JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 85, NO. C5, PAGES 2773–2778, MAY 20, 1980

Air Deployment of Satellite-Tracked Drifters

ROBERT E. CHENEY

NASA/Goddard Space Flight Center, Greenbelt, Maryland 20771

PHILIP L. RICHARDSON

Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543

BARRY P. BLUMENTHAL

U.S. Naval Oceanographic Office, Bay St. Louis, Missouri 39522

Six free-drifting buoys tracked by the Nimbus 6 satellite were successfully launched by C-130 aircraft in a series of deployments during 1977–1979. The buoys were launched in Gulf Stream rings which had been identified with airborne XBT surveys and satellite infrared images. This is the first operational test of these air-deployable buoys.

INTRODUCTION

During the past 10 years, satellite-tracked drifting buoys have enhanced our ability to measure remotely any near-surface ocean currents. These buoys have been found particularly useful for tracking rings associated with the Gulf Stream [*Richardson*, 1980], the Kuroshio [*Cheney et al.*, 1980], the Agulhas Current [*Grundlingh*, 1977], and the East Australian Current [*Cresswell and Nilsson*, 1977].

A new improvement of satellite-tracked drifters has been the development of a relatively inexpensive air-deployable version [*Anderson et al.*, 1977]. The added dimension of speed provided by air-deployable buoys gives several advantages over those deployed from ships. The buoys can be launched relatively inexpensively in remote areas of the world, such as the Southern Ocean. In addition, they can be launched quickly in response to an oil spill or to aid search and rescue operations. A satellite-tracked buoy lowered into the water from a helicopter was successfully used to follow the *Argo Merchant* oil spill off Nantucket in December 1975. A third application of air-deployable drifters is in conjunction with rapid measurement techniques, such as satellite infrared imagery and airborne XBT surveys, to monitor specific oceanographic features. The long lead time required to schedule ships makes it almost impossible to respond quickly to observations of interesting but transient oceanographic phenomena.

This report discusses a series of operational tests during 1977–1979 in which six buoys were air dropped into Gulf Stream rings.

THE BUOYS

The buoys were manufactured by Polar Research Laboratory (PRL), Santa Barbara, California, and are called Cosrams (Continental Shelf Rams) buoys. They transmit to the Nimbus 6 satellite Random Access Measurement System (Rams), and the position of the buoy is calculated by the Goddard Space Flight Center from the Doppler-shifted signal. Estimated accuracy of the position is 1–2 km. Components of the air-deployable version of the buoy are listed below and are shown in Figure 1.

1. *Buoy.* The basic Cosrams buoy is 3 m long and is constructed of a 0.32-cm thick-welded aluminum hull with a fibreglass antenna housing. It weighs 86 kg and contains batteries for 6 months of operation (extra batteries can be added for longer lifetimes). The buoy and drogue assembly fits onto a wooden pallet, which is used for sliding the buoy out of the plane.

2. *Drogue and Tether.* A 1.8 m × 13.7 m window shade drogue weighing 68 kg is suspended beneath the buoy to reduce the effect of wind on its movement. A sensor in the bottom of the buoy determines whether the drogue is still attached and relays this information with each signal. The drogue sensor consists of an on/off switch which is activated by a 23 kg load to the tether attachment point. Several different types of tethers were used (see Table 1).

3. *Parachute.* A 7.9-m diameter parachute is attached to a collar just below the antenna. A static line to the parachute cover is attached to the plane before launch.

4. *Saltwater-activated systems.* When the buoy enters the water, several release mechanisms are activated. An external 9-volt battery connected to a saltwater switch causes two explosive cutters to fire. One fires immediately upon splashdown, severing the parachute line, and the other fires 30 s later, cutting the drogue restraining line. The drogue deploys approximately 30 min later when salt tablets dissolve and allow the wooden pallet to separate. After the drogue unrolls, only the wooden housing remains attached to the buoy, and this is released in 1–2 hours by the corrosion of magnesium links.

