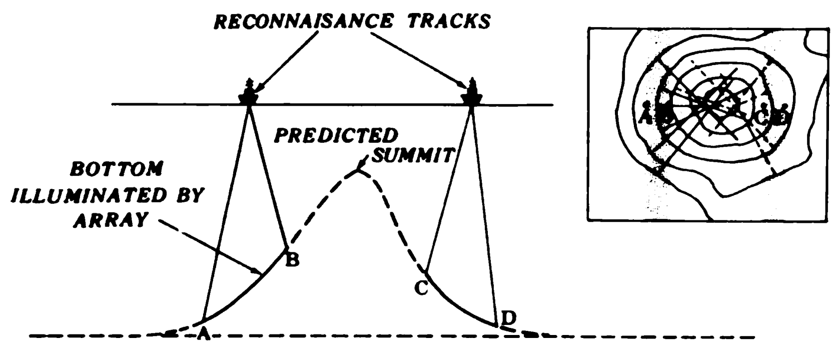

Figure 2 — Analysis of multibeam data across seamount flakes

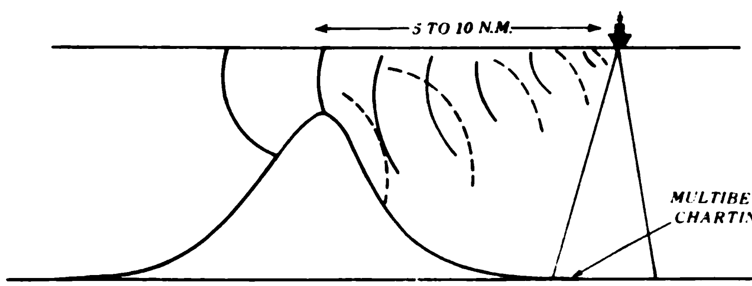

Figure 3 — Side-looking sonar

gravity and magnetic anomalies (Figure 4). Small positive thermal anomalies should also exist over seamounts (Figure 5), resulting from the conservation of vorticity as currents flow over the feature. Preliminary studies are underway to see if such anomalies are detectable by satellite-infrared. Another possible method is to measure "equipotential bumps" by satellite radar altimeter (Figure 6). Among the geological approaches, Figure 7 shows that shoals occur along Mid-Oceanic Ridge crest, fracture zones, hot spot trails, and island arcs. Shoals are also more common in the coral reef zone (Figures 8 and 11) and tend to form at characteristic spacings; the volcanic vents being controlled by crustal fractures. An analysis of North Pacific bathymetry (Figure 12) provides confirmation that shoals are not radomly distributed through the ocean. Seamount height above the ocean floor appears limited by isostasy—the older and thicker the lithospheric plate, the higher a magma column in equilibrium with it (Figure 10). Some features of the sediment layers near a seamount might also reveal its presence (Figure 11).

If there are any lessons to be drawn from bathymetry's evolution to date, it is that future problems will require increasingly sophisticated, multi-discoplinary approaches, and close communication between operational and research projects.

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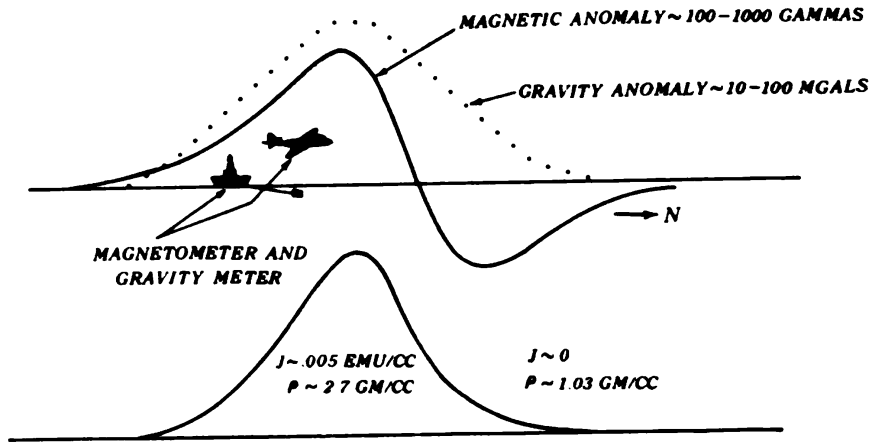

