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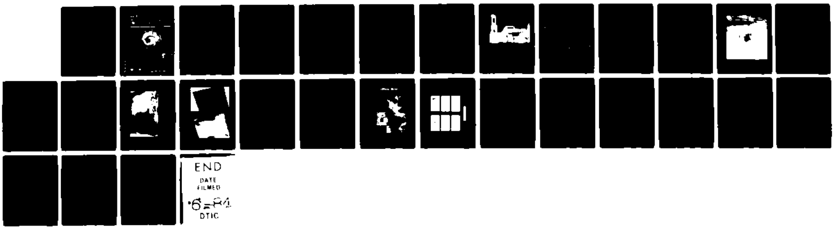

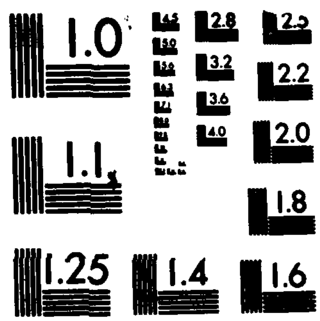

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Ocean Optical Remote Sensing Capability Statement

OCEAN RESEARCH AND DEVELOPMENT ACTIVITY

ABSTRACT

The capability of the Naval Ocean Research & Development Activity ~~(NORDA)~~ Remote Sensing Branch ~~(Code 321)~~ in ocean optics is described. A summary of the facilities, programs, scientific contributions and basic research issues is outlined. The application of remote sensing in the study of ocean optical properties is described in addition to present image processing software and satellite receiving capability. Different optical field instruments which the Remote Sensing Branch has obtained are presented. Results of optical data are illustrated in relation to other oceanographic parameters.

Navy programs which have supported the Remote Sensing Branch's developments in water optics are described. The Navy relevance of water optics to these programs is indicated.

OCEAN OPTICAL REMOTE SENSING CAPABILITY STATEMENT

NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY REMOTE SENSING BRANCH (CODE 321)

I. INTRODUCTION

The Naval Ocean Research and Development Activity (NORDA) Remote Sensing Branch (Code 321) has been conducting investigative programs in water optics since 1977. The major thrust of these investigations has been the application of visible satellite sensors toward the measurement of oceanographic bio-optical parameters and to mesoscale circulation studies. Visible satellite sensors measure the upwelling radiation from the sea surface which is influenced by the bio-optical chemical properties of the water mass. Understanding the correlation of optical properties within the water column with the spectral radiance received by the remote sensor has been a major concern of the remote sensing community. Recent satellite sensors (e.g., Coastal Zone Color Scanner) have improved spectral sensitivity and repeat times which allow for detecting the subtle horizontal and temporal variability of ocean color.

The purpose of this capability statement is to focus attention of interested Navy managers upon the potential value of this emerging capability, remote sensing of oceanic optical properties, at NORDA. This statement will summarize the Remote Sensing Branch's facilities, programs, scientific contributions, and personnel working in this area of research. The full payoff for the investment that has been made over the last several years to establish this capability will be realized when applied to Navy objectives and programs in optical remote sensing. The statement has been sectioned as follows: II Facilities, III Programs, IV Basic Research in Optics, V Naval Relevance, VI Scientific Contributions, and VII Publications.

II. FACILITIES

A. IMAGE PROCESSING

The first order of business when the Remote Sensing Branch was established was to develop an image processing capability. Such a capability was vital to nearly every remote sensing program. The Interactive Digital Satellite Image Processing System (IDSIPS) has been developed to meet that need. IDSIPS is unexceeded among general purpose image processing systems dedicated to oceanography. An upgrade of IDSIPS facilities is presently underway. New 32-bit super-mini computers are replacing the slower HP-3000, and I^2S Model 70 display hardware is being replaced with Model 75 display systems offering new advanced features. The present upgrade insures that NORDA's satellite image processing system will be at the forefront of the rapidly changing image processing field for several years to come.

In addition to general purpose image processing capabilities, several software modules have been developed that are specifically related to ocean optics. These modules are designed for the Coastal Zone Color Scanner (CZCS) launched in 1978 aboard NIMBUS-7. This experimental sensor is dedicated to studying the multispectral aspects of ocean color. The scanner has six narrow spectral channels (443, 520, 550, 670, 750 and 1150 nm) designed for detection of phytoplankton concentration, yellow substance, suspended sediment concentration, optical parameters, and sea surface temperature. CZCS has a pixel resolution of 825 m^2 and a repeat time by which three consecutive days of collection are followed by two days in which data is not available. This repeat time has significant attributes for studying the temporal variability of bio-optical properties. Results from processing of CZCS data have been extensively published and significant results in water optics have been established, some of which will be addressed in the following sections. Specific software modules which have been developed for quantitative processing of CZSC imagery have been listed below.

- Ingest CZCS tapes in NOAA or NASA formats.
- Calibrate CZCS data in units of absolute radiance.
- Extract anchor point information from CZCS tapes and perform image registration based on the latitude and longitude values of the anchor points.
- Perform image navigation by means of orbital calculations and modeling of the CZCS scanner.
- Perform Rayleigh scattering atmospheric corrections. This correction is a function of solar and satellite zenith and azimuth angles. It is therefore variable across an image and requires calculations of the sun-pixel-scanner geometry.
- Apply the single-scattering model atmospheric correction for atmospheric aerosol correction based on the 670/750 nm channel.
- Use interactive techniques to vary the Angstrom exponent of the aerosol phase function in real time permitting the analyst to observe the result of changing the atmospheric correction parameters and thereby choose optimal values.
- Produce images of quantitative values of chlorophyll-a and diffuse attenuation coefficient and absolute upwelling spectral radiance from CZCS data.

The software developed for CZCS processing is of a general nature, in that processing of other satellite visible sensors such as the Thematic Mapper on Landsat 4 can be done with a limited additional investment. Transition of this software would permit similar quantitative results for the Thematic Mapper as for CZCS. Since Landsat is presently an operational satellite, with high spatial resolution capability, this software capability is related to several areas of MC&G research.

B. SATELLITE RECEIVING STATION

NORDA satellite receiving equipment for direct readout and relayed transmission of GOES, NOAA, and DMSP satellite data is scheduled for completion in spring 1984. A CZCS receive capability is not included in the plan because the present CZCS on Nimbus-7 has already surpassed its operational life expectancy. However, when the next color scanner is placed in space (possibly aboard a NOAA satellite in 1985-1987), a small additional investment in equipment and/or software will allow the station to receive CZCS data at that time. Very limited access to CZCS data from Nimbus-7 has been a serious problem limiting scientific progress in the past. A receive capability for the next CZCS will definitely enhance research capability at NORDA.

Field operations of the Remote Sensing Branch have been aided by near real time data transmission of satellite imagery from National Space Technology Laboratories (NSTL) to ships at sea. These IDSIPS enhanced satellite thermal IR imagery depicting the position of mesoscale ocean thermal fronts have been transmitted to major experiments in the Gulf of Mexico. Their daily transmission clearly provided information on the movements of the Loop Current and acted as a guide for conducting optical measurements within various water masses while at sea. With the newly installed receiving station, worldwide coverage and transmission of processed imagery will be available for support of optical research programs.

A major NORDA program in chemical dynamics in ocean fronts will utilize this facility since the frontal movements are critical for the detailed sampling survey required for this program.

C. FIELD INSTRUMENTATION

Field optics instruments are available within the Remote Sensing Branch for use in remote sensing experiments. Their use is necessary for several basic reasons. Field measurements which provide the vertical structure of the optical properties can be correlated with the upwelling water color sensed by the remote sensor. The measurements also indicate the horizontal variability of the optical parameters both within a sensor pixel and across ocean features. Additionally, field optics measurements provide the direct link between the bio-chemical properties of a water mass and the spectral signals of visible remote scanners.

Optical properties of the ocean are frequently classified into two categories: inherent and apparent. An optical property is inherent if its value at a point is not dependent on the radiance distribution at that point. Apparent optical properties depend jointly on the inherent properties of the ocean water and the geometrical distribution of the radiant energy within the water. A water optics program must have the capability to measure both inherent and apparent optical properties at sea. NORDA Code 321 has acquired considerable at-sea equipment and experience in measuring several of the more widely used inherent and apparent properties of sea water.

