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# environmental support for naval operations—a profile of Fleet Numerical Weather Facility, Monterey, California*

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## 1. Introduction

The recent report entitled "Effective Use of the Sea" [1] not only focused our nation's long-term oceanographic interests, but also reminded this writer that the U. S. Navy's Fleet Numerical Weather Facility (FNWF) is unique in that it fulfills, in its dual operational and R & D mission as assigned by the Secretary of the Navy, at least three of the four implied goals for a national oceans program. Essentially, the marine interests of the United States are: strategic, economic, academic, and social. But these are not mutually exclusive! To employ the sea for enhancement of national security, for example, requires prior knowledge of processes and phenomena in the sea. To extract protein or minerals from the sea, moreover, requires access to those regions—that is, freedom of the seas. This apparent circularity of interests and motivations is such that this activity's products and by-products are rendered inseparable.

The oceanographic "state of the art" at Fleet Numerical Weather Facility has not been told heretofore to UST readers. Suffice it to say that if FNWF's methods and products were of strategic importance only, then their scope and national impact would be too limited for wide readership. But, such is not the case. The FNWF approach to oceanographic problem solving differs markedly, in fact, from numerous parallel but different approaches because of a combination of reasons which will be discussed later.

## 2. Historical sketch

Fleet Numerical Weather Facility, under the command of Capt. Paul M. Wolff, USN, is an activity of the U. S. Naval Weather Service. Although presently located on the grounds of the Naval Postgraduate School at Monterey, Calif., it began in 1958 as a Navy Numerical Weather Problems Group (Project NANWEP) by personnel attached to the Navy's Fleet Weather Central at Suitland, Md. Relocation to Monterey occurred in July 1959.

Initial efforts were devoted to reprogramming for the CDC 1604, and to the development and checkout of automatic data processing (ADP) programs, and to objective analysis and prediction techniques. The first oceanographic research projects included methods of presenting ship reports, a ship tracking program, and objective sea surface temperature and sea state analyses.

In 1961, Project NANWEP became known officially as the Fleet Numerical Weather Facility. The Secretary of the Navy assigned to FNWF the dual mission to provide numerical products on an operational basis peculiar to the needs of the Navy, and to develop and test numerical techniques in both oceanography and meteorology.

Staffed currently by 85 military and civil-service specialists in the environmental sciences and in computer technology, FNWF uses electronic computers both for environmental problem solving and for rapid communications (raw data input—finished product output). Many programs are already running on the Giant CDC 6500 recently installed. Other computers being used: Two CDC 1604's, two CDC 3200's, and a CDC 8090. All programming, computer operation and maintenance, and development and fabrication of communications and interface devices are performed in-house.

By comparison with the early oceanographic efforts (1960), enormous advances have been made, both in quantity and quality. If one had to pick the single most important consideration leading to these advances, it would be the treatment of the atmosphere and the oceans as a single environment. Thus, the transfer of both heat and momentum to and from the sea surface is the vital link in the single environment concept. Such a concept is possible only in an activity which generates all of the required meteorological and oceanographic data fields.

Admittedly, much remains to be learned about the complex processes which take place at or near the interface. But FNWF employs an engineering application of computer technology in its environmental problem solving. The required oceanographic programs are already operational. Future improvements in synoptic range-of-scale oceanography, therefore, are envisioned as being dependent upon the distribution and density of observations rather than upon the initiation of models and their early development.

* Portions reprinted from *UnderSea Technology*, **8**, Aug. 1967, 17–21.

[1] The final report of the Panel on Oceanography of the President's Science Advisory Committee, Government Printing Office, Washington, D. C., June 1966.

## 3. Concept of operations

FNWF is the master computer center and controller of the Navy's worldwide Environmental Data Network (NEDN). Its hemispheric analyses and prognoses of both oceanographic and meteorological parameters are transmitted simultaneously, on highspeed data communications circuits, to the network's primary computer sites at Guam, Pearl Harbor, Norfolk (Virginia), and Rota (Spain).

