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REPORT TO THE INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION ON OCEANOGRAPHIC DRIFTING BUOYS

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Chairman, SCOR Working Group 66:
Oceanographic Applications of Drifting Buoys.

(SC-82/CONF.218/COL.36)

Contents:

This is a preliminary version of the report requested by IOC, and has been prepared by the WG66 chairman with minimal consultation with the members. It is hoped that a final version will be forthcoming which will incorporate the suggestions of the membership.

1. Introduction

The availability of satellite systems for locating low power transmitters and storing the data they have transmitted has made it possible to track relatively small and inexpensive drifting buoys anywhere on the Earth's oceans. Such buoys have now been in use in oceanography for nearly a decade. This report attempts to provide a brief summary of the current level of technological achievement, and to outline some future possibilities and needs.

2. Background

Drifting buoys have a long history of use in oceanography, principally for the measurement of currents by following the motions of floats attached to some form of sea anchor or drogue. Such techniques are normally restricted to limited areas by the tracking method employed. Shore based visual, radar or radio direction finding tracking systems suffer from range limitations, while the finite speed and endurance of ships and aircraft combine with their high operational cost to make it impractical to track more than a few buoys for a few days or weeks.

The advent of artificial satellites carrying systems for collecting data from remote transmitters of relatively low power eliminated many of these restrictions. However the necessity of determining buoy position by reference to some existing navigation system resulted in comparatively expensive systems limited to working within the coverage of the navigation system. The development of systems which permitted the calculation of the position of a buoy or other remote platform directly from information received by the satellite, independent of other navigational aids, has removed even these limitations. The availability of satellite data collection and location systems which can routinely determine the position of a relatively inexpensive and low power station on a global basis has led to the present interest in oceanographic applications of drifting buoys and similar automatic platforms.

In the decade for which practical satellite tracking systems have been available, satellite-tracked drifting buoys have already made significant contributions to oceanography. Buoys tracked by the Eole satellite, and later by the RAMS system aboard Nimbus IV, helped reveal the nature of the eddy field in the Tasman Sea. The trajectories of drifters deployed as part of the NORPAX project contributed to the description of the easterly drift in the North Pacific. Drifting buoys deployed in the Gulf

Stream and Kuroshio have helped describe the nature of the meandering and eddy-shedding processes in these currents. Similarly, the trajectories of buoys in the Agulhas Current helped clarify ideas regarding the path of that current and its interactions with bottom topography. Tracks of drifters in the North Atlantic have confirmed several old ideas about the current patterns at the tail of the Banks. The large array of meteorological drifting buoys deployed in the Southern Hemisphere for the FGGE has produced a great deal of information about current systems and the statistics of meso-scale motions in the Southern Ocean. Equatorial regions in all three oceans have been studied using drifting buoys, which have revealed details of both time dependent behaviour and the structure of the mean currents. One of the earliest applications of satellite-tracked automatic stations was in studying the movement of Arctic pack ice, and such stations have been in almost continual use in both the Arctic and the Antarctic ever since. The attached bibliography gives references to all but the most recent work.

With care in the design, construction and handling of the buoy and its components, lifetimes of a year or more are not unusual. Of the 368 buoys deployed for the FGGE, 263 continued to transmit for more than 6 months, 177 for more than a year, and 56 for more than 18 months.

In almost all cases the main interest of oceanographers has been in the buoy tracks, even though many of the buoys were equipped with other sensors. Data from buoys equipped with drogues in the upper mixed layer is considered to be an accurate measure of the currents in that layer. However, the drogues do not last as long as the buoys, so that there has been considerable interest in interpreting the data from buoys without drogues. Rather surprisingly, the movements of such buoys are not obviously dominated by the wind, to the extent that, for some buoy types, it is difficult to tell from the buoy track whether or not a drogue is attached to the buoy.

The most commonly measured parameters have been barometric pressure and surface water temperature. Both types of measurements have been made reliably over long periods as part of both research and operational programs. The main difficulty in using the data has been that it is often hard to detect drifts or shifts in the sensor calibrations, due to a lack of other comparison data in the very isolated regions where the buoys are most valuable.

Although most drifting buoys have been launched from research vessels or other scientifically oriented ships, many have been deployed by normal commercial vessels, including container ships. A number have also been launched from aircraft, with no apparent degradation of their performance.

