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PRESENT STATUS AND FUTURE DIRECTIONS OF DRIFTING BUOY DEVELOPMENTS

A SUMMARY OF PRESENTATIONS MADE AT A DRIFTING BUOY WORKSHOP HELD AT THE WOODS HOLE OCEANOGRAPHIC INSTITUTION ON JULY 11 & 12, 1978

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16. Abstract

A summary is presented of the talks and discussions held during a Drifting Buoy Workshop at the Woods Hole Oceanographic Institution on July 11-12, 1978. The summaries provide a means for relating experiences and findings by both analysts and experimenters in the field of drifting oceanographic buoys. In addition, a series of key problem areas and both immediate and long range needs are given. Lastly, suggested approaches to the solution of specific problems are presented as elements of a long range plan for effectively using Lagrangian oceanographic buoys for the acquisition of useful scientific data.

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SUMMARY OF PRESENTATIONS

AT THE WOODS HOLE DRIFTING BUOY CONFERENCE,

JULY 11 & 12, 1978

1. INTRODUCTION

On July 11 and 12, 1978, a small group of ocean scientists and technologists gathered at the Woods Hole Oceanographic Institute in Woods Hole, Massachusetts for the purpose of relating their experiences with surface-trackable drifting buoys and expressing their needs and desires for the future. In addition, efforts were made to plan for the achievement of the goals outlined. In organizing the conference, an attempt was made to keep the number of participants small enough so that those involved could freely present and discuss their material in an atmosphere of informality conducive to free interchange.

This report presents a summary of the contents of the talks presented by invited speakers and a summary of the conference recommendations. Appendix A is a schedule of the conference speakers and a general title of their topic. Appendix B contains the list of Attendees. Because no formal detailed proceedings were to be published from the conference, no formal written paper was requested from the speakers. This document represents the only written summary of the presentation.

2. PRESENTATIONS

2.1 Introduction - W. Vachon
ADL

Mr. Vachon welcomed the conference attendees and acknowledged the sponsorship of the conference by the Office of Naval Research (ONR). Further, he acknowledged the planning assistance provided by Jim McCullough and some of the staff of the Woods Hole Oceanographic Institute (WHOI) as well as the gratitude for being able to use the facilities of the WHOI for the conference.

He outlined the desired informal format and schedule of the conference and the method of disseminating a conference summary a few weeks later. He outlined the following conference objectives:

(1) Assemble both ocean scientists and technical personnel together for a fruitful interchange of test experiences, scientific and technical needs, and future plans.

(2) Identify key issues and areas of concern.

(3) Provide a planning exercise with a resulting document by which future programs can be configured.

2.2 Satellite System Status

by
John Masterson
NCAR

Satellite History

Mr. Masterson provided a brief history of satellites with on-board location and data collection systems. A summary is shown in Figure 1. He pointed out that it is estimated that the long-awaited TIROS N satellite with the on-board ARGOS system will be launched in September of 1978. The second such satellite will be launched as soon thereafter as possible; the minimum time between satellite launches is approximately 75 days. Therefore, the earliest NOAA-A satellite would be launched in early December. The second and subsequent launches will be called NOAA-A through G. NESS/NOAA will strive to maintain two such satellites in orbit at all times through 1985.

Satellite Data

Mr. Masterson outlined that the present plan for FGGE data from the TIROS and NOAA satellites will follow the planned route to Alaska (or Wallops Island) to NOAA/Suitland, Maryland to CNES (Toulouse, France). The data will be distributed free of charge to FGGE users.

Non-FGGE users are concerned that the planned cost per data point may be too high and are looking very hopefully at a new Ground Terminal development that will have the capability to receive and interpret satellite transmissions which are made immediately after receiving an input from a ground-based transmitter. The satellite must be in a direct line-of-sight with both the buoy and the ground terminal in order to make the system work. It is felt that a single ground terminal can cover an area of approximately 1400 nautical mile radius for TIROS-N and 1600 nautical mile radius for Nimbus 6.

FIGURE 1

METEOROLOGICAL SATELLITES WITH

LOCATION AND DATA COLLECTION SYSTEMS

Nimbus B, May 1968, aborted
Nimbus 4, April 1969, IRLS
Eole, August 1971, range-rate
Nimbus 6, July 1975, TWERLE/RAMS
TIROS N, 4th Q, 1978 Argos
NOAA A, 4th Q 1978, Argos
NOAA B through G to $\sim$1985

The ground terminal development calls for N.A.S.A. acceptance testing at Goddard in late July 1978. It was pointed out by NOAA Data Buoy Office (NDBO) personnel that NDBO is buoying two terminals - one for test and the other to monitor their buoy program. The projected station cost was $38K, but is felt to be creeping upward due to software costs.

The CNES cost for buoy position and data transmittal was originally pegged at $20 per buoy per day for non-FGGE users. It was pointed out by NDBO that the target price is presently $5 per buoy per day.

2.3 NDBO's Drifter Development Program

by
Edmund G. Kerut
NDBO

Mr. Kerut presented a summary of the following two types of drifting buoy development programs in which the NOAA Data Buoy Office (NDBO) is involved:

(1) Hardware developments with industry participation

(2) Experiments and numerical model development to study the effectiveness and performance of drifting buoy systems.

Mr. Kerut presented a series of figures which are shown in Kerut (1978) and available from NDBO. Figure 2, taken from this document, is a summary of the history of NDBO drifter hardware developments from 1971 up to what is expected in 1981. Mr. Kerut explained the role and purpose of each type of buoy shown in Figure 2. He indicated that NDBO will be testing a vertical wind sock-type drogue with relief holes as a result of work carried out by Dr. John Nath at Oregon State University. He pointed out that the results of the C. S. Draper Laboratory drogue test field experiment would be used to decide whether the window shade drogue should be replaced by the vertical wind sock-type drogue.

Work will also continue to decouple the drogue from the surface buoy element. Elastic tether lines and a floating tether line, using a separate float, is being studied with the numerical model. Further testing is planned.

Mr. Kerut presented a series of figures which served to describe the various test activities carried out by various institutions in an effort to select the proper drogue and buoy as well as understand its performance. The results of each test were useful in the evolution of buoys and drogues in Figure 2.

