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Summary

The objective of the investigation was to develop a commercial remote sensing system for providing near-real-time data (within one day) in support of commercial fishing operations. The Airborne Ocean Color Imager (AOCI) had been built for NASA by Daedalus Enterprises, Inc., but it needed certain improvements, data processing software, and a delivery system to make it into a commercial system for fisheries. Two products were developed to support this effort: the AOCI with its associated processing system and an information service for both commercial and recreational fisheries to be created by Spectro Scan, Inc.

The investigation achieved all technical objectives: improving the AOCI, creating software for atmospheric correction and bio-optical output products, georeferencing the output products, and creating a delivery system to get those products into the hands of commercial and recreational fishermen in near-real-time. The first set of business objectives involved Daedalus Enterprises and also were achieved: they have an improved AOCI and new data processing software with a set of example data products for fisheries applications to show their customers. Daedalus' marketing activities showed the need for simplification of the product for fisheries, but they successfully marketed the current version to an Italian consortium. The second set of business objectives tasked Spectro Scan to provide an information service and they could not be achieved because Spectro Scan was unable to obtain necessary venture capital to start up operations.

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Table of Contents

1.0 Overview

1.1 Objectives and Scope

The Earth Observations Commercialization and Applications Program (EOCAP) sponsored this investigation as part of its effort to commercialize remote sensing technology developed by the National Aeronautics and Space Administration (NASA). The objective of the investigation was to develop a commercial remote sensing system for providing near-real-time data (within one day) in support of commercial fishing operations. The Airborne Ocean Color Imager had been built for NASA by Daedalus Enterprises, Inc. under the Small Business Innovation Research Program, but it needed certain improvements, data processing software, and a delivery system to make it into a commercial system for fisheries.

Fisheries information is very volatile: today's information probably will not be valid in two or three days. So there is a market for repeated data acquisitions (and sales) but also requires rapid data processing and rapid delivery of the information into the hands of the ultimate user. Initial focus was on the menhaden fishery because that fishery was receptive to remote sensing approaches. The recreational fishing industry showed promise for more sales of data products during fishing tournaments so the target markets were expanded to include them. In addition to developing the remote sensing system, we anticipated that the initial commercialization would be carried out by Spectro Scan, Inc. who would purchase an instrument, an aircraft, and computers, obtain the data processing software and delivery system, and sell data products to the fishing community. In summary, we had two products we wished to develop, the Airborne Ocean Color Imager (AOCI) with its associated processing system and a potential information service for both commercial and recreational fisheries.

1.1.1 Technical objectives– Aside from improving the AOCI, the major objective was to develop the software necessary to process the raw AOCI data (1) to correct for atmospheric effects (which can be up to 90% of the signal in the blue bands), (2) to apply bio-optical algorithms for calculating the phytoplankton biomass in the water (expressed as total pigment concentration) and the turbidity of the water (expressed as the diffuse attenuation coefficient), and (3) to geo-locate the total pigment concentration image so that fishermen could find the areas of interest in the open ocean. All these tasks were to be accomplished in near-real-time, 12–20 hours after take-off.

1.1.2 Business objectives for the AOCI instrument product– After building the AOCI as an interchangeable spectrometer for their AADS-1268 digital multispectral scanner system, Daedalus had received queries about producing an AOCI type instrument for fisheries applications. However, no example data sets existed to demonstrate that such an instrument could be successfully applied to fisheries support. In particular, the data processing software and data product output software did not exist. So the first business objective was to develop the data processing software and produce example data products that could be used in marketing. Additional business objectives included better defining the potential market for an AOCI instrument product, developing a complete AOCI fisheries support instrument package, and developing a marketing plan and approach to sell the instrument.

