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Naval Ocean Research and
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Operation Guiding Light—Scientific Program and Field Plan

The Pilot Field Experiment for NORDA Project
Chemical Dynamics in Ocean Frontal Areas



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Ocean Science Directorate
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March 1985

ABSTRACT

This document describes the scientific program and field plan for operation GUIDING LIGHT, the pilot field experiment for the NORDA project Chemical Dynamics in Ocean Frontal Areas. The study area for GUIDING LIGHT is the western North Atlantic Ocean off the eastern coast of the United States. The operation will be conducted from 18 April to 10 May 1985. The fronts to be examined during this pilot experiment are the Gulf Stream front and shelf-slope front off New England. GUIDING LIGHT will employ rapid sampling and analytical capabilities to measure chemical-biological-physical variations in surface waters at these frontal boundaries. Both shipboard and remotely sensed observations will be made. The field operation will be conducted from one ship (USNS BARTLETT), three aircraft, and the space shuttle (STS 51-B). Participants in GUIDING LIGHT include investigators from the Naval Ocean Research and Development Activity, the National Aeronautics and Space Administration, University of California, Texas A & M University, Old Dominion University, Florida State University, University of Southern Mississippi, and the University of Texas.

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The author wishes to thank all the GUIDING LIGHT investigators who contributed information for this operational plan. Special thanks are due to Robert A. Arnone who supplied the remote sensing imagery and Ms. Janet H. Watkins who drafted most of the figures and compiled the final document. This report (and GUIDING LIGHT) was supported the Naval Ocean Research and Development Activity under Program Element 61153N, Herbert C. Eppert, Jr., Program Manager.

I. INTRODUCTION

An oceanic front may be broadly defined as a region of abrupt change in the horizontal distribution in one or a set of ocean-related parameters. Frontal boundaries are ubiquitous in the surface ocean (see Figure 1). Fronts are important in ocean dynamics since they are regions where exchange between different water masses is intense. Large scale fronts traverse entire ocean basins and have important effects on weather and climate. Fronts have important implications to underwater acoustic propagation and are thus important to fleet operations. Fronts are also areas of high biological productivity for all of the food chain from phytoplankton to fish to marine mammals. From a biochemical point of view, oceanic fronts can be viewed as giant chemical reactors fueled by components supplied via water mass transport with the resultant chemical reactions biologically mediated by photosynthesis, respiration and microbial degradation. While the chemistry of the world oceans is understood on a broad scale, only recently--with the discovery of current spin-off rings and ocean thermal fronts--has a true appreciation of oceanic chemical and biological variability been realized. We no longer view the ocean surface as a homogenous mass with only vertical gradients all in steady state. Rather, more judicious chemical and biological sampling efforts and the ability to use remote sensing to view large areas has led to the realization that the surface ocean is like a mosaic picture, with ocean fronts as the boundaries of the pieces.

In spite of the recognized importance of biological and chemical processes at frontal boundaries, chemical variability in frontal areas is relatively unstudied, except in coastal upwelling areas. To bridge that gap in our knowledge, the U.S. Naval Ocean Research and Development Activity (NORDA)--in conjunction with researchers at several universities--has undertaken a project to study the important chemical processes at ocean frontal boundaries. This project is called Chemical Dynamics in Ocean Frontal Areas. It combines the efforts of chemical, biological, physical and remote sensing oceanographers to determine the horizontal and vertical distributions of hydrographic parameters, phytoplankton, micronutrients, trace gases and plant pigments in frontal regions. The plan of this project is to measure in detail the chemical, biological and physical variability across selected ocean frontal areas in an attempt to identify and understand the processes and mechanisms responsible for chemical variability in frontal boundaries.

This will not be simple. The study of dynamic processes at ocean frontal boundaries is complex. The notorious difficulty in making effective physical, chemical and biological field measurements at fronts has resulted in the avoidance of these difficulties by scientists in favor of studying more tractable problems. Yet those regions, by their dynamic nature, are critical to a complete understanding of chemical oceanographic processes. Advances in remote sensing, current measurement capabilities and automated chemical analytical systems now make it possible to study fronts effectively.

The western north Atlantic Ocean off New England meets all of these criteria and was chosen for OPERATION GUIDING LIGHT.

II. OPERATION GUIDING LIGHT

A. Operational Area

OPERATION GUIDING LIGHT is a fronts pilot field experiment which will be conducted from 18 April-10 May 1985 off the eastern coast of the United States in the shelf/slope and Gulf Stream fronts. The cruise will depart from Morehead City, North Carolina on 18 April 1985 and return to New London, Connecticut on 10 May 1985. A NOAA map of the western north Atlantic is provided for reference (Figure 2). The stippled region shows the planned operational area. The lines indicating mean position of the Gulf Stream are of the left-hand side of the flow facing downstream.

The region of the shelf-slope front is shown in Figure 3. While the frontal boundary is not marked, it's location is obvious from examining the contours of organic carbon in the surface sediments. Sediment organic carbon levels greater than one percent are found in a narrow band along the shelf-slope break due to higher primary productivity at the shelf-slope front above.

B. Evaluation of Fronts to be Studied -- Kim D. Saunders

Two entirely different major frontal areas will be studied during operation GUIDING LIGHT: the shelf-slope front and the Gulf Stream front. These fronts have different spatial and temporal scales which will have significant impacts on our ability to interpret the physical, chemical and biological data expected from this experiment.

The shelf-slope front (or shelf-break front) as its name implies, is located near the inshore edge of the continental shelf. It extends, as far as this study concerns, from Nantucket Shoals to Cape Hatteras and separates shelf water with temperatures in the range of 3-6 deg. C and salinities in the range of 30-33.5 o/oo from the slope water with temperatures in the 12-14 deg. C range and salinity near 35 o/oo. The shelf water has a mean drift toward the southwest of 3-6 cm/s, but is subject to wind forcing with periods of 2-4 days and very strong forcing from the semi-diurnal tide (12.4 hr period). At the shelf break, most of the kinetic energy appears to be concentrated in the frequency band between the diurnal and semi-diurnal tidal peaks, with a very strong inertial signal (Beardsley, et al., 1976). Remotely sensed infrared observations and CZCS data indicate a highly complex, convoluted frontal structure (see Figures 4 and 5). In fact, it is difficult to attribute the term "front" to this region as it appears to consist of numerous very sharp fronts which separate the inshore water from the slope water. At the time of the projected cruise, the thermocline will have begun to develop, and there may be expected "sporadic intrusions of colder surface water into the shelf region south of New England" (Beardsley and Flagg, 1976).

FY85 CRUISE OP AREA

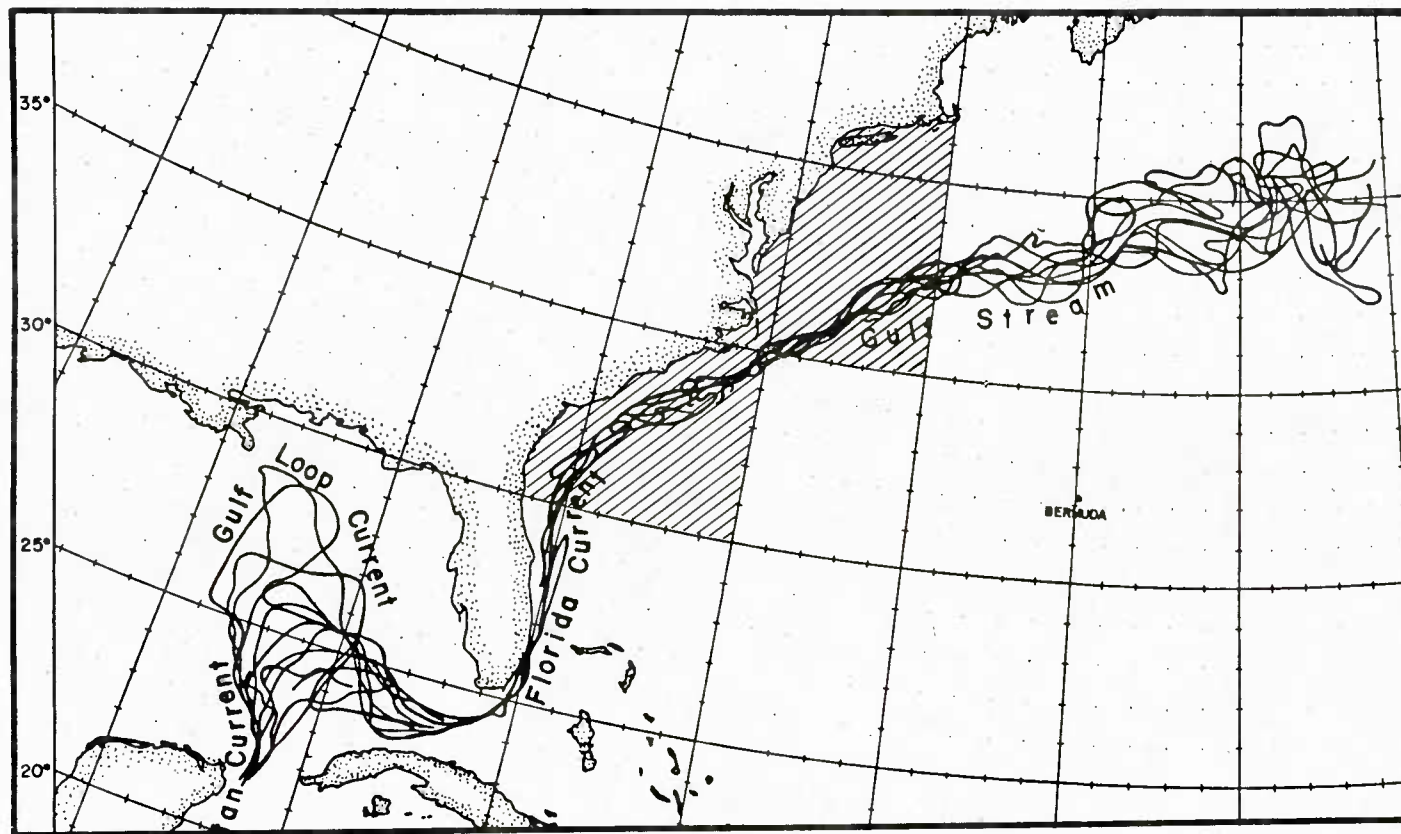


Figure 2. NOAA map of the western North Atlantic Ocean showing the mean position of the Gulf Stream. Stippled region is the planned operational area for 18 April-10 May 1985.