Among the more interesting conclusions presented was that the drifter program has been plagued by basic hardware problems such as shackles and terminations rather than large, complex engineering problems. Mr. Kerut indicated that NDBO has no evidence of drogue failure because they have recovered very few deployed buoys. Parenthetically, it should be mentioned that Dr. Phil Richardson has recently retrieved a few buoys from which the drogue was torn free, but in some cases, the drogue indicator was still telemetering a signal saying that the drogue was on (see Section 2.5). Mr. Kerut also described a computerized numerical model analysis of a drifting buoy and drogue that was developed and tested by the Polar Research Laboratory, Inc. Air Force certification has been received to airdrop drifting buoys developed for the Global Weather Experiment. Airdrop work will continue to include drogued buoys and buoys with thermistor lines for subsurface temperature measurements.

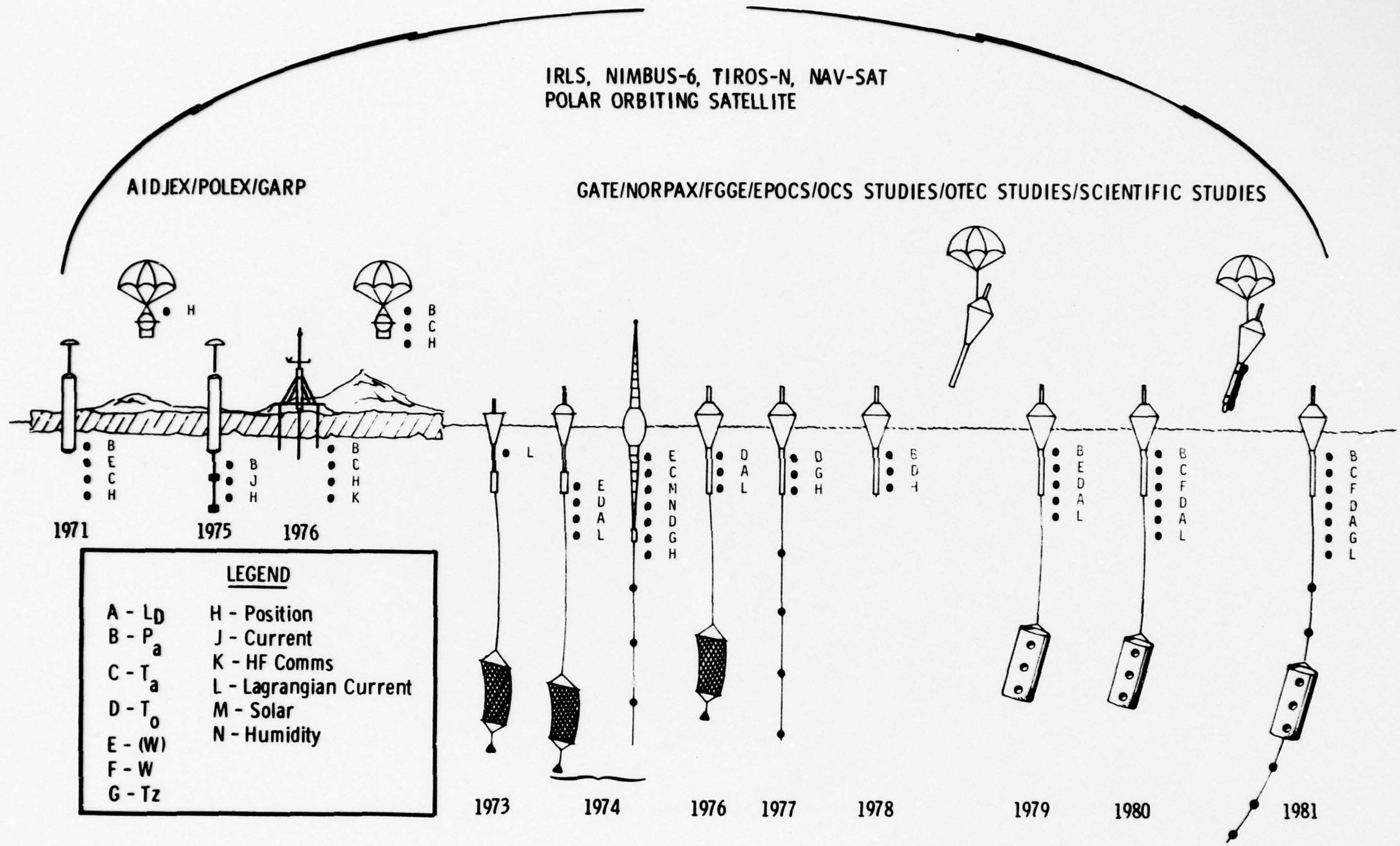

FIGURE 2 - NDBO

DRIFTING BUOY DEVELOPMENT PROGRAM

In follow-up discussions, it was pointed out that NDBO is studying the cost impact of processing the ARGOS satellite data from the ground terminal readout system under development (see Section 2.2). The system may be expanded to process position data for ocean investigations if computer resources are available and the interest is sufficient.

2.4 Drifter Data from the ADS and NORPAX Experiments

by
Gerard McNally
Scripps Institution of Oceanography

ADS Data

Mr. McNally very briefly discussed the drifter experiences which he and Dr. A. D. Kirwan of Texas A. & M. University had in the Anomoly Dynamics Study (ADS) as part of the North Pacific Experiment (NORPAX). The standard system which they have employed was developed by Mr. McNally at Scripps. It consists of a cylindical fiberglass spar buoy which measures approximately 38 centimeters in diameter by 3-meters long. When ballasted, it has an in-air weight of approximately 600-pounds. A 9-meter diameter cargo parachute is generally used and set for a depth of approximately 35 meters. In the ADS-0 deployment, pairs of buoys with plough steel tether lines were released in an attempt to look at buoy separation. Within six weeks, all drogues were lost. After the drogues were lost, they got five months of good data. During that time, the buoys separated very little and described an interesting mesoscale phenomenon in which they went in 100 Km-diameter circules at 10 cm/sec speeds over a 30-day period. In subsequent deployments a nylon line (3/4" Sampson cord) was used instead of plough steel in an attempt to absorb a portion of the dynamic energy imparted to the drogue by the buoy.

In later deployments of June and September of 1976 and in May/June, 1977, interesting mesoscale phenomenon were again observed. Of 22 buoys still telemetering data, 25% indicate that the drogue is still on. Of note is the observation that whether the drogue is on or not, according to the drogue indicator switch on the buoy, the trajectories are essentially the same. This observation leads to one of two conclusions, either:

(1) the drogue never worked anyway, or
(2) the upper 35 meters of water moves as a slab.

