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Columbia University in the City of New York

LAMONT GEOLOGICAL OBSERVATORY
PALISADES, NEW YORK

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EXPERIMENTS AND HYDROGRAPHIC SURVEYS OFF SANDY HOOK, NEW JERSEY (1963)

Report prepared by: T. Ichiye

Technical Report No. CU-18-65 to the Atomic Energy Commission Contract
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ABSTRACT

Dye diffusion experiments carried out off Sandy Hook, New Jersey on August 7 and October 15 through 18 in 1963 are described. Aerial photographs from a low flying airplane in October experiments showed fine structures of dye patches, such as striations, owing to calm weather. A shipborne fluorometer indicated that dye was thinly spread vertically only above seven meters in October although thermocline was located at about 25 meters. Hydrographic data off Sandy Hook Bay were collected at three different tidal stages on August 6 to 7. These data indicate that advection of water in the bay by tidal currents occurred independently at each level without much vertical mixing. Relationships between spectrum of mean square deviations of concentration and that of turbulent energy are discussed in relation to dye diffusion process.

1. Introduction

A project of dye diffusion experiments by the Lamont Geological Observatory has been carried on off Sandy Hook, New Jersey since 1961 (R. Gerard and others, 1963). In the previous series of experiments, the main purpose was to determine gross features of diffusion in the oceans like change of mean square separation with time and energy dissipation in the inertial sub-range (Ichiye and others, 1964). However, it was found that many dye patches had rather complicated patterns, such as, striation, elongation and curvature besides a general tendency of spreading as predicted by a theory of isotropic turbulence. A set of experiments was carried out off Long Island in order to determine the mechanism of elongation and curvature of dye patches (Ichiye, 1964). A series of experiments reported here were made off Sandy Hook as another trial to examine small scale features of dye patches like elongation and striation.

The field work was done on two occasions: August 6 to 7 and October 15 through 18. On the first occasion, a fishing boat 45 feet long was utilized to release dye and to make hydrographic surveys of Sandy Hook Bay. On the second occasion, R/V CHALLENGER of the Sandy Hook Marine Laboratory was utilized to set up buoys with current meters suspended and to make measurements of currents, waves and dye concentration besides dye release and conventional hydrographic works. On each occasion, aerial photographs of dye patches were taken from a light plane.

2. August Survey

Ten hydrographic stations were repeatedly taken in Sandy

Hook Bay from 10:02 to 12:10 (EST, all the time in this report is EST) and from 12:55 to 14:30 on August 6 and from 13:54 to 15:30 on August 7, in order to get information of general hydrographic features of the bay which is to be utilized as a field of small scale dye diffusion experiments. The bay is a shallow body of water with maximum depth of about 30 feet, shielded by Sandy Hook (Fig. 1). Predicted tides at the inside end of the bay were as follows: On August 6, high water at 08:14 and 20:34, low water at 14:32; on August 7, high water at 08:59 and 21:19, low water at 03:02 and 15:18. Although predicted tides indicate that most of the survey stations were taken at the ebb tide, the actual current measurements on the second day indicate the flood currents on that survey. Temperature and salinity were measured with a portable salinometer of Industrial Instrument Company and currents were measured with a drogue.

During the three surveys, temperatures have a range of 24.0 to 26.5° C at the surface and 21.5 to 24.5° C at twenty feet depth and salinities have a range of 25.8 to 26.7 o/oo at the surface and 26.4 to 27.6 o/oo at a twenty-foot depth. Although there is no strong effluent into the bay, the salinity is relatively low. Stratification of temperature and salinity is small due to shallowness and lack of eminent effluent except at western stations. Temperature and salinity relations (Fig. 2) indicate that higher temperatures correspond to lower salinities throughout the area at all depths. This suggests that the water moves with shear flow at different depths, but is modified very little by mixing. Horizontal distributions of temperature and salinity at the surface and fifteen feet depth

are shown in Figure 3 which indicate that the water of low temperature and high salinity is found in the northwestern section of the bay.

The change of temperature and salinity from one survey to another seems to be caused mostly by tidal advection. The difference between the first and second survey, which were made respectively in the beginning and the end of the ebb tide, is characterized by a decrease in salinity and an increase of temperature with time in most stations and most layers. The third survey was made on August 7 at the end of the ebb tide. However, since the transect of stations was in reverse order, the tidal stages of Stations 5 to 1 in the third survey were about one hour after changing from ebb to flood, while those of Stations 7 to 10 in the third survey are almost the same as those of corresponding stations in the second survey. These differences of tidal stages in two groups of stations are reflected in an increase of salinity and a decrease of temperature in the first group and no systematic change in the second group.

This situation can easily be explained by a model of tidal advection, which was discussed elsewhere (Ichiye and others, 1961). The transport equation of concentration due to horizontal advective currents is given by

$$\partial c/\partial t + v_n(\partial c/\partial n) = \text{Diffusion terms} \qquad (1)$$

in which n is the direction of gradient of c and v_n is the velocity component in this direction. Between the first and second survey, the ebb current was flowing out the bay, as indicated in Fig. 4, and, in general, temperature or salinity was decreasing or increasing respectively to the direction of the current. Therefore, the difference of concentration in the

second and first survey is an increase in temperature and a decrease in salinity, as indicated by Equation (2)

$$c(2) - c(1) = -\int_1^2 (v_n \cdot \partial c / \partial n)\, dt \tag{2}$$

in which c(1) and c(2) are values at the first and second survey, respectively and the diffusion terms are neglected. The difference between the third and second survey is more complicated, because there were two tidal cycles (two ebbs and floods) between the surveys and thus, the gradients of c were changed during the interval. However, the differences at Stations 1 to 6 are systematic in agreement with Equation (2), since the tidal stage in the third survey was in flood tide and thus, the relationships between directions of v_n and grad c averaged over the interval between the two surveys are opposite to those between the second and first survey, both in temperature and salinity.

On this survey, about five gallons of dye were dumped twice from a container at about 10 A.M. and 11 A.M. on August 7 at 39°28' N, 73°58' W. There was no fluorometer reading owing to difficulties in the power source on board the makeshift fishing boat. Therefore, in Fig. 5 only dye pattern sketches obtained from aerial photographs and vertical distributions of temperature and salinity near the dumping station are presented.

The characteristics of the dye patches on this survey are lacking in any striking elongation, which was observed in many previous experiments in the same area. However, the striation along the direction of winds is eminent although wind speed is only about ten

knots. In the second patch, a thin tail was extended to the east in the deeper layer but disappeared within half an hour without any noticeable change in hydrographic conditions. A rather striking thermocline was found between twenty-five and thirty-five feet, between which temperature decreased from 23°C to 13°C, suggesting that the tidal currents in the area are rather weak and do not cause strong turbulence which might destroy thermocline. The depth which the dye reached was above the thermocline, indicating clearly that the thermocline inhibits vertical diffusion.

