Title

Stable Research Platform Workshop

Authors

Fisher, F H
Bishop, C B

Publication Date

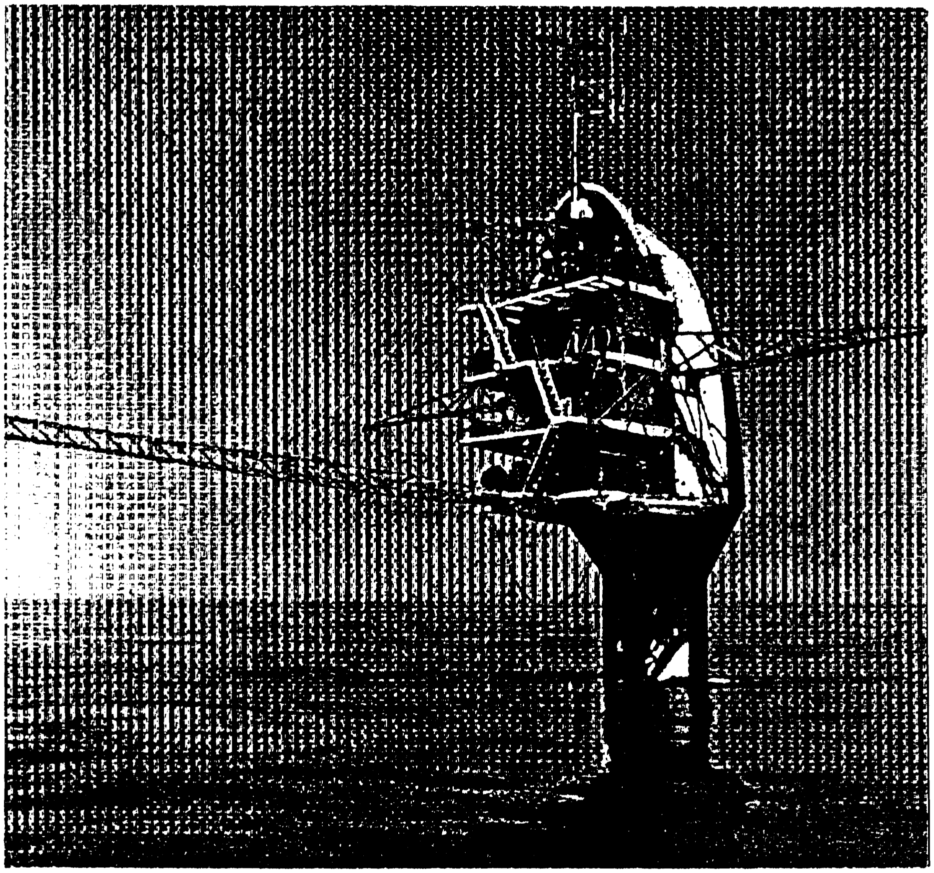
1988-04-01

STABLE RESEARCH PLATFORM WORKSHOP

held on 29-30 June 1987
at the Marine Physical Laboratory
of Scripps Institution of Oceanography
of the University of California San Diego
San Diego, California

Edited By
F. H. Fisher and C. B. Bishop

SIO REFERENCE 87-29



April 1988
Marine Physical Laboratory
Report No. MPL-U-56/87

Published by the Marine Physical Laboratory,
Scripps Institution of Oceanography, San Diego,
California, 1988. Additional copies are
available from MPL at University of California,
San Diego, P001, San Diego, CA 92152.

Workshop organized with the assistance of the
Office of Naval Research, Department of Navy,
under Contract N00014-80-C-0220.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

A workshop on stable oceanographic research platforms was held at the Marine Physical Laboratory June 29-30, 1987. Research needs of several scientific disciplines, including physical oceanography, air-sea interaction, biological oceanography (especially bio-optics), and acoustics were discussed in detail with respect to the advantages of various stable platforms.

This workshop was stimulated by recent requests involving the use of FLIP in weather conditions beyond its original capabilities, with more equipment and people than it can hold, and by the naval architect's opinion that FLIP, after 25 years of service, may be approaching the need for some expensive structural rework. While the immediate purpose was to consider requirements for a new FLIP, the workshop adopted a much broader approach recognizing the unique advantages of different stable platforms for particular research needs.

The physical oceanography, bio-optics, and acoustics communities, from their experience working with FLIP, cited very specific reasons for a new FLIP with increased capabilities for rough weather operation (100 foot wave survivability, 60-80 foot wave operations), improved laboratory, living and working spaces and increased power capability. It should continue to retain deep water mooring capability, and to present a minimal cross-sectional area both in air and water.

SWATH ships and submarines, stable platforms with mobility, were also discussed. In addition to their ability to provide improved work platforms for a variety of oceanographic experiments in higher sea states, small high-speed SWATH ships could increase dramatically the sampling region about a moored or drifting stable platform. Small submersibles, manned or autonomous, could also be launched and recovered from a large platform using present technology. For expeditious gathering of data under the Arctic ice pack, a manned research submarine is virtually the only means by which this area can be studied.

The payload capability of a flippable barge or a larger FLIP could make possible all-weather operations possible with either autonomous or manned submersibles, by providing them with a deep underwater garage for launch and recovery. A track system for bringing the vehicle through the surface to a station for crew rotation and resupply would eliminate the dangers from rough seas associated with present operations.

The acoustics community also was interested in the capabilities of a large semi-submersible from the standpoint of handling very large and powerful sound sources as well as for deploying multiple acoustic arrays for three dimensional measurements of the ambient noise field.

The biological community also was interested in a large platform such as a semi-submersible which would be suitable for time-series studies (Appendix A) and which would have resupply capability at sea for logistics as well as personnel rotation.

Typically, large rigs can pick up 300 ton packages from resupply vessels. Such large lift capabilities also enhance the utility of a large platform to launch and recover highly mobile vehicles to capture and return for analysis samples with minimum delay time, a key unique feature of an Iron Island station for biologists along with the stability necessary for high accuracy laboratory work at sea. Similarly, a moored rig would make possible long term benthic studies including sampling by remote underwater manipulator (RUM) type vehicles which have already been used by the biological community in deployments from the Research Platform ORB (Appendix B). Results of an NSF funded study on the need for long time-series measurement studies, while not presented at the workshop, are included (Appendix A) since they complement and reinforce our conclusions.

The scale of operations for large platforms, especially semi-submersibles, becomes similar to that of the Deep Sea Drilling Project, requiring steady use by a large base of scientists that may require an international effort in order to be economically feasible.

The unexpected, rather broad, pluralistic approach this workshop adopted in considering requirements of the research community for stable ocean platforms made the proceedings both more interesting and complex. A wide variety of platform types was considered, all of which already exist in some form. Each had unique contributions for satisfying the particular requirements of various research communities for stable ocean platforms. It may be, as we focus on the realities of operations and needs, that hybrid combinations of existing platforms will evolve as candidates for future use. Just as the original FLIP was designed as a simple platform for a particular acoustics experiment but with other potential users in mind, its evolution as a platform useful to other interests may serve as a model for the development of future larger stable platforms.

Readers of this report are encouraged to correspond with its editors to expand the interest in and knowledge of floating stable platforms. Twenty-five years of operations have demonstrated the value of R/P FLIP as a platform for collecting time-series data on physical characteristics of the ocean. Twelve years of operations of SSP KAIMALINO have demonstrated the value of the SWATH ship as a mobile platform for research and development in demanding sea conditions. Floating stable platforms offer the possibility of measurements in higher sea states and wider latitude variations, of "sea truth" measurements for observations from space, and for coordinated multi-disciplinary time-series measurements of oceanic ecosystems.

I. INTRODUCTION

Under the sponsorship of the Office of Naval Research (ONR) and with the cooperation of the University-National Oceanographic Laboratory System (UNOLS), a workshop was conducted on 29-30 June 1987 by the Marine Physical Laboratory (MPL), Scripps Institution of Oceanography, UCSD, to consider concepts and uses for future stable oceanographic research platforms.

MPL's involvement with the development and operation of floating research platforms began with its initiation of the ONR-sponsored FLIP project in 1960, as a means to make accurate measurements of the arrival angles of sound paths in the ocean. The variety of scientific experiments conducted in FLIP's 25 years of operations (Appendix B) has demonstrated the value of a stable-floating platform for research at sea, particularly in the fields of physical oceanography, air-sea interaction and underwater acoustics. While its capabilities as a platform for the deployment of various sensors are considerable, its ability to support multi-disciplinary research efforts is limited by the available space, and its ability to support measurements in the demanding environment found at high latitudes is limited by the physical dimensions of the platform. In recent years, several interesting operations have been proposed which would have required performance beyond the limits of FLIP's capabilities, and it can be expected that the future will bring more.

With the encouragement of the Advanced Ship Replacement Committee of UNOLS, the agenda was expanded to include other floating platforms which offer promise for some aspects of seagoing research. In addition to a new version of FLIP, the workshop also considered the "flippable" barge concept; the Small Waterplane Area Twin Hull (SWATH) ship; the large semi-submersible platform; the underice submarine; various moorings; and hybrid combinations of these platforms.

FLIP'S OPERATIONS

Since its launching in 1962, FLIP has made several operations per year in support of Navy research programs. While principally involved in underwater acoustic projects which study the effects of the ocean environment on the propagation of acoustic energy and on the recognition of signals in the ambient noise field, FLIP also has provided a stable base for measurement of ocean currents in the upper ocean, internal waves, sea surface acoustic electromagnetic and optical scattering properties, seafloor geology; and storm-generated waves. These operations have been conducted in the Pacific Ocean, mostly off the California coast, but also north of Hawaii and in the Western Atlantic; and have resulted in her transition from horizontal to vertical (and return) 287 times. Originally equipped with hydrophones attached to steel girders extending from the hull, FLIP has had sensors mounted at various locations on her hull, deployed from 60'-100' booms extending out from the superstructure, and deployed vertically on cables down to several thousand meter depths. The variety of measurements made, and of instruments used, gives testimony to the value of the stable ocean platform for research at sea, particularly for the collection of time series data *in situ*.

OBJECTIVES

The workshop addressed the following questions:

1) What future research would depend upon, or be enhanced by, a stable floating platform such as FLIP?
2) What other floating platforms offer stability characteristics attractive for the support of research at sea?

Participants included seagoing scientists, research ship/platform designers and operators, and representatives of program sponsor agencies. (Appendix C)

PROCEDURE

The workshop agenda (Appendix D) opened with presentations on research requirements related to several scientific disciplines, including:

Physical Oceanography
Meteorology
Air-Sea Interaction
Underwater Acoustics
Biology
Bio-Optics
Submersible Operations

The participants then formed themselves into four working groups; on Acoustics, Physical Oceanography, Biology, and Platforms.

The first three groups discussed the related scientific requirements, and then interacted with the Platform Group after it had debated the potential capabilities of the various platforms.

The Workshop culminated in a General Discussion in which the leaders of all four working groups presented their conclusions and recommendations for general debate and discussion, leading to a consensus as outlined in the Executive Summary of this report.

II. WORKING GROUP REPORTS

Working Group reports were drafted at the workshop by the participants. They were combined and completed by the Working Group Chairman and represent the consensus of the participants.

WORKING GROUP I - BIOLOGY - OPTICS

WORKING GROUP I

T. Dickey (Chairman), K. Kaulum, D. Laible, F. Spiess, A. Vine, and E. Widder

INTRODUCTION

Unfortunately, several of the biologists invited to participate were unable to attend. One group of them, augmented by participating physical oceanographers, had already articulated a number of requirements for a large stable platform. Their input was made available to the workshop and has since been refined and published by the American Geophysical Union in EOS. Rather than rephrasing their work we have, with their permission, reprinted the EOS paper in its entirety as Appendix A of this report.

NEEDED CAPABILITIES

General

1. Space for more scientists and laboratories.
2. Moored operational mode.
3. Long term deployments.
    a. Resupply and refuel.
    b. Exchange personnel and instrumentation.
    c. Cost effective.
4. Accommodate small submersibles and ROVs.
5. Coordinate with tow vessels, submersibles, ROVs, remote sensing observations - for maximum scientific production.

Specific

1. Laboratory needed with minimal motion and vibration.
2. Laboratory needed with temperature and light control.
3. Laboratory needed with wet analytical capacity.
4. Provisions for cabling (tethering).
5. Provisions needed for pump sample hoses.
6. Provisions needed for fiber optics.
7. Provisions needed for net trawling.
8. Provisions needed for long booms and rotation (minimize ship influence on light field).
9. Provisions needed for light sensing arrays (bioluminiscence, active light scattering).
10. Provisions needed for elevator for deploying submersibles and ROVs.

WORKING GROUP II - Physical Oceanography, Air-Sea Interaction, and Meterology

WORKING GROUP II

R. Weller (Chairman), P. Dennis, R. Pinkel, O. Shemdin, R. Stewart, and K. Watson

NEEDED CAPABILITIES

Working Group II formulated the following requirements for a future stable platform to be used in field experiments in physical oceanography, air-sea interaction, and meteorology. C. Friehe and C. Dorman did not attend the workshop, but did contribute to discussions before the workshop, and their ideas about a platform for use in meteorological and air-sea interaction work are included. The requirements are presented below as a list. That list is followed by a brief discussion of the priorities assigned to the list by the members of the working group.

1. Hull Design

The platform should be minimally disturbing of both mean and turbulent conditions. Air flow, the sea state and sea surface, and the ocean should be minimally disturbed by the presence of the platform. Thermal and acoustic discharge should be able to be discharged at various depths as required by the science parties to minimize their effects on the measurements. Exhaust stacks should be placed to minimize their noise and heat. One symmetrically shaped tube penetrating the water is preferred to multiple struts in order to minimize disturbance of the surface waves and upper ocean. A holding tank should be used to capture all discharges that would contaminate the surface, including soap, oil, etc. The ability to obtain clean sea water from various depths is needed, with plumbing running to a wet lab. Cool water from the bottom of the platform might also be used for air conditioning.

2. Daily Operating Cost.

The daily rate for the platform should be comparable to the present FLIP (approximately $1500/day). Increases by factors of 2 or 3 would be acceptable; but beyond that, costs would greatly restrict usage.

3. Habitability

Habitability of the new platform should approach that of the present research vessels. Accommodations should provide for female scientists. Habitability in a new flippable platform should be improved in both the horizontal as well as vertical orientations. Sleeping quarters should have improved separation from heat and noise, improved ventilation, and improved storage space.

4. Endurance

The platform should have sixty days endurance without necessity to refuel and resupply. The ability to remain on station, taking data, for six to ten weather events is needed for meteorological, air-sea interaction, and upper ocean experiments. If synoptic weather events occur roughly every four to five days, then fifty days of data is required. These fifty days plus ten days for transit and set-up/take down determine the sixty day endurance requirement.

5. Range

The platform should be able to work anywhere on the ocean, with the exception of areas in which ice would be encountered. Thus, the design should permit transiting the Panama Canal. The design should also be suitable for the climates encountered in equatorial, as well as in far northern latitudes.

6. Sea State

The platform should be able to continue to work routinely in waves of ±30-40 feet, and should survive a 100 foot wave. The preference for the design is for a very stable platform. If, as in the present FLIP, this would lead to a platform not suitable for use in high latitudes, it is recommended that a second, surface-following platform be considered for high-latitude use rather than compromise the design of the stable platform desired for equatorial and mid-latitude use.

7. Electrical Power

The power plant on the platform should have twice the capability of the present plant; at least 100 KW should be available. Further, the design of the plant should be worked out with input from the probable users. Specific concerns of working group members are: that the power to the lab never need to be interrupted while at sea (as for oil changes for generators); that there be multiple generators with a range in size for flexibility; that there be separate circuits; with filtered power available to the labs and with the ability to switch off lower decks when they are awash without shutting down the labs; and that care be taken in grounding the electrical systems.

8. Azimuth

Control of azimuth should be less than or equal to ±2 degrees in up to 15 knot winds. A readout of heading to 0.1 degree should be available to data logging equipment belonging to the science party. The orientation of the platform should be able to be controlled by a thruster, with the coordinate system of reference being chosen by the science party. Both geographic coordinate (east-west, north-south) and environmental coordinate (platform oriented with respect to wind or ocean currents, for example) systems should be available. The thruster should be able to be located at various depths and mounted on extensions to vary the moment arm. Different experiments will desire the disturbance of the ocean by the thruster to be minimized by mounting it at depths away from their sampling volume.

9. Tilt

Tilt should be less than or equal to 2 degrees rms in ±30-40 foot seas. Readout of two axes of tilt to 0.1 degree should be available for logging by the science party. The platform should be trimmable in the two axes so that mean tilts associated with loads deployed asymmetrically on the booms can be adjusted.

10. Heave

Heave should be 5% or less (rms) of significant wave height.

11. Platform Shape

The platform should be symmetric. Neither the winds nor the currents should cause weather vaning.

12. Lab Space

Lab space should be double that of the present FLIP, roughly 1000 square feet. The lab areas should be environmentally controlled, with the ability to hold 70 °F and less than 90% humidity in areas to be used for electronics and computers. A working or wet lab should be available separate from the electronics labs for instrument repair and work requiring seawater. A flexible mounting system such as the Unistrut system used on research ships should be incorporated. Dockside access to the labs should allow instrument packages with dimensions 4'x8'x8' to be lowered into the lab.

Space should be planned for a science hold for storage of packing material, supplies, and spares so that these need not be kept in the working lab. This space could be remote from the labs, in a part of the platform not desirable for berthing or lab space. If so and if the space is a significant distance in the vertical from the lab, there should be elevator access to move gear between decks rather than require manhandling gear between decks on ladders. In general, some consideration should be given to how gear is moved between decks and into position for deployment.

13. Science Party

A science party of up to and including sixteen persons should be able to be accommodated for sixteen days.

14. Science Payload

Double that of the present FLIP, in terms of both total weight and moment specifications.

15. No Self Propulsion

That platform need not be self-propelled; and, in order to keep operating costs low, it is recommended that it should not be. The design should, however, incorporate features to improve towing, hook-up, and docking. One of these could be a dedicated thruster for maneuvering or use of the orientation thruster for the same purpose.

16. Booms

The platform is to be used to deploy vertical and horizontal arrays of instruments in the ocean and the atmosphere. Horizontal and vertical booms are required to make this possible. Two types of horizontal booms are needed. One type would reach out away from the disturbance of the platform; these booms would be close in length to three times the platform's widest diameter, though the exact length will depend on the results of wind tunnel studies. The second type would be designed for heavy loads, up to 2000 pounds per boom, and would be shorter. Such booms would be available below the surface as well as above the surface; and an above-surface boom could be used with a below-surface boom to deploy, for example, a wave follower on a cable tensioned to 1000 pounds. A vertical boom, perhaps a telescoping jack-up tower, should be available as well, with the ability to reach up to perhaps 50 meters above the sea surface.

Booms should be able to be attached on every quadrant of the platform. Mounting systems should be flexible and provide the ability to mount a mix of both types of booms simultaneously. Use of six or more booms at once may be anticipated. Boom deployment should be simple and flexible, perhaps by hydraulics. Horizontal booms should be able to be lowered at angles below horizontal to bring instrumentation near the sea surface and should be rigged to take instrumentation at various points along their length.

Boom use should be considered as part of the design, and efforts should be made to develop booms that would be strong, lightweight, and durable. Booms should provide access to the instrumentation. Horizontal booms should have walkways, and vertical booms should have ladders. Booms should have provisions for cable runs and movable mounting blocks or travellers that can be moved in and out (up and down) independent of the boom.

17. Hull Mounts

The hull should provide a means for mounting instruments such as Doppler sonar arrays weighing up to 10 tons for deployment below the surface at depths of up to 90 meters. The mounting systems should be of a steel that is easily worked and does not require special welding. A "bolt-on, bolt-to" mounting rail or other structure should be considered, but any such structure should provide alignment references so that instruments can be mounted and sighted in with accuracy relative to the platform itself. Further, this mounting system should be coordinated with a system for easily running cable back to the labs. A flippable hull provides easy opportunities to mount equipment while at the dock that will, after flipping, be deployed at the desired depth. In non-flippable platform designs, a vertical railway or other system should be included to permit both easy (no divers) installation and at-sea access to the equipment.

18. Communication Gear

A Marisat link for telephone and data communication is needed. This is also important in that it will provide an alternative to HF radio. Much of the science gear is sensitive and easily disturbed by HF radiation, so that routine traffic should have an alternate route because it may be necessary to secure HF radios during some work. Science will also need a link for passing and receiving digital data, including satellite imagery, at 9600 baud or better. Work with aircraft is anticipated, and aircraft band radio gear should be provided.

19. Positioning and Navigation

GPS and Loran C should be available, with digital (RS 232) outputs of the data stream available for logging by the science party. A submarine warning beacon should be attached to minimize the need to move the platform out of submarine lanes. Navigation capability should include the ability to deploy hull-mounted transducers at various depths for implementing acoustic navigation of platform or of other vehicles relative to platform.

20. Horizontal Platforms

Horizontal working space is required in addition to the lab spaces. This space would probably be outside; this deck space is needed for instrument and winch mounting, for instrument assembly, for storage, etc. Not all that space need be capable of bearing heavy loads, but some should be constructed of heavy expanded metal grating for easy spotting of heavy winches and other loads. Other horizontal working areas will be needed for launching balloons, working with tethered balloons, and mounting upward-looking meteorological sensors. A horizontal area high up on the platform should be considered to serve both as an area for instrumentation and as an area, once the vertical boom and nearby antennas are lowered, for hover-only helicopter access for medical airlifts and resupply.

21. Deck Gear

For moving gear on deck and between decks a small crane should be available. In addition compressed air and hydraulic power should be available at a variety of locations to run air tuggers, portable capstans, and winches.

22. Mooring Capability

The platform should be able to be moored with one-, two-, three-, or more- point moors. The platform should be able to tension the lines and to rotate once moored.

PRIORITIES

The working group assigned the highest priority to the requirements that the platform be minimally disturbing of the air, the sea surface, and the ocean; be stable; and be comparable in daily operating cost to the present FLIP. Essentially, the group envisioned a second generation FLIP or flippable spar that provided improved performance and habitability and increased payload relative to the present.

WORKING GROUP III

F. H. Fisher (Chairman), Ira Dyer, W. S. Hodgkiss, Ed Franchi, John Hanrahan, R. C. Tyce, and E. Slater.

NEEDED CAPABILITIES

The principal needs for a new FLIP centered on limitations already apparent to current users of FLIP for underwater acoustics, just as for the physical oceanographers.

The more challenging environments, rougher water and farther north, are what both scientists and sponsors are interested in. As a platform, the FLIP concept provides stability, mobility, and economy of operation with its small crew. With its capability to be placed into a tight, three point mooring in deep water, it has proved to be an extremely useful platform for obtaining ambient noise and acoustic propagation (including seismic) data in the ocean.

The present FLIP suffers from limited operational capability in rough water, limited laboratory space, comparatively poor habitability and already has lasted five years more than the twenty-year life projected at its launching in June, 1962.

The combination of limitations of the present FLIP along with the need for working in rougher water means that a new, more capable platform is required. The advantages cited above for the present FLIP, stability, mobility, economy of operation and deep-sea mooring capability, lead us to the conclusion that a larger FLIP, capable of working in 60 foot seas and surviving 100 foot waves, would meet the needs of the underwater acoustics community and, in addition, by virtue of its larger size, would make possible the deployment of groups from different laboratories and disciplines.

For example, we already run into crowding problems with both equipment and personnel if we attempt to have two groups operating in conjunction with each other. In the past we have attempted to coordinate both acoustic and internal wave groups on board FLIP and encountered difficulties with modest experiments. Now, with Pinkel's large sophisticated sonars for studying internal waves and sea-surface slope distribution, and with the large acoustic arrays we now deploy from FLIP, we simply could not effectively combine these assets to attack outstanding problems in underwater acoustics, surface reverberation, and surface decorrelation.

In our workshop panel discussions we focussed on the unique characteristics of the present FLIP which should be preserved in a larger version,

UNIQUE CHARACTERISTICS OF FLIP

1. Stability.
2. Deep sea mooring capability (long term/short term).
3. Potential for quiet acoustic platform.
4. Array deployment capability in joint moorings with other platforms.
5. Unique interdisciplinary joint research efforts.

