OCEAN PROFILING WORKSHOP

June 2-4, 1976

Sponsored by NOAA DATA BUOY OFFICE
Under the Auspices of
NATIONAL SCIENCE FOUNDATION

This report documents the results of the Ocean Profiling Workshop conducted June 2 - 4, 1976, by the National Oceanic and Atmospheric Administration's Data Buoy Office (NDBO) under the auspices of the National Science Foundation (NSF) Office for the International Decade of Ocean Exploration. Funding was provided under NSF Grant OCE 76-12177 and by the NDBO. The contents do not necessarily reflect the official views or policy of NOAA or NSF.

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ACKNOWLEDGMENTS

The NDBO appreciates the support and guidance provided by the panel chairmen, participants and data users in the research institutions, laboratories, and operational groups represented in the workshop. The assistance of Dr. E. W. Bierly, Dr. G. A. Flittner, and Messers. L. H. Clem, G. W. Withee and M. M. Autrey in the preparation of this report is especially appreciated.

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FOREWORD

An Ocean Profiling Workshop, jointly sponsored by the National Science Foundation and the National Oceanic and Atmospheric Administration's Data Buoy Office (NDBO), was held June 2-4, 1976, at the Data Buoy Office, National Space Technology Laboratories, Bay St. Louis, Mississippi. The major objectives of the workshop were to assemble a group of scientific, technical, and management representatives from the various national oceanographic data users to:

(a) identify and categorize the various uses and applications for subsurface water temperature and salinity data, primarily in the upper layers of the oceans;

(b) define the near-term and long-range data measurement requirements and characteristics for these applications and the sensitivity of the user's application to the required data; and

(c) establish any commonalities that may exist between these various data measurement requirements.

These requirements were to be expressed in detail so that they could be used as a guide for technical direction and economic considerations for possible hardware developments.

A supplementary goal of the workshop was to update and refine the findings of the most recent data users survey conducted for NDBO by Arthur D. Little, Inc., that were documented in "Performance Characteristics for an Ocean Data Vertical Profiling System", dated April 1973.

The participants, drawn from U. S. Government agencies and academic institutions, were primarily oceanographers and represented diversified interests in oceanographic research, climate dynamics and marine observations.

The first day of the workshop was devoted to invited presentations by representatives from each of the user categories on the use, or potential use, of temperature and salinity/ conductivity data in their respective programs. These presentations and the ensuing technical discussions served both as orientation for the participants and to set the stage for the working panels the next day. The NDBO presented an overview of the engineering potential for ocean profiling from environmental data buoys and information on pertinent hardware capabilities and problems.

On the second day, the participants met in individual working panels representing the various user categories. The Scientific and Climate Dynamics panels were combined into one panel because the participants did not believe the two categories could be discussed independently. Each panel was chaired by a nationally recognized leader in the group who was responsible to guide the work to a successful documentation of the technical findings and conclusions.

On the final day, the chairman of each working panel presented his panel's report to the total workshop for acceptance and/or discussion.

The following report documents the proceedings of the Ocean Profiling Workshop.

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EXECUTIVE SUMMARY

The purpose of the Ocean Profiling Workshop was to determine the various user needs for ocean temperature, salinity and measurement depth data with emphasis on the needs for continuous vertical profiles versus data from discrete levels. A supplementary goal was to update and refine the earlier surveys of requirements for these types of data.

FINDINGS

The first column of Table I summarizes the range of acceptable data needs for the various applications discussed at the workshop and covers the important measurement characteristics. The remainder of Table I, as labeled, extracts from these data needs a common "core" set of measurement requirements and characteristics that should satisfy the minimum acceptable operational and many of the scientific user applications. This common "core" set of requirements appears to be technologically feasible to achieve in long term, unmanned applications. Insufficient development has been accomplished to date to totally evaluate the economics of various approaches.

Additional general findings include:

- The workshop panel members identified firm applications for which they agreed there exists a strong need for temperature/salinity/depth data at least from the upper levels of the ocean (i.e. the upper few hundred meters).
- There was general agreement that present data sources are inadequate and that a capability is needed to acquire time series data at selected locations of the deep oceans and continental margins.
- It was agreed that for some applications there was a need for Lagrangian measurements of these data as opposed to time series at a fixed location.
- The desirable and minimum acceptable data measurement requirements and characteristics for each application were identified and listed on tables.
- The need for data at discrete levels or from continuous vertical profiles was identified for each application.
- Some operational users, most notably the U. S. Navy, require continuous profiles of ocean temperature in the near-surface region (depth to 200 meters). These requirements are based on the Navy's needs for acoustic predictions and ranging techniques. The U. S. Navy, National Weather Service, and National

Table I. Summary of Measurement Requirements

Data Requirement (Units)	Range of User Needs	Common "Core" Requirements		
		Deep Ocean	Continental Shelf	Drifters
Temperature:				
Range (°C)	-2 to 35	-2 to 35	-2 to 35	-2 to 35
Accuracy (°C)	± 0.002 to ± 1.0	± 0.1	± 0.1	± 0.1
Digitization Increment (°C)	0.0005 to 1.0	0.05	0.1	0.05
Salinity:				
Range (°/oo)	0 to 40	30 to 38	0 to 38	0 to 38
Accuracy (°/oo)	± 0.003 to ± 1.0	± 0.1	± 0.1	± 0.1
Digitization Increment (°/oo)	0.001 to 1.0	0.1	0.1	0.1
Depth:				
Range (m)	0 to 600	0 to 400	0 to 200	0 to 150
Accuracy (m)	± 0.1 to ± 10	± 2.0	± 1.0	± 2.0
Digitization Increment (m)	0.05 to 10	2.0	1.0	2.0
Sampling Duration (min)	Instantaneous to 360	10 (Discrete) Instantaneous (Profile)	10 (Discrete) Instantaneous (Profile)	10 (Discrete) Instantaneous (Profile)
Interval of Observation (hrs.)	0.1 to 24	1 (Scientific) 3 (Operational)	1 (Scientific) 3 (Operational)	1 (Scientific) 3 (Operational)
Time Period Needed	1 mo. to Indefinitely	Indefinitely	Indefinitely	Indefinitely
Applications:	U.S. Navy, NWS, NMFS Monitoring and various scientific programs	USN; NWS; NMFS; Replace OSV's; Climate Monitoring; Mixed Layer, Oceanographic Process, and Acoustic Research	USN; NWS; NMFS; Replace Lightships; Climate Monitoring; Oceanographic Process, Acoustic, and Coastal Upwelling Research	Monitoring and Research of Transition Zones and Major Ocean Currents

Marine Fisheries Service all have a need for real-time ocean temperature, salinity and depth measurements.

- The Scientific Panel identified no present requirement for continuous vertical profiles or real-time data availability but specified a need for precise measurements at discrete levels to better understand the physical processes and statistical characteristics that govern the ocean environment.
- Probably no one measurement system will serve all requirements, however all users clearly indicated the need for a reliable system with data of a consistent quality, e.g., high relative accuracy, at a reasonable price.
- Although there is an apparent difference between the scientific and operations panel requirements relative to real-time data availability, how they are measured and the amounts or density of data versus time, it may be possible to meet both requirements with one approach. The high frequency data needed for the scientific process-oriented studies could be obtained by an accurate system and stored aboard the measurement platform for later retrieval, while selected averages of the data could be processed and transmitted to meet the real-time requirements for monitoring.
- The importance of spatial considerations in the horizontal was noted for climate monitoring, acoustic predictions and ranging techniques, and tracking of fishery species that are migratory in nature.

RECOMMENDATIONS

The workshop participants agreed on the following recommendations for required action:

- Since the development and implementation of automated systems for the measurement of ocean profiles are required, the approach should follow an evolutionary process. It should begin with a continued development, demonstration and use of a reliable, stable, discrete-level temperature/depth (pressure) measurement system. Salinity/conductivity measurement capabilities should be added to the system at an early date.
- Existing continuous vertical profiling systems should be thoroughly tested and evaluated to determine the technical and economic feasibility of continued development. Successful development of reliable, no maintenance ocean profiling components, such as a winch, stable probe and probe launcher will have spin-off applications throughout the marine community. These developments should be pursued in an orderly, phased manner.

WELCOME ADDRESS

JAMES W. WINCHESTER
DIRECTOR, NOAA DATA BUOY OFFICE

Good morning, Gentlemen!

I want to welcome you to NOAA's Data Buoy Office. Also, as a Californian turned Mississippian, I welcome you to our part of the country. I hope that you will find the workshop technically stimulating and your stay with us personally enjoyable.

If my staff or I can help you in any way, please call on us.

I am sure that you have received correspondence that stated the objectives of this workshop, but I would like to tell you what I hope will result from these meetings.

First, I would like to know if there are a sufficient number of users of temperature and salinity profiles from a fixed location in the deep ocean to justify undertaking an expensive developmental program.

Second, if there <u>are</u> a number of valid users, we need agreement on data requirements; in other words, to what depth, the number of data points per profile, frequency of observations, data format, accuracy, etc.

Third, I need some commitment from funding agencies that they will give both moral and financial support to the developmental program and to the procurement of systems if an operational profiling ocean sensor does, in fact, become a reality.

I think we must satisfy these objectives before we proceed with a significant developmental effort.

The Office of Naval Research and the National Science Foundation supported a developmental effort in the earlier days of NORPAX, but that effort did not produce an operational profiling ocean sensor. I believe the sensor's lifetime was only a matter of days.

Even though NDBO has the development of buoy technology for use by the entire marine science community as part of its mission, our present and projected budget levels will not permit us to assume the total responsibility for funding a program of this magnitude in view of other, higher NOAA priorities.

So if you conclude that a profiling ocean sensor is needed, some additional funding from agencies other than NOAA will be required. I would like to request that funding agency representatives in attendance give some thought to a jointly-funded developmental program during these discussions.

Also, if the development of an ocean profiling system is successful, I believe that I should point out to you some potential future funding problems in the procurement of operational buoys.

The addition of profiling ocean sensors will significantly increase both the acquisition and operational costs of buoys.

In the past, the most significant opposition to the use of buoys has been the high cost of acquisition, operations, and maintenance. We have made great progress in correcting that situation, so I want to avoid re-creating the same problem.

Based upon my experience of defending the buoy program in OMB, just moral support from outside NOAA is not enough to justify the procurement of very many deep ocean moored buoys.

OMB's position has been made clear to me; namely, the data user must pay at least some of the acquisition and maintenance costs. Other elements of NOAA are data users and they reimburse NDBO for buoy procurements. I am sure that increasing the acquisition costs will tend to create greater resistance from some people in NOAA to buying buoys.

In conclusion, I do not want to lead you down a primrose path. NDBO does not have an unlimited R&D budget, and OMB, in all probability, will not allow NOAA to procure large numbers of expensive buoys on the sole justification that there are many users of deep ocean temperature and salinity profiles.

Your requirements for a profiling ocean sensor may not be attainable unless you can commit some dollars to both the developmental program and the follow-on procurement.

Moral support of the buoy program is necessary, but not sufficient.

With these realistic considerations as guidelines, I'm sure we can work together in the next few days to come up with a consensus of what is really needed in the way of ocean profiling. We should state those requirements with enough detail so that the ocean engineers have a clear picture of what is necessary for an operational ocean profiling system if its development is justified. I believe that we can develop such realistic and detailed requirements.

I hope that you have a productive and enjoyable workshop.

Thank you, Gentlemen!

PRESENTATIONS OF ATTENDEES
(WITH DISCUSSIONS)

The following section contains the presentations, with questions and discussion, as presented by workshop attendees.

ENGINEERING POTENTIALS AND CONSIDERATIONS FOR OCEAN PROFILING FROM DATA BUOYS

R. H. Canada, G. W. Withee, NDBO, and L. S. Trest, Sperry Support Services, National Space Technology Laboratories, Bay St. Louis, Mississippi

Abstract. This paper presents engineering background material for the Ocean Profiling Workshop to be held on June 2-4, 1976, in Bay St. Louis, Mississippi. A recent survey of available SOA hardware for salinity and temperature profiling is provided. These systems all have problems when considering their use in remote unattended automatic data buoys. The problems are basically summarized as follows: insufficient reliability over a one-year duration, inability to accurately measure temperature and salinity over a year's time without recalibration, lack of a reliable unattended mechanism for lowering and raising sensors, and the need for excessive power. These problems and other considerations are detailed. Alternative approaches that have some promise are presented, but no real solutions are offered at this time. The forthcoming conference results on profiling requirements are expected to provide a basis for formulating a detailed and effective engineering approach.

Introduction - The history of the development of the physical dynamics and other aspects of oceanography is familiar to most. A chronology of this history and the evolvement of oceanographic measurement systems (Refs. 1,2,3) is depicted in Fig. 1. It is important to note the extent to which the development of instrumentation has followed the requirements of the data users.

The Bathythermograph, invented by Spilhaus in 1938, was the first automatic system to give continuous profiles of temperature versus depth in the upper ocean layers. The current generation of oceanographic instruments began appearing in the 1950's. These include the electrical bathythermograph (BT), thermistor strings, resistance element thermometers and inductive (electrodeless) conductivity sensors. A short time later, the more elaborate STD systems were developed which enabled fixed or continuous profile measurements. A new phase of oceanography also began in the 1950's when it became apparent that a great deal more data were required to meet the needs in developing the potential of the oceans. An effort was started to integrate the existing basic measuring instruments into self-contained automatic systems for long-term in situ operation. Since few resources were available for development, these systems in general were unsuccessful and did not provide the quantity or quality of data required.

In the late 1950's and early 1960's, to provide for the capability for acquisition of ocean data at a national level, large oceanographic ships and automated data buoys designed specifically for ocean exploration and research were constructed. It was at this time that the present developments began for oceanographic instrumentation, resulting in a number of sophisticated oceanographic data systems being rapidly developed and pressed into operational usage. It is appropriate, then, that the present day requirements in such important areas as ocean research, environmental modeling, development and conservation of natural resources, etc., of the oceans should provide the basis for development and application of future oceanographic instrumentation systems. However, these requirements must be realistically defined so that cost-effective technical decisions employing the latest engineering technology can be made.

The State-of-the-art in Ocean Profiling - In a 1973 survey (Ref. 4), accomplished by the Ocean Affairs Board of the National Academy of Sciences (NAS). some 18 "popular" STD systems were shown to be in use along with, of course, the traditional Nansen and, more recently, Niskin systems. Table I presents those STD instruments most widely used in 1973 and Table Ia presents some later STD systems in use or under development. In addition, many "one or two of a kind" systems were being developed and used by universities and laboratories around the country, such as the temperature profiler of C. S. Cox (Ref. 5) and the ocean profiler of J. Van Leer (Ref. 6).

All of these profiling systems work and certainly fulfill a purpose in gathering physical data from the world's oceans. However, because they were not developed for long-term, continuous, unattended, remote use, none of them fulfill the need for time-continuous and near vertical space-continuous profiling ocean data. This need had been established by two recent surveys (refs. 4 and 7). Both surveys showed that the majority of the user community has a definite and unfilled need for continuous ocean data sampled in both vertical and horizontal space. The data that were required on a regular basis were the ocean parameters of temperature, salinity, pressure, ocean current, and, to a lesser extent, sound velocity. These surveys also showed that the parameters measured by the STD were of greatest importance to the most users. Thus, the Ocean Profiling Workshop to be convened by NDBO and NSF in June 1976 and this paper concentrate just on the parameters of temperature and salinity.

Characteristic Design Considerations for Automated Ocean Profiling - As stated previously, the state-of-the-art in ocean profiling today, whether accomplished with discrete level sensors or a lowered and raised sensor package, does not meet requirements for unattended use since the emphasis has been on measurements from ships and manned platforms. However, if continuous time series of profiles over many positions are desired, as indicated by previous user surveys, then shipboard techniques will not provide a cost-effective means of obtaining that data and the use of unattended platforms must be considered. The effectiveness of these, of course, will depend on whether or not an acceptable profiler can be developed for use on unattended platforms such as data buoys. The following discussion will provide a more in-depth understanding of the problems involved.

Table II gives some of the relationships between engineering design parameters and user requirements. Many of these engineering design parameters have, no doubt, been considered by present SOA profiling manufacturers; however, the requirements that govern the designs for shipboard systems are not the same as for automated, unattended systems. For example, the maintenance-free deployment period requirements under present consideration are for one year. This long-term requirement impacts almost every design parameter listed, and yet has not been a major consideration or requirement of designers of SOA profiling equipment.

While the primary considerations in the requirements directly affect a substantial number of engineering design factors, related requirements also interact with each other to affect engineering decisions. For example, the deployment vehicle itself interacts with many engineering requirements. This vehicle could be a wave surface follower, impacting motion of the profiling sensor package; it could be a subsurface float making retrieval difficult; or it could be a stationary platform which is large and expensive.

When considering the requirements for ocean profiling data, it is important to weigh the value of the data to be acquired against the costs of obtaining it. The value might seem to justify almost any cost; however, the available budget may dictate a compromise on costs. It is a generally accepted proposition that the more severe the requirements, particularly in terms of data precision, reliability and data timeliness, the higher are the costs. How well these factors in the requirements are met is essentially a function of the quality of the development, engineering, and production efforts expended. Even if we can assume an almost perfect design of an ocean profiler, we find that there are still factors which we have not learned to control, and are peculiar to the environment being measured, that sometimes affect the results in an undesirable way. These factors must be considered along with the engineering aspects and the costs when setting overall requirements for ocean profiling data.

Potential Profiling Techniques - Several techniques have been proposed as possible candidates for unattended, automatic ocean profiling. Some of the techniques which may be operated from an unmanned data buoy are shown in Figure 2. The presentation of these measurement techniques and considerations is not intended in any way to bias, from an engineering sense, the establishment of realistic user requirements.

The first concept utilizes the method of fixed or discrete level sensors employed on a multiple conductor electrical cable. To prevent entanglement, the sensors and electrical cable are either attached to the buoy mooring line or are an integral part of the mooring line. A thermistor string such as is used on NDBO's Prototype Environmental Buoys (Figure 3) is an example of this type system. The greatest problems are associated with deployment and retrieval operations, broken electrical wires, and some uncertainty of thermistor depths.

Another concept for measuring temperature profiles is the Multiple Moving Sensors concept in which a relatively close spacing between sensors is maintained and the complete system is periodically moved up and down to cover the total vertical column being measured. This technique, called the Limited Excursion Thermistor String (LETS), has inherent mechanical problems that would be exceedingly difficult to solve, and is therefore considered to be an approach of last resort.

The "rabbit" concept is well known and consists of a single sensor package supported on a taut mooring cable or wire. The sensor is programmed to travel up and down the mooring at a constant rate by controlling a variable buoyancy device utilizing a gas. One such instrument in use is the Cyclesonde under development for NDBO by the Rosenthiel Oceanographic Laboratory, University of Miami. NDBO is investigating the use of the gas from a seawater battery for movement of such a device in the vertical. The Naval Research Laboratory is developing a Moored Environmental Profiler (MEP) which also uses the "rabbit" concept (Ref. 9).

The wire XBT concept uses a standard expendable XBT which is wired to an onboard data system during the descent for data acquisition, and separates from the buoy when it has reached the lower limit. In order to adapt it for unmanned data buoy applications, a launcher, loading and storing device, and data interfaces would have to be provided. It would be programmed to launch an XBT at planned time intervals.

The acoustic XBT concept is similar to the wire XBT application except the data taken during descent is transmitted acoustically to the data buoy for receipt and processing. A hydrophone and equipment similar to that needed for a wire XBT are required to operate on the data buoy.

A Profiling Ocean Sensor (POS) is another method of ocean profiling which uses a single non-expendable sensor connected by electrical cable to a data processor on the data buoy. The system uses a deck-mounted automatic real system much like a spinning-type fishing reel. The sensor cable is paid out freely during the sensor descent and is then reeled in slowly at a nearly constant rate during ascent. A profiling oceanographic sensor was developed by General Dynamics under NSF and ONR funding (Refs. 10 and 11). It uses a specially designed hydrodynamic transducer housing which contains a platinum-wire thermometer, a strain gage type pressure transducer, and associated signal processing components. During free-fall to its limiting depth, the sensor drops at approximately 2.5 meters per second. Temperature and pressure data are sampled and digitized within the sensor at the rate of one data sample for each 4 centimeters of depth. The accuracy of temperature data over the range of 0 to 30°C is ± 0.034°C. The accuracy of pressure data over the range from 0 to 33 bars is ± 0.04 bar. Both temperature and pressure data are communicated to the surface through a signal cable that also serves as the means for returning the sensor to the winch mechanism within the buoy hull. The winch consists of an articulated spool with its axis vertical during sensor deployment to permit the cable to freely spool as the sensor falls. This configuration effectively decouples the falling sensor from any surface motions at the winch support. For the retrieve cycle, the winch spool is rotated until its axis is horizontal, after which the sensor cable is wound onto the spool by a motor drive. A complete drop-and-retrieve cycle requires approximately 5 minutes. The POS system has been deployed previously, but experienced consistent mechanical failures including loss of probes. The system did provide good data, but lasted only a few days. Figure 4 is a sample of the data obtained from the POS.

The system characteristics for each of these profiling concepts are tabulated in Table III. The table also lists NDBO's evaluation of the development status and some of the operational characteristics, design considerations, and projected costs of these systems.

Conclusion - The profiling systems on the market today have been designed for shipboard or manned platform use and therefore do not meet all of the stringent requirements for use on unattended, remote, automatic platforms. There are several promising techniques for profiling from unmanned platforms but, obviously, a good deal of effort is needed in this area, both to synthesize data requirements for ocean profilers and to concentrate on the engineering design of unmanned profilers to meet these requirements.

Our experience has shown that some of the more difficult engineering problems result from the effects inherent in the environment being measured and the use of the measurement techniques selected. Some examples of these effects are the natural environmental variability of the measured parameters, the unpredictability of surface and near-surface conditions which imparts motion errors and unavoidable averaging of the measurements, and the physical configuration of sensors that may be dictated by some of the requirements and, as a result, is not optimum for other requirements. To insure a proper approach in the engineering design, all of these factors need to be considered, and the requirements defined accordingly.

Historically, oceanographic measuring instruments have been developed based on the needs of man to acquire more and better information of the environment. To insure the continuing availability of high quality instruments at reasonable costs, detailed but realistic requirements are essential. Therefore, the next phase vertical-profiling ocean systems should be limited to realistic and realizable performance goals with room allowed for growth. The performance of later generation systems could then be increased to meet desired goals based on the experience accumulated with the initial systems.

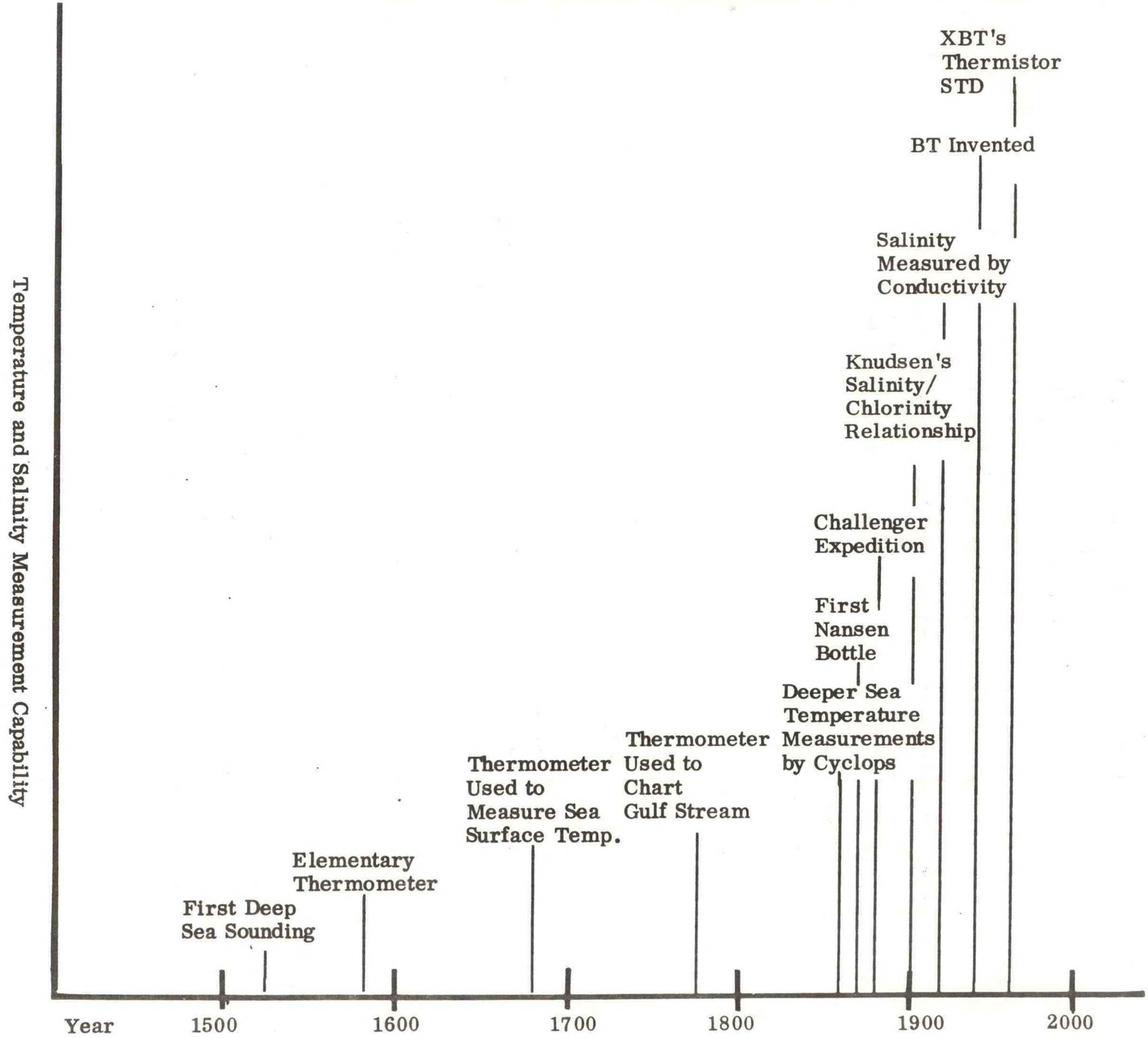

Figure 1. Development of Temperature and Salinity Instrumentation.

Table I. Typical STD Systems in Use in 1973. (From Continuously Sampled Oceanographic Data, Reference 4)

Manufacturer	Model
Plessey	9006
Plessey	9007
Plessey	9040
Plessey	9060
Plessey	9070
Guildline	8101A
Howaldt Bathysonde	T81
EG&G	775-24
Martek Instrument	Mark I
Tsurumi Precision	Model III
Beckman	R55
Hydrolab	TM70
Inst. Oceanol. Akad. Sci., USSR	AIST-2
NUS	TR-4
Ocean Industries	-
Ramsay	SVTD
WHOI/Neil Brown	#2
Yellow Springs Inst.	33

Table Ia. Some Later STD Systems in Use or Under Development.

Manufacturer	Model
Plessey/Sippican (XSTD)	9090
Guideline (CTD)	8700
Martek Instruments (CTD-WQMS)	MK 3
Beckman (CTD)	RS 6
Beckman (Sal.)	RS 7-B
Ocean Data (CTD-WQMS)	101 A
NuSonics (C/SV/TD)	1641
NuSonics (CTD/SV)	3200-3004-170
Rosenthiel (CTD/CM)	Cyclesonde MK II
InterOcean Systems (C/S/T/D)	660

Table II. Effect of Requirements on Engineering Design Parameters.

Engineering Design Parameters	Requirements: Deployment Period	Vertical Resolution	Temporal Resolution	Sampling Rate	System Accuracy	Depth Desired	Data Format	Data Availability
Depth Capability	X	X	X		X	X		
System Time Constants		X	X	X				
Static Accuracy			X		X		X	
Dynamic Accuracy		X	X		X		X	
Deployment Vehicle	X			X			X	X
Vehicle and Probe Stability	X				X			
Deployment Method	X	X	X	X	X	X		
Ascent/Descent Rate	X	X	X	X				X
Sensor Housing Design	X	X	X					X
Energy Requirements	X			X		X		X
Fouling	X				X			
Analog or Digital Electronic Conditioning		X	X	X	X		X	X
Reliability	X							

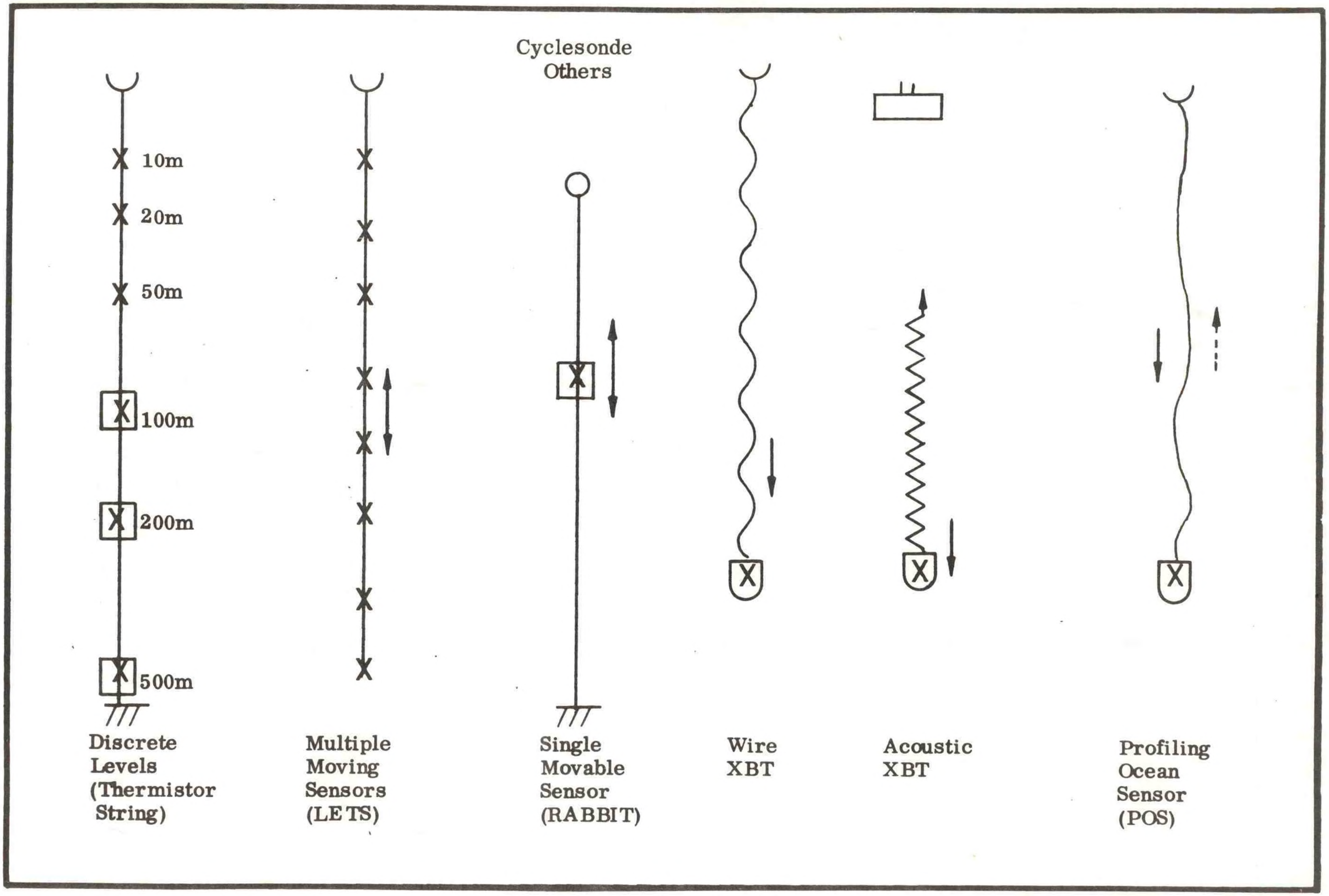

Figure 2. Ocean Temperature Profiling Techniques.

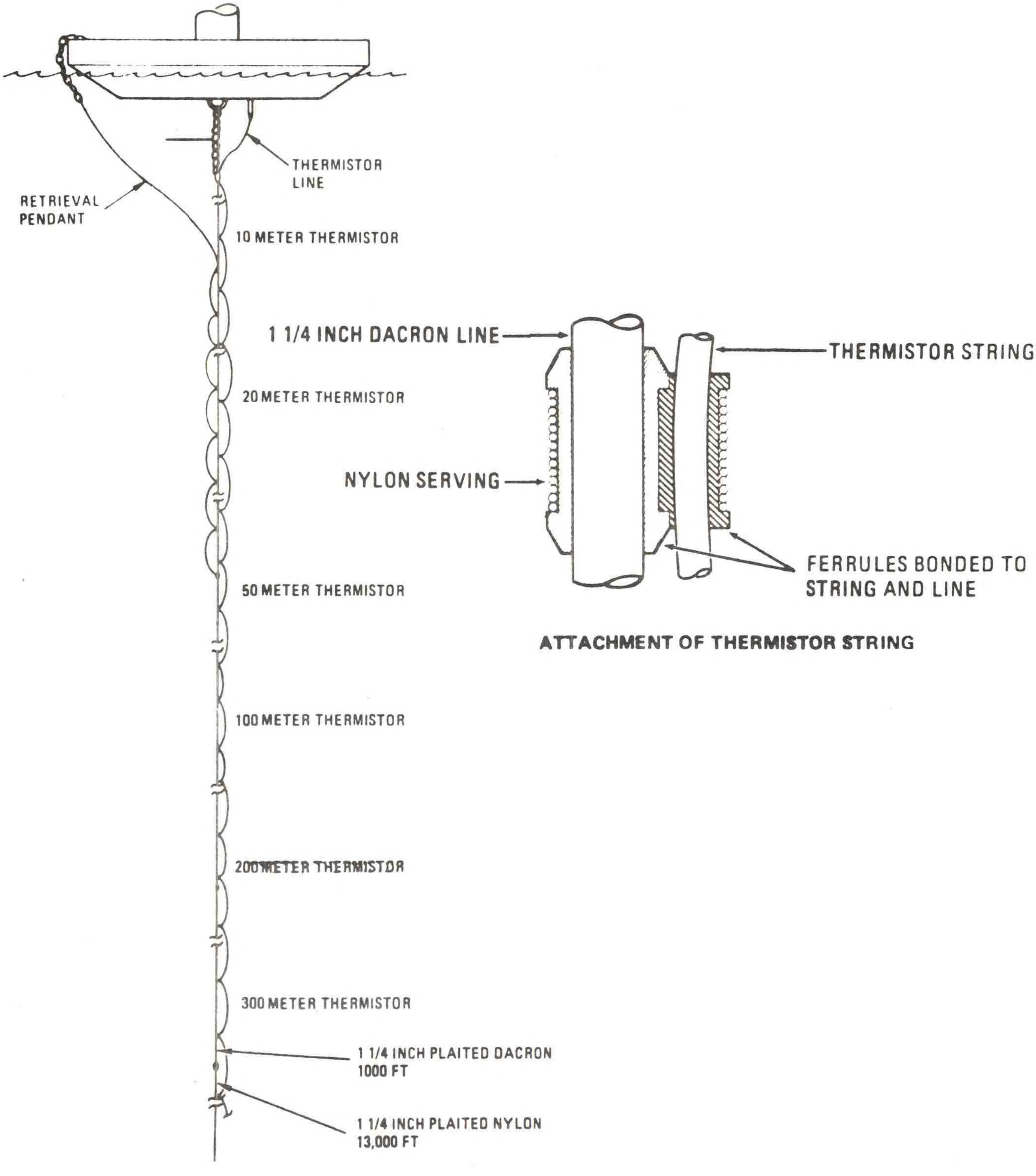

Figure 3. PEB Thermistor String Installation.

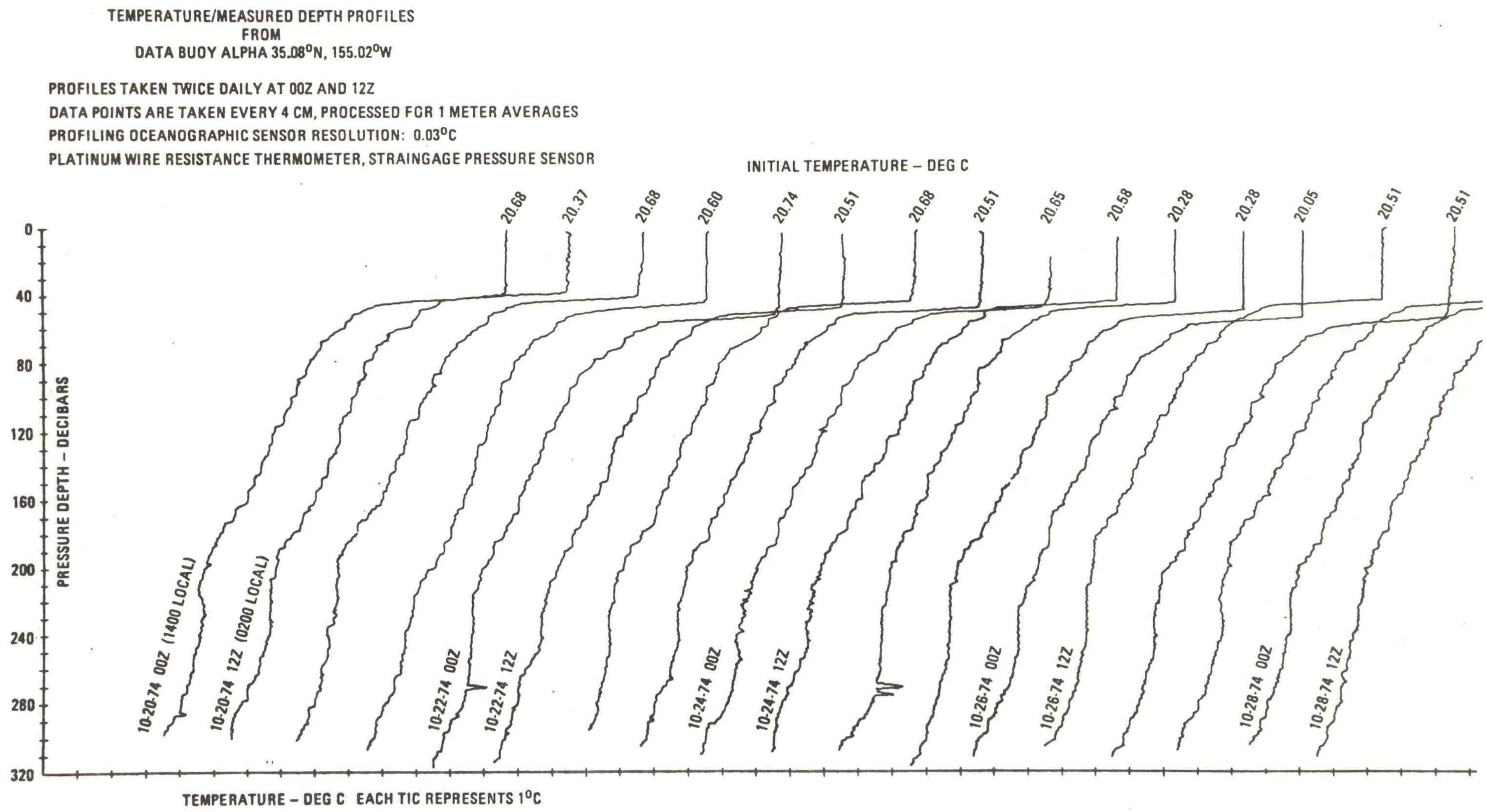

Figure 4. Typical Temperature/Depth Profiles.

Table III. System Characteristics of Potential Unattended Ocean Profilers.

Category	Thermistor String	Limited Excursion Temperature System	RABBIT	Wire XBT	Acoustic XBT	Profiling Ocean Sensor
Development Status	Developed; reliability improvements needed	Motion generator to be developed	In development; long-term gas generator needed	Platform launcher and receiver needed	Development needed	Development needed
Operational Status	Used on buoys and fixed platforms	T&E of line planned	Under field T&E by NRL	Used in manned applications	Pre-prototype hardware for T&E	T&E results show significant engineering problems
Data Accuracy	0.37°C (PEB)	0.37°C	Unknown	0.2°C	0.2-2.0°C	0.02-0.1°C
Data Reliability	High	High	Dependent on transmission scheme	High	Dependent on transmission scheme	High Potential

Table III. System Characteristics of Potential Unattended Ocean Profilers (Contd).

Category	Thermistor String	Limited Excursion Temperature System	RABBIT	Wire XBT	Acoustic XBT	Profiling Ocean Sensor
Power Requirements	Minimal	Approximately 25 watt-hours per profile	Dependent on transmission scheme	Dependent on launch mechanism	Dependent on launch mechanism	Approximately 25 watt-hours per profile
Design Considerations	Depth location of thermistors	Depth location of thermistors	Gas supply limits life	Expendable; limited storage capacity	Expendable; limited storage capacity	Past cable failures and loss of probes
	Attached to mooring to eliminate entanglement	Mooring entanglement	Hangs up on line	Mooring entangelements and damage	No entanglement anticipated	Mooring entanglements
	Launch/ retrieval complications	Cable wear and tear	Requires taut mooring	Wire ejection	Multi-path and acoustic noise	Cable torquing
	In situ replacement difficult	Mechanical complexity for vertical oscillation	Retrieval of data	Mechanical complexity of loading and launching	Mechanical complexity of loading and launching	Reliability of winch operation
	Number of thermistors required	Launch/ retrieval complications	Launch/ retrieval complications	Electrical continuity on the buoy	Hydrophone location	Electrical continuity through the mechanical system
		Number of thermistors required	In situ replacement difficult		Probe hydrodynamics	Probe hydrodynamics
			Lifetime limitations		In situ servicing of hydrophone difficult	LRU weights critical to in situ replacement

Table III. System Characteristics of Potential Unattended Ocean Profilers (Contd).

Category	Thermistor String	Limited Excursion Temperature System	RABBIT	Wire XBT	Acoustic XBT	Profiling Ocean Sensor
Developmental Costs	Nominal (improvements only)	Approximately 75K — 125K	Unknown	100K — 200K	150K — 300K	500K — 1000K
Operational Costs (excluding maintenance)						
Non-recurring	Approximately 10K	Approximately 25K	Unknown	Approximately 50K	Approximately 60K	Approximately 50K (TD) 60K (CTD)
Expendables	-0-	-0-	Unknown	Approximately $18 per profile	$25 — $100 per profile	-0-

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QUESTIONS AND DISCUSSION

Dr. AUSTIN: From the point of view of the National Marine Fisheries Service, at least, we'd love to put XBT launchers on every single fishing boat in the United States. Right now the tuna fleets in the eastern tropical Pacific are using them.

Mr. CANADA: During our survey, some people in Fisheries expressed concern about damage to the nets.

Dr. AUSTIN: They were probably referring to the plankton nets, which have a very fine mesh and are sort of fragile. But even then, I know I've caught XBT's in plankton nets and didn't damage them. Maybe they misunderstood the question.

Dr. FLITTNER: They are in extensive use in the Pacific and have been for nearly a decade. So that's a key point, that there is a valid application that is time-tested.

Dr. AUSTIN: The National Marine Fisheries Service is primarily interested in data from the areas where fishing is being conducted. So we consider ships of opportunity and the fishing fleet in combination of key importance to our operations.

Mr. LANDIS: *Do you know what it would cost for the fixed or discrete level systems, but with a salinity sensor added?*

Mr. CANADA: We have not looked closely at salinity. Our efforts have been concentrated on solving the electrical conductor problems. We are looking at adding pressure to our existing thermistor strings. Our approach has been to solve temperature and depth applications from a buoy first, and then add salinity. We will be looking at salinity measurements downstream. However, a lot will depend on what this workshop says about the need for salinity measurements.

DR. WYRTKI: *Who makes the requirements to get temperature, and why was pressure not included?*

MR. WINCHESTER: I don't think there was ever a requirement saying we don't need pressure for depth measurements. When we went with the Prototype Environmental Buoy, it was an experimental development program, and the first thing we wanted to try to show was whether or not we could actually get temperatures from a buoy thermistor line. It was, "Let's do the best we can from an experimental point of view and still keep the cost down," because we were running into all kinds of problems of cost creeping up. NDBO's operational measurement requirements are established by NOAA's Office of Environmental Monitoring and Prediction after coordination with all users and using the results of workshops such as this one.

MR. CANADA: In 1972, NDBO contracted with Arthur D. Little, Inc., for a user survey on vertical profiling. The results of this survey are documented in their report titled, "Performance Characteristics for an Ocean Data Vertical Profiling System." This workshop should re-evaluate the results of the A. D. Little survey during the panel meetings.

Answers to some fundamental questions are also needed. "What is the need for a fixed point, time series, subsurface temperature data?" Some people have questioned the value of fixed point data relative to good spatial coverage where you use aircraft or ships for monitoring. The need for an actual profile, like an XBT drop versus discrete level monitoring, should be addressed. There are some significant cost differences in those approaches. Please address these questions during your deliberations.

NDBO's approach on the Prototype Environmental Buoy is to marry the thermistor string to the mooring system and thereby avoid entanglement that could cause a failure in the main strength member. Ferrules are molded on both the main mooring line and the thermistor string. The ferrules on the two lines are then mated, served with nylon, and taped. The thermistor string on EB-16 failed and was retrieved in May. The amount of mooring line elongation was miscalculated, causing a high tension in the thermistor string. As a result, many of the ferrules were sheared off and multiple copper conductor failures were experienced. We believe our redesign will eliminate the majority of the problems. The Prototype buoy measures water temperature at the surface and depths of 10, 20, 50, 100, 200, and 300 meters. NDBO is planning to add at least one pressure sensor.

MR. WINCHESTER: We must reiterate that the thermistor chain has not worked satisfactorily in an operational configuration thus far. We got about 4 or 5 months' operation from it, which isn't enough to call it an operational system.

DR. BAKER: *Do you have any development going on in terms of the moorings themselves; trying to make moorings last a long time, as opposed to the sensors themselves?*

MR. CANADA: We are doing very well on moorings. Our large buoy moorings have lasted in excess of 3 years. The smaller buoy moorings have lasted well in excess of a year. Normally, the projects using smaller buoys end after a year and are retrieved. There would be no reason structurally why they could not have stayed on station longer.

We do have an ongoing program to evaluate new materials and applications, but we feel quite confident that we can deploy a buoy for at least 3 years without having to retrieve the mooring, and we're shooting for 5 years. We are now leaving the mooring down and putting new buoys on the existing mooring. We think that mooring designs are well within the state-of-the-art.

DR. BAKER: *What about the person interested just in making profiles from drifting buoys?*

MR. WINCHESTER: That's part of our overall plan.

MR. CANADA: We have some developments to suspend thermistor strings from drifting buoys. On drougued drifters, we plan to use the strength member between the drogue and the buoy to provide a discrete level monitoring of temperature. Continuous profiles would not be cost effective and probably not feasible from drifters. The small drifters just don't have the storage capacity. While drifter requirements can be mentioned, and included, the primary interest of this workshop is moored buoys.

MR. WINCHESTER: Also discuss the need for a continuous profile versus discrete levels. Because even on the moored buoys, we are pursuing discrete level measurement of temperature using a thermistor chain. We talk now about whether you need something more specific than that; in effect, a larger number of data points on a profile.

MR. DISHON: *Do you have development plans for surface wind field measurements at the same time that you measure the ocean temperature?*

MR. WINCHESTER: We measure wind speed and wind direction now from essentially all our buoys. On the large buoys, it's at a 10-meter height and on the smaller ones, it's down at 5 meters.

MR. CANADA: On our existing buoys, we measure wind speed and direction, barometric pressure, air temperature, sea surface temperature, and wave spectra. We are developing a wave directional spectra sensor, but we are not forecasting when that problem will be solved. Our buoys acquire more data than just temperature and salinity.

MR. WINCHESTER: We have been quite successful in acquiring one-dimensional wave spectra.

MR. HOLBROOK: *What limitations do you have on the number of sensors you can tie in to the thermistor chains?*

MR. CANADA: The major limitation is data capacity in the processing system.

MR. HOLBROOK: *You can process, then, more than 5 levels of thermistor data?*

MR. CANADA: We have a 32-channel, hard-wired system on the prototype buoy. We are developing some more flexible systems using microprocessors to give us more flexibility to accomodate changes. When NDBO's existing programs were started, the cheapest approach was the hard-wired processors. We were going for very low power, which was then represented mostly by CMOS technology. But one of the big disadvantages of going to a hard-wired system is that a change in requirements or the need for more data capacity forces a redesign of the whole package. It's not just a simple wiring change. You have to change the connectors and cables and modify the package; that becomes a significant cost factor. So we are trying to adjust to get more flexibility through the use of microprocessors to accomodate any profilers or any increased data capacity required for discrete level monitoring.

COMMANDER TATRO: *So it would be a fairly significant increase in cost if you went to conductivity and depth sensor probes as well as temperature sensors at fixed depths?*

MR. CANADA: We are projecting overall system cost savings. One of the big things we are doing now is a phase-over program from HF communications to UHF communications. This gives us a significant cost savings. Deletion of the HF antennas also allows savings in the hull construction cost. A reliable HF system to cover the various frequency spectrums that are needed to accommodate atmospheric variability costs approximately $60,000 per buoy. Once UHF is fully operational, communication costs will be in the order of ten or eleven thousan dollars, with a flexible interrogate command structure. UHF costs should be five thousand or less for self-initiate only. Costs for adding data capacity after development can be absorbed by the communication cost savings. If approached properly and using microprocessor technology, greater flexibility can be achieved without having significant cost increases. Today's electronics technology is not all that expensive. One of the biggest cost items is the packaging and cables.

DR. WYRTKI: *What problem would you see putting perhaps a hundred thermistors on a string?*

MR. CANADA: That many starts to press the allowable message length. You would have to re-examine the data processing approach to stay within the allowable message length. More sophisticated data compaction techniques would probably be required on the buoy and at the shore data collection station.

DR. FLITTNER: *The issue of message length is a serious one, especially in dealing with cooperative ship platforms which have to be another part of the mix of instrumentation on the high seas. How heavily have you delved into the message length, data compaction problem in engineering your buoys systems?*

MR. CANADA: Each time we go into it, we address that problem. We are in continuing discussions with the National Environmental Satellite Service on command repertoires, message length, clock stability, because as they expand and make changes we must stay compatible. The GOES is our primary UHF communications link, although we do use other satellites for more limited applications. They have been very cooperative in accommodating our needs. But it's only been in about the last 3 months that we reached enough definition to address the problem very well. It's not just message length that is a problem. Clock stability is a problem. As you have the number of users go up, you can accommodate less and less drift. As a result, we asked NESS for somewhat limited interrogate capability for these buoys. Rather than having expensive clock systems on the buoy, it may be cheaper to reset remotely. We have that capability on our existing systems. Those systems are HF/UHF, dual mode operation, which adds significantly to their cost.

DR. MERRILL: *If you went out for a large buy, you say these 10-meter buoys could be as cheap as maybe two hundred thousand, somewhere in that area. What do you get for that? Do you get the standard met package that you developed?*

MR. WINCHESTER: What you'd get for that would be the wind direction, wind speed, barometric pressure, air temperature, sea water temperature, one-dimensional wave spectra, and hopefully subsurface temperatures, some number of discrete levels. Our lifetime for the thermistor chain now has been about 4 to 5 months, but hopefully we will improve. So that's what you would get.

DR. MERRILL: Cost has come way down since last time!

MR. CANADA: When we started in 1970 we were talking $750,000 to $1,000,000 per station. And we're trying to grind that down significantly. A lot depends on what the application is.

OCEAN PROFILING NEEDS OF NORDA

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Introduction - The research efforts at the Naval Ocean Research and Development Activity will strive for results that contribute to the effectiveness of Naval operations. To fulfill this mission, knowledge of certain oceanic conditions is required in advance in order to make predictions. Consequently, emphasis is placed on theoretical and numerical modeling in order to develop prediction techniques of various physical conditions. This effort also includes research to expand knowledge on the behavior of various parameters that the mathematical models use so that prediction systems can be tuned to correspond more closely to physical reality in both time and space.

In the subsurface layers, since water masses are of limited horizontal dimensions, the initial models may most conveniently be done for the basic water masses. However, the boundaries between water masses are not lines, but are zones or areas. Knowledge about the physics of boundary layer processes, distribution and variation of the boundaries, and the formation and dissipation of submasses as a result of interaction between water masses are examples of conditions on which prediction effectiveness will depend to a rather large extent.

Profiling Applicability - Subsurface data are sparse in most of the ocean areas. However, specific interests in certain regions require larger number of observations than in others. A few illustrations may summarize the nature of the effort for which extensive profiling might be necessary.

Figure 1 shows temperature and salinity profiles about 600 miles west of Ireland. The water mass of the upper layers at this location is rather simple. If there is sufficient information on the geographical extent of the water mass, seasonal variability of physical properties, causes and periodicity of eventual thermal anomalies, mean flow, variations of velocity field, internal waves, and propagation downward of surface thermal conditions, then a satisfactory prediction system for the thermal regime may be worked out in the layers to about 400-500 m. The physical conditions may, however, be considerably more complex. Figure 2 shows another profile also west of Ireland but about 300 miles to the north of the first one. Here we have evidence of boundary type activity between the depths of 100 m and about 400 m. Amplitudes of vertical temperature perturbations exceed one degree centigrade and vertical sound velocity perturbations exceed four m/sec, which is about four to five times larger than the change in the surface mixed layer of about 40 m thickness. Such vertical perturbations normally occur within the interaction space between two water masses in the main thermocline. There may be a question whether such perturbations occur frequently enough to worry about while attempting to work out prediction systems. It appears, however, that the region in the upper layers with boundary type processes is not negligible.

An example of the horizontal distribution of vertical perturbation amplitudes is shown in Figure 3 in depth layer between 660 and 780 m west of the Iberian

Peninsula and Northern Africa to the Azores. Shallow Mediterranean water is often observed at these depths (see Howe and Tait 1972, Howe, Abdullah and Deetae, 1974). The perturbation amplitudes were determined by computing the coefficients of a Fourier series of temperature variations from the smoothed trace in the depth segment of 120 m. The contours of amplitude summation for four wave lengths show two major zones with significant temperature perturbation amplitudes. A value of ten in this summation is obtained when the vertical perturbations show well marked temperature inversions. Contours of 15 (dashed) and higher values indicate major interaction centers of the water masses.

Figure 4 represents salinity distribution on the $\sigma_t = 27.4$ surface in the same area and at about the same layer as in Figure 3. The high salinity spreads northward and westward in various branches. Low salinity tongues penetrate the high salinity water mass along boundaries which are marked in Figure 3 by significant vertical thermal perturbation zones. The areas indicated by dotted lines represent high amplitude perturbation centers with values of 15 and more in the previous figure. An example of the resulting and participating water masses in such an interaction area is shown in Figure 5 by temperature salinity graphs extending through the 120 m layer. The opposing high and low salinity penetrations, represented at stations 38 and 30 respectively, result in an intermediate subwater mass in a high amplitude perturbation area around Station 22. Similar effects can be detected in other interaction centers although the proportions of participating water masses may vary. Figure 6 shows a time series of stations taken in the same general area off Ireland as the profiles shown in the first two figures. The first station of this presentation was taken on June 27, 1973 at 0352. Two days later the ship came back to the same location and took 11 profiles at approximately four-hour intervals. Vertical perturbations with the highest amplitudes occurred below 600 m and temperatures are shown between 660 m and 1140 m, contoured every 0.2°C. Dotted (cold water) and dashed (warm water) lines show thermal features that were not continuous in time at the location. Cold and warm water patches were being advected, lasting at times only between two lowerings, but frequently were evident for considerably longer. There seems to be a certain continuity between the whole series and the station data taken two days earlier. The water column in these layers is in a state of significant vertical perturbations. Temperature inversions exceeding 1°C occurred in about 30 m depth intervals at some layers. The perturbation features appear to have been constrained between thin layers of high vertical gradients. There may also be significant lateral gradients since the warm and cold features seem to be of rather limited horizontal dimensions.

This is the type of information that may be obtained with an ocean profiler deployed from a buoy or other platform, only in more detail if lowerings are more frequent. We also would be able to follow the processes for considerable periods of time and obtain information on the time change of these perturbations at the same location.

While time series profiling data is important in boundary process investigations, three-dimensional space information will also be needed that could be obtained by grouping two, three and more buoys in a selected region. Buoys, however, tend to be expensive; a very limited number of them might be made available for an investigation in one particular area. If profiling is needed to cover a limited area with many observations, some other complimentary profiling methods would have to be worked out, such as combining the buoys with ships and planes. Complimentary systems must, however, be of low price and usually low price does not go along with high quality.

A dense network of quasi-synoptic data would certainly be useful for some studies of boundary problems if a convenient and not too expensive system could be developed. Technically, it should not be too difficult to make a freely sinking, retrievable profiler that could be operated from a helicopter. Only a relatively simple mechanism of surfacing would be needed to combine it with any existing sensor package. The probe could be triggered to rise after reaching a certain pressure level. One helicopter operating with two such profilers could obtain 30-40 profiles in 12 hours within radar range of a ship.

Water mass boundaries are not confined to certain regions but are located throughout entire oceans. Therefore, associated problems may have different spatial dimensions. Information on boundary type processes may be of a scale that would show the general distribution of boundary type interactions at various depths of the upper layers, the extension of submasses that may form as a result of interaction, advection and mixing, or the constancy of boundary type interaction and the submass area.

On a smaller scale, the process itself has to be studied and understood. The entertainment of water patches into the velocity field, advection, dissipation, shear, stability distribution and variation across the inversions, step wise structure, changes along the advective distance of variance spectra, and the correlation between vertical temperature and salinity variations are all processes and results of a complex phenomenon.

The submasses that are formed in boundary type interactions may at times be predominantly warm or predominantly cold. Admixed to the surface by winter convective mixing, they may influence surface temperatures. Thus, the modeling of surface conditions may have to consider some subsurface effects. Time series data taken by ocean profiling in the upper layers will be needed for testing models and prediction systems.

But, profiling is also needed in relatively uniform water masses. Tangible effects of surface conditions can be traced to about 150 m. Now is the time to learn how surface information gained from remote sensors could be translated into subsurface structure data. The surface and subsurface relationship might include seasonal thermal variations, temperature anomalies, internal wave energy, upwelling and tidal effects on the mean flow.

Conclusions - Various investigations of the ocean require accurate instruments. The dependability and accuracy of profilers operated from the buoys could be countered, however, by adverse conditions such as extremely stormy weather, time drift of sensors, corrosion, biological growth, and others. It remains to be seen whether a satisfactory level of performance can be achieved, but in general, research efforts at the Naval Ocean Research and Development Activity should benefit from data that can be collected by automatic profilers from buoys.

