GPS–Cellular Drifter Technology for Coastal Ocean Observing Systems

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ABSTRACT

A drifter for observing small spatial and temporal scales of motion in the coastal zone is presented. The drifter uses GPS to determine its position, and the Mobitex terrestrial cellular communications system to transmit the position data in near–real time. This configuration allows position data with order meter accuracy to be sampled every few minutes and transmitted inexpensively. Near-real-time transmission of highly accurate position data enables the drifters to be retrieved and redeployed, further increasing economy. Drifter slip measurements indicate that the drifter follows water to within ~1–2 cm s^{-1} during light wind periods. Slip values >1 cm s^{-1} are aligned with the direction of surface wave propagation and are 180° out of phase, so that the drifter "walks" down waves. Nearly 200 drifter tracks collected off the Santa Barbara, California, coast show comparisons with high-frequency (HF) radar observations of near-surface currents that improve by roughly 50% when the average drifter values are computed from more than 25 observations within a 2-km square HF radar bin. The improvement is the result of drifter resolution of subgrid-scale eddies that are included in time–space-averaged HF radar fields. The average eddy kinetic energy on 2-km space and hour time scales is 25 cm^2 s^{-2}, when computed for bins with more than 25 drifter observations. Comparisons with trajectories that are computed from HF radar data show mean separation velocities of 5 and 9 cm s^{-1} in the along- and across-shore directions, respectively. The drifters resolve scales of motion that are not present in HF radar fields, and are thus complementary to HF radar in coastal ocean observing systems.

1. Introduction

Understanding ocean circulation in the near-shore region is a necessary component of resource management and protection in the coastal zone. For example, governing agencies are interested in the movement of larvae, pollutants, and objects that are lost at sea. Advances in the knowledge of coastal ocean circulation depend largely on the availability and quality of observational data.

Historically, ocean circulation patterns were obtained from tracking the movement of floating objects that included ships and drift bottles. Recent advances in technology have led to the development of drifting buoys, or drifters, that are designed to record and transmit their position while following water parcels. Drifters provide exactly the information that is neces-

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sary to determine how surface currents transport passive objects. In addition, they give useful information for understanding the physics of the flow field they observe.

Drifters are characterized by three primary components: a subsurface drogue, attached to a surface float, a positioning system, and a data communications system. The drogue produces the necessary drag so that the drifter follows a "tagged" water parcel. The surface float provides necessary buoyancy stabilization and may house part or all of the drifter electronics. Common surface drifters use a handful of drogue design and surface float combinations with drag area ratios (drogue/float) that are larger than 40 (Niiler et al. 1995). When the drag area ratio threshold is met, drifter slip is observed to be mostly less than 3 $cm\ s^{-1}$, or roughly 0.1% of the wind speed (Davis 1985; Niiler et al. 1987; Niiler et al. 1995).

The drifter position in the open ocean has typically been obtained by Doppler ranging with a 402-MHz radio signal through the Argos system on Nimbus operational satellites (Niiler et al. 1987). Argos ranging gives position data up to 14 times per day (depending on location), with an accuracy of ~300–1000 m. The spatial and temporal resolutions that are afforded by Argos are sufficient for resolving characteristic scales of motion in the open ocean, but not within the coastal zone. Radio direction-finding triangulation systems, such as Loran C, have been used to track drifters with greater resolution in both space and time. However, radio beacon technologies require the overhead of deploying and managing a number of base stations (Davis 1985).

More recently, the global positioning system (GPS) has been used to track drifters with high spatial and temporal resolution (i.e., George and Largier 1996; Hitchcock et al. 1996; Johnson et al. 2003). The GPS position data are typically recorded internally and are not transmitted, or are transmitted infrequently. GPS receivers and data transmission systems both require relatively large amounts of power, which cannot be adequately supplied in a small drifter package. Drifters are visually monitored for short time periods (a few hours), and their position data are accessed after instrument retrieval. GPS–cellular (GPS–C) drifter technology has been proven feasible, but was implemented with marginal success (Hitchcock et al. 1996). The first-generation terrestrial-cellular (hereafter "cellular") networks required heavy phone units, drawing large amounts of power, and cellular coverage was often poor, especially in coastal waters. An energy-efficient GPS drifter that uses a modern cellular communications system to transmit data in near–real time is presented here.