1.1.3 Business objectives for the information service product– Daedalus Enterprises identified Spectro Scan, Inc. as the most likely of their commercial U.S. customers to buy a Daedalus AADS-1268 scanner system in the near future and, as such, they were the most likely candidate company to provide the first commercialization of the AOCI system. At the time, Spectro Scan was looking for significant capitalization to buy equipment and expand operations; they still are. Their business objectives included defining the product, surveying the market, developing a marketing plan, obtaining capital, buying equipment, and expanding operations.

1.2 Approach to Commercialization

1.2.1 Technical approach–The actual technical approach largely followed the technical approach outlined in the original proposal but was modified to conform to the actual situations as well as make some improvements. The effort was divided into three phases roughly corresponding to three years of funding. During the initial phase, the main task of the technical approach was the acquisition of baseline data over the Gulf of Mexico. The second phase included the improvement of the AOCI and the development of the atmospheric correction and bio-optical algorithms. The atmospheric correction program was ready for testing in late 1989 and ready for use a couple of months later. The bio-optical algorithms were derived from the database acquired for use with the Coastal Zone Color Scanner. The third phase first completed tasks remaining from the first and second phases and then moved on to conducting the demonstration programs and documenting the entire technical effort. The design of (1) the user information products and (2) the near-real-time techniques both took a major step forward with the utilization of the geo-referencing capability NASA's Stennis Space Center had created within their Earth Resources Laboratory Analysis System

(ELAS) for the AOCI: resampling the bio-optical output product into a geographic data base, mosaicking multiple flight lines together, and using the mosaicked data base in the personal-computer-based CAPT SAM system developed for the National Marine Fisheries Service Center (NMFS) at Stennis Space Center for display and transmission to remote sites.

1.2.2 Business approach for the AOCI product– The actual approach to the AOCI product development and marketing has been dictated by a complex of unexpected technical and administrative problems encountered during the program. Funding was not available to improve the AOCI until the 1989-1990 winter. The primary impact of this delay was to cause the use of conservative estimates of AOCI performance in early discussions with prospects for system purchase. The unexpected difficulties encountered in transforming AOCI measurements into geocoded image products has had a much more serious impact on marketing the AOCI system as a product.

It was originally planned that phase three would consist mainly of the demonstration of the developed technique of using the AOCI in an operational, menhaden fishery support role, and transfer of the technology to a commercial service organization. However, Spectro Scan's difficulties in raising capital coupled with the above problems prevented this transfer from occurring. As a result, the example materials and financial data on operational procedures and costs were not generated by this program.

The overall impact of these financial, administrative, and technical problems has caused Daedalus to take a considerably modified approach to the development of the AOCI instrument product market. The small number of data products from the menhaden demonstration phase has meant that advertising brochures and sample data sets directly applicable to fisheries could not be created. Thus, the market analysis has been confined to attempting to define a market need without using market stimulating advertising and promotion materials. Instead, general materials describing the goals of the project and some preliminary data products have been used to try to measure market interest. In addition, details have been gathered on target fisheries and current operating techniques to determine how an AOCI fishery support system might fit a particular fishery. Finally, market information has been gathered on competing techniques so that potential competitive advantages of the AOCI system might be assessed.

It is now clear that most of the actual market development and promotional activities will have to take place in the post-EOCAP I time frame using the best materials that can be culled from the large amount of data acquired during EOCAP I. It is also likely that the early sales prospects for the AOCI instrument product may be users whose primary interest is in acquiring oceanographic information with fisheries as a secondary interest. The market development plan is now a two-pronged approach dealing with the AOCI instrument for both oceanographic and fishery applications and this will probably entail two different instrument packages.

1.2.3 Business approach for the information service product– The original approach to developing AOCI data for delivery to commercial fishing interests on a routine basis was hampered by an early realization that no commercial fishing concern in the USA was willing, or probably able, to assume the responsibility of guarantor for a market. The expense of operating an aircraft with an AOCI sensor, a dedicated computer system for manipulating and delivering the data, and a dedicated receiving system for the data was too great for one user or even a small base of users.