Windage

Mr. McNally discussed the role of windage in the trajectory data. He presented plots of wind heading (from FNWC data) versus buoy trajectory heading which showed a predominant wind direction approximately 30 degrees to the left of that of the buoy. The results were presented without taking out geostrophy. The results generally display more coherence (i.e., less dispersion) in winter than in summer. When attempts were made to account for wind-induced trajectory deviations, it was analytically estimated that, after corrections, the buoy should go upwind if a drag coefficient of 1.2 were used on both the dry and wetted portions of the buoy. This result seems physically unrealistic so it is felt that either the drag coefficient on the dry part of the buoy is too high or the value for the wetted part of the buoy is too low. The results of this work are presented in Kirwan et al (1978).

Mr. McNally mentioned that the buoy trajectories sometimes approximate the lines of dynamic topography or even bathmetry charts. For example, one Kuroshio deployment indicated a noticeable effect from bottom topography which was a few thousand meters below the buoy.

In summarizing his presentation, Mr. McNally indicated that he is still unsure of what the buoy is really measuring and would like to see if this questions could not be addressed in future test and development work.

2.5 The Use of Drogues in Tracking Rings and the Gulf Stream

by
Dr. Philip Richardson
Woods Hole Oceanographic Institute

Dr. Richardson presented his experiences using drogued drifting buoys to track Gulf Stream rings. In many cases, the buoys have become trapped in and end up tracking the Gulf Stream itself for periods of time.

Dr. Richardson pointed out that Gulf Stream rings are formed from meanders that pinch off from the stream. Cyclonic (i.e., counterclockwise) rings are cold core rings that are found south of the Gulf Stream while the anticyclonic rings exhibit a warm core and are found north of the Gulf Stream. In tracking the rings he has employed NDBO-recommended buoy hulls and in most cases their recommended drogue too. He has generally used a 200-meter, 5/8" diameter nylon tether to the drogue. He has used a buoy-mounted temperature sensor to indicate surface water temperature. On several occasions he has tried the use of only a long piece of 1 1/4-inch diameter polypropylene line as a drogue in an attempt to avoid the dynamic interaction of the drogue and still get a large drag area.

In summarizing his drogue experiences, Dr. Richardson stated that in 1976 he deployed 6 NOVA fibreglas hulls with satellite transmitters made by the American Electronics Laboratory (AEL). The buoys lasted periods of 4 to 132 days with a mean-time-to-failure (MTF) of 50 days. In the following years he employed Polar Research Lab (PRL) aluminum hulls with better success. Of the first 10 PRL buoys, he got a MTF of 317 days with buoys that had only 9-month batteries. With a larger battery pack, it was felt that system life could have been increased.

Dr. Richardson described the details of his system design variations and the observed results. Five meters of chain was installed above the 1 1/4-inch polypropylene line. The only line that was recovered was after ~80 days at sea. None of the others had any line - most had been out ~1 year. This design was contrasted with a "softer" system with nylon to a drogue. By the use of a ship-board satellite receiver and radio direction finder (NDBO), WHOI personnel were able to recover five of the buoys, one additional buoy was recovered by a fisherman. It was found that the stiffer line with a weight caused the drogue sensor to jam - indicating that the drogue was on always (even when gone).

This problem is being remedied by Polar Research Lab, Inc. The new system was tried for ~80 days and worked fine. The line drogue 1-1/2" propylene was recovered in good condition. It was also found that a safety shackle has corroded away after 300 days at sea. In another case, a thimble beneath the chain was all that was left. It was surmised that chafing and or fish bite had caused the nylon to wear and part.

They are also trying the installation of a 1-inch diameter rubber line below the chain to a jacketed wire rope tether to a drogue in order to try to avoid fishbite possibilities and the shock loading problems. This version is still at sea.

Dr. Richardson briefly discussed his involvement in successful tests of air-launched drogued buoys using a Coast Guard C-130. He described the launch of a pallet-mounted PRL hull and drogue from 500-600 feet at an air speed of approximately 140 mph. A salt water switch was designed to cut the drop chute away after impact and the drogue would then self-deploy. In practice, the drop chute did not drop away within the 10 minutes before the ship left.

Dr. Richardson presented and discussed the general aspects of the oceanographic data that he has measured. He described how he uses satellite infrared photographs to initially find the rings. He then goes to the site and seeds it with buoys after which he conducts an extensive hydrographic survey to depict temperature in three dimensions. He indicated that the buoys stay with rings for extended periods, and in some cases until the rings coalesce with the Gulf Stream again. He also noted that drogue trajectories indicate a strong effect from seamounts as deep as 3000 meters below. He felt that this technique for acquiring data was extremely useful for his types of studies. However, he still indicated strong questions about the accuracy of drogue trajectories as indicators of current at drogue depth. He would also like to see drogue life extended and be sure he knows when the drogue is off.

2.6 Drifter Experiences and Some Future Plans at A.O.M.L.

by
Dr. Donald Hansen
A.O.M.L.

Dr. Hansen presented the results of drifter tests conducted by the Atlantic Oceanographic and Meteorological Laboratory (AOML) primarily in the areas of the equatorial Pacific and Gulf of Alaska. He has generally employed the NDBO-recommended buoy and drogue designs with 30-meter nylon tether lines. In the early deployments he employed no drogue indicator switch. Summer deployments have been much more successful than those in winter in terms of system longevity, but mostly summer deployments have been made in the later stages of engineering development.

In the Gulf of Alaska AOML has supported the Bureau of Land Management in predicting where oil will go if set adrift in the oil lease area. Surface drifters should be an excellent tool for this type of study. In general, he found that buoys deployed anywhere near shore seem to go ashore in the northern Gulf of Alaska. For example, in the summer of 1976 some buoys deployed south and southeast of Prince William Sound, off Yakutat Bay, went into Prince William Sound and eventually ashore. Those designs did not include a drogue sensor, but when recovered indicated drogues were still attached.

AOML has deployed drifting drogued buoys at 150 to 150°W. longitude on the equator in pilot studies for NOAA project plans in the equatorial Pacific. The buoys were released downstream of the moorings in the region of the equatorial divergence. Instead of going west as expected they went east, right by the moorings. There was poor agreement between currents measured by drogues at 30 - 35 meters and D. Halpern's Aanderaa current meters at 50 meters. One buoy, without a drogue indicator, initially went east for a long time, then turned north and eventually went to 168° west -- lasting a total of 450 days. Another similar buoy went ashore at Kawajalein Island after a year. No data on the drogue condition or presence was obtained.