At these sites the received data fields[2] are used as inputs for other computer programs which tailor the products to the user's specifications (form, scale, and projection). These tailored products get to the operating forces via the Navy's radioteletype and radiofacsimile broadcasts. In response to a particular request for environmental support, distribution is made by priority addressed message. In the near future, however, products will be relayed to the fleet via communications satellites.

For shore-based installations, environmental support has been enhanced by the establishment of data tielines. Thus far an East Coast- and a West Coast-Tieline have been activated. Each tieline is currently supporting nine shore activities. Each station is equipped with automatic digital plotting and printout hardware. Controlling stations transmit products simultaneously, but a particular product may be sent to fewer than the total number of stations. The U. S. Tieline configuration is shown in Fig. 1.

Where do the observations come from? In 1965 a significant advance was made in data collection. At that time, the Air Force's Digital Automated Weather Network (DAWN) became operational. This system, with intercept sites at Fuchu, Japan, and High Wycombe, England, provides all available environmental data (in their respective areas) to Tinker AFB, Okla., via highspeed data circuits. At Tinker AFB, North American data are added to the collection. FNWF was the first numerical activity to subscribe to this collection system. On this circuit FNWF receives data at speeds the equivalent to 6000 teletyped words per minute. About 95% of all incoming observations are obtained from the DAWN network. The remainder, such as bathythermograph observations, are received both from conventional Navy communications and from other NEDN sites.

[2] All computations are performed on a $63 \times 63$ matrix of points with grid spacing of 381 kilometers (at 60 North). By "data field" is meant that a functional value (a sea surface temperature value, for example) is assigned to each of the 3969 grid points (the geographical equator is an inscribed circle in this grid array).

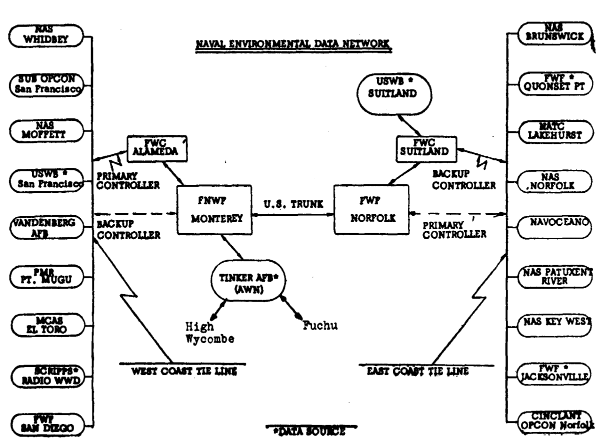


FIG. 1

## 4. Postulates of progress

It was stated earlier that FNWF's uniqueness was attributable to a combination of factors, or postulates of progress, as they will be referred to in this section. It will be seen that all four postulates must be incorporated in any national environmental support system, in general, or in the Navy's support system, in particular.

*Postulate 1. Computerized operations.* There are seven distinct steps in an environmental flow scheme: observation, collection, process, analysis, prognosis, distribution, display. Each step takes time. But forecasts don't improve with age. To provide adequate and timely environmental products and services (the reason for existing), one must engage in a struggle against time itself!

Massive quantities of raw observations are required for accurate, consistent analyses (and forecasts). Reports must be edited. For "hand" analysis the reports (a small portion of them, that is) must be plotted on a chart. As a consequence only a small fraction of the available number of reports gets plotted. An objective computer analysis, on the other hand, bases its output on all the available reports. Thus, its analysis is both reliable (same analysis every time from a given set of reports) and more representative of existing conditions.

Then comes the analysis function. Most analysts begin by drawing isolines of reported, pertinent parametric values. The "better" analysts begin with some assessment of the accuracy or credibility of each report. This is clearly too massive a task for hand methods. The accuracy of the analysis, moreover, is very often affected by the health or mood of the analyst. Will he take the necessary "pains" today? Will another analyst interpret the reports the same way? The computer will.

The next task is to make an accurate forecast. To do so by hand, on a hemispheric scale, without violating the physical laws of the atmosphere or oceans, is impossible! The task requires billions of arithmetic computations. It is too vast a problem for the time allowed.

