YALE
PEABODY
MUSEUM

P.O. BOX 208118 | NEW HAVEN CT 06520-8118 USA | PEABODY.YALE. EDU

JOURNAL OF MARINE RESEARCH

The *Journal of Marine Research,* one of the oldest journals in American marine science, published important peer-reviewed original research on a broad array of topics in physical, biological, and chemical oceanography vital to the academic oceanographic community in the long and rich tradition of the Sears Foundation for Marine Research at Yale University.

An archive of all issues from 1937 to 2021 (Volume 1–79) are available through EliScholar, a digital platform for scholarly publishing provided by Yale University Library at https://elischolar.library.yale.edu/.

Requests for permission to clear rights for use of this content should be directed to the authors, their estates, or other representatives. The *Journal of Marine Research* has no contact information beyond the affiliations listed in the published articles. We ask that you provide attribution to the *Journal of Marine Research*.

Yale University provides access to these materials for educational and research purposes only. Copyright or other proprietary rights to content contained in this document may be held by individuals or entities other than, or in addition to, Yale University. You are solely responsible for determining the ownership of the copyright, and for obtaining permission for your intended use. Yale University makes no warranty that your distribution, reproduction, or other use of these materials will not infringe the rights of third parties.

This work is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License. https://creativecommons.org/licenses/by-nc-sa/4.0/

Journal of Marine Research, 42, 207–219, 1984

Nephelometer and current observations at the STIE site, Panama Basin

by W. D. Gardner,[1] J. K. B. Bishop[1] and P. E. Biscaye[1]

ABSTRACT

The LDGO-Thorndike film recording nephelometer was used in three modes (profiling, short-term tethered and long-term moored) to measure changes in particle concentrations on time scales of minutes to weeks and space scales of meters to 25 km while measurements were being made on production and settling rates of particles. Although the nepheloid layer had no large near-bottom increase suggestive of local resuspension, there was an unusually thick nepheloid layer due to resuspension and advection of sediment from the basin walls. The concentration of particles increased by a factor of 3 between 900 m and the seafloor at 3840 m, while the vertical flux of particles measured in traps increased by only a factor of 1.7 over that distance. The horizontal flux of particles past traps at all depths is estimated to have varied by less than 20% and, therefore, does not appear to influence the flux measured with sediment traps. Changes with time in small-particle concentrations measured by the moored nephelometer were less than 30%, but the concentration of large particles changed by 100%.

1. Introduction

The distribution of particulate matter in the water column is an important factor controlling and resulting from the vertical flux of particles in the ocean. Since the goal of the Sediment Trap Intercomparison Experiment (STIE) was to compare fluxes measured with sediment traps of different designs which were spread throughout the water column, an important environmental parameter to measure in time and space was the concentration of particulate matter. Measuring this parameter was one of the contributions to STIE of the C-FATE group (Composition, Flux And Transfer Experiments) of Lamont-Doherty Geological Observatory. This measurement was particularly important since STIE was carried out in a narrow trough at the base of the Coiba Ridge in the Panama Basin where vertical, horizontal, and temporal changes were likely to be larger than in the open ocean, away from complex topography. The depth of the east-west oriented trough is 3840 m, but the walls shoal to a depth of 200 m only 20 km northeast and 50 km southwest of the center of the site (Fig. 1). To the east the sill depth is 3550 m and to the west, 2800 m. There is a narrow southern

---

[1] Lamont Doherty Geological Observatory of Columbia University, Palisades, New York, 10964, U.S.A.