1. Beam Transmissometer

One of the most widely measured inherent optical properties is the beam attenuation coefficient, defined as the fraction of energy in a beam removed by both scattering and absorption per unit distance traversed by the beam. This measurement which is made with a beam transmissometer has application in remote sensing studies in that it defines the vertical optical structure and enables a comprehensive understanding of how water optical properties are associated with the regional oceanography. For example, in a recent experiment in the Mediterranean, cross sections of the beam transmittance across a frontal area were associated with cross sections of temperature, chlorophyll concentrations, and suspended sediment concentrations. The Remote Sensing Branch has a beam transmissometer (MARTEK) for measuring this property at sea over a one meter folded light path. The transmitted light intensity is measured relative to another beam which does not traverse the water path. Fluctuations in intensity of the beam and other errors tend to cancel in this kind of a relative measurement. The instrument is, therefore, easy to calibrate and provides very reproducible results. A filter holder is included in the instrument design so that transmission/attenuation measurements can be performed in specific portions of the spectrum.

The instrument output is digitized and recorded by computer on floppy disk and displayed on the computer screen in real time. The digital recording format makes subsequent data display and analysis very convenient. The transmissometer, shown in Figure 1, has been deployed at sea by Code 321 personnel on several occasions. Figure 2 shows a depth profile of transmissometer, temperature and chlorophyll data from a recent cruise in the Mediterranean. Notice the high variability of the optical layers and their association with chlorophyll layers and position of the thermocline. Figure 3 shows the beam transmittance at 520 nm at several stations along a line perpendicular to the Spanish coast just inside the Strait of Gibraltar. Transmittance values from the individual casts have been contoured to give a transmittance cross-section. Note the clearer (high transmittance) water at the offshore end of the line to the right in Figure 3, and the more turbid water (lower transmittance) toward the coast of Spain. Notice an upward protrusion of clearer (95%) water occurring at depth (25 m) at approximately 22 km from the coast. This optical characteristic is directly related to the chlorophyll and coastal sediment concentration and provides a mechanism of illustrating the complex dynamics occurring along the coast.

The beam transmissometer is equipped with a conductivity cell and a temperature probe. Experimental data collected with this instrument can be used to

Figure 1. Beam transmissometer with control unit and associated HP-85 hardware.

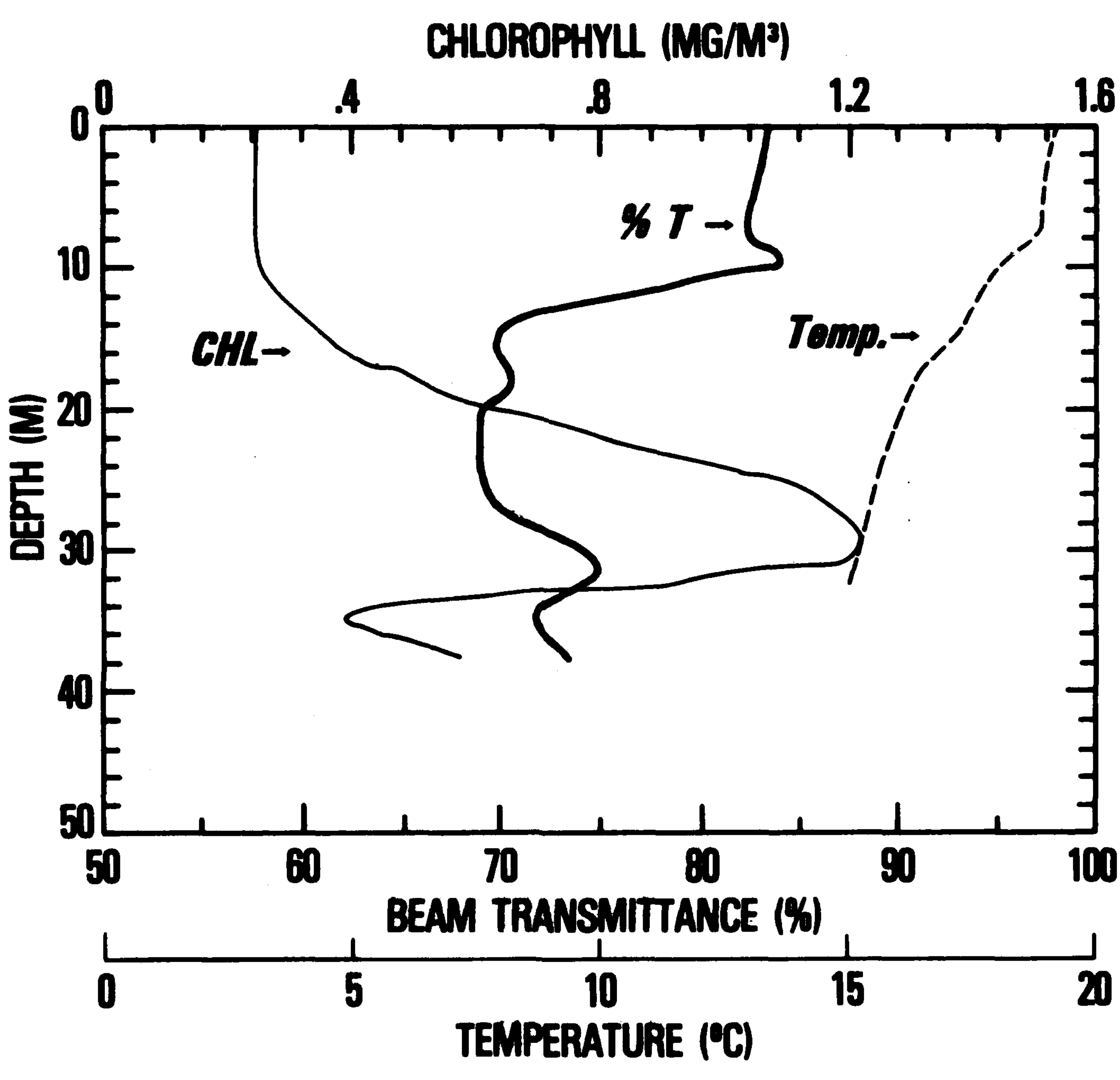

Figure 2. Profiles of Beam transmittance, temperature, and chlorophyll concentration in the western Mediterranean Sea.

