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A LAGRANGIAN AND EULERIAN DIFFUSION STUDY IN THE COASTAL SURFACE LAYERS

Progress Report
for Period July 1, 1979-June 30, 1980

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ABSTRACT

Our research project addresses a fundamental problem in turbulence theory, the relation between Lagrangian and Eulerian statistics, by carrying out, analyzing, and interpreting a set of field experiments in the coastal waters off the south shore of Long Island. The study will not only provide information on the relation between the Lagrangian and Eulerian autocorrelations but also between the various experimental methods for quantitatively estimating turbulent diffusion. Two experiments, one in summer and one in winter, consisting of simultaneous measurements of dye diffusion, drogue dispersion, and Eulerian current velocities in a typical coastal locale were planned. In order to ensure a match between the Lagrangian (drogues, dye) scales of motion and the Eulerian (current meters) scales, however, a preliminary experiment, consisting of a 6 mooring current meter array and a short (~ 3 hours) drogue experiment, was conducted during March 1980. Results of this preliminary experiment and their implications to our experimental program are discussed in this progress report. The principal results were:

- 1) An improved design of our current meter array, and
- 2) A wider variety of drogue experiments, i.e., multi-level, multi-scale, and continuous source simulation.

Details of our redesigned summer experiment, scheduled for 14-29 July 1980, are given.

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INTRODUCTION

The disposal in natural waters of man-produced wastes--radio-activity, sewage, heat, etc.--gives rise to many scientific questions. Of fundamental importance are the physical processes of transport and mixing. Knowledge of these processes by which contaminants are mixed and dispersed in the marine and/or aquatic environment is essential for the evaluation of pollution levels. That is, in order to solve the appropriate equations governing the spreading of water borne contaminants, it is necessary to assign appropriate numerical values to the coefficients which quantify the turbulent mixing processes i.e., diffusivities. At present, there is no way in which these values can be determined *a priori*. As a result, our present understanding of turbulent diffusion has come mostly from experimental field studies.

Various methods and techniques have been developed and used in experimental studies on oceanic diffusion. They range from purely Lagrangian methods, the use of identifiable particles such as drogues or dye tracers, to an Eulerian method, the use of moored current meters. Nevertheless, few have attempted to make a serious comparison of the results obtained by these various techniques so that the use of one particular method in a diffusion experiment can properly be justified or treated as an approximation. There is no theoretical basis for assuming that concurrent estimates of the eddy diffusivity obtained experimentally by the two techniques will yield identical

values of these coefficients. What was required, therefore, was a series of field experiments in coastal waters consisting of simultaneous measurements of dye diffusion, drogue dispersion, and Eulerian current velocities.

To meet this need, our research program, as originally designed, consisted of two diffusion experiments to be conducted in the coastal waters off the south shore of Long Island. Each experiment, one in winter (unstratified conditions) and one in summer (stratified conditions), was to consist of simultaneous measurements of dye diffusion by both direct measurement and aerial photography, drogue dispersion, and currents so that the diffusion characteristics obtained by the respective methods may be compared properly and any discrepancies in their estimation by these methods discussed.

EXPERIMENTAL

It has been necessary to modify our program of field experiments as originally designed, however, in light of information exchanged at two informal workshops with colleagues interested in problems associated with comparing Eulerian and Lagrangian statistics. The first informal workshop, attended by Carter and Wilson, was held at the Netherlands Institute for Sea Research, Denberg-Texel, the Netherlands on 2 and 3 April 1979 prior to but in anticipation of funding for our project (LEDS). A second follow-up workshop was held here at MSRC, SUNY, Stony Brook on 1-2 October, 1979 subsequent to funding of our project. Expenses to the project were minimal, however, as all outside participants

paid for their own travel and were subsisted with one of the project investigators. Appendices A and B contain additional information about these workshops.

At both workshops, participants stressed the requirement that the current meters must be spaced so that the measured flow field gradients would be comparable to the Lagrangian gradients as determined by the drogues and dye. *That is, the meters should be placed so that the records are coherent both alongshore and on/offshore for all scales larger than the scale of the energy-containing eddies.* To obtain this information for the area of interest, therefore, a preliminary experiment was planned and carried out during March of 1980. The experiment consisted of six (6) current meter moorings arranged in an L-shaped array with one nearsurface ($\sim 15'$) meter on all moorings except the one at the corner of the "L" which contained meters at 15, 40, 60, and 80 feet (4.6, 12.2, 18.3, and 24.4 meters). See Figure 1. In addition, our drogue design was tested and six drogues were deployed and followed on one day for approximately three hours. Details of the experiment and such preliminary results as are available at this time are discussed in later sections of this report.