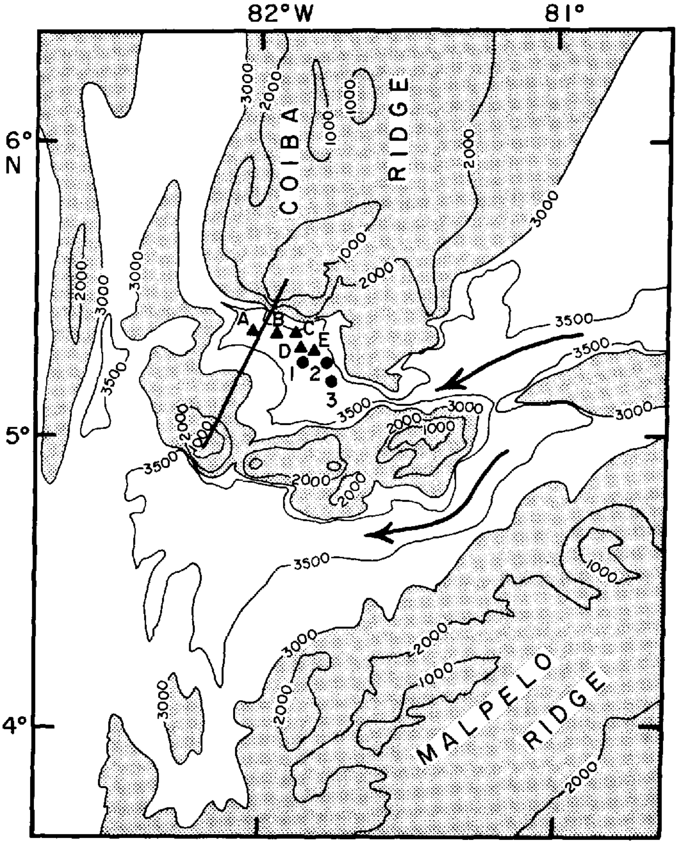

Figure 1. Topography of a portion of the Panama Basin shows it is composed of several small basins. The STIE site was in a trough at the foot of the Coiba Ridge. Triangles indicate mooring locations (A–E), circles, the nephelometer profiles (1–3), and the line shows the transect drawn in Figure 3. Arrows indicate mean bottom water flow.

gap with a sill at 3000 m. Based on the distribution of bottom-water properties, a mean westerly flow is implied for the basin (Lonsdale, 1977).

2. Methods

The LDGO-Thorndike nephelometer (Thorndike, 1975) was used in three different sampling modes to optically measure the concentration of particulate matter in the water. The instrument records on film the intensity of light scattered at forward angles between 8° and 24° as well as the intensity of a direct beam of light. The ratio of the two intensities is reported as log E/E_D where E is scattered light and E_D is direct light. The instrument has been calibrated against particle concentration for deep Atlantic water by filtering and weighing particulate matter from adjacent water samples

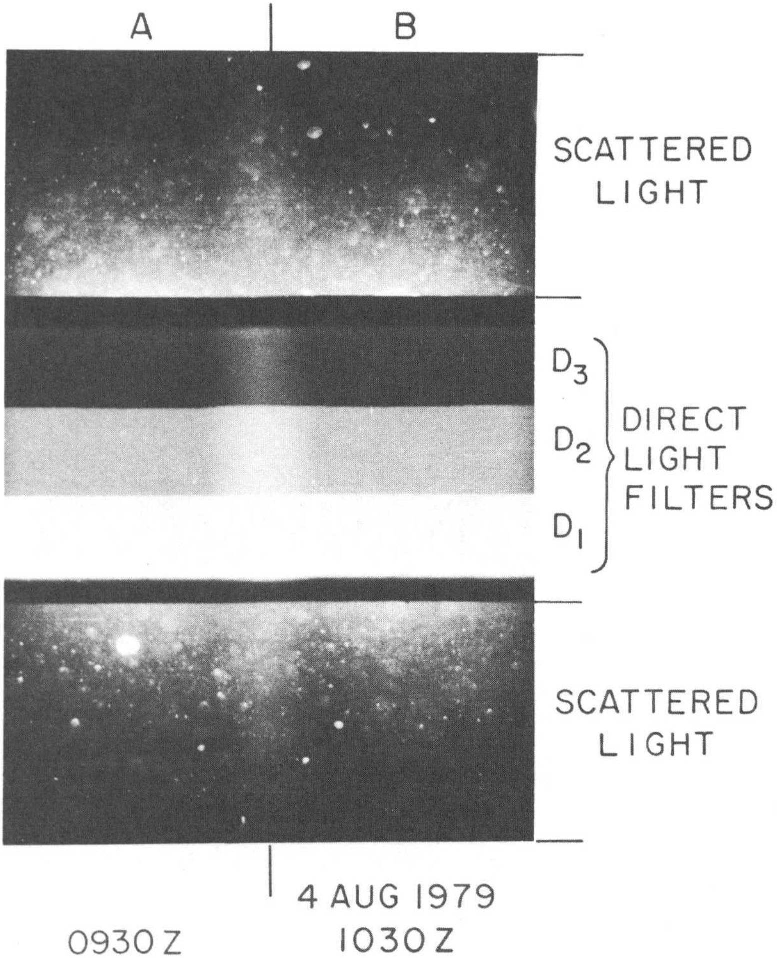

Figure 2. Two consecutive exposures, A and B, from the nephelometer record consist of a direct light beam passed through three different density optical filters and recorded on film, and the scattered light clouds the film on either side of the direct beam. A slight overlap of the two frames caused the bright portion in the center. The presence of large discrete particles is also recorded on the film record as discrete white dots.

