DATA BUOY CO-OPERATION PANEL

The Low-cost Barometer Drifter

By the Technical Co-ordinator of the Data Buoy Co-operation Panel

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1) Introduction

Since its third session, the DBCP has been increasingly involved in efforts to persuade meteorologists, and oceanographers to collaborate on combined meteorological and oceanographic drifting buoys.

Developments have been conducted in two directions of collaboration: (i) to install thermistor strings onto non-Lagrangian regular meteorological buoys (developments conducted by meteorologists at Météo-France), and (ii) to equip standard SVP Lagrangian drifters with barometer ports (developments conducted by oceanographers at the Global Drifter Center). Both developments are successful. The two devices are complementary since we now have buoys capable of measuring wind and sub-surface temperature profiles on one hand, and buoys capable of measuring sea surface currents on the other hand. Both devices measure Atmospheric Pressure and Sea Surface Temperature. However the cost of the meteorological buoys equipped with thermistor strings remains relatively high. This article only deals with the Lagrangian drifter equipped with a barometer port (refer to the DBCP annual report for 1992 for more details regarding the other device).

The Global Drifter Center (GDC, at Scripps Institution of Oceanography, La Jolla) of the WOCE and TOGA Global Surface Velocity Program (SVP) was responsible for the development of a low cost Lagrangian Drifter equipped with a barometer port. The DBCP collaborated actively with the GDC in the field test of some 25 prototypes "barometer" drifters. Meteorological Agencies of Australia, Canada, France, and the United Kingdom, as well as the GDC purchased and deployed 25 units, including a total of 16 units deployed at sea during the period August 1992 to February 1993 (figures 6 and 7).

The NOAA National Ocean Service in collaboration with the Scripps Institution of Oceanography are now confident enough in the new design of the low cost barometer drifter to purchase and plan for deployment in 1994 of 86 units in the Southern Hemisphere as part of the WOCE and TOGA programs. Commercial production will start in late 1993 with a purchase cost of US$ 4600 per unit.

At its ninth session in Athens, 19-22 October 1993, the Data Buoy Cooperation Panel recognized that the design was successful. It stressed that this new situation opens the door for direct cooperation between meteorologists and oceanographers particularly because the design meets both communities requirements, and because it is much less expensive than previous designs of buoys measuring atmospheric pressure. For example implementation of common oceanographic and meteorological buoy programs would be very cost effective for both communities and would therefore make it possible for the same cost to dramatically increase the data return. Such rationalized and standardized programs could then very well be integrated in the Global Ocean Observing System (GOOS) and the Global Climate Observing System (GCOS).

The DBCP therefore urged its participants, and all others involved in drifting buoy programmes to look as much as possible for opportunities of co-operation at the national level between oceanographers and meteorologists. It is to assist them in this task that the DBCP decided to include this article in the present DBCP annual report for 1993.

2) Design of the low cost "barometer" drifter:

2.1) Background:

The low cost barometer drifter is basically a standard SVP drifter to which an air pressure port has been added (figure 2, figure 3). The standard SVP drifter (figure 1) is now a proven and reliable design and it has been deployed at sea in large quantities for oceanographic research programs as part of the World Ocean Circulation Experiment (WOCE) and the Tropical Ocean and Global Atmosphere programme (TOGA). For the period 1 July 1991 to 31 January 1993, the WOCE Surface Drifter Data Assembly Centre has processed data from 1315 drifters (WOCE Report No. 104/93) deployed in the Pacific and North Atlantic oceans. It is capable of accurately measuring sea surface currents (+/- 1 cM/S) in 10 M/S winds and sea surface temperature (+/- 0.1 C). Nominal life time is 18 month. It has been shown that half life time of standard SVP drifters is in the order of 440 days (Figure 5).

2.2) Surface current measurement

For measuring Surface Velocity, standard SVP buoys have been designed to be good Lagrangian drifters (buoys which follow the water motion well) and very specific requirements of drogue and surface float design have been developed (large holey sock drogue, spherical floats and thin wire tethers...). Laboratory and at sea tests have been conducted to guarantee the reliability of SVP drifter measurements.

