NOTES AND CORRESPONDENCE

A Compact, Low-Cost GPS Drifter for Use in the Oceanic Nearshore Zone, Lakes, and Estuaries

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ABSTRACT

The design of small, compact, low-cost GPS drifters that utilize ''off the shelf'' components is described. The drifters are intended for use in confined or nearshore environments over time scales of up to several days and are a low-cost alternative for applications that do not require drifters with full ocean-going capabilities.

1. Introduction

Lagrangian techniques have been widely used in the study of oceans and large lakes, both for fundamental fluid dynamics and as for environmental problems. The data provided by current-following ''drifters'' are particularly valuable in observing the spatial structure of the flow field and providing a different insight into the flow dynamics than that which is obtainable from Eulerian data. Lagrangian data also allow diffusion coefficients to be estimated more realistically than with fixed current meters (Pal et al. 1998). This capability is important for ecological investigations of, for example, the fate of pollutants, algal blooms, and artificial fertilization.

A comprehensive overview of the development of ocean-going Lagrangian drifters is given by Davis (1991). Early examples include the experiments of Stommel (1949) and Swallow (1955). Recent drifters use SOFAR for sub-surface applications (Rossby and Webb 1970) and satellite systems such as Argos for near-surface applications. To date the use of Lagrangian drifters has been largely limited to the deep ocean and large lakes. Some work has been done over smaller scales, for instance in coastal regions (Davis 1983; List et al. 1990; George and Largier 1996).

More recently, one of the position-fixing technologies utilized in Lagrangian drifters has been the global positioning system (GPS; Muzzi and McCormick 1994; Okumura and Endoh 1995; George and Largier 1996). GPS is a worldwide radionavigation system that employs a constellation of 24 satellites; up to 8 are used at any time to determine the position of a receiver. Until May of 2000, ''selective availability'' (SA) deliberately degraded the publicly available signal for military purposes and limited the accuracy to approximately 100 m. This practice effectively restricted the scales of motions that could be resolved. Improved position fixing was possible with differential correction but required a fixed base station and additional signal processing. The removal of SA now allows flow features on the order of 10 m to be resolved with nondifferential GPS.

The aim of this paper is to describe GPS drifters that are suitable for coastal, estuarine, or limnological investigations over short time scales (a few hours to several days) and distances (tens of meters to several kilometers). We describe a small, simple, low-cost device, built using ''off the shelf'' components, that may be more appropriate for these environments when the full capabilities of larger, more complex drifters are not required. The construction is well within the capabilities of most research groups, requiring only a minimal level of expertise and workshop facilities.

The basic design is intended for measuring currents in the surface layer and, by using different types of drogue arrangements, is suitable for different environments; as an example, the drogue arrangement for surfzone use is described and its performance is assessed. For subsurface applications, a slight design modification that decouples the electronics package and the antenna is used, and this configuration is also described.

2. Design of the receiver unit

The GPS receiver units, shown in Fig. 1, have four primary components: an instrument casing, a receiver–

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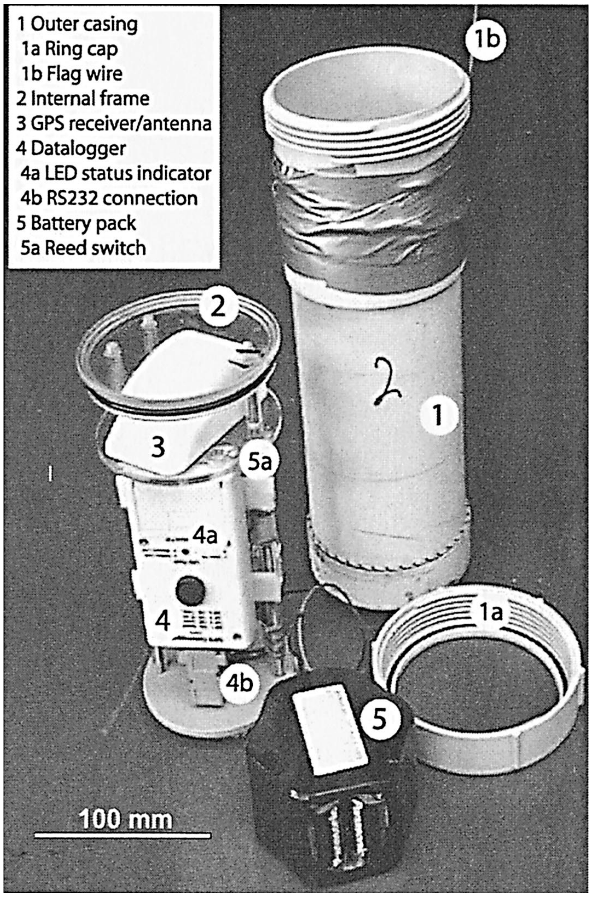

