A Field Evaluation of New Satellite-Tracked Buoys: A LORAN-C Position Recording and a Sonobuoy Type Drifter

PAPER

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ABSTRACT

Two types of satellite-tracked, drifting data-buoys were tested in Lake Michigan for twenty days. One type was a sonobuoy-size (0.9 m long, 12 cm diameter) buoy made by Metocean Data Systems and one was a mid-sized (1.8 m long, 20 cm diameter) buoy made by Polar Research Laboratory. The two Metocean buoys came equipped with sensors for barometric pressure, air temperature, and seven levels of water temperature from the surface down to 100 m. The Polar Research buoy was without sensors and was modified to carry a LORAN-C position-recording system. The Metocean buoy sensors compared well with those of the National Oceanic and Atmospheric Administration (NOAA) meteorological buoy in the center of Lake Michigan and with the Conductivity, Temperature, Depth (CTD) data taken at the launch site. Shortly after launch, however, the bottom weight broke off one of the subsurface temperature cables on these buoys. This failure allowed the temperature cable to stream along near the surface, so that no subsurface data were obtained. The other buoy, however, provided useful subsurface data for fifteen days until its ballast weight was lost after contact with bottom. The add-on LORAN positioning on the Polar Research buoy provided more frequent and precise positions than were available from satellite tracking alone. The LORAN-C data suggest that infrequent yet large satellite positioning errors may occur and may be difficult for the user to detect.

INTRODUCTION

Drifting data-buoys are used in limnology and oceanography to study both the large and small scale aspects of near-surface circulation. Current measurements inferred from buoy trajectories provide circulation information that complements data obtained from moored current meters. Time series data on the velocity from moored instruments are well suited for identifying the temporal scales that comprise the circulation at fixed locations. Drifting data-buoys are not as well suited to those tasks, but are better suited for data acquisition in remote regions of the world, for providing information on circulation in shallow seas where moored instruments may not be practical, and for generating circulation statistics over large areas.

In the Great Lakes, these buoys have been used mainly in circulation-dispersion studies (Lake Michigan: Clites, 1989, McCormick et al., 1985; Lake Ontario: Murthy et al., 1987; Lake Erie: Campbell et al., 1987; Lake St. Clair: Schwab et al., 1989). For these types of studies, the buoys are limited by the time between satellite positions (several hours) and by the accuracy of these positions (0.3 km) (Pickett et al., 1983). These two factors restrict their application to only large-scale circulation studies. The modified Polar Research buoy, evaluated for this paper, provides the positioning required for smaller-scale studies.

In other applications, drifting buoys are used simply as data stations in remote areas of the world. Both the U.S. Coast Guard (Thayer et al., 1988) and the Navy (Pickett, 1989a,b) have been testing drifting buoys for this purpose. Buoys designed for this purpose must be expendable and air-deployable, and have a multitude of sensors packed in a small, light-weight container. The Metocean buoy used in these tests was designed to meet these needs.

FIELD TESTS

Polar Research Buoy

One Polar Research Laboratory "mini-TOD" and two Metocean "sonobuoy drifters were deployed in Lake Michigan from September 7 to September 26, 1989. The Polar Research buoy was modified before deployment by adding a LORAN-C position-recording system (described in Miller et al., 1989). The Metocean drifters were deployed as received from the factory.

The Polar Research buoy is a 1.8 m long, 0.20 m diameter cylinder weighing 48 kg. The unmodified buoy can either be thrown overboard from a ship or parachute-deployed from a large cargo (C-130-type) aircraft. The buoy was equipped with a 3 m long, 0.6 m wide canvas cruciform drogue, which resulted in the cross-sectional area presented to the water by the drogue-buoy system being eighteen times its cross-sectional area to the wind. For this evaluation, a 2.5 m tall LORAN-C antenna was mounted outside the buoy and a LORAN receiver-recorder fitted inside the hull. Although the buoy normally has battery capacity for up to eighteen months, the added LORAN

equipment reduced its lifetime to about one month (at a 15 min sampling interval) because of greater power drain and a reduced stowing capacity for on-board batteries. For these tests, the LORAN recorder was set to record hourly positions before the buoy was ship-launched.