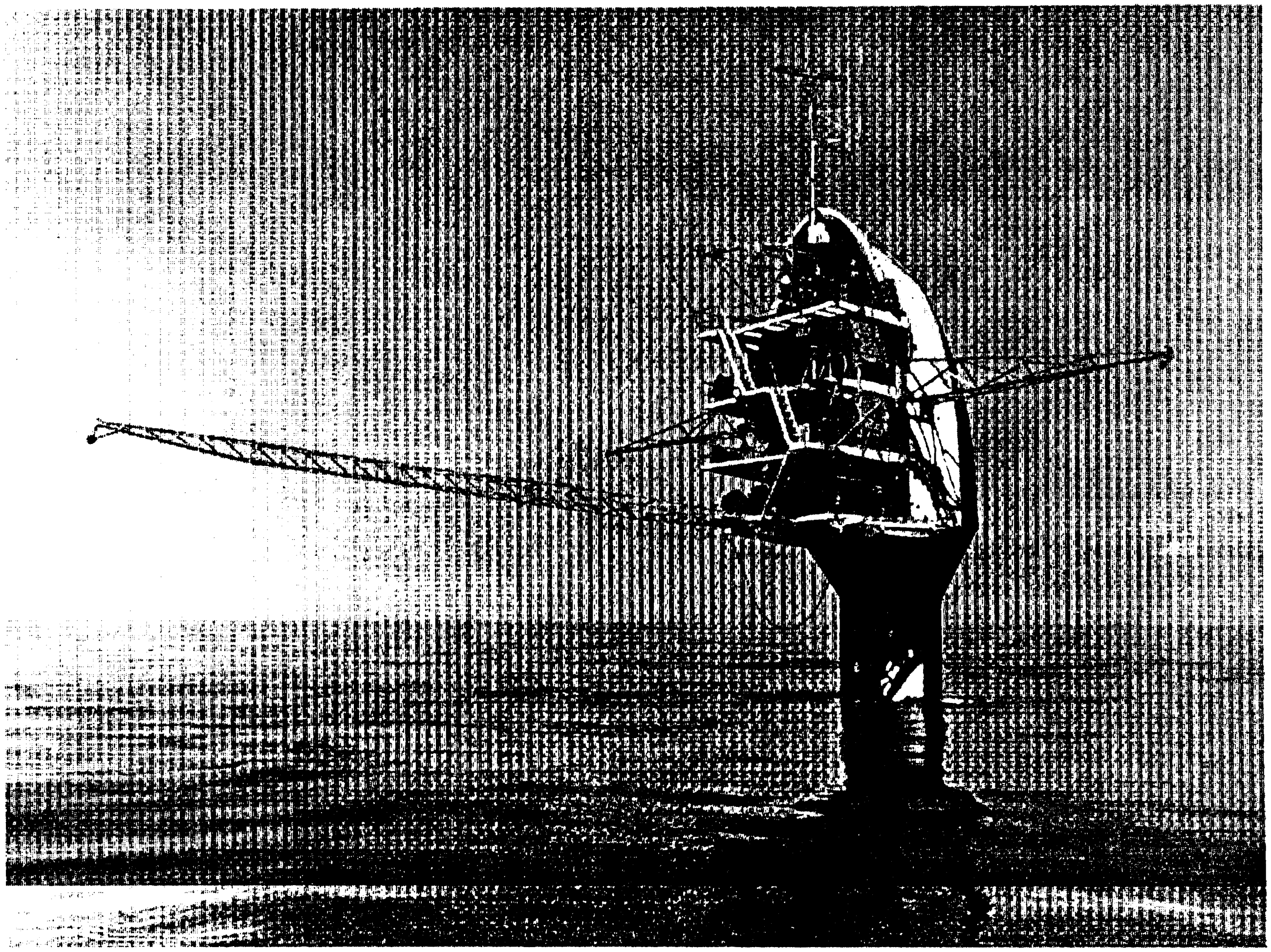
PRINCIPAL REQUIREMENTS FOR ACOUSTIC USES OF NEW FLIP

1. Greater rough water operating capability: 60 foot waves with 100 foot survivability.
2. Increased electrical power (~1000 Kw).
3. Increased laboratory space/multiple separate laboratory spaces.
4. Weather proofed platforms and winches .
5. Heavier capacity winches and booms, hydraulic booms, winches with 10 ton or greater capacity.
6. Continued capability for mooring, jointly/singly.
7. Improved habitability.
8. Safer rough weather personnel/equipment transfer capability.
9. Environmentally controlled computer space.

PRINCIPAL AREAS OF ACOUSTIC RESEARCH FOR NEW FLIP

1. Ambient noise directionality, 2D/3D, high resolution.
2. Topographic effects on downslope conversion, target discreteness.
3. Cross-correlation, signals/noise, as function of separation of vertical arrays.
4. Out-of-plane scattering.
5. Monostatic reverberation, Low Frequency Active.
6. Gound truth for SURTASS.
7. Propagation addressing 2D/3D acoustic-ocean models/validation.
8. Rainfall rates/noise/ground truth for satellites.
9. False target problem (biology, etc.).

Note: There was no participation by the seismic community even though FLIP has been used for crustal anisotropy studies.



WORKING GROUP IV - Platforms

WORKING GROUP IV

C. B. Bishop (Chairman), S. Beck, S. Burley, H. Chalmers, I. Dyer, D. Efird, R. Gaul, L. Glosten, J. Harlett, T. Hoopes, and W. Webster.

CONCEPTS

Seven different platform types were considered:

1. FLIP-II is the advanced version of FLIP, however large and capable that might turn out to be.
2. The Flippable Barge is an outgrowth of the FLIP concept, and has already been through a certain amount of development for transporting heavy loads through the interface.
3. Semi-submersibles are available from the off-shore oil industry. New models that have been built include triangular semi-submersibles by Cubic Corp. and by Navy Civil Engineering Laboratory.
4. SWATH (**S**mall **W**aterplane **A**rea **T**win **H**ull) ships, which are high speed semi-submersibles, began with the Navy's KAIMALINO in 1973.
5. Research submarines, which would be needed to conduct under-ice measurements.
6. Moorings include submerged instrumentation platforms that are anchored to the seafloor.
7. Hybrids include combinations of any of the above six concepts, e.g. the concept of a semi-submersible as a base platform from which SWATH ships operate or moorings are deployed.

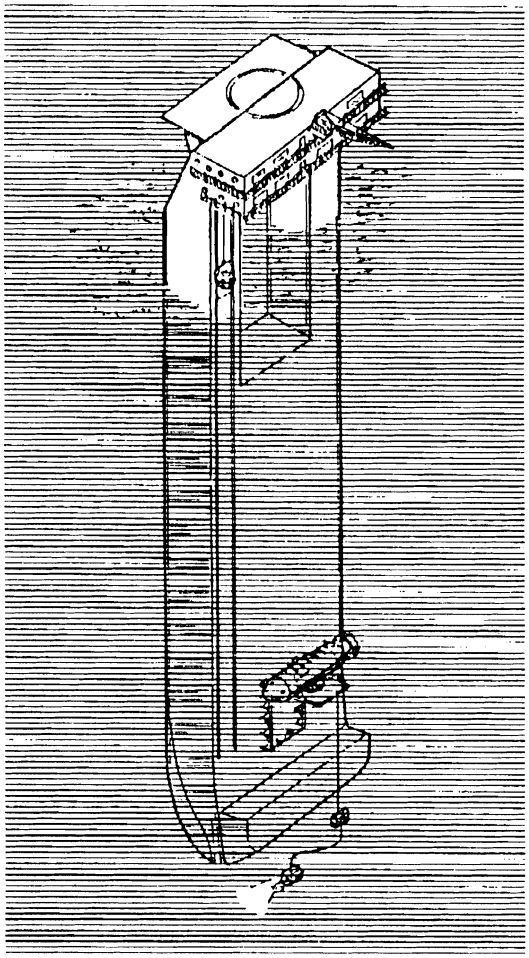
FLIP-II

The requirements for FLIP-II are discussed in detail in the report of Working Group II.

FLIP itself continues to operate effectively as a stable research platform, and should do so for several more years. Analysis of her structural condition is ongoing, based upon strain gage data, annual hull inspections, and operational cycles. Glosten Associates, the design architects for FLIP, continue to appraise her condition, and have estimated that another 6-10 years of operations is achievable before significant structural strengthening may be required.

Flippable Barge

The Flippable Barge (or twin-Flip catamaran) is a logical outgrowth of the original FLIP concept, emphasizing the ability to carry much larger payloads in the horizontal position and to make the transition to the vertical with the load attached in order to carry the load through the interface. An extensive study of this type of craft, including scale model operations were done[1].



It was conceived in the context of assembly of large area stable structures (e.g. airfields) at sea. In this scenario it carried a deck-load of long spar buoys that, after transition to vertical, were assembled with cross-bracing to make a large area frame that could then be decked over to provide the desired work area, shops, etc.

The barge, having the same vertical motion response as the individual spar buoys, provided not only for their transport, but was the proper vehicle to be the initial operating base (housing, machinery, etc) during assembly of the final structure. It could

---

[1] Spiess, F.N., May, A.E., Tomooka, L.S., and Bellows, D.R. Flippable Barge for Ocean Engineering Support. *SIO Reference 74-30*, Scripps Institution of Oceanography, La Jolla, CA (1974).

be used to make successive trips to the site and be incorporated into the final assembled complex if appropriate.

Once the initial concept had been investigated it became clear that the basic craft had a number of additional possible uses. If massive units (e.g. seafloor work vehicles or large active acoustic transducers) were to be used in mid-water, they could, with their winches, be mounted on deck and swung well below the surface while rigidly constrained and then lowered to appropriate depth from a (relatively) stable suspension point. By ballasting the massive load to be close to neutrally buoyant, and recognizing that the small motions of the suspending vehicle require only minimal compensator dynamic range, it would be possible to use a suspension cable designed solely for power transfer rather than having to cope with very large tensile strength requirements due to dynamic loading.

The barge could also be used to handle and tend intermediate size submersibles (e.g. Aluminaut dimensions). The submersible would be carried below the waves secured to the barge, and access to the submersible for personnel, battery charging, etc., would be available through the barge, with a mating hatch arrangement similar to that used in the submarine rescue context.

This type of craft would provide a good base for seafloor work vehicles and the extended area version could be assembled to meet the needs for the long term observation platform discussed in Appendix A.

Semi-submersibles

There are about 200 semi-submersibles throughout the world. The oil business is such that about 50% of those have been released. They are characteristically about 150 ft. wide and 250 ft. long, and with a vertical extent of 120 ft. and 15 to 18 ft draft. when deballasted. They are available now at greatly reduced cost, and possibly at no purchase cost for research institutions as tax laws may allow. (Western Pacesetter II illustrated at end of Working Group IV Section). This will last for another two or three years before they find their way to the scrap piles or they get back into service.

Conceptually, a semi-submersible is a group of FLIP's hooked together. An important distinction is that a single hull, in order to be vertically stable, has to be relatively long. If, on the other hand, several of these are coupled together, they no longer retain their individual tilt aspect, and will then tilt as a unit. Addition of underwater pontoons provides the damping force which results in a heave period for semi-submersible rigs of about 25 seconds. That means it does not move with the sea surface for very long period waves, which can be very high. Therefore, a large clearance is needed, typically 45 to 50 feet from the main waterline.

The result is a stable platform with large area and volume available for work and personnel support. It creates an operating base concept as opposed to a specialized small profile instrument platform. It will support multiple simultaneous measurements continuously for long periods of time, providing the opportunity for time-series database development achievable by no other means. It can be used as a base of operations for other vehicles, surface, submerged and airborne, since it has both large lift capability and deck space. Semi-submersibles are currently capable of being moored in 1000 foot water depth, but are able to maintain position in deep water using dynamic positioning systems. Some move independently with onboard propulsion systems, while others are towed by one or more tugs at speeds ranging from three to ten knots.

Six to ten men can meet minimum maintenance requirements, with the addition of six or eight people to support scientific operations. There will be plenty of space for scientific operations, and for the accommodation of the scientific party. The basic operating crew in this situation, aside from the stewards and cooks, would be the crew needed to maintain the navigation early warning systems, pumps, electrical power and utilities. Typical on-station time of thirty days to four or five months would be normal, and it might be perfectly reasonable to put such a platform out to sea and not bother it for years. This capability could provide a new approach to long term measurements of air-sea interaction of underwater acoustics, of open-ocean storm wave conditions, as well as in biology and chemistry.

SWATH

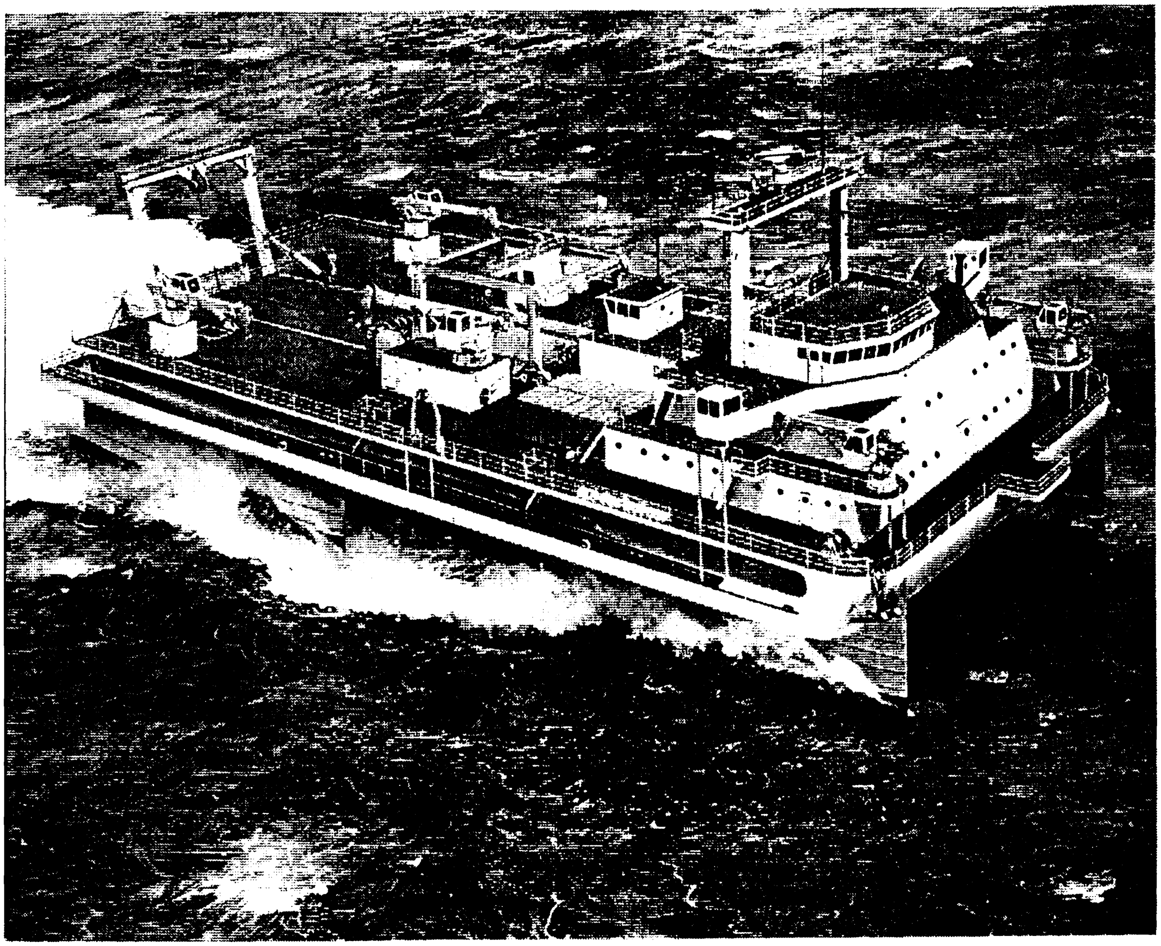
KAIMALINO, the first of this new class of ships was built at the U.S. Coast Guard shipyard in Maryland in 1973 for the Naval Undersea Center. With a length of 90 ft and a beam of 45 ft, it is capable of 25 kts on gas turbine propulsion. After its arrival in Hawaii for duty with the NUC Hawaii Laboratory, it was modified with the addition of diesel engines for economy and maneuvering. It has operated successfully since 1975 in support of research projects and test programs at the BARSTUR range off Kauai, often in sea conditions that abort other surface craft operations.

The most distinctive feature of the SWATH ship is its stability in rough seas, both static and dynamic. The underwater hulls provide a damping force which considerably reduces heave, roll, and pitch motions, and the horizontal control surfaces (canards) make level forward motion easily attainable. The box-like upper structure provides a large deck area and a comparatively large internal volume. This SWATH ship has a center well to support equipment deployments. The net result is a vessel that provides ample space, good speed, and excellent conditions for working at sea. Since the struts that support the upper structure are narrow, the tons-per-inch immersion figure is lower than for a conventional hull resulting in a lower payload capacity.

As a stable-floating research platform, the SWATH ship offers promise for a variety of missions. Small versions could be deployed from large semi-submersibles to conduct experiments and collect data in the vicinity. SWATH-size ships could be useful for coastal research projects, particularly where speed and seakindliness are more important than long-haul accommodations and endurance. Larger SWATH ships, such as those built in Japan, are capable of larger loads including ROVs, submersibles, and multiple research instruments. Lower fuel costs and increased operating days at sea, coupled with increased effectiveness of personnel makes the SWATH an attractive platform for research at sea. Early concerns about greatly increased construction costs have been allayed by the experience of those already built.

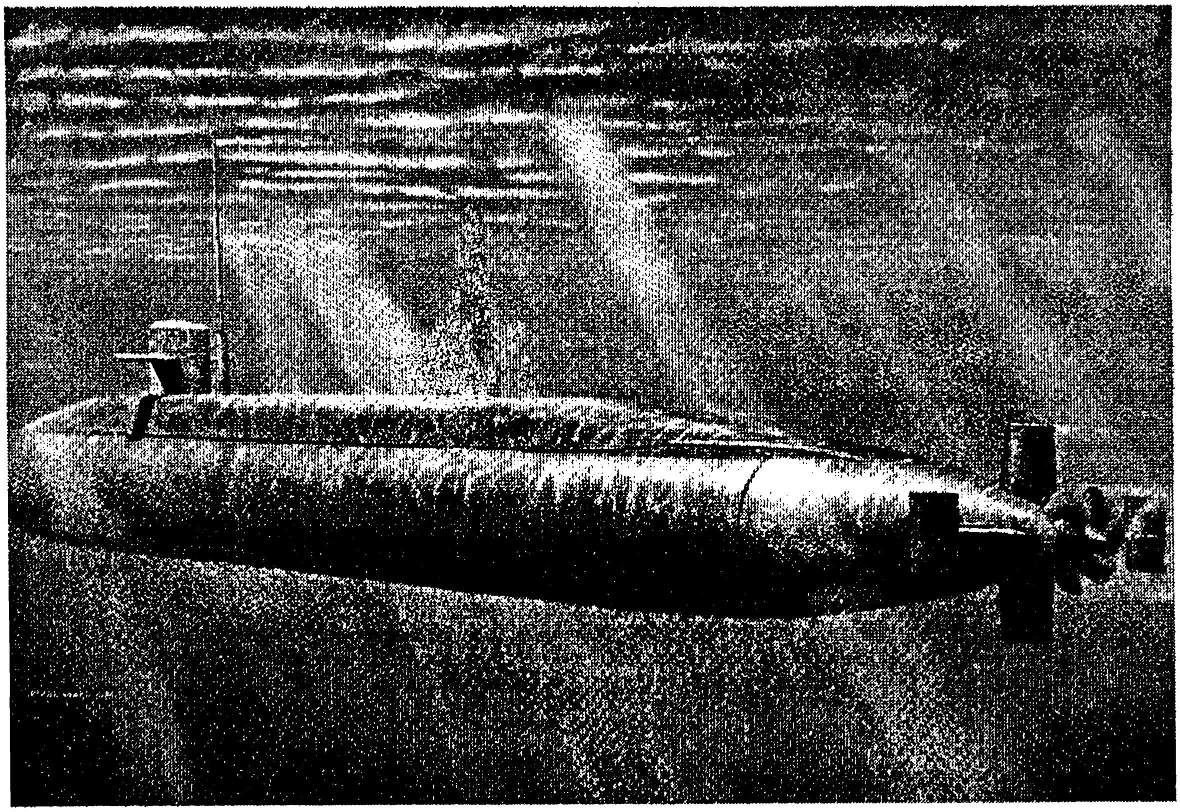
Submarines

The Arctic is a place where one can make measurements easily from the ice itself, which is steadier than any other surface platform. Even a few miles into the ice's edge



in the marginal ice zone, surface wave motion is insignificant for most oceanography. The issue in the Arctic Ocean is that if you do experiments from the ice platform, you are then at the mercy of where the ice takes you. That is fine for some experiments, but not for all. An alternative would be to move along the top of the ice in a vehicle and scan through the ice to study the environment below. That could be effective for some instruments like magnetometers, but the cost would be very high for the collection of limited data.

The preferred alternative is to use a submarine as the platform to collect data from below the ice. The only realistic submarine is a nuclear-powered submarine, because the experimental objectives, including high-resolution topographic measurements, magnetics and acoustics, need considerable movement throughout the Arctic Ocean, and would require the endurance of a nuclear sub. There are research



needs in the larger submarine community that deal with technology development for new submarine capabilities. This suggests the possibility that a nuclear sub might become available for several months of scientific research per year. Should that happen, it could be used in the open ocean as well as in the Arctic.

Among the things that could be done in the Arctic with a nuclear submarine is the definition of the acoustic properties of the underside of the ice cover. In the open ocean, fine scale sonar observations could be made of the nature and disposition of bubble cloud distributions, which have an effect on the scattering of underwater sound. In addition, from the point of view of ambient noise generation, the location of breaking waves and how they generate noise could be studied.

For a precedent, at one time the Navy committed a submarine to oceanography for a period of several years. Also, the Navy has conducted a series of nuclear submarine operations under the Arctic ice for many years. Every time they go they do some geodesy, mapping, and occasionally some scientific investigations. The more our submarines operate in the Arctic Ocean, the more it would seem that they need the answers to scientific questions about that environment.

Moorings

Moorings are added to the list for completeness. Some data could be obtained using moorings with fewer special requirements than those placed on the other platforms. Although limited in capacity and power supply, moorings do offer capability for *in situ* data collection.

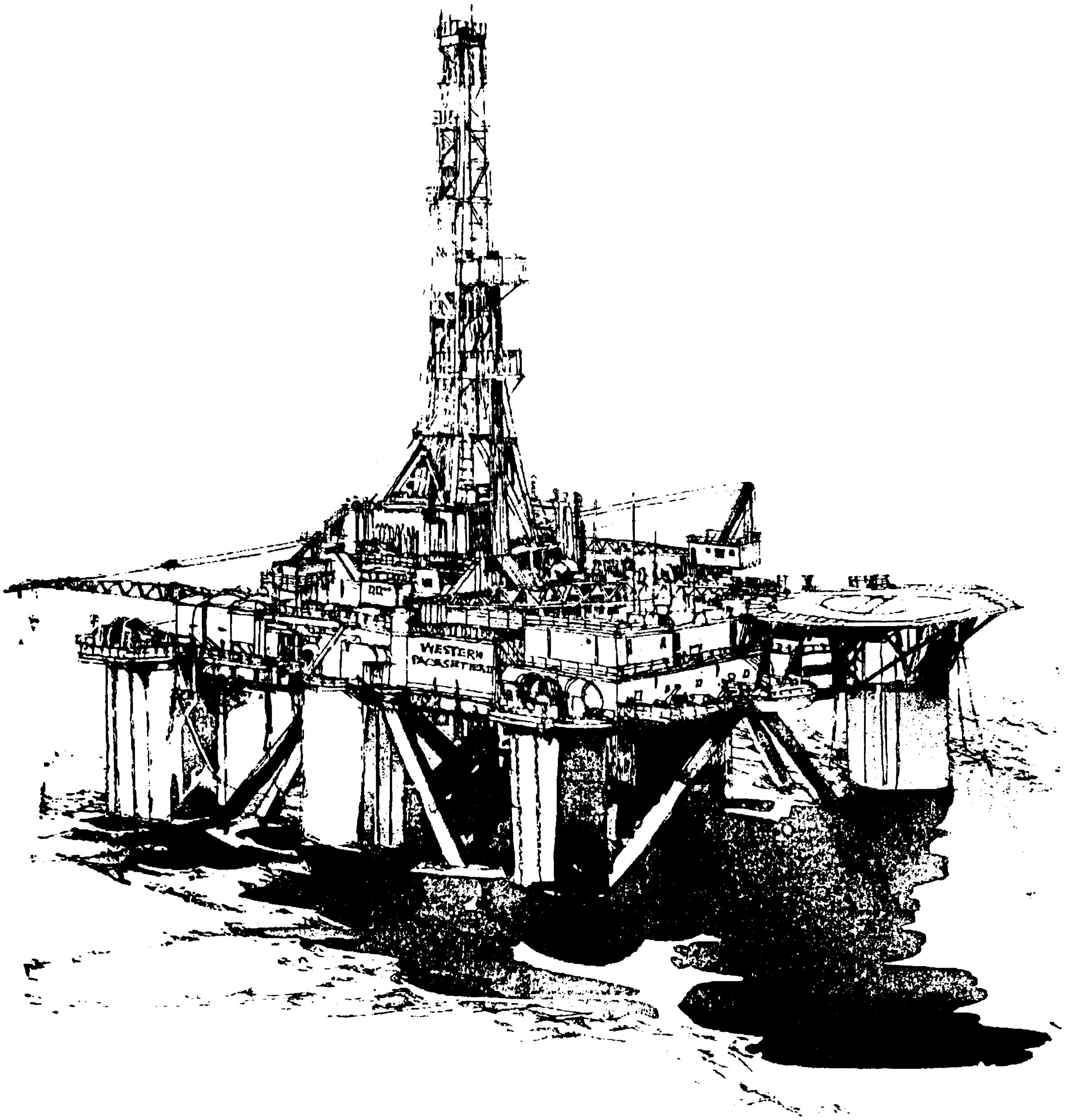
Their characteristics are that:

they communicate in some way with the laboratory
they may involve adaptive sampling techniques
they may have some capability to receive instructions to modify sampling
they can be good for several applications
they can be single purpose
they may be the cheapest way to obtain long-term samples. A major disadvantage is that they cannot provide for surface layer measurements in the upper ocean.

Moorings are mostly used now for physical oceanography.