FIG. 1. Receiver units, showing the casing, battery pack, and internal frame with GPS receiver–antenna and datalogger attached. Note that the duct tape around the casing is simply to attach the flag wire, which carries a small ribbon to aid visibility; it has no other structural purpose.

antenna system, a datalogger, and a power source. The design aims were simplicity, ease of construction, and low cost. No special skills other than the machining of the internal instrument frame are required in the construction. We detail the specific hardware that was used, but there are other options, and it is not our intention to promote a particular product.

The main casing is a 100-mm polyvinyl chloride (PVC) sewerage pipe with standard end fittings from a hardware store, for a total length of 320 mm. This construction withstands pressure testing with up to at least 40 m of seawater. The GPS receiver and the datalogger are mounted on an internal instrument frame, and a battery pack at the bottom of the casing powers the electronic components and acts as ballast, providing the unit with upright stability.

The GPS receiver is a Garmin GPS 36 integrated receiver–antenna, which is a standard marine unit. The default device setting outputs National Marine Electronics Association (NMEA) 0183 $GPRMC data sentences at a frequency of 1 Hz. All of the initialization and satellite acquisition is carried out automatically by the receiver. However, this unit also provides a full configuration interface that can be used if required.

The datalogger is a DGPS-XM Data Logger from R. I. Keskull (Sydney, Australia). It can be wired directly to the GPS 36 output through an RS232 connector. Once a good fix is obtained by the GPS 36, the logger starts reading the NMEA 0183 sentences and stores position, time, and date at 1 Hz. The logger can store 95 200 points, equivalent to 26 h of continuous operation. An optional operating mode can change the data recording frequency to 0.1 Hz, extending memory life to 260 h. A light-emitting diode (LED) display on the logger indicates the status of the device, indicating power on/off, whether good data are being received, low memory, full memory, and low battery power. Data are downloaded from the logger via the RS232 connection to the COM port of a personal computer using software provided with the logger. Output data also include a status code that marks the start of each data sequence so that the logger can be used for multiple deployments without downloading operations.

Seven standard alkaline D-cell batteries provide sufficient power for 40 h of continuous use at 1 Hz, or at least 260 h at 0.1 Hz. The power on/off is a reed switch latch relay that is activated with a small magnet, avoiding any penetration of the casing by a switch and enhancing the water-tight integrity of the device. The entire unit can be simply turned on and off for each individual deployment.

The total cost of components and materials is approximately \$350 per unit (at the time of writing). For a single unit, an estimated 8 h of labor at \$50 h^{-1} puts the overall cost at around \$750. When constructing multiple units, the labor time per unit is very significantly reduced, and the total cost for 10 units is \$500 each. This is about a factor of 10 less expensive than commercially available GPS drifters. Most commercial units have data-transmission capability, the lack of which is a limitation of the design described here and makes it unsuitable for deployments over long periods and distances. Implementation of a transmission interface for the existing design is possible with minimal modifications but introduces an additional level of complexity and cost that is contrary to the fundamental idea of the device described herein, namely low cost and ease of construction.

3. The performance of nondifferential GPS

The removal of SA has greatly improved the performance of nondifferential GPS. However, there are still errors in the reported positions caused by precision limits in the GPS receiver, satellite clock error, errors in the ''known'' satellite positions, atmospheric effects on the speed of light, and multipath reflection of signals off large obstacles (Hofmann-Wellenhof et al. 1997). Some of these errors are white noise, and others, such