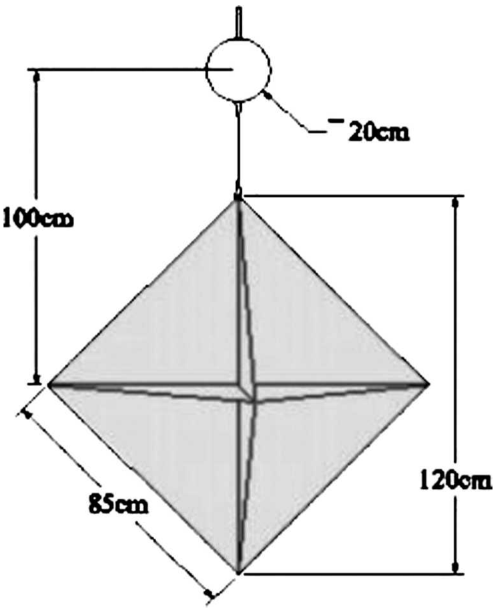

FIG. 1. Schematic of the coastal drifter.

2. Drifter design and construction

Drifters for use in the coastal ocean must be small and space efficient for transport and deployment from small boats, and must be economical so they can be deployed in large numbers. In addition, coastal drifters must have a spatial resolution of a few meters, and sample their position every few minutes to properly resolve characteristic scales of motion in the coastal ocean. Near-real-time data telemetry is required so that the drifters can be used to aid in the tracking and recovery of missing objects, and to give recent positions so the drifters can be recovered without visual monitoring. Recoverability and redeployment (catch-and-release) greatly enhances drifter economy. Drifter electronics must be energy efficient so they can operate for a number of days while sampling and transmitting every few minutes.

A corner-radar-reflector-type drogue was selected for the coastal drifter for two primary reasons (Fig. 1). First, this is a known calibrated drag element in existing use. Second, the design allows the drogue to be collapsed so that a large number can be stowed on, and deployed from, a small (<20 ft) skiff. The drogue is constructed with three 85 cm^2 planes of nylon cloth that are held in place by a wood frame. Central to the frame is a galvanized steel rod that serves as ballast. The rod retracts from a 1-in. polyvinyl chloride (PVC) tube. An acrylonitrite butadiene styrene (ABS) plastic spherical surface float, roughly 20 cm in diameter, holds the electronics (power supply, and positioning and telemetry systems). The float also provides buoyancy, supporting the drogue at a centered depth of 1 m. The spherical shape minimizes drifter slip resulting from surface wave forcing. A 25-cm length of 1/8-in. Dacron line connects the drogue to a female pipe fitting, which then connects to the surface float. This allows the drogue to be disconnected to further save space when transporting, and for easy replacement if it is damaged.

Drifter position is obtained with GPS technology. GPS gives position data with the highest spatial and temporal resolution at the lowest possible cost. State-of-the-art GPS receivers require significantly less power than their predecessors. Data transmission in near–real time can be carried out through either satellite or cellular systems. A satellite allows for a large coverage area, but comes at a significant cost. Data transmission using existing satellite systems, such as GlobalStar, ORBCOMM, and Argos range in cost from $5.00 to $15.00 per drifter day for 10-min updates, if transmission of that much data is possible. Cellular systems require that the drifters sample within a limited line-of-sight radius of cellular base stations. However, cellular communications costs are near $0.50 per drifter day for 10-min position records, and there are few restrictions on the quantity of data that can be transmitted.

The Mobitex (information available online at http://www.mobitex.org) cellular communications system was selected for data transmission. Mobitex is a packet-switched, narrowband, data-only technology that is ideally suited for applications such as interactive messaging, e-mail, telemetry, telematics/positioning, alarms, and forms-based transmissions. Mobitex was designed by Ericsson specifically for the transmission of "short bursty data," which is exactly the nature of drifter data. It allows for two-way communications so that drifters can be commanded remotely. Mobitex base stations (i.e., cell sites) are located primarily in and around U.S. metropolitan areas, which, incidentally, are locations requiring data on the transport of pollutants in the coastal zone. Limited coverage exists in Europe and Asia. Coverage is excellent in coastal southern California, from Point Conception to the Mexican border within ~40 km of shore.