(Biscaye and Eittreim, 1977; Biscaye *et al.*, 1980). In the standard vertical profiling mode a light source shines continuously while film is transported past the lens at a constant rate. The vertical sampling resolution is therefore controlled by the rate of instrument lowering. During daylight hours the record in the upper 100 m, the euphotic zone, is lightstruck and therefore useless. The second sampling mode uses a unit with a flashing strobe to make discrete, instantaneous measurements every 40 seconds. This unit, hereafter referred to as a Rapid Rate Nephelometer (RRN), was suspended below the Large Volume *in situ* Filtration System (LVFS) whenever it was

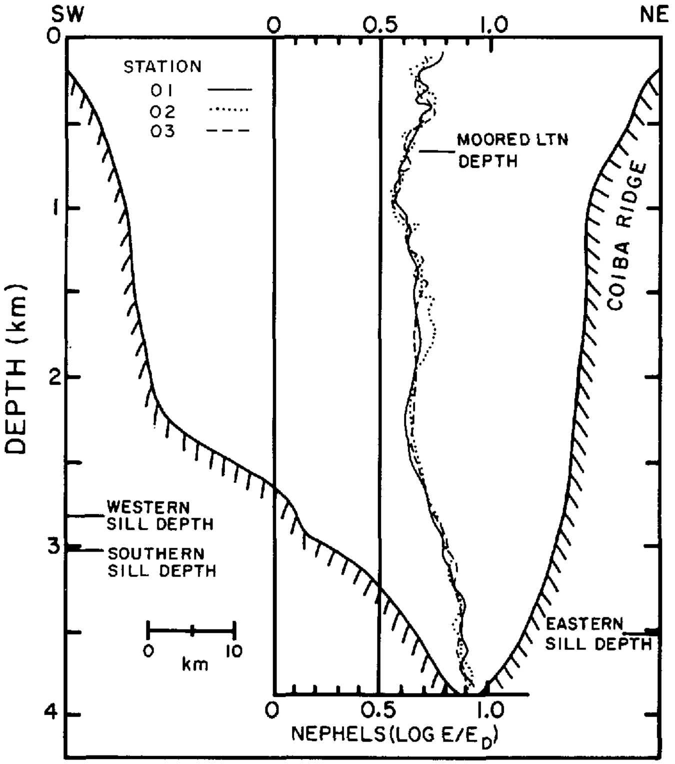

Figure 3. Three nephelometer profiles, although taken over a period of 8 days, are nearly identical in their major features. The horizontal scale of light scattering, log E/E_D, is positioned on the cross section so that the bottom of the profile coincides with the bottom of the trough. Vertical exaggeration of the basin is 50 times.

used on the deployment cruise (*Knorr* 73-17). Since most of the shallow LVFS lowerings were made at night and since this unit advanced the film after each measurement, the record of the upper 100 m of water column was preserved. The third sampling mode involved a flashing strobe unit which sampled once every hour. This unit, hereafter called a long-term nephelometer (LTN), was attached to mooring A of STIE at 675 m depth, immediately below one of our sediment traps.

With a continuous light source and continuous film transport, as in the standard vertical profiling mode, the light scattered from particles is recorded on the film as a general fogging. Data reduction involves digitization of the ratio of scattered to direct light using a photodensitometer (Thorndike, 1975). Most of the light scattering is caused by particles smaller than the photographic image resolution of the nephelometer, so even when a strobe light source is used to obtain measurements at discrete points in time or space, the record still appears as general fogging. An advantage of a strobe source in the nephelometers, however, is that images of large discrete particles can be seen on the film (Fig. 2). Particle size cannot be determined with the present strobe

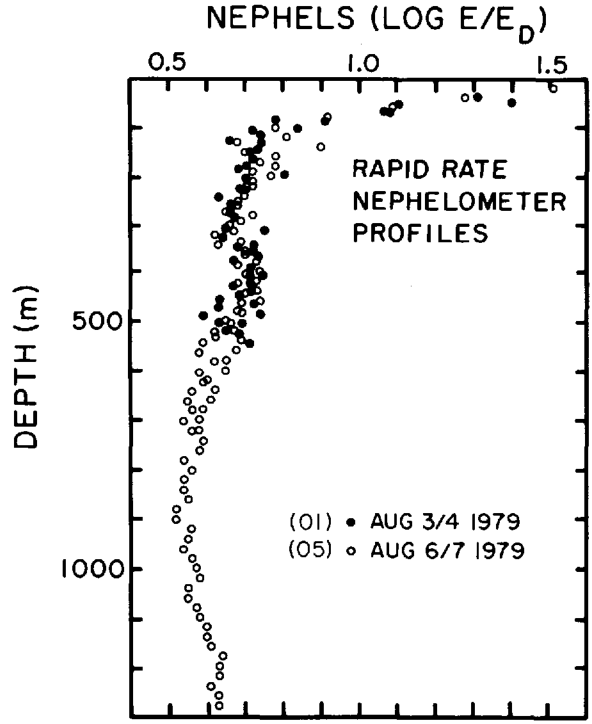

Figure 4. Composite data from the Rapid Rate (strobe) Nephelometer (RRN) profiles 01 and 05 hung below the LVFS pump.

systems because the particle distance from the film is not known. We have counted these large particles in some of our nephelometer records using a microfilm reader to look for temporal or spatial variations in the population of "large" particles. Spatial and temporal variations in "small" particles come from measurements of film fogging.

