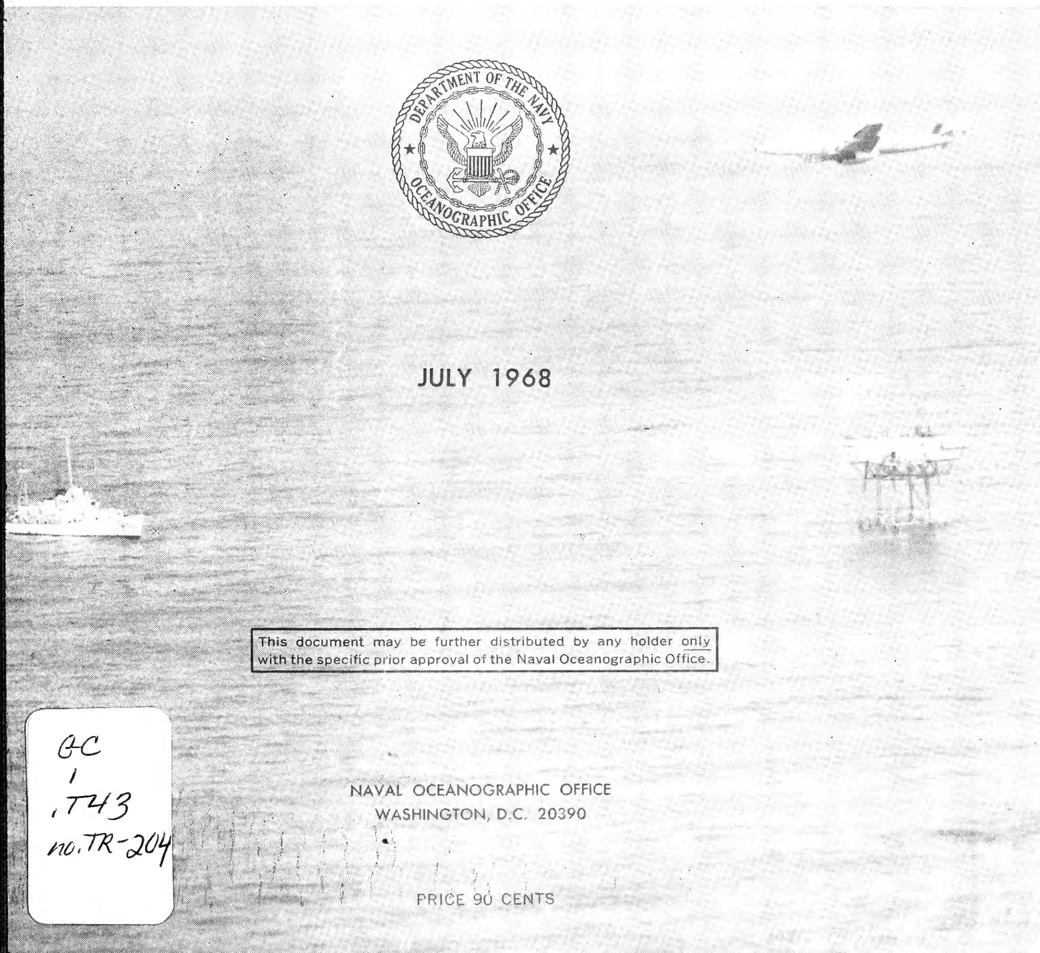
TR – 204

Technical Report

COMPARISONS OF REMOTE AIRBORNE OCEANOGRAPHIC SENSORS



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ABSTRACT

This report compares a number of remote sensors to determine the feasibility of using these sensors for detecting oceanographic features from space. The sensors include an infrared scanner, infrared radiation thermometer, radar scatterometer, radar wave profiler, and a microwave radiometer. Two aircraft flew a series of flight tracks across the Gulf Stream near Cape Hatteras and over ARGUS ISLAND Tower located southwest of Bermuda. The sensors were compared and evaluated by means of simultaneous measurements.

In addition, a quantity of Rhodamine-B dye released in the water was photographed to determine if certain characteristics of water flow could be estimated from aerial photographs.

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FOREWORD

Synoptic oceanographic data are required for preparing analyses and predictions of thermal structure conditions in support of both civilian and military programs. Most environmental data are now acquired by ships and aircraft. Orbiting spacecraft may also provide an effective means of rapidly acquiring synoptic environmental data.

The Naval Oceanographic Office, in cooperation with the National Aeronautics and Space Administration, has conducted field experiments to determine the feasibility of making oceanographic measurements from space. A number of sensors were tested aboard aircraft and compared with the satellite sensors to determine which oceanographic features can be successfully interpreted by remote sensing. The results of the field tests are contained in this report.

T. K. TREADWELL
Captain, U. S. Navy
Commander

CONTENTS

Page

INTRODUCTION

The first experiments in oceanographic remote sensing were conducted during World War II, when photoreconnaissance aircraft recorded surface wave patterns on film. The resulting photographs provided wave height and wavelength measurements, as well as an indication of nearshore bathymetry.

In following years, the Woods Hole Oceanographic Institution, the Naval Research Laboratory, and the Naval Oceanographic Office devised some remote oceanographic sensors. Airborne surface temperature and surface wave sensors were built and tested.

In 1964, the National Aeronautics and Space Administration (NASA) suggested the use of spacecraft as platforms for collecting remote oceanographic measurements. A conference was sponsored by NASA and the Woods Hole Oceanographic Institution at Woods Hole, Mass., from 24 to 28 August 1964 (Woods Hole, 1965). The conclusion reached was that sufficient technology in remote sensing existed to warrant a research program. As a result, NASA agreed to join with the U.S. Navy in a series of research studies to determine if available remote oceanographic sensors could be used on orbiting satellites.

The Spacecraft Oceanography Project was established at the Naval Oceanographic Office (NAVOCEANO) in 1965. The object of this Project was to determine which features of the ocean could be detected from space and which sensors could be used. This report describes the first experiment of this Project.

OVERALL OBJECTIVE

The first remote sensing experiment compared remote sensors on the NASA aircraft and the Navy Antisubmarine Warfare Environmental Prediction Services (ASWEPS) aircraft with controlled surface measurements. Since some of these sensors had never been flown over water, the experiment would also demonstrate the nature of the records received on overwater flights.

The majority of the experiment was conducted in the vicinity of Bermuda between 6 and 12 March 1966. Bermuda was selected because the Office of Naval Research tower, ARGUS ISLAND, could provide reference measurements. Four types of reference measurements were required: (1) sea surface waves in the form of power spectra, (2) a time series of sea surface temperatures, (3) meteorological observations, and (4) dye concentration measurements. Some detailed records and sample data from the tower reference measurements are contained in appendix A.

In addition to the tests at Bermuda, infrared and microwave sensors were operated on the way to and from Bermuda over the northern boundary of the Gulf Stream.

PLATFORMS

NASA Aircraft

Background

In October 1964 NASA acquired a Convair 240-A (figure 1) through the cooperation of Wright Air Development Directorate, Wright-Patterson Air Force Base, Dayton, Ohio (Toy et al., 1966). In addition to testing GEMINI subsystems, the aircraft is used for the NASA Earth Resources Survey Program conducted within the Office of Space Science Applications. This program is directed toward employing earth-orbiting spacecraft for scientific applications (NAVOCEANO, 1966). Controlled experiments using the Convair 240-A were begun in December 1964.

Initial flights over geological test sites used only photographic cameras and infrared scanners. The aircraft has since been modified to carry additional sensors and recording equipment. A gas-turbine auxiliary power unit was installed to provide power for the sensors and pressurization for high altitudes. The aircraft cruises at 330 km/hour and has a range of more than 800 km.

Figure 1 NASA Aircraft

Sensors

Multiband Camera: The NASA aircraft is equipped with a nadir-directed 9-lens Itek camera (Toy et al., 1966). This camera simultaneously photographs nine contiguous, narrow bandwidths between approximately 0.360 and 0.900 microns. Optimum f stops are possible in each band, and objects with the slightest differences in reflective spectra are discernible. The camera has a focal-plane shutter and nine 15-cm, Leity, high-resolution lenses with 21° square fields of view. Gelatin filters are used with each lens. Both cameras were used to relate a dye experiment to mass transport.

Color Camera: A Wild-Heerbrugg RC-8 camera is also used (Toy et al., 1966). This nadir-directed unit obtains color photographs in the infrared region. The system has a 15-cm Aviagon lens cone with a resolution of 50 lines/mm in the center of the field and approximately 25 lines/mm in the corners. Exposure time is continuously variable from 1/100 to 1/700 second at f stops of 5.6, 6.3, 8, 11, and 16.

Infrared Scanner: The Reconofax IV infrared scanner on the NASA aircraft, manufactured by HRB Singer, Inc., is a passive, single-channel system that measures radiation in the 7.3- to 13.5-micron region. Radiation from the ocean surface is reflected by a scanning mirror onto a detector. The detector converts the radiation to an electrical signal, which modulates the intensity of a lamp. The light from the lamp is swept across a film strip in phase with the radiation scanning mirror. The result is a film strip recording of sea surface temperature based on intensity variations proportional to radiation differences of the ocean. An automatic gain control regulates the absolute intensity of the light source (Harris and Woodbridge, 1962).

Radar Scatterometer: The Ryan scatterometer measures the radar (13.3 GH_z) reflective properties of the ocean surface as a function of the angle of incidence of the radiation. Doppler spectra fore and aft of the aircraft are recorded simultaneously on magnetic tape. The spectra are then filtered for a particular angle of incidence using multiple-filter spectral analyzers. The reflectance curves obtained are related to surface roughness. The total field of view of the instrument is 120° fore and aft and 3° port and starboard (Toy et al., 1966).