The slip (i.e. the motion of the centre of the drogue relative to the moving water parcel) has been minimized. Many phenomena can induce slip; the main ones are wind stress, surface gravity wave effects and vertical shear of currents. Therefore tests have been conducted on various shapes of floats and drogues (NOAA data report 1990). These tests show that the most efficient shapes are small, spherically-symetric surface and subsurface floats, thin-wire tethers and a large semi-rigid drogue. The drogues which have a high drag coefficient and stable water following characteristics are the TRISTAR (Niiler, et al., 1987) and the Holey Sock (Nath, et al., 1979). The drag area ratio is the drag coefficient of the drogue times the frontal area divided by the sum of the products of the drag coefficient and the largest projected frontal areas of floats and tethers. A drag area ratio for the drifter greater than 40 will give the instrument the capability to make current measurements accurate to within 2 cM/S. Using a correction formula, a wind correction will then improve this accuracy to 1 cM/S if the wind is known within 4 M/S (Figure 10). In extra tropical areas, if an optimized network of low-cost barometer drifters is maintained, the air pressure field and consequently the wind field will be known to a better accuracy.

The same general design as for the standard SVP Lagrangian drifter has been chosen for the low-cost barometer drifter.

2.3) Drogue detector (Submersion switch)

A drogue detector is necessary for ascertaining if the drogue is still attached. A Drifter without a drogue, is of little value for surface velocity measurements. Since the surface float goes under the water more often when the drogue is attached, one principle is to install a submersion detector (switch) on the surface float and to analyze the time series in order to deduce if the drogue is still attached.

2.4) Sea Surface Temperature measurement

The low cost "barometer" drifter is also equipped with a Sea Surface Temperature sensor that is designed to make measurements accurate to 0.1 Celsius. Once again, experience gained with the standard SVP drifter has been used. To obtain this accuracy, tests show that one must install the temperature sensor outside the hull of the drifter float. Also, calibrations of a number of thermistors while connected to the electronics circuitry in a test tank in various range of temperatures must be done. Only these kind of tests and calibrations can provide accurate coefficients to be used to convert raw data (resistance) into physical values (Celsius) within +/- 0.1 Celsius. The life time of the sensor will exceed that of the transmitter.

2.5) Atmospheric Pressure Measurement

The air pressure port has been designed to withstand frequent immersion with no loss of accuracy. The port is elevated to some height above the float itself to avoid Venturi effects caused by air flow over the curved float surface. The total surface of the mast is lower than 10% of the total frontal area so that wind stress does not induce a substantial slip effect compared to the one induced through the hull itself. The design is based on a port used on moored buoys by the United Kingdom Meteorological Office, which has had extensive field tests in the wind tunnel. Internal baffling is provided against submergence surges and sufficient back up volume of air assures that water does not enter the barometer duct.

The barometer port design as shown in figure 4, is based on the following rationale (WOCE/TOGA Lagrangian Drifter with Barometer Port, May 1991):

(i) Field observations indicate that the surface float of the SVP Lagrangian drifter is pulled under the water to a depth of 1-2 m at the crests of wind waves, therefore an overpressure of 200 hPa can be expected on the barometer. Data from the submergence switch on drifters in WOCE Heavy Weather Drifter Test (Sybrandy and Niiler, 1991) indicate that they spend about 20-30% of the time under the water in winds in excess of 15 m/s. Upon resurfacing, the port has to clear from sea-water quickly and completely. Flaps and valves to close a port will fail or become encrusted. An inverted port, with sufficient backup volume of air which can be compressed upon submergence so the water is kept out of the barometer air duct was incorporated in the design.

(ii) A long air pressure duct to the barometer can collect condensation in the extreme changes of moisture and temperature which occur in synoptic weather systems. This problem was solved by placing the barometer very close to and above the air intake. Specially configured barometers were made for this application for GDC by several manufacturers.

(iii) In a wind stream, the surface float produces a lowering of air pressure due to the Bernouilli effect. In 10 m/s wind, this effect produces less than 0.1 hPa pressure lowering at a distance of one radius of a sphere. The barometer port air intake is placed on a mast 24 cm above the top of the sphere. A second Bernouilli effect is produced by the airflow around the mast. This problem has been studied extensively, and a tabular wind shield, with air intake holes inside an inserted, second sleeve is adopted (Osmund and Painting, 1984).