Another feature of the dye patches in this survey to be noted is that the tail which was below the surface developed windward (southward) contrary to many other cases frequently observed (Gerard et al, 1963; Ichiye, 1964). It was probable that the tidal current flowed to the north, opposing the wind of about ten knots. The distances of striations are fifteen to twenty meters and rugged demaracation was more distinguished in the leading edge of the patch.

3. October Survey

The October survey was carried out from October 15 through October 18. The purposes of the experiments were to obtain data of fine structures of dye patches by determining the relationships between patterns of dye patches and energy spectrum of turbulent flows. In order to observe details of dye patches, 16 mm motion pictures as well as frequent aerial photographs were taken from a low-flying light plane in coordination with shipboard observations of dye patches including

fluorometer recordings and photographic measurements. In order to determine energy spectra of turbulence which contributes to diffusion of dye patches with linear scales of a few tens of meters to a few kilometers, four buoys of different mutual distances from 800 m to 1800 m were set up and one or two self-recording type current meters (Braincon Co. and Geodyne Co.) were installed at each buoy (Fig. 6). It was planned to determine auto-correlations of currents measured by each meter and cross-correlations of each other. The auto-correlations will yield energy spectrum of turbulence at each buoy station, while the cross-correlations will give a check of homogeneity of turbulence (Lumley and Panofsky, 1964). Dye release experiments were designed so that the dye patches might pass through arrays of current meters and thus change of concentration of dye will be related to the spectrum of turbulent flows measured with these current meters (Frenkiel, 1953; Ichiye, 1963).

The operation of the survey was started on October 15 by setting up an array of four buoys, as indicated in Fig. 6. On October 16, each ten gallons of Rhodamine B dye was dumped from the boat to the surface at 11:30 and at 13:07. On board the boat a Roberts current meter, a hand anemometer, a wave pole and smoke bombs were used to measure currents, winds, waves and wind directions, respectively, besides hydrographic data and dye concentration. The plane was flying over the dye patches for about four hours, taking aerial photographs and 16 mm. moving pictures. On October 17, the

same amount of dye as the previous day was dumped at 11: 50 and at 14:00. The plane flew over from 11:30 to 12:30 and 14:00 to 15:30. Radio contact between the plane and the ship was extremely good in the afternoon, resulting in good coordination between the two. On October 18th the buoys with current meters were retrieved. It was unfortunate that among six current meters installed at buoys, only one produced records. One meter was flooded, camera lenses of two meters came off and a film spool of one meter fell off the sprocket. Besides, a rotor of one meter was broken and film spools of most of the meters became loose. The shipborne Roberts current meter was also not usable, because in most cases, the currents were less than 10 cm/sec, which is the threshold speed.of the meter used in this survey.

4. Dye Experiments on October 16

About ten gallons of Rhodamine B dye was pumped in the surface at 12:32 (EST) near B. (Buoy) 4. The sequence of changes of its patterns is sketched in Fig. 7. Most of the aerial photographs were taken at the altitude of 100 to 150 meters. In the initial ten minutes a long meandering tail was developed, but during the next ten minutes a head part was broadened and at 30 minutes after release a rather broad tail with clockwise curvature (from head to tail) was developed. This pattern was quite stable and remained almost the same while expanding during the rest of the observation period of about four and one-half hours. The tail part showed curved striations at about 13:15, but at 14:01 a freighter passed the tail and the resulting ship waves caused ribs of almost uniform widths perpendicular

to the tail. These ribs were still observed at 12:05. The drift of the patch was to the north and the current velocity measured with timber chips was less than 5 cm/sec.

The wind during the observation was about 4～5 knots from SSW (at 12:30) and the sea was calm with swells of less than 30 cm coming from the northeast. The vertical distributions of temperature, salinity and sigma-t were plotted in Fig. 8, which indicates no stratification above fifteen meters.

The second release of dye was made at 14:07. In the first twenty minutes, a head part showing dye only at the surface and a tail part with dye sinking down were clearly distinguished. The tail part was much broader than in the first patch. In this stage, the tail was extending to the left of leeward direction. In the next ten minutes, the boundary between the head and tail parts became obscure and the tail showed clockwise curvature, with striations or rather wide splits along the direction of its extension. There was a gap in aerial reconnaissance between 14:50 and 15:15, during which the tail part seemed to be conspicuously deformed, making rugged outlines. At about one hour and twenty minutes after the release, the patch was quite elongated with a long tail having a clockwise curvature. The aerial photographs taken at 15:55 to 16:00 indicated that the head part consisted of dye thinly spread near the surface, because the passage of the R/V CHALLENGER with about a 2.5 meter draft was clearly marked by a black trace in the patch. Also, the smoke signal discharged in the middle of the patch indicated that the head was to the right of leeward and the tail was curved

clockwise, as suggested by the hodograph of Ekman spiral discussed in a previous paper (Ichiye, 1964).

In Fig. 8, the vertical distribution of dye concentration is also plotted. It is to be noted that the dye concentration suddenly dropped to less than 10% of the surface value at about twenty feet and dye did not reach deeper than twenty feet both in head and middle parts notwithstanding the fact that there was no thermocline. The thinness of dye in the head part was also confirmed in the second vertical readings.

5. Dye Experiment on October 17

The first dumping of dye was made at 11:50. In the first fifteen minutes, the development of patterns of the patch was very similar to the second patch on October 16. A head part was thinly spread near the surface and a tail was trailed windward behind the head. At about thirty minutes after the release, the tail was rather abruptly elongated to about 80 to 100 meters with weak striations along its direction with widths of about ten meters. Curvature was not recognized. The shipboard observation indicated that dye was not present at all at the surface except in a small portion of the head part and thus, a Secchi disk could be clearly seen down to about 2 meters (in the middle part of the patch) and suddenly it disturbed dye below the depth. At one and one-half hours after the release, the patch was conspicuously elongated and distinction between the head and tail part almost disappeared. The crossing of the ship in the middle part at this stage marked a clear dark trace in the picture because dye was thinly spread between 2 and

4 meters depth, as indicated by fluorometer data and visual observation with Secchi disk. The smoke signal indicated that the elongation of the patch was slightly deviated from the wind direction. The wind was calm during the observation (NNW 3kt at 11:40). The temperature and salinity distributions (Fig. 8) showed no significant difference with those of the previous day. The drift of the patch was to SSE with speed of about 0.1 knots.

The second dumping was made at 14:00 at the center of the buoy array. Within five minutes, the patch elongated to about 80 meters to NNE. In the next ten minutes, the patch showed a curved pattern with split tails and the curvature seemed to be anti-clockwise from head to tail. A half an hour after the release, the patch was elongated in both directions and there was almost no distinction between head and tail. At about 14:33 the supposed tail part encountered a tide line which was indicated by convergence of acid dumped by a factory in New Jersey. The convergence line of acid showed an interesting pattern similar to the curled vortex sheet flow determined by Rosenhead (1935). About thirty minutes later, the convergence line moved to the head of the patch and stayed there almost two hours. Meanwhile, the head showed a rather irregular spreading without conspicuous striations. At about 15:34 the elongation of the whole patch reached more than one-half kilometer. The visual observation with a Secchi disk on board indicated that dye was spread at the layer 2 to 3 meters below the surface in the most part of it.