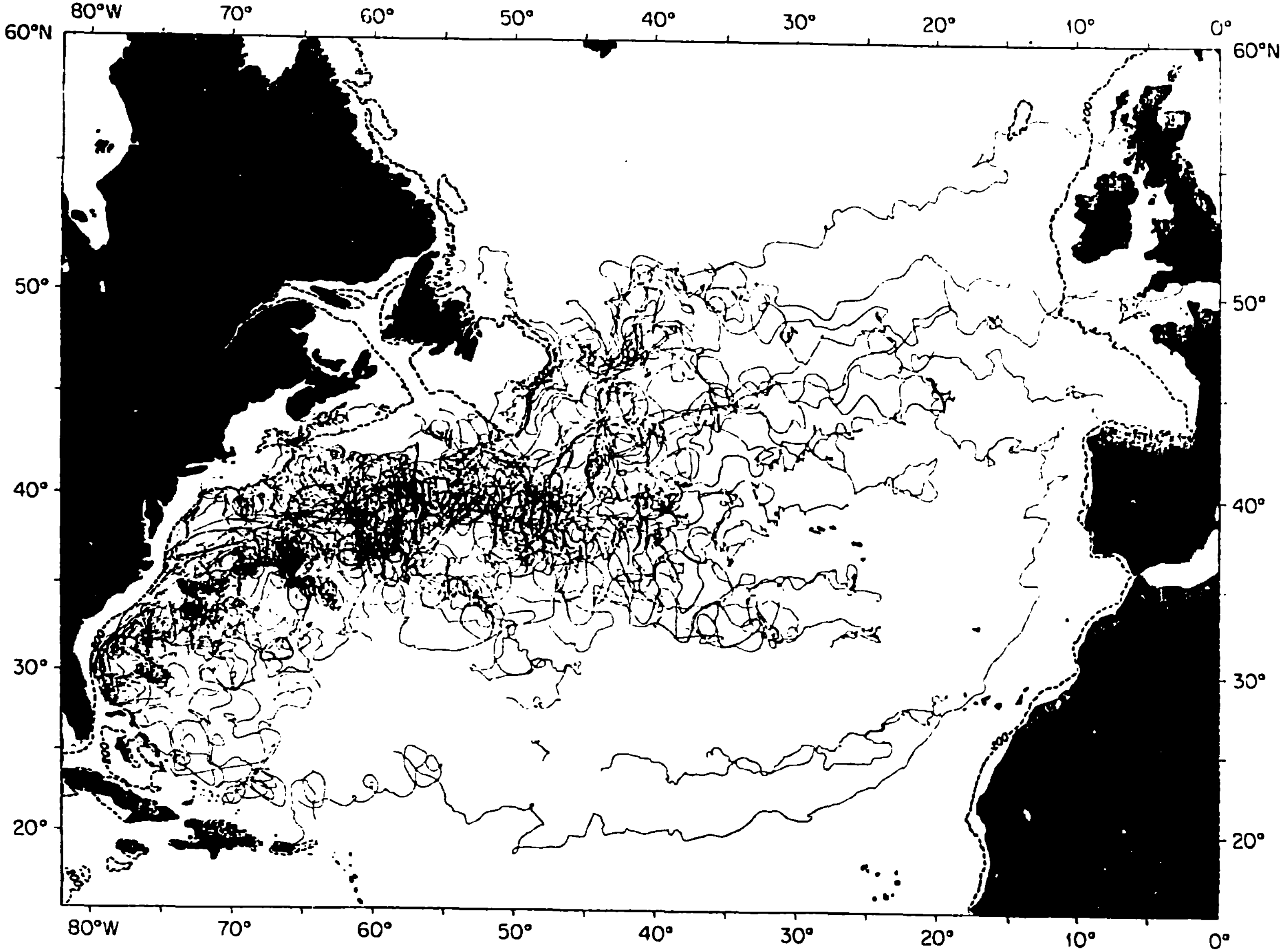


Figure 1. Tracks of drifting buoys in the North Atlantic)
(courtesy P. Richardson, WHOI)