Components that are housed within the surface sphere that help acquire and transmit data include a main controller board, a Motorola low-voltage 12-channel GPS receiver, a low-voltage and low-power Mobitex telemetry transceiver, a dual-band (GPS/Mobitex) quarter-wave antenna, a submergence sensor, and a rechargeable or disposable battery pack. At some predetermined time interval (presently 10 min) the GPS receiver is activated and begins its attempt at determining position. Given sight of a sufficient number of GPS satellites, time and position are recorded. If a sufficient number of satellites are not available within 30 s, the drifter goes to sleep until the next sampling time. Once a GPS position record is acquired, it is stored in a last-in-first-out (LIFO) data buffer on the main controller board. Along with position and time, ancillary GPS information that is recorded includes the number of GPS satellites that are visible, the number that are used to determine position, the time needed to acquire the position fix, and a 2-byte data quality string. The drifter identification number and an in-water flag are also included in each data record. Firmware algorithms optimize control of the GPS receiver to minimize the time that is spent obtaining a position, thus, minimizing power consumption.

Data transmission occurs immediately after a position record has been added to the data buffer. The most recent data record and a cellular signal strength value are sent to a host computer via the Mobitex network. Upon successful receipt, the host returns a positive acknowledgment to the drifter. The data record is removed from the drifter data buffer once a positive acknowledgment is received. If additional records are present, the next record is sent, and so on, until either the buffer is empty or data transmission fails. Data transmission failure can occur if the drifter is out of range of a base station, or if the line of sight is temporarily blocked. Landmasses, boats, and surface wave crests can block transmission. The data buffer holds up to 500 records. Thus, even if a drifter leaves cellular coverage range, all data can be obtained if the drifter moves back into range, or can be recovered.

Transmitted data records are received in near–real time by a host computer that is continuously connected to the Web. The host computer permanently archives the data. Users can access data records from any computer that is connected to the Web through either a Web browser or ftp. Data acquisition is regulated by passwords that allow access to data records with specific characteristics, such as drifter identification numbers, times, and locations. Data can also be transmitted to devices on the Mobitex network, such as a portable pager or laptop computer, enabling data transfer to locations without Internet access. The nearly instantaneous availability of highly accurate position data enables the drifters to be recovered, and, thus, used in a catch-and-release manner.

3. Drifter management

A map-based drifter-monitoring software system, developed in Matlab, facilitates drifter management (Fig. 2). The Matlab Coastal Drifter Tracking Software