The sea was calm throughout the experiment of the second

patch. Swells were also small with 30 cm high, 10 meters long coming from SE (at 15:35). The fluorometer readings taken at head, center and tail indicate that the center part has maximum concentration and the tail has a thin layer of dye distributed only between 2 and 3 meters in accordance with the observation by a Secchi disk. In general, these fluorometer data showed that the dye was spread thinly above 3 meter depth. The general drift of the patch during the experiment was to the south with speed of about one-half knot for about one hour after the release and after that, the patch remained at the same place for one and one-half hours.

6. Discussions on the Diffusion Experiments

In the present experiments, the dye patches showed fine structures presumably caused by turbulence which is always prevalent in the upper layer of the part of the sea without a conspicuous energy input from the winds. It is rather striking that these dye patches indicated somewhat regular patterns of striations, although the resularity was less pronounced compared with other cases of strong winds reported before (Ichiye, 1964). According to a general concept on energy transfer of turbulence among different wave number ranges in the fluid motion without any disturbing forces having special spectral structures, the non-linear inertia terms generate breaking up of eddies of larger scales into those of smaller scales, thus causing transfer of energy spectrum from lower wave numbers to higher wave numbers. Such is the process in turbulent motion which has been treated mathematically by many authors in the last two decades. Therefore, a passive scalar field

like a dye patch is developed into ever more convoluted strings owing to this spectral transfer of turbulence energy as time progresses, if molecular diffusion is neglected (Corrsin, 1959).

On the other hand, the appearance of the striations suggests that the spectrum of turbulence energy has a peak in the neighborhood of a wave number corresponding to motion which may cause periodic patterns of the patch. In general terms, such a peak is produced when an energy input with a spectrum having a peak at such wave number and/or when the medium has resonance mechanism near this wave number. In a previous study (Ichiye, 1964) the cellular circulation near the surface due to wind stresses was considered as the primary cause for such striations and treated analytically. From a point of view of energy spectrum, this model corresponds to the case of an energy input at a certain wave number range. In the following, different aspects of the problem are stated.

It was frequently observed from foam lines, drifting debris, oil patches and streaks of smooth surface among ripples are aligned along the direction of the wind. These phenomena are called Langmuir streaks or circulation, after Langmuir, (1938) who first described the observation that Sargassum was aligned almost instantly in the direction of the wind in the North Atlantic. He explained this phenomenon as caused by alternate left and right helical vortices whose axes are parallel to the wind and he confirmed his deduction through observation of motions of foam and leaves in Lake George, New York. He considered that the cellular circulation was produced primarily by wind action for two reasons. One of the reasons

is that orientation of the streaks followed a change in wind direction almost at once. The other is that the row spacings are approximately proportional to the depth of the mixed layer which in turn becomes deeper as the wind speed increases.

Woodcock (1944) derived the conclusion that the helical vortices are asymmetrical with narrow clockwise cells (in the vertical plane facing leeward) owing to the Coriolis force, from the predominant "right-or-left-handedness" of Physalia in the northern or southern hemisphere, respectively. Later Faller and Woodcock (1964) analyzed statistically the visual data of the spacings of Sargassum in the vicinity of 39°N, 60° W. The spacings seem to increase with wind velocity with significant correlations.

In the Eulerian formulation diffusion process of some dynamically passive quantity θ in a fluid is expressed by the equation

$$\partial \theta / \partial t + u_i \partial \theta / \partial x_i = \mu \nabla^2 \theta \qquad (3)$$

where u_i is the velocity vector of the fluid and μ is the molecular diffusivity of the quantity θ. This equation indicates that the quantity θ can be determined accurately if the velocity components u_i are known besides the initial and boundary values of θ. However in the ocean information on u_i is limited owing to lack of adequate current meters. Therefore, in most cases of previous studies on diffusion in the ocean, only the averaged value of θ over either a certain time interval or a limited space is discussed. If we assume that quantities θ and u_i are composed of the averaged values and the fluctuations

$$\theta = \bar{\theta} + \theta' ; \quad u_i = \bar{u}_i + u_i' \tag{4}$$

where the bars and the primes denote the average and fluctuations, respectively, the average of Equation (3) yields

$$\partial \bar{\theta} / \partial t + \bar{u}_i \partial \bar{\theta} / \partial x_i + \partial (\overline{u_i' \theta'}) / \partial x_i = \mu \nabla^2 \bar{\theta} \tag{5}$$

Since this equation cannot be solved without information on fluctuations contained by the third term of the lefthand side, it is usually assumed that the term $\overline{u_i \theta'}$ is proportional to $-\partial \bar{\theta} / \partial x_i$ and the proportional coefficient is called eddy diffusivity. Heretofore, many studies have been devoted either to determine the change of $\bar{\theta}$ with time for assumed values of the eddy diffusivity or to determine the eddy diffusivity from observation of $\bar{\theta}$.

However, in the ocean and probably in the atmosphere, it is easier to measure θ than u_i with a great accuracy, as indicated in many experiments using dye. Therefore, it is worthwhile to derive statistical behaviors of fluctuation velocities u_i' in terms of the mean and fluctuating values of θ. The statistical behaviors of a fluctuating quantity $f(x_i, t)$ in turbulence theory are represented most effectively by a spectral function defined by Fourier transforms in space coordinates x_i. This method of representation of fluctuation velocities u_i has been applied successfully to the homogeneous, isotropic field and produced the spectral theory of turbulence, in which the energy spectrum of turbulence in a certain range of wave numbers is explicitely determined in terms of wave numbers and the total energy of turbulence, (Batchelor, 1953).

However, in a shear flow as encountered in the natural environment, the spectral theory has a great difficulty owing to the non-linear terms corresponding to the advective term of Equation (3). On the other hand, if we use the passive quantity θ, as expressed by Equation (3), the advective term becomes linear either for θ or for u_i. This is true for the spectral representation of θ and u_i expressed by

$$B(\vec{n}, t) = \int \exp(i\vec{n} \cdot \vec{x})\, d\vec{x} \tag{6a}$$

$$A_j(\vec{n}, t) = \int u_j \exp(i\vec{n} \cdot \vec{x})\, d\vec{x} \tag{6b}$$

since Equation (3) can be transformed into (Batchelor and others, 1959)

$$\partial B(\vec{n}, t)/\partial t + i \int n_j' A_j(\vec{n} - \vec{n}')\, B'(\vec{n}')\, d\vec{n}' = -\mu n^2 B(\vec{n}, t) \tag{7}$$

where $\vec{n}$ is wave number vector with components n_j; and the integration domain of the second term of the right hand side of (7) is extended over the entire wave number space. It is immediately seen that $A_j(\vec{n}, t)$ can be determined as a solution of a linear integral equation for any time t if $B(\vec{n}, t)$ is known. However, in order to determine the statistical features of the spectrum of θ and u_j we have to derive an equation for the spectrum of $(\overline{\theta'})^2$ and $\overline{u_j' u_k'}$ which is expressed by