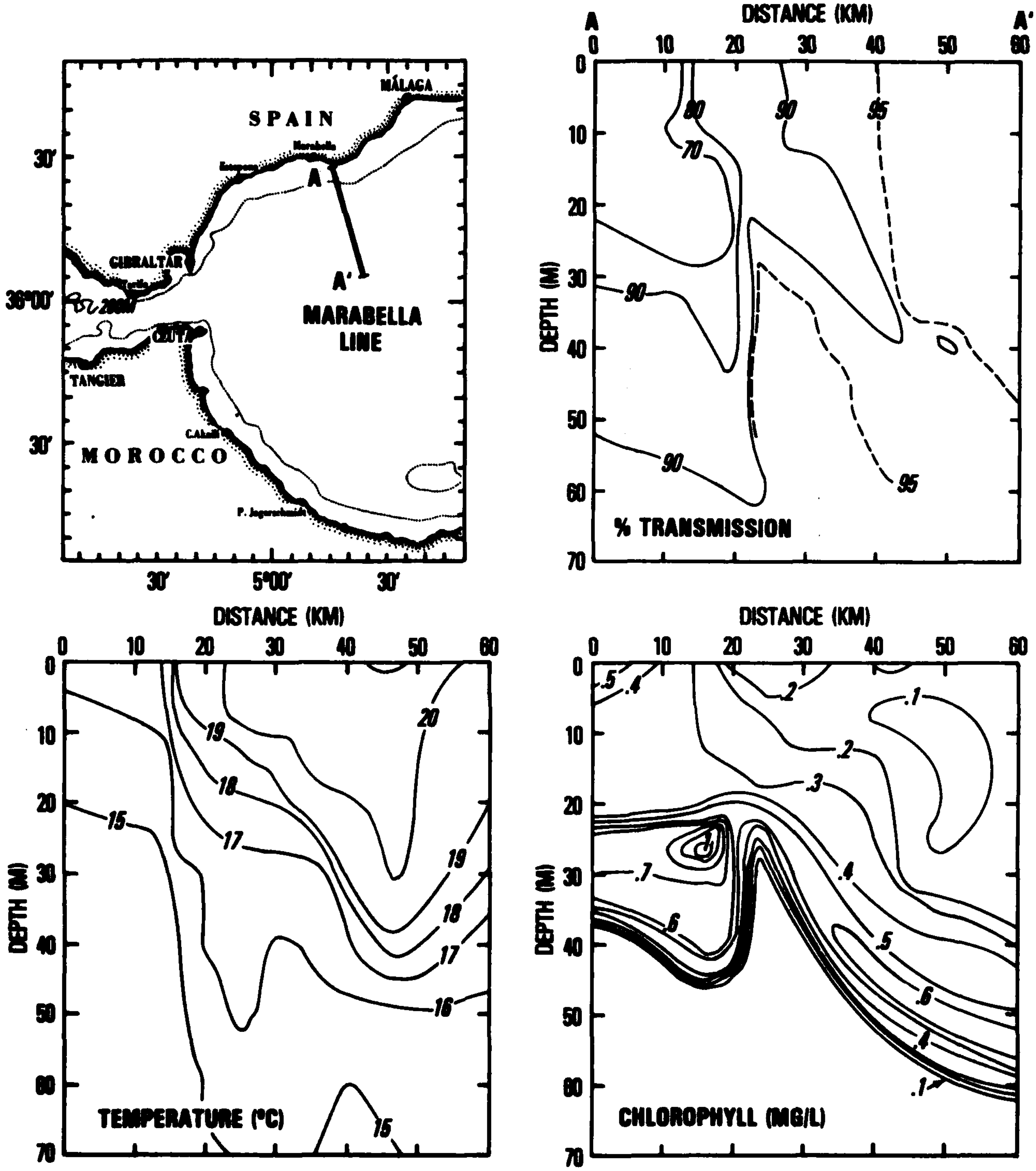

Figure 3. Cross sections through the Alboran front for transmissivity, temperature, and chlorophyll concentration.

study the relationship between the beam attenuation coefficient and temperature and salinity which are of primary importance to the physical and bio-chemical oceanographer.

2. Underwater Irradiance Meter

One of the most widely measured apparent optical properties is the diffuse attenuation coefficient, or more correctly, the attenuation coefficient for irradiance, which is defined as the logarithmic depth derivative of the irradiance. An irradiance attenuation coefficient can be defined for each wavelength for upwelling irradiance, downwelling irradiance, or scalar irradiance. NORDA Code 321 has acquired state-of-the-art field equipment for measuring this apparent optical property at sea. We have deployed this equipment on several cruises. The instrument is presently being upgraded by the manufacturer to provide improved data acquisition speed.

In addition to the underwater unit, the irradiance meter contains a deck unit to measure the spectral irradiance of the ambient daylight. Both the underwater and deck units have monochrometers in their optical systems that permit spectral measurements of irradiance (380-840 nm) with a 7 nm bandwidth.

All data acquisition, data logging, and instrument control functions are microprocessor controlled. All signals are A/D converted at the sensor, so data transmission over cables is digital; and therefore, noise free. Figure 4 shows the irradiance meter being deployed at sea by personnel from the Remote Sensing Branch.

Figure 5 shows spectral diffuse attenuation coefficient data obtained with this instrument in the Mississippi Sound and in the Mediterranean. Note the higher attenuation in the Mississippi Sound than in the Mediterranean. Along with the overall shift in attenuation coefficient values, there is also a shift in the wavelength of maximum transparency from 500 nm in the Mediterranean to 580 nm in the Mississippi Sound. This permits a method of classifying water masses by their spectral optical properties.

The diffuse attenuation coefficient is one of the optical properties for which CZCS algorithms have been developed. The underwater irradiance meter system is therefore a major source of surface truth for CZCS remote sensing work.

3. Sun Photometer

Correction of CZCS data for the backscattered radiance of the atmosphere is one of the major scientific problems facing the CZCS user community. The optical depth of the atmosphere at the wavelengths of the CZCS channels is a key parameter required for making that atmospheric correction. We have recently acquired a Volz sun photometer that provides us with a convenient way to measure the atmospheric optical depth at sea. The sun photometer is a hand held narrow field-of-view

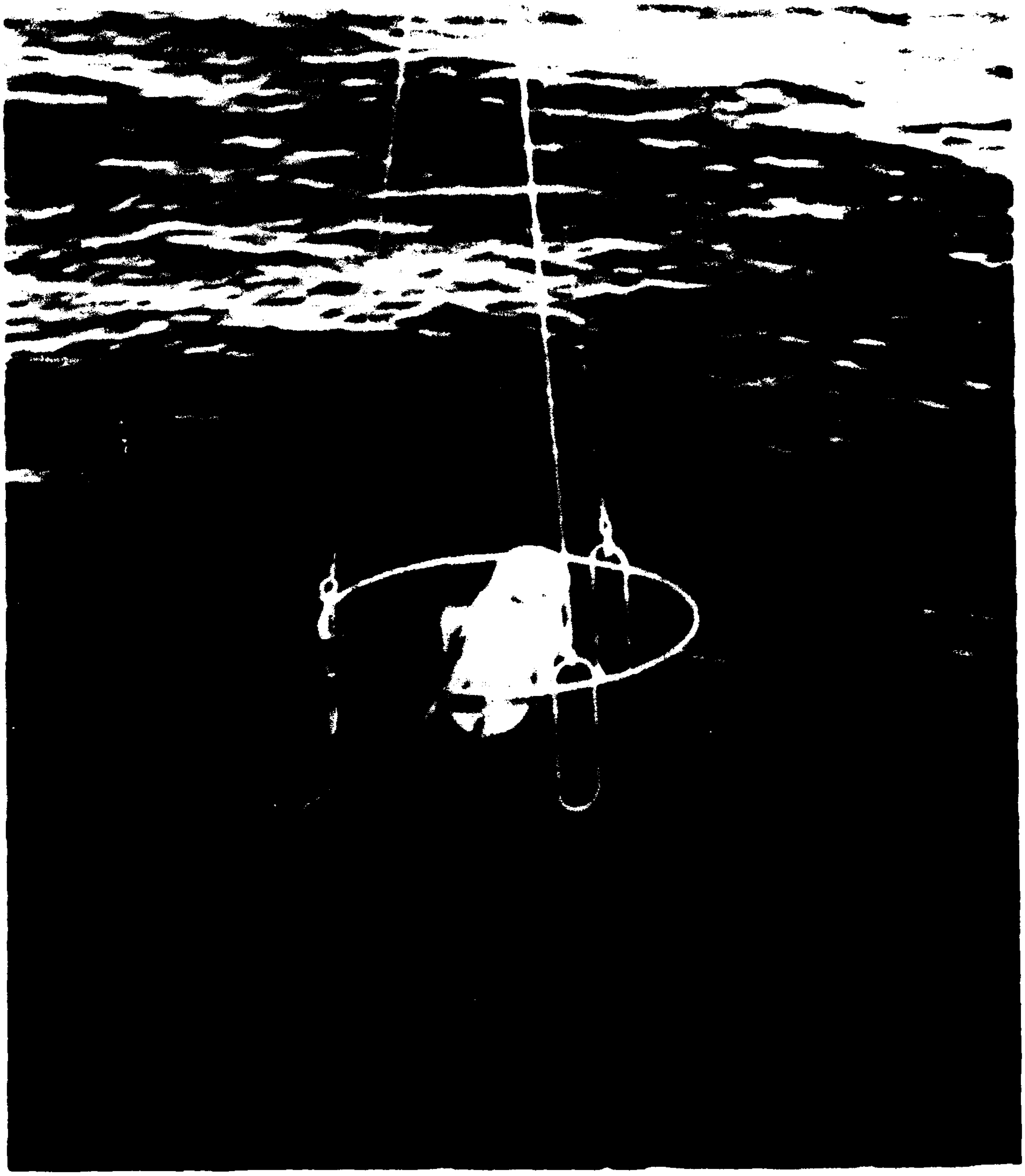

Figure 4. Spectral irradiance meter being deployed at sea.