THE PRELIMINARY CURRENT METER/DROGUE STUDY

Chronology of the Study

Although planning for the experiment was essentially complete before 1 January 1980, we were held up until March 1980 due to delays

associated with availability of current meters and with obtaining proper materials for, and manufacture of, the drogues. Our goal was to deploy six current meter moorings arranged so as to provide on/offshore meter intervals of 0.3, 0.7, and 1.0 km and alongshore meter intervals of 0.7, 1.3, 2.0, 3.0, 4.3, and 5.0 km at a time when the coastal waters were unstratified (winter).

Meters were deployed at "A", "C", and "F" with the R/V ONRUST on 17 March 1980. Strong northwesterly winds and heavy rain prevented work on 18 March, however conditions moderated on the 19th and the remaining meters were installed at "B", "D", and "E". Figure 1 shows the location of the moorings; horizontal separations of the meters are given in Table 1. Information on vertical shear was obtained at "C" with meters located at 15' (4.6 m), 40' (12.2 m), 60' (18.3 m), and 80' (24.4 m). The current meters were Endeco Model 105's and 174's. They were distributed on the moorings as shown in Figure 1. The Model 105's recorded 30 minute averages of speed and direction on film; the Model 174's recorded two minute averages of speed and approximately instantaneous values of direction, conductivity, and temperature every two minutes on magnetic tape. Both models sense speed with identical, ducted, flow reversible, eight-bladed propellers and are moored by means of rope tethers that effectively decouple the meters from the mooring motion. Large fins together with the propeller design eliminates most of the error associated with wave motion making them ideal for use in shallow water. Both sense direction with magnetic compasses; the Model 174's sense temperature with a thermistor and conductivity with a Balsbaugh series 1210 electrodeless conductivity probe.

Table 1
Current Meter Intervals at 15' (4.6 m) as Installed

<u>On/Offshore</u>	<u>Alongshore</u>
A to B* - 490 m	C to D - 628 m
A to C - 974 m	D to E - 1732 m
B* to C - 484 m	E to F - 2452 m
	C to F - 4812 m
	C to E - 2360 m
	D to F - 4184 m

* Meter flooded, no data

Figures 2 through 7 show the vertical distribution of temperature, salinity, and σ_t at each of the six moorings on 19 March. Figure 8 provides similar information at "A" on 27 March. The data were taken with an InterOcean System, Inc. Model 550 CTD. It is obvious from Figures 2 through 8 that conditions were essentially unstratified during the experiment.

Figure 9 is a stick diagram showing the winds at the Fire Island CG Station, some 40 nm to the west[#]. It can be seen from Figure 9 that there were at least three significant wind events during our study. The first occurred late on 17 March when the area experienced winds of 25 knots from the southeast which then veered through south and southwest to the northwest late on the 18th. There was also heavy rains throughout the day. The second significant wind event

[#]Winds from the Tiana Beach meteorological tower (TBMT on Figure 1) were not available at the time this was written.

Figure 2. Vertical distribution of temperature, salinity, and σ_t at "A" on 17 March 1980.

Figure 3. Vertical distribution of temperature, salinity, and σ_t at "B" on 17 March 1980.

Figure 4. Vertical distribution of temperature, salinity, and σ_t at "C" on 17 March 1980.

Figure 5. Vertical distribution of temperature, salinity, and σ_t at "D" on 17 March 1980.

Figure 6. Vertical distribution of temperature, salinity, and σ_t at "E" on 17 March 1980.

Figure 7. Vertical distribution of temperature, salinity, and σ_t at "F" on 17 March 1980.

Figure 8. Vertical distribution of temperature, salinity, and σ_t at "A" on 27 March 1980.