$$S(\vec{n}, t) = \overline{B(\vec{n}, t)\, B^*(\vec{n}, t)} \; ; \; E_{jk}(\vec{n}, t) = A_j(\vec{n}, t)\, A_k^*(\vec{n}, t) \tag{8}$$

respectively, where the star indicates the conjugate complex number and the bar indicates the ensemble average or the average about the phase. The equation for S can be obtained from Equation (7) and its conjugate

form by multiplying B^* and E, respectively. There is no explicit form in terms of S and E_{jk} for the integral term of Equation (7) representing the transfer of S spectrum among wave numbers except in certain cases. One such case is that correlations between $A_j(\vec{n} - \vec{n'})$ and $B(\vec{n'})$ is very small as treated by Batchelor and others (1959). Then, the equation for spectrum of $\overline{\theta^2}$ is given by

$$\partial S / \partial t + E_{jk} \int n_j n_k S \, d\vec{n} = - 2 \mu n^2 S \qquad (9)$$

This seems to be very useful for determining turbulence energy spectrum E_{jk} from measurements of S spectrum but the results of diffusion experiments in the ocean suggest that the assumption of small correlation between $B(\vec{n'})$ and $A_j(\vec{n} - \vec{n'})$ is doubtful. However, we need further experimental evidence for testing such an assumption by measuring simultaneously spectrum of S and E_{jk} although the latter spectrum is very difficult in the present stage of techniques. Another approach to explicitly express the transfer among wave number terms is to apply an idea analogous to Heisenberg's hypotheses on energy transfer in the isotropic turbulence (Heisenberg, 1948). Then instead of (9) we have

$$-(\partial/\partial t) \int_0^n S(k)\, dk = \left[\mu + c \int_n^\infty \sqrt{\left\{ E(k)/k^3 \right\}}\, dk \right] \int_0^n 2 S(k) k^2 \, dk \qquad (10)$$

where c is a numerical constant and $E(n) = E_{ii}(n)$. Equation (10) is expressed as an isotropic model but the form for a non-isotropic model can easily be derived. Equation (10) is derived on the assumption that only eddies with smaller scales than a scale of an area containing most of the $\overline{(\theta')^2}$- values contribute to diffusion of the quantity of θ. Equation (10)

again yields the function $E(n)$ if $S(n,t)$ is known.

The spectral approach to the diffusion of dye patches leads to two future programs which are now underway. One is to determine spectral function $S(n)$ for $\overline{(\theta')^2}$ from the observed data on dye concentration. For this purpose, a conventional fluorometer is not suitable because its low resolution in determining space distributions of dye and also because of its non-synoptic nature in measurement. In order to cover such deficiencies of a fluorometer, it is now planned to determine dye concentration by measuring the light intensity of aerial dye photographs with a photographic densitometer. The other approach is to integrate spectral equations for S corresponding to (9) or (10) numerically for a given initial value of $S(n)$ and for a certain model of spectral functions of turbulence $E_{jk}(n)$. Ogura (1962 a, b) integrated numerically the equation for the energy spectrum function similar to (9) or (10) as an initial value problem for two and three dimensional isotropic turbulent flows. He found that the rate of energy transfer is greater toward the larger than toward the smaller scales in two-dimensional turbulence, contrary to the generally accepted behavior for the three-dimensional turbulence in which the energy is transferred from larger to smaller eddies. It is yet to be seen whether there are similar differences between two and three dimensional diffusion. Also, the numerical solution for the spectral function S can be used for checking the observed values determined from densitometry of dye photographs.

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APPENDIX

Equation (10) is numerically integrated with a special form of the energy spectrum E(k) obtained by Kolmogoroff. Equation (10) is differentiated with n and is substituted by

$$E(k) = \epsilon^{2/3} k^{-5/3} \qquad \text{(A-1)}$$

where ϵ is the rate of dissipation of turbulence energy. A non-dimensional form of the resulting equation is given by

$$\partial S(k, t)/\partial t = -(R_s^{-1} + a k^{-4/3}) k^2 S + (4/3) a k^{-7/3} \int_0^k S(n, t) n^2 dn \qquad \text{(A-2)}$$

in which k and t are non-dimensional forms of wave number and time, respectively, and R_s and a are non-dimensional parameters defined, respectively by

$$R_s = (2\mu T K^2)^{-1} \qquad \text{(A-3)}$$

$$a = (6/7) \cdot c \epsilon^{1/3} T K^{2/3} \qquad \text{(A-4)}$$

where T and K are characteristic scales of time and wave number, respectively. R_s is a product of Reynolds number and Schmidt number which is defined as the ratio of the kinetic viscosity to the matter diffusivity (Lumley and Panofsky, 1964). Two kinds of the initial value of S are given by the following equations

$$S(k, o) = \exp(-k^2/b^2) \qquad \text{(A-5)}$$

$$S(k, o) = m(-k/b)^4 \exp(-k^2/b^2) \qquad \text{(A-6)}$$

where b and m are constants.

In the numerical calculation, the following values are used:

$R_s = 1000$, $m = 1$, $b = 5$ and $a = 0.1$ or 1. The results are shown in Fig. 9, where the groups of curves designated with A and B represent those for $a = 0.1$ and 1, respectively and the groups with 1 and 2 represent those for the initial function of (A-5) and (A-6), respectively. As noticed by Ogura (1962 a, b), the values of S' become negative for some k owing to truncation errors, when t exceeds a certain range. Therefore, only the curves which have no large negative values are shown in this figure. Also, integration of Equation (A-2) with k yields

$$\partial \int_0^\infty S(k,t)\, dk/\partial t = - R_s^{-1} \int_0^\infty S(k,t)\, k^2\, dk \qquad \text{(A-7)}$$

This relation shows that the total area bounded by S -curve and k- axis always decreases with time. However, the groups of curves A-1 and B-1 shows increase with time, owing to truncation errors. Details of computational procedure and S functions computed with different initial conditions and energy spectra will be discussed in another paper. The curves of A-1 and B-1 indicate that the power transfer in the S- spectrum is from smaller eddies to larger eddies when the initial distribution is concentrated in large scales, contrary to the turbulent energy transfer in a three-dimensional space treated by Ogura (1962b). On the other hand, the curves A-2 and B-2 for the initial distributions with a peak at a finite wave number show a tendency similar to the energy transfer, that is, from larger eddies to smaller eddies. The numerical computation was made with IBM 1620.

Explanation of Figures

Fig. 1 - Location of Sandy Hook Bay and Dye Experiment Stations (Upper Left: Cross, for August 7th experiment; Solid Triangle, for October experiment - Depth in Fathoms (Coast and Geodetic Survey Chart 1000)
Right: Location of hydrographic stations and depth in feet (Coast and Geodetic Survey Chart 1215)

Fig. 2 - T - S diagrams from hydrographic stations on August 6th and 7th (Crosses and solid circles indicate data, respectively, below five feet and between 0 and 5 feet in Sandy Hook Bay. Open circles indicate data at the dye experiment station shown in Fig. 1 with a cross.)