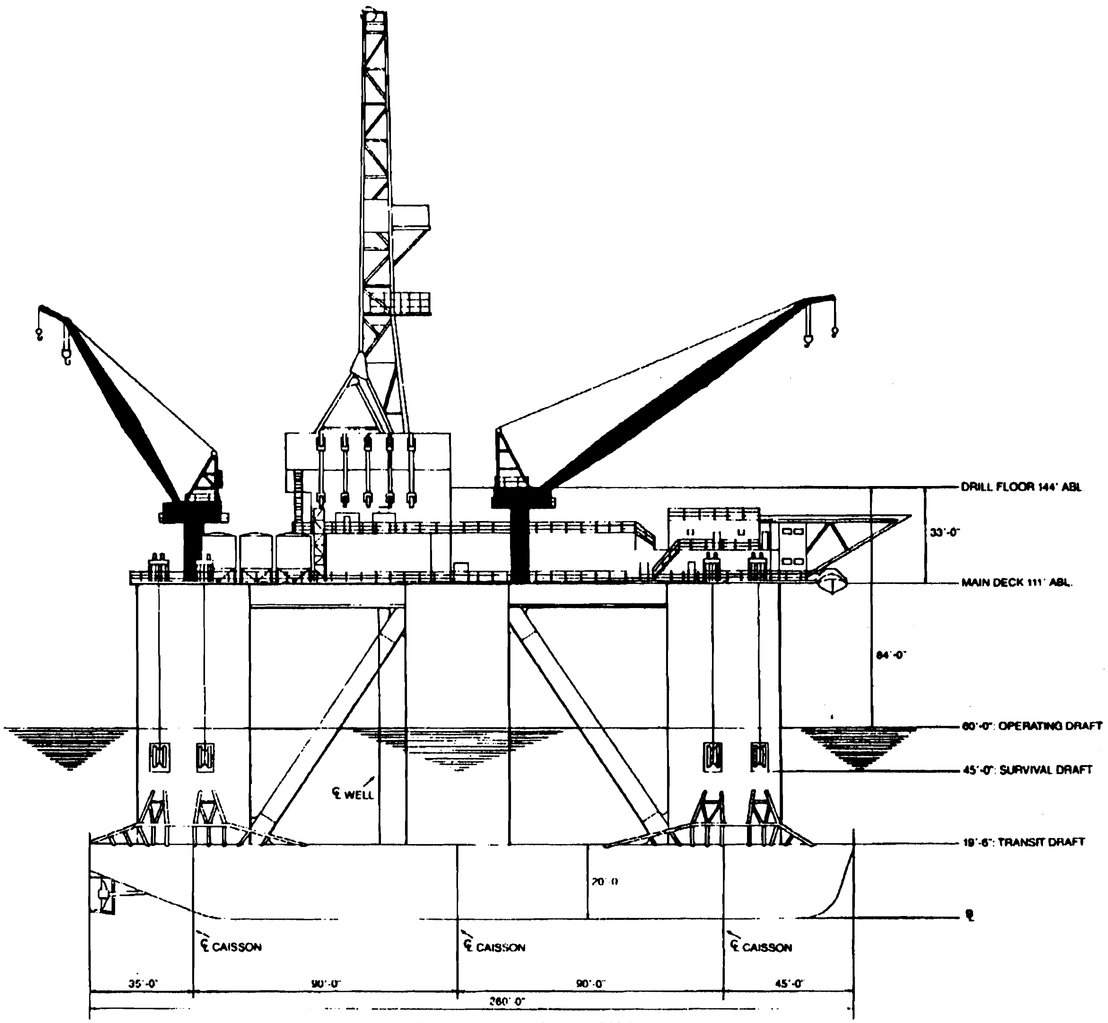
WESTERN PACESETTER II

Semi-Submersible for 1500 ft. water depth



WESTERN PACESETTER II

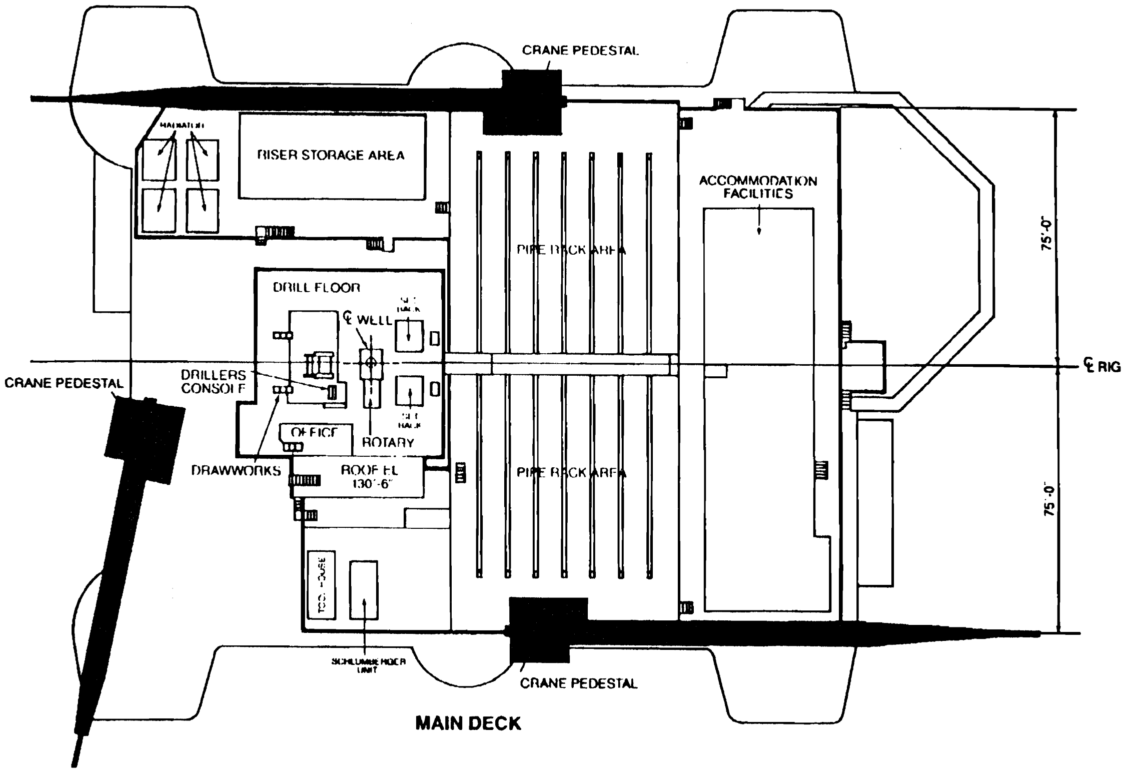
Semi-Submersible for 1500 ft. water depth



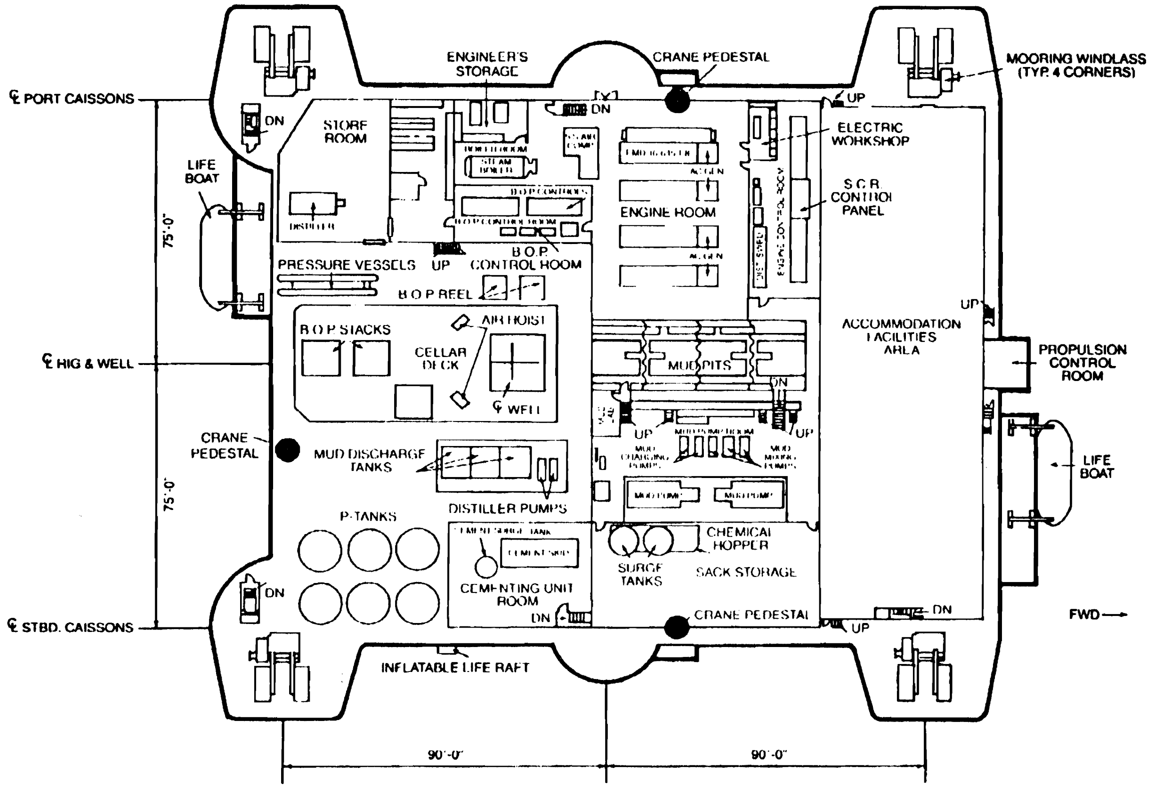
OUTBOARD PROFILE STARBOARD SIDE

WESTERN PACESETTER II

Semi-Submersible for 1500 ft. water depth



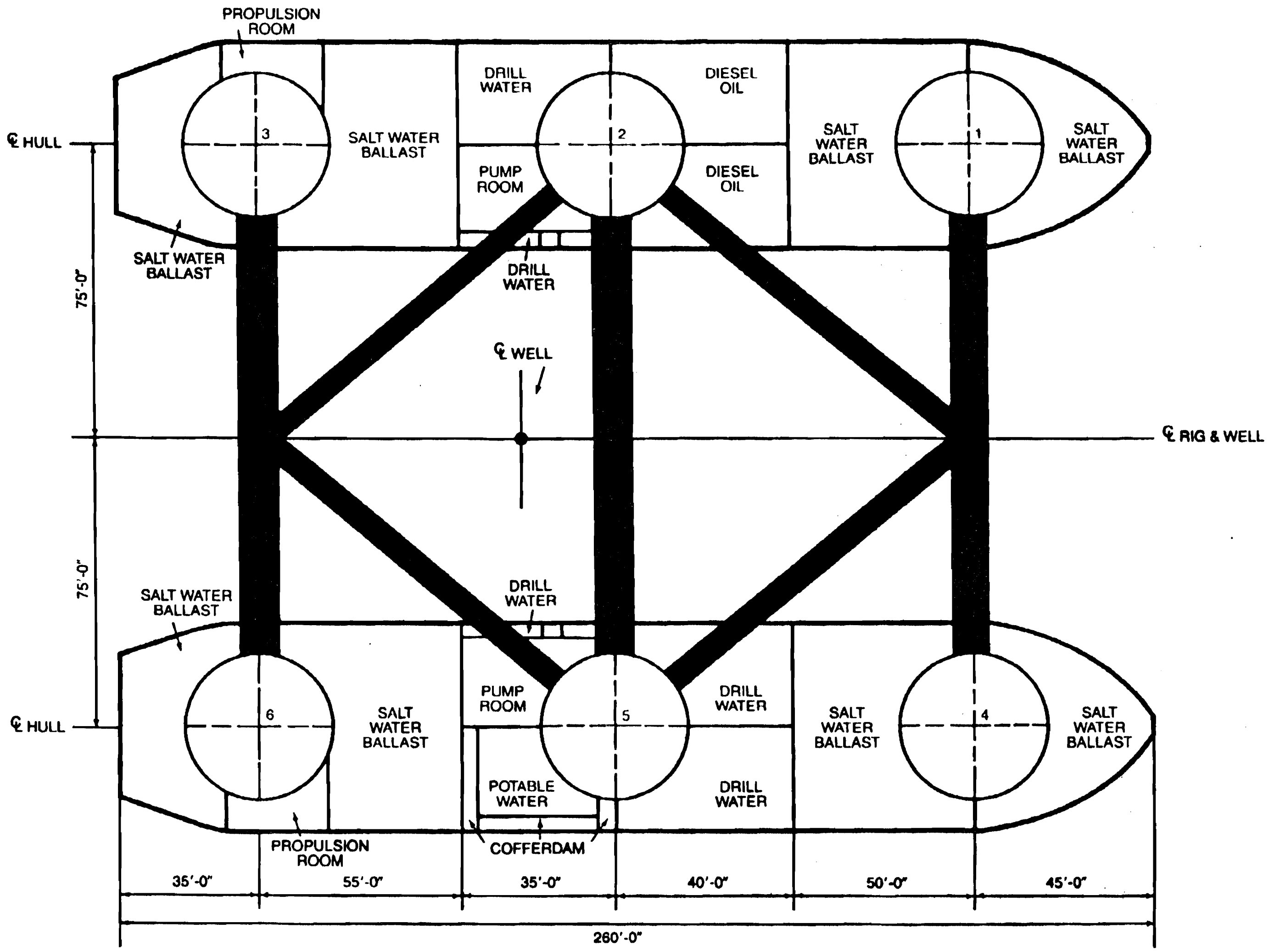
MAIN DECK



MACHINERY DECK

WESTERN PACESETTER II

Semi-Submersible for 1500 ft. water depth



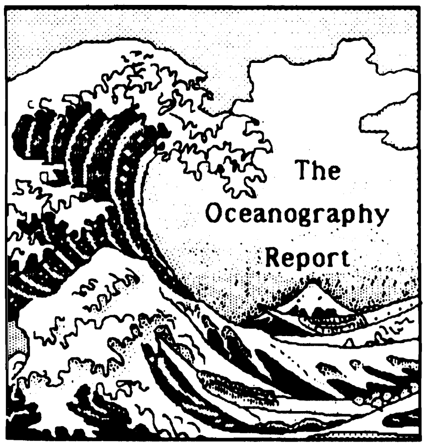
PLAN OF LOWER HULLS

APPENDIX A

"Long Time Series Study of Oceanic Ecosystems"*
by Peter H. Wiebe, Charles B. Miller, John A. McGowan, and Robert A. Knox

Reprinted with permission from *EOS, Vol. 68, No. 44, pp. 1178-1190 (November 3, 1987).*

Eos Vol. 68, No. 44, pages 1178-1190, November 3, 1987



The Oceanography Report: *The focal point for physical, chemical, geological, and biological oceanographers.*

Editor: David A. Brooks, Department of Oceanography, Texas A&M University, College Station, TX 77843 (telephone: 409-845-5527).

Long Time Series Study of Oceanic Ecosystems

Peter H. Wiebe, Charles B. Miller, John A. McGowan, and Robert A. Knox

Introduction

Better understanding of the structure and function of natural ecosystems is now widely regarded as essential to protecting the habitability of our planet. Fortunately, the oceans are not yet at the stage of exploitation and rapid alteration that terrestrial environments, especially the tropical rain forests, are now experiencing. Our wise use of the oceans in the future, however, will depend upon having a firm and fundamental understanding of why marine ecosystems are structured the way they are, how they function, and what are the forces that hold them together or make them change. There is still time to acquire the requisite knowledge, and we believe that prolonged direct observation at open ocean sites can contribute greatly. The logistics for this are of a reasonable scale. New (but tested) measurement and data processing techniques can produce a very extensive yet manageable data set. Therefore, to enhance our basic scientific understanding and to provide information for future management decisions, we propose that a program for multiyear occupation of midocean stations should be designed and fielded by the international oceanographic community.

The rationale for establishing prolonged midocean sampling is that we do not know the frequencies, amplitudes, or phase relations among changes in biological oceanographic variables for any oceanic site. We cannot, at present, judge the relative impact of short, energetic, and relatively frequent events, such as storms, as compared to slower, large, and infrequent events, such as El Niño. Short events have been difficult to observe in sufficient detail by our traditional irregularly timed and spatially scattered cruises. These gaps can be filled by a program for continuous occupation and observation at a series of carefully chosen sites in the open ocean. At the outset, emphasis must be on the amplitudes and phase relations of variables over the annual and shorter periods that can be well represented by a few years of data from each of a sequence of sites. We believe that these time series of data will markedly advance the explanatory and predictive capability of our science. This article documents the need and discusses several approaches for obtaining time series data on critical ecosystem components.

Existing time series of oceanographic data demonstrate strong annual and interannual periods of change in components of oceanic ecosystems (see examples in Figure 1). Long period variations affect the entire spectrum of marine processes: transfer of radiant and kinetic energy to the sea, large-scale circulation, vertical mixing, internal wave activity, phytoplankton nutrient availability, species composition, and standing stocks of organisms from phytoplankton to zooplankton to fish and squid. While low-frequency variations dominate the spectra of many oceanic variables [*Chelton et al.*, 1982; *Quinn et al.*, 1986; *Soutar and Isaacs*, 1974; *Wyrtki*, 1985], recent oceanographic results from some areas suggest that critical events determining the basic hydrographic and perhaps ecological features of these areas can, in some cases, be quite abrupt or short-lived [*Joyce et al.*, 1984; *Emery et al.*, 1985; *Ortner et al.*, 1984]. Both the dominance of low frequencies in present time series and the possible setting of the mean ocean conditions by rare, brief events suggest that progress in understanding many aspects of oceanography will depend upon enhancing our ability to carry out long-duration, rapidly repeated sampling at selected ocean sites.

The Value of Serial Oceanographic Data

The utility of the time series approach to the study of open ocean dynamics is demonstrated with three examples (Figure 1) that have yielded powerful and unexpected insight into the functioning of ocean systems.

Sub-Arctic Pacific

A long series of data [*Anderson et al.*, 1977; *Fulton*, 1983] obtained from ships stationed at Weather Station *P* (50°N, 145°W) has provided ample evidence that the seasonal cycles of primary and secondary production and the resultant effect on standing stocks do not fit the classical Atlantic paradigm for a spring bloom. While there is a strong spring increase in primary productivity and a commensurate increase in macrozooplankton biomass, plant biomass changes little in the Pacific sub-Arctic. Further, there are interannual variations in macrozooplankton stocks. It was postulated in the 1950s [*Henrich*, 1957] that the lack of pronounced variation in phytoplankton biomass is a result of macrozooplankton grazers reproducing before the bloom, instead of in response to it, thereby reducing the typical lag between producer and consumer to zero.

More recent work (SUPER Program) has shown that this fundamental difference in reproductive strategy and consequent difference in grazing activity is actually based on parallel and linked small plant and large plant food chains. The importance of the weather ship time series is the demonstration of the permanence of the plant-grazer relationship. Without the time series, our new insights about mechanisms would have no foundation. We would not even know that an explanation is required.

California Current

In contrast with the sub-Arctic Pacific, *Chelton et al.* [1982], using the long CalCOFI (California Cooperative Oceanic Fisheries Investigation) data series, have shown that there are very strong interannual variations in macrozooplankton in the California Current, but very weak seasonality, especially in the south. Contrary to conventional expectations, changes in macrozooplankton abundance are uncorrelated with variations in indices of coastal upwelling intensity, but they are strongly correlated with interannual changes in mass transport from the north.

Northern North Atlantic

The continuous plankton recorder survey of the northern North Atlantic, begun in 1948, has yielded evidence for significant multiple year shifts in zooplankton biomass and species abundance [*Colebrook*, 1978, 1985; *Colebrook and Taylor*, 1984; *Radach*, 1984]. Space-averaged time series show a long-term trend for the spring bloom of zooplankton to be progressively later and the autumn decline to be progressively earlier in this oceanic area. Thus there appeared to be a shorter growing season and less annual production. More recent data indicate this trend may have been reversed about 1984 [*Colebrook et al.*, 1984]. Whether these observations reflect an in situ change in system function or simply a shift of a biogeographic boundary is still unresolved, although *Colebrook* [1978] argues that "...about half of the observed variability in the annual means can be attributed to density-independent, physical environment processes."

These three examples have yielded results that are convincing and in many ways unexpected. They illustrate the power that even relatively crude time series offer in testing hypotheses and predictions and show how they can provide new and nonintuitive insight into the functioning of oceanic systems. They are particularly useful in establishing the relative importance of physical forcing of biological events, as opposed to purely intrinsic biological causes.

Despite their importance to oceanographic understanding, the extant series are weakened because relatively few components of the system were measured. If, in any of the three cases, a broader array of physical, chemical, and biological properties had been measured, the mechanisms behind the remarkable changes could be examined. Further, if the relative rates of change of compo-

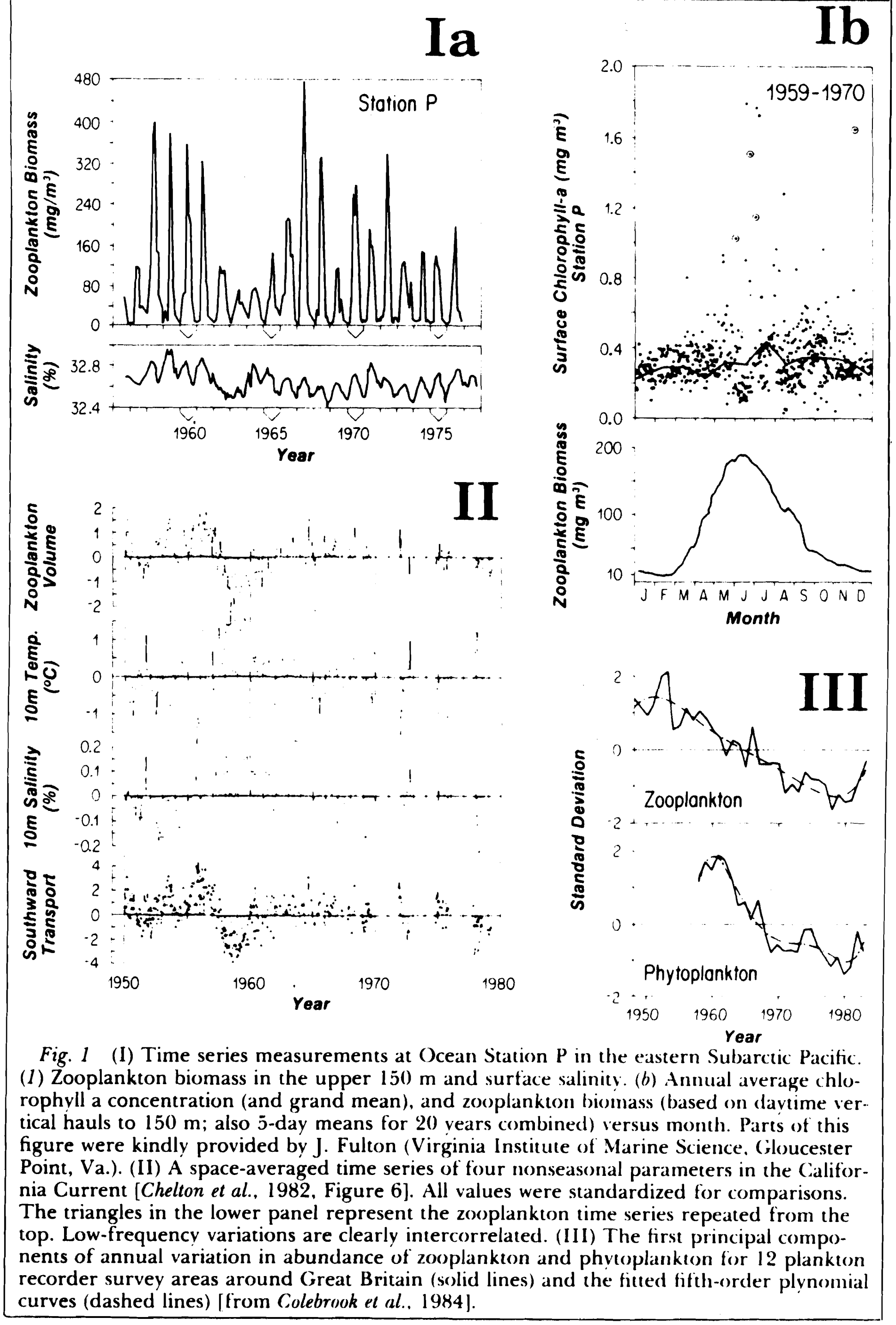


Fig. 1 (I) Time series measurements at Ocean Station P in the eastern Subarctic Pacific. (*1*) Zooplankton biomass in the upper 150 m and surface salinity. (*b*) Annual average chlorophyll a concentration (and grand mean), and zooplankton biomass (based on daytime vertical hauls to 150 m; also 5-day means for 20 years combined) versus month. Parts of this figure were kindly provided by J. Fulton (Virginia Institute of Marine Science, Gloucester Point, Va.). (II) A space-averaged time series of four nonseasonal parameters in the California Current [*Chelton et al.*, 1982, Figure 6]. All values were standardized for comparisons. The triangles in the lower panel represent the zooplankton time series repeated from the top. Low-frequency variations are clearly intercorrelated. (III) The first principal components of annual variation in abundance of zooplankton and phytoplankton for 12 plankton recorder survey areas around Great Britain (solid lines) and the fitted fifth-order plynomial curves (dashed lines) [from *Colebrook et al.*, 1984].

nents could be analyzed for pattern, continuity, lags, or phase shifts, there is little question that our understanding of the regulation of ecosystem structure and function through the interaction of components would be vastly enhanced. That is, we can ask, How do climatic perturbations of a given magnitude affect the upper layer physical structure? Which direction do the physical responses to climatic perturbations, in turn, drive the state of the biological system? How and when does the system recover?

Another potential for powerful new insight would come from strictly comparable time series done at different sites but in analogous systems (the Pacific central gyre and eastern subtropical Atlantic, for example). The three extant time series cannot be compared in this way, and yet such comparisons could be a powerful tool in our search for new insight. Oceanic ecosystems should be one of the principal test sites for the unifying theories now available in ecology. That is because, for all their complexity, they are in many ways simpler and easier to measure than terrestrial ecosystems. They are, above all, mobile systems where stirring and mixing are significant processes that tend to smooth out small-scale heterogeneity. Further, they lack the structural features of cover and intense gradients in basic habitat properties that characterize the land.

That multiple stable points in ecosystem structure are a distinct theoretical possibility has been discussed and reviewed in detail by *Holling* [1973], *Pimm* [1980, 1984], *Connell and Sousa* [1983], *Beddington* [1984], *Steele and Henderson* [1984], and *Steele* [1985]. They are particularly concerned with the response of multispecies systems to perturbations. It is clear from their works, and others, that we are very much limited by data in this effort to understand the system behavior of communities. Long-term characterizations of major oceanic ecosystems, their climate, and their hydrography should make basic contributions to the testing and elaboration of these theories.

Formulation of a Time Series Program

Although we have learned much from existing time series, it is clear they are inadequate to enable us to address many current and future problems. Some of these problems are circumscribed by the questions listed in the box labelled "Scientific Questions." We need a new program to address these issues that will take advantage of the new techniques for rapid and efficient measurement of components omitted from previous time series. It will build upon our current understanding of the structure and function of oceanic ecosystems and of how these are influenced by upper-layer physical processes. We believe that the following data acquisition guidelines should be used in developing such a program.

Data Acquisition Guidelines

- We should measure those variables that we know how to measure efficiently and at high frequency over a period of years. The choice of properties or components to measure as a matter of routine should be limited to those that can be analyzed quickly (for example, chlorophyll and cell size frequency, as opposed to phytoplankton species counts).
- Measurements should be made at oceanic sites where horizontal gradients are relatively flat, i.e., where advection is weak or where shifts in physical or biogeographic boundaries cannot corrupt or bias the time series. Such a site should also favor the determination of the regional (mesoscale) ocean circulation by means of suitably chosen direct observations and remotely sensed data (sea surface temperature (SST), altimetry, color) in conjunction with numerical ocean models.
- We need to provide mechanisms for integration of nonroutine measurements in the sampling protocol; that is, the routine, ongoing time series should serve as a foundation or umbrella program. A wide variety of other studies that are not in themselves "time series" or that are not easily measured as a matter of routine can be included. They would benefit greatly from being embedded in the program and would contribute to the interpretation of the basic data set. Such projects might include intensive periods of study of microstructure, internal waves, or phytoplankton species structure to assess the variability of these under different conditions.