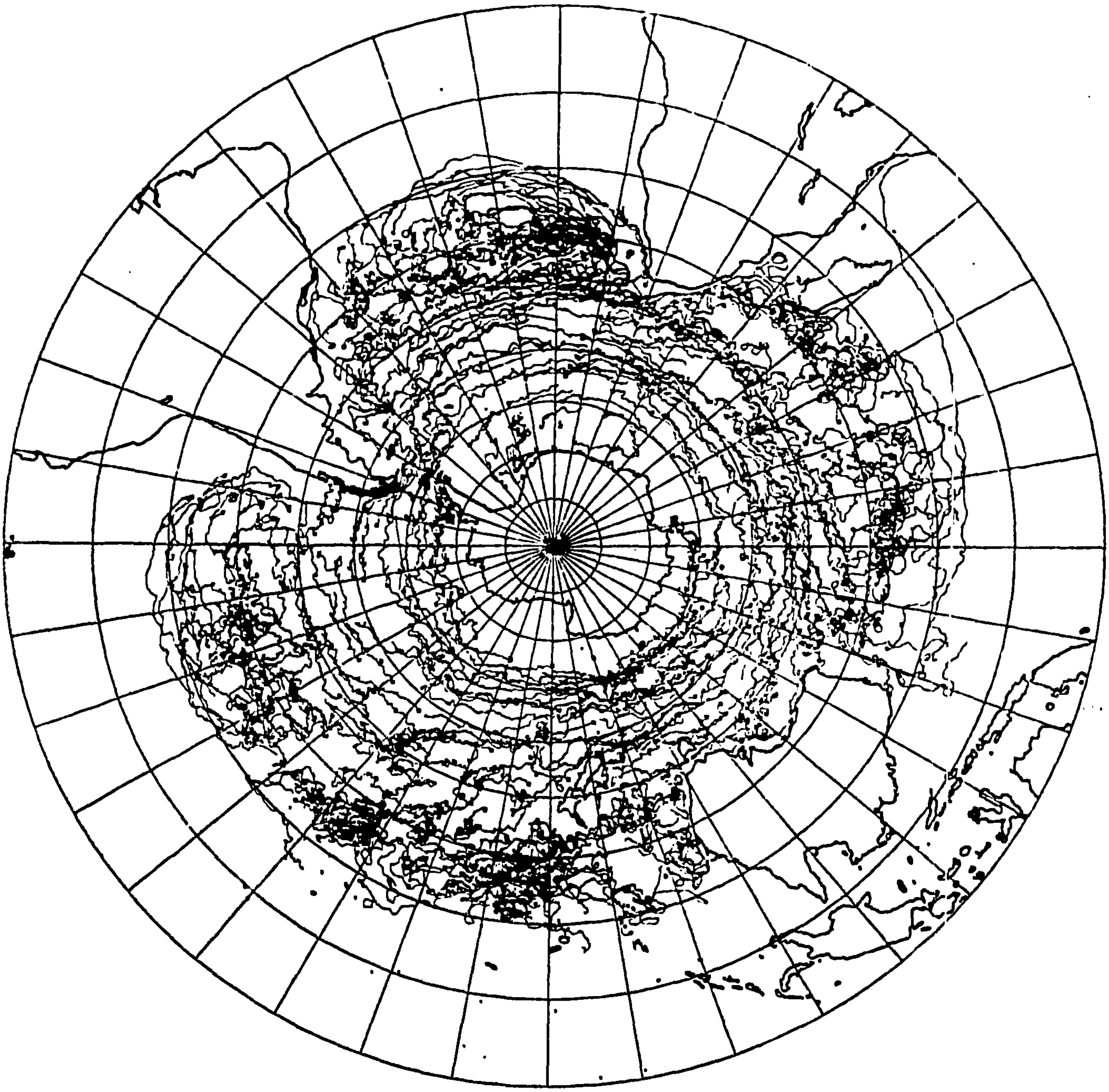


Figure 2. Tracks of drifting buoys launched south of 20° South during the FGGE

3. Current Status

3.1 Data Collection and Location System

At the present time, the only operational satellite-based data collection and location system is the Argos system carried aboard the NOAA series of polar-orbiting satellites. This system first went into service in late 1978, and is planned to continue until at least 1987. The accuracy of buoy positions obtained with this system depends on the stability of the buoy transmitter, but is usually better than 1 km. with currently available commercial transmitters. There are normally two satellites in operation, which means that a minimum of 4 positions per day are obtained from a buoy in equatorial regions, and up to 28 positions per day in polar areas. In temperate latitudes 8 positions per day are typically provided. These are not equally spaced in time due to the fact that the angle between the orbital planes of the two satellites is approximately 60°, rather than the 90° which would give equal spacing of the data.

The special buoy transmitters used with Argos transmit at intervals of approximately 1 minute, and can send up to 64 data words of 8 bits each on every transmission. By sending different parts of the message in subsequent transmissions up to 256 data words can be sent with good probability of reception of the entire message.

The Argos system is administered by Service Argos, which is located in Toulouse, France and is part of the French space agency, Centre National d'Etudes Spatiales (CNES). To avoid interference between buoys a registration procedure must be followed, in which each buoy is given a unique identification code by Service Argos. Similarly, transmitters for use with the system must meet certain technical criteria and be approved by Service Argos. The frequency band used (401 MHz) is reserved for environmental purposes, so that programs using the Argos system must be related to environmental studies, and be accepted by the joint NOAA-NASA-CNES Argos Operations Commitee which normally meets two or three times a year. Details on the various administrative procedures which must be followed may be obtained by contacting Service Argos at the address given in Annex 1. This administrative process should be begun several months before the first transmissions are planned.

Depending on the requirements of the buoy user, there are several ways in which the data collected by the Argos system may be obtained. In addition to overseeing the administration of the system, Service Argos also operates a data processing centre in Toulouse, which can calculate buoy positions and also decode data transmissions. The resulting positions and data are then available to the user on computer compatible tapes on a monthly or fortnighly basis. They are also available in computer files accessible by telephone, or telex, within between 1.5 hours and 8 hours after the time of transmission. Data meeting the necessary criteria , including an appropriate format for the transmissions from buoy to satellite, may be distributed automatically over the Global Telecommunications System (GTS) operated by the World Meteorological Organization (WMO), again within 1.5 to 8 hours after being transmitted by the buoy.

Although the administration of the Argos system is supplied without charge, the data processing service is operated on a cost recovery basis, with charges based on the number of days for which transmissions are received for each buoy plus the costs of data delivery. For 1982 the standard rate was 125 French Francs per buoy day, plus 5 FF per day for access to the computer files, and 500 FF for each magnetic tape containing data from one experiment and sent outside the European Postal Union. However the rate structure is complicated and these are only examples, so that Service Argos should be contacted for details. Government and other non-profit users may reduce their costs by participating in the Argos Joint Tariff Agreement, which involves payment of a fixed cost covering all buoy usage up to a certain maximum. The best source of information is again Service Argos.

Buoy users requiring data within times shorter than a few hours after transmission have also the possibility of receiving the data directly from the satellite. Each buoy transmission is rebroadcast by the satellite as soon as it is received, so that anyone with a suitable receiver within radio range of the satellite can receive the data. Such receivers, or Local User Terminals (LUTs) are already being operated by a number of agencies, and are also available commercially. Although buoy positions can be determined from the information received by a LUT, the accuracies achieved so far are measured in tens of kilometers, much worse than those obtained through Service Argos's Toulouse processing centre. Transmitters for use with LUTs must still follow the Argos administrative procedures, to avoid interference aboard the satellite. There is no charge for use of the satellite with an LUT if the Argos processing centre is not also used. Some LUT operators have found it prudent to take advantage of the "back-up" service offered by Service Argos, which permits a rapid change from LUT to Argos processing centre in the event of a malfunction of the LUT, as well as allowing recovery of data up to three months after it was transmitted.

Buoy users have generally been very happy with the technical performance of the Argos system, and with the position accuracy in particular. On the other hand, the complexity of the administrative procedures has resulted in confusion and delay for many. Also the fact that the cost of data processing and position calculation, which must be paid by the user, is comparable to the cost of the buoy itself has restricted many users programs.

3.2 Buoys

Although many of the drifting buoys used by oceanographers continue to be built in laboratories or by small companies closely associated with laboratories, most of them follow similar basic designs. The most common consists of a cylindrical spar buoy, typically 20cm in diameter by 2 to 4 m in length, with a conical floatation collar in the region of the water line. The batteries, transmitter and other electronics are located inside the spar, which may be of metal or plastic material, and the antenna is located in a fibreglass reiniforced plastic cone or cylinder at the top. Depending on the complexity of the electronics and the battery life desired, the buoys weigh between 70 and 150 kg. Commercially available buoys built along such lines have demonstrated good reliability under all ocean conditions. Two examples are shown in Figure 3. A list of major known suppliers is given in Annex 2.