Passive Microwave System: Passive microwave radiometers that measure sea surface temperature by determining the intensity of electromagnetic radiation are also installed on the aircraft. Four radiometers with frequencies of 9.3, 15.8, 22.2, and 34.0 GH_z were installed in a radome located in the aircraft nose. The grazing angle of the radiometers can be varied approximately 50° from nadir with either horizontal or vertical polarization. Data are recorded on strip-chart recorders and magnetic tape.

ASWEPS Aircraft

Background

The Naval Oceanographic Office initiated the ASWEPS program in 1959 to provide environmental services to the Navy. The program concept included the use of Fleet aircraft for collection of oceanographic data. For development of sensors and techniques, a research aircraft (Super-Constellation NC-121K) was placed under the technical control of NAVOCEANO in March 1961. Operational control was assigned to Air Development Squadron Eight at Patuxent Naval Air Station, Maryland.

After several months of test flights, suggestions were made for aircraft modifications (Peloquin, 1961). In May 1961 another Super-Constellation was delivered to Lockheed for extensive internal modifications, including installation of aperture and launching mechanisms.

The modified aircraft (figure 2) was delivered in 1962. The cruising speed was 330 km/hour and operating range was more than 6,600 km with a maximum flight endurance in excess of 20 hours (Wilkerson, 1966).

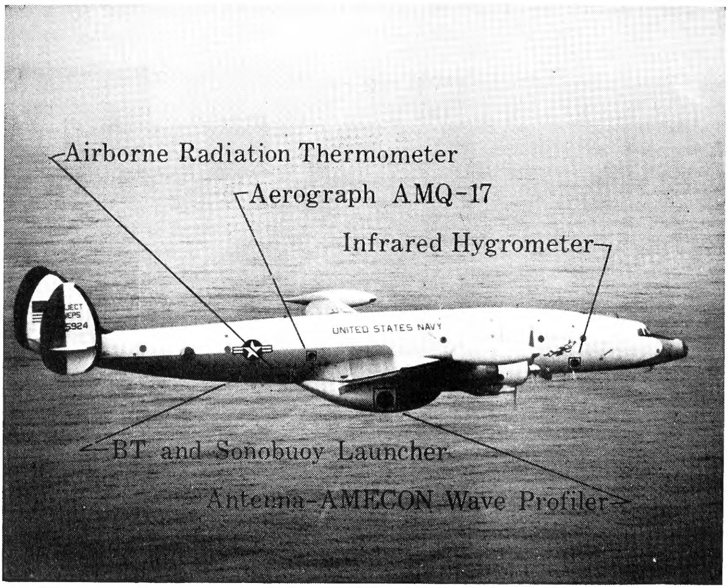


Figure 2 ASWEPS Aircraft

Sensors

Airborne Radiation Thermometer: The aircraft is equipped with a Barnes Model 14-320 airborne radiation thermometer which measures sea surface temperature by recording the intensity of infrared radiation from the ocean surface in the 7.3- to 13.5-micron band. This nadir-directed instrument is normally flown at low altitudes to reduce atmospheric interference. The infrared signal is averaged over a 6-meter square spot at a 300-meter altitude. Surface temperature is measured by comparing the intensity of incoming infrared radiation with that from a temperature-controlled cavity contained in the instrument. Measurement accuracies of $\pm 0.2^{\circ}C$ have been achieved in the laboratory (Peloquin and Weiss, 1963), and field accuracies are $\pm 0.5^{\circ}C$ 95 percent of the time for daytime flights in the altitude range of 60 to 550 meters after correction for atmospheric effects (Pickett, 1966).

Radar Wave Profilers: The aircraft is also equipped with a radar wave profiler. This sensor is an FM-CW radar device operating at a center frequency of 4.3 GH_Z with frequency modulations of ± 12.5 MH_Z. The wave meter, normally flown at an altitude of 150 meters illuminates a spot on the sea surface 5 meters in diameter (Radcom-Emertron, 1963). Waves 100 feet or more in wavelength (greater than 3-second periods) can be recorded. The output is a profile of the sea surface along the flight path.

Meteorological Sensors

A. AN/AMQ-17 Aerograph. The AN/AMQ-17 simultaneously measures flight-level air temperature, relative humidity, and pressure. Air temperature is measured with a platinum wire resistor over the range of -50° to $49^{\circ}C$. A carbon-coated resistor is used to measure relative humidity between 0 and 90 percent; a mechanical bellows linked to a potentiometer measures atmospheric pressure between 50 and 1,050 mb. The recorder has both analog and digital outputs.

B. Infrared Hygrometer. The infrared hygrometer measures absolute humidity from 0 to 35 gm/m^3. Two infrared beams of different wavelengths are alternately passed through a one-meter path of atmosphere. One wavelength (1.37μ) is attenuated by water vapor, and the other (1.34μ) is unaffected by water vapor. The difference in energy of the two beams received by a detector is proportional to the absolute humidity.

ARGUS ISLAND Tower

Background

ARGUS ISLAND tower (figure 3) was selected for the test site because of available sensors and its proximity to deep water. ARGUS ISLAND was built during the summer of 1959 under the direction of the Office of Naval Research. Through the cooperation of that Office, the tower has been used by NAVOCEANO since 1961 as an experimental platform.

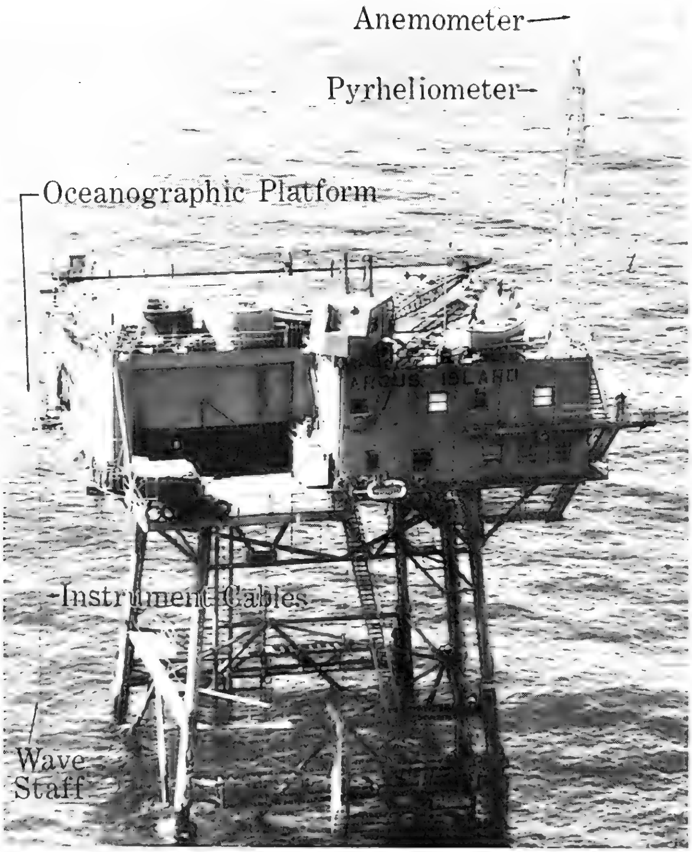


Figure 3 ARGUS ISLAND Tower

ARGUS ISLAND is located 22 miles southwest of Bermuda on Plantagenet Bank at 31°56'55"N,65°10'45"W. Plantagenet Bank is a seamount rising to within a nearly uniform 60 meters of the surface. The dimensions of the Bank are 5 km in the east-west direction and 8 km in the north-south direction. ARGUS ISLAND is located approximately 2 km within the southern edge of the Bank in 58.5 meters of water (Pickett and Beckner, 1966). The tower has oceanographic and meteorological sensors. Oceanographic data are obtained by lowering sensors on instrument guide cables to desired depths.

Sensors

Wave Staff: A wave staff manufactured by Atlantic Research Corp. consists of a nichrome wire (resistance 3.3 ohms/m) stretched under 18 million dynes of tension along the axis of a 15-meter long cylindrical monel tube. The tube is slotted every 10 cm along its length to allow sea water access to the wire. The staff is normal to the sea surface and half submerged. The nichrome wire is electrically shorted to the tube as sea water passes through the slots. Waves up to 15 meters in height register as a change of resistance. A sea surface profile accurate to ±15 cm is obtained (Pickett, 1964).

Thermistor Chain: The thermistor chain temperature-measuring system consists of a vertically submerged electrical cable. Thermistors are located at intervals of 3 meters. The resistance of each thermistor is inversely proportional to the water temperature. Output is measured with an accuracy of ±0.05°C and recorded on magnetic tape. Each thermistor is recorded once a minute.

Anemometer: A Bendix-Friez anemometer, located 43 meters above the sea surface, records wind velocity continuously on strip-chart recorders located at several positions on the tower.

Solar Radiometers: Solar radiation measurements for determining heat budget are obtained with Eppley pyrheliometers and a Thornthwaite net radiometer. These sensors are mounted on a 6-meter-long beam extended from the tower over the water.

The pyrheliometer measures incoming and reflected solar radiation (0.3- to 2.5-microns wavelength) and consists of a thermopile mounted beneath thin black-and-white concentric rings. White rings are coated with magnesium oxide which has a high reflectance and black rings are coated with Parson's Optical Black, which has a high absorption nature. A temperature differential proportional to the intensity of radiation generates a voltage difference across the thermopile.