Fig. 3 - Temperature and salinity distributions in Sandy Hook Bay (Numbers in parenthesis in 0_m-charts indicate the time of hydrographic sampling.)

Fig. 4 - Surface currents measured in the afternoon of August 6th (left) and differences of temperature and salinity at five-meter depth between August 7th data and August 6th afternoon data (right).

Fig. 5 - (A) Sketches of a dye patch drawn from aerial photographs in the experiment of August 7th. (Numbers in parenthesis indicate the time when each photograph was taken)
(B) Vertical distribution of temperature and salinity at the dye experiment station indicated by a cross in Fig. 1.

Fig. 6 - Arrangement of four buoy stations

Fig. 7 - Sketches of dye patches drawn from aerial photographs in the experiments of October 16th and 17th. Time of each photograph is shown at the upper part of each sketch. Wind directions determined with a smoke bomb is indicated with an arrow denoted by SB. The scale for a series of sketches is shown for the first picture of the series. "AL" in the second dye patch of October indicates the convergence line of industrial waste or acid.

Fig. 8 - Vertical distributions of temperature and salinity determined with a salinometer and concentration of dye on October 16th and 17th. (Numbers in parenthesis in dye concentration figures indicate the time of fluorometer readings. S, C and N of October 17th data indicate respectively, south, center and north part of the dye patch).