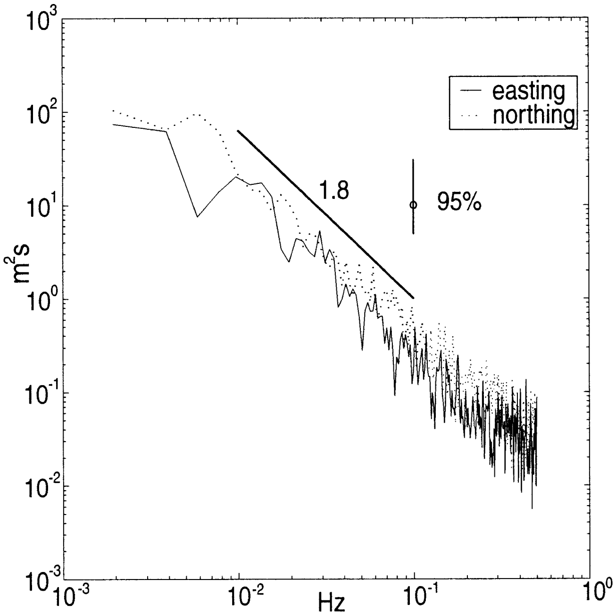

FIG. 2. Spectral density of the relative position error for a stationary drifter for 45 min of data. The relative position error is computed by converting the recorded positions to universal transverse Mercator coordinates and subtracting the average. The power spectra are averaged estimates of five overlapping sections of 512 s. Each section was windowed with a Hanning window and transformed with a 512-point FFT. The log-scaled spectra are not variance conserving.

as the atmospheric effects, produce position errors that oscillate with a preferred frequency. A distinction is made between absolute and relative error. The absolute deviation from the true geographic position is usually not important. However, the relative error contaminates any calculations of the velocity of a moving receiver.

The change of the position error as a function of frequency was estimated by leaving a drifter in a fixed location for 45 min. The power spectra of the displacement of the recorded position from the mean time-averaged position are shown in Fig. 2. The -1.8 slope of the spectrum in the 0.01–0.1-Hz region is very similar to that of Nebot et al. (1998), who found a value of -2.0 for a similar test prior to the removal of SA. However, in contrast to their results, the spectral power in the frequency region below 0.01 Hz does not show the large increase from the effect of SA. The standard deviation of position from the mean was 1.3 m in the easting direction and 1.6 m in the northing direction. Maximum displacements from the mean position were 4.2 and 5.2 m. Repeated tests at different locations and different times yield the same spectral shape as the one presented in Fig. 2.

By comparing the recorded position of a stationary drifter to that of one moving in a particular flow regime, it is possible to estimate the magnitude of error relative to true signal at any particular frequency. For a given flow measurement, the x component of the true position is $x = X - r$, where X is the recorded position and r is the position error. It is reasonable to assume that the position error r will be uncorrelated with the true position x at the low velocities in environmental flows. At any frequency f, the power ratio of true signal to noise is then

$$\mathcal{R}(f) = \frac{S_{XX}(f) - S_{rr}(f)}{S_{rr}(f)}, \tag{1}$$

where S_{XX} is the spectral density obtained from the recorded position and S_{rr} is the spectral density of the error, which can be estimated from a stationary test as described above. The same applies for the y component. An indication of which frequencies can be reliably sampled in a particular flow is then provided by the magnitude of $\mathcal{R}(f)$. In environmental flows for which the drifters described here are suitable, $\mathcal{R}(f)$ is generally at least 10 at the frequencies of the mesoscale features of the flow; mesoscale is defined here as $O(10^{-1}L)$, where L is the length scale of the environment of interest. In other words, the true signal power is at least one order of magnitude larger than the error for frequencies at or less than mesoscale frequencies. By low-pass filtering the recorded data, the noise (and signal) at higher frequencies is removed.

4. A design modification for subsurface applications

The drifters have been employed to measure subsurface currents between 2.5 and 8.5 m in the surface layer of Lake Kinneret (Israel). The experimental outcomes are detailed in Stocker and Imberger (2003); the design modifications to the basic unit described above, which are applicable to a wide range of subsurface investigations, are briefly described. For subsurface applications, the factors that influence the performance of a drifter as a Lagrangian current follower are wind-induced slippage and wave drag on the surface float, drag on the tether for large depths, and the drag from the finite size of the drogue (Murthy 1975; Niiler et al. 1987, 1995). Niiler et al. (1995), in particular, pointed out the critical importance of the ratio between the drag area of the drogue and the surface float area, where the drag area of a component is defined as its area times its drag coefficient. They showed that for an area ratio larger than 40, wind-induced slippage is less than 1 cm s^{-1} in a 10 m s^{-1} wind.