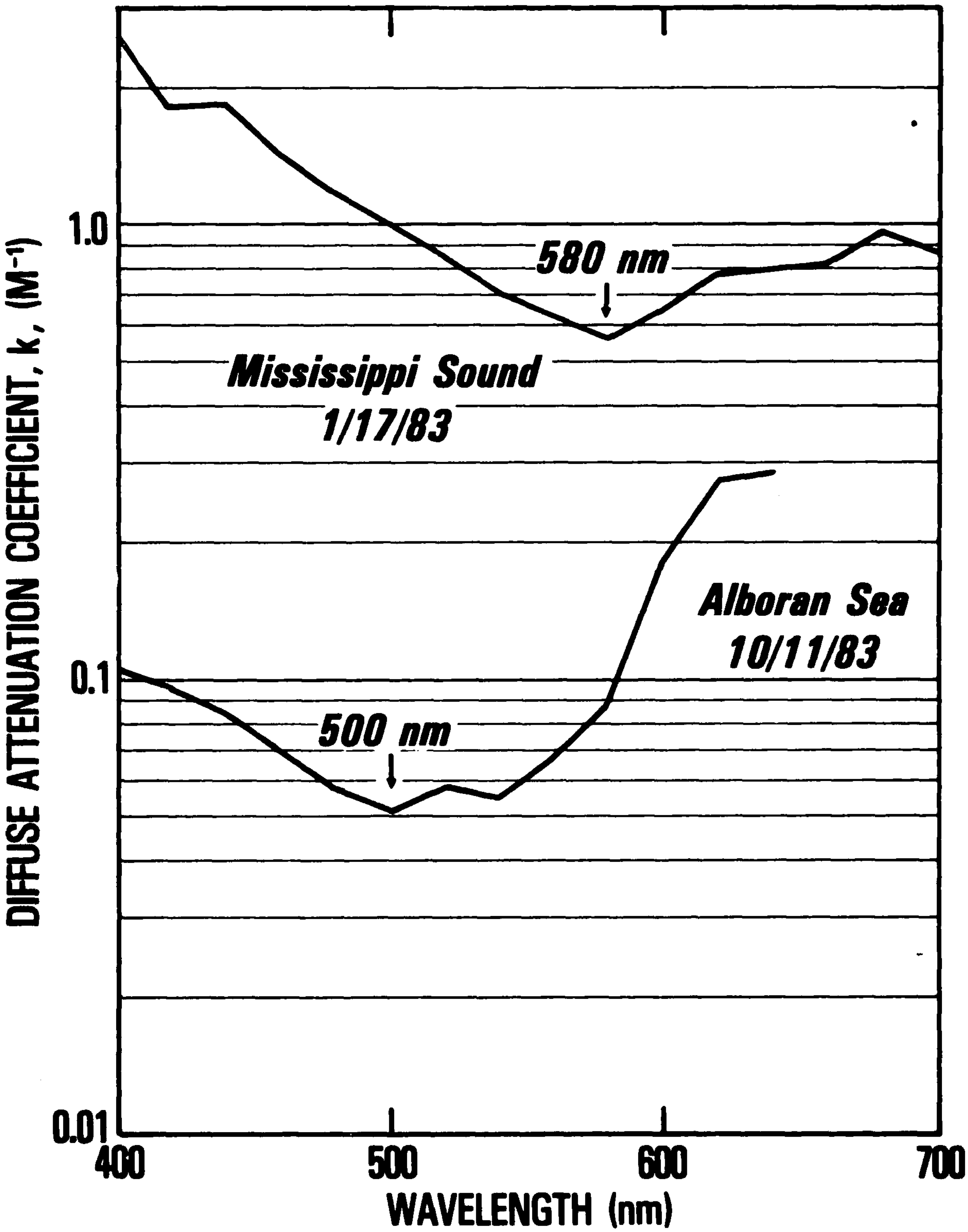

Figure 5. Spectral diffuse attenuation coefficients in Mississippi Sound and the Alboran Sea.

photometer that is sighted toward the sun by the user. Since the sun can be considered as a target of known constant (within a few percent) radiance, the solar brightness measured by the sun photometer can be used to indicate atmospheric transmittance or optical depth. This device is equipped with filters corresponding to each of the CZCS spectral bands.

4. Laboratory Instrumentation

A suite of laboratory equipment has been established for calibration of optical sensors. The major pieces of equipment are a standard lamp system and a pyroelectric radiometer. These two instruments provide independent, National Bureau of Standards traceable methods for measuring absolute radiance/irradiance levels. These major pieces of equipment plus minor equipment such as an optics bench, filters, lasers, etc. permit complete radiometric and wavelength calibration of our underwater irradiance meter system.

III. PROGRAMS

A. 6.1 CORE PROGRAM

A basic research program in ocean optics has been conducted within the Remote Sensing Branch for the past five years. An early priority of that program was to establish the facilities required for performing water color remote sensing research. The facilities described in the previous section result primarily from the 6.1 core program.

The main scientific issue addressed in the core program was atmospheric correction of CZCS data. A new statistical technique based on Principal Components Analysis was developed. The new method does not have many of the drawbacks that plagued earlier methods based on single-scattering theory. The new method is useful for descriptive studies but it does not result in quantitative estimates of upwelling ocean spectral radiance as does the single-scattering method. Therefore, at the present stage of development. the Principal Components Method is not useful for quantitative work with chlorophyll-a concentration or diffuse attenuation coefficient. However, a descriptive analysis is all that is required for many important Naval applications; for example, the position of major fronts and eddies. The principal components atmospheric correction work on CZCS is being transferred into 6.2 in FY-84, and into 6.3 in FY-85. NORDA Report entitled, "Imaging the Ocean Surface with the Coastal Zone Color Scanner through a Warm, Humid Atmosphere," No. 60, now in press, reports on the Principal Components Method and its initial evaluation for Navy application.

Bob Arnone and Ron Holyer are associate investigators in the NORDA Remote Sensing Branch for the 6.1 program "Chemical Dynamics in Ocean Frontal Areas" which is a new start in the core program in FY-84. This program is a joint effort with the Biology/Chemistry Branch (Code 333) and the Physical Oceanography Branch (Code 331). The basic research program is designed to study the enhanced chemical/biological variability observed in ocean frontal areas and to identify the causative processes. Although a funding reduction has limited the Remote Sensing Branch's involvement, this program would support some of the continuation of the basic water optics research in the future.

B. 6.1 ONR

Remote Sensing Branch personnel participated in the Donde Va? experiment in the Mediterranean in October of 1982. This experiment was an international cooperative effort led by NORDA with most of the Navy participation funded by ONR. Water optics ground truth data was collected and the CZCS data for the period was subsequently processed and analyzed using an atmospheric correction technique to obtain quantitative optic properties. This CZCS data set is unique in that cloud-free conditions prevailed over the experiment site for several weeks. This permitted acquisition of 15 excellent CZCS images over a period of 30 days. This frequent coverage permits observation of the spatial and temporal variability of the bio-optical activity at the site in a way that is seldom possible. Analyses of this data set is directed at determining the accuracy of quantitative measurements from CZCS and determining the spatial and temporal variability in frontal dynamics. Some results will be shown in a following section. A second Western Mediterranean Experiment has been proposed in which the major objectives are to derive the circulation and causes of the circulation. The application of visible satellite imagery and the subsequent bio-optical properties will permit an understanding of the chemical-biological transport processes which are driven in part by the circulation.