FIG. I

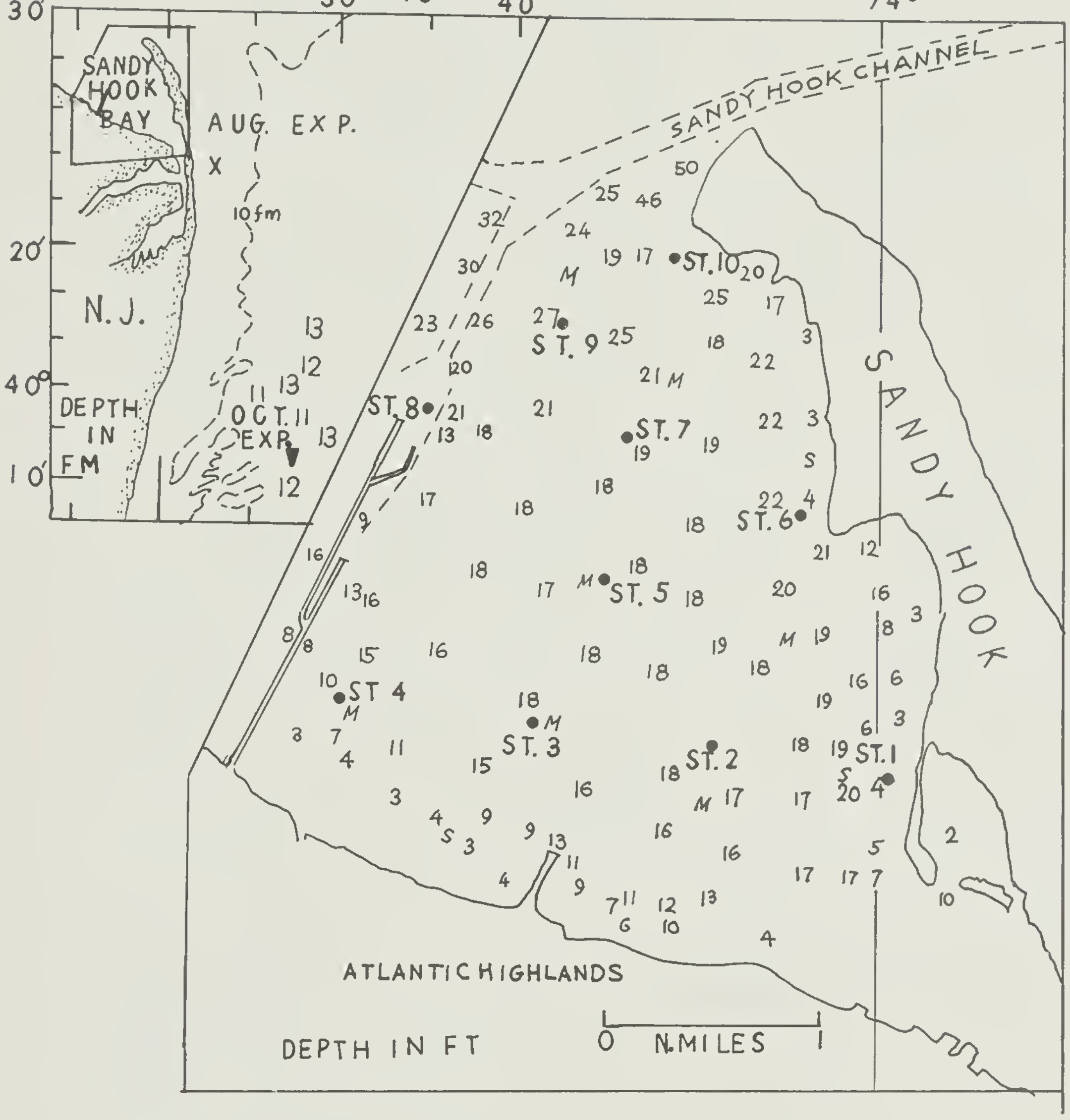


Fig. 2

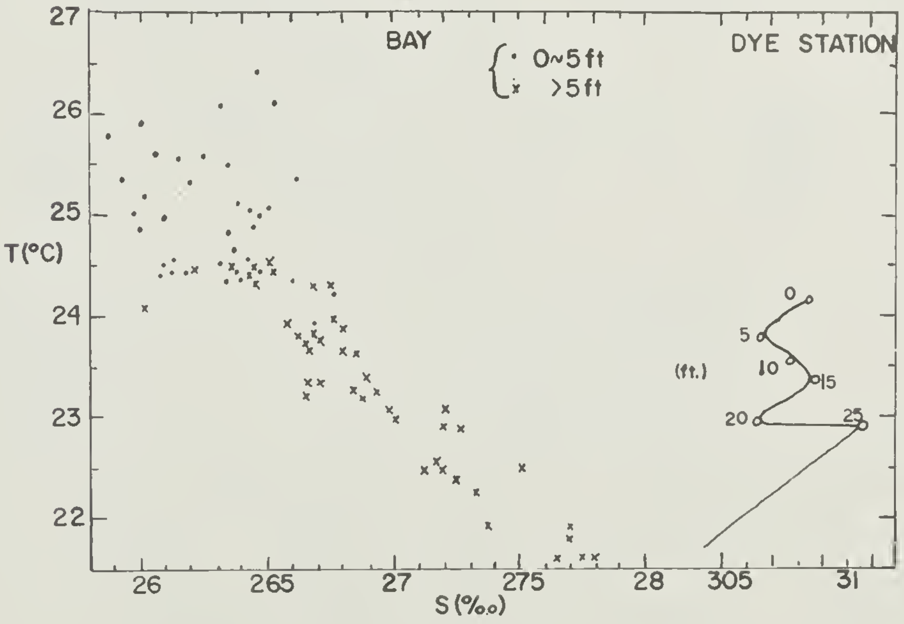


Fig. 6

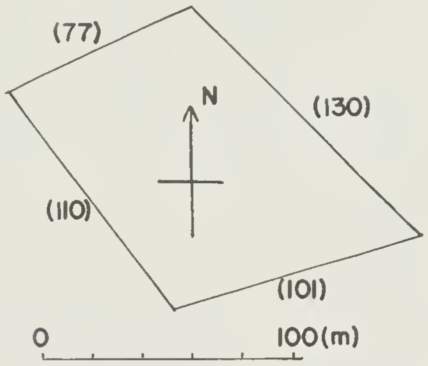


Fig. 8

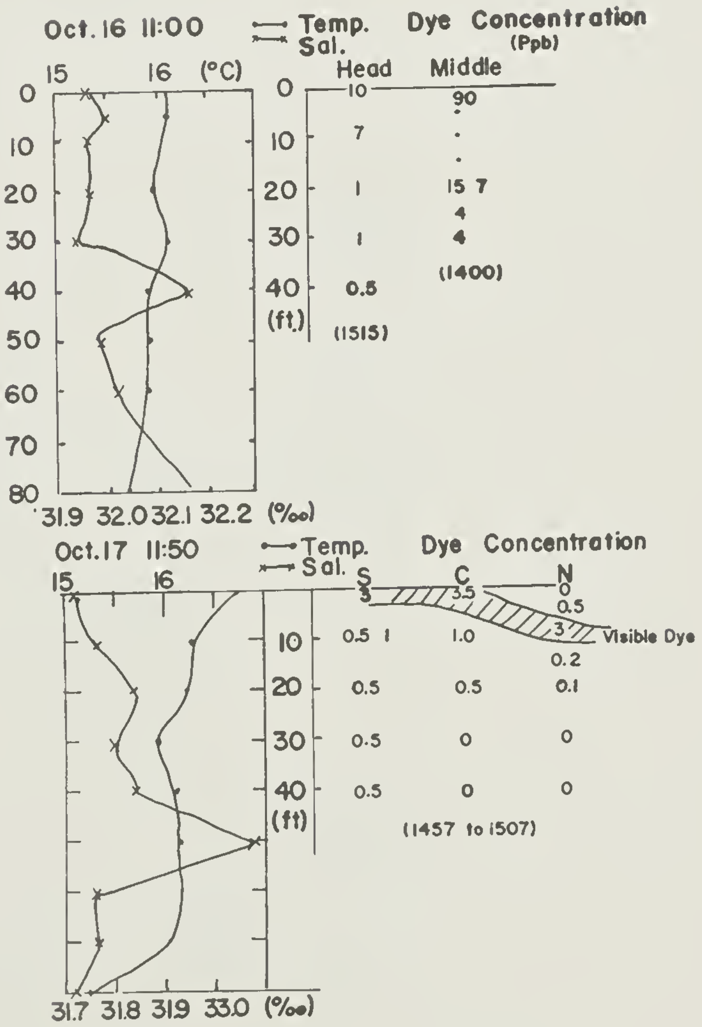
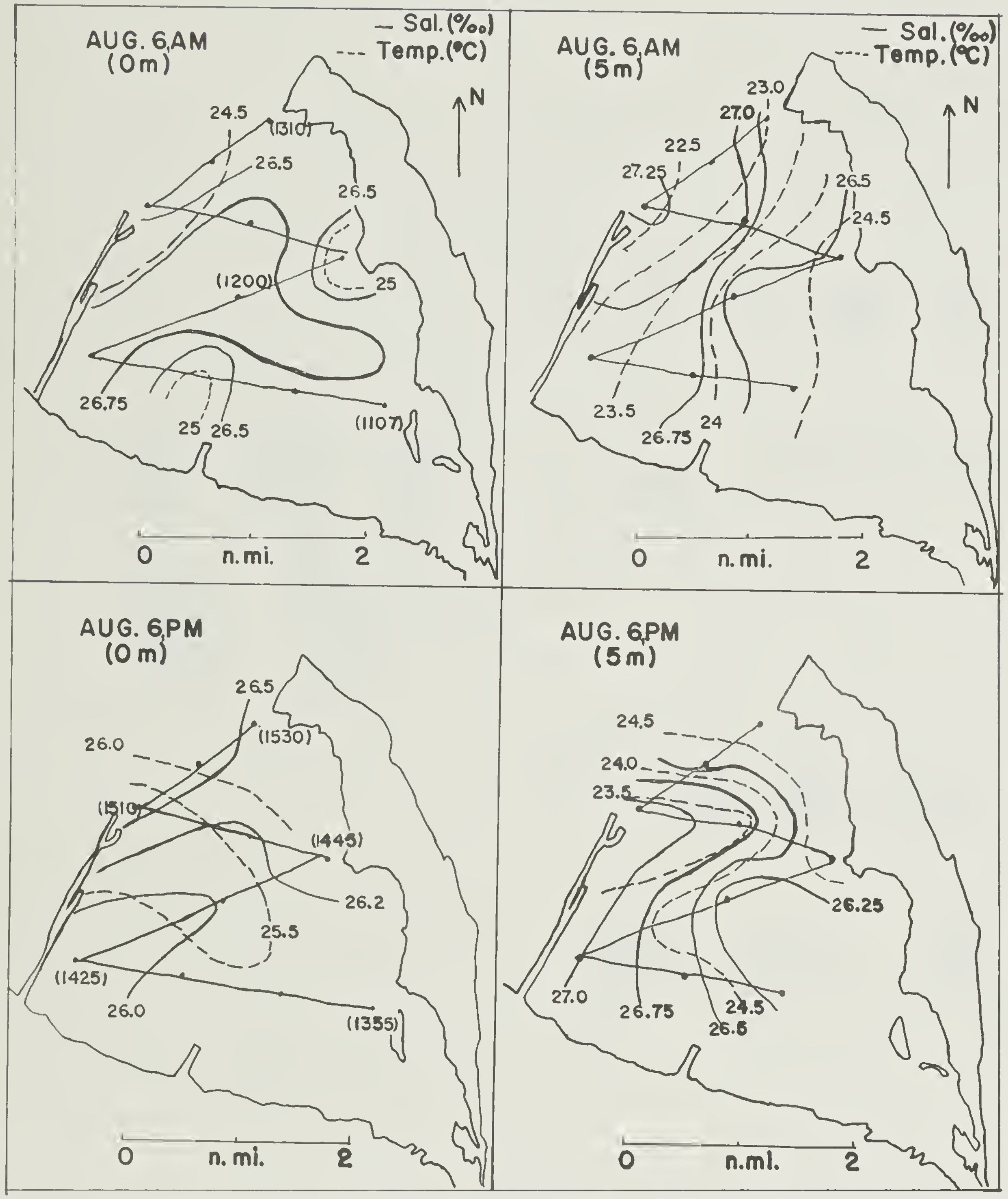