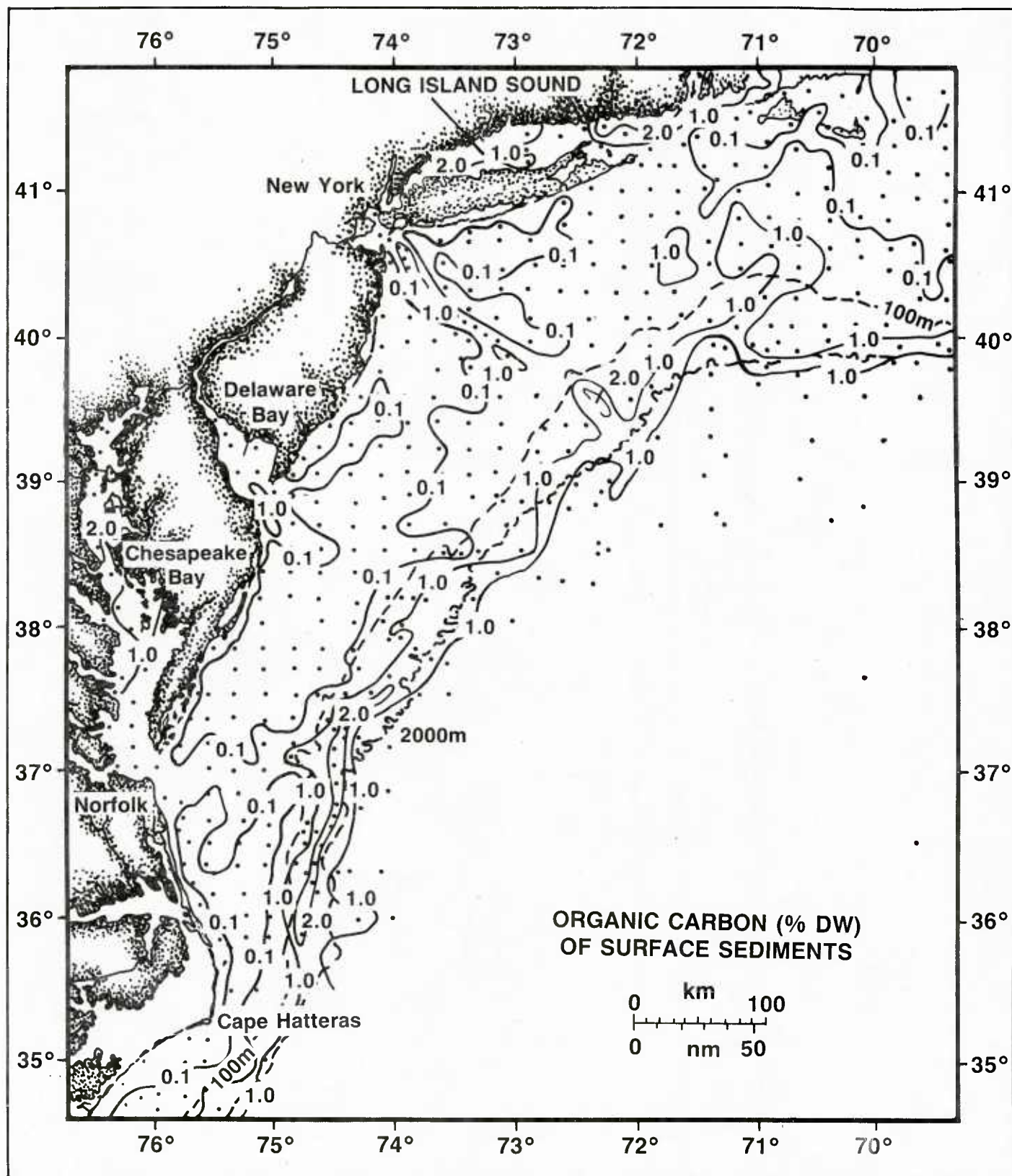


Figure 3. Map of organic carbon in surface sediments in the GUIDING LIGHT operational area. Higher organic carbon content at the shelf-slope break results from enhanced biological activity at the shelf-slope front.

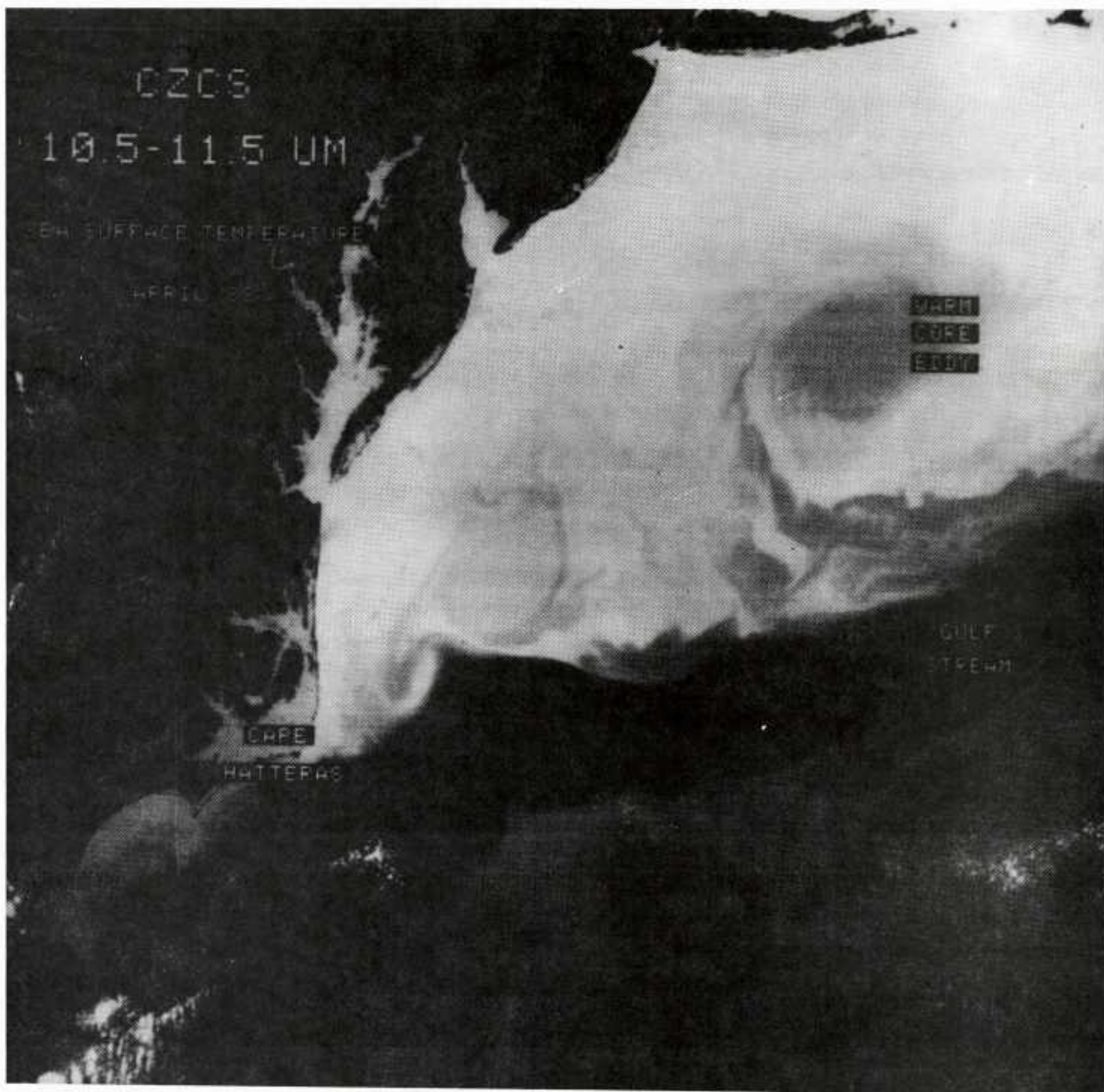


Figure 4. Coastal Zone Color Scanner sea surface temperature map for the GUIDING LIGHT operational area for April 1982. Produced by R. Arnone, NORDA Remote Sensing Branch.

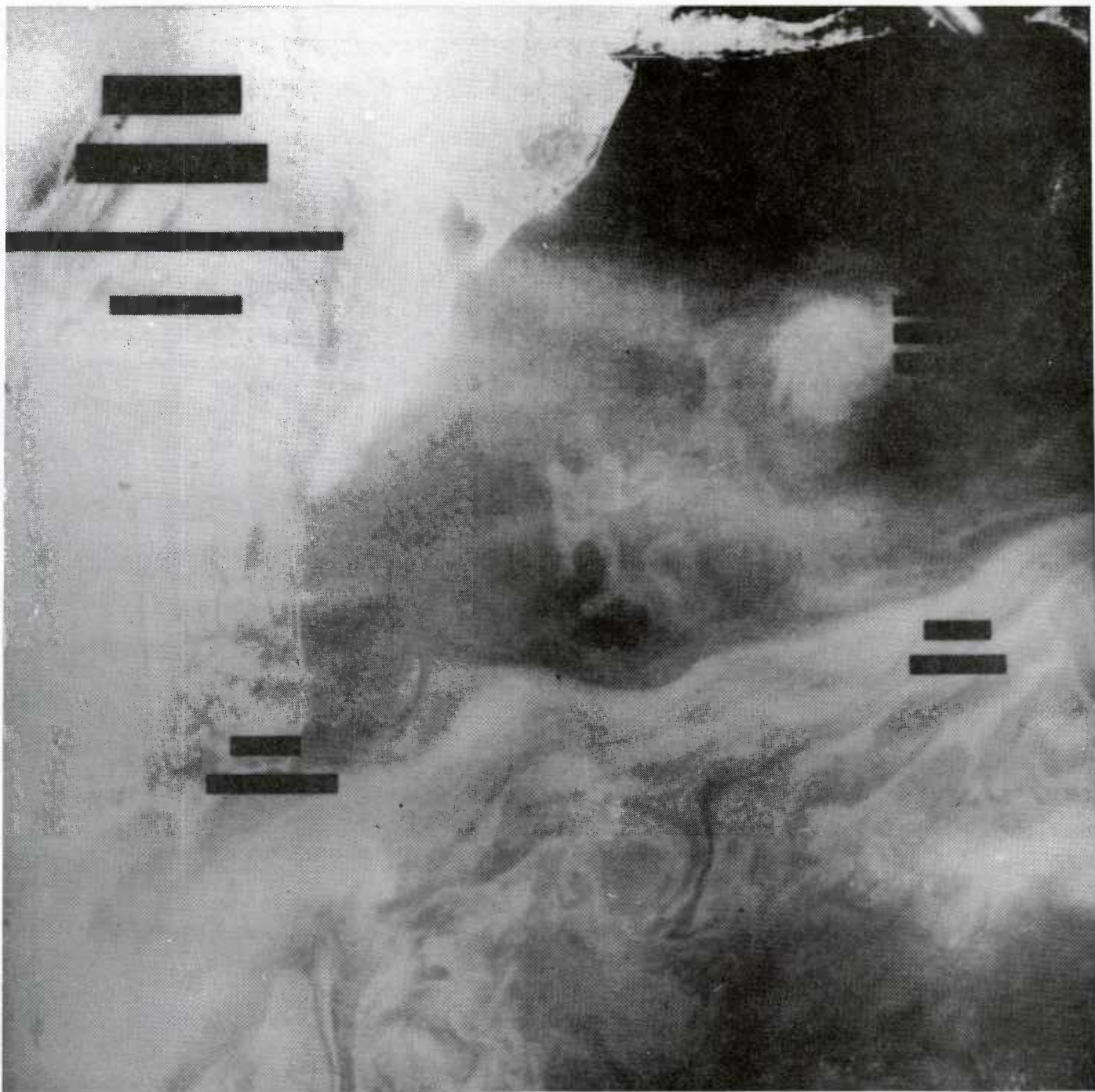


Figure 5. Coastal Zone Color Scanner chlorophyll absorption map for the GUIDING LIGHT operational area for April 1982. Produced by R. Arnone, NORDA Remote Sensing Branch.