The standard designs have not yet fully explcited the possibilities for simple, small lightweight buoys which are permitted by the low power requirements of the transmitters. Some indications of these possibilities are given by Hermes Electronics' "air drop drifter", shown in Figure 4a, and the CEIS CML 80 MP beacon, shown in Figure 4b. The former, which is suitable for deployment from light aircraft and small vessels, can be packaged in a cube 60 cm on a side, complete with drogue, and weighs 29 kg with batteries for 6 months operaticns. The latter, which was developed for attachment to the deck of sailing yachts participating in long distance races, is 40cm in diameter and 15 cm in height, with batteries for three to six months, and could be equally well attached to any sort of simple float of buoy to create an oceanographic drifting buoy.

3.3 Drogues

Confidence in the ability of drifting buoys to represent ocean currents is greatly enhanced by the addition of a sea anchor or drogue to increase the cross-sectional area of the buoy system at the depth at which the currents are to be measured. The most widely used forms of drogue have been parachutes and window-blind drogues. The drift of the buoy comes about as a result of the combined forces of wind drag, drag due to the motion of the buoy hull with respect to the water, and drag on the drogue and drogue line due to their motion with respect to the water at their respective depths. In the simplest case, where the drogue is in the surface mixed layer, the current seen by the buoy and by the drogue may be assumed to be the same, so the only forces which must be considered are the wind drag, generalised to include related ocean surface boundary layer effects acting in the direction of the wind, and the drag due to the movement of buoy and drogue through the water. The ratio between these two forces will depend on the relative densities of air and water (1/1000) and the ratic of the cross-sectional areas exposed to air and water. For a cylindrical buoy with equal areas above and

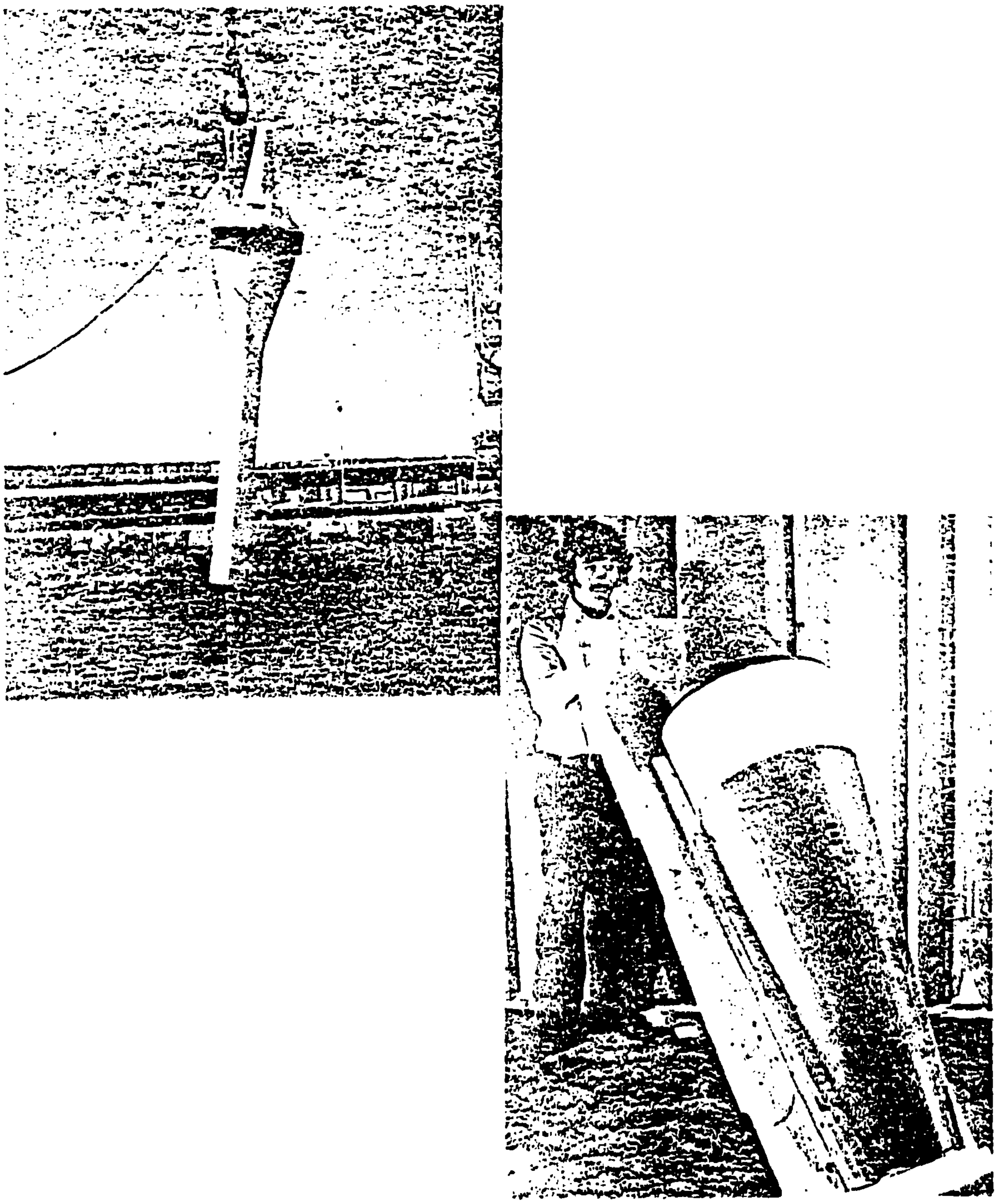
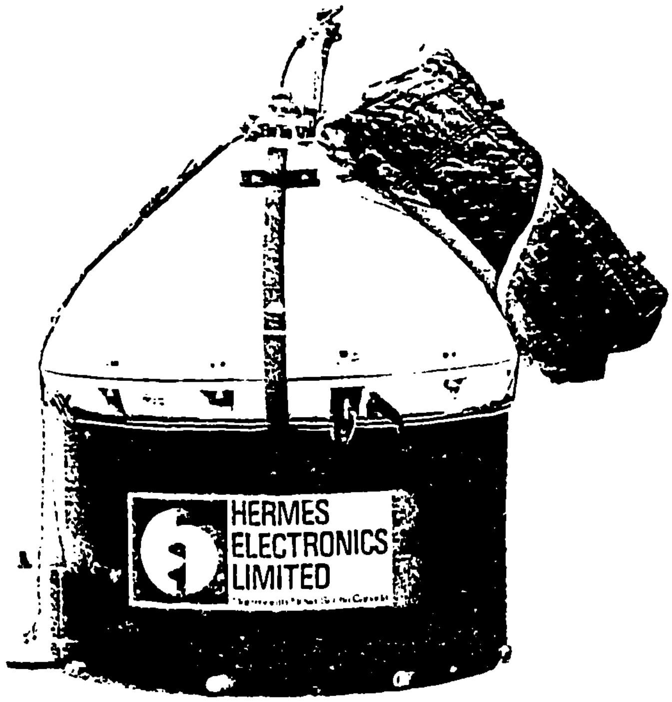