The net radiometer measures the difference between total incoming radiation and total reflected radiation. A protected thermopile is also used in this sensor. Both the upper and lower surfaces are finished with flat black paint to permit uniform absorption of long- and short-wave radiation. The temperature difference between the upper and lower surfaces is proportional to the difference between incoming and reflected solar radiation.

Current Meters: Current measurements at ARGUS ISLAND are obtained with a combination Savonius rotor current meter and Hytech current direction-finder. One pair of instruments was located at a depth of 8 meters and another at 30 meters. The plastic Savonius rotor transmits pulses to a surface receiver. Current speed is proportional to the number of pulses per second (Beckner, 1966). The direction-finder consists of a movable vane which alines itself with the direction of the current and transmits its alignment relative to a magnetic compass.

Fluorometer: The portable dye-monitoring equipment consists of a Turner Model-111 fluorometer. The equipment is operated from a small boat so that measurements can be taken throughout a dye patch. Dye concentrations are measured by exciting the dye molecules in a water sample to fluorescence with the green line (0.546 micron) of mercury. The intensity of fluorescence is proportional to the concentration of dye. The fluorometer contains an optical bridge which measures the difference between light emitted by the sample and that emitted by a reference source. A single photomultiplier views light alternately from the sample and a reference, and generates a proportional electrical signal. A recorder indicates the concentration of dye in the sample (Fisher and Gallagher, 1962).

GENERAL PROCEDURE

Cape Hatteras to Bermuda

The NASA and ASWEPS aircraft departed Elizabeth City, North Carolina, on 6 March 1966. Simultaneous infrared scanner, microwave, and radiation thermometer measurements and multiband photography were obtained over the Gulf Stream near Cape Hatteras (figure 4).

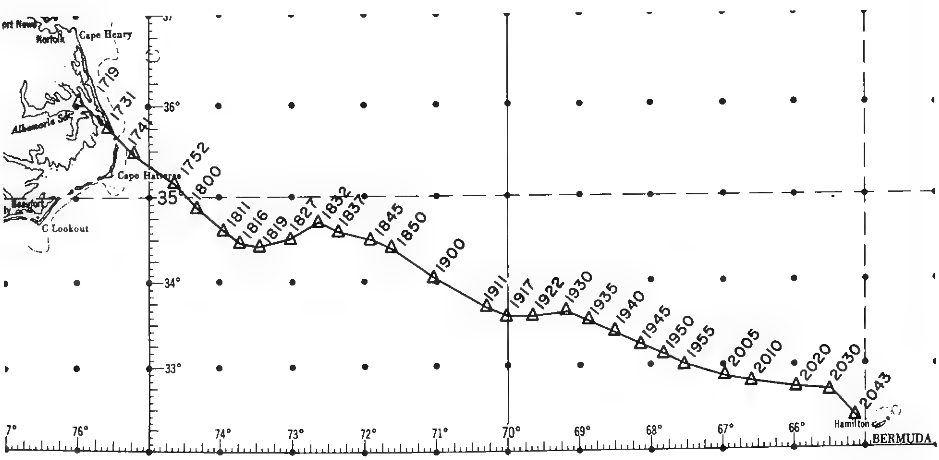


Figure 4 Flight Track, U. S. to Bermuda—6 March 1966

Both aircraft flew at an altitude of 300 meters; the NASA aircraft was approximately 0.8 km directly behind the ASWEPS aircraft. Air speed was 350 km/hour. After crossing the Gulf Stream the ASWEPS aircraft descended to an altitude of 150 meters. Simultaneous wave profile, scatterometer, and microwave measurements were obtained along the track shown in figure 4.

Bermuda

On 7 March 1966 both aircraft flew a series of flight tracks (figure 5) over ARGUS ISLAND to obtain scatterometer and radar wave profile measurements. The ASWEPS aircraft flew at an altitude of 150 meters; the NASA aircraft flew at 215 meters and approximately 1.6 km behind the ASWEPS aircraft. The first track was flown downwind and the second track upwind. Six additional tracks were flown, each 45° to the right of the preceding track. The ARGUS ISLAND wave recorder was operated continuously during these flights.

Both aircraft flew patterns (figures 6 and 7) on 8 and 10 March to obtain surface temperature data. The flight tracks extended from Bermuda over Challenger and Plantagenet Banks and terminated over deep water. Simultaneous radiation thermometer and infrared scanner measurements were made. Infrared color and multiband photographs were also obtained. On both days the ASWEPS aircraft flew at an altitude of 550 meters, and the NASA aircraft flew at 490 meters and approximately 0.8 km directly behind the ASWEPS aircraft.

The two aircraft flew a series of flights over ARGUS ISLAND on 10 and 11 March at altitudes of 150, 300, 610, 1,520, 3,050, and 4,120 meters to determine the effect of altitude upon microwave radiometer and radiation thermometer measurements. Flights were made on the afternoon of 10 March and before dawn on 11 March.

A dye study was conducted on 9 March 1966 near ARGUS ISLAND. One hundred and fifteen liters of a fluorescent dye (Rhodamine-B) were released 0.5 km northwest of ARGUS ISLAND at 1350Z. Surface concentrations were monitored from a boat with the fluorometer for 4 hours, while aerial photographs of the dye patch were made with the multiband and infrared color cameras.

Bermuda to Cape Hatteras

Simultaneous radiation thermometer and infrared scanner measurements were obtained over the Gulf Stream in the Cape Hatteras area along the return flight path (figure 8) on 12 March 1966. Both aircraft flew at an altitude of 300 meters with the NASA aircraft approximately 0.8 km directly behind the ASWEPS aircraft. Air speed was 350 km/hour.

