106-MILE DUMPSITE PHYSICAL OCEANOGRAPHY PROJECT

EOPB PROGRESS REPORT FOR 1990

January 1991

U.S. DEPARTMENT OF COMMERCE
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106-MILE DUMPSITE PHYSICAL OCEANOGRAPHY PROJECT:

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Estuarine and Ocean Physics Branch
Office of Oceanography and Marine Assessment
National Ocean Service
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Notice

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AVHRR	Advanced Very high Resolution Radiometer
CTD	Conductivity/Temperature/Depth
EOPB	Estuarine and Ocean Physics Branch
EPA	Environmental Protection Agency
LSD2	Low Slip Drifter
MAB	Middle Atlantic Bight
NAS	National Advanced Systems
NESDIS	National Environmental Satellite, Data, and Information Service
NEFC	NorthEast Fisheries Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
ODBA	Ocean Dumping Ban Act
OMA	Oceanography and Marine Assessment
OPC	Ocean Products Center
POD	Physical Oceanography Division
SOOP	Ship Of Opportunity Program
SSIPS	SST Satellite Image Processing System
SST	Sea Surface Temperature
TOGA	Tropical Ocean Global Atmosphere
USCG	United States Coast Guard
WOCE	World Ocean Circulation Experiment
XBT	EXpendable Bathy-Thermograph

ABSTRACT

The Estuarine and Ocean Physics Branch (EOPB) of NOAA's National Ocean Service shares responsibility with the EPA to address physical oceanographic questions relating to the physical and chemical fate of sewage sludge being dumped at the 106-Mile Dumpsite. This document reports on progress made during the calendar year 1990 by the EOPB on both an observational and modeling effort.

Measurements include remote sensing of sea surface temperature (SST), seasonal deployment and satellite-tracking of near-surface drifters, and hydrographic sampling. An image processing system has been established in the EOPB and images of the SST structure are analyzed on a daily basis for the Middle Atlantic Bight. Eight drifters were deployed in August 1990 from the outer continental shelf to the Dumpsite over the continental slope. These drifters are being tracked in relationship to the SST structure. Further seasonal deployments of four drifters each will be carried out during 1991. During the same August 1990 cruise (DELAWARE II, 90-08) CTD/Transmissometer and XBT profiles were obtained in support of biological/chemical sampling and to do a synoptic hydrographic survey of the 106-Mile Dumpsite region.

The modeling effort during 1990 included an evaluation of a variety of models and historical data sets as to their potential for application towards determination of the fate of sludge and to identify possible deposition areas. As a result of this evaluation, some data-based probability calculations are underway and further numerical circulation, concentration, trajectory and deposition model calculations are planned.

1. INTRODUCTION

The Ocean Dumping Ban Act of 1988 (ODBA) amends the Marine Protection, Research and Sanctuaries Act of 1972 ("the Ocean Dumping Act") to provide for the cessation of ocean dumping of sewage sludge and industrial waste by the end of 1991. At present such dumping is restricted to disposal of sewage sludge at the 106-Mile Deepwater Municipal Sludge Dump Site. In response to the ODBA, in March 1989 EPA, NOAA and the USCG convened a workshop (EPA, 1989) to address sludge dumping and its effects at the 106-Mile Site. Building upon the results of this workshop, these agencies developed a strategy for research and monitoring of physical conditions and the effects of sludge disposal at the 106-Mile Dumpsite. The final draft planning report (Battelle, 1990) describes the overall objectives of this project and shows that physical oceanographic research tasks are to be shared between NOAA and EPA.

The fundamental objective of physical oceanography research in the 106-Mile Dumpsite Project is to address the basic management question:

> " What is the physical (and chemical) fate of the sewage sludge dumped at the 106-Mile Dumpsite?"

The two major components of NOAA's efforts (EOPB, 1990a) involve an observational part, including remote sensing, tracking of surface drifters and hydrography and a modeling part, including model evaluation and implementation. This document reports on progress made during 1990 in each of these components.

1.1 Background and Pre-1990 Activities

A wealth of information on physical and chemical characteristics and baseline biological conditions at the 106-Mile Site has been compiled in the past decade (Battelle, 1990). The history of physical oceanographic measurements directly related to the 106-Mile Dumpsite dates from 1974 (NOAA: 1975, 1977 and 1981; Battelle, 1988; McDowell et al., 1988). Informative overviews of the circulation and hydrographic characteristics in the Middle Atlantic Bight (MAB) and at the Dumpsite are provided by Bisagni, 1983; Aikman, 1984; and by Ingham, 1988.

Recent monitoring of the nearfield and short-term fate of sludge (Battelle, 1990) has led to the conclusion that the majority (80 - 90 %) of the sewage sludge solids remain in suspension in the mixed layer and thermocline for a significant length of time (depending on dumping rate). All but the heaviest sludge particles are expected to remain in the water column for weeks to months; thus studies of the farfield and long-term fate of sludge are the object of current activities.

2. OBSERVATIONS

2.1 Introduction

The NOAA physical oceanography observational effort includes remote sensing, tracking of quasi-Lagrangian drifters, and hydrography (CTD/transmissometer and XBT profiles). Remote sensing of the SST field is continuous and ongoing; drifter deployments are seasonal, but the tracking is continuous and ongoing; CTD/transmissometer surveys are done, when possible, during drifter deployments, and in support of the biological/chemical surveys; and XBT transects are taken approximately weekly. Although each activity is described separately below, the interdependency of each is an essential ingredient of the observational effort.

2.2 Remote Sensing

2.2.1 Image Processing System

The EOPB image processing system was established in the spring of 1990. SSIPS (SST Satellite Image Processing System), a PC-based image processing software system, was obtained from NOAA's Ocean Products Center (OPC) and the hardware was assembled according to OPC specifications. A Matrix Multicolor Analog Film Recorder was added in September, 1990. This allows color prints to be produced in film formats from 35mm slides to 8" x 10" sheet film. A User's Guide (Hess and Empie,1990) describes the system and its operation and is available to all potential users.

In the operational mode Advanced Very High Resolution Radiometer (AVHRR) data from NOAA's TIROS polar-orbiting satellites (NOAA-10 and/or NOAA-11) is accessed daily. Using the OPC as a conduit for data we produce SST fields for the western North Atlantic, focusing our attention on the Middle Atlantic Bight, the 106-Mile Dumpsite and the region occupied by the drifters. The SST field is monitored using the NOAA SST display and analysis system. Each image is examined for cloud cover, allowing selection of 'clear' passes that are useful for SST mapping. On average, 3 to 4 images per week are saved, including images processed at 4 km resolution and finer scale images processed at 2 km resolution.

In addition to application in the 106-Mile Dumpsite Project, the Image Processing System is being used to monitor SST structure in the Long Island Sound and Tampa Bay, in support of other EOPB projects.

2.2.2 Sea Surface Temperature Imagery

The SST imagery is being used in two ways:

A. To analyze surface drifter tracks. It is used to identify the surface water mass that the drifter is in, as well as help explain the relationship between surface features (e.g. fronts, warm core rings) and the tracks of the drifters. Several examples of drifter tracks overlain on SST images are presented in the next section on preliminary results of the August, 1990 drifter deployment (see Figures 3-6). The relationship of the drifter positions and tracks to water mass boundaries such as the shelf-slope front and Gulf Stream front is discussed in that section.

B. In near-real time, when the images are clear, the SST information is used to decide where to deploy surface drifters and/or locate ship stations. Images are analyzed for location of water mass boundaries, and the results are used to assure the selection of appropriate surface water masses for drifter deployments, CTD stations and biological/chemical station positions. This was attempted during the August, 1990 DELAWARE II cruise (see the following section on hydrography). However, due to the summer heating of the surface layer and extensive cloudiness during this period, it was very difficult to distinguish shelf water from slope water. Only the Gulf Stream maintains a strong surface temperature signature in summer.