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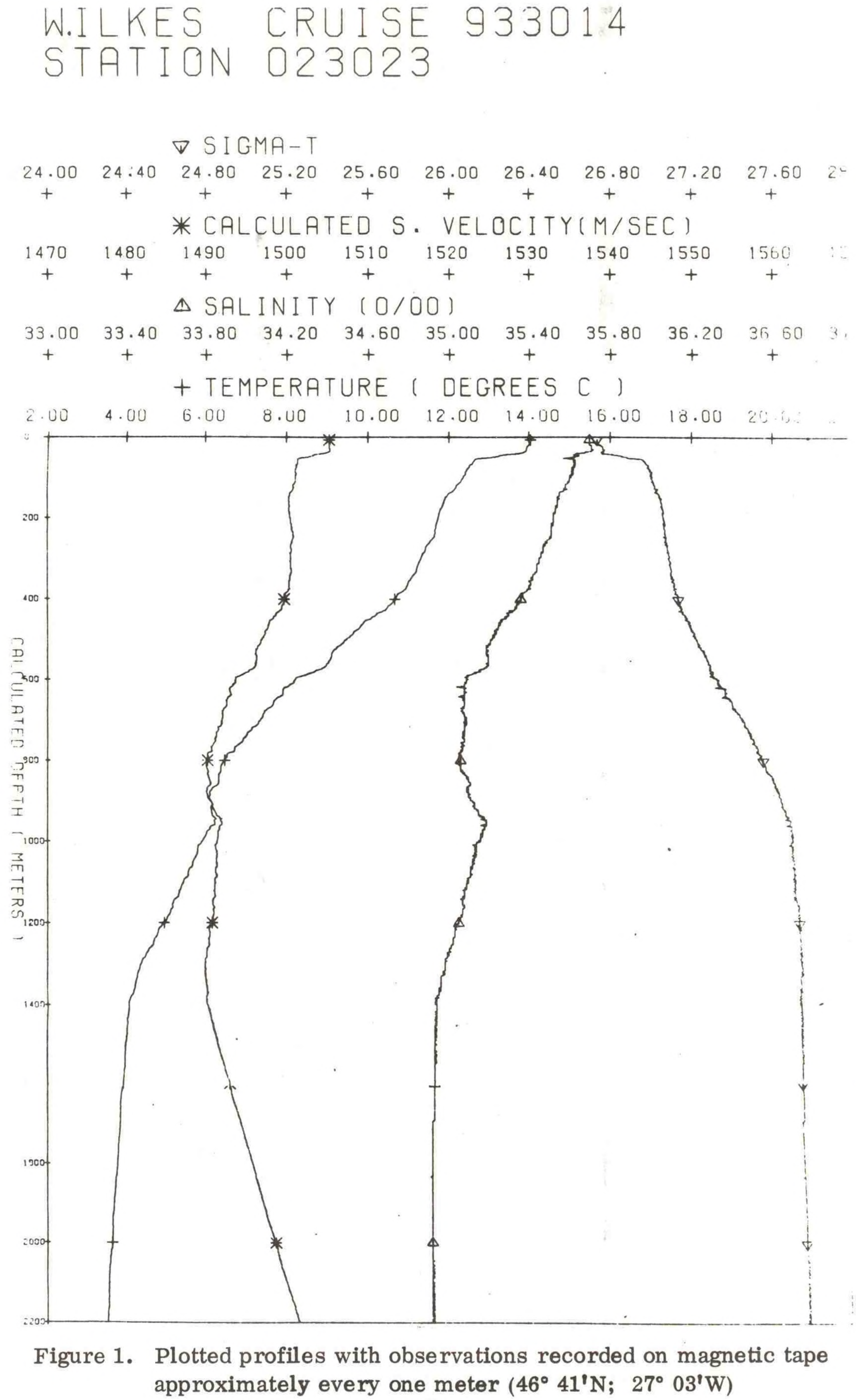

Figure 1. Plotted profiles with observations recorded on magnetic tape approximately every one meter (46° 41'N; 27° 03'W)

Figure 2. Plotted profiles with observations recorded on magnetic tape approximately every one meter (53° 00'N; 29° 37'W)

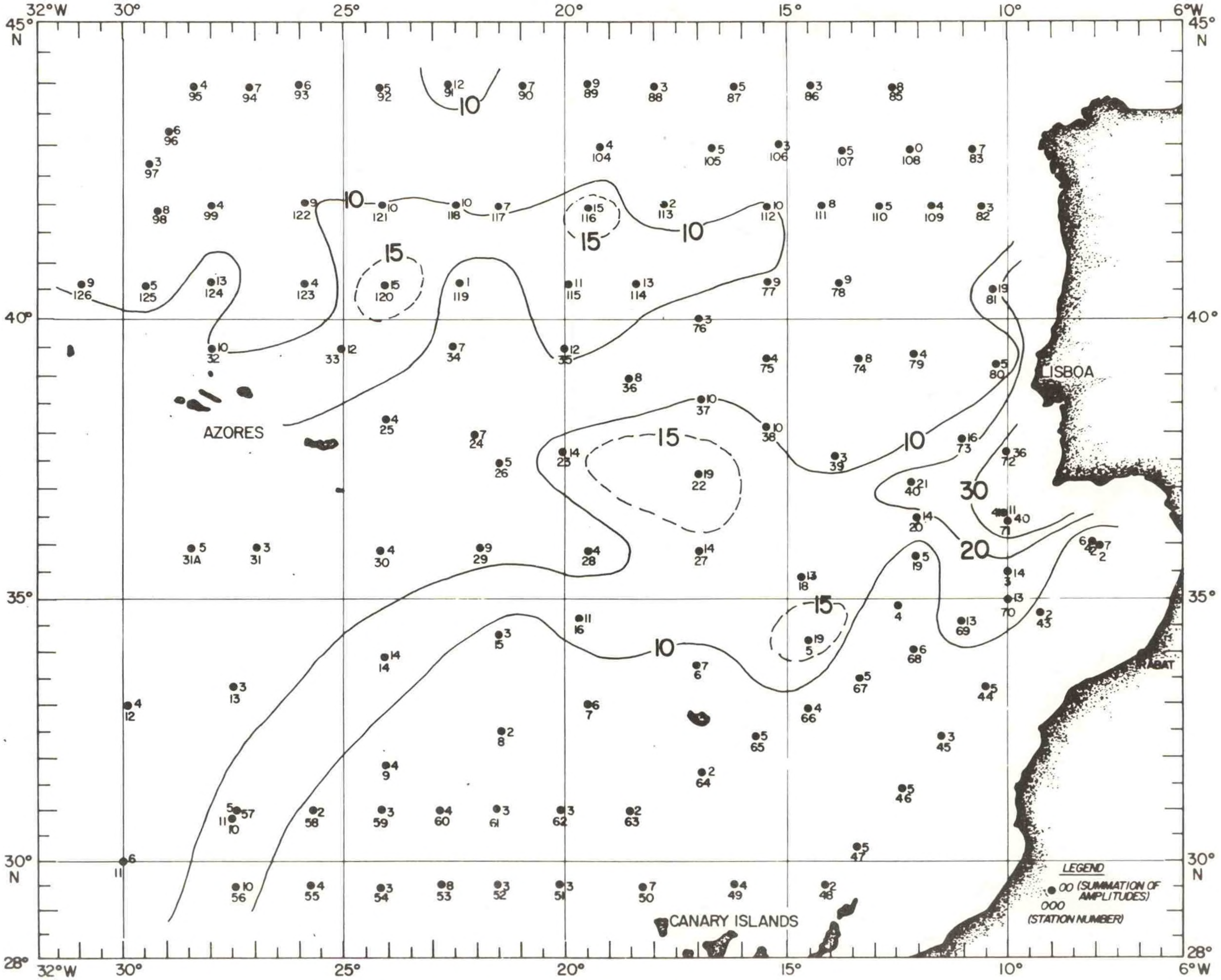

Figure 3. Distribution of vertical temperature perturbation amplitudes (amplitude summations for wave lengths of 20, 30, 40, and 60 m) in the depth interval of 660 to 780 m in °C$\times 10^2$. USNS Sands and USNS Kane, July, August, September 1971

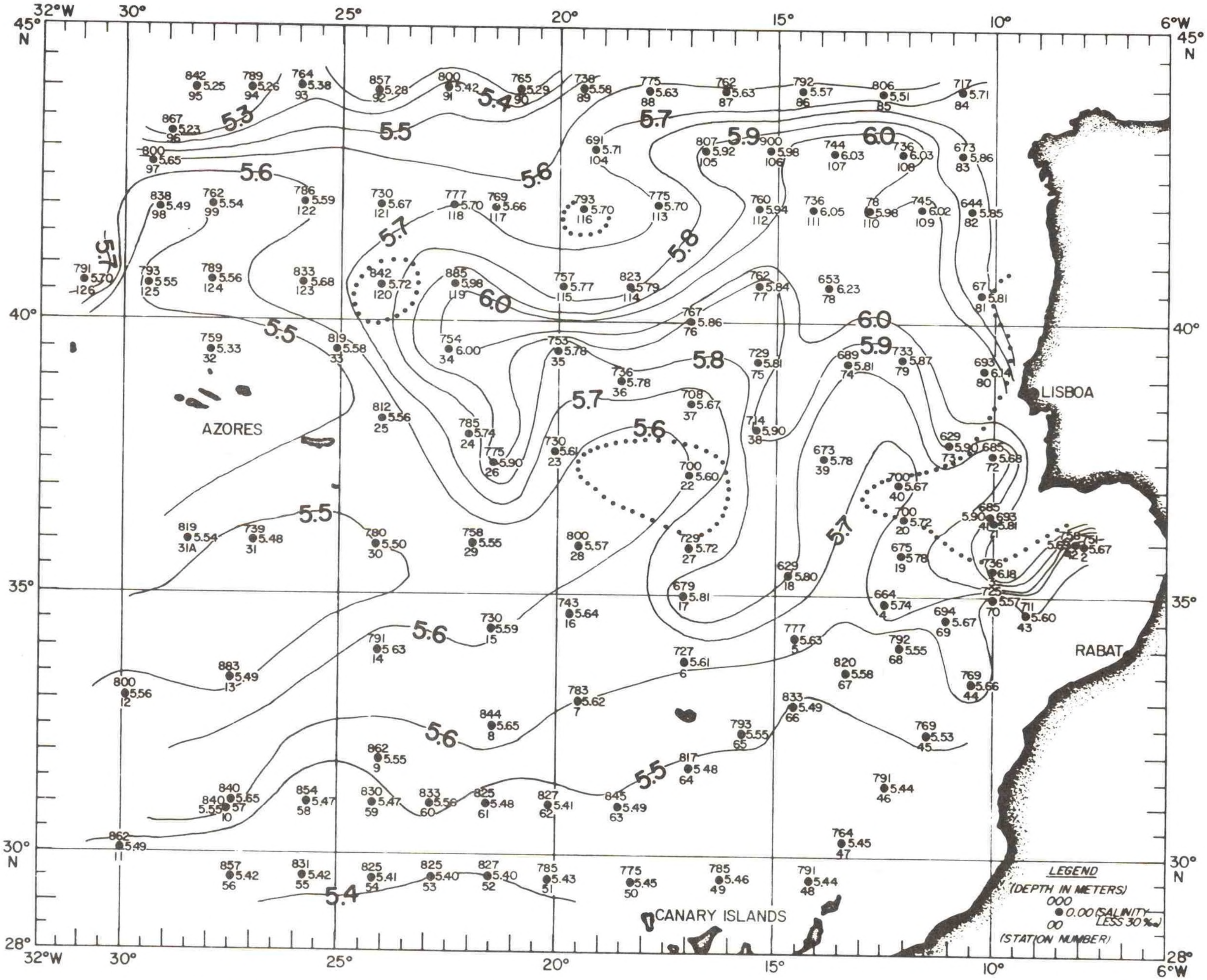

Figure 4. Salinity distribution on $\sigma t = 27.4$ surface. USNS Sands and USNS Kane, July, August, September 1971. (Dotted lines represent areas where amplitude summations exceed 15 in Figure 3)

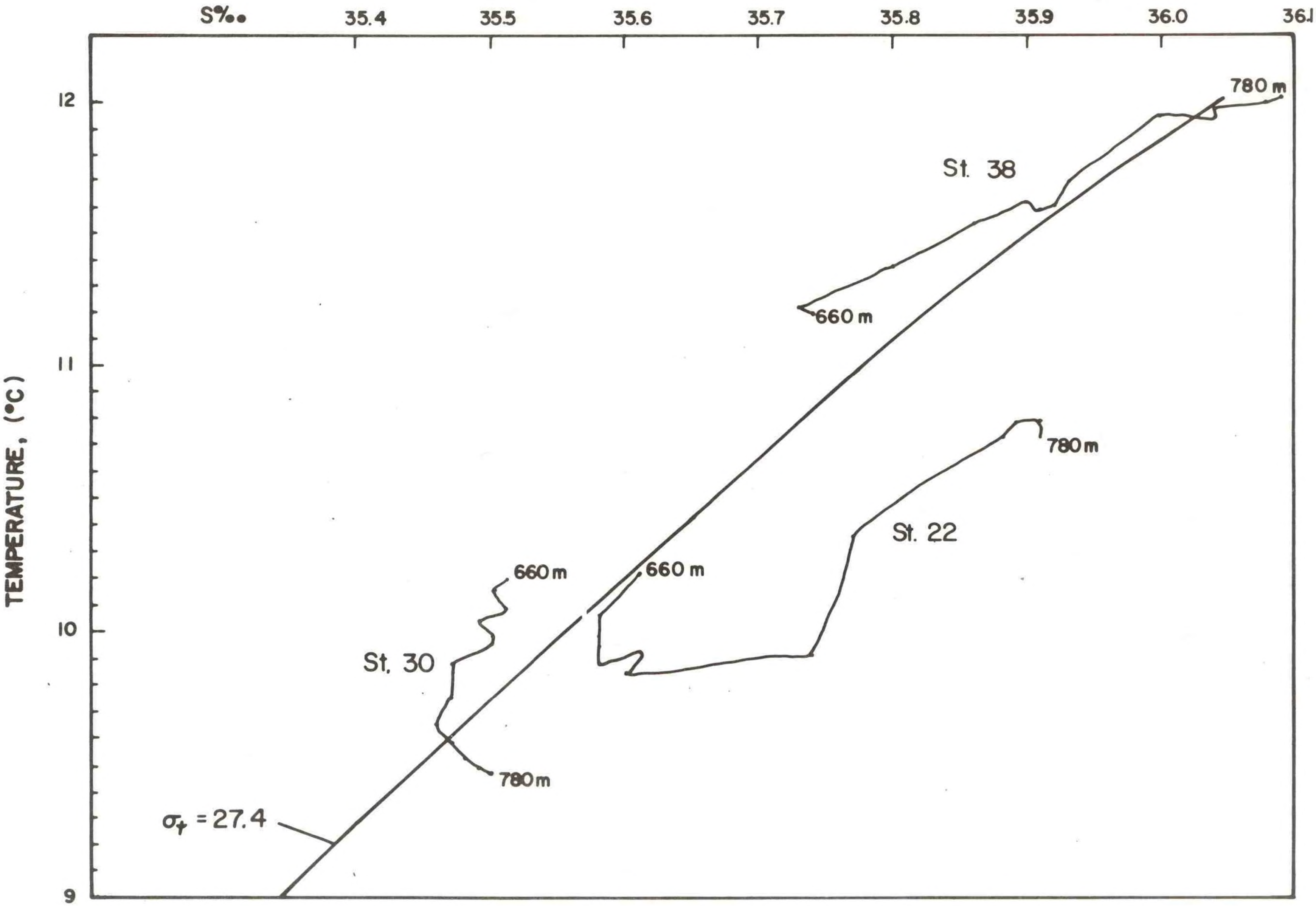

Figure 5. Temperature-salinity graphs for depth segment between 660 and 780 m at stations 38 and 30 corresponding to high and low salinity water masses that are intermixing in vertical perturbation area represented by station 22. USNS Kane, July, August, September 1971

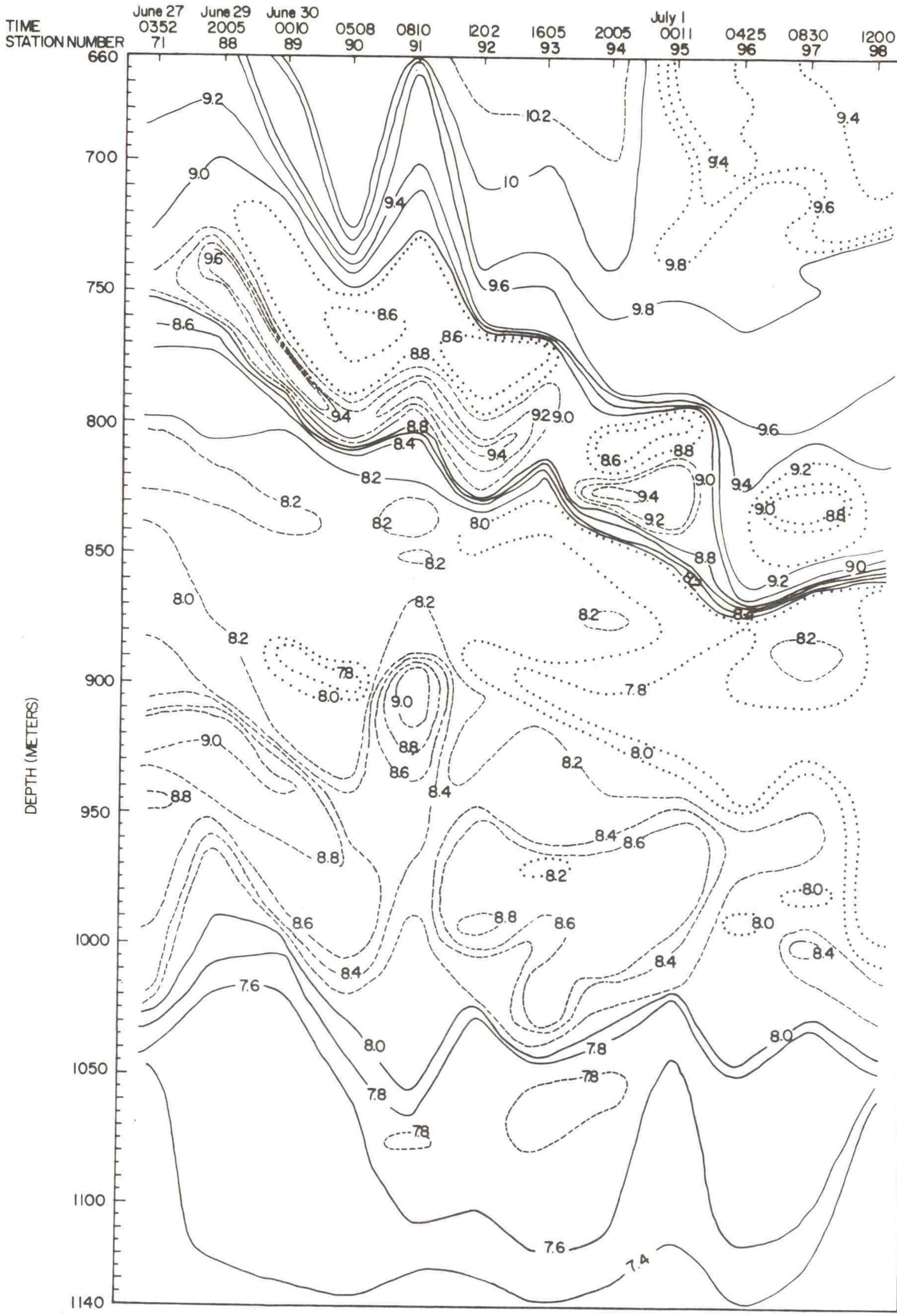

Figure 6. Vertical time distribution of temperatures. USNS Wilkes, June 27 - July 1, 1973 (50° 20'N; 16° 55'W) (dotted and dashed lines represent cold and warm water features)

THE USE OF VERTICAL PROFILING WITH A CTD IN THE STUDY OF NATURAL VARIABILITY IN THE OCEAN

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Abstract. A sampling is presented of the scientific and technical activities over the past four years using the W. H. O. I. /Brown CTD at Woods Hole Oceanographic Institution. The 1000 stations processed have demonstrated data quality equal to the best hydrographic techniques. The densely sampled vertical profiles of temperature, salinity, and recently oxygen can be used in the study of scales of variability from the general circulation, mesoscale eddies, internal waves, to small scale vertical mixing. Examples of these studies are presented from data collected principally in the western North Atlantic during the MODE and IWEX field programs. Applications of vertical profiling to the studies of the benthic boundary layer and sea surface temperature observations are illustrated. Recent data from the Antarctic Polar Front show large inversions in temperature, salinity, and dissolved oxygen characteristic of isentropic mixing.

Introduction - We will review some of the scientific activities at Woods Hole Oceanographic Institution involving a lowered CTD (conductivity-temperature-depth) developed at W. H. O. I. by Neil Brown. Over the past four years the instrument has been routinely used to collect over 1000 profiles of temperature, salinity and recently oxygen from North Atlantic, Mediterranean and Antarctic waters. The detailed vertical resolution and the accuracy of the data has made W. H. O. I. /Brown CTD a versatile instrument for studying scales of oceanic temperature and salinity variability from the water mass identification to fine structure analysis. Before describing the scientific activities, the instrument will be briefly reviewed.

Instrument - The W. H. O. I. /Brown CTD fish shown in figure 1 records 30 scans per second of pressure, temperature and conductivity to a resolution of .1 decibars, .0005°C and .001 mmho/cm respectively (Brown, 1974). These combine to yield a salinity resolution slightly greater than .001 ppt. Careful laboratory calibrations of the CTD sensors and monitoring of the conductivity sensor at sea are essential to obtaining hydrographic quality measurements of salinity, temperature and pressure. The methods of calibration, data handling and the performance we experienced during the MODE (Mid-Ocean Dynamics Experiment) field program are documented by Fofonoff, Hayes and Millard (1974). Conductivity was monitored against the stable N. A. D. W. O/S relationship shown in figure 2 and rosette water sample salinities. A histogram of salinity differences at various depths between calibrated CTD stations and simultaneously collected water samples is shown in figure 3. Conductivity cell factor adjustment took place between 3000 and 4000 meters. The mean error of all salinity comparisons in figure 3 is .0002 °/oo with a standard deviation of less than .003 °/oo. To put the salinity scatter into perspective a histogram of duplicate salinity comparisons appears in figure 4. It also shows the same scatter indicating the error is in the water sampling technique while a mean difference of .003 °/oo is observed evaporation due to the several day delay in running the duplicates. Temperature and pressure calibrations have proved better than hydrographic measurements.

Scientific Activities

1. Survey/Mapping - The CTD was used extensively during MODE. Together with other profiling instruments a data set was acquired which allowed the synoptic structure of the mesoscale field to be mapped during a four month period. In figure 5 we show a map of the dynamic height field between 500 and 1500 decibars for a single 12 day interval from the MODE Synoptic Atlas (1974). In the center of the region can be found the signature of the "MODE Eddy" which drifted westward through the region at 2-3 cm/sec. Also shown are CTD stations to be discussed later. The temperature within the thermocline closely parallels the dynamic height field. This is not true of the sea surface temperature (SST).

Voorhis, Schroeder and Leetmaa (submitted, JPO) have compared dynamic heights relative to 1500 decibars to SST. Some of these comparisons are shown in figure 6. A mean north/south variation in SST, seasonal variability and other factors combine to make the relationship of SST to dynamic height less than obvious. However, tongues of warm and cold surface waters can be seen advected by the dynamic topography.

2. Smaller-scale Studies - With the advent of continuous profiling devices the temperature and salinity structure was found to be quite variable. This "fine structure" in the CTD profiles taken during MODE was studies statistically by Hayes, Joyce and Millard (1975). An overall profile of temperature, salinity, potential temperature gradient and buoyancy frequency is shown in figure 7. Indicated on the figure are the various water masses into which the water column was divided for fine structure analysis. Typical traces of temperature variability are shown in figure 8. The temperature spectra of these regions (figure 9) show energy variations of 1000 but a common slope of -2.5. The greatest variability occurs in regions of highest vertical temperature gradient. Temperature and salinity observations can be jointly studied to see if observed variability is due to vertical motion/mixing or lateral processes, i.e., "interleaving". Throughout the main thermocline in the Sargasso Sea the former process is dominant (Joyce, 1976). Thus the temperature spectra can be converted to ones of vertical displacement by dividing them by the square of the mean potential temperature gradient. The resulting displacement spectra (figure 10) vary only by a factor of 2 with the exception of the Mediterranean Water where lateral mixing processes cause the conversion from temperature to vertical displacement to break down as was shown by Hayes (1975a). Garrett and Munk (1975) suggested that small scale internal waves able to propagate throughout the water column could account for the variability. In figure 11 we show the WKBJ stretched vertical spectra from the previous figure. Except for the Mediterranean Water again the scaling works well, particularly at longer wavelengths.

Since internal waves are a periodic phenomena, repeated profiles can give a better indication of the physical origin of fine structure. During IWEX (Internal Wave Experiment) the CTD was used to collect a time series of vertical profiles. Profiles were repeated at 6 minute intervals through the main thermocline where the buoyancy period was 20 minutes. The isotherm displacements over 7 hours are shown in Figure 12. Hayes (1975) analyzed the persistence of the temperature structure. In figure 13 vertical wavelengths of 50-300 meters are seen to be predominantly internal waves since the correlation function tends to oscillate with a near inertial periodicity. Smaller scales, once uncorrelated, remained that way. In figure 14 we show, from Hayes, the loss in coherence of temperature profiles as a function of time for lags of 12, 24 and 48 minutes. Variability with vertical scales 10 meters and less is incoherent after only 12 minutes. These results are inconsistent with present models of internal waves. Temperature and salinity profiles indicate a steppy rather than wavelike nature on scales of 1-10 meters. Mixed regions possibly formed by breaking internal waves are separated by thin sheets of high temperature gradient. These have been modeled statistically by Joyce and Desaubies (1976) to aid in the interpretation of moored temperature measurements.

Recall figure 5 which showed the dynamic height field between 500-1500 decibars of the MODE Eddy. The CTD stations indicated were subjected to analysis of temperature fine structure in the thermocline (Joyce, 1976a). A non-dimensional index of fine structure variability is the ratio of temperature gradient variance to the square of the mean temperature gradient. A correlation (figure 15) between regions of high geostrophic shear and large fine structure index suggests an interaction between the largest and smallest fields of variability heretofore discussed.

Temperature and salinity fine structure statistics along 70°W from the Sargasso Sea to the continental slope have been studied by Joyce (1976) who found the above fine structure index to increase linearly by a factor of 2 as the slope is approached from the south (figure 16). This indicates a variation in fine structure on the general circulation scales.

3. Other Processes, Other Places - Profiles taken within 3 meters of the bottom during MODE have revealed a well mixed region as shown in figure 17. The signature of stations, over the Abyssal Plain is consistent with the mixing of temperature-salinity gradients above the layer but in regions of topography the signature becomes more complicated (also figure 18). Bottom profiles taken near moorings were compared to deep current meter velocities. The layer height as a function of C. M. velocity is shown in figure 19 from Armi and Millard (1976). The observed thickness is six times that expected from an Ekman boundary layer.

Recent measurements from the Antarctic Polar Front taken as part of the ISOS field program in the Drake Passage are from a region characterized by large lateral gradients of temperature, salinity and dissolved oxygen. Signatures of interleaving of horizontally separated water masses can be seen in figure 20. Note that cold layers tend to be fresher and higher in oxygen than their warm counterparts. The density increases smoothly through the interleaving layers. Much of the T/S variability is correlated so that density variations are small. Thus large changes of temperature and salinity occur along a density surface. This is pointed out in figure 21 where we show two stations separated only 2.7 kilometers on a line perpendicular to the front. T/S variations from the mean of these two sections lie orientated along lines of constant σ_t.

Conclusion - A sampling of uses of continuous measurements of salinity, temperature, and pressure has been presented from our personal experiences with the W.H.O.I./Brown CTD. Vertical profiling of the ocean is orthogonal to temporal sampling from moored buoys. Both NDBO and W.H.O.I. have had a great deal of experience with the latter. We have found both methods of observation incomplete, with a combination of two giving a much truer picture of our four dimensional world.

Acknowledgments - We wish to gratefully acknowledge all authors whose material we have used for this review and also to the following sources of financial support for the work reported: Office of Naval Research contract N00014-74-C-0262 NR 083-004; Applied Physics Laboratory, The Johns Hopkins University contract 372111; National Science Foundation grants GX-29054 and ID075-14056.

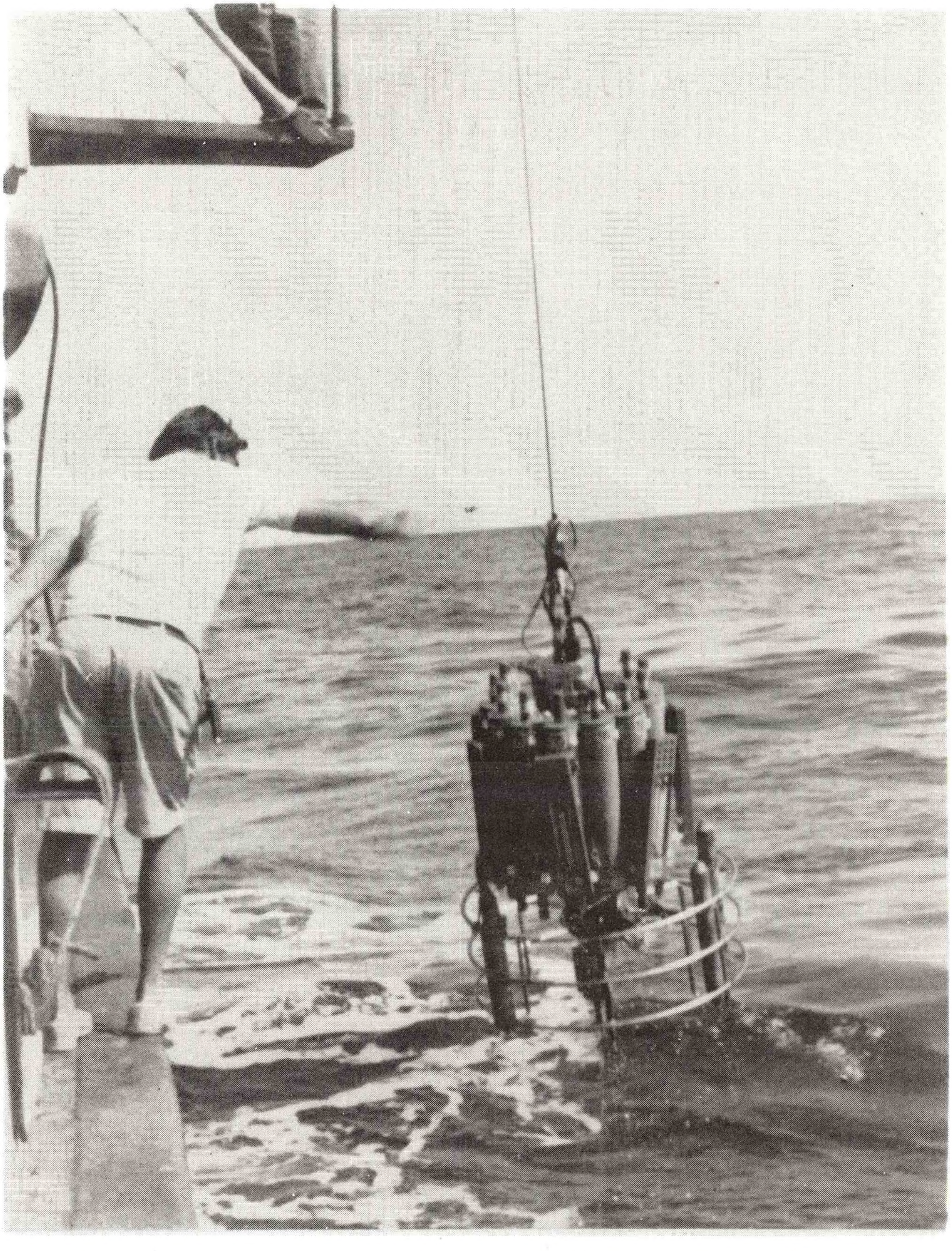

Figure 1. Recovery of W.H.O.I./Brown CTD microprofiler with rosette sampler aboard R/V Chain.

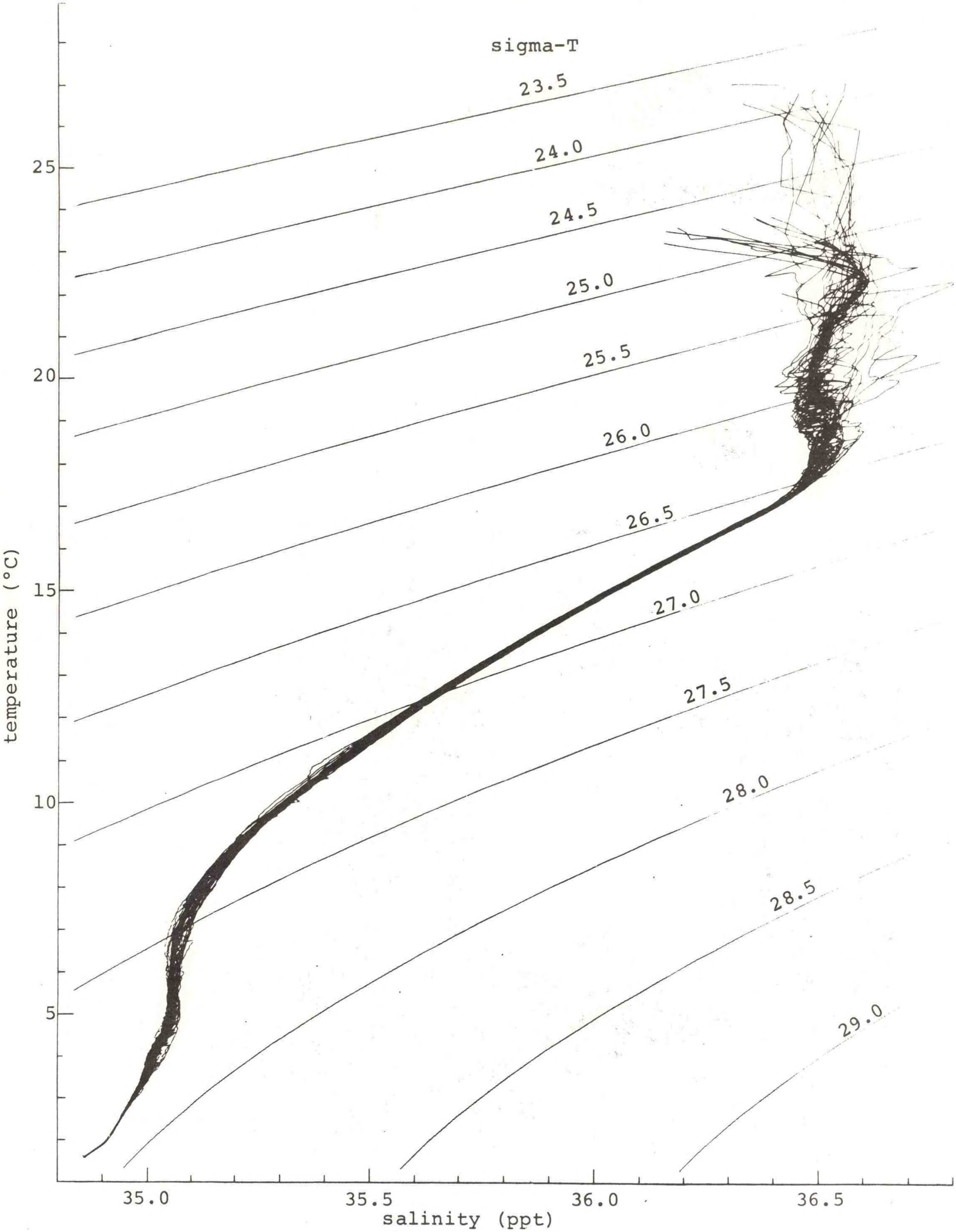

Figure 2. Potential temperature/salinity curves from 38 MODE-I CTD stations.

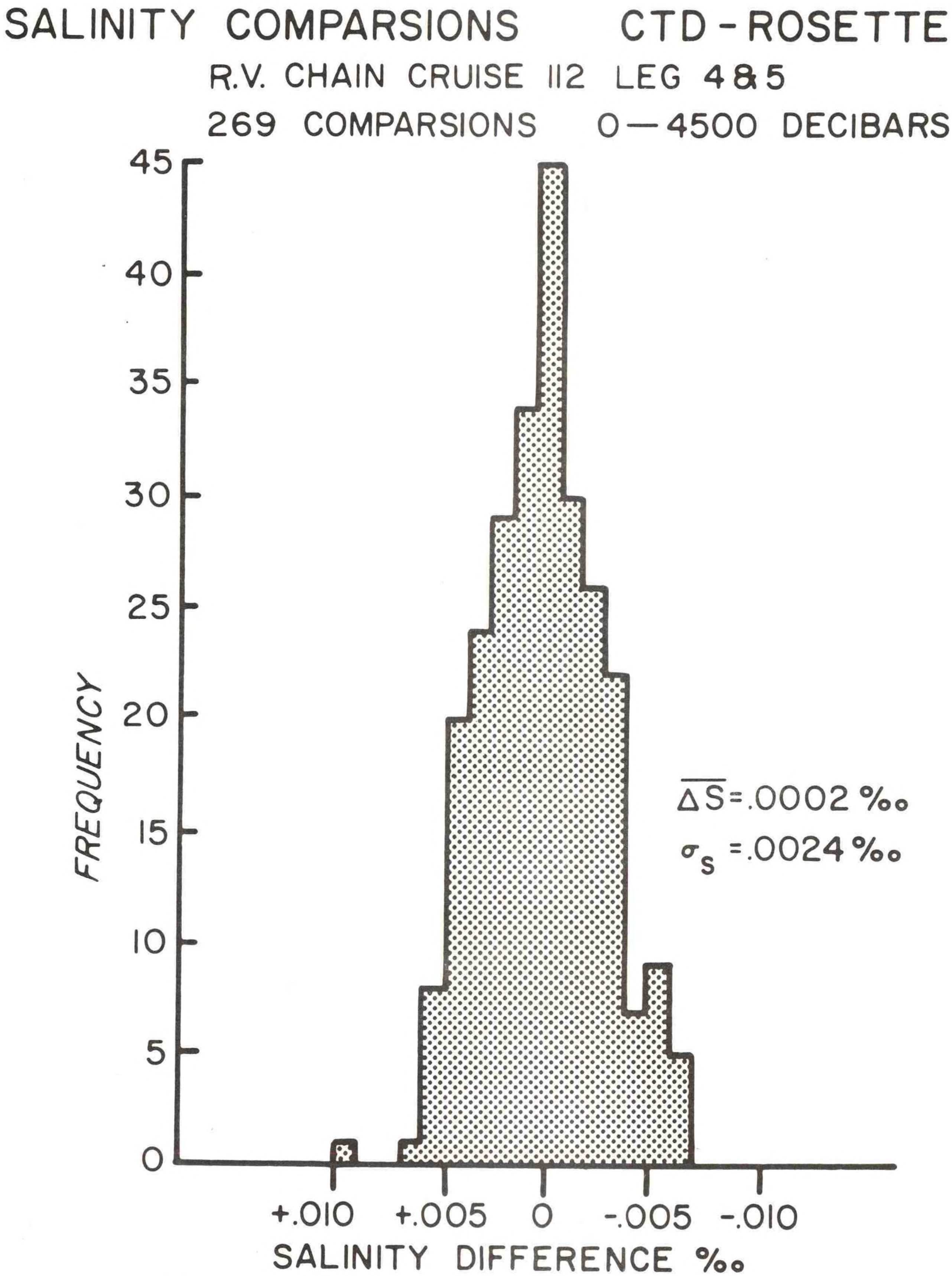

Figure 3. Distribution of 269 salinity comparisons between water samples and the corrected CTD salinities over zero to 4500 decibar pressure range.

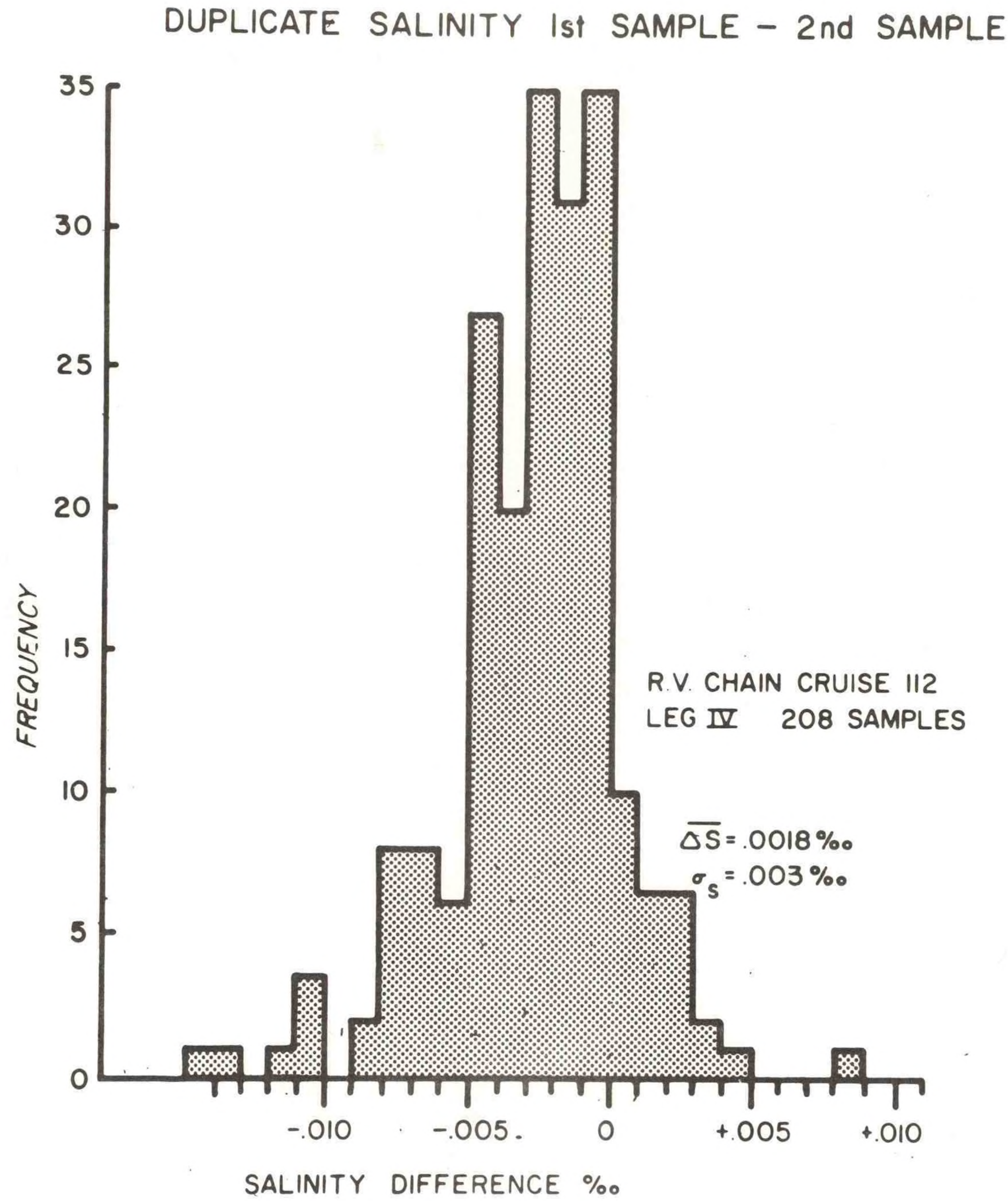

Figure 4. Distribution of 208 salinity comparisons from duplicate water samples left standing several days and first thermostatic salinometer determinations. $\Delta\bar{S}$ = -.0018 °/oo; σ_s = .003 °/oo.

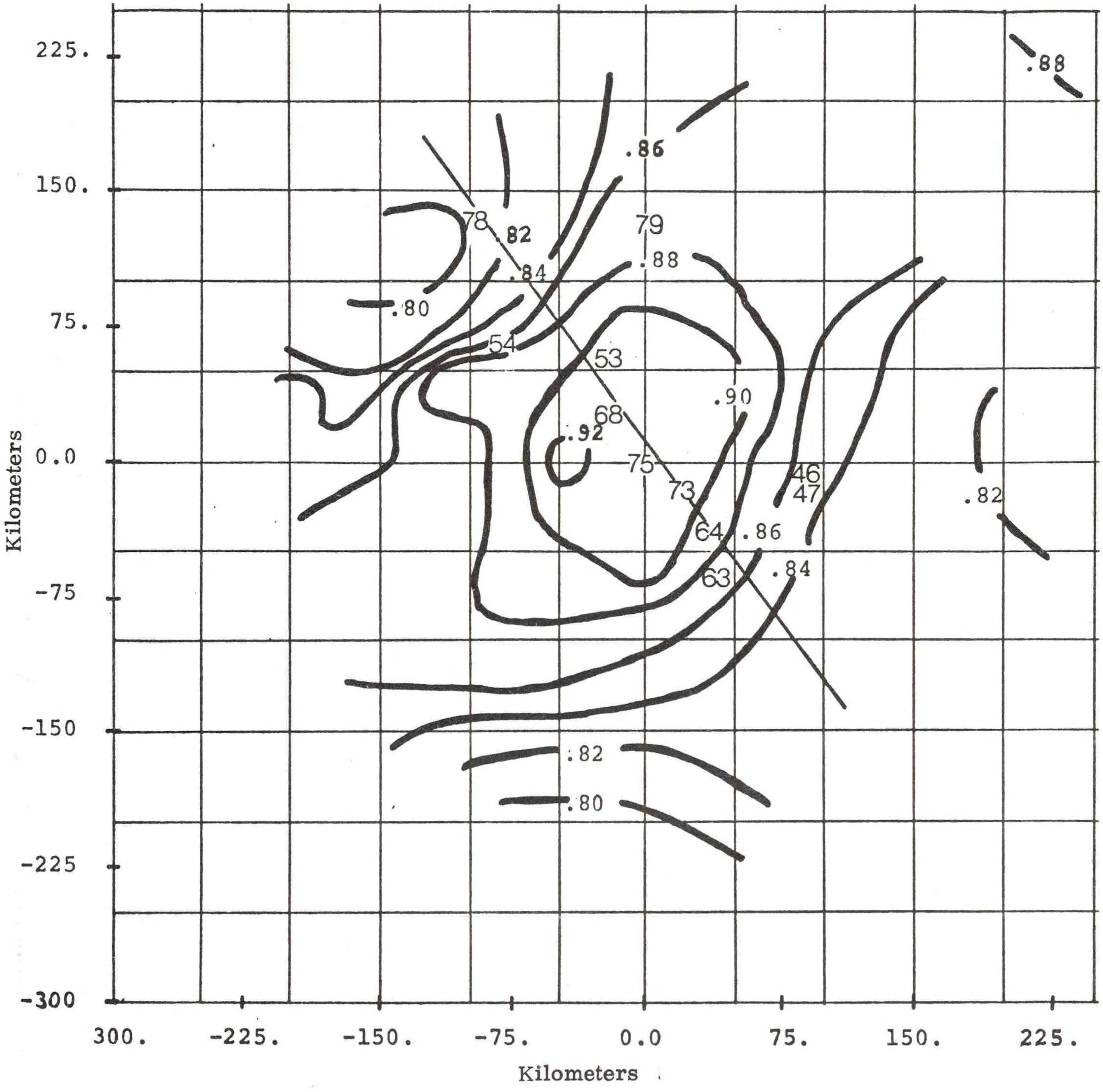

Figure 5. Dynamic heights between 500-1500 dbars at the MODE central mooring (28°N, 69°40'W) for days 129-140 (9-20 May, 1973) from the MODE-I atlas. The bold numbers are the CTD stations selected for fine-structure analysis.

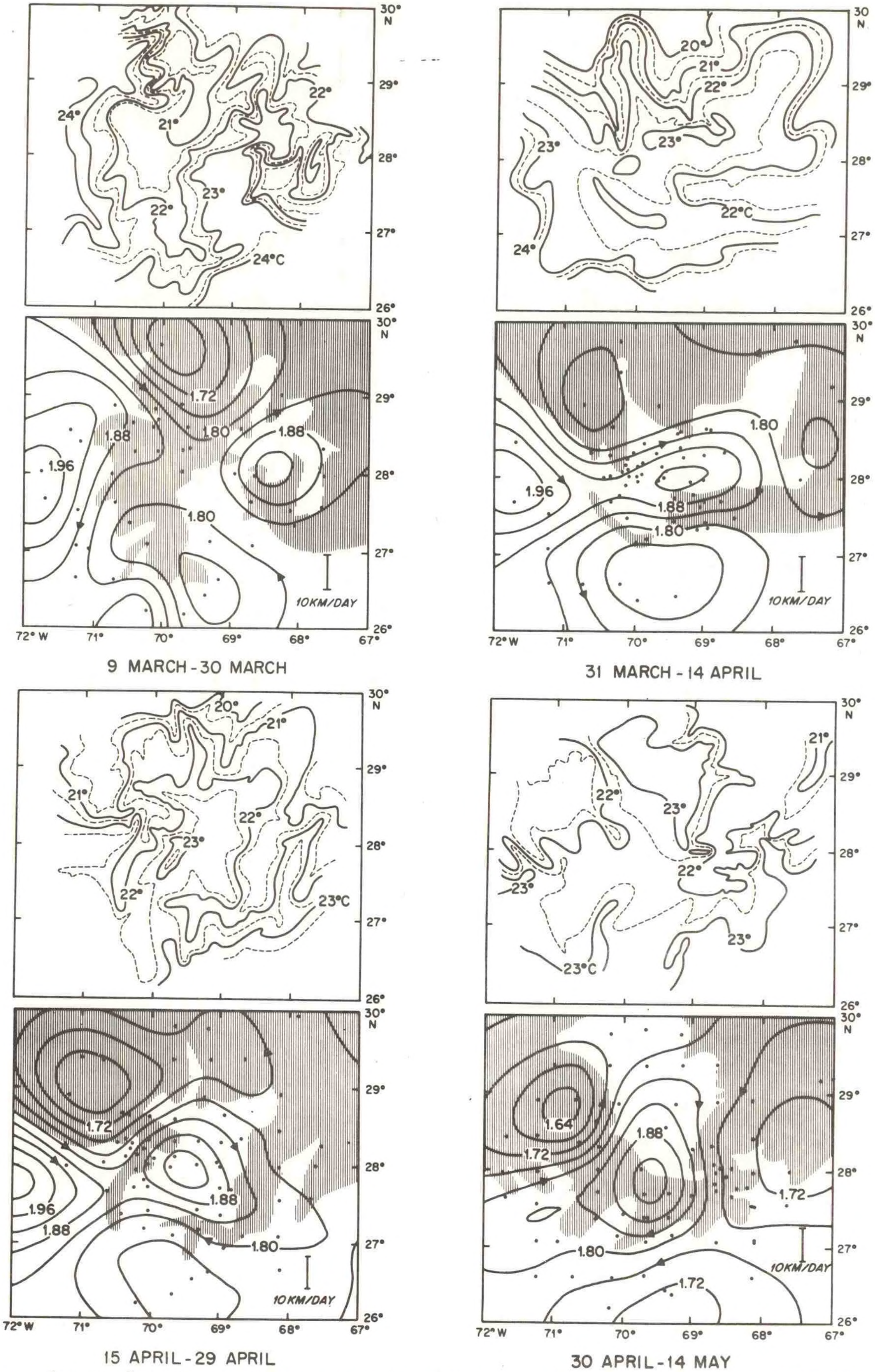

Figure 6. Sea surface temperature maps (upper) and surface dynamic topography (lower), relative to 1500 db, of the MODE area for four successive periods in the first half of the experiment. The cross hatched area on the maps of dynamic height show all surface water cooler than the mean for that period.

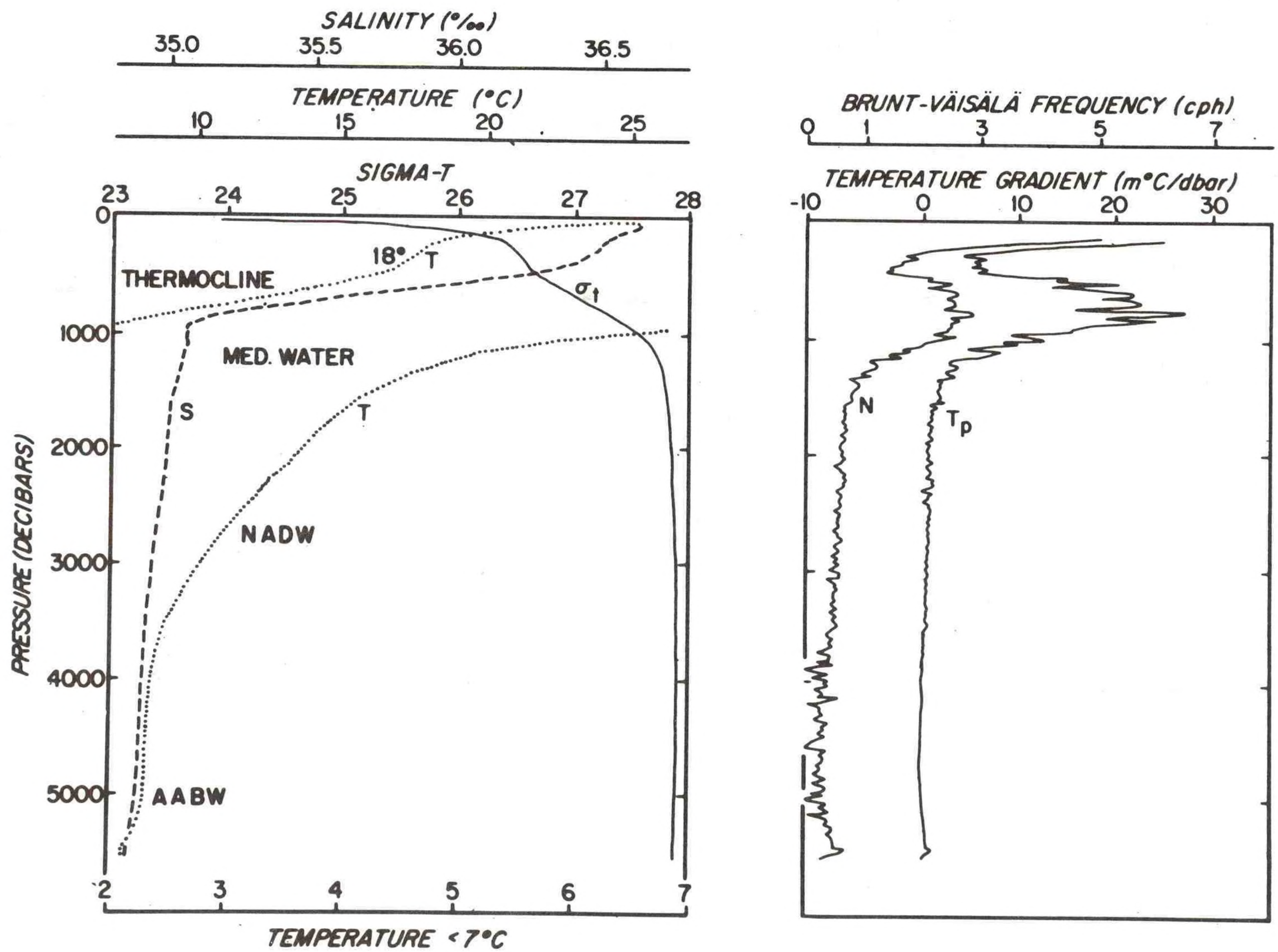

Figure 7. (a) Representative profile of temperature, salinity, and sigma t.
(b) Profile of vertical temperature gradient and Brunt-Väisälä frequency.

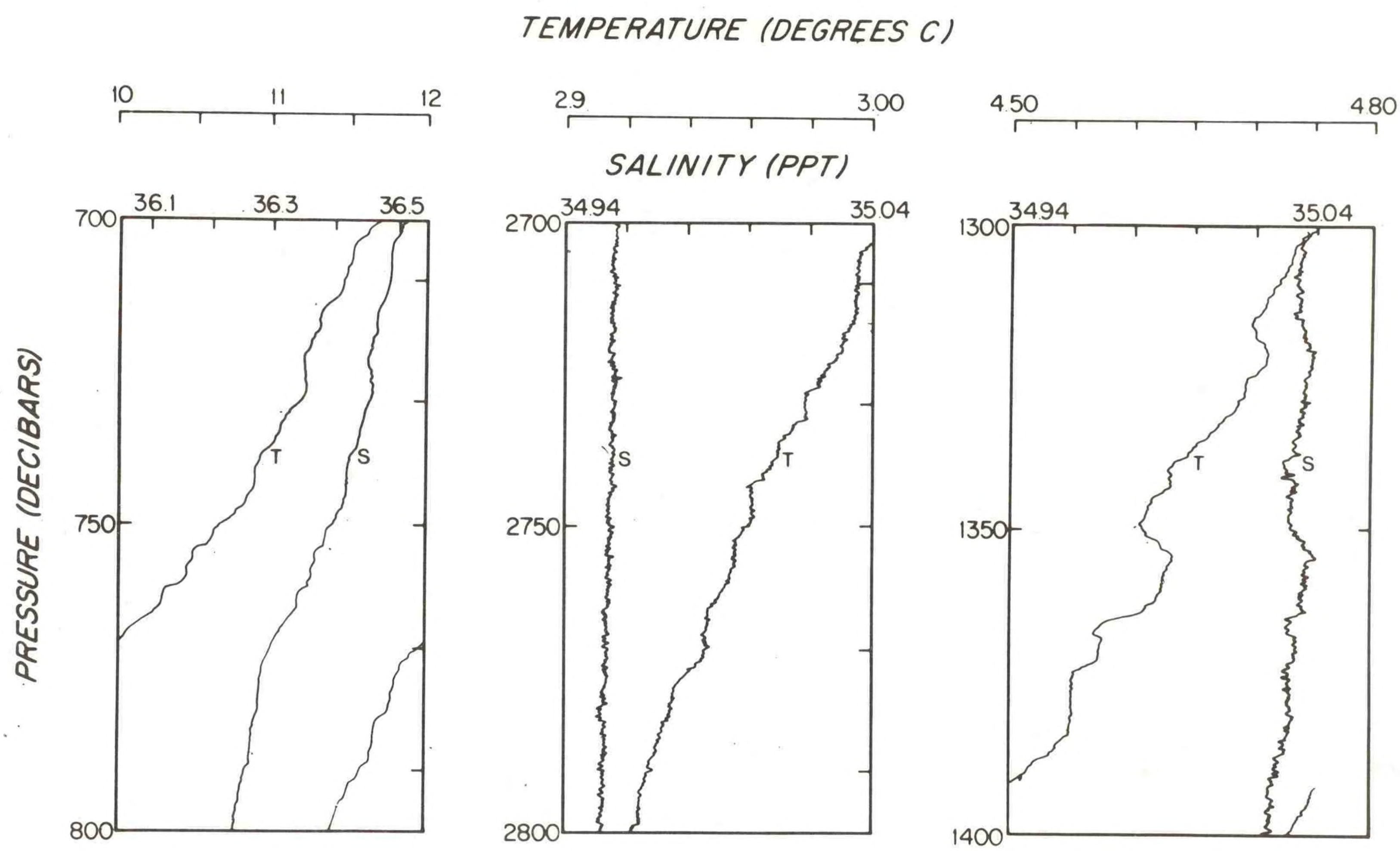

Figure 8. Portion of the temperature and salinity profiles of (a) main thermocline (700-800 dbar). (b) North Atlantic deep water (2700-2800 dbar). and (c) Mediterranean water (1300-1400 dbar).

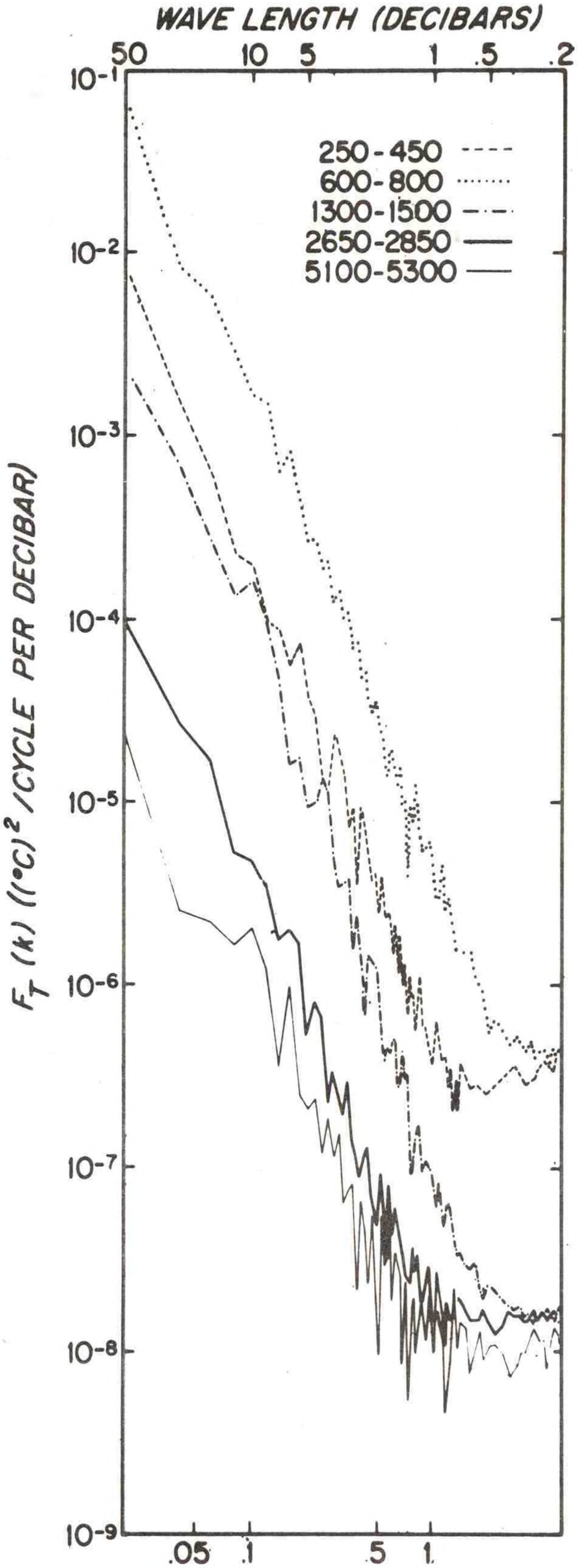

Figure 9. The ensemble-averaged vertical wave number spectra of the temperature variance for five depth intervals. The spectra for the 250- to 450- and the 600- to 800-dbar intervals have been corrected for the temperature response time. The 95% significance interval for 24 d. f. is shown. This interval, typical for low wave numbers, is smaller for high wave numbers where band averaging is done.

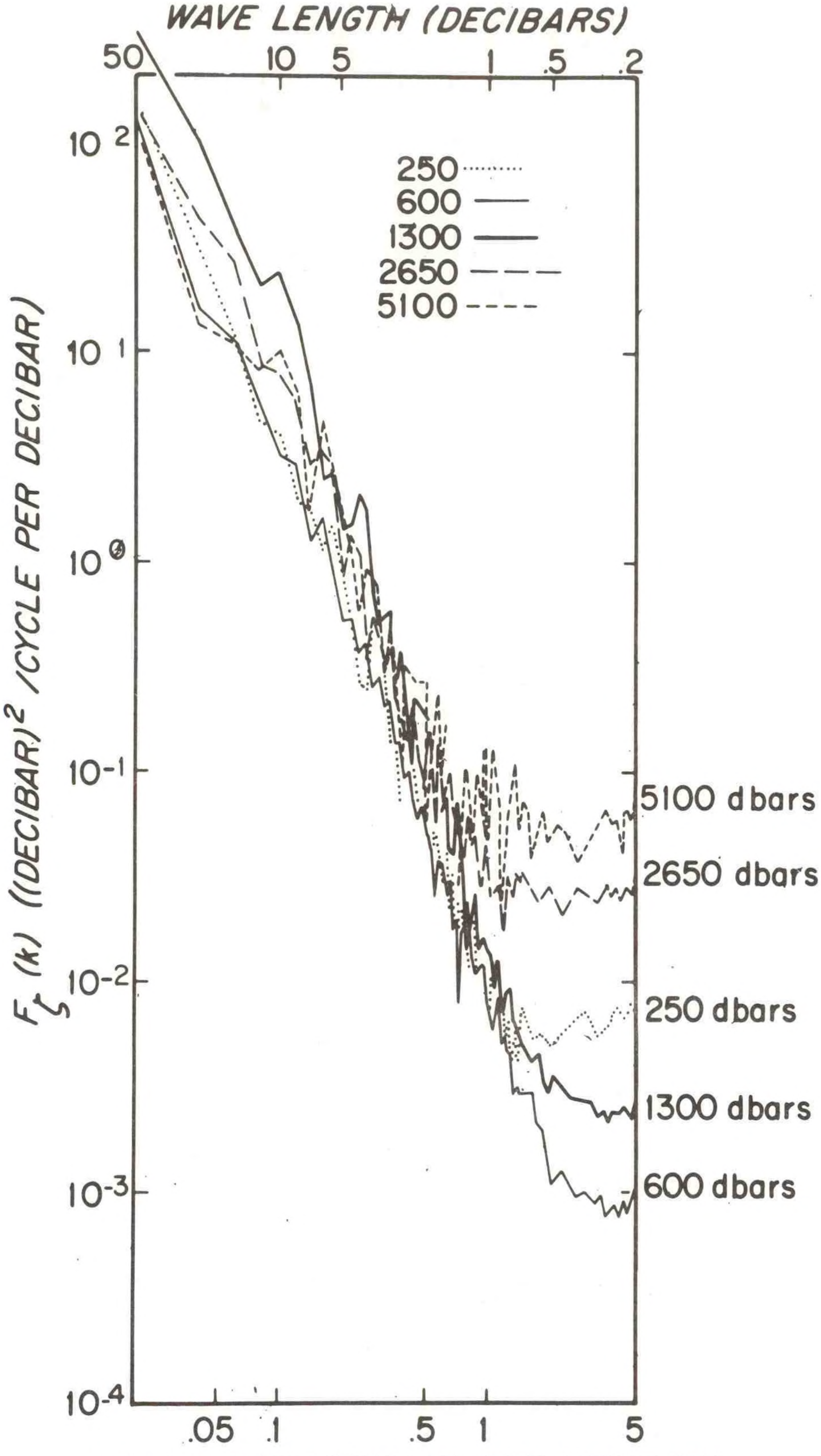

Figure 10. The ensemble-averaged spectra of the vertical displacement for the five depth intervals.