In summary, Dr. Hansen indicated that he had obtained a 153-day MTF on drogues for six buoys deployed in the Bering Sea in summer, all of which had 6-month battery packs. All of these buoys had drogue indicators. In the NORPAX Shuttle Program of last winter, he obtained a drogue MTF of 66-days for those deployed in the Fall and a MTF of 48-days for those deployed on January 20, 1978. The satellite tracker is still on for 11 of 13 of these buoys. One buoy that went aground 100 miles south of Tahiti lost the drogue tether at the thimble beneath the buoy and no drogue was present.

Dr. Hansen indicated a strong role for drifting buoys in future AOML plans. He outlined a role for the buoys in monitoring both the OTEC resource off of Brazil and in the Global Weather Experiment (FGGE) in January 1979.

2.7 Drogue Slip Experiments at Woods Hole

by
James R. McCullough
Woods Hole Oceanographic Institute

Mr. McCullough discussed two basic topics within the framework of drifting buoys.

- Drifters as Drifting Moorings
- Techniques for Measuring Slip

He outlined the general history of drifters and summarized by saying that as system and mooring reliability was to moored current meters, the satellites will be to surface trackable drifters. In other words, we now have the tools and capabilities available by which more elaborate drift experiments can be planned.

Mr. McCullough discussed the results of both the WHOI drogue slippage tests and also a dye technique that he has developed which will permit the measurement of lagrangian currents. He summarized the results of the first WHOI test (see Saunders, 1976) and a later two-thirds scale test in which an acoustic travel time (ATT) and a Vector Averaging Current Meter (VACM) were supported by a thin spar at the same depth as a window shade drogue. The spar was interconnected to the drogue system by a rigid subsurface boom. The system was tested four times at sea with the result that it is felt that drogue slip can be measured with a reasonable accuracy with an ATT sensor supported as described. They did not, however, always get good closure on a system force balance unless the conditions were steady. A strong, linear correlation was derived between measured wind and slip displacement. An average drogue slip rate of 0.7% of the wind speed was measured for the system tested, using 39 hours of data converted to fifteen-minute averages each hour. Little dispersion from a straight-line correlation was observed even though this correlation did not necessarily hold true for certain shorter periods of time for which the data were available. As a result, Mr. McCullough felt that we have data and one simple model to support the contention that if we know the coefficient by which to multiply the wind velocity, we have a mechanism to estimate drogue slippage to first order in wind driven seas. Tests in higher sea states than those observed are needed.

Mr. McCullough went on to describe a dye system for measuring true Lagrangian currents near the surface. The system involves buoying a Shelton spar of variable length (~3-inch dia.) beneath the surface and allowing it to trail in line with the Lagrangian current aft of a moored small boat or ship. (See McCullough 1977, 1978.) Dye released at one end of the spar is sensed by dye sensors (fluorometers) at specific points along the spar. If the spar doesn't line up with the Lagrangian current, the system does not give a signal output.

2.8 The Free Drift Velocity of a Floating Object in Waves

by
Dr. John H. Nath
Oregon State University

Dr. Nath discussed both his work in developing a computerized, two-dimensional lumped parameter, dynamic model of buoy and drogue response as well as his model verification work in the Oregon State wave-making facility.

Model Development

Because Dr. David Brooks was scheduled to spend time discussing John Nath's model and results Dr. Nath spent only a short time reviewing the model. Dr. Nath described the types of inputs the model can accept. It is possible to put in a wind velocity at a certain height, a wave height (linear or Dean's stream function); and they buoy, tether, and a drogue parameters including size and drag coefficient as well as elasticity, masses, and added masses. The model is run using a fourth order Runge-Kutta forward differencing computer algorythm using a predictor-corrector to shorten integration time steps if needed. When a few wave periods of response data are run, the computer time amounts to a few minutes on a CDC machine. The model development effort is summarized in Nath (1977a).

Model Validation Tests

Dr. Nath described the purpose of the validation tests as follows:

- Check the analytical model
- Look at drogue performance in order to improve system design.

In the first test phase, Dr. Nath conducted scale model wind tunnel tests, which identified a holey sock (i.e., a vertical cylinder with holes) as the best candidate drogue from the point of view of expected hydrodynamic response. This work is reported in Nath (1977b). In another phase, Dr. Nath conducted flow visualization studies from which recommendations were made to remove approximately 20% of the area of a sock and window shade drogue in order to provide suction relief and greatly minimize vortex shedding.

In later tests, a series of scale model and full-scale hydrodynamic tests were conducted in the Oregon State wave tank facility measuring 33.5 m. (long) x 3.66 m. (wide) x 3.5 m. (deep). The tests were run on one-quarter and full scale models of the Polar Research Lab Inc. (PRL) hull. The results are given in Nath (1977c). The report describes that one-quarter scale drift tests with the buoy and holey sock generally did not given good correlation with the numerical model prediction because the drogue was too near to the surface. In addition, the drag and added mass coefficients are a function of the dynamic conditions and are really unknown.

Dr. Nath also described some drift tests of both the one-quarter scale buoy, a ping-pong ball, and a small discus buoy in waves. All test objects had no drogue attached. Their speeds were predicted rather well by the numerical model as well as by third order stokes drift theory and that of Longuet-Higgins. The full scale buoy drift tests in waves produced results with large scatter and poor correlation with the model and other predictions.

Dr. Nath pointed out that the analyses employed were useful only in periodic waves and that a nonlinear transfer function was needed to predict the drift velocity of a buoy in a wave spectrum. He also recommended adding relief holes to window shade drogues, not only for stability, but also to augment the downward force of the ballast weight.

2.9 Dynamic Response Tests of Full Scale Drogued Drifters

by
John M. Dahlen & Narender Chhabra
C. S. Draper Laboratory

Mr. Dahlen led off by describing the types of buoys and sensor systems employed in carrying out an extensive series of buoy and drogue intercomparison tests in Bermuda. The tests had only been completed approximately one week before the presentation. Therefore, the data which they discussed was very preliminary and somewhat incomplete because most of it had not yet been reduced to a presentable form.