(iv) The sampling and averaging scheme for the air pressure has to be sensitive to when the port is under the water. Tests have run at sea under 15 m/s wind conditions off San Diego, Ca. (WOCE/TOGA Lagrangian Drifter with barometer port, May 91, Sybrandy and Niiler) where pressure was sampled at 2Hz inside the surface float. A laboratory standard barometer of identical construction was used to obtain data at identical rates about 3 meters above sea level in a semi-enclosed laboratory on a ship. No significant wind effect, or delay times, were observed on the barometer port response on the surface float in the water.

The sensor itself is an AIR SB-1A model. It is a ceramic diaphragm capacitance sensor equipped with a built-in temperature compensating circuit. AIR sensors have been carefully tested for WOCE and finally proved reliable (Payne et al, IMET). Accuracy is +/- 1 hPa with a stability of +/- 1 hPa over a one year period. Sensor output is digital in tenth of hPa.

In the latest scheme (proposed at the joint DBCP-SVP workshop 4-6 May 1993), data are sampled at 1 Hz, and averaged over a 80 seconds period. A dedicated despiking algorithm was designed to remove from the average these air pressure measurements made while the barometer port is submerged:

"The algorithm will first average the lowest 20 of 80 measurements; it will then throw away all measurements within the entire 80 measurement set with values greater than 1 hPa over that average, and transmit the median point of the remaining values."

The latest average of every hour is stored on-board. The last 24 hourly measurements are memorized on-board and transmitted through Argos using multiplexing techniques. It is expected that the full serie of 24 hourly measurements will be recovered every day. Hence the latest available air pressure and tendency measurements (real time) as well as the synoptic air pressure measurements will be distributed on GTS (deferred-time).

3) Field tests:

The Data Buoy Co-operation Panel participated actively in the testing of a total of 25 prototype Barometer drifters (MOD-1):

* The Atmospheric Environment Service purchased 3 units and deployed them in December 1992 in the North East Pacific Ocean.

* The Australian Bureau of Meteorology purchased 3 units and deployed 2 in February 1993 in the Tasman Sea.

* The Global Drifter Center purchased 11 units and deployed 3 units in August 1992 and 4 units in January 1993 in the California Currents system.

* Meteo-France purchased 3 units and deployed them in in August 1992 in the Golfe de Gascogne.

* The United Kingdom Meteorological Office purchased 5 drifters and deployed 4 in the North Atlantic Ocean.

A joint DBCP-SVP workshop was held 4-6 May 1993 in San Diego in order to evaluate the quality of the prototypes and to propose design changes (SIO Ref Series 93/28, WOCE report 108/93). At the time of the meeting, 16 prototypes had been deployed at sea. In general, despite limited success with some of the buoys, the test participants were pleased with the performance of the SVP drifter fitted with barometer. In particular it was demonstrated that the quality of pressure data in general was as good as for regular FGGE type meteorological buoys (see figures 8 and 9).

The meeting agreed that the main problems detected with the first 16 prototypes deployed at sea were: (i) Through hull connector failure, (ii) Upper hemisphere failure (lack of fiberglass), and (iii) Despiking algorithm problem. These problems are believed to have caused premature death for 6 out of the 16 prototypes. In order to hopefully show the eventual reliability of the system, the meeting proposed some design modification (for MOD-2):

Hardware modification: to replace the high power Lithium batteries with Alkaline batteries, to increase the hull diameter, to reinforce the new hull, to improve the hemisphere sealing, to increase the diameter of the port attach, and to improve the strength of the SST probe;

Software modifications: to change the Argos message format, and to improve the "despiking algorithm.

Another field test was proposed in order to validate the decided design changes. New prototypes (MOD-2) have already been shipped to the participants and some have been deployed:

- The Atmospheric Environment Service of Canada deployed 2 units in September 1993 in the North-West Pacific Ocean;

- The Australian Bureau of Meteorology will deploy 2 units at the end of November 1993 in the Tasman Sea;

- The Global Drifter Center deployed 5 units in September 1993 in the California currents System;

- Meteo-France deployed 1 unit in September 1993 in the Golfe de Gascogne;

- The UKMO will deploy 2 units at the end of November 1993 in the North Atlantic Ocean.