Spectro Scan believes the proper approach to commercializing an AOCI data distribution service requires coupling the AOCI data delivery with other information delivery services that are compatible enough to be incorporated into a single delivery system. Possible combinations include weather data, AVHRR data, AOCI data and other valuable information to the boat operator. Such a delivery system would be valuable not only to the commercial fishing operators but to recreational boaters as well, and it would provide a much larger potential market base.

1.3 Product Description

Both products are still in a state of flux and their final configuration will depend on the particular implementation chosen for hardware and software which will, in turn, depend on each customer's requirements. Each product will be described as it currently exists. The AOCI product consists of the AOCI instrument itself, a digital recording system, an inertial navigation system with a TACAN update, a navigation data recorder, and a software system which provides calibration, atmospheric correction, bio-optical products, geo-location, and georeferencing. The AOCI instrument consists of an AOCI spectrometer mated to the Daedalus Enterprises multispectral electro-mechanical scanner Model AADS-1268. The software system begins with a program, FIT5LATLONG, to smooth the latitude and longitude data with a second order regression. The program PROCESS uses the smoothed navigation data and the AOCI data to calculate atmospherically corrected imagery for all bands requested and also calculate bio-optical output products (total pigment concentration and diffuse attenuation coefficient).

Both programs were written in FORTRAN and exist in the public domain. Two georeferencing procedures were employed: one used the public domain ELAS (Earth Resources Laboratory Analysis System) modules available from NASA Stennis and the other used a set of stand-alone programs initiated by Spectro Scan and implemented by NASA Ames.

The information service product, as it exists (i.e., without other information delivery services), uses the AOCI system product and then carries on from the georegistered, bio-optical total pigment concentration database at 60 meters spatial resolution (0.00054 degrees). The database is resampled down to a 512 × 512 image of a selected area. The 512 × 512 image is reformatted for the CAPT SAM software display system on a personal computer. Either the 512 × 512 image or the CAPT SAM version of it can be sent over phone lines to remote CAPT SAM systems for local use.

1.4 Results and Conclusions

The technical goals of this investigation included taking a state-of-the-art instrument, the AOCI, improving it, creating software for atmospheric correction and bio-optical output products, georeferencing the output products, and creating a delivery system to get those output products into the hands of commercial and recreational fishermen in what was defined as near-real-time. This investigation was successful in achieving all those goals. The AOCI has the highest sensitivity of all available commercial, aircraft remote sensing instruments. The data processing software works well, runs efficiently, and has been implemented on a variety of computer systems; it is available as public domain software. The georeferencing software was developed by others for other purposes but it also works well, runs efficiently, has been implemented on a number of computer systems, and is available under ELAS as public domain software. Functionally equivalent stand-alone georeferencing programs were also developed by Spectro Scan and implemented by NASA Ames but they remain under the purview of Spectro Scan. The delivery system used, CAPT SAM, was a serendipitous outgrowth of work for NMFS Stennis by the State of Mississippi which is trying to commercialize that system separately. All these achieved goals can be considered to be technical in nature but they were necessary for the implementation of the business goals.

The first set of business goals revolved around Daedalus Enterprises. To be successful in marketing the AOCI for fisheries applications they not only needed an improved AOCI and data processing software, but a set of example data products acquired for fisheries applications to show their customers some of the capabilities of the instrument. With the example data products in hand, Daedalus could better develop their marketing plans and strategies. This goal was achieved by this investigation. Daedalus now has some hardcopy imagery to use in their promotional activities and they have requested more from the wealth of data acquired under this investigation. In addition, and as a result of this investigation, Daedalus has identified the market need for a fisheries support version of their AOCI product that is much simpler and cheaper. They have also identified the need for a better data recording system that avoids the necessity of a separate (expensive) decommutation system which will also improve data throughput. Daedalus has developed their marketing plan to include an analysis of the competition, positioning of the AOCI in the market, a market penetration strategy, a marketing schedule, as well as budgets and pricing. They intend to proceed with marketing the current version of the instrument while engineering and marketing studies proceed during the next year for the new version. Daedalus expects to sell a current version of the instrument to a European customer within the next few months and is holding discussions with a South American customer for the new version to better define a whole turn-key package. Gross revenue projections for the next five years are $2.1 million, $7.1 million, $9.2 million, $5.1 million, and $4.1 million, respectively.