To reduce the effects of wind-induced slippage and wave drag (drag on the tether was found to be negligible for deployment in the surface layer) while keeping the size of the drogue as small as possible, we chose to put the main casing at depth with the drogue, unlike Muzzi and McCormick (1994) and Okumura and Endoh (1995). Although no verification of the effective performance of the drifters was attempted, it is easy to achieve a drag area ratio of 40 or larger with relatively small drogues, because of the small size of the surface float. In Lake Kinneret we used 85-L polyethylene buckets having a surface area of 2250 cm^2. In still water, the submerged and emerged portions of the surface float had surface areas of 40 and 48 cm^2, respectively. The smallness of the entire device (drifter plus drogue) minimizes the ''filter effect'' [whereby the effect of motion at scales smaller than that of the drogue is ''filtered out''; see Murthy (1975)] and makes it a very practical tool for use in shallow or confined water bodies as well as for frequent deployment.

Because the GPS signal cannot travel through water, deployment at depth of the main casing implies a decoupling of receiver and antenna, because the antenna has to stay above the water surface. The top plate of the internal instrument frame was modified to incorporate the antenna cable connection. A low-profile antenna (Garmin GA27C, 2-cm height, 5-cm diameter) was supported at the surface by a small polystyrene half-sphere float (15-cm diameter).[1] The device showed good stability even in steep waves, and the splashing and rolling of the antenna caused by waves up to 1 m high resulted in virtually no loss of data.

A telemetry system (Titley Electronics, Sydney) was used for recovery. The floats were equipped with two-stage waterproof radio transmitters of 25 mm by 15 mm, powered by their own 3-V dc battery, with frequencies around 150 MHz and a power output of 5 mW. A three-element Yagi direction-finding antenna fixes the drifter location to within 100 m, close enough for a visual fix of the float, which was painted with fluorescent orange spray. The 10-km detection range (for an antenna at 3 m above water level) makes this recovery system suitable for water bodies the characteristic size of which is up to a few tens of kilometers. A typical retrieval time for six drifters in Lake Kinneret (10 km by 20 km) was 3 h. The cost of the telemetry system for six drifters is less than $1500 (at the time of writing).

5. Deployment in the surf zone

The surf zone is a challenging environment in which to make hydrodynamic measurements. Instruments must be very robust to withstand wave breaking, and there are significant difficulties in deployment and retrieval. Despite their being valuable in revealing the horizontal current structure, because of the practical difficulties few Lagrangian measurements have been made.

We have used the basic drifter unit described in section 2 to make Lagrangian measurements in the surf zone. To prevent the drifter from surfing when caught in breaking waves, a parachute-type drogue system was attached to the standard GPS drifter unit described in section 2. This type of drogue, shown in Fig. 3, opens and dramatically increases its drag when there is a differential velocity between the upper and lower parts of the water column, as is the case in wave breaking. The parachute drogue also stabilizes the drifter and prevents it from rolling excessively. The drifter floats with only 2 cm of the receiver casing above the water, and so the effect of windage is expected to be very small.

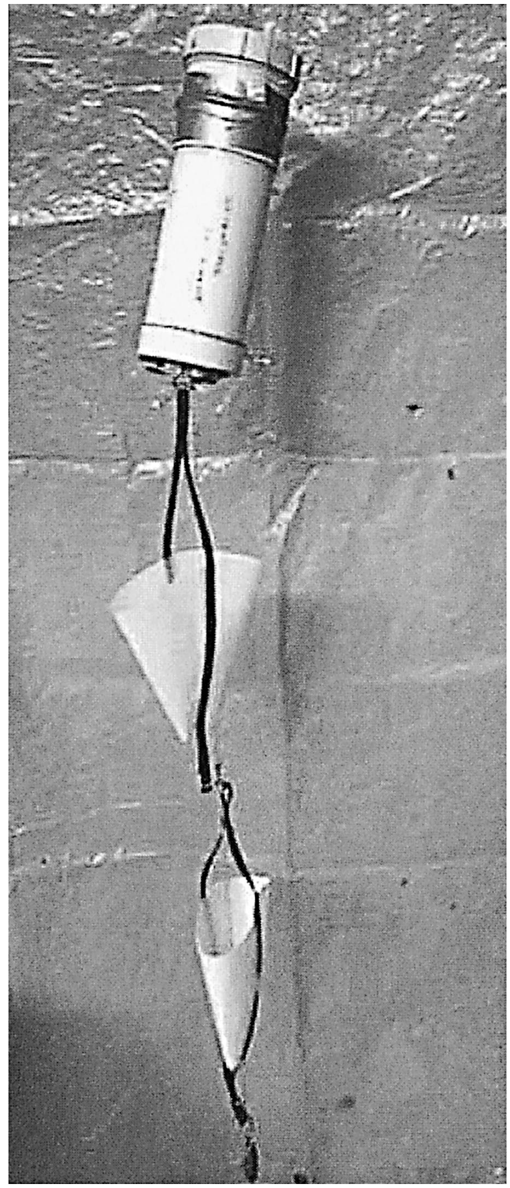

FIG. 3. Drifter with parachute drogues attached for use in the surf zone.