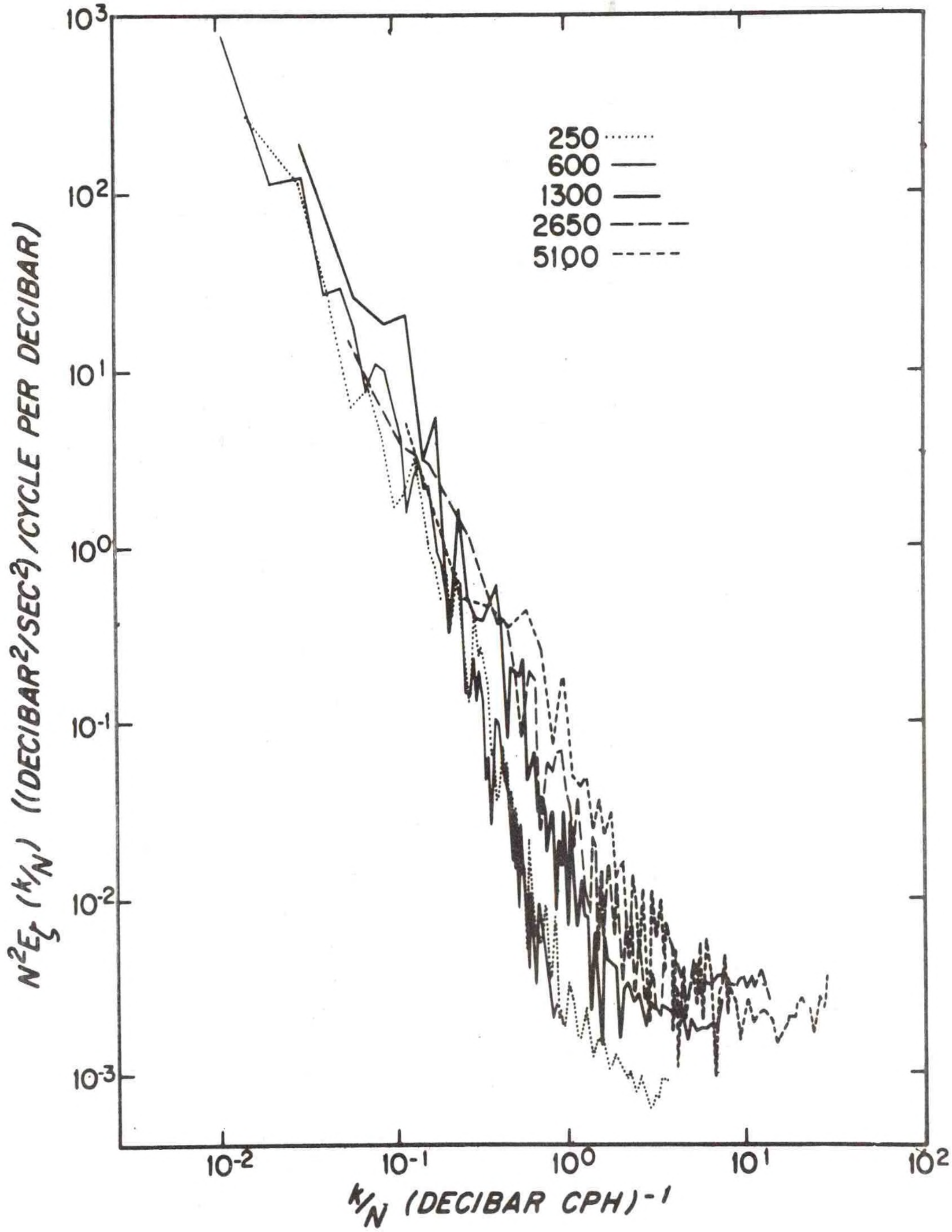

Figure 11. Normalized displacement spectra assuming WKBJ internal waves, n = N/1 cph.

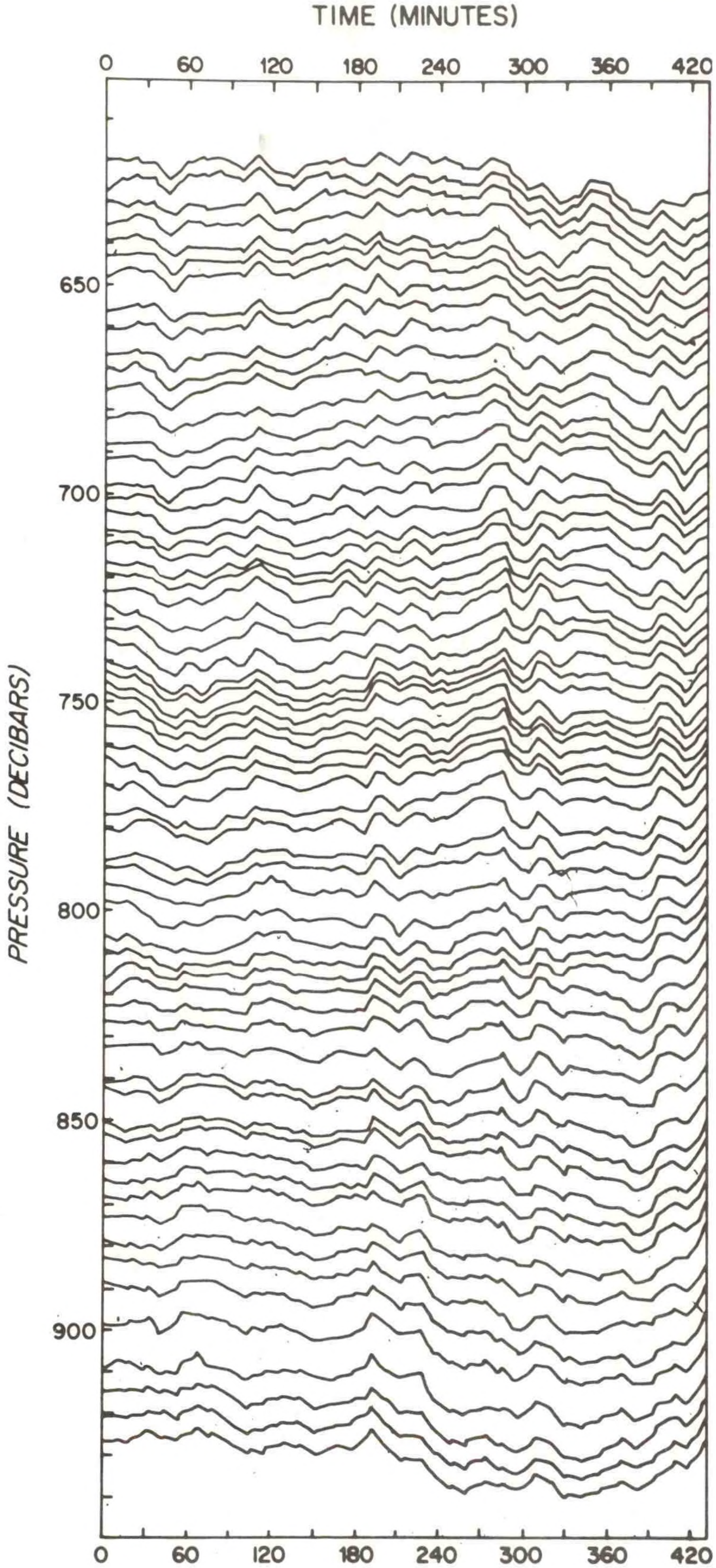

Figure 12. The time series of isotherm depths for the 7-hour segment of KN34 data. The temperatures contoured are from 13.7° to 7.4°C in 0.1°C intervals.

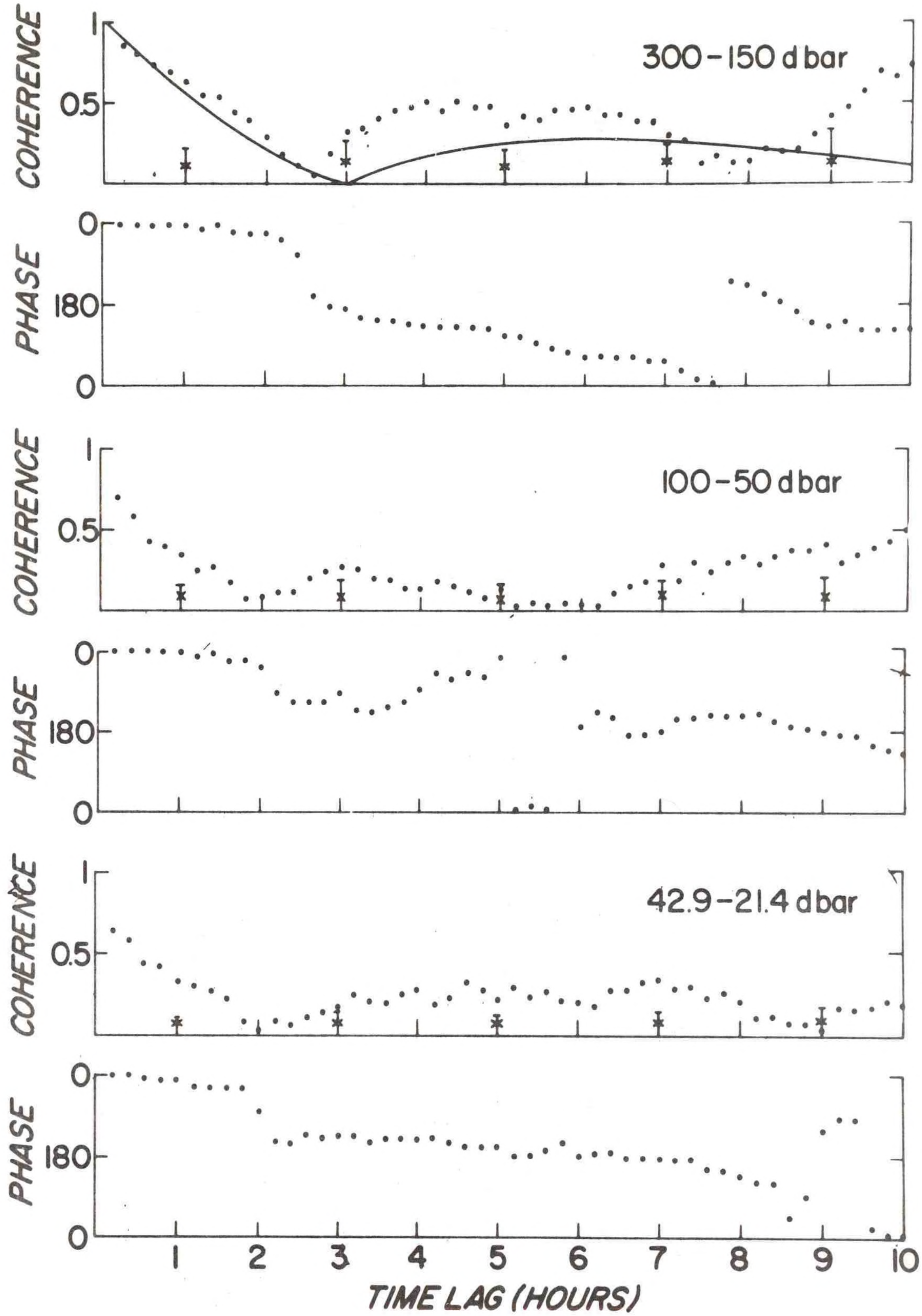

Figure 13. The coherence and phase between vertical temperature profiles as a function of time separation for three vertical wavelength bands. The dots represent the measured values (one every 12 min.). The solid line is the coherence predicted by Garrett and Munk [1975]. The asterisks indicate the bias in the coherence measurements, and the horizontal bars indicate the 95% confidence level for the null hypothesis.

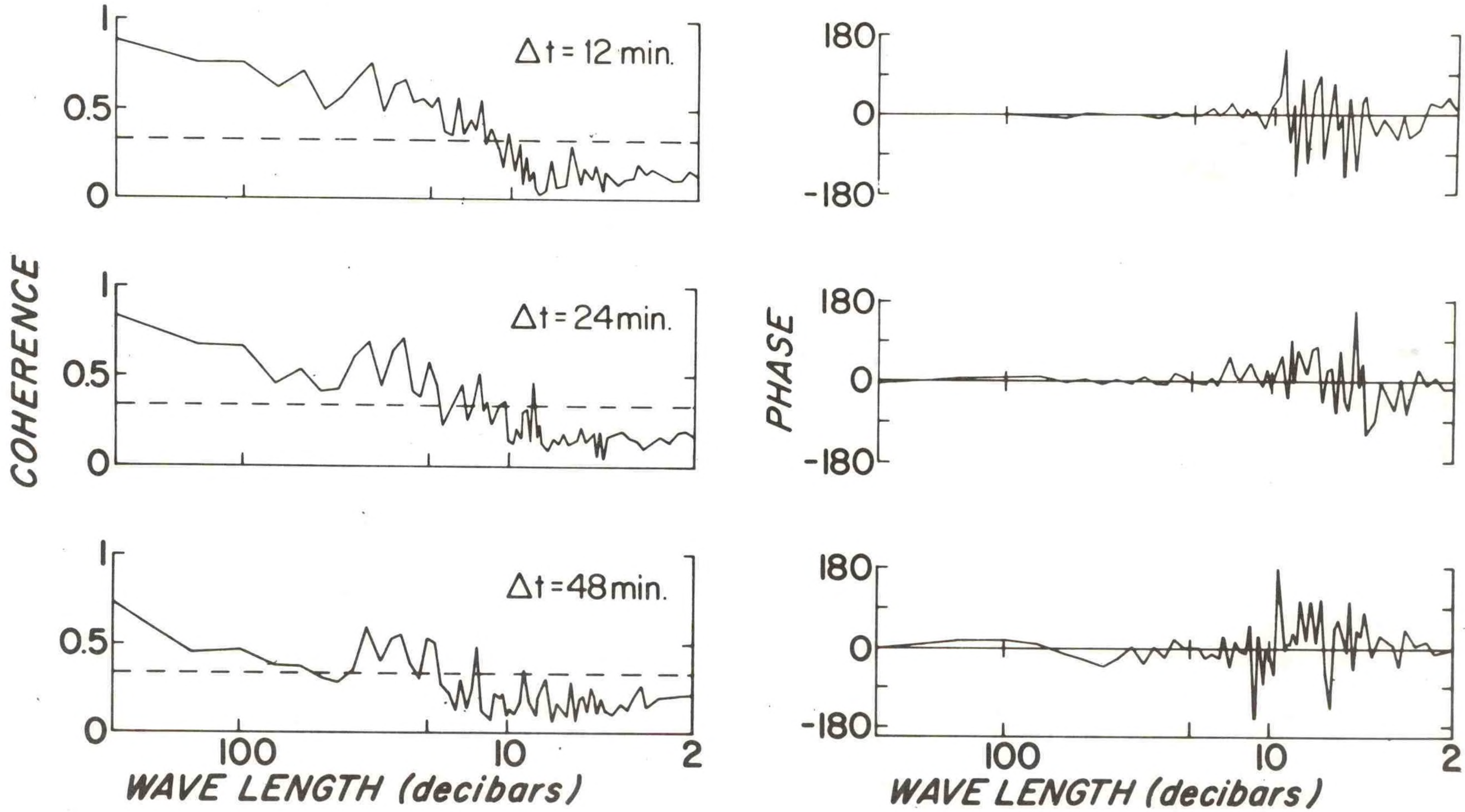

Figure 14. The coherence and phase as a function of vertical wavelength for temperature profiles separated in time by 12, 24, and 48 min.

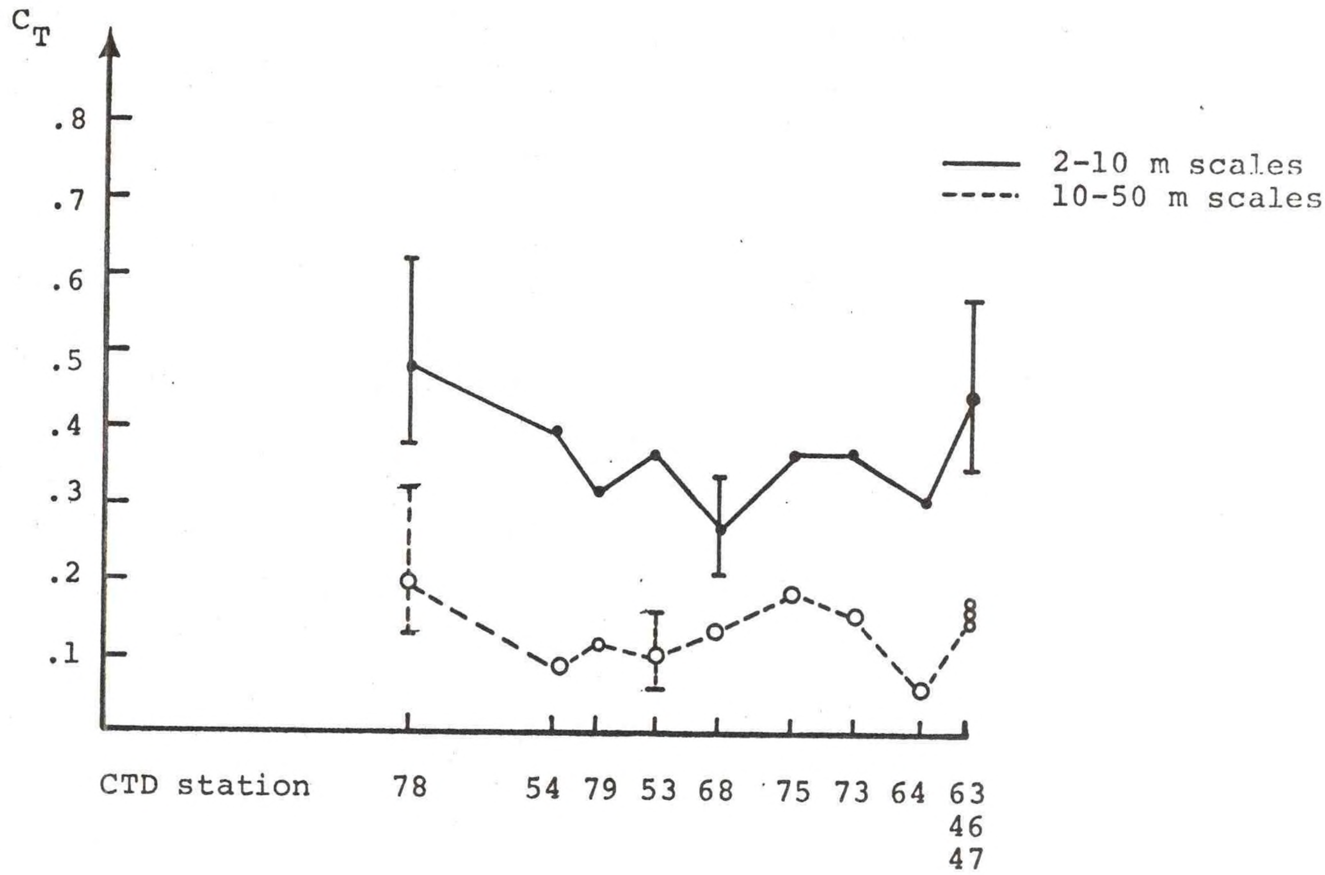

Figure 15. The variation of C_T across the MODE eddy along the line shown in Figure 5 for each wavenumber band. Error bars are 95 percent confidence limits.

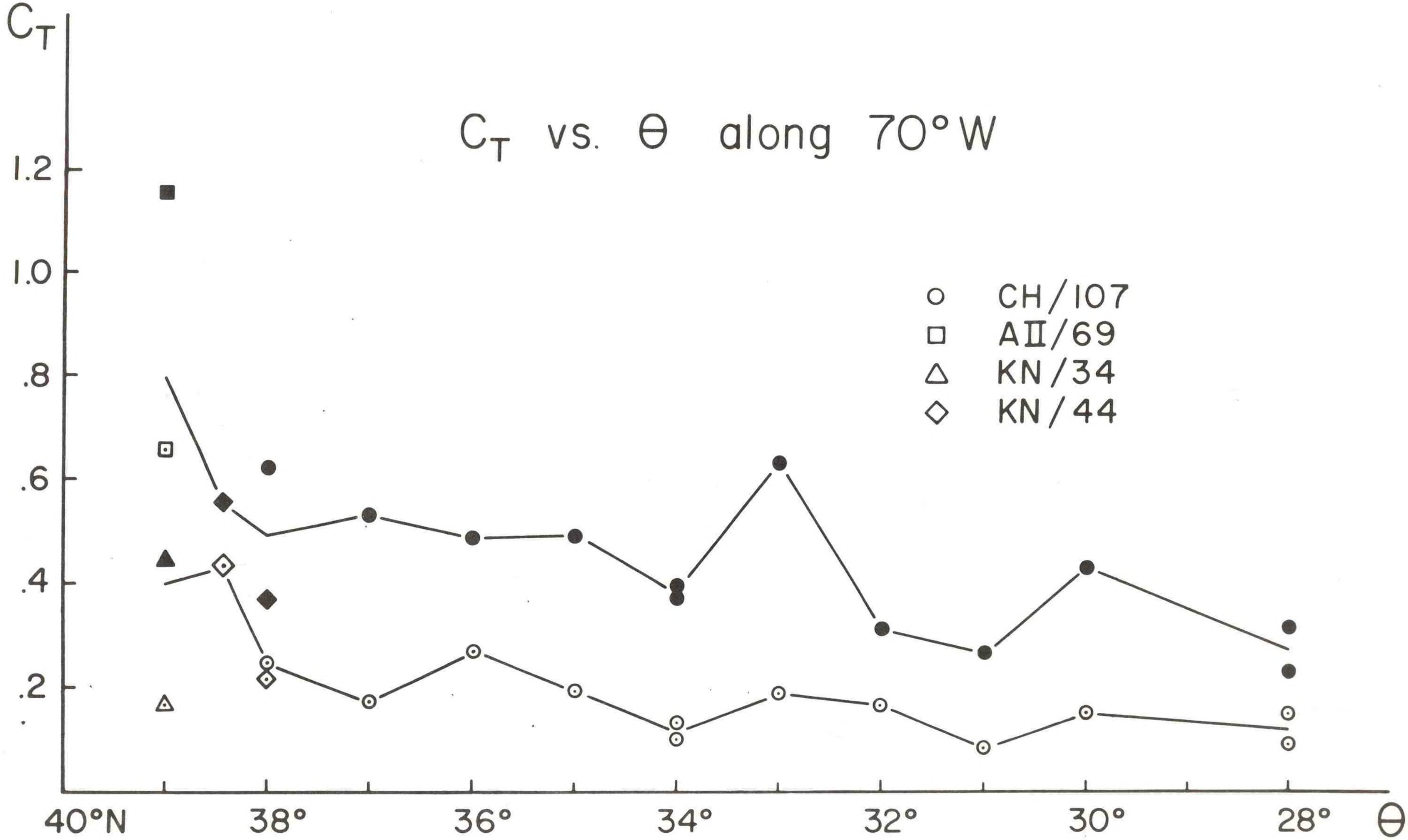

Figure 16. Variation of ratio of temperature gradient variance to squared mean temperature gradient for the main thermocline of the Northwest Atlantic for two wavenumber bands: solid symbols (2-10 meters) open symbols (10-50 meters). Cruises from different seasons and years have been combined in this composite.

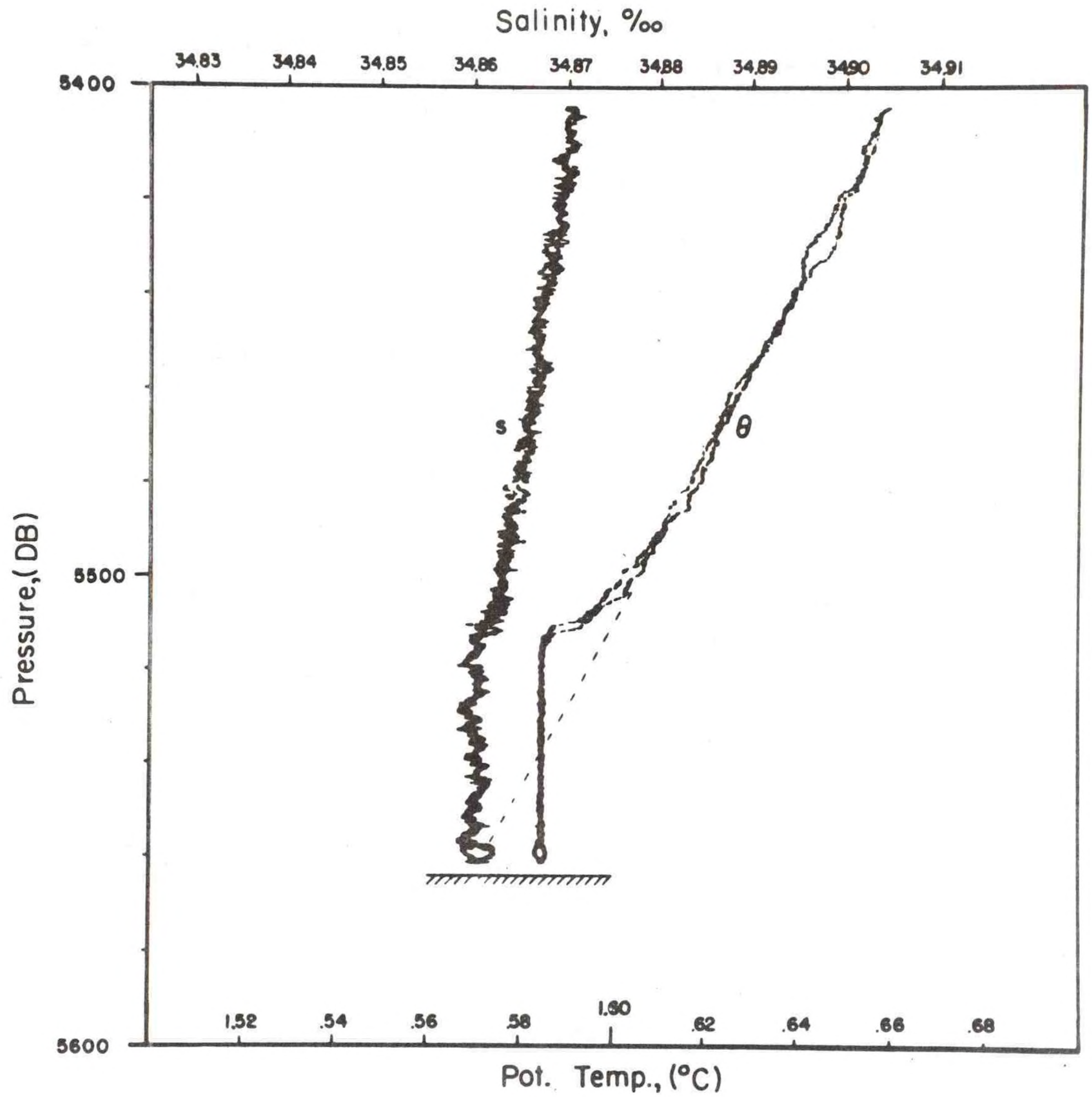

Figure 17. A salinity, potential temperature profile made in the middle of the Hatteras Abyssal Plain. Dotted line indicates structure could have formed by mixing up the stratified region above. The traces from both the lowering and raising of the profiler are shown.

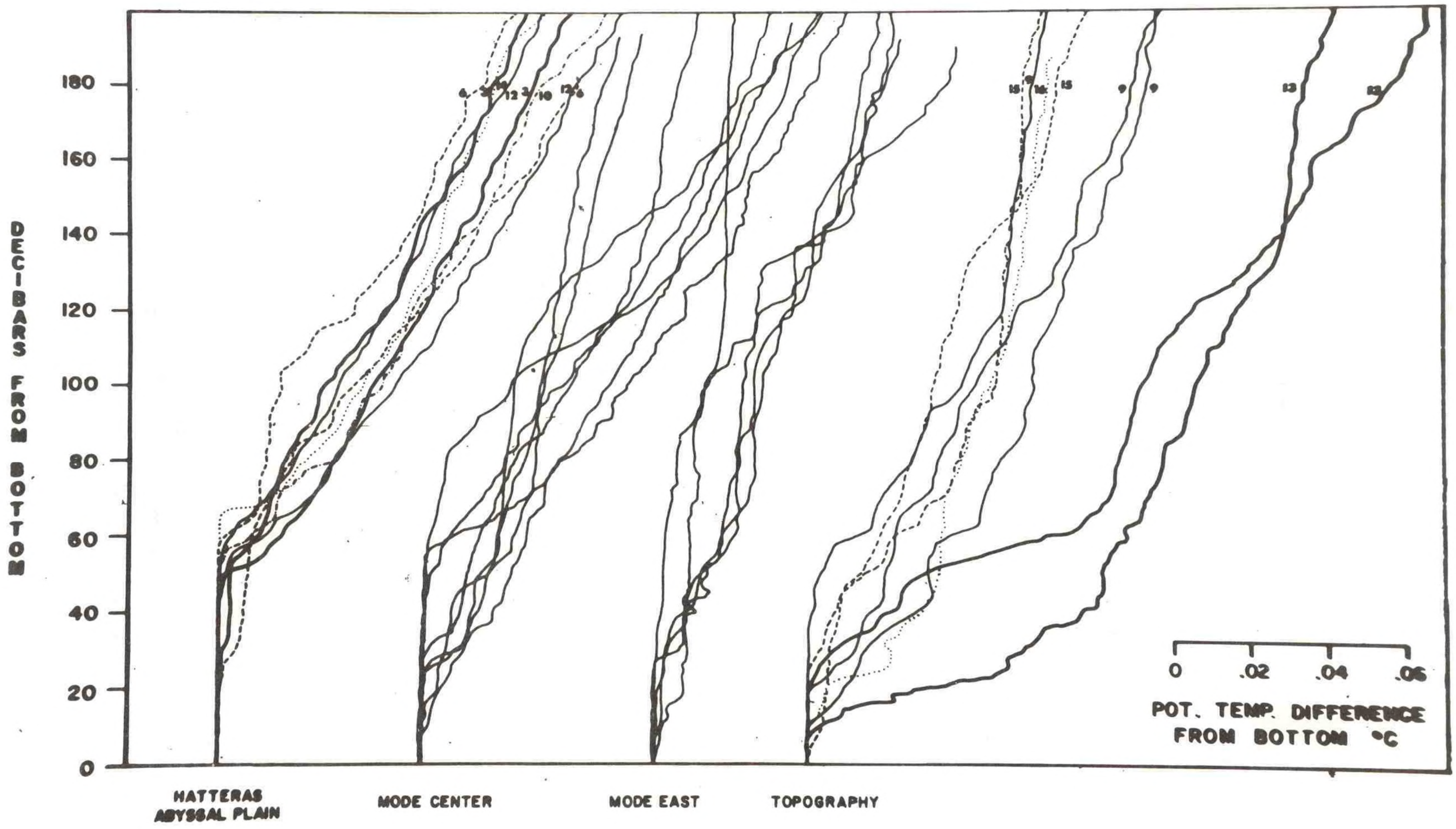

Figure 18. Potential temperature profiles plotted relative to the bottom in four groups.

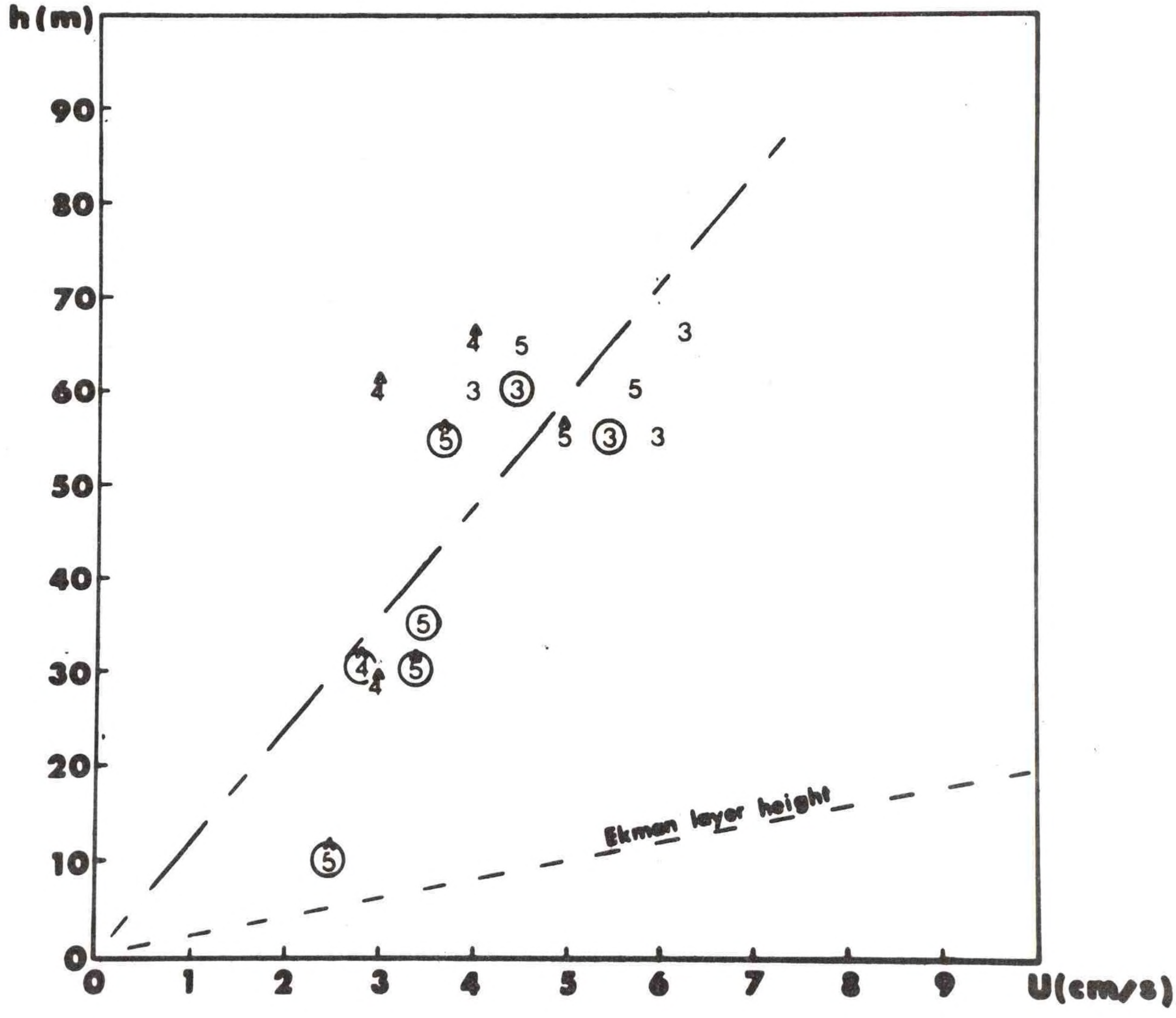

Figure 19. Correlation of penetration height of the well-mixed layer with velocity for stations on the Hatteras Abyssal Plain. Nominal depths of deepest current meters (3 = 3000 m, 4 = 4000 m, 5 = 100 m off bottom) are indicated. A data point is circled if velocity average was taken over one day period preceding time of profile. Stations made at the MODE central mooring indicated by $\wedge$.

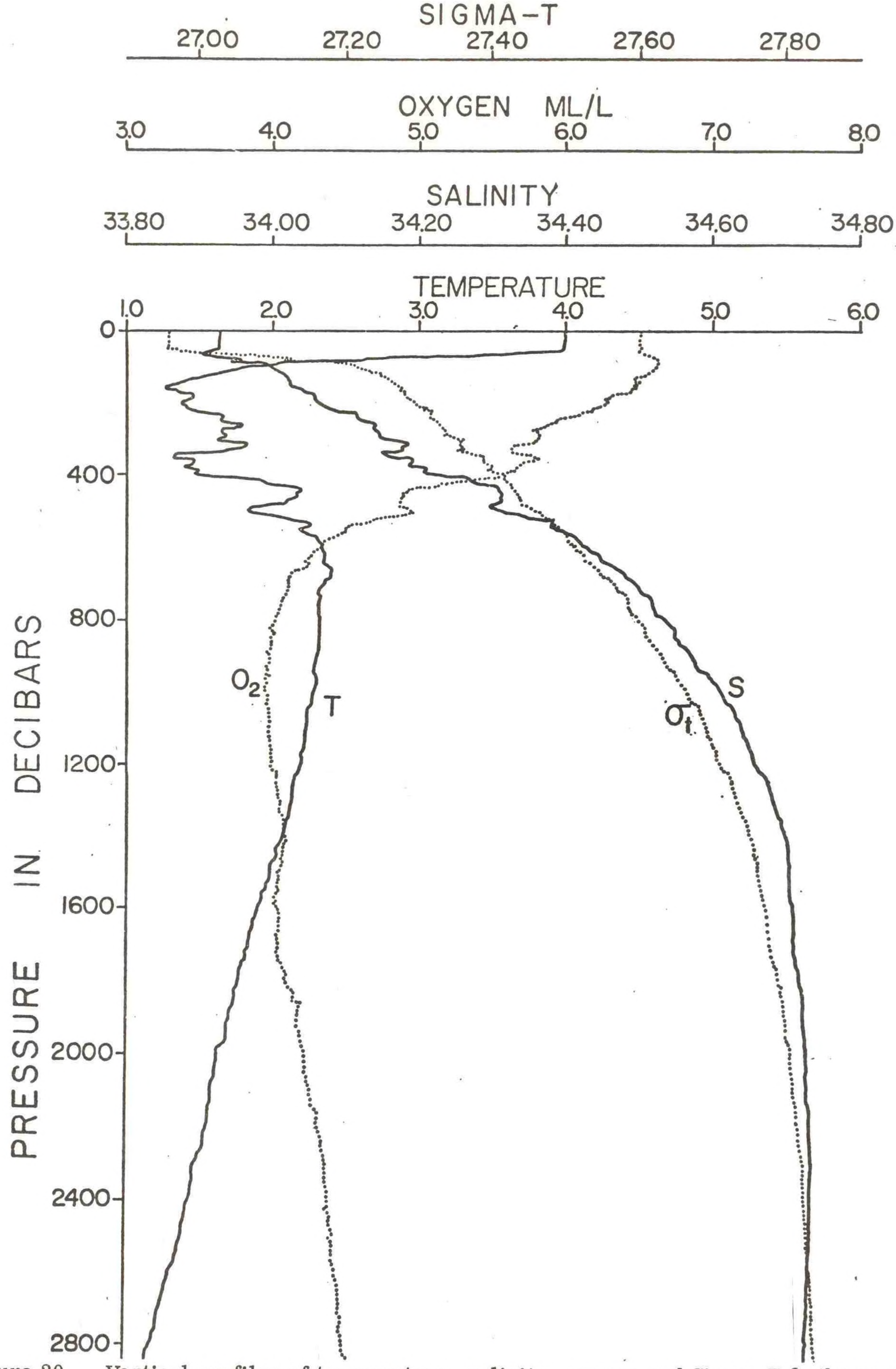

Figure 20. Vertical profiles of temperature, salinity, oxygen and Sigma-T in the regions of the Antarctic front at 57° 08.8'S and 63° 42.8'W on April 4, 1976. Note the "interleaving" region between 200 and 500 decibars.

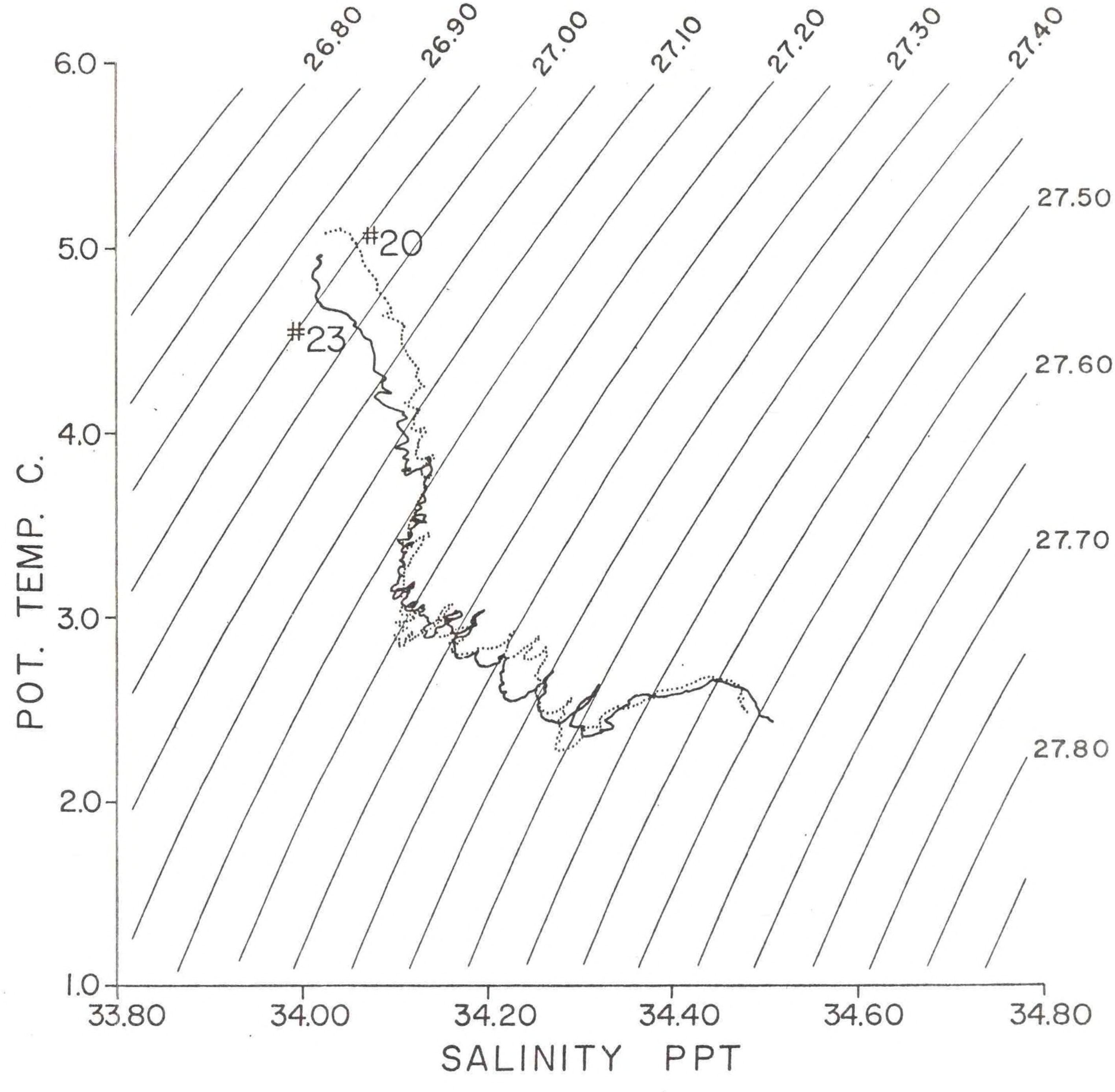

Figure 21. Potential temperature-salinity diagrams for two stations separated by 2.7 km in the region of antarctic front. Note θ/S variations from the mean of these stations orient along the reference lines of constant Sigma-T.

QUESTIONS AND DISCUSSION

DR. MERRILL: *When you showed us the salinity comparison of the WHOI/Neil Brown system and the classical hydrography, was that against the Washington Bridge?*

MR. MILLARD: That was against the Schleicher Bradshaw salinometer.

DR. MERRILL: *Does that include observations in the thermocline? You had zero to 4500 decibars. Did you look at just the deep stations?*

MR MILLARD: No. That particular comparison includes observations over the entire water column. Roughly, two tenths of the observations are actually made in the region of the calibration, but mind you, the calibration was for the average. A comparison was made between the local potential temperature-salinity relationship, as defined by the water samples collected during the experiment, and the historic potential temperature-salinity relationship. No difference was found and therefore calibrations were made to the historic relationship of Worthington and Metcalf.

DR. MERRILL: *Did the conductivity drift slowly on the Neil Brown instrument or does it behave more like a Bisset Berman when it hits the ship?*

MR. MILLARD: No, it shows a rather well behaved drift that seems to be consistent with the cell becoming coated with some sort of material, and it's being speculated that it's calcium carbonate. It presents problems with moored applications.

DR. MERRILL: Yes. That's what I was curious about.

MR. MILLARD: Neil's planning to make a larger conductivity cell which will reduce the drift associated with coating. Also, he's looking at things like fouling problems. I think fouling would be, for near surface applications, a rather severe problem.

DR. MERRILL: Thank you.

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TS CURVES IN THE PACIFIC AND THEIR APPLICATION TO DYNAMIC HEIGHT COMPUTATIONS

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Abstract. Mean TS curves are computed from all available hydrographic data at three ocean weather stations in the Pacific. The standard deviations in salinity over these curves are small at two of the three weather stations. Variations in salinity deviations for different space and time averages are examined. The mean TS curves are used at all three stations to compute dynamic height from temperature data alone. At stations November (30N, 140W) and Victor (34N, 164E) the rms differences between dynamic heights thus computed and dynamic heights computed from observation of both salinity and temperature are smaller than the uncertainty in a standard dynamic height computation. The large rms difference at station Papa (50N, 145W) was due to the presence of a temperature inversion above 40°N.

The computation of mean TS curves is extended to all 10° squares between 20°S and 40°N. The standard deviations in salinity as well as the mean curves themselves reveal interesting details about the distribution of various water masses and the frontal zones between these water masses. The mean TS curves are also used to compute dynamic height from temperature data. Root-mean-square differences between these dynamic heights and standard dynamic heights indicate that in large portions of the Pacific mean TS curves can be used for reliable dynamic height computations.

Regions of large rms differences are found to coincide with frontal zones between water masses. Mean TS curves in 5° squares allow some distinction between different intermediate water masses in one 10° square. Different intermediate water masses are identified through the study of TS curves from individual stations. The distribution of available hydrographic data is examined to determine where TS curves may be computed for smaller horizontal areas.

One of the standard tools of physical oceanography is a plot of temperature versus salinity. As early as 1918 Helland-Hansen made the observation that TS curves were very similar over large parts of the ocean. This was the beginning of the application of TS curves to the study of the water masses of the ocean.

The consistency of the TS relationship suggests that it might be possible to use this relationship to derive salinity from measurements of temperature alone. With the advent of the bathythermograph this possibility received added importance since it meant that computations of dynamic height could be carried out using BT measurements rather than the traditional hydrographic stations. Professor Stommel investigated this method of dynamic height computation in 1947 and concluded that in some regions careful application of bathythermograph data and TS curves could lead to meaningful dynamic height computations.

Recently the use of the expendable bathythermograph and the increased number of hydrographic observations has spurred new interest in computing dynamic height from temperature profiles via a mean TS curve. In the MODE region a mean TS curve was used to compute density at stations where salinity measurements were lost due to equipment failure. According to Dr. Scarlet comparisons were made between true dynamic height, calculated from observations of temperature and salinity and dynamic height computed using a TS curve (Fig. 1). As would be expected from this TS curve good agreement was found between these two measures of dyanmic height. Therefore the TS curve was used routinely for those stations with missing salinities.

As an exploratory study I looked at data at three ocean weather stations in the Pacific to evaluate the possibility of using mean TS curves to do dynamic calculations (Fig. 2). At the weather stations, November, Victor and Papa there were many hydrographic stations from which mean TS curves and standard deviations in salinity could be calculated. The mean curves were computed by averaging salinity over temperature intervals of 0.1°C. These curves were then smoothed with a nine point moving average. The standard deviations in salinity were also calculated along each curve.

At two of the three weather stations the TS curves had small salinity deviations and appeared tight. At station Victor (Fig. 3) TS curves were computed for the four seasons as well as the annual mean -- in order to determine if there were significant seasonal changes. As seen here all of the seasonal changes occur above 100 m. Below this depth all the curves are very similar. Also the standard deviation in salinity is relatively small small below 100 m.

At station November (Fig. 4) the salinity deviation above 100 m is again larger than that below 100 m. As at Victor this is due to seasonal heating and cooling being restricted to the upper layer. The salinity deviation below 100 m was somewhat larger at station November than at Victor.

Station Papa (Fig. 5) was the exception with the largest salinity deviations occurring over the 751-1000 m depth range. This was later found to be due to the presence of a temperature inversion.

These three TS curves were used along with the temperatures from hydro stations to compute what I call TS dynamic height. Dynamic height was then calculated at the same stations from observations of T and S. The RMS differences between dynamic and TS dynamic height were then computed for all available hydrocasts.

This table (Fig. 6) gives the RMS differences for different combinations of data. Both 500 m and 1000 m reference levels are shown and at Victor the various seasons are shown. At November stations were taken from progressively larger areas around the weather station. In general all values at Victor are less than 2 dyn. cm while at November the differences increase moving away from the station. As expected at Papa the differences were very large with little improvement seen in using seasonal curves.

To evaluate the meaning of these differences it is necessary to look at the size of changes in dynamic height at these locations (Fig. 7). From Dr. Wyrtki's atlas we see that at Papa and November the standard deviation in 1000 m dynamic height is about 5 dyn. cm (Fig. 8). At Victor it is about 15 dyn. cm. Thus at

November and Victor TS dynamic height would be a good measure of dynamic height while at Papa it would not.

In an effort to understand why Papa was so unique the histograms of the differences between TS dynamic and dynamic height were plotted (Fig. 9). At November and Victor the differences appear to follow a Gaussian distribution while at Papa the distribution is skewed to the right. Examination of TS curves from individual hydro stations at Papa helped to explain this skewness (Fig. 10). The three stations shown here are representative of the different TS curves found at station Papa. The inflections in all curves are due to a temperature inversion located at about 100 m. These different stations show that the inversion changes in shape and in intensity. These changes result in the mean curve not being representative and the skewness is caused by more stations being to one side of the mean curve.

From only three weather stations it was not possible to evaluate where and when in the Pacific mean TS curves could be used to compute TS dynamic height. The failure of the method at station Papa suggested that TS curves should not be used everywhere to compute dynamic height. To answer the question of where the method should be used, all available hydrographic data in the Pacific between 40°N and 20°S were examined by Dr. Rich Wert and myself. The boundary at 40°N was set to avoid areas with temperature inversions. I am presently working with the hydro data north of 40°N in an effort to find a way to parameterize a mean TS curve in the presence of a temperature inversion.

An arbitrary area of 10 degrees square was chosen as an averaging interval. Within each square the data were screened to eliminate obviously erroneous salinities. Mean curves and standard deviations in salinity were computed as at the weather stations (Fig. 11). These mean curves taken together reveal details of water mass distribution not expressed in the mean TS curves of Sverdrup or Dietrich. The common value of temperature and salinity at the lower end of all curves indicates the uniformity of bottom water over the entire region. (Note for presentation curves were cut off at 1.5 and 25°C.)

The curves furthest to the south have a salinity minimum characteristic of Antarctic intermediate water while the northernmost curves show a less saline salinity minimum representative of subarctic water. The curves between 10 and 20°N represent transitions between these two intermediate waters (Fig. 12). This transition can best be seen as an increase in salinity deviation at the temperature of the salinity minimum. This figure also shows clearly the transition zone in upper waters between 0 and 10° N. Here the salinity deviation is large over the temperature range 10-25°C while below 10°C the curves appear tight. The influence of seasonal variations is also most clearly demonstrated in this diagram as a sudden increase in salinity deviation at the tops of most curves.

Individual scatter diagrams of the TS points used to compute the mean curves give further insight into the composition of these transition regions (Fig. 13). In this curve at 5°N, 165°E the points above 10°C group about the lines of salinity deviation with few points lying along the mean line. These groups correspond to the upper water masses north and south of this 10° square.

The transition in intermediate waters is also clearly depicted by the scatter diagrams (Fig. 14). In this square at 15N, 145W the abrupt termination of points at 10°C shows that the northern extent of Antarctic intermediate water lies within this square. The points to the left correspond to the subarctic intermediate water.

As with the weather stations these curves were used in conjunction with temperature data to compute TS dynamic height. Again the RMS differences between dynamic and TS dynamic height were computed as an estimate of the uncertainty in using the method. Here are shown these differences for the 500 m reference level as well as the number of stations used in the computation of each difference (Fig. 15). It is interesting to note that the large values (black squares) correspond to the regions of water mass transition between 0 and 10°N and along the west coast of North America.

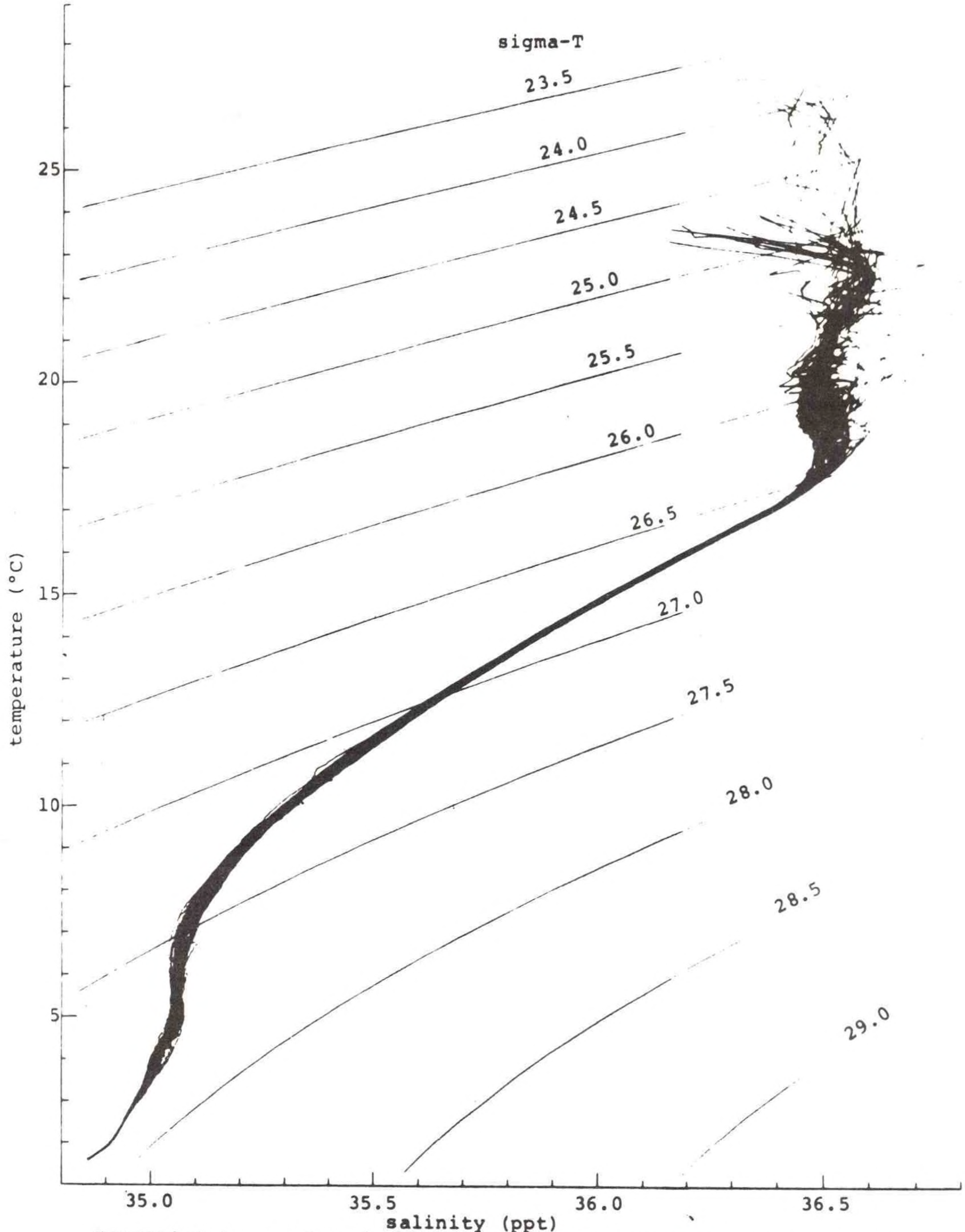
Recently a student of Dr. Wyrtki's has compared fluctuations of TS dynamic height with corresponding changes in sea level. His results give qualitative support to the values of TS dynamic height uncertainty shown in this figure (Fig. 16). Using average temperature data from XBT's in 5° squares between Hawaii and California he correlated TS dynamic height in square A with sea level at Honolulu, and TS dynamic height in square H with sea level at San Francisco (Fig. 17). As would be expected from the RMS differences the correlation was low at San Francisco (Fig. 18) and high at Honolulu.

The RMS differences which represent the uncertainty in TS dynamic height are only meaningful when one decides what level of accuracy is required for dynamic height. If an absolute measure of dynamic height is required the uncertainty in TS dynamic height is frequently larger than the 2 to 4 dyn. cm error inherent in traditional calculations of dynamic height (Fig. 19). Compared with the available information on the standard deviation in dynamic height, however (again from Dr. Wyrtki's atlas), the uncertainty in TS dynamic height often appears small.

One recurrent question in this study is why were 10° squares chosen. As I have said the choice was arbitrary and was made mainly to make the data reduction tractable. It is clear from the results presented that in many areas a different grouping of data in time and space should lead to better mean curves and reduced salinity deviations. As a preliminary investigation of this problem Dr. Vladimir Cooksa and I examined data in the 10° square around Hawaii (Fig. 20). This square was chosen because it showed the presence of three intermediate waters and it contained many hydrographic stations. The first step was to recompute the curves for 5° squares (Fig. 21). The four curves, shown here only for the intermediate waters, show a definite north-south distinction between curves. There are also more subtle east-west differences. Unfortunately the salinity deviations did not decrease substantially due to the omnipresence of California Intermediate Water. To better differentiate the water masses, we examined individual hydrographic stations (Fig. 22). In this way we were able to clearly define a boundry between Antarctic and Subarctic intermediate waters.

A limitation in refining the present 10° TS curves is the distribution of available hydrographic data (Fig. 23 - 26). These sections of the Pacific show the distribution of hydrographic data from west to east. The many problems of uneven and often inadequate coverage greatly add to the difficulty of making better TS curves. I am hoping in the future to refine these curves on the basis of these data and later STD data as it becomes available.

In summary these studies have indicated that in many regions of the Pacific temperature measurements alone can be used to compute density and dynamic height from a mean TS relationship.



Potential temperature/salinity curves from 38 MODE-I CTD stations

Figure 1.

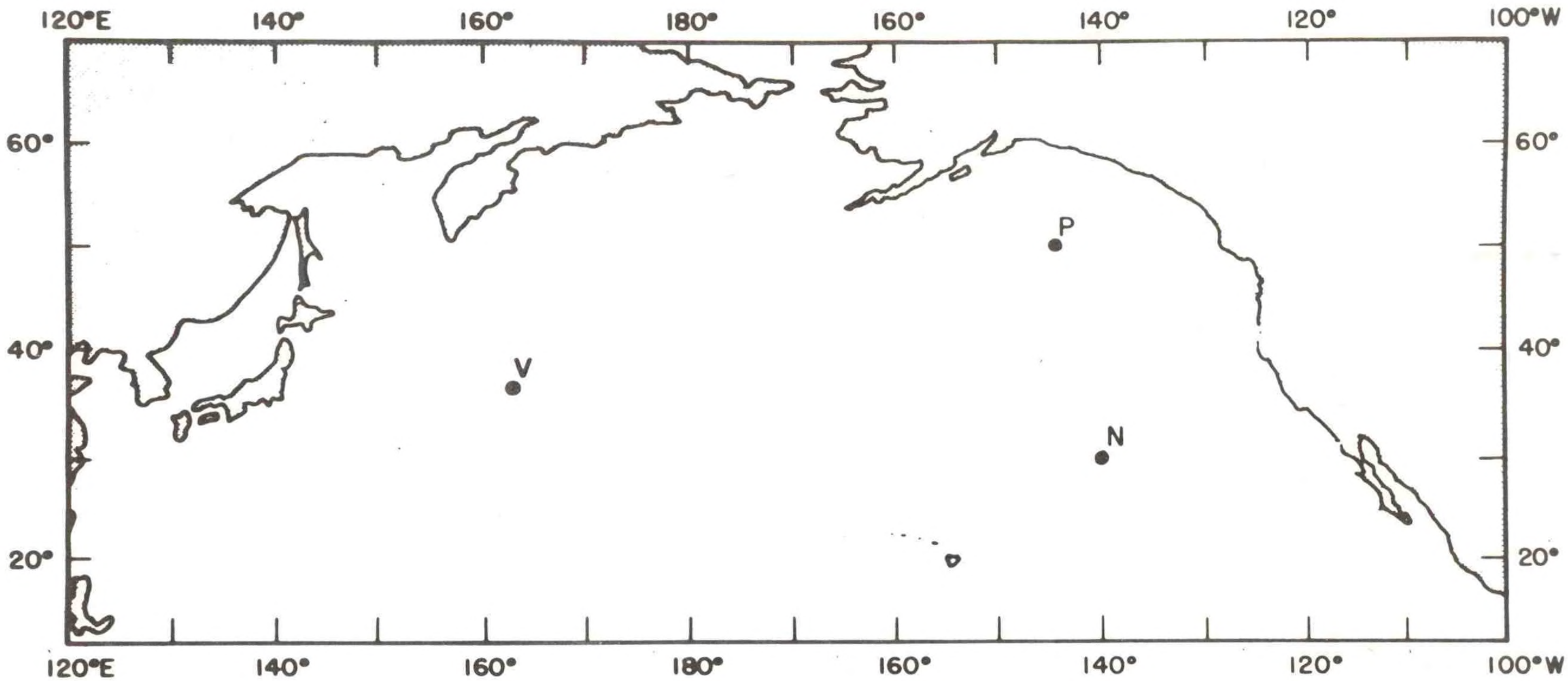


Figure 2.