A second set of business goals revolved around the choice of Spectro Scan, Inc. as a company to develop an information service for the fishing industry based on the AOCI. Spectro Scan was to obtain capitalization separately from this investigation and buy an AOCI, buy or lease a Learjet, buy the necessary computers, follow the software development, port the software to their computers, determine the commercial viability of the AOCI data products, and market the AOCI data products to both commercial and recreational fishermen. They have not obtained their capitalization so Spectro Scan has not been able to participate at the level envisioned. Spectro Scan's marketing studies determined that it was not economically feasible to acquire, process and deliver AOCI data alone but that if it were part of other information services to be delivered it would be more feasible. They expect to pursue this approach with a test market in southeast Florida.

Overall, this investigation achieved its technical objectives; the business objectives are being pursued by the companies involved. In particular, the business objectives were achieved with respect to Daedalus Enterprises and they are beginning to sell their systems. Spectro Scan, despite a significant setback, is exploring the marketing of a product as an outgrowth of this investigation.

2.0 Introduction

2.1 Original Objectives and Scope

The goal of the Earth Observation Commercialization and Application Program (EOCAP) is to take existing remote sensing technology that NASA sponsored and make it available in the commercial arena. Commercialization of remote sensing technology carries a high degree of risk. EOCAP was formulated to help commercial partners surmount some of that risk. They would provide their own resources to participate in the program, but they would work with NASA investigators familiar with the technology to develop products they could market.

The original objective of this investigation was to develop a commercial remote sensing system for providing near-real-time data (within one day) in support of commercial fishing operations. The Airborne Ocean Color Imager had been built for NASA by Daedalus Enterprises, Inc. under the Small Business Innovation Research Program. It was designed to be an airborne simulator for the next generation satellite ocean color instrument to follow the very successful Coastal Zone Color Scanner (CZCS), but it needed data processing software, a delivery system, and other improvements to make it into a commercial system for fisheries.

Fisheries information is very volatile: today's information probably will not be valid in two or three days. This fact creates a market for repeated data acquisitions (and sales) but also requires rapid data processing and rapid delivery of the information into the hands of the ultimate user. Initial concepts revolved about the menhaden fishery because it was suitable for remote sensing approaches (the fishery used spotter planes and had been involved in a remote sensing demonstration with Landsat). The recreational fishing industry showed promise for more sales of data products during fishing tournaments so the target markets were expanded to include them. In addition to developing the remote sensing system, we anticipated that the initial commercialization would be carried out by Spectro Scan, Inc., who would purchase an instrument, an aircraft, and computers, obtain the data processing software and delivery system, and sell data products to the fishing community. In summary, we had two products we wished to develop—the Airborne Ocean Color Imager with its associated processing system and a potential information service for both commercial and recreational fisheries.

2.1.1 Technical objectives– The original technical objectives were to improve the Airborne Ocean Color Imager (AOCI), develop data processing software and define a data delivery system. As delivered under the Small Business Innovation Research Program, the AOCI did not meet the original specifications for the sensitivity of the shorter wavelength bands. Subsequent engineering analysis indicated the fault was a misinterpretation of the use of the diffraction grating for the visible band spectrometer. That spectrometer was refitted with a new grating and detector array so as to obtain the required sensitivity. A notched blocking filter had been recommended to eliminate scan angle effects due to an oxygen absorption line at 760 nm but it was not included in the original instrument due to cost; it was considered a useful improvement for a commercial version of the instrument. In addition, there were a number of smaller improvements that had been suggested as a result of experience with the AOCI which would optimize its performance. All of these improvements were packaged together as one of the technical objectives of this investigation.