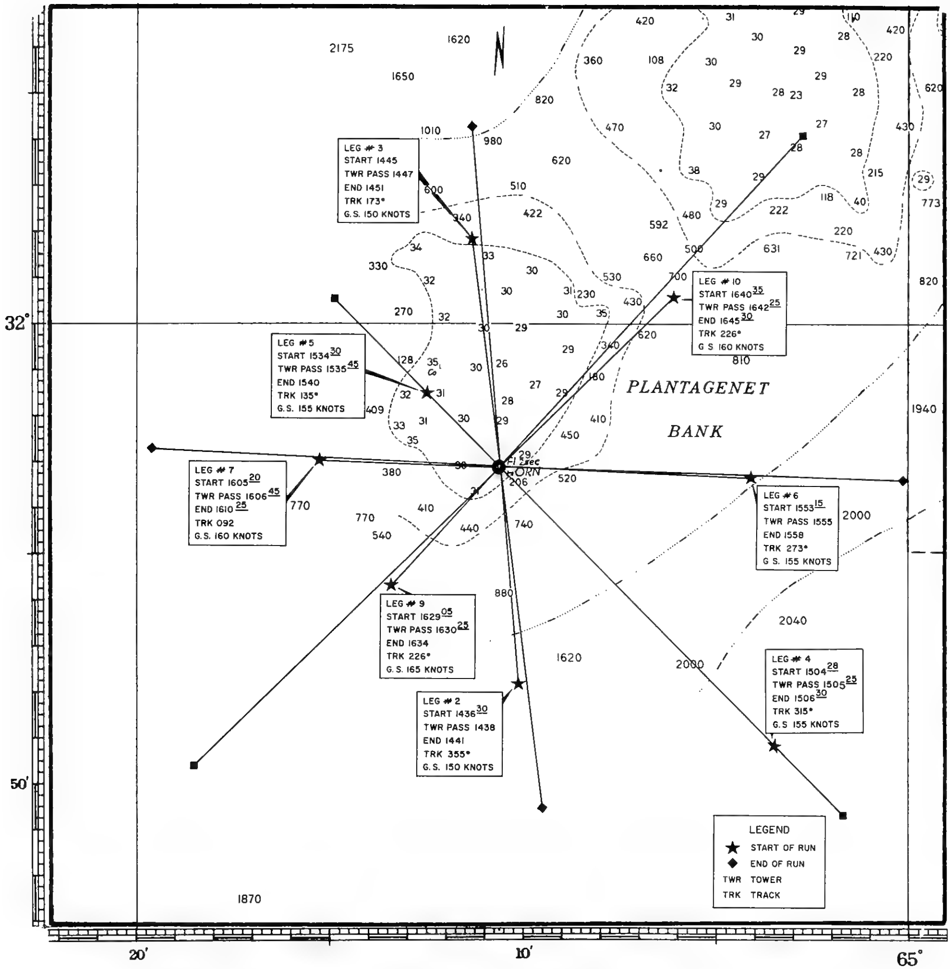


Figure 5 Flight Tracks to Obtain Wave Height Measurements—7 March 1966

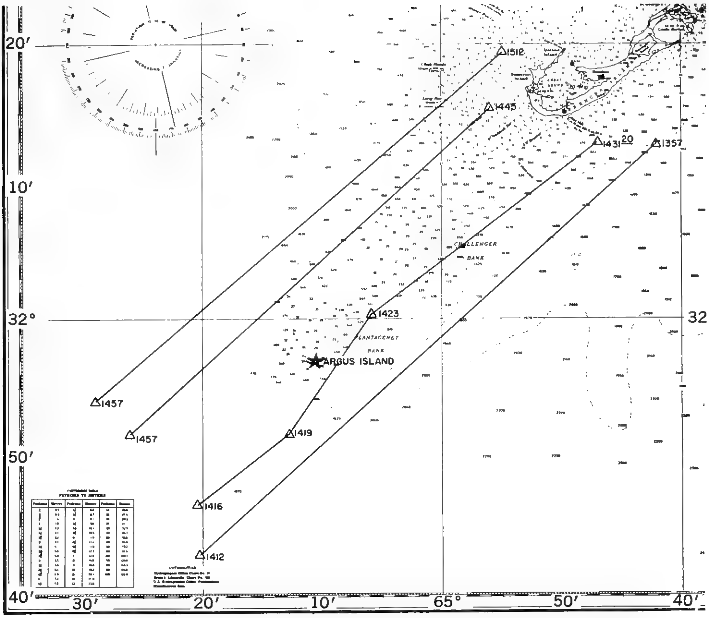


Figure 6 Sea Surface Temperature Flight Track—8 March 1966

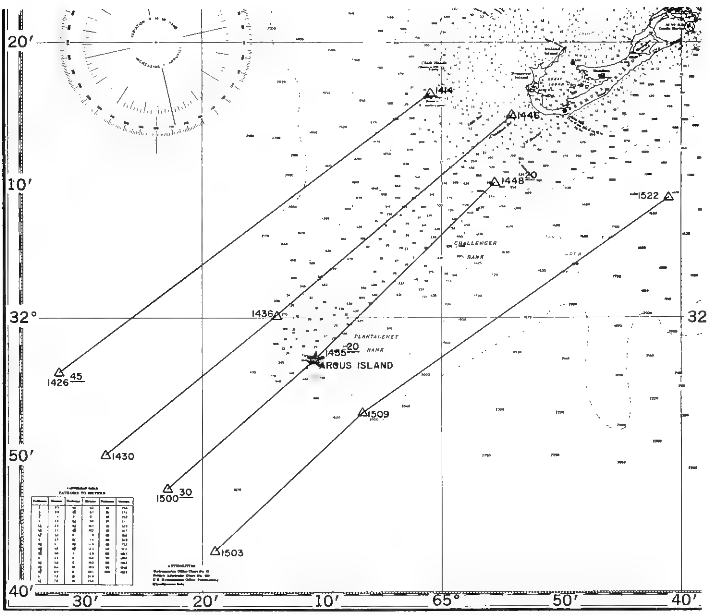


Figure 7 Sea Surface Temperature Flight Track—10 March 1966

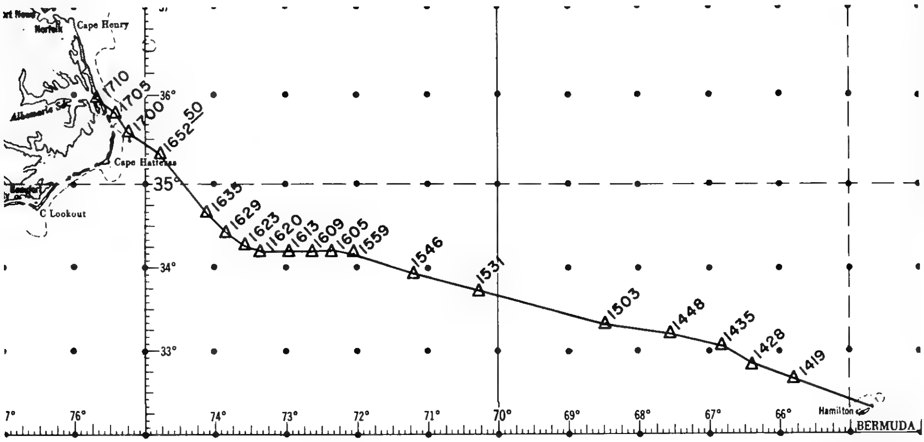


Figure 8 Flight Track, Bermuda to U. S.—12 March 1966

EXPERIMENTS

Infrared Measurements

General

The amount of radiation emitted from the sea surface is proportional to the fourth power of its absolute temperature. For the usual range of ocean temperatures (275°-305°K) this radiation is in the infrared portion of the spectrum. Maximum radiation occurs around 10 microns.

Infrared radiation is strongly absorbed by water vapor in the atmosphere. There are, however, certain zones called "windows" through which infrared radiation is propagated with minimum loss. One such window exists between wavelengths of 8 and 14 microns—the region of the maximum intensity of radiation from the sea. The airborne radiation thermometer measures sea surface temperature by comparing the infrared radiation emitted from the sea in this 8- to 14-micron region to an internal reference source.

The infrared scanner does not measure temperature but merely determines relative infrared intensities within an area. The mechanism scans areas on both sides of the flight path. The result is a thermal contrast image of an area (HRB Singer).

The radiation thermometer and infrared scanner were operated simultaneously over the northern boundary of the Gulf Stream to compare the response of the two instruments to large thermal gradients. At Bermuda, both systems were operated over ARGUS ISLAND to compare their response to small thermal contrasts. In addition, radiation thermometer measurements were made at relatively high altitudes over ARGUS ISLAND during daytime and nighttime flights in order to determine altitude and diurnal effects on the absolute accuracy of this device.

Results

Cape Hatteras to Bermuda: Radiation thermometer and infrared scanner data of 6 March 1966 are shown in figure 9. The tracks were a northwest to southeast transect of the northern boundary of the Gulf Stream near Cape Hatteras.

The radiation thermometer record (top figure 9) shows that the Gulf Stream's northern boundary consists of a series of thermal steps. There are three major steps and a minor step to the southeast. The gradient in each step was a nearly uniform 4.2°C/km. The actual gradient was probably stronger since the radiation thermometer time constant (about 2 seconds) limits any gradient to about 4.2°C/km. The total temperature steps (progressing from northwest to southeast) were 2.0°, 1.3°, 4.0°, and 0.3°C.

Flight Over ARGUS Tower: Figure 10 shows the results of a north-to-south flight over ARGUS ISLAND with the radiation thermometer on 8 March. The tower appears as a spike near the middle of the radiation thermometer record.

The radiation thermometer shows a fairly smooth temperature distribution in the water around the tower with a warming trend to the north. Since the shallow water of Plantagenet Bank lies north of the tower, the 0.3° to 0.4°C warming trend is probably a result of insolation in this area. This warmer region did not appear on the scanner record owing to the small gradient.

Bermuda to Cape Hatteras: On the return flight on 12 March, the northern boundary of the Gulf Stream was crossed at about 1700Z (figure 11). The flight pattern duplicated the outbound track on 6 March.

The radiation thermometer record (top figure 11) shows the Gulf Stream (on the right) to be about 21°C. Near the boundary the temperature began to drop gradually, then rapidly, until approximately 13°C. From the appearance of the record, the 13°C water is apparently a cold band intruding into the uniformly cooling interface water.

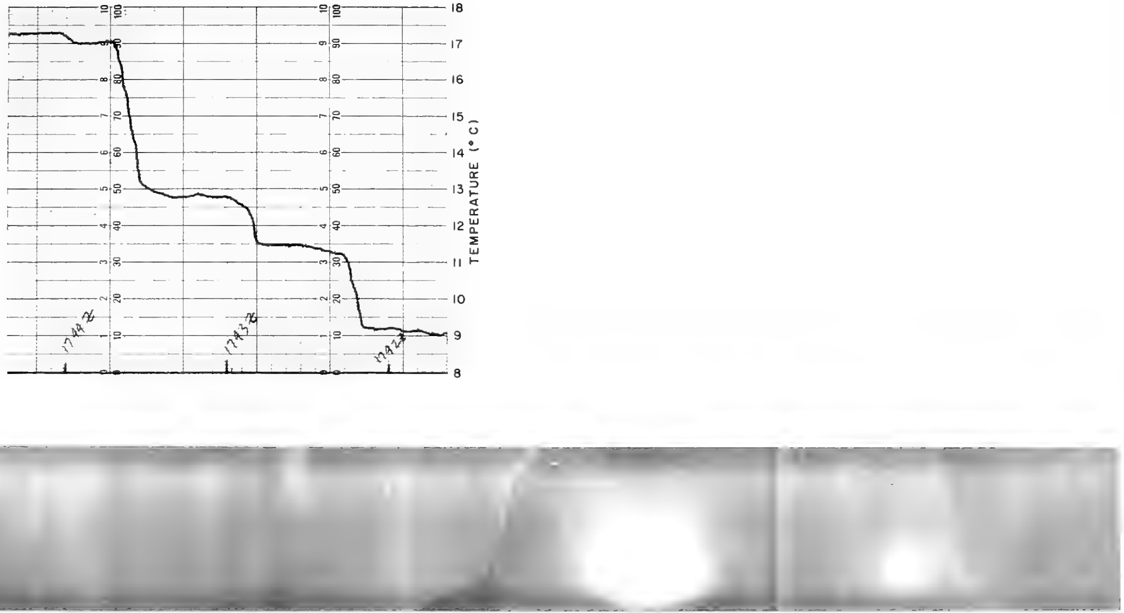


Figure 9 Radiation Thermometer and Infrared Scanner Records Over Gulf Stream—
6 March 1966