Qualitatively the drifters have performed well in rip-current experiments. They follow the fast offshore flow of the rip currents and have resolved large circular motions in the rip head that are presumably eddies. Despite the fact that the whole receiver unit is occasionally completely submerged, the data acquisition rate is remarkably good at over 99%, with data gaps rarely exceeding 10 s.

Although difficult to do in the surf zone, we have attempted to validate the drifter velocities with simul-

[1] As we learned after the completion of the experiments, a whole sphere is less subject to wave drag (Niiler et al. 1987).

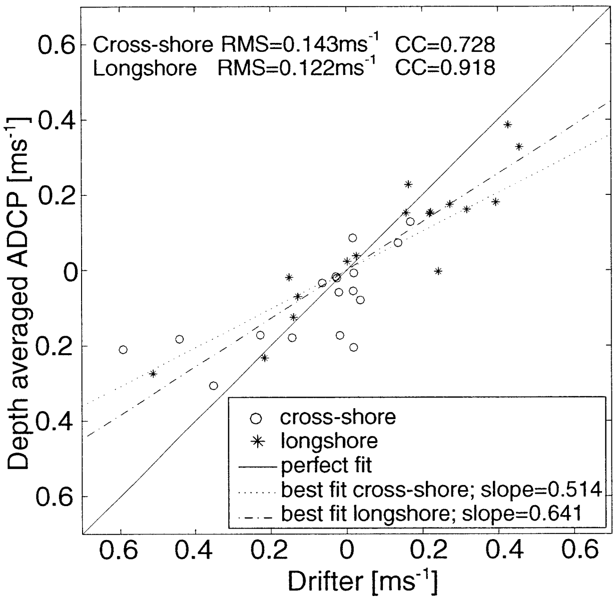

FIG. 4. Comparison of ADCP depth- and wave-averaged horizontal currents with time-averaged drifter velocities. The time averaging is centered on the time of nearest approach and s of length that is 2 times the peak wave period. Rms values of the difference and correlation coefficients (CC) between the drifter and depth-averaged ADCP velocities are shown on the figure.

taneous measurements from an upward-looking ADCP. The difficulty in validation of drifters in the surf zone is that the high current speeds coupled with a high degree of spatial variability mean that the two instruments are only experiencing similar velocities for very short periods of time. At the same time, however, the ADCP and the drifters both require some averaging to reduce the noise to an acceptable level. In addition, because wave-averaged velocities are of interest because they are normally used in the description of horizontal surf-zone circulation, averaging should be over at least one peak wave period.

The data used for the validation are from a series of surf-zone experiments made using both the drifters and the ADCP, both sampling at 1 Hz. The ADCP data are averaged over all bins below the instantaneous water surface (as determined from an onboard pressure sensor). When the drifter approaches within 10 m of the ADCP, the ADCP and drifter data are averaged over two peak wave periods, with the averaging centered around the time of closest approach. The data from the two instruments are shown in Fig. 4. The agreement is reasonable given the difficulties in the validation method, with the alongshore component showing better agreement than the cross-shore component. The best-fit lines for the data indicate that the drifter velocities are higher than those measured with the ADCP. It is well known that surf-zone wave-averaged velocities have vertical variation, with stronger velocities near the surface and the amount of shear greater in the cross-shore direction. Because the drifter and drogue do not span the entire water column, drifter velocities will tend to be greater than the depth-averaged flow.

6. Summary

We have described the design, construction, and use of small compact GPS drifters. The basic drifter design has been used successfully in lakes and the surf zone with the modifications detailed above. Although not described here, the drifter units have also been used for monitoring of pollution dispersion from a recreational mooring area and for a study of tidal fronts.

We believe that small GPS drifters are valuable instruments in studies of circulation and dispersion in a whole range of aquatic environments in which Lagrangian measurements are scarce. These environments include the nearshore zone, small- and medium-sized lakes, rivers, and estuaries. In these applications, the full capabilities of more sophisticated drifters that currently exist may not be required, and very simple, low-cost devices may be more appropriate.

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