C. 6.2 NAVAIR

Two projects pertaining to water optics were addressed by the 6.2 NAVAIR program. One project applied a Principal Components Method for elimination of the atmospheric contamination which is a follow on to the 6.1 core program. The second project applied a more conventional method of eliminating the atmospheric contamination by a weighted subtraction of the 670 nm channel of CZCS. Results of this correction method provided quantitative measurements of the bio-optical properties.

1. Optical Ocean Techniques

In FY-82 a study was conducted to demonstrate the ability of CZCS to image mesoscale features in the deep ocean. The Principal Components Method of atmospheric correction was used for four CZCS images which were processed as case studies. A major point demonstrated by these case studies was the ability of the CZCS to provide detection and classification of these features through a warm, humid atmosphere that is opaque to IR sensors.

Figures 6 through 8 illustrate the potential of the CZCS for sensing through the tropical atmosphere. Figure 6 is a TIROS-N AVHRR image from 19 June 1979. This IR image shows a portion of the Loop Current in the northeastern Gulf of Mexico. The

Figure 6. Thermal IR image in Gulf of Mexico.

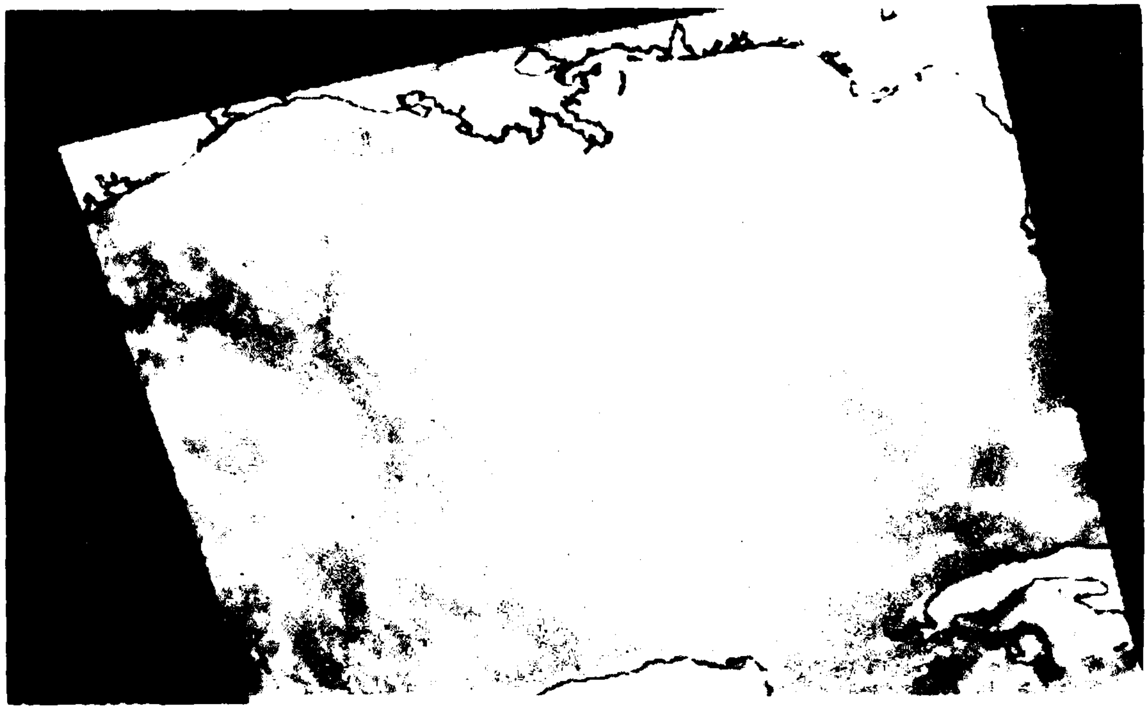

Figure 7. Coastal Zone Color Scanner image of Gulf of Mexico—uncorrected for atmospheric contamination.

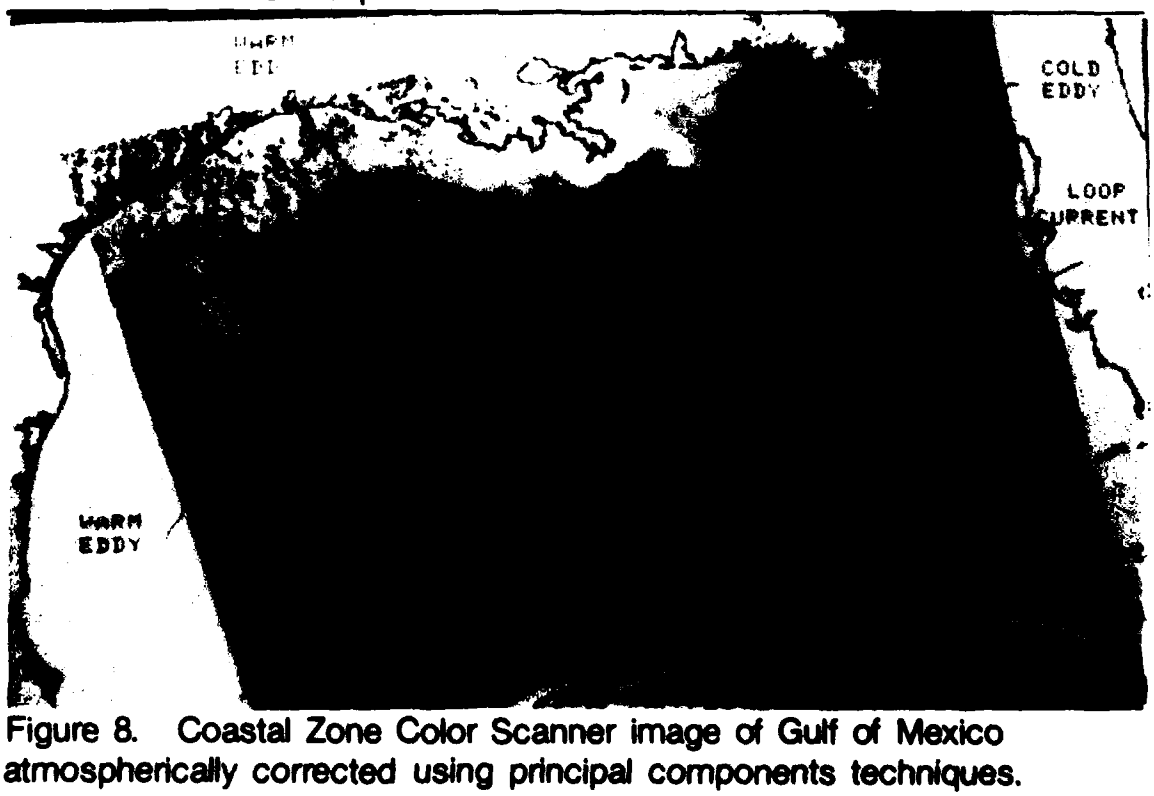

Figure 8. Coastal Zone Color Scanner image of Gulf of Mexico atmospherically corrected using principal components techniques.

Loop Current is visible here because of an unusual late season outbreak of cool, dry continental air over the northeastern corner of the Gulf. However, the rest of the Gulf remains under the warm, moist atmosphere that is typical of the Gulf of Mexico at this time of year. Notice that we observe no sea surface temperature patterns in the portion of the Gulf covered by the tropical air mass.

Figure 7 shows the CZCS image from 19 June 1979. We see no discernible oceanographic features in this CZCS image because of atmospheric haze. However, applying Principal Components Analysis to this data results in the atmospherically corrected image shown in Figure 8. Note in this figure that the Loop Current boundary is delineated all the way back to its origin in the Yucatan Straits. Also, three eddies are clearly visible in Figure 8. Two warm eddies are seen in the northern Gulf, one off the Louisiana coast and one off the Texas coast. A cold eddy is also shown to the SSE of Mobile Bay. None of these features could be identified from the IR imagery.

This 6.2 ocean optic techniques project was inactive in FY-83, but in FY-84 a one year time series of CZCS imagery in the Gulf of Mexico is attempting to track eddies, such as those shown in Figure 8. A major purpose of this work is aimed at verifying the results of NORDA modeling studies which predict a WSW drift for eddies shed from the Loop Current.