Figure 3. Two examples of commercially available drifting buoys: a)Safare-Crozet Marisonde, b)Hermes Electronics FGGE Drifter



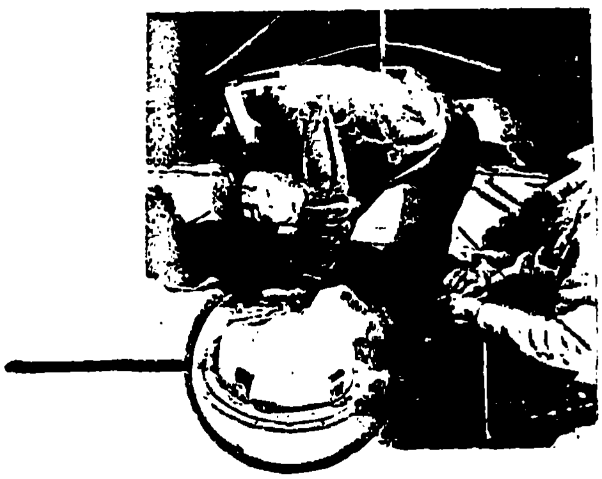


Figure 4. Two examples of advanced designs exploiting the compactness of Argos beacon transmitters: a)Hermes Electronics Air Deployable Drifter, b) CML-80-MP from C.E.I.S.Espace,Centre Commercial de Gros, Avenue de Larrieu, 31094 Toulouse Cedex, France

below the water-line, and no drogue, the drift would be about 3% of the wind speed if the logarthmic boundary layers were neglected. In practice the wind drag seems to be much smaller than would be expected from theorectical calculations, perhaps due to the modification of the wind profile by waves or to the reduction in the buoy drag coefficient due to the high levels of turbulence in the atmospheric boundary layer. With the addition of a drogue it is possible to reduce the calculated drift to less than 1 or 2 cm/sec under all but the most extreme wind conditions.

In the case where the drogue is at a depth where the current is significantly different from that in the upper mixed layer the situation becomes much more complex. If the current shear is sufficiently large, the main balance of forces is between the drag on the buoy hull, the drag on the drogue and the drag on the tether line connecting them. Here the relative speeds of the hull and drogue with respect to the water at their particular levels will be inversely proportional to the square roots of their respective areas. This makes it much more difficult reduce the drift of the drogue relative to the water at its level to less than a few cm/sec, which may be quite significant if the currents at that depth are only a few cm/sec. Differences in direction between the currents in the surface layer and those at the drogue depth may also lead to a large errors in the apparent current at drogue depth.

The parachute is attractive for use as a drogue because of its relatively low cost and weight and the large surface area which can be obtained with from a compact predeployment package. Also, because of the horizontal length of the shroud lines, the buoy may move relatively freely in the vertical direction in response to waves. On the other hand, a parachute requires a certain minimum drift through the water to remain open, and there is always concern that, once collapsed, it will remain closed due to tangling of the shroud lines. In most cases where parachutes have been used, they have been deployed at depths of greater than 30m.

The other widely used type of drogue is the "window blind", which resembles a square sail suspended by a line attached to its upper yard. This has the advantage of remaining deployed even when it has no motion relative to the water. It is also relatively compact and is easily packaged with the buoy when the spars of the drogue are shorter than the buoy hull. Its main disadvantage is its great resistance to vertical motion, which, in the presence of waves, results in high loads on the buoy, the drogue support line and the drogue itself. To reduce this it is necessary to allow sufficient stretch or compliance in the drogue support line.

Many other types of drogues are possible. These include the "sock" (a vertical cylinder made of fabric with open hoops at the ends), various shapes made of rigid material, and long lengths of rope weighted at the free end.

One of the problems with most currently available drogues is that their average lifetime is less than that of the buoy. In many cases, it is not possible to unambiguously detect in the buoy trajectory the point at which the drogue has been lost. Several different principles have been used in attempting to design a sensor which will indicate whether the drogue is still attached, but the results have generally proven to be as unreliable as the drogue, introducing further uncertainties.