Another technical objective was to develop the software necessary to process the raw AOCI data to (1) correct for atmospheric effects (which can be up to 90% of the signal in the blue bands), (2) apply bio-optical algorithms for calculating the phytoplankton biomass in the water (expressed as total pigment concentration) and the turbidity of the water (expressed as the diffuse attenuation coefficient), and (3) geo-locate the total pigment concentration image so that fishermen could find the areas of interest in the open ocean. All these tasks were to be accomplished in near-real-time, 12-20 hours after takeoff. Atmospheric correction was deemed important because atmospheric effects not only made up the majority of the signal received at the sensor from high altitudes but the atmospheric effects varied from point to point and from day to day so that a consistent interpretation of the data would not be possible without such correction. Use of the bio-optical algorithms was an attempt to convert the raw AOCI data into meaningful quantities for fisheries purposes. Phytoplankton biomass is the first step in the food chain for fish. Menhaden are filter feeders and are tightly coupled to the planktonic biomass, particularly the zooplankton which feed directly on the phytoplankton. With respect to turbidity, the Landsat demonstration found menhaden catch locations occurred where the Secchi depth, a measure of turbidity, was small. Fish sought by recreational fishermen tend to be found just outside the boundary marking the interface between turbid and clear water; that boundary is well delineated by the total pigment concentration although much simpler representations would suffice. Geo-location was considered to be extremely important. Without adequate geo-location, fishermen would not be able to orient themselves in the imagery or find any features of interest in the open sea. They navigate using Loran-C to find a location by latitude and longitude. Our original concept was to use the aircraft inertial navigation data to draw lines of equal latitude and longitude in the imagery. Since inertial navigation systems are known to drift, they are updated by navigational aids periodically. Even so, they can be in error by a mile or more. To aid in visual orientation as well as permit the user to assess the navigational inaccuracy, we thought it would be useful to superimpose the coastal boundary whenever it intersected the image.

2.1.2 Business objectives for the AOCI instrument product– Daedalus developed the original AOCI instrument as an interchangeable spectrometer for the NASA Ames Daedalus AADS1268 digital multispectral scanner system under a Small Business Innovation Research program. The intent was to commercialize this system as an addition to the Daedalus product line of airborne multispectral imagers which are marketed internationally. Daedalus had received inquiries about producing an AOCI type instrument for fisheries applications. However, no example data sets existed to demonstrate that such an instrument could be successfully applied to fisheries support. In particular, the data processing software and data product output software did not exist. Therefore, the first business objective was to develop the data processing software and produce example data products that could be used in marketing. Additional business objectives included better defining the potential market for an AOCI instrument product, developing a complete AOCI fisheries support instrument package, and developing a marketing plan and approach to sell the instrument.

2.1.3 Business objectives for the information service product– Daedalus Enterprises identified Spectro Scan, Inc. as the most likely of their commercial U.S. customers to buy a Daedalus AADS-1268 scanner system in the near future and, as such, they were the most likely candidate company to provide the first commercialization of the AOCI system. At the time, Spectro Scan was looking for significant capitalization to buy equipment and expand operations. When they were pressed for their initial concept of a business or marketing plan, they responded it was too early for such a plan because a product, per se, did not yet exist. The business objectives included defining the product, surveying the market, developing a marketing plan, obtaining capital, buying equipment, and expanding operations.

Since Spectro Scan is still looking for significant capitalization, their first order of business is to obtain that capitalization; that effort is outside the scope of the present investigation. The current status of that effort is involved in the funding for their participation in the Florida Agricultural Demonstration Project. Congress voted to fund the Project but USDA has yet to release the funds, some $10 million which would cover the needed capitalization. If that funding materializes, Spectro Scan probably would devote their initial efforts to agricultural users and postpone involvement with fisheries until the Agricultural Demonstration Project was under way.

