degree of sample loss during the ensuing in situ period. Both are enhanced by increasing the tube diameter or decreasing the bottle volume. The ideal dimensions will vary with different field situations, in particular, the duration of salinity extremes and the period of incubation (hours to weeks). For each application, the accuracy of the apparatus should be determined to ensure that it falls within the needed limits. In regions where strong currents are expected, the inlet and outlet tubes should be shielded to prevent venturi effects from drawing out the bottle contents. Small taps may be inserted in the tubes to facilitate the collection and handling of the bottles without sample displacement.

Although it is not highly accurate, the method is extremely simple and robust, and large numbers of samples can be collected over a wide area at very little cost.

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Design of a Lagrangian surface current tracer

Abstract—A Lagrangian tracer has been developed for offshore surface current studies which responds to flow in the uppermost meter of the water column. The tracer emits dye to aid in visual sighting and is equipped with a radio beacon which permits relocation for several days by aircraft. The tracers can be deployed by aircraft or by surface vessels, and once deployed exhibit minimal windage.

Currents in the upper meter of water in the ocean or estuaries are hard to measure with Eulerian devices because of interference from surface waves. Extrapolation of subsurface Eulerian current data to the surface layer is tenuous because of the wind-induced shear within a meter of the sea surface (Gordon and Gerard 1973). This surface portion of the water column is important as the neustonic layer which is inhabited by various plankters either diurnally or at different developmental stages. A knowledge of surface currents is also important in predicting oil spill trajectories and the motion of ocean-dumped flotsam.

Lagrangian techniques are the best way of tracking surface currents, here defined as those within a meter of the surface. Drift cards and drift bottles, widely used to study sea surface circulation (e.g. Bumpus and Lauzier 1965), yield only indirect current data. Large drogued buoys tracked by ship or satellite extend below 1 m and their motion does not accurately reflect surface currents because of the wind-induced shear. Other Lagrangian devices suited to the study of surface currents, and representative references, include vinyl rafts filled with freshwater (Duxbury 1967), plywood sheets, aluminum powder, and dye (Ramey 1968), computer cards (Assaf et al. 1971), and shallow drogues (Cook 1971). These de-
devices have usually been tracked by time-lapse aerial photography, although stereo-photographic pairs have been used to determine instantaneous velocities (e.g. Keller 1963). Offshore, boats with known positions appearing in aerial photographs or direct sensing of Loran C signals by aircraft have provided a navigational reference. Small radio-equipped drogues have been tracked from shore with direction-finding equipment (Klemas et al. 1975). A shortcoming of such devices has been the difficulty in relocating them after a few hours of observation. Diffuse tracers (computer cards, aluminum powder, or dye) quickly disperse. Rafts, plywood sheets, and drogued buoys can be relocated only by intensive searching if monitoring is interrupted. Tracking of devices for longer than 1 day has been possible only by radio direction-finding, which has limited accuracy.

We describe a new aircraft deployable Lagrangian tracer designed for surface current studies. It can be used offshore and will last for several days. A radio beacon housed within the tracer allows an aircraft to home on the device from distances of 15–50 km, and dye released from the tracer then enables visual location. These tracers have been used successfully in a major study of surface currents on the New England outer continental shelf.

The design is shown in Fig. 1. The assembled unit looks like an elongate vertical cylinder with four equally spaced radial arms just below the water surface. Major structural elements include an outer tube, an inner tube, flotation devices, and the arms.

The tubes are made of low density polyethylene. The inner tube, which extends the full 132-cm length of the tracer, is capped and ballasted with lead. The lower portion is packed with a waxylike mixture of hydacid uranine concentrate (fluorescein dye), polyethylene glycol, and oleic acid. This section of the inner tube has eight vertical slits which expose the dye mixture. The inner tube is separated from the outer tube by four thin vertical strips of styrofoam. The shorter outer tube rests at its upper end against a wooden dowel driven through the inner tube. An end cap at the bottom of the outer tube has a one-way rubber check valve which admits water into the tracer. A polyethylene collar just above the dowel has four high density polyurethane arms attached to it radiating horizontally outward from the collar where they overlap at right angles to each other. Seated just between the arms and an upper collar is a ring of styrofoam surrounding the inner tube. A styrofoam cylinder of similar length is housed within the inner tube and held in place by dowels. The 8 kg (in air) tracer floats vertically like a spar buoy with the waterline a few centimeters below the top of the flotation ring. Thus, about 20 cm of the unit is above the water surface and 112 cm below. The arms attach 15 cm below the surface.

Vertical currents resulting from passing waves cause water to enter the interior of the tracer through the end valve. As this water moves upward between the inner and outer tubes, it entrains dissolving dye through the inner tube slits. The water and entrained dye arc discharged at the top of the outer tube just below the water surface. Diffusion of the negatively buoyant fluorescein dye creates a bright green patch which can be seen from an aircraft. The vertical shear of wind-induced currents causes the downward-diffusing dye to lag behind the tracer, creating a streak pointed upwind. Downwind slippage of the tracer is a minor contributor to this streak.

The rate of dye dissolution increases with both higher water temperatures and a lower concentration of oleic acid. We have found proportions of dye, polyethylene glycol, and oleic acid of 6:13:1 well suited to water temperatures of 5°–20°C. This mixture releases dye strongly for 3 days and at a diminishing rate for several more.