DEPLOYMENTS

1977. Air deployments of prototype buoys were made on January 27 and February 3, 1977, near Monterey, California, by PRL and the Coast Guard, using a C-130 aircraft and a 29-m Coast Guard cutter for the buoy retrieval. The first test consisted of deploying two buoys without drogues and two buoys with window shade drogues. All four buoys were successfully launched and recovered, and no failures were encountered.

The successful buoy deployments by PRL encouraged us to try one ourselves, in conjunction with the U.S. Coast Guard who provided a C-130. The target was a Gulf Stream warm ring which had just formed, according to satellite infrared im-

Paper number 80C0208.
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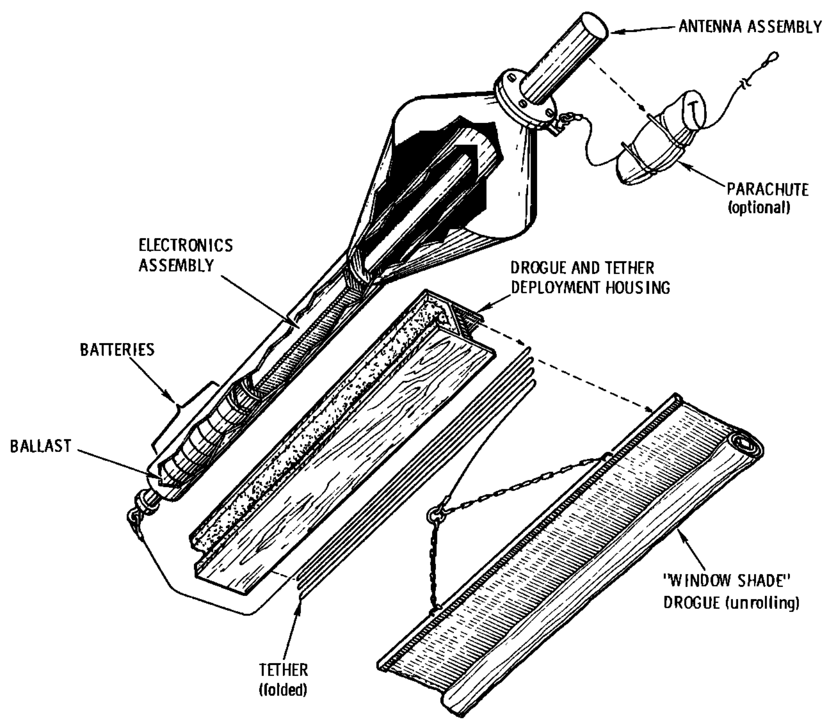

Fig. 1. Components of the air-deployable Cosrams buoy (courtesy Polar Research Laboratory).

agery. In the aircraft the buoy and its pallet were lashed down over a set of rollers on the rear cargo ramp (Figure 2*a*). When the launch site was reached, the aircraft descended to an altitude of 146 m, the cargo ramp was opened into a horizontal position, the lashings were removed, and the buoy slid out, cone end last (Figure 2*b*). The chute opened properly (Figure 2*c*) and the buoy hit the water 15–20 s afterward. The wind, estimated from the inertial guidance equipment, was 9 m s^{-1} from 325°. Before leaving the buoy, we flew over it for about 10 minutes. During that time the parachute was still attached to the buoy and was fully deployed above the water, pulling the buoy over at about a 45° angle. We do not know whether the chute was subsequently released by the line cutter after we left. The first transmission via satellite indicated that the drogue had deployed (corrosion of the magnesium links should cause the drogue to deploy in 1–2 hours even if the explosive cutter fails to fire).

The buoy was launched in a warm core ring which was partially connected to the Gulf Stream; the buoy was carried around the ring and into the Gulf Stream where it moved eastward.

1978–1979. Despite failure of the parachute release, the 1977 drop demonstrated the ease with which an air deployment could be made. We estimate that up to 10 buoys could be deployed during a single flight. Five more PRL drifters were ordered for air deployment in cold rings during early 1978, but these flights were postponed until the drop procedure could be tested and certified by the Air Force. The trials, conducted in May 1978, consisted of nine drops of buoys made by both PRL and American Electronics Laboratory. The ensuing report [*Wuest*, 1978] recommended a sturdier pallet, a longer static line for opening the parachute, and a slight modification to the parachute packing.