2.2 Commercial AOCI Remote Sensing and EOCAP Objectives

The goal of EOCAP is to create joint research efforts to increase the commercial use of NASA's remote sensing technology. To further this goal EOCAP's objectives are (1) to provide operational users access to advances in remote sensing for improved services, (2) to stimulate broader uses of the technology and access to it by the private sector for profit-motivated applications, and (3) to emphasize private sector/university/government partnerships with joint initiative and resources. Objectives 2 and 3 appear to refer to the Commercial EOCAP investigations such as the present one.

Since the AOCI was developed for NASA and is one of the operational remote sensors flown by NASA's aircraft, it fits the definition of "NASA's remote sensing technology" which EOCAP wishes to commercialize. The present investigation has broadened the use of the AOCI by applying it to fisheries, both commercial and recreational (with commercial considerations for the latter), in conjunction with two private sector companies with profit-motivated applications. Daedalus Enterprises wishes to sell AOCI systems to organizations or governments on a world-wide basis. Spectro Scan wishes to create a business of acquiring, processing and distributing, for sale, information useful to various fisheries. Hence, the present investigation complies with Objective 2. It also complies with Objective 3 since we have three private sector companies, Daedalus Enterprises, Spectro Scan and Zapata Haynie Corporation (the largest menhaden fishing company), in partnership with two governmental organizations, NASA Ames and the National Marine Fisheries Service (NMFS) at Stennis Space Center, who have all contributed resources to the investigation. While the main thrust of EOCAP concerns the use of satellite data, the use of aircraft instruments and data is appropriate for coastal fisheries because the spatial resolution of the satellite instrument that has been proposed (SeaWiFS) is too coarse, 1-4 km versus the 30 meter resolution of the AOCI, for coastal waters.

2.3 Original Approach

The original technical approach consisted of several phases spanning a period of three years. The initial phase was the acquisition of baseline data over the Gulf of Mexico using the NASA Ames ER-2 aircraft and the implementation of improved sensitivity of the existing AOCI instrument. These data were to be used to develop new software for geo-location, atmospheric correction, calibration and bio-optical relationships for the AOCI. The software was to be based on algorithms developed for the CZCS as far as possible. During this data acquisition period, surface truth measurements would be supplied by the fisheries and the National Marine Fisheries Service (NMFS Stennis). The second phase would test the new algorithms and include the acquisition of AOCI data from lower altitudes (40,000 feet versus 65,000 feet) using the Learjet at NASA's John C. Stennis Space Center (NASA Stennis) to provide data similar to that which would be acquired operationally. These data were to be used to refine data processing algorithms and to demonstrate the information that can be extracted to support fisheries operations. This phase also was to include the initiation of near-real-time information extraction techniques and the identification of the information products required by the fisheries. The data processing and distribution system would be ported to Spectro Scan for installation on their computers in preparation for later use. The final phase was to include demonstration operations in the NASA Stennis Learjet and testing of near-real-time information extraction and delivery techniques. With all the equipment and techniques in place and operational, an AOCI, purchased by Spectro Scan, was to be installed in Spectro Scan's aircraft and flown by Spectro Scan in an operational demonstration. The resulting AOCI data was to be processed and delivered to fishermen by Spectro Scan. At the end of the final phase, the goal was that Spectro Scan would be operational as the first commercialization of the system.

The definition of the original business approach was more sketchy than for the technical approach. In fact, the original proposal only discussed the AOCI system as a product to be marketed. Subsequent clarifications added more detail and included the information service as a product. For the AOCI system product, Daedalus Enterprises indicated they would take responsibility for the development of a market plan in the third phase. Their marketing activities had developed inquiries from Mexico, Chile, Argentina, Brazil, Australia, the Seychelles and Iceland. Daedalus Enterprises proposed to use the results from the demonstration activities to develop proposals, advertising brochures, and image samples for use in an international marketing campaign. They would identify the total market in terms of size, location, specific customers, customer requirements and price sensitivity. A targeted marketing plan would be designed to approach specific customers with a system package designed for their particular needs. The marketing plan would outline the schedule for approaching each targeted customer; it would develop an overall marketing budget and a sales forecast for the entire market.