The region is undoubtedly very interesting, but the interpretation of data from this area may be extremely difficult unless a particularly small frontal area is carefully chosen from satellite photographs and tracked during the experiment. The advection expected from the tidal forcing is typically much larger than either the wind or baroclinic forcing. If the tidal forcing is primarily barotropic, the front will be advected as a whole and may still be studied by referencing the measurements to one or more drogues near the study area. There is some doubt whether this is a good assumption. Beardsley, et al. (1976) "...expect baroclinic (tidal) effects to be important perhaps all the time in the deeper water near the shelf break and over most of the shelf during the warmer months when a strong seasonal thermocline has formed."

The northern wall of the Gulf Stream is the other front that will be studied during this operation. This front forms the boundary between the Sargasso Sea water (upper North Atlantic Central Water) and the slope water. In the upper layers, the slope water is typically 12-14 deg. C with salinity near 35 o/oo, while the central Atlantic water has temperatures near 20 deg. C and a salinity near 36.5 o/oo. This front is not as complicated as the shelf-slope front: typical length scales of the frontal wave are in the range of 140-365 km with periods ranging from about 10 to 37 days (Fofonoff, 1981).

From the infrared satellite imagery, it appears that the Gulf Stream front is sufficiently stable over a proposed 2-4 day observation period to allow reasonable interpretation of VCTD observations (see Figures 6 and 7). On the other hand, the strong shears will advect the chemical and biological constituents rapidly and differentially with depth. Without good up- and down-stream observations, certain assumptions must be made regarding either spatial or temporal variability, some of which may be verified by appropriate sampling strategies, and inclusion of the AXBT survey.

C. Resources to be Applied

The cruise will be conducted aboard the USNS BARTLETT (T-AGOR-13), a 208.8 foot (63.6 m) Navy oceanographic research vessel with a beam of 39.5 feet (12.1 m) and a draft of 18 feet (5.5 m). The BARTLETT has a cruising speed of nine (9) knots, a range of 12,000 nautical miles, an endurance of 25 days at sea, and the capability to accommodate up to 14 scientist. BARTLETT has four winches: one equipped with standard 3/16-inch hydrographic wire, one containing 1/4-inch conducting cable (1H0250), an intermediate winch which has slip ring capability and can be spooled with cable up to 0.50 inches in diameter, and the deep sea winch which can be spooled with any cable up to 0.70 inches in diameter. Power available for scientific use includes 115 VAC (regulated and unregulated), 220 VAC (60 amp, 60 Hz) and 440 VAC (30 amp, 60 Hz). Figure 8 shows the fantail arrangement of BARTLETT and Figure 9 shows the scientific laboratory layout on the main deck.

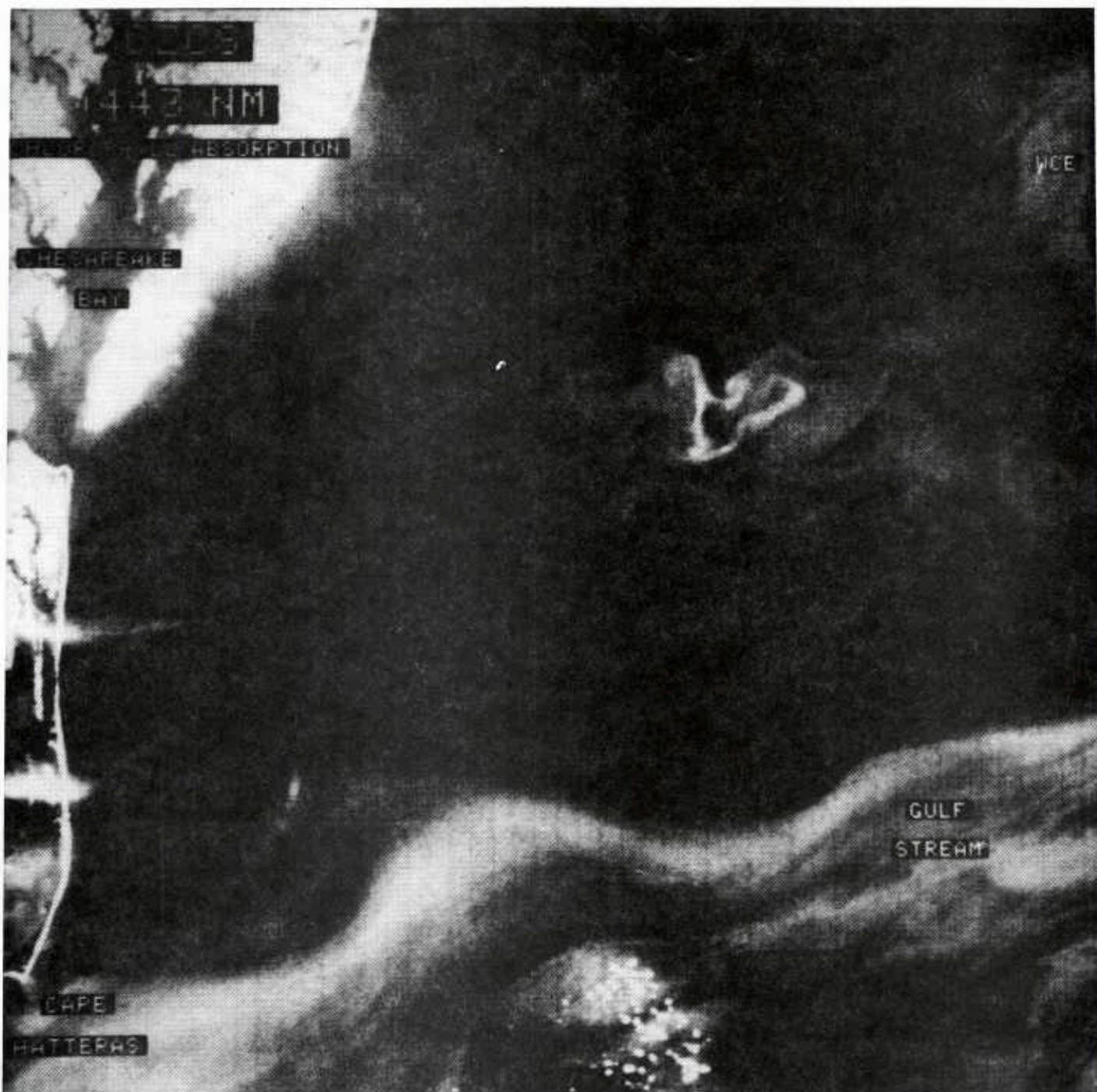


Figure 6. Coastal Zone Color Scanner sea surface temperature map of the Gulf Stream front in April 1982. Produced by R. Arnone, NORDA Remote Sensing Branch.

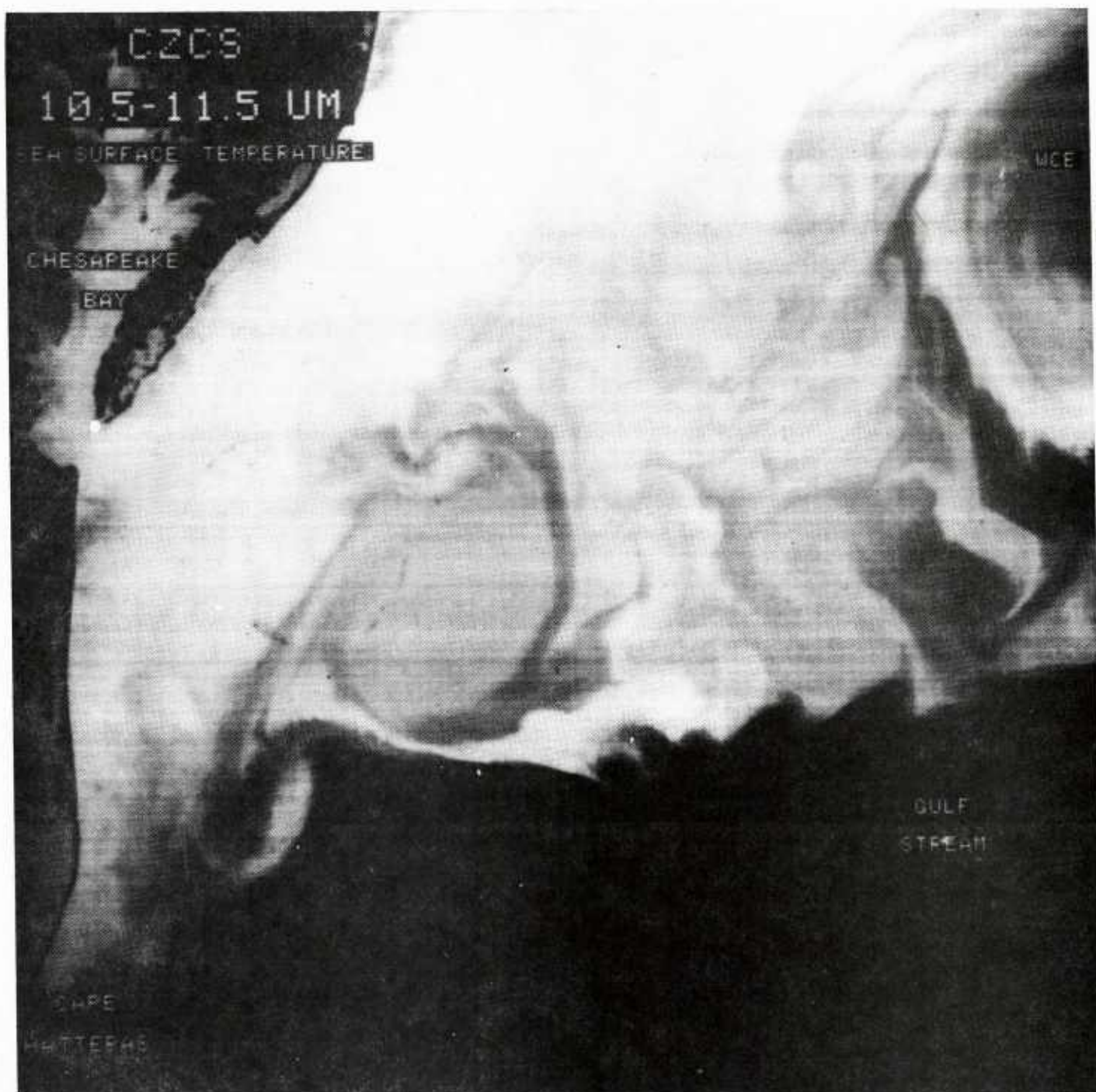


Figure 7. Coastal Zone Color Scanner chlorophyll absorption map of the Gulf Stream front in April 1982. Produced by R. Arnone, NORDA Remote Sensing Branch.