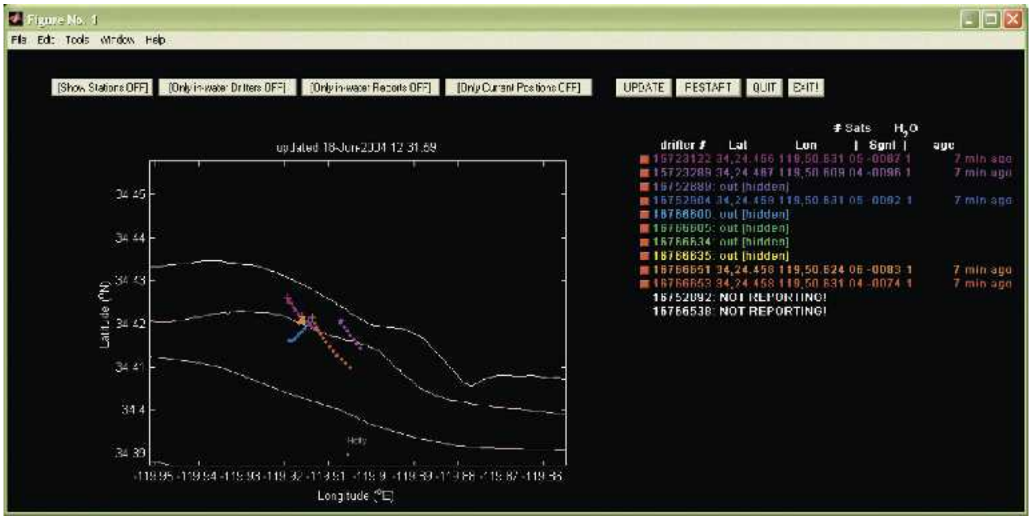

FIG. 2. Coastal drifter–tracking software screen. The interactive software displays tracks for selected drifters, along with status data for the entire fleet. Drifter tracks to be displayed are selected by toggling the drifter identification number: "out [hidden]" on the status table indicates the drifter is sampling but its track is not being displayed on the map. "NOT REPORTING!" indicates the drifter is not activated. The screen shows data collected on 6 Dec 2002, played back on 18 Jun 2004.

(CDTS) was developed to monitor movement so that units could be retrieved prior to beaching, leaving the cellular coverage range, or leaving a study region. Viewing the relative positions of all of the drifters on a map also facilitates an efficient order of recovery. The CDTS obtains drifter data from the host computer every minute, or upon user request, and displays it in a seven-column table. Column 1 gives the drifter identification number; the most recent position is given in columns 2 (latitude) and 3 (longitude); the number of GPS satellites that are used to determine most recent position fix is given in column 4; the strength of the cellular communications signal is given in column 5; an in-water flag is shown in column 6; time since the last position update is given in column 7. Tracks can be selected for display on a map by toggling the drifter number in column 1 of the table, or any part of a track displayed on the map. The display toggle helps manage drifter retrievals because a track can be eliminated from the display once it has been successfully recovered. Drifters in the user's database that are not active are labeled "not reporting" so that all units are accounted for in the display.

Presently drifter recovery is carried out by having the land-based CDTS operator supply the most recent position of the next-to-be-recovered drifter to the boat. This is done by voice using either cellular phone or shortwave communications. The position can then be entered into the boat's GPS system, which gives a direction and distance to the drifter. If a drifter is moving rapidly, and/or a significant time has elapsed since the last position update, movement direction may also be necessary for recovery.

4. Drifter testing

a. GPS accuracy

To test the variance in GPS position data, a set of 14 drifters were activated in fixed positions. Each drifter obtained position data every 10 min for nearly 2 days (269 position records per unit). Standard deviations in position for each of the 14 drifters ranged from 2.9 to 6.8 m. The overall standard deviation in GPS position data for all of the drifters was 4.06 m.

b. Drifter slip

To quantify water-following characteristics, a drifter was configured with a pair of current meters, and drifter slip was recorded. The current meter–equipped drifter contains a central vertical tube running the length of the drogue that contains two Nortek Aquadopp acoustic current meters and a Motorola UT Oncore GPS receiver. The Aquadopp transducer heads are at the top and bottom of the tube, nominally 0.45 and 1.55 m beneath the surface, respectively. Each Aquadopp was configured to measure within a bin beginning 0.35 m from the transducer head and extending out 0.75 m. The sampling frequency was set to 0.33 Hz to maximize instrument precision (1.4 cm s^{-1}). The measured 2D

TABLE 1. Summary of Aquadopp drifter deployments. Values are means over each deployment lasting ~30 min. Aquadopp current quantities (upper, lower, slip, and shear) are given as a velocity followed by the direction of motion. Wind and wave values are given as the direction they are coming from. Slip is computed as the average of the upper and lower mean Aquadopp velocity vectors. Shear is the difference between the mean velocity vectors (lower-upper). Wind values are from the NOAA/NDBC east Santa Barbara channel buoy. Wave height and direction are from local visual estimates.

