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A continuous turbidity monitoring system for coastal surface waters¹

Abstract—A continuous, time-referenced turbidity monitoring system utilizes a keel mounted optical transmissometer with a modified strip chart recorder; it allows detailed study of the distribution of suspended particles in surface waters.

It is of interest to measure turbidity continuously in surface waters of channels, bays, and estuaries. Drake (1972) used an in situ optical transmissometer to monitor turbidity for his studies of the distribution and transport of suspended matter in the Santa Barbara Channel. Ludwick and Melchor (1972) clearly demonstrated the value of spot-monitoring turbidity with an optical transmissometer by delineating many circulation patterns in the mouth of Chesapeake Bay. We have extended the use of the optical transmissometer for surface circulation studies by coupling the instrument to the keel of a research vessel so that turbidity can be monitored continuously over a short time, providing a way of resolving small-scale surface circulation structure over a wide area if repeated traverses of the area are made. Such small-scale surface circulation studies have been almost impossible with spot turbidity measurements, and we have found no similar system reported in the literature. The continuous surface turbidity monitoring system can be used by itself or to complement

the traditional technique of spot measurements by vertical casts.

We wish to express our appreciation to J. C. Ludwick and J. R. Melchor for their advice and assistance on the instrument modifications, to T. Gardner for technical help in metal fabrication, and to R. Bray and the crew of the RV *Linwood Holton* for shipboard assistance.

To continuously monitor turbidity we have devised a system that couples a modified dual-beam optical transmissometer probe and an automatic null-balancing circuit with a modified strip chart recorder. It is operated aboard a research vessel on which the transmissometer probe is keel mounted so that it will pass through an undisturbed portion of the top surface layer (Fig. 1).

We measure turbidity with a Bendix/Marine Advisers C-2 transmissometer probe. This instrument gives a direct indication of light transmittance in water, the degree of light attenuation with a fixed-beam path-length, expressed generally as the attenuation coefficient, α , where

$$\alpha = -\frac{1}{(\text{beam path-length})} \ln(\text{transmittance})$$

for a homogeneous medium. The beam path-length of our probe has been reduced from the standard 1 m to 0.430 m to make it operable in the turbid waters characteristic of the Chesapeake Bay and other estuarine environments. Figure 2 shows the optical construction of the probe. Only

