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Development and Testing of a Spectroradiometer for Measuring the Upwelling Spectral Irradiance of the Ocean

F I N A L R E P O R T

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This is the final report under National Aeronautics and Space Administration Contract NAS-12-2119. Funds became available under this contract about June 6, 1969.

Items 2 and 3 of the work statement of this contract required the carrying out of simultaneous measurements above and below the ocean surface to determine the effect of water surface reflection on the detection of surface chlorophyll.

This was to be done as a cooperative effort with Dr's. George Clarke and Gifford Ewing, who would make measurements with a TRW spectroradiometer from an aircraft at various altitudes above the ocean surface. At the same time the principal investigator would obtain measurements below the surface with the Scripps spectroradiometer. It was planned to do this experiment at Woods Hole Oceanographic Institution and the ship GOSNOLD was reserved for this purpose.

Approval was obtained to attend the conference on "The Color of the Ocean" (on August 5 and 6, 1969), which was a NASA/ERC supported program at Woods Hole Oceanographic Institution and was directly related to the work of the above referenced contract.

Approval was also obtained for Mr. R. W. Austin to attend this conference and for him to participate in the measurement program on the ship GOSNOLD.

We were at sea on the ship GOSNOLD during the period from August 13 to about the first of September and were able to obtain data on upwelling and downwelling spectral irradiance underwater for a large variety of chlorophyll concentration along a track from George's Bank to the northern part of the Sargasso Sea. We also obtained some data on spectral radiance from one meter above the water.

During the expedition the Woods Hole aircraft flew over the ship's position and obtained data with the TRW spectroradiometer. Surface chlorophyll concentration were obtained by means of an automatic recording fluorometer in accordance with Item 4 of the contract.

The data obtained by this Laboratory under contract NAS-12-2119 was processed and forwarded to Dr. George Clarke. We have not received all the data obtained from the aircraft and have consequently not been able to make any comparison or analysis of the combined underwater and above water data.

Item 1 of the work statement required that this Laboratory construct suitable instrumentation for airborne measurement of the spectroradiometric characteristics of ocean water.

Since continued cooperation with the effort being conducted at Woods Hole Oceanographic Institution was planned, it was desirable to have an instrument that would conform in its optical characteristics to the TRW instrument. In order to accomplish this the University of California entered into a bailment agreement with TRW Systems for the loan of one of their experimental spectroradiometers. The agreement provided that the University could modify the instrument in any way that did not adversely affect its performance as a spectroradiometer.

The agreement was written for one year, from about January 1, 1970 to January 1, 1971, and is renewable by consent of both parties.

The period from January 1, 1970 to about the end of April was spent in modification of the TRW instrument optically and electronically and in acquiring the remaining components necessary to complete it as an instrument for airborne use. The modifications of the TRW system were as follows:

I. Optical

A. Scanning slits.

The scanning wheel has 15 slits which scan the spectrum in rotation. As received, seven of these slits had dual-color filters for wavelength indentification. The color filters have been removed, identified and safely stored. A didymium filter was installed over one of the 15 slits for backup wavelength verification.

B. Light leaks were found and were blocked with black tape. Some improvement was made in the baffling between the window and the objective lens.

C. Wavelength indication.

A small lamp was mounted behind a pinhole and a photo-diode mounted behind a second pinhole to receive the emitted light. This subassembly was mounted astraddle the edge of the wheel so that the slits would pass between the two pinholes and an electrical pulse would be generated with the passage of each slit. A timing adjustment allows the setting of the leading edge of the pulse to appear when the scan is at 400 nm. A second lamp-diode assembly is used to indicate 700 nm.

An additional slit was machined in the scan wheel. This slit is inside the radius of the scan slits and is used with a third lamp-diode assembly to produce a pulse each revolution of the scan wheel. The timing of this pulse is adjusted to make the leading edge occur after the scan of the slit with the didymium filter and before the start of the next slit scan.

II. Electronic

A. Photomultiplier.

1.) The photomultiplier was completely rewired and all the resistors replaced with high quality resistors.

2.) An operational amplifier was installed and used in the transresistive configuration to sense the anode current signal and provide a proportional voltage output signal.

B. Logic circuit.

1.) Start-stop circuit. When "Reset" and "Start" button are pushed, the circuit waits until the start pulse immediately following the scan of the didymium filter and then provides the logic to start the recording of the data. After one full cycle of the scan wheel, 15 slit scans, this circuit stops the recording of data. The record cycle is restarted by pushing the start button.

2.) Wavelength indication circuit. This circuit provides the logic, triggered by the wavelength diodes, which indicates the 400 and 700 nm points in each scan.

3.) Other parts of this logic circuit provide command signals for computer processing purposes.

C. Readout and auxiliary components procured or supplied by the Visibility Laboratory.

1.) High voltage power supply for photomultiplier tube.

2.) $\pm$ 15 V power supply for operational amplifier and power supply for logic circuit.