Deployment date	Water depth (m)	Upper velocity (cm s^{-1})–(°)	Lower velocity (cm s^{-1})–(°)	Slip (cm s^{-1})–(°)	Shear (cm s^{-1})–(°)	Wind (m s^{-1})–(°)	Waves (m)–(°)	Drifter movement (cm s^{-1})–(°)
6 Aug 2004	15	0.15–183	1.03–240	0.56–234	0.96–247	<1–315	<1–210	7–330
18 Aug 2004	90	1.00–61	2.73–203	1.02–185	3.57–213	2.0–299	<1–210	30–185
31 Aug 2004	5	0.68–146	0.79–68	0.57–103	0.94–22	<1–228	<1–230	6–352
31 Aug 2004	125	0.23–179	0.21–184	0.22–181	0.03–318	<1–228	<1–280	14–39
13 Sep 2004	5	1.72–233	2.56–198	2.04–211	1.54–157	2.5–270	1.0–225	13–324
13 Sep 2004	25	0.0–131	2.96–229	1.47–222	3.01–234	2.5–270	1.0–245	77–315

velocities were converted to east–west and north–south components using onboard compass and sensor tilt information. Mean velocities were computed to further improve instrument precision. Finally, drifter slip was computed as the mean of the upper and lower Aquadopp velocities. Drifter slip gives the rate and direction that water parcels slip by the drifter.

Several preliminary slip performance tests were carried out. First, the drifter was pulled through the water in a known direction with an estimated velocity to verify the data processing scheme. It was assumed that the slip velocities that were measured would push the Aquadopp precision limits. To investigate measurements of near-zero velocities the drifter was deployed in a sheltered finger of Los Carneros Lake, a small (~25 acre) enclosed lake in Goleta, California [near the University of California, Santa Barbara (UCSB) campus]. The drifter was deployed in the morning when winds were light (from the south-southwest at 1–2 m s^{-1}), and the lake surface appeared to be completely calm. During the course of the 20-min deployment period, the drifter moved roughly 8 m to the north (mean drifter velocity < 1 cm s^{-1}). Mean velocities that are recorded by the upper and lower Aquadopps were 0.53 cm s^{-1} toward 116°, and 0.99 cm s^{-1} toward 332°, respectively. Total slip, computed as an average of the upper and lower velocities, was 0.32 cm s^{-1} toward 2°. Finescale motions resulting from convective and wind forcing likely exist, but mean velocities are expected to be very near zero. The results of the lake test indicate that mean Aquadopp velocities of the order of 0.1 cm s^{-1} are most likely indicative of instrument noise, and not necessarily slip.

A total of six Aquadopp drifter deployments were performed off the Santa Barbara coast during August and September 2004 to quantify drifter slip (Table 1). Each deployment lasted for roughly 30 min. The first was conducted approximately 0.3 km off the end of Goleta Pier at 0900 LT 6 August 2004. The National Oceanic and Atmospheric Administration (NOAA) National Data Buoy Center (NDBC) east Santa Barbara channel buoy (46053) reported a mean wind speed of ~0.5 m s^{-1} from 315°, during the deployment. The Scripps Institution of Oceanography (SIO) Coastal Data Information Program (CDIP) wave rider buoy located at Goleta Point (NOAA/NDBC 46216) reported a mean significant wave height of ~0.5 m from 257°. Locally, in Goleta Bay, the waves were visually estimated at <0.25 m from 210°. The drifter traveled toward 330° at an average velocity of 7 cm s^{-1}. The upper and lower Aquadopps recorded average velocities of 0.15 cm s^{-1} toward 183°, and 1.03 cm s^{-1} toward 240°, respectively. Total slip was 0.56 cm s^{-1} toward 234°.

The second deployment occurred ~5 km directly offshore of the Santa Barbara harbor at 1200 UTC 18 August 2004. Although the time and location were chosen to sample rougher conditions, the winds were light and the waves small (Table 1). Drifter slip was computed to be 1.02 cm s^{-1} toward 185°. The third and fourth deployments occurred on a single day at two locations off of the Goleta coast (Table 1). Initially, the drifter was deployed just beyond the surf zone, and then it was redeployed ~1 km offshore. This pattern was repeated for the fifth and sixth deployments. The inshore and offshore sampling pairs allowed investigation of the role of wave steepness on drifter slip. For both pairs, inshore slip is larger than the corresponding offshore value (Table 1). The inshore slip for the 13 September deployment is the largest value recorded (2.04 cm s^{-1}). The upper Aquadopp velocity on this day (1.72 cm s^{-1}) is anomalously large. The reason for the increased slip value on 13 September is not known.