Figure 9. Wind data from the Fire Island Coast Guard Station. Wind vectors point toward the direction the wind is blowing; the line on which they originate is $270^{\circ}\text{M} - 090^{\circ}\text{M}$.

took place on 21 and 22 March 1980. Early on 21 March the wind strengthened from the southeast to 15-20 knots and steadily increased until 1500 at which time it exceeded 40 knots. It then veered to north at 30 knots on the morning of 22 March. By the end of the 22nd it had diminished and was blowing steadily at ~ 15 knots from the northwest. On 23 and 24 March the winds were 10 knots or less but by 0600 on the 25th of March the wind has picked up to 25 knots from the northeast (third event). By evening, however, this had diminished to less than 10 knots from the northwest. Winds were mostly less than 10 knots for the remainder of the study.

All meters and moorings were recovered on 27 March 1980 without incident by the R/V ONRUST and the field portion of our preliminary experiment terminated. On removal of the film cartridges (105's) and magnetic tapes (174's) on 28 March 1980, it was found that all meters provided data except for 174112 which was located at "B". It had flooded, apparently through the conductivity probe[#]. The tapes and films have been processed; preliminary results will be discussed in a later section of this report.

Results of the drogue study

On 24 March 1980 six drogues were released approximately 6 km offshore and 2.9 km west of Shinnecock Inlet. The objectives were threefold: 1) It was necessary to test the drogue design (see Figure 10) before the main experiments scheduled for July, 2) The logistics

[#]Endeco's repair estimate for 174112 is \$5,500.00.

Figure 10. Details of the MSRC drogue.

of the planned experiments could be better evaluated after a trial run, and 3) Preliminary estimations of diffusivities and velocity gradients were desirable for designing future experiments.

All six drogues were placed at a depth of 15 feet, released approximately in a straight line (see Figure 11) and tracked for 3 hours. A Motorola Mini-Ranger III System was used to fix boat positions by measuring the distance from two transponders at separate locations ashore. The R/V ONRUST, the vessel used for tracking, was too large to maneuver within the drogue cluster without disturbing the drogues. Hence drogue positions were estimated relative to the boat and the boat positions were fixed with the Mini-Ranger as the boat made a traverse parallel to the major axis of the drogue cluster.

As a result, the measurement errors ($\pm 4-5$ m) in the drogue positions are greater than those imposed by limitations of the Mini-Ranger System. In future experiments smaller and more maneuverable boats will be used and the drogue positions will be limited only by the precision of the Mini-Ranger III System.

Positions of the drogues, as the experiment progressed, are shown in Figure 11. The tide was in its flood phase and the drogues moved northwestward toward the shore. Initially the centroid speed was about 15 cm s^{-1} and had decreased to 6.5 cm s^{-1} by the end of the experiment. The components of the centroid velocity are shown in Figure 12. The net movement of about 1200 m in a period of 3.1 hours suggest that one tidal excursion will be about twice the dimensions of the current meter array.

Figure 11. Positions of six drogues at various dispersion times on 24 March 1980.

Figure 12. Mean velocity components (u and v) of the drogue cluster. 80% confidence intervals are also shown.

The linear regression analysis of Okubo and Ebbesmeyer (1975) was used to calculate velocity gradients and horizontal turbulent diffusivities. Velocity gradients are plotted as a function of time in Figures 13-16. The 80 percent confidence intervals of these parameters indicate that our future work will require more drogues (say 10 ~ 20) to reduce the error. Also more accurate measurements of drogue position will be made in future experiments as noted earlier.

As is seen in Figures 13-16, there is a clear trend for the errors to be reduced in magnitude as the experiment progressed. Two explanations are proposed. First drogue position errors, compared to movement relative to the centroid, were probably greater initially than in the later stages of the experiment simply because the scale of the cluster was smaller in the beginning. Secondly, since the method of analysis makes no distinction between random motion and measurement errors it is possible that the apparent randomness of the drogue motion is greater compared to motion caused by velocity gradients for smaller cluster dimensions. In any event, increased drogue numbers and more precise position measurements will reduce the confidence intervals of evaluation of velocity gradients in the future experiment.

The temporal behaviors of turbulent diffusivities are shown in Figure 17. These diffusivities are due to small-scale turbulent components (eddies). However, there is no clear observable trend to suggest that the diffusivity increases with the four-third power of the scale of diffusion.

Figure 13. Velocity gradient ($\partial u / \partial x$) versus time with 80% confidence intervals.