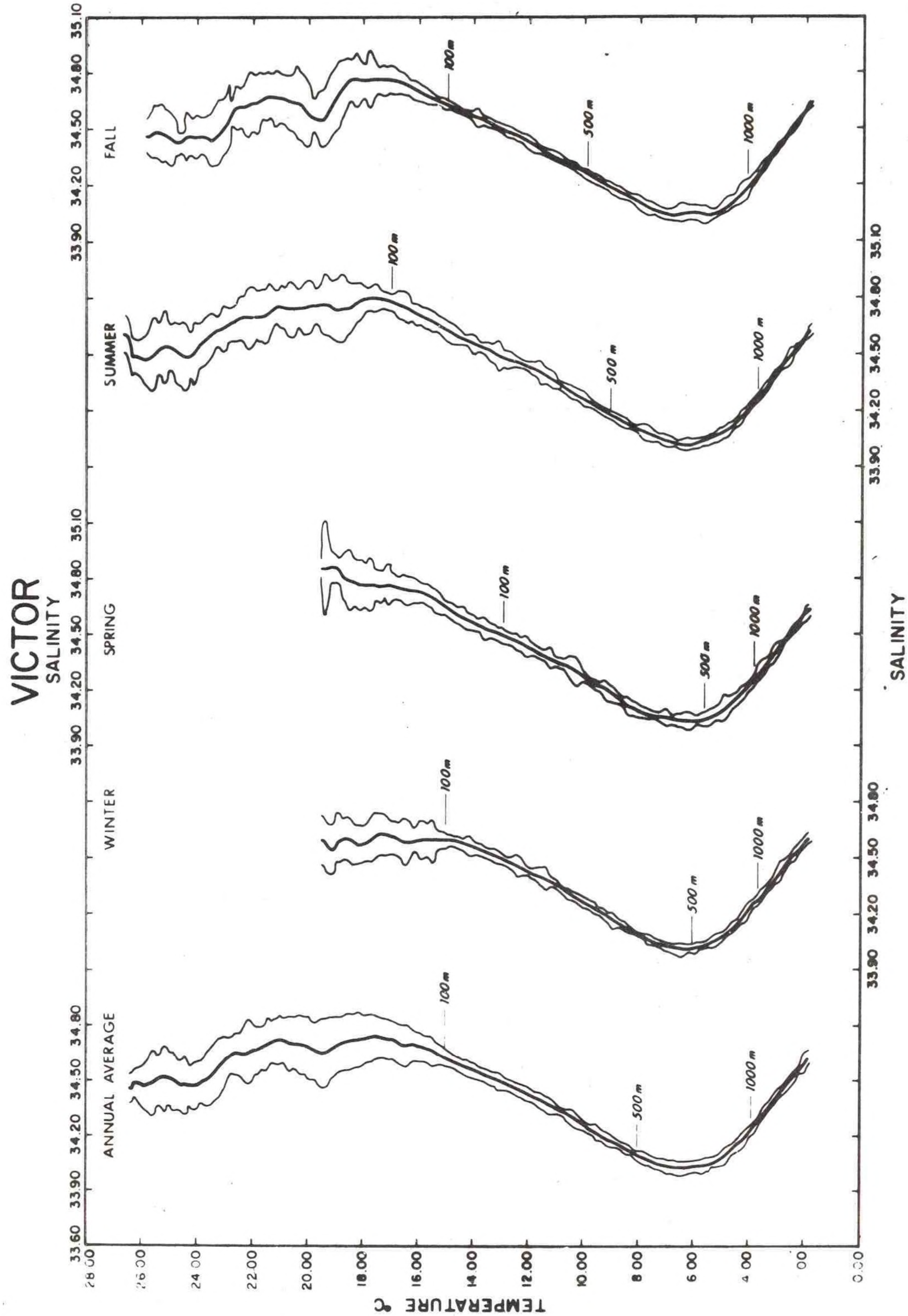
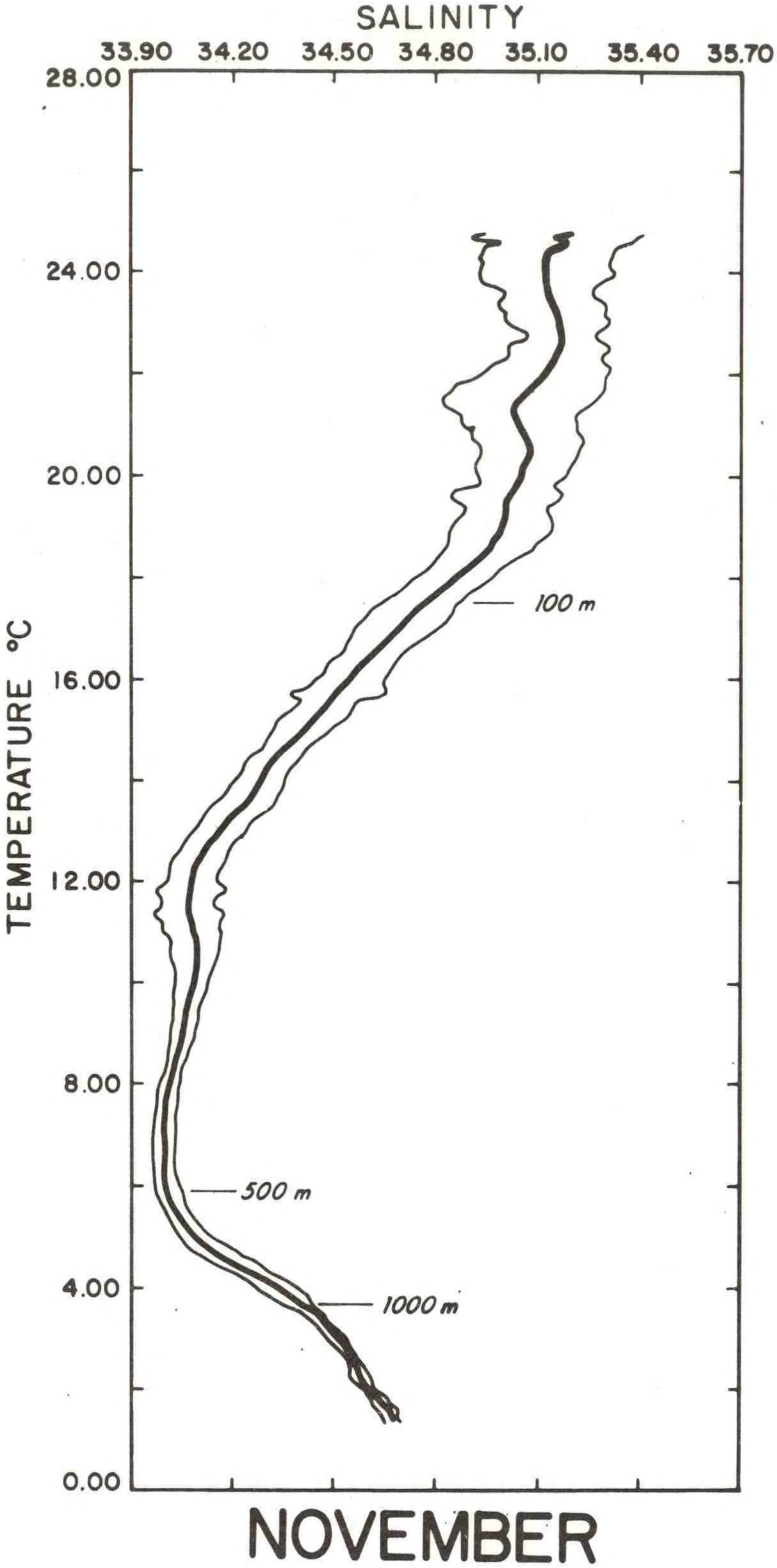

VICTOR
SALINITY
ANNUAL AVERAGE
WINTER
SPRING
SUMMER
FALL
100m
500m
1000m
SALINITY
TEMPERATURE °C

Figure 3.



SALINITY
33.90
34.20
34.50
34.80
35.10
35.40
35.70
28.00
24.00
20.00
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12.00
8.00
4.00
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TEMPERATURE °C
100 m
500 m
1000 m
NOVEMBER

Figure 4.

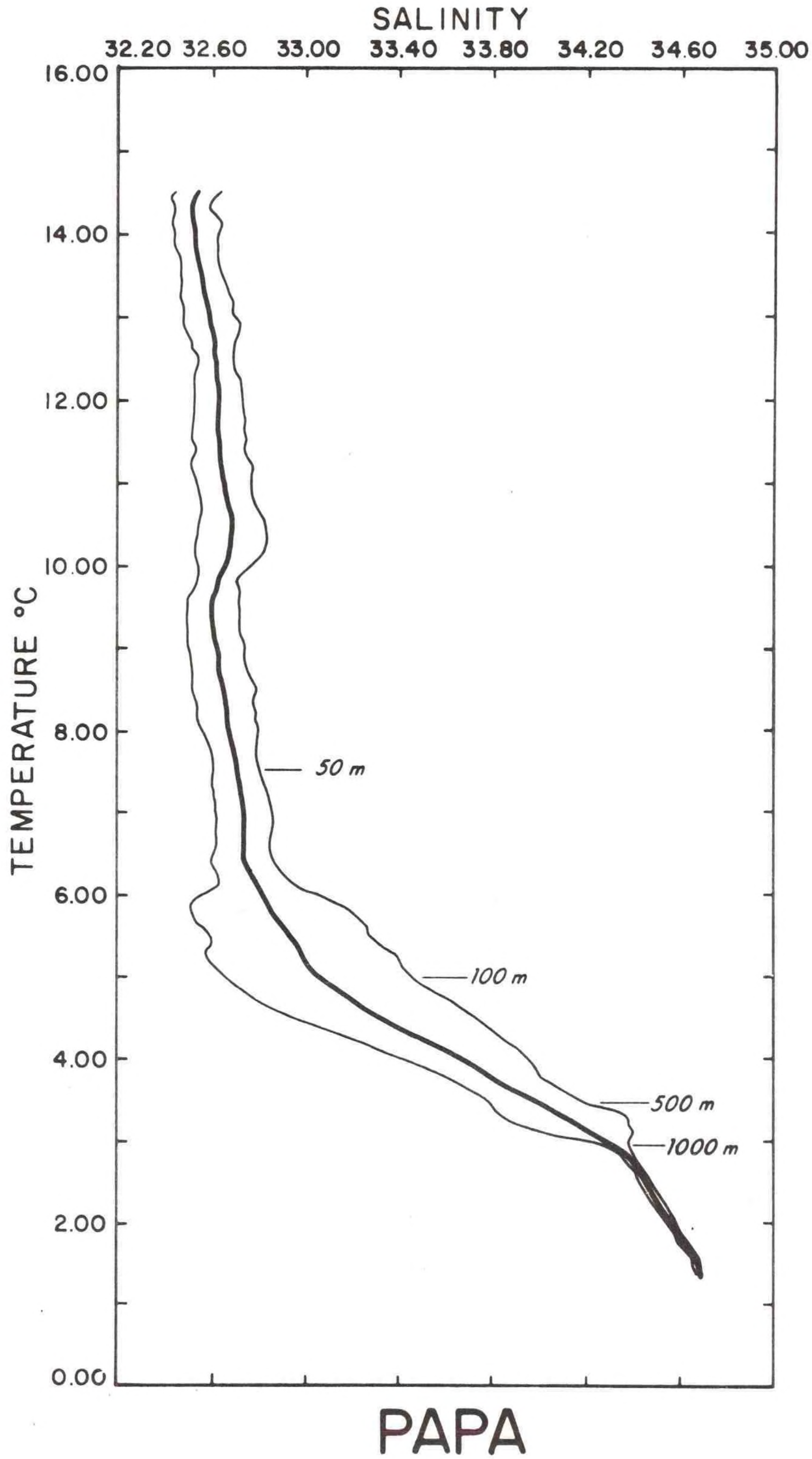
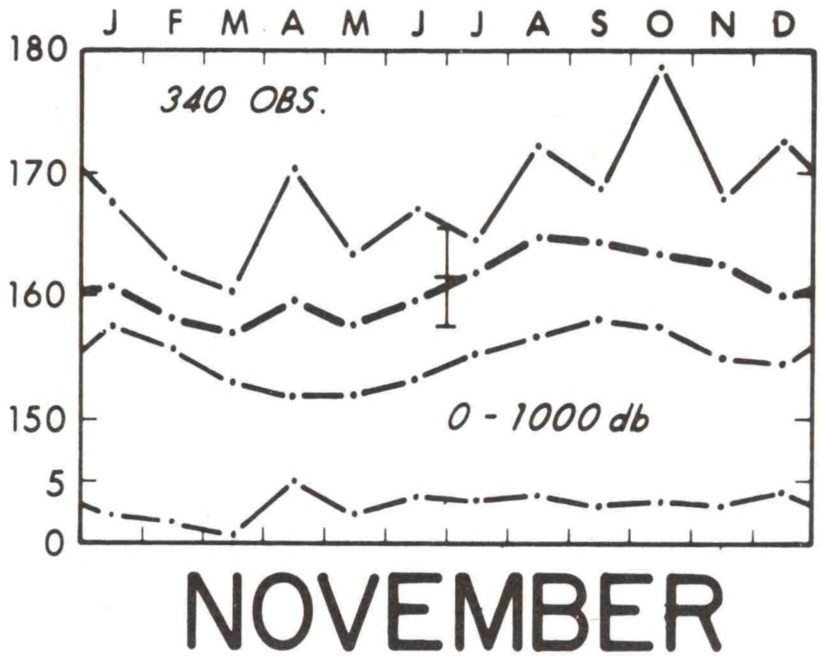

SALINITY
32.20 32.60 33.00 33.40 33.80 34.20 34.60 35.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
TEMPERATURE °C
50 m
100 m
500 m
1000 m
PAPA

Figure 5.

Steric Height Parameters at Three Pacific Weatherships

Region	Size of Area	Time Period	Reference Depth (Meters)	P	P'	Number of Observations	P-P' (dyn cm)
	2°	Annual	1000	26.443	26.441	172	1.8
Station	2°	Annual	500	12.922	12.920	302	1.4
VICTOR	2°	Spring	1000	26.598	26.597	45	2.0
	2°	Summer	1000	26.335	26.331	60	1.2
	2°	Fall	1000	26.377	26.379	37	1.5
	2°	Winter	1000	26.510	26.511	30	1.6
	2°	Annual	1000	26.470	26.472	149	1.9
Station	2°	Annual	500	12.914	12.918	211	2.2
NOVEMBER	6°	Annual	500	12.904	12.905	131	2.7
	10°	Annual	500	12.923	12.962	82	5.6
	2°	Annual	1000	26.960	26.885	158	10.2
Station	2°	Spring	1000	26.982	26.901	51	10.2
PAPA	2°	Summer	1000	26.937	26.885	53	9.9
	2°	Fall	1000	26.933	26.861	47	8.9
	2°	Fall	500	13.288	13.273	60	5.3
	2°	Winter	1000	26.978	26.900	44	9.6

Figure 6.


J F M A M J J A S O N D
180
170
160
150
5
0
340 OBS.
0 - 1000 db
NOVEMBER

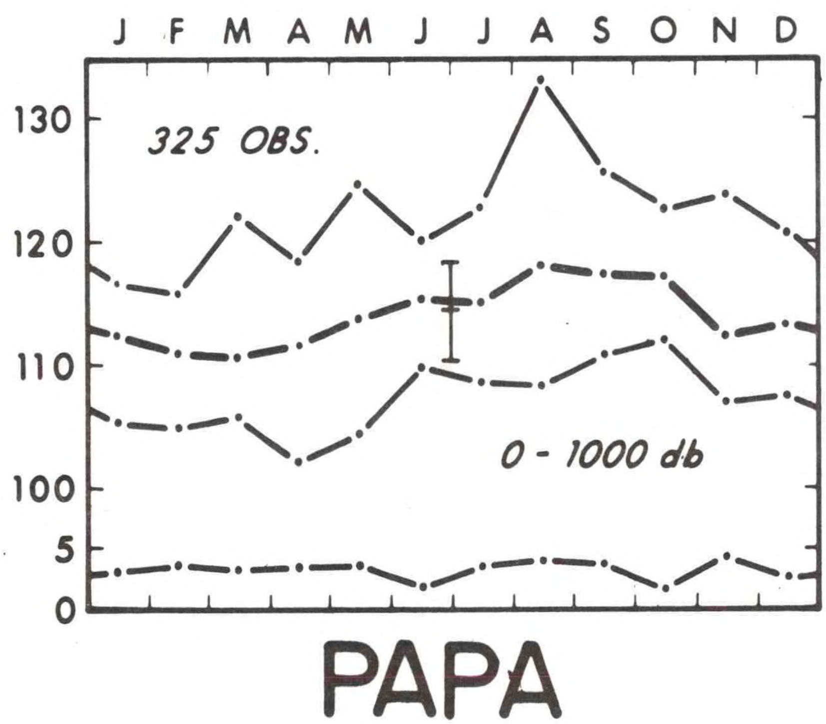

J F M A M J J A S O N D
130
120
110
100
5
0
325 OBS.
0 - 1000 db
PAPA

Figure 7.

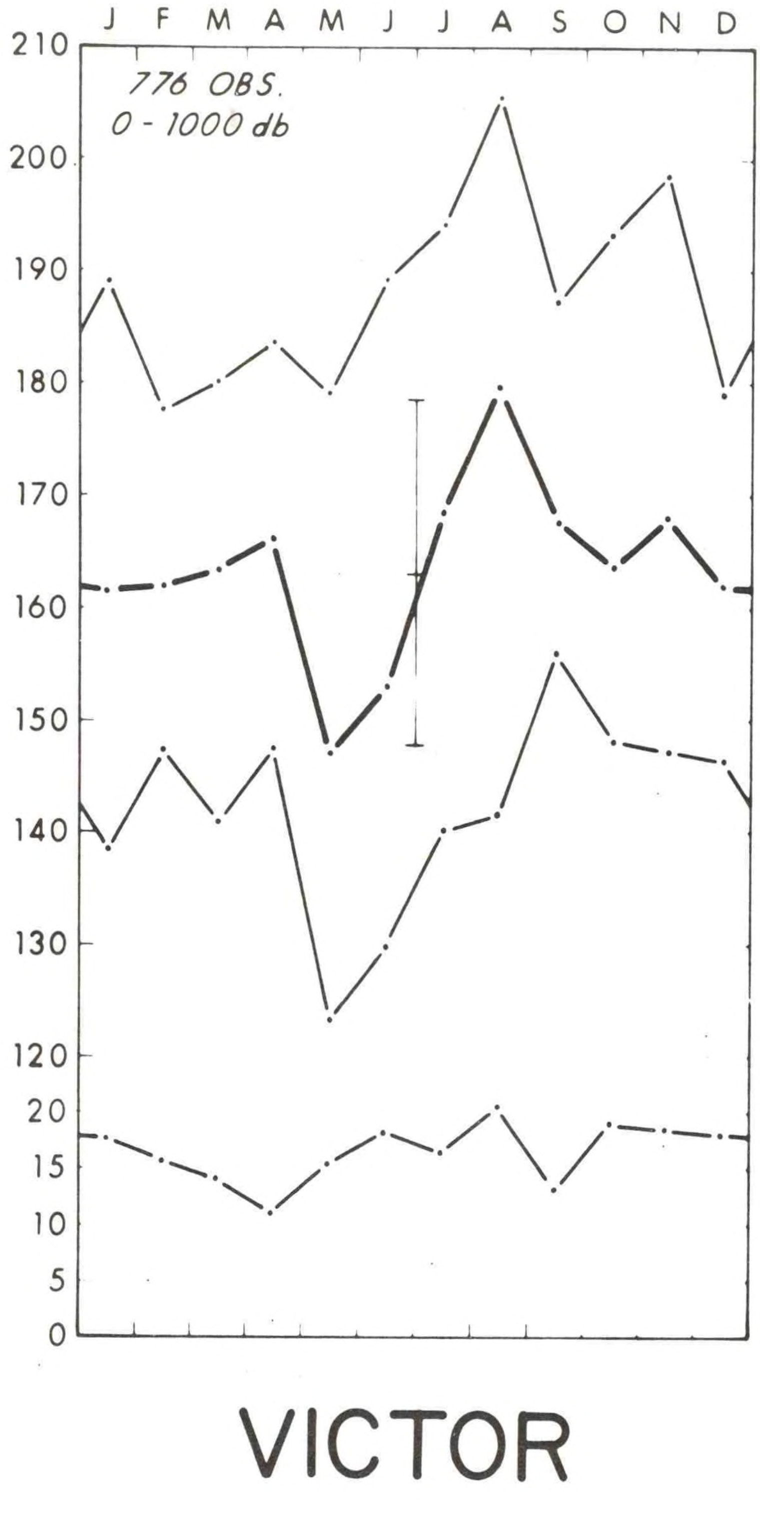
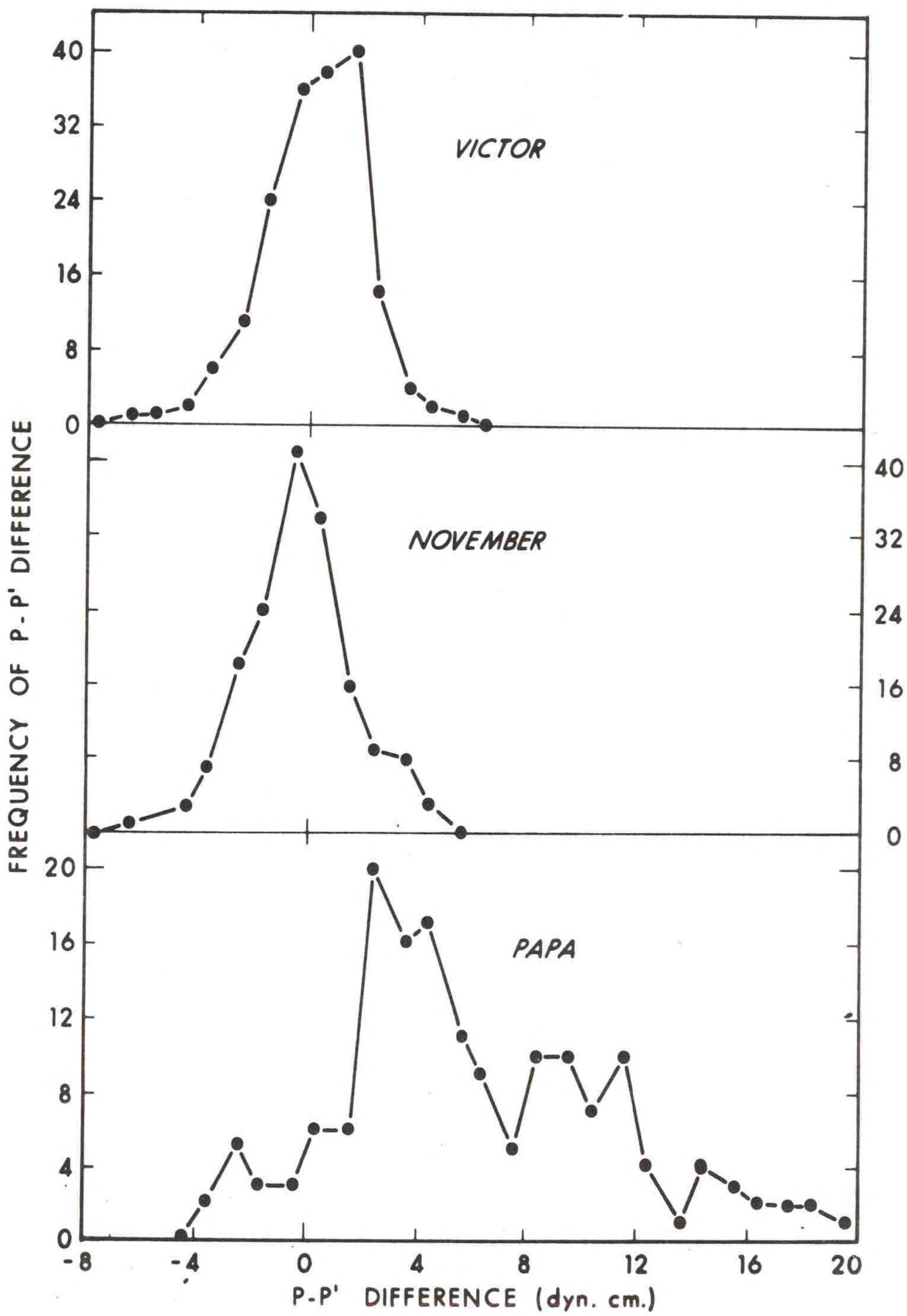

J F M A M J J A S O N D
210
200
190
180
170
160
150
140
130
120
20
15
10
5
0
776 OBS.
0 - 1000 db
VICTOR

Figure 8.



VICTOR
NOVEMBER
PAPA
FREQUENCY OF P-P' DIFFERENCE
P-P' DIFFERENCE (dyn. cm.)
0
8
16
24
32
40
0
4
8
12
16
20
-8
-4

Figure 9.

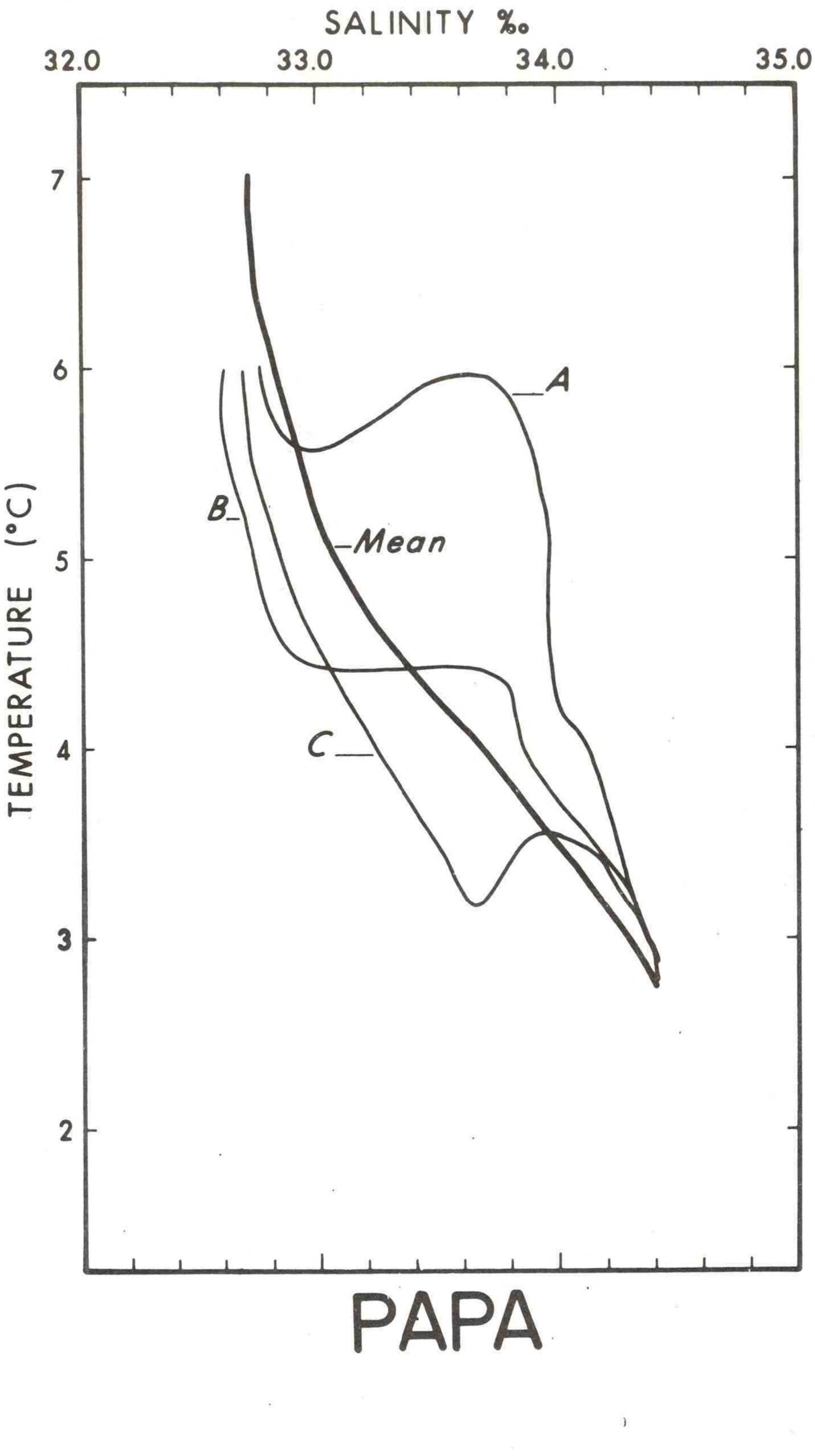


Figure 10.

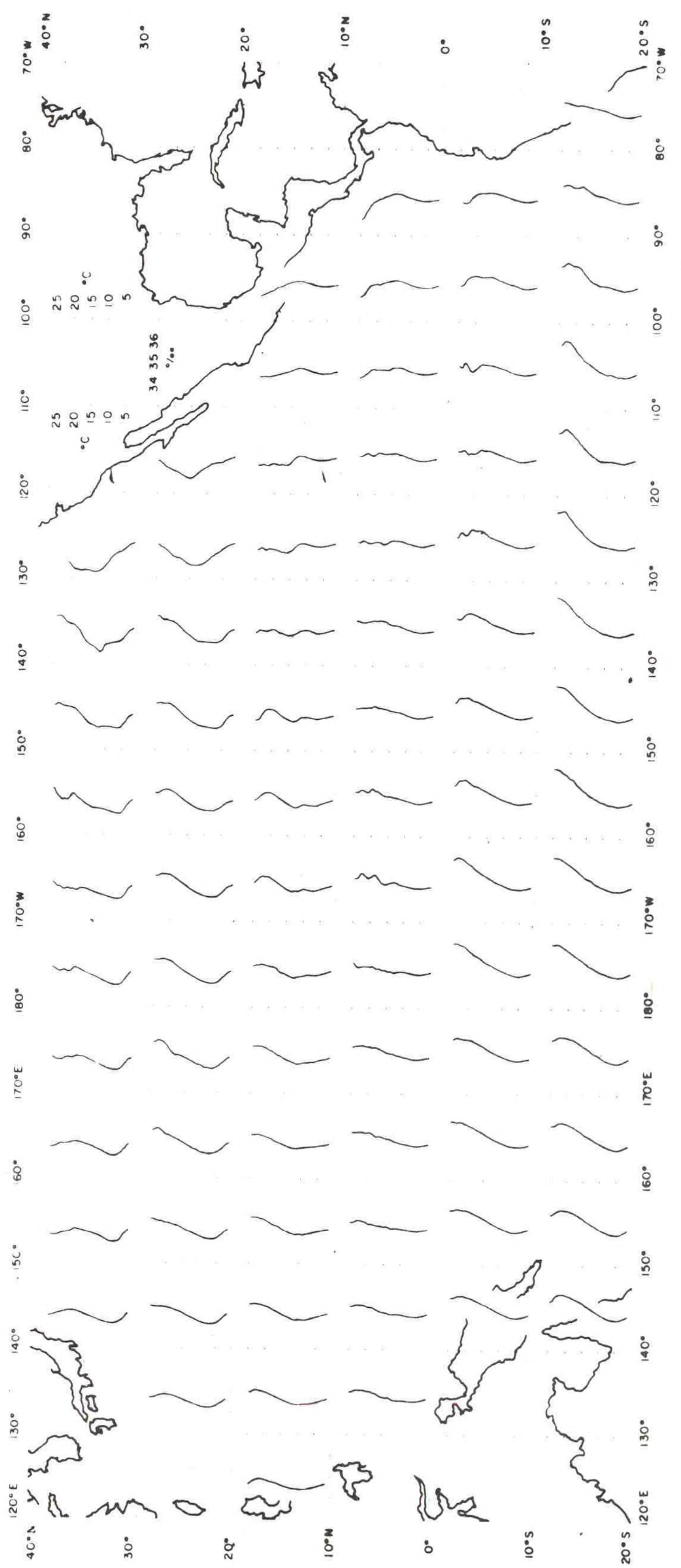

120°E
130°
140°
150°
160°
170°E
180°
170°W
160°
150°
140°
130°
120°
110°
100°
90°
80°
70°W
40°N
30°
20°
10°N
0°
10°S
20°S
25 20 15 10 5 °C
34 35 36 ‰

Figure 11.

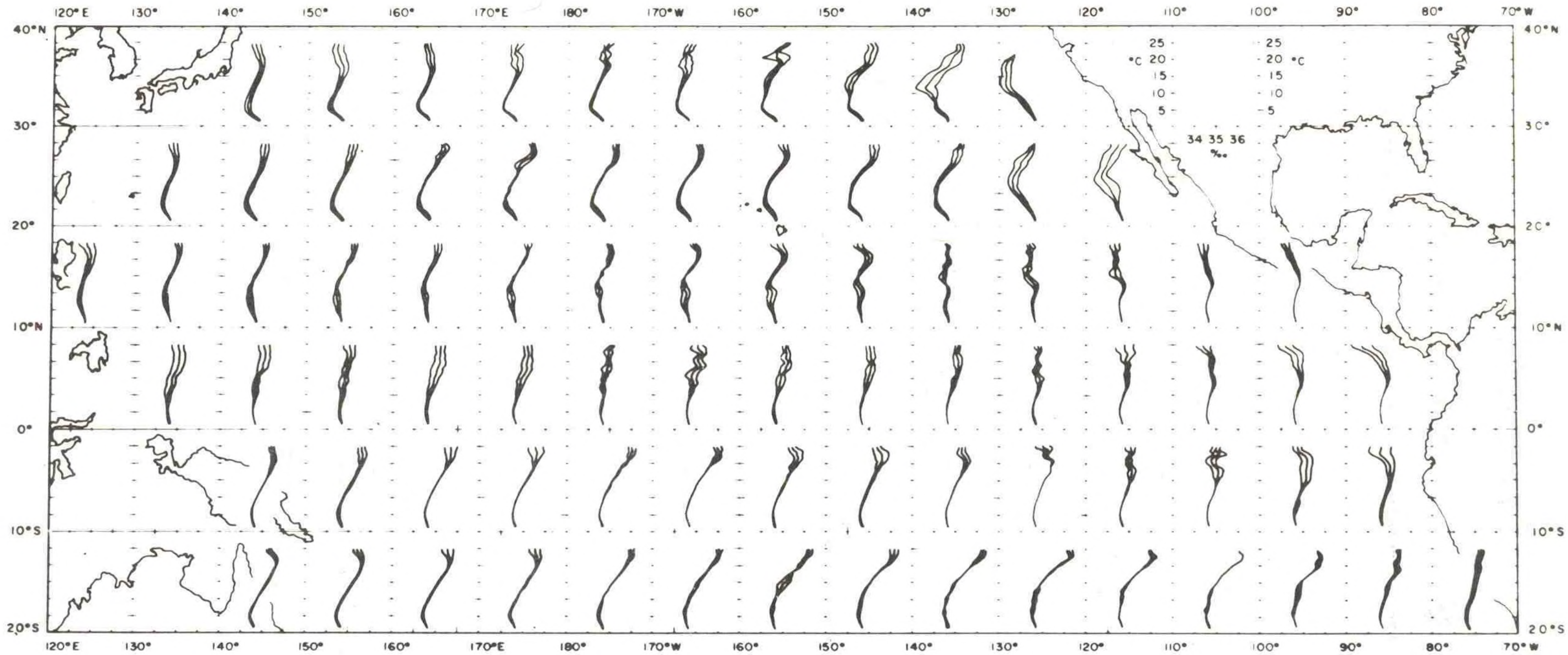

120°E
130°
140°
150°
160°
170°E
180°
170°W
160°
150°
140°
130°
120°
110°
100°
90°
80°
70°W
40°N
30°
20°
10°N
0°
10°S
20°S
25
°C 20
15
10
5
34 35 36
‰

Figure 12.

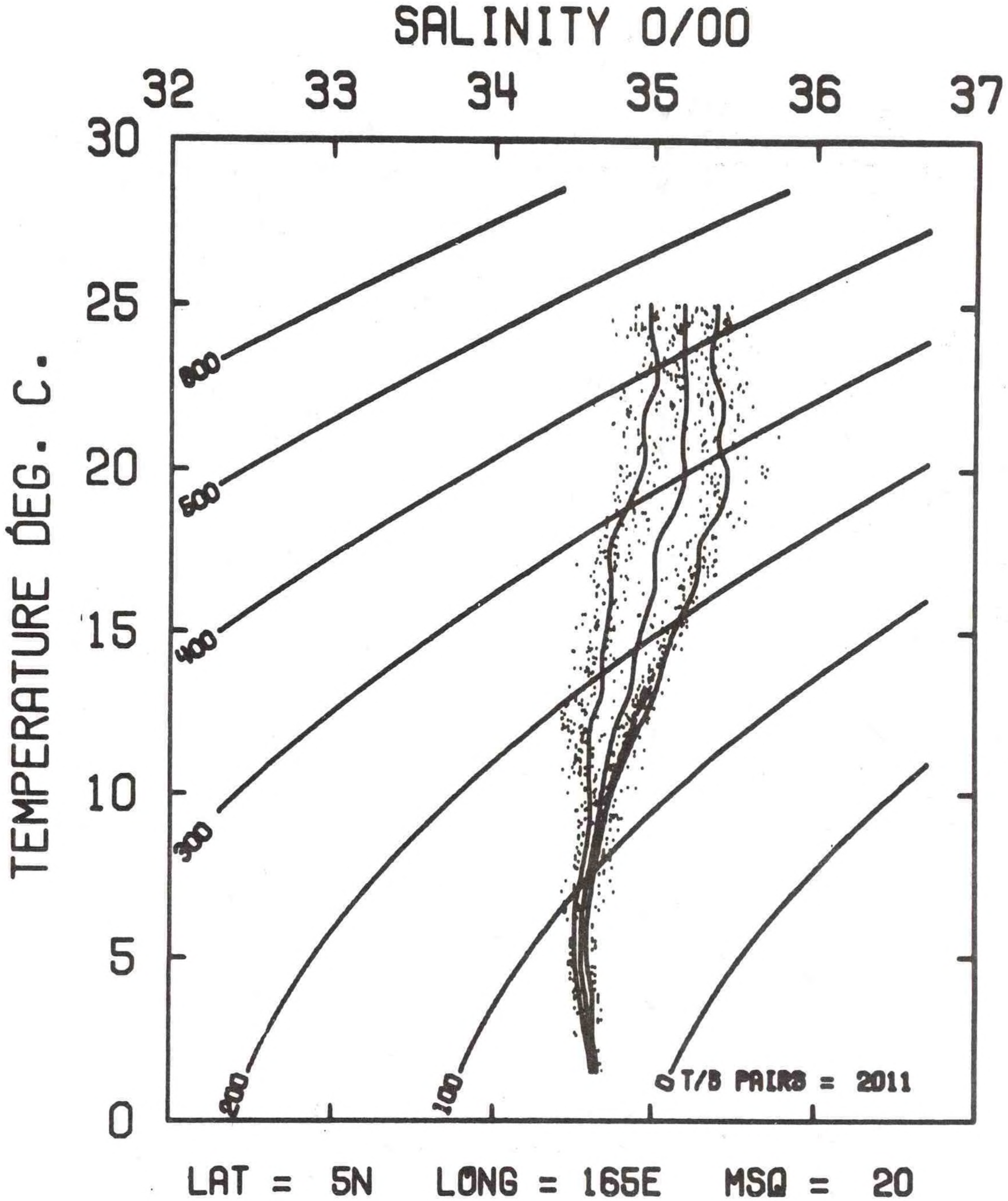

SALINITY 0/00
32
33
34
35
36
37
30
25
20
15
10
5
0
TEMPERATURE DEG. C.
800
600
400
300
200
100
T/S PAIRS = 2011
LAT = 5N LONG = 165E MSQ = 20

Figure 13.

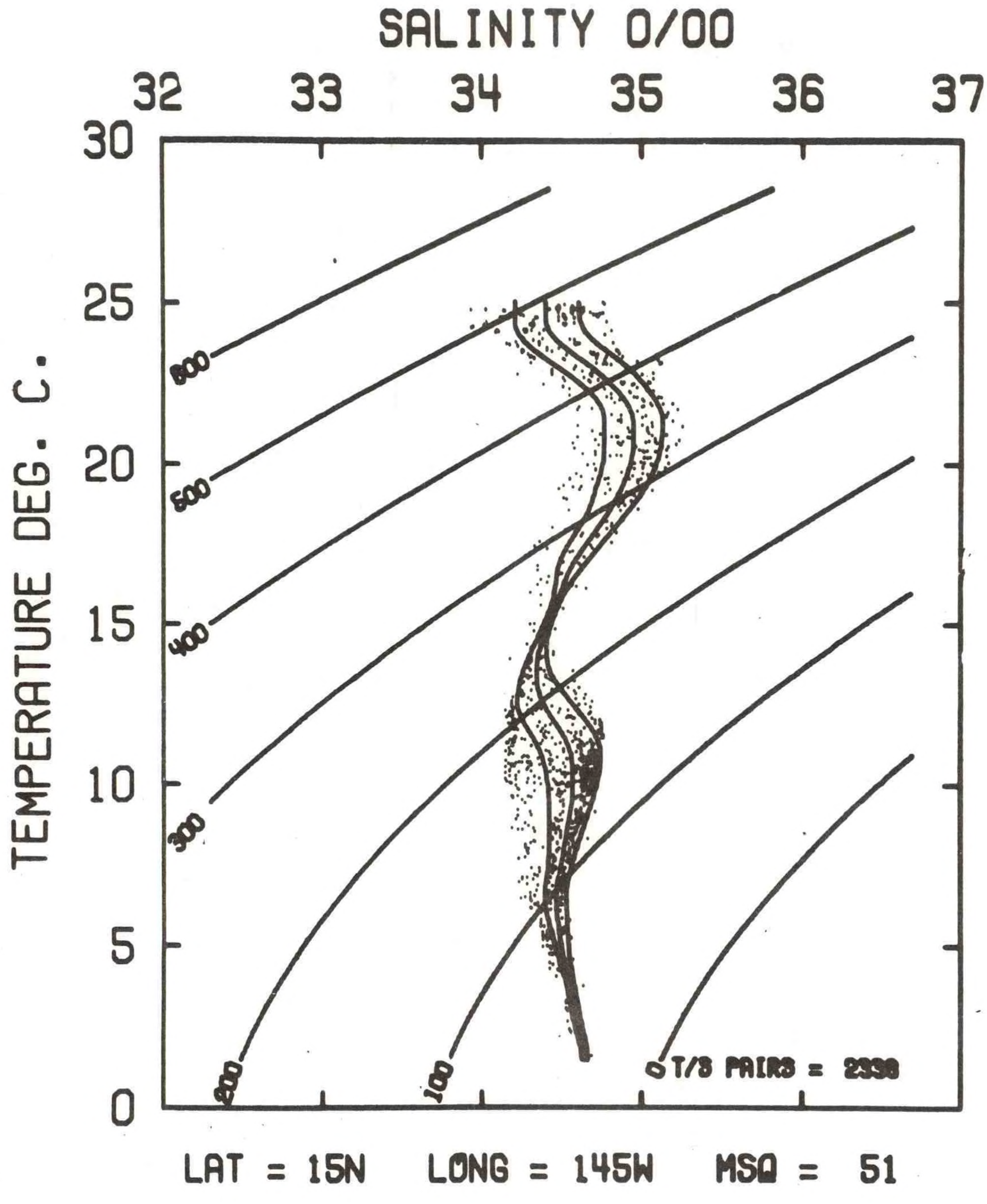
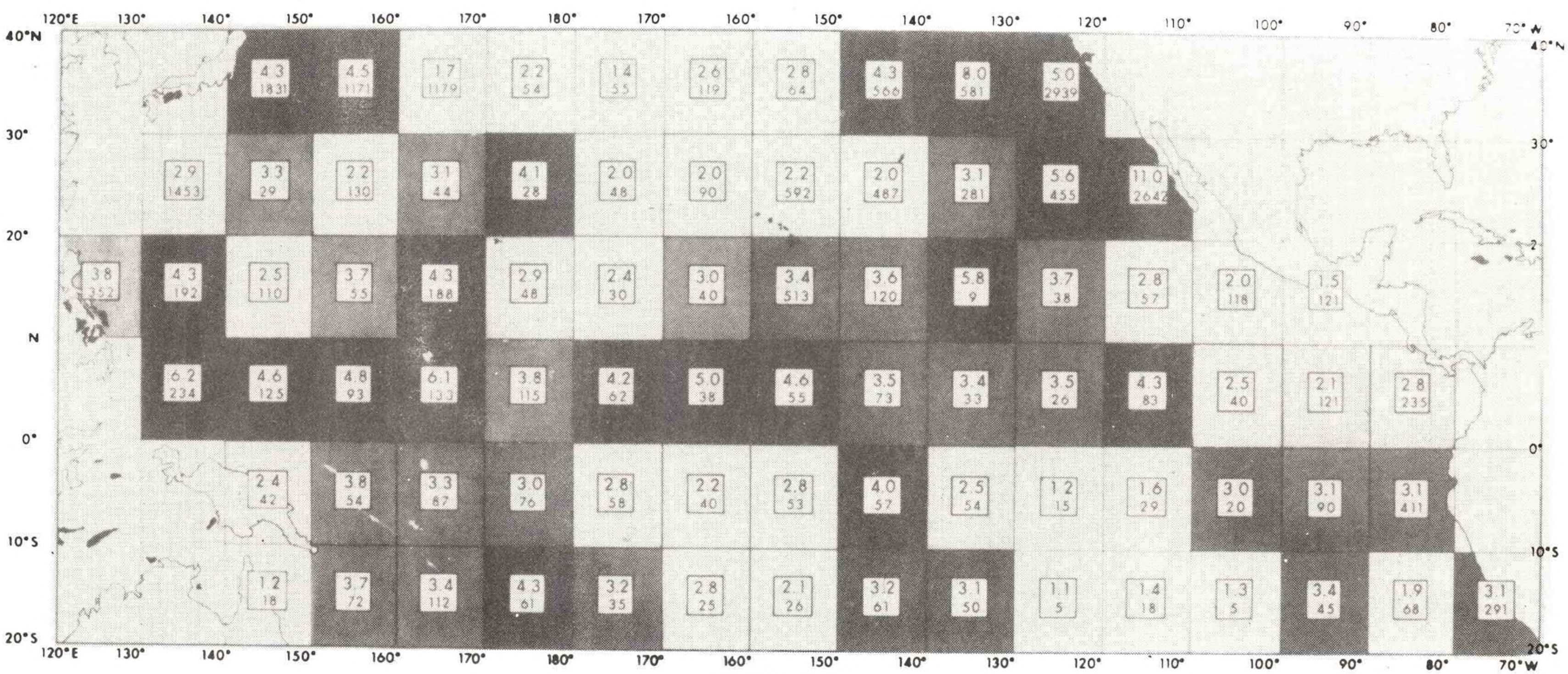

SALINITY 0/00
32
33
34
35
36
37
TEMPERATURE DEG. C.
30
25
20
15
10
5
0
600
500
400
300
200
100
T/S PAIRS = 2338
LAT = 15N LONG = 145W MSQ = 51

Figure 14.



UNCERTAINTY IN
TS DYNAMIC HEIGHT (0/500)

Figure 15.

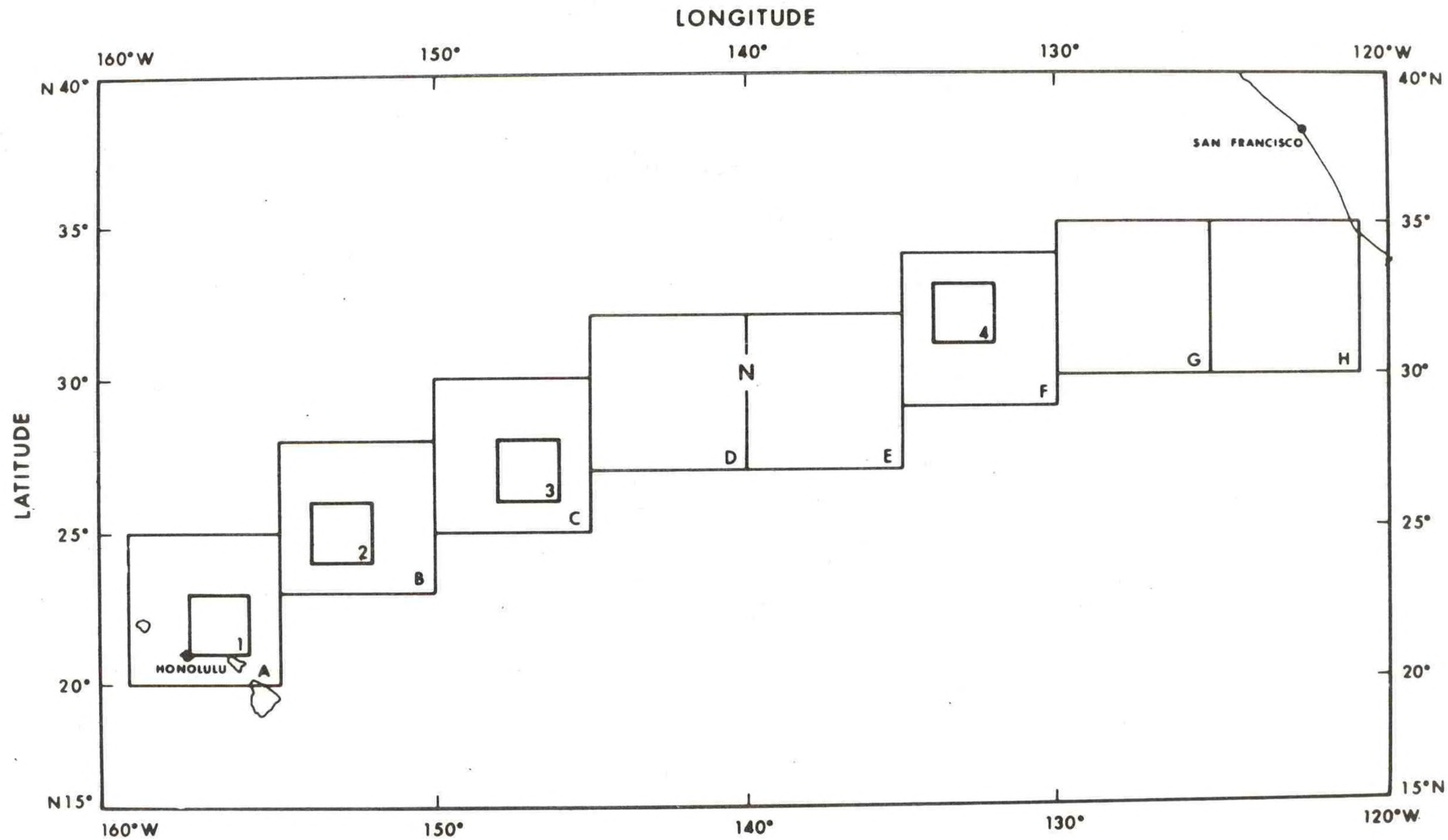

LONGITUDE
LATITUDE
160°W
150°
140°
130°
120°W
N 40°
35°
30°
25°
20°
N15°
40°N
15°N
SAN FRANCISCO
HONOLULU
A
B
C
D
E
F
G
H
N
1
2
3
4

Figure 16.

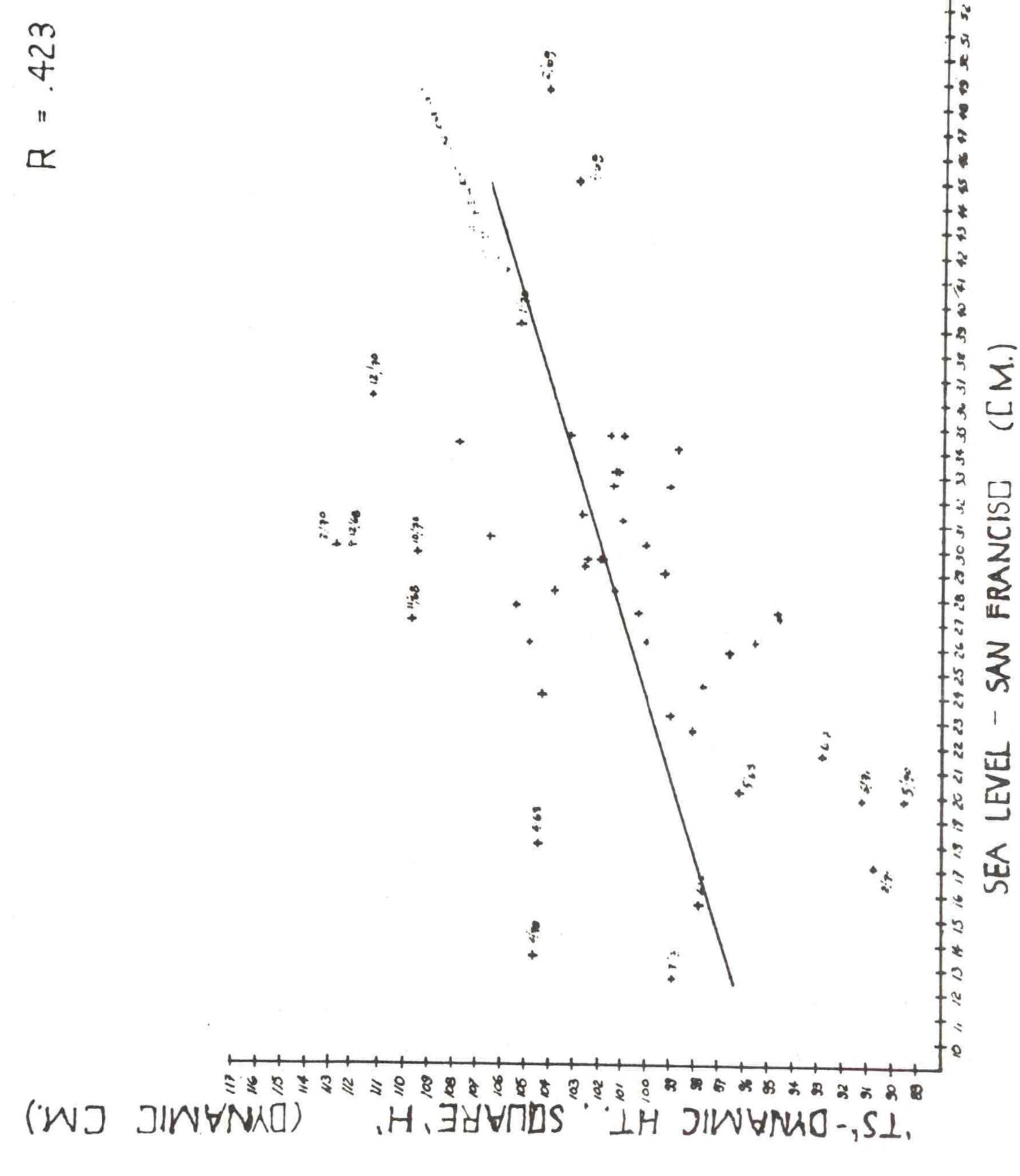

R = .423
SEA LEVEL - SAN FRANCISCO (CM.)
'TS'-DYNAMIC HT. 'SQUARE' H' (DYNAMIC CM.)

Figure 17.

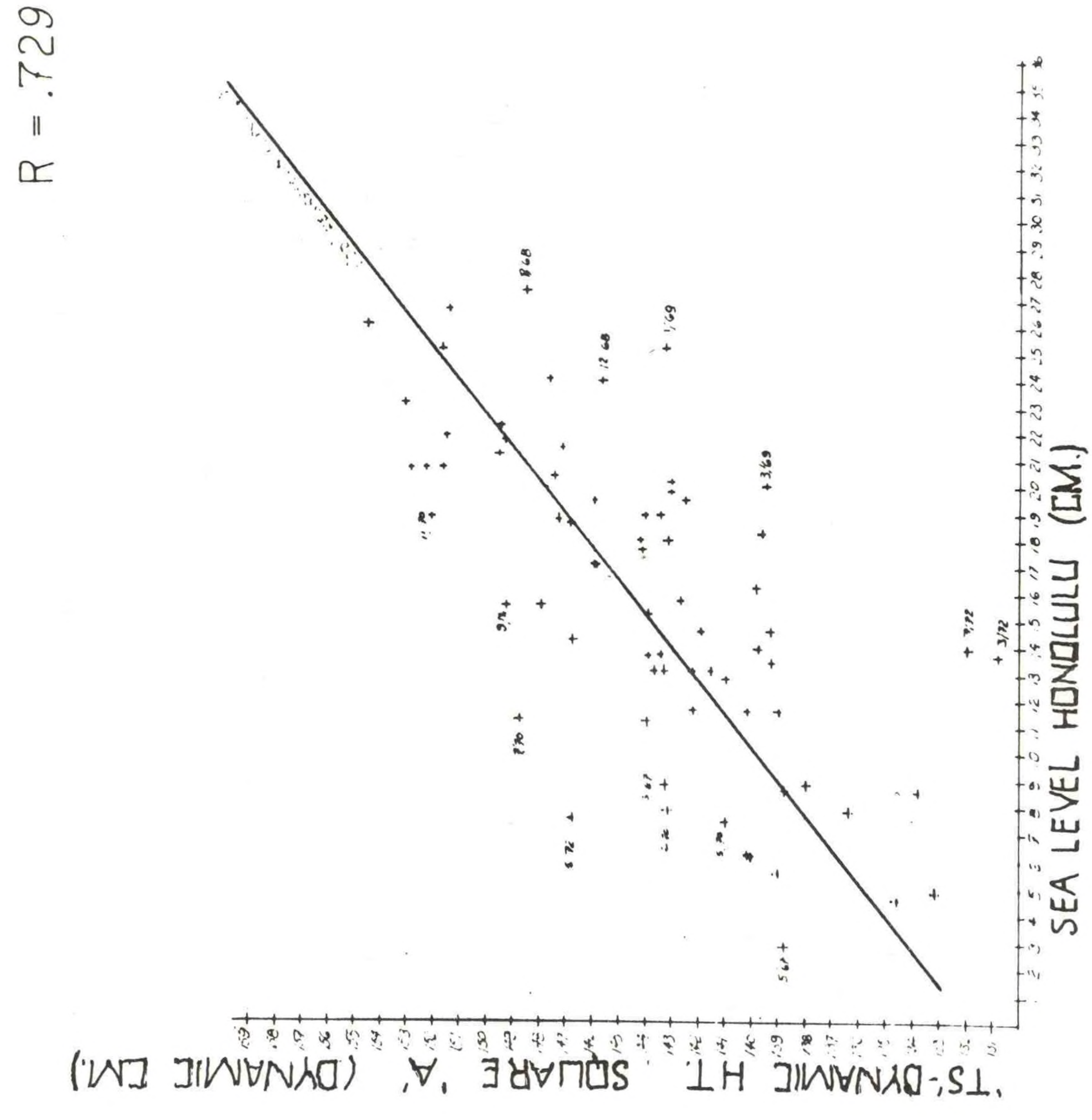


Figure 18.

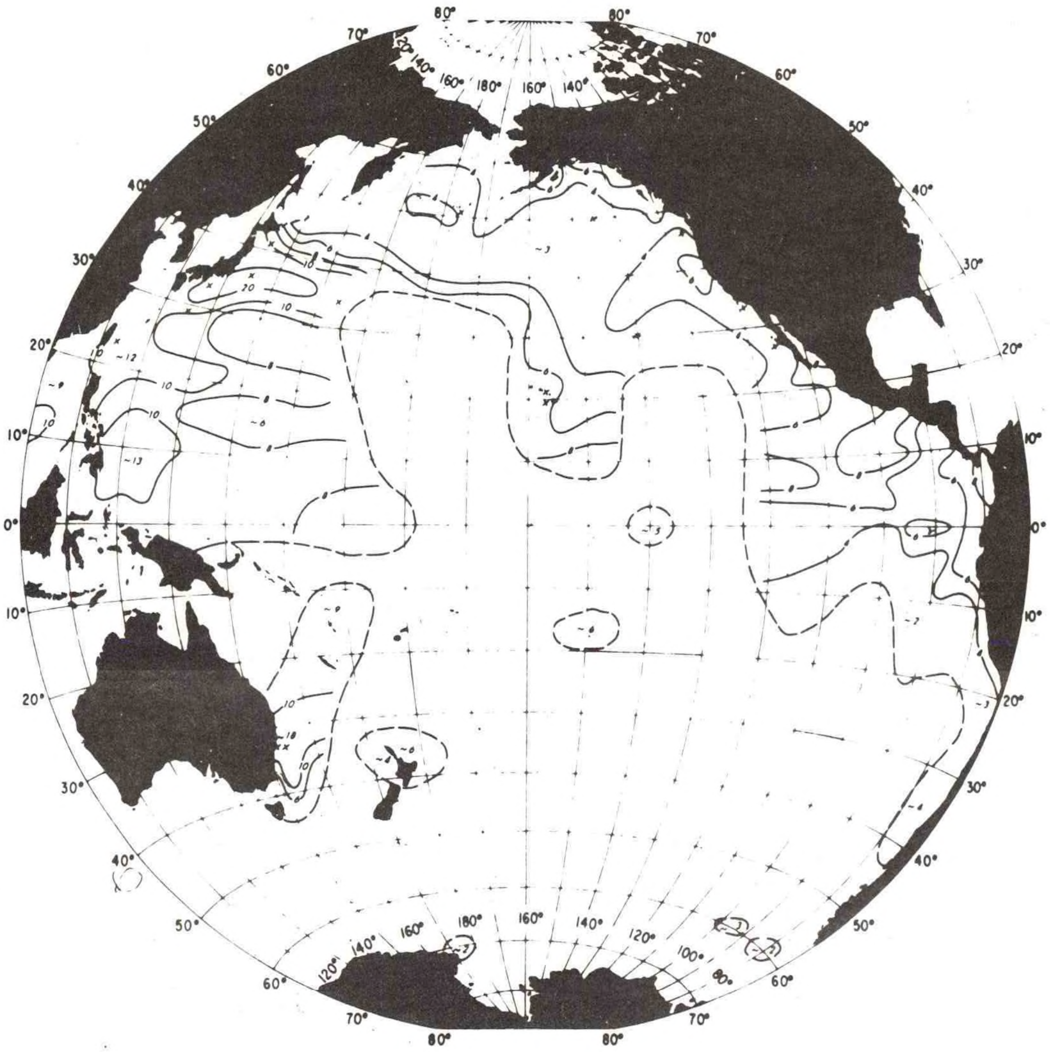

80°
80°
70°
70°
60°
60°
50°
50°
40°
40°
30°
30°
20°
20°
10°
10°
0°
0°
10°
10°
20°
20°
30°
30°
40°
40°
50°
50°
60°
60°
70°
70°
80°
80°
140°
160°
180°
160°
140°
120°
140°
160°
180°
160°
140°
120°
100°
80°

Figure 19.

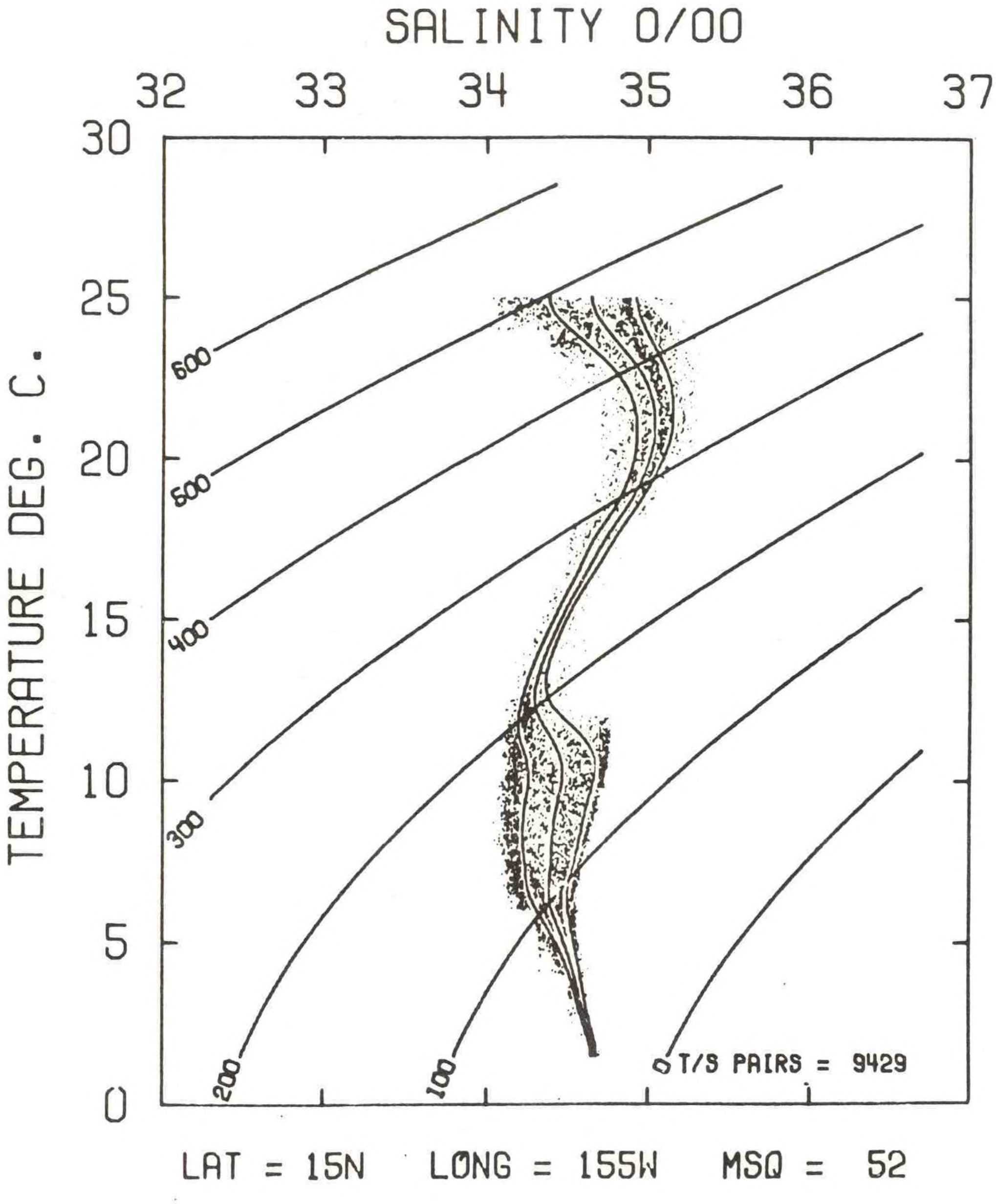

SALINITY 0/00
32
33
34
35
36
37
30
25
20
15
10
5
0
TEMPERATURE DEG. C.
600
500
400
300
200
100
0
T/S PAIRS = 9429
LAT = 15N
LONG = 155W
MSQ = 52

Figure 20.