Currents and temperature were sampled at 7.5 minute intervals over the four-month duration of STIE using vector averaging current meters (VACM) attached at four depths on three sediment trap moorings. Daily averaged data were shown in Honjo *et al.* (1982). Other aspects of the data are discussed here.

3. Results

The major features of the three nephelometer profiles taken at the STIE site (Fig. 1) over a period of eight days in July and August, 1980, were identical (Fig. 3). Slight maxima occurred at 400 m and 1700 m. The 400 m maximum corresponded roughly to the depth of the deep-scattering layer observed on the 12 kHz echo sounder records. The minimum in light scattering occurred at 900 m (log E/E_D of 0.55 equals 6–11 μg/l, depending on the calibration used; Biscaye and Eittreim, 1977) and, with the

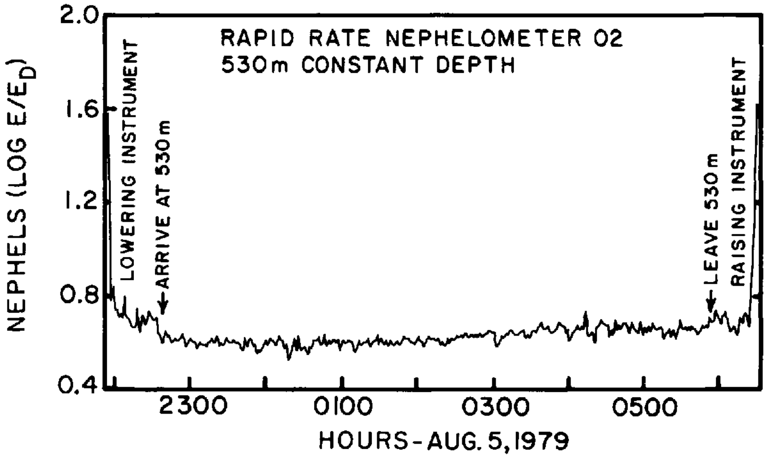

Figure 5. Record of the Rapid Rate Nephelometer hung below the LVFS pump showing data collected while lowering and raising the instruments as well as for the six hours (local time) the instruments were at constant depth at 530 m.

exception of a slight minimum at 2250 m, the intensity of light scattering increased gradually all the way to the bottom. The intensity of light scattering never rose above log E/E_D of 0.95 (equivalent to 18–28 μg/l), but since the nepheloid layer is defined as the region below the minimum in light scattering (Biscaye and Eittreim, 1977), the thickness of the nepheloid layer was very large (2900 m), contrary to the statements of Honjo *et al.* (1982), and the particle concentration increased by a factor of three over that depth interval. There was no intense, near-bottom nepheloid layer.

A composite of several vertical profiles obtained from the RRN hanging below the LVFS pump (Fig. 4) shows a curve that is very similar in structure to the curves of the profiling nephelometer. The discrete and continuous profile records were obtained over a time period of 12 days and a spatial separation of no more than 25 km (Table 1), indicating that these features were persistent over time and space scales of at least those magnitudes.

During one of the LVFS deployments, the pump and RRN were lowered to a depth of 530 m and held for 24 hours of continuous sampling. One six-hour segment of that time (Fig. 5) shows very little change in the concentration of particulate matter. Most of the changes on the time scale of minutes are only slightly above the noise level and, over the six-hour period, the change in light scattering represents a change in particle concentration of less than 2 μg/l. Echo sounding records showed the deep scattering layer was at the surface during the sampling period, but started downward at about 0600. All observed migrations of the scattering layer during the cruise occurred above the 530 m sampling depth.