Figure 14. Velocity gradient ($\partial u / \partial y$) versus time with 80% confidence intervals.

Figure 15. Velocity gradient ($\partial v / \partial x$) versus time with 80% confidence intervals.

Figure 16. Velocity gradient ($\partial v / \partial y$) versus time with 80% confidence intervals.

Figure 17. Turbulent diffusivities (K_x, K_y, K_{xy}) versus time.

Figure 18 shows the relation between the gross diffusivities, calculated as a half of the time rate change of the variances, i.e., the second moments of the drogue positions about the centroid, and time. Unlike the small-scale diffusivity, a trend for the gross diffusivity to increase with time is evident. The geometrical mean diffusivity appears to increase in a fairly linear manner with time. Thus if the drogues are released from a point, or infinitesimally small source, the cluster dimensions might be about 1,000 m after 10 hours, as we consider $3(\sigma_x \sigma_y)^{\frac{1}{2}}$ to be the scale of dispersion.

After this preliminary drogue study we have reached the conclusion that the drogue designed for the experiment was essentially adequate. However, minor modifications will be made so as to assemble and deploy the drogues easier. Also the measurement errors for the drogue position should be decreased to $\pm 1 \sim 2$ m; this can be achieved by the use of small boats to track the drogues.

Figure 18. Gross diffusivities (X,Y,M) versus time. The diffusivity is computed from a half of the time rate of change of the variance.

Some Preliminary Results of the Current Meter Study

Figure 19 shows time series of both the alongshore and on/offshore velocity components from meter 174032 at mooring "C" (see Figure 1) over the period of the experiment. The alongshore direction corresponds to the mean direction of local isobaths which is approximately 69°T . Even these relatively short time series show clearly that significant fluctuations in both longshore and on/offshore velocity components occur at periods ranging from several days (subtidal periods) to minutes (supertidal periods). The intensity of velocity fluctuations at supertidal periods appears to increase substantially during storms from what it is during quiescent periods when tidal oscillations are dominant.

Frequency spectra for both the alongshore and on/offshore velocity components in Figure 19 for a quiescent period and for a storm period are shown in Figures 20 and 21. The quiescent period was chosen to extend from 0000 19 March to 1200 21 March 1980 and the storm period from 1200 21 March to 0000 24 March 1980 (see Figure 19). The spectra for the storm period show an increase in spectral density at both subtidal frequencies and supertidal frequencies when compared to spectra for the quiescent period. It should be mentioned that the semidiurnal peaks in Figure 20 are rather broad for two reasons: resolution at low frequencies is poor for this short record length and the spectra have been smoothed slightly.

To examine more carefully the characteristics of the increase in spectral density at supertidal frequencies, fluctuations, with

Figure 19. Time series of alongshore velocity component U (positive towards east) and on/offshore velocity component V (positive towards north) from meter 174032 at mooring "C". Alongshore direction corresponds to 69°T .

Figure 20. Spectral density computed for longshore velocity component at mooring "C" for the period 0000 19 March to 1200 21 March (A); for the period 1200 21 March to 0000 24 March (B). Velocity records were first subject to a low pass filter with a cutoff at approximately 0.5 hours.

Figure 21. Spectral density computed for on/offshore velocity component at mooring "C" for the period 0000 19 March to 1200 21 March (A); for the period 1200 21 March to 0000 24 March (B). Velocity records were first subject to a low pass filter with a cutoff at approximately 0.5 hours.

periods larger than approximately 4 hours were filtered from the records before taking the spectra. Figures 22 and 23 show that much of the increase in spectral density at periods shorter than 4 hours was confined to a few distinct frequency bands. The associated periods range from approximately 2.5 hours to 0.5 hours. Especially noticable in Figures 22 and 23 is the increase in spectral density in the longshore component at periods of approximately 2.5 hours, and the increase in spectral density in the on/offshore component at roughly $\frac{1}{2}$ this period. Velocity fluctuations within this range of periods appear to be associated with edge waves.

Figure 24 shows cross spectra for both the longshore and on/offshore velocity components between meters at stations "A" and "C" in the on/offshore direction and between meters at station "C" and "F" in the longshore deviation. In addition to the expected high spectral density at tidal and subtidal frequencies, there are noticable peaks at frequencies corresponding to periods between approximately 1 hour and 0.5 hours.