2. <u>Hydrographic Application</u>

A second 6.2 project started in 1980 was originated as a hydrographic applications development for satellite remote sensing. This project was directed at coastal charting and defining water properties and dynamics in coastal waters. The project evolved into defining coastal optical properties from satellite, namely CZCS. The atmospheric correction technique applied to CZCS data for this project utilizes the spectral dependence of the aerosol concentration on the 670 nm channel of CZCS. The basic assumption is that the ocean has zero upwelling radiance at the 670 nm channel, or that the signal returned in this channel arises from the aerosol concentration and the Rayleigh scattering contribution. The weighted subtraction of this channel from the other channels (443, 520, 550 nm) should eliminate the atmospheric contamination and result in absolute upwelling radiance for each CZCS channel. Algorithms have then been developed which relate the ratio of the absolute upwelling radiance in these CZCS channels to the diffuse attenuation coefficient, chlorophyll concentration, and sediment concentration. The basic assumption for the 670 nm channel is true for deeper oceanic waters with little suspended sediment, but for highly turbid coastal waters the upwelling water radiance at 670 nm is significant. Thus the correction process has problems in high sediment areas in coastal waters. Presently an effort is underway to determine the ability to extract quantitative data using this atmospheric correction technique for coastal water types.

A second objective which the hydrographic applications' project addressed was the application of optical remote sensing data into numerical circulation and sediment dispersion models in coastal areas. Visible remote sensors respond to high suspended sediment concentration which is the major influence on optical properties in coastal areas. The interrelationships of optical and suspended sediment distribution in the Mississippi Sound was examined to determine (1) measurement capabilities from remote sensors and (2) dynamic response of the circulation. Work was begun to incorporate CACS derived measurements of optical properties and suspended sediment concentration into a three-dimensional circulation model of the Sound. Methods of incorporating satellite derived parameters in the model were identified and presently are being investigated.

D. 6.3 DMA

A program was developed in 1981 in which a manual was written for interpreting coastal features from Landsat imagery. This manual provided introductory background on using Landsat imagery for coastal charting applications and included chapters on water optics, multispectral scanning systems, sunglint, ocean waves and a series of case histories.

The Defense Mapping Agency (DMA) is presently developing several hydrographic charting systems which are strongly dependent on water optical properties (e.g., HALS, MAPS, photogrammetry). NORDA has a program with DMA to develop a guide of worldwide coastal optical properties to be used by Operational Planning for the deployment of hydrographic charting systems. Presurvey knowledge of the water optical conditions will permit improved reliability, efficiency, and accuracy of the hydrographic charting system. IN FY-82 a seasonal atlas of optical properties of world coastlines was compiled from existing data bases and open literature. This atlas is composed of 20 charts at a scale of 1:12,200,000. An example of one chart is illustrated in Figure 9. Worldwide coverage (+40 latitude) is contained on four charts for each of the four seasons (16). Additionally, the atlas includes four charts of the annual mean optical values. Water optical values are divided into 5 secchi depth values and are averaged over one degree squares for coastal waters in 500 meters or less. In many areas where little data exists, the oceanographic, meteorologic, and geomorphic conditions were used to extrapolate the water optical climate. The two major concerns that surfaced from this atlas development were: 1) very limited optics data exists on a worldwide basis especially in coastal areas and 2) the spatial and temporal variability of coastal optical properties is so high that present ship data is inadequate.

The application of quantitative optical measurements from CZCS to these problems is being addressed. A second regional atlas using CZCS is presently being developed for the Western Mediterranean. Analyses of monthly CZCS data are being processed for the diffuse attenuation coefficient at full resolution (800 meters^2) and a quantitative, digital atlas will be completed this year. Techniques used for these analyses were described in the image processing facilities section. Preliminary checks indicate the satellite derived diffuse attenuation coefficients agree well with ground truth values. The temporal and spatial variability of optical parameters appears to be much more dynamic than originally theorized. The bio-optical response in the surface waters varies on a daily basis and can be monitored by CZCS. The dynamic spatial and temporal variability of the bio-optical properties are demonstrated by sequential CZCS imagery in Figure 10. Each of the six images for the Alboran Sea has been atmospherically corrected and represents quantitative measurements of the diffuse attenuation coefficients. The color scales range from

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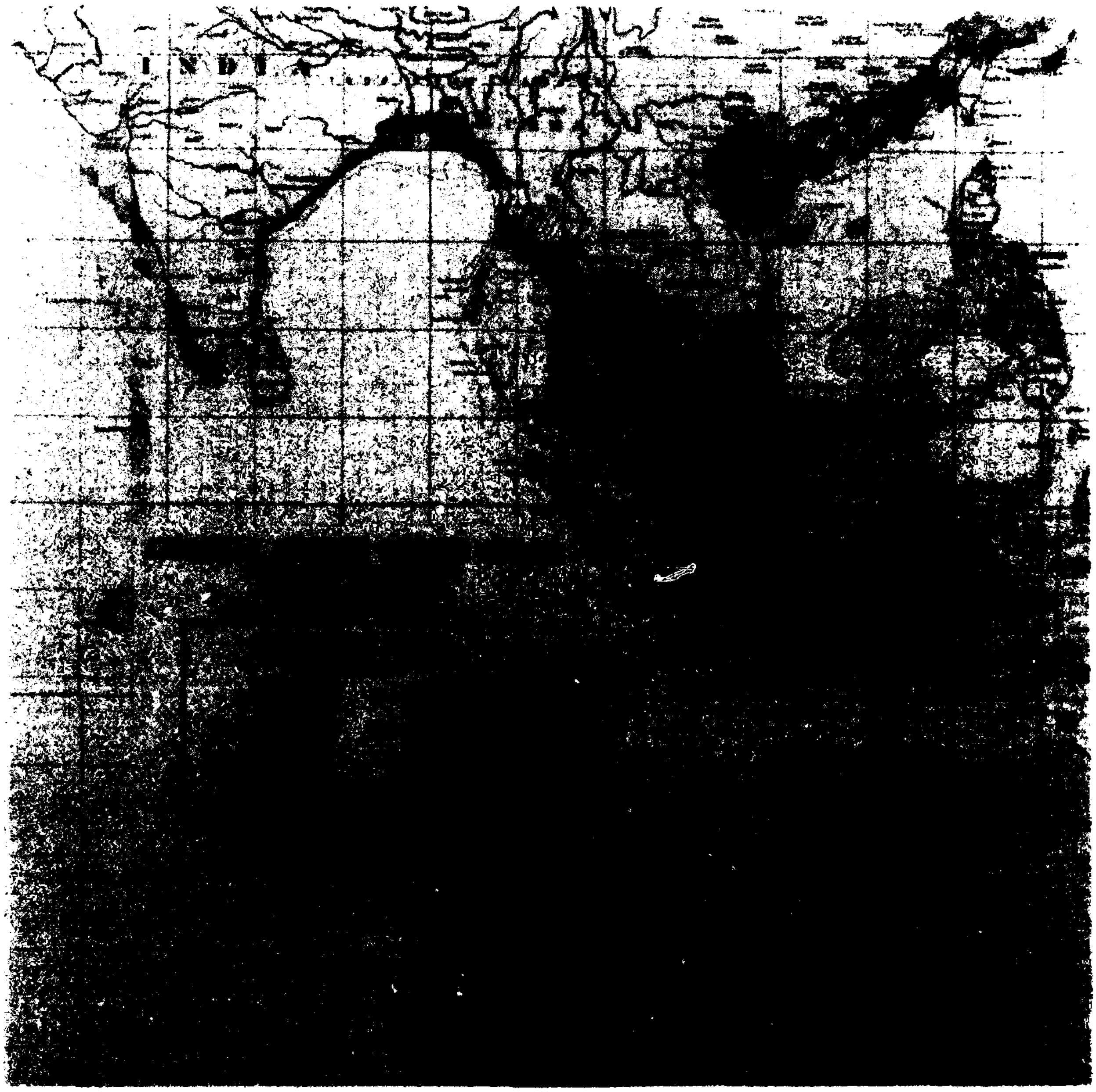

Figure 9. Annual mean secchi depth for SE Asia coastlines taken from "Secchi Depth Atlas for World Coastlines."