Spectro Scan's business approach was hampered by the lack of solid proof that AOCI data could be correlated with fish catch and by the lack of knowledge about the operational requirements necessary to support fisheries. As a result, Spectro Scan considered the development of a marketing plan to be premature but that experience gained by the third phase should permit it.

2.4 Organization

NASA Ames was to take the lead role. In addition, it would be responsible for developing the data processing software, transferring it to NASA Stennis and Spectro Scan, and processing the AOCI data up until the demonstrations. Daedalus Enterprises was to be responsible for the improvement of the AOCI and the development of the marketing plan for the AOCI system and assist in the commercialization of the information service product. Spectro Scan was to be an advisor for operational considerations and keep abreast of the software development during the first two phases. During the third phase they were to transition to full participation and take responsibility for acquiring, processing and distributing the AOCI data. NMFS Stennis and Zapata Haynie were to be responsible for surface truth (both fish catch data on location and quantity as well as environmental data on phytoplankton biomass, turbidity, and temperature) during each AOCI data acquisition as well critiquing the data products and establishing the operational requirements. The involvement of Zapata Haynie as a potential customer for the information service product was intended to enhance the utility of that product.

3.0 Approach to Commercialization

3.1 Actual Technical Approach

The actual technical approach largely followed the original technical approach outlined in the proposal but was modified to conform to a number of realities or make some improvements.

During the initial phase, the main tasks were the acquisition of baseline data over the Gulf of Mexico, the development of new algorithms for processing AOCI data, and improvement of the existing AOCI instrument. The first attempt at acquiring baseline data was a single ER-2 flight with the AOCI on September 5, 1988, Labor Day. The AOCI data was excellent but no surface data were collected, neither environmental data nor fish catch locations. The NOAA research vessel finished its regular work early and could not remain on station to collect environmental data since the Interagency Agreement between NASA and NMFS Stennis was not yet in force and the NMFS Stennis effort was not funded. Due to the holiday, the menhaden fishing fleet did not work that day and their spotter pilots saw no fish either. Weather or low ER-2 priority prevented additional acquisitions. The second attempt occurred May 10-19, 1989 and resulted in an excellent AOCI data set acquired on May 11th. NMFS Stennis coordinated environmental sampling by five chartered vessels and one Zapata Haynie vessel (all 30–40 feet in size) along transects as well as more detailed sampling by their large research vessel. NMFS Stennis also compiled fish catch locations and spotter pilot observations provided by Zapata Haynie. Heavy seas curtailed some of the environmental data collection but menhaden fishermen reported good catches. Stringent rules on acceptable weather conditions prevented any additional data collection during the May 10-19 period. The September 1988 and May 1989 data sets provided examples to use for the development of new AOCI algorithms. Although a contractor was assigned and funded to develop these algorithms soon after initial project funding, he did not begin work in earnest for a full year because of other duties. The improvement of the existing AOCI instrument was delayed in the first phase by required procurement procedures. Soon after the initiation of the investigation, it became obvious the improvement of the AOCI would have to occur during the winter months of 1989-1990. The impact of the year delay was minimal since (1) the AOCI would be ready for the demonstration periods and (2) the baseline data acquisition and algorithm development efforts did not depend on the improvements.