2.3 Hydrography

2.3.1 CTD/Transmissometer Survey

NOAA conducted a hydrographic survey of the MAB and the 106-Mile Dumpsite region in August 1990 (DELAWARE II, Cruise 90-08) and deployed eight satellite-tracked quasi-Lagrangian near-surface drifters across the site from the outer shelf to the outer slope (see Figure 1). This work corresponded with the National Marine Fisheries Service (NMFS) mid-water fish survey of the same region. The hydrography consisted of conductivity/temperature/depth (CTD) profiles with a transmissometer sensor to examine particle concentrations in the water column, and XBT drops. The intent of this survey was to:

(a) provide water mass identification at all stations where mid-water fish trawls were taken;

(b) do a synoptic survey of the Dumpsite region; and

(c) identify surface and subsurface water mass structure at the drifter deployment sites.

Coupled with the drifter studies and the real-time SST imagery, this survey will enable us to characterize the three-dimensional water mass structure in the vicinity of the Dumpsite at the time of drifter deployments and to later track these drifters in relationship to the SST structure as derived from the satellite imagery.

As previously mentioned, SST images produced by the Image Processing system were of limited use during the August cruise because of the uniform heating of the surface layer in summer and because of significant cloud cover and haze. However, the additional use of Oceanographic Features Analysis charts of the SST structure, provided by the Ocean Products Center, aided the selection of station sites based on these two sources of information on the SST structure.

A report of the physical oceanographic component of this cruise was distributed in September, 1990 (EOPB, 1990b), as was an overall cruise report for this 106-Mile Dumpsite Mid-Water Fish and Oceanography Study (NEFC, 1990).

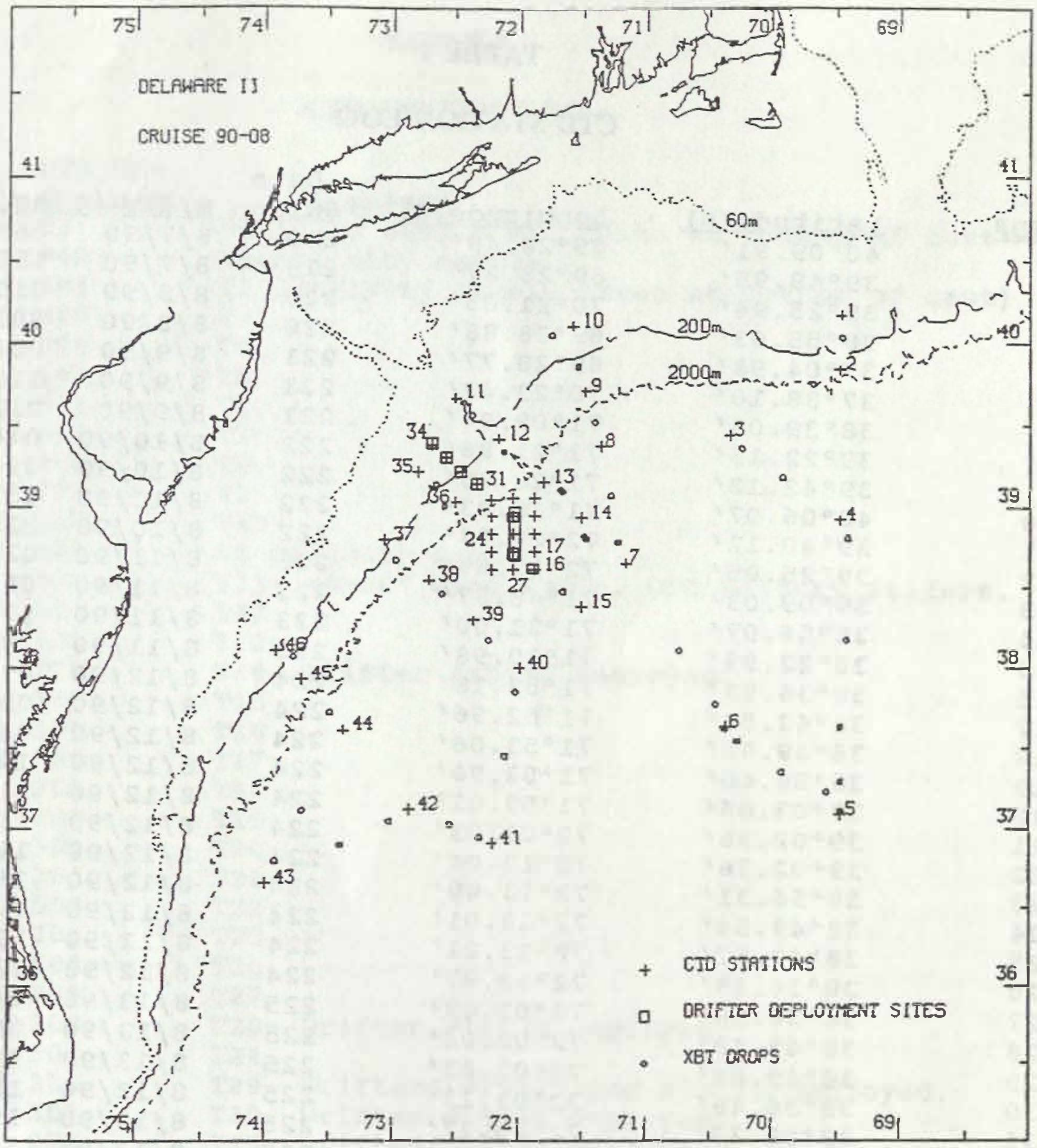

Figure 1: Location of CTD, XBT and drifter deployment sites in the Middle Atlantic Bight from the DELAWARE II Cruise 90-08 of 6-18 August, 1990. The three isobaths shown are 60, 200 and 2000 meters. CTD stations are marked by pluses, XBT drops by small circles and drifter deployment sites by squares. The 106-Mile Dumpsite is the rectangle outlined in the center of the figure with its upper right corner at 39 N, 72 W.

TABLE 1

CTD STATION LOG

CTD#	Latitude(N)	Longitude(W)	Date Julian	m/d/y	Time(UT)
1	40°09.91′	69°28.49′	219	8/7/90	0855
2	39°49.95′	69°28.87′	219	8/7/90	1504
3	39°25.94′	70°21.05′	220	8/8/90	0104
4	38°55.03′	69°28.88′	220	8/8/90	0851
5	37°04.98′	69°28.77′	221	8/9/90	0028
6	37°38.10′	70°23.47′	221	8/9/90	1152
7	38°39.06′	71°09.94′	221	8/9/90	2124
8	39°22.15′	71°21.86′	222	8/10/90	0445
9	39°42.12′	71°28.96′	222	8/10/90	0943
10	40°06.07′	71°35.03′	222	8/10/90	1517
11	39°40.12′	72°29.88′	222	8/10/90	2218
12	39°25.05′	72°09.89′	223	8/11/90	0238
13	39°09.03′	71°48.87′	223	8/11/90	0815
14	38°56.07′	71°31.00′	223	8/11/90	1320
15	38°22.99′	71°30.98′	223	8/11/90	2023
16	38°36.93′	71°53.18′	224	8/12/90	0138
17	38°43.51′	71°52.96′	224	8/12/90	0525
18	38°49.98′	71°53.06′	224	8/12/90	0640
19	38°56.40′	71°52.90′	224	8/12/90	1024
20	39°03.05′	71°53.01′	224	8/12/90	1146
21	39°02.96′	72°03.03′	224	8/12/90	1318
22	39°02.76′	72°13.04′	224	8/12/90	1452
23	38°56.31′	72°13.00′	224	8/12/90	1607
24	38°49.84′	72°13.01′	224	8/12/90	1717
25	38°43.57′	72°13.21′	224	8/12/90	2138
26	38°36.88′	72°12.97′	224	8/12/90	2257
27	38°36.98′	72°03.02′	225	8/13/90	0439
28	38°43.49′	72°03.04′	225	8/13/90	0559
29	38°49.83′	72°02.83′	225	8/13/90	1116
30	38°56.46′	72°03.17′	225	8/13/90	1240
31	39°08.37′	72°20.27′	225	8/13/90	1520
32	39°13.05′	72°27.14′	225	8/13/90	1643
33	39°18.03′	72°34.14′	225	8/13/90	1758
34	39°23.04′	72°41.03′	225	8/13/90	1905
35	39°12.93′	72°47.95′	225	8/13/90	2044
36	39°01.97′	72°29.93′	226	8/14/90	0024
37	38°47.83′	73°04.04′	226	8/14/90	0830
38	38°33.06′	72°43.13′	226	8/14/90	1314
39	38°17.94′	72°21.90′	226	8/14/90	1833
40	38°00.00′	72°00.16′	226	8/14/90	2333
41	36°54.36′	72°12.84′	227	8/15/90	0857
42	37°07.05′	72°52.00′	227	8/15/90	1609
43	36°39.20′	74°00.04′	228	8/16/90	0107
44	37°37.13′	73°23.85′	228	8/16/90	0934
45	37°56.08′	73°43.07′	228	8/16/90	1415
46	38°06.93′	73°55.04′	228	8/16/90	1910