When sampling with both the LVFS and RRN was done at depths of 12, 32, 50, and 75 m for periods of 0.5 to 1.5 hours, there were observable variations in particle

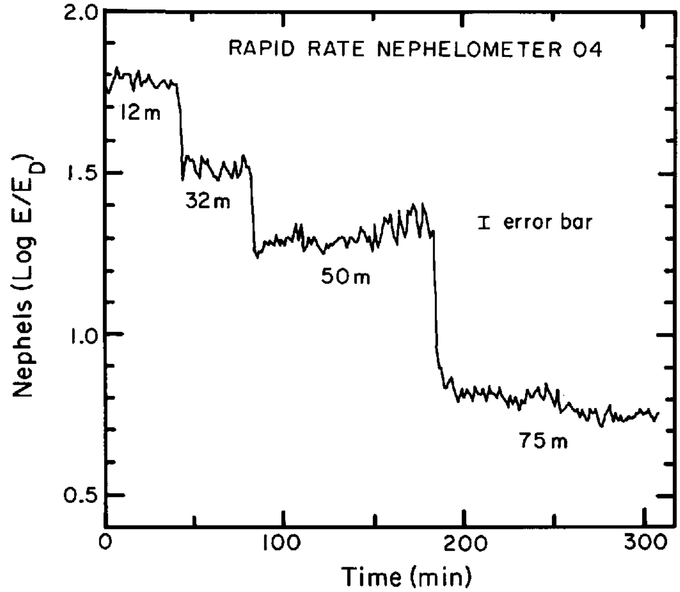

Figure 6. Rapid Rate Nephelometer (RRN) record at four depths. The thermocline was at 55 m.

concentration (Fig. 6). Some periodic spikes occurred at 32 m and 50 m that were larger than the one standard deviation error bar, but their period (less than 10 min.) is shorter than the shortest possible internal wave period of 20 minutes. At 50 m and 75 m there were increases and decreases respectively in the levels of light scattering during the sampling periods. XBT records during the sampling time showed isotherms deepening while pumping at 50 m and shoaling while pumping at 75 m which would expose the instrument to water increasingly higher and lower in particle concentration at the respective depths. The long-term changes in light scattering are thus believed to reflect the passing of internal waves.

The discrete photographs from the RRN record Neph 01 (Table 1) were examined to see if a change in the number of large particles could be detected as a function of depth (Fig. 7). Although the mean in large-particle counts decreased uniformly with depth by 8% between 100 and 530 m, the one standard deviation error bars over the depth range overlap. By comparison, the decrease in small-particle concentration between those depths is significant. Changes in large-particle counts during a 6-hour sampling period at 530 m (Neph 03, Table 1) were not significant.

The LTN, which functioned for only 15 days after deployment, showed no significant temporal variation in the concentration of small particles other than the random peaks which were greater than the error bar. The peaks indicated a change of 2–3 μg/l against a background of about 5–7 μg/l (Fig. 8). There was, however, a slight increase with time in the average number of large particles, and a peak in the number

Table 1. Location of nephelometer measurements.

Standard Profiling Nephelometer

						Position	
Neph.	Hydro.	Date	Time (GMT)	Depth sta.	Depth neph. reached	Latitude (N)	Longitude (W)
01	1126	26/7/79	0245–0620	3824 m	3817 m	5°14.1′	81°51.2′
02	1128	01/8/79	2240–0219	3939 m	3831 m	5°14.1′	81°47.7′
03	1129	03/8/79	2142–0100	3839 m	3835 m	5°10.9′	81°46.8′
Long Term Nephelometer (LTN)							
01		28/7/79		675 m		5°21.8′	82°01.4

Rapid Rate Nephelometer

					Position			
					Begin		End	
Neph.	*In Situ* Pump	Date	Time (GMT)	Depth levels (m)	Lat. (N)	Long. (W)	Lat. (N)	Long. (W)
01	01	02/8/79	0538–1927	100, 180, 200, 350, 510	5°10.0′	81°50.6′	5°04.8′	81°45.5′
02	02	04/8/79	0253–1134	530 m	5°10.7′	81°49.7′	5°09.2′	81°50.5′
03	03	04/8/79	1638–0425	530 m	5°05.2′	81°50.6′	5°00.4′	81°47.7′
04	05	06/8/79	0510–1036	12, 32, 50, 75	5°07.5′	81°49.8′	5°08.5′	81°49.9′
06	06	06–07/8/79	1354–0950	720, 910, 1083, 1268	5°09.4′	81°48.9′	5°07.7′	81°43.3′

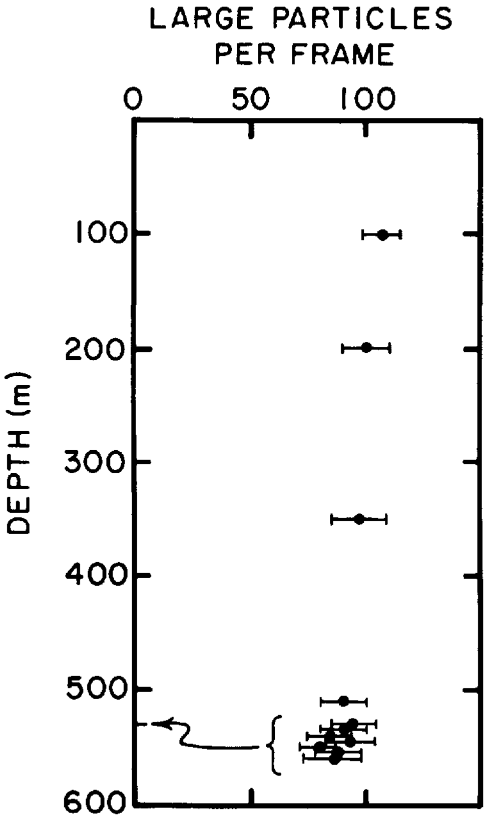

Figure 7. Large particle counts from the RRN. Each point averages measurements made during three hours of sampling and shows error bars of one standard deviation. The cluster of points were measurements made at 530 m over a single 24 hour period.