The reason for making the measurements at oceanic sites where horizontal gradients are relatively weak is to insure that they are as representative as possible of surrounding regions, in the sense that local changes in time predominate over advective changes of the fields of interest. In terms of physical fields, such locations are in the eddy-weak portions of subtropical gyres, far from boundary currents and their associated nearby zones of strong perturbation (for example, Gulf Stream rings). No location is devoid of mesoscale eddy activity, of course, and if the measurements were strictly confined to a single point, interpretation would suffer. However, as noted below, we envision our "station" as incorporating a modest level of regional, spatially distributed measurements from research vessels and from a workboat based on a floating platform. A regional array of moored instruments is also desirable. With an appropriate combination of such strategies, it should be possible, in a "quiet" midocean area, to obtain data sufficient to map the local mesoscale field and its evolution. This mapping problem will be made easier with the advent of regional eddy-resolving, data-assimilating numerical models combined with satellite observations (scatterometer winds, altimetry, SST) with which to constrain their evolution. By the time that the program that we envision could be set in motion, satellite data sets such as these ought to be available and perhaps even routine.

Scientific Questions

- What are the temporal scales of variability of basic ecosystem properties such as climate, hydrography, nutrients, and biological functional groups? Are there trends for some frequencies to show the largest and therefore the "most important" changes?

- If various components of the physical-chemical-biological system interact to influence each other's magnitude or concentrations, and if this happens in a consistent and patterned way, there should be detectable statistical relationships between them in spite of a large amount of noise. A dense data set will be essential in detecting these relationships. What are these cross-correlation (or coherence) functions between the various time series?

- What types of atmospheric or hydrographic perturbations affect the biotic system, and what types do not? There are many kinds of disturbance/perturbations, ranging from microscale turbulence to El Niño phenomena. Although almost all of them have been implicated one way or another, some of them seem to represent severe disturbances to the structure and function of systems, while others do not. Which ones, then, are which? For example, does a single large storm have greater effects than, say, a month or two of merely "bad" weather? How, and in what direction, does the system respond to different kinds of physical events?

- It seems likely that the mean state of ecosystems is set by the cumulative effects of variability on many scales rather than a single one, but if there are multiple, quasi steady (mean) states, how are shifts between them brought about? That is, is it necessary for driving forces to change on all scales for a shift from one system "steady" state to another? Can communities change state due to biotic interaction alone, operating independently of the physical environment?

- Can a long time series of measurement of the products of nonlinear phenomena help up understand the limits of predictability and modeling? Most of our conceptual notions (i.e., models) of how pelagic ecosystems work are based on first principles and/or the determination of rate functions, but it has proven to be difficult to obtain enough measurements to define these unambiguously. This is because of both measurement problems and sampling error. Further, most of these functions are thought to be nonlinear and therefore cannot be averaged or otherwise lumped.

Predictions based on models of complex systems with such very limited knowledge should (and usually do) fail within a very few generations. However, the product of various rate functions, namely changes in biomass or the switching of biomass or nitrogen or calories from one system compartment to another, can be measured with a known amount of sampling error. Thus the state of the system with regard to relative abundances or concentrations can be defined, and changes in state can be quantitatively described.

An inverse model can now be proposed: "What kinds of dynamic interactions can result in the sort of system we have observed?" Such an approach should give new insight. This is not envisioned as merely a curve fitting exercise but rather the beginning of a new conceptualization of the dynamics that are responsible for the structure of pelagic ecosystems.

The core time series data set that we believe is required involves the acquisition of information about the basic water column structure and dynamics. Our suggestions for essential data are given in the box "Components of the Core Time Series Data Set."

Operational Modes for Serial Oceanic Observations

To accomplish the goal of obtaining time series of water column variables, it will be necessary to occupy deep water sites with scientifically capable and physically stable platforms. For many purposes, it will be best if that occupation can be fully continuous and far removed from the influence of islands. These purposes require that the platforms be large enough to carry the full field complement of scientists and that they be seaworthy in essentially all winds and sea states. The advantage of continuous occupation is continuous data, round the clock and round the year. Large platforms will allow operations to continue at moderately high winds (40 to 50 knots, or 20 to 25 m/s) and sea states. Thus the importance of energetic events in setting the oceanographic mean condition can be evaluated. There are several possible platform configurations:

Semipermanent Platform

The study site could be occupied by a semipermanent, floating station that would be continuously occupied for the full term of study at one site. The station would be serviced, and scientists and crew changed, by an oceangoing supply/survey ship. Platform designs would expand on the general idea of FLIP (Floating Instrument Platform). Large, deeply submerged floating pylons (spar buoys) would support a multiple deck housing and operations structure (literally a platform) well above the sea surface. Some deepwater drilling rigs are towed to sea in very nearly the configuration envisioned. It is possible that modifications to an existing structure could make a very satisfactory deep ocean station.

Various data (thermistor chain profiles, net tows, small- to mesoscale variability) would require sampling underway, and the platform would require a boat, capable of towing a variety of gear, that could be lowered from the platform. This would need to be of substantial proportions, perhaps 18 meters, with a modest laboratory, several winches, and a sizeable (4 × 10 m) operations deck. It would be of the order of 30 tons, and the platform design must anticipate lifting and balancing a load of that magnitude.

A major issue in design of a permanent oceanic station would be propulsion and mooring. If the station were required to maintain closely its geographic site, it would need propulsion equipment to move the whole structure at a speed of about a knot. Because of the high drag of the deep flotation, this could require substantial engines and substantial (if variable) fuel transport, storage, and consumption. It might also be possible to select oceanic sites such that the platform could mostly operate as an enormous Lagrangian float.

Ship-Occupied Station

The site could be occupied in the mode adopted for permanent occupation of oceanic weather and rescue stations shortly after World War II. This was most fully realized at Station P in the sub-Arctic Pacific from the mid-1950s until 1981 by alternation on station of two 120-m ships. Each ship spent 49 days at sea, then 43 days in port. Crews were given most of the time in port for rest, although some crew days before and after each patrol were used in shutdown and refit operations. Most refitting and supplying, however, were done by a permanent shore crew. Ships required for the program that we envision would need to be large enough to hold a full suite of laboratories and sleeping quarters for perhaps 40 scientists. Because they would be at sea for periods of about 2 months, they would also need to be large enough to withstand heavy seas and to provide substantial living amenities (similar to those now available on the research vessel *SEDCO-470*). Like the platform option, ships large enough to meet the overall requirements may not be maneuverable enough to gather some kinds of data in an underway mode. A sizeable launch, as described above, would be necessary, together with launching and recovery facilities.

An advantage of ships over spar-buoy platforms is that they are self-powered. They can maintain station with little variation or move about in a subregional sampling grid, if that is wanted. A disadvantage is that both ships would require fully equipped laboratories and deck handling equipment.

In either mode, permanent occupation of a deep-water site would require a marine superintendent in charge of a modest shoreside support facility. This would include the following:

- Docks, shops, a provisioning office, and storehouse;
- Scientific supplies and an equipment acquisition, inventory, and transfer system;
- A sample curation and distribution facility.

The logistical support for such operations could be handled by one or several of the participating oceanographic institutions, using (at least in part) facilities already in existence. Since study sites would change each few years, it probably would be best if the location of the shoreside support facility could also move. A combination of logistics and scientific considerations should determine the order in which sites are studied. Site selection and sequence must be addressed early in the development of the program.

Island Station

Island stations located away from strong advective regimes and away from coastal areas are a low-cost alternative to dedicated ships or platforms for time series measurements of numerous biological processes. Island stations offer the following advantages over an autonomous ocean platform:

- easy logistics
- relatively low cost
- chance to show the value of time series with very little "spin-up" time.

Scientists, technicians, and electronics personnel could spend only the amount of time necessary for their respective projects. Island stations permit personnel to visit according to the sampling frequency demanded by their individual scientific projects. Sophisticated island-based laboratories offer advantages, especially if they complement a nearby floating laboratory (i.e., on the scale of a weather ship). Some of the longest existing time series are monitored from oceanic islands, e.g., Bermuda. Island stations may permit easier deployment and recovery of automated sampling packages deployed from moorings and free-drifting buoys. Automated sampling packages can be serviced, cleaned, and collected on a routing basis in order to maintain high-quality data collection.

The most serious difficulty with island stations is that "island effects" seriously compromise the generality of the serial data sets. Significant breaks would occur when stormy weather prevented investigators from occupying the sampling site. Site requirements include hydrographic, chemical, and biological aspects of the surface waters and perhaps the benthos.

In summary, the advantage of removal from island effects is that the time series data then would represent most accurately conditions over a large oceanic area, which is in fact free of island influence. The disadvantages are added expense and added logistical complexity. However, the platform(s) needed is (are) not larger than typical merchant ships, and the expense of several of those should not be beyond the reach of the U.S. (or international) scientific establishment. Costs will be far below those now incurred by the ocean drilling program.

Components of the Core Time Series Data Set

High-Frequency Suites
(daily or continuous in some cases)

Physics (atmosphere)
- Outgoing long-wave radiation
- Wind speed and direction
- Relative humidity
- Barometric pressure
- Surface air temperature
- Light 0.3 to 3 µm

Physics (ocean)
- Wave conditions
- Sea surface temperature
- Conductivity, temperature, depth (0–1000 m)
- Currents (0–200 m; acoustic profiling of ocean currents, or APOC)
- Currents (greater than 200 m; moorings)
- Submarine light to less than 0.1% of surface illumination

Chemistry
- Dissolved nutrients (NO$_3$, NO$_2$, NH$_4$, Urea, SiO$_4$, PO$_4$; 0–500 m)
- Total CO$_2$, alkalinity, pCO$_2$
- O$_2$

Biology
- Microbial carbon (in euphotic zone)
- Phytoplankton carbon (in euphotic zone)
- Chlorophyll profile (plus phaeopigments)
- Microzooplankton carbon (euphotic zone plus integrated 0–1000 m)
- Macrozooplankton carbon (euphotic zone plus integrated 0–1000 m)
- Micronekton by acoustics
- Size frequency distributions of living matter (euphotic zone)
- Primary production (to 0.1% light)

Lower-Frequency Suites
(weekly or so)

Physics (ocean)
- Lagrangian currents (drifters)
- Deep conductivity-temperature-depth (CTD) casts (0–2000 m)
- Deep currents (moorings)

Chemistry
- Argon, ^{3}He
- particulate organic carbon (POC), nitrogen (PON), phosphorous (POP), and silicon (PSI), (0–2000 m)
- dissolved organic carbon (DOC), nitrogen (DON), and phosphorous (DOP)
- Dissolved nutrients (0–2000 m)
- Deep total CO$_2$, alkalinity, pCO$_2$
- Sinking particles (traps—upper 2000 m)

Biology
- Depth stratified sampling for all size categories (day/night to 1000 m)
- Replicate water column primary production (three to four per depth per day biweekly)

Conclusion

Few statistical descriptions exist of the state of oceanic ecosystems. We cannot at this time even infer how climatic and hydrographic changes or episodic perturbations affect the state of these systems, how fragile or how resilient they may be, or the degree to which physical forcing overrides or modulates intrinsic biological regulation. Such knowledge will be essential for a new understanding of this, the world's largest habitat. A research and sampling program designed to remedy these deficiencies is proposed here. Resources for establishing long-term station occupations far from continental influence are of reasonable scale. We suggest that the international oceanographic community establish a program for generating and interpreting long time series of oceanographic data from a selection of open ocean sites.

Acknowledgments

Many of the ideas expressed in this article were articulated at a workshop sponsored by National Science Foundation/Ocean Drilling Program (ODP), which was convened to address the problems associated with obtaining serial data from remote ocean locations in conjunction with ODP's R/V *JOIDES Resolution*. The workshop was held at the Woods Hole Oceanographic Institution, Woods Hole, Mass., November 4–6, 1985.

The purposes of the workshop were to develop the scientific rationale for long-time series measurements of open ocean systems from physical, chemical, biological/paleontological viewpoints; consider how the R/V *JOIDES Resolution* might be used to carry out the objectives formulated at this meeting; consider alternate means of obtaining long-time series observations form the open ocean.

There was a consensus that scheduling and operation considerations made time series research of more than several weeks an incompatible piggyback activity on the *JOIDES Resolution*, either in the present phase of ocean drilling (1985–1990) or in the future (1990–1995). A number of alternative strategies were discussed that are the subject of this article.

References

Anderson, G. C., R. K. Lam, B. C. Booth, and J. M. Glass, A description and numerical analysis of the factors affecting the processes of production in the Gulf of Alaska, *Spec. Rep. 76 (Ref. No. M-77-40)*, 231 pp., Dept. of Oceanogr., Univ. of Washington, Seattle, 1977.

Beddington, J. R., The response of multispecies systems to perturbations, in *Exploitation of Marine Communities*, edited by R. M. May, pp. 209–225, Springer-Verlag, New York, 1984.

Chelton, D. B., P. A. Bernal, and J. A. McGowan, Large-scale interannual physical and biological interaction in the California Current, *J. Mar. Res.*, *40*, 1095, 1982.

Colebrook, J. M., Continuous plankton records: Zooplankton and environment, North-East Atlantic and North Sea, 1948–1975, *Oceanol. Acta, 1*, 9, 1978.

Colebrook, J. M., Continuous plankton records: Overwintering and annual fluctuations in the abundance of zooplankton, *Mar. Biol.*, *84*, 261, 1985.

Colebrook, J. M., and A. H. Taylor, Significant time scales of long-term variability in the plankton and the environment, *Rapp. P. V. Reun. Comm. Int. Explor. Mer, 183*, 20, 1984.

Colebrook, J. M., G. A. Robinson, H. G. Hunt, J. Roskell, A. W. G. John, H. H. Bottrell, J. A. Lindley, N. R. Collins, and N. C. Halliday, Continuous plankton records: A possible reversal in the downward trend in the abundance of plankton of the North Sea and the Northeast Atlantic, *J. Cons. Cons. Int. Explor. Mer, 41*, 304, 1984.

Connell, J. H., and W. P. Sousa, On the evidence needed to judge ecological stability or persistence, *Am. Naturalist, 121*, 789, 1983.

Emery, W. J., T. C. Royer, and R. W. Reynolds, The anomalous tracks of North Pacific drifting buoys 1981 to 1983, *Deep Sea Res.*, *32*, 315, 1985.

Fulton, J., Seasonal and annual variations of net zooplankton at Ocean Station "P", 1956–1980, *Can. Data Rep. Fisheries Aquatic Sci. 374*, 65 pp., 1983.

Henrich, A. K., The breeding and development of the dominant copepods in the Bering Sea, *Tr. Vses. Gidrobiol. Ova.*, *8*, 143, 1957.

Holling, C. S., Resilience and stability of ecological systems, *Ann. Rev. Ecol. Systematics, 4*, 1, 1973.

Joyce, T. M., et al., Rapid evolution of a Gulf Stream warm-core ring, *Nature, 308*, 837, 1984.

Ortner, P. B., R. L. Ferguson, S. R. Piotrowica, L. Chesal, G. Berberian, and A. V. Palumbo, Biological consequences of hydrographic and atmospheric advection within the Gulf Loop Intrusion, *Deep Sea Res.*, *31*, 1101, 1984.

Pimm, S. L., Food web design and the effects of species deletion, *Oikos, 35*, 139, 1980.

Pimm, S. L., The complexity and stability of ecosystems, *Nature, 307*, 321, 1984.

Quinn, W. H., V. T. Neal, and S. E. Antunez de Mayolo, Preliminary report on El Niño occurrences over the past four and a half centuries, *Rep. 86-16*, 36 pp., Coll. of Oceanogr., Oregon State Univ., Corvallis, 1986.

Radach, G., Variations in the plankton in relation to climate, *Rapp. P. V. Reun. Comm. Int. Explor. Mer, 185*, 234, 1984.

Soutar, A., and J. D. Isaacs, Abundance of pelagic fish during the 19th and 20th centuries as recorded in anaerobic sediment off the Californias, *Fish. Bull.*, *72*, 257, 1974.

Steele, J. H., A comparison of terrestrial and marine ecological systems, *Nature, 313*, 355, 1985.

Steele, J. H., and E. W. Henderson, Modelling longterm fluctuations in fish stocks, *Science, 224*, 985, 1984.

Wyrtki, K., Water displacements in the Pacific and the genesis of El Niño cycles, *J. Geophys., Res.*, *90*, 7129, 1985.

Peter H. Wiebe *is with the Woods Hole Oceanographic Institution, Woods Hole, Mass.* Charles B. Miller *is with the College of Oceanography, Oregon State University, Corvallis.* John A. McGowan *and* Robert A. Knox *are with the Scripps Institution of Oceanography, La Jolla, Calif.*

APPENDIX B

Research Conducted from FLIP

F. H. Fisher
Marine Physical Laboratory

CURRENT STUDIES

1. Fluctuations due to inhomogeneities, gradients
2. Storm generated waves
3. Internal waves
4. Ambient noise
5. Propagation, attenuation, 50 Hz to 100 kHz
6. Crustal anisotropy
7. Radar backscattering from surface waves
8. Acoustic backscattering from surface waves and bubbles
9. Biological scattering and target strengths and taxonomy
10. Physical oceanography of upper 1000 m by Doppler sonar
11. Meteorological, oceanographic studies, BOMEX in Atlantic
12. Current shear and turbulence studies
13. Mills Cross ambient noise arrays, high resolution, high gain
14. High resolution bottom profiling, acoustic layering
15. Scatterer distributions with near-field array

FUTURE STUDIES

1. Physical oceanography immediately before and following storms
2. Long term biological studies with FLIP moored, rotating teams
3. Acoustic studies in Kuroshio region, eddies, fronts, storms
4. Multiple arrays for ambient noise and propagation studies
5. Tomographic related studies
6. Rainfall calibration at sea for satellite sensors
7. Acoustic ambient noise measurements in South Pacific, storm noise

TABLE B.I

Types of Research Utilizing FLIP

Project	Principal Investigator
A. OCEAN ACOUSTICS/UNDERWATER SOUND	
Phase and amplitude fluctuations, inhomogeneities	F. H. Fisher
Crustal anisotropy	G. G. Shor
Ambient noise	V. C. Anderson F. N. Spiess G. B. Morris R. C. Tyce F. H. Fisher W. S. Hodgkiss J. A. Hildebrand
Sea surface noise	V. C. Anderson
Sound propagation	F. N. Spiess G. B. Morris R. C. Tyce F. H. Fisher D. A. Ramsdale N. Booth W. S. Hodgkiss J. A. Hildebrand
Bottom-bounce propagation	F. H. Fisher
Coherent recombination of multipaths	W. S. Hodgkiss R. Brienzo
Attenuation in sediments	R. Brienzo
Biological acoustic scattering and taxonomy	P. Greenblatt
Sound absorption as function of pressure	H. Bezdek
Acoustic backscatter from surface waves	S. McConnell H. Medwin
Point vs planar scattering from density layers	V. C. Anderson G. T. Kaye
Doppler current meter (10 MHz)	P. Rudnick
High frequency (90 kHz) echo sounder	F. Fisher
Design & development of high resolution Doppler Sonar for FLIP	R. Pinkel

B. PHYSICAL OCEANOGRAPHY

Internal waves by thermistor yo-yos	R. Pinkel K Zalkan
Internal waves by doppler sonar	R. Pinkel
Langmuir circulation by doppler sonar	R. Pinkel J. Smith
Sea surface slope distribution	R. Pinkel
Storm generated waves	W. H. Munk
Wave direction using FLIP	P. Rudnick
Mixed Layer Dynamics/Air Sea Fluxes (MILDEX)	R. A. Weller
Langmuir cell, Ekman Circulations (MILDEX)	R. A. Weller
VMCM Measurements	R. A. Weller R. Pinkel
Ocean optics (ODEX)	J. J. Simpson
Ocean waves (OWAX)	C. Friede C. Paulson J. J. Simpson
Ocean natural resources	R. Yoder
Radar backscatter from waves	?
Surface wave directional spectra (BOMEX)	R. Davis L. Regier
Wind profiling between wave peaks BOMEX	?
Air turbulence, MET surface waves (POLE)	R. Davis L. Regier C. Friehe C. Paulson J. Simpson
Turbulence and microstructure	R. B. Williams

APPENDIX C

PARTICIPANTS: RESEARCH PLATFORM WORKSHOP 1987

ATTENDEE/AFFILIATION/PHONE/WORKING GROUP

Steve Beck, MPL/SIO, (619) 534-2384, WG IV
Charles Bishop, MPL/SIO, (619) 534-1795 / WG IV
Earl Bronson, MPL/SIO (Ret.), (617) 782-3611 / WGII
Stuart Burley, PMRF, (808) 335-4231 / WG IV
Harold Chalmers, NOSC (Hawaii), (808) 254-4454 / WG IV
Jim Dawson, PMRF Detachment, San Diego, (619) 522-4210 /
CMDR Patrick J. Dennis, CNO OP-006 OCEANAV, (202) 653-0105 / WG II
Tom Dickey, USC, (213) 743-8367 / WG I
Ira Dyer, MIT, (617) 253-6824 / WG IV
Dewitt Efird, MPL/SIO, (619) 534-1650 / WG IV
Fred Fisher, MPL/SIO, (619) 5341796 / WG III
Ed Franchi, NRL, ((202) 767-3288 / WG III
Roy Gaul, Blue Sea Corp., (713) 893-6566 / WG IV
Larry Glosten, Glosten Associates, (206) 624-7850 / WG IV
John Hanrahan, NUSC, (203) 447-3261 /
John Harlett, APL/UW, (202) 543-1366 / WG IV
William Hodgkiss, MPL/SIO, (619) 534-1798 / WG III
Terry Hoopes, MPL/SIO, (619) 460-1390 / WG IV
Keith Kaulum, OCNR-112, (202) 696-4531 / WG I
Duane Laible, Glosten Associates, (206) 624-7850 / WG I
Ivor Lemaire, NOSC, (619) 225-7111 /
Marvin Moss, ONR-10, (202) 696-4511 /
Robert Pinkel, MPL/SIO, (619) 523-2056 / WG II
Ken Richter, NOSC, (619) 225-6561 /
Omar Shemdin, JPL/Cal. Tech., (818) 354-6980 / WG II
Eric Slater, MPL/SIO, (619) 5346814 / WG III
Fred Spiess, MPL/SIO, (619) 534-2866 / WG I
Bob Stewart, IGPP/SIO, (619) 534-2140 / WG II
Bob Tyce, URI, (401) 392-6853 / WG III
M. van Orden, USN (Ret.), (703) 532-5366 /
Al Vine, WHOI, (617) 253-6824 / WG I
Kenneth Watson, MPL/SIO, (619) 534-1803 / WG II
Robert Watts, NOSC, (619) 225-2447 /
Wade Webster, NAVSEA, (202) 692-2964 / WG IV
Bob Weller, WHOI, (617) 548-1400 / WG II
Edie Widder, UCSB, (805) 961-3639

APPENDIX D

Agenda of the Research Platform Workshop

Naval Oceans Systems Center
San Diego, California
June 29-30, 1987

Monday, 29 June 1987

Time	Activity
0800	*Informal Coffee*
0830	**Opening Remarks and Overview** Dr. Kenneth M. Watson, Director, Marine Physical Laboratory
0840	**Purpose** Dr. Fred N. Spiess, Marine Physical Laboratory
0900	**Research Requirements**
	Physical Oceanography R. Pinkel, Marine Physical Laboratory
0925	**Meteorology** R. Weller, Woods Hole Oceanographic Institution
0950	**Air Sea Interaction** O. Shemdin, Jet Propulsion Laboratory, California Institute of Technology
1015	**Acoustics** F. H. Fisher, Marine Physical Laboratory
1040	**Biology** E. Widder, University of California, Santa Barbarba

1105 **Bio-optics**
T. Dickey, University of Southern California

1130 **Submersible Operations**
F. N. Spiess, Marine Physical Laboratory

1200 Discussion-Lunch-Form Working Groups

1300 **Working Group Sessions**

Tuesday, 30 June

0800 *Coffee*

1000 **Working Group Reports**

1130 *Break for Lunch*

1300 **General Session**

1430 **Conclusions and Recommendations**
F. N. Spiess, Marine Physical Laboratory

1700 **Adjournment**

APPENDIX E

Invited Contributions

Meteorological Needs

R. Weller, C. Friehe, C. Dorman

Perspective: FLIP has been the central platform in BOMEX (1968), Norpax POLE (1974), ODEX (1982), and MILDEX (1983). FLIP will, under current plans, be the central platform in a proposed surface wave program (SWAPP) and in an air-sea flux instrumentation development program (1991). These are but a few of the meteorologically oriented programs that have required and will require a FLIP-like platform. (**Figure techniques for work in the atmospheric boundary layer**). A less attractive and less useful alternative is a fixed location platform such as that used in HEXOS (**Figure HEXOS platform**).

The primary goals of meteorological programs likely to use FLIP's replacement would be to: 1) Make measurements of the air-sea fluxes, 2) Investigate the vertical structure of the Marine Atmospheric Boundary Layer (MABL) near the air-sea interface, 3) Investigate the structure of the MABL up to the cloud base, and 4) Study surface wave processes.

Meteorological Needs

1. Platform for measurements of air-sea fluxes

2. Platform for studies of the detailed vertical structure of the Marine Atmospheric Boundary Layer (MABL) near the surface.

3. Platform for studies of the structure of the Marine Atmospheric Boundary Layer (MABL) up to the cloud base.

4. Platform for surface wave studies, including generation of surface waves, surface wave characteristics, and effects of surface waves on fluxes and flow near the air-sea interface.

5. Good payload, duration, range. Adequate lab space, good power, cable runs to outside, and reasonable habitability.

Air-Sea Flux Measurements

Methodology:

1. Bulk formulae estimates based on observations of mean wind velocity, air temperature, sea surface temperature, relative humidity, barometric pressure, shortwave and longwave radiation, and precipitation.

2. Turbulent flux estimates either by direct, eddy correlation (<u'w'>, <w'T'>, for example) or by spectral methods based on fast response sensor measurements and time derivatives of velocity, temperature, and humidity.