Figure 4 – Gravity and magnetic field anomalies

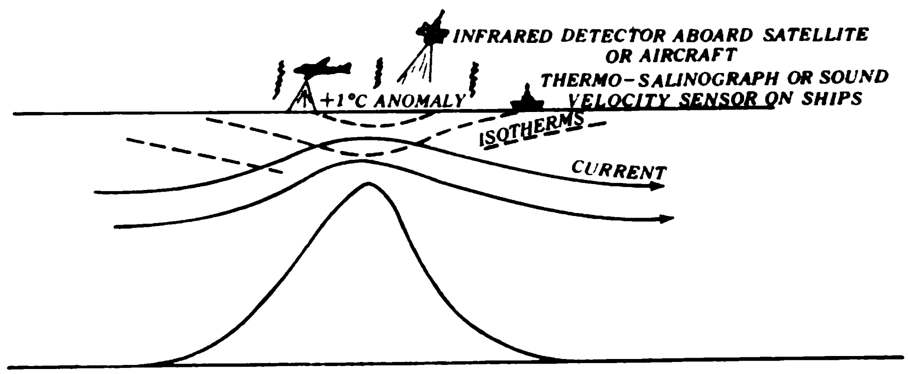

Figure 5 – Ocean surface thermal anomaly

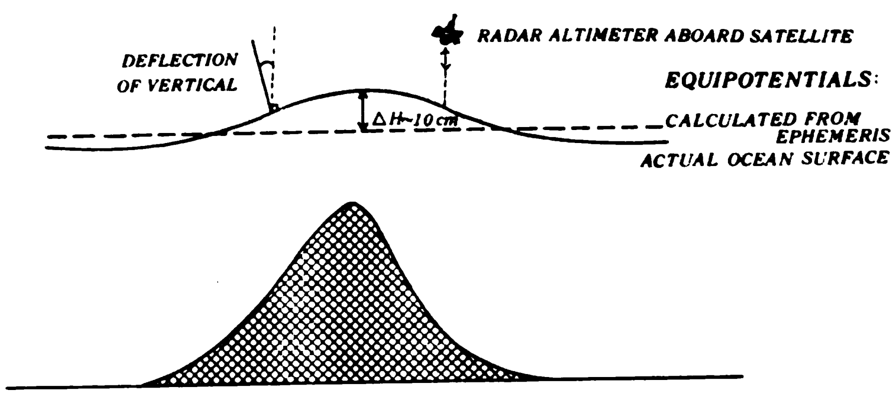

Figure 6 – Ocean surface (equipotential) bump

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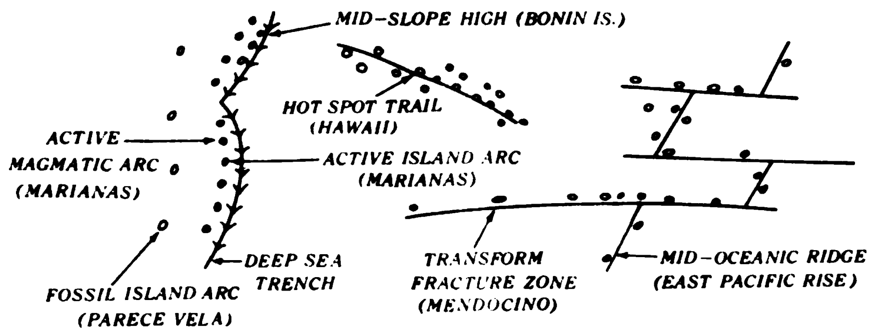