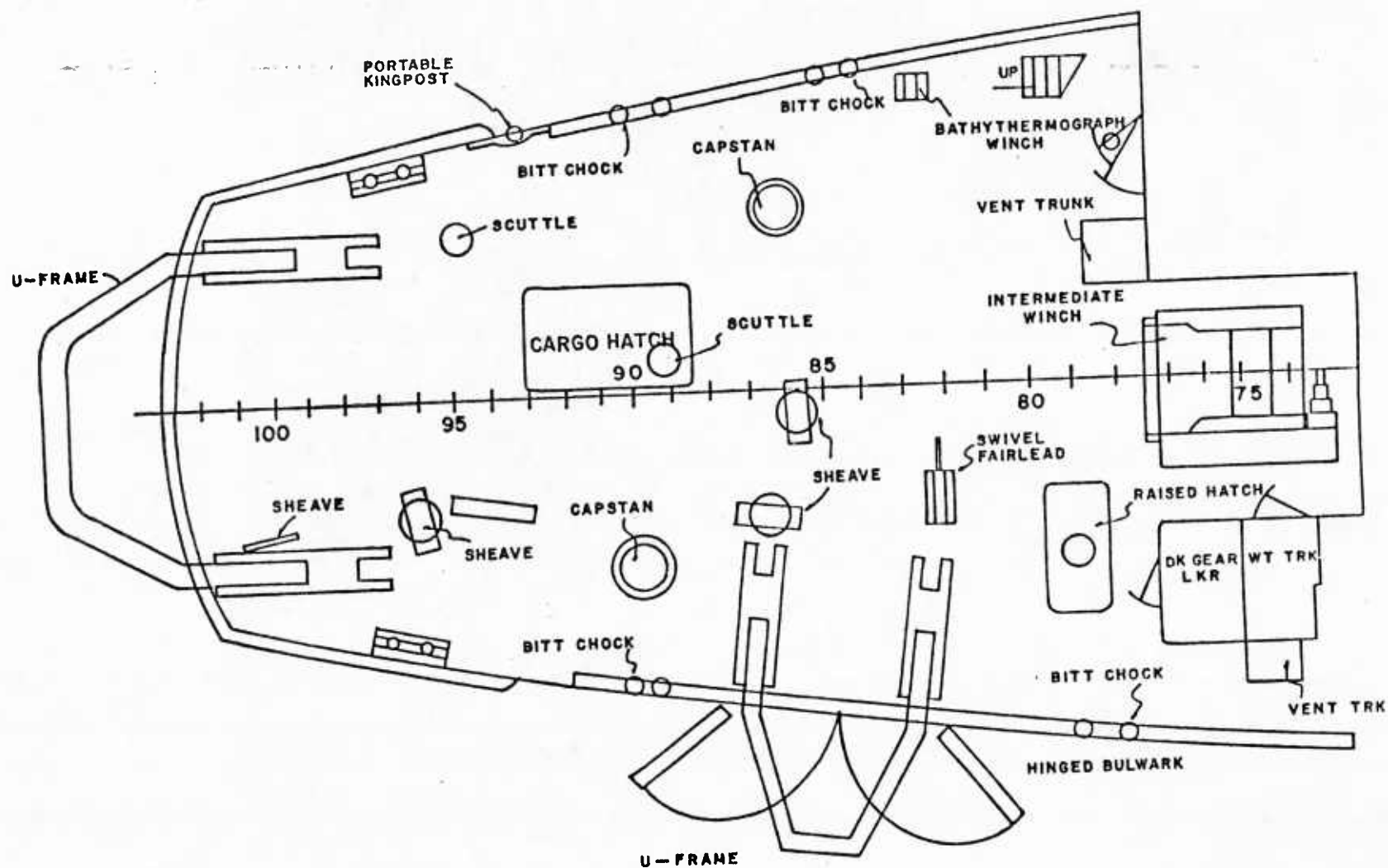


Figure 8. Fantail arrangement, USNS BARTLETT.

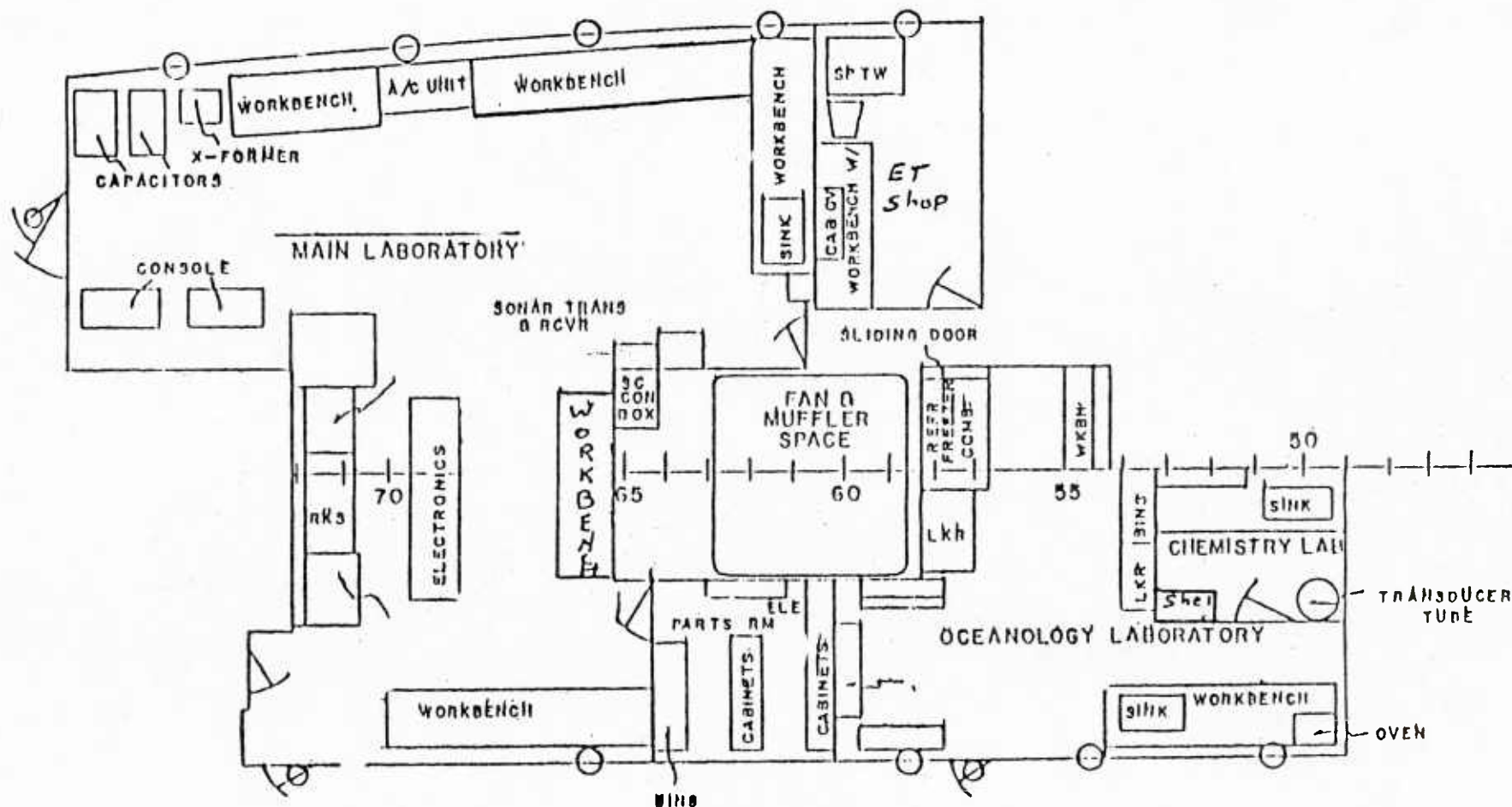
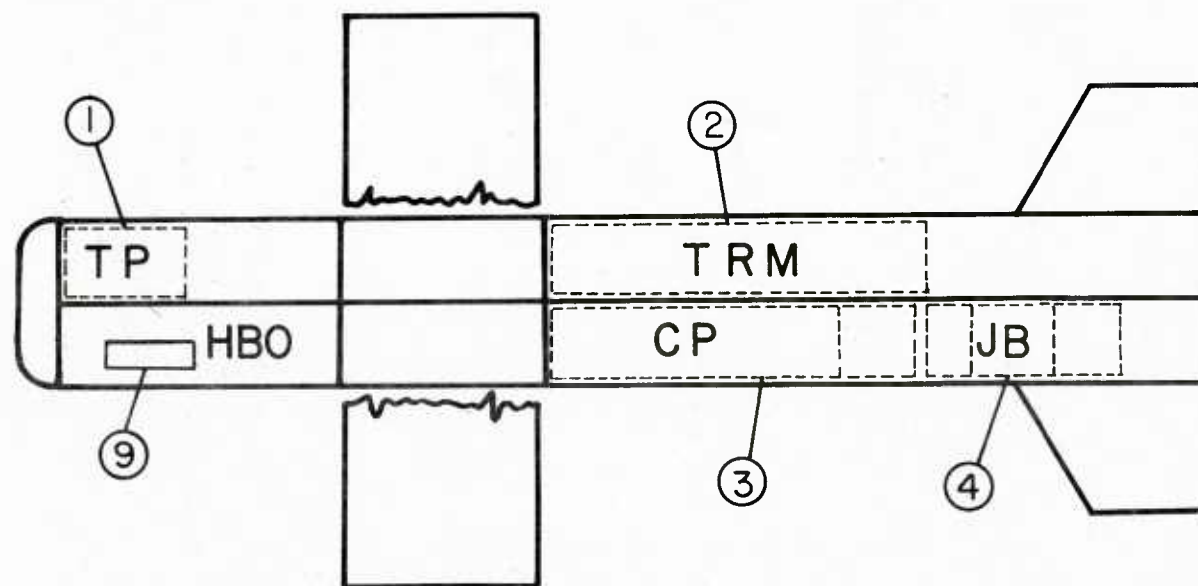


Figure 9. Scientific laboratory layout, main deck, USNS BARTLETT.

Shipboard sampling gear to be used will include (1) a vertical profiling CTD system with a Rosette sampler capable of holding up to 12 30-liter bottles (NORDA Code 333)--this CTD system is also equipped with an in situ transmissometer and fluorometer; (2) a vertical velocimeter/CTD system for measuring three-axis current velocities using an independent winch (NORDA Code 331); (3) an optical profiling system including a transmissometer and spectral irradiance sensors (NORDA Code 321); and (4) a towed underwater pumping system (TUPS) designed to provide water to the deck of the ship while being towed at speeds of up to ten knots (NORDA Code 333). The tow fish is complete and capable of being towed at the surface continuously. The fish contains a CTD and in situ sensors capable of measuring fluorescence, beam transmission, and upwelled and downwelled irradiance, along with the submersible pump for pumping water to analytical instruments in the deck laboratory. The instrumentation layout for the completed TUPS fish is shown in Figure 10. The winch and cable system for towing the fish at depth are on order, but will not be delivered in time to be used in April 1985. Since this system is not complete, only surface pumping will be available during this pilot field experiment. A vertical pumping system which will attach to the CTD-rosette system is being readied to pump water from depths down to 100 m while on station. This pump will be used for the yo-yo stations to be described later.