of large particles, centered on 9 August (Fig. 8). The peak, in which the number of large particles doubled, lasted for about three days. A current meter on the same mooring at 866 m (nearly 200 m below the nephelometer) recorded semi-diurnal temperature variations of over 0.4°C during the peak in large particles compared with variations of 0.2°C at other times.

A few days after deployment of the nephelometer, an unidentified, filamentous organism was caught on the instrument and appeared in the nephelometer pictures for a few frames, obscuring the data. This demonstrates an advantage of the photographic nephelometer over optical nephelometers and transmissometers in that a cause of anomalous data may be determined.

The mean current *velocities* at 866 m and 1970 m were 3–6 times greater than at 3292 and 3671 m as seen in the progressive vector diagrams (Fig. 9) and in Table 2. The currents at the two upper meters were to the east, while the net flow was to the south at 3292 m and to the west at 3671 m. Despite the large differences in mean

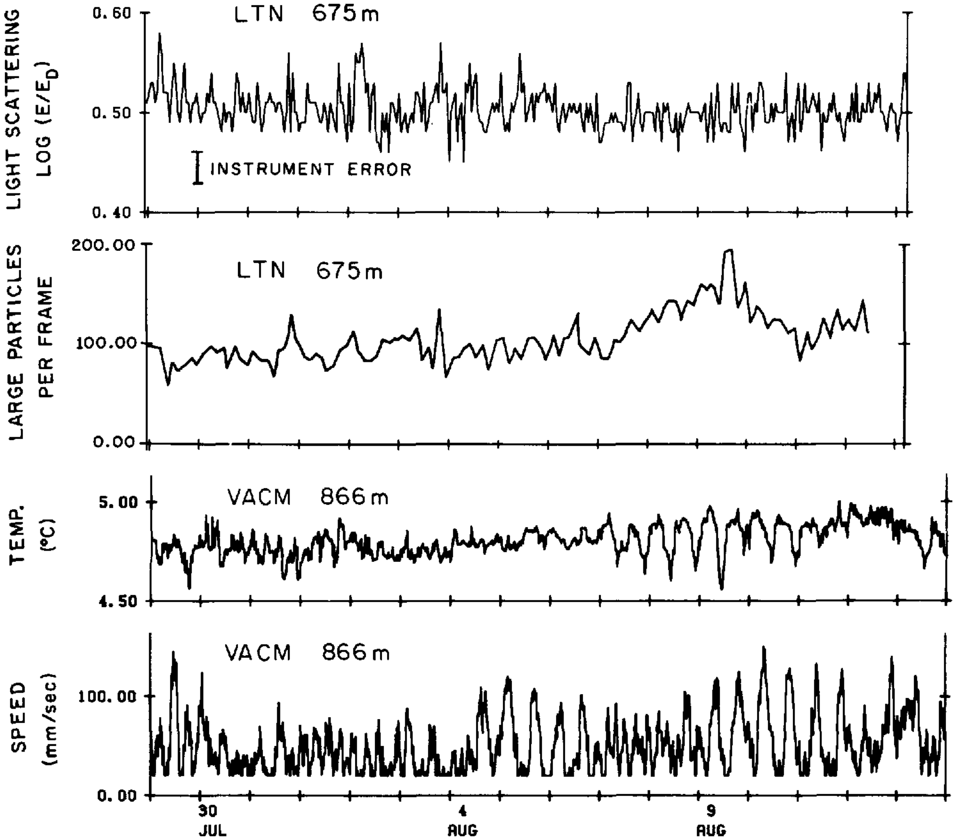

Figure 8. The LTN, which was attached to mooring A at 675 m, shows no long-term changes in particle concentration, although there are times when changes in concentration are larger than the error bars (scale is highly expanded). The optical density of the film can be read to 0.01 units of log E/E_D. A 14-day period of a four-month LTN record from a tranquil area of the deep Pacific Ocean had a standard deviation of ±0.015 units of log E/E_D and is used as the one standard deviation error bar for the LTN (unpublished data). The white dots in the nephelometer record (Fig. 2) were counted in every third frame and plotted as large particles. Note that the 3-day peak in large particle concentration centered on 9 August is not at all represented in the concentration of particulate matter as measured by overall fogging of the film. Temperature fluctuates strongly during that time as discussed in the text. Temperature and current speed were recorded nearly 200 m below the LTN.

velocities in the upper and lower water column, the mean current *speed* differed by less than a factor of two with the upper two meters registering 5.8 cm sec^{-1} and the two lower meters registering 3.3 cm sec^{-1} (Table 2). Stick diagrams in which tidal variations have been averaged out (Honjo *et al.*, 1982) do not show this similarity.