3.4 Sensors

The sensors which have been used most often on drifting buoys have measured surface temperature and barometric pressure. Although experience with such sensors goes back for several years, and includes the FGGE where more than 300 buoys with these sensors were used, much care is still required by the manufacturer and buoy user to ensure accurate and reliable measurements. In order to obtain barometric pressure measurements to an accuracy useful for the computation of geostrophic winds, careful attention must be giver to the choice of pressure sensor and to the design of the pressure inlet or port. An accuracy of 1 mb over the life of the buoy is still difficult to achieve, and even more dificult to verify. If barometric pressure measurments are required, it is recommended that one of the manufacurers with experience in the FGGE be consulted, as well as the meteorological agencies with experience in using drifting buoys.

Measurement of the water temperature at a shallow depth on the buoy hull is fairly straightforward, and standard techniques will yield an accuracy of 0.1 °C. The main problems are radiational heating of the sensor, and sensor drift over the buoy lifetime. One manufacturer encountered reliability problems because housing for the temperature sensor was made of a material which was electrochemically active with the buoy hull, and consequently corroded, reducing the sensor life. Others have avoided such problems by placing the temperature sensor inside the buoy, in thermal contact with the metal hull. The true accuracy of buoy temperature observations at sea has been difficult to assess due to the buoy sensors having different time constants and being at different depths from other conventional sensors.

Much work has been done on developing systems for obtaining water temperature measurements below the surface, with the result that such systems can now be expected to have a reliable life of several months and to not cost more than the rest of the buoy. The main problem has been in the mechanical engineering of the connection between the cable containing the temperature sensors and the buoy hull, which usually has a very "lively" motion in the ocean wave field. In the earlier versions, repeated flexure of the cable under load led to breaking of the electrical conductors. This problem seems to have been solved independently by the Polar Research Laboratory, the Bedford Institute of

Oceanography, and the Laboratoire d'Océanographie Physique du Muséum d'Histoire Naturelle in Paris, all of whom have built thermistor chains which have survived several months at sea. The systems built to date only measure in the upper 100 to 150m, but efforts to extend this depth are continuing. Much improvement in such sensors can be expected in the next few years if the present level of development effort continues.

The measurement of wind speed and wind direction have also received some attention, but no satisfactory technique has resulted. The main problems are in finding an anemometer which will function reliably in the harsh environment close to the sea surface, and in deciding how to interpret measurements from a level usually below the average height of the wave crests.

Wave measurments have also been made from drifting buoys. In view of the similarity in size and heave response between typical drifting buoys and commercially available wave measuring buoys such as the "Waverider", these operationally proven systems can be readily adapted for use with multipurpose drifters. Also, commercially available wave measuring buoys equipped with appropriate satellite transmitters can be used in a free drifting mode if so desired.

Other sensors which have been considered, but which have not yet received any serious development effort, include air temperature, wet bulb temperature, air-sea temperature difference, incident radiation, and ambient noise for precipitation and wind speed. It has also been suggested that drifting buoys equipped with echo sounders could provide bathymetric data in regions which are presently poorly known, such as parts of the South Pacific and the Arctic Oceans.

One of the major problems with drifting buoy sensors is that of determining their accuracy under operational conditions. They are normally deployed in remote areas, where there are very few sources of more conventional data for use in comparisons. The sampling charactersitics of the buoy sensors may be so different from sensors carried aboard the ship launching the buoys that comparisons are difficult, even when special procedures are followed. A sensor which was operating perfectly at time of launch may drift or fail in some subtle way in the months following. In planning drifting buoy programs in remote areas no opportunity to obtain data which could verify buoy sensor performance should be neglected.

3.5 Interpretation of drifting buoy data

To the extent to which drifting buoys follow the motion of water particles, their data may be considered to be Lagrangian, in contrast with the Eulerian data obtained with sensors which are fixed relative to the Earth. Lagrangian data requires an entirely different set of techniques for analysis and interpretation, much of which is yet to be developed.

Considerable progress has already been made in theoretically relating the statistics obtained from Lagrangian measurements in a number of simple flow fields to those obtained from Eulerian measurements of the same flows. In practice, however, most of the work using drifting buoys in a quantitative way has relied on transformation of the buoy data into a quasi-Eulerian form. This usually involves an assumption that the flow is steady, or at least that the time required for features to change is much longer than the time required for a buoy to cross them.

Qualitative interpretations of buoy tracks have also proven to be useful in a variety of ways. They can be used to relate the locations of ship based observations to surrounding dynamic features. Also they may reveal flow patterns related to bottom topography, in the deep ocean as well as on the continental shelf, and thus aid in interpreting moored current meter data. Some types of oceanic features involve surface convergences, and will consquently trap drifting buoys, which then can be used to track the positions of the features.

The lack of understanding surrounding the effects of wind on drifting buoys and on the currents of the uppermost few meters of water has made many oceanographers justifiably cautious about directly relating buoy motions to ocean currents. Indirect evidence is beginning to accumulate which seems to indicate that wind effects are less important than might be expected. An example of this is shown in Figure 5, where the eddy kinetic of buoy motions in the North Atlantic is clearly out of phase with the eddy kinetic energy of the winds.