No attempt has yet been made to estimate the characteristic length scales associated with eddies producing the velocity fluctuations of different periods.

SPECTRAL DENSITY
(RELATIVE SCALE)

Figure 22. Spectral density computed for longshore velocity component at mooring "C" for the period 0000 19 March to 1200 21 March (A); for the period 1200 21 March to 0000 24 March (B). Velocity records were first subject to a high pass filter with a cutoff at approximately 4.5 hours.

SPECTRAL DENSITY
(RELATIVE SCALE)

Figure 23. Spectral density computed for on/offshore velocity component at mooring "C" for the period 0000 19 March to 1200 21 March (A); for the period 1200 21 March to 0000 24 March (B). Velocity records were first subject to a high pass filter with a cutoff at approximately 4.5 hours.

CROSS SPECTRAL DENSITY
(RELATIVE SCALE)

Figure 24. Cross-spectral density computed for longshore velocity components at moorings "A" and "C" (A); on/offshore velocity components at moorings "A" and "C" (B); longshore velocity components at moorings "C" and "F" (C); on/offshore velocity components at moorings "C" and "F" (D).

The Summer Lagrangian/Eulerian/Diffusion Study (LEDS)

The summer experiment consisting of a series of simultaneous dye studies, drogue studies, current meter measurements, and aerial photographs in the same locality will be conducted during July 1980. The experimental site, as in March, is off the southshore of Long Island approximately 6 km south of Shinnecock Inlet some 100 km east of New York City. Currents in this area are predominantly shore parallel and consist mainly of tidal motions (amplitude ~ 20 cm/s) and wind-induced fluctuations superposed on a westward drift of approximately 5-10 cm/s. The water depth in the area is approximately 25-30 m.

Modifications to Proposed Experimental Design

The proposal called for a rectangular Eulerian array consisting of four (4) current meter moorings separated 0.5 to 1 km in the offshore direction and 1 to 2 km in the alongshore direction. Each mooring was to contain two meters, one at 3 m below the surface and the second at 3 m above the bottom. At the time the proposal was prepared, we felt that this spacing was sufficient to provide a match with the Lagrangian scales of motion as measured by the dye and drogues. Based on what we learned from the two workshops, however, we felt that better information was required before the current meter spacing could be fixed. The preliminary March experiment, discussed elsewhere in this report, was designed to, and did, provide that information for the drogues. Scales of motion associated with the dye experiments were inferred from two dye releases in the coastal waters off Maryland (Carter, 1978) and

Okubo's Oceanic Diffusion Diagram (Okubo, 1968). Figure 25 shows the resulting redesigned current meter array for the July experiment. It can be seen from Figure 25 that we have provided for separations of 250, 500, 750, 1000, 1250, 1750 meters in the longshore direction and of 250, 500, and 750 meters in the on/offshore direction which our preliminary analysis of the drogue and available dye data suggests will provide a match between the Eulerian and Lagrangian scales. Table 2 shows how the meters will be located on the six moorings.

Table 2
Distribution of Current Meters

<u>Location</u>	<u>Depth, m</u>			
	5 m	15 m	19 m	23 m
A	E174	-	-	-
B	E174	E105	-	-
C	E174	E105	B197	B198
D	E174	-	-	-
E	E174	E105	-	-
F	E174	-	-	-

E is Endeco
B is Braincon

Our proposal also described the drogue experiments as follows:

"On a typical field day, two small boats will arrive at the geometric center of the survey area, i.e., the dye source. Eight drogues will be launched in a small cluster at the depth (say between 5 and 10 m) of maximum dye concentration. A typical launch will require approximately 30 minutes. While the first small boat

Figure 25. Current meter array for July 1980 LEDS experiment showing orientation and separation of the current meter moorings and location of the dye source.

CURRENT METER ARRAY FOR JULY 1980 LEDS EXPERIMENT
 Ⓢ LOCATION OF DYE RAFT

launches drogues, the second will record positions. As soon as all eight drogues are launched, the second small boat will begin its observations. It is expected that each drogue will be observed on the average every 10 to 15 minutes. As the drogues become quite dispersed, far-ranging ones will be retrieved and be replaced at closer ranges. Near dusk, all drogues will be retrieved."