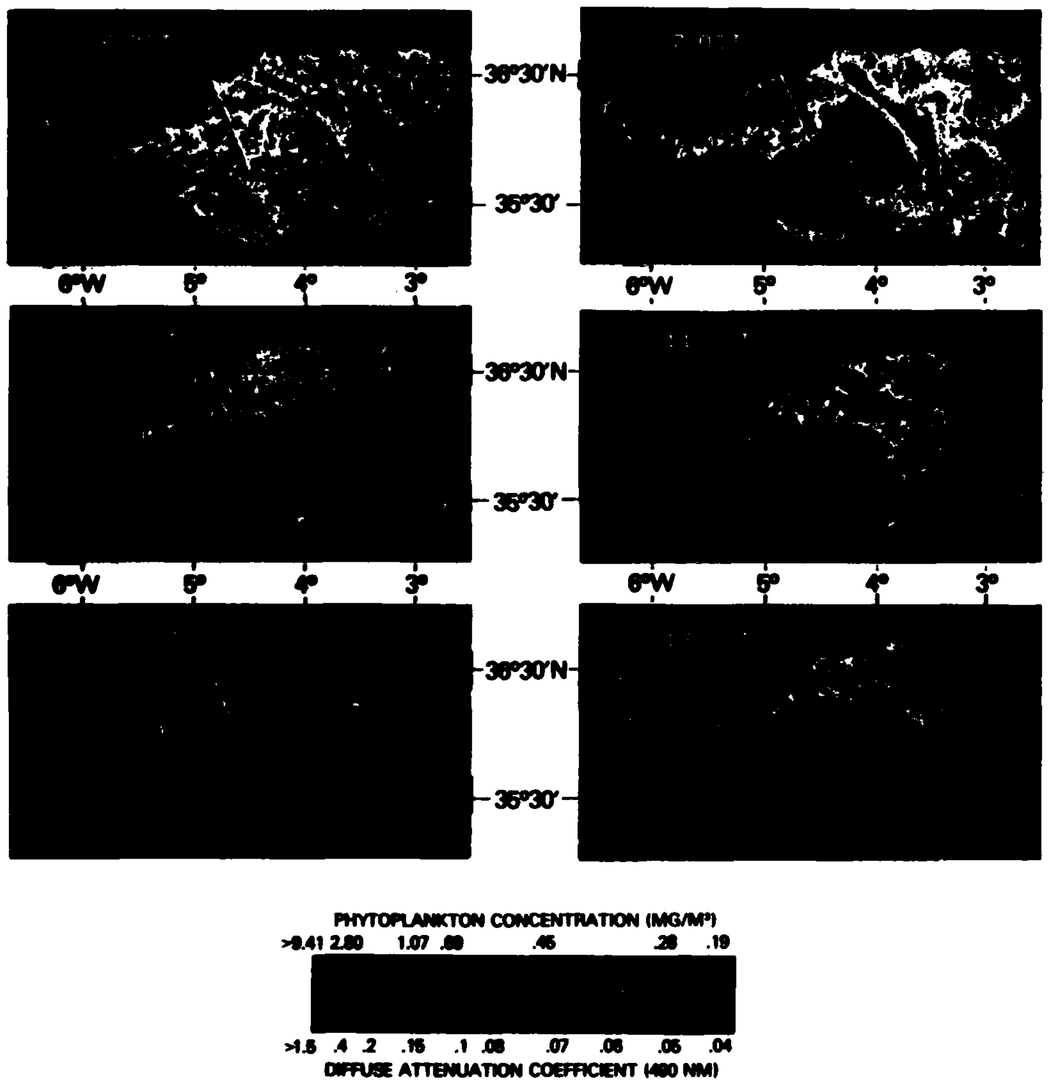

Figure 10. Coastal Zone Color Scanner imagery atmospherically corrected for diffuse attenuation coefficient and phytoplankton concentration. This 6-day sequence shows the temporal and spatial variability in the Alboran Sea, 1982.

turbid coastal (red) to shelf (yellow) to clear ocean (blue). The temporal variability which is shown to change on a daily basis includes both the frontal feature movements and the non-conservative nature of the water mass itself. That is, the temporal bloom or decay of the chlorophyll concentration for a water mass and associated optical properties is shown as a daily change.

IV. BASIC RESEARCH ISSUES IN OPTICS

As a result of the remote sensing efforts in ocean optics, basic issues have surfaced. Other investigators in related fields have expressed similar issues, especially in the potential impact of satellite optical oceanography. It is essential that these issues be addressed in order to improve our understanding of remote sensing of water color. A list of these issues follows:

- Determine how the upwelling radiation at the sea surface (as measured by satellite) relates to the bio-optical properties with the water column. The change in chlorophyll and suspended sediment concentration that is observed with depth, has significant effects on the spectral backscattering of light that reaches the surface. It can be hypothesized that different depth profiles of the bio-optical properties can give rise to similar spectral upwelling radiance values at the surface. In order to assess the significance of this depth dependence, stations of various bio-optical properties will be correlated with the upwelling spectral radiance at the surface.

- Assess the temporal and spatial variability of optical properties in different regions where major physical and bio-chemical processes are occurring. In order to improve our understanding of optic variability in the ocean areas, it is necessary to determine the time and space scales which affect the optical properties. The daily/weekly/monthly scales of the optical properties can be rapidly assessed by satellite processing of specific types of oceanic processes (i.e., fronts, eddies, straits, river plumes, etc.). In addition, the changes in optical properties which occur between water masses need to be examined. For example, the exchange in optical properties between coastal, shelf, and open ocean can result in an abrupt or diffussion type mixing process and the bio-chemical properties which cause the optical variability may be significantly different.

- Develop an improved understanding of how upwelling visible radiation "ocean color", and sea surface temperature are correlated with the upper dynamics of the oceans in order to fully exploit satellite sensed data. In some instances there are major differences between the ocean color frontal position and the sea surface temperature position as sensed by satellite imagery. These two data sets provide for a classification scheme which has previously been used in land use classification for Landsat. A water mass can be classified by its "color"/temperature relationship. In this manner, the classification processes are responding to both the physical and bio-chemical processes which control it. Techniques such as these have not been used in oceanic areas, nor related to the upper ocean dynamics.

- Perform parallel processing of identical data sets through the NORDA, Scripps Visibility Laboratory, University of Miami, NOAA, and other atmospheric correction algorithms for the purpose of comparing and evaluating each of the methods.

- Expand the principal components atmospheric correction work to examine the possibility of deriving quantitative estimates of ocean optical parameters from CZCS data corrected by this method.

- Use aircraft multispectral scanner studies to collect water color imagery under controlled experimental conditions. This would permit us to look at systematic errors in chlorophyll or diffuse attenuation coefficient algorithms that depend on solar zenith angle, sensor zenith angle, ambient skylight conditions, or other factors.

- Use our interactive atmospheric correction software to compile global statistics on Angstrom coefficient values.

V. NAVAL RELEVANCE

The ocean optics programs being addressed by this capability statement have specific naval relevance to the areas outlined below.

1. Optical communications, e.g., SLCSAT and SLCAIR.

2. Mesoscale oceanography -- (detection of major frontal, eddy features when thermal IR imagery is limited).

3. Input to mixed layer deep thermodynamic models as an indicator of the radiation budget.

4. Input into the coastal optics data base for atlas development.

5. Improve performance of electro-optical hydrographic charting systems (HALS, MAPS).

6. Improve understanding of biological/chemical processes (bioluminescence).

7. Direct visual detection of submerged targets.

8. Application in performance criteria in underwater construction.

9. Monitoring water pollution resulting from Navy sources.

10. Bathymetry measurements from multispectral scanning systems.

11. Aerosol concentrations of atmosphere is required by meteorologist (this is a spin-off of the atmospheric correction process used in CZCS).