The difference in velocities that are recorded by the Aquadopps at two depths indicates the presence of shear over the vertical distance of the drogue (0.45–1.55

m beneath the surface). This vertical shear is not expected to be uniform with depth. Thus, velocity measurements at the top and bottom of the drogue may not accurately integrate true slip. [For example, consider an idealized two-layer system where the top layer extends from the sea surface to just beyond the top of the drogue, and the second layer extends over the remaining majority (99%) of the drogue. Then, if the top current meter records x cm s^{-1} and the bottom records 0, simple integration would give a slip of $x/2$ cm s^{-1}, which would be an overstatement.) This integration effect, combined with the small slip values measured, suggest drifters are following the mean flow over the drogue area to within ~1–2 cm s^{-1} during the low wind conditions encountered. For deployments demonstrating a slip larger than 1 cm s^{-1}, the slip is aligned (180° out of phase) with the wave stress to within 25°, suggesting that surface waves are "pushing" the drifter through water. A more comprehensive investigation of slip for a number of different drogue designs during a wide range of wind and sea conditions is in progress. A true understanding of slip requires knowledge of vertical shear over the drifter depth.

5. Drifter deployments

After a series of test deployments during the instrument development period in 2002, 15 deployments of roughly 12 drifters have occurred on the Santa Barbara shelf throughout 2003. Drifters were initially released within a 1.5 km × 3 km irregularly spaced grid, located on the inner shelf (water depths between 15 and 80 m), early in the morning. Drifters almost always moved in the up-coast and onshore directions, and were recovered in the afternoon to avoid beaching. A few drifters sampled continuously within the Santa Barbara channel for up to 5 days while traveling westward to near Point Conception and across the channel to the northern coast of Santa Rosa Island. Conditions during the deployments ranged from calm to rough (sustained winds over 12 m s^{-1} and 1–2-m waves at the east Santa Barbara channel buoy 46053). Only a single drifter has failed to be recovered. The drifter stopped transmitting presumably after exhausting its battery power. These drifter data are the subject of a manuscript in progress discussing inner-shelf dynamics.

6. Discussion

High-frequency radar systems (hereafter HF radar) have become a popular means of obtaining surface current data near the coast. The HF radars use a Doppler technique to measure currents in the radial direction from each instrument. Radials must then be smoothed by averaging. Typical HF radar data are generally presented as hourly average velocities on a spatial grid near a 1–2-km square, depending on radar frequency and radial averaging radii. The HF radar coverage begins somewhere on the shelf and reaches the horizon. The inshore extent is regulated by the radar frequency and the relative location of radar pairs, and can be as far as 3–5 km from the coast.

The HF radar performance has been demonstrated to have an accuracy of about 10 cm s^{-1} (Paduan and Rosenfeld 1996; Chapman and Graber 1997; Emery et al. 2005, manuscript submitted to *Fisheries Bull.*). Validation has occurred through the comparison of HF radar data that are space and time averages with data from a single current meter that is only a time average. Comparisons with drifter-derived velocities use few tracks, so averaging is over the limited locations and times of drifter sampling, and not the same space and time domains that are used to compute average HF radar values. Meaningful comparisons with HF radar velocities require measurements that are made on commensurate time and space scales.

The GPS–C drifters that are deployed in a dense sampling array off of the Santa Barbara coast give up to 41 velocity observations distributed throughout a 2-km square HF radar grid cell in 1 h. Velocity is computed as a first difference from the position nominally sampled every 10 min. A comparison of drifter- and HF radar–derived velocities when there is at least one drifter velocity observation in a time/space bin gives root-mean-square (rms) velocity errors of 9.8 and 9.9 cm s^{-1} for the east–west (u; mainly alongshore) and north–south (v; mainly across shore) velocity components, respectively (Fig. 3). As the number of drifter-derived velocity observations within each 2-km bin for a given hour increases, the rms velocity error decreases. For time and space bins when there are at least 34 drifter-derived velocity observations, the rms velocity error decreases to 6.7 and 6.1 cm s^{-1} for the u and v velocity components, respectively.