3.) Serializer parallel to serial converter which outputs signals in proper format for entry onto magnetic tape. Provides means of entering fixed identification data.

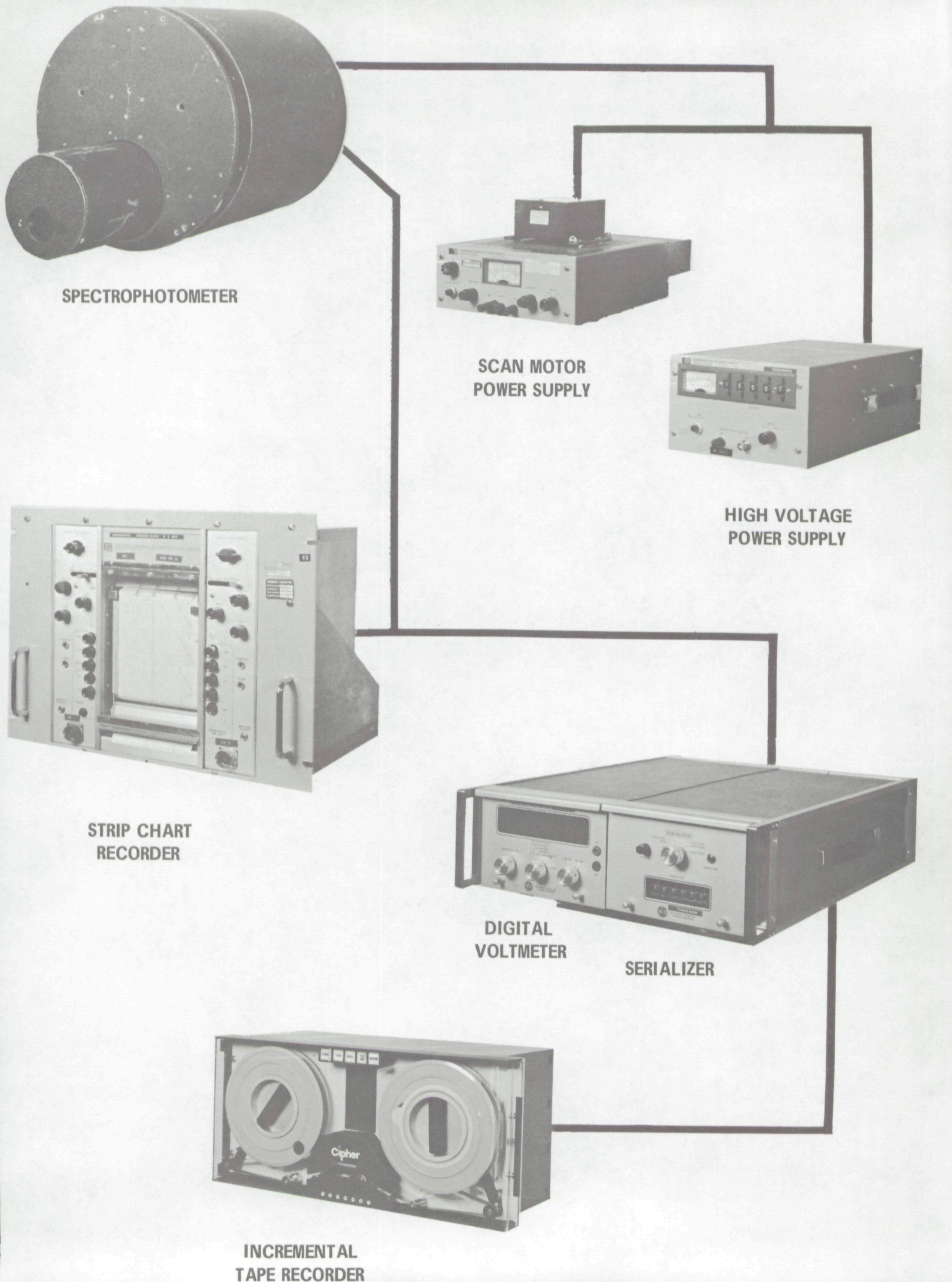
4.) Incremental tape recorder.

5.) Digital voltmeter for visual display of signal.

6.) Strip recorder for immediate access to data and visual verification of instrument operation.

In addition to these modifications, it was necessary to provide electronic sub-assemblies which would permit recording on strip-chart recorder and on magnetic tape for computer processing. The finished instrument is illustrated in the attached photograph.

The completed instrument was calibrated on the photometric bar at the Visibility Laboratory. It was found to respond to radiant energy linearly with magnitude. A wavelength calibration with a mercury-arc source was


SPECTROPHOTOMETER
SCAN MOTOR POWER SUPPLY
HIGH VOLTAGE POWER SUPPLY
STRIP CHART RECORDER
DIGITAL VOLTMETER
SERIALIZER
Cipher
INCREMENTAL TAPE RECORDER

used to adjust the wavelength calibration. The relative calibration of the 15 slits was performed and recorded, and an absolute calibration was performed using a Ba SO_4 plaque irradiated by a standard of spectral irradiance.