Figure 7 – Occurrence in geologic/volcanic provinces

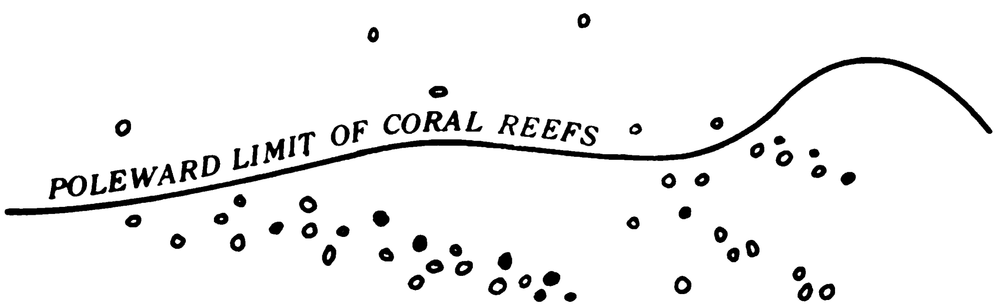

Figure 8 – Coral reef growth zone

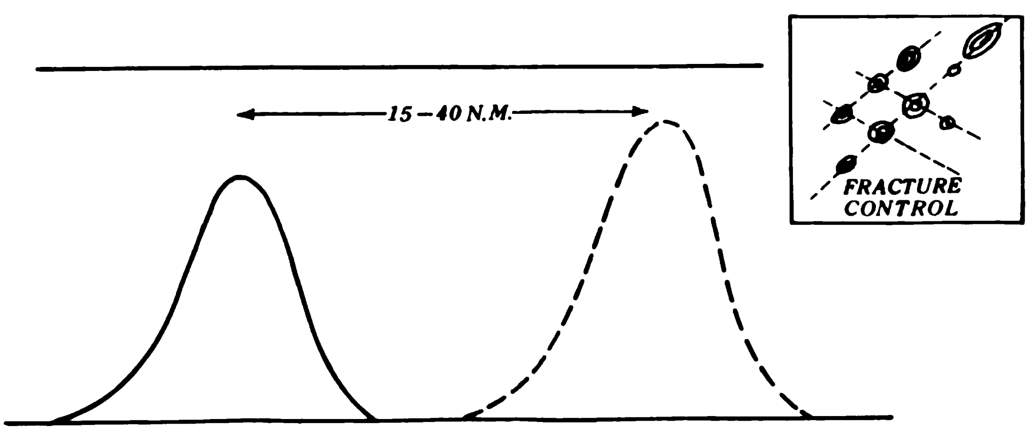

Figure 9 – Proximity to known seamounts

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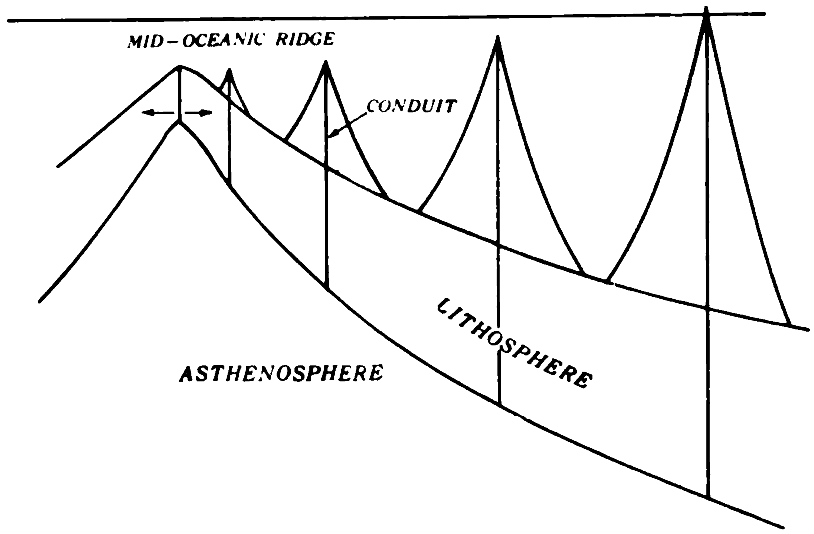