3. Profile methods; using, for example, measurements of velocity at more than one height together with a functional form for the wind profile to infer the friction velocity.

4. New methods validated by intercomparison, including WOTAN, infrared absorption hygrometers, precipitation sensors, etc.

Air-Sea Flux Measurements

Requirements on New FLIP:

1. Low aerodynamic drag and weather-vaning shape.

2. Small profile to the wind to minimize flow disturbance.

3. Wind tunnel studies of flow disturbance around New FLIP to ensure proper boom length and placement for measurements to be made in undisturbed air.

4. Extended duration to allow a reasonable number of synoptic events (4 to 5 day time scale) to be sampled; six weeks on station is desired.

5. Stability better than present FLIP to permit eddy correlation measurements and other direct measurements such as that of insolation to be done without correcting for platform motion.

6. Minimum vibration from pumps and generators.

7. Minimum thermal contamination of air, sea from platform, exhausts, cooling water discharge.

8. Vertical as well as horizontal booms.

9. Extended capability to work in more severe environments, both higher winds and sea state and tropical conditions; this is critical to extending the parameter range over which the bulk formulae have been validated.

10. Surface wave sensing capability.

11. Low RF contamination of radiometric, hot film, and other sensitive instruments.

Near-Surface Structure of the MABL

Methodology:

1. Marine equivalent of the Kansas tower experiment. A stable, vertical tower for mounting anemometers and other instruments at various heights in the constant flux layer. Instruments should be able to be mounted both above the lab decks, up to perhaps 50 meters above the surface, and down to the surface.

2. Mounting platform for acoustic (SODAR), laser (LIDAR), and radar remote sensing instruments.

Near-Surface Structure of MABL

Requirements on New FLIP:

1. Vertical tower, reaching to 50 m. Good access to lower 10 m without being subject to flow distortion.

2. Wind tunnel studies.

3. Mounting area, vertical window for acoustic, laser, and radar sounders.

4. Fixed heading keeping ability.

5. Minimum acoustic contamination in air (acoustic sounder).

Structure of the MABL up to the cloud base

Methodology:

1. Remote sensing by laser, radar, acoustic sounders.
2. Tethered balloon or kitoon.
3. Free-balloon launches.

Requirements on New FLIP:

1. Balloon launching area and hanger for tethered balloon (approx. 15 feet long) and/or kitoon. Winch for tethered balloon or kitoon.
2. Helium bottle storage area.
3. Mounting platform for Doppler radar (dome up to 3 m diameter) and other remote sensors or accommodations for van housing these instruments.
4. Ability to work with research aircraft, including aircraft band radio gear.
5. Instrumentation for heading, position, and speed.

Surface Wave Studies

Methodology:

1. Downward looking microwave or ultrasonic probes on three booms or wave staff arrays.

2. Pressure or other probes for measurements just above the waves.

3. Microwave and optical sensing of wave breaking, wave characteristics.

4. Acoustic sensing of breaking, bubbles injected by breaking waves, and wave characteristics.

Requirements on New FLIP:

1. Ability to work under a variety of sea states.

2. Stable, quiet platform. Minimal acoustic contamination under water.

3. Ability to mount instruments close to sea surface.

4. Instrumentation for and access to data for platform motion (pitch, roll, accelerations), heading, position, speed.

The Use of Stable Platforms for Bio-optical Measurements

T. Dickey

University of Southern California, Los Angeles
Los Angeles, California

1. PAST USE OF R/P FLIP FOR BIO-OPTICAL MEASUREMENTS
2. REVIEW OF STATE-OF-ART BIO-OPTICAL SENSORS AND MEASUREMENT SYSTEMS
3. CONSIDERATIONS FOR FUTURE BIO-OPTICAL MEASUREMENTS USING STABLE PLATFORMS.

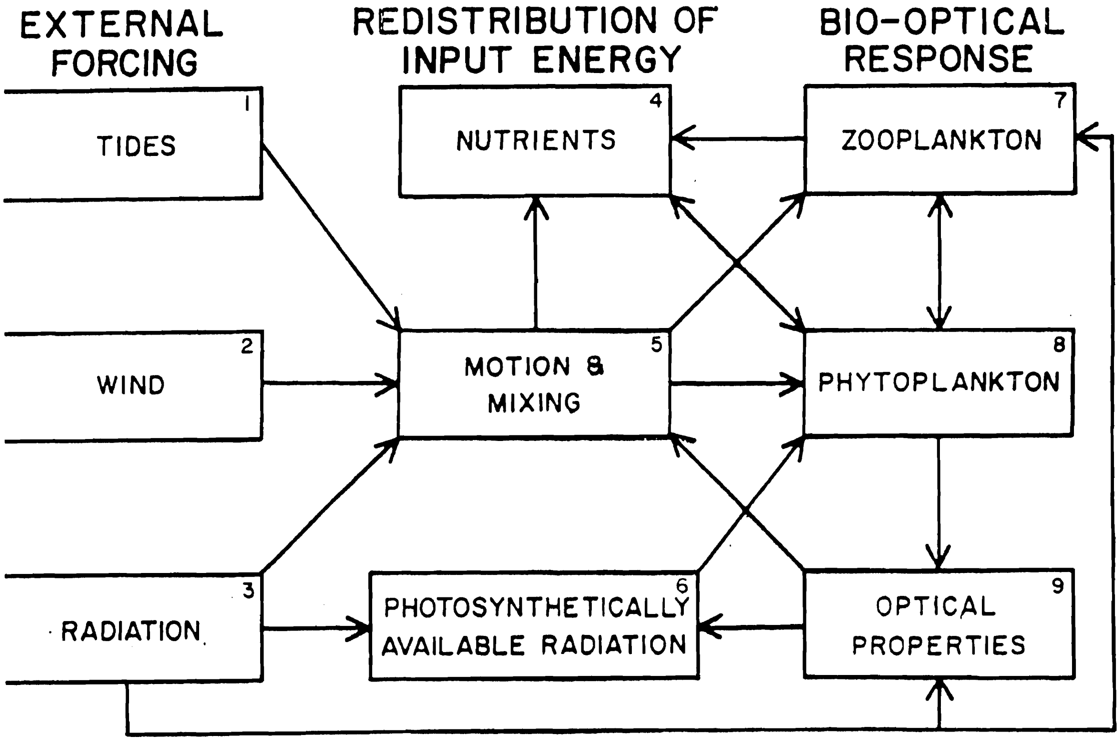


Figure 1

I. DISCUSSION

FIGURE 1. THE CONCEPTUAL MODEL OF THE OCEANIC ECOSYSTEM ILLUSTRATES HOW VARIOUS COMPONENTS INTERACT.

FROM PHYSICAL FORCING THERE IS A REDISTRIBUTION OF INPUT ENERGY WHICH LEADS TO A BIO-OPTICAL RESPONSE.

I WILL DESCRIBE MEASUREMENTS WHICH RELATE TO THE Q COMPONENT BLOCKS OF THE MODEL.

THE CHOICE OF RELEVANT VARIABLES FOR A PARTICULAR PROBLEM DEPENDS ON WHAT ASPECT OF THE ECOLOGICAL SYSTEM IS TO BE STUDIED.

THE BLOCK DIAGRAM GIVES A GUIDE.

IF ONE IS INTERESTED IN MODELING THE ENTIRE SYSTEM, THE DATA ARE REQUIRED FOR EACH OF THE NINE BLOCKS.

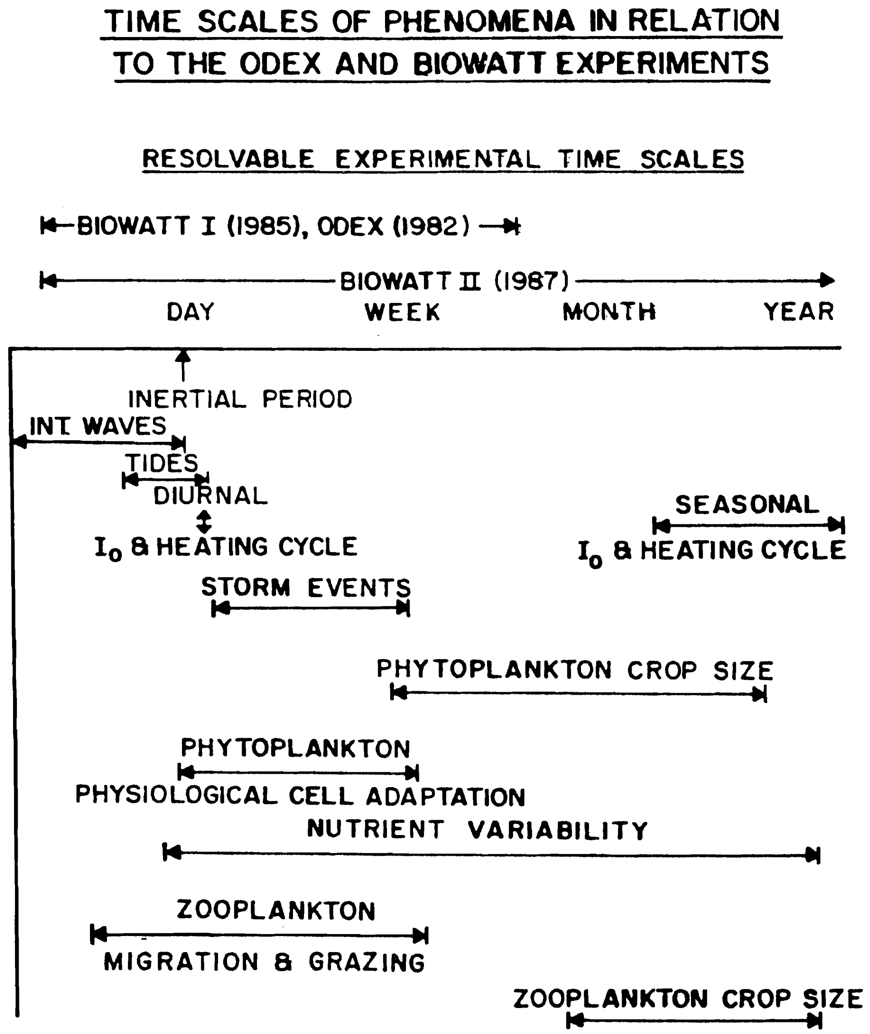

TIME SCALES OF PHENOMENA IN RELATION TO THE ODEX AND BIOWATT EXPERIMENTS
RESOLVABLE EXPERIMENTAL TIME SCALES
BIOWATT I (1985), ODEX (1982)
BIOWATT II (1987)
DAY
WEEK
MONTH
YEAR
INERTIAL PERIOD
INT WAVES
TIDES
DIURNAL
I_0 & HEATING CYCLE
SEASONAL
I_0 & HEATING CYCLE
STORM EVENTS
PHYTOPLANKTON CROP SIZE
PHYTOPLANKTON
PHYSIOLOGICAL CELL ADAPTATION
NUTRIENT VARIABILITY
ZOOPLANKTON
MIGRATION & GRAZING
ZOOPLANKTON CROP SIZE

Figure 2

Table 1. Sensors and Their Applications

Sensor	**Measurement**	**Derived Quant.**	**Block**	**Deployment**
Physical:				
Pressure	P	D	4-9	PMTS
Thermistor	T	ρ, Strat, Ri	5,7,8	PMTSX
Conductivity	C	S, ρ, Strat, Ri	5,7,8	PMTX
Current Meter	U,V	Shear, Ri, Adv.	2,5	PMSX
ACM	U,V	Shear, Ri, Adv.	5	PMS
Chemical:				
Dissolved O_2	Dissolved O_2	Water mass, Prod.	7,8	PM
Autoanal.	Nutrients	Water mass, Prod.	4	PMT
Bio-optical:				
PAR	PAR	$z_{1\%PAR}$, K_{PAR}	6,8	PMT
Spect. Irr.	Up/Dn Irr.(λ)	K(λ), a(λ)	6,8,9	PMT
Spect. Rad.	Up Rad (λ)	Chl-a, b(λ).	8,9	PMT
Beam Tran.	c(660nm)	Particle con.	7,8,9	PMT
Fluorometer	Fluorescence	Chl-a	8	PMT
Zooplankton:				
Part. Count.	Part. Amt., Size	Particle Size Dist.	7,8	PT
Mult. Nets	Zoos by Size	Biomass/ Grazing	7,8	T
Plank. Rec.	Zoos by Size/Type	Biomass/ Grazing	7,8	TS
Acoustics	Zoos by Size/Amt.	Biomass/ Grazing	7,8	PT
Light imag.	Zoos: Type/Amt.	Biomass/ Grazing	7,8	PT
Holography.	Zoos: Type/Amt.	Biomass/ Grazing	7,8	P
Bioluminescence:				
Bathyphot.	Stim. Biolum.	Biolumin. Pot.	7,9	PTS
Photometer	Nat. Biolum.	Nat. Biolumin.	7,9	M
CCD	Nat. Biolum.	Nat. Biolumin.	7,9	M

P = Profile
M = Moored
T = Tow
S = Sub
X = Expend

SOME OF THE IMPORTANT SPACE SCALES ARE SHOWN IN TABLE 1. CLEARLY THE MEASUREMENT SYSTEMS NEED TO RESOLVE THE SPACE SCALES PERTINENT TO THE PROCESSES OF INTEREST.

Table 2

System	Measurement	Derived Quant.	Block	Deploy
FLIP	Mets., C, T, P, c, Fl, Dn Spect. Irr. (12 λ's), Ros. Samples, Horiz. Curr.	S, ρ, Strat., Part Conc, K (λ), K_{PAR}, Shear, Adv., Ri	1,2,3,4,5,6,8,9	P
Biowatt Mooring Program	Mets & Sfc. Rad., C, T, Fl, Horiz. Curr., c, DO_2, Up/Dn Irr. (5 λ's), Up Rad. (6λ's), PAR, Biolum.	S, ρ, Strat., Shear, Ri, Adv., K(λ), K_{PAR}, Part. Conc., Chl-a, Resp., Natural and Stimulated Biolum.	1,2,3,5,6,7,8,9	M
MAPS	C, T, P, Fl, Zoo's Using 21 Acoustic Freq.	S, ρ, Strat, Chl-a, Zoo Size & Amt., Biomass	5,7,8	P,T

TABLE 2 SUMMARIZES SEVERAL SENSORS ALONG WITH THEIR MEASURED QUANTITATIVE, DERIVED QUANTITIES, BLOCKS IN FIGURE 1 AND DEPLOYMENT MODES. MANY OF THE MEASUREMENTS CAN BE DONE CONTINUOUSLY.

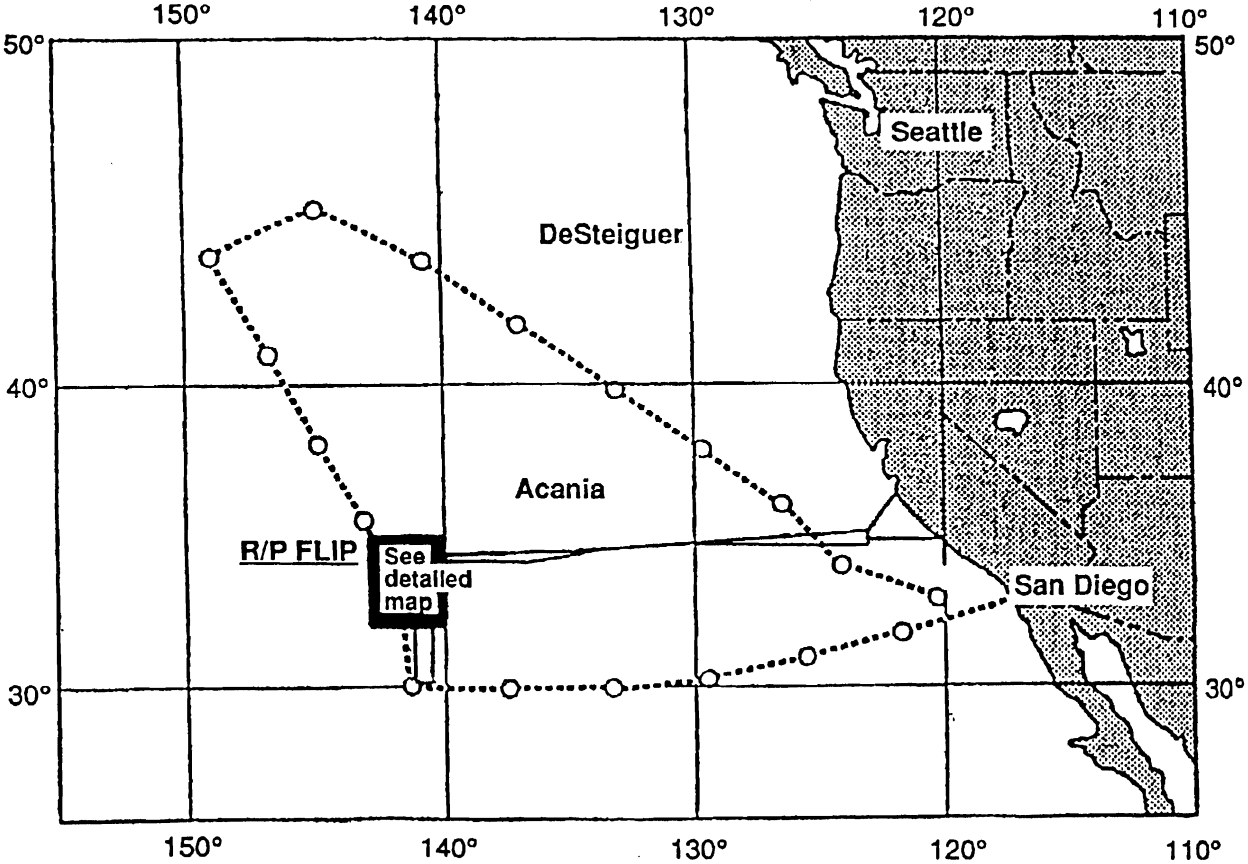

150°
140°
130°
120°
110°
50°
40°
30°
Seattle
DeSteiguer
Acania
R/P FLIP
See detailed map
San Diego

Figure 3

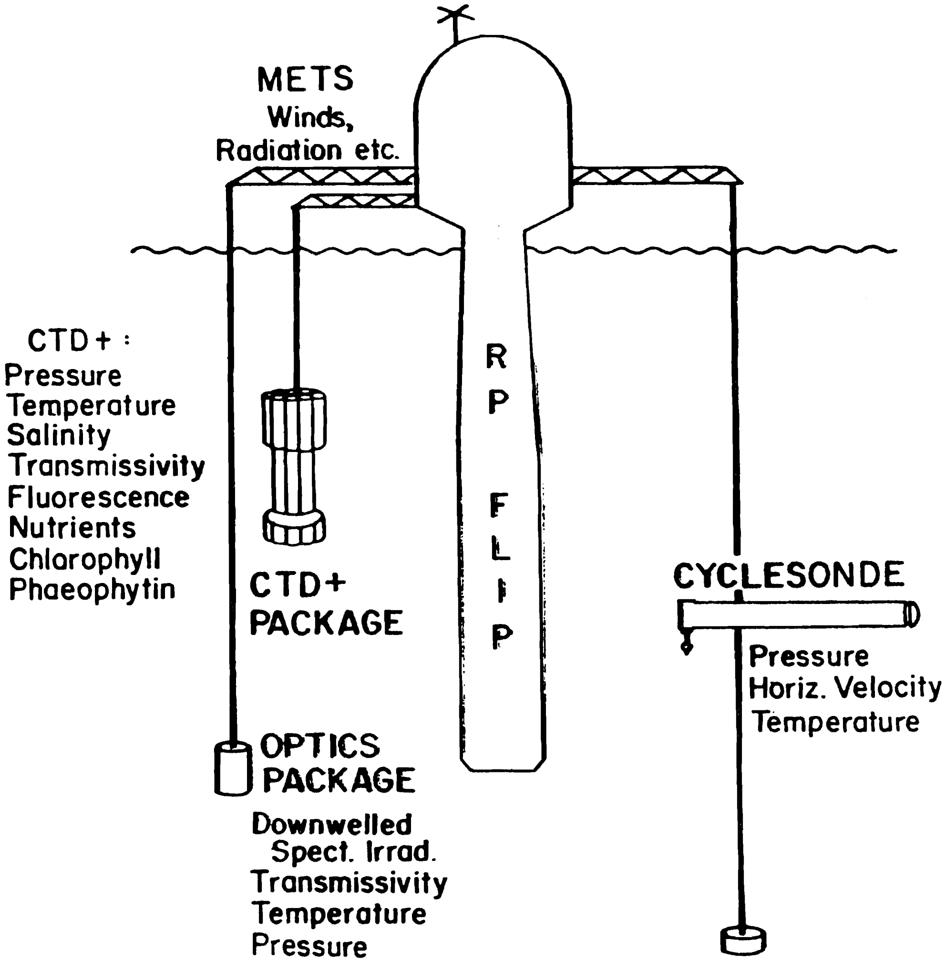
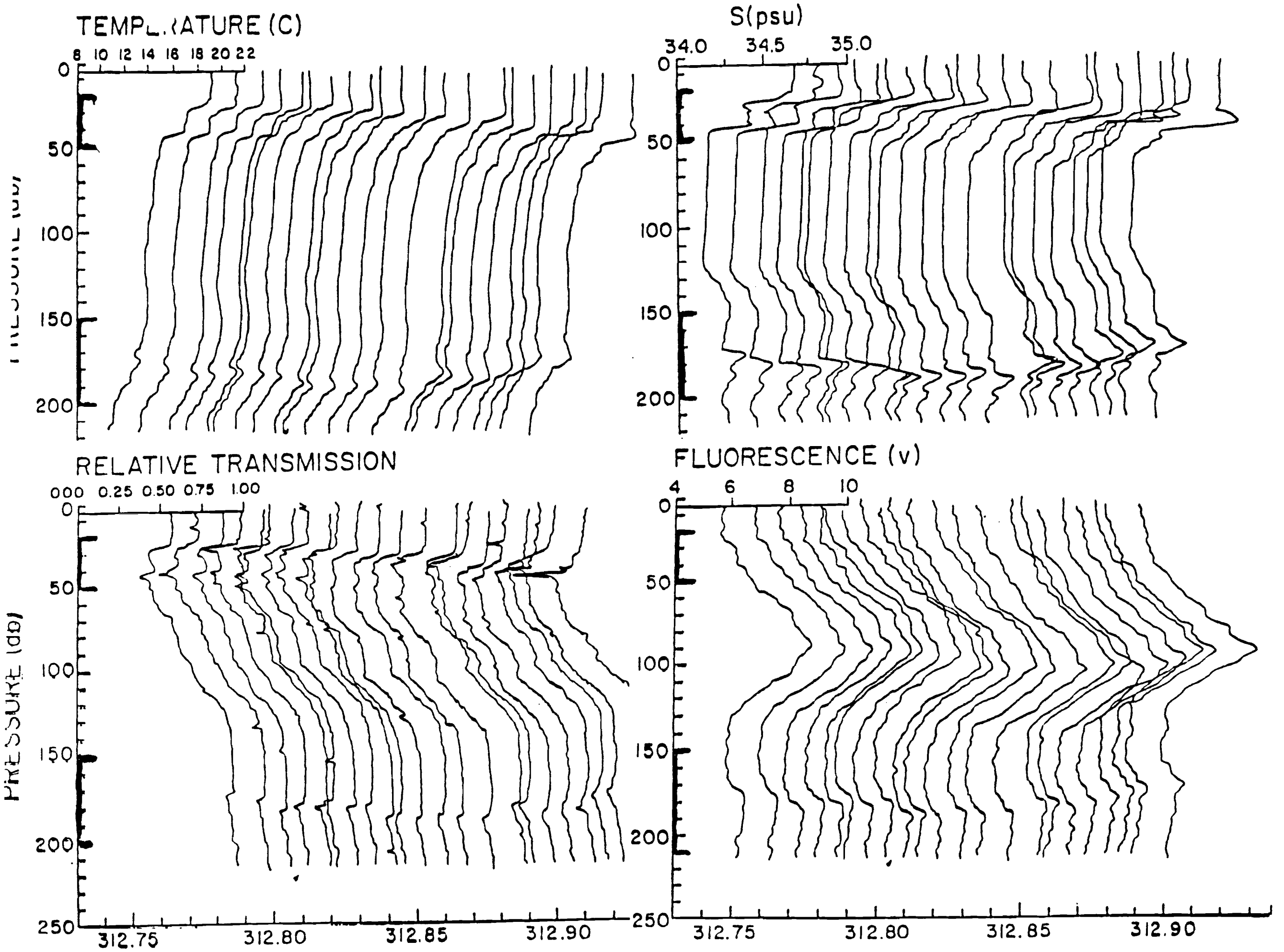

METS
Winds,
Radiation etc.
CTD+ :
Pressure
Temperature
Salinity
Transmissivity
Fluorescence
Nutrients
Chlorophyll
Phaeophytin
CTD+
PACKAGE
R P FLIP
CYCLESONDE
Pressure
Horiz. Velocity
Temperature
OPTICS
PACKAGE
Downwelled
Spect. Irrad.
Transmissivity
Temperature
Pressure

Figure 4



Dickey, Siegel, and Bratkovich (19

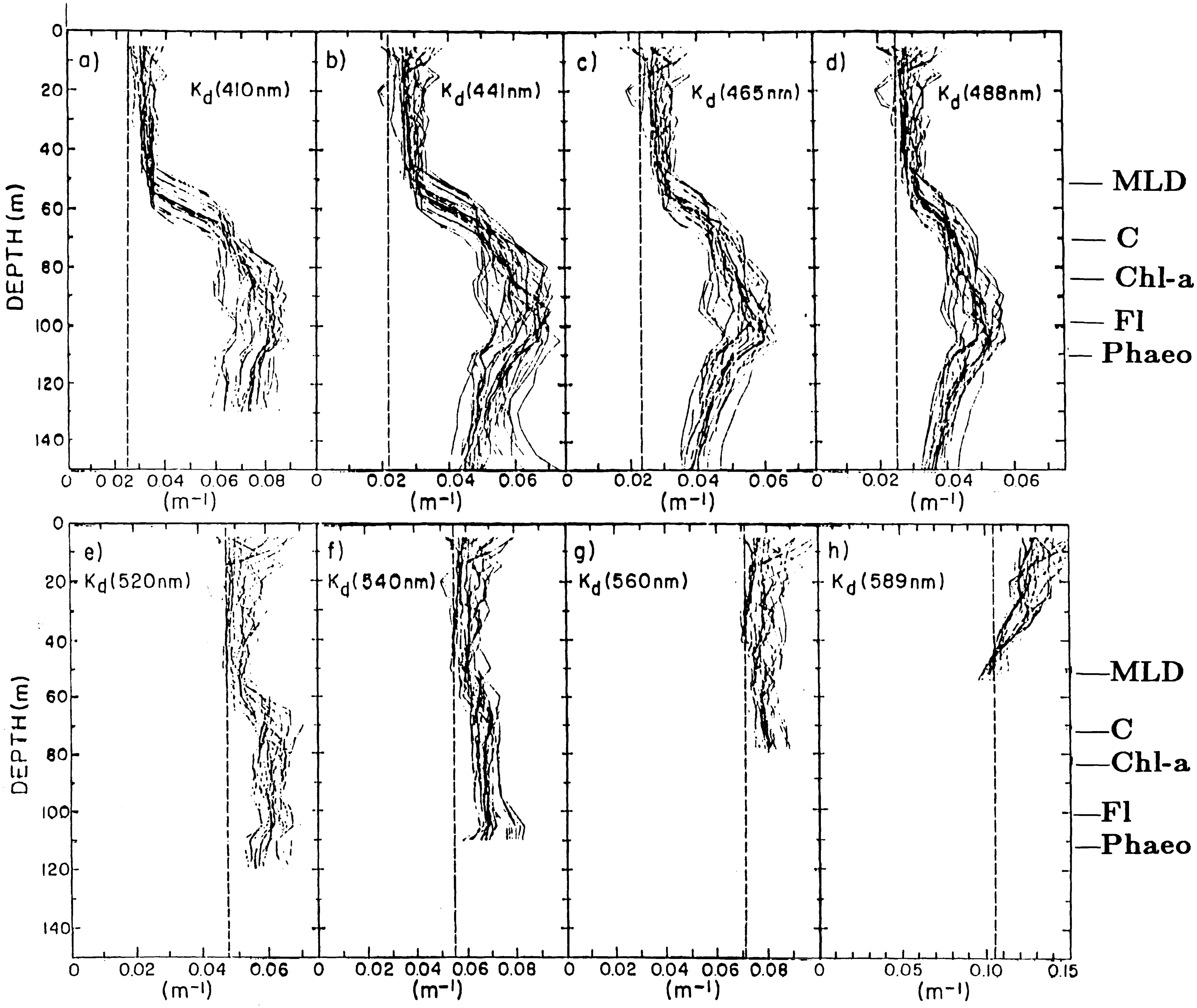
Figure 5

A SPECTRORADIOMETER WAS USED TO DETERMINE THE SPECTRAL DIFFUSE ATTENUATION OF DOWNWELLING IRRADIANCE OR K_d.