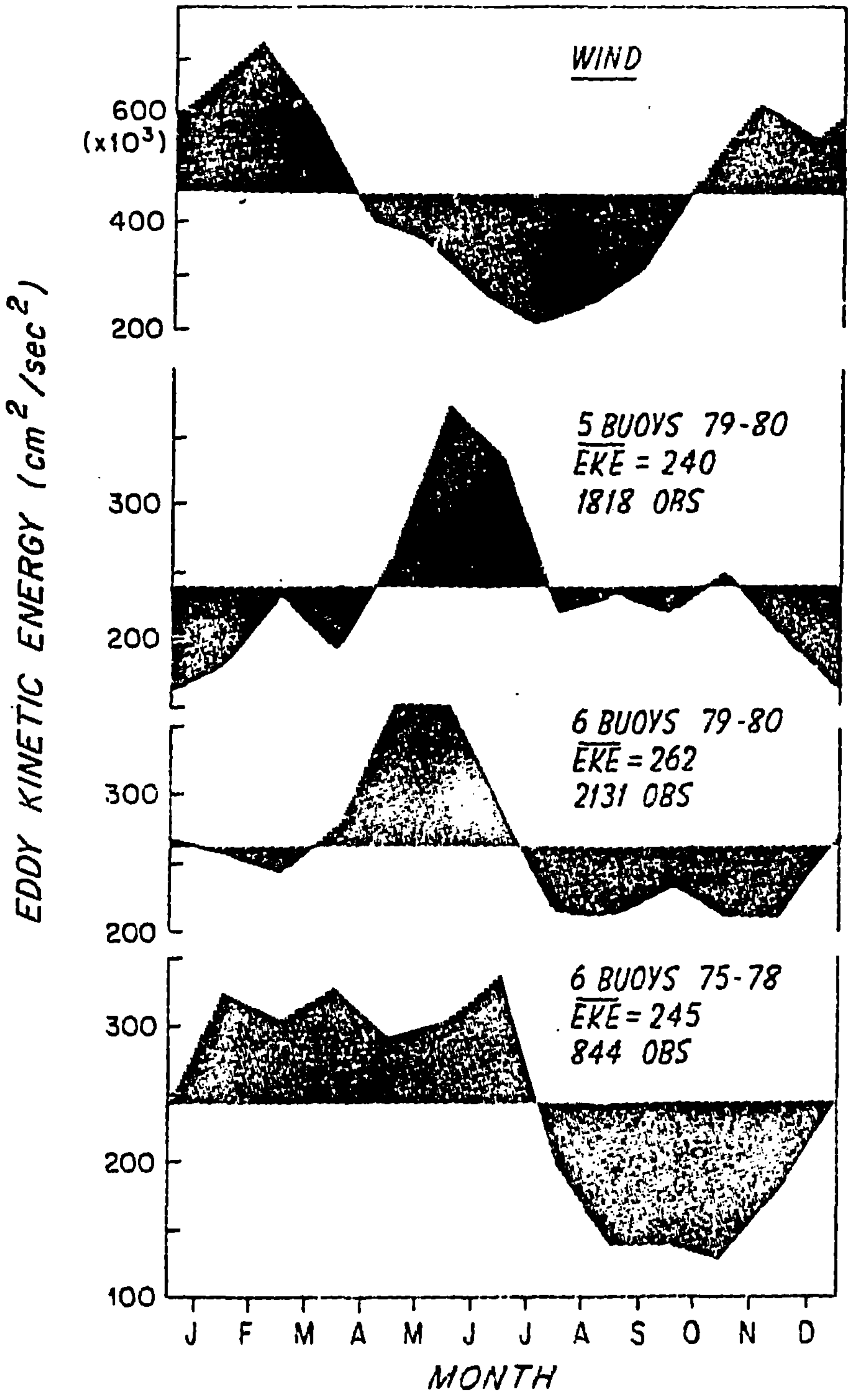


Figure 5: Eddy kinetic energy of winds and drifting buoy motions in the western North Atlantic, as a function of time during the year. (supplied by P.Richardson, WHOI)

4. Future prospects and needs

Drifting buoys have obviously been accepted as one of the standard techniques available to oceanographers, even though, like the other standard techniques, they have some limitations. Unlike some of the other techniques, which have reached a plateau of evolution, the drifting buoy technique is still under active improvement and development along clearly defined lines. One of these is in the area of sensors, particularly for subsurface measurements, but also for surface observations. Another area in which the technique can be expected to evolve is that of velocity measurement, where improvements in drogue performance and reliability will combine with improved understanding of the behaviour of the upper few metres of the ocean to reduce or eliminate many of the uncertainties currently experienced in interpreting buoy movements in terms of ocean currents. Thus there is every reason to expect increased scientific use of drifting buoys in programs requiring measurements from the upper ocean.

Although oceanographers can take credit for the initial demonstrations that small drifting buoy systems were feasible, much of the subsequent improvement in reliability and measurement capability has been achieved in response to the needs of meteorologists. The planning and implementation of the First Garp Global Experiment, with clearly stated requirements and definite deadlines, provided the momentum which brought substantial advances in drifter technology. The FGGE buoy array clearly demonstrated the capabilities and cost-effectiveness of such buoy systems, but their incorporation into operational meteorological systems has been much slower than hoped for. In the absence of a well defined meterological demand for more, better, and cheaper buoys, would-be buoy developers have been faced with an unorganized oceanographic research community in which every investigator wants things done according to his own ideas. This has slowed the pace of development of standard "operational" buoys, but will hopefully result in the most rapid evolution of a new generation of sensors and buoys, provided sufficient resources are available to permit experimentation.

The only currently foreseen large scale experimental requirement for drifting buoys, aside from operational meteorolgical arrays, lies in the World Climate Research Program (WCRP). Unfortunately the specifications for the observing systems to be used in the various experiments within this program are currently being established, before the evolution of the newer generation of drifting buoy systems is very far advanced. If drifting buoy techniques are to make an optimum contribution to the WCRP, a more organised and coordinated effort is required. Such an effort might also provide a focus for funding.

Although the use of drifting buoys in operational meteorology has been less than expected, it is still not insignificant. To the extent that their requirements are not mutually exclusive, meteorologists and oceanographers have much to gain by cooperation. Buoys deployed primarily for oceanographic purposes may contribute useful meteorological data if equipped with suitable sensors, and meteorological buoys may similarly provide oceanographic data. Hardware developments aimed at one application may be beneficial to the other. One community may be able to assist the other in the testing, deployment or tracking of buoys. This might take place on a local, national, regional or global scale. Suitable coordination mechanisms would greatly facilitate this.