Remote sensing research will be accomplished from satellite, aircraft and space shuttle. Thermal data from the advanced very high resolution radiometer (AVHRR) on the NOAA-7 or NOAA-9 satellites will be collected at the NORDA Remote Sensing facility, enhanced and relayed to the BARTLETT on about a six hour delay using the MARISAT satellite. This data will be used to determine sampling strategies and to define specific sites for survey. Data will also be collected from the coastal zone color scanner (CZCS) on the Nimbus-7 satellite. These images will be processed after the cruise to estimate regional chlorophyll distributions in the areas studied. The NAVOCEANO P-3 aircraft will be used for airborne expendable bathythermograph (AXBT) survey and will contain a PRT-5 thermal irradiance probe for sea surface temperature measurements. Aircraft measurements will also be made by NASA personnel using the Airborne Oceanographic Lidar (AOL) operated from the NASA P3-A aircraft. This device can obtain laser-induced chlorophyll a and phycoerythrin fluorescence together with water Raman backscatter for water clarity corrections. The AOL system will also collect multispectral ocean color data along nadir. Sea surface temperature is also continuously measured and AXBT drops can/will be dropped at selected points. Efforts will be made to coordinate the two aircraft to maximize coverage during the field experiment.

Astronauts on the Space Shuttle (Mission STS 51-B) will be using a special camera to measure bioluminescence in the ocean and also take color photography of ocean color and sunglint. The Naval Research Laboratory (NRL) P-3 aircraft with NORDA personnel aboard will also be flying over our survey area on 20 April 1985 with the NORDA low light



1 - Trim Pots

2 - Transmissometer

3 - Computer

4 - Junction Box

5 - CTD Sensors

6 - Fluorometer

7 - Light Sensor

8 - Submersible Pump

9 - Hose Break Out

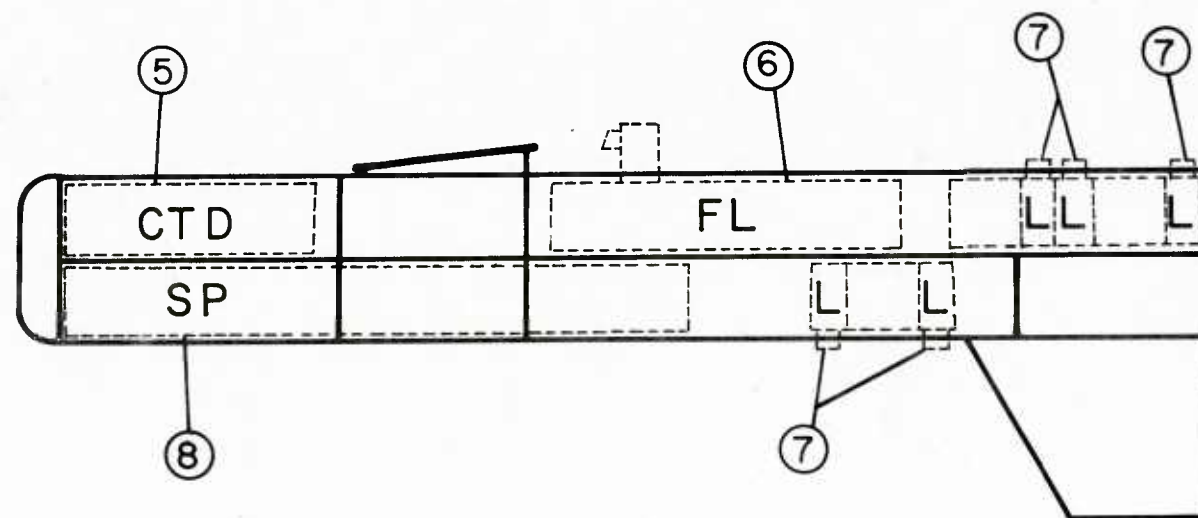


Figure 10. Instrumentation layout for the Towed Underwater Pumping System (TUPS) towed fish.

level television camera to measure bioluminescence. It is hoped that the data we take aboard the ship can be correlated with the measurements from both the Space Shuttle and the NRL P-3 aircraft.

D. Sampling Strategy

Various sampling strategies were considered at the planning meeting. The primary shipboard sampling method to be employed during this field experiment will be continuous underway surface sampling using the NORDA towed underwater pumping system (TUPS). When completed, this system will be able to pump water samples from depths down to 200 m while the towing vessel is underway at speeds up to 10 knots. For this pilot experiment, TUPS will only be able to pump from the near surface (5 m). For a complete study, however, station sampling will be required to complement the underway data. Vertical stations must be occupied to provide subsurface data on this cruise and on all Chemical Fronts cruises to allow the physical oceanographers an opportunity to measure mass transport with their VCTD. The best balance between transect time with TUPS station time for the VCTD and other measurements was a major topic of discussion at the planning meeting.

At the planning meeting four sampling strategies were discussed for studying frontal boundaries by combining transects with stations. These four ideas are shown schematically in Figure 11. In this figure, the dashed lines are the transects of the ship and the open circles are vertical stations. The number of crossings of the front is not significant in the schematic and will be decided later based on the length scales and time scales to be examined. The four strategies considered were (refer to Figure 11):

A. Sawtooth Box: The frontal area is divided into boxes of appropriate size and transects are done with VCTD stations being taken at the vertical edges and where the transect turns.

B. Center Station Box: Same as A, but with a line of stations across the front at the center of the box, and few or no stations where the transect turns.

C. Expanding Square: A central station is taken at the front and then transects are run in an expanding square pattern until far from the front, where a final station is done.

D. Follow the Water: A transect is run back and forth across the front, perhaps using a tracking buoy to make sure the same water mass is sampled on each pass.

The consensus of the planning meeting was that a modification of the Sawtooth Box (Figure 11, A) would be the best plan for the work we will undertake during GUIDING LIGHT. The modified sampling scheme is shown in Figure 12. In this scheme, a line of four or five stations will be taken across and perpendicular to the front. When this line is complete, a 24 to 48 hr transect will be run back and forth across the front using TUPS. Upon completion of the transect, four or five

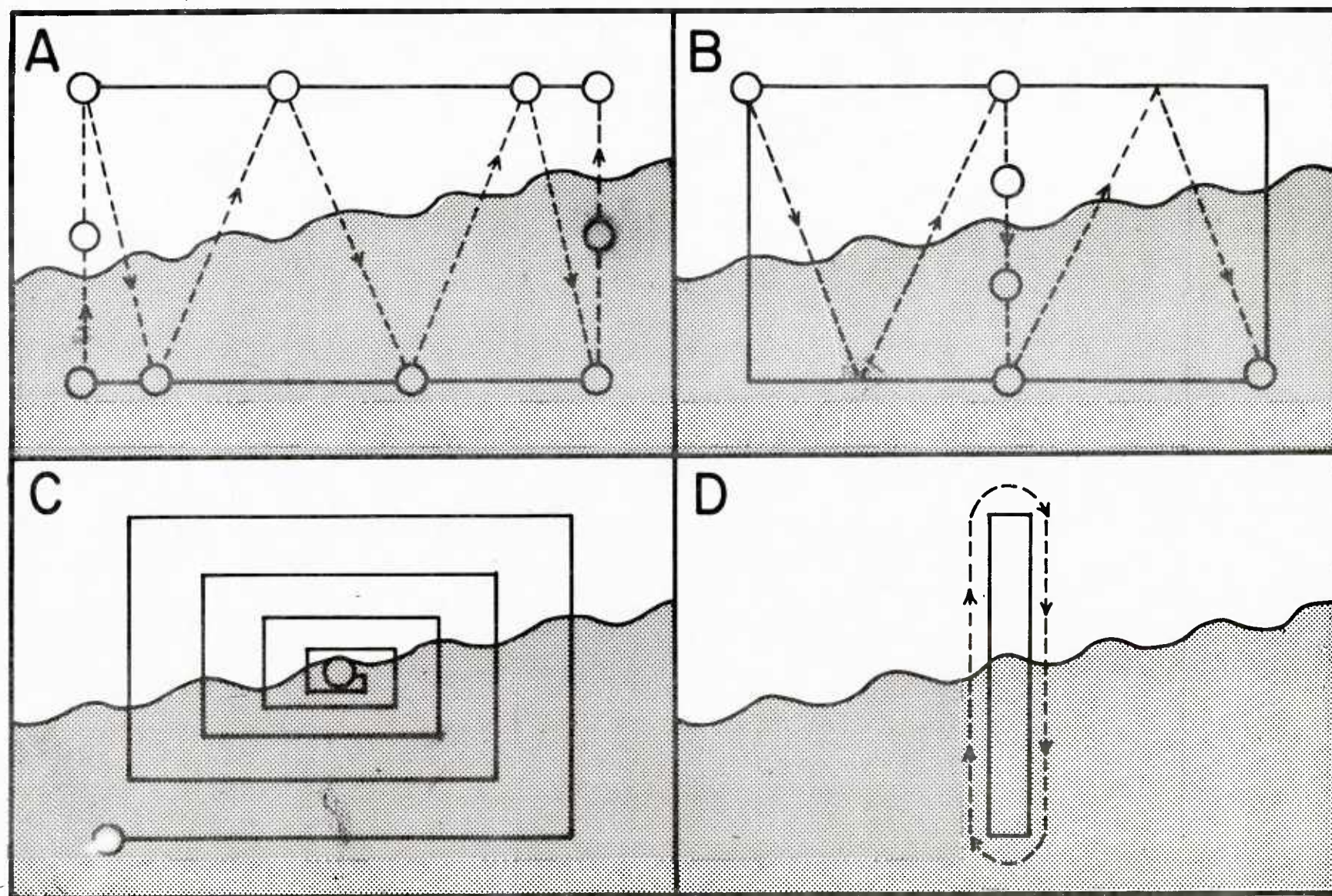


Figure 11. Proposed sampling/transect strategies for GUIDING LIGHT.
 A) sawtooth box, B) center station box, C) expanding square, D) follow the water.