Although this procedure will be followed on the first day, and possibly the second day, we have planned several different types of drogue experiments for days 3 through 6. On two of the remaining days we will release drogues sequentially in time at the site of the dye raft. From this experiment we hope to (1) relate the envelope of the drogue trajectories to the standard deviation in the lateral direction of the dye plume and (2) estimate the Lagrangian autocorrelation function. Another day will be devoted to tracking two sets of drogues simultaneously with one set at ~ 5 m and the second at or near the top of the pycnocline ($\sim 10-15$ m). Simultaneously we will make an instantaneous release of approximately 50 kg of Rhodamine WT dye solution (20%) at the same location. We hope to show by analyzing the drogue data as a single set, that this type of drogue experiment is a reasonable substitute for a dye experiment. If time permits, we will track two sets of drogues whose initial envelopes are quite disparate, i.e., one set will have an initial envelope whose diameter is of the order of 100 m or less while the second set's initial envelope will be of the order of 500 m. We hope to cover two Lagrangian scales simultaneously by this method.

No changes are contemplated in the dye portion of the

experiment as outlined in the original proposal. That is, both continuous (plume) (3-4 days) and instantaneous (patch) (1-2 days) type experiments will be conducted. Also as proposed; aerial photography will be conducted on 4-5 days by a local aerial mapping concern. The aircraft, a Cessna 180, will be equipped with a Wild RC-8 Mapping Camera. The camera will be filtered with a Wratten 21 filter (orange) so that the dye will appear as a white cloud on a black background (the sea). We plan to make 3 flights in the AM and 3 in the PM. Our goal is to relate the visible threshold in the photographs to the measured standard deviations of the plume or patch.

Chronology of July LEDS Experiment

Following is the chronological plan for our July field study.

<u>Date</u>	<u>Event</u>
26 June 1980	At sea on R/V ONRUST testing dye sampling gear, fluorometers, Motorola Mini-Ranger, and data logger.
10 July 1980	Load R/V ONRUST @ Port Jefferson, NY
11 July 1980	Install Motorola Mini-Ranger Reference Stations at Shinnecock Inlet Lt and Tiana Beach Met. Tower; R/V ONRUST to Shinnecock Bay
14,15 July 1980	Install current meter moorings and deploy meters @ "A","B","C","D","E", and "F". See Figure 10.
19 July 1980	Rig R/V ONRUST for dye sampling.
20 July 1980	Survey party consisting of 8-9 persons, R/V SIOME, and rental drogue boat to Shinnecock Bay. Prepare to begin field study on 21 July 1980.
21-26 July 1980	Conduct dye and drogue studies; aerial photography. See Table 3.

<u>Date</u>	<u>Event</u>
27 July 1980	Survey party to Stony Brook with R/V SIOME
28 July 1980	R/V ONRUST remove current meters and moorings.
29 July 1980	R/V ONRUST to Port Jefferson; offload

A more detailed chronology of the events planned for 21-26 July are provided in Table 3 below.

Table 3

Planned Sequence of Events						
<u>Activity</u>	<u>July Date</u>					
	21	22	23	24	25	26
Continuous Dye:	X	X	X	X		
Instantaneous Dye:					X	X (if located)
Drogue Measurements:						
Single Scale, Single Depth Exp.	X	X				
Sequential Exp.			X	X		
Two Depth Exp.					X	
Two Scale Exp.						X
Aerial Photography:	X(PM)	X	X	X	X	

References

- Carter, H.H. and R.J. Regier. 1978. A physical assessment of the Maryland coastal waters to receive wastewaters. Chesapeake Bay Institute, The Johns Hopkins University Special Report 62, Ref. /8-2.
- Okubo, A. 1968. A new set of oceanic diffusion diagrams. Chesapeake Bay Institute, The Johns Hopkins University Technical Report 38, Ref. 68-6.