The four arms radiating from the tracer increase the underwater area and thus the coupling with surface water. When color-coded, they provide the unit with a unique identification. Polyurethane paint colors providing the best visibility
from the air include yellow, orange, medium blue, and black. By painting each arm a single color and varying the sequence, we can get about 30 distinguishable combinations. The 10-× 60-cm arms are visible from altitudes up to 1,000 m. The overlapping arms also serve as a roto-chute when the tracer is deployed from an aircraft, orienting it vertically and slowing its descent. Terminal fall ve-
localities of the tracers range from 14 to 18 m·s⁻¹ and impact damage is usually negligible.

Our primary aid in relocation is a VHF radio beacon mounted in selected units. These beacons are aircraft emergency locator transmitters, made to survive high shock loads; the output is modified to radiate at permitted frequencies for experimental purposes. The small, 0.23-kg beacon package fits into the open inner tube at the top of the tracer, and a 30 cm long antenna extends into the air. These beacons are available with six nonemergency frequencies in the 121.6–121.8 MHz range (Glatzer Ind., White Plains, N.Y.). Each frequency has one of six different audio codes, which gives 36 individual beacon identities. Alkaline batteries yield 3–10 days of operation depending on type. The beacons produce a continuous signal which can be homed on by aircraft with direction-finding equipment having a left-right direction indicator and an audio output. More sophisticated direction finders give a range and a bearing to the beacon. The distance from which a beacon can be sensed varies with aircraft altitude and signal strength. For the first 50% of battery life, the beacon transmissions can be sensed with the simpler direction finders from about 25 km at an altitude of 200 m and from 100 km at 3,000 m.

A successful Lagrangian surface current tracer must not be unduly deflected by wind. By comparing data acquired with drift cards and drift bottles, Monahan et al. (1975) showed how such wind effects can distort measurements of surface circulation patterns. Direct wind transport, defined as leeway, was an important factor in the development of our tracer. Drag calculations made assuming a vertically uniform current and no flexing of the horizontal tracer arms predict that direct wind stress on the exposed upper 20 cm of the tracer will result in downwind transport of the unit at 0.96% of the wind speed. We made field tests to measure wind-induced tracer displacement relative to zero leeway markers, which are 30-cm-long dye-emitting devices having negligible exposure above the surface. Relative to these markers, the tracers showed downwind motion at an average of 0.5% of the wind speed in five 30-min trials. The discrepancy between the field observations and theory probably results from wave-caused flexing of the tracer arms, which significantly increases the projected drag area. The observed leeway for the tracers is comparable to that of other floating Lagrangian devices. For example, downwind slippage of the radio-tracked drogued buoys (Klemas et al. 1975) and those used by Cook (1971) occurs at 0.7 and 0.6% of the wind speed. We have observed that the tracers move downwind faster than dye dispersed in the upper 2 m of the water column but more slowly than floating aluminum powder. These observations along with the leeway data suggest that the tracers track motion of water within 1 m of the surface with reasonable accuracy in the absence of strong winds.

We have deployed 670 surface current tracers, including 215 equipped with radio beacons, as part of a study of the New England outer continental shelf (Flynn and Cook 1978). The study area, centered on Georges Bank, lies 80–300 km offshore; Loran C was used exclusively for navigation. Tracers were deployed with a small cargo aircraft (like the Beechcraft G-18) flying at 130 km·h⁻¹ at an altitude of 200 m. During transport the radiating arms are fixed to the side of the tracers with masking tape, which breaks when the tracer is thrown out of an open doorway. Clusters of up to nine tracers have also been wrapped in water-soluble polyvinyl alcohol and thrown out as a unit. Radio beacons are activated by connecting redundant transmitter and antenna leads just before a tracer is released. About 98% of the tracers and 95% of the beacons have survived air deployment. Deployment from a surface vessel simply involves throwing the tracers overboard.
A Cessna Skymaster 337-G aircraft, equipped with vertically mounted cameras, a Loren C navigation unit, a belly-mounted view scope, and radio direction finders, was used for tracking. Our ability to relocate the tracers has depended strongly on the design of individual studies. In examinations of small-scale phenomena such as shear across frontal zones, short (1–2 km) lines of up to a dozen unbeaconed tracers have been visually relocated at 30-min intervals for several hours. Radio beacons are essential for day-to-day relocation in regional circulation studies where dozens of tracers have been distributed over 25,000 km². Success in these studies has been a function of the available search time per tracer, the condition of the beacon batteries, and the extent of dispersion. Typically, 80–90% of 30 beaconed tracers have been relocated on the first 3 days of a regional study. An experienced pilot can maneuver the aircraft directly over a tracer by using the beacon homing system, practically eliminating the need for visual searching.

The tracers can survive in the ocean for several weeks to months. Our practice has been to label them with return addresses and requests for information on recovery time and location. Eight tracers (1.2% of those deployed) have been recovered to date.

The cost of materials for assembling the tracer, based on buying enough to make 1,600, was $31 per unit (1977 prices). The manufactured unit cost was $65. The beacons, bought with batteries in lots of 150, cost $130 each in 1977.

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References


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