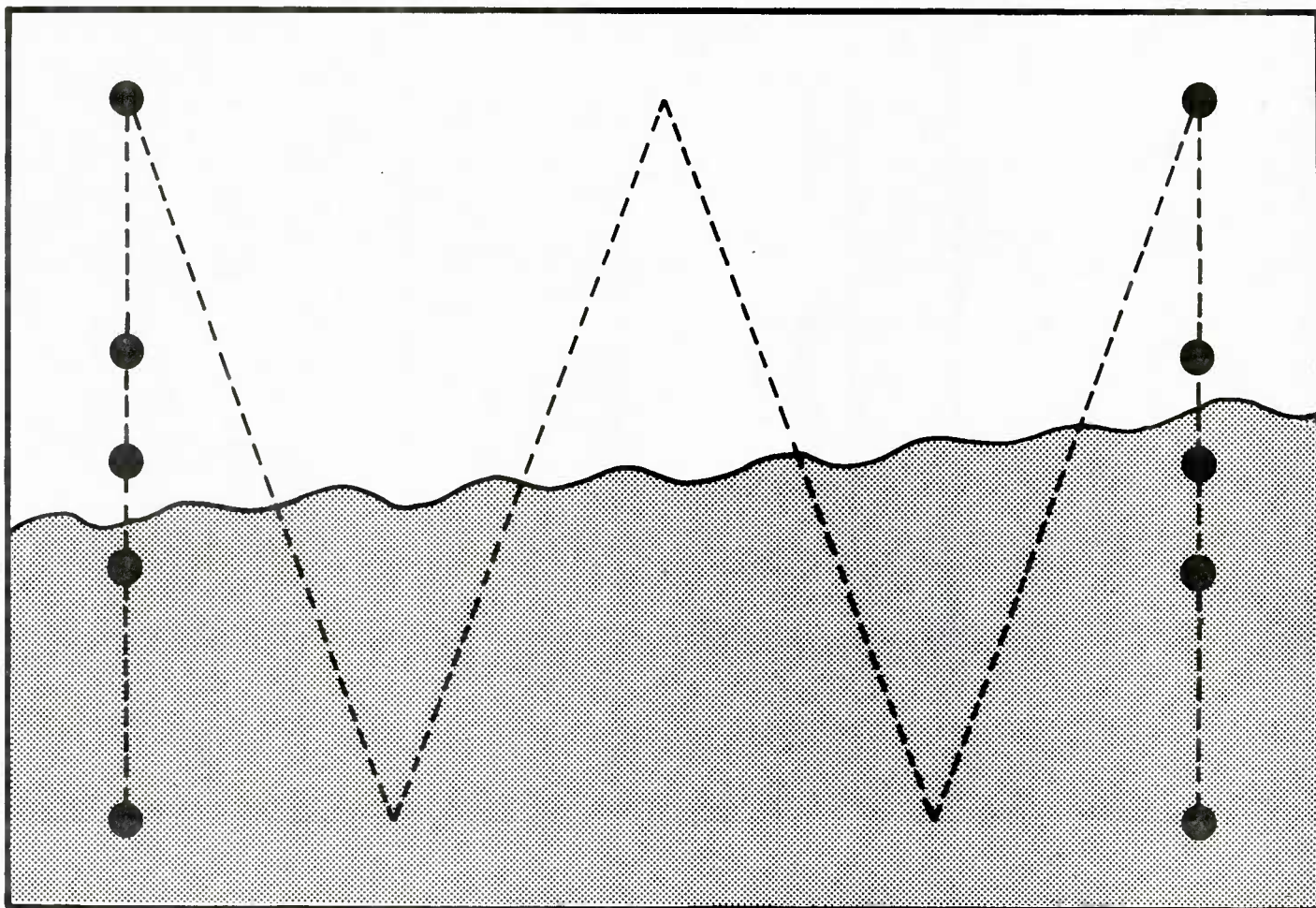


Figure 12. Modified sawtooth box sampling scheme to be employed during GUIDING LIGHT frontal surveys. Solid circles are stations and the dashed lines are the planned cruise track.

more stations will be taken, again across and perpendicular to the front, at the opposite end of the sampling pattern. After the completion of the sampling transect and station line, a 24 hr CTD, vertical pumping station will be made as close to the frontal boundary as possible. Then the sampling scheme will be repeated, either in the same area or at another frontal location.

III. CALENDAR OF EVENTS

September 1984:	Prepare draft operational plan using information provided by participants
November 2, 1984:	One-day cruise planning meeting at the National Space Technology Laboratories (NSTL)
December 1984:	Final decision on personnel who will participate aboard the BARTLETT
January 1985:	Final cruise plan details completed
February 1985:	Cruise card delivered to NAVOCEANO
March 4, 1985:	Mail final operational plan to all participants
March 1985:	All BARTLETT participants complete physicals and paperwork necessary to work on Navy research ships
March 1985:	Prepare equipment for shipment to Morehead City, NC via NAVOCEANO or GBL
April 1984:	Apply for submarine op area clearances
April 1, 1985:	Deliver equipment inventory to NAVOCEANO
April 15-17, 1985:	Load equipment aboard BARTLETT
April 18-May 10:	At sea -- OPERATION GUIDING LIGHT
10-13 May 1985:	Offload equipment from BARTLETT, New London, CT
13-30 May 1985:	Analysis of samples returned to labs
June 1985:	Initial data assessment and exchange
July 1985:	Cruise data base established on NORDA VAX 11/750 minicomputer
August 1985-?:	Data evaluation, interpretation and publication
December 1985:	Present papers on GUIDING LIGHT at fall AGU meeting in San Francisco

IV. FIELD PLAN FOR 18 April - 10 May 1985

A. Shipboard Survey

The shipboard operations are constructed to study three major frontal locations which will be determined from satellite observations. Each of the three survey areas will be examined with two 2-day surveys which will be separated by one day for collecting data at a single 24 hr vertical station. The two 2-day surveys will include surface surveys with TUPS and vertical stations as shown in Figure 12. The TUPS surveys will allow large areas to be covered quickly, the vertical station lines will provide detailed data with depth and the 24 hr yo-yo station will allow diurnal changes to be examined.

The planned survey areas are shown in Figure 13. Exact station locations will not be available until the remote sensing data is processed for each area -- approximately two (2) days before the surveys are to be run. A proposed chronological table of events is given in Table 1. Figure 14 provides a schematic representation of the day by day operational plan for the BARTLETT cruise.

The BARTLETT will depart Morehead City, NC and proceed directly to undertake a transect from the coast out through the Gulf Stream front towing the TUPS fish at the surface. At the end of this transect, a station will be done to provide a shakedown of vertical sampling gear and make final estimates of time required to take a station. BARTLETT will then proceed back to survey area ALPHA and implement the appropriate sampling strategy. BARTLETT will then move to the frontal boundary and occupy a 24 hr yo-yo station. After this station, survey BRAVO will be accomplished. During the 24 hr yo-yo station, the underway analysis group will process data, re-evaluate the sampling protocol and examine the newest AVHRR remote sensing images for determination of the exact location of the next survey area. After completion of the frontal study in the first area, BARTLETT will steam to survey areas CHARLIE and DELTA and perform the same studies across a wall of the Gulf Stream. After completion of the second study area, BARTLETT will proceed to survey areas ECHO and FOXTROT to complete the pilot experiment by studying the shelf-slope frontal boundary off New England (see Figure 13).

B. Remote Sensing Plan

Advanced very high resolution radiometer (AVHRR) thermal infrared (IR) data will be collected and processed at NORDA using the downlink located in the NORDA remote sensing branch. Geometrically registered images of the sea surface temperature will be collected twice a day for the period two weeks prior to, during, and two weeks after the GUIDING LIGHT experiment. The data will be processed within several hours of receipt. The registered images with longitude and latitude markings noted will be sent to the ship by way of a slow scan television system via the MARISAT communication satellite. The ship will receive full resolution (1 km) images of the operating area and a subsample of the entire coastal and Gulf Stream waters. Images will be stored on a video recorder aboard the ship such that follow on data

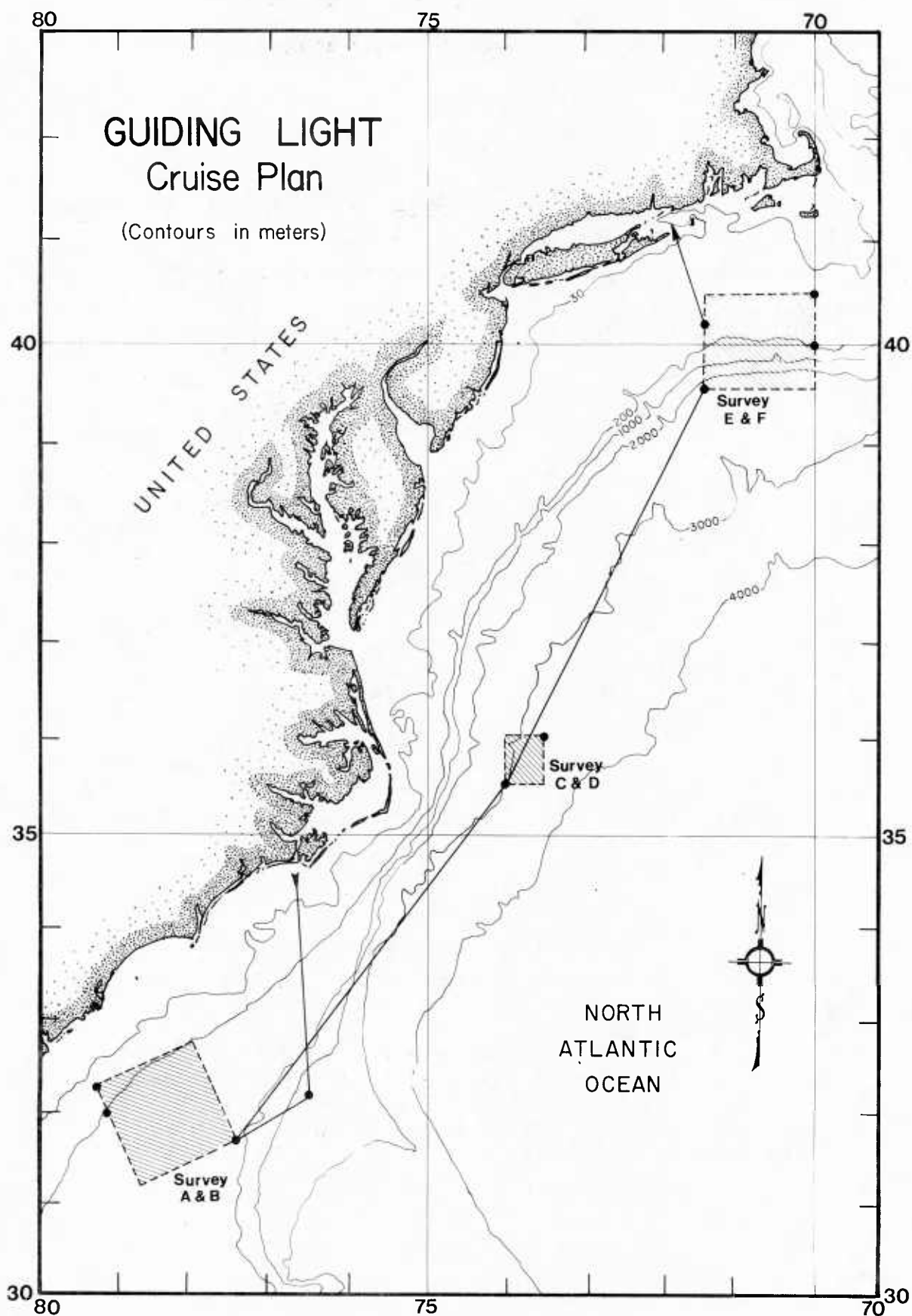


Figure 13. Frontal survey areas planned for operation GUIDING LIGHT.