Figure 10 — Volcano height controlled by plate age and isostasy

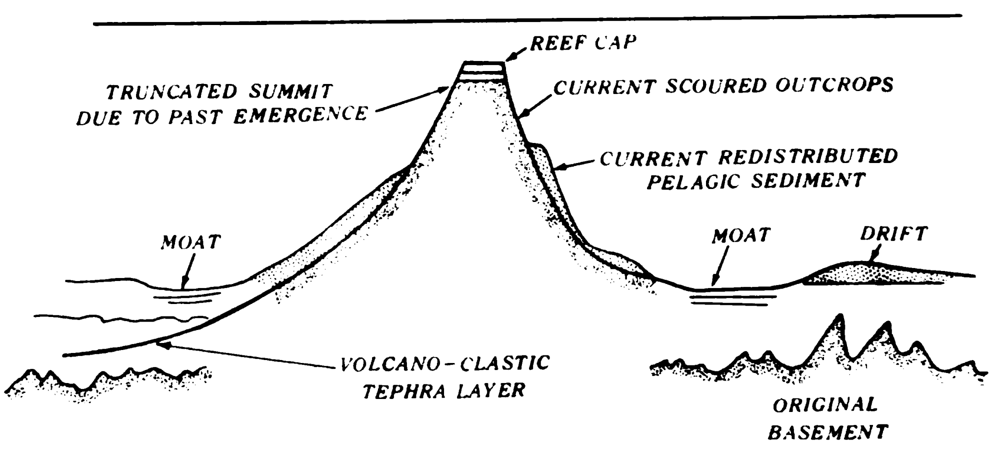

Figure 11 — Seismic reflection features

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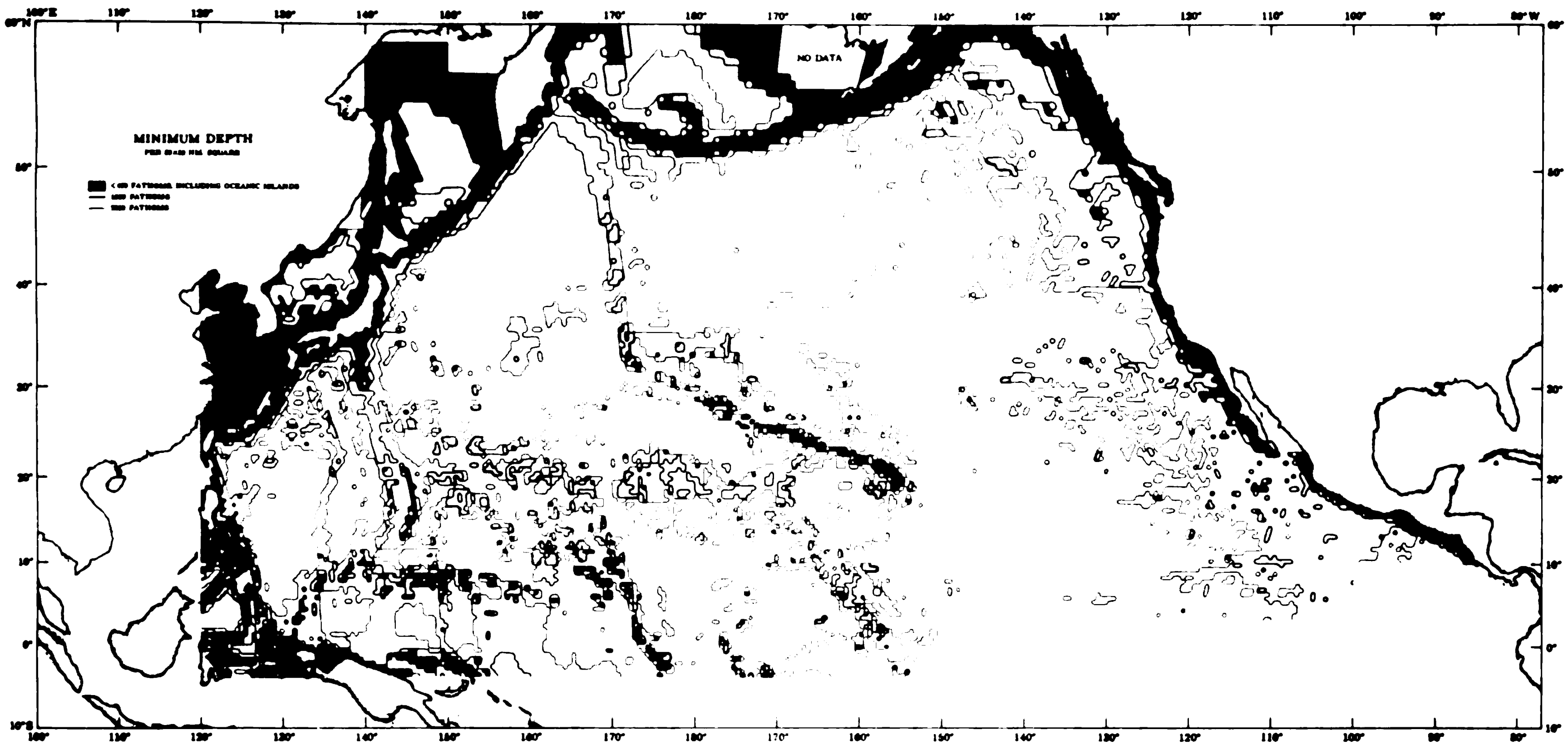

Figure 12 — Minimum depths per 30 × 30 nautical mile square in the North Pacific Basin

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Research Notes

Real-Time Satellite Data Used in Airborne Oceanographic Survey

Oceanographers of the U.S. Naval Oceanographic Office have developed a unique way to use satellite data to aid ongoing ocean survey operations. Several of the recent satellites placed in orbit have the ability to transmit their collection of terrestial data directly to APT (Automatic Picture Transmission) stations located within their line of sight. Since these data can be transformed into pictorial images showing details of the ice in polar regions, it was felt that their direct reception during a survey would be invaluable.