Metocean Buoy

The two Metocean buoys were 0.9 m long, 0.12 m diameter, 10 kg cylinders. They are certified for deployment from aircraft sonobuoy launchers (from 100 to 10,000 m altitude; from 0 to 350 knots airspeed). As in the case of the Polar Research buoy, a parachute deploys to slow descent, and a seawater-switch activates the buoy on contact with seawater. This switch causes the flotation collar to fill, the antenna mast to pop up, and the thermistor cable to drop from the bottom of the buoy. For this evaluation (in fresh water using a ship), salt was poured over the seawater-switch before the buoy was thrown overboard beside the Polar Research buoy.

Metocean buoys measure and transmit 10 min averages of barometric pressure, air temperature, and water temperature at seven depths (0, 5, 10, 20, 30, 50, and 100 m) as well as pressure at the bottom of the subsurface cable (to allow corrections for cable lift from currents). Attached to the bottom of the cable is a 1.5 kg weight to minimize cable lift. The buoy has no drogue other than the cable itself. As a result, the water-to-air ratio is only 5:1. The buoys have battery capacity for three months of operation.

Data generated by both buoy types are satellite-relayed (about eight times per day at 40 degrees north), converted to standard units and formats, and loaded onto the global telecommunications system by Service Argos.

RESULTS

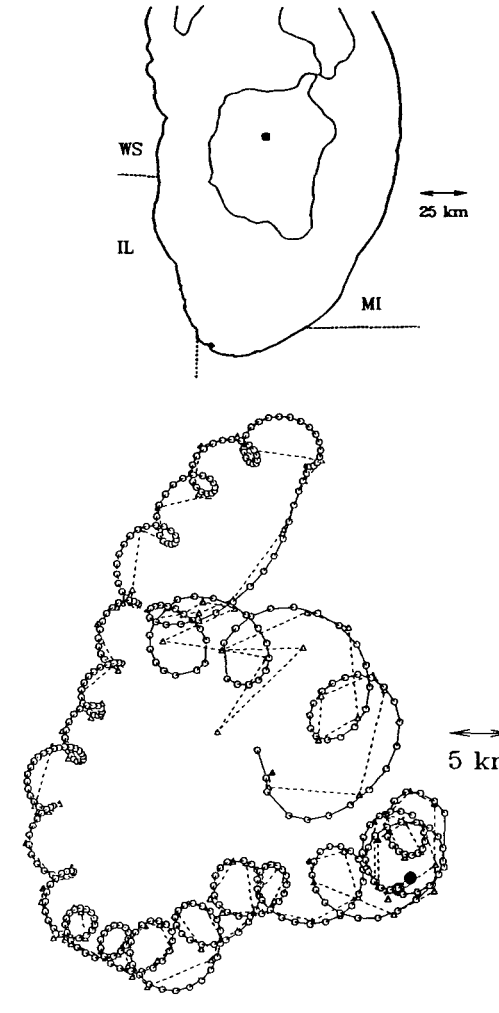
Polar Research Buoy

Figure 1 shows both the satellite and LORAN-C tracks of the Polar Research buoy as it drifted around southern Lake Michigan. The solid circle marks the launch site and the solid square marks the NOAA moored buoy. The figure is based on hourly LORAN positions, which were obtained until the last day (September 26). At that time, the Polar Research buoy's add-on LORAN-C antenna broke off. The antenna failure probably resulted from damage incurred three days earlier, when gale winds and waves with significant heights as great as 5.5 m (recorded at the moored buoy) swept across the lake.

