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A New Method of Measuring Coastal Surface Currents with Markers and Dyes Dropped from an Aircraft

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ABSTRACT

This paper describes a new low-cost method of measuring coastal surface currents with markers dropped from a light aircraft at each of a series of stations. Each marker consists of a cloth bag containing floats and a different dye. One marker, with anchor attached, remains stationary while a second marker, with drogue attached, moves with the current. The specific dye with each marker disperses slowly and continuously through the cloth into the water and aids in the subsequent location of each marker. Following a predetermined lapse of time, the distance and direction of the moving marker from the stationary marker can be determined from the aircraft.

Introduction. As background for an investigation into the disposal of shore effluents into the water around Cape Town, a knowledge of the general coastal circulation was needed. The initial project, a study of the circulation of surface water in False Bay (approximately square and about 17 mi. [27 km] across), called for the following requirements:

(i) Obtain spot readings of surface-current speed and direction at a maximum of about 20 stations spread over an area of about 300 mi.² (780 km²);
(ii) Complete the observations within about two hours to exclude tidal influences;
(iii) Consider water depths up to 50 fathoms (91 m); and
(iv) Keep the cost of one series of observations to $200 or less.

The method devised to meet these requirements has proved to be so satisfactory that it is now used for practically all surface-current measurements required in this program, including those in very shallow near-shore water. With modification, the method could be used to determine shear irrespective

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of water depth, but reliability would be more difficult to attain than in the simple case of surface-current measurements.

**Description.** The package of apparatus used at a station consists of two markers, one of which is maintained in a stationary location by means of an anchor while the other, with a drogue attached, floats freely with the current (Fig. 1). The stationary marker, which consists of a cloth bag containing a float and sodium fluorescein dye, is attached to the anchor by means of nylon cord of diameter 0.016 in. (0.04 cm). The free-floating marker consists of a cloth bag containing a float and rhodamine dye; to this a drogue is attached. The stationary marker has a buoyancy of about 10 oz. (280 g) and a cross-sectional area of about 10 in.² (65 cm²).

The cloth used for the bags must be of a mesh size that permits adequate dye to be given off so that the dye can be spotted from the air; at the same time, care must be taken that the dye is not dispersed so fast that the supply will be exhausted prior to the completion of the observations. For the False Bay work, satisfactory bags for the fixed marker were made from a double thickness of tightly woven unbleached calico. (For observations where the currents are
stronger and produce increased scouring action, a cloth of still closer weave would be necessary, or, the rate of dissolution could be reduced to the desired level by placing the marker in a polythene bag having small perforations.) For the drifting marker, which has no flow past it, a cloth with a much more open weave was used; this was a cotton cloth commonly known as mutton-cloth or cheesecloth. The openings in this material constitute about half of the area of the cloth.

The floats for both markers were made of cylindrical blocks of polystyrene. The sizes of the floats are limited by the dimensions of the tin cannister into which they are placed prior to launching. The sizes used were 15 in.\(^3\) (250 cm\(^3\)) for the free-floating marker and 20 in.\(^3\) (330 cm\(^3\)) for the fixed marker.

The dyes chosen were sodium fluorescein (green) and rhodamine BN\(_{450}\) (red), both of which were supplied by Imperial Chemical Industries. Following exhaustive tests on most of the commercially available dyes in Cape Town, only these two met the requirements of slow dissolution and of sufficient brilliance to be seen from an aircraft. Since the fluorescein is by far the more clearly visible of the two, it was used with the fixed marker because it produced a larger patch of color and could be spotted quickly from the air. In the False Bay study, 5 oz. (140 g) of fluorescein and 3 oz. (85 g) of rhodamine were used.

The anchor or weight, which also serves as a container for the other components during launching, is a tin can from which one end is removed; the can used was 7 in. (17.8 cm) high and 3 in. (7.6 cm) in diameter. When removing the end, care should be taken to leave no sharp edges. The tins used had circumferential ridges, which gave them added strength.

About 1.5 lb. (680 g) of molten lead are poured into the bottom of the tin, an amount that assures proper vertical attitude during descent and guarantees proper settling of the anchor on the sea bottom.

The drogue, which is attached to the free-moving marker, consists of a 12 x 5-inch (30 x 13-cm) piece of calico stapled to steel and wooden rods that are 3.5 in. (9 cm) long and 3/8 in. (0.95 cm) in diameter. For the work in False Bay, the string that was used to attach the drogue to the marker was six feet (1.83 m) long. It was felt that the depth of the drogue with this length of string gave a fair picture of the water movement in the surface layer.

**Assembly.** For the fixed marker, the float and fluorescein were placed inside the cloth, and the ends of the cloth were tied to form the bag. The nylon cord was then wound around the bag after its end had been secured to the marker; the other end of the cord was attached to holes in the side of the can. The assembly was then placed in the bottom of the can as indicated in Fig. 1. For the moving marker, the float and rhodamine were similarly placed in the cloth, and the drogue was attached to the bag with the string. It was then placed in the can above the stationary marker.
It is essential that the two markers be placed in the can as indicated in Fig. 1. This will ensure satisfactory operation.

The tissue cover over the open end of the can consists of four layers of square cosmetic tissue paper (64 in.²; 410 cm²), secured with masking tape as shown. The excess tissue below the tape should not be trimmed off since its air drag aids in keeping the can vertical during descent. The tissue not only holds the markers in the can during launching but prevents the airplane from being contaminated with the dyes.

Inhalation of the finely powdered dyes and contamination by them of clothing and work area during assembly of the markers are almost unavoidable, hence great care should be taken in the handling of these chemicals. Care should also be taken to avoid soiling of the airplane. These remarks apply particularly to rhodamine, which has more powerful staining properties than fluorescein.