MISCELLANEOUS

Time and Effort of Principal Investigators

<u>Investigator</u>	<u>Percentage of time on project as of 1 July 1980</u>
H.H. Carter	25%
A. Okubo	17%
R.E. Wilson	17%
D.W. Pritchard	4%

Publications

- 1) Okubo, A. 1980. Diffusion and Ecological Problems: mathematical models. Springer-Verlag, New York. 254 pp.
- 2) Okubo, A., R. Dayal, I. Duedall, and A. Ramamoorthy. 1979. Radionuclide redistribution mechanisms at the 2800 m Atlantic nuclear waste disposal site. Deep-Sea Research 26:1329-1345.
- 3) Okubo, A., C.C. Ebbesmeyer, and J.M. Helseth. 1980. Description of iceberg probability between Baffin Bay and the Grand Banks using a stochastic model. Deep-Sea Research 27 (in press).
- 4) Okubo, A. 1980. Lagrangian diffusion equation and its application to environmental dispersion problems (in preparation).

Appendix A

Report on Workshop Held at NIOZ, Denburg-Texel
on 2&3 April 1979

1. Introduction

a) Mr. Carter and Dr. Wilson explained the proposal by the MSRC for carrying out experiments in the Atlantic Ocean near Long Island. Principal goals are: testing the relationship between Eulerian and Lagrangian statistics and looking for the most economical way to quantify diffusivity. Each experiment should involve: continuous and instantaneous releases of Rhodamine B, drogue releases, current meter measurements in a rectangular array of width 5-10 km. Each experiment should last for 1 week in seasonally stratified water of approximately 20 m depth. Mean velocities are of order $10 - 20 \text{ cm s}^{-1}$. Tidal velocity amplitudes are of order 5 cm s^{-1} .

b) Zimmerman discussed first the recent results from the STROVAR experiments by KNMI in the Southern North Sea. Principal goal: calibration of an existing numerical model by means of field measurements of current velocity - difficulties arising from spatial irregularity of the velocity field over the gridsize of the model (37 km^2). Principal interests: subtidal frequencies (residual currents), wave length's of the order of the current meter array (10 nautical miles). First result: residual vorticity on the array scale is of the order 10^{-6} s^{-1} . Total experiment includes 8 different test sites of which 4 have been covered up to now. NIOZ should like

to participate with a drifting drogue cluster to estimate: 1) relationship between drift of mass center and velocity field derived from current meter array, 2) idem for the linear shear tensor of cluster and the shear derived from the current meter array 3) determination of diffusivity of the cluster (to be compared with diffusion of a dye patch).

Secondly, a joint experiment, initiated by F.A., in the late summer of 1979 was discussed. Principal goals: 1) To estimate diffusivities from current velocity meter measurements and to compare them to diffusivities calculated from the dispersion of a dye patch: 2) To provide current velocity information for a simulation model of diffusion using discrete particles. The experiment will last for 1 month at a position west of Hoek of Holland in unstratified water of approximately 30 m depth having tidal currents of maximum 1 m s^{-1} and residuals in the order of $1 - 10 \text{ cm s}^{-1}$.

II. Discussion of the various measurement techniques

a) Current meter arrays

It seems rather difficult to obtain useful diffusivity information from current meters as diffusivities are basically related to Lagrangian velocity statistics. Zimmerman stressed the need to have complete information over at least one or two decades both in the Eulerian frequency and wavenumber domain before one will be in a position to tackle the Euler-Lagrange transformation and the subsequent expression of the diffusivity in Lagrangian statistics. Van Dam noted that the transformation and the expression of velocity statistics in diffusivities may be avoided using the Eulerian velocity

information in a simulation model. Anyhow, a successful experiment should at least aim at determination of the velocity field in a "STROVAR like manner" on two different length scales. It was decided to perform the 1979 summer experiment in the North Sea, if possible, in that way. Wilson was interested in having a criterion for the applicability of a direct use of the Eulerian autocorrelation spectrum to determine the Lagrangian autocorrelation spectrum. It seems doubtful whether such a procedure is allowed in cases where the high frequency part of the Eulerian velocity spectrum - which is the only part of the spectrum for which it might be successful - is not separated from the lower frequencies by a spectral gap. It appears that the situation near Long Island is rather different from that in the North Sea due to the difference in relative importance of residual and tidal currents. No conclusion was reached on this point.

b) Drogues

Drogues seem to be useful for either estimating Lagrangian velocity statistics over a rather long time interval or for determining the shear tensor at different separations of the drogues. As in both the North Sea and Long Island experiments the duration of a drogue experiment seems to be too short for the former goal, it is generally felt that drogues should principally be used for testing shears over scales intermediate between those covered by the current velocity meter array. Moreover the drogues may also provide diffusivities at different scales.