TABLE 1

CTD STATION LOG

Water Depth(m)	CTD Max. Depth(m)	Comments
85	81	Salinity sample #T1 taken at bottom of cast
1400	302	No salinity sample
2500	501	T2 (Salinity sample taken at bottom of cast)
3014	480	T3
4500	490	T4
4000	445	T5
2800	501	T6
2555	500	T7
1427	503	T8
87	78	T9
105	102	T10
1100	301	No salinity sample
2208	301	T11 40-50° wire angle. CTD Battery failure.
2450	503	T12
2800	503	T13
2650	300	T14 Drifter #15130 deployed.
2653	300	T15
2562	300	T16
2287	300	T17
2196	301	T18
1800	300	T19
1800	300	T20
2048	303	T21
2536	502	T22
2635	302	T23
2196	500	T26
2653	300	T27
2610	303	T28 Drifter #15131 deployed.
2470	300	T24
2350	300	T29 Drifters #15132 and #15133 deployed.
1000	301	T30 Drifter #15134 deployed.
287	275	T25 Drifter #15135 deployed.
140	138	T31 Drifter #15136 deployed.
100	96	T32 Drifter #15137 deployed. Large wire angle.
92	90	T33
1300	253	No salinity sample. Wire angle > 45°
133	130	T34
2550	503	T35
2818	500	T36
3000	500	No salinity sample
3477	500	T37 789m wire out.
2930	504	T38
2440	300	No salinity sample
2507	300	T39
1630	500	T40
118	103	No salinity sample

The CTD/Transmissometer and XBT data from this August 1990 cruise is now being processed. Preliminary processing indicates the CTD/ transmissometer data are of high quality. All sensors were laboratory calibrated before the cruise. A Niskin bottle attached above the CTD provided a single salinity sample at the bottom of each cast to compare to CTD salinities. Table 1 catalogs the basic header information for each of the forty-six CTD/Transmissometer stations. Correspondingly, Table 2 lists similar information for the 45 XBT profiles. A data report of the hydrographic results from the DE II 90-08 cruise is planned for April 1991.

2.3.2 XBT Transects

NOAA collects, analyzes and transmits to EPA the data from near-weekly XBT transects across the continental shelf and slope from the NEFC's Ships Of Opportunity Program (SOOP). This is an extension of a program that has been maintained by the NMFS for over a dozen years. These data will allow us to examine the strength, variability and evolution of the thermocline near the Dumpsite. They also provide near-surface temperature measurements on a regular basis to compare to the SST derived from the AVHRR satellite data. The near-weekly sampling began in March, 1990 as an extension of the pre-existing regular monthly transects, and will continue for the duration of the 106-Mile Dumpsite Project (the end of 1991).

2.4 Drifters

2.4.1 Objectives

A significant component of the observational program in the 106-Mile Dumpsite Project is the deployment and satellite-tracking of near-surface drifters in the MAB. EPA has arranged with permittees to deploy one drifter per week, on the average, at the site. The NOAA seasonal drifter studies are intended to supplement this work by examining the behavior of drifters deployed quasi-simultaneously across the site in different water masses and by providing statistics on dispersion of two or more drifters deployed simultaneously in the same water mass . The objectives of the seasonal deployments, coupled with the weekly EPA drifter deployments at the site, are to provide information necessary to examine the following phenomena and to ascertain their impact on sludge dispersal:

(1) the large-scale southwest drift over the Middle Atlantic Bight continental shelf and slope and the hypothesized recirculation of the slope sea gyre;

(2) the existence and role of convergence at the shelf break;

(3) entrainment by the Gulf Stream versus possible transport to the South Atlantic Bight.

The drifter studies will also aid in estimating the effects of features such as wind events, warm core rings, Gulf Stream meanders and mesoscale shelf break eddies.

TABLE 2

XBT LOG

XBT#	Latitude(N)	Longitude(W)	Date Julian	1990 m/d	Time (UT)	XBT Type	Depth(m)
1	40°01.8′	69°27.6′	219	8/7	1335	T10	104
2	39°44.8′	69°41.1′	219	8/7	2122	T4	1954
3	39°21.4′	70°15.3′	220	8/8	412	T4	2500
4	39°10.5′	69°55.5′	220	8/8	626	T4	2500
5	38°48.09′	69°25.36′	220	8/8	1338	T4	3000
6	38°10.4′	69°26.2′	220	8/8	1713	T4	3000
7	37°37.67′	69°28.18′	220	8/8	2100	T4	4500
8	37°17.6′	69°29.10′	220	8/8	2300	T4	4560
10	37°06.1′	69°28.9′	221	8/9	010	T4	4580
11	37°13.7′	69°35.4′	221	8/9	409	T4	4500
12	37°21.0′	69°56.2′	221	8/9	903	T4	3000
13	37°32.75′	70°17.45′	221	8/9	1100	T4	4075
14	37°37.50′	70°23.61′	221	8/9	1140	T4	4000
15	37°46.53′	70°27.84′	221	8/9		T4	4000
16	38°06.56′	70°45.0′	221	8/9	1756	T4	3000
17	38°46.70′	71°13.66′	222	8/10	110	T4	2700
18	39°03.88′	71°17.30′	222	8/10	300	T4	2500
19	39°31.17′	71°24.81′	222	8/10	834	T4	2500
20	39°51.20′	71°32.66′	222	8/10	1352	T4	442
21	40°02.7′	71°44.77′	222	8/10	1802	T10	91
22	39°33.58′	72°22.48′	223	8/11	115	T10	110
24	39°20.18′	72°07.38′	223	8/11	612	T4	647
25	39°06.04′	71°40.66′	223	8/11	1141	T4	2200
26	39°05.35′	71°39.64′	223	8/11	1153	T4	2200
27	38°48.92′	71°29.57′	223	8/11		T4	2500
28	38°47.98′	71°29.02′	223	8/11	1733	T4	2500
29	38°28.31′	71°39.52′	224	8/12	005	T4	2800
30	39°07.96′	72°39.39′	225	8/13	2320	T10	262
31	39°00.14′	72°35.27′	226	8/14	0359	T4	1300
32	38°40.22′	72°58.95′	226	8/14	1118	T4	650
33	38°27.85′	72°36.53′	226	8/14	1705	T4	2400
35	38°10.60′	72°14.61′	226	8/14	2207	T4	2944
36	37°51.23′	72°01.73′	227	8/15	233	T4	3000
37	37°27.34′	72°06.66′	227	8/15	457	T4	3000
38	36°56.48′	72°18.97′	227	8/15	1307	T4	3000
39	37°01.42′	72°32.67′	227	8/15	1430	T4	2800
40	37°02.79′	73°01.74′	227	8/15	1949	T4	2983
41	36°53.64′	73°25.07′	227	8/15	2153	T4	2882
42	36°47.68′	73°55.13′	228	8/16	410	T4	2400
43	37°06.69′	73°42.95′	228	8/16	615	T4	2452
44	37°43.63′	73°30.27′	228	8/16	1235	T4	2500
45	38°04.61′	73°46.90′	228	8/16	1823	T4	1000

2.4.2 The August 1990 Deployment

The quasi-Lagrangian drifters used employ a 6 meter long holey-sock drogue, centered at 10 meters. The LSD2 (Low Slip Drifter) is produced by Clearwater Consultants of Newton, MA. Its choice was based on the results of several drifter inter-comparison tests done for large-scale oceanographic programs (i.e TOGA, WOCE), as well as to be exactly compatible with drifters being deployed for EPA in the 106-Mile Dumpsite Project (see below).