This simple performance analysis suggests that previous comparisons with HF radar velocities may have overstated discrepancies near 50%, or ~3–4 cm s^{-1}, by failing to resolve the same time–space motions that are included in typical 2-km square and 1-h averages. More importantly, the analysis indicates coastal flows are highly variable on time and space scales shorter than typically resolved with HF radar data. Eddy kinetic energy (EKE) is 15.1 cm^{-2} s^{-2} when computed on spatial scales less than 2 km and hour time scales, with all drifter data used in the drifter–radar comparison (Fig. 3). EKE increases 67%, to 25 cm^{-2} s^{-2}, when computed

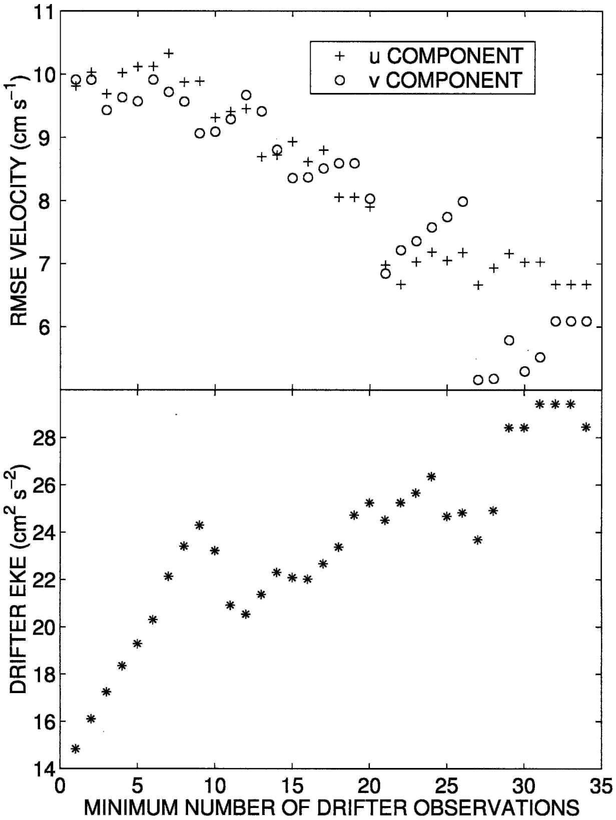

FIG. 3. (top) Rms error between HF radar– and drifter-derived average velocity components. Average velocities are over 2-km-square bins and 1 h. Rms error is computed using average velocities where at least *x* drifter observations are used to calculate the average. The *u* velocity component is east–west and mostly alongshore in the study region. The *v* component is north–south and mostly across shore. (bottom) Associated EKE from drifter data. EKE is computed as $0.5(\langle u'u' \rangle + \langle v'v' \rangle)$, where u' and v' give deviations from the average *u* and *v* velocities, respectively, and the angle brackets denote mean quantities. EKE is computed separately for each time (1 h) and space (2-km grid) bin. Data for 2 days that give a relatively large contribution to a single space bin were removed to avoid spatial biasing.

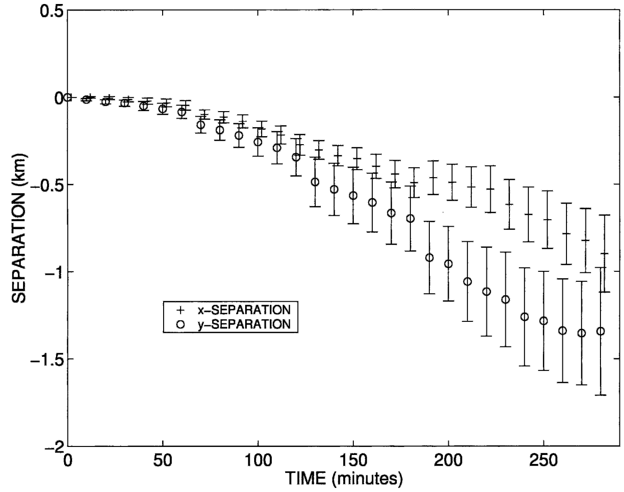

FIG. 4. Average separation distance, as a function of time, between observed drifter tracks and tracks computed from HF radar–derived velocities. Components are given in the east–west (*x*; mostly alongshore) and north–south (*y*; mostly across shore) directions. The HF radar tracks are computed from hourly average velocities on a 2-km grid using fourth-order Runge–Kutta integration. The number of track pairs that are used to compute mean separation distances varies from 88 (at 10 min) to 9 (at 280 min), and decreases fairly linearly. Error bars show the standard error (std dev divided by the square root of the sample size).