It is essential that the nylon cord that secures the stationary marker to the weight be long enough to avoid having the marker pulled below the surface by the current. The length of cord required can be determined by the formula, 

\[ \tan \psi > \frac{F}{B} \]  

(see Fig. 2); here \( \psi \) is the angle of the cord from a vertical line, \( F \) is the horizontal drag force on the marker caused by the current, and \( B \) is the buoyancy of the marker.

Since the dimensions of the float are limited by the size of the can, the buoyancy and drag in a given current are fixed. Hence, the nylon length must be adjusted according to the water depth and the expected current speed. Experiments have shown that the drag formula,

\[ F = \frac{1}{2} \rho A v^2 C_D, \]

is applicable if \( C_D \) is taken to be 1.05; here \( F \) is the drag force, \( \rho \) is the density of the water, \( A \) is the cross-sectional area of the complete marker, \( v \) is the current speed, and \( C_D \) is the drag coefficient. A simple calculation gives the minimum length of nylon required for any given water depth.

It was found in practice that the drag of the nylon cord could be disregarded if the calculated length is increased slightly. This disregard for the drag force was possible because of the relatively shallow depths and the thin layer of surface currents in False Bay; however, under different conditions this drag could be much greater than that of the marker and would have to be taken into consideration.

**Operational Procedure.** Stations should be selected for ease of location by means of transits on landmarks. Regularity of bottom topography should also be considered.

When the package is launched, the tissue paper disintegrates almost immediately in the water and the markers emerge. As they float to the surface and the can sinks to the bottom, the nylon cord around the stationary marker
unwinds, and the drogue on the drifting marker opens. When the stationary marker has achieved its fixed position at the surface, the current flowing past it slowly distributes the fluorescein in the water and carries it along, thus producing an elongated patch that is readily visible from the airplane. The moving marker, with the drogue attached below, moves with the surface current, and the dissipated dye gives rise to a small circular red patch.

Two types of airplane were used for the launching of the packages at the selected stations: a Piper Cruiser (high-wing monoplane) and a Piper Cherokee (low-wing monoplane). From the Piper Cruiser the packages were launched through the window and from the Piper Cherokee through a hole cut in the bottom of the fuselage. An altitude of 2000 feet (610 m) and a speed of 100 to 120 mph. (161 to 193 km/hr.) were found to be suitable for launching, since this permitted the packages to achieve a vertical attitude prior to striking the water. Under these conditions the horizontal distance traveled by the marker before striking the water was measured to be about 170 feet (52 m). This small displacement may usually be disregarded.

Following a suitable lapse of time (in the False Bay work this was about one hour), the plane makes a second run over the stations to measure the distance between the markers. The measurements are made from a position vertically above the markers (Fig. 2). The stationary marker is located at the upstream end of the green streak and the moving marker is usually seen downstream from the stationary marker in the center of the red patch.

With the Piper Cruiser, the plane was steeply banked and a simple two-armed pointer, with pivot held next to the eye, was used to estimate the angle subtended by the two markers (angle $\theta$ in Fig. 2). With the Piper Cherokee, a convex lens with calibrated ground-glass screen at the focal length was mounted over the hole in the fuselage. Thus an inverted image of the markers appeared on the screen, and from this the angle $\theta$ could be calculated. This latter procedure produced more accurate results. With currents stronger than one knot it would be necessary to take observations from an altitude greater than 2000 feet (610 m) to keep the angle $\theta$ within reasonable bounds.

Since great accuracy in this type of investigation is unnecessary, these simple methods are usually adequate; for example, an error of 50 feet (15 m) in altitude or of one degree in angle would result in an error of only about 0.01 knots (0.5 cm/sec.) in current speed.

The direction of the current was obtained by aligning the plane with the markers and noting the gyrocompass reading. For greater accuracy more sophisticated methods could be used.

**Plotting of Results.** The current speed at a particular station is found from the formula,

$$v = \frac{2H \tan \theta/2 + (2D \delta + \delta^2)^{1/2}}{t},$$
where $H$ is the altitude of the plane, $\theta$ the angle subtended at the plane, $D$ the depth of water, $\delta$ the excess length of nylon over and above the water depth, and $t$ the elapsed time between launching and observation. See Fig. 2.

Current vectors can now be plotted. If a sufficiently close network of stations has been worked, the synoptic nature of the measurements permits the sketching in of streamlines.

For convenience, the spacing of these may be made inversely proportional to the current speed. In this form the main features of the current distribution are clearly displayed.

Fig. 3 shows a typical series of observations for False Bay. Although the stations are not close enough and there is no reading for the center of the Bay, the streamlines have been inserted to illustrate the principle. In this instance, it is evident that the westerly winds prevailing at the time were causing a general anticlockwise circulation in the Bay. The distribution of currents suggests upwelling on the west coast of the Bay and sinking of water along the northern coast.

**Discussion.** With early designs, the system was very unreliable. The chief difficulty encountered was the nonemergence of either one or both markers due to the tangling of the nylon or the crushing of the can on impact. With
improvements in design the proportion of successful attempts increased, and now it is rare for more than 5% of the apparatus to fail.

Costs have been low. In South Africa, materials for one set of markers cost about $2.00 and the plane rate was about $15.00 per hour. In comparison with alternative methods, these figures are quite insignificant.

In addition to the above application, colleagues at the Council for Scientific and Industrial Research in Durban have successfully used from the air only one fixed marker containing a float and a much larger amount of fluorescein as a point source of dye for circulation studies in the surf zone.
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