The first phase of the NOAA drifter program commenced this past summer. During the August 1990 DELAWARE II Cruise 90-08, eight satellite-tracked drifters were deployed from the outer shelf to the outer slope across the 106-Mile Dumpsite (see Figure 1). Table 3 catalogs the drifter deployment information. Portions of drifter tracks for the first three and one half months of their drift in the MAB (Aug. 13 - Nov. 30, 1990) are shown in Figure 2. All but one drifter (# 7) had exited the MAB to the east by this time.

Pairs of tracks are shown superposed on various SST images (Figures 3-6) in what follows, and the individual tracks are more easily discerned. Several features are evident from these preliminary tracks.

Drifters 1 and 2, deployed (in slope water) offshore of the Dumpsite and in the southern part of the Dumpsite, respectively, move southwestward for about a week (at ~16 cm/s) before turning eastward and eventually northeastward along the north wall of the Gulf Stream. In Figure 3 these tracks are superposed on a 4 km resolution SST image for September 25, 1990. On this date the drifters were at the top of their anticyclonic loop around the warm core ring centered at approximately 39 N and 67.5 W.

Drifters 3 and 4, deployed (in slope water) simultaneously in the northern part of the Dumpsite, drift southwestward at ~12 cm/s, slowly converging towards the shelf break, before turning northeastward just north of Cape Hatteras and following the north wall of the Gulf Stream at ~70 cm/s. Figure 4 shows these two tracks superposed on a 2 km resolution SST image for earlier in the day on September 25, 1990. These two drifters are intended to provide statistics on dispersion since they were deployed at the same time and in the same water mass, and it is evident from Figure 4 that the two drifter tracks correspond remarkably well.

Drifters 5 and 6, deployed shoreward of the Dumpsite but seaward of the shelf break, both cross the shelf break onto the shelf. These two tracks are shown superposed on a 2 km resolution SST image for October 9, 1990 in Figure 5. Drifter 5 crosses onto the shelf immediately in a cyclonic loop, presumably caught up in a shelf break mesoscale eddy, but unfortunately the SST imagery for August 1990 is very poor, both because of clouds and the lack of any clear SST definition of the shelf break front due to summer heating. Both drifters stay on the shelf for about two months before eventually exiting just north of Cape Hatteras and becoming entrained in the Gulf Stream.

Drifters 7 and 8, deployed at the shelf break and on the outer shelf, respectively, track the shelf break well (at a mean speed of ~12 cm/s) to just north of Cape Hatteras. In Figure 6 these two tracks are shown superposed on a 2 km resolution SST image for November 16, 1990. Drifter 8 is entrained at the north wall of the Gulf Stream within one month of deployment and moves off

TABLE 3

DRIFTER DEPLOYMENT LOG

Drifter	Latitude(N)	Longitude(W)	Date Julian	Date m/d/y	Time(UT)	Water Depth(m)	Comments
15130	38°37.16′	71°53.83′	224	8/12/90	0242	2650	Station 16.
15131	38°42.78′	72°03.25′	225	8/13/90	0650	2610	Station 28.
15132	38°56.28′	72°03.19′	225	8/13/90	1320	2350	Station 30.
15133	38°56.28′	72°03.19′	225	8/13/90	1325	2350	Station 30.
15134	39°08.55′	72°20.33′	225	8/13/90	1557	1000	Station 31.
15135	39°13.22′	72°27.48′	225	8/13/90	1717	278	Station 32.
15136	39°18.25′	72°34.25′	225	8/13/90	1818	138	Station 33.
15137	39°23.39′	72°40.97′	225	8/13/90	1918	99	Station 34.

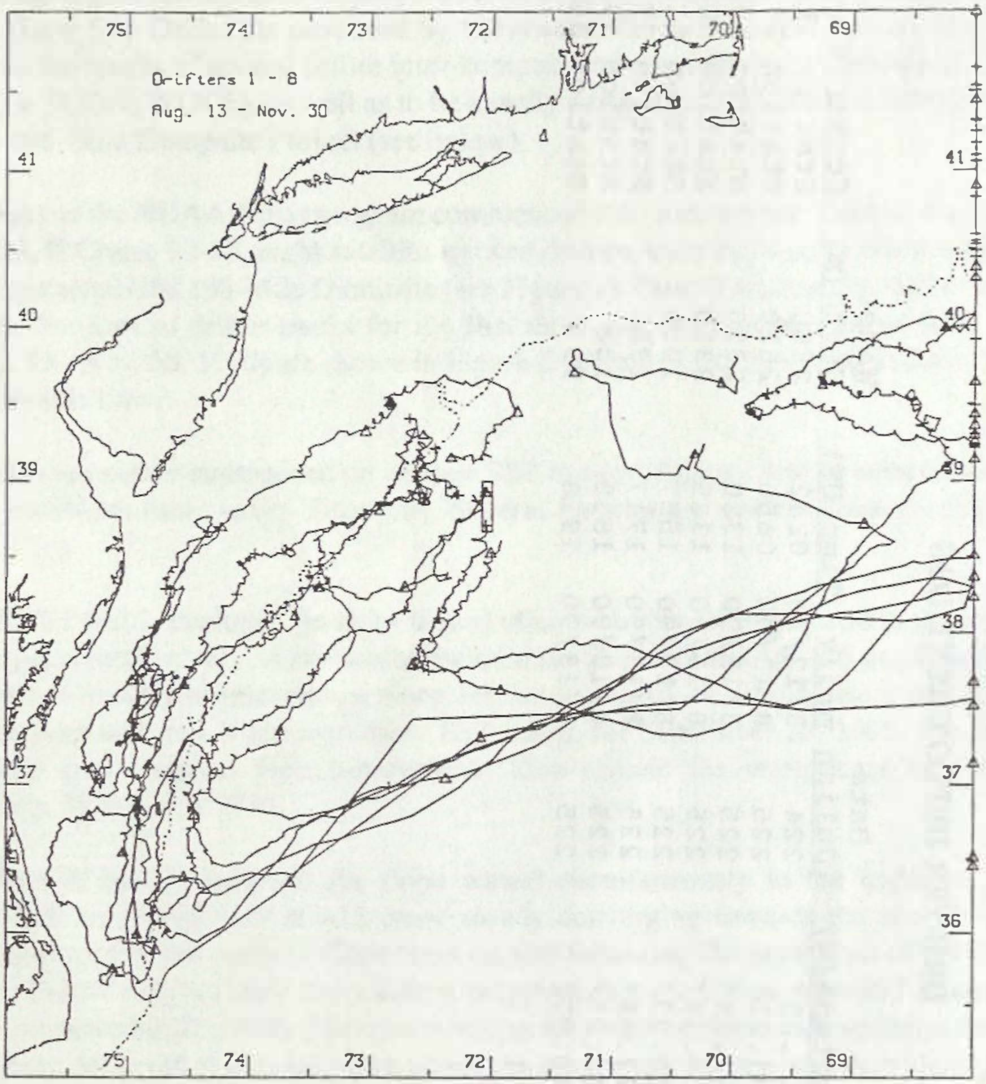

Figure 2: Drifter tracks for the eight drifters deployed on August 13, 1990 during the DELAWARE II 90-08 Cruise. Drifter 1 was deployed farthest offshore, just seaward of the 106-Mile Dumpsite. Drifter 2 in the southern part of the Dumpsite, drifters 3 and 4 simultaneaously in the northern part of the Dumpsite, and drifters 5-8 in a line progressing shoreward from the Dumpsite. Represented here are the portions of these tracks in the MAB for the period 13 August to 30 November, 1990. The dashed line is the 200 m isobath.