Table 1. Chronological Table of Events, USNS BARTLETT Cruise 1305-85

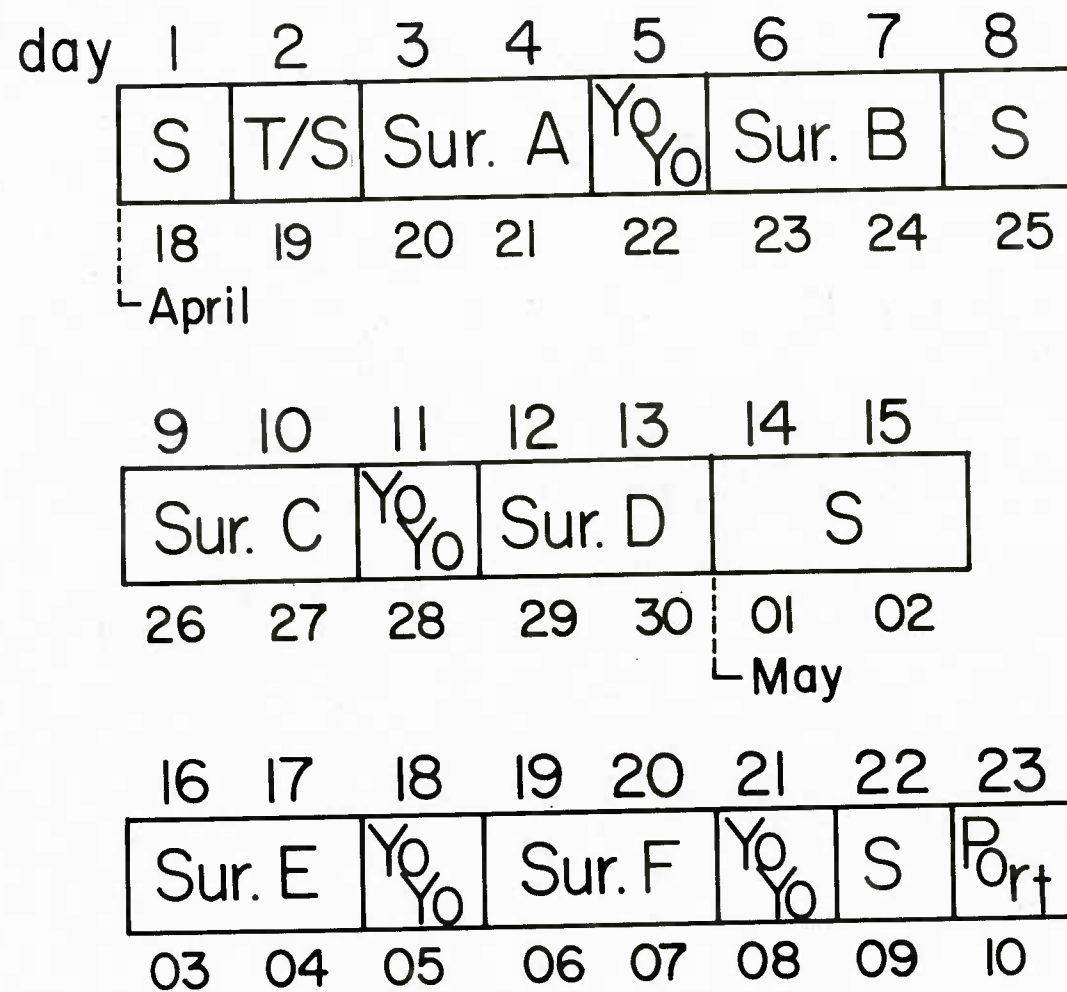
USER: NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY

OPERATION TITLE: GUIDING LIGHT

DATES: 18 APRIL - 10 MAY 1985 (at sea)

EVENT NO.	DAY NO.	POSITION (LAT/N, LONG/W)	DEPTH (m)	EVENT DESCRIPTION
1	1	34 40, 76 45	10	Depart Morehead City
2	2	32 10, 76 30	2184	CTD Station, 6 casts
3	2	32 10, 76 30	2184	Depart station
4	3	31 40, 77 30	764	Begin survey ALPHA *
5	4	32 15, 79 15	42	End survey ALPHA
6	5	32 00, 79 10	146	24 hr CTD station
7	6	32 00, 79 10	146	Depart station
8	6	32 15, 79 15	42	Begin survey BRAVO
9	8	31 40, 77 30	764	End survey BRAVO
10	8	31 40, 77 30	764	Depart survey area B
11	9	35 30, 74 00	2866	Begin survey CHARLIE
12	11	36 00, 73 30	3294	End survey CHARLIE
13	11	36 00, 73 30	3294	24 hr CTD station
14	12	36 00, 73 30	3294	Depart station
15	12	36 00, 73 30	3294	Begin survey DELTA
16	14	35 30, 74 00	2866	End survey DELTA
17	14	35 30, 74 00	2866	Depart survey area D
18	16	39 30, 71 25	2184	Begin survey ECHO
19	18	40 30, 70 00	66	End survey ECHO
20	18	40 00, 70 30	153	24 hr CTD station
21	19	40 00, 70 30	153	Depart station
22	19	40 30, 70 00	66	Begin survey FOXTROT
23	21	39 30, 71 25	2184	End survey FOXTROT
24	21	39 30, 71 25	2184	Depart survey area F
25	21	40 10, 71 25	89	24 hr CTD station
26	22	40 10, 71 25	89	Depart station
27	23	41 20, 72 07	10	Arrive New London, CT

* Note: Each survey will consist of 8 to 10 CTD stations and a set of transect lines back and forth across the front. Exact station locations will not be available until the remote sensing data is processed for each area -- approximately two (2) days before the surveys are to be run. Positions given are approximate. The transect lines will involve towing a submerged tow vehicle at a depth less than 10 meters.



S- Steaming
T/S-Test Station
Sur.- Fronts Survey
YoYo-24hr. Station

Figure 14. Schematic diagram of the GUIDING LIGHT operational plan.

analysis and ship movements can be coordinated with the satellite frontal analysis. It is anticipated that an imagery update will be available about every other day, provided cloud-free conditions exist.

In each of the three survey areas (see Figure 13), an airborne expendable bathythermograph (AXBT) survey will be made (by Paul A. LaViolette) using the NAVOCEANO P-3 aircraft. Each highly-detailed AXBT survey (70 launches) should determine the thermal structure within a short period of time (4 hr) and within a small area (20 x 20 nautical miles) being surveyed by the surface ship. The AXBT survey will be done on the first day of the ship survey and the results forwarded to the ship during the second day by WEFAX in the form of contour plots. This subsurface analysis will provide detailed information to be used in determining vertical station positions.

The NASA Wallops P-3A aircraft will only collect detailed data in the southern survey areas (A & B). These AOL overflights should be survey (map) flights of a prescribed ocean frontal area (20 x 20 nautical miles) based on the AVHRR satellite data and ship analysis. The flight pattern of this aircraft with the NASA AOL will be coincident with the NAVOCEANO P-3 and a detailed analysis of fluorescence within the frontal area should be available the next day. This data analysis should be sent by WEFAX along with the AXBT data.

V. SCIENTIFIC GROUPS AND MEASUREMENTS

The study of complex interactions of physical, biological and chemical processes at ocean fronts requires a multi-disciplinary group of scientists working together in an interdisciplinary effort. The following groups will participate in OPERATION GUIDING LIGHT, either on the BARTLETT or as part of the remote sensing effort. This section lists the groups involved, the group leader, and measurements to be undertaken. Names, addresses and phone numbers of all participants are given in a later section.

A. Groups Aboard BARTLETT

1. NORDA Biology and Chemistry -- Denis A. Wiesenburg

Measurements will be made of chlorophyll fluorescence, in-situ transmissometry, dissolved oxygen, light levels (total broadband and 441 and 488 nm wavelengths), temperature, salinity and pressure using electronic sensors in the tow fish of the pumping system towed from the starboard U-frame. Shipboard measurements will include chlorophyll by continuous fluorescence measurement on pumped water and chlorophyll a measurements on filtered water samples. Dissolved trace gas analysis measurements will not be made since the gas analysis system has not been completed in time for this pilot experiment. Continuous measurement of pH will be recorded from sensors in the flow stream from the pumping system. NORDA biology/chemistry will also provide salinity measurements by AutoSal on the vertical station samples and periodically on the pumped water. Navigation data

(Loran-C) will also be recorded every minute along with measurements of sea surface and air temperature, barometric pressure, light levels and relative humidity. This data will all be recorded automatically using a Zenith Data Systems Z-121 computer which is part of the TUPS Environmental Sensor System (TESS).

Methods for chlorophyll analysis are the standard techniques. Water samples (500 ml to 1000 ml, depending on levels) will be filtered through 0.2 um pore size, 47 mm diameter Nucleopore filters. The filters will be extracted immediately after sampling with 90% acetone for 24 hrs in a freezer. Analysis will be done aboard ship and available for contouring within 30 hrs after sampling. A Turner Designs Model 10 fluorometer will be used for discrete sample analysis and another identical unit will be used to continuously measure chlorophyll fluorescence in the flow stream from the pumping system. Chlorophyll measurements will also be made on the station vertical profiles. Dissolved gases will eventually (but not on this cruise) be extracted from the flowing seawater stream using a gas equilibrator and the extracted gases will be analyzed using a Perkin-Elmer Sigma 2 gas chromatograph.

2. NORDA Physical Oceanography -- Kim D. Saunders

Measurements will be made using the NORDA profiling, three-component velocimeter/CTD instrument (VCTD). Profiles of velocity relative to the ship will be taken as often as time and sampling for water chemistry permit. Conductivity and temperature will also be measured at the same time since the VCTD has a Neil Brown CTD probe incorporated within it.

Method of deployment of the VCTD will be from a motion compensation winch and control system. The VCTD will be deployed from the stern U-frame to obtain vertical profiles, when the towed pumping system is not in use. Vertical profiles will be made to a maximum depth of 300 meters. Optimally, a series of three casts should be made to ensure high quality velocity data and good navigational fixes are required to get absolute velocities. Data from the VCTD will be logged on a minicomputer system and the times synchronized with a master clock.

3. NORDA Optics Program -- Dennis M. Lavoie

Measurement of optical parameters will be made only at the vertical station using a Geochemical Optical Profiling System (GOOPS) which has an instrument suite similar to the towed underwater pumping system fish. The GOOPS has a Neil Brown CTD system, fluorometer, transmissometer, and other optical sensors, as well as a 12-bottle Rosette system for obtaining water samples. Measurements will be made on the water samples to determine total suspended matter (TSM) and particle size distribution. Samples of suspended particulates will also be collected for later image and elemental analysis.

Method of analysis for particle size distribution is by Elzone Particle Counter. For TSM determinations, large volumes of water (4-26 liters) are filtered through preweighed Nuclepore filters. Other samples will be filtered for later optical analysis by scanning electron microscopy (SEM) coupled to an image analysis system. CTD and optical sensor data will be recorded on a HP9825 microcomputer and vertical profiles of temperature, salinity, fluorescence, transmissometry and light levels will be plotted and available aboard ship for comparison with other data.