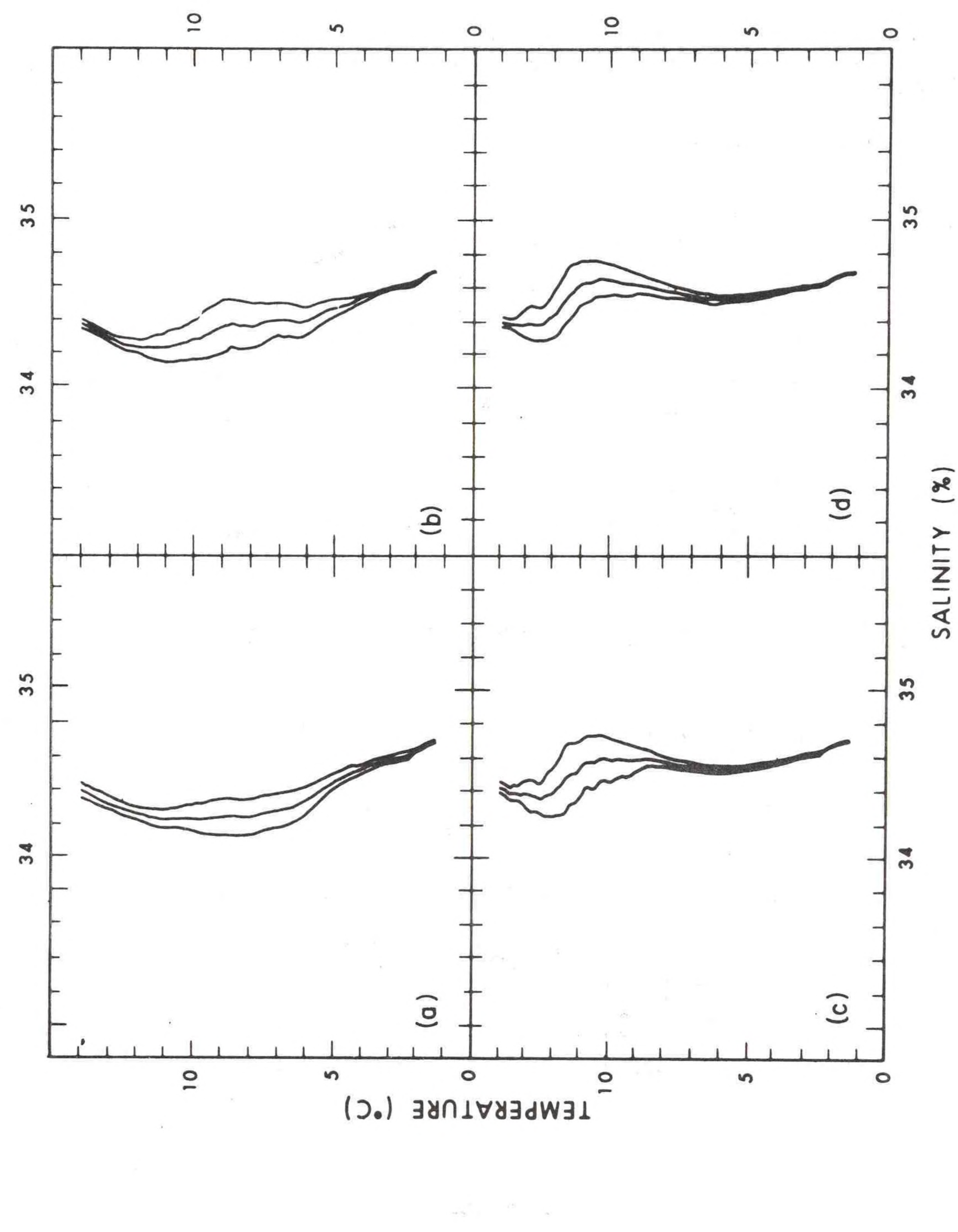


Figure 21.

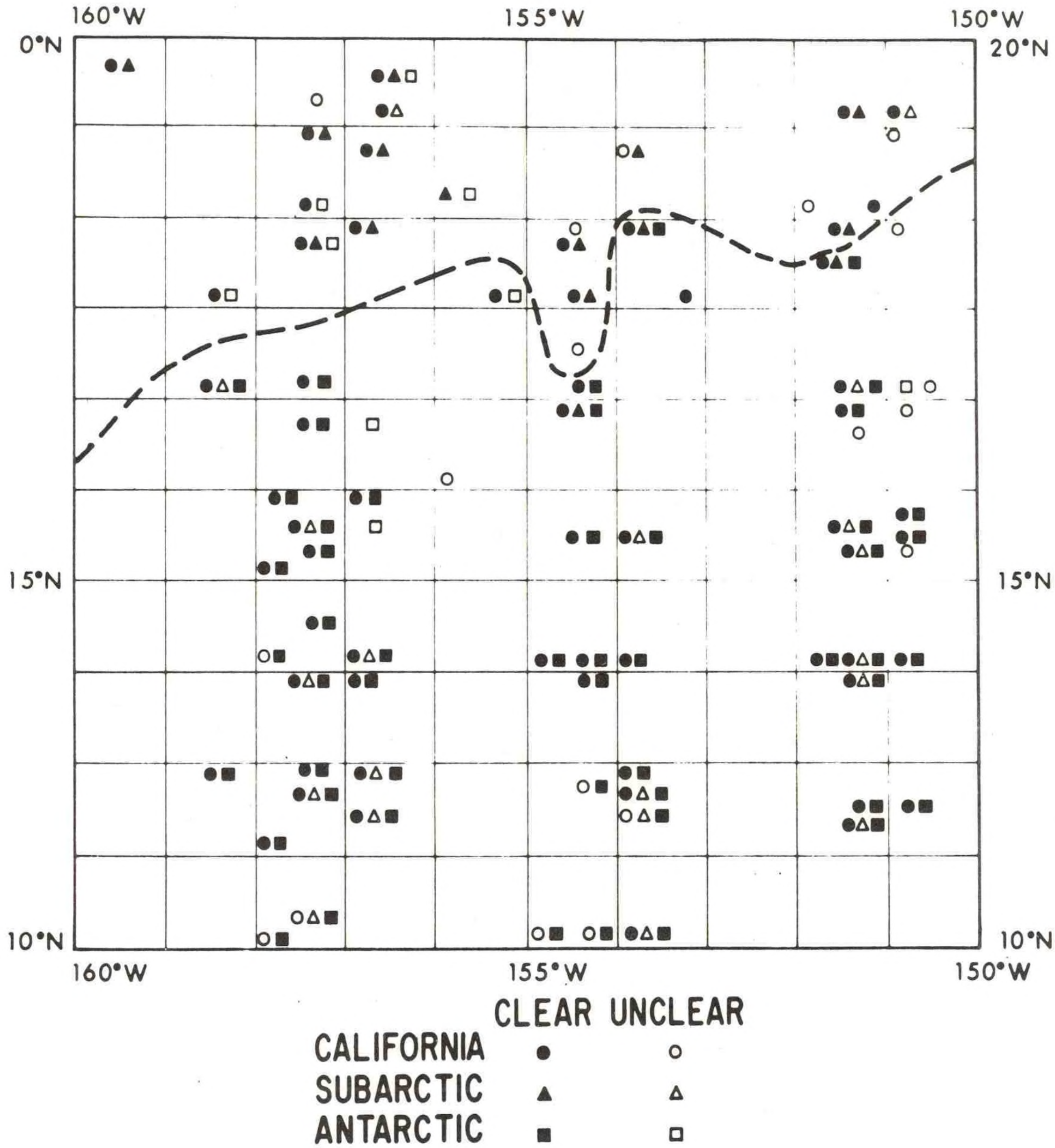

160°W
155°W
150°W
0°N
20°N
15°N
15°N
10°N
10°N
160°W
155°W
150°W
CLEAR UNCLEAR
CALIFORNIA
SUBARCTIC
ANTARCTIC

Figure 22.

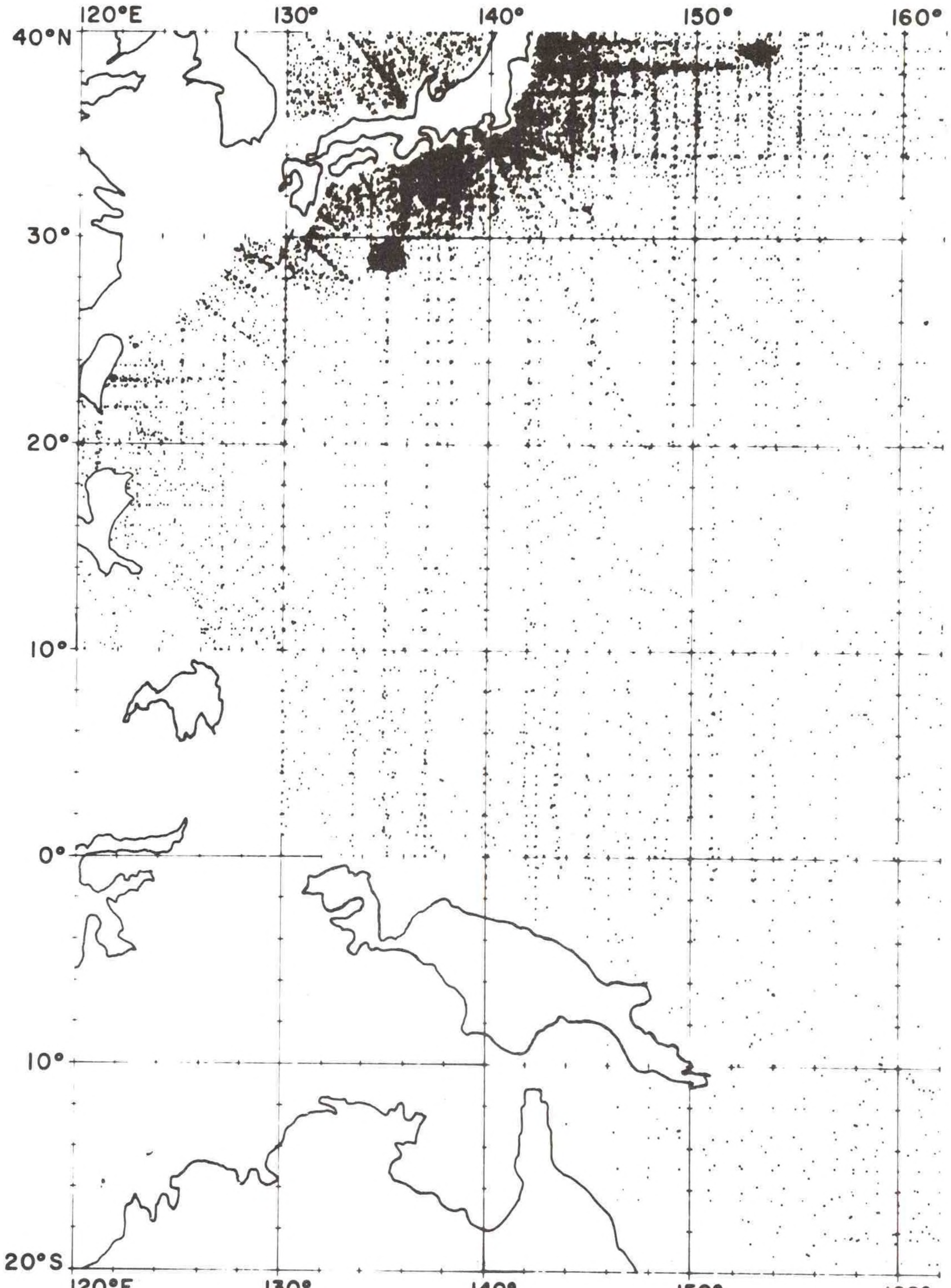


Figure 23.

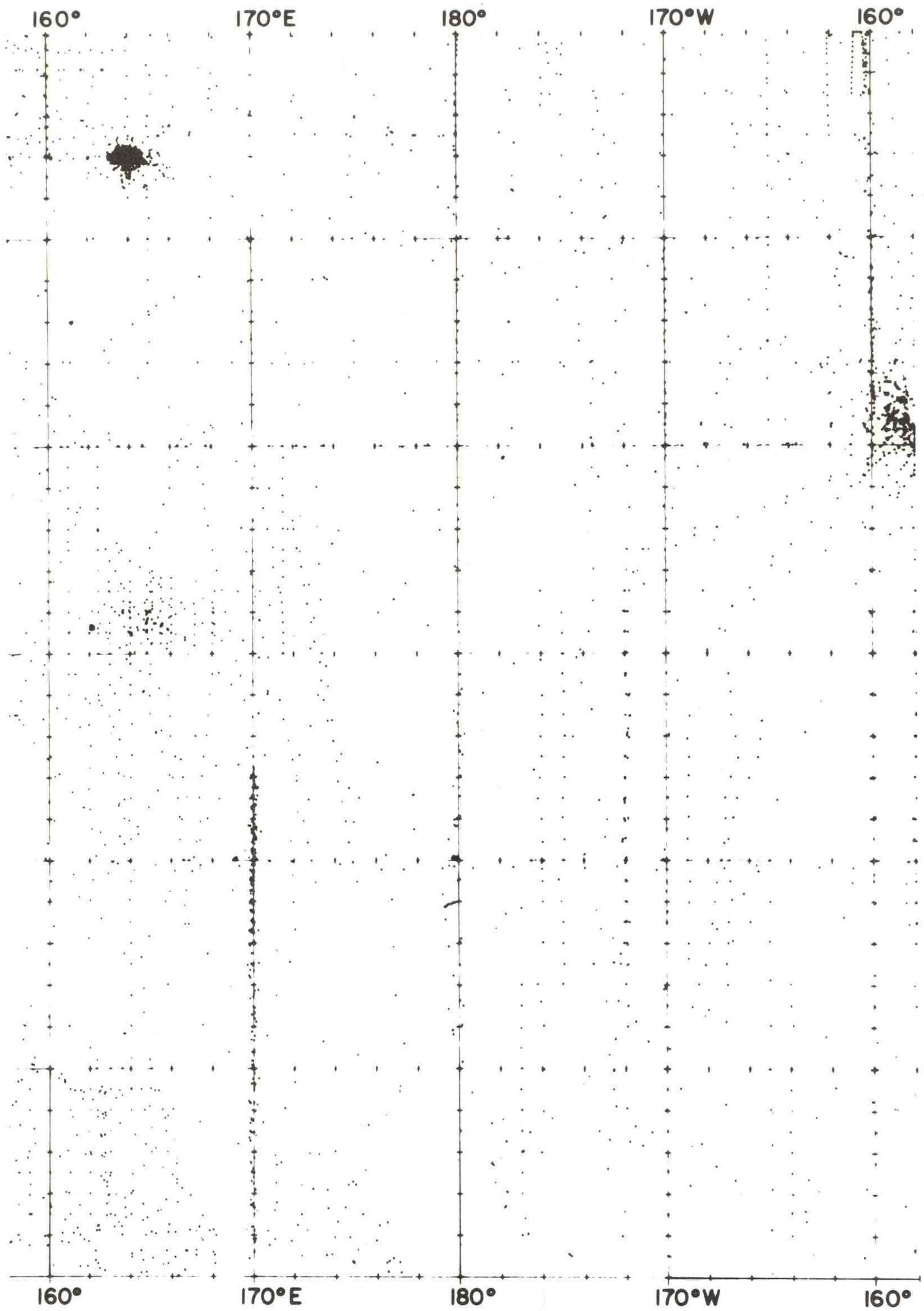


Figure 24.

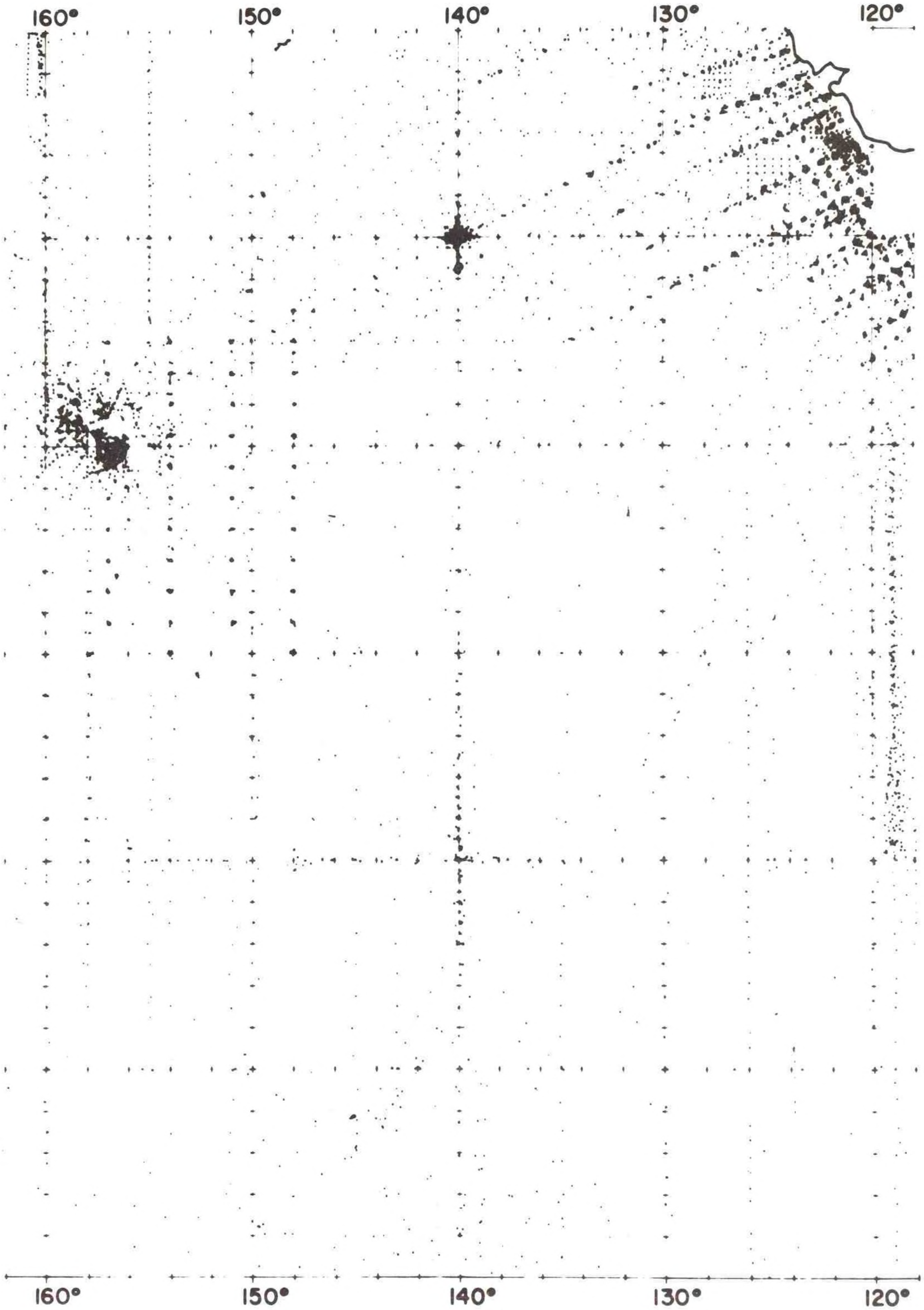


Figure 25.

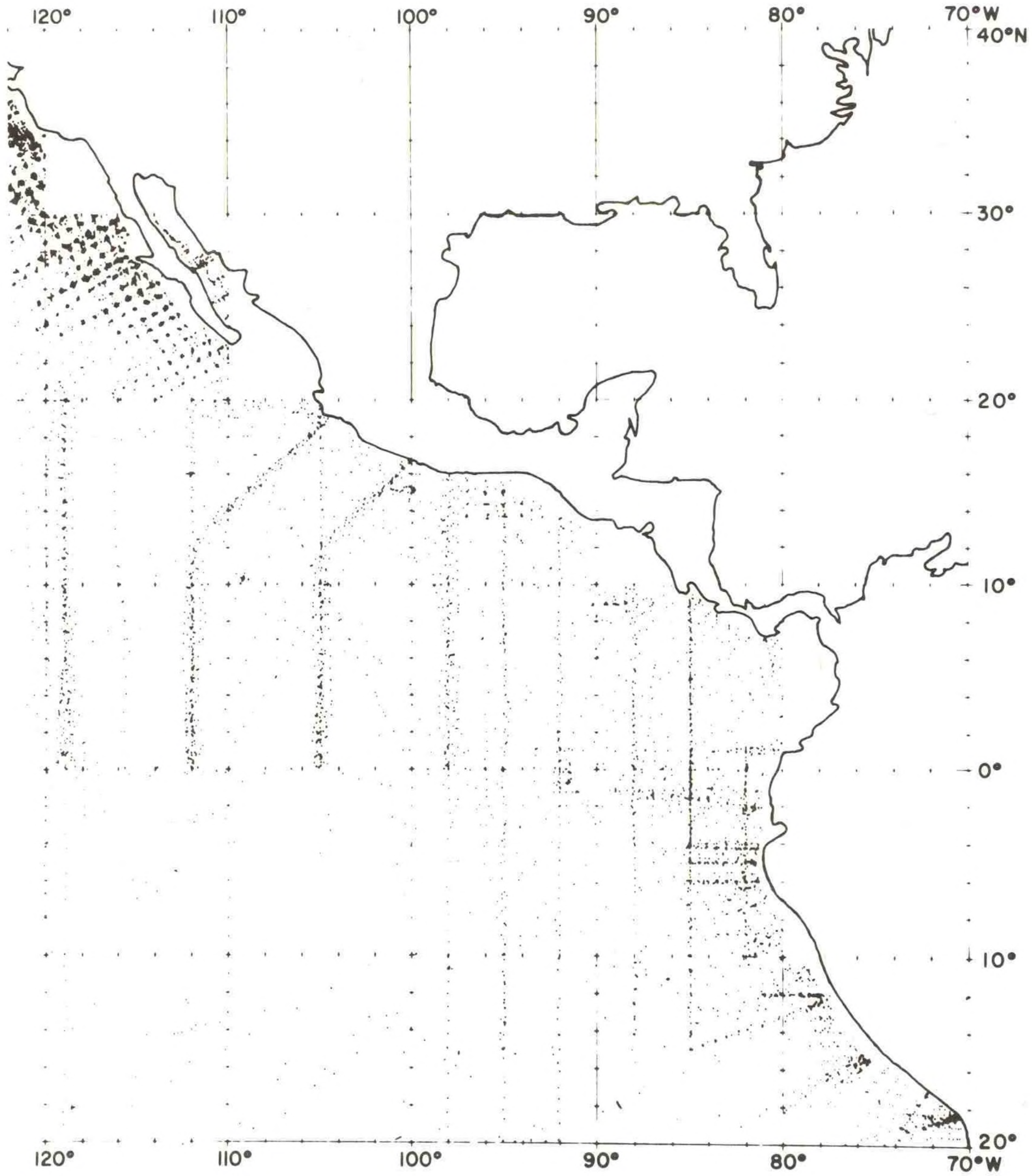


Figure 26.

QUESTIONS AND DISCUSSION

MR. HOLBROOK: *Can you give me a number for the areas where you feel salinities do not need to be measured, that gives me an idea of the RMS variation? In other words, what sort of variation in salinity can you get with this sort of technique? What's our accuracy?*

DR. EMERY: If you look at any of these plots, it depends on what interval of depth it is.

MR. HOLBROOK: If it's in the lower part where it seemed to be pretty good.

DR. EMERY: I think the number that I once came up with when I was forced to do that was smaller than .2, say .13 or something like that. But it depends over what interval of the TS curve, again.

MR. HOLBROOK: *And a rough ballpark number for the near surface variations of salinity?*

MR. EMERY: Well, it turns out the near surface, as you saw on all of those, has a very large salinity deviation. You're talking about even .5. But that, because it is over a small interval of depth, is a small part of the dynamic height computation and has not been a problem.

DR. FLITTNER: *Would you care to delineate those sectors of the Pacific Ocean that you have looked at, where you do not feel that we need to monitor salinity? You gave us areas of the plots, but you did not contour or delineate it in any particular way. From a Washington planner's point of view, it would be neater if we could delineate these regions where we have primary interest and should focus our attention, and to recognize other areas where we do not need to plan a great deal of measurement* or *observation of salinity.*

DR. EMERY: The only plot that comes even close to approaching that answer is the plot of the RMS differences (Fig. 15). I chose not to contour it because it's block averaging by 10° squares. The only caution that needs to be applied in using that to decide where we don't need to measure salinity is mainly that the areas which look very good are very limited in the number of available data. So I don't know if that's a limited data problem or not. I suspect no, but I think you'd have to check it out. That's why I presented this data distribution thing. It would be very nice if we had some more data in those areas to really finally answer that question. But I would, on the basis of this map, say that the central Pacific between 20° south and the equator looks very good. I think that the TS relationship there is quite stable. There are a few exceptions which perhaps should be studied individually, but by and large that's very good. Again, north of 20° and south of 40° there are large regions in the central ocean that look very good. But I don't want to deemphasize the problem of data distribution.

MR. MILLARD: *Have you estimated the geostrophic velocity errors associated with this technique? I know it depends on what spacing or separation you use, but I think that's one thing you probably want to address. We're after geostrophic velocities, I assume, or at least that's one thing we would like.*

DR. EMERY: You may be. That may be your application. And the student of Klaus' that's working with this will have to address the problem since he is looking at geostrophic velocities. The whole approach here was to see if you could do dynamic topography. Again, if you are interested. But I would say since that's a difference, it shouldn't be any worse. I have not done the calculations. It has been mentioned to me that I should, but I never got around to it.

MR. MILLARD: *I think I saw gradients of dynamic topography over the Pacific of something like 6 dynamic centimeters; is that correct. Zero to 5?*

DR. EMERY: That wasn't a picture of gradients. That was standard deviations. That was not a picture of dynamic topography.

MR. MILLARD: *What is the dynamic topography variation over a region of 300 to 500 kilometers?*

DR. WYRTKI: Well, 20, 30 dynamic centimeters.

MR. MILLARD: *On which you would assign an error of about, 2 dynamic centimeters associated with the near surface variation:*

DR. WYRTKI: I would say so. Yes. And that's the error that you have in your station anyway. If you go to make a station now and take it an hour later or make it 20 miles away from your point, your error is about plus or minus 3 dynamic centimeters.

MR. MILLARD: I've done those calculations as far as the western north Atlantic and found internal wave sources of contamination on the order of .8 dynamic centimeters.

DR. WYRTKI: That depends entirely on the area you were working in.

MR. MILLARD: Oh, very definitely.

DR. WYRTKI: And the quotes are nice except, I would say, in Indoneasia in waters where the dynamic topography changes with the tidal cycles by plus or minus 10 dynamic centimeters.

MR. RODEN: I have an answer for Glenn Flittner. It's not correct to ask the question which phases of the ocean can we consider where we don't need any salinity measures. We have to put it a different way. The first of what you say is your main interest, geostrophic currents. Then you don't have to know a detailed salinity knowledge between, let's say, 20° south, 40° north. You can use existing TS relationships. Because there are many more other problems in the ocean, even in the tropical latitudes. But otherwise, you have to know the salinity and also those other problem things, for example, regions where the mixing is intense and such things. So I say the answer to this really depends on the problem you are trying to solve. You can't generalize.

DR. EMERY: Yes, I think that's really true. That's a question I really hesitated to answer.

DR. EMERY: As a bit of an advertisement, I just want to say there is a report out, a Scripps report by Rich Wert and myself that contains the curves that you have seen here, and you can write to Rich or myself. We can furnish you with that.

MR. CANADA: *What's the title of that book?*

MR. EMERY: Mean TS Curves in the Pacific and Application of TS Dynamic Height Computations.

ON VERIFICATION DATA FOR NUMERICAL MODELS OF THE MIXED LAYER

Mr. Michael D. Cox, Geophysical Fluid Dynamics Laboratory, NOAA, Princeton, New Jersey

Abstract. An important link between numerical models of the atmosphere and oceans is a model of the mixed layer of the ocean. Several such models have been proposed, but long time sequences of data from the ocean suitable for checking the different mechanisms involved are very scarce. In particular, the efficiency of the transmission of K.E. into the mixed layer from the wind as a function of the depth of the mixed layer must be known better in order to employ the Kraus-Turner model accurately. Many long term data sets are needed to determine this and other unknowns about the mixed layer.

Our primary purpose at GFDL is the 3-dimensional numerical modeling of both oceans and atmosphere, with the ultimate goal of having a coupled model of ocean and atmosphere to do climate predictions.

The importance of the oceans on the climate has been well established by previous studies, two of which have been done at our lab by Manabe and Bryan. They find that the effects of the ocean are very important, particularly in the lower latitudes. Another study, which was done at our lab by Shukla, of the dependence of rainfall over India on the sea surface temperature of the Arabian Sea, indicated a fairly high correlation there.

The way these coupled air-sea models are run at GFDL is that the atmosphere gives the ocean the boundary conditions of wind stress, heat flux, and water flux across the surface. In return, the ocean gives the atmosphere the sea surface temperature; only one quantity. Typically, the resolution of our ocean models would be, say, around 50 kilometers up to around 500 kilometers, depending on the size of the region of the ocean they were covering. For the world ocean, with the computers we have now, it still has to be on the order of hundreds of kilometers. And typically we run about 10 layers in the vertical, ranging from about 50 meters thickness at the surface on down to, say, a thousand meters or 1500 meters at the bottom. Our ocean model is just the Navier Stokes equations solved as an initial value problem. We make 3 basic assumptions; the Boussinesq approximation, the hydrostatic assumption, and the turbulent viscosity hypothesis. At this point, I think it's important to point out that the prognostic variables which our model predicts are not temperature at any one particular place or salinity at any one particular place or velocity at a certain place, but the average of these quantities over a certain volume. We have grid boxes stacked together covering an entire ocean. The prognostic variable is actually, in the case of temperature, heat content of that box, even though we represent it as an average temperature over the volume of that box. Coming back to what I have said about a coupled air-sea model, the ocean has to give the atmosphere the sea surface temperature. So you can see the problem we have. We are predicting quantities of heat within an upper layer of the ocean, but what the atmosphere needs to know is the actual temperature at the surface. This is the motivation for a reasonably good mixed layer numerical model for the ocean, that we can take the heat content of the upper layers and predict sea surface temperature.

Several mixed layer models have been proposed over the past 10 years or so. The first of these is the one by Kraus and Turner, which has come to be known as the energy model. Denman had a model which is very similar to Kraus and Turner's. Pollard, Rhines, and Thompson had a somewhat different model. Mellar and Niiler have also developed models recently.

Two years ago Rory Thompson did a survey of all these models in which he programmed them up for a computer and compared the results of all the different models using observed data. It was like an Olympics of mixed layer models. I think it's interesting to note the comments that he makes in his paper concerning his efforts to get a set of data which was appropriate to test these models. He had a very difficult time coming up with a good set of data. He finally did come up with some data from Ocean Weather Station November.

At GFDL we haven't done very much mixed layer modeling. But we are getting more interested in it because it is so critical to these coupled models. And the model which we've taken the most interest in is the energy model of Kraus and Turner. The basic mechanism in this model for the deepening of the mixed layer is conversion of kinetic energy input by the wind into the mixed layer, to potential energy in the upper ocean. Shallowing of the mixed layers is caused by surface heating.

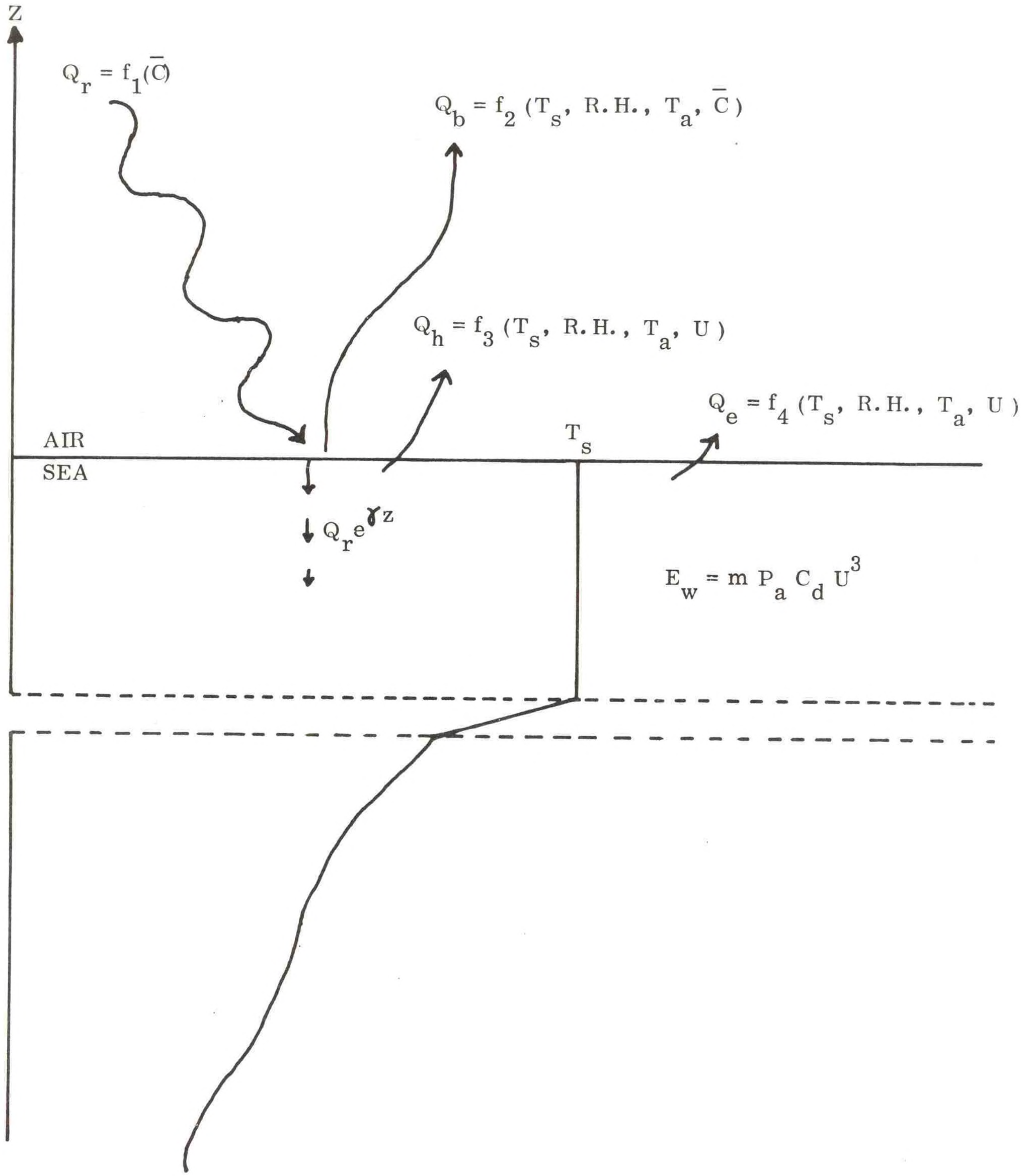
This is a very simple picture, which I'm sure most of you are familiar with in one form or another, of what's needed to make a gross prediction of the mixed layer depth. First of all, you need to know the surface heat input to the mixed layer. Think of that as being the sum of the four Q's. Short wave radiation from the sun is a function of the cloudiness in the area. Assume this is distributed downwards within the upper layer as an exponential function of gamma z, where gamma is called the extinction coefficient, and is determined by biological turbidity. Long wave radiation is a function of the surface temperature of the ocean, relative humidity above the ocean, the atmospheric temperature at the interface, and again, the cloudiness. The sensible heat loss from the ocean is a function of surface temperature, relative humidity, and the temperature of the atmosphere as well as the wind speed of the atmosphere. The latent heat of evaporation is a function of the surface temperature, the relative humidity, the atmospheric temperature, and the wind speed. As I said, the basic deepening mechanism for the Kraus-Turner model is kinetic energy put into the mixed layer by the wind stress on the surface. You can think of this as being given by the equation $m\rho_A C_D U^3$, where ρ_A is the density of air and C_D is the drag coefficient. The most important unknown factor here, obviously, is m. It's been found in some of the preliminary tests of the Kraus-Turner model using constant m, that deepening proceeds too rapidly, particularly when the mixed layer is deep. This suggests that m is a function of the depth, so that, as the mixed layer gets deeper, m gets smaller.

This is a function that can be determined by data from buoys such as we're talking about here (possibly by looking at the depth of the mixed layer as a storm comes across to determine how much of the wind energy is transmitted into potential energy within the mixed layer).

In summary, then, the data needed for testing out a prospective model of the mixed layer depth is relative humidity, temperature of the sea surface, temperature of the air above the sea surface, biological turbidity, wind speed, and cloudiness. Then, as a check on the model, we also need to know the actual mixed layer depth.

The next qestion which needs to be answered, is what happens at the bottom of the mixed layer. The question here is, how is heat transported downward from the mixed layer? To investigate this, it's very important to measure well below the mixed layer. We talked earlier about whether we need to have short term measurements over a wide range or long term measurements over a fairly narrow range. We feel that it's very necessary to have longer term measurements of these quantities. Data covering periods of maybe 2 or 3 years at one place would be very useful. We have snapshots of the ocean by different experiments that have been carried on, but we have very little data over a very long time scale.

I haven't been very specific about what our data needs are. The people who have worked directly on these mixed layer models could point out the specifics better than we could at GFDL as to what needs to be measured.


Z
$Q_r = f_1(\bar{C})$
$Q_b = f_2\ (T_s,\ R.H.,\ T_a,\ \bar{C})$
$Q_h = f_3\ (T_s,\ R.H.,\ T_a,\ U)$
$Q_e = f_4\ (T_s,\ R.H.,\ T_a,\ U)$
AIR
SEA
T_s
$Q_r e^{\gamma z}$
$E_w = m\ P_a\ C_d\ U^3$

QUESTIONS AND DISCUSSION

MR. WITHEE: *This is a little outside the conference, but do you think that relative humidity or dew point is a worthwhile parameter to measure from buoys, particularly from the model standpoint?*

DR. COX: Well, I think it's worthwhile depending on where you are in the ocean. If you're just off the Somali Coast in the summertime, it's very important, because there is strong evaporation there. At other places in the ocean, of course, it wouldn't be as important. My comments here are very general. At any particular place, perhaps one or more of these quantities wouldn't be needed.

MR. RODEN: I have two comments to make. First the models that are used are mostly one-dimensional, I think that the progress will come by looking at what are the features of lateral intrusions and entertainment into the mixed layer. The other thing I have tried to mention at many other meetings is that the term "mixed layer", should be defined more precisely. In classical oceanography, the mixed layer was defined in terms of temperature alone. This is no longer correct and we must specify whether we mean by mixed layer the isothermal layer, the isohaline layer, or the isopycnal layer. This distinction is particularly important in higher latitudes. Because there, the difference makes layers have different depths. In wintertime it's exclusively controlled by the halocline around 100 meters deep. If you have storms passing by with say 60 knots of wind, you don't drastically decrease the depths of the mixed layers but you get oscillations of the halocline which may be 20 to 30 meters from the mean condition. And I have heard it said many times that the mixed layer deepens at the end of the autumn season from summer of 30 meters to about a hundred meters. This is not quite correct. It's true that surface cooling and wind mixing eliminates the mixed layer due to the thermocline and that does disappear. Then you have left the mixed layer due to the halocline which is a year round feature. So we are talking here about two different mechanisms and it would be very important to distinguish between these.

DR. COX: Yes. Well, I agree with you that T and S both need to be measured. And as for your first comment about the lateral intrusions, I think that is very important as well. But it's a matter of how many buoys you have for how long a time. I suppose what would be good would be to have a star of buoys over an area the size of the MODE region so that you could resolve mesoscale eddies within the star and you could make some attempt then to evaluate horizontal advection of temperature and salinity into the mixed layer.

DR. PASKAUSKY: This problem of the 1-D that Gunnar mentioned is one that I wanted to bring up. The 1-D models have severe limitations. They tell you something, but you really don't get the full story. You talked about long term averages, and they really work on that. I think some of the 1-D modelers are coming up with the idea that they need to worry about the lateral effects and come up with more aspects. So perhaps for this group it might be good to consider something where down the road they may need more buoys or more data measurements on the horizontal scale with the time scales on something less than a year or two years. It might be nice to have the long record to look at the variability, but with this type of model, the 1-D, you should use station Papa or November, like you've done, and go with that. But there are probably regions in the ocean where this would not be adequate, and I think we need to look at that. And your comment about the halocline is excellent.

DR. COX: Well, I agree. Obviously, the more places we could have data the better. If we could have an area well covered by buoys, that would be much better than having one. There's no doubt about that. It's just a case of economics, I suppose.

DR. PASKAUSKY: Well, I just feel that we haven't adequately answered all the questions or even a good part of them with the 1-D method. It's a good first start.

DR. COX: I think another point here is that, when we put a 1-D mixed layer model into our three dimensional model, it's not really a one dimensional model any more. We have horizontal advection of heat and salinity in addition to the one-dimensional mixed layer dynamics.

DR. PASKAUSKY: Yes.

DR. COX: But as far as checking a 1-D mixed layer model independently, your point is well taken.

DR. BAKER: There was a paper by Summerville, and this is going to appear in the proceedings of the Urbeno Conference, where he talks about the sensitivity studies that have been made by various modelers, the FT model and the GISS model and the NCAR model. And at the end he says we are able to place some tentative requirements on an upper ocean observing system. Should have a global distribution of sea surface temperature with a horizontal resolution of 200 to 500 kilometers and an accuracy of 1° centigrade.

DR. DISHON: *In the ocean?*

DR. BAKER: Yes, sir. That's what he says. In the case of his models, that's what the models need, he says, the atmospheric model.

Now, since you're a modeler, will you comment on that?

DR. COX: Well, I think if you assume you're not going to have an ocean model to run with your atmosphere, that's true. But what we're saying is we'd like to have an ocean model which correctly simulates the ocean so that you don't need to specify actual oceanic quantities.

DR. BAKER: I didn't think that's what he was saying here. He's saying that the sensitivity of forecasting models to air and atmospheric temperatures leads up to estimate that sea surface temperature needs to be specified to about 1° centigrade. *Now, you are saying that's wrong or right, irrelevant?*

MR. KIRK: *We talking about only input into the atmosphere?*

DR. PASKAUSKY: Yes, trying to make predictions from the global models, large scale models.

DR. COX: Yes, I think his comment is probably correct.

DR. PASKAUSKY: My guess is that since the atmospheric model is large scale, it's input of heat would be sufficiently determined from sea surface temperature. But for an ocean model we have a problem. The atmospheric model has a grid spacing so large that it can not define the location of an atmospheric front on a scale adequate for oceanic front prediction. It eliminates the whole problem of the front, just runs right over it. So we need a smaller scale on the ocean. It's a problem that may not be solvable.

CAPTAIN WARD: But we're trying to go to a smaller scale model that circumvents this. For example, both the National Weather Service and the Navy are working on a smaller scale tropical model, and surely we want sea surface temperatures and better resolution than what's indicated in there for the tropical model.

CLIMATE FLUCTUATIONS, OCEAN MONITORING AND BUOYS

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Abstract. Various ideas about short-term climatic fluctuation, ocean monitoring, and the use of buoys are discussed with some relation to the North Pacific Experiment.

I would like to present you a potpourri of some ideas about climate and buoys. First of all let me start off with a bold statement: I believe that the next great breakthrough in the geosciences will be made by predicting the climate, unless the people predicting earthquakes come ahead of us. Second, since we are here at the National Data Buoy Office, one should very well put the climate problem in perspective to the buoys. And third, I would like to say that I am volunteering here my own opinions and ideas and not those of the steering committee of NORPAX.

When we are talking about climate, we cannot do so without simultaneously talking about climate changes. Your grandmother has complained about climate changes, the Romans have known climate changes. They are intimately connected with the word climate. Climate is nothing static. So if we want to talk about climate, let us first think with which kind of time and space scales we are really concerned. When we're talking about changing climate we mean something that goes on over an appreciable period of time, from months to years to decades to centuries. When we consider these time scales we need to think of big space scales. In fact, we can make the statement that climate is global. Whatever we do in trying to understand climate we have to look on the global scale. We cannot look on any smaller scale. Climate involves also all the parts of our globe, the atmosphere, the ocean, the ice caps, the land surfaces, and therefore, we must consider the coupling of all of these parameters.

Now, I would like to restrict the considerations here somewhat so that we come to those time and space scales that are really relevant to our work. Why has climate in the present time become so important to us and why are we talking so much of climate? That's chiefly because we are living in a world of limited resources, and therefore, the changes in climate have a very direct effect on our lives and will have more so in the future when food supply becomes a very serious limitating subject. Therefore, we would like to restrict our consideration to time scales that are more familiar to us, namely to the scales from seasons to years, maybe to decades. This is the time frame in which we would like to have a prediction. It's rather academic to think about whether we are getting a new ice age. It's not really of much relevance to our present day lives. So I will be talking in particular about those changes that have time scales from the order of a few months to the order of a few years.

How do we study such time scales? There are several ways. You can study them either by a deterministic model or you can study them by statistical methods. Both ways are being pursued and you just have heard some discussion about numerical models that are being used. Numerical models are -- at least if we are looking at climate and at the time scales that we have defined right now, namely from several months to several years -- in a very early stage of development. There's no doubt about that. There are good models to predict weather over a few days. At the meeting in Grenoble it was said that the limit of integration is really only a few days, that means somewhere between six or eight days before these models degenerate into statistics. There is no real deterministic model right now to deal with the climate problem on the time scale of months to years. That means we will have to resort to statistics. I might point out that people have tried to run general circulation models of the atmosphere and made response studies to the ocean. Those of you who have been following the work of Namias about the coupling of the atmosphere and the ocean know that there are anomalies in the ocean and atmosphere over the North Pacific Ocean and they are positively correlated. That means a negative pressure deviation is associated with a negative sea surface temperature anomaly. All the atmospheric circulation models show just the opposite. So there must be something seriously wrong. Not with the ocean, but with the models.

Whether we want to use a model or statistics to predict climate we need to have data to either work out the statistics or to start our integrations. And these data can only come from monitoring. That means from systematic observations of the changes and the status of the atmosphere and the ocean and the ice caps. And here comes the question how often, what, and where should you monitor. It's already clear that it needs to be global. But before we go on, I would like to show you a few particular examples about the time scales and the space scales that are associated with various events in the ocean in particular.

I want to mention here a few items that we can monitor, and want to comment briefly on their time scales. These time series from 1947 to 1972 are for the southeast trade winds of the Pacific Ocean, and what you see is a fine curve giving you the five months running mean and the heavy curve given you the twelve months running mean (Figure 1). Each of these time series is for an area of 10° north-south and 30° east-west, which is a substantial area, but small if you look at the whole ocean. The upper two time series in the eastern part, 90-120W, are dominated by the annual signal, and the long term changes are relatively small. You see other areas in the central Pacific Ocean, 120-150W and 150-180W where the annual variation is relatively small and where the long term departures are rather significant. But you see that these long term departures are of the order of many months to 1-1/2 years in this case and are distributed over rather large parts of the ocean. That means that they represent a rather big anomaly in space. This is not only true with the wind field, but it's also true for other properties.

In Figure 2 you see curves from some equatorial stations, Christmas Island, temperature and sea level; Canton Island in the central Pacific, temperature and sea level; and at the Equator, the wind. Anomalies in one property correspond to anomalies in other properties, like sea level and temperature; wind and sea level; and wind and temperature. And you see also how large these time scales are, lasting from many months to several years. So these are the scales we have to deal with when we are talking about the short term climatic changes in the ocean atmosphere system.

The question is then how to monitor such a system. And now I would like to say a few words about monitoring. In the equatorial Pacific Ocean, we have a system of ridges and troughs in the dynamic topography (Figure 3). This system of ridges and troughs represents the flow or the circulation in the equatorial area, namely the four major currents, the north equatorial current, the equatorial countercurrent, and the south equatorial current, and another branch of the south equatorial current, being north of the equator. You see that the contrast of dynamic topography in the Pacific is from about 140 in the east to 220 in the west; that's a maximum of 80 dynamic centimeters. A typical drop across the north equatorial current is about 40 dynamic centimeters. These are the scales of sea level differences we have to deal with.

The question is: can you monitor such a structure? And in order to do so I want to show you first a north/south profile of sea level from 30N to 20S (Figure 4). You recognize the various ridges and troughs of the system and you recognize the currents, the north equatorial current, the countercurrent, the south current, the equatorial trough, and a small increase from the equatorial trough to the equatorial ridge representing that part of the south equatorial current that's normally north of the equator. Along that profile we have a number of sea level stations. From the time series of equatorial sea level we have already seen what the time scales of these changes are. We can use differences in sea level to learn something about the fluctuation of the currents (Figure 5). You see that during certain periods some currents are dominated by regular seasonal signals; during other period not at all. The long term changes, in particular in the countercurrent, have almost the same magnitude as the value of the current itself. Again, rather long time scales are involved in these changes of the circulation.

A power spectrum of these currents is shown in Figure 6, and you see the annual signal, and the first harmonic of it, and you note that a lot of the power, particularly in the north and south equatorial current, is in the very low frequency, in excess of one year. I forgot to mention one important matter before. If we are looking at the time scales from a few months to a few years in ocean and atmospheres, this includes the annual signal. And in fact, the annual signal is a very important one. First of all, it's a forced signal, and second in most of the world it's the signal with the largest amplitude. Therefore, we can expect that the dynamics of many of these changes, which are going on in the time domain from a few months to a few years, will have dynamics very similar to the annual cycle. Thus, understanding the annual cycle is a very important subject. And so far I'm not aware that coupled models have really been able to simulate the complete annual cycle of the ocean-atmosphere system.

Next you see the network of the various stations observing sea level that we have established in the Pacific Ocean (Figure 7). With this system we would like to monitor the changing topography of the ocean. In NORPAX, and in particular in view of the forthcoming First Global GARP Experiment, we are planning another experiment, namely to find what and by what means we can best monitor this equatorial structure in the Pacific Ocean.

Sea level over a period of five years is shown for the Galapagos Islands and the Solomon Islands (Figure 8), and you see that substantial changes are occurring. During that period sea level was about 15 centimeters higher in 1970/71, and I want to compare that with the total east-west slope across the Pacific of about 40 to 50 centimeters. Later, sea level in the Solomons was about 25 centimeters lower. While sea level was falling in the western Pacific, sea level in the Galapagos Islands was rising to 20cm above normal. This indicates that sea level in the equatorial Pacific Ocean was reacting in a wave-like fashion and this event led to the 1972 El Nino of South America. In order to demonstrate to you that this effect is not limited to the Soloman Islands, sea level in Guam is shown in Figure 9, and has the same signal. In fact, the Guam sea level for three months was 44cm below the long term mean, essentially wiping out the east-west slope of the Pacific during that time. The same depression happens in Kwajalein, and Turk (Figure 10). In contrast to that, in Honolulu and in Wake, there was no similar effect. You had an ordinary seasonal cycle developing during that period when the Pacific Ocean made the east/west flip-flop.

In NORPAX we want to use -- and I am giving you that only as an example for monitoring -- a combination of various approaches to learn something about the dynamics of these equatorial circulation systems and the associated long term changes. During FGGE, and starting next year in preparation for it, we want to run a shuttle from Hawaii to Tahiti using a research ship going up and down, using various aircraft flights to make additional air XBT sections, using a network of buoys profiling temperature, and using sea level gauges (Figure 11). The aim is to monitor the changing circulation and to find out which of the systems can most simply and inexpensively monitor such a system of circulation because you know, money is always a very important consideration. We will also have a variety of ship of opportunity XBT sections going somewhat inclined through this area. By the use of such a mix of observation we hope to learn how we can do the monitoring most simply.

Figure 12 shows how thin our data coverage over most of the ocean is. This coverage does not allow us to draw any conclusions about the time variations of ocean circulation, if you want to know what's going on from month to month or from year to year. It's just not possible. Therefore, we have to resort to other possibilities. A research ship is a very expensive tool for monitoring. Figure 13 shows two temperature sections from Hawaii to Alaska taken with XBT's by Coast Guard vessels. The big change from summer to winter is essentially restricted to the upper layer of the structure. For a variety of such sections, we have integrated the heat content from 25N to 45N from the surface to 400 meters depth. And these dots (Figure 14) represent the heat content for the various XBT sections. You see, for instance, that in 1972 all the dots are higher, and this was preceded by a rather mild winter and also a warm summer of relatively low storm activity. The heat content in 1972 is considerably higher than the average. The annual amplitude is about nine units, and the deviation from the mean curve is plus and minus 2. So in a particular year this section may store plus or minus 20 percent of the annual signal in heat. That is quite a tremendous anomaly of heat storage. In particular, consider what effect that may have on the overlying circulation if that heat is given off to the atmosphere. Another year, 1969 was consistently cooler along that section.

Finally, I would like to come to the buoys. In NORPAX we want to study the heat content of an ocean and see in which way it behaves and in which way it interacts with the atmosphere. You know that NORPAX has started off as a project that was intended to put a network of buoys over the North Pacific Ocean, it never got to that. First of all, because ten years ago the technology was not yet ripe and, moreover, there was not enough money. Our NORPAX budget is small compared to that of the NOAA Data Buoy Office. And even the NOAA Data Buoy Office is not placing a network of dozens of buoys all over the ocean. To do something like that is certainly a major job. In spite of this fact, we may be hoping that at some time in the future when money becomes more readily available, or when increased interest in monitoring for climate is dictating such an effort, we may get a network of buoys in the ocean.

Let us discuss a few ideas about what that network might be. We have basically two types of buoys that we can use. One is a fixed deep ocean moored buoy that can do all the tricks and that might be used as a fixed network, giving us the desired information. But this buoy is very expensive, partly because of its mooring. Whatever information we would desire we do not want to discuss here at this moment. Then, we have would desire we do not want to discuss here at that moment. Then, we have another group of buoys, namely freely drifting buoys. They can give us information about the surface of the ocean in which the people in FGGE are particularly interested in, namely surface pressure, surface temperature, and surface wind as an input for the models. To the oceanographer they will, in addition, give the trajectories of surface flow. And this is very valuable information indeed. These buoys are relatively cheap compared to the big deep ocean moored full capability buoy, which is a very expensive item.

These two prototypes of buoys are in many ways already working, and we must also say that other groups not concerned with surface buoys, but with subsurface moorings, are quite successful in getting deep ocean information all the way from the bottom of the ocean to about 500 meters. But the layer of interest in climate is the upper ocean, zero to 500 meters. And this is where the problem is.

At this time we do not yet have a system that can economically and with the necessary duration and the reliability, observe the upper layer of the ocean. I have no doubt that this is only a question of technical development and time. But there may be another possibility, namely to use a combination of the two. While the full capability moored buoy is a relatively expensive proposition, and from the simple surface drifter, which is comparatively inexpensive, we don't get the information we want, one might try to go somewhere in between, namely to a drifting buoy that has instrumentation attached which can monitor the upper ocean. And that may perhaps be a compromise in cost and efficiency.

We have given a little bit of though in Hawaii to that idea, and it came handy that we had someone who had developed a very nice computer program by which we could run a diffusive advective model of the north Pacific circulation. If you want to use a diffusive advective model, it's easy to put in the mean circulation. You take ship drift observations and compute mean vectors. In question is the exchange coefficient. But there we have done a trick, namely we have computed the eddy energy from these ship drift observations and an exchange which is proportional to eddy energy has been used.

The mean energy of the surface

circulation (Figure 15) is in the western boundary current and in the equatorial circulation only. The dynamic range goes from about 1,000, in the Kuroshio, to values of the order of 10 in the gyre. If you look at eddy energy (Figure 16) you still find essentially the same distribution, namely maximum energy in the western boundary current and in the equatorial circulation, but the dynamic range is only from about 1,400 to 400. We have used eddy energy as an input for the eddy exchange coefficient. We have similar computations for the whole world. And now we start off with a field of drifting buoys. Our initial distribution is in the center of the big subtropical gyre (Figure 17). The question is do they get out of it or not.

After 100 days (Figure 18) some buoys have moved west with the north equatorial current, some have come into the north Pacific current. After 200 days, the field has considerably expanded (Figure 19). After almost a year (Figure 20) the first buoys have reached the Philippines, but not yet the coast of California; after 400 days (Figure 21) the first buoys have come into the Kuroshio, others go south with the Mindano current. The field spreads out very nicely.

After 500 days (Figure 22) more buoys have moved to the Philippines. In the central gyre the buoy density has gone down to less than half of its initial density. After 600 days (Figure 23) I think we stopped the calculations. We have done this work just before I went to this meeting, and we have done a few other runs. Starting with a buoy field off California, most moved southwest and west, some moved into the Alaska gyre. It was interesting to note that none of the buoys had a tendency to go into the center of the subpolar gyre. We made another experiment putting the buoys out in the western Pacific, which was very unfortunate, because we didn't put them right into the Kuroshio, but we put them on its sourthern boundary. So hardly any buoys went east. They first circulated back, and only after about 500 days they got out of the Kuroshio region. So it's very critical where you initially put drifting buoys. I think one could learn quite a few things and get ideas from these kinds of experiments.

This is about the end of what I want to say, except that I would like to make another general comment. I saw a kind of wishing list of buoy sensor specifications, and I can't help but have the suspicion that the goal is to design "the" buoy. And I think this goal is elusive. There is no such thing as "the" motor. There are electric motors, jet propulsion engines, car engines, and so on. And in the same way, depending on whichever problem we want to address, we will need a variety of buoys with a variety of capabilities and payloads and purposes. And I think we should keep this variety of purposes in mind, if we get together and try to design something that can help us in studying the various problems.

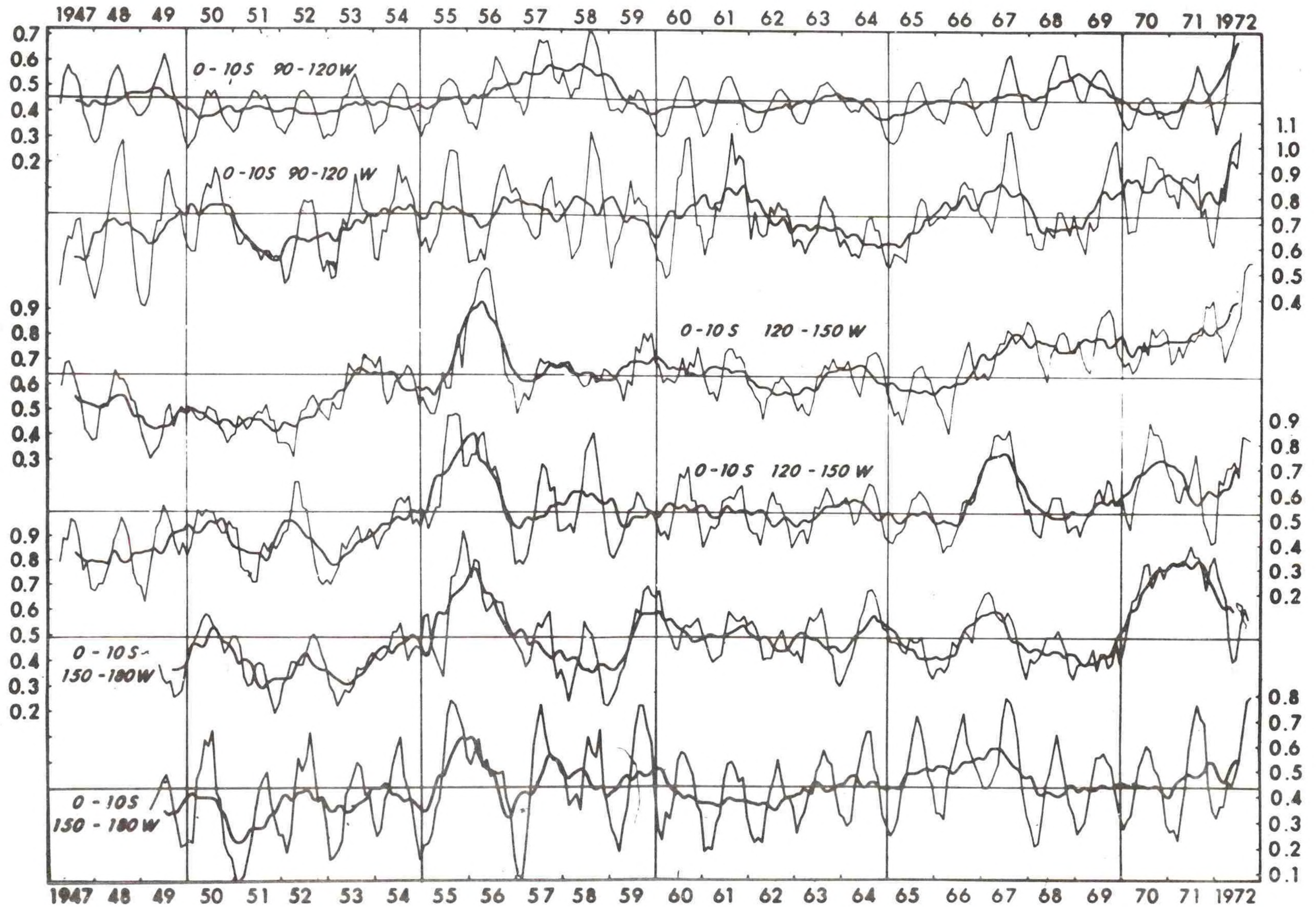


Figure 1. Zonal component of the wind stress in six sections of the Southeast trade wind region from 1947 to 1972 (in 0.1 N.m^{-2}, positive to the west). Thin lines give the five month running mean, heavy lines the twelve month running mean.

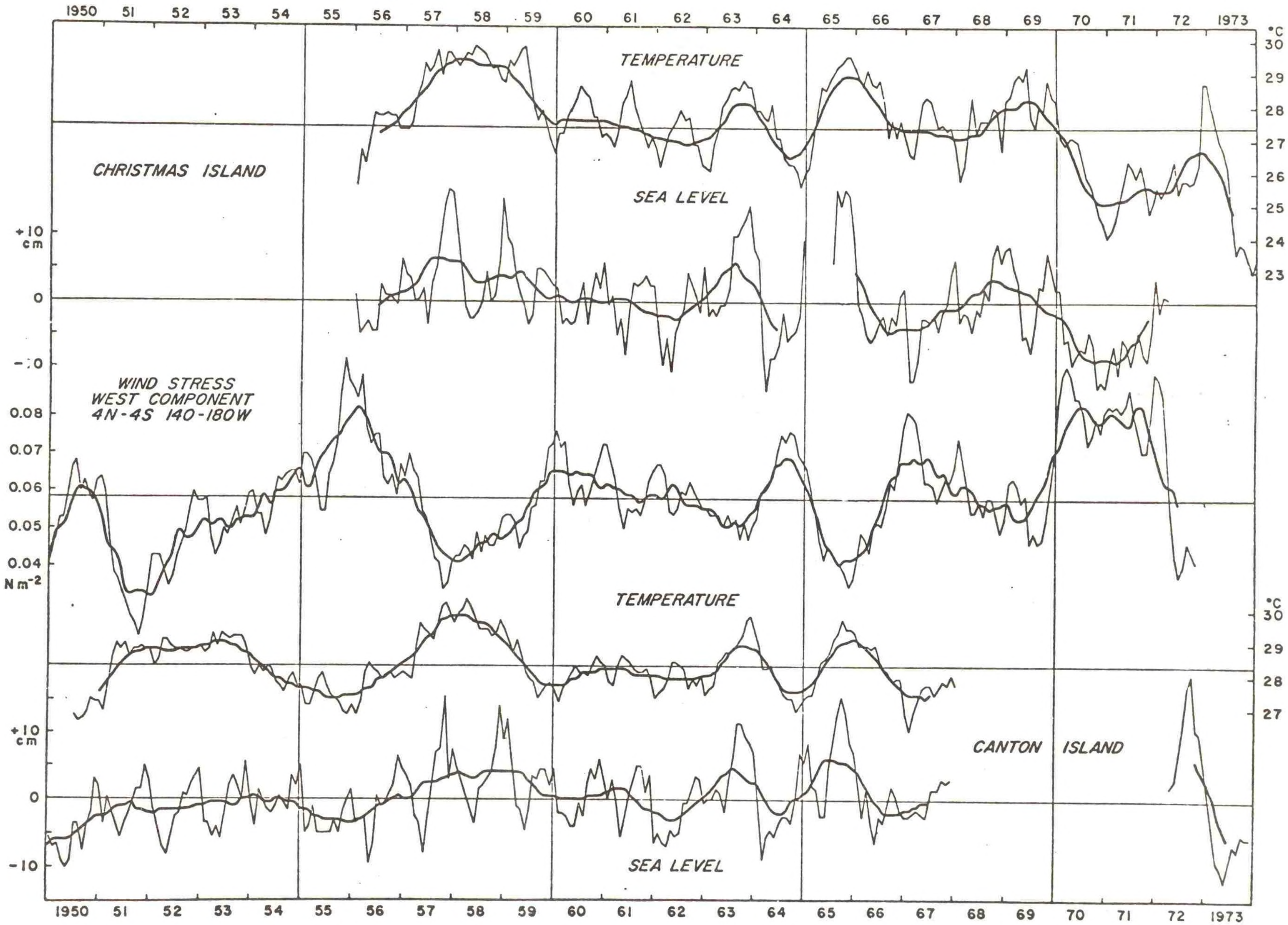


Figure 2. Sea surface temperature and sea level at Christmas Island and at Canton Island, as well as the zonal component of the wind stress at the equator from 1950 to 1973.