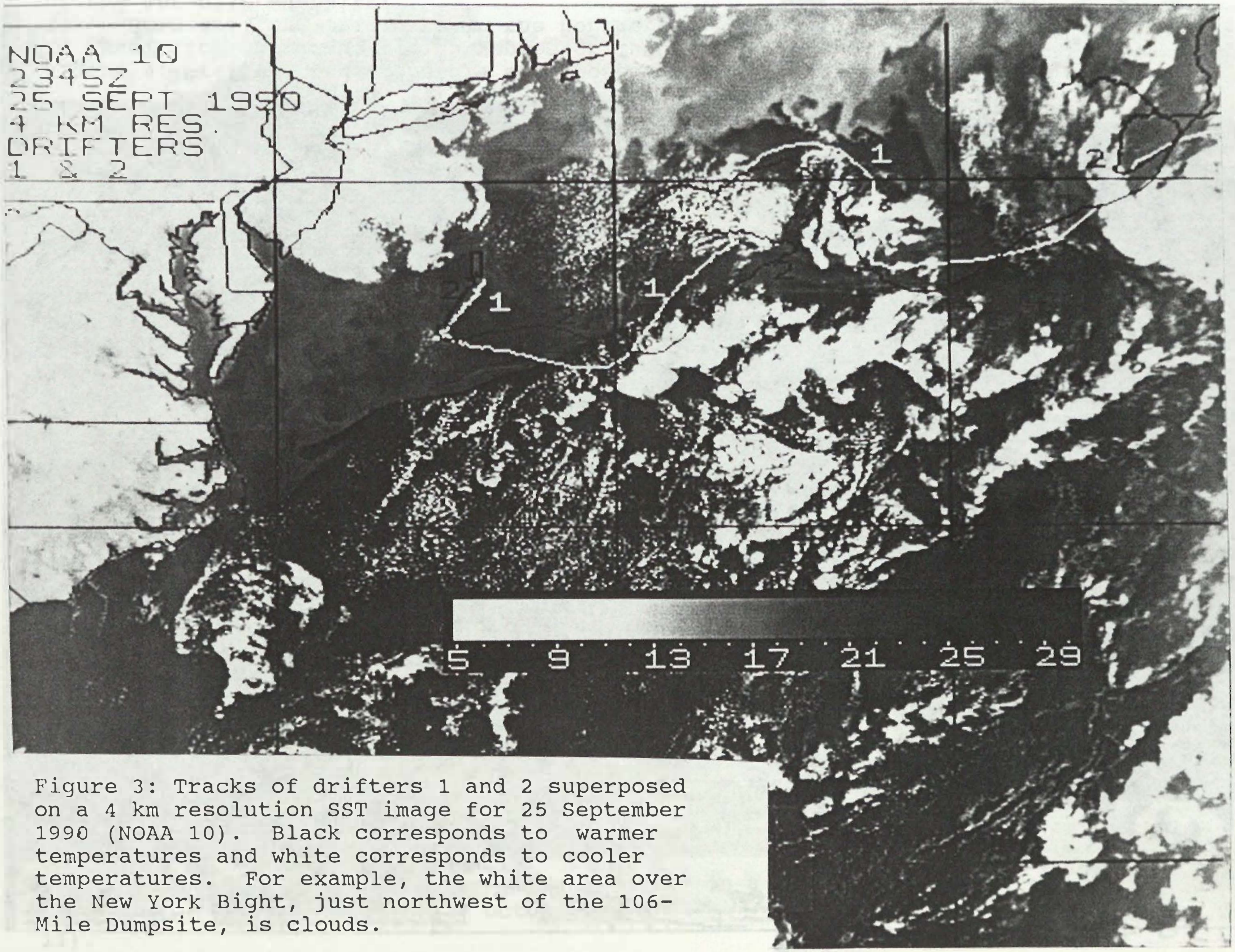

Figure 3: Tracks of drifters 1 and 2 superposed on a 4 km resolution SST image for 25 September 1990 (NOAA 10). Black corresponds to warmer temperatures and white corresponds to cooler temperatures. For example, the white area over the New York Bight, just northwest of the 106-Mile Dumpsite, is clouds.