4. NORDA Remote Sensing -- Robert A. Arnone

Measurement of vertical profiles of spectral upwelling and downwelling irradiance will be made at selected stations at various frontal locations. These data will be correlated with both the multispectral data collected by the Coastal Zone Color Scanner (CZCS) and the NASA AOL data collected from the P-3A aircraft. Additionally, the spectral irradiance measurements will be correlated with the biochemical properties within the water column. Those data will include the type, size and concentration of the phytoplankton across the front.

Light measuring irradiance sensors (441 and 488 nm wavelengths) will be used to measure the upwelling irradiance from the towed fish. The vertical properties in the upper ocean are directly related to the water-leaving radiance at the sea surface (ocean color). Spectral irradiance measurements by the towed fish provide integrated optical properties from what is occurring in the vertical water column. The diffuse attenuation coefficient will be computed from the spectral water leaving radiance and contour maps of this property will be constructed. The optical properties determined from the water leaving radiance will be correlated with the vertical bio-optical properties.

5. Univ. of California, Santa Barbara -- Kenneth S. Johnson

Measurements will be made of four (4) seawater micronutrients: silica (SiO_4), nitrate (NO_3), nitrite (NO_2), and either phosphate (PO_4) or ammonia (NH_3). One of the primary interests during the cruise will be nitrogen cycling and dynamics in the frontal region. Thus, in addition to measuring nutrients during horizontal transects and vertical stations, short-term changes (e.g. day vs. night) in nutrient structure will be determined at 24 hr stations near the front. Temperature will also be measured. Nutrient measurements will be made at one minute intervals from the pumped water. Data will be stored on a HP8700 minicomputer and realtime printouts of uncorrected nutrients will be provided aboard ship. Contour plots of data from vertical sections can also be provided.

Method used will be flow injection analysis. This method will allow rapid, continuous analysis of seawater nutrients. Measurements will be made at one minute intervals from pumped water. Detection limits are approximately: 0.1 μM NO_3 , 0.05 μM NO_2 , 0.1 μM NH_3 , 0.5 μM SiO_4 , and 0.05 μM PO_4 .

6. Texas A & M University -- Robert R. Bidigare

Measurements will be made of phytoplankton pigment distributions by filtering one-liter water samples, freezing the filters in liquid nitrogen and returning them to the laboratory for pigment analysis. Pigments determined will include chlorophyllide a, chlorophyll c, peridinin, phaeophorbide a, fucoxanthin, neoxanthin, diadinoxanthin, chlorophyll b, chlorophyll a, phaeophytin b, carotene, and phaeophytin a. The biological significance of each pigment to be measured is given in Table 2. Samples will be processed from individual vertical stations (5 m intervals) as well as from the underway pumping system.

Method of pigment analysis for porphyrin and carotenoid pigments will be separation by high performance liquid chromatography (HPLC) and concurrent detection by fluorescence and absorption spectroscopy, respectively. Filters for analysis will be extracted in 90% acetone. Separations will be performed with a Spectra-Physics Model SP8100 Liquid Chromatograph equipped with a Radial-PAK C-18 column (5 u) at a flow rate of 8 ml per minute. Porphyrin pigments will be detected with a Perkin-Elmer Model 650-40 Spectrofluorometer at excitation and emission wavelengths of 434 and 670 nm respectively. Carotenoid pigments will be detected with a HP 8451A Diode Array Spectrophotometer which is capable of providing absorbance spectra during the chromatographic run.

7. Old Dominion University -- Kimberley G. Davis

Measurements of biological and optical interest will be made on individual phytoplankton cells (1-150 um) by flow cytometry using a Becton-Dickinson FACS Analyzer. By this instrumentation, a small volume of seawater is channeled into a stream flow so narrow that contained particles are lined up single file for analysis. Simultaneous assessments of chlorophyll fluorescence, phycoerythrin fluorescence, particle volume, and 90 degree light scatter (a function of refractive index and size) are then made on each cell. Data will be processed by a Hewlett-Packard Consort 30 and stored in list mode to allow later statistical treatment. Attempts will be made to have particle volume data available at sea.

Samples (approximately 3 ml each) will be collected via the towed pumping system and vertical casts. To achieve best resolution, sampling frequency will be increased as distance to the frontal boundary decreases.

8. Florida State University -- Paul A. LaRock

Measurements to be made aboard BARTLETT are bacterial and total planktonic (phyto- and bacterioplankton) growth rates. These rates should vary in response to temperature, nutrients, light levels, etc. which will be measured by other investigators. Vertical samples will be taken from the CTD casts and horizontal samples will be collected from the pumped water across the frontal boundary.

Table 2. Pigments used as biomarkers for characterizing suspended particulate matter (Jeffrey, 1974).

Pigments	Algal type or biological process indicated
Chlorophyll-a Chlorophyll-c Fucoxanthin Diadinoxanthin	Diatoms and/or chrysomonads
Chlorophyll-b Neoxanthin	Green algae
Peridinin	Dinoflagellates
Chlorophyllide-a	Senescent diatoms (due to chlorophyllase activity)
Phaeophorbide-a	Copepod fecal pellets
Phaeophytin-a	Copepod fecal pellets
Astaxanthin	Copepods present
High chlorophyll-c:a	Senescent phytoplankton or detrital material

Methods to be employed include isotopic pulse labeling, direct cell counts and turnover of isotopes (isotope dilution).

9. University of Southern Mississippi -- Gary Anderson

Measurements of phytoplankton distributions and individual species identifications will be made along with estimates of total phytoplankton biomass. Water samples will be collected from the surface pumping system. Approximately 40 liters of water will be pumped into a conical tank, the phytoplankton will be concentrated into a one-liter cod end and stored in plastic jars. The sample will be preserved and returned to the laboratory for sorting and counting.

Samples will be collected during all the horizontal transects across the frontal boundaries, with higher sampling densities closer to the front. Samples will also be collected from the vertical pumping system on some of the stations to examine the biomass and species depth distributions. Decision of which depths to sample will be based on the in situ fluorometer data available on the vertical CTD system.

10. Univ. of Texas, Marine Science Institute -- John Cullen

Measurements of photosynthetic uptake (P) as a function of light intensity (I) will be made using a photosynthetron. These measurements will be made on all the vertical stations to determine P as a function of I at each depth stratum. These determinations will allow time course changes of P vs. I to be determined as a function of natural light intensity and proximity to the front. Conventional carbon-14 bottle technique measurements for productivity will be made for comparison. Productivity will be calculated and integrated to various depths.

The method for P vs. I measurements requires placement of a series of 1 ml water samples in liquid scintillation vials with carbon-14 labeled bicarbonate. The vials are placed in a chamber and illuminated with a high intensity lamp. Samples are illuminated for 20 minutes. Neutral density filters are used to vary the amount of light reaching each of the vials so a complete P vs. I plot can be obtained on one run. The samples are then filtered and the filters fixed and returned to the laboratory for carbon-14 counting and calculation of photosynthetic uptake rates.

B. Remote Sensing Efforts

1. NORDA Remote Sensing -- Robert A. Arnone

Measurements of sea surface temperature will be collected by examining data from the AVHRR on one of the NOAA polar-orbiting satellites. The data will be collected at NORDA, reprocessed using the NORDA IDSIPS system and transmitted to the ship via a satellite link. Ocean color data from the CZCS will be requested from NASA and processed after the cruise (3-4 months) for evaluation of the regional chlorophyll and optical variations and for comparison with shipboard measurements.

Methods for processing the AVHRR imagery include registering the data to a standard Mercator projection, providing an atmospheric correction using a multichannel sea surface temperature (MCSST) algorithm (± 0.5 deg. C), overlaying the longitude and latitude lines, contouring and overlaying specific isotherms on the image, and enhancing the image before transmission to the ship. The CZCS data will be atmospherically corrected and Mercator registered. Absolute concentrations of phytoplankton pigments and the diffuse attenuation coefficient will be obtained from the imagery. It is anticipated that at least three CZCS images a week will be processed to obtain the temporal variability.

2. NASA-Wallops Island -- Frank E. Hoge

Measurements will be made of surface layer (upper 3 m) chlorophyll a, phycoerythrin, water Raman backscatter, and Gelbstoff fluorescence as well as ocean surface temperature and water column temperature profiles. Two lasers, a frequency double Nd:Yag laser (532.1 nm) and a excimer laser (308 nm), will be fired on an alternating basis. Each laser will be fired 6.25 times per second to provide a total active spectra sampling rate of 12.5 pps. Between each laser pulse, a passive ocean color spectrum will be acquired between 340 nm and 745 nm. The Nd:Yag laser excites phytoplankton chlorophyll-a and phycoerythrin photopigments as well as the water Raman backscatter line at 650 nm. The water Raman backscatter signal is used to correct the photopigment laser induced fluorescence for variations in water attenuation properties. The corrected chlorophyll-a fluorescence has been shown to have a linear relation to chlorophyll-a measurements made using standard extraction techniques. The excimer laser excites Gelbstoff ("yellow substance") fluorescence from dissolved organic matter of terrestrial origin (largely fulvic acid) and also produces a water Raman backscatter signal at 343 nm which is used to correct attenuation. The passive diffuse solar reflectance data (ocean color) are used to compute chlorophyll-a concentration. Navigation is performed using a Litton LTN-51 Inertial Navigation System and post-flight positioning of the aircraft observations is performed using recorded Loran-C data. Continuous profiles of the above parameters are recorded and simultaneously displayed onboard the aircraft in real-time. Positions of significant features can be radioed to the ship in near real-time. AXBT's can also be deployed from the aircraft at various points within the study area.

The NASA Airborne Oceanographic Lidar (AOL) is flown onboard a Lockheed P-3A aircraft at an altitude of 150 m at an approximate air speed of 100 m/sec. The AOL fluorosensor is composed of 36 separate, contiguous channels each 11.25 nm in width.

3. NORDA Biology and Chemistry -- Richard V. Lynch

Measurements of oceanic bioluminescence will be made on a single flight on the night of 20 April 1985, while BARTLETT is undertaking survey ALPHA. An RCA low light level television camera will be used

from the NRL P-3 aircraft to make the measurements of bioluminescence which will be recorded on video tape for later comparison with surface water measurements made with the TUPS fish.

4. NASA - Space Shuttle

The Space Shuttle (Mission STS 51-B) is presently planned for launch on 30 April 1985. The shuttle astronauts have been requested to take color photography detailing ocean surface color and sunglint in the Gulf Stream during the 7-day flight. Previous color photography of this area from the space shuttle has clearly depicted the position of the Gulf Stream and the strong shear zone to the west. Integrated ocean slick patterns have been observed in the sunglint photographs, though little is known of the originating processes which cause these features. Measurements made during the fronts cruise will be compared with the shuttle photography in order to improve our understanding of photographic oceanography from space and assess the spatial distribution of ocean processes.

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