4) Production and commercialization:

Since the NOAA National Ocean Service in collaboration with the Scripps Institution of Oceanography purchased 86 low-cost barometer drifters to be deployed in 1994 in the Southern Ocean as part of the TOGA and WOCE programmes, the commercialization process already began. Orders were placed with two manufacturers at a rate of $4600 per unit:

Technocean Associates
4422 SE 9th Ave
Cape Coral, FL 33904
USA
Tel: (+1) (813) 945 7019
Fax: (+1) (813) 574 5613

Clearwater Instrumentation
49 Walnut Park, Building No 2
Wellesley Hills, MA 02181
USA
Tel: (+1) (617) 239 3305
Fax: (+1) (617) 239 3314

Early 1995, the Global Drifter Center will publish a construction manual for the low-cost Barometer drifter for distribution to the oceanographic and meteorological communities. Copies of the manual may be obtained from Pr. Pearn P. Niiler, Global Drifter Center at Scripps Institution of Oceanography, La Jolla, California 92093, USA (Fax: (+1) 619 534 7931).

5) Opportunities for Cooperation between Oceanographers and Meteorologists:

For the reasons detailed below, the low-cost Barometer drifter is a device which can be shared by both oceanographic/research and meteorological/ operational communities:

-1- For oceanographers (research):

- Good water following characteristics:
  - High drag area ratio (>40)

- Low wind stress (small spherical hull etc...)

* Long life time (half life = 440 days)

* Capability of measuring Sea Surface Temperature

* Capability of measuring Air Pressure (a good Air Pressure field leads to a good wind field which in turn can be used to substantially deduce wind stress from computed surface velocities).

* Series of hourly data are available. Normally the system should be able to recover all the 24 hourly data collected by the platform every day (redundancy).

-2- For meteorologists (operational):

* Stays in a given area longer (the drifter is drogued at 15 meters)

* Long life time

* Capability of measuring Air Pressure

* Capability of measuring Sea Surface Temperature

* Data distributed on GTS in real time

* Hourly data are measured. Hence synoptic as well as the latest measured data are available (real time). Redundant data are filtered.

The cost of the Lagrangian drifter equipped with a barometer port (less than US$5000) is well below the cost of a regular FGGE type meteorological buoy (in the order of US$15000) which is capable of measuring the same physical variables (SST, Pressure) plus Air Temperature. Life time and quality of measurements of both devices are very similar. The DBCP recognized at its eighth session (DBCP-VIII, Paris, Oct. 92) that Air Temperature measurements from buoys were not especially reliable. Hence FGGE type meteorological buoys remain competitive only when capable of measuring addition physical variables such as wind and sub-surface temperature profiles (cost > US$20000 in that case). In addition, it has been shown that wind data from drifting buoys can be better than these from ships (DBCP annual report for 1992).

Hence to be cost-effective and to satisfy a wide community of users, a drifting buoy program should ideally only include a mixture of standard SVP drifters (surface currents, SST), low cost barometer drifters (surface currents, SST, Air Pressure), wind buoys (SST, Wind, Air Pressure) and wind buoys equipped with thermistor strings (SST, Wind, Air Pressure, Sub-surface temperature profile): Wind buoys and standard SVP drifters could for example be deployed inside the tropics where the atmospheric gradient is weak (except in tropical cyclonic systems) and geostrophic relationship is not valid near the equator. Barometer drifters could be deployed in large quantities outside the tropics. Thermistor strings wind buoys would be deployed wherever an express need for sub-surface temperature profiles (0 to 150 meters depth) is required.

Conclusion: As demonstrated on the example presented in Annex A, based on 1993 commitments, it is clear that both oceanographic and meteorological communities would benefit from a large scale cooperation based on new co-operative drifting buoy programmes provided that these programmes principally rely upon the low-cost barometer drifter. If desired, such programmes could be placed under the GOOS and GCOS umbrellas. It is basically at the national level that such steps should be taken although the DBCP can assist meteorological and oceanographic agencies to collaborate at the international level.