32 PROFILES ARE SHOWN FOR EIGHT WAVEBANDS IN FIGURE 6. AT THE RIGHT ARE INDICATED THE MIXED LAYER DEPTH, THE BEAM TRANSMISSION MINIMUM OR PARTICLE MAX., AND THE DEPTHS OF THE CHL-A, FLUOR. AND PHAEOPIGMENT MAXIMA.

THE PROFILES ARE RELATIVELY UNIFORM IN THE MIXED LAYER AND THE BLUEGREEN WAVEBANDS CORRELATE WELL WITH TOTAL PIGMENT CONCENTRATIONS.

THE INTER-PROFILE VARIABILITY IS CAUSED BY SURFACE AND INTERNAL WAVES.



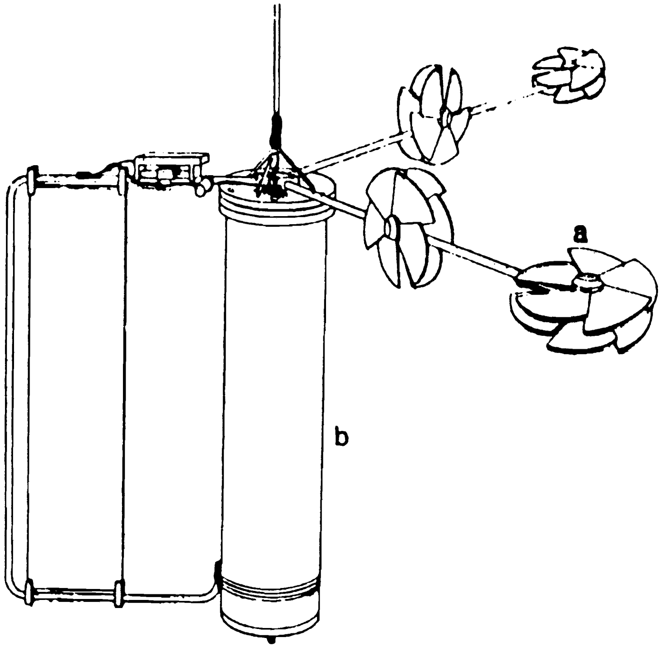
$$K_d(z,\lambda) = \frac{d}{dz}\left[\ln E_d(z,\lambda)\right]$$

Figure 6

THE FLIP WAS USED IN DECEMBER 1982 TO MEASURE THREE-DIMENSIONAL FLOW WITHIN THE MIXED LAYER BY BOB WELLER AND CO-WORKERS AT A SITE SOUTHWEST OF THE SAN CLEMENTE ISLAND.

THE SUITE OF INSTRUMENTS INCLUDED VMCM'S FOR HORIZONTAL VELOCITIES, A REAL-TIME PROFILER FOR VERTICAL VELOCITIES, A CONDUCTIVITY SENSOR, A TEMPERATURE SENSOR, AND JOHN MARRAS'S *IN SITU* FLUOROMETR (FIGURE 7).

THESE TYPES OF MEASUREMENTS HAVE RELEVANCE TO SEVERAL BIOLOGICAL PROBLEMS INVOLVING THE TRANSPORT OF NUTRIENTS, PHYTOPLANKTON, AND ZOOPLANKTON.



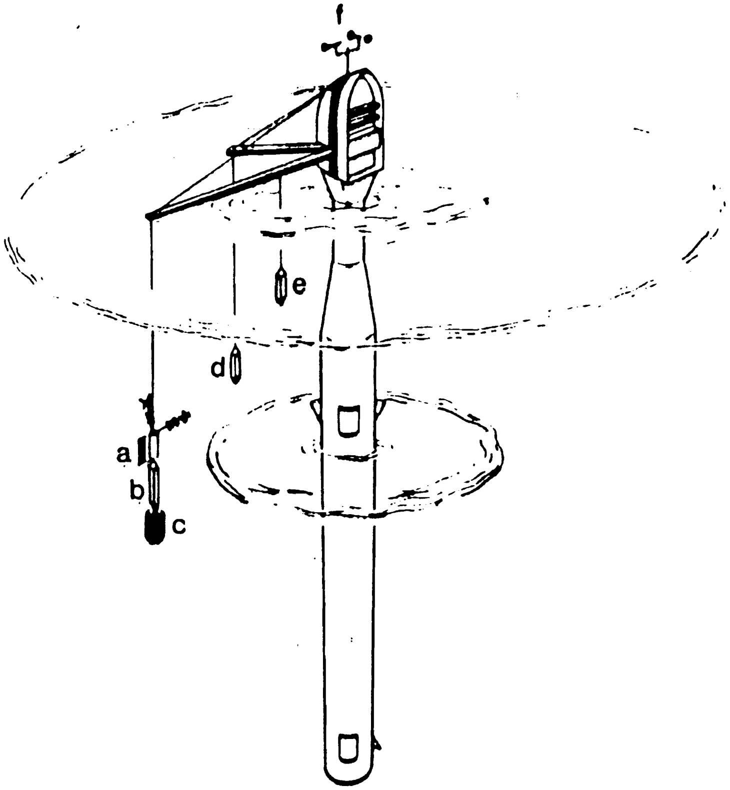


Fig. 1 (left). The real-time profiler was used to measure vertical and horizontal velocities, temperature, conductivity, and pressure. The electronics package also measured the orientation and tilt of the instrument. The propeller sensors (a) were 0.22 m in diameter; the pressure case that housed the electronics (b) was 1.22 m in length and 0.19 m in diameter. Fig. 2 (right). The Research Platform *FLIP* as rigged in December 1982. The instruments were: (a) the real-time profiler, (b) a vector-measuring current meter (VMCM), (c) the SeaMarTec fluorometer and data logger, (d) a profiling VMCM, (e) a VMCM held at a depth of 2 m, and (f) meteorological sensors.

(Weller et al. 1985)

Figure 7

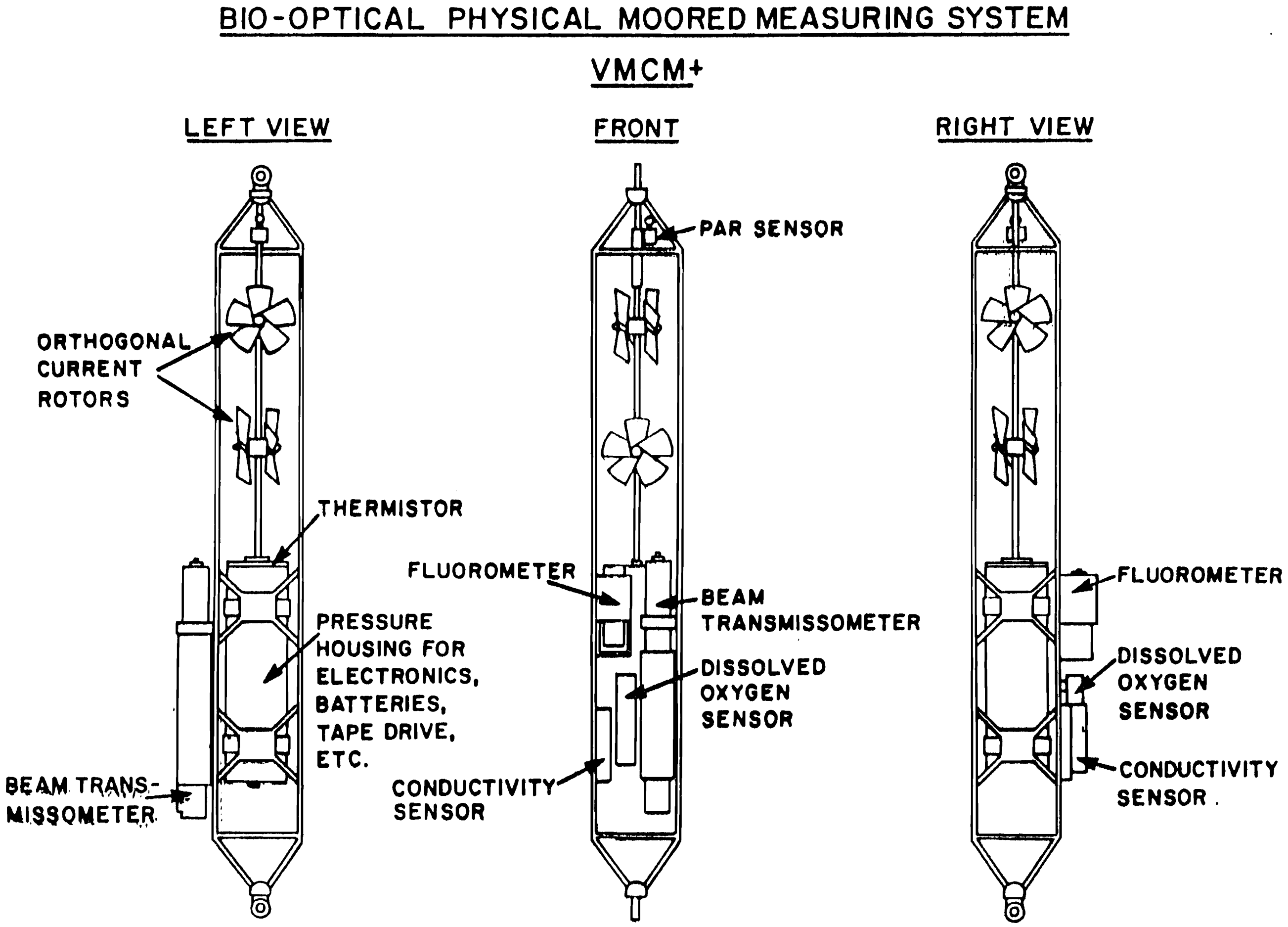
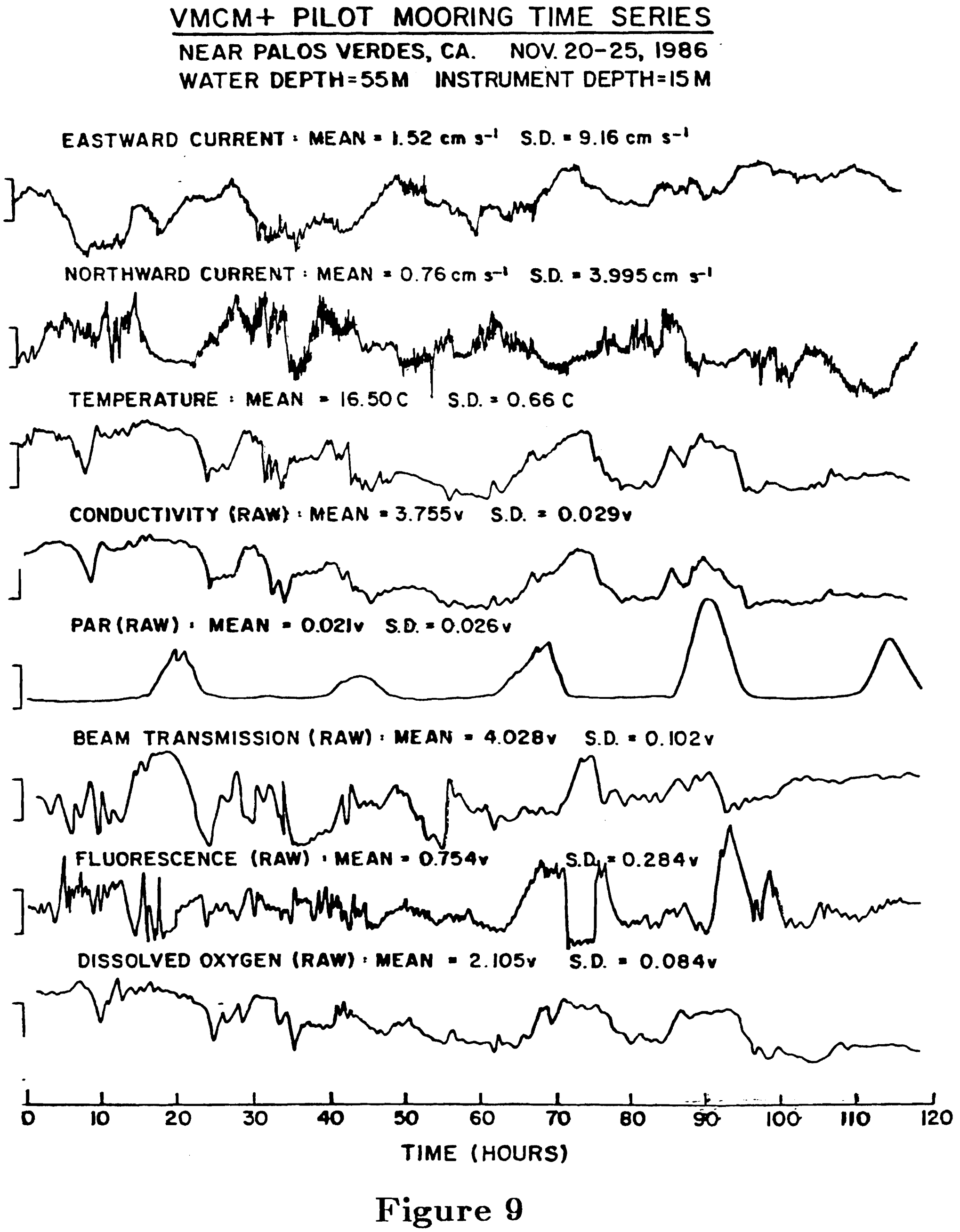


Figure 8

SHOWN IN FIGURE 8 IS THE VMCM'S WHICH WE HAVE DEVELOPED FOR BIOWATT. PARAMETERS WHICH WE MEASURE IN TIME-SERIES MODE INCLUDE: CURRENTS, PAR, TEMPERATURE, CONDUCTIVITY, XINIAS, FLUORIDE, AND DISSOLVED OXYGEN.

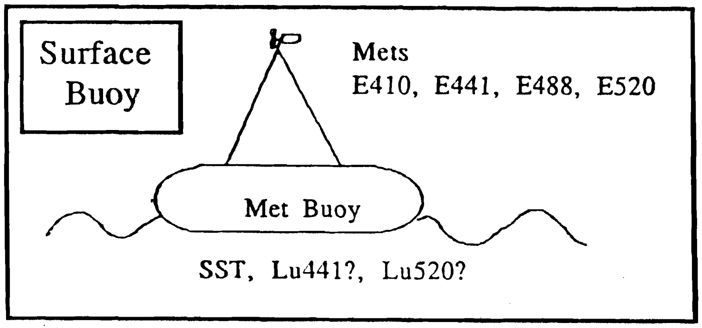


VMCM+ PILOT MOORING TIME SERIES
NEAR PALOS VERDES, CA. NOV. 20-25, 1986
WATER DEPTH=55M INSTRUMENT DEPTH=15M

Figure 9

PRELIMINARY DATA TAKEN DURING TESTS OFF THE COAST OF LOS ANGELES ARE SHOWN IN FIGURE 9. WE HAVE RECENTLY RECOVERED INSTRUMENTS DEPLOYED IN THE SARAGASO SEA AT 8 DEPTHS FROM FEBRUARY TO MAY 1987.

The Biowatt Mooring



Depth	VMCM+ sensors:	v	T	c	PAR	F	X	DO
10	VMCM+	*	*		*	*	*	*
20	VMCM+	*	*	*	*	*	*	*
30	BOMS & BLMS		*					
40	VMCM+	*	*		*	*	*	*
50	BOMS		*					
60	VMCM+	*	*		*	*	*	*
70	VMCM+	*	*	*	*	*	*	*
80	BOMS & BLMS		*					
100	VMCM+	*	*		*	*	*	*
120	VMCM+	*	*		E488	*	*	*
160	VMCM+	*	*	*	E488	*	*	*

Figure 10

MULTI-FREQUENCY ACOUSTIC PROFILING SYSTEM

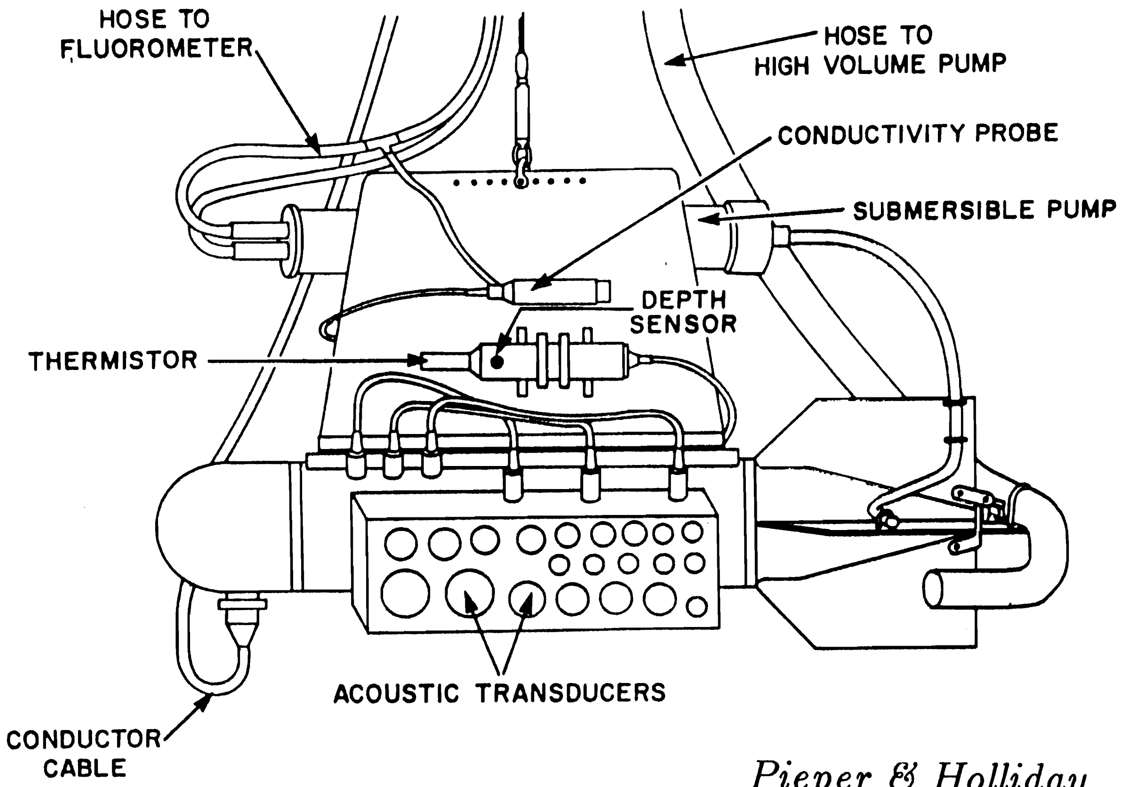


Figure 11

Pieper & Holliday

RICK PIEPER AND VAN HOLLIDAY HAVE DEVELOPED A SYSTEM CALLED THE MULTI-FREQUENCY ACOUSTIC PROFILING SYSTEM OR MAPS (FIGURE 11).

THE SYSTEM IS PRIMARILY DESIGNED TO DETERMINE THE DISTRIBUTIONS OF ZOOPLANKTON BY SIZE CLASSES IN RELATION TO PHYTOPLANKTON AND THE PHYSICAL ENVIRONMENT.

THE SENSORS INCLUDE:

21 ACOUSTIC TRANSDUCERS WITH FREQUENCY RANGING FROM 0.1 to 10 MHZ;
Conductivity
Temperature
Pressure
AND PUMP HOSES FOR SAMPLING PLANKTON

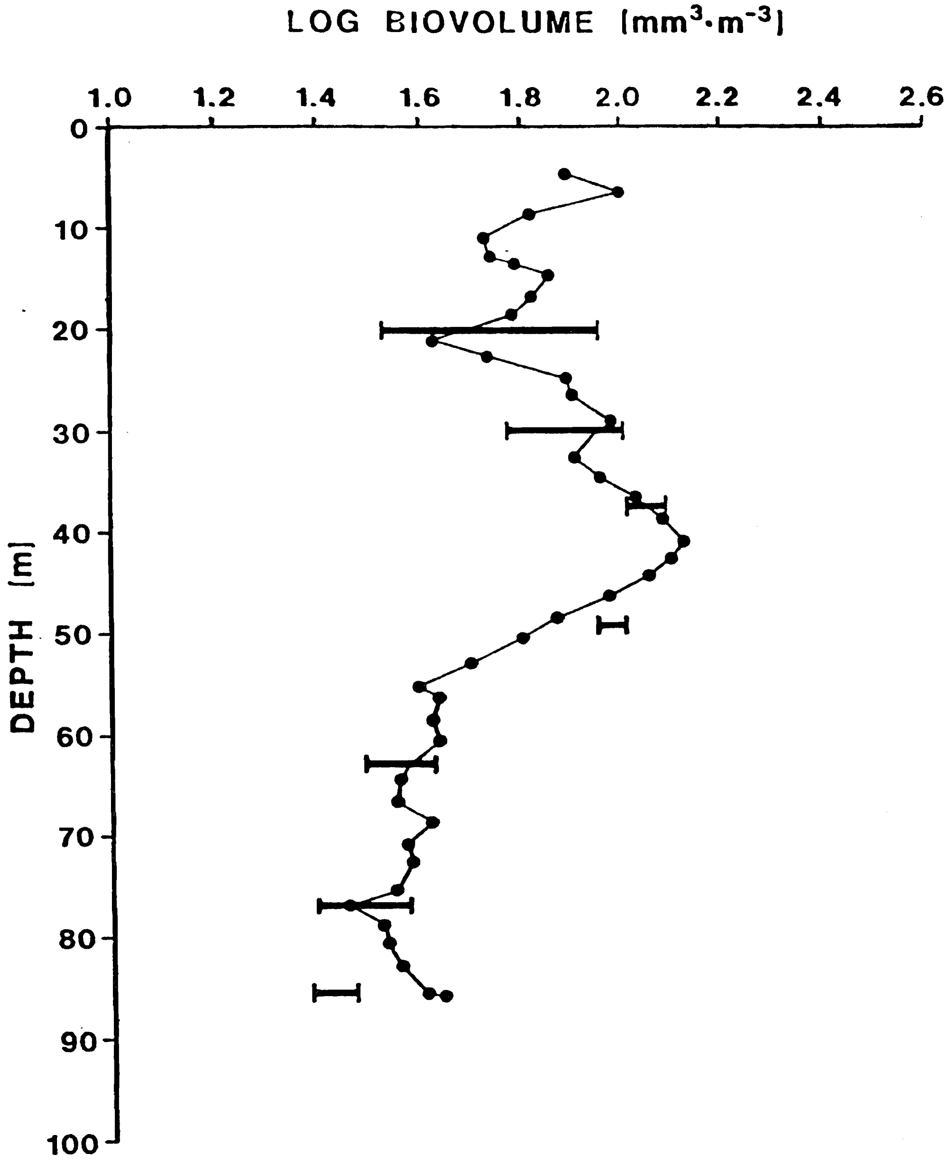

LOG BIOVOLUME [mm^3·m^{-3}]
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
DEPTH [m]
0
10
20
30
40
50
60
70
80
90
100

Figure 12

II. CONSIDERATIONS FOR FUTURE BIO-OPTICAL MEASUREMENTS USING STABLE PLATFORMS

IT WILL BE DESIRABLE TO:

A. BE ABLE TO DO TIME SERIES MEASUREMENTS OF PHYSICAL/CHEMICAL/BIO-OPTICAL/METS. VARIABLES USING MOORED STABLE PLATFORM FOR YEAR OR LONGER.