Fig. 3


AUG. 6,AM
(0m)
— Sal.(‰)
--- Temp.(°C)
N
24.5
(1310)
26.5
26.5
(1200)
25
26.75
25
26.5
(1107)
0
n. mi.
2
AUG. 6,AM
(5m)
— Sal.(‰)
---- Temp.(°C)
N
23.0
27.0
22.5
27.25
26.5
24.5
23.5
26.75
24
0
n. mi.
2
AUG. 6,PM
(0m)
26.5
(1530)
26.0
(1510)
(1445)
26.2
25.5
(1425)
26.0
(1355)
0
n. mi.
2
AUG. 6,PM
(5m)
24.5
24.0
23.5
26.25
27.0
26.75
24.5
26.5
0
n. mi.
2

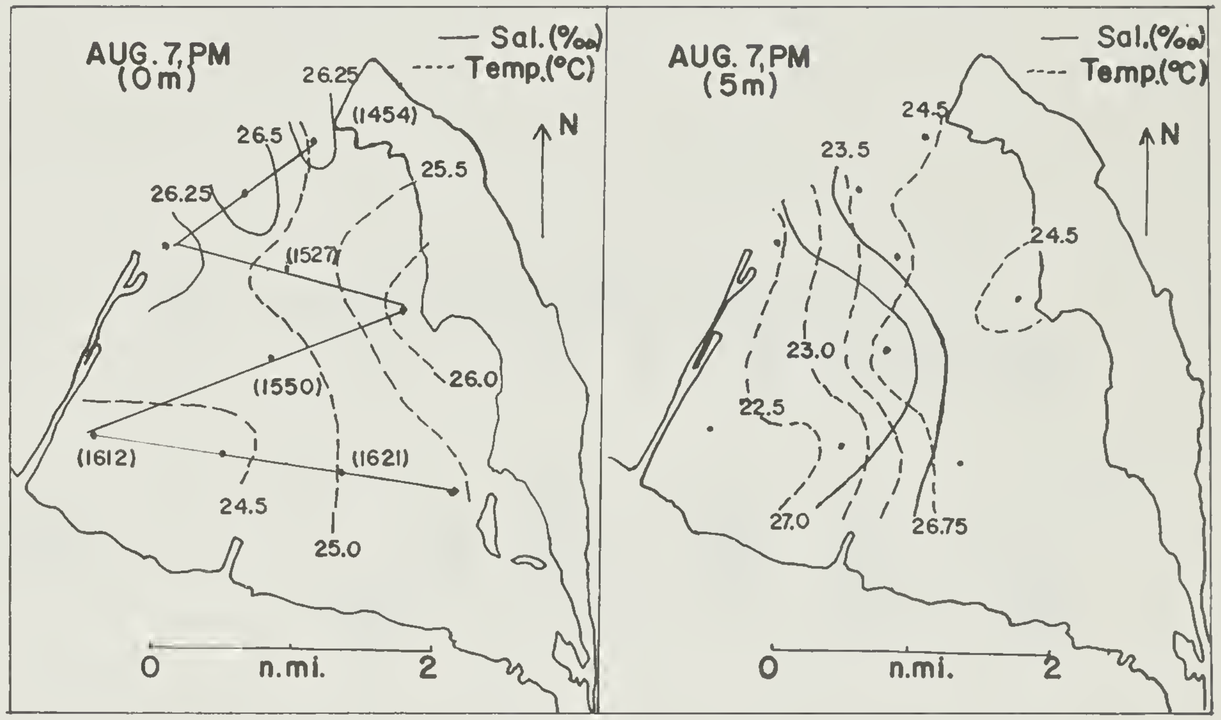

AUG. 7,PM
(0m)
— Sal.(‰)
---- Temp.(°C)
N
26.25
(1454)
26.5
26.25
25.5
(1527)
(1550)
26.0
(1612)
(1621)
24.5
25.0
0
n. mi.
2
AUG. 7,PM
(5m)
— Sal.(‰)
---- Temp.(°C)
N
24.5
23.5
24.5
23.0
22.5
27.0
26.75
0
n. mi.
2

Fig. 4

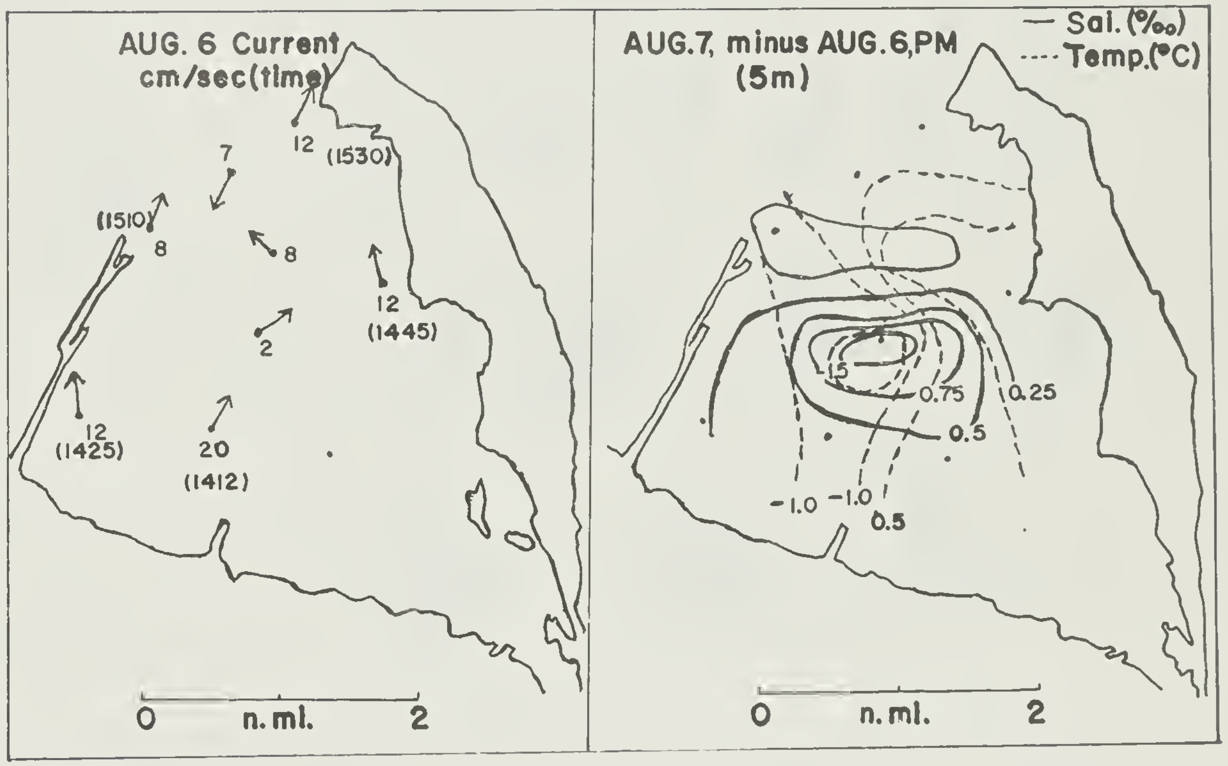

AUG. 6 Current
cm/sec(time)
12
(1530)
7
(1510)
8
8
12
(1445)
2
12
(1425)
20
(1412)
0
n. mi.
2
AUG. 7, minus AUG. 6,PM
(5m)
— Sal.(‰)
---- Temp.(°C)
1.5
0.75
0.25
0.5
-1.0
-1.0
0.5
0
n. mi.
2