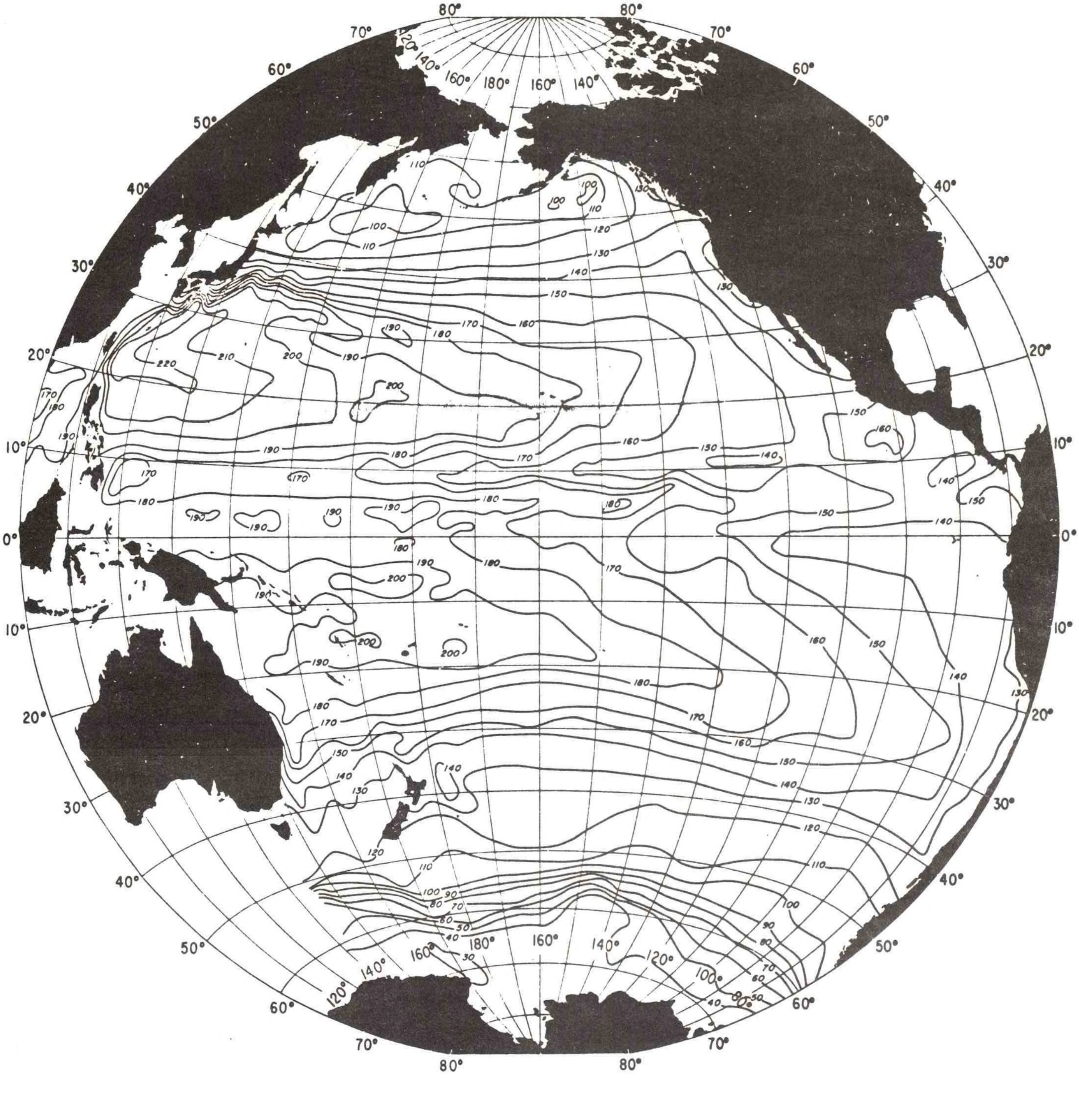


Figure 3. Mean annual dynamic topography of the sea surface relative to 1000 db in dyn cm; 36,356 observations.

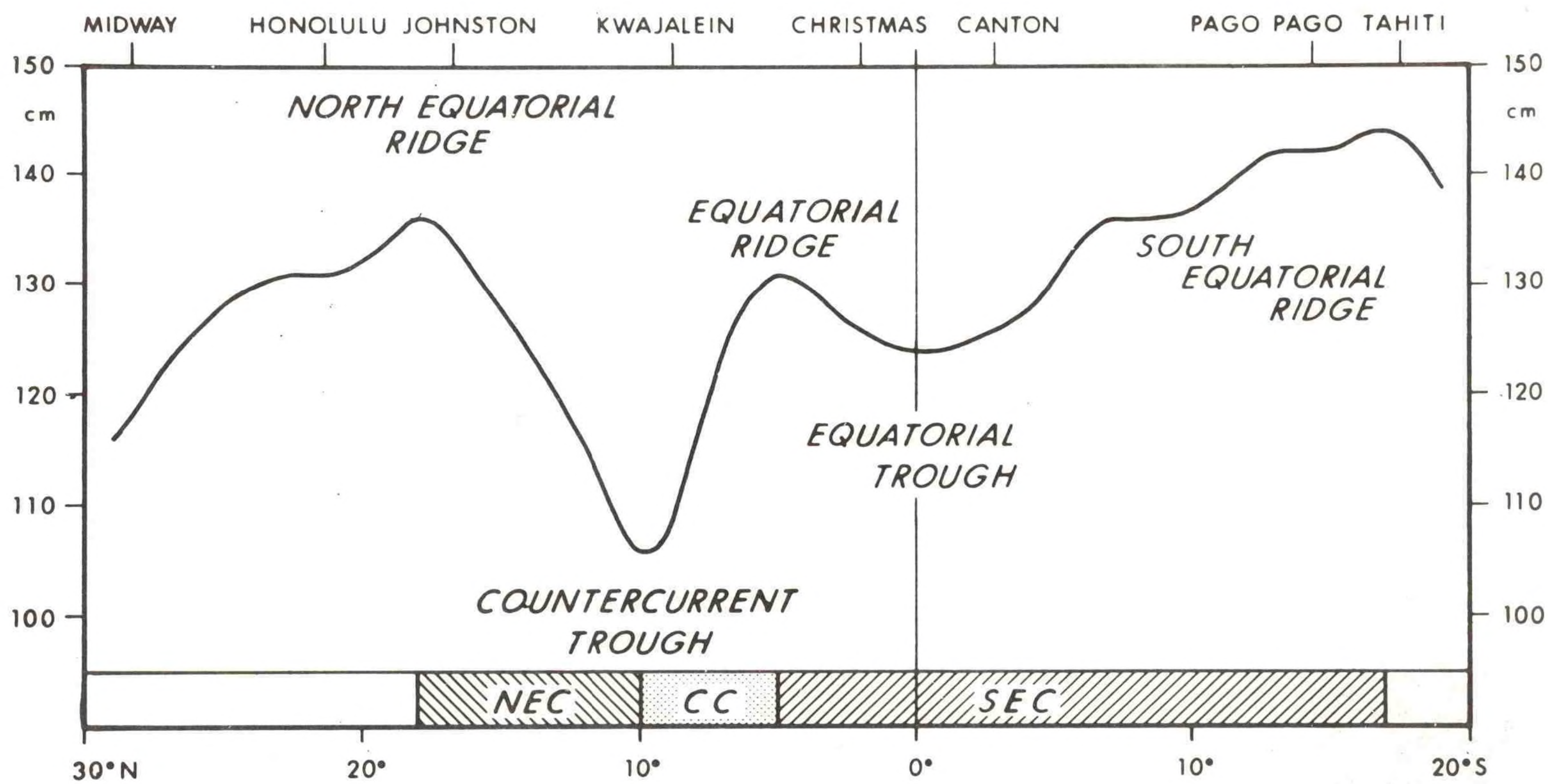


Figure 4. Meridional profile of dynamic height relative to 500 db averaged zonally between 140W and 170E together with positions of sea level stations, topographic features, and currents.

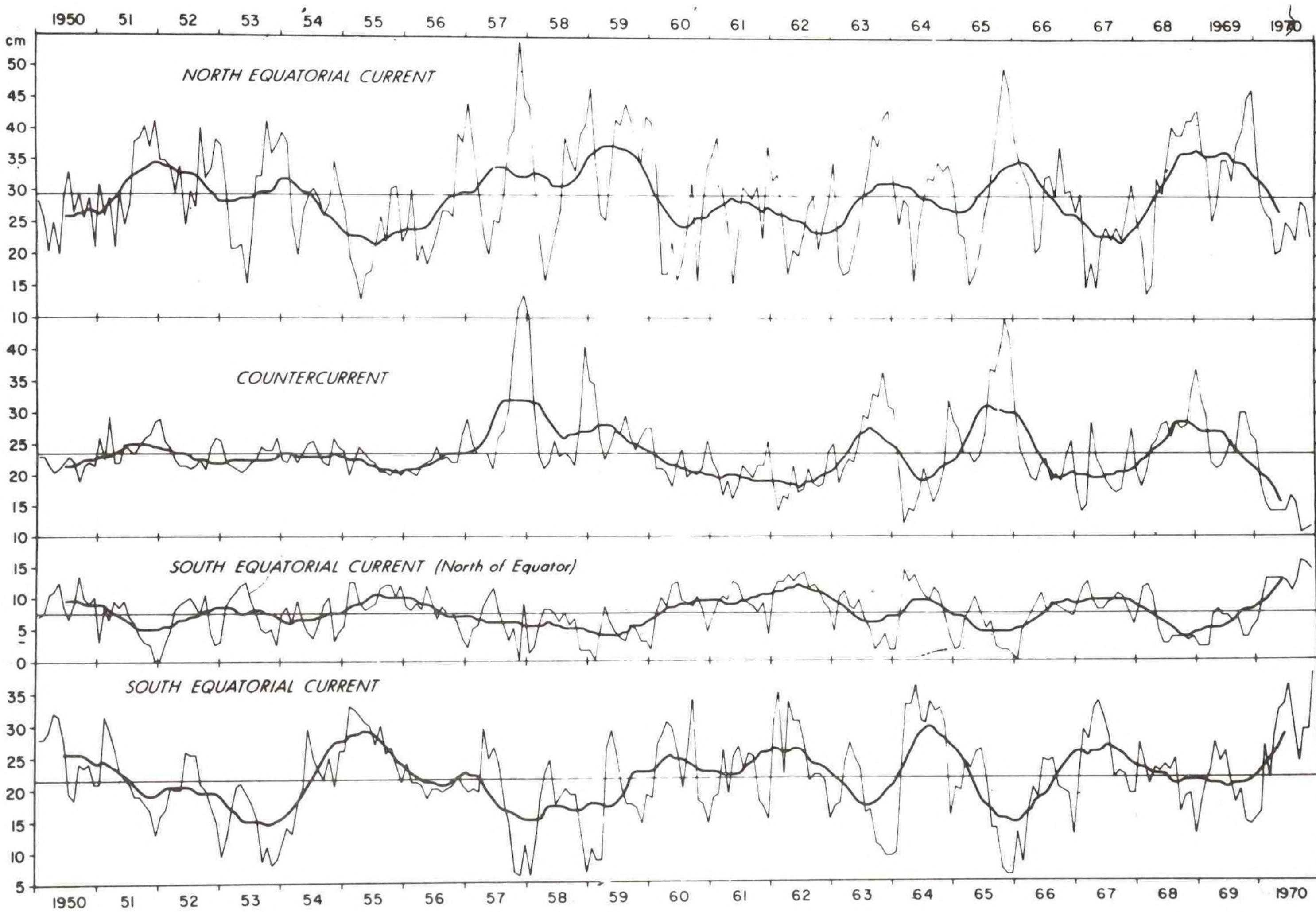


Figure 5. Time series of sea level difference across zonal currents of the western central equatorial Pacific, 1950 - 1970. Thin curves give monthly averages, heavy curves 12-month running means.

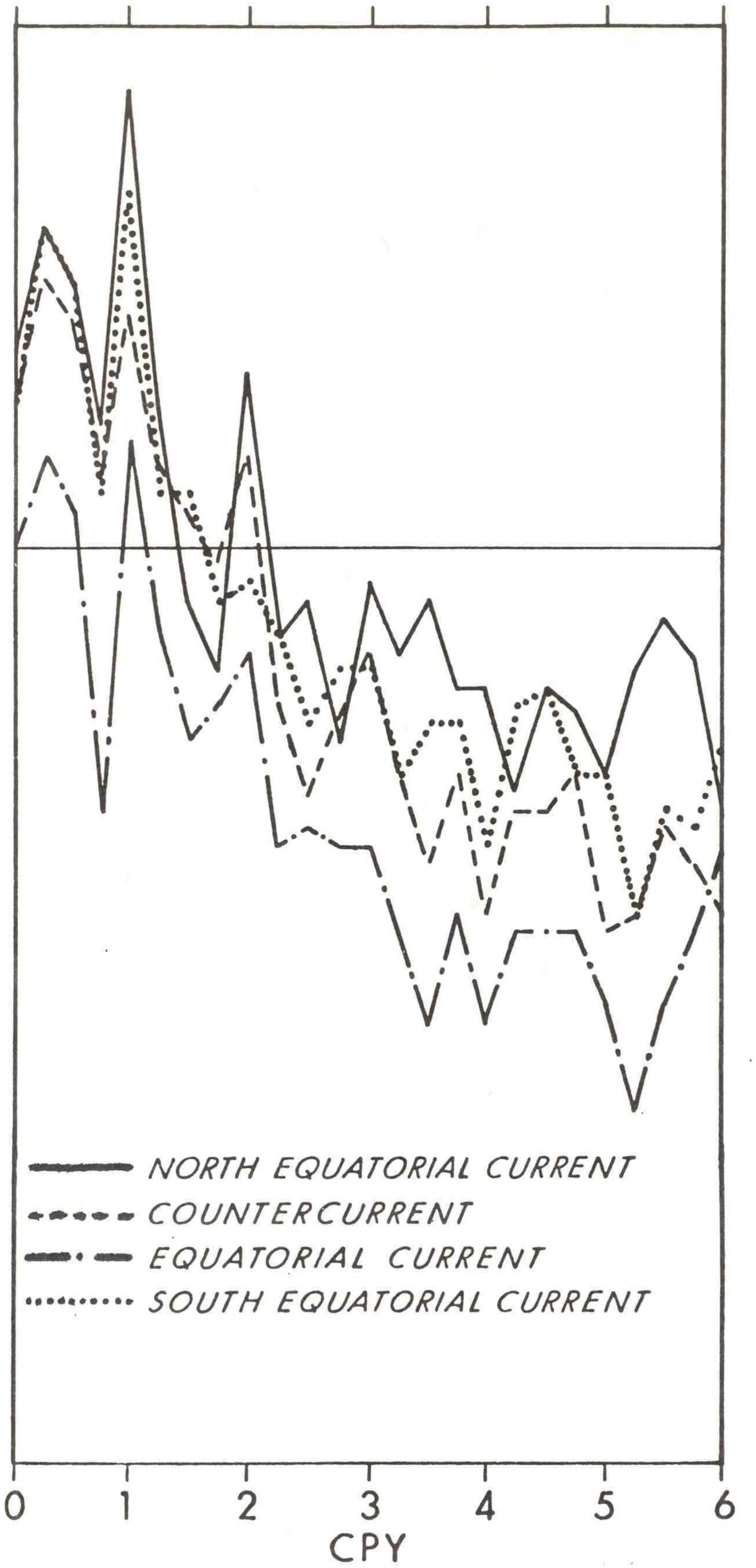


Figure 6. Power spectra for the equatorial currents in the Pacific Ocean between 0 and 6 cycles per year.

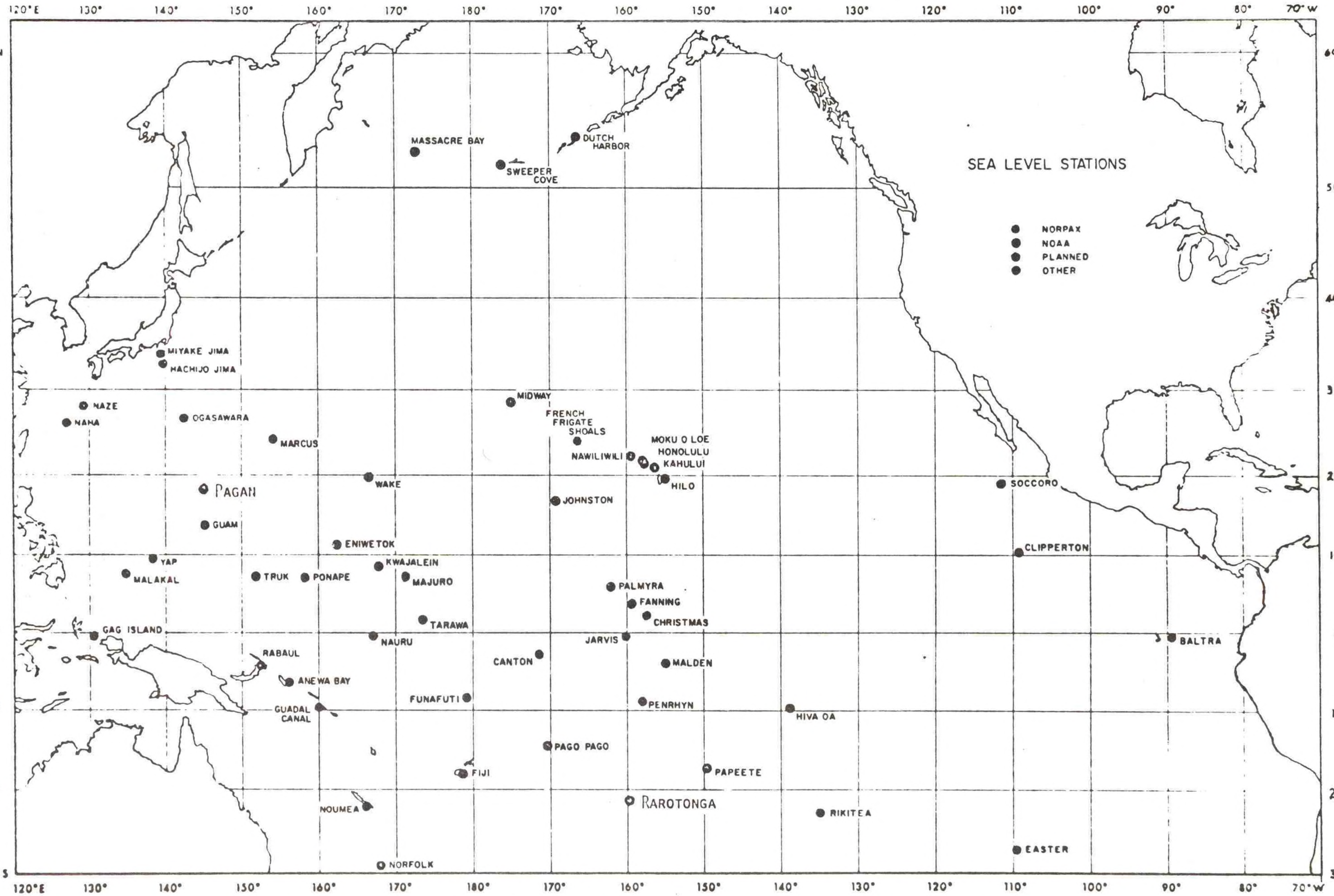


Figure 7. The network of sea level stations on Pacific islands used by NORPAX.

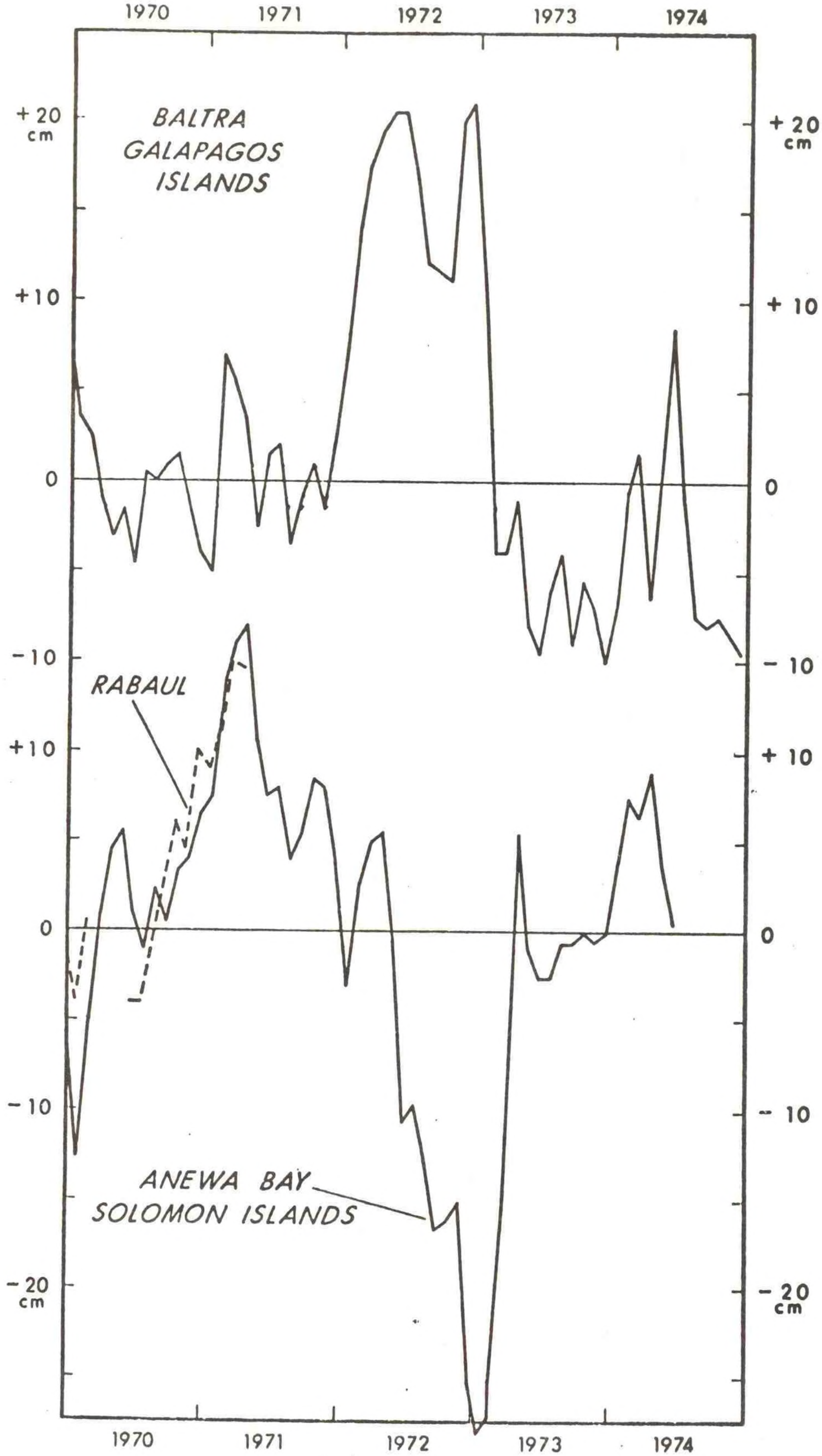


Figure 8. Sea level at the Galapagos Islands and in the Solomon Islands from 1970 to 1974.

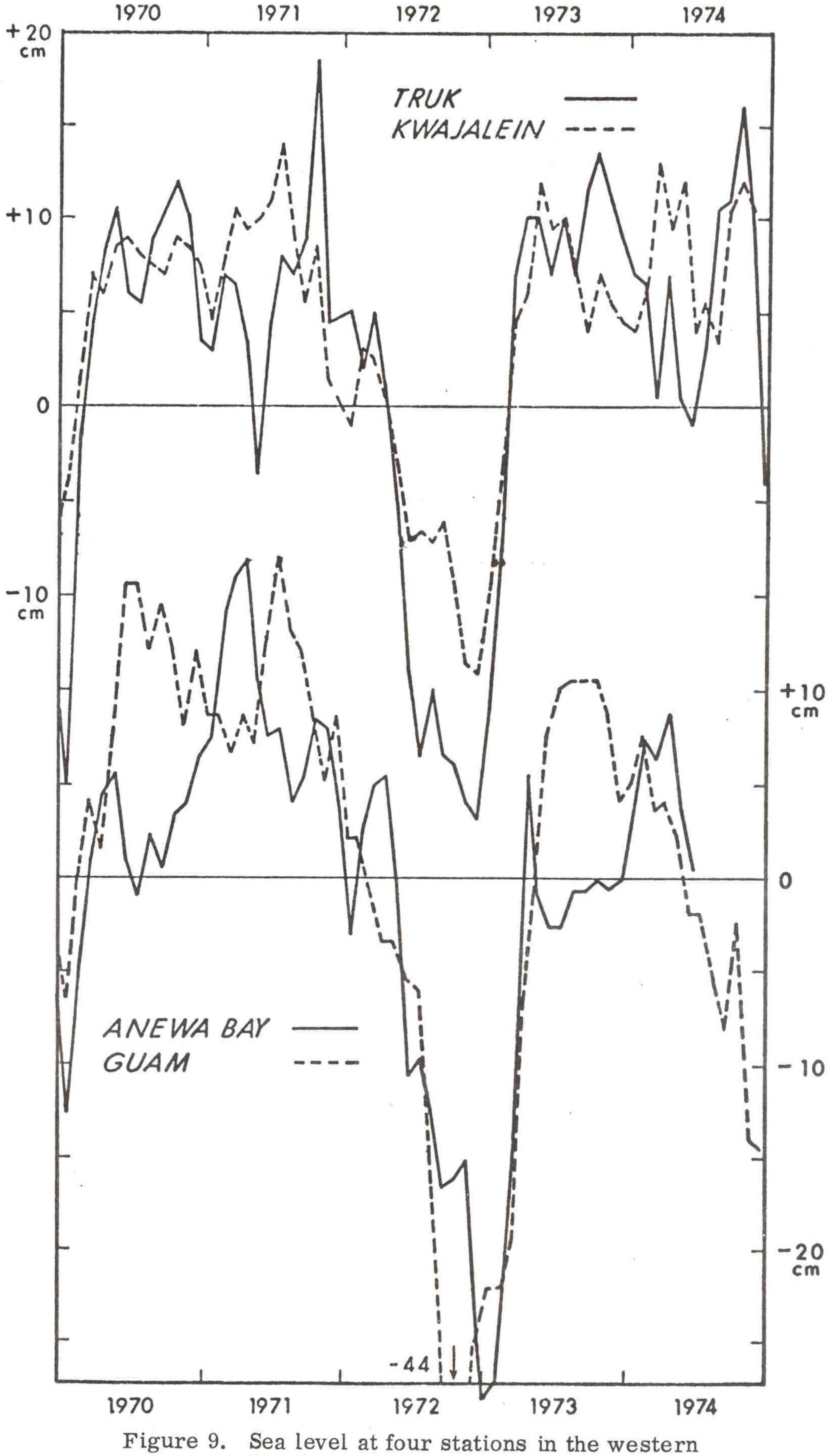


Figure 9. Sea level at four stations in the western Pacific Ocean from 1970 to 1974.

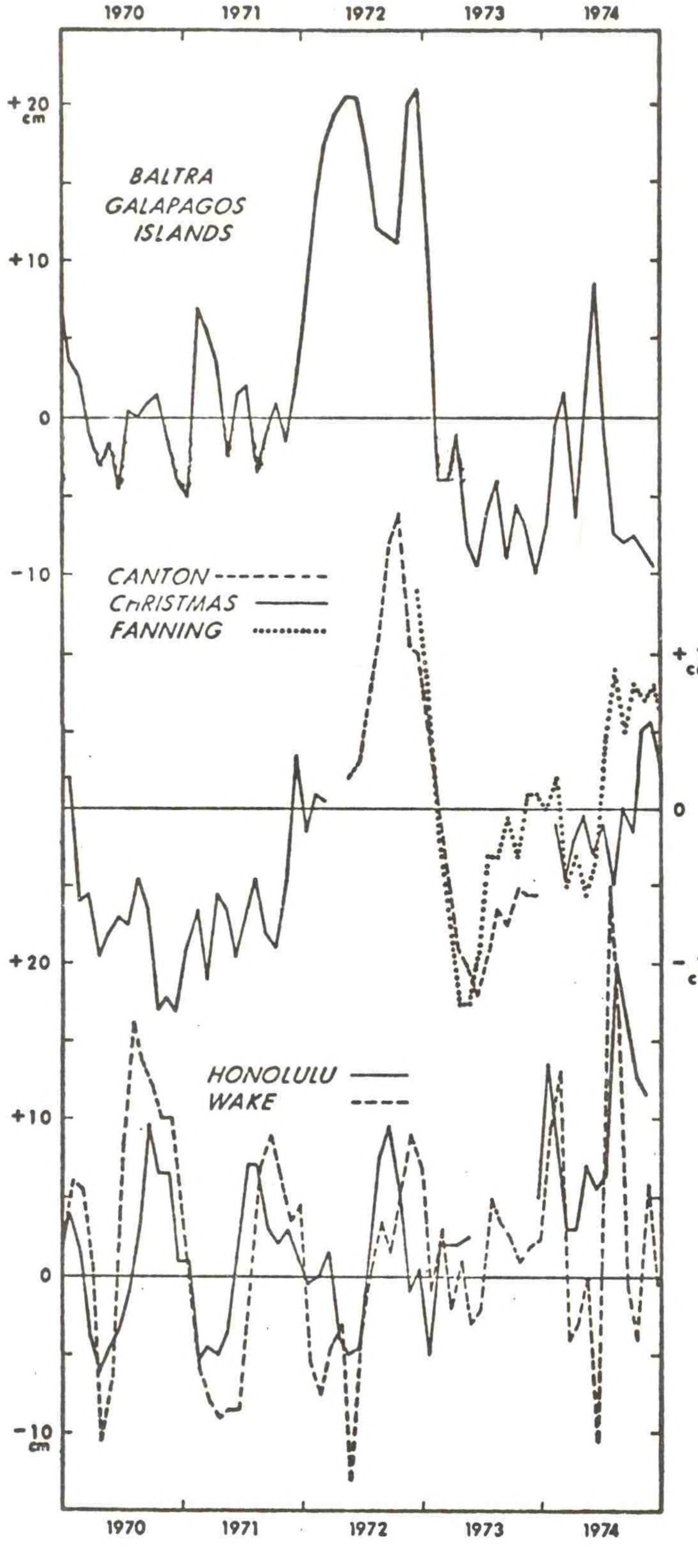


Figure 10. Sea level at the Galapagos Islands, in the central equatorial Pacific and at Honolulu and Wake from 1970 to 1974.

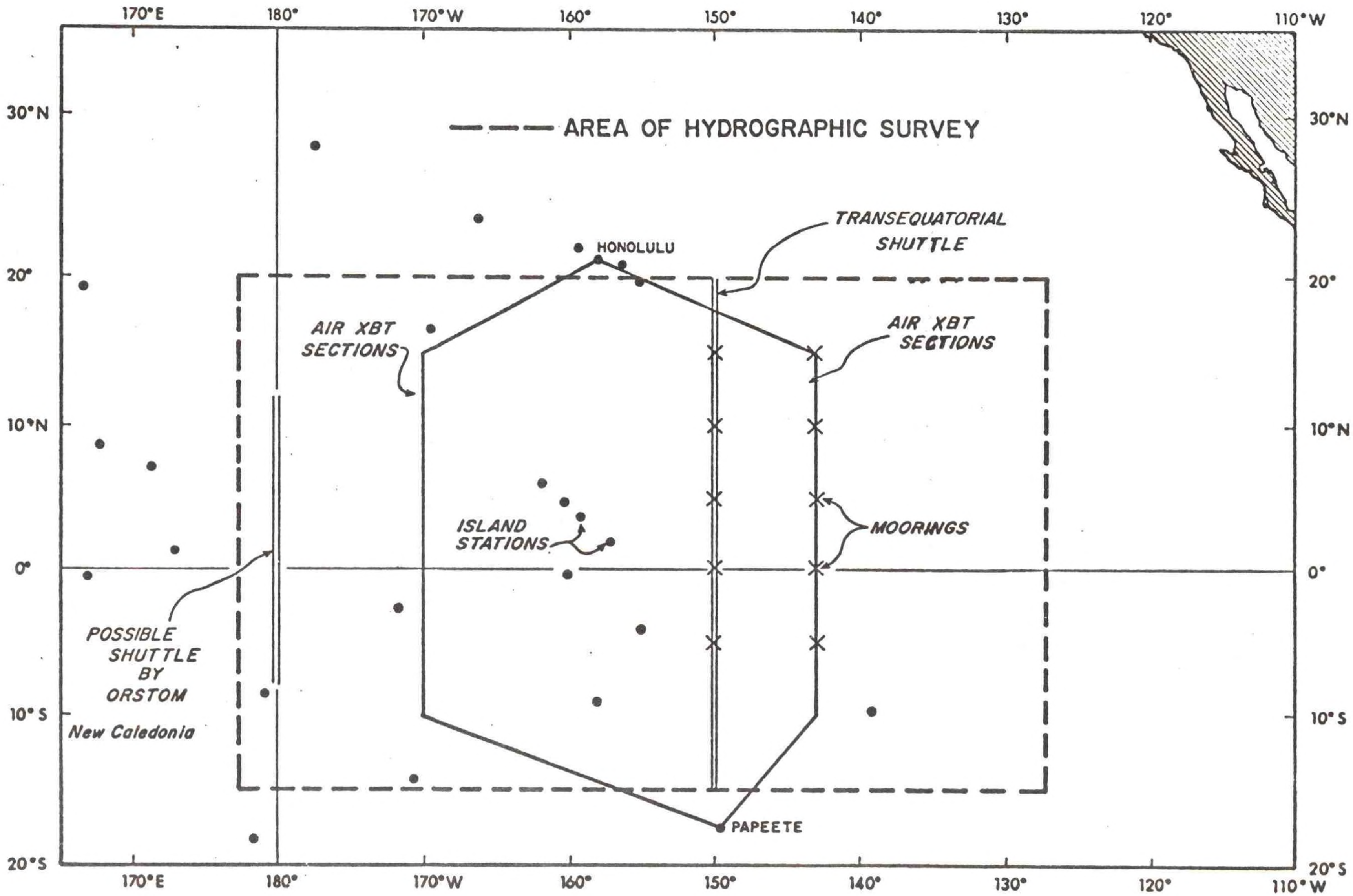


Figure 11. Area of the planned NORPAX equatorial experiment during FGGE.

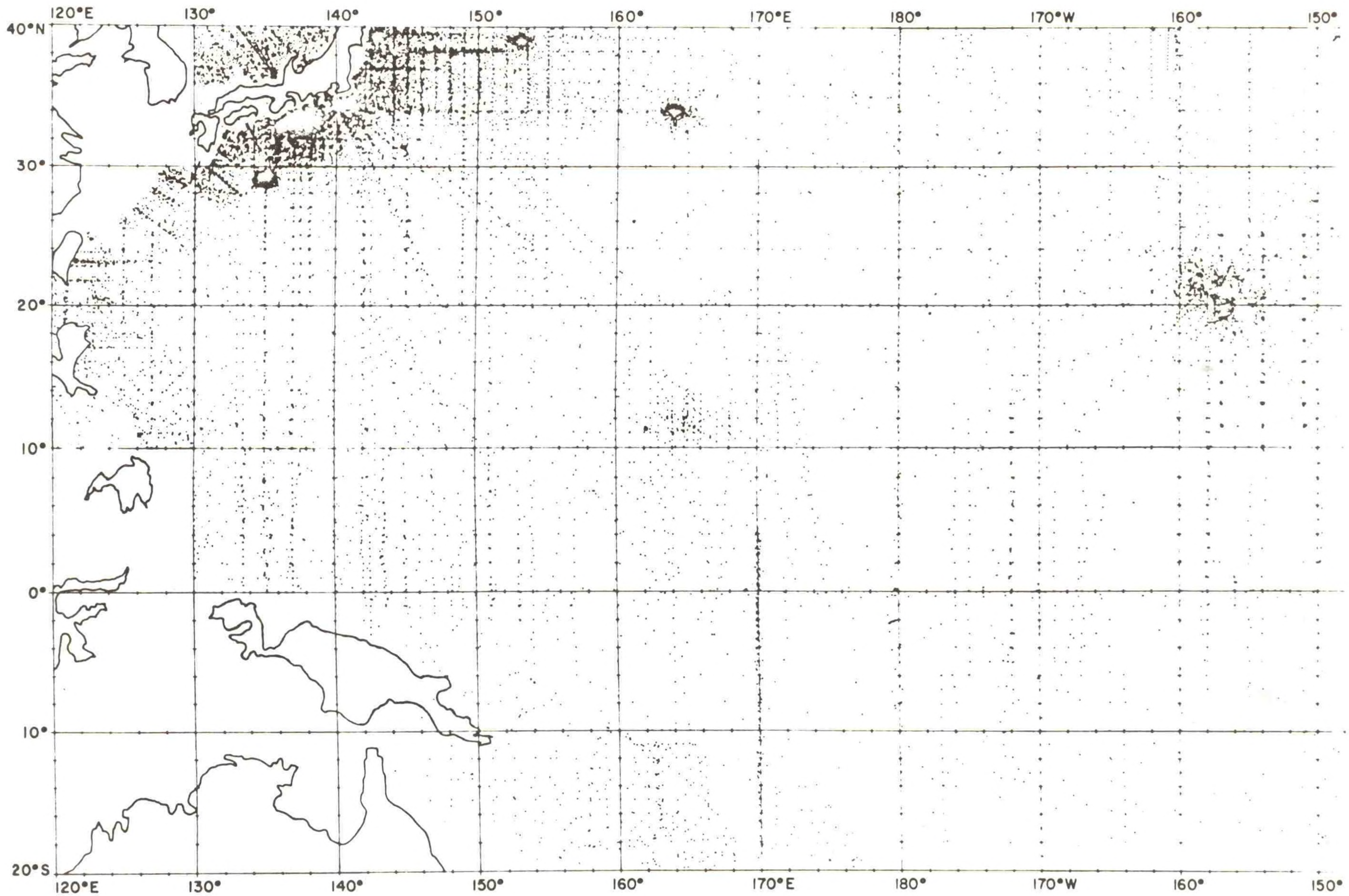


Figure 12. Distribution of hydrographic stations in the western Pacific Ocean.

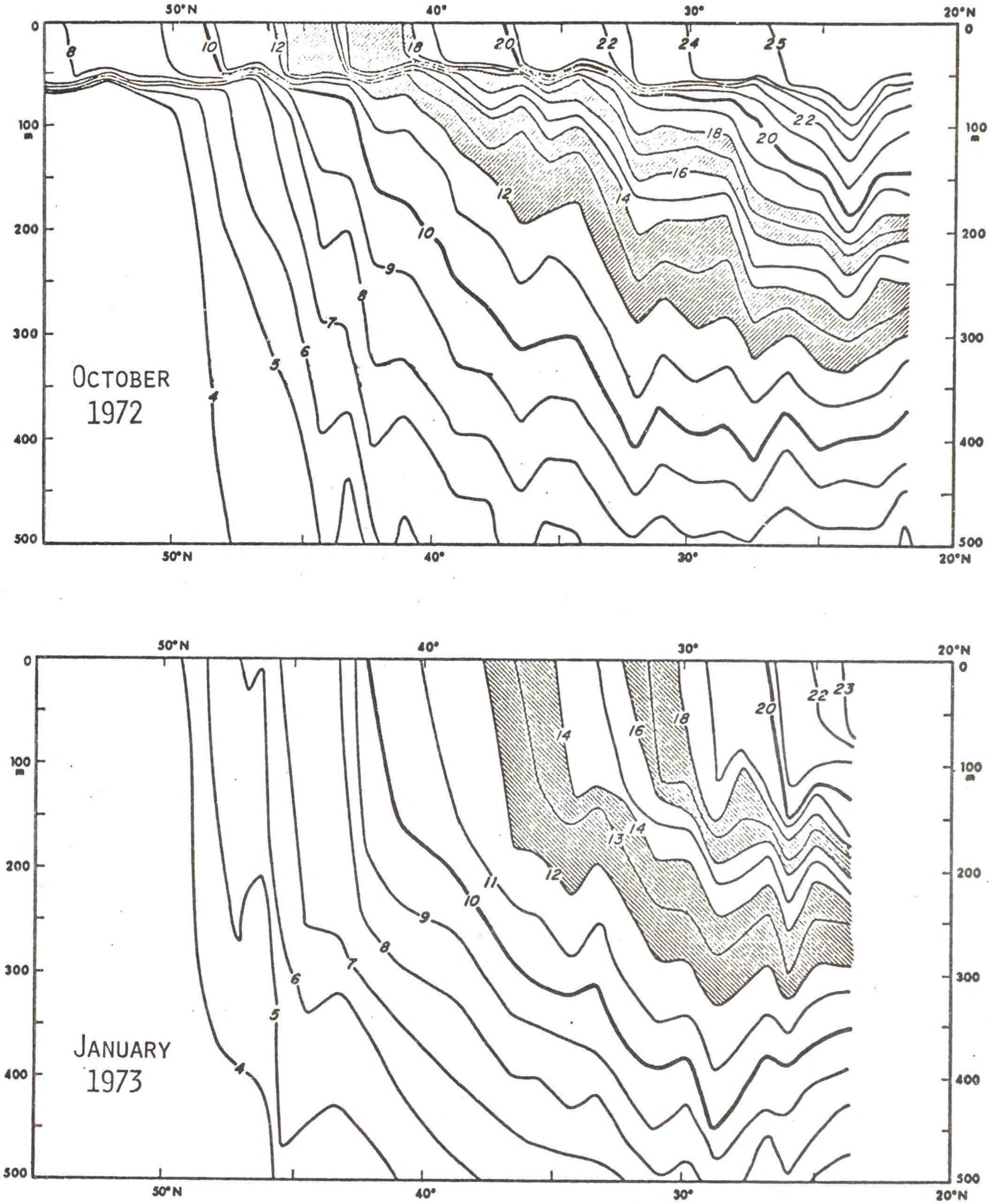


Figure 13. XBT sections to 500 m depths between Hawaii and Alaska in October 1972 and January 1973.

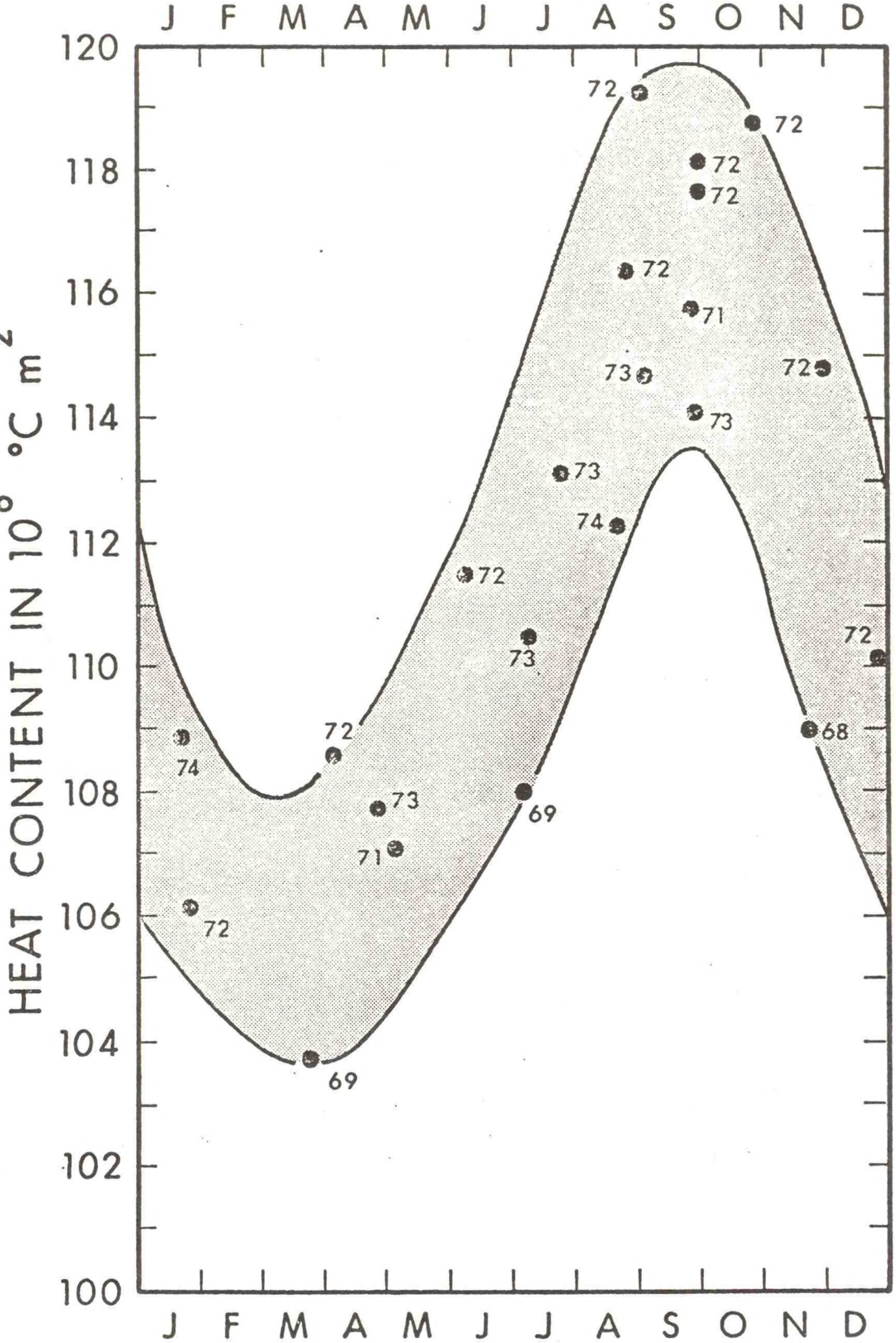


Figure 14. The seasonal variation of heat content between 25N and 45N and between the surface and 400 m depths. The numbers give the year of observations.

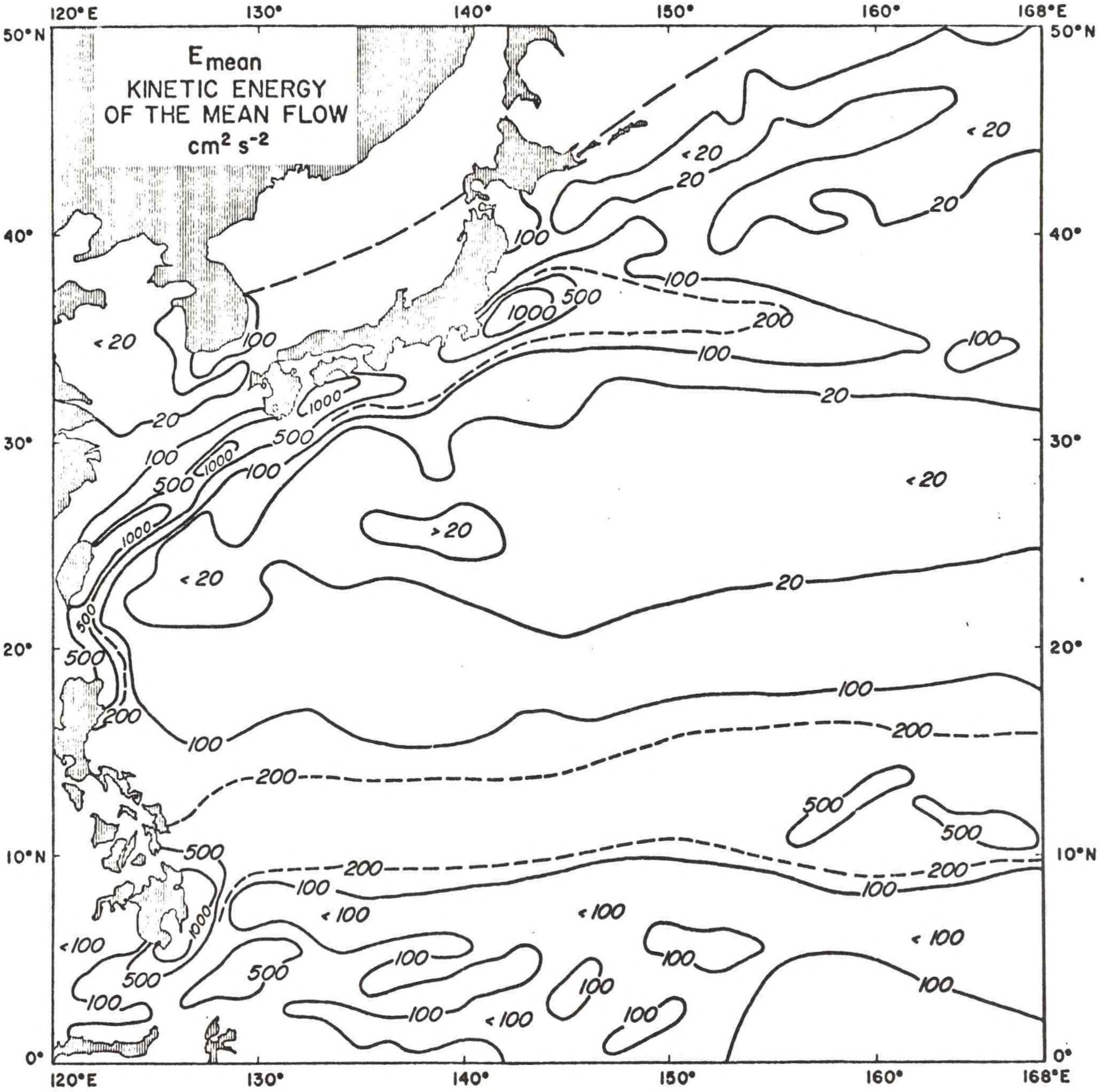


Figure 15. Kinetic energy of the mean flow in the western Pacific Ocean.

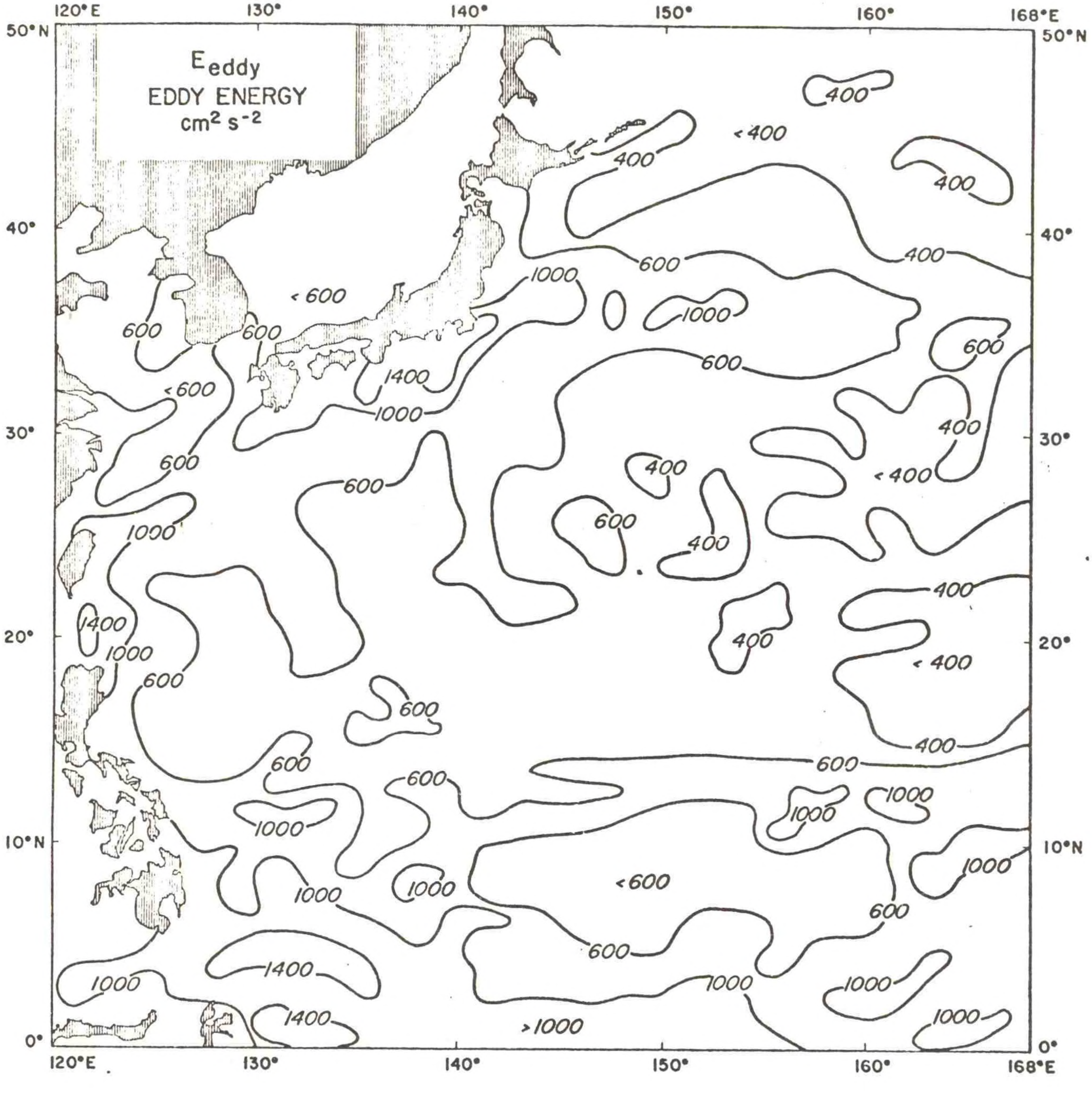


Figure 16. Eddy kinetic energy in the western Pacific Ocean.

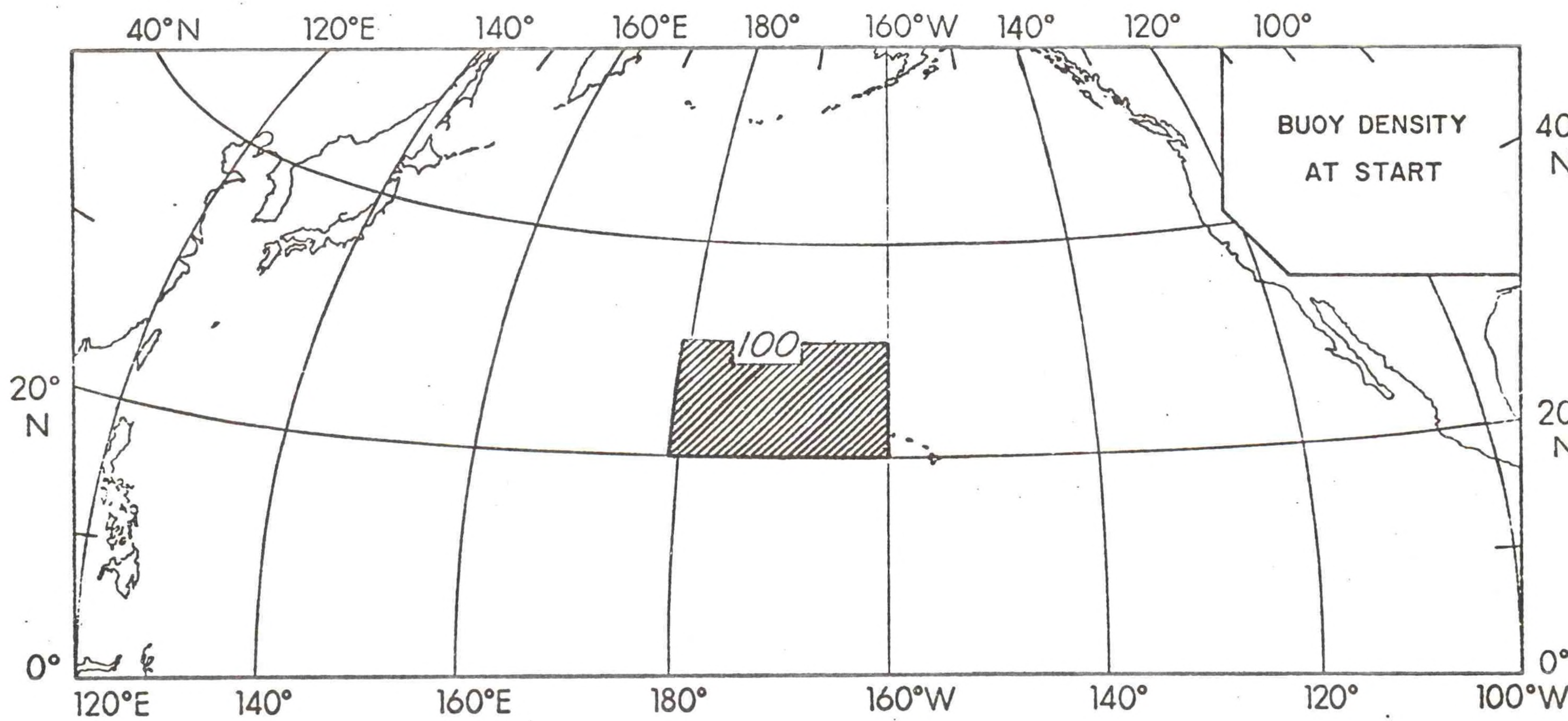


Figure 17. Distribution of buoy density at the start of the numerical experiment in per cent.

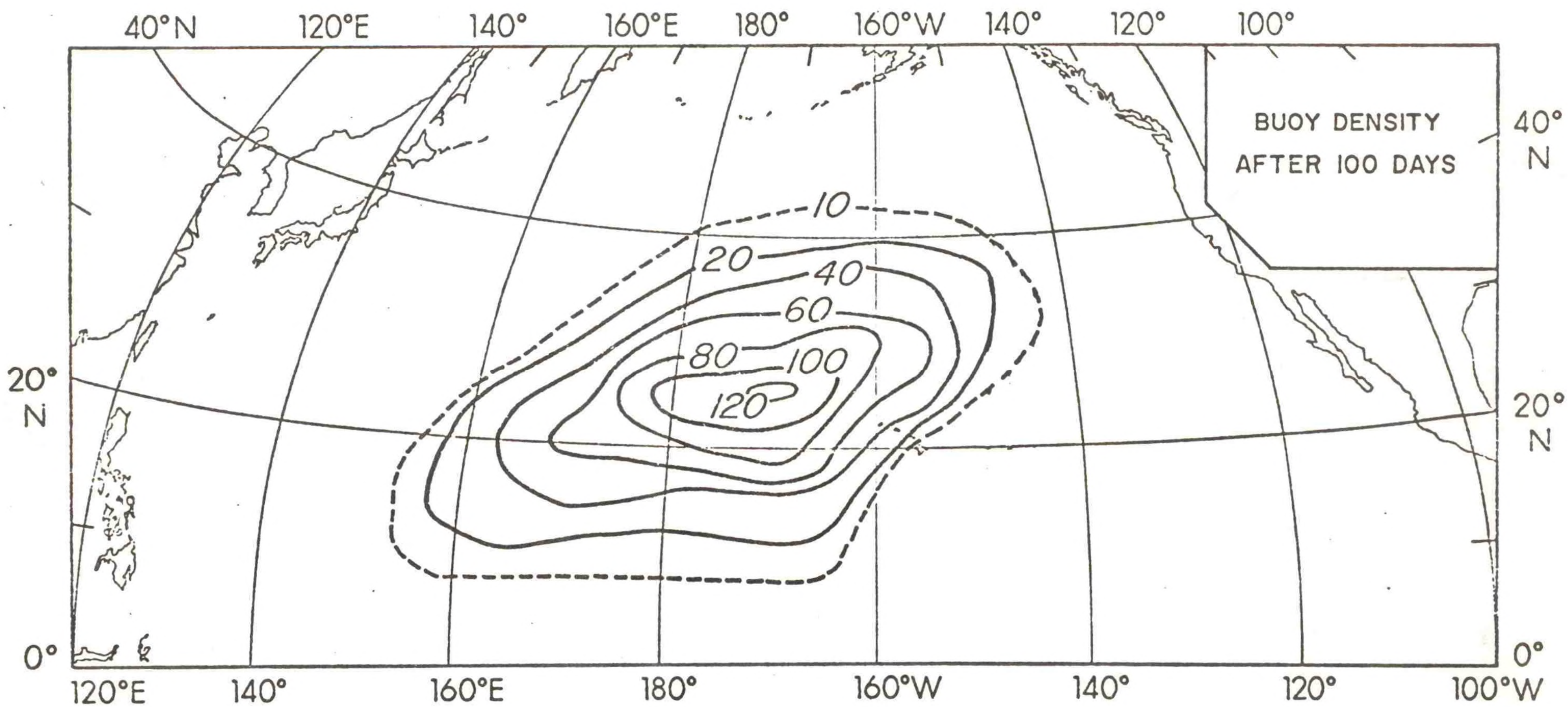


Figure 18. Buoy density 100 days after the start of the experiment in per cent.