Annex A: Example of cooperation meteorologists/oceanographers

In 1993 oceanographers maintained (basically under the WOCE programme) a network of approximately 550 regular Lagrangian drifters (SST and surface currents only) in various ocean areas. In order to save Argos costs, approximately 380 of these drifters transmitted only 1/3 of the time through the system. Hence a total of about 297 PTT.Years were purchased from Service Argos:

Hardware cost	550 * $4000	$ 2 200 000
Argos costs	297 * $4000	$ 1 188 000

Approximate Total cost for oceanographers $ 3 388 000

In 1993 meteorologists maintained approximately 180 meteorological buoys in various ocean areas. All buoys reported full on via Argos:

Hardware cost	180 * $15000	$ 2 700 000
Argos costs	180 * $4000	$ 720 000

Approximate Total cost for meteorologists $ 3 420 000

Of course, since the buoys did not meet both communities requirements, oceanographers could only use the data from oceanographic buoys (550 buoys) and meteorologists could obtain GTS pressure data only from meteorological buoys (180 PTT.Year of Pressure data).

For our example, based on the same level of commitments than for 1993, below is detailed the approximate data return that each community could have expected if both communities had collaborated in 1993 on common programmes.

In their different drifting buoy programmes, both communities made commitments for approximately $ 6 808 000. Suppose that for the same cost they had planned to deploy a mixture of 5% meteorological wind buoys and 95% of low-cost barometer drifters as part of common drifting buoy programmes.

For a total of N buoys, hardware cost would have been:
0.05*N*$20000 + 0.95*N*$5000.

If the buoys were reporting full on through Argos, Argos cost would have been:
N*$4000.

The equation is therefore $ 6808000 = N * $ 9750

Hence for the same cost they would have deployed a total of 698 buoys,
i.e. 663 low-cost barometer drifters and 35 wind buoys.

Benefits for oceanographers would have therefore been:

- 113 additional buoys capable of measuring sea surface currents
- All the 663 buoys would report full on through Argos (instead of 1/3 for 380 of these)
- All the buoys would be equipped with a barometer port therefore improving the accuracy of the wind field analysis outside the tropics therefore improving the accuracy of the computed surface velocities.

Benefits for meteorologists would have been:

- 518 additional PTT.Year of Air Pressure data.
- 35 wind buoys (versus less than 10 in 1993)
- All the operating buoys would be reporting on GTS (since this is a co-operative programme)

Annex B: Figures

Figure 1: The standard SVP drifter and surface float Close-up

Figure 2: The low-cost Barometer Drifter Surface Float (MOD-1 prototype, the new MOD-2 is a 16" reinforced hull with an increased diameter for the port attach and with Alkaline battery pack)

Figure 3: Photograph of a fully-assembled 1992 low-cost Barometer drifter (MOD-1).

Figure 4: Schematic of the Barometer Port designed by GDC. The air path goes through a wind shield, two baffles, Goretex shields, and into a long tygon tube. (Courtesy of GDC).

Figure 5: Survivability of standard SVP drifters deployed in late 1992 and in 1993 (Courtesy of GDC).

Figure 6: Trajectories for M t o-France prototypes deployed in August 1992.

Figure 7: Trajectories for GDC prototypes deployed in August 1992 in the California Currents from August 92 to November 92

Figure 8: Monitoring Statistics for M t o-France prototypes deployed in August 1992.

Figure 9: Trajectories and intercomparison between SVP Barometer drifter 1356 and FGGE type meteorological buoy Marisonde 5794 soon after August 1992 deployment.

Figure 10: A model for the interpretation of slip data: Downwind Model Us=a*W/R + b*D/R, Crosswind Model Us=c*D/R. A comparison of the modeled and observed slip of drifters down-wind (upper panel) and crosswind (lower panel). The slip units are in cM/S. The least square fits give a=3.8, b=9.5, c=10.2, where W is the wind speed in M/S, D is the measured velocity difference across the drogue in cM/S and R is the drag area ratio. This model accounts for 87% of

the variance of the observed data.

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