The satellite-derived positions shown in this figure were first edited to remove any repeated positions or positions fixed within fifteen minutes of one another. The resulting 127 observations are plotted in the figure and it shows strong inertial oscillations occurring along the larger, nearly-circular path of the buoy. In general, the satellite-derived and LORAN-derived tracks compare well even at this small scale. However, on two occasions the satellite and LORAN positions differed by over 5 km and 7 km.

A total of thirty-eight pairs of satellite and LORAN positions were fixed within ten

FIGURE 1. Study area (top) showing southern Lake Michigan, the 100 m depth contour, and the NOAA moored buoy (solid square). Tracks of the Polar Research buoy from September 7 to 26, 1989, from satellite (dashed) and LORAN-C (solid line) positioning are enlarged (bottom) with all available positions plotted. The buoy launch-site (solid circle) was 8 km north of the moored buoy (solid square). The high precision of the LORAN versus satellite positions is evident.



minutes of one another and were used to further examine positioning errors. The mean difference and standard deviation between the two systems was 0.7 km and 1.4 km, respectively. If the two largest errors are removed, the statistics are dramatically improved (mean error 0.4 km, standard deviation 0.2 km). The estimated current statistics were equally influenced by the large errors (satellite: mean 0.26 m/s, standard deviation 0.20 m/s; satellite minus the two suspect positions: mean 0.23 m/s, standard deviation 0.13 m/s; LORAN-C: mean 0.24 m/s, standard deviation 0.13 m/s).

Unfortunately, without the LORAN-C data or some assumption to severely limit the maximal drifter speed, there exists no simple editing criteria to identify these errors. The two errors discussed here occurred under unremarkable conditions (<1 m significant wave heights) with no obvious clues to explain their presence.

Metocean Buoys

The top of Figure 2 shows the tracks of the two Metocean buoys in the same region of Lake Michigan. The tracks are radically different from one another because of bottom-weight losses. The bottom weight on Metocean Buoy 55 broke off one day after deployment, and the weight on Buoy 54 broke off after fifteen days. The weight on 54 broke off only after being dragged along the bottom for three days. (Based on these experiences, the manufacturer has since strengthened the bottom-weight attachment.) Once this weight is lost, the thermistor cable provides no subsurface data because it strings out along the surface. In addition, the buoy accelerates and becomes mainly wind-driven. The large difference in trajectories between Buoys 54 and 55 in Figure 2 highlights this wind-driven effect. The wind-driven dominance of 55 is clearly evident in the qualitative similarity between its track and a progressive vector diagram of the wind based on data from the moored NOAA buoy (bottom Figure 2).

Sensors

Table 1 compares barometric pressure, air temperature, and surface water temperature from the two Metocean buoys with data from the moored buoy. Because both buoys showed comparable correlations with data from the NOAA meteorological buoy, only the results from 54 have been plotted (Figure 3). The air temperature and barometric pressure sensors on the moored buoy were approximately 5 m above the water surface, in contrast with the 0.15 m and 1 m instrument heights, respectively, on the Metocean buoys. Only data sets recorded within thirty minutes of each other were used in these comparisons. Metocean Buoy 54 remained within 35 km of the moored buoy, while 55 traveled 70 km northwest of this reference buoy.

The figure and table show that the barometric pressure, surface water, and air temperatures were well correlated with those

FIGURE 2. Trajectories of the two Metocean buoys (54 and 55) in Lake Michigan from September 7 to 26, 1989 (top). The solid line is the track of 55 and the dashed line is 54. The solid square is the NOAA moored buoy. The loss of the bottom weight on Buoy 55 on the first day results in a higher-speed, wind-driven path that goes 70 km away from the moored buoy. The bottom figure shows buoy 55 trajectory (solid line) and a progressive vector diagram of the wind (dotted line) scaled to 4% of the wind velocity recorded at the NOAA moored buoy. All trajectories start at the solid circles.