The actual approach in the second phase included the improvement of the AOCI and the development of the atmospheric correction and bio-optical algorithms. Daedalus Enterprises delivered the improved AOCI to NASA Ames in April 1990 but one of the improvement tasks could not be accomplished within NASA's schedule due to a long lead time item, recoating the imaging lens. It was scheduled for the next opportunity when the AOCI could be available for an extended period. The atmospheric correction program was ready for testing in late 1989 and ready for use a couple of months later. The bio-optical algorithms were derived from the database acquired for use with the Coastal Zone Color Scanner; Moss Landing Marine Laboratories used the AOCI relative response functions to make bio-optical algorithms specific to the AOCI. They were appended to the atmospheric correction program and the whole program was sent to NASA Stennis for implementation on their Concurrent computer in March 1990. Modifications to the atmospheric correction program to account for the lower flight altitudes to be used in the demonstrations had been incorporated in the program from the start so the task to do so was unnecessary. Design of the user information products was begun in the second phase but not completed. It focused on the use of videocassette tapes or FAX images, either black and white or color. Design of the near-real-time techniques was also to occur in the second phase; it was postponed until the programs were implemented at NASA Stennis where the demonstrations would be conducted.

The actual approach in the third phase first completed tasks remaining from the first and second phases (improvement of the AOCI, the design of the user information products and the design of the near-real-time techniques) and then moved on to conducting the demonstration programs and documenting the entire technical effort. Training of the intended commercial operator of the information service did not occur because Spectro Scan has not yet become operational. Final improvements of the AOCI were completed in early December 1990 with the recoating of the imaging lens; other enhancements were accomplished at the same time (gain optimization and replacement of the diffraction grating in the near-infrared spectrometer). The design of (1) the user information products and (2) the near-real-time techniques both took a major step forward with the suggestion by NASA Stennis systems analysts to utilize the geo-referencing capability they had created within their Earth Resources Laboratory Analysis System (ELAS) for the AOCI for their own purposes. After making some format changes and adding the aircraft navigation data at the end of each scan line of AOCI data, their suggestion permitted resampling the bio-optical output product (total pigment concentration) into a geographic data base, mosaicking multiple flight lines together, and using the mosaicked data base in the NMFS Stennis PC-based CAPT SAM system for display and transmission to remote sites. The original approach used either FAX or VCR products of individual flight lines with latitude and longitude lines superimposed on the bio-optical output product; clearly, the NASA Stennis approach coupled with CAPT SAM was vastly superior to the original approach. Spectro Scan, using a similar approach, wrote stand-alone programs to create a similar geographic data base, but they were not implemented in time for the demonstrations.

The initial approach for transferring AOCI data onto computer disks from the NASA Stennis Learjet tapes used an existing ELAS program, RDAOCI. Analysis of the Functional Check Flight data for the first demonstration period revealed RDAOCI was not designed to read the aircraft PCM tape as assumed. An interim approach attempted real-time programming by Stennis analysts to transfer the raw data but failed due to time limitations and other problems during the first demonstration period. The final approach for transferring the AOCI data involved completely rewriting the decommutation algorithm to speed the process and convert the eight-bit data into sixteen-bit data on the fly. Despite intense efforts the algorithm was not debugged until after the second demonstration period. An unplanned final demonstration period was scheduled for June 1991 to partially recover from the failure of the two demonstration periods. No funding for environmental sampling remained for June 1991 but NMFS Stennis compiled fish catch locations and spotter pilot observations provided by Zapata Haynie. NMFS Stennis also extended the use of the CAPT SAM system by predicting the most probable locations for finding menhaden based on analysis of the relationship between current fish catch locations and AOCI-derived total pigment concentrations.

3.2 Actual Business Approach

3.2.1 AOCI product– The original business approach for the AOCI instrument product was to participate in the first two phases of the program to define and improve the instrument package through the technical tasks, and then to develop a market plan in phase three. The market plan would capitalize upon the phase three demonstration program as a source of materials for AOCI system proposals, advertising brochures, and sample data products.

The actual approach to the AOCI product development and marketing has been dictated by unexpected technical and administrative problems encountered during the conduct of the program. The AOCI improvements were