The computer is as suited to distribution as it is to collection. The essential requirement for environmental prediction is accuracy, but the rapidity of distribution is a close second.

Numerical methods have been making significant strides in the display of products also, particularly through the use of automatic digital plotters and highspeed printers.

But something far more subtle has been taking place. The availability of reliable, accurate, tailored products has led to the evolution of a numerical philosophy—one which embodies the efficient use of highly trained specialists in the field. To be resource effective, the Ph.D., or M.S., must no longer be permitted to "draw isolines" or check raw data. His proper role has more to do with matters of interpretation and judgment —to critical analysis and feedback. In short, computer operations have changed the whole business.

*Postulate 2. Single environment.* Atmospheric and oceanographic analysis and forecasting problems have been faced before—in the universities, in industry, in government agencies. To my knowledge, however, no other activity has treated the atmosphere and the oceans as a single environment, with its complex interactions. Correct solution to environmental problems demands this approach.

Implied in the single environment approach is the transfer of heat and momentum to and from the sea surface. This means that the task of environmental analysis and forecasting must be done at an activity which generates all required fields—both oceanographic and meteorological!

The Navy has sufficient motivation to treat the two environments as one. Its environment is larger than that of other environmental activities, because it extends from the ocean floor to the operating limits of its highest-flying weapons system. Fortunately, most Naval operations have been at or relatively near the air-ocean interface. As a consequence, FNWF has concentrated on environmental problem solving in that region.

Many operational programs at FNWF utilize heat exchange and momentum exchange terms. Prominent among these are the sea-surface temperature and sub-surface temperature, mixed- and transient-layer depth, wind-driven and thermal current, and underwater sound map programs. (Others will be discussed later.)

*Postulate 3. An engineering approach.* If it is true that all truths are tentative, it is most certainly true in the environmental sciences. The optimum approach, therefore, would involve utilization of theoretical equations (today's truth) in combination with proven synoptic principles (the "tuning" constant). At FNWF there is extensive comparison between the forecast and the observed features—and their time variations. The criterion of acceptance for a "model" is a simple one: when the machine product betters the hand product on a consistent basis, the former becomes operational. Systematic errors are easily eliminated. In other words, it is an engineering approach. It is a matter of optimizing the output to resemble the real environment. Until such time as the universal truths about the environment are known, the engineering approach is the only logical choice.

*Postulate 4. Management for mission.* An old Navy saying has it that "nobody knows the needs of the Navy better than a sailor"—but, this is true in every endeavor. It is industry's justification for the development of management from within a particular organization. One gets to know the problems. One becomes mission oriented (hopefully). At FNWF there is a strong feeling that this is particularly true in matters relating to the environmental support of the fleet. Its efforts have been organized and directed by Naval officer environmental specialists; that is, by men who were trained in and responsive to the needs of the fleet.

The implications are staggering. It means that the specialist in the field must be an interdisciplinarian: a Naval officer (to be sure), a meteorologist, an oceanographer, and a computer expert.

## 5. General applications of environmental information

The increasing amount of attention being given to "innerspace" is well justified. There is the obvious submarine threat to the United States. Counterdevelopment of the Fleet Ballistic Missile Submarine system further increases the need for accurate specification of the ocean environment—for offensive and defensive purposes. As a consequence, the principal national interest in ocean science and technology in the next decade will be the strategic use of the sea to enhance national security. The Navy's environmental support should and will be toward this end.

But, before describing the main oceanographic products and services provided for fleet operations and planning by Fleet Numerical Weather Facility, it will be of interest to UST readers to learn of a few of the economic applications of its products.

Foremost among the requirements to be met in the next 50 years will be the tripling of the world's protein needs. A larger portion of the total must come from the sea. Likewise, an enormous mineral source remains to be tapped on the continental shelves. Regardless of the motivation to use or to exploit the sea, all pursuits will require adequate, timely environmental support. These may be wind and sea warnings (for offshore drilling), or sub-surface thermal and current structure (for fishing, or underwater harvesting). Ocean currents are already useful for navigation, fishing, and ship routing purposes.