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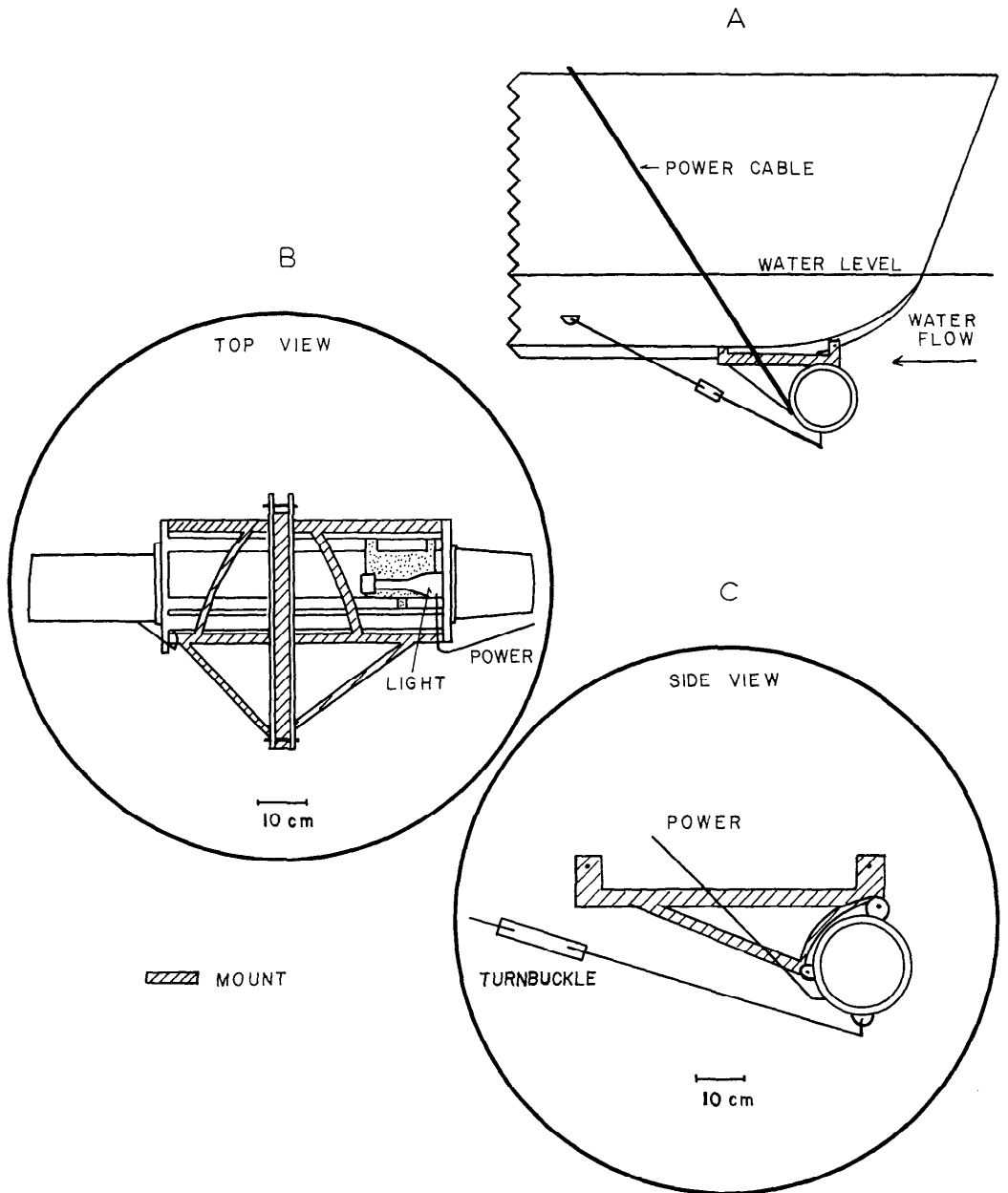


Fig. 1. A. General configuration of the transmissometer probe keel mounted on the research vessel. Not drawn to scale. B. Top view of the transmissometer probe with steel mounting bracket (10 to 1 scale reduction). All joints are welded. C. Side view of the transmissometer probe with steel mounting bracket and 6-mm steel stabilizing cable (10 to 1 scale reduction).

light produced by the source is sensed at the receiver. Two matched Wratten No. 16 filters are used to control the wavelength, yielding for this probe a band-pass of

about 50 nm centered at 525 nm, with two Schott BG-18 filters installed to block the red energy above 700 nm.