The completed instrument was tested by taking advantage of a "ship-of-opportunity" as follows:

In my capacity as Chairman of a working group for the Scientific Committee on Oceanic Research I was called upon to organize an expedition on the DISCOVERER (an ESSA ship berthed in Miami, Florida). The completed TRW system was included as part of the scientific equipment on the DISCOVERER cruise (May 2 to June 6, 1970). The original plan was to permanently install the TRW system in the bow observation chamber of the ship and to visit it once a day to make a recording of the upwelling spectral irradiance, which is the optical signal available for remote sensing.

Unfortunately, we were frustrated in this effort for several reasons. The chamber itself was not air-conditioned, and the walls were sweating copiously with condensed water vapor. This was deemed a highly undesirable environment in which to install unprotected electronic components. In addition to this difficulty, the windows of the observation chamber were not clean enough for the measurements we wanted to obtain, and the five hatches which led to the chamber were dangerously small and would have required complete disassembly of the equipment for installation or removal.

Rather than jeopardize the equipment with frequent trips to the bow chamber, it was decided to run a series of tests with the instrument held above the water. Several spectra were recorded in this fashion.

During that portion of the expedition between Miami and the Panama Canal, Dr. Ewing overflew the ship and, I understand, took spectroradiometric data from several altitudes.

In addition, the following measurements were made by the scientific party on board:

- Chlorophyll concentration as a function of depth, including surface chlorophyll
- Spectroradiometric measurements with submersible spectroradiometers
- Plankton identification
- Nutrients
- Measurements of primary productivity

The spectroradiometric data obtained by the Visibility Laboratory has been processed and forwarded to Dr. George Clarke along with data on surface chlorophyll. We have received no data taken by the instrument in the aircraft and are consequently unable to make any analysis or comparison of underwater versus above water spectroradiometric measurements.

Discussion:

It has been suggested by Dr. Nils Jerlov, by Dr. G. Clarke, and others that a sensitive indicator of oceanic change in color from clean water to water containing phytoplankton might be the ratio of radiant energy in the blue region of the spectrum to that in the green region of the specturm. Spectroradiometric data obtained underwater tend to support this suggestion as can readily be seen by reference to the book, "Measurements of Spectral Irradiance Underwater," by J. E. Tyler and R. C. Smith (Gordon and Breach Science Publishers, New York, 1970).

We do not have available the correlating spectroradiometric data obtained from overflying aircraft and can only speculate that from the air the "blue-green" ratio will be less sensitive than it is underwater. The reasons for this are that the ocean surface, by reflection, adds a substantially constant amount of energy to both blue and green regions of the primary signal, and the atmosphere, when clear, tends to deprive both blue and green signals of the same fraction of blue light. At the same time, the clear air will scatter into the path of sight a fraction of the irradiating sun and sky light, and this will be predominately blue light. All three of these effects will tend to reduce the blue-green ratio. The first effect will depend on the time-averaged slope of the ocean surface and the distribution of radiant energy in the sky dome. The second two effects will depend on the length of the atmospheric path, the condition of the atmosphere, and on the magnitude and geometry of the ambient lighting.

Recommendations:

It is my opinion that hurried conclusions are being voiced about the detection of surface chlorophyll from the air and that they are based on inadequate and insufficient data. It seems to me that the problem of remote sensing of surface chlorophyll in the ocean can be reduced to a few basic questions:

1.) What are the optical properties of the radiant energy returned to the surface by the scattering from particles in the ocean?

2.) Can the optical properties of this signal be quantitatively correlated with the chlorophyll concentration?

3.) What optical degeneration is brought about by the air-ocean interface, and can the resulting degenerate signal be adequately detected and related quantitatively to the chlorophyll concentration?

4.) What optical degeneration is brought about by a clear atmosphere, and can the remaining degenerate signal still be detected and related quantitatively to the surface chlorophyll?

I would recommend that these questions be addressed in a careful and methodical manner, and in the order stated, concentrating on situations involving minimum signal degradation. If quantitative data of good quality produces negative results of a sufficiently compelling nature, the remaining questions need not be answered.

The Visibility Laboratory has already published quantitative data in answer to question No. 1. The Visibility Laboratory also has a large amount of data relating to question No. 2 and can easily obtain additional data on this important question. Question No. 3 can be answered for certain, special cases from information already in the document and data files at the Visibility Laboratory.

I seriously question the usefulness of data taking from aircraft until question No. 3 has been answered. If question No. 3 is definitely negative, there is obviously no need to take data from the air, at least not until some method of circumventing the negative answer for question No. 3 can be found.

I strongly recommend that grant funds (not contract funds) be made available to this Laboratory to obtain additional data on the signature from the ocean and on chlorophyll concentration to determine a conclusive answer for questions 1 and 2 and that further grant funds be made available to make engineering estimates to answer question No. 3.