Mr. Dahlen described the type and quantity of dynamic sensing packages which were employed in the experiment. A single package, called an Oceanic Environmental Sensing Equipment (OESE), was packaged to monitor either the dynamics of a Scripps/McNally buoy (38 cm. dia. x 3 m. long spar with damping plates) or a Polar Research Lab hull (see section 2.12). This battery-operated, internally-recording OESE package contained three (3)-rate gyros and three (3) servo accelerometers integrally mounted with their sensitive axes mutually orthogonal. The package recorded a set of data points every 0.25 seconds for many minutes in a burst fashion -- after which it would shut down until the next burst occurred many minutes later. The OESE package timing was synchronized with that of all other dynamic sensors.

The dynamics (i.e., response, behavior) of various drogues was monitored by the use of four (4) Force Vector Recorders (FVR) which were either mounted at the apex of parachute shroud lines or at both the top and bottom of the window shade or holey sock drogues. The FVR is a spherical dynamic sensing package that contians accelerometers for specific force measurements, magnetometers for orientation information, and strain gage load cells for line tension or strain gage pressure sensors for depth. The units are self-powered and self-recording. Because the units can power up only six (6)-channels at once, it was necessary to optimally select the best sensor combination for the particular FVR mounting location and information desired.

During the series of tests, data were gathered using the Lagrangian sensors listed in Table 2.9.1.

A series of three day-long drift tests were conducted under moderately dynamic sea conditions (i.e., up to 2 1/2-meter sea height) in order to obtain dynamic response data useful in design and load intercomparison as well as mathematical model verification. The intercomparison tests included the following buoys in the water at the same time with drogues at a 20-meter depth suspended by 3/8-inch nylon diameter line.

Test 1:

- SIO buoy with parachute
- SIO buoy with window shade drogue

Test 2:

- SIO buoy with parachute
- PRL buoy with window shade drogue

Test 3:

- SIO buoy with parachute
- PRL buoy with holey sock.

During each test the polyform float buoys, wave rider buoy, and dye tracers were employed to obtain better estimates of the true current at the surface and at the depth of the drogue.

Preliminary results from instruments and drift trajectories indicate that an abundance of useful data is available. Window shade drogue tension fluctuations above the drogue are on the order of 0-180 pounds with a ballast weight of only 64-pounds. Those for the holey sock appear to be larger. Trajectory comparisons indicate that, to first order, the parachute drogue follows the water mass as well as other drogues. Further, dye tracers indicate that the surface crossed vane polyform float is not a good follower of surface water or else there is a large near-surface shear.

The detailed results of the tests will be published in reports and papers during the next year.

TABLE 2.9.1

TEST BUOYS USED IN BERMUDA TEST

Quantity	Description	Drogue
2	Scripps/McNally Spar (i.e. SIO Buoy)	1 With Parachute = Standard* 1 With Window Shade
1	PRL Buoy	1 Test = Window Shade
		1 Test = Holey Sock
1	Polyform Float & Pole	Holey Sock at ~20 meters +
1	Polyform Float & Pole	Surface Crossed Vane
1	Wave Rider Buoy	Surface Follower
1	Dye Tracer at Surface (Attached to Crossed Vane)	

*SIO Buoy and Parachute in Water for all Tests and Used as Standard of Comparison.

+For best estimate of current at 20 meter depth (i.e., $\simeq$ ground truth)

2.10 Future Requirements of Drogued Buoys and Sensors

by
Dr. James McWilliams
National Center for Atmospheric Research (NCAR)

Dr. McWilliams began by the outlining the requirements that he felt should be placed on drifting buoys if they were to be used in the ocean and air-sea interaction studies of short-term climate fluctuations. He indicated his awareness that many requirements are not yet fully developed, but felt that by setting clear requirements and goals it is possible to develop the full capabilities over the next decade. The requirements are described as follows:

Large Number of Buoys Per Deployment

Dr. McWilliams felt that in order to get a representative statistical sampling for a region, it is necessary to have 50 to 100 buoys per deployment. Further, in order for the sampling of the oceans and atmosphere to be spatially coherent, it is necessary for the buoys to be disbursed over ranges of 50 to 1000 km. He recognized the expense associated with his goal and underlined the fact that a long range program must therefore evolve to solve the technical problems of drifters.

Aircraft Deployments

Because satellite-linked and tracked Lagrangian drifters are most useful in remote regions, it is necessary to deploy the buoys by air. Such deployments are estimated to be usually cheaper than ship deployments - especially if the buoys are deemed expendable. Furthermore, a capability for air deployment makes possible a quick reseeding of a given area if initial buoy deployments disburse too widely or do not capture the phenomenon of interest. It is, however, necessary to employ large aircraft that can carry on the order of ten or more buoys per flight in order to be cost effective. It was pointed out that NDBO is working on this problem and is apparently making progress.

Air and Water Measurements

Dr. McWilliams pointed out that in order to study air/sea interaction phenomenon, it is necessary to have simultaneous air and water measurements. He classified his measurement requirements under two headings as follows:

Class I: Water Velocity (speed at drogue depth)
Surface Water Temperature
Water Temperature at Various Depths
Air Temperature
Air Pressure
Wind Velocity

Class II: Water Flow Past Drogue
Air Humidity
Surface Radiation

Dr. McWilliams felt that it should be possible to make reliable Class I measurements, remotely on a drifter, within the next several years. He felt that Class II measurements should be addressed with expected success over a longer time period. He felt that a very appropriate price goal for the type of drifting buoy he is seeking is less than $10,000 with the present dollar value. He is, however, aware of the strong trade-off that is inherent between sensor price, reliability, and accuracy in any of his desires.

Known Slippage

Dr. McWilliams pointed out that it is essential to know that accuracy of the drogue slippage to a "very few centimeters per second". A realistic goal is to have an acceptably small slippage or provide a means of incrementally calculating the true buoy trajectory if slippage were not present by possibly using barometric pressure and wind data. He pointed out the strong need for a definitive field program to measure drogue slippage under representative wind and sea conditions such that modellers can use the results for the purpose described. Verifying the model predictions of slippage is crucially important.

Satellite Communication

Because it is planned to use drifters in remote locations for long periods of time (at least a year), it is essential to maintain a satellite data collection and position system for the next ten years. The orbital parameters and the number of satellites in orbit preclude a certain satellite data sampling rate. Therefore, it is necessary to do a certain amount of data preprocessing on the buoy before telemetry.

In summary, Dr. McWilliams indicated that he sees a strong need for a program and organization to agressively attempt to meet the requirements outlined. The program should be strongly geared to acquiring empirical data on such parameters as drogue slippage. Also, it is necessary to further develop the scientific planning for buoy experiments once the instruments are available. Others agreed that at present it is not possible to do good oceanography purely from satellites.