The probe mounting configuration is

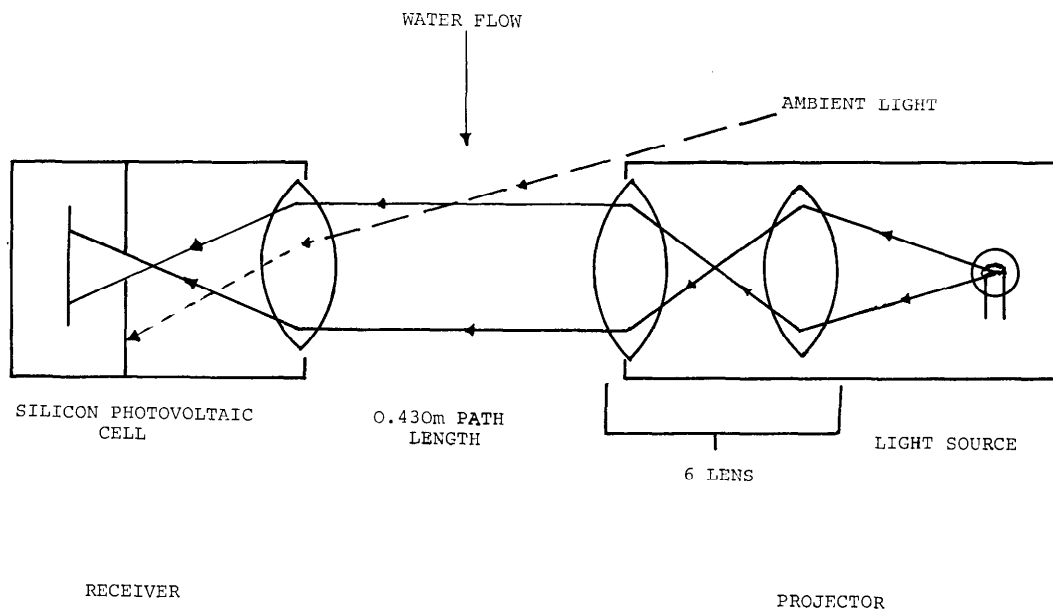


Fig. 2. Optical construction of the transmissometer probe. Ambient light is occulted by the field stop.

shown in Fig. 1B and C. The RV *Linwood Holton*, a 20-m steel hull with a mean draft of 1.68 m, is used as the platform. Two mounting holes are cut in the keel so that with the instrument mounted the beam will be 1.4 m below the mean waterline of the vessel when fully loaded. At either end of the transmissometer stainless steel stabilizing cables 6 mm in diameter are attached with steel U-bolts to eye plates welded to the hull about 1.3 m aft of the instrument. The mounting bracket itself is of steel, and all joints are welded so that the 52-kg transmissometer probe is held firmly. The transmissometer probe is hoisted over the bow in calm water. Two SCUBA divers swim the probe under the vessel to the keel mounting position while it is still being supported by cables attached to the deck hoisting rig and secure it with two mounting bolts and two stabilizing cables with turnbuckles; this takes 15 min, as does removal. No instrument distortion during ship movement has been observed with this arrangement in more than 10 field runs at speeds up to 18 km hr⁻¹ for periods not less than 4.5 hr. Optimum running speed is from 11–14 km hr⁻¹

due to vibration of the power cable against the hull above water. Tension is maintained on this cable during operation. Sea states up to code 4 (wave height maximum of 2.44 m) have posed no instrumentation problems. During vessel operation the keel angles, with the bow positioned slightly higher in the water than the stern, so that the probe actually records transmittance at a mean depth of 1.2 m below the water surface and is thrust forward of the hull region where entrained air and foam might cause interference. Water movement through and around the probe during operation does not effect the transmission record for tested speeds up to 18 km hr⁻¹, and the probe at no time leaves the water as the vessel pitches and rolls except in heavy seas.

The transmittance is recorded on a modified Moseley model 80A-2 strip chart recorder with an automatic balancing circuit that replaces the conventional manual read-out of the probe. The circuitry, including modifications for this particular system, has been reported by Bryant (1973). A crystal controlled, two pulse per second generator, when selected, produces a chart speed of

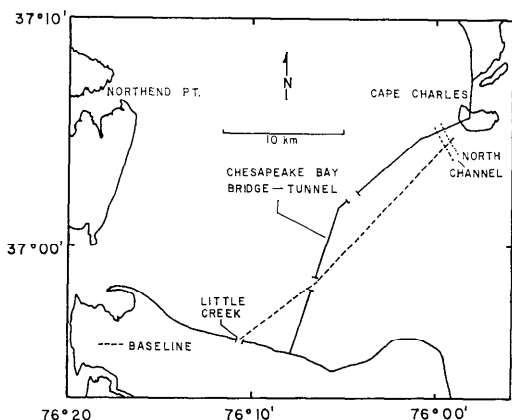


Fig. 3. Chesapeake Bay mouth with the baseline location used to generate the transmittance profiles shown in Fig. 4.

1.270 cm min^{-1} within 0.1%. The chart drive velocity is therefore independent of powerline frequency, which on a small vessel is not necessarily well regulated. By recording an accurately time-referenced transmittance and coupling it with known ship speeds and navigational checks, precisely located turbidity baselines can be established.