These changes were made, and a series of Gulf Stream cold ring deployments began in fall 1978. Each buoy was launched in conjunction with AXBT surveys by a separate Naval

TABLE 1. Cosrams Buoy Air Deployments in Gulf Stream Rings

	0557	0760	1317	1321	1011	1027
Date launched	Sept. 13, 1977	Sept. 22, 1978	Sept. 22, 1978	Nov. 16, 1978	March 19, 1979	March 19, 1979
Position	41°31′N 64°00′W	33°30′N 69°00′W	34°30′N 66°00′W	35°35′N 66°35′W	33°45′N 62°50′W	34°30′N 70°20′W
Altitude	146 m	152 m	151 m	305 m	305 m	305 m
Parachute/drogue released?	no/yes	yes/yes	yes/yes	no/no	yes/yes	yes/yes
Tether type	50 m of 1.0 cm nylon line	20 m of 2.5 cm nylon line	5 m of chain	10 m of 1.0 cm nylon line	10 m of 2.5 cm nylon line	5 m of chain
Drogue type	window shade	window shade	window shade	window shade	window shade	window shade
Drogue endurance, days	11	127*	≥54†	did not deploy	211*	≥42†
Period of buoy tracking, days	157	240, recovered May 20, 1979	34	249	257	30

*Tethers remained attached for entire tracking periods.
†Drogue sensors indicated tension until buoy transmissions ceased.

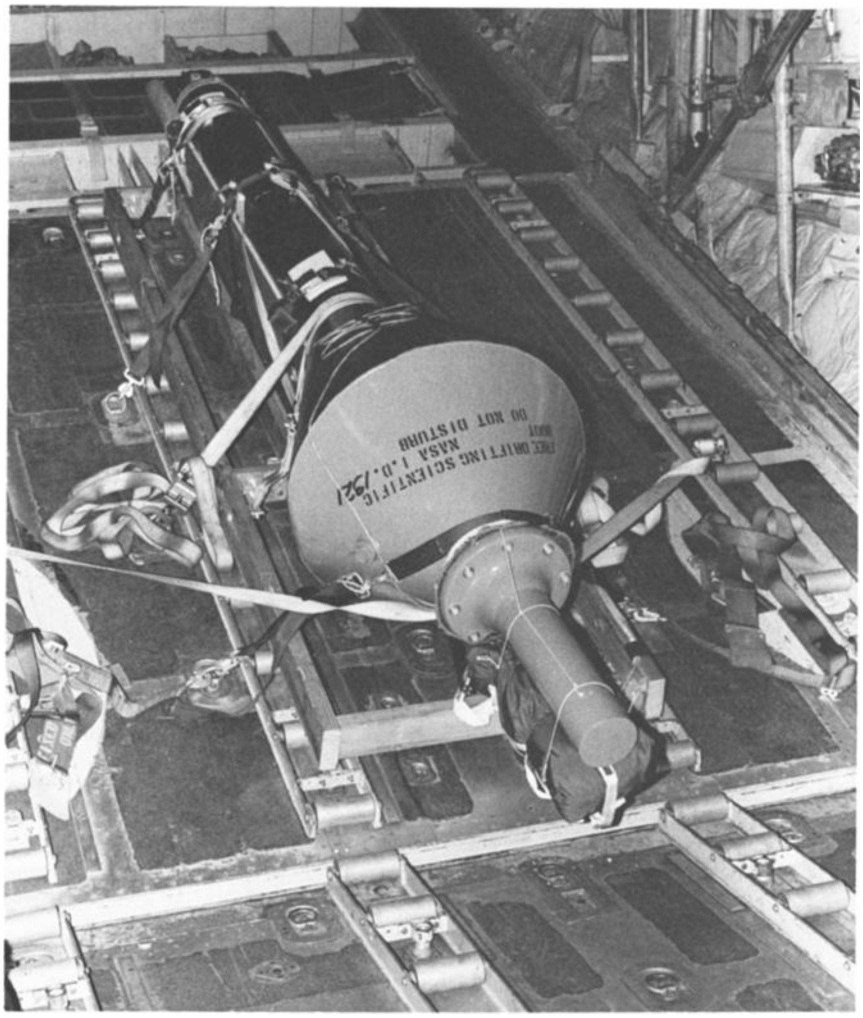

Fig. 2*a*. Air deployment sequence. The buoy is secured to the rear cargo ramp of the aircraft.