Currents at all depths were dominated by semidiurnal tides. The currents at 3292 m and 3671 m also had a weak diurnal component in the east-west direction, and a weak

STIE CURRENT METER DATA 1979

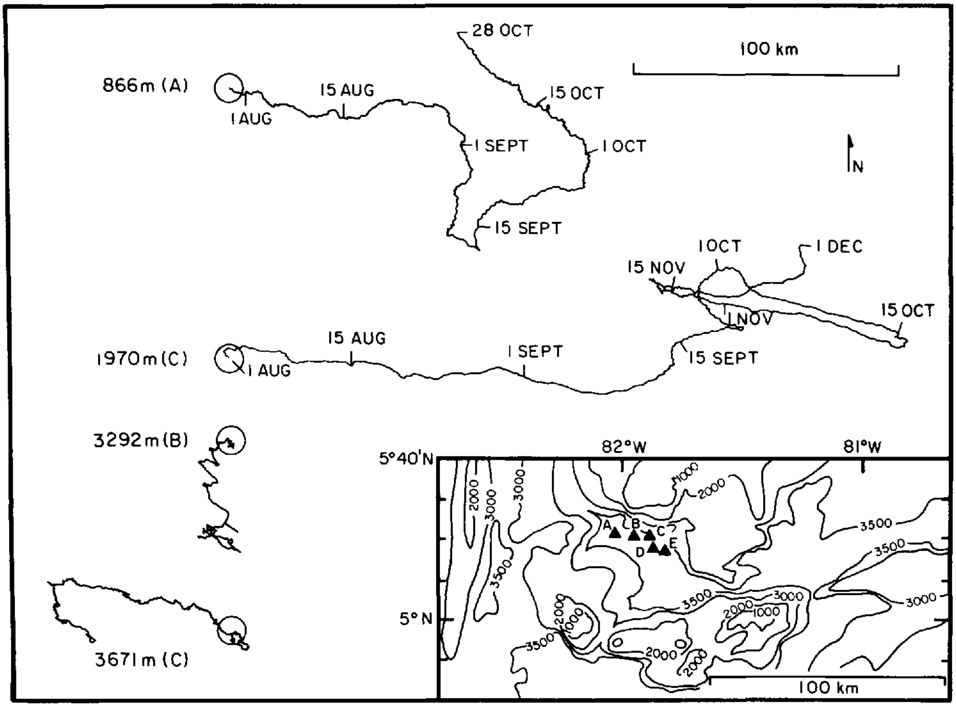

Figure 9. Progressive vector diagrams of currents recorded at four depths on moorings A, B, and C in the basin at the base of the Coiba Ridge during STIE. Flow was strong to the east in the upper two kilometers, but more weakly to the south and west below the sills of the basin.

6.5 hour peak in the north-south direction. The latter frequency may be related to seiches reflecting off the basin walls and may facilitate horizontal advection of any resuspended sediments.

4. Discussion

During the two weeks the ship was at the STIE site there did not seem to be a significant change in the vertical structure of the particle concentration profile. No

Table 2. Horizontal flux of particles.

Depth (m)	Mean velocity (cm sec^{-1})	Maximum speed (cm sec^{-1})	Mean speed (cm sec^{-1})	Concentration (μg l^{-1})	Horizontal flux (μg cm^{-2} sec^{-1})
866	1.10 @ 77°	17.2	5.84	6.6	0.0385
1970	2.10 @ 79°	22.5	5.77	8.0	0.0462
3292	0.37 @ 197°	8.6	3.27	13.9	0.0455
3671	0.51 @ 267°	11.2	3.34	14.6	0.0488

nephelometer profile was made four months later when we revisited the area for the recovery of the STIE moorings, but the particle concentrations measured by filtering small volumes from Niskin bottles and large volumes with the LVFS showed that the particle concentrations had decreased slightly. The purpose of the LTN at 675 m on mooring A was to measure changes in concentration at one depth during the four months as an environmental indicator. Unfortunately, it functioned for only 15 days. Although no changes in small-particle concentration were seen during that time, there was a doubling in the large-particle count during one 3-day interval indicating that the large-particle concentration, and therefore most likely the total flux, changed during that time.