Figure 3 shows the area used to generate two representative transmittance profiles shown in Fig. 4. The baseline totals more than 24 km and is traversed repeatedly every 18 days in less than 2 hr. After many repeated runs during different tide cycles and under sharply different weather conditions specific peaks and depressions begin to recur consistently in the turbidity record. An example of this is the two bracketed depressions shown in Fig. 4, which have reappeared consistently at this point in the Little Creek to Cape Charles record. Examination of the area reveals that the North Channel (see Fig. 3) coincides with the surface turbidity depression. Suspended load values were also obtained along the baseline during each profile (Freitag et al. 1974); these were as high as 72 mg liter^{-1} in the North Channel area on 13 February 1973, at least four times greater than load concentrations for the 26 January 1973 profile. Figure 4 clearly shows the marked

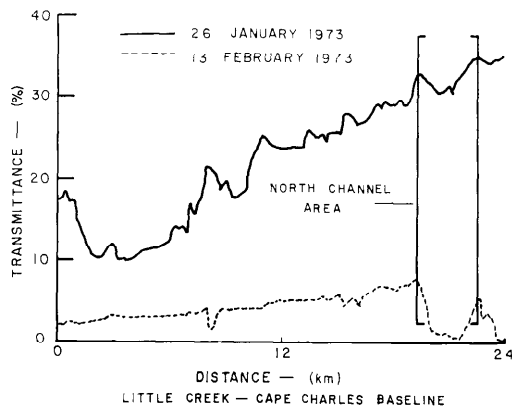


Fig. 4. Transmittance profiles generated across the mouth of Chesapeake Bay on two selected days.

difference in transmittance levels for the two days, showing that transmittance levels in a profile are indicative of actual suspended load concentration in the surface layer. Multiple turbidity runs made over a long period add additional information by taking into account variables such as tidal, weather, and stream-discharge fluctuations. Correlation of transmittance records over such an interval provides an efficient method for determining suspended load movement at the surface and relative load quantities.

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A comparison of vertical drift-envelopes to conventional drift-bottles^{1,2,3}

Abstract—A comparison of the recovery sites of vertical drift-envelopes and of ballasted drift-bottles released simultaneously at common locations in Nantucket Sound off Cape Cod substantiates a preliminary conclusion, based on small tank experiments and simple calculations, that vertical envelopes move more rapidly through the water due to direct wind influence than do ballasted bottles. The bottles therefore provide a truer indication of surface currents than do the envelopes.

Many types of surface floats have been advocated for use as lagrangian indicators of surface currents. Setting aside the dozens of drogue system designs (Monahan and Monahan 1973*b*) where the drogue-buoy's position is monitored frequently during the drift, and considering only those small surface drifters that are released in clusters, one still has at least a dozen distinct designs to choose among (Monahan and Monahan 1973*a*). Two of the currently most popular surface drifter designs are the ballasted drift-bottle and the vertical drift-envelope. The drift-bottle has been in use as a surface current marker since 1763 (Carruthers 1956; Gakkel' and Samsoniya 1961), while the vertical drift-envelope has been introduced since the close of the Sec-

ond World War. Before comparing these two types of surface drifters we must state specifically the criteria to be used in evaluating them.

Clearly it is impractical in any measurement program to use a drifter type that does not net a significant number of post-card returns for the number of drifters released. Thus any acceptable drifter must be able to survive at sea for an extended period, must be able to reach the shore through the surf, and once stranded, must be of such a nature that it attracts attention.

A good drifter must not only satisfy these practical criteria, but must move in unison with the surface current. Here one has to decide what the term "surface current" means in the particular context. In a study of the transport of surface film material "surface current" might mean the horizontal motion characteristic of the upper millimeter or less of the water column: for such a study horizontal drift-envelopes (Olson 1951; Duncan 1965) or horizontal drift-cards (Duncan 1965; Stander et al. 1969) should be considered. The selection of ballasted drift-bottles and vertical drift-envelopes for our study reflects our interest in the average horizontal advective velocity of the upper meter or so of the water column and accords with the more common usage of the term "surface current."

While surface currents are usually wind induced, a good surface drifter (if it is to move with the surface current) must suffer minimal direct wind influence, and thus must have a very small ratio of sail area (area exposed to wind) to drogue area (area exposed to current). An initial esti-

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