FNWF has worked very closely with the U. S. Bureau of Commercial Fisheries in the past few years. Much is already known about the relationship of fish behavior and ocean state parameters. Laevastu [3] pointed out that, aside from improvements in fishing vessels and related gear, fish yield per amount of effort is dependent upon the application of this knowledge; that is, the generation of fisheries forecasts to minimize scouting time.

Fig. 2 shows the "preferred" ocean temperatures for several tuna species. Thus, FNWF's sea-surface temperature and mixed-layer depth analyses and prognoses are being used to direct the tuna fleets to more profitable grounds. In the coming year, products will be used to enhance the king crab operation in the Gulf of Alaska.[4]

Another FNWF product [5] being produced every twelve hours is the "Ocean Front" Analysis. These ocean fronts

[3] FNWF Technical Noté No. 19.
[4] VanCamp Sea Food Company.
[5] FNWF Technical Note No. 20.

depict water type boundaries (zones of strong packing in the horizontal temperature structure). Under certain conditions one may consider these zones as high nutrient zones (from the implied current convergences); and therefore, regions for excellent fishing.

This coming year, the U. S. Bureau of Mines will use wind and sea-state forecasts from FNWF to support their offshore drilling operations in the Gulf of Alaska.

Other economical and social applications of FNWF's single environment output should be exploited in the future. The applications noted above serve to illustrate that the products conceived to enhance strategic interests are equally useful for other purposes.

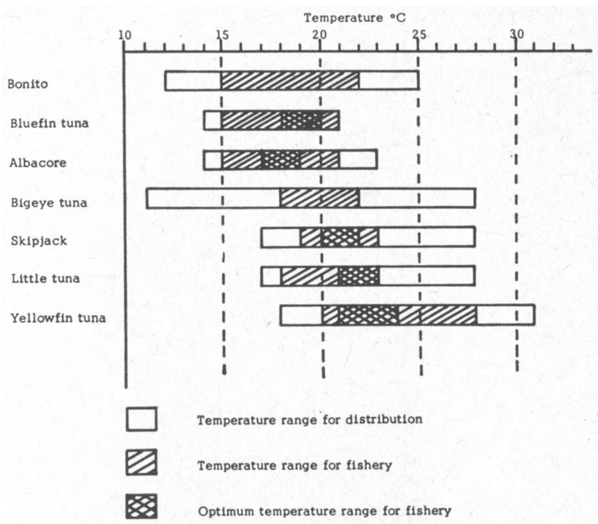


Fig. 2. Temperature range for distribution and fishing of tuna species.

## 6. Support for naval operations

FNWF performs hemispheric analyses and forecasts every twelve hours of all of the pertinent ocean-state parameters required for environmental support of the fleet.[6] The FNWF ocean model is complex in the sense that it is based on theoretical considerations, as well as historical and observational data. The following specific products are available routinely.

- Sea surface temperature analyses and prognoses
- Wind wave analyses and forecasts (direction, period, height)
- Swell analyses and forecasts (direction, period, height)
- Combined sea analyses and forecasts (direction, period, height)
- Surface current analyses and forecasts (stream and transport)
- Ocean-atmosphere heat exchange analyses (total, latent, sensible)

[6] FNWF Technical Memorandum 11-1.