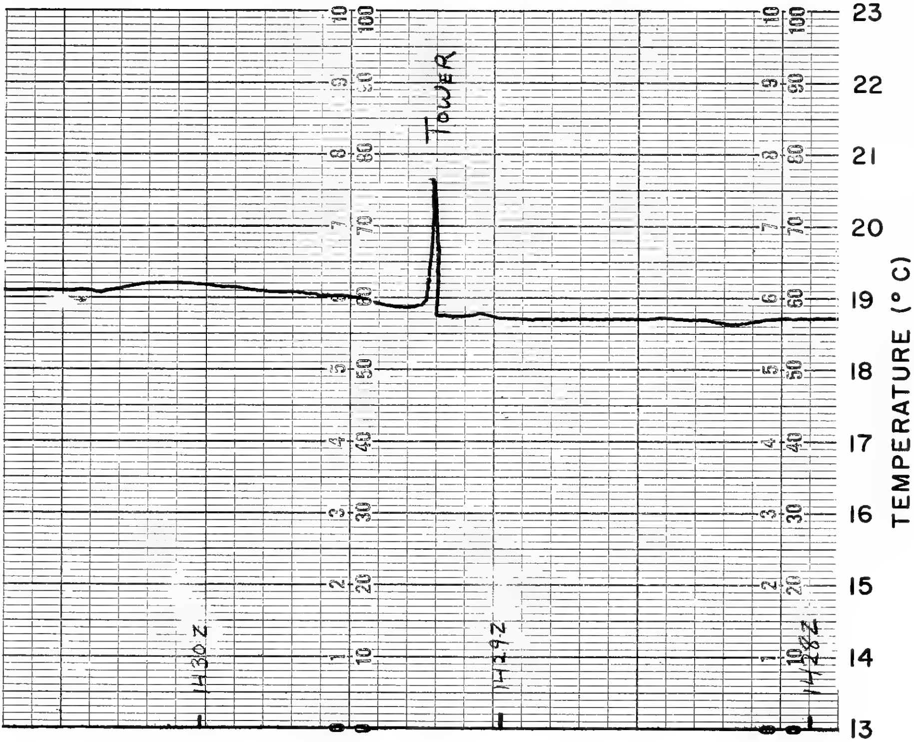


Figure 10 Radiation Thermometer Record Over ARGUS ISLAND— 8 March 1966

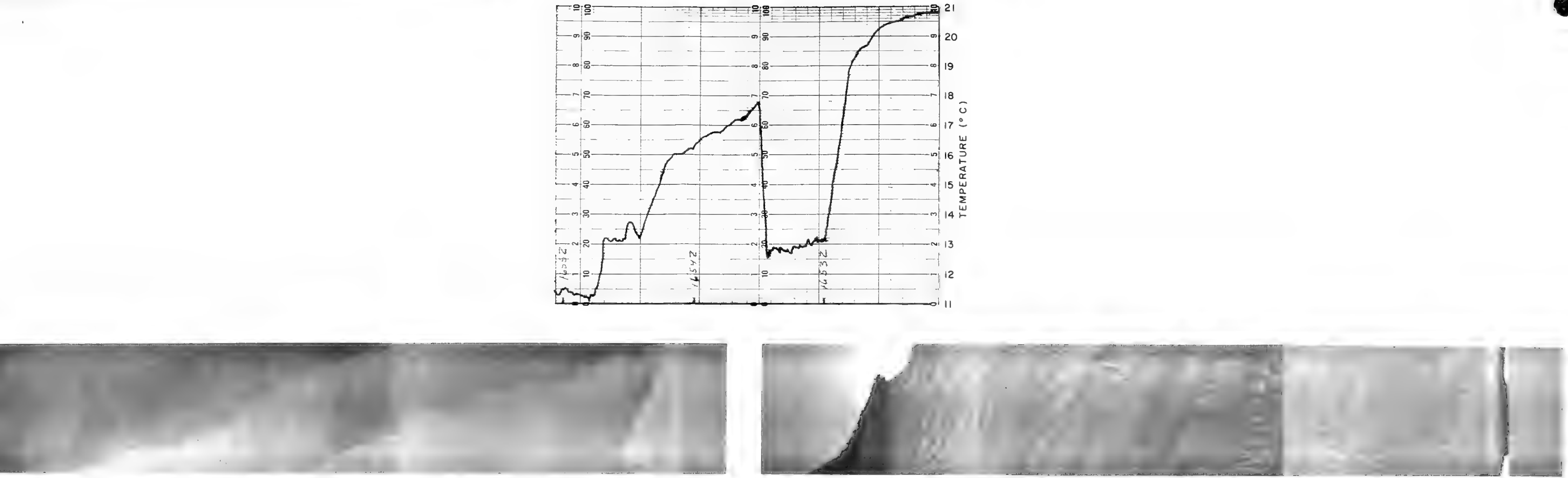


Figure 11 Radiation Thermometer and Infrared Scanner Records Over Gulf Stream—
12 March 1966

The scanner image (bottom figure 11) shows incredible detail. The first sharp temperature drop appears as a perpendicular band at the right side of the film strip. Within the cold region there are many small bands about 50 meters in width. Toward the right these small bands are randomly oriented and toward the left they are parallel to the temperature step. The left edge of the cold band is alined along 080°T.

Further to the left (northeast) there is an homogeneous warm region. The radiation thermometer shows that this water is cooler toward the left. The scanner does not show these weak gradients.

Still further northeast, other bands are detectable on the scanner as the water cools. At the extreme upper left (northeast) edge of the record, the water has cooled to about 11°C.

High Altitude Flights: Flights were made at altitudes up to 3 km from 1500 to 1600Z 10 March and up to 2.5 km from 0600 to 0700Z 11 March. ARGUS ISLAND provided surface temperatures for each pass. A plot of radiation thermometer error (surface temperature minus radiation thermometer) for both flights is shown in figures 12 and 13. The least-squares regression lines are also shown. Weather charts indicated no major change in meteorological conditions during or between these flights. During both flights the sky was clear and the wind was from 030°T at 7.7 m/sec. The difference between daytime and nighttime data must arise, therefore, from diurnal effects on the infrared radiation.

During the daytime flights, the radiation thermometer error increased about 0.9°C/km of altitude. Extrapolation to the surface yields a negative bias of 1.2°C for the radiation thermometer. This error is removed in routine flights by application of an environmental correction (Pickett, 1966).

At night, the error increased by 1.6°C/km of altitude. Thus, the nighttime error appears to increase with altitude almost twice as fast as the daytime error. Extrapolation to the surface gives a negative bias of only 0.1°C for the nighttime data. Nighttime errors are small at low altitudes but increase more rapidly with altitude than the daytime error. This suggests that there is more water vapor at low levels during the day and that night flights at low altitudes will yield optimum accuracy.

Conclusions

The infrared scanner shows detail in regions of very strong temperature gradients but is of limited value in regions of moderate gradients. Even in regions of strong gradients, however, the scanner shows only thermal contrast between adjacent regions. The radiation thermometer, on the other hand, does not have two-dimensional coverage but yields reasonably accurate measurements.

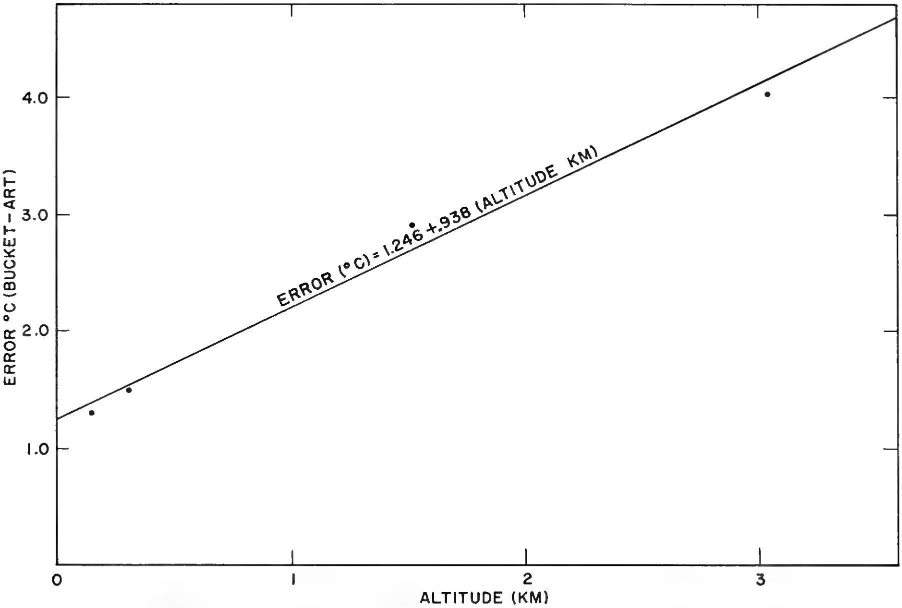


Figure 12 Radiation Thermometer Error as a Function of Altitude—Daytime

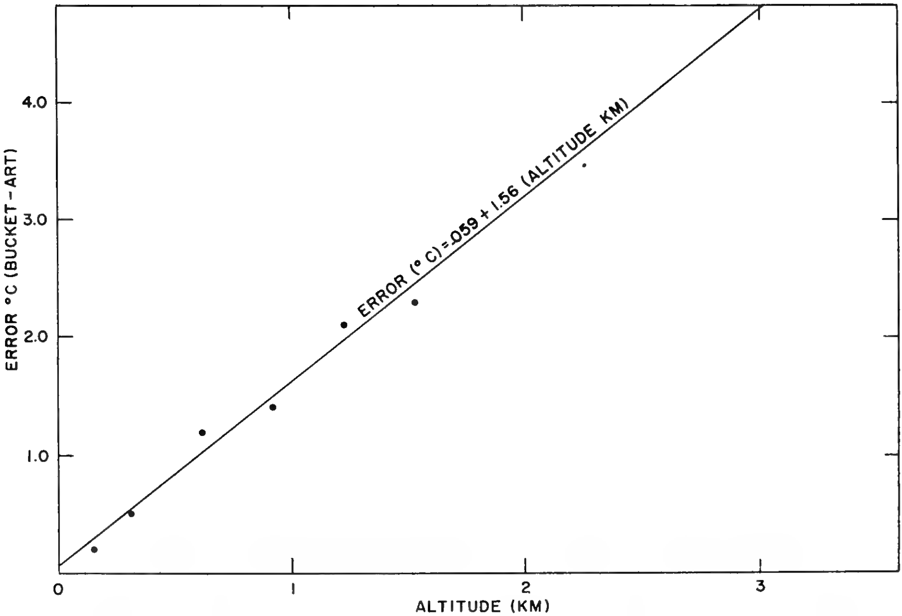


Figure 13 Radiation Thermometer Error as a Function of Altitude—Nighttime

Use of either system for collecting oceanographic data from a satellite presents the problem of extensive atmospheric interference. In the case of the radiation thermometer, the data from higher altitudes indicate a formidable problem. Corrections would change with daytime and nighttime observations and with meteorological conditions. Observations could not be made during rain, fog, or cloudy skies.