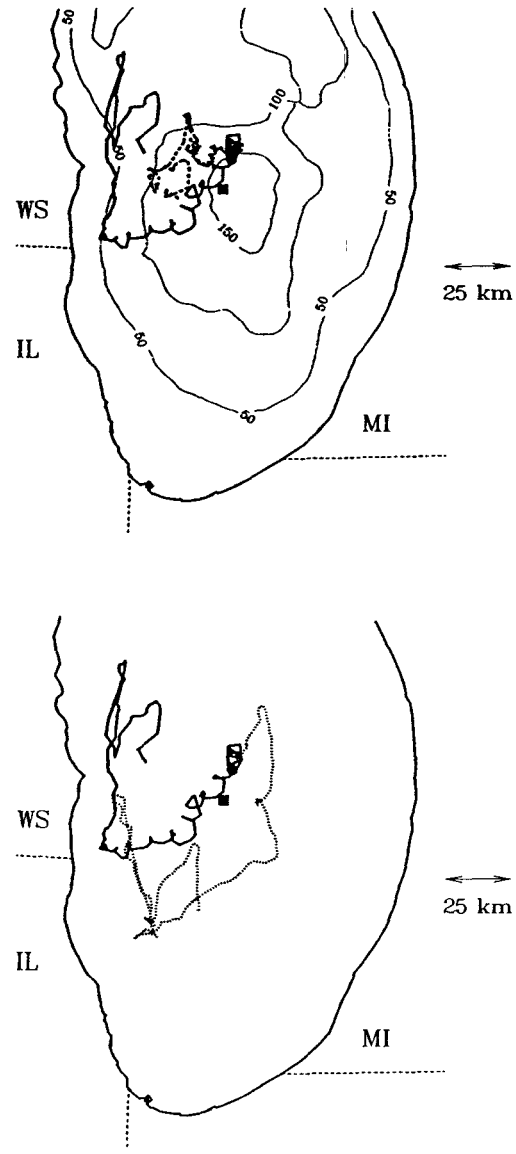


TABLE 1. Sensor comparisons between NOAA's (National Data Buoy Center) meteorological buoy 45007 and Metocean drifters 54 and 55. Linear regressions of drifter data on NOAA data are shown with b = slope, a = intercept, and ρ = correlation coefficient. Metocean thermistor data are compared against data obtained with a Sea-Bird Electronics, Inc. CTD.

ID	N	Min	Max	Mean	Std. Dev.	b	a	ρ	RMSE
				Air Pressure (mb)					
54	127	1005.	1029.	1019.	5.4	0.985	15.0	0.997	0.5
NOAA	127	1004.3	1028.9	1019.3	5.5	(Std. Error = 0.4)			
55	121	1004.	1028.	1018.	5.4	0.983	15.4	0.995	1.7
NOAA	121	1005.1	1028.9	1019.2	5.5	(Std. Error = 0.5)			
				Air Temperature (C)					
54	127	8.0	25.8	18.2	3.3	1.010	0.4	0.939	1.3
NOAA	127	8.7	22.2	17.6	3.1	(Std. Error = 1.2)			
55	121	7.0	25.3	18.1	3.5	1.017	0.3	0.927	1.4
NOAA	121	8.7	22.2	17.5	3.2	(Std. Error = 1.3)			
				Surface Water Temperature (C)					
54	127	16.9	22.4	20.1	1.2	0.979	0.8	0.988	0.4
NOAA	127	16.5	21.9	19.8	1.2	(Std. Error = 0.2)			
55	121	17.2	22.2	20.1	1.2	0.981	0.7	0.977	0.4
NOAA	121	16.5	21.9	19.8	1.2	(Std. Error = 0.3)			

Subsurface Temperatures (C)

ID	Depth (m)	5	10	20	30	50	100
54		20.9	20.9	20.8	5.1	4.6	3.6
CTD		21.2	21.1	20.9	5.3	3.9	3.8

measured by the moored buoy. For atmospheric pressure, the standard error for Buoy 54 was less than the +/− 1 mb accuracy claimed by the manufacturer. The standard error on 55 was higher than the 1 mb stated accuracy, however, but was probably the result of its separation from the moored buoy. Thus, the air pressure sensors on both drifters are most likely of comparable accuracy.