c) Dye patches

As a lot of experience is available concerning dye patch studies; these were discussed rather superficially. There was general agreement that the dye distribution reflects exactly what the fate of dissolved substances is in the sea. Any modelling of diffusion should therefore be in accordance with the results obtained by means of dye patch studies. In contrast to the methods discussed above the dye patch is also able to provide insight into diffusive processes in which the vertical coordinate plays a central role, as for instance in vertical-shear diffusion. The latter could be especially important in the stratified waters near Long Island in the summer.

The differences between continuous and instantaneous releases were discussed. It was felt that a continuous release would not be very useful in the North Sea experiment, but could provide information on diffusive processes over short time scales in the Long Island experiment.

III. Conclusions

1. At this moment mutual assistance will be most effective in the analysis of the results rather than in the execution of joint experiments.

2. Future assistance during joint experiments could be particularly important for current meter measurements as it seems that a large number of current meters are needed to obtain a wide coverage of spatial scales.

3. It would be useful to set-up a workshop in the near future. Both for overall analysis as for the special analysis of current meter measurements.

4. As the basic problem seems to be in the interpretation of the current meter measurements, frequent contact between Wilson and Riepma could be very fruitful.

5. If possible, Carter will attend the summer experiment 1979 in the North Sea by FA/KNMI as an observer.

6. Zimmerman will act as the liaison person between MSRC and the various groups in the Netherlands.

IV. List of Participants

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Appendix B

*Report on Internal Workshop held at MSRC,
SUNY, Stony Brook, NY on 1-2 October 1979.*

I. List of Participants

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E.E. O'Brien, Rene Chevrey
3. NIOZ, Denburg, Texel, The Netherlands
J.T.F. Zimmerman
4. Royal Dutch Meteorological Institute (KNMI)
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H.W. Riepma
5. National Water Res. Inst.
Burlington, Ontario, Canada
C.R. Murthy

II. Agenda

October 1, 1979

0900	Coffee/Danish	
0930	Welcome	J.R. Schubel, Director, MSRC
0945	Introductory remarks regarding the purpose of workshop, goals, scope and history of LEDS	A. Okubo
1030	Hydrography of experimental area	R.E. Wilson
1100	Description of experimental techniques (dye, drogues, current meters, aerial photographs)	H.H. Carter, R.E. Wilson
1200	Lunch	

1330	Current Meter Analyses (Eulerian)	C.R. Murthy
1500	Coffee/Tea	
1530	Eulerian-Lagrangian relations in turbulence	R. Chevrey E.E. O'Brien
1700	Adjourn	

October 2, 1979

0930	Coffee/Danish	
1000	Discussion of comparison between drogue data and current meter records and between drogue data and dye data	All
1200	Lunch	
1330	General discussion of the experimental design, changes, etc.	All
1500	Coffee/Tea	
1530	Continue discussion of experimental design	All
1700	Conclusion	

III. General

No formal minutes were taken but the two days of presentations and discussions were considered by all to be constructive if not overly instructive. By this is meant that the problems associated with relating Lagrangian to Eulerian statistics are formidable but that continued discussions and cooperation between the various groups working in this area such as NIOZ, MSRC, and the National Water Res. Inst. should be encouraged. With respect to MSRC's upcoming experiments off Long Island, there was general agreement that it might not be possible to compare the Eulerian and Lagrangian autocorrelation functions since the drogue measurements would probably be limited in duration to 12 hours or less. There was also considerable discussion

that such a comparison would require a spectral gap between the high frequencies and low frequencies. That is, absence of such a spectral gap might also prohibit such a comparison since this was felt to be a prerequisite for Taylor's "frozen field" hypothesis.

Additional discussions related to resolving Eulerian records subtidally, tidally, and supertidally according to frequency and expanding the subtidal and tidal portions of Eulerian records in an array in a Taylor's series so as to estimate velocity gradients at these lower frequencies.

It was further recommended that MSRC conduct a preliminary experiment be conducted prior to a major comparison study so as to better define the dimensions of the current meter array thus ensuring an overlap of Eulerian and Lagrangian scales.