The altitude effect is not as important for the infrared scanner. The NIMBUS II infrared scanner, for example, could detect the Gulf Stream when skies were clear (Wilkerson, 1967). The Reconofax IV infrared scanner was used in this experiment. Similar experiments should be performed with later model scanners. Data should be acquired at various altitudes over other strong currents, such as the Kuroshio and Agulhas Currents, to determine if these currents can be defined as easily as the Gulf Stream.

Radiation thermometer data should also be acquired from high altitudes over a surface vessel equipped with a radiation thermometer in order to determine water vapor corrections for high-altitudes.

Dye Tests

Description

The primary objective of the dye experiment was simultaneous sampling and photographing a Rhodamine-B dye patch with different filters and films to determine the optimum combination for maximum contrast between dyed and undyed water.

A secondary objective was determination of which characteristics of a water mass can be measured from a time series of aerial photographs of dye. During the photography, changes in dye concentrations were monitored with a fluorometer from a small boat so that the relationship between area and concentration could be calculated. Water samples collected hourly after the dye release were analyzed for dye content. By tracing the movement and concentration of the dye patch with the boat and by continuously recording wind and currents at ARGUS ISLAND, the measured characteristics of the surface circulation were related to the time series of photographs.

Results

Figure 14 shows dye patch photographs in the nine frequency bands of the Itek camera. The greatest contrast occurred in band 4. This band has maximum sensitivity at 0.560 micron and extends from 0.550 to 0.620 micron (cutoff based on 1-percent transmittance levels). Thus, the maximum separation of the reflectance spectra of sea water and sea water containing Rhodamine-B dye occurs near 0.560 micron (the yellow-green region).

Examples of photographs from the RC-8 camera are shown in figure 15. These photographs were taken at intervals of 0.2, 4.3, 32.9, and 259.9 minutes after dye release. The irregular nature of the flow is evident.

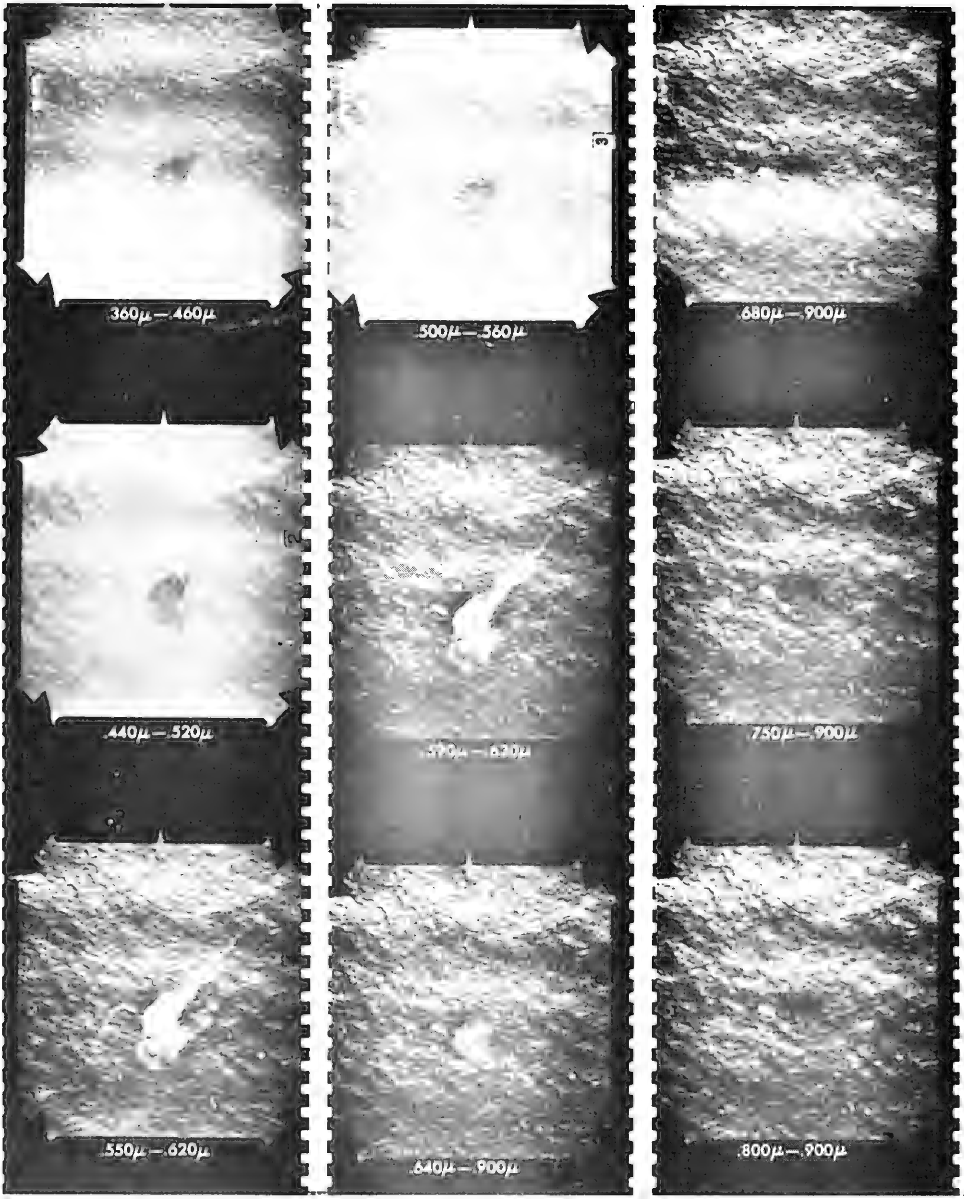
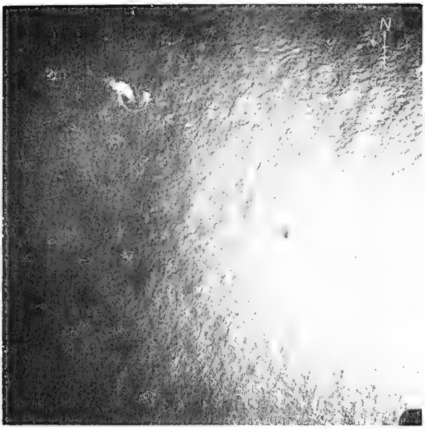
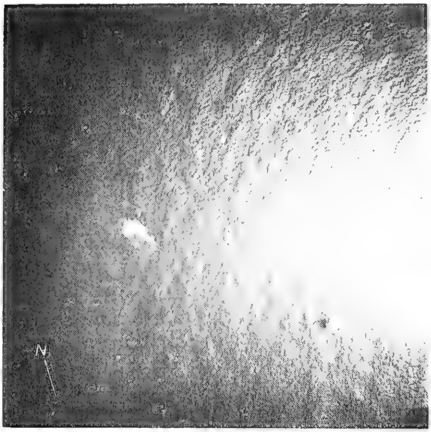


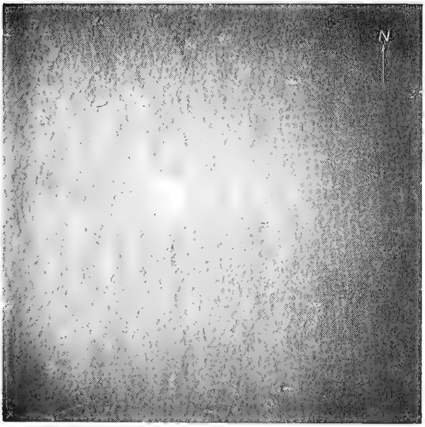
Figure 14 Multiband Exposure of Rhodamine-B Dye in Vicinity of ARGUS ISLAND— 9 March 1966; Altitude 3,000 feet



0.2 Minutes



4.3 Minutes



32.7 Minutes

259.9 Minutes

Figure 15 Rhodamine-B Dye After Release; Altitude 3,000 feet

Figure 15B shows two plumes moving rapidly toward 150° with speeds up to 0.40 meters per second. In figure 15C the main patch has caught up with the plumes. In figure 15D a large diffused plume again projects from the main dye patch. These photographs suggest turbulent flow accompanied by near-surface jets.

Data recorded at ARGUS ISLAND during this period are shown in appendix A. The values averaged over the hour following dye release were: wind toward 150° at 7.7 m/sec, current at 8-meter depth toward 210° at 0.20 m/sec, and current at 30 meters toward 130° at 0.12 m/sec.

Judging from the area of greatest concentration, the set of the dye patch was initially toward the southeast. Within 30 minutes, however, the direction had changed slightly and the patch drifted more southward. The initial set of the dye patch was apparently due to wind action on the surface layer of water. After the dye diffused downward it began to move more in agreement with currents at the 8-meter depth.