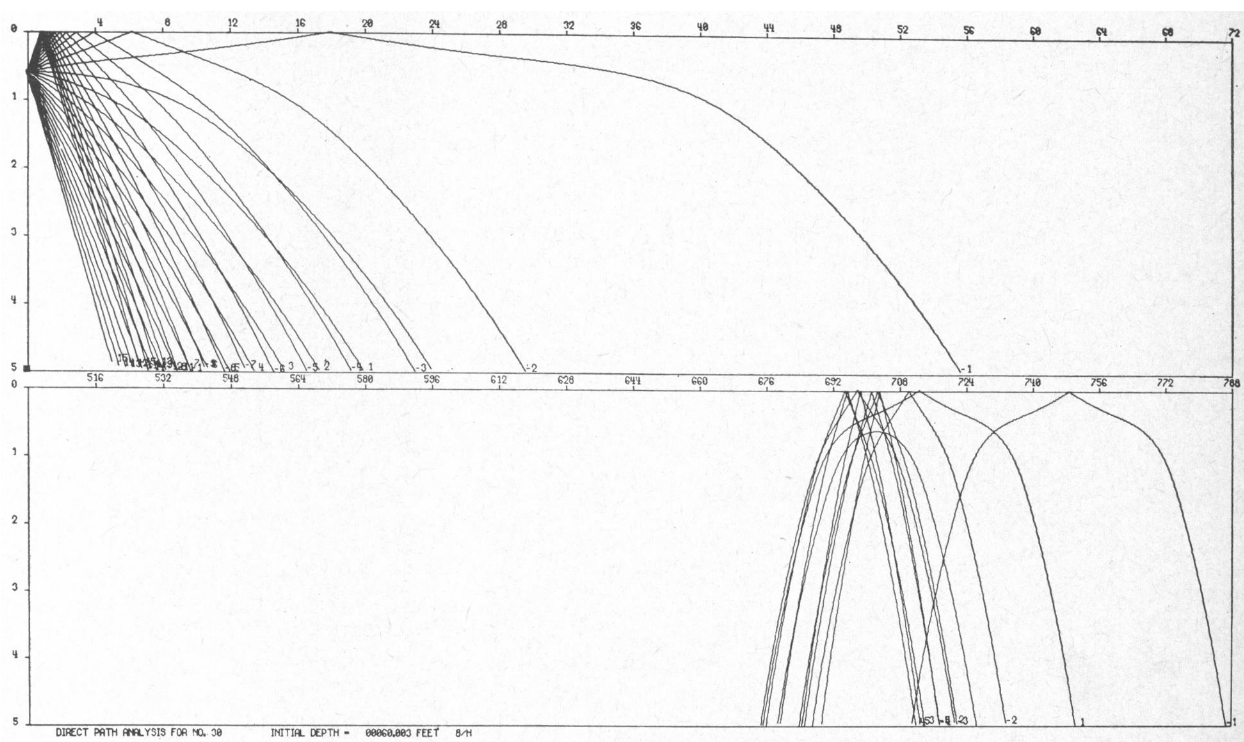

Fig. 3. Ray Trace Plot of the continuous paths of typical sound along a horizontal path: top, direct path sound propagation field out to about 7200 yards; bottom, "convergence zone" field depicting a region of high intensity at approximately 70,000 yards. (The vertical scale extends to a 500 ft depth in both instances.)