2.11 The NDBO Drifting Buoy Computer Model as a Design Tool

by
Dr. David Brooks
Sperry Rand

Dr. Brooks provided a brief history of NDBO's involvement with computer models for drifting buoys. He indicated that they had originally used an Oceanics Inc. frequency domain mooring response model that was modified for drifting buoy work. This model proved to be inadequate in the case of non-linear wave effects. Therefore, in 1975 and 1976 NDBO had Dr. John Nath of Oregon State University develop a two-dimensional time domain model as a tool for providing design and analysis guidelines (see Nath, 1977a). The lumped parameter model incorporates non-linear effects as well as large amplifications. The computation time has run approximately one to two times the real time for a five node model and four to six times the real time for a ten node model. He felt that computer time could possibly be saved by obtaining initial conditions with the frequency domain analysis first.

Dr. Brooks indicated typical applications for computer model use would be:

- Systems design for Southern Oceans use
- Limiting wave height versus tether length (i.e., size tether)
- Lagrangian drift error
- Drifting buoy thermistor configuration
- Studies of different buoy configurations
- Predict minimum wave height for zero tether line tension.

He presented computer plots of sample runs for typical drifting buoy configurations, indicating conditions of zero tether line tension and shock loading.

It was pointed out that besides the NDBO drifting buoy dynamic model there are models that were developed at the C. S. Draper Laboratory (3-dimensional, time domain) and at the Naval Ship Research and Development Center (NSRDC).

2.12 Experiences with the Polar Research Lab (PRL) Drifting Buoy

by
Mr. Walter Brown
Polar Research Lab, Inc.

Mr. Brown began by pointing out that they have been building buoys for drifting drogued applications for only about two years. The first buoys were built quickly and deployed early in the Bering Sea. NDBO had an in-house drogue and tether design effort as well as outside consultants. Therefore, PRL's initial buoy-tether-drogue designs and dimensions were provided by NDBO.

Mr. Brown pointed out that not all PRL customers order tether lines with their buoys, some supply their own. When customers order tethers, they have installed 3/8-inch, 8-strand plaited nylon for the last year and one-half, based on NDBO and Coast Guard recommendations. With this design, he felt that fishbite was a potential problem below 40 degree latitudes. The little feedback that he has had indicated that line fatigue and abrasion through thimbles has been a strong drogue failure mode. He indicated that potting the thimble may be the solution and is being investigated. He also felt that abrasion from clinging plant or animal life may sever a line. Others felt that fish would clean the line off.

Mr. Brown indicated that past experience has shown that drogue failures have occurred when shackle pins come loose. They now use stainless steel pins and weld them. He also felt that vandalism should not be discounted in that fishermen have picked live buoys up in the past. He also felt that some fishing boats may use buoys for target practice.

Mr. Brown discussed the problem with the drogue indicating switch on the bottom of the PRL hull that had recently been discovered by buoy retrievals by Dr. Phil Richardson at Woods Hole. He pointed out that observed damage to heavy rubber springs in the switch has lead to an electronics indication that the drogue is always present (even when gone). He felt that tension loads in excess of 300 pounds are necessary to get such damage. To remedy the problem his company has redesigned the sensor to limit plunger travel and spring expansion in order to avoid overstressing the rubber.

In summary, Mr. Brown felt that more successes could be achieved if scientists and technical people coordinated their efforts more and feed the results back to manufacturers. He felt that everybody is doing their own thing too much. He recommended that NDBO be a focal point for all statistical data relative to buoy and component failure rates and estimated causes.

2.13 A LORAN-C to HF Radio Link for Positioning a Drifting Buoy

by
Clayton Collins
Woods Hole Oceanographic Institute

Mr. Collins discussed a WHOI effort to take an existing automatic LORAN-C receiver (i.e., a Teledyne TDL-701) and package it in a drifting buoy. The LORAN-C time difference information will then be automatically sent back to a shipboard or shore-based receiving station via a high frequency (HF) single sideband (SSB) radio link using a 4.135 megahertz frequency in the ground-wave mode. They will purchase a low power, low cost HF transmitter and make up an engineering prototype model for testing in a real "drifting buoy of opportunity" which they will scrounge from the WHOI warehouse.

The Teledyne LORAN-C receiver is a $3500 unit that is packaged in a 2-1/2" x 9" x 11" volume weighing 13 pounds. It already has a binary-coded decimal (BCD) output of the LORAN-C time differences. The LORAN-C receiver will draw 12-watts of power (with no display lights) which, when combined with the SSB transmitter will permit 60 days of operation with a 160-amp-hour battery on the buoy.

It was pointed out that this system has the potential of providing higher accuracy position data in real time at more frequent intervals than the satellite systems. Costs for equipment could potentially be much less if a large purchase were made from the proper vendor.

2.14 Plans for Drogued Drifters in Pacific Equatorial Studies

by
Dr. William Patzert
Scripps Institute of Oceanography

Dr. Patzert began by agreeing with the discussion presented by Dr. McWilliams that the future applications of drifters require large arrays and that a long term program objective should be the solution of the technical and oceanographic (i.e., data handling) problems which will make these types of studies possible.

Dr. Patzert went on to describe a rationale and a planned program for using drifters in the equatorial Pacific for studying East-West variability in both currents and transport. He pointed out how past data from moored temperature and current sensors as well as drifter trajectories indicate a correlation between the North-South variability in dynamic height and the latitudinal transport and currents at certain depths. Limited data indicate that this correlation is not uniform in an East-West manner. He proposed to study the problem by deploying a total of forty (40) drifters in a grid between the equator and 20 degrees North in 5 degree longitudinal increments between 135 and 150 degrees West. Three deployments would occur: one during the FGGE Special Observing Periods (SOP), another in late summer '79, and again in the winter '79-'80. These deployments would essentially provide a year-long series of "snap-shops" of near-surface transport at various longitudes that would be difficult to obtain by any other means.

2.15 EXPERIENCES WITH THE CANDIAN FGGE DRIFTER

By

Andrew Reid
Hermes Electronics Ltd.