VI. SCIENTIFIC CONTRIBUTIONS

Atmospheric correction of CZCS data was the initial problem encountered by the scientific community attempting to use CZCS data for oceanographic applications. Figure 11 illustrates the significance of the atmospheric correction problem. In the figure, the solid curve represents the upwelled spectral radiance of the ocean as measured by NORDA Code 321 personnel from the USNS Lynch on 3 December 1978 in the Gulf of Mexico. The five bars in the figure represent the radiance at satellite altitude by the five CZCS spectral bands at the same time and place. The difference between the position of the curve and the height of the bars results from light that is scattered into the satellite sensor's field of view by the molecules and particles in the intervening atmosphere. This path radiance, as it is frequently called, is much larger than the ocean radiance. As shown here, the radiance measured by the satellite is typically an approximate 90% - 10% mixture of atmospheric and oceanic radiances respectively. Thus, even if one can correct for the atmospheric radiance with an accuracy of +/- 10%, the remaining error in the corrected data is still as large as the ocean radiance.

Two contributions to the solution of the atmospheric correction problem have come from NORDA Code 321. The first is a statistical method of atmospheric correction based on Principal Components Analysis. This method has produced excellent results for cases where the objective was the descriptive analysis of the imagery. Extension of this work to permit measurement of spectral radiance is one of the areas we would like to pursue.

The Remote Sensing Branch has also developed an interactive approach to the type of atmospheric correction based on single-scattering theory. Atmospheric correction techniques for CZCS imagery which are presently being conducted at leading universities (University of Miami, Scripps) and US governmental agencies (NOAA, Goddard Space Flight Center) are different from the one Code 321 uses. Our approach permits the analyst to change some of the key correction parameters (such as the Angstrom exponent of the aerosol phase function) and watch the effect of the parameter changes on the corrected image displayed before him. Parameters can be adjusted manually as the result is observed until the haze disappears from the displayed image. Interactive technique permits rapid analyses over the entire image instantly. The technique permits analyses of different aerosol optical thickness across the image and is not confined to open ocean areas as other standard methods

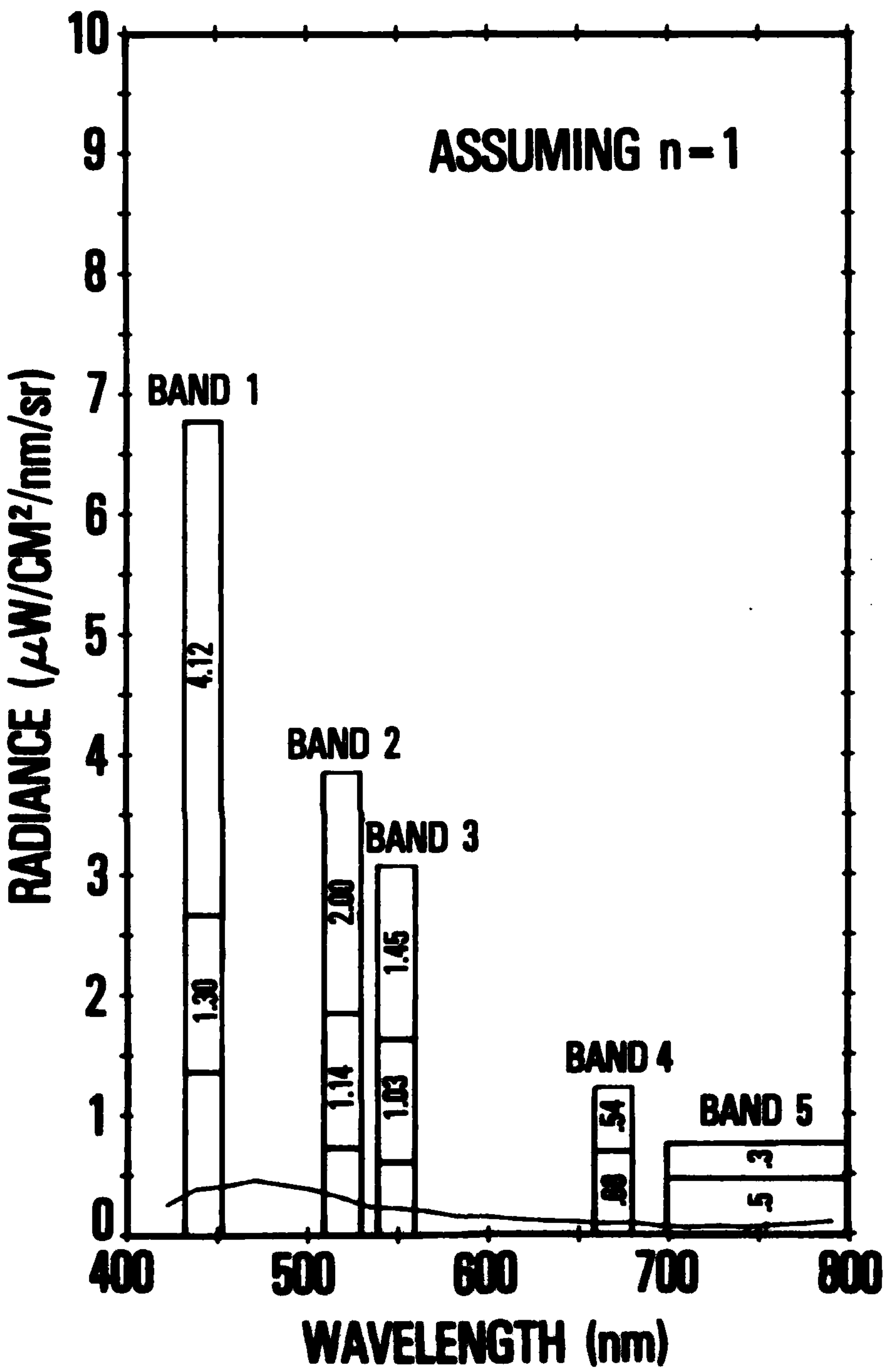

Figure 11. Radiation budget for spectral channels of the Coastal Zone Color Scanner.

utilize. The Remote Sensing Branch's techniques rely heavily on the software/hardware capabilities of the I^2S system and can't be duplicated on all image processing systems. Comparison of these techniques with others developed elsewhere would be a fruitful area of study that would lead to better understanding of the CZCS atmospheric correction problem.

The problem of accurately earth locating a CZCS pixel has also been addressed as part of NORDA Code 321 water optics program. A scan line resampling algorithm, called scan line linearization, has been developed to increase the accuracy of image registration. We now typically earth locate CZCS pixels in open ocean to within 4-5 km. With landmarks to work with, the location is usually within 1 km. The National Marine Fisheries Service has adopted the NORDA scan line linearization algorithm for their CZCS processing in support of fisheries' operations and environmental monitoring of coastal waters.

An improved understanding of the variability of water optics has been demonstrated by the generation of a seasonal atlas of world coastlines. This atlas, although compiled from existing data bases and literature review, highlights the inadequate, highly limited amount of optics data presently available. Additionally, the spatial and temporal variability of the optical properties is demonstrated to be quite dramatic. This acknowledges the need for synoptic coverage by remote sensing measurements.

This dynamic variability of optical properties was demonstrated to occur on a daily basis by a sequence of CZCS imagery in the Alboran Sea. Chlorophyll concentration changes in the surface layers are shown to be bloom and decay on a daily basis. These changes are shown to affect the optic properties. Quantitative measurements of the bio-optical properties by application of satellite remote sensing has indicated that "water color" variability is much more dynamic and complex than originally surmised.

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The capability of the Naval Ocean Research and Development Activity (NORDA) Remote Sensing Branch (Code 321) in ocean optics is described. A summary of the facilities, programs, scientific contributions, and basic research issues is outlined. The application of remote sensing in the study of ocean optical properties is described in addition to present image processing software and satellite receiving capability. Different optical field instruments which the Remote Sensing Branch has obtained are presented. Results of optical data are

illustrated in relation to other oceanographic parameters.

Navy programs which have supported the Remote Sensing Branch's developments in water optics are described. The Navy relevance of water optics to these programs is indicated.