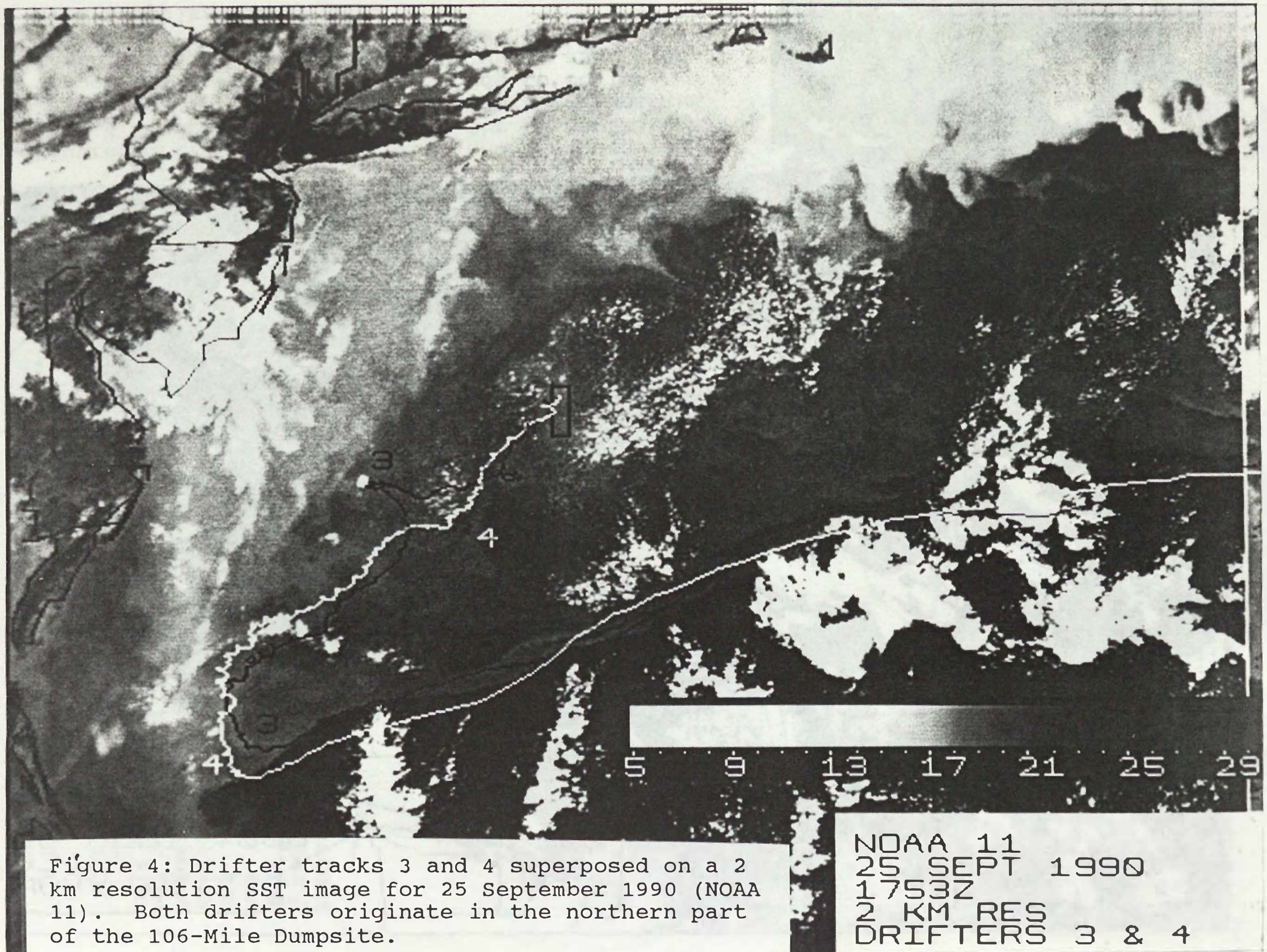

Figure 4: Drifter tracks 3 and 4 superposed on a 2 km resolution SST image for 25 September 1990 (NOAA 11). Both drifters originate in the northern part of the 106-Mile Dumpsite.

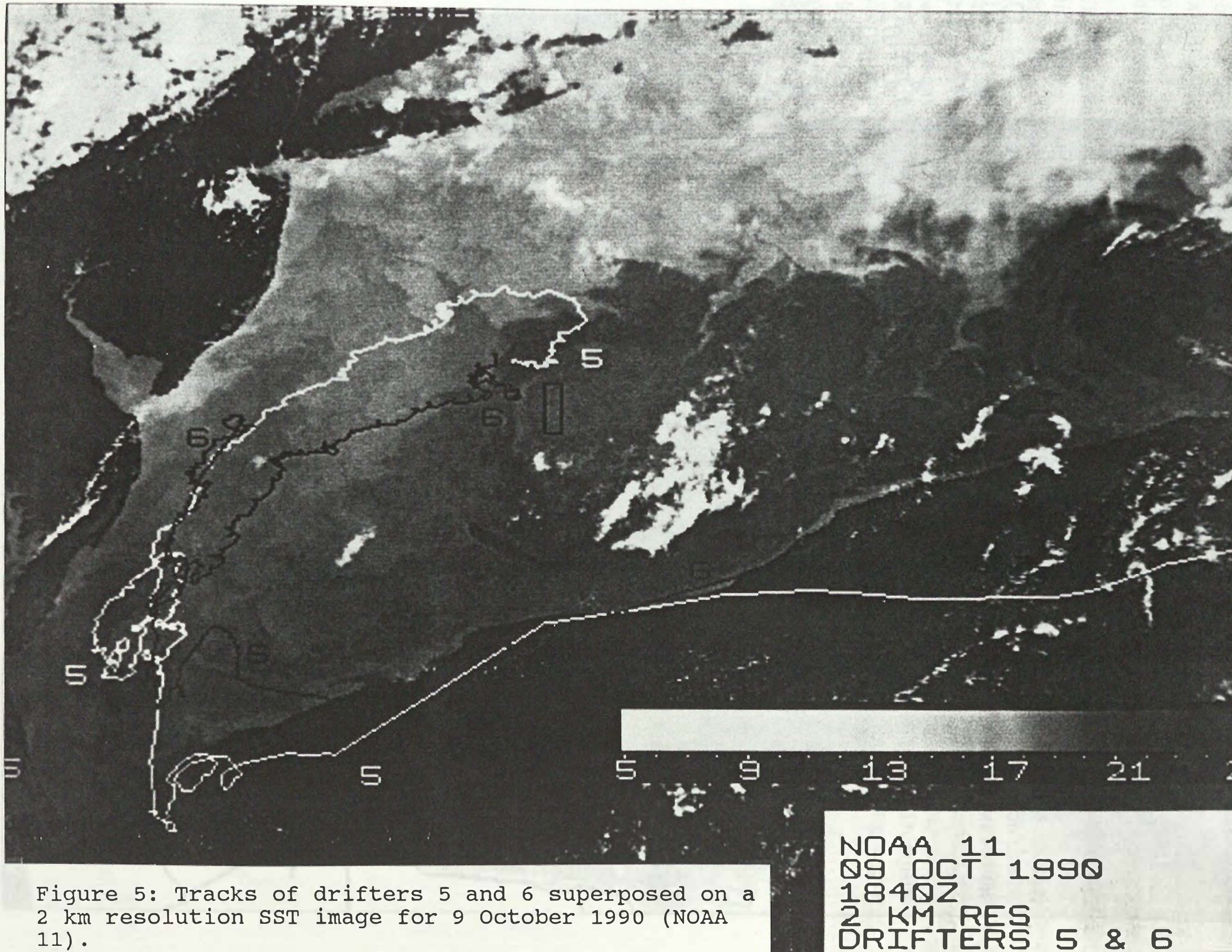

Figure 5: Tracks of drifters 5 and 6 superposed on a 2 km resolution SST image for 9 October 1990 (NOAA 11).