Mr. Reid began by describing the surface drifting buoy an undrogued variety of which has been developed by Hermes Electronics Ltd. for the First GARP Global Experiment (FGGE). The aluminum-hulled, foam-filled buoy is made in the shape of a 2-meter long truncated cone. In drogued applications, the buoy employs a foamed collar at the water line which provides 400 pounds (180 Kg) of reserve buoyancy. The top portion of the buoy is made of fiberglass in order to be transparent to radio signals being telemetered to the satellites. The buoy contains a Paroscientific Digiquartz barometric pressure transducer and an internal hull-mounted water temperature sensor. An alkaline battery pack capable of one year of service at 10°F and 6 months at 0°C ambient temperatures is employed. The system is actuated on launch by a fool-proof magnetic switch. The buoy can be dropped from ships of opportunity from as high as 21 meters (70 feet) above the water at ship speeds to 15 knots.

Mr. Reid described the design of the barometric pressure measurement system which minimizes errors caused by the dynamic pressure from wind, water entrapment, and moisture influx. He also described how tests have shown that even though the buoy may be under water a large part of the time, there has been no degradation of satellite position and sensor data.

Mr. Reid summarized the undrogued buoy field experiences to date. Aside from a few early failures due to mechanical and electrical problems, most buoys have lasted for an average life of approximately 450 days.

Mr. Reid described how the FGGE drifter with a foam collar has been drogued with a 2-1/2 x 8-meter window shade drogue at an 8-meter depth. In order to increase system compliance, a rubber snubber is used between the buoy and drogue. Without the drogue, the buoy will overturn. Past experience shows no difference between the trajectories of drogued and undrogued buoys.

Lastly, Mr. Reid described a unique above-water sail drogue buoy with a submerged thermistor string for doing wind-driven transects of large areas of interest. Velocities of 200-400 km/month have been observed.

2.16 Intrepreting Satellite - Tracked Drifter Trajectories In The Indian Ocean

By
Dr. Henry Stommel
Woods Hole Oceanographic Institute

Dr. Stommel began by indicating that Dr. Lloyd Regier has recently returned from the Indian Ocean and they have not had a chance to organize all of the recent data. He did, however, state that, based on past drifter trajectory records, it is difficult to determine the nature of the Indian Ocean data. But, based on limited calculations related to a few trajectories, he would try to build up a catalog of trajectories and illustrate their sensitivity to possible oceanographic phenomena that could give rise to them. He referred to this exercise as builidng a "catalog of horrors."

Dr. Stommel defined the three following oceanographic parameters as a means for developing representative trajectories:

$\overline{V}$ = Mean drift velocity of the oceanwith x and y components of u and v respectively

C = Eddy propagation speed with components C_x and C_y

A = Water particle velocity

These velocities are generally illustrated in Figure 2.16.1

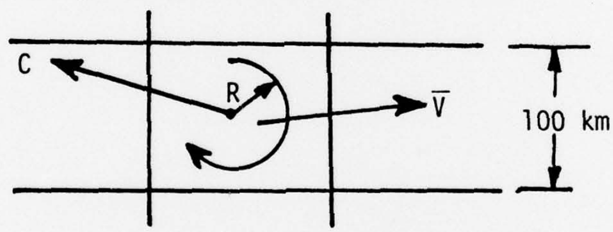

Figure 2.16.1 - Velocity Field Description in 100-km Grid

For analysis purposes, he assumed that the ocean is made up of checkerboard of 100-kilometer square grids each of which is assumed to contain an eddy. A lagrangian drifter imbedded in one of the eddies will exhibit a trajectory described by wave equations for the x and y velocity components. Dr. Stommel went on to summarize the results of the mathematical exercise. He showed that as the particle velocity, A, exceeds the eddy propagation speed, C, trapped regions in the field result. Similarly, for particle velocities less than the eddy propagation speed, sinusoidal trajectory motion results. Both cases are sketched in Figure 2.16.2 for the cases of east-west motion only.

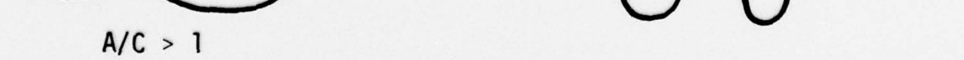

Figure 2.16.2 - Generalized Trajectory Motions

Dr. Stommel further showed that by varying the amplitude of each velocity component, it is possible to mathematically give rise to almost any type of trajectory.

The main conclusions from the exercise were the following:

(1) If the magnitude of the mean ocean drift, $\overline{V}$, is at or near zero, many interesting phenomena such as trapping can result.

(2) If the magnitude of $\overline{V}$ is increased, some phenomena are masked, and coherent trajectory motions result.

(3) If $\overline{V}$ is of the same order as the velocity of the kinematic field, A, the ability to predict the mean ocean drift velocity from the center of gravity of a float cluster also increases.

(4) Drogue slippage acts like a change in $\overline{V}$, the mean ocean drift.

Lastly, Dr. Stommel posed the question as to whether one could design SOFAR floats and surface drifters with periodic self-swimming capability to permit the sampling of a wider area of the ocean.

2.17 ADDITIONAL COMMENTS BY ATTENDEES

By

W. A. Vachon

During discussions which related to increasing the reliability and longevity of the drogues on drifting buoys, it was recommended that a suitable means be developed for installing compliance between the buoy and drogue. The two primary suggestions for including compliance involved the following design changes:

(1) Install distributed buoyancy on the tether line from the buoy to below the wave zone.

(2) Install elastic compliance in the tether in the form of shock cord (i.e., bungee cord) or the equivalent.

The first method of building compliance has been used by a few individuals over recent years. Both Dr. John Garrett of Environment Canada and French researchers have used it with varying degrees of success. The three main areas of concern with the approach seem to be the following:

(1) Buoy surge forces are converted to vertical tether line tension variations because the water acts like a low friction pulley in transmitting axial motion.

(2) Surface wave action on different portions of the system can cause axial tension variations which can cause zero line tensions and subsequent high tension values and shock loading.

(3) The system is cumbersome to package and potentially more difficult to deploy from ships and aircraft.

Dr. Philip Richardson of the Woods Hole Oceanographic Institute plans to deploy and test a distributed buoyancy drifter this year in order to gain experience.

The second method of building compliance is much simpler and more straighforward than the first. It presently suffers from lack of experience on the behavior of elastic materials under cyclic loading conditions in an ocean environment. Mr. Edward Brainard of Environmental Devices, Inc. provided the information shown in Table 2.17.1 on the properties of representative sizes of shock cord that might be used on drogue tether lines.