In similar fashion, the surface water and air temperature sensors also seem to be within the manufacturer's specification of +/− 0.2°C. Some of the scatter in the surface water temperature data, and possible bias, may be caused by different depth locations of the sensors on the moored and drifting buoys. Also, the slightly greater scatter and apparent bias in air temperature, relative to the other data, could well be explained by the existence of a vertical air temperature gradient combined with the variety of sensor heights.

Another comparison test was performed on the buoy's subsurface temperature data. Several casts were made at the launch site during deployment using a Sea-Bird Electronics CTD instrument to measure the subsurface temperature profile. The profile closest in time (twenty minutes) to the satellite-relayed buoy sample was compared with data from 54. The down-cast and up-cast from the CTD were averaged into one-meter intervals. These averages are listed in Table 1. The Metocean buoy's subsurface temperatures appear to be within the manufacturer's claim (+/− 0.2°C) except for the 50 m thermistor, which appears to be out of calibration.

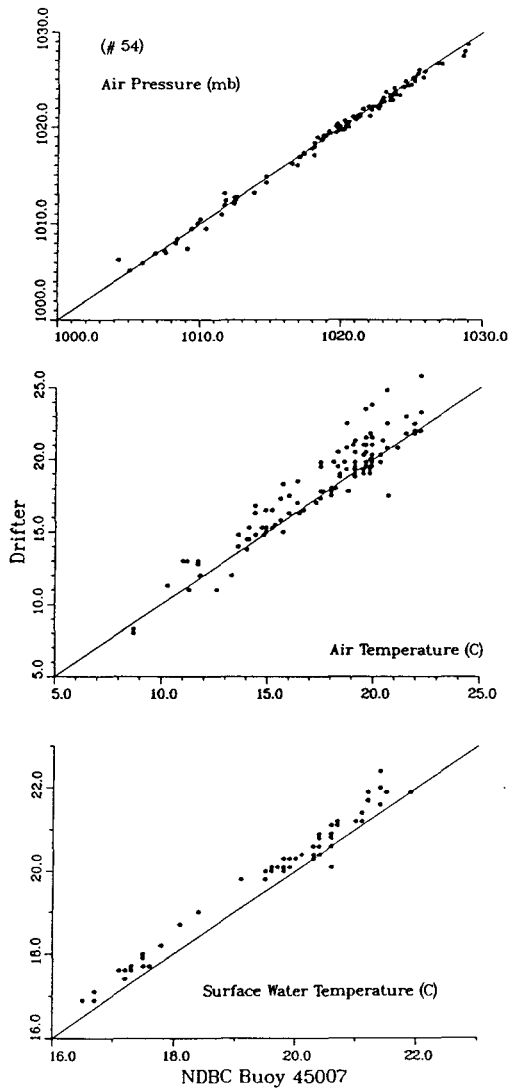
CONCLUSIONS

The addition of a multitude of sensors to a small air-deployable buoy allows easier collection of meteorological and oceanographic data in remote areas. The sensors used on the Metocean buoys appear to be reasonably accurate and should be useful oceanographic tools.

The addition of LORAN-C to drifting buoys provided data that were useful in detecting two large errors in the satellite-derived positions. In the Great Lakes, and similar environments, errors like these may also be detectable through careful editing, however, in oceanic settings such errors may not generally be detected from satellite-derived data alone.

And finally, the combination of LORAN's high frequency and precision positions offers Lagrangian measurements on time and space scales that previously required many people performing time-consuming, expensive, on-site measurements.

FIGURE 3. Air pressure, air temperature, and surface water temperature sensor comparisons for Metocean Buoy 54 and NOAA's (National Data Buoy Center) moored buoy 45007. The perfect correlation line is shown. The sensors on this buoy appear to be within specifications.



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