B. MINIMIZE SHIP EFFECTS UPON OPTICAL MEASUREMENTS (LONG BOOMS/ROTATION OF PLATFORM).

C. FACILITATE OPTICAL MEASUREMENTS (LASER SCATTERING, ACTIVE AND PASSIVE BIOLUMINESCENCE).

D. ENABLE PUMPING OF WATER SAMPLES TO THE PLATFORM FOR BIOLOGICAL AND CHEMICAL ANALYSIS.

Air-Sea Interaction

Omar Shemdin

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

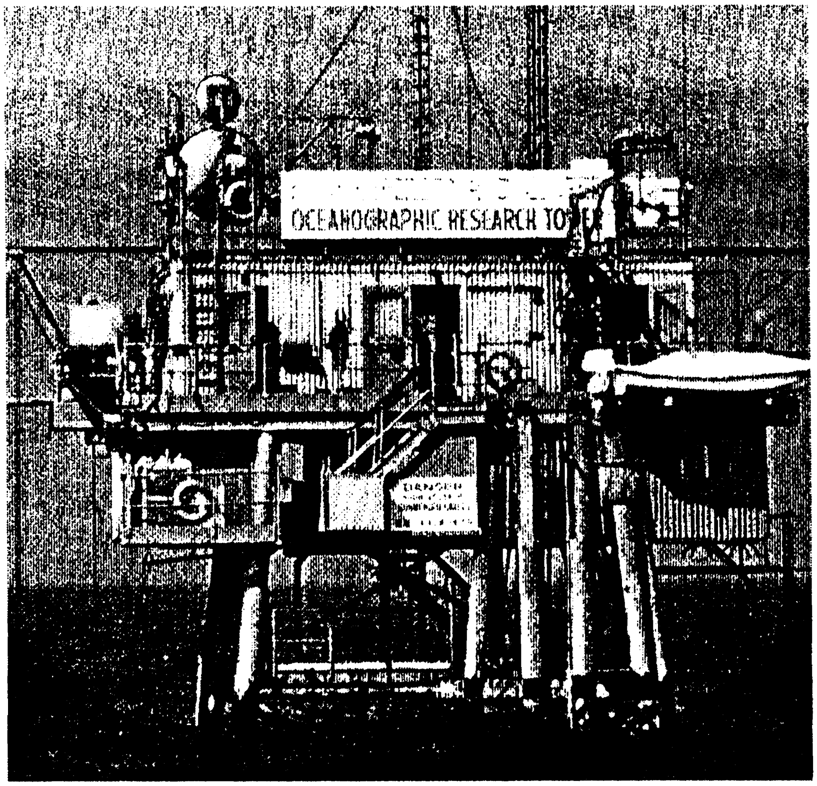


Figure 1

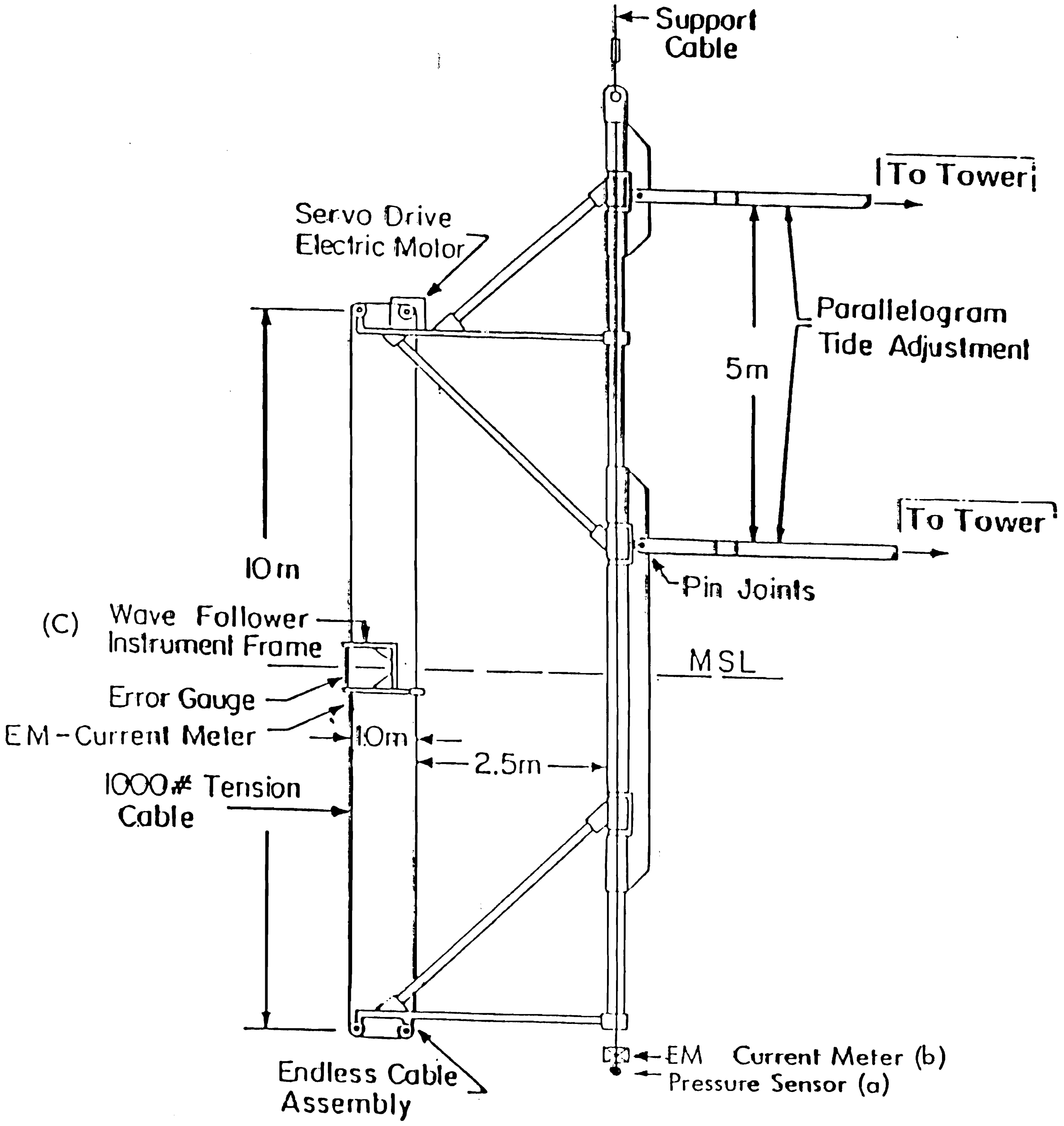

Support Cable
To Tower
Servo Drive Electric Motor
Parallelogram Tide Adjustment
5m
To Tower
10m
Pin Joints
(C) Wave Follower Instrument Frame
MSL
Error Gauge
EM-Current Meter
1.0m
2.5m
1000# Tension Cable
EM Current Meter (b)
Pressure Sensor (a)
Endless Cable Assembly

Figure 2

"C-FRAME" OF WAVE FOLLOWER

FRAME RIDES UP AND DOWN ON LONG WAVES
OPTICAL RECEIVER DEPICTS SLOPES OF WAVELETS
RETICON CAMERA MEASURES HEIGHT OF SLOPE POINT

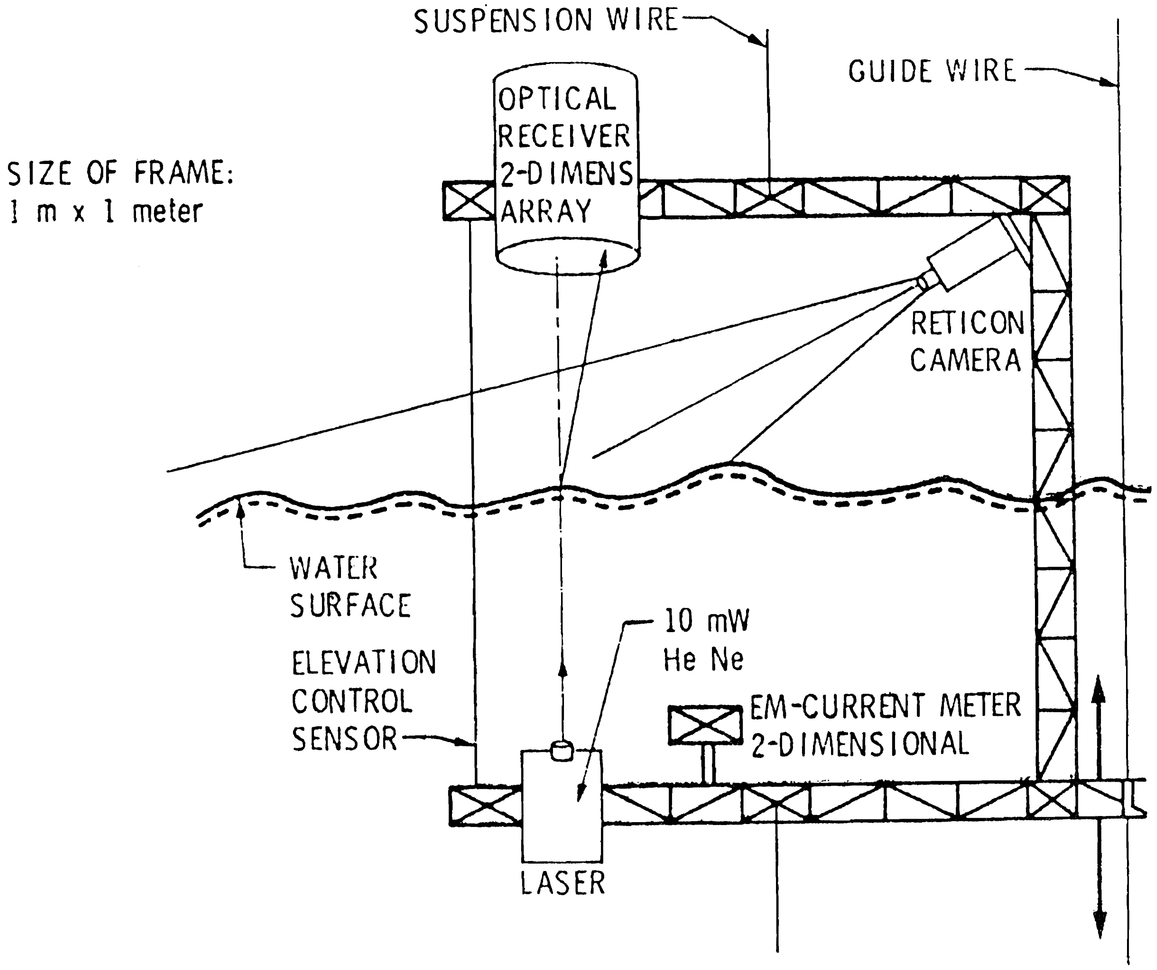


Figure 3

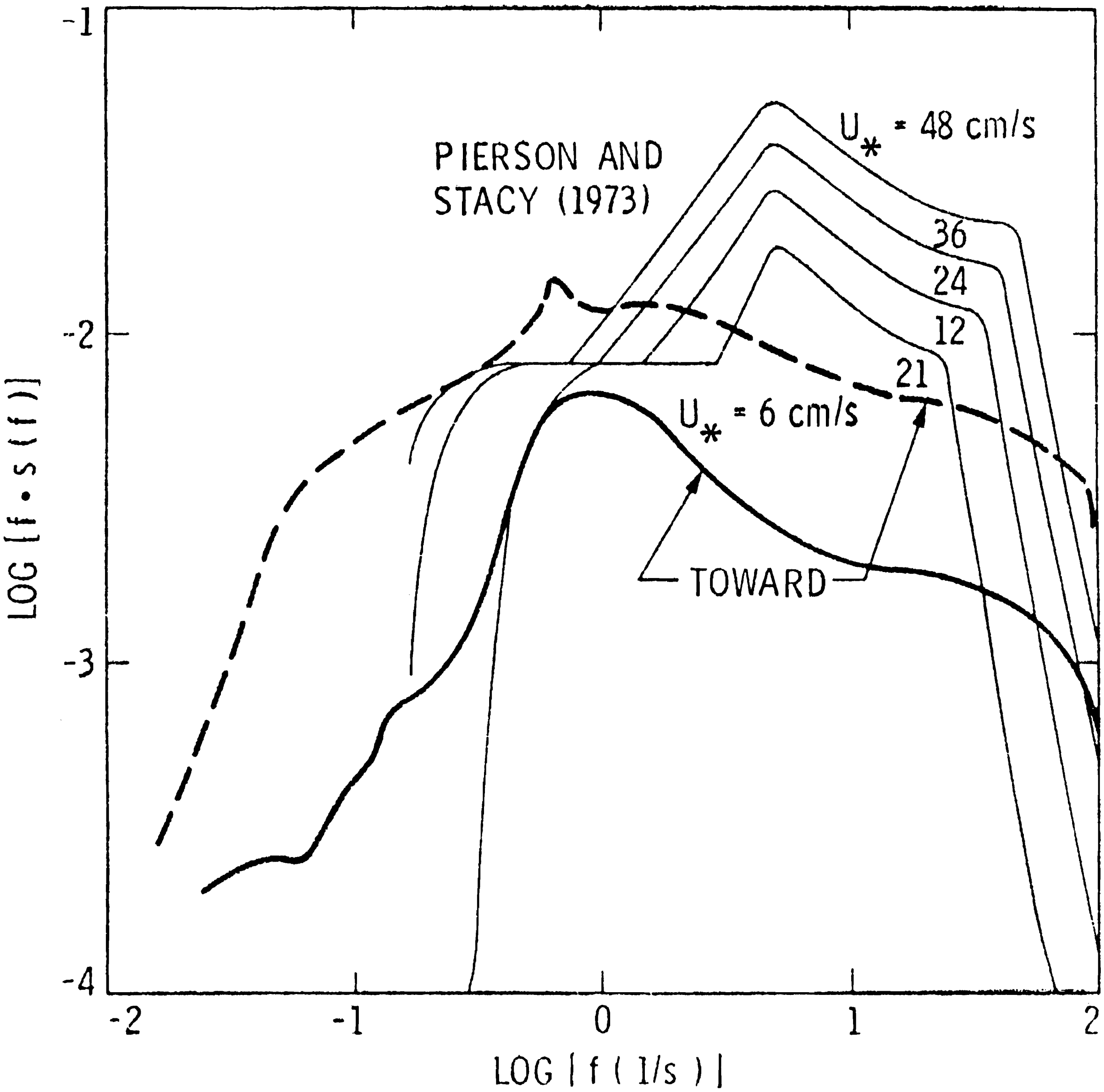

-1
-2
-3
-4
-2
-1
0
1
2
LOG [f • s (f)]
LOG [f (1/s)]
PIERSON AND STACY (1973)
U_* = 48 cm/s
36
24
12
21
U_* = 6 cm/s
TOWARD

Figure 4

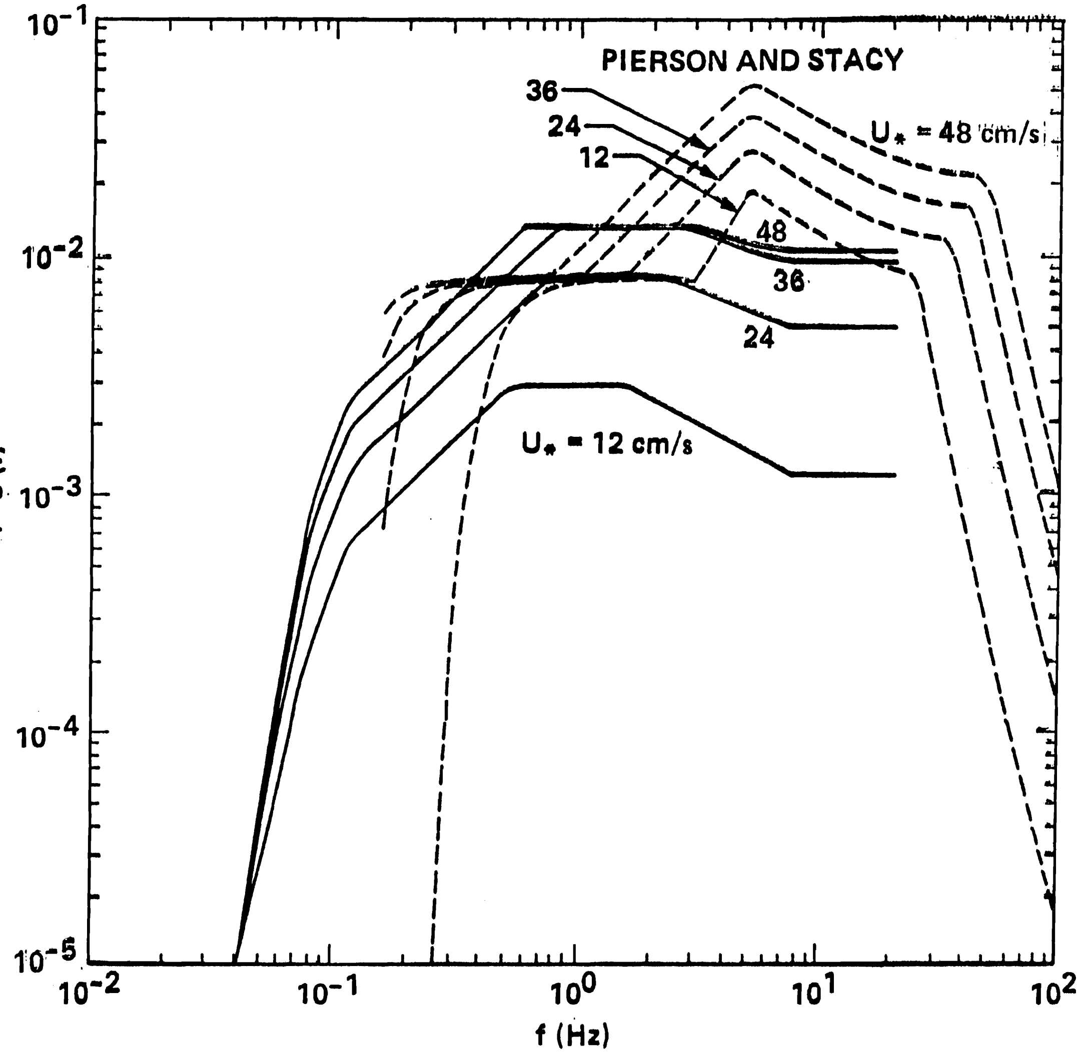

PIERSON AND STACY
36
24
12
U* = 48 cm/s
48
36
24
U* = 12 cm/s
f · S (f)
10^-1
10^-2
10^-3
10^-4
10^-5
10^-2
10^-1
10^0
10^1
10^2
f (Hz)

Figure 5

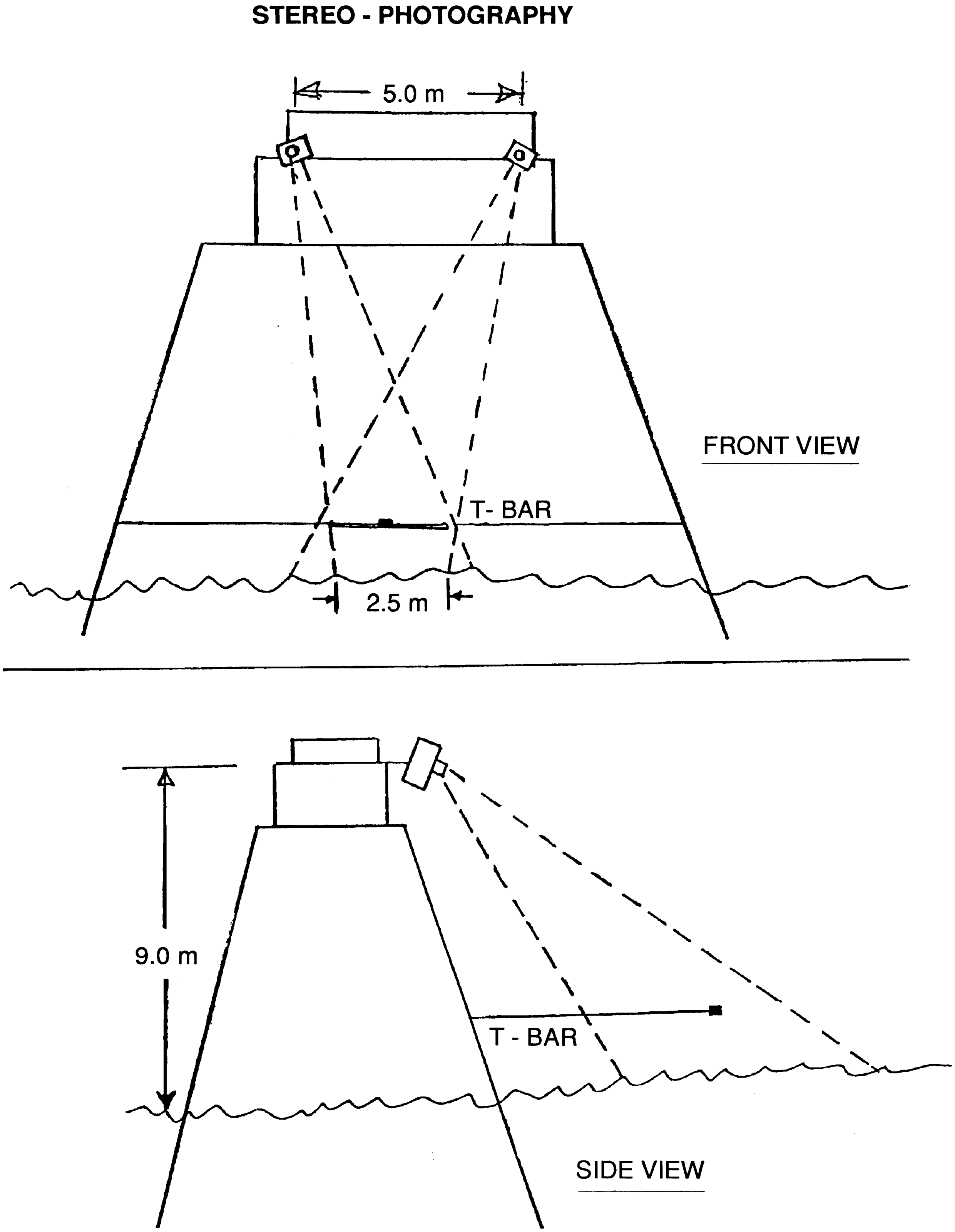
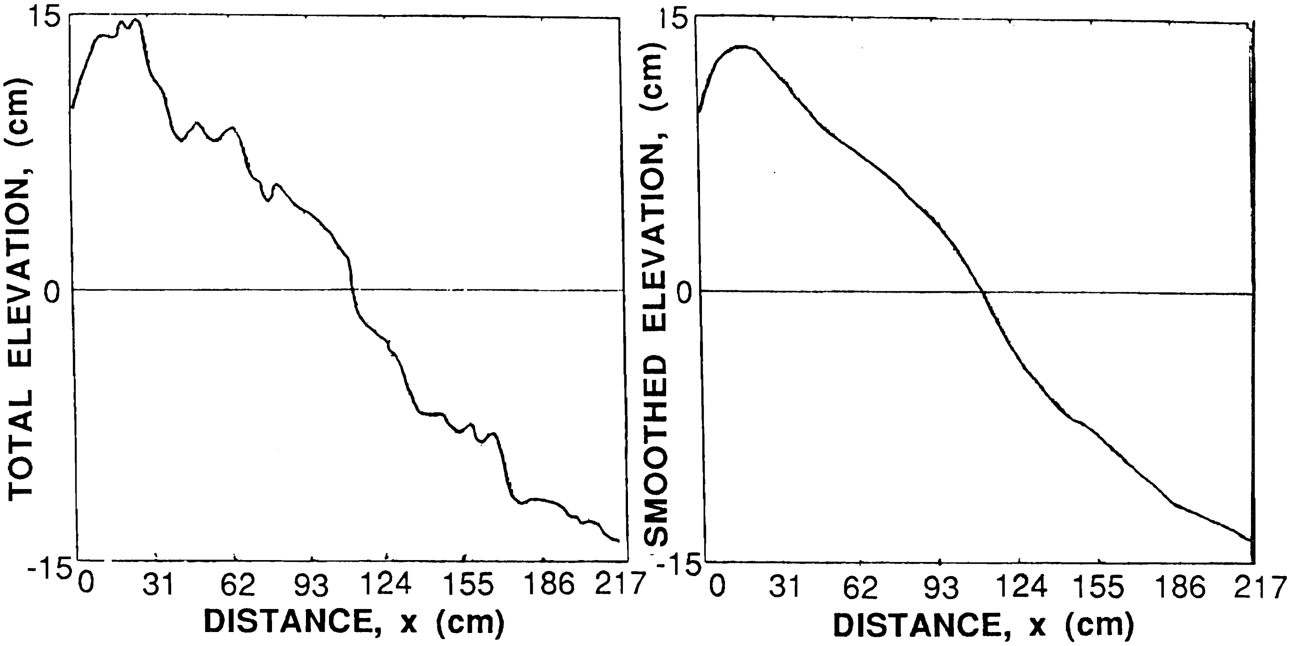
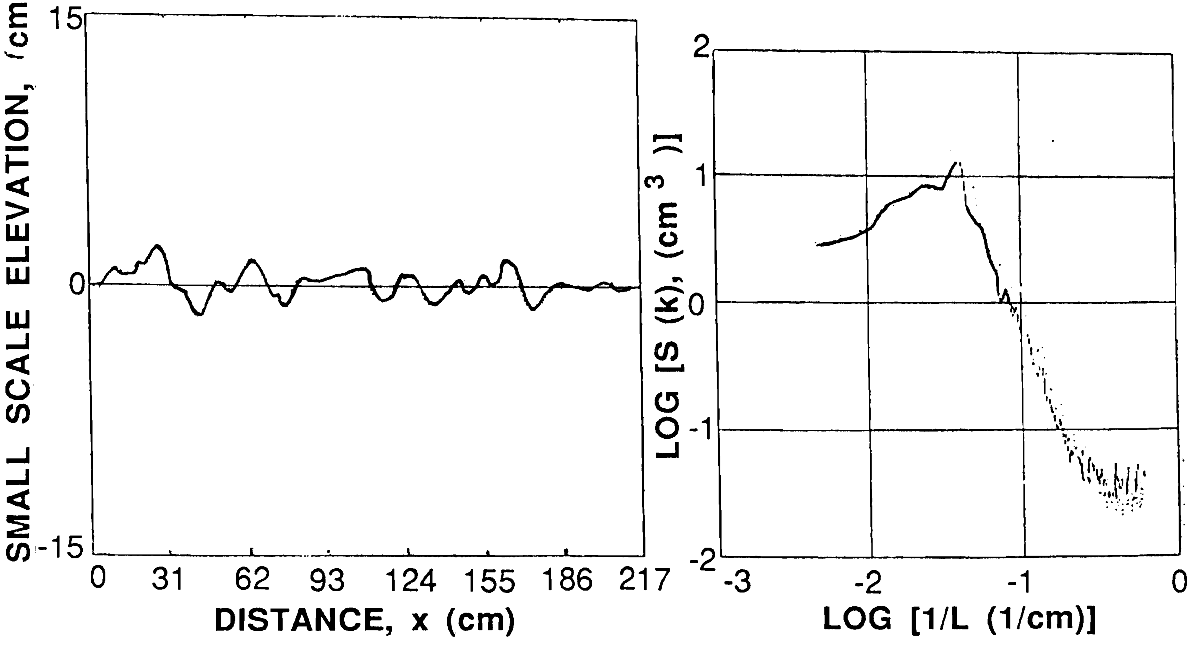