3.0 SUMMARY AND RECOMMENDATIONS

By

All Attendees

Figure 3.1.1 contains an encapsulated summary of the comments and recommendations of the conferees. The figure is broken into the major subject headings which seemed to logically evolve from the presentations and discussions at the conference. The two major recommendations that seem to summarize the feelings of participants is as follows:

(1) More at-sea tests are needed in which systems are retreived for periodic inspection and examination of failure modes. Military supply ships and Coast Guard vessels may be of use for this purpose in open ocean deployments. For more controlled tests, a drogue or buoy farm concept or semi-enclosed basin test is recommended.

(2) A comprehensive series of instrumented full scale at-sea tests are needed in which at-sea measurements are made of all parameters forcing the system (e.g., wind and seas) and the resultant drogue slippage and system dynamic response.

TABLE 2.17.1

SHOCK CORD LOAD PROPERTIES

Elongation (Percent)	Load (Pounds) for 3/4" Dia. Line	Load (Pounds) for 1" Dia. Line
Breaking Strength	900	2000 (@ 110% Elongation)
100	440	600
75	219	440
50	186	300

Systems Survival		Slippage	Modelling Studies	Trajectory &/or Data Interpretation	System Costs
Buoy	Tether/Drogue				
1. PRL Hull: More test data needed 2. Scripps/ McNally Hull: Reliable & proven, but heavy. 3. Satellite transmitter problems generally solved.	1. Need more broken pieces for study. 2. Examine need for more compliance in design (e.g., shock cord or distributed buoyancy) 3. Need more rugged tether/drogue designs for severe environments 4. Need for "drogue farm" tests or bath tub for periodic retrieval with minimum vandalism. 5. Need fishbite data vs. fish cleaning lines 6. May be able to eliminate thimbles or pot terminations 7. Organization to provide focal point for buoy performance and survival statistics	1. Ability to make direct slip measurements with special system design under special conditions. 2. No real ability to predict slip. 3. Need comprehensive series of full scale tests to measure slip and buoy-drogue dynamics. 4. In order to better analyze existing trajectory data for when drogue dropped off, need good wind data.	1. Analytical model development well enough in hand to require full scale hard data. 2. Data from Draper Lab tests in Bermuda will update models and help improve tether/ drogue designs for survival.	1. Need large, coherent arrays to increase value of data. 2. Wind field data in deployment area useful for trajectory interpretation.	1. PRL: • Basic: $3500. • With Drogue & Tether: $4100. • Add $225 for T_{water}

FIGURE 3.1.1 SUMMARY OF COMMENTS AND RECOMMENDATIONS FROM CONFEREES

REFERENCES

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Kirwan, A.D., Jr., G.J. McNally, S. Pazan, and R. Wert, 1978, "Analysis of Surface Current Response to Wind", Texas A&M University, Dept. of Oceanography, College Station, Texas, 77843 (Submitted for Publication).

McCullough, J.R., 1977 "Problems in Measuring Currents Near the Ocean Surface", MTS-IEEE OCEANS-77 Conference Proc., Vol. 2, pp. 46A1-A7.

McCullough, J.R., 1978, "Near Surface Ocean Current Sensors: Problems and Performance", NOAA-Sea Grant Conf. on Current Measurement, Newark, Delaware.

Nath, J.H., 1977a, "Laboratory Validation of Numerical Model Drifting Buoy - Tether - Drogue System", Final Report to NOAA Data Buoy Office, National Space Technology Laboratories, NSTL Station, MS, 39529, on Contract No. 03-6-038-128.

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Saunders, P.M., 1976, "Drifting Buoy Lagrangian Test", Final Report on Woods Hole Contract NAS 13-5 with the NOAA Data Buoy Office.

APPENDIX A

DRIFTING BUOY CONFERENCE SCHEDULE

- First Day Schedule -

Tuesday, July 11, 1978

8:30 a.m.	Coffee, Get Acquainted	
9:00 a.m.	Introduction	Mr. William Vachon, ADL
9:15 a.m.	Satellite System Status	Mr. John Masterson, NCAR
9:30 a.m.	NDBO's Drifter Development Program	Mr. Edmund G. Kerut, NDBO
10:00 a.m.	Drifter Data from the ADS and NORPAX Experiments	Mr. Gerald McNally, SIO
10:30 a.m.	Break	
10:45 a.m.	The Use of Drogues in Tracking Rings and the Gulf Stream	Dr. Philip Richardson, WHOI
11:15 a.m.	Drifter Experiences and Plans at AOML	Dr. Donald Hansen, AOML
11:45 a.m. ↓ 1:15 p.m.	Lunch, WHOI Carriage House	
1:15 p.m.	Drogue Slippage Experiments at the Woods Hole Oceanographic Institution	Mr. James McCullough, WHOI
1:45 p.m.	The Free Drift Velocity of a Floating Object in Waves	Dr. John Nath, OSU
2:15 p.m.	Break	
2:30 p.m.	Woods Hole Physical Oceanography Seminar	Dr. David Halpern, PMEL
3:45 p.m.	Dynamic Response Tests and Dynamic Modelling of Full Scale Drogued Drifters	Mr. John Dahlen & Mr. Narender Chhabra, C. S. Draper Lab.
4:15 p.m.	Future Expectations and Uses of Drogued Drifters	Dr. James McWilliams, NCAR
5:00 p.m.	Adjourn Until Wednesday	
6:30 p.m.	Cocktails--Clark Laboratory, Fifth Floor	

DRIFTING BUOY CONFERENCE

- Second Day Schedule -

Wednesday, July 12, 1978

9:00 a.m.	The Use of the NDBO Drifting Buoy Computer Model as a Design Tool	Dr. David Brooks, Sperry Rand
9:30 a.m.	Experiences with the Polar Research Lab (PRL) Drifting Buoy	Mr. Wally Brown, Polar Research Lab (PRL)
9:45 a.m.	A System for Automatically Positioning a Drifting Buoy by LORAN-C Using a HF Return Link	Mr. Clayton Collins, WHOI
10:00 a.m.	Plans for Drogued Drifters in Pacific Equatorial Studies	Dr. William Patzert, SIO
10:15 a.m.	Break	
10:30 a.m.	The Canadian FGGE Drifter	Mr. Andrew Reid, Hermes Electronics, Ltd.
10:45 a.m.	Interpretation of Satellite-Tracked Drifter Trajectories in the Indian Ocean	Dr. Henry Stommel, WHOI
11:15 a.m.	Summary Plans and Recommendations	All Participants

APPENDIX B

LIST OF ATTENDEES

DRIFTING BUOY CONFERENCE

JULY 11 & 12, 1978

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