Fig. 2*b*. Launch procedure consists of lowering the ramp into a horizontal position and pushing the buoy out the back of the aircraft.

Fig. 2c. A static line connected to the ramp causes the parachute to deploy seconds after launch.

Oceanographic Office P-3 aircraft. Ring positions were transmitted to the Elizabeth City Air Station, where the C-130 flights originated, and the buoys were launched 1–3 days later. Five rings were tagged (Figure 3): two in September 1978, one in November 1978, and two in March 1979. Information on each drop is provided in Table 1. The September and March deployments were completely successful. Two buoys were launched on each flight. Visual confirmation of the parachute cutaway was obtained on each drop, and the first satellite messages indicated that the drogues had unfurled. Launch procedures were essentially the same each time, although the last two drops were made from an altitude of 305 m, rather than 150 m, to allow the parachute more time to open in case of a malfunction. Quick-release straps were used to secure the buoy to the rear door so that it could be unlashed and launched in a few seconds when we were over the target drop site.

The November deployment was also completed without problems except that the explosive cutters failed. During the 15 minutes that we circled, the collapsed parachute lay on the surface of the water, still attached to the buoy. According to the messages relayed by the satellite, the drogue also failed to deploy. During the buoy's 8 months of operation, we never received any indication of tension on the tether. One possible explanation is that the parachute lines wrapped around the buoy and became entangled with the drogue and tether. Failure of the explosive cutters was believed to have been due to insufficient voltage on the external seawater activated battery. On subsequent deployments, fresh batteries were used, and the cutters were connected with lower resistance wires. This arrangement worked satisfactorily and seemed to solve the cutter problem; an additional all-soluble or all-corrodable deployment system could provide a convenient backup system.

Detailed analyses of the buoy trajectories and ring movements will be presented in a separate report. Figure 4 shows a sample trajectory from one of the rings that we tagged. Buoy 0760 was trapped in this ring's circulation for 3.5 months before it drifted out into the Sargasso Sea. During this time it completed 19 loops around the ring center with an average period of approximately 6 days. The ring moved westward at 9 cm s^{-1} for the first month and then abruptly stopped, remaining within the same 1° square for the next 2.5 months. The

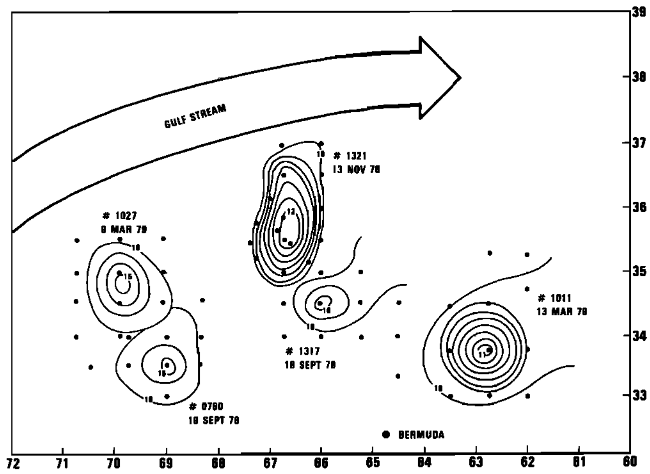

Fig. 3. Locations of the five cold rings tagged with drifters between September 1978 and March 1979; 300 m temperatures (°C) are shown for each ring, together with the AXBT's used to locate their centers.

continuous, real time information provided by the buoy enabled us to direct transiting ships through the ring center to obtain XBT sections and study its thermal structure.