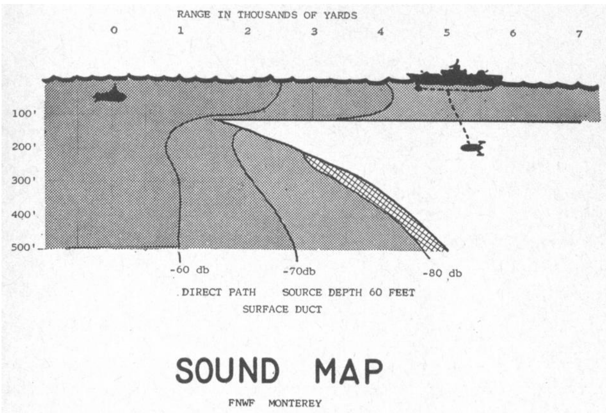


**Fig. 4**

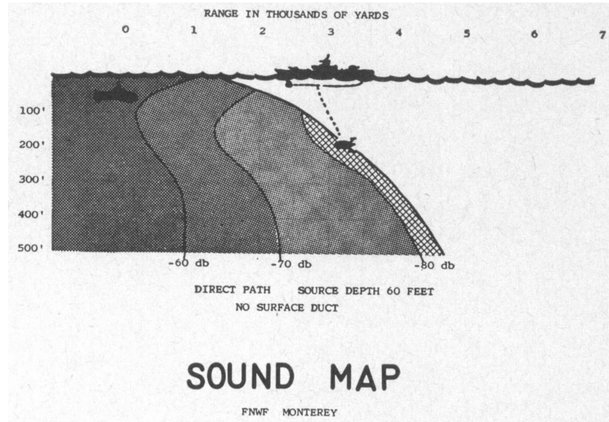


**Fig. 5**

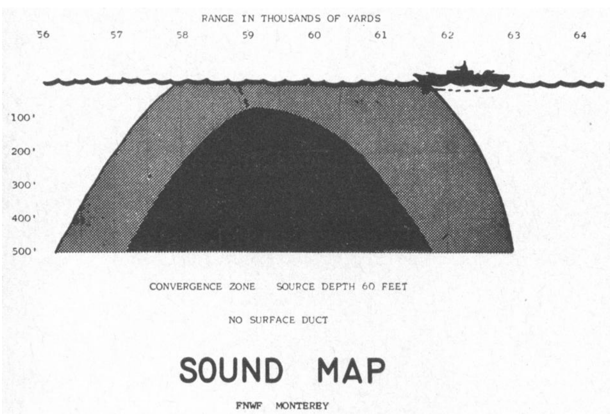


**Fig. 6**

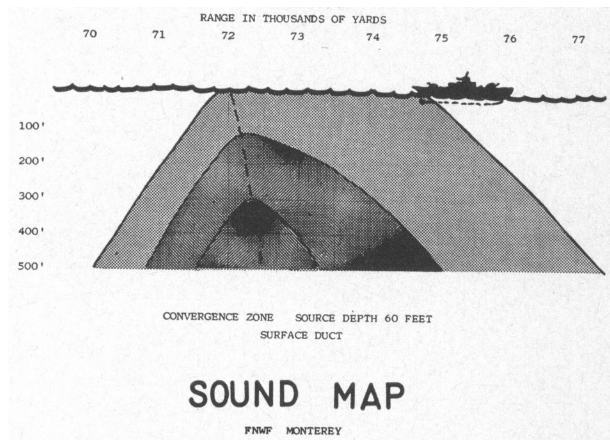


**Fig. 7**

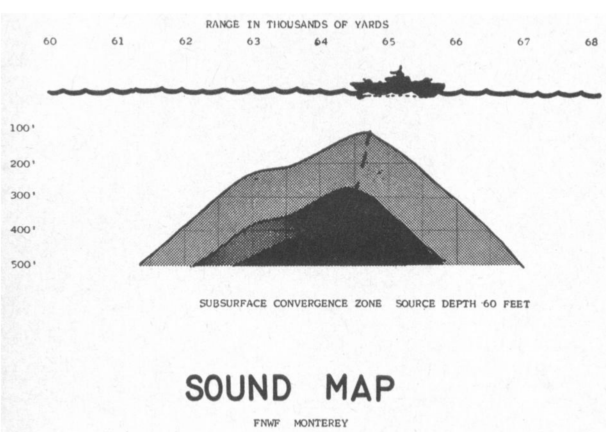


**Fig. 8**

## OCEANOGRAPHIC OUTLOOK

1. AREA
2. TIME PERIOD
3. SEA SURFACE TEMPERATURE
4. SUBSURFACE THERMAL STRUCTURE
   MIXED LAYER: DEPTH, VARIABILITY, GRADIENT, TRANSIENTS (EXISTENCE, PERSISTENCE)
   GRADIENT IN THERMOCLINE
5. BOTTOM
   DEPTH IN AREA
   BOTTOM TYPE
   BOTTOM REFLECTIVITY
6. CURRENTS
   PERMANENT
   TIDAL
7. SEA STATE - CLIMATOLOGICAL STATISTICS
8. NOISE
   BIOLOGICAL
   TRAFFIC
9. SONIC CONDITIONS
   SURFACE SOUND VELOCITY
   SOUND VELOCITY PROFILES: SURFACE TO 1200 FEET, SURFACE TO BOTTOM
   SOUND CHANNELS/DUCTS: SURFACE, SUBSURFACE
   DIRECT PATH SOUND FIELD: SHALLOW SOURCE, DEEP SOURCE
   BOTTOM BOUNCE SOUND FIELD: RANGE, OPTIMUM SONAR DEPRESSION ANGLE
   CONVERGENCE ZONE: RANGE TO ENERGY CENTER, WIDTH, SPATIAL VARIABILITY, SONAR SETTING
10. SYNOPTIC FORECASTS
   BT/SV FORECASTS
   OTHER UPDATE DATA
11. TACTICAL RECOMMENDATIONS - OPTIONAL SECTION
   PASSIVE (AIRCRAFT): BUOY SPACING, BUOY DEPTH
   ACTIVE (AIRCRAFT): BUOY SPACING, BUOY DEPTH
   VARIABLE DEPTH SONAR