Fig. 5A

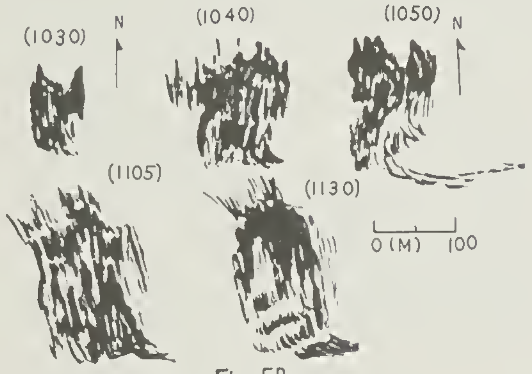


Fig. 5B

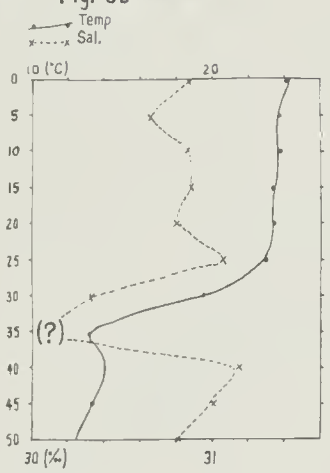
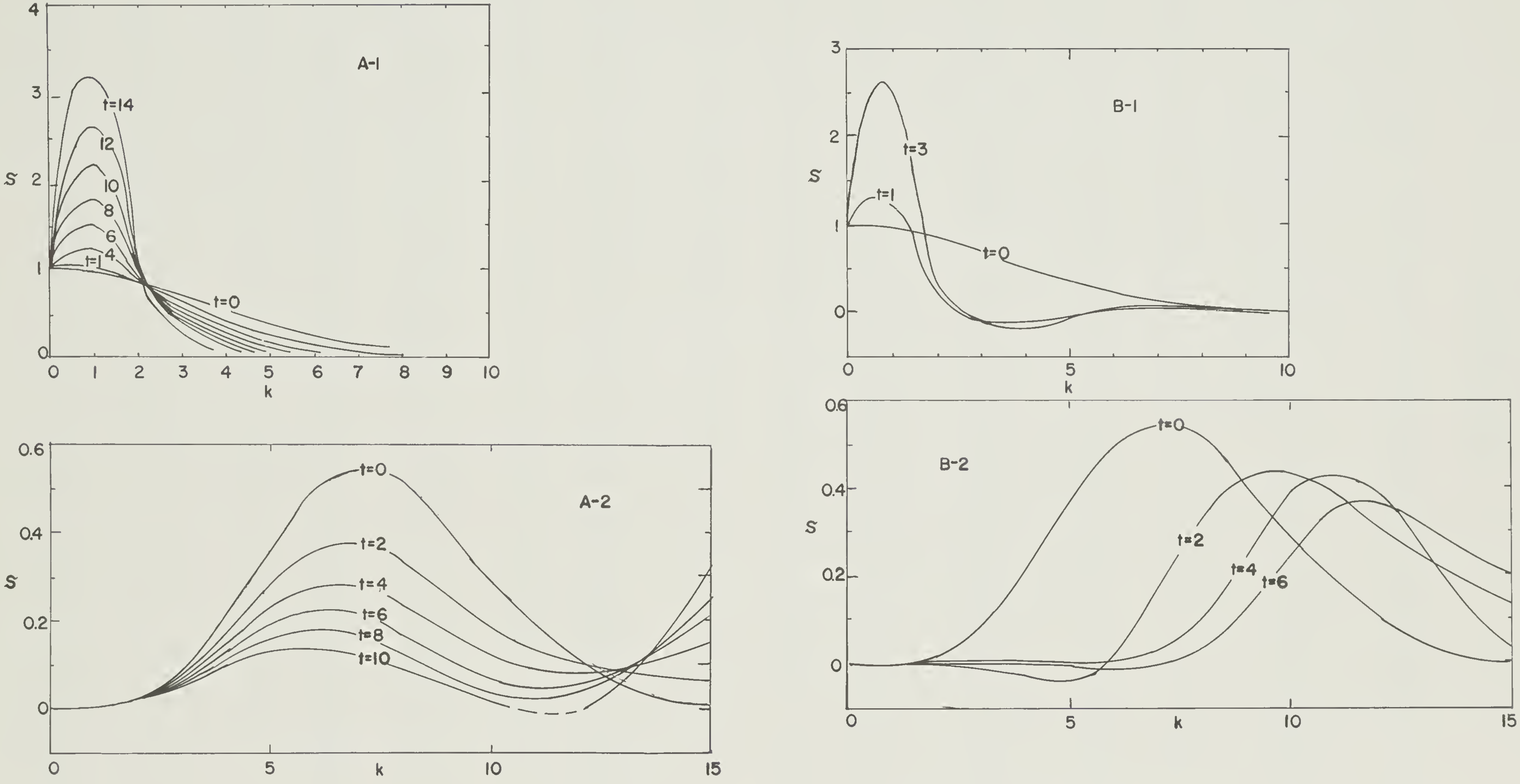


FIG. 7

FIGURE 9


A-1
S
0
1
2
3
4
k
0
1
2
3
4
5
6
7
8
9
10
t=14
12
10
8
6
4
t=1
t=0
B-1
S
0
1
2
3
k
0
5
10
t=3
t=1
t=0
A-2
S
0
0.2
0.4
0.6
k
0
5
10
15
t=0
t=2
t=4
t=6
t=8
t=10
B-2
S
0
0.2
0.4
0.6
k
0
5
10
15
t=0
t=2
t=4
t=6

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13. ABSTRACT

Dye diffusion experiments made near Sandy Hook, New Jersey in August and October of 1963 are described. Hydrographic data of Sandy Hook Bay obtained during the August survey indicates that the change of temperature and salinity with time is mostly caused by advective effects of tidal currents. Dye diffusion experiments made during two days of October showed that dye was spread approximately only between two and seven meters deep in the area deeper than 25 m, probably due to calm weather and weak currents. The dye patches of these experiments indicated striations and elongation notwithstanding calm weather. A theoretical discussion on origins of striations from spectral aspect of passive diffusant is presented.

14. KEY WORDS

Hydrographic and dye diffusion data taken near Sandy Hook, New Jersey in August and October, 1963 are discussed.