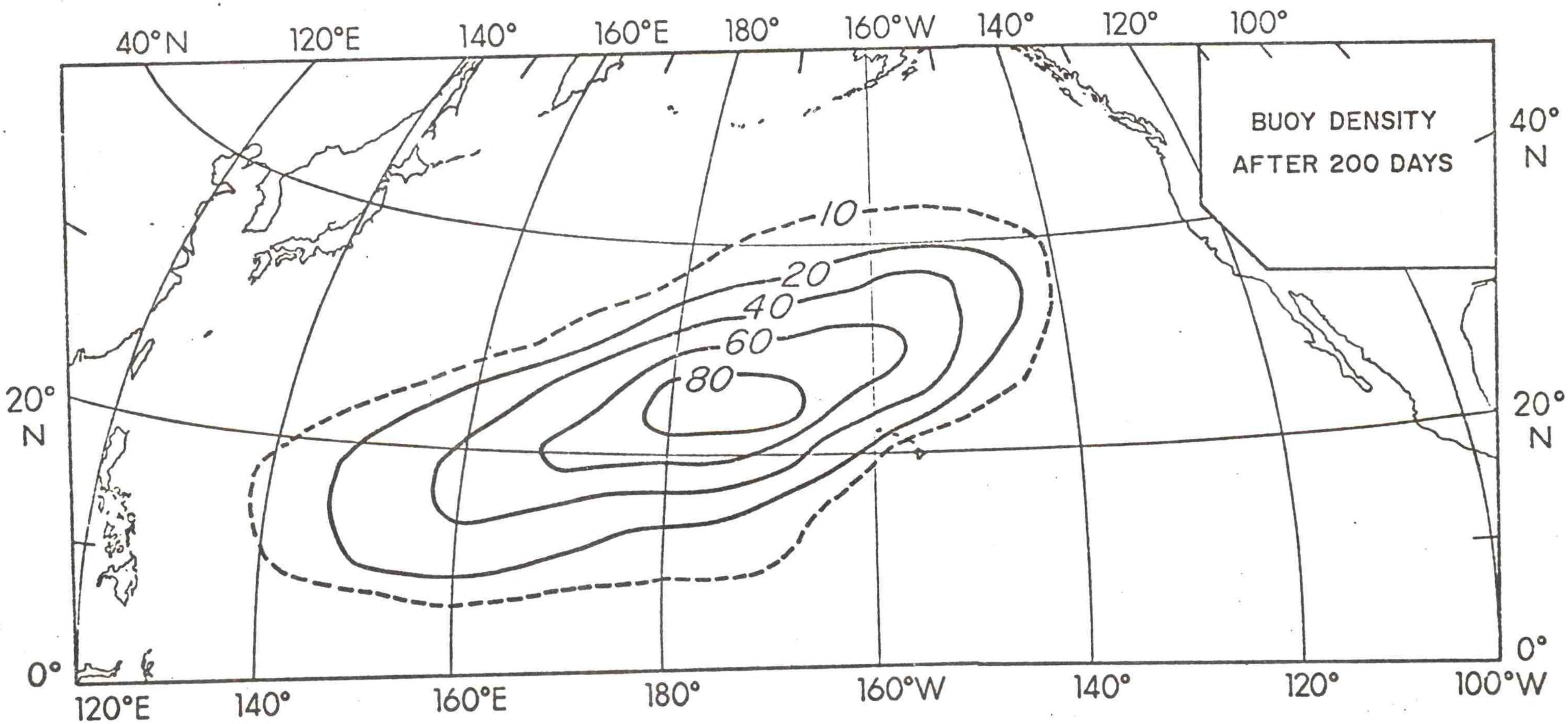


Figure 19. Buoy density 200 days after the start of the experiment in per cent.

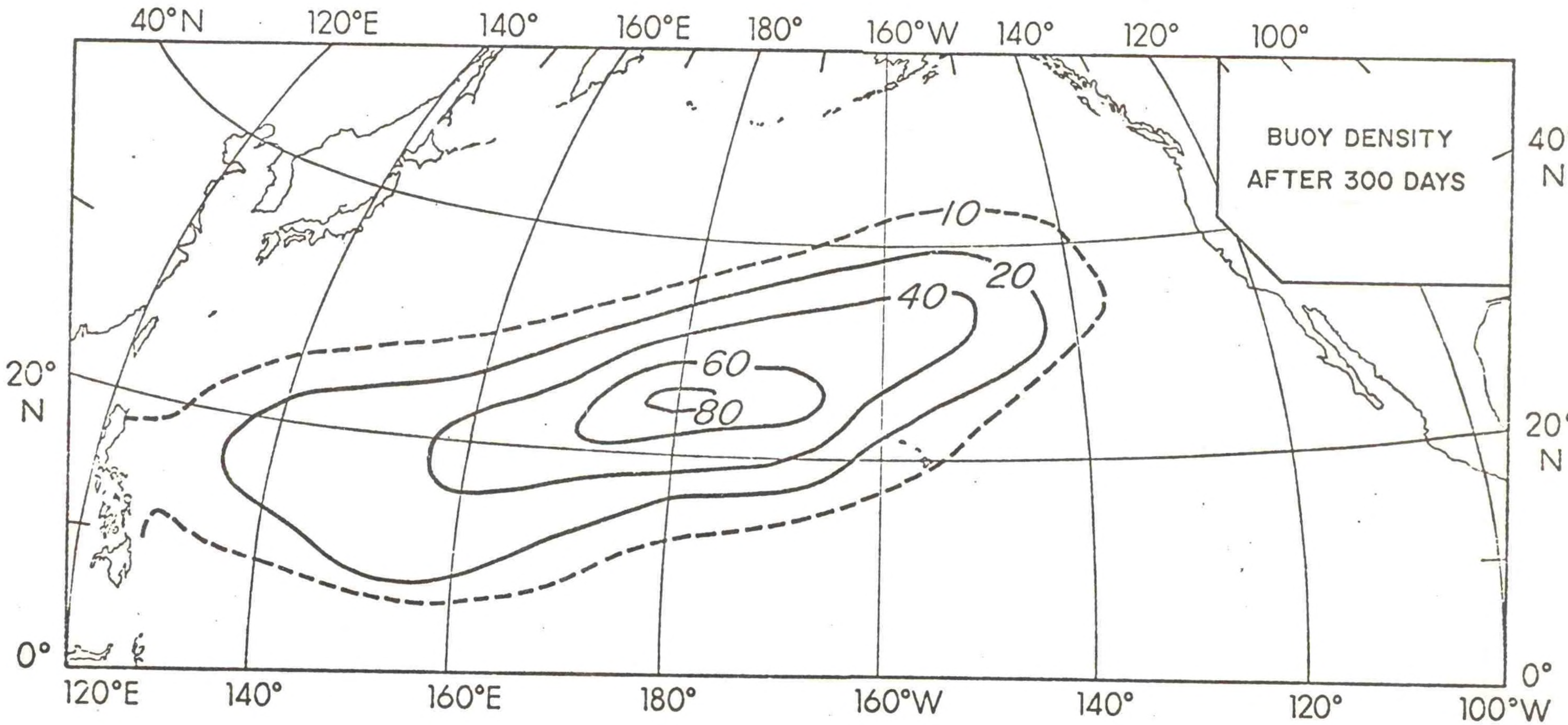


Figure 20. Buoy density 300 days after the start of the experiment in per cent.

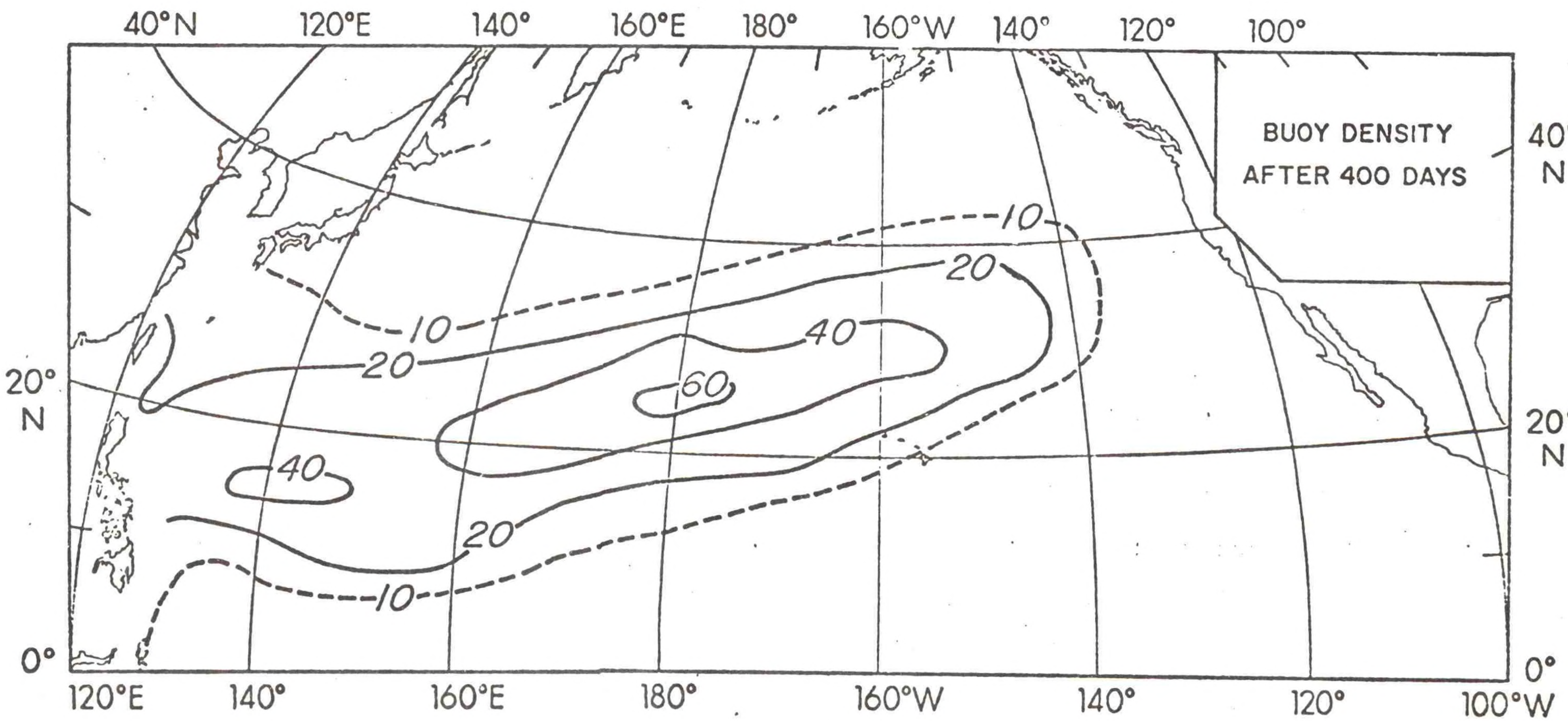


Figure 21. Buoy density 400 days after the start of the experiment in per cent.

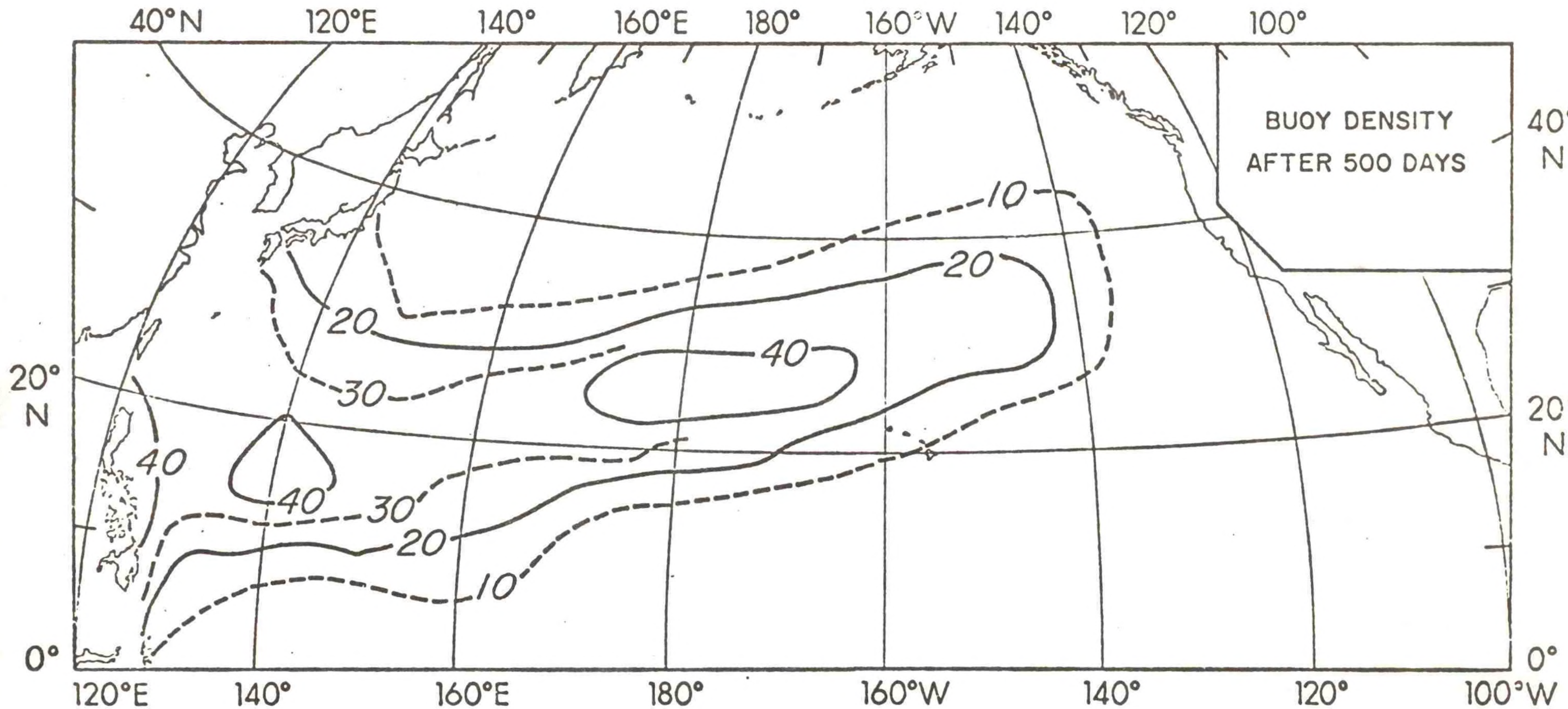


Figure 22. Buoy density 500 days after the start of the experiment in per cent.

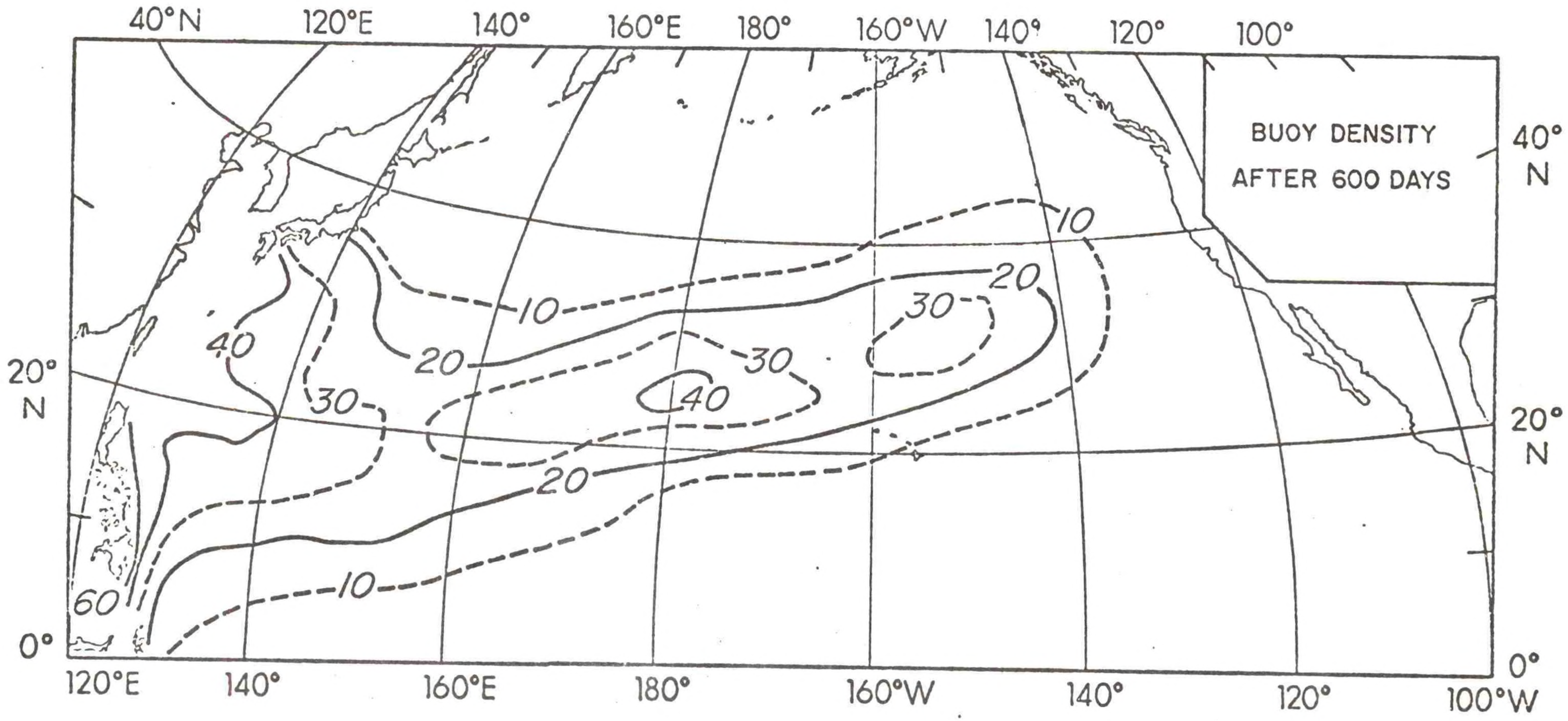


Figure 23. Buoy density 600 days after the start of the experiment in per cent.

QUESTIONS AND DISCUSSION

MR. WINCHESTER: I would like to make a comment. I think Dr. Wyrtki certainly gave a very good analysis of the problems in this climate area. I certainly concur with you that in spite of some of the things you hear, it's not my idea that we will have one buoy to do all jobs. I think we learned fairly early in this game after I came here that that was a fallacy, that you could not have one buoy do all the jobs. And we have repeatedly referred to a family of buoys, and the little presentation I gave you showed that we do have a family of buoys in our developmental program. I think that's something we all certainly have to keep in mind, that a buoy -- like the big monster type buoy is good for some purposes, and I think primarily it's good for putting in a very severe part of the ocean to provide meteorological information to the weather forecasters. I think that's its main primary function, and always will be. And certainly it's our desire to make all of our buoys perform every function that they can possibly perform economically and efficiently. But I certainly concur. We don't want to try to make all buoys do everything.

DR. FLITTNER: *Do you have an explanation for why none of your drifters in your model exercise here never approached the west coast of the United States?*

DR. WYRTKI: Oh, no, they come there, but not within 600 days.

DR. MERRILL: *And you don't include wind blowing on the buoy in the amount of days? It's just current, not wind current!*

DR. WYRTKI: There's no wind current included. It's just a try to understand some of the mechanics involved.

DR. FLITTNER: I believe you understated the problem in the interpretive application of drifters here. Your point, I think was very well taken, the placement of the buoy and release is extremely important.

DR. WYRTKI: Very important.

DR. FLITTNER: And should be emphasized more.

DR. WYRTKI: Such calculations will at least in part answer that.

DR. DISHON: *What did you use to compute your time periods for the period 1947 to 1972? You seem to have quite a lot of details in that. It seems surprising you had the various parts started.*

DR. WYRTKI: Well, we have used in the trade wind area of the Pacific 30 north to 30 south approximately, I think, 5,000,000 ship wind observations, observations by merchant ships. They are all on magnetic tape; accessible part of the ocean.

OCEAN THERMAL PROFILING NEEDS OF THE NAVY

Captain C. R. Ward, USN
Director, Naval Oceanography and Meteorology

Abstract. The Navy has a vital interest in the Ocean Thermal Structure (OTS) in an operational sense for two reasons. First, as an input to a global atmospheric model and second, and more importantly with regard to sub-surface OTS, as an input to numerical acoustic prediction models.

To support these operational needs, the Fleet Numerical Weather Central in Monterey, California collects and analyzes ocean thermal observations daily for the northern hemisphere. The data input to this analysis is 200-250 reports per day, mostly bathythermograph observations.

Ocean data buoys have the potential to both improve and enlarge the data base for the OTS analysis. The primary environmental factor of concern is subsurface temperature measurements in the vertical. Temperature should be measured in continuous vertical profile from the surface to 1200 ft with frequencies up to every 3 hours. Secondary environmental factors of concern are salinity, sound velocity and ambient noise at selected frequencies.

The Director, Naval Oceanography and Meteorology has been tasked by the Chief of Naval Operations to command assigned activities to administer oceanographic/meteorological programs relating to collection, analysis, prediction and dissemination of oceanographic/meteorological information requisite to Naval air, surface, and subsurface operations; to provide technical guidance in assigned oceanographic/meteorological matters throughout the Naval Service; to insure fulfillment of other DOD requirements for oceanographic prediction services; and to coordinate, as directed, research, development, test and evaluation related to, and supporting, the integrated Naval Oceanographic/Meteorological Program.

During the past 15 years, numerical forecasting has gradually assumed a dominant role in Naval Weather Service operations. Numerical objective analyses and prognoses have largely replaced the old ponderously-produced, subjective manual products.

The decision to explore the feasibility of adopting numerical forecasting in the Navy was motivated by the realization that the huge volume of available hemispheric data had outrun man's ability to digest it efficiently. With the improvement in computer capability, they offered an exciting prospect of being able to do a much better job. A further strong consideration in the Navy was the requirement for a wider range of high-quality tailored products, particularly in the oceanographic area.

The Fleet Numerical Weather Central (FNWC) at Monterey, California was established in the early 60's and was given the responsibility for provision of basic atmospheric and oceanographic parameters through the U. S. Navy Fleet Weather Centrals located at Guam, MI; Pearl Harbor, Hawaii; Norfolk, Va.; and Rota, Spain.

Our operational philosophy was laid down at the time the decision was made for the Naval Weather Service to "go numerical." The original principles, to a surprising extent, are still in effect, and these organizational rocks and shoals have done much to shape the unique character of FNWC as a centralized production facility. There are two areas under which FNWC's operating principles can be grouped-- (1) customer orientation and (2) applied engineering approach.

FNWC is customer-oriented. This relationship dictates that the operating Navy initiate product requirements. All of our operational procedures and program development are designed around the specialized operational requirements of their seafaring clientele. Since most of the Navy's operations involve the environment at the interface between the air and the ocean, the pioneering efforts have been mostly in this area. The atmosphere and the oceans are treated as a coupled medium, so that the interactions of the two are reflected in the FNWC tailored products that go to the Fleet.

The FNWC applied engineering approach flavors both the operations and development areas. Some examples are:

- Computers are fast, obedient, and trustworthy. These qualities are exploited to the hilt, --in engineering style.

- FNWC does not abandon the time-tested methods of hand analysis and interpretation; rather, the efforts at FNWC are engineering applications using computers to imitate successful manual operations.

- At FNWC, the data processing, analysis, and prognostic routines are all fully automated.

- Quality control of FNWC products is an important part of the operational and development routine.

- Reflecting the engineering approach, we tend to allow for much empirical influence in program development. Basic theory is used as a starting point, but the facts of life--the data--help to shape the final form of the programs.

- Our goal is always a useable operational product. Accordingly, the output is designed in a format that will be of maximum help to the field forecaster or operator in dealing with the particular operational problem at hand.

FNWC program development has always been characterized by its practicality. In large measure, this is probably because the bulk of the program development has been done by (or tightly supervised by) hard-nosed, pragmatic, experienced and well-educated Naval Officer environmentalists.

In keeping with this philosophy, environmental operations have been carried out at FNWC for over 15 years, using available synoptic and climatic data with computer solutions of combined theoretical and empirical equations; increasing the data base as possible and replacing the empirical approximations and constants by more exact relations as they were determined. All of this process is tempered by a requirement for user acceptance of the products. Required for this approach, in addition to manpower, are resources of computers, software (systems, models, and applications), real-time data (communications), and product distribution systems. The Navy's predominant interests in oceanography have been reflected in the provision of resources to develop the FNWC system.

In oceanography, recent instrumentation such as the XBT, AXBT, and STD have made synoptic analyses meaningful. These instruments extend the depth of temperature measurements to as much as 2500 feet from the earlier 450-foot level. The manual BT required calibration attention seldom provided in non-research applications. Our knowledge of the ocean's temperature structure has probably doubled since the advent of Sippican instrument.

The Navy has a vital interest in analyzing the temperature patterns of the world's oceans for two reasons. First, because of the role sea temperature plays in determining atmospheric weather conditions, and second because of the impact sub-surface temperature distribution has on underwater sound propagation. As stated earlier, the analysis process starts with the collection of synoptic data observations from around the world. The data is then analyzed and the analysis would serve as a starting point for a prediction model; however, we do not yet operationally predict subsurface temperature structures nor sea surface temperature.

Because the Navy operates at the interface of the atmosphere and the ocean, surface winds and waves are among the most important environmental parameters which we determine. FNWC applies the calculated heat fluxes to a Planetary Boundary Layer (PBL) model as a part of the larger atmospheric predictive model to determine surface winds and they in turn are used to calculate the ocean wave heights, direction and periods in a spectral wave model. High winds or seas can render a task force helpless, so knowledge of the surface conditions is very important to our Naval commanders. An equally important, but less obvious application of the wind and wave forecasts is in the area of optimum track ship routing (OTSR). OTSR is based on the principal that the fastest, most economical and safest route may not be the shortest. Millions of dollars are saved each year by routing ships in accordance with forecasted wind and wave patterns.

Below the surface of the ocean, in the realm of the submarine, the primary environmental factors of operational concern to the Navy are those affecting underwater sound transmission. Submarine warfare tactics (pro and anti) are based in part on underwater sound transmission, and in today's world of missile launching submarines this is vital business indeed for the Navy and the nation.

As sound transmits from a source, it is propagated through waters of different densities. As it does, the sound velocity changes and the sound is refracted much like light is refracted in a prism. Changes in density in the ocean are caused by temperature, salinity and pressure variations. The most critical variations are those in the vertical and this is especially true for temperature. Pressure is assumed to be a function of depth only so there is no variation with respect to time. Salinity changes are assumed to be so small that they can be neglected (more on this later). Temperature, thus, is the major physical factor affecting underwater sound transmission and in particular the changes to sound transmission patterns. Let us examine this in a little more detail. In layers of isothermal water the pressure effect with depth causes the sound velocity to increase with depth. This refracts the sound upward. If temperature decreases with depth enough to overcome the pressure effect as it does in a thermocline the sound velocity will decrease with depth and the sound will be refracted downward. In a typical ocean vertical temperature profile there will be several layers with different temperature gradients and the sound transmission will be characterized by ducts and shadow zones created by the varying patterns of upward and downward refraction. The interaction of the environment on sound transmission is so complex that the Navy has developed sophisticated acoustic prediction models that use environmental inputs of temperature and wave heights and calculate the propagation and attenuation of the underwater sound. For active sonars, where the intensity of the initial sound source is known, it is possible to predict the detection ranges for targets. For passive sonars, that listen for other peoples' noise, the sound intensity is not known and the models predict db loss as a function of propagation range. There are several variations of these models in operational use and the predictions they produce are key factors in determining the proper submarine warfare tactic to employ. Last year FNWC transmitted over 26,000 separate acoustic predictions to fleet units.

FNWC analyzes the ocean thermal structure (OTS) on a daily basis to provide the required temperature input to numerical acoustic prediction models. These acoustic models in turn produce acoustic range predictions in support of fleet ASW operations.

The input data available to the OTS analysis program consists of 200-250 sub-surface reports daily. Almost all of these reports are bathythermograph observations. They all represent vertical temperature profiles at geographical points.

Before the analysis takes place each report is processed and values are extracted for each parameter that is to be analyzed. During the actual analysis the set of data values for each given parameter is analyzed (independent of the other parameters) in a horizontal field for the northern hemisphere with a grid spacing of about 200 NM.

Prior to 27 Feb 1976 the OTS analysis used nine parameters. Eight of these were temperatures at fixed levels in the ocean (surface, 100, 200, 300, 400, 600, 800, and 1200 ft). The ninth was a variable level called the mixed layer depth (MLD). When a vertical temperature profile was needed for an acoustic prediction the nine values would be extracted from the fields at the given point. The profile would be based on those nine values; it would be isothermal from the temperature at the surface down to the MLD, then linear to the point defined by the temperature at the next deepest standard level below MLD and then in a linear fashion between each of the points defined by temperatures at the standard levels.

Starting 27 Feb. 1976, a new OTS analysis program was introduced. The new program uses the same system of extracting parameters from the vertical temperature observations and then analyzing them as horizontal fields with 200 NM grid spacing. In this sense there has been no change and the horizontal resolution remains the same. There are, however, several changes that have resulted in improvements.

1. Application of Fields by Information Blending Analysis Technique. This is a numerical analysis technique that is superior to the old technique. It has been used in atmospheric analysis programs at FNWC for several years.

2. Number of parameters. The new program uses twenty-two parameters (Figure 1), as compared to the nine used before, with the result that there is more detail in the extracted vertical profile. Twenty-one of the parameters are direct values of temperature at standard and significant depths and values of temperature differences between depths. The 22nd value is Primary Layer Depth (PLD) which is described in more detail further on.

3. Gradient in the mixed layer. The new program allows for positive and negative gradients in the mixed layer as compared to the old program which always treated the mixed layer as isothermal.

4. Vertical consistency. Because the new analysis program uses temperature differences as well as temperatures at depths the parameters are dependent. The actual analysis of each parameter is, however, done independently so when a vertical profile is extracted weighting factors are applied to each parameter. This provides a vertical check that the old program did not have.

5. Shape of the thermocline. The new analysis fits an exponential curve between PLD and PLD+100 ft and then interpolates for values of temperature at PLD+25 ft and PLD +50 ft.

6. PLD. The concept of MLD was based on the theory that the ocean can be divided into layers with a well mixed isothermal layer above a well defined strong thermocline. This is not always the case and when the upper ocean is not well mixed or when there is not a strong thermocline the MLD becomes discontinuous in time and space. This has always created severe problems when trying to analyze MLD over a large area. The new analysis program uses a parameter called PLD which is roughly defined as the major vertical temperature gradient discontinuity. In effect it uses a complex algorithm as compared to the simple definition of MLD. When each observation is being processed a value is calculated for the curvature at each inflection point. PLD depends then on the relative magnitude of these curvatures plus the absolute magnitudes of the temperature changes below each point of curvature plus horizontal consistency with other reports. It should be noted that there is no difference between PLD and MLD in those areas of the ocean where there is a well defined layer. It is only in the "grey" areas such as when the reports are near isothermal all the way to the bottom that PLD and MLD may be different.

In summary:

A. The new analysis program is an improved and expanded version of the older type of analysis rather than a totally new concept.

B. The new program provides a more detailed and therefore more meaningful vertical profile. It is also more conservative with regard to day-to-day changes in the fields and the horizontal patterns are closer to accepted science.

C. Then analysis is still limited by the sparse data input and by the lack of horizontal resolution due to the large grid spacing.

The data input for the OTS analysis consists of 200 to 250 reports per day, most of which are bathythermograph reports, which are concentrated in the naval operating areas and along shipping lanes. To do the job properly, we need more data. Theoretically, one observation per day in each homogeneous water mass region is sufficient to support computations of low frequency sound propagation. However, greater coverage is required to determine water mass boundaries, provide horizontal continuity, calculate heat fluxes, and for high frequency sound work. The coverage shown in Figure 2, with water masses shown as an overlay, is considered to be a minimum to insure Northern hemisphere synoptic oceanographic temperature analyses of good quality. One of the potentially valuable sources of coverage, at least in areas of the eastern Pacific and western Atlantic, is the National Buoy Program.

Temperature-depth data from moored ocean buoys can take two forms. Vertical profiles from probes that are dropped from the buoy or data points from discrete fixed points such as when thermistors are attached to the mooring cables. The former method is much preferred by the Navy because we are most interested in vertical gradients and layer depths and need detail in the vertical.

The latter method (discrete points) as it is presently employed has been unsatisfactory for naval operational needs. If technology and/or expense preclude a bathythermograph type of sensor, a compromise method that may be acceptable would be to increase the number of discrete points to one every 5 meters (or closer) and thus provide the required vertical definition in this manner. The Navy requirement for vertical definition of the temperature structure is the most important point to be made in this paper.

Additional requirements with regard to the instrumentation are that the measurements extend to at least 400 meters, that the temperature sensors have an accuracy of $\pm .1$°C and that the observations be reported every 3 hours. These requirements are to make the observations compatible with the other reports that go into the analysis. One desirable point with regard to the transmission of the reports is that they should be secure in a war-time environment.

There are three types of secondary data that should be observed if at all possible. The first is salinity. It was noted above that salinity changes are considered small when calculating sound transmission, but this is not true in areas such as the Labrador - Gulf Stream confluence area. Salinity should be measured at 3 depths (just below the surface, 100 M, and 300 M) and reported on a synoptic basis. The second type of secondary data is ambient noise. This data would be most helpful in predicting acoustic conditions. The third and final type of secondary data is direct measurements of sound velocity.

In conclusion, the operational Navy has a very real need for ocean thermal structure data. Detailed vertical definition is the most important Navy requirement with regard to instrumentation, and this requires either a bathythermograph type of instrument or closely spaced discrete point valves. Geographical coverage of buoys should be planned to monitor the most important of the oceans features, such as the gulf stream and the various water masses and within the favored geographic areas, priority should be given to those areas where we have the least expectation of observations from the various BT programs.

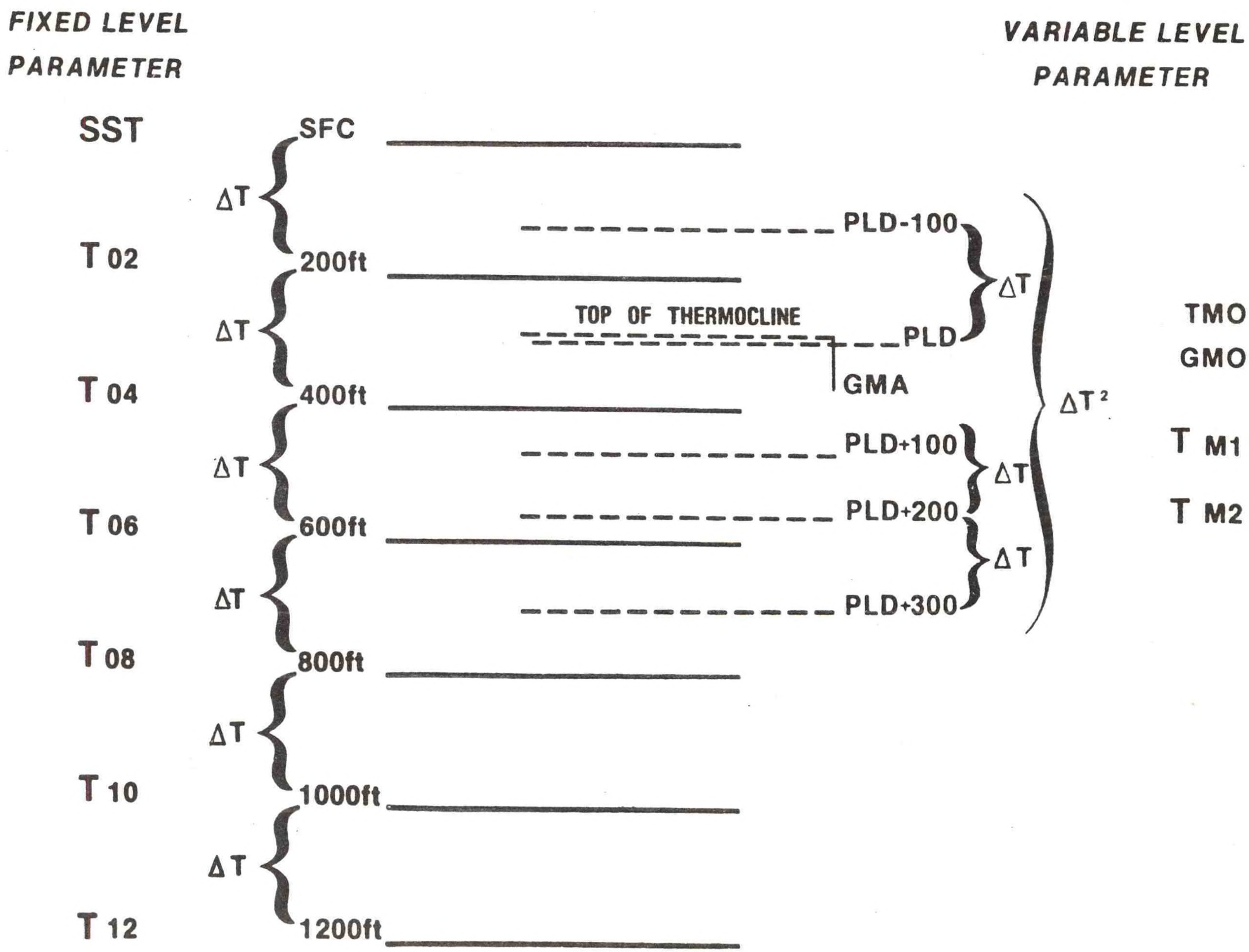


Figure 1. Ocean Thermal Structure Fields (See Notes on Figure 1.)

FIXED LEVEL PARAMETER ————————

NOTES FOR FIGURE 1

VARIABLE LEVEL PARAMETER- - - - - - - -

OCEAN THERMAL STRUCTURE FIELDS

Name	Parameter	Units
Sea Surface Temperature	SST	°C
Temperature at 200 ft	T02	°C
Temperature at 400 ft	T04	°C
Temperature at 600 ft	T06	°C
Temperature at 800 ft	T08	°C
Temperature at 1000 ft	T10	°C
Temperature at 1200 ft	T12	°C
Temperature at the top of the thermocline	TMO	°C
Thermocline Gradient	GMO	°C/100 ft
¢Primary Layer Depth	PLD	ft
Temperature at PLD + 100 ft	TM1	°C
Temperature at PLD + 200 ft	TM2	°C
$First Temperature Difference PLD - (PLD-100 ft)	GMA	°C/100 ft
First Temperature Difference (PLD+200) - (PLD +100)	GM1	°C/100 ft
First Temperature Difference (PLD+300) - (PLD+200)	GM2	°C/100 ft
First Temperature Difference (200 ft-surface)	G00	°C/200 ft
First Temperature Difference (400 ft-200 ft)	G02	°C/200 ft
First Temperature Difference (600 ft-400 ft)	G04	°C/200 ft
First Temperature Difference (800 ft-600 ft)	G06	°C/200 ft
First Temperature Difference (1000 ft-800 ft)	G08	°C/200 ft
First Temperature Difference (1200 ft-1000 ft)	G10	°C/200 ft

Second Temperature Difference (centered at PLD+100 ft)	CM1	°C/(100 ft)

¢ The major vertical temperature gradient discontinuity.

$ The gradient above PLD.

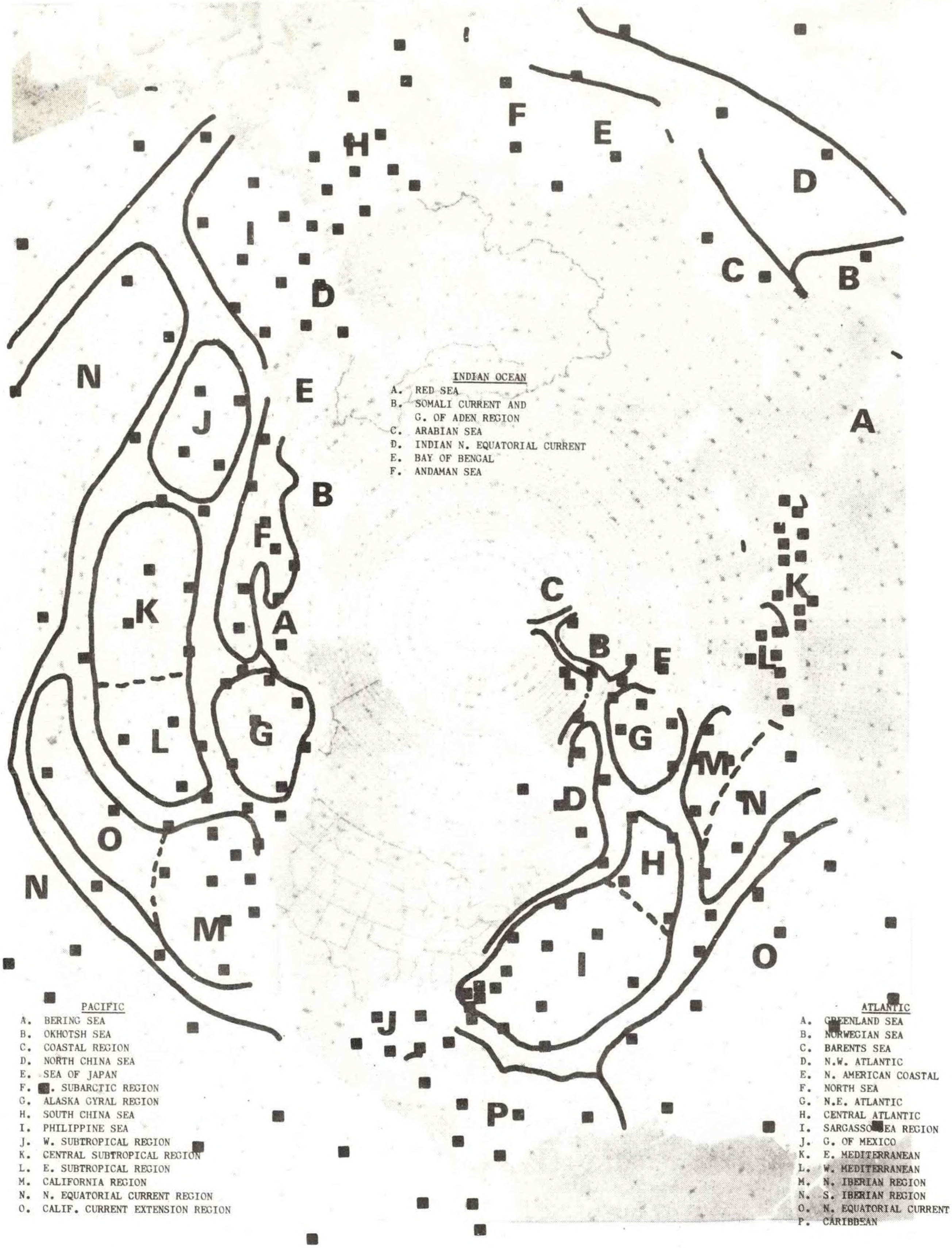


Figure 2. Proposed Minimum Bathythermograph Coverage with Major Water Mass Regions Superimposed

QUESTIONS AND DISCUSSION

MR. RODEN: I want to draw attention to the temperature inversions. You said that they are not very common in the ocean, but in fact, in the northwestern Pacific temperature inversions in winter are not transitory features, but cover large scales and may vary in intensity from anywhere from .2 to 2° centigrade.

In some of these regions, the temperature inversions even persist throughout the summer months. They seem to be a permanent annual feature. And the importance, I think, lies in the mixed layer dynamics. Of course, if you have a temperature inversion in winter, mixing really can speed the warming of the upper mixed layer.

MR. LANDIS: *One remark that kind of intrigued me, you said in a war-time condition you would expect that the data should be secured. Does that then mean that it's the Navy's policy to classify this information now and leave it unclassified until we get into a war-time situation and then classify it? And at that time, would data taken by other people outside the Navy system be of any value to you?*

CAPTAIN WARD: Was that a question or a statement? Well, obviously this data would be extremely valuable to a potential enemy, and I am not suggesting that it should be treated as classified data now. Far from it. But I say if you look at a war-time environment, you've got a different sort of problem, and we've always had this kind of problem. I mean, the weather ships didn't operate freely in war-time. And so I'm just reminding everyone that there is a problem which is really with us.

MR. WINCHESTER: The old surface weather messages from ships were classified during World War II.

CAPTAIN WARD: Yes.

DR. AUSTIN: Well, there is an interdepartmental board, chaired by Colonel Barney (NOAA/EM-7) that handles this type of situation. I remember when I was in NOAA, preparing a shopping list for the Navy, the concepts provided that in war-time essentially all ships, aircraft, buoys, and everything run by NOAA go military anyhow, which, you know, would give the Navy the prerogative to do what they wanted with all the buoys, because they'd be theirs.

CAPTAIN WARD: I think what I'm suggesting is that this might increase the cost of the buoy if we were to consider this problem.

MR. KIRK: *Captain, has the new program had any luck in improving the blend between analysis and the input sheets?*

CAPTAIN WARD: I think so.

This question of secured data, if we go to a line of sight transmission to a satellite, we've got a relatively secure data transmission right now. So I'm not suggesting that this is a problem which is unsurmountable, but I'm just reminding everyone that this is something that DOD would be concerned about.

MR. MILLARD: *Captain, what about the dissemination of data now? Is it available to the scientific community in general?*

CAPTAIN WARD: Yes, NOAA buoy data is available to everyone as far as I know.

MR. MILLARD: *But your prediction maps and what have you?*

CAPTAIN WARD: Our maps are available in general to the scientific community, but we try to work with NOAA on this.

DR. AUSTIN: If I could comment on that. Pacific environmental group, which is colocated with Fleet Numerical in Monterey, draws heavily on their data base. Glenn, maybe you can comment a little more in detail on that.

DR. FLITTNER: Well, in particular, in one area there is a free interchange of all unclassified thermal structures, now going on between Fleet Numerical and the National Weather Service. And that's a sizeable body of data.

CAPTAIN WARD: Yes. My answer was very evasive only to the point that I can't envision Monterey becoming a major production facility for the entire community. What I would like to do is dump it on the National Weather Service and let them distribute it.

MR. MILLARD: My question was motivated by a past experience. I was on a Russian ship last summer and they had excellent sea surface temperature maps for the Norwegian Sea, for which probably you were the original source.

MR. CANADA: *I think Weather Service dumps most of that data on NODC, do you not?*

DR. FLITTNER: The data go two ways. The data that goes into the archives indeed go into the NODC complex. Certain of the XBT and other thermal substructure data do get into the integrated local ocean station network. And some of those data do go to World Data Center B as well as World Data Center A. But that's a fraction of the available data, and it is not a very large fraction at the moment, certainly, because we have message acquisition and compilation problems. But the data are used in two modes, real time globally and in archival form both nationally and internationally.

NATIONAL WEATHER SERVICE - SYNOPTIC OCEANOGRAPHIC SERVICES

Dr. Glenn A. Flittner, Chief, Ocean Services Division, National Weather Service (W16), NOAA, Silver Spring, MD

Abstract. About three years ago, the National Weather Service (NWS) set out to develop an operational oceanographic services program. Progress has been slow, largely because program resources have not been available, and because our national interests and economic activities have been slow to respond to marine environmental problems and issues. NWS is organizing a program to describe the initial state of the hydrosphere, to measure and report key physical characteristics of the upper layer of the sea, and to predict changes in these characteristics. Problems of time and space scale differences between the coupled atmospheric and fluid media are recognized, and the need for ocean data is described. The role of buoys in ocean data acquisition is treated, as are the deficiencies in our present system of observations. The need to develop a base of experience is discussed, and the differences between two basic philosophies of approach are outlined.

About three years ago, the National Weather Service set in motion a series of events leading to the development of an operational oceanographic services program. The Headquarters structure was rearranged so as to accommodate, for the first time in the agency's history, the office of an operational oceanographic specialist. Building in part upon recommendations arising from the Stratton Commission report, "Our Nation and the Sea," NWS has responded to both the recommendations of the Commission, and more recently to the NOAA Office of the Administrator, in attempting to build an oceanographic environmental monitoring and prediction capability in the civil sector of our government.

In keeping with the basic worldwide synoptic observation and communication network, established by the World Meteorological Organization (WMO), and drawing upon the reservoir of automatic data processing and numerical modeling expertise within the National Meteorological Center of NWS, and among the several laboratories of the NOAA Environmental Resources Laboratories, we have been asked to assemble a fully operational program to serve the needs of the national (and international) marine user community.

However simple the expectations of our Nation's legislative and executive leaders, fulfillment of the task appears to be a formidably difficult and slow process. Development of a program having significant potential to the public requires resources which, today, are extremely hard to come by. It is a hard fact of life that only yesterday, so to speak, our Nation's priorities precluded any meaningful operational services activities to mariners outside of the Navy and a handful of high seas shipping lines. Only recently have the problems of the offshore oil exploration, fishery management, and mining interests been brought to the forefront. The continuing debates over the Law of the Sea, and over the Extended Jurisdiction Zone out to the 200 miles from our shores have served to sharpen the potentials for conflict -- and for the U.S. to move to protect its interests in the oceans. Coastal zone management and other issues associated with burgeoning industrial, residential and recreational use of the coastal zone has created new demands for environmental information on a scale unanticipated ten to twenty years ago. We in NWS are attempting to build a program that will provide the basic information and forecasts to serve the users just enumerated.

The Challenge - To describe the initial state of the hydrosphere; to measure and report key physical characteristics of the upper layer of the sea; and to predict changes in these characteristics in both time and space scales commensurate with the processes that are observed.

And finally, given a sufficiently long base period of observations to determine the "environmental signature" unique to localities and regions and time of the season or year.

The Program - We are taking steps to prepare analyses and forecasts of selected parameters in several dimensions: a) horizontal, b) vertical, c) time, and d) rates of change. At the beginning, we plan to concentrate on two physical measures: 1) temperature structure and 2) conductivity (salinity). Given these two basic measurements, we should be able to describe flow regimes that are the consequence of variations in mass fields. Because we are vitally interested in the physical coupling between atmosphere and hydrosphere, we intend to give particular attention to ocean currents in the surface layer and along continental boundaries which result from atmospheric forcing. Wind set-up will be a special interest of those elements of our field structure serving communities bordering on shallow estuaries and embayments.

So far, I have described a straightforward physical-descriptive approach which is conceived to be compatible with the synoptic time/space scale of the air/sea (surface wave) interface. (I'll return to the subsurface time/space scale problems later.) The basic analytical unit will be frequent enough to permit secondary users, such as the Fisheries people, to combine, to integrate, and otherwise accumulate data, as is necessary to their applications. We will emphasize the maintenance of time and space continuity where practicable, and we will assist in developing derived ocean climatological data as well.

Need for Ocean Data - The subject recently has received a great deal of international attention. We envision a mixture of fixed, moored, free-drifting and mobile marine platforms, as well as satellite systems, to provide these simple physical measurements. I feel that the development of the expendable platinum-bead thermistor bathy-thermograph (XBT) is the equivalent of the meteorologists' radiosonde. Potential addition of an expendable conductivity sensor to this system makes the cooperative vessel platform the most cost-effective system yet available for subsurface data acquisition. NWS is now moving ahead to develop the Shipboard Environmental Data Acquisition System (SEAS) to relay data in semi- or automatic mode to shoreside receiving points via satellite communications relay.

Nevertheless, cooperative ships are not always in the right place at the right time -- and too often today are skilfully routed away from areas where we need the measurements. So, the buoy technology has a definite and viable role to play in the business of ocean data acquisition. The primary value seems to be in the maintenance of a time-continuous record of events from a fixed, remote point. The significant value of these points has been amply demonstrated by Ocean Weather Stations Papa, November and Victor in the Pacific, and by Bravo, Echo and Hotel in the Atlantic. Others here at this Workshop can testify to the value of these simple observations.

Role of Buoys in Ocean Data Acquisition. The potential merits of fixed-moored and free-drifting buoys have been described elsewhere. I will now present our views as to where the buoy technology can best serve a NOAA-NWS synoptic oceanographic program:

1. Disparity in spatial coverage by cooperative ships - Many areas of the Southern Hemisphere oceans, the high latitudes and a large triangle between Hawaii, the Equator and the West Coast of Central America are seldom traversed by cooperative vessels. A few buoys stationed at key centers of activity, or in seldom-visited regions, will assist in filling in the data analysis grid.

2. Need for time-continuous reference points - Mobile platforms do not provide the needed information about variability through time. We need buoys in strategic locations relatively close to the Continental Shelf to provide measures of variability that ships do not give. Topographic boundaries, current fronts, upwelling zones, and river plumes could be better described by data buoy platforms.

3. Subsurface structure and variability at fixed points - These measures are of great interest in the Continental Shelf zone. Continuous monitoring of bottom temperatures for demersal fisheries (e.g., shrimp, cod) would be enhanced by fixed buoy stations. Profiling of the vertical thermal and/or salinity structure is essential to resolution of the baroclinic components of motion.

4. Continue the development of a long-term surface meteorological data base - Buoys can take over the former functions of navigational lightships and weather station vessels. Marine climatological data must be observed continuously through time so as to provide better understanding of the flux of heat energy from atmosphere to ocean, and vice versa.

While this discussion has shown primary emphasis on the marine mobile platform as the basic tool to measure ocean substructure, the NWS is keenly aware of the potential long-term value of an effective ocean data buoy network to "calibrate" data from other sources, such as satellite sensors. Our program will be devised to give appropriate weight to measurements from buoy systems that are state-of-the-art in measurement precision and reliability. You can be certain that it may be many decades before we have to worry about data saturation in the subsurface region of the global oceans. In the meantime, we'll have to learn to do the best with what we can afford -- and acquire.

Up to this point in our discussion, you may have observed that I have not made a strong case for ocean profiling measurements to support present NWS programs. There are two schools of thought within NWS at the moment:

One view is that the atmospheric Primitive Equation (PE) model does not require subsurface information to support significant improvements in the model's predictive skill; there are other, more serious, faults in the atmospheric elements of the model. The satellite SST data are sufficient to describe the basic ocean thermal structure. Further, there is no demonstrable civil sector requirement for subsurface information, outside of the Fisheries; the cost of acquiring subsurface data is prohibitive and to be avoided if possible.

The other (minority) view is that atmospheric prediction skills in the extended range mode cannot be developed independent of knowledge of heat storage, transport and flux into the atmosphere. Subsurface measurements are essential to the development of statistical models of the coupled air/sea systems. Many decision functions must be exercised in today's society that need not await the development of complete understanding of the physical-dyanmic processes involved -- and that reasonably skillful statistical estimation schemes indeed have prime value to management decisions that must be made far in advance of events. In time, full understanding of complex oceanic processes will be achieved, and we can then move to more deterministic prediction schemes.

Time is of the essence; we must start to operate now to develop the experience base which is essential to the development of this understanding.

QUESTIONS AND DISCUSSION

COMMANDER TATRO: *I have two questions, Glenn. One is how far offshore is NWS going to analyze these various parameters such as temperature/salinity ranges?*

DR. FLITTNER: Well, we analyze a global -- surface wind model now, and it seems to me to be a logical extension of our global analysis capability. If we're going to talk about the air and the sea as coupled systems we have to have a handle on at least the upper part of the mixed layer. Our basic data processing structure is such that we handle two polar stereographic projections in a mid latitude grid in between, and I think it's much the same as Fleet Numerical has got. That, I don't think is the problem. The problem is how do you justify in the U.S. national interest the acquisition of data in the Southern Hemisphere oceans.

COMMANDER TATRO: That's part of my question.

DR. FLITTNER: Especially to the OMB types.

COMMANDER TATRO: *A different, unrelated question. You made two references to the need for continuous data. Did you mean continuous or did you mean sampling at some finite interval for a long period of time?*

DR. FLITTNER: Sampling at finite intervals, but in a continum, that is, there are no lapses in observational record. There are no voids.

COMMANDER TATRO: The finite intervals could be measured in hours, for example.

DR. FLITTNER: I emphasized the point earlier in the talk, commensurate with the time and space scales of the processes that we're concerned about. But there have to be a continum mode of such measurements. They cannot be started and stopped such as the ocean weather stations.

CAPTAIN WARD: May I respond to a problem you raised, and say that we have recognized a problem in processing the buoy data, the subsurface thermal structure data. We have found it largely unusable in a real time mode because of the missing levels from time to time. And of course, Bill has got some examples of what is missing in those points does to our analysis scheme, and so if we're going to use the data in a real time mode, and certainly we will and your organization will, we'll have to pay careful attention to a quality control effort.

DR. FLITTNER: Yes. I'd like to respond to your last point by reporting that Burt Thompson, who is the Chief of our Oceanographic Services Branch, has assumed a very responsible role in trying to take off the Navy's hands a difficult quality control problem and processing the IGOS, BT data. I cannot overemphasize the necessity to commence right now rather rigorous data quality control programs. The meteorological community have had these fairly well shaken down over the years. The oceanographic community has not yet established international protocols which have been tested by time and practice. And we're just making the first steps in this direction. It's an important problem.

DR. AUSTIN: Along the same line is also the problem of when Weather Service's computers cut off the inflow of data, because I remember looking at the synoptic charts over a period about 6 weeks ago in which I was keeping track of when the buoys were reporting. And this was just meteorological data, and they were never appearing on the charts because, you know, they were being cut off.

DR. FLITTNER: Yes. This is another aspect of this time space scale data handling processing disparity. The upper atmospheric multi-layer model which is driven by aviation requirements requires a time chop on or about the fortieth minute past the hour. Most of the marine data, that is, the data from marine sites, whether fixed or moving, generally have to go through a shore receiving station and relay point. The majority of the data never make the chop time for the first run at NMC. They have to be delivered prior to the fortieth minute if they're going to get into the analysis. So the time space demands for the 48 hour physical dynamical predictive model force the acquisition of data not later than 40 minutes past the observational hour, because the machine has to go into the grind. And the marine applications community so far has been left standing at the dockside because they are not articulate, vocal, and they don't have a great deal of clout in Congress. They have not been able to press their requirements as successfully as the aviation industry.

MR. LANDIS: *Is this the same time chop for the fine mesh models?*

DR. FLITTNER: Yes, same thing.

Now, Bob Landis has just raised another point. The National Meteorological Center right now in the hemisphere analysis is analyzing on a 320 kilometer interval. Mesoscale features oftentimes are not picked up until they reach a certain limiting size. A classical example was the storm which crossed Lake Superior last fall which took down an ore carrier. The limited fine mesh model which analyzes on a 160 kilometer grid mesh picked up that deeply intensifying storm in the southern great plains about 12 hours earlier than the basic forecast model did, simply because it was able to detect development of that rapidly deepening center quicker. But to put the analytical program on to the LFM grid mesh requires another generation of computer capability which we presently don't have.

MR. CLEM: We have recognized this problem of data getting in late and have coordinated that with NMC. We have collapsed our processing time and rescheduled data transmission. I think you'll find now most of the buoys' data are in time, well within the forty minutes. Most of them are in 20 minutes now. So we think we've corrected that problem. The buoy data are now back on the maps.

DR. FLITTNER: The systematic programming out of the marine data acquisition system of the human I think is the only practical approach here. And this is what is forcing us to develop the shipboard environmental system. We hope to automate the acquisition of this synoptic marine meteorological observations as well as the XBT profile and to put it on a data collection and transmitting device which will be keyed by the GOES satellite relay system and played out at Wallops Island or some other facility for transmission to National Meteorological Center.

The hard facts are that it's going to be decades before we get many of these systems into operations. In the meantime, we have to have humans taking the observations and using the old HF radio transmission mode to get the data in. The only practical approach as I see it is to require marine operators to prepare their observations well before the synoptic hour and to get it in to the shore stations well before the hour instead of afterwards. And this requires heavy public relations work at all of the waterfront locations. Worldwide, as a matter of fact.

MR. KIRK: I don't understand how the model runs that quickly. You don't get your upper air data in that soon.

DR. FLITTNER: There's a first transmission that gets cranked in pretty early. Yes. There's a first cut and then a second analysis later. And I think Fleet Numerical does much the same thing.

CAPTAIN WARD: Yes. We do an early surface map. I think NMC uses something called the RADAT data. They transmit the 500 millibar data separately and early, and we don't. We don't use that because our interest over the water is great and there's nothing available over the water in that time frame.

DR. FLITTNER: Again, Captain Ward has emphasized the difference of approach. The National Weather Service has served aviation historically for several decades and has looked upward instead of downward. And so the whole processing scheme and the priorities that have been applied have been quite different.

ENVIRONMENTAL SIGNATURES, PROFILING NEEDS FOR LIVING MARINE RESOURCE MANAGEMENT

Herbert M. Austin, Division of Research Management, NMFS, Washington, D.C. and Gunter R. Seckel, Pacific Environmental Group, NMFS, Monterey, California

Abstract. The operations and research of the National Marine Fisheries Service (NMFS) are directed towards the support of management for living marine resources. The physical measurements made by buoys are supporting environmental information and thus of secondary priority to NMFS budgeteers. Secondary priority budget items generally receive no increases at budget time; consequently, there is a certain degree of frustration by NMFS oceanographers.

There is an evolution within NMFS as the importance of physical-chemical environmental information is becoming apparent to resource managers, particularly as it relates to predicting resource abundance. Temperature and salinity changes are the signatures of environmental processes and so can be an index of changes in resource distribution and abundance, particularly in the long term. It is within this context that NMFS will support future measurement programs.

NMFS research is directed towards a series of objectives all of which focus on six Goals, primarily Goal 1, living marine resource management (attachment I). Physical measurements are environmental support information and of secondary priority to NMFS budgeteers. Data and information for resource management decisions receive primary support. We need the data, but moneys for their collection are cut. We therefore look to sister MLC's like NWS & NOS, charged with making environmental measurements, to supply the data for us.

Temperature and salinity changes are the signatures of environmental processes - and it is in this respect that the subsurface properties observed from buoys will find their most important uses. To fisheries, temperatures and salinities traditionally have been used in terms of their physiological effect on the biota and in identifying water types and "domains" within which specific species of fishery resources live, and these will continue in the foreseeable future. However, the prediction of changes, management, and protection from pollution of marine resources will primarily depend upon our understanding of the dynamics of the ocean system at a wide range of time and space scales.

1. Budget studies - Understanding of the dynamics in the ocean's troposphere is gained through studies of heat, salt, and momentum budgets. These of course involve measurements of temperature salinity and currents from the surface to well into the permanent pycnocline as well as measurements of the properties in the atmosphere above the sea surface for the computation of heat and water fluxes and the wind stress. It is assumed that the conference will be concerned with the routine measurements from buoys. At the present time current measurements do not fall into this category and are therefore excluded from the comments given below.

Special cases of budget studies concern changes in ocean structure, mixed layer dynamics, and the various modes of vertical transfer of the steady state advection-turbulent-diffusion balance or events of "burst-like" transfer due to breaking internal waves or turbulent "storms". Another example is the relationship between the "measured" wind stress curl and changes in vertical structure of the water column reflecting the divergence or convergence of water. These processes affect all stages in the food chain such as nutrient supply and productivity, larval survival, the concentration of forage, etc.

2. Monitoring - Data obtained from buoys placed in key locations can be used to monitor changes in the environment: a. water types and domains, b. baroclinic flow, c. processes discussed in (1) above. A single profile is generally sufficient in the first case. Two or more profiles are necessary to monitor the baroclinic flow. Arrays of several profiles may be necessary to monitor processes.

Time Scales - Present and long range measurement requirements are interpreted to mean near-term and climatological respectively. Near-term or short range requirements are essentially those involved in a particular study.

1. Near-term and limited time - Use of buoys in experiments of budget studies generally fall in the near-term or limited time category. Buoy placement, vertical sampling interval and frequency of sampling will depend on the particular experimental design. In this application a higher number of temperature and/or salinity sensors may be required than in the monitoring application. Sampling frequency should be sufficient to resolve internal waves and tidal periods. In an experimental application telemetering of data may not be necessary.

2. Long-range or climatological - The long-range uses of vertical profiles would fall primarily in the monitoring applications. Emplacement of buoys should be preceded by experiments and other studies in order that the monitoring data have optimum value. For monitoring applications telemetering of data will be an important requirement.

We would like to see, and this is reiterated from the NMFS/EDS climate fisheries workshop held in Columbia, Mo. last month, the maintenance of existing long term records such as the now decommissioned OSV and coastal light stations discontinued by the USCG. In addition to the maintenance of these long established time series it is important to consider placement in areas that are of oceanographic significance, but with little ship traffic.