**Fig. 9**

Potential mixed layer depth analyses and forecasts
Sub-surface thermal structure (any level to 1200 ft)
Temperature vs. depth profile forecasts (for any oceanic point)
Sound velocity vs. depth profile forecasts (for any oceanic point)
Ocean fronts
Underwater sound mapping (involves ray tracing from a sound source)
Scale separation of sea-surface temperature analyses (depicts small-scale and large-scale anomalies)
Derived parameters (see FNWF Technical Memorandum 11-1)
Oceanographic outlooks

It is regrettable that an adequate description of each product is far beyond the intent of this article. Numerous scientific and technical memoranda are available upon request for that purpose.

Since FNWF is concerned principally with specific military applications of its oceanographic products, it is fitting to describe the type of support being given to the Navy's ASW forces.

Essentially, the ASW commander is concerned with detection; both in the offensive and defensive sense. Detection, moreover, requires appropriate hardware (sonar) and considerable knowledge of the underwater sound field. Problem: Given a sound source in the sea (location and intensity), where will each emanating ray travel and how much will its initial intensity be reduced along the way? FNWF has ray trace programs running operationally at present.

To accomplish the task, temperature profiles from the sea surface to the ocean bottom are constructed both from standard level analyses (from 100 to 1200 ft) and from deep water soundings and climatology. Sound velocity profiles are computed as a function of temperature, salinity, and pressure. Interpolation between profiles is performed to obtain a continuous two-dimensional sound field along the path of interest. Sound intensity loss along each ray path is computed as a function of spherical and cylindrical spreading, absorption, and surface and bottom loss.

There are an infinite number of sound velocity profiles in the sea, but in spite of the variations—the propagation of underwater sound may be evaluated according to the type of propagation. At FNWF attention has been given to "direct path," "convergence zone," and "bottom bounce" propagation types.

A companion Ray Trace Plot program is also operational. It plots the continuous paths of typical rays along a horizontal range in two sections (see Fig. 3): the first is a plot of the "direct path" sound propagation field out to a distance of 7200 yards horizontally from the sound source (top section of Fig. 3); the second is a plot of the "convergence zone" sound propagation field (the bottom section of Fig. 3 depicts a region of high intensity sound approximately 70,000 yards from the source). Note that both have vertical scales down to 500 ft. In this example the source depth was 60 ft.

Figs. 4 through 8 depict a few of the possible types of idealized sound propagation, with a source depth of 60 ft. Fig. 4 shows the direct path method at a time when there exists a surface sound "duct" (a region of relatively slow speed). Note that a hull-mounted sonar would be effective, but the VDS (variable depth sonar) would be in a relative sound shadow zone. In Fig. 5 there is no surface duct, and the direct path method is ineffective. The VDS, on the other hand, would be useful if correctly placed. Figs. 6 and 7 depict the regions of high intensity sound as a result of convergence zone propagation. They differ more with respect to range than with respect to intensity. Fig. 8 depicts a sub-surface convergence zone wherein VDS would be more effective than a hull-mounted sonar.

There are many other possibilities, of course. These illustrate but a few. More importantly, this type of information is currently available to ASW commanders. In fact, all of this information is contained in FNWF's standard oceanographic outlook (see Fig. 9), which is available upon request.

## 7. Summary

Effectiveness of Naval operations has been enhanced considerably by this type of heretofore unavailable environmental support. As a result, fleet requirements have more than doubled in the past year (the "word" got around). FNWF's postulates for progress set it apart from similar activities. Its products and services for support of the Fleet qualifies FNWF as the world's leading oceanographic forecast center.