STEREO - PHOTOGRAPHY
5.0 m
FRONT VIEW
T- BAR
2.5 m
9.0 m
T - BAR
SIDE VIEW

Figure 6



(a) TOTAL LINE SCAN RECORD

(b) 50 cm RUNNING AVERAGE APPLIED TO (a)



(c) SMOOTH RECORD (b) SUBTRACTED FROM TOTAL RECORD IN (a)

(d) WAVE-NUMBER SPECTRUM OF RECORD IN (c)

Figure 7

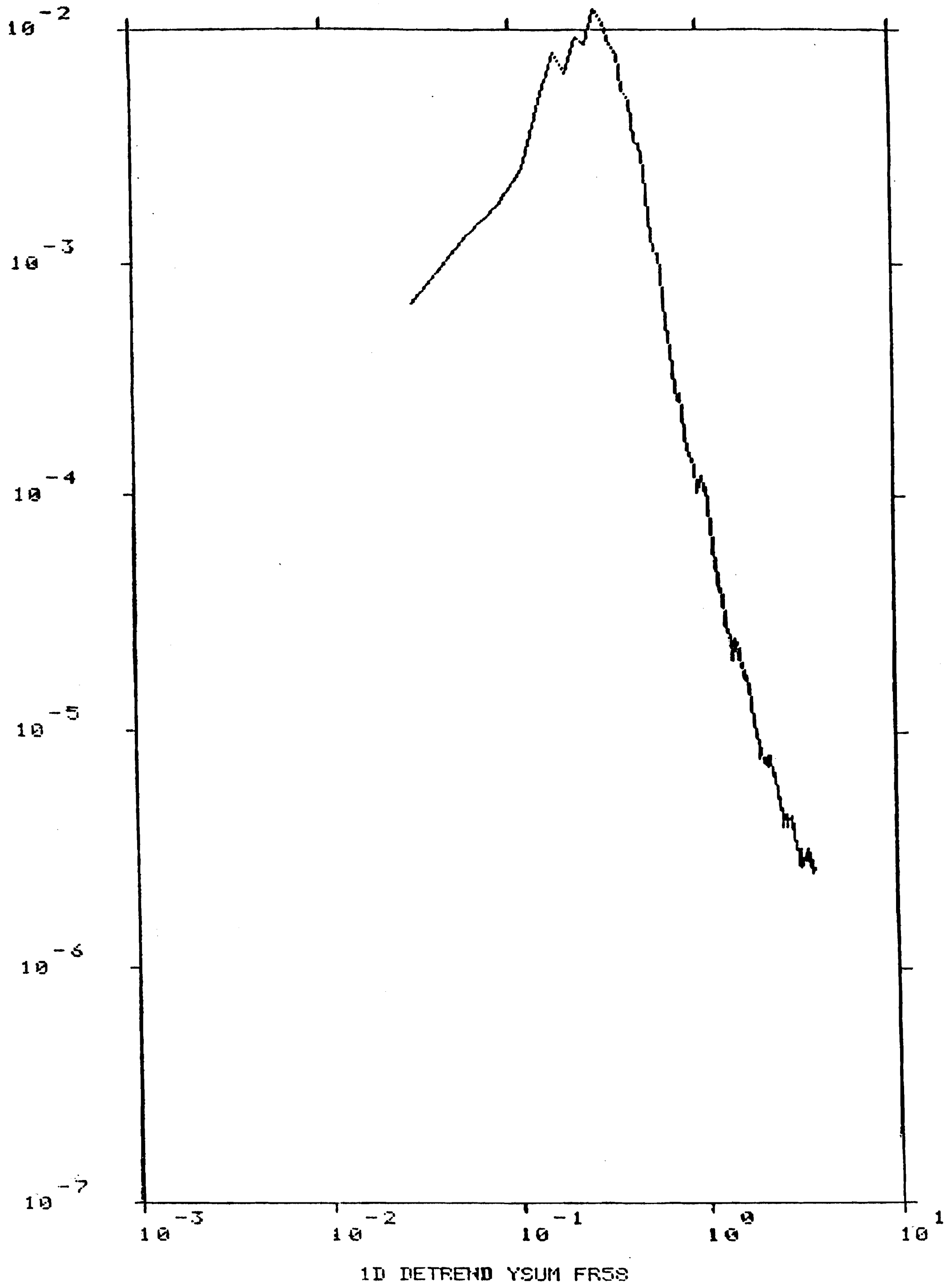

10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
1D DETREND YSUM FR5S

Figure 8

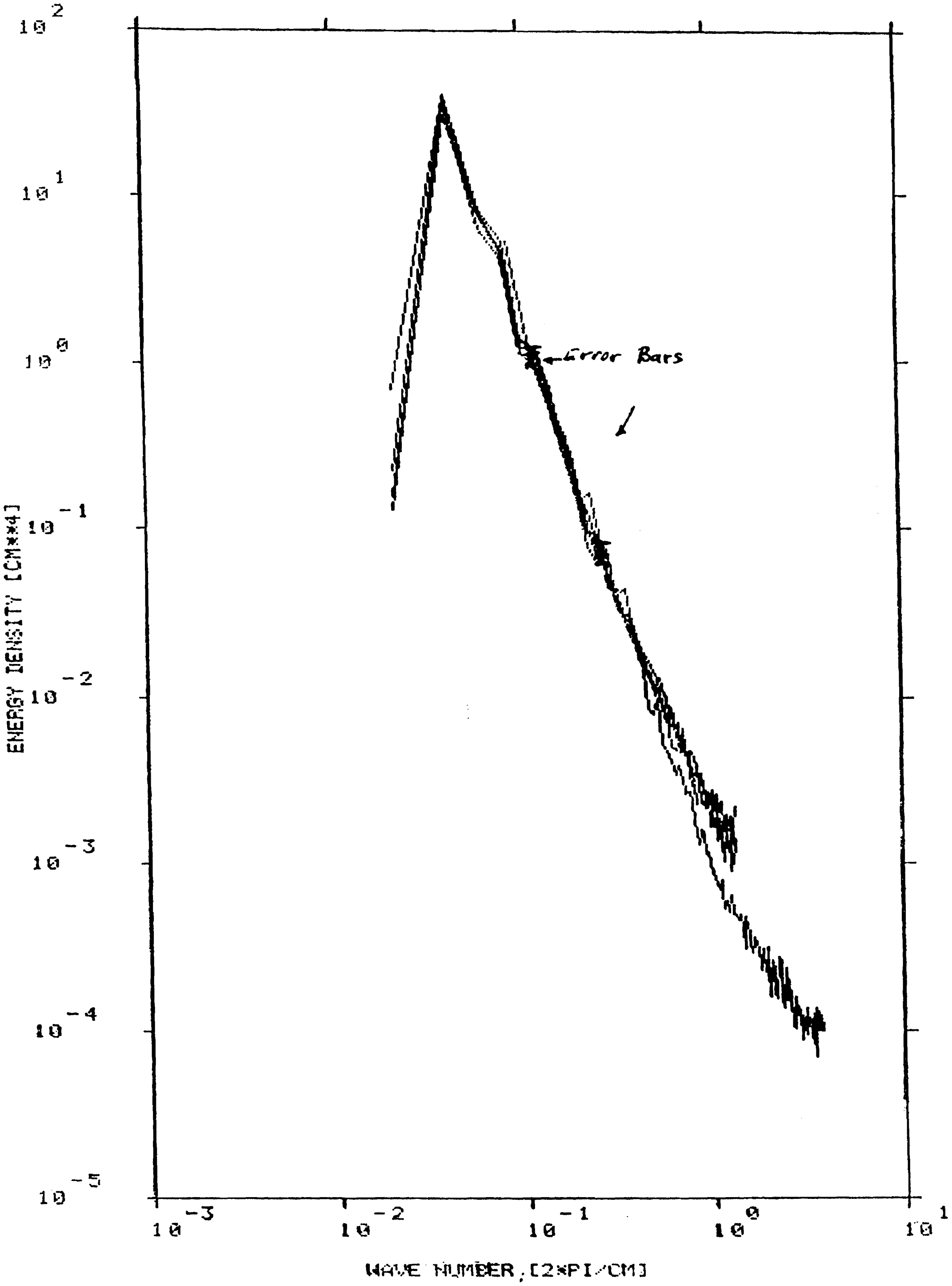

10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
ENERGY DENSITY [CM**4]
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
WAVE NUMBER,[2*PI/CM]
Error Bars

Figure 9

TABLE 1

Frame	Slope			
	±Scan X Sum	Scan Y Sum	(9) Omn / Dir	(8) Omni Dir / K
FR058	-2.59	-2.75	-2.53	-3.47
FR58B	-2.55	-2.55	-2.46	-3.46
FR58B	-2.43	-2.42	-2.42	-3.32
FR58C	-2.51	-2.50	-2.42	-3.42
FR58D	-2.55	-2.48	-2.40	-3.47
Mean Valid $10^{-1} \leq k \leq 10^{\circ}$ (cm) $6 \leq \lambda \leq 60$ (cm)	-2.52	-2.54	-2.54±0.05	-3.43 ±0.06

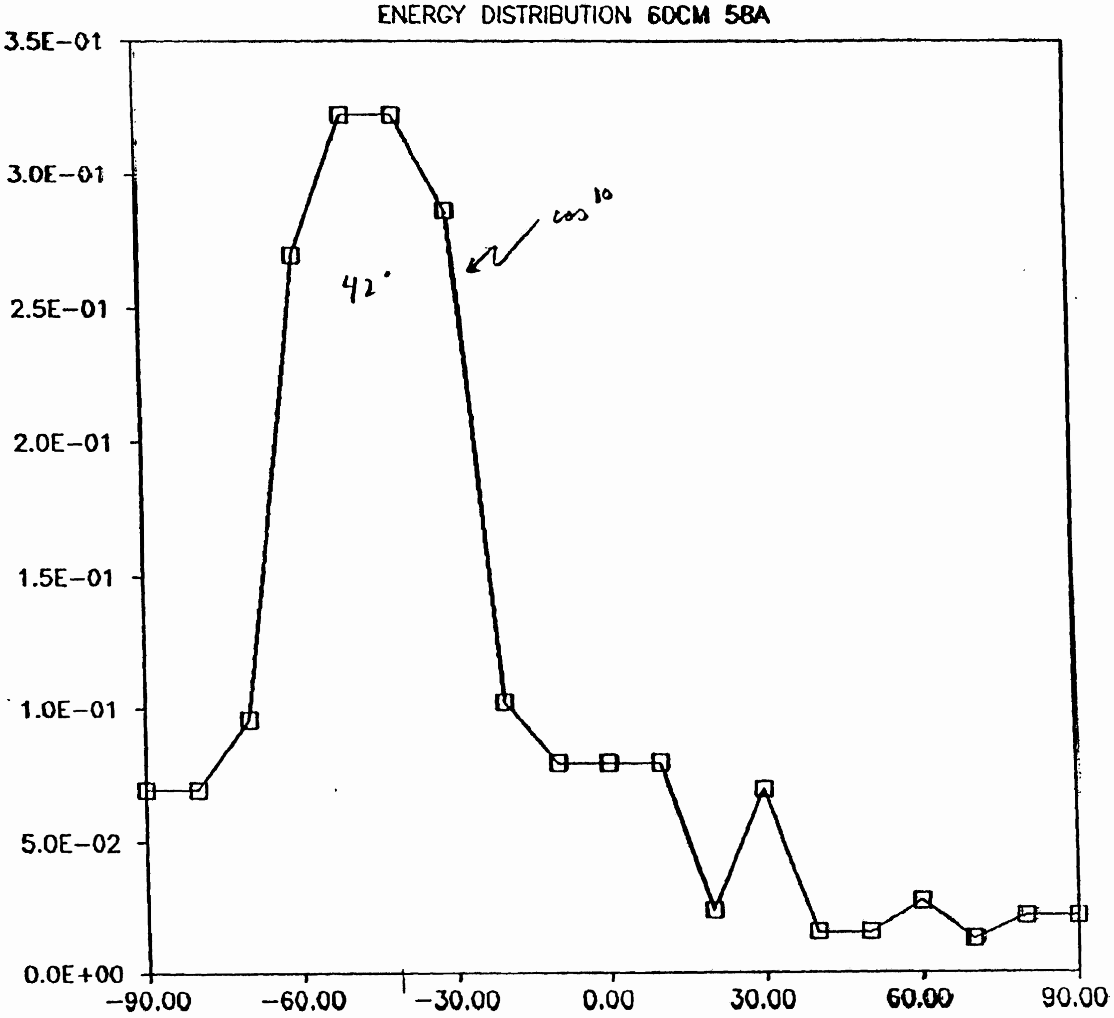

ENERGY DISTRIBUTION 60CM 58A
3.5E-01
3.0E-01
2.5E-01
2.0E-01
1.5E-01
1.0E-01
5.0E-02
0.0E+00
-90.00
-60.00
-30.00
0.00
30.00
60.00
90.00
cos10
42°

Figure 10

SAXON 88/90
PROPOSED ASSETS TO BE DEPLOYED

OCNR TOWER

- WAVE FOLLOWER WITH MULTI-BEAM LASER OPTICAL SENSOR
- STEREO-PHOTOGRAPHY
- MULTI-FREQUENCY RADAR: 10-100 GHz
- SURFACE TENSION SENSORS
- LONG WAVE DIRECTIONAL PROPERTIES
- INTERNAL WAVE ARRAYS
- CURRENT METERS
- METEOROLOGICAL MEASUREMENTS

FLIP

- DOPPLER ACOUSTIC SENSORS
  - SURFACE WAVES DIRECTIONAL PROPERTIES
  - INTERNAL WAVE DIECTIONAL PROPERTIES
  - AMBIENT CURRENT PROFILE

SAXON 88/90

PROPOSED ASSETS TO BE DEPLOYED (contd)

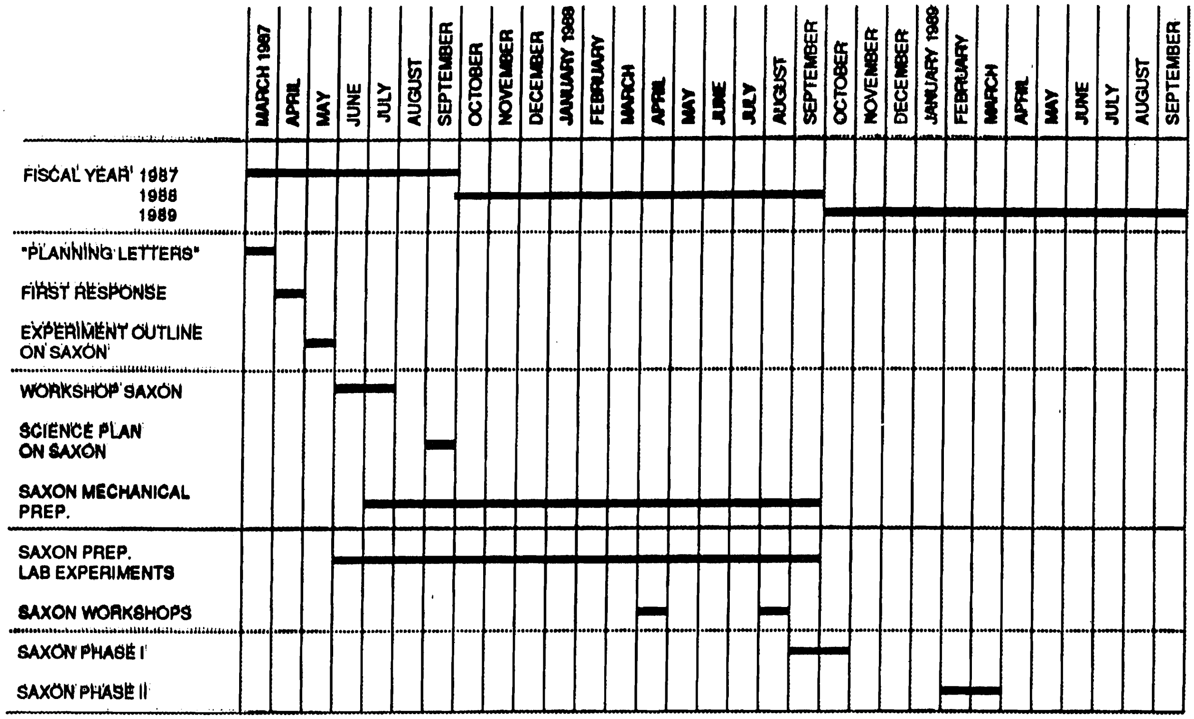
FLIP (contd)

- CTD's
- WAVE FOLLOWER WITH MULTI-BEAM LASER OPTICAL SENSOR
- STEREO PHOTOGRAPHY
- MULTI-FREQUENCY RADAR: 0.5 - 35 GHz
- WAVE HEIGHT GAGES
- WIND STRESS, SPEED AND DIRECTION
- AIR AND WATER TEMPERATURES
- SURFACE TENSION SENSOR

AIRCRAFT

- NASA: DC-8 WITH JPL SAR
  P-, L-, AND C- BANDS
- NAVY P-3 WITH ERIM SAR
  L-, C-, AND X-BANDS
- NRL P-3 WITH C-BAND RAR
- ARMY OV-1 WITH X-BAND RAR

SAXON SCHEDULE OF EVENTS



APPENDIX F

Welcoming Remarks

FLIP AND PHYSICAL OCEANOGRAPHY

Robert Pinkel

Marine Physical Laboratory
Scripps Institution of Oceanography
San Diego, California

While originally designed for research in ocean acoustics, physical oceanographers were quick to appreciate FLIP's capabilities. Open ocean measurements of surface waves were made from FLIP in the mid 1960's, as part of Walter Munk's classic "Waves across the Pacific" experiment. Shortly thereafter an internal wave measurement program was started, conducted by graduate student Bob Zalkan. In 1967-68 FLIP was in the Caribbean, participating in the BOMEX air-sea interaction experiment. Surface wave and meteorological measurements were made. By this point FLIP had sprouted the first generation of deployable booms, used to suspend instruments away from the hull for unimpeded operation. The engineering and rigging of these light-weight structures required considerable care. By 1970 FLIP had assumed her present personality: half submarine and half square-rigger.

In the early 1970's, radar measurements of the sea surface were made from FLIP. These were compared with other surface and subsurface measurements, in an effort to understand the physics of radar backscatter from the sea surface. The radars used in the study were designed to have the narrowest possible beams, in both the horizontal and vertical planes. This, in retrospect, was a mistake. FLIP's modest tilting motion, ±2° rms, was sufficient to significantly displace the radar "footprint" on the sea surface, modulating the backscatter amplitudes. We now know that a fan shaped beam, narrow in azimuth, but broad in the vertical would be ideal for this sort of work. Operating like a side-scan sonar, the radar would be little affected by tilt.

In early 1973 we began to investigate methods for increasing the aperture of the FLIP internal wave array At that point the horizontal dimensions of the array were limited to about 40 meters by the physical size of the booms used to deploy the instruments. Range-gated Doppler sonars, a then unexploited technology, was identified as a promising technique. Development was begun in earnest in 1974, with publishable quality results being obtained two years later. In January 1977 accurate measurements were attained to a range of 700 meters. By 1980 maximum range was of order 1 km. Today ranges of order 1.5 km are common.

Since the early 1970's FLIP has continued participating in air-sea interaction experiments. POLE (1974), MILDEX (1983), ODEX (1984), and PATCHEX (1986) are notable examples. In a 1982 test trip, Bob Weller measured vertical velocities in excess of 15 cm/s in the mixed layer, associated with particularly intense Langmuir cell activity. This was a first sign of the enormous efficiency of Langmuir cells in mixing momentum from the wave zone into the interior of the mixed layer. More detailed studies of the cells themselves occurred in MILDEX. A new experiment, SWAPP (1990), is planned to investigate the interaction of surface waves and Langmuir cells.

In addition to participation in major experiments, FLIP has often been used to test new instruments and develop new observational techniques. The cost to the user for FLIP time is sufficiently low that it is possible to have routine access to the deep sea. It is not necessary to convene planning meetings, coin acronyms and appoint steering committees to justify funds sufficient to leave the dock. Early evaluation of sonic annemometers and hot-film sensors for meteorology, the VMCM current meter, volume and surface scattering Doppler sonars were all performed from FLIP. Without this inexpensive source of access to the deep sea, our understanding of the performance limits of these devices would have been more difficult to attain.

As FLIP passes her 26th birthday, we look forward to the creation of a second generation platform, with increased space and payload. We advocate that the virtues of the present FLIP, minimal environmental disturbance and economy of operation, be passed to her successor.

RESEARCH REQUIREMENTS FOR AIR-SEA INTERACTION STUDIES USING STABLE PLATFORMS

*Omar Shemdin**

Ocean Research & Engineering
749 Foothill Boulevard
La Canada, California

Introduction

The physics of the air-sea interface will remain an important area of investigation over the next decade. Interest in this field has been amplified by the advent of remote sensing applications in oceanography. It is now demonstrated that remote sensing techniques can provide useful information on both surface as well as subsurface processes. Of interest are: the dynamical processes in the upper 100 m layer of the ocean, the associated air-sea interaction and the marine boundary layer above. Such investigations require the use of a stable, deep-water platform.

In the past research interest has focused on various aspects of long surface waves. With the recent interest in remote sensing a profound shift to short surface waves has evolved. Radar backscatter from the sea surface is primarily from short surface waves. The modulation of these short waves by near-surface velocity fields, included by long surface waves or internal waves, allow detection of the latter by radar. Imaging radar systems allow detection of surface and internal waves from airborne or spaceborne platforms.

A central objective of current research in remote sensing is the understanding of how and under which environmental conditions internal waves or surface waves can be detected by radars operating at various frequencies. Such investigations require ***in-situ*** measurements of short surface waves and radar backscatter measurements, simultaneously. Both require use of stable platforms to minimize the influence of platform tilt.

Present techniques that measure short surface waves reliability utilize laser-optical sensors that are deployed on wave followers, stillwell photography and stereo photography. Similarly, near surface radar backscatter measurements require stable platforms (tilts $\leq 2^\circ$). Such measurements are required in both deep and shallow water.

---

* Previously at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91104

Processes to be Investigated

The following processes require detailed investigations. They provide insights on dynamical interactions at the air-sea interface and on the mechanisms by which remote sensing techniques can be utilized to study the oceans.

1. Investigation of short surface waves, including the modulation of short waves by long surface waves (swell) and internal waves.
2. The influence of the microlayer (sea slicks) on the small scale processes at the air-water interface.
3. Wave breaking in intermediate and high sea states.
4. The interaction of internal waves with the near surface layer, and their surface expression.
5. Shear currents in the upper ocean layer and their surface expression.
6. The influence of surface waves on the mixed layer.
7. Wave generation by wind in high sea states.
8. Fluxes of heat, energy and momentum across the air-sea interface, and the delineation of the role of short surface waves in these transfers.
9. Near surface oceanographic processes in the marginal ice zone. These include current instabilities at the ice edge, wave propagation through the ice, stratification and mixing near the ice edge among others.

Measurement Needs

The following measurements are considered essential for investigating the processes indicated above:

1. Measurement of surface waves with wave length in range 1-100 cm. These require the use of capillary wave sensors which use laser-optical technology. Use of stable platforms is essential in high sea states for operating such sensors. Recently, stereo photography has been demonstrated to provide wavenumber spectra of short surface waves. Stable platforms are essential also for operating the latter in high sea states.
2. Radar backscatter from the sea surface using radars with frequencies in range of 1-100 GHz. Stable platforms are mandatory for acquiring and interpreting data sets from such sensors.
3. Measurement of surface tension, compressibility and elasticity are required in a continuous mode. The sensors are mounted on wave followers, which require stable platforms.
4. Directional properties of long surface waves (swell). These can be obtained with directional buoys deployed away from a platform, or with a Doppler sonar deployed on a platform.

5. Micro-meterological measurements (e.g. turbulent fluxes near the air-sea interface). Here, sonic anemometers are considered essential in any complement of meterological measurements to investigate the processes near the interface. Use of stable platforms is considered desirable.
6. Simultaneous measurements of internal waves and shear currents are required with the above in order to delineate the interactions indicated in the previous section.

Stable Platform Requirements

The following platform requirements are considered necessary for executing the air-sea interaction requirements indicated above:

1. RMS tilt $\leq 2^\circ$ in ± 10 m operating seas.
2. Operate routinely in 20 m crest to through surface waves.
3. Operate in latitudes from the equator to the ice edge.
4. Have $\leq 5\%$ of RMS wave height or $\leq 1\%$ of significant wave height.
5. Platform direction controlled to $\leq 2^\circ$ with respect to wind or geographic direction in wind speeds up to 15 knots.
6. Operate off the east coast of the U.S., i.e. can transit from the Panama Canal.
7. Inertial navigation system adequate for measuring location within 0.1° accuracy.
8. Above water booms available, extending to a minimum distance of three hull widths.
9. Underwater booms available, extending to a minimum distance of three hull widths.
10. 1000 kw electrical power, salt water grounding and air conditioned instrumentation laboratory.
11. Routinely operate over a period of 60 days, including tow time.
12. Ship transfer and helicopter hover transfer capabilities.
13. No oil slicks during data acquisition phase.
14. Communications to including Marisat telephone, data transfer via satellites, transmission and receiving of images.