The area and concentration of the dye patch determined from photography are shown in figure 16. Appropriate least-squares regression lines are also shown. The areas were determined from aerial photography, and concentrations were measured from the boat. The area increased linearly during the 5-hour period; concentration decreased as the negative 2.5 power of time.

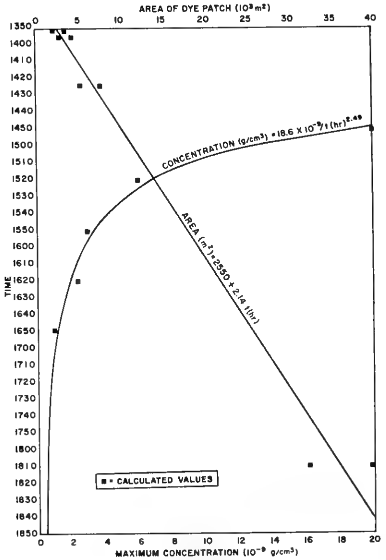


Figure 16 Characteristics of Dye Patch as a Function of Time

If the dye patch is described by a mean radius $\bar{R}$, the surface area can be expressed as:

$$\text{Surface area} \propto \bar{R}^2$$

and from observations:

$$\text{Surface area} \propto T$$

where T is time elapsed after dye release.

Therefore, $\bar{R} \propto T^{0.5}$

The concentration data can be expressed as:

$$\text{Concentration} \propto \frac{1}{\text{volume of dye}} \propto \frac{1}{\bar{R}^3}$$

and from observation:

$$\text{Concentration} \propto T^{-2.5}$$

Therefore, $\bar{R} \propto T^{2.5/3.0}$

or: $\bar{R} \propto T^{0.8}$

The two results are:

From area measurements: $\bar{R} \propto T^{0.5}$

From concentration measurements: $\bar{R} \propto T^{0.8}$

The more rapid increase of radius by the concentration measurements implies that the dye is sinking.

In summary, the measurements indicated turbulent mixing processes; presence of near-surface jets; that the dye first followed the wind, then the current; that the dye was sinking; and that motion in the surface waters approximated an Ekman spiral.

Conclusions

Certain characteristics of the water flow can be estimated from aerial photographs of dye patches. These include nature of the flow (turbulent or laminar), the mean flow (if a reference point is available), and the amount of near-surface shear. If surface concentration measurements are available, the vertical motion might be estimated. The photographs indicated that Rhodamine-B dye is best photographed with a high-speed black-and-white film with a filter centered at 0.560 micron.

Other dye experiments should be made at higher altitudes with photographs made from various angles using the 0.560-micron band. Experiments could be extended to areas of swift currents using air-dropped, sintered dye bricks. If high-altitude experiments show good contrast in the 0.560-micron band then experiments at orbital altitudes should be attempted.

Microwave Radiometers

Description

A microwave radiometer detects electromagnetic energy emitted in the microwave region. The energy available in this region of the spectrum is about one ten-thousandth of that available in the infrared region; however, powerful amplifiers are used for microwave frequencies. Theoretically, microwaves can penetrate clouds to measure ocean temperature.

Four microwave radiometers were operated over the Gulf Stream on the flight tracks shown in figures 4 and 8 and during the thermal grid flight track (figures 6 and 7). In addition the radiometers were used at a variety of altitudes, weather, roll, and day-night tests over water. The radiometers were operated with vertical polarization and a 45° grazing angle.

Results

The 9.3-GH_z radiometer failed to operate during the experiment, the 34.0-GH_z radiometer was too noisy to be read, and the magnetic tape recording system was unsatisfactory. Judging from the strip chart, the 15.8- and 22.2-GH_z radiometers did not respond to the temperature change across the northern wall of the Gulf Stream. Both radiometers, strongly affected by roll motion, deflected toward higher radiation levels when the aircraft turned, when flown over land masses, and when flown into rain. In the altitude range of 150 to 4,120 meters the 15.8- and 22.2-GH_z radiometers were increasingly deflected toward higher radiation levels with increased altitude. The 22.2-GH_zradiometer, which operates at a dipole resonance line of water vapor, was deflected less than the 15.8-GH_z radiometer.

Conclusions

The microwave experiment was incomplete owing to recurrent failures in the system. The experiment should be repeated when the microwave system has been repaired and tested.

Wave Detection

Description

The objective of the wave experiment was to compare sea surface characteristics measured by the scatterometer, the wave staff, and the radar wave profiler. The wave staff is an electrical resistance-wire device which records heights of surface waves; the radar profiler is a high-resolution altimeter that determines height of the sea surface from an aircraft; the scatterometer measures the intensity of a reflected radar beam.

Statistical properties of the sea surface vary with time and space. A fixed sensor, such as a wave staff, yields information on the temporal variability of the sea surface at one point. Both aircraft systems, however, move so rapidly over the sea surface that they yield information with spatial variability that is essentially free of time changes.

For this experiment, the wave staff at ARGUS tower operated continuously while the other recorders were flown in a crisscross pattern above the tower. The result was a star-shaped flight track, the center of which was located over the tower.

A curve of scattering versus depression angle was plotted for all legs of the scatterometer track. Wave power spectra (frequency versus variance) were computed along the radar wave profiler track and for the wave staff on ARGUS. These space and time spectra were then compared to the scatterometer reflectivity curves. Figure 17 is an example of a scatterometer reflectivity plot.

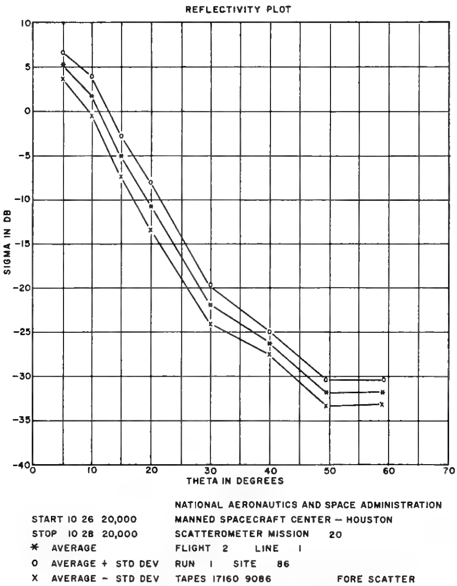


Figure 17 Example of a Scatterometer Reflectivity Plot

Results

The values of variance obtained from the wave staff were:

	DATE	VARIANCE
1430-1450	7 March 1966	0.32 m^2
1450-1510		.35
1510-1530		.37
1530-1550		.42
1550-1610		.39
1610-1630		.45

Application of an F test at the 95-percent confidence level shows a significant increase in the energy of the sea surface during the experiment.

The wave staff spectra show that the sea was a mixture of swell with energy around 11 seconds and sea with energy around 7 seconds. Toward the end of the observation period, the sea portion of the spectra increased considerably and produced the significant increase in variance.

The airborne wave profiler showed that the field was not homogeneous. The significant change in variance along the northeast-southwest legs (.26 m^2 to .36 m^2) probably resulted from shoaling of waves as they moved into the area northeast of the tower. The significant variation between legs is expected, owing to the attitude of the flight track relative to wave progression.

The reflectance curves from the scatterometer were similar, regardless of the path or position within the wave field. Furthermore, fore-and-aft scatter patterns were generally similar throughout the area. There was no significant change in reflectance anywhere in the pattern for observation angles near the nadir.

At 30° and 55° angles from nadir there was a significant change in reflectance between legs. For 30° angles from nadir, the maximum reflectance occurred on a southwest to northeast track, and minimum reflectance occurred on a northwest to southeast track. For 55° angles from nadir, the maximum reflectance occurred on a northwest to southeast track, and the minimum reflectance occurred on a southeast to northwest track.

Conclusions

Since the wave field was neither stationary nor homogeneous, the response of the scatterometer to simple variations of sea state could not be tested. However, certain characteristics of the scatterometer are evident. Variations in reflectance of the sea surface between waves is comparable to variations caused by moderate sea state or incident angle changes. Thus wave-to-wave variations in reflectance are of the same magnitude as moderate (but significant) changes in sea state.

No relationship between variations in reflectance and sea state or angle of incidence could be found. This, however, could have arisen from the mixed sea that was present during the experiment.