Several operational air deployments have taken place since the end of our experimental series. As part of FGGE (First Garp Global Experiment), the NOAA Data Buoy Office launched 19 drifters in the south Atlantic and south Pacific Oceans in May 1979. Air Force C-141 transports operating out of Australia, New Zealand, and Argentina made the deployments during several long-range flights. Most drops were made from low altitude, similar to our deployments, but a few buoys were launched from high altitude (5.2 km) to conserve fuel and allow longer flights. Other air deployments have been made off the coast of Labrador by the Coast Guard Oceanographic Unit for the International Ice Patrol to gain information on the currents responsible for the transport of icebergs. One buoy was launched in April 1979 and three others in May and June.

DISCUSSION

Two problems should be mentioned, although they are not directly related to the air-deployment technique. The first is that two of the six buoys launched in this series stopped transmitting prematurely (see Table 1). A buoy with a standard supply of batteries should last for 6 months, but drifters 1317 and 1027 were successfully tracked for only 1 month. Each was heard for 2–3 weeks thereafter, but with insufficient messages to permit a fix. There was no indication of battery deterioration. PRL has suggested that the frequency of the transmitted signals might have drifted outside the allowable limits.

A second problem in using free-drifting buoys in areas of strong currents and high waves is failure of the drogue to stay attached to the buoy for long periods of time. An associated difficulty is determining whether the drogue is attached or not. Most of the 23 buoys launched during a Gulf Stream ring experiment during 1976–1978 [*Richardson et al.*, 1979] had drogue sensors that became overloaded and jammed in a 'drogue on' position. This problem was corrected on the drogue sensors used in the air deployments, and a wide range of drogue lifetimes was obtained (see Table 1). Buoy 0557 was drogued for only 11 days, while the drogue on 1011 lasted 211 days. Drogues on 1027 and 1317 remained attached at least as long as signals were received, 42 and 54 days, respectively.

Retrieval of buoy 0760 after 240 days adrift provided an opportunity to verify the drogue sensor messages; 0760 had telemetered 'drogue on' messages for the first 127 days, then sent a combination of 'on/off' messages for the next 66 days, and finally returned to 'drogue on' for the last 47 days. Upon recovery the buoy's drogue was found to be gone, although the 20 m nylon tether was still attached. Failure had occurred at the shackles (welded closed) connecting the tether to the top bar of the drogue. The tether was covered with a dense growth of barnacles which weighed more in water than the 23 kg required to activate the drogue sensor. On deck the sensor worked correctly. The evidence suggests that the drogue came off after 127 days, but the barnacle-covered tether was still sufficiently heavy to give the intermittent drogue on signals. Continued growth of the barnacles eventually added sufficient weight to keep the drogue sensor in the on position after 193 days at sea.

A similar sequence of signals was received from buoy 1011: 211 days of on messages followed by 46 days of on/off. The drogue must have fallen off after 211 days, leaving the tether suspended below the buoy. Because the tether on 1011 was only 10 m long (compared to 20 m on 0760) the growth of barnacles was insufficient to produce a continuous on signal. These results demonstrate the need for improved drogue designs and drogue sensors. With present systems, long apparent drogue lives must be verified by visual inspection at sea.

Drogue-tether failures can be caused by chafe, by fishbite, and by high shock loads induced by large waves. To counter all three of these, we are presently experimenting with four prototypes of a partly buoyant tether system designed to decouple the vertical motion of the buoy from the drogue and to reduce tension on the tether. A 35 m section of stiff, buoyant, plastic-coated wire lies on the water surface and connects the buoy to a 100 m length of plastic-coated wire attached to a window shade drogue. Several plastic floats on the 100 m wire support the weight of wire and drogue. Unfortunately, the present PRL drogue sensor will not work with this configuration. Although these drogue-tether systems were launched from a ship, they could probably be incorporated into an air-deployable package.