Causes for the increase in large-particle concentration are probably biological. Either there was an increase in primary and secondary production, or a weak front—frequently the site of enhanced biological activity—may have been moving past the mooring. The presence of a front is suggested because the large temperature variations (Fig. 8) must result either from vertical excursions of nearly 100 m or by tidal oscillations of a horizontal temperature gradient such as might occur with the passage of a front.

Had the LTN been deployed at a depth of 400 m, as originally intended, we might have detected migration of the scattering layer or more readily detected changes in primary and secondary particle production. Based on the concentrations of particles measured with the LVFS during times when the scattering layer was and was not moving up past the pump, however, it does not seem likely that the LTN would have detected the scattering layer with the small-particle measurement, although large particle images might have indicated changes in the scattering layer.

The minimum in light scattering at 900 m also corresponded with the minimum in apparent vertical flux calculated from many of the sediment traps (Spencer, 1981). The nearby basin walls, both to the north and south, appear to be furnishing resuspended sediment by lateral transport to a degree that increases both the particle concentration and vertical flux with depth in the basin below 900 m. Although the particle concentration increased by a factor of three below 900 m, the increase in particle flux measured by the traps was only a factor of 1.7. Had the LTN operated longer, we might have had some indication of whether the time-varying fluxes measured with the time-series traps of Farrington and Honjo at depths of 1267 m and 2265 m (Honjo *et al.*, 1982) were from changes in surface productivity or resuspended sediment advected horizontally below the LTN.

Some concerns have been voiced that the rate of particle collection in traps is related to the horizontal flux of particles past a trap. We can multiply the mean current speed during STIE times the particle concentration derived from the nephelometer profiles shown in Figure 3 to estimate the horizontal flux of particles past traps at four depths. Assuming that the particle concentration profiles remained as constant from July to November as during the eight days in July and August, the horizontal fluxes are listed in Table 2. The horizontal flux of particles moving past traps at four depths varied by only 20%, while the vertical fluxes measured by traps varied by 170% (Spencer, 1981). The low correlation between horizontal flux and the collection rate in traps suggests the fluxes measured by traps are not controlled by the horizontal flux of particles.

Although the fine-particle concentration in the Panama Basin is only slightly higher than in mid-ocean areas, the large-particle flux measured by the sediment traps is many times higher than in other parts of the ocean. This may be due either to rapid grazing and downward transport of the particles produced at the surface, or advection of particles from the basin walls. The current meter, nephelometer and organic carbon data (Spencer 1981; Gardner *et al.*, 1983) strongly suggest that advection of material resuspended from the basin walls is responsible for the increase with depth in the flux of particles. Aggregation or packaging must occur by some biological or physical processes in which small particles are transformed into larger ones, allowing them to fall rapidly so that they are measured by devices which measure fluxes (traps), but not by devices which measure instantaneous concentrations in small volumes of water (nephelometers, transmissometers, Niskin bottles).

Acknowledgments. We wish to thank Lawrence Sullivan, Edward M. Thorndike, Mary Parsons and Dan Schupack for instrument design and modification, data collection and reduction, and Drs. Roger Flood and John Marra for reviewing the manuscript. We thank Dr. Derek Spencer for access to the current-meter data. This work was supported by ONR contracts N0014-75-C-0210, N0014-80-C-098 and OCE79-10585. This is contribution number 3563 of the Lamont Doherty Geological Observatory.

REFERENCES

Biscaye, P. E. and S. L. Eittreim. 1977. Suspended particulate loads and transports in the nepheloid layer of the abyssal Atlantic Ocean. Mar. Geol., *23*, 155–172.

Biscaye, P. E., W. D. Gardner, R. J. Zaneveld, H. S. Pak and B. Tucholke. 1980. Nephels! Have we got nephels!, EOS Trans. Amer. Geophys. Un., *61*, 1014.

Gardner, W. D., K. R. Hinga and J. Marra. 1983. Observations on the degradation of biogenic material in the deep ocean with implications on the accuracy of sediment trap fluxes. J. Mar. Res., *41*, 195–214.

Honjo, S., D. W. Spencer and J. W. Farrington. 1982. Deep advective transport of lithogenic particles in Panama Basin. Science, *216*, 516–518.

Lonsdale, P. 1977. Inflow of bottom water to the Panama Basin. Deep-Sea Res., *24*, 1065–1101.

Spencer, D. W. 1981. The sediment trap intercomparison experiment—some preliminary data. WHOI Technical Memorandum 1-81.

Thorndike, E. M. 1975. A deep sea, photographic nephelometer. Ocean Engng., *3*, 1–15.

Received: *9 August, 1982;* revised: *18 October, 1983.*