for bins with at least 25 drifter observations. The GPS–C drifters provide a tool for measuring the small-scale motions that become "averaged out" in HF radar velocity maps.

Tracks computed from hourly 2-km-averaged Eulerian HF radar fields, using a fourth-order Runge–Kutta integration scheme, are compared with tracks recorded with the coastal drifters. Mean separation distances for the east–west (mainly alongshore) and north–south (mainly across shore) directions, are computed every 10 min (Fig. 4). Mean east–west separation grows to −65 m after 60 min, to −273 m after 120 min, and to −673 m after 240 min. The negative values indicate trajectories, computed from HF radar velocities, that are moving faster in the westward direction than the drifters. Mean north–south separation grows at almost the same rate out to 90 min and then begins to grow faster. The mean north–south separations at 120 and 240 min are −358 and −1260 m, respectively, indicating that the HF radar–derived trajectories move slower than drifters in the onshore direction.

Significant directional biases and a larger difference in the across-shore component are noteworthy results of the simple preliminary analysis. Results suggest that subgrid-scale models for rectifying trajectory discrepancies should not be isotropic. A thorough analysis of trajectory separation will come with additional drifter data so that separation can be quantified by location, flow properties, and HF radar–sampling characteristics. The comparisons with HF radar data presented here are meant as an example of how coastal drifters can be used to help learn how to more accurately compute trajectories, or pathways, with Eulerian HF radar fields. Each HF radar installation requires "calibration" in a variety of wind and wave conditions and GPS–C drifters can provide a platform for these calibrations.

7. Summary

A drifter for observing small spatial and temporal scales of motion in the coastal zone is presented. The velocity scales that are resolved match those seen in coastal biological and chemical fields (Powell 1995). The drifter uses GPS to determine its position and the Mobitex terrestrial cellular communications system to transmit the position data. The cellular communications system allows position updates to be transmitted as frequently as every minute at a substantial cost savings, compared with satellite communications ($15.00 versus $300.00 per drifter month). Data are transmitted in near–real time, making the drifters recoverable. The Mobitex communications system is the crucial improvement to the standard Argos-tracked drifter. This communications network could be used to transmit data from other nearshore instruments as well.

The GPS–C drifters described here are being manufactured by Pacific Gyre Inc. as the "Microstar" (information available online at http://www.pacificgyre.com). Cost is less than $2000 per unit, and depends on power configuration (disposable or rechargeable batteries) and quantity purchased. Data are archived by Pacific Gyre at no additional cost. Nearly 200 drifter tracks have been collected off the Santa Barbara coast with a fleet of 15 Microstars deployed throughout 2003. The tracks are mostly a few hours in length, with a position recorded every 10 min. Only a single drifter has not been recovered during the deployments.

Comparisons between drifter and HF radar velocities over a limited region of the northern Santa Barbara shelf indicate improved agreement as the number of drifter observations within a space–time (2 km and 1 h) HF radar bin increases, so that similar time–space averages are evaluated. This result, supported by EKE computations, points to the small space- and time-scale, or sub–HF radar grid scale, motions that must be considered in the coastal ocean. Comparison between observed drifter tracks and tracks computed with Eulerian HF radar fields shows the two diverge at rates of roughly 5 and 9 cm s^{-1} in the along- and across-shore directions, respectively. The drifters resolve small time and space scales that are not present in HF radar–derived velocities as a result of required averaging. Velocity is measured in a Lagrangian framework. GPS–C drifters are, thus, complementary to HF radar–based coastal ocean observing systems.

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