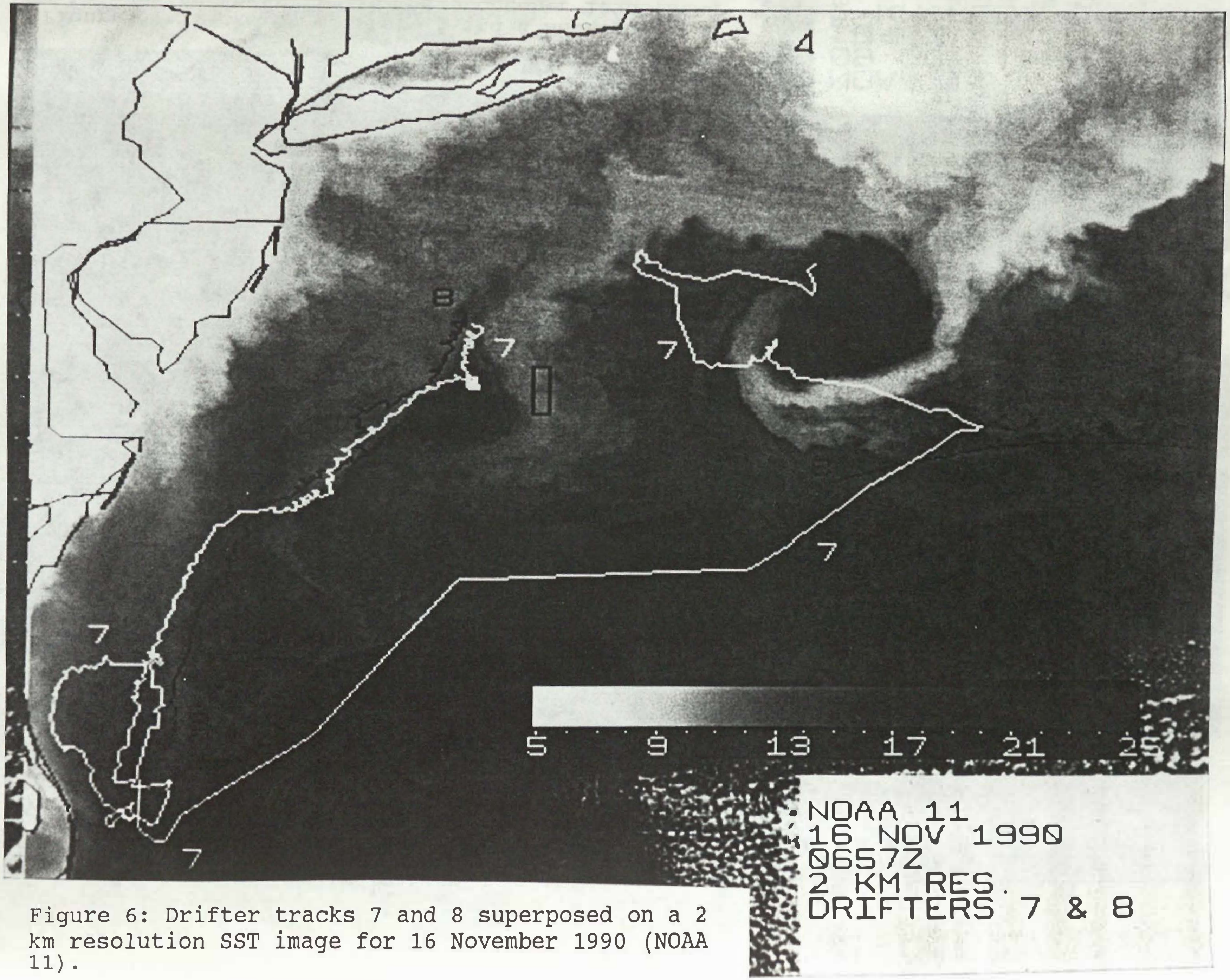

Figure 6: Drifter tracks 7 and 8 superposed on a 2 km resolution SST image for 16 November 1990 (NOAA 11).

rapidlyto the northeast. In contrast, drifter 7 makes an anticyclonic turn over the shelf and slope just north of Cape Hatteras before becoming entrained into the Gulf Stream in late October. Drifter 7 exits the Gulf Stream in early November and is caught up in a warm core ring, evident in Figure 6 to the east of the 106-Mile Dumpsite. As of this writing, drifter 7 was apparently still caught up in this warm core ring as it approached the Dumpsite from the northeast.

These preliminary drifter tracks show that, while mesoscale variability can be considerable, the picture of a mean southwestward flow and eventual entrainment along the north wall of the Gulf Stream is evident. Based on this single realization, and to the extent that drifters track sludge, material from the Dumpsite does not appear to move onto the shelf. A similar conclusion can be drawn from the preliminary results of weekly drifters deployed for EPA by the Permittees at the Dumpsite (Paul Dragos, Battelle - personal communication). However, a single realization does not result in any statistical confidence. Thus, NOAA will make a series of four seasonal deployments of four drifters each over the next year. The deployment sites will extend from the Dumpsite shoreward to the mid-shelf, and are intended to provide four independent realizations of Lagrangian trajectories from both shelf and slope water masses.

3. MODELING

3.1 Objectives

Modeling was identified as an important ingredient for addressing the basic management question (EPA, 1989): What is the physical (and chemical) fate of the sewage sludge dumped at the 106-Mile Dumpsite? Accordingly, model studies can be used to assess the fate of the sludge and to define depositional regions (including concentrations of contaminants). These models are conceptualized as containing a water circulation component and a sludge fate component. The objective of NOAA's 1990 effort, as stated in the Plan (Battelle, 1990), was the assessment of the suitability of various circulation models of the Middle Atlantic Bight, and of the suitability of historical data that would be needed for a modeling effort. Thus, this progress report will discuss the results of the model and data evaluation.

3.2 Accomplishments

During 1990 NOAA has assessed the suitability of circulation and deposition models to determine their utility in predicting the fate of the sludge, including predicting advection and dispersion, defining depositional areas and assessing transport from the slope to the shelf. Nearfield and farfield conditions were considered, as was the influence of density gradients. When selected, an appropriate model can be used to design field studies as well as to interpret statistical evaluation of farfield fate studies. Numerical model output can also provide estimates of currents in the near and farfields.

In 1990, NOAA has also assessed the suitability of various circulation data sets that can be used by the models. Here, circulation is defined to include water current speed and direction, descriptive parameters such as salinity and temperature, plus the identification of localized features such as the locations of fronts and jets. Viable historical data includes hydrographic measurements (CTDs and XBTs), data from moored current meter experiments, such as the Shelf Edge Exchange Processes (SEEP I and II) and Middle Atlantic Slope and Rise (MASAR) programs, as well as more recent observations associated with the Dumpsite (drifters, moored current meters, current profilers, SST imagery).

Because it is believed that the majority (80 to 90 %) of the sewage sludge remains in suspension in the mixed layer and thermocline for weeks to months (Battelle, 1990), and because there is a reasonable amount of Eulerian current meter data available in the MAB at these levels, it was decided to apply the methods ("Visitation Frequency") laid out by Csanady (1983) and Churchill (1987) to examine the probability distribution of sludge material originating at the Dumpsite, but confined to particular laminae. Dr. James Churchill, of Woods Hole Oceanographic Institution, is applying this method using current meter data from the SEEP I and II and MASAR experiments.

3.2.1 The Model Evaluation Task

Under this task is the evaluation of existing models and completion of a literature search. Some of the models which were considered include:

- particle deposition models (Partch, 1985; Fry and Butman, 1990)

– concentration models (Walker et al., 1987; Churchill, 1987)

– the conceptual model of Csanady and Hamilton (1988)

– the GFDL 3-D prognostic model (Mellor and Ezer,1990)

– the Harvard Gulf Stream model (Robinson and Walstad, 1987)

– the ASA data-based hydrodynamic model (Robertson and Spaulding, 1985)

As a result of the literature survey, we group the modeling approaches into four categories, as follows.

A. Particle Deposition Models

These models estimate the areas on the ocean bottom that would be impacted by the deposition of the heaviest sludge particles. The horizontal position of the drifting particle after release from the dumpsite is determined by integrating the horizontal velocity over time. The vertical position is determined by the settling velocity, and the point of deposition is found when the particle depth equals the total water depth. Typically, the approach is to simulate (a) horizontal motion with observational data from a nearby mooring with current meters at several depths, (b) diffusion by a random walk method or based on the statistical variability of the horizontal currents, and (c) vertical motion as a constant. This approach is based on a paper by Csanady (1983) and was used by Partch (1985) and, most recently, by Fry and Butman (1990). Laboratory measurements of sludge settling velocities have been published by Hunt and Pandya (1984) and Lavelle et al. (1988).

The predicted areas of impact have been found to be within 200 to 300 kilometers downstream (southwest) of the Site, and on the order of 50 kilometers in the direction normal to the downstream flow. There is no direct validation of these predictions.

Although not validated, results from these models can be used for comparison with output of more sophisticated models.

Models of this type have limited utility for the Dumpsite Project because: (a) heavier particles comprise only 10 to 20 percent of sludge mass; (b) settling velocities of sludge in the ocean are difficult to determine; (c) vertical density gradients, which can significantly affect the settling rate, are not included; and (d) observations of horizontal currents are relatively sparse and do not cover the entire far-field domain.

B. Fixed-Layer Concentration Models

These models typically simulate concentration or dilution factors assuming release from a point source in a surface layer or other layer of uniform depth. Typically, a sludge plume of variable concentration is simulated by: (a) the frequent injection of particles that represent the center of mass of a package of sludge that is expanding at a given rate (Churchill, 1987); or (b) a continuous analytic solution for a constant source on a two-dimensional plane with a constant velocity in one direction (or possibly a slightly curved direction) and lateral spreading normal to the downstream direction determined by a representative diffusion coefficient (Walker et al., 1987).

With respect to the fate of sewage sludge from the 106-Mile Dumpsite, a fixed-layer concentration approach is a viable tool for estimates of sludge transport confined to layers. This is due to the fact that a majority (80-90%) of the sewage sludge is believed to remain in suspension for a significant length of time (weeks to months), and because of the existence of current meter data at the appropriate levels (mixed layer and thermocline). For more on this see section 3.3.1.