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APPENDIX A

ARGUS ISLAND TOWER

REFERENCE DATA

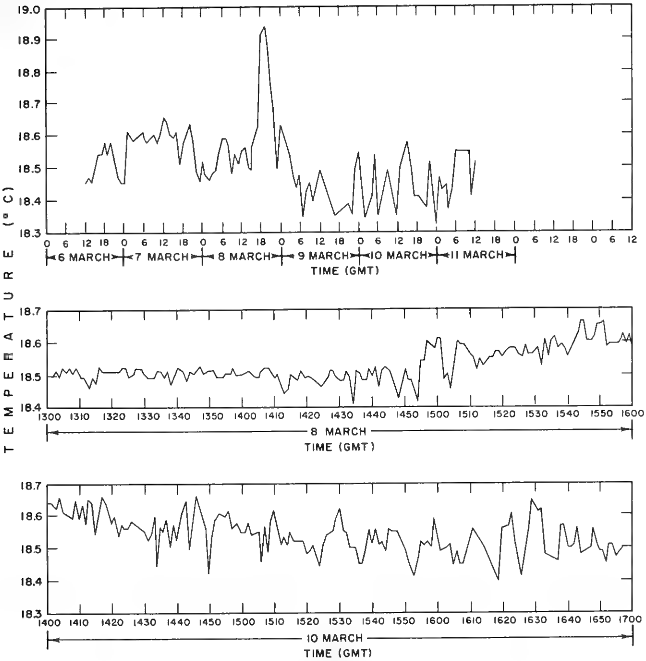

FIGURE A-1 Sea Surface Temperature, ARGUS ISLAND 6—11 March 1966

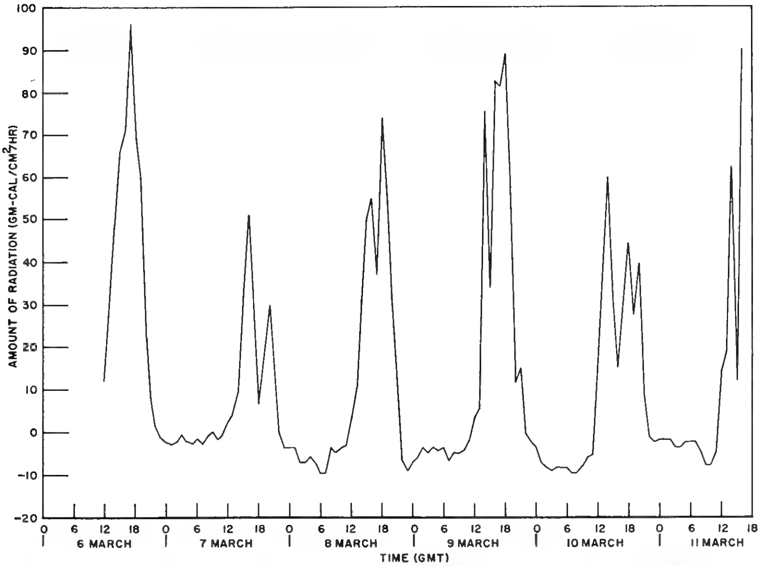

FIGURE A-2 Total Flux (Net Radiation), ARGUS ISLAND 6—11 March 1966

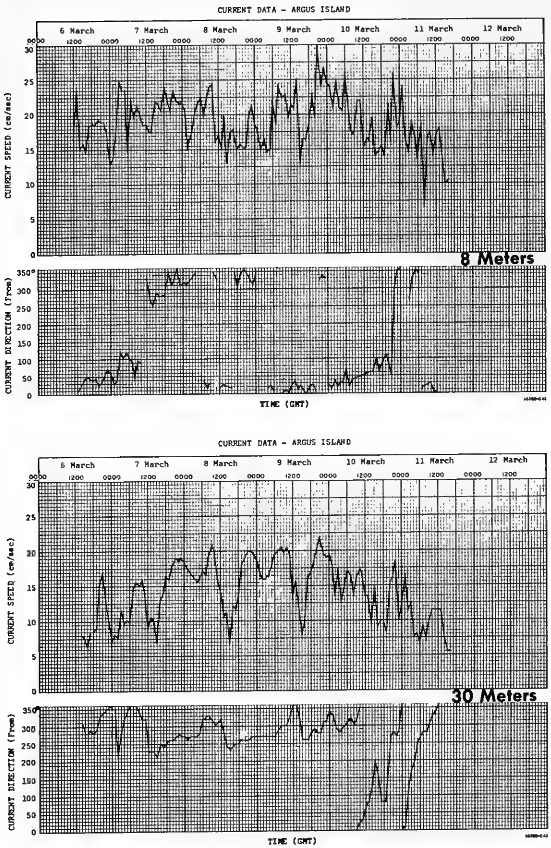

FIGURE A-3 Current Speed and Direction, ARGUS ISLAND 6—11 March 1966

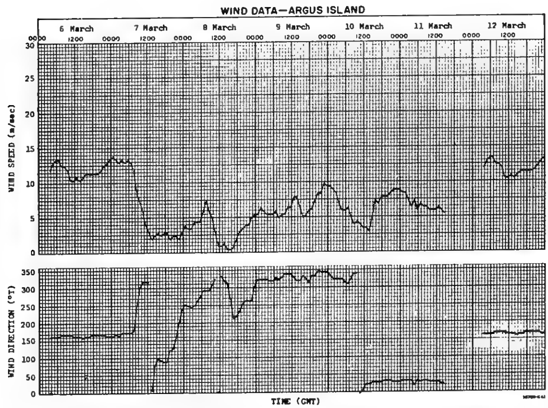

FIGURE A-4 Wind Speed and Direction, 47 Meters, ARGUS ISLAND 6—12 March 1966

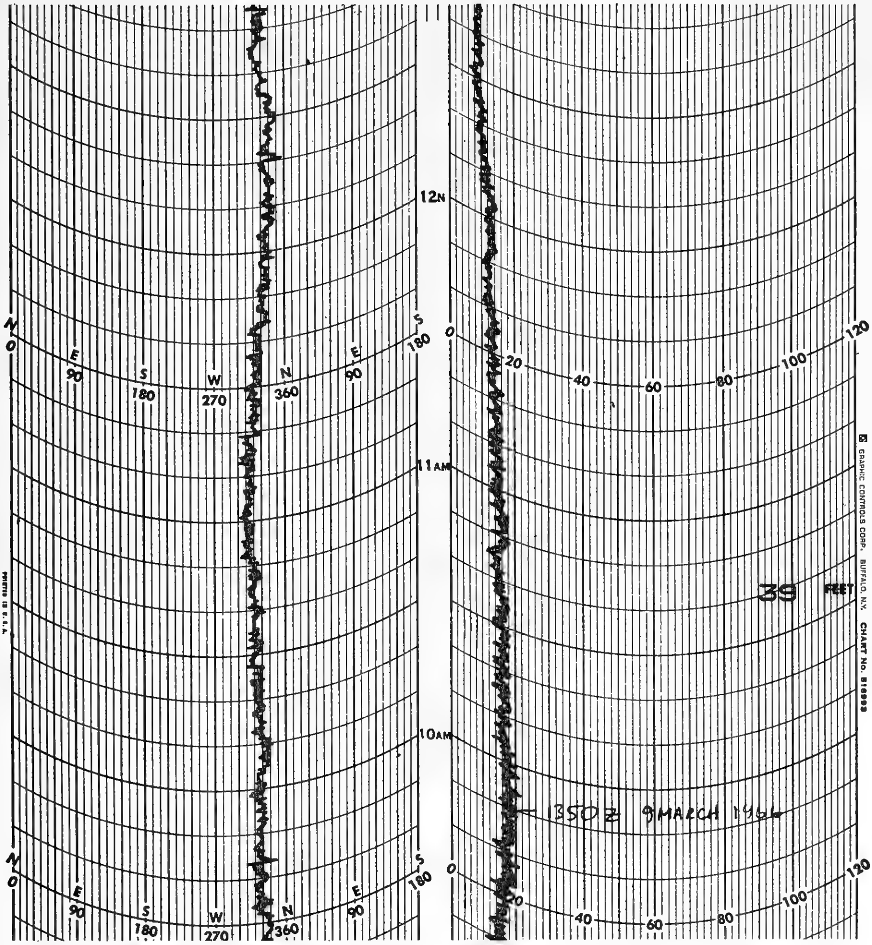

FIGURE A-5 Wind Speed and Direction, 47 Meters (Knots, °T), ARGUS ISLAND 9 March 1966

U.S. Naval Oceanographic Office
COMPARISONS OF REMOTE AIRBORNE OCEANOGRAPHIC SENSORS by C.F. Beckner, Jr., July 1968. 39 p., including 22 figs. (TR-204)

Compares a number of remote sensors to determine feasibility of using them for detecting oceanographic features. Includes infrared scanner, infrared radiation thermometer, radar scatterometer, radar wave profiler, and microwave radiometer. Aerial photographs of a Rhodamine-B dye patch were also made to determine flow characteristics.

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2. Remote oceanographic sensing
3. Instrumentation

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13. ABSTRACT

This report compares a number of remote sensors to determine the feasibility of using these sensors for detecting oceanographic features from space. The sensors include an infrared scanner, infrared radiation thermometer, radar scatterometer, radar wave profiler, and a microwave radiometer. Two aircraft flew a series of flight tracks across the Gulf Stream near Cape Hatteras and over ARGUS ISLAND Tower located southwest of Bermuda. The sensors were compared and evaluated by means of simultaneous measurements.

In addition, a quantity of Rhodamine-B dye released in the water was photographed to determine if certain characteristics of water flow could be estimated from aerial photographs.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
AIRCRAFT						
NAVAL AIRCRAFT						
OCEANOGRAPHIC AIRCRAFT						
RECONNAISSANCE PLANES						
RESEARCH PLANES						
ART						
(Airborne Radiation Thermometer)						
EARTH RESOURCES SATELLITES						
ELECTRONIC EQUIPMENT						
ELECTRONIC RECORDING SYSTEMS						
EXPERIMENTAL DATA						
INFRARED EQUIPMENT						
INFRARED DETECTORS						
MEASUREMENT						
METERS						
THERMOMETERS						
INFRARED THERMOMETERS						
OCEANOGRAPHIC EQUIPMENT						
INFRARED IMAGER						
MICROWAVE RADIOMETER						
RADIATION THERMOMETERS						
SCATTEROMETER						
WAVE PROFILER						
OCEANS						
RADAR EQUIPMENT						
SEA WATER						
SPACECRAFT OCEANOGRAPHY						
TEMPERATURE						
OCEANIC TEMPERATURE						