Geographic Areas - Specific points, or locations, are hard to define at this time; however, several principles apply. One is the location of the decommissioned OSV positions and another the decommissioned lightship stations. Under the NMFS reorganization, research will be conducted by regions, initiated by Regional Councils. The various centers, each in a region, are to be involved in 1 local studies. These include: Northeast Fisheries Center: George's Bank, Atlantic Bight shelf (groundfish); Southeast Fisheries Center: Onslow Bay, N. C. (menhaden) Gulf of Mexico, near shore (shrimp); Southwest Fisheries Center: California Current (tunas, forage) Eastern Tropical Pacific (tunas); Northwest Fisheries Center: Bering Sea (groundfish, environmental, assessment) Northeast Pacific Ocean (groundfish)

Additionally the Pacific and Atlantic Environmental Groups (PEG and AEG) are involved in studies that cross regional boundaries which may produce budget problems during regional budget gyrations. PEG's efforts are directed more towards macroscale, open ocean climatological studies, and the development of mesoscale environmental indecies while AEG is more concerned with mesoscale resource survey support, and environmental assessment studies almost entirely on and along the edge of the continental shelf. All of these are, or are about to be, within the 200 mile limit. Several will require the use of drifters ideally with a profiling or thermistor system; these will include the studies of forage organism associated with upwelling fronts off the California coast and of larval drift of the Carolins and in the Gulf of Mexico. Generally, however, NMFS studies over the Continental Shelf will require fixed buoy locations for long term monitoring of temperature and salinity.

Vertical Range - NMFS is interested in sea surface measurements as this is where many pelagic fish feed, migrate, reproduce, and are caught. Additionally most fish eggs are found within a meter or so of the surface. As such, surface meteorological data are also important for assessment of surface transport of ichthyoplankton. Of equal importance are bottom temperatures as this is where the demersal or bottom fish feed, migrate and reproduce. In terms of resource assessment and management a secondary importance in placed on mixed layer analysis. As an aid to industry (tuna fleet) however, real time forecasts of MLD and SST are vital.

Accuracy - Returning to the introductory theme, temperatures and salinities are signatures of the processes taking place. The thermocline structure is important however in the interpretation of the thermal ocean signature. An understanding of environmental processes is important to resource management, more so than temperature or salinity per se.

We (with Dr. Flittner) have given consideration to a hierarchical scheme for our needs. Measurements, by NDBO buoys are as accurate as technology and budgets allows and, hopefully, users require; this is the first order. NWS and NMFS groups like PEG/AEG and SWFC provide data analyses; this is the second order. The third order is the applications level; from within NMFS these are the resource managers, and from without, the industry. The real time albacore advisory service at SWFC provides analyses to the tuna fleet where they find application in their fishing operations. The accuracy, acceptable error, and acceptable delay are most critical at the first order and decrease through the third order as data are massaged to become information.

Discrete depth measurements vs. profiling - Standard depth sampling (IAPSO) with linear interpolation generally provides a fair picture of general ocean structure. On the continental shelf and in the deep ocean fish or their forage may be found at a level that is between standard depths, or they are found along the bottom with its own environment. Profiles would be more useful on the Continental Shelf and/or through the ML in the open ocean.

For monitoring of climate scale processes, on the other hand, the vertical resolution provided by a profiling system is probably too variable to be of use. A monitoring system, incorporating discrete level measurements, appears to be quite adequate for our present uses.

QUESTIONS AND DISCUSSION

DR. FLITTNER: *You didn't indicate the time and space scales that might be suitable for measurements in support of fishery's applications. Could you elaborate upon temperature and salinity?*

DR. AUSTIN: Again it's going to depend on what the specific regional problem is. To scientist, working on the Continental Shelf, the tidal cycle, which is 12 hours has got to be hit 4-5 times; for example, maximum flood, slack before the ebb, maximum ebb, and slack before the flood. Essentially then, every three hours, this would also cover waves on the Shelf. The breaking of internal waves on the Shelf brings nutrient rich waters near the surface and makes them available for utilization during primary productivity. In the case of the studies by the Southwest Center where they're interested in oceanic fronts, the measurements should be within the time scale of the meteorological fronts that come through, set up upwelling and establish the fronts along the California and Oregon coast.

DR. FLITTNER: Okay. But other than the tidal regimes, most of the information that your people require falls into the order of days and accumulated days, weeks, months.

DR. AUSTIN: That's right. In terms of, say, the menhaden studies, they're looking at daily surface transport and working out averages. Because a fish like the menhaden hits a peak of spawning for 4 or 5 days, then the peak is over. The menhaden may go on spawning for a couple of weeks, but fewer of the eggs are fertile. There may only be a fertile reproduction or spawning that lasts for a matter of a few days. On the other hand, the labs are interested in the movement of whole stocks of groundfish. The cod, for example, have been shown, essentially with monthly averages to extend their seasonal range during the cold period of the mid 1960's. In this case, they were looking at monthly averages from seasonal groundfish survey data. So it depends on which particular fish or which resource you're dealing with.

DR. FLITTNER: My objective in asking this question is to try to bring in sharper focus the division of interest that their, the engineer's part here within the NDBO. They've got to answer up to two communities, and their requirements don't necessarily jive in all aspects.

DR. AUSTIN: Although we don't reject late data.

MONITORING PROBLEMS UNIQUE TO THE MARINE ENVIRONMENT USE OF IN SITU SENSORS

Mr. William C. Muir, Oceanographer, Environmental Impact Branch,
EPA Region III, Philadelphia, PA

Abstract. Due to the passage of the Marine Protection Research and Sanctuaries Act of 1972, the U. S. Environmental Protection Agency Region III has implemented an intensive monitoring program designed to respond to the immediate and ultimate fate and effects of pollutants discharged into ocean waters. The immediate or short-term effects include study of dispersion, transport and acute effects on the biota. The long-term studies include baseline monitoring, the ultimate fate of pollutants, the chronic effects on the biota and the predictive capabilities for potential irreversible impact.

The design and implementation of the Ocean Monitoring Program has been presented with many unique challanges, some of which have yet to be met. As a regulatory requirement salinity/temperature profiles are necessary in the determination of allowable mixing zones for the wastes developed. It is financially prohibitive to continuously monitor the disposal area from a ship at an average cost of $2,000 per day for ship time alone. As a second example, dispersion models have been prepared for the prediction of wast dilution and accumulation on the bottom. These models are dependent upon the salinity/temperature and current regimes. Techniques which would allow for long-term capabilities at minimum exposure would greatly enhance our present program.

The use of remote sensors with long-term capabilities must be perfected and be made available to meet the ever growing federal statutory requirements.

Introduction - Vast quantities of pollutants enter the oceans each year from a myraid of sources. These sources include the atmosphere, the river, coastal runoff, ocean outfalls, accidental spillage of materials at sea and ocean dumping. Based upon the assumption that the ocean is not an infinite sink and could eventually become saturated, the "Marine, Protection, Research and Sanctuaries Act of 1972" was passed to regulate those sources deemed controllable. The "Act" prohibited the dumping of any materials which would adversely affect human health, welfare or the marine environment except under the severe constraints that no alternatives presently exist; no irreversible damage has occurred; and, an implementation plan be enacted to eliminate the discharge from the ocean.

To comply with the intent of the "Act" the EPA, Region III set up an intensive monitoring program which we have been conducting since May 1973 in the dumpsite areas shown in Figure 1 off the Delaware and Maryland coasts. The objectives of the program are to provide a system for the evaluation, control, and regulation of ocean disposal. The goals we hope to attain are as follows:

1. Determine the present condition of the marine environment at, and contiguous to, the disposal site;

2. Identify the short and long-term effects of disposal on the marine environment;

3. Provide a long-term accounting system of the accumulation of pollutants in the marine environment;

4. Determine the dispersion rates, diffusion, and biological concentration factors of pollutants and their fate and behavior;

5. Provide information to support any enforcement actions and to determine the effectiveness of abatement actions;

6. Predict the potential for impact before irreversible effects occur; and

7. Provide a better scientific understanding of the ocean.

Region III Ocean Monitoring Program Objectives - The design of the monitoring program is based upon the assumption that the ocean is a dynamic medium and that any material injected into it will be acted upon by physical, chemical and biological processes. The interaction of the processes are shown in Figure 2 (Ketchum, 1967). Our program has been structures along similar lines. The program is split into two distinct tasks (short and long-term) as shown in Figure 3. The first is to assess the immediate effects of the pollutants upon impact into the ocean. The second is to determine the ultimate fate and effects on the marine environment.

Prime objectives of the short-term study are to determine safe discharge rates (F.R. 198 pt. II, 1973) and to determine how the pollutants will behave. These objectives are accomplished by determining the initial dilution factors, the dispersion with time, and the toxicity on the organisms as the pollutants are diluted.

The prime objectives of the long-term study are, first, to determine an environmental baseline against which the effects of the dumping can be compared; second, to determine the ultimate fate of pollutants and the pathways by which pollutants are distributed; third, to assess the impact of these pollutants on the marine biota; and last to predict the potential for impact before irreversible effects occur (NAS, 1971).

With the above objectives as background for what we want to accomplish, I will proceed with our monitoring methods to achieve these goals and outline areas needing further development.

Integration of Salinity/Temperature Buoys into Ocean Dumping Program - The Region has spent the bulk of our efforts in establishing long-term trends based upon the earlier studies in the area (Faulk, 1972) and a basic knowledge of the waste characteristics as shown in Table I (Lear, 1975). Trend surveys have been conducted on a semi-annual basis since program conception in 1973 as shown in Table II. Emphasis has been placed upon the possible uptake of pollutants in the benthic organisms and community structure.

When the wastes are dumped, a large portion of the particulate fraction settles to the thermocline during stratified and to the bottom during unstratified conditions (Faulk, 1972). During the stratified period, the materials may be transported for long distance before settling or may remain in suspension indefinitely. During the unstratified period, the materials will fractionate with the particulates quickly going to the bottom along with most of the pollutants.

Models have been developed for prediction of waste dispersion and accumulation on the bottom (Koh, 1973). Verification of these models is dependent upon well defined temperature/salinity profiles. An integrated system using several STD profile buoys could provide the detail necessary for physical modeling and greatly enhance our predictive capabilities. As an example, on a recent cruise survey we found "a distribution of temperature which indicates isothermal conditions, but with an intrusion of colder southeast slope water as shown in Figure 4. The salinity structure, Figure 5, shown a generally low salinity pattern attributable to runoff (Lear, 1976). This appears to be a normal condition of this area (Beardsley, 1975).

Regulatory Use of Salinity/Temperature Profile Buoys - As defined in Section 227.73 of the Final Criteria and Regulations, Volume 38, No. 198 of the Federal Register published on October 19, 1973, the mixing zone is "the column of water immediately contiguous to the release zone, beginning at the surface of the water and ending at the ocean floor, the thermocline or halocline, if one exists, or 20 meters, whichever is the shortest distance", as shown in Figure 6. The use of salinity/temperature profiles are therefore mandated and must be collected. Quarterly surveys provide a portion of this information but daily observations over a long period, one year, would be desirable.

Conclusions and Summary - The EPA has begun to assess the effects of ocean disposal on the marine environment. The needs have been identified and the mechanisms established via a Marine Monitoring Program.

Conventional techniques using ships need to be supplemental with long-term remote in situ sensors. The use of integrated multi-buoys arrays would add a new dimension to our present degree of sophistication.

A summary of the specific capabilities and requirements are identified in Attachment I.

Table 1. Annual Input Delaware Dumpsites

DuPont*	Total Input	Philadelphia
118,000,000	gal/yr	150,000,000
446,700,000	1/yr	568,000,000
1.9	spec grav	1.03
531,573,000	kg/yr	584,500,000

Specific Metal Input

		%			%
Fe	21,360,000	95.8	kg/yr	946,000	4.2
Cu	2,400	2.8		83,150	97.2
Cr	39,600	34.4		75,670	65.5
Al	364,000	25.0		1,094,000	75.0
Ag	270	10.4		2,314	89.6
Mn	572,000	87.5		81,400	12.5
Pb	5,630	3.7		145,000	96.3
Co	4,800	35.5		8,740	64.5
Ni	4,752	10.2		41,655	89.8
V	74,300	97.1		2,226	2.9
Cd	338	5.2		6,200	94.8
Zn	18,300	5.2		334,000	94.8
Ti	733,000	99.2		5,851	0.8

*Estimates based on DuPont reports submitted for period February 6 - July 11, 1974.

Table 2. Monitoring Survey Efforts - Region III

Cruise Number	Operation	Date
73 - I	Quicksilver	5/1-5/73
73 - II	-	7/13-14/73
73 - III	-	9/73
73 - IV	Fetch	11/5-11/73
74 - I	Ides	3/11-15/74
74 - II	Piggyback	8/7-9/74
74 - III	Deep Six	8/7-15/74
75 - I	Midwatch	2/5-10/75
75 - II	Bioassay	4/1/75-6/18/75
75	Buoy	5/13/75-10/1/75
75 - III	Dragnet	6/11-18/75
75 - IV	Sub-Strate	8/17-21/75
75 - V	Wakefall	9/8-18/75
75 - VI	Touchstone	12/10-16/75

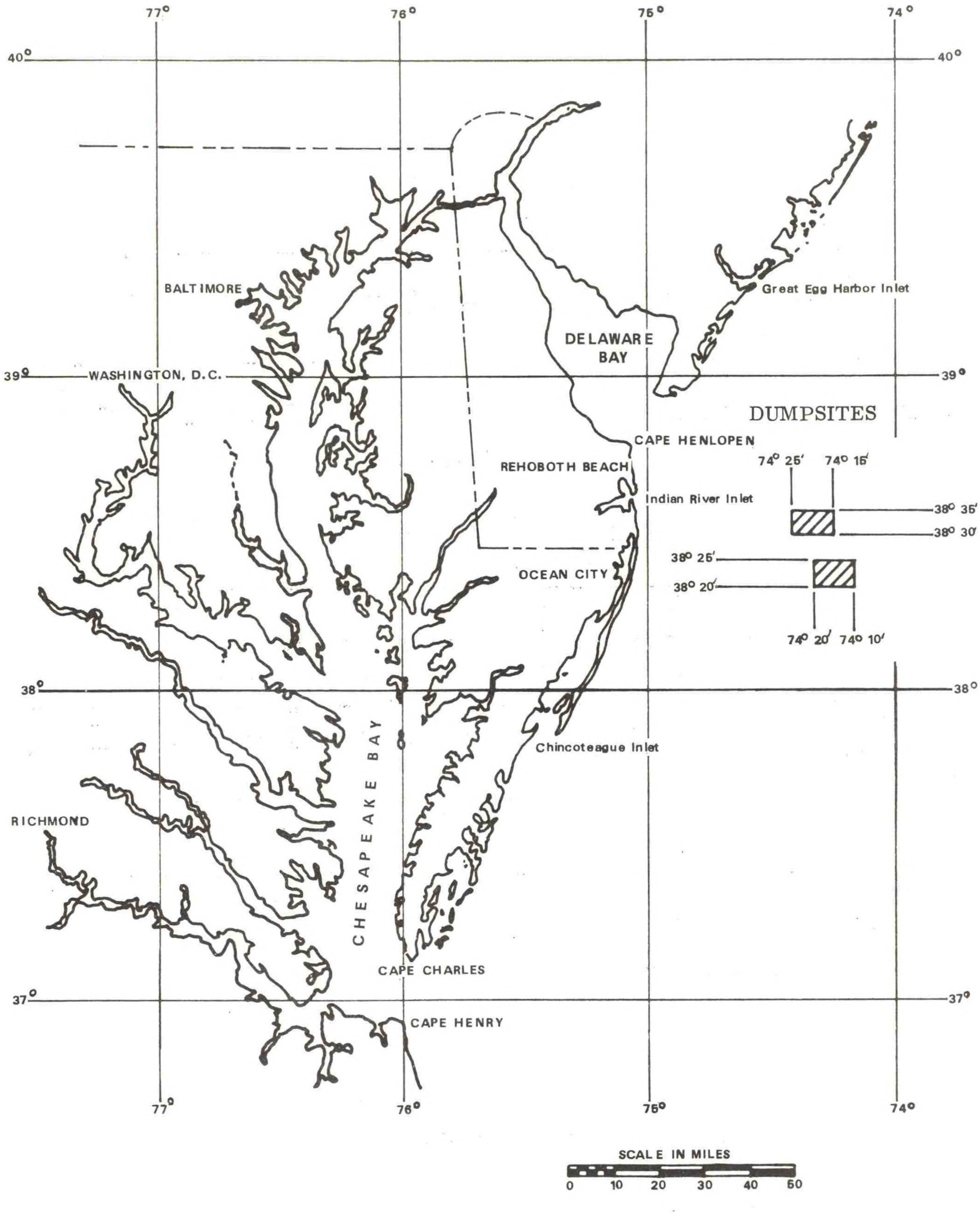


Figure 1. Area of Study

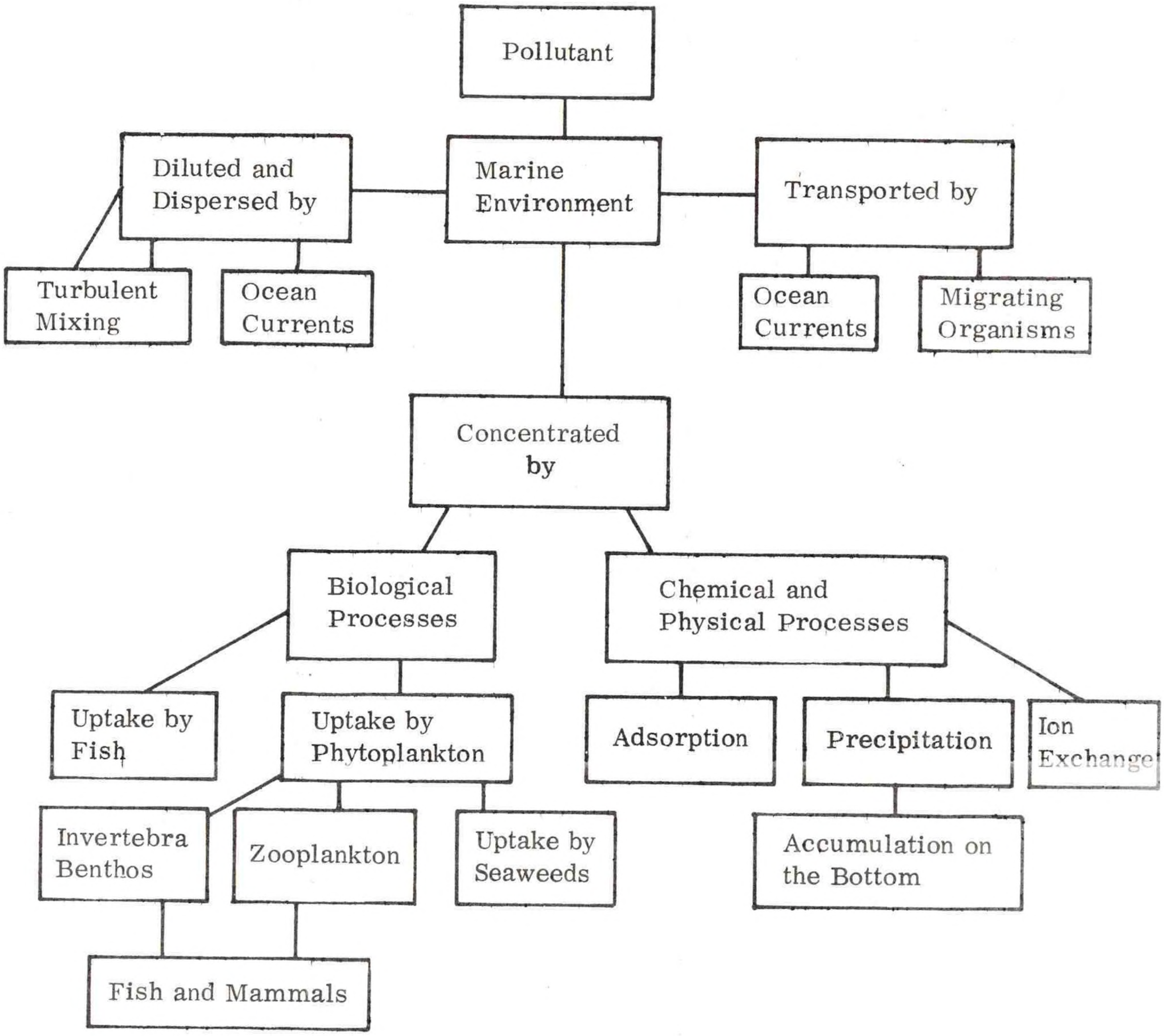


Figure 2. Processes Which Determine The Fate and Distribution of Pollutants in the Marine Environment. (Ketchum, 1967)

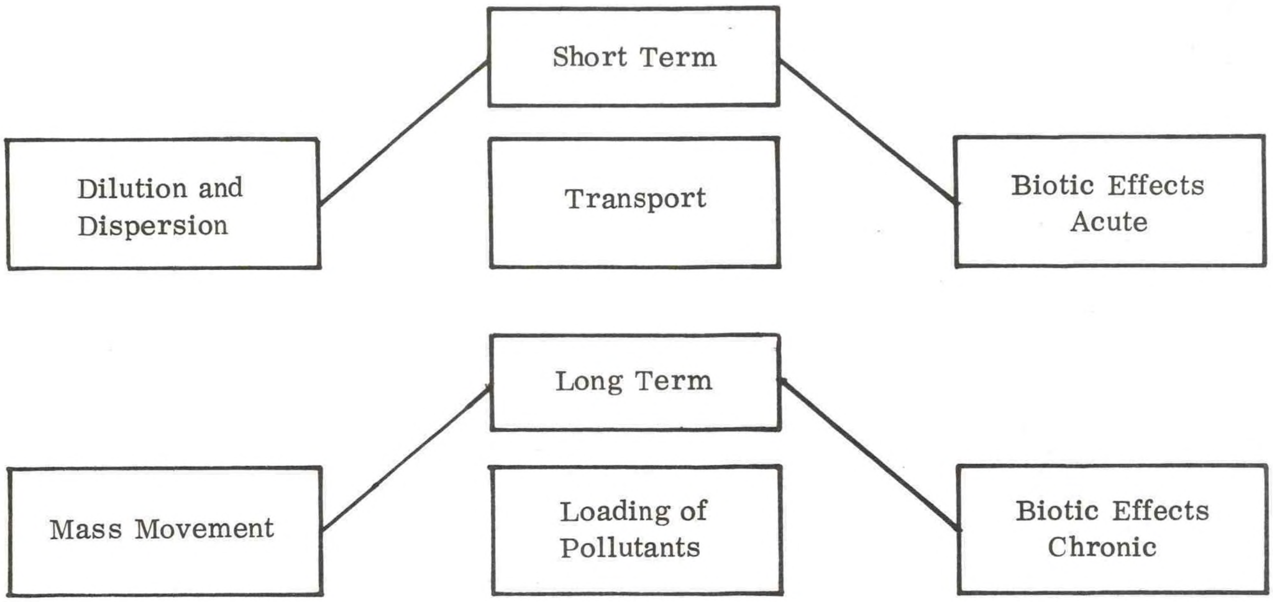


Figure 3. Region III Ocean Monitoring Program.

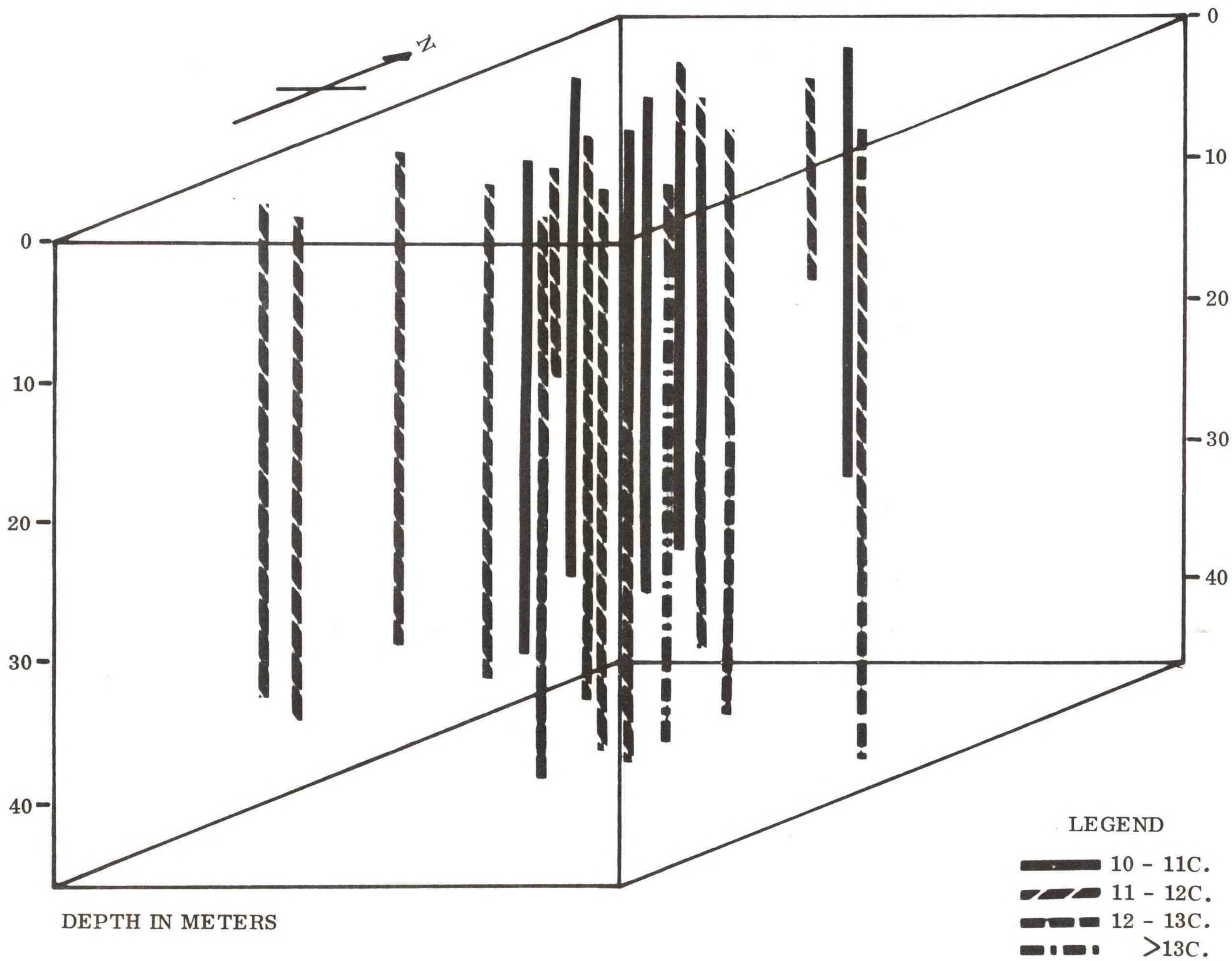


Figure 4. Observed Distribution of Temperature

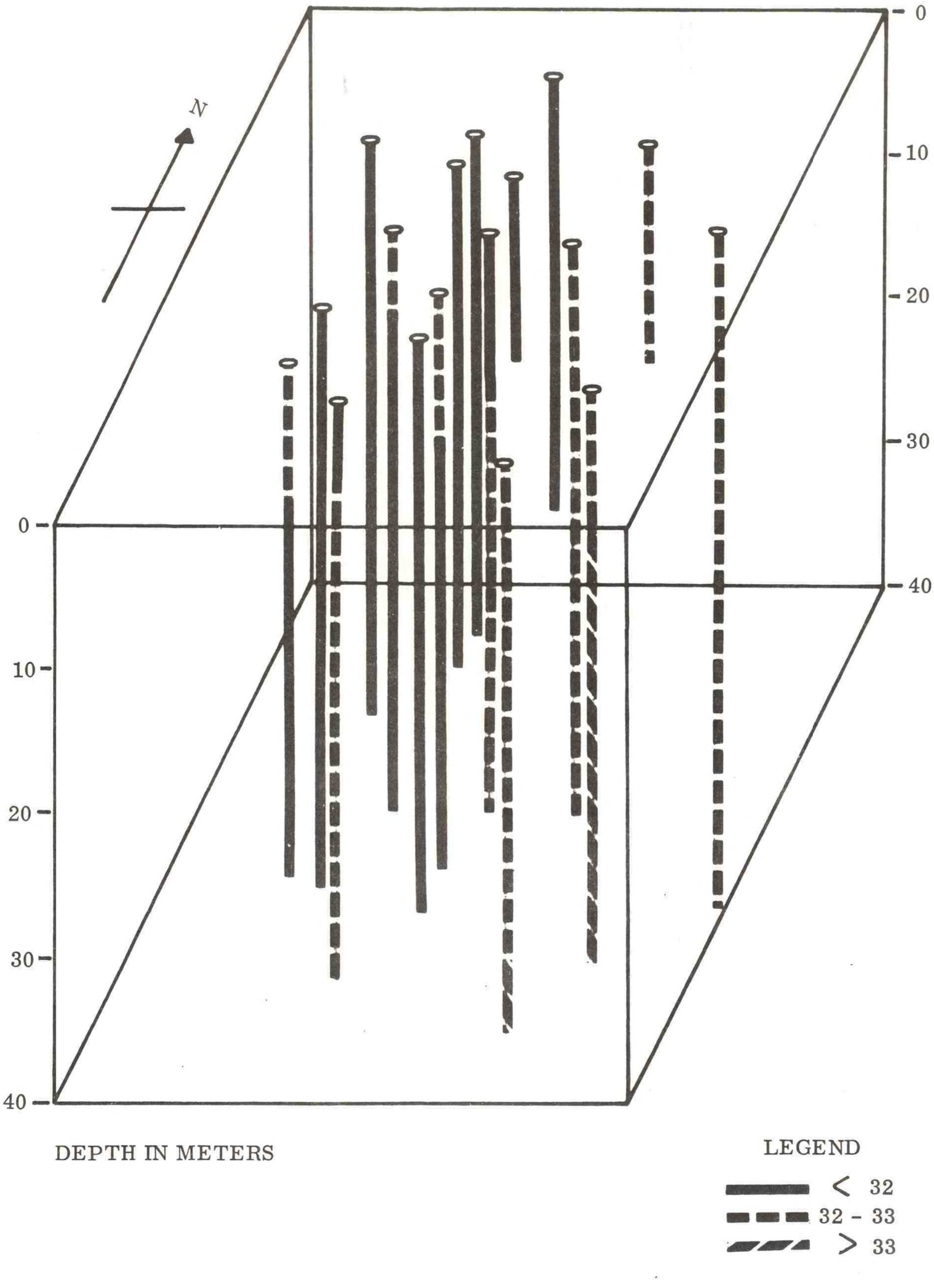
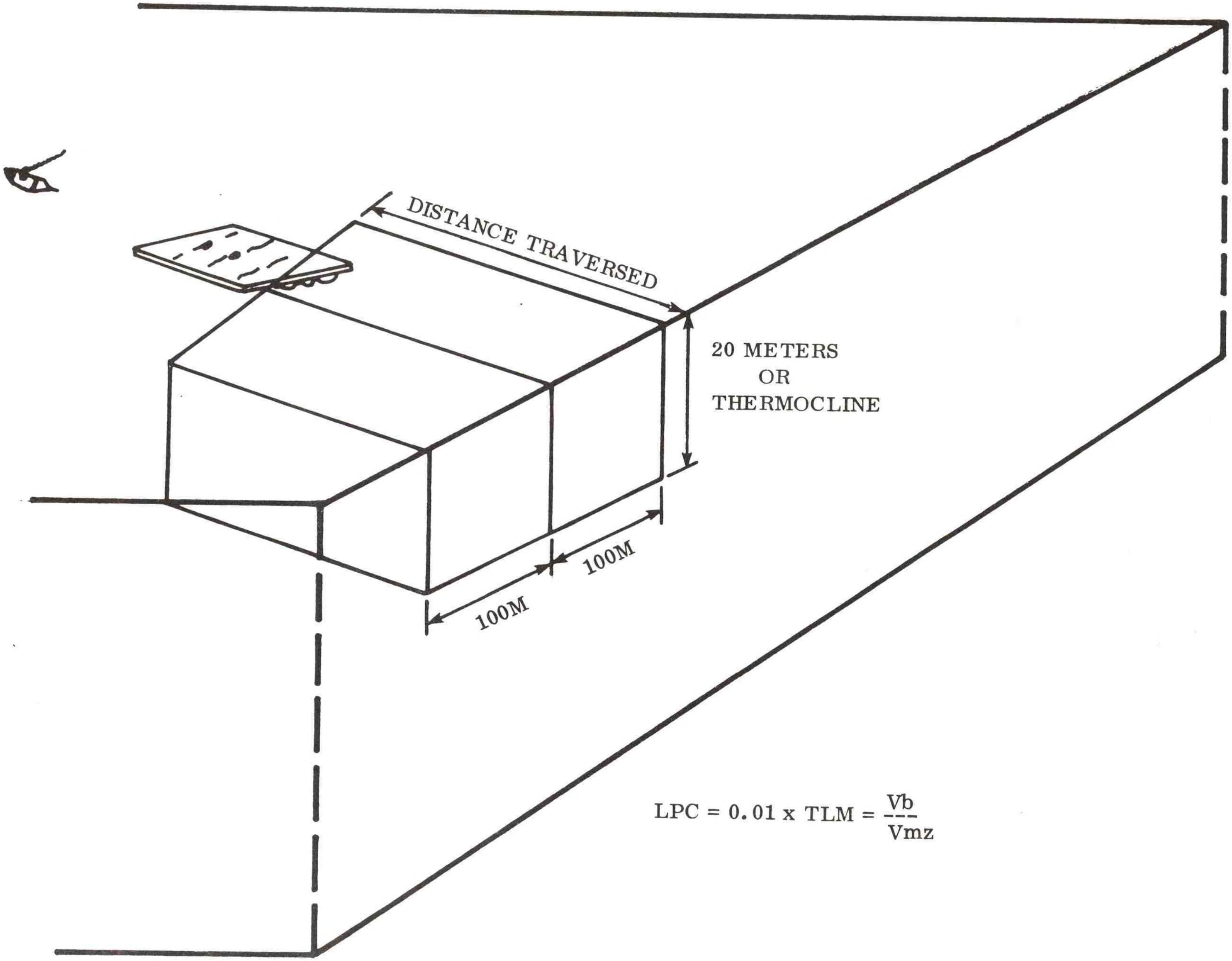


Figure 5. Observed Distribution of Salinity



$$LPC = 0.01 \times TLM = \frac{Vb}{Vmz}$$

Figure 6. Release and Mixing Zone

Attachment I

Profiling Requirements Summary

A. Application of STD Profiling Data - Regulatory.

B. Geographical Location - Of prime importance to EPA Region III is the Mid-Atlantic Bight. However, EPA also has a number of dump sites in the New York Bight and the Gulf of Mexico.

C. Vertical Depth Range - There are two groups of disposal sites, one on the shelf and one on the slope. The depth range is from 20 to 100 meters for the shelf sites and 1,500 to 2,500 meters for the slope sites. At the present time, profiling and modeling efforts are concentrated in the shelf sites.

D. Profiling Range - The purpose of the profiling is to determine thermal and haline gradients on the shelf. Continuous vertical profiles would be desirable. Maximum vertical depth spacing of 10 meters would be acceptable.

E. Horizontal Spacing - For regulatory purposes a single vertical profile at center of each disposal area is sufficient.

F. Times of Observation - It would be desirable to have daily observations during each season of the year. Shorter periods of 30 to 60 daily observations per season would be sufficient if sampling periods were properly chosen.

G. Parameter Measurement -

1. Range	Temperature: 5° to 25°C Salinity: 28 to 38 ppt.
2. Accuracy	Temperature: ± .5°C Salinity: ± .5 ppt.

H. Data Delivery - Real time turn around is not necessary or desirable for our program. It would be most desirable to get monthly data outputs. The format of output would require graphical display for regulatory use and digital output for modeling purposes.

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OCEAN PROFILING

WORKSHOP PANEL REPORTS

OCEAN PROFILING WORKSHOP PANEL REPORTS

INTRODUCTION

The following panel reports show an apparent difference of requirements as determined by the scientific and operational panels, relative to the need for discrete level sensors versus continuous profiling systems. Some operational programs require vertical profiles of temperature, whereas fundamental research programs presently need precise measurements at discrete levels. Nevertheless, the scientific panel recognized that, at some future time, scientists may express a specific interest in vertical profiling systems to support their research.

While the Department of Defense/U. S. Navy is responding directly to the need to refine acoustical ranging techniques, they have not ruled out the acquisition of discrete-level measurements, especially at great depths. All participants recognized the potential long-range contributions of long-time series data from fixed locations to the understanding of physical processes that govern the ocean's thermal structure and its role in weather and climate.

No one system will serve all requirements. As needs change with scientific advances, the engineering development programs must be prepared to adjust to meet these needs.

REPORT OF THE SCIENTIFIC PANEL

June 4, 1976

The Scientific Research and Climate Dynamics Panels joined together to consider the questions of concern to this workshop. It was agreed that the overwhelming scientific need is to understand the physical processes and statistical characteristics that govern the ocean environment. This need is true for short-term process studies and for long-term climate-related studies in the surface as well as the deep layers of the oceans. After considerable discussions, the panel recommended that an evolutionary process be implemented for ocean profiling, beginning with a continued development and use of a stable, discrete level temperature-pressure measurement system. Salinity/conductivity measurements should be added to the system at an early date. The logical sequence of the engineering and scientific development begins with a technique to yield average properties of the surface layer and evolves through measurement of properties at discrete levels, ultimately to provide a vertical profiling system. No real-time requirement for a profiling system could be established except to determine that the system is working.

It was the consensus of the assembled scientists that existing techniques have not yet been exploited fully. Until good data are available to the scientific community from a number of existing and planned process studies, there is no need to accelerate the development program for a cost-effective, continuous, profiling system. It was felt that as a result of the process studies, the oceans will be understood better so that requirements for a profiling system eventually can be specified. It may be that a profiling system will prove to be longer lasting for use at sea than a discrete level system, although at this time that seems unlikely. This forms another rationale for continued development of a profiler, at least until the fixed sensor system has proven itself. Velocity measurements eventually will be required. There are difficulties in using measurements from a quasi fixed level sensor and from a profiling sensor in computing vertical energy/momentum fluxes. An integrating sensor that will eliminate vertical aliasing has certain advantages over discrete level sensors that are widely spaced. It should be pointed out that for climate-related studies, horizontal averaging may be more important than vertical profiling.

It was noted that there are a number of process experiments at present that are using non-automatic profiling systems. As much information as possible concerning the system performance, environmental effects on the system, and important physical phenomena should be obtained from these non-automatic profiling systems. In addition to process studies, there are a few attempts to establish initial monitoring efforts in the ocean, notably the existing XBT Ships-of-Opportunity programs. The results of all of these studies should be used as input data to the development of an automatic-profiling system. Once such a system is developed, its availability and the deployment locations should be brought to the attention of the scientific community.

The responsibility for monitoring the areas of the world's oceans that are of interest to the United States is within the mission of the National Oceanic and Atmospheric Administration (NOAA). Therefore, NOAA should be encouraged to take whatever steps are necessary to accomplish that mission, in particular, to support the logical development of an upper ocean monitoring system. This mission requirement is even more important since the determination of climate changes and climate variability depends to a high degree on monitoring programs.

Unmanned ocean platforms provide the potential for studies of important oceanic processes not economically possible by existing techniques. The demonstrated capability of buoys to collect measurements over long periods of time in remote or stormy locations and without human intervention will make them an effective tool, provided methods can be developed to measure variables as a function of depth in the water column. The particular choice between a continuous profiling device and observations at discrete depths is a decision to be based both on the scientific requirements, and technical and economic feasibility.

To place in perspective the kinds of requirements of the Scientific Panel (including climate dynamic inputs), the following statements are offered. The panel was concerned with process-oriented and monitoring studies. Process-oriented studies concentrate on an understanding of the typical physical processes. Monitoring studies emphasize the desire to describe the ocean over a long period of time. Process studies, in many cases, require large quantities of high-frequency, short-term (seconds to minutes) averaged observations for relatively short periods (up to months). Monitoring studies usually require a lower frequency of longer time-averaged observations for periods of years. Nevertheless, the contrasting data requirements for monitoring and process studies do not imply that two different measurement systems are needed. As a matter of fact, it should be possible to collect the high-frequency data to serve both needs. The high-frequency data needed for process-oriented studies could be stored aboard the measurement platform for later retrieval, while selected averages of the data could be processed and transmitted in order to meet the real time requirements of the monitoring studies. Of course, the horizontal spatial requirements of these two kinds of studies may be different.

Seven classes of oceanic studies have been identified that need data collection that buoys might supply. They are discussed below in the numbered paragraphs. Following this discussion are definitions and tables giving desired and minimally acceptable requirements for the process studies and climate monitoring.

Some remarks are in order. For many scientific purposes a profiling sensor that gives a high relative accuracy during a single profile is important, while absolute accuracy can be sacrificed. There are other times when high relative accuracy is not that important and then it may be possible to use either a profiler or fixed sensors. No attempt has been made to indicate in the following table the possible trade-off between vertical and time resolution at a single depth implied by the measurement method.

1. Surface Mixed Layer - the upper layers of the ocean in conjunction with lower level atmospheric measurements. A large effort is needed to understand the evolution of the "mixed" layer in response to air/sea boundary fluxes.

2. Bottom Layers - time variations of frontal systems and intrusions of diverse water types into the thermocline. These processes are important mechanisms of large-scale lateral mixing in the ocean. A better understanding of the relation of these processes to driving forces is needed.

3. Other Oceanographic Processes - the collection of data under stormy conditions is needed and yet difficult to achieve with manned vehicles.

4. Internal Waves and Small-scale Mixing - the time variation of internal wave energy and small-scale mixing in the ocean. There is a close relation of these studies to Items 1 and 3 because some internal waves and mixing processes may be driven by energy from the surface of the ocean. There is a special need for understanding the response of the internal field to storms.

5. Acoustic R&D Higher Frequencies - the time history of acoustic profiles. The explanation of changes of profiles probably is related closely to Item 2.

6. Coastal Upwelling and Other Processes - long-term measurements of other oceanographic processes such as coastal upwelling, equatorial and topographic waves, mesoscale movements and the bottom boundary layer.

7. Climate Monitoring - climate studies require periodic observations of the physical state of the oceans for periods of years. However, the particular variables to be measured have not been determined yet.

CONCLUSION

The Scientific Panel recommends that R & D of possible profiling systems be investigated on a continuing but low level basis. Fixed level temperature and pressure measurement systems should be made to work and provide data operationally. These data not only will satisfy present scientific needs, but will clarify better the scientific community's evolving needs, in particular their profiling needs. Salinity measurement sensors should be added at an early date.

REPORT OF THE OPERATIONS PANEL

JUNE 4, 1976

BACKGROUND

The operations panel of the Ocean Profiling Workshop, consisting of representatives from National Marine Fisheries Service, National Weather Service, and Navy, are in general agreement as to their operational oceanographic data expectations from environmental buoys. These requirements are stated in terms of desired and minimum acceptable specifications for deep ocean moored, continental shelf moored, and drifting data buoys.

GENERAL REMARKS

Both the military and civil agency representatives agreed upon the following generalizations:

- All agencies have a common, primary need for temperature data with depth; a secondary requirement is the concurrent recording of salinity/conductivity with depth down through the halocline.
- Measurements should be taken at appropriate intervals from the surface down to at least 400m (1200 ft.).
- All agencies have a common need to describe and predict atmospheric forcing of the upper mixed layer of the sea. However, interests diverge in the subthermocline region; Navy is most interested in acoustical processes, whereas NOAA is most interested in observing and describing physical-dynamic processes, and process rates.
- Deep ocean measurements are judged to be informative and potentially useful. Operational systems should be designed to accommodate the taking of deep measurements where practical to assist in the assembly of an up-to-date climatology.

The panel feels very strongly that NDBO should proceed with RDT&E for a sensor system that will provide detailed subsurface vertical ocean temperature data. It is recognized that there are several methods/systems capable of obtaining these required data and the panel does not feel enough evaluation has been done to endorse or recommend a particular system at this time.

One major question the operations panel has is: At what vertical sampling rate does a profiler or XBT system become less costly than a thermistor chain if the number of thermistors is increased in an effort to obtain the required vertical data?

During the workshop, it was noted that the Federal Plan developed by ICMAREP for environmental data buoys for FY75 gave the need for detailed vertical temperature data a relatively high priority and also called for continuous development work on a profiling system. As such, we feel an appropriate level of RDT&E should be maintained for a temperature profiling system with support from ICMAREP membership.

REQUIREMENTS

The approach was to consider three classes of data buoys - deep ocean, shelf, and drifter.

1. Parameter Range

a. Salinity - In the deep ocean, the range is narrow (30-37^{o}/oo); however, in shelf waters where runoff and ice melt are important, the range is from 0 to 38^{o}/oo. The lower limit of 0 is not absolute and may have to be slightly higher.

b. Temperature - (-2 to 35^{o}C) this is the normal range of ocean temperatures.

c. Depth - 400m is the minimum acceptable lower depth for deep ocean applications. Broader, it is the range of the present synoptic analysis. The use of the term "synoptic" is intended to convey the meaning of semi-instantaneous synopshots of oceanographic processes that are commensurate with our understanding of oceanic time scales. The term does not necessarily imply adherence to or acceptance of the meteorological time scale. 200m was specified for a shelf buoy because that depth defines the shelf. 150m was specified for the drifter class because of practical limitations.

2. Accuracy Variable

a. Temperature - $\pm$ 0.1^{o}C is the accuracy of present bathythermograph reports and is also the same for OTS analysis. For NMFS, $\pm$ 1.0^{o}C is adequate.

b. Salinity - $\pm$ 0.3^{o}/oo represents the minimum accuracy because this value has the same effect on sound transmission as a .1^{o}C temperature accuracy. NMFS requires -.5^{o}/oo.

c. Depth - Minimum acceptable value of $\pm$ 0.5% for synoptic purposes. NMFS requires $\pm$ 2.0%.

d. Reporting precision for most variables is the same as the accuracy specified above.

e. Position - This is not an important parameter. Whatever navigational accuracy is required by NDBO to relocate the buoys is adequate for synoptic purposes.

f. Time - Not critical. Within 1-1/2 hours of observation time is adequate.

3. Temporal Variables

a. Sampling Duration - Not critical for synoptic analysis. Either instant readings for a profiling system or a time average for discrete thermistors would be adequate.

b. Interval of Observation - In the open ocean, measurements every 24 hours would be adequate because this is the period of the synoptic analysis. Reports every 3, 6, or 12 hours would be desired but not any more frequent than 3 hours. Three hours was specified for shelf buoys because of the tidal cycle.

c. Synopticity - Synoptic analyses require that observations be taken within a given time interval, both in the horizontal and vertical space scales. Data from all depths should be obtained within a 10-minute interval.

d. Reporting Time Period - Data is required in near real-time (within 2 hours after observation time). In the foreseeable future, all ocean thermal data must be reported in near real-time to Navy-FNWC and NOAA-NMC. NDBO should urge all buoy users to report ocean thermal data at appropriate intervals for real-time applications.

4. Spatial Variables

a. Standard Levels - The only standard level required is the surface (within 2m). NMFS also desires bottom temperatures from shelf buoys. The present system of discrete thermistors at a few standard levels is unsatisfactory for the synoptic analysis.

b. Significant Levels/Vertical Spacing or Profile Digitization - The primary requirement of the operational oceanographers is for detailed vertical temperature. This is necessary to define variable layer depths and gradients. There are several acceptable methods for obtaining this data:

(1) XBT's from a buoy

(2) Re-usable profiler

(3) Thermistor chain with sensors 5m apart in the upper 200m. Up to 50m separation would be acceptable below 200m.

(4) Salinity sensors are only required at the surface, 400m, and one point in between.

c. Horizontal Spacing - Variable depending on the area.

d. Areas of Interest:

(1) Replacement for OSV

(2) Areas of low BT coverage

(3) Across boundaries of water masses

(4) NMFS has need for shelf buoys at Grand Banks, Georges Banks, and the Bering Sea.

(5) Areas of atmospheric cyclogenesis (such as off Cape Hatteras and the Gulf of Alaska)

(6) Upwelling regions (such as off Peru and California)

SPECIFIC AGENCY COMMENTS

NAVY

1. The requirements stated herein do not imply in any way that the Navy will be able to provide funds for either the R&D or deployment costs associated with a buoy program.

2. Navy is interested in obtaining, in a synoptic time-scale, all possible oceanographic data. As the only Federal agency presently doing synoptic subsurface oceanographic analysis, based upon SBT, AXBT, and satellite data, Navy is in a unique position to integrate available buoy data with data from all other sources, and to provide the quality control required if the buoy data are to be useful to the rest of the oceanographic community.

3. Navy priorities are as follows:

a. Continuous (profiling) measurements of temperature in the near-surface region ($Z = 200m$), or closely spaced thermistors ($Z = 5m$).

b. Discrete, but more widely spaced measurements of temperature, down through the pycnocline.

c. Salinity at a few locations, preferably near the surface, 400m and perhaps one point in between.

NATIONAL WEATHER SURVICE

NOAA - NWS recognized the lead role that Navy has played in developing synoptic oceanographic analysis and forecasting techniques. NWS plans to adopt time-tested technology developed by Navy where practicable. One fundamental different exists, however: Navy's oceanographic needs center around description and forecasting of physical processes and their relation to atmospheric forcing and climate. NOAA - NWS approach will differ only in degree of emphasis. Deviations from present systems will be determined by priorities established by NOAA - NWS. Areas of primary emphasis may differ substantially from Navy's; where necessary, compromises will have to be reached that will accommodate both civil and military requirements.

NATIONAL MARINE FISHERIES SERVICE

Current NMFS real-time operational needs for subsurface ocean structure data are those in support of the open ocean tuna fleet. Eventually near-bottom data will be required over the continental shelf in support of the demersal (cod, flounder, etc.) fisheries. As such, current and foreseeable data precision requirements are less stringent than those of the NWS or USN. NMFS would require, however, a closer vertical spacing of sensors and horizontal spacing of buoys due to the migratory nature of the fishery resources in question. It would be our position that profiles will be of greater importance than individual spaced sensors. These profiles when over the shelf would have to include bottom temperatures and later salinities.

Location priorities are: 1) The maintenance of OSV and lightship data time series and, 2) The major shelf fishing grounds such as the Bering Sea and Georges Bank.

DEFINITIONS FOR PROFILING WORKSHOP PANEL

REQUIREMENTS SUMMARY TABLES

Requirements of interest are all those data characteristics which are needed to satisfy the data needs of a particular application. The desirable requirements are stated such that improvement of these characteristics will not significantly benefit the results of the data application. The minimum desirable are those characteristics that the data will still be of some meaning, but beyond which the data would be insufficient.

PARAMETER RANGE refers to the expected variation of the sea temperature, salinity, and depth at the geographical locations and time periods of interest.

ACCURACY VARIABLES are of two types. The sea temperature, salinity, depth, position and time of measurement are to be specified as one sigma standard deviation-type numbers - in other words, the absolute error that is desirable to stay within at least 68% of the time. These accuracies will be interpreted by the engineers as the total measurement system values which contain not only contributions from the sensor but from such items as mooring line motion and fouling. If the maximum errors are easier to comprehend, please mark (max) by the appropriate accuracy variable. For engineering purposes, the maximum accuracy will equate to three times the one sigma standard deviation. The digitization increment for reporting sea temperature, salinity and depth is an attempt to arrive at the precision as well as the relative accuracy requirements. If the accuracy for a parameter is sufficient, then the reporting increment need only be on the order of the system accuracy value specified. However, if the relative accuracy of a profile is an important factor, then the digitization could be significantly less than the absolute system accuracy value.

The TEMPORAL VARIABLES are explained as follows: The sampling duration is the time it takes to measure one complete observation. If the measurement method is a fixed sensor line, this time refers to the averaging that may be desired. If the method is a profiler, it should be so stated in the sampling duration block, insert (profiler). NOTE: for a descent speed of two m/sec and a depth of 400m, it will take six minutes 40 seconds to take one complete observation. The period of observation is the interval at which the data are obtained (e.g. every 3 hours). Synopticity refers to the requirement for all platforms or vertical sensing to take data at the same time. If synopticity is required, please indicate the allowable deviation from a desired time. The data availability delay is the time difference between when the parameter was measured and the time it should be delivered to the data user. The time period needed is the length of time during which data would be required for a particular application. Specific dates are desirable if known.

The SPATIAL VARIABLES address the requirements for both horizontal and vertical sampling. Standard levels refer to requirements for the same set of levels every observation. The IAPSO levels at 0, 10, 20, 30, 50, 60, 75, 100, 150, 200, 250, 300 and 500m are examples of standardized fixed levels. The fixed level output, of course, may be achieved by a profiler, or a sensor at each level. If the location of a specific data characteristic such as the thermocline is required, then significant levels may be required. The vertical spacing or profile digitization refers to the vertical distance between samples in the case of discrete level measurements or the sampling from the continuous profile for reporting purposes. Horizontal spacing refers to the distance between measurement platforms, if more than one is required for the application. The area of interest is the geographical region for which this application is of interest. Specific latitude/longitude coordinates are desirable.

Other requirements not listed above can include any data characteristics or other items of interest that should be noted when considering the particular application addressed.

OCEAN PROFILING WORKSHOP
SCIENTIFIC PANEL REQUIREMENTS SUMMARY

REQUIREMENTS OF INTEREST	SURFACE MIXED LAYER		BOTTOM LAYERS		OTHER OCEANOGRAPHIC PROCESSES		INTERNAL WAVES AND SMALL SCALE MIXING		ACOUSTIC R&D HIGHER FREQUENCIES		COASTAL UPWELLING AND OTHER PROCESSES		CLIMATE MONITORING	
	Desirable	Minimum Acceptable	Desirable	Minimum Acceptable	Desirable	Minimum Acceptable	Desirable	Minimum Acceptable	Desirable	Minimum Acceptable	Desirable	Minimum Acceptable	Desirable	Minimum Acceptable
Parameter Range														
Sea Temperature (°C)	15 to 26	Location Dependent	-2 to 30	2 to 15	-2 to 30	Same	5 to 25	Same	4 to 30	Same	0 to 30	Same	-2 to 30	Same
Salinity (°/oo)	34 to 36.5	Location Dependent	29 to 39	34 to 36	30 to 40	Same	33 to 37	No Salinity	33 to 36	34 to 36	25 to 35	Same	30 to 40	Same
Depth (m)	* 0 to 500	0 to 200	0 to 6000 decibars	0 to 300 (shelf)	0 to 600	0 to 300	1000	300	1000	500	0 to 200	Same	0 to 1000	0 to 300
Accuracy Variables														
Sea Temperature (°C)	± 0.1	± 0.3	± 0.002	± 0.02 (shelf)*	± 0.02	± 0.1	± 0.02	± 0.05	± 0.1	± 0.5	± 0.02	± 0.1	± 0.01	± 0.1
Sea Temperature Digitization Increment (°C)	0.02	0.3	0.0005	0.01 (shelf)	0.02	0.1	0.02	0.05	0.1	0.5	0.01	0.1	0.01	0.1
Salinity (°/oo)	± 0.05	± 0.1	± 0.003	± 0.03 (shelf)	± 0.02	± 0.1	± 0.02	∞	± 0.5	± 1.0	± 0.02	± 0.1	± 0.01	∞
Salinity Digitization Increment (1/oo)	0.01	0.1	0.001	0.01 (shelf)	0.01	0.1	0.02	—	0.5	1	0.01	0.1	0.01	.05
Depth (m)	± 0.5	10	± 0.05% of Depth	± 0.1% of Depth	± 0.1	± 10	± 0.1	10	± 1	± 5	± 1	± 2	± 1.0	± 10
Depth Digitization Increment (m)	0.5	10	0.1 decibars	1 decibars	0.05	10	0.1	10	1	5	0.5	2	0.5	10
Position (n. m.)	LORAN-C Navigation	± 5	± 0.2	± 0.5	± 0.1	± 10	5	50	1	Same	± 0.5	± 3	0.5	10
Time of Measurement (min)	1 part/10^6	1 part/10^5	1 part 10^6	1 part 10^5	60	180	± 0.1	± 0.2	10	60	± 7.5	± 15 to 60	± 5	1 day
Temporal Variables														
Sampling Duration (averaging - min)	**20	** 10	10	30	1 hour	6 hours	Depends on Method	Same	10	Instantaneous	7.5	60	15	15
Interval of Observation (hours)	20 min.	1	10	30	1 hour	6 hours	15 minutes	30 minutes	0.1	0.1	7.5	60	1	12
Synopticity (min. or no)	Yes - if array		Yes	± 30 min.	Yes	-	Yes if array	No array needed	No	Same	Yes - if array	Yes	No	No
Data Availability Delay (hours, days, weeks)	Weeks	Months	1 year	2 months	1-3 months	6 months	-	-	Depends on availability of other equipment - otherwise weeks		Months	Same	Weeks	Weeks
Time Period Needed (months, years)	**Up to 3 months	**Up to 1 month (Internal waves)	1 year	2 months	20 years	1 year	1 yr	months	Years	-	Months to years	Same	Years	Years
Spatial Variables														
Standard levels; e.g., IAPSO (yes or no)	No	Same	No	Same	No	-	-	-	No	Same	No	Same	No	No
Significant levels (yes or no)	-	-	No	Same	No	-	-	-	No	Same	No	Same	Yes	Yes
Vertical Spacing or Profile Digitization (m)	5 above 100 25 below 100	10 above 100 50 below 100	1	10	1	3	-	-	1	5	5 to 20	Experiment Dependent	10	20
Horizontal Spacing (n. m.)	10	-	2.5	Single Mooring	Not Applicable	-	-	-	5	-	Experiment Dependent		Unkown at this time	
Areas of Interest (Lat., Long., or Descriptive)	Various locations especially in stormy latitudes		Western N. Atlantic		Open ocean with storms and waves up to 80 ft. - North Pacific		Stormy N. Pacific, e.g. 50°N, Over rough topography, over smooth topography		North of 15°N	-	N. Pacific, N.W. Africa, Peru, NE Gulf of Alaska, etc.		Max. heat transfer to atmosphere	Central Oceans
Other Requirements not Listed Above					Must withstand waves up to 80 ft.		These data can either be recorded by profiling sensor (most valuable) or by fixed level sensor (5 level minimum - 20 desired).						Horizontal averaging techniques, vertical averaging by resistance wire	

NOTES: (Pertains to Surface Mixed Layer column only.)
*Assumed maximum mixed layer depth (could be greater). This is location dependent.
**These values are appropriate to high frequency (interval wave) studies (1-3 months duration). Daily averaged values would be more appropriate for seasonal studies (1-3 years duration).

*These specifications apply only to Continental Shelf observations.

OCEAN PROFILING WORKSHOP
OPERATIONS PANEL REQUIREMENTS SUMMARY

REQUIREMENTS OF INTEREST	FIXED STATION DEEP OCEAN MONITORING FOR U.S. NAVY AND NATIONAL WEATHER SERVICE		FIXED STATION CONTINENTAL SHELF MONITORING FOR U.S. NAVY AND NATIONAL WEATHER SERVICE		DRIFTING STATION MONITORING FOR U.S. NAVY AND NATIONAL WEATHER SERVICE		FIXED STATION DEEP OCEAN MONITORING FOR NATIONAL MARINE FISHERIES SERVICE		FIXED STATION CONTINENTAL SHELF MONITORING FOR NATIONAL MARINE FISHERIES SERVICE		DRIFTING STATION MONITORING FOR NATIONAL MARINE FISHERIES SERVICE	
	Desirable	Minimum Acceptable	Desirable	Minimum Acceptable	Desirable	Minimum Acceptable	Desirable	Minimum Acceptable	Desirable	Minimum Acceptable	Desirable	Minimum Acceptable
Parameter Range												
Sea Temperature (°C)	-2 to 35	Same	-2 to 35	Same	-2 to 35	Same	-2 to 35	Same	-2 to 35	Same	-2 to 35	Same
Salinity (°/oo)	30 to 38	Same	0 to 38	Same	0 to 38	Same	30 to 38	Same	0 to 38	Same	0 to 38	Same
Depth (m)	0 to 1500	0 to 400	0 to 200	Same	0 to 150	0 to 100	0 to 1500	0 to 400	0 to 200	Same	0 to 150	0 to 100
Accuracy Variables												
Sea Temperature (°C)	± 0.1	Same	± 0.1	Same	± 0.1	Same	± 1.0	Same	± 1.0	Same	±1.0	Same
Sea Temperature Digitization Increment (°C)	0.05	Same	0.1	Same	0.05	Same	1.0	Same	1.0	Same	1.0	Same
Salinity (°/oo)	± 0.1	± 0.3	± 0.1	± 0.3	± 0.1	± 0.3	± 0.5	Same	± 0.5	Same	± 0.5	Same
Salinity Digitization Increment (°/oo)	0.1	0.3	0.05	0.3	0.1	0.3	0.5	Same	0.5	Same	0.5	Same
Depth (m)	± 2	± 0.5% of Depth	± 2	± 0.5% of Depth	± 2	± 0.5% of Depth	2% of Depth	Same	± 1.0	Same	± 0.2% of Depth	Same
Depth Digitization Increment (m)	2	0.5% of Depth	2	0.5% of Depth	2	0.5% of Depth	± 2% of Depth	Same	1.0	Same	0.2% of Depth	Same
Position (n. m.)	5	Same	5	Same	5	Same	5	Same	5	Same	5	Same
Time of Measurement (min)	60	90	30	Same	30	Same	60	90	30	Same	30	Same
Temporal Variables												
Sampling Duration (averaging - min)	10	Instantaneous	10	Instantaneous	10	Instantaneous	10	Instantaneous	10	Instantaneous	10	Instantaneous
Interval of Observation (hours)	3	24	3	Same	3	12	3	24	3	Same	3	12
Synopticity (min. or no)	Freefall	10	Freefall	10	Freefall	10	Freefall	12	Freefall	12	Freefall	12
Data Availability Delay (hours, days, weeks)	1.5 hours	12 hours	1.5 hours	Same	1.5 hours	6 hours	1.5 hours	12 hours	6 hours	Same	12 hours	Same
Time Period Needed (months, years)	Indefinitely	Same	Indefinitely	Same	Indefinitely	Same	Indefinitely	Same	Indefinitely	Same	-	-
Spatial Variables												
Standard levels; e.g., IAPSO (yes or no)	Yes	Same	Yes	Same	Yes	Same	Yes (Surface)	Same	Yes (Surface & bottom)	Same	Yes (Surface)	Same
Significant levels (yes or no)	Yes	Same	Yes	Same	Yes	No	Yes	Same	Yes	Same	Yes	Same
Vertical Spacing or Profile Digitization (m)	5	Variable 5 to 20	5	Same	5	Same	5	Variable 5 to 20	5	Variable 5 to 20	5	Variable 5 to 20
Horizontal Spacing (n. m.)	Variable	Same	Variable	Same	Variable	Same	35	Same	10	Same	Variable	Same
Areas of Interest (Lat., Long., or Descriptive)	Replace OSV	Same	Lightships	Same	Gulf Stream California Current N. Pacific Transition Zone	Same	Grand Banks Georges Banks	Same	-	-	California Current	-
Other Requirements not Listed Above							Bering Shelf	Same			N. Pacific Transition Zone	