Recent modifications and improvements have been made that increase the usefulness of satellite buoys. A new tracking

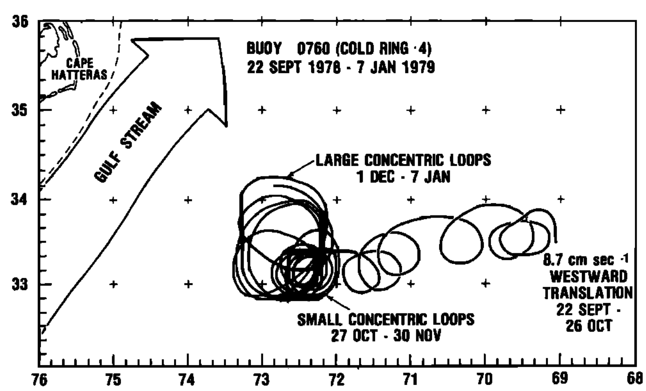

Fig. 4. Trajectory of buoy 0760 during its 3.5-month drift in the cold ring. It completed 19 loops around the ring center with an average period of 6 days. The ring moved westward during the first month but then remained within the same 1° square for the next 2.5 months.

system, Argos, was launched on the Tiros-N satellite in October 1978. The Argos system will be carried aboard a total of eight satellites between 1978 and 1985 providing more fixes (5–10 per day) and a greater accuracy than the Rams system. Argos buoys must meet more stringent specifications, and these buoys appear to be better and more reliable than the Cosrams buoys we used. Power consumption in the buoy has been reduced, increasing the potential life of the buoy.

SUMMARY

We have demonstrated that free-drifting satellite-tracked buoys can be successfully and easily deployed from a rear door aircraft. The combination of AXBT surveys and of satellite infrared images to locate Gulf Stream rings and the air deployment of buoys into these features has provided a quick and relatively inexpensive method to study rings. Although we experienced a problem with drogue-tether failures, we are presently testing an improved system which may provide a solution.

Acknowledgments. Many people deserve credit for the success of these deployments. We would like to thank the participating officers and crew from the Coast Guard Air Station, Elizabeth City, North Carolina, especially T. Pigage and L. Farmer. The first air-deployable buoy was provided by D. Clark of the NOAA Data Buoy Office. J. Anderson of PRL provided technical guidance. R. Doblar of the Naval Oceanographic Office was responsible for the first series of AXBT surveys. R. Weir of the Coast Guard Oceanographic Unit participated in the November deployment. The buoy recovery was made possible by J. Price of the University of Rhode Island, who kindly shared some of his time on *Oceanus* with us. This experiment was partially funded by the Office of Naval Research Contract N00014-74-C-0262, NR 083-004 to the Woods Hole Oceanographic Institution. This is contribution number 4413 from the Woods Hole Oceanographic Institution.

REFERENCES

Anderson, J., W. Brown, and V. Nguyen, An air deployment capability for drifting buoys, *Tech. Rep. 3,* Polar Research Laboratory, Santa Barbara, Calif., 1977.

Cheney, R. E., P. L. Richardson, and K. Nagasaka, Tracking a Kuroshio cold ring with a free-drifting surface buoy, *Deep Sea Res.*, in press, 1980.

Cresswell, G., and C. Nilsson, Three eddies monitored simultaneously by satellite-tracked buoys off southeast Australia, *POLYMODE News,* no. 32, 1977.

Grundlingh, M., Vortices in the southwestern Indian Ocean, *POLYMODE News,* no. 21, 1977.

Richardson, P. L., Gulf Stream ring trajectories, *J. Phys. Oceanogr.*, *10*(1), 90–104, 1980.

Richardson, P. L., J. J. Wheat, and D. Bennett, Free-drifting buoy trajectories in the Gulf Stream system, 1975–1978, *Tech. Rep. 79-4,* Woods Hole Oceanographic Institution, Woods Hole, Mass., 1979.

Wuest, M. R., Drifting buoy air-drop system, *Tech. Rep. 78-12,* Air Force Flight Test Center, Edwards Air Force Base, Rosamond, Calif., 1978.

(Received August 1, 1979;
revised January 31, 1980;
accepted February 1, 1980.)