A large amount of drifting buoy data has been collected in the last decade. Although the holdings of individual investigators may not seem very large, the total data set is potentially useful for large scale circulation studies, and climatologically oriented research. An effective way of collecting and archiving drifting buoy data is needed to improve its availability for such purposes.

One of the attractive features of the current situation is that the Argos data collection and location system provides global coverage, so that the same buoys may be used anywhere in the world. In view of the small size of the total drifting buoy market, this helps to keep the cost of buoy electronics below what it would be if each country were using something different. It also means that buoys which drift out of the area of interest of their original deployer may still be used by anyone willing to pay the cost of the tracking. The most important feature of the current satellite tracking system is that even the most remote areas are covered, where the rarity of data makes buoy observations most valuable. In order to be sure of the future availability of such systems, buoy users must continue to make their needs known to the agencies planning and operating satellites.

It seems clear that drifting buoys have earned a permanent place in the "tool-kit" of the research oceanographer. As long as suitable tracking and data recovery systems are available, there will continue to be an interest in their use. Indeed, the increasing costs of building and operating research vessels may be expected to stimulate the use of automatic platforms of all kinds, either to substitute for ships in some kinds of work or to improve the effectiveness of ship operations. On the other hand, the development of buoys, automatic platforms and related sensors requires funds and effort which seem to be increasingly hard to find within the research community. Without some definite commitments, realization of the full potential of such systems will take much longer than it would if even relatively modest resources were available. In any case the rapid evolution of sensor technology and the expanding use of microprocessors combined with the availability of a global satellite data collection and location system makes it practically certain that drifting buoys and other automatic platforms will play a major role in future oceanographic experiments and ocean monitoring systems.

Annex 1: How to Contact Service Argos

Address:

Service Argos
Centre Spatial de Toulouse
18, avenue Edouard-Belin
31055 Toulouse Cedex
France

Telephone: (61) 53.11.12

Telex: 531081 F

Annex 2: Major Commercial Buoy Suppliers

The following manufacturers all supplied buoys which performed satisfactorily during the FGGE, and have since supplied buoys to various agencies.

Hermes Electronics Ltd.
P.O. Box 1005
Dartmouth, Nova Scotia
Canada B2Y 4A1

Telephone:(902) 466-7491
Telex:019-21744

Polar Research Laboratory, Inc.
123 Santa Barbara St.
Santa Barbara, California 93101
U.S.A.

Telephone:(805) 963-1929
TWX: 910-334-3465

Safare-Crouzet
B.P. 171
06005 Nice Cedex
France

Telephone:(93) 84.72.79
Telex: 460813 F

Simrad as
Offshore and Naval Division
P.O. Box 6114 Etterstad
N-Oslo 6
Norway

Telephone: 47 2 67 04 90
Telex: 16136 sim n

Annex 3: Bibliography on Drifting Buoys

The following bibliography was compiled by the members of SCOR WG 66, to cover the period from 1972 through 1981. As well as published articles, it includes many internal and manuscript reports. For convenience it has been divided into three sections:

(A) Scientific applications and results
(B) Technical information
(C) Interpretation of Lagrangian data.

In cases where material in a document is relevant to more than one of the sections it is listed in all relevant sections.

Rather than repeating the addresses of sources for unpublished material, they have been listed separately and are referenced by superscripts in the citations.

Addresses of Sources for Unpublished Material

Superscript	Source
1	NOAA Data Buoy Office National Space Technology Laboratories NOAA NSTL Station, Mississippi 39529 U.S.A.
2	CSIRO Division of Oceanography P.O. Box 21 Cronulla, N.S.W. 2230 Australia
3	Tropical Ocean-Atmosphere Newsletter Dr. David Halpern JISAO University of Washington AK-40 Seattle, Washington 98195 U.S.A.
4	Polymode News Woods Hole Oceanographic Institution Woods Hole, Massachusetts 02543 U.S.A.
5	World Meteorological Organization Case Postale No. 5 CH-1211 Geneva 20 Switzerland
6	Etablissement d'Etudes et de Recherches Meteorologiques Ministere des Transport 77, Rue de Sévres 92106 Boulogne-Billancourt Cedex France
7	Laboratoire d'Océanographie Physique Museum d'Histoire Natuelle 43-45 rue Cuvier 75231 Paris Cedex France
8	CSIR National Research Institute for Oceanology P.O.Box 320 Stellenbosch 7600 South Africa

9 Centre Oceanologique de Bretagne
CNEXO
B.P. 337
29273 Brest Cedex
France

10 NOAA Environmental Research Laboratory
Boulder, Colorado 80302
U.S.A.

11 Hawaii Institute of Geophysics
2525 Correa Road
Honolulu, Hawaii 96822
U.S.A.

12 Scripps Institution of Oceanography
University of California
La Jolla, California 92093
U.S.A.

13 INDEX Coordinator
Nova University Ocean Sciences Center
8000 North Ocean Drive
Dania, Florida 33004
U.S.A.

14 Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543
U.S.A.

15 Argos Users Conference
Service Argos
Centre Spatial De Toulouse
18 ave Edouard-Belin
31055 Toulouse Cedex
France

16 Polar Science Center
University of Washington
Seattle, Washington 98195
U.S.A.

17 National Meteorological Center
NOAA
Camp Springs, Maryland 20233
U.S.A.

18 NASA Goddard Space Flight Center
Greenbelt, Maryland 20791
U.S.A.

19 National Centre for Atmospheric Research
P.O.Box 3000
Boulder, Colorado 80307
U.S.A.

Part A: Scientific Applications and Results

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