The first time such data was operationally used was during an airborne oceanographic survey conducted by the Naval Oceanographic Office of the ice condition in the east Greenland drift-stream in April 1972. During the survey, earth-oriented satellite imagery was received inflight by the research aircraft ARCTIC FOX. These pictorial images, broadcast directly from the satellites NIMBUS 4 and ESSA 8 were received aboard the aircraft by means of a portable APT satellite receiver equipped with a specially-modified airborne satellite communications antenna. The imagery derived from the satellite data showed the ice and cloud conditions for the Greenland Sea as they existed during each flight (Figure 1).

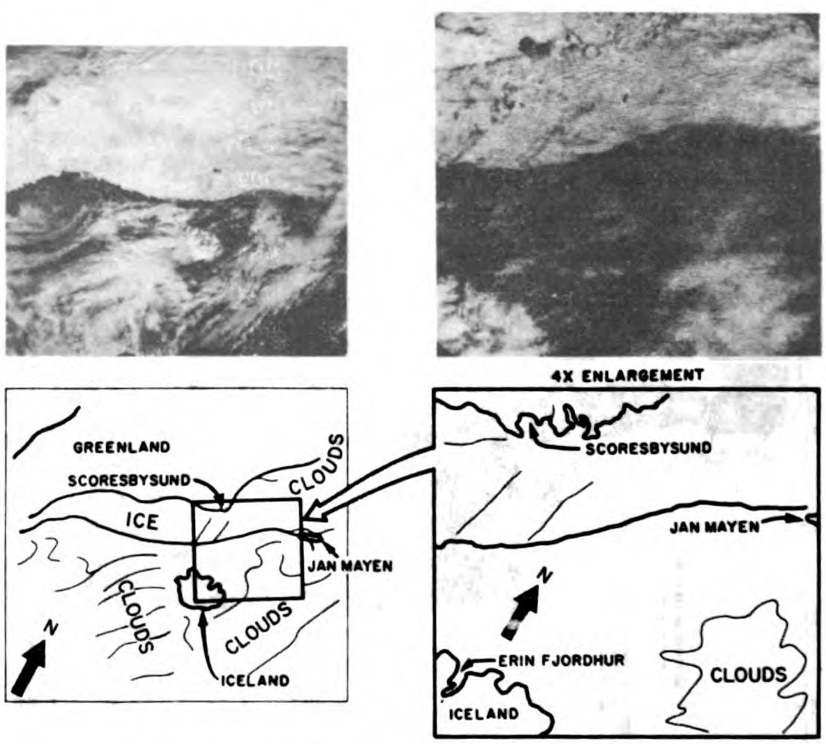

Figure 1 – Satellite Imagery Photograph of Survey Area - NIMBUS 4 Pass 9966, 19 April 1972

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The satellites used during the experiment were in polar orbits. This north-south orientation of orbit created an overlap in the data collected during each consecutive orbit that increased toward the poles. In the latitudes of the Greenland Sea, the overlap in the paths of each consecutive orbit was approximately 50 percent, Thus, it was possible to use the early morning satellite imagery in the pre-flight planning sessions to examine the general conditions of ice distribution and weather over the entire Greenland Sea, and to locate regions within the study area having the specific ice and cloud conditions required for that day's survey. Imagery obtained late in the morning and early in the afternoon were used to delineate the exact extent of the ice and cloud conditions in the chosen survey region.

The success of this survey has since prompted the use of an airborne APT station on a number of oceanographic surveys. Since some satellites transmit infrared as well as visual-range data, the APT imagery show temperature variations in the ocean's surface and thus, may be used to locate thermal ocean front. Using such imagery the Naval Oceanographic Office has increased its ability to survey complex ocean regions such as the Gulf Stream.

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Cover Caption

Oceanographic survey ship USNS Silas Bent. See page 1.

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