In general, the limits of fixed-layer concentration models are that: (a) these models are inherently two-dimensional; (b) the observations of horizontal currents that do exist are limited in both space and time; and (c) there are no good estimates of horizontal diffusion on which to base predictions. However, the lack of a horizontal diffusion coefficient can be overcome by using the "visitation frequency" approach. To some extent, spatial variability in currents can be accounted for by considering the cross-shelf location of current observations. The results of such an approach is discussed in Section 3.3.1.

C. Three-Dimensional Particle Transport Models

This approach would use either an observational data set or a model data set (Mellor and Ezer, 1990) to provide water currents as input to a three-dimensional Lagrangian particle transport model of sludge (Robertson and Spaulding, 1985). The idealization of sludge as a cloud of particles has the advantage of being able to tag individual particles and can be computationally efficient. The major problem is the simulation of diffusion.

The most suitable model found is the Geophysical Fluid Dynamics Laboratory (GFDL) eddy-resolving coastal ocean model (Mellor and Ezer, 1990a and 1990b). The model has been applied by Dynalysis of Princeton to the eastern U.S. continental margin and to the Gulf Stream. The model is three-dimensional and time-dependent with a free surface, contains salinity and temperature (and thus water density) and operates on a orthogonal curvilinear grid in the horizontal and a sigma coordinate system in the vertical. Model forcing includes winds and heat fluxes at the free surface, a climatological Gulf Stream transport at the southern boundary, a climatological Labrador Current transport at the northern boundary, a mean flux from the Sargasso Sea, and a water level at the remaining boundary. Using this model, the currents have been computed for the northwestern Atlantic continental margin over a 5-year period (G. Mellor, personal communication), based on climatological forcing without wind stress.

The GFDL model predicts currents, water levels, and water density, but does not contain a sludge component. A Lagrangian drifter simulation, such as discussed above, is required. The model is also computer-intensive and so requires extensive computational resources.

Another coastal ocean model is the Harvard model (Robinson and Walstad, 1987). This model is three-dimensional and time-dependent, but it is primarily a deep water ocean model; it has not been applied to the Middle Atlantic Bight. It also predicts ocean currents but does not contain a sludge component.

A third model is the Applied Science Associates (ASA) acid waste dispersion model (Robertson and Spaulding, 1985). This model uses particle transport to simulate concentration changes due to advection and diffusion. It has limited applicability because currents and diffusion coefficients are required for input.

D. Three-Dimensional Advection-Diffusion Models

This approach would use either an observational data set or a model data set for water currents to provide an input to a three-dimensional concentration model of sludge. The use of a continuous concentration to idealize the sludge works best for small particles, and the method can accommodate settling.

The major drawbacks are that the method requires diffusion coefficients and that the simplest 3-point finite-difference solutions have difficulty handling large concentration gradients.There is a wide variety of numerical techniques (including upstream differencing, flux-corrected transport, 5-point schemes, Eulerian-Lagrangian methods) devised to alleviate the large gradient problem. More research is required to select a method that could be used for the Dumpsite.

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In summary, and based on this model evaluation, we have concluded that the best approach is a strategy of integrating the best available circulation model data to represent the circulation, followed by the application of either a 3-D time-dependent concentration model or a 3-D Lagrangian particle trajectory model. This approach has the highest probability of yielding useful results. Model water currents could be obtained for the period of the drifter study (1990 through 1991). These could then be used to drive a particle transport or concentration model with simple advection based on the water velocity, diffusion included by random walk or other method, and possibly settling. A distribution of particle settling velocities could be employed, and spatial patterns of long-term concentration and areas of impact could be delineated by simulation of the fate of thousands of particles.

3.2.2 The Data Evaluation Task

Under this task is the evaluation of existing historic data and data that is currently being collected for its value and applicability in modeling studies. Available data includes:

— Historic hydrographic (CTD/XBT) data

— Historic current meter data (i.e. SEEP, MASAR, Site D)

— Drifter data (i.e. near-surface currently collected by EPA, NOAA; sub-surface RAFOS floats)

— Eulerian current meter data (i.e. currently collected by EPA)

— Wind Stress (i.e. NDBO Buoys, EPA mooring, LFM winds)

— AVHRR imagery

— Sediment trap data (SEEP; currently collected by EPA)

Most of this data is readily available. The historic Eulerian current meter data from the SEEP I and II and MASAR experiments is already being used (see Section 3.3.1). The other data sets are being considered for both validation and/or comparison to numerical models. Any numerical circulation study in the MAB would need the historic hydrographic data to provide climatic boundary conditions (e.g. Herring and Kantha, 1990), and data currently being collected as part of this project (i.e. drifter, wind stress, and sediment trap data) will be essential for comparison to numerical circulation or concentration calculations.

3.3 Conclusions

3.3.1 Data-based Probability Calculations

As mentioned above (Section 3.2), it was decided to apply the "Visitation Frequency" approach (Csanady, 1983; Churchill, 1987) to calculate the probability distribution of sludge particles originating at the Dumpsite and confined to particular laminae.

Using historic Eulerian current meter data from the SEEP I and II and MASAR experiments' moored arrays in the MAB, Dr. James Churchill of Woods Hole Oceanographic Institution is using this method to do calculations of the probability of sludge particles "visiting" a particular location. These calculations are based on observed current meter time-series at fixed depths (10 to 100 meters), and thus will result in estimates of the distribution of particles confined to the mixed layer and thermocline. In addition, he will examine moored current meter data (Acoustic Doppler Current Profiler) and moored transmissometer data from the SEEP II experiment to estimate the probability of material being transported onto the shelf.

This phase of the modeling effort (data-based probability calculations) is presently underway and will serve as a comparison to both previous concentration estimates in fixed layers, and to future numerical calculations.

3.3.2 Numerical Calculations

As mentioned in Section 3.2.1, a strategy of integrating the best available numerical model data to represent the circulation, in combination with the application of either (or both) a 3-D Lagrangian particle trajectory model or (and) a 3-D time-dependant concentration model were identified as the two approaches that had the highest probability of yielding useful results.

The first approach would be a one year numerical circulation simulation, using model currents as input to a Lagrangian trajectory submodel. A model simulation for 1990-91, while EPA and NOAA drifters are in the water would enable comparisons of ensembles of drifter tracks to ensembles of model-derived water particle trajectories (thus the real wind field is very important). The statistics derived from the suite of near-surface drifter tracks (i.e. mean trajectories and velocities, standard deviations, decorrelation time scales, etc.) can be compared to similar model-derived statistics.

The second approach would involve a similar numerical circulation simulation, but with a concentration equation for a passive tracer. This is so that calculations can be made of the dispersal patterns of passive sludge introduced as a point source at the Dumpsite. These calculations could also possibly include a depositional (non-passive) component, so that areas of potential impact by the sinking of the heaviest sludge particles could be estimated and compared to previous estimates (i.e. Fry and Butman, 1990).

In either (or both) approaches, validation of such a model would be based on the ability to:

(a) simulate the statistics of the vector current variability as measured in MAB observational arrays, such as SEEP I and II and MASAR;

(b) simulate the statistical fate of a large number of near-surface drifter tracks, as will be available from the 106-Mile Project;

(c) compare to previously-modeled estimates of particle concentrations and/or bottom depositional patterns; and to

(d) compare to the results of sediment trap and current meter arrays currently in place in the environs of the 106-Mile Site.

Although desirable, a fully prognostic 3-D hydrodynamic model that is verified by data and that accurately predicts shelf-slope exchange processes (including Gulf Stream meanders and Gulf Stream rings) does not exist and would not be realistic nor possible considering the time and budgetary constraints of the 106-Mile Dumpsite project. However, an eddy resolving coastal ocean model, extended to include the Gulf Stream (Mellor and Ezer, 1990a and 1990b), holds the prospect of doing both circulation and concentration studies and for providing a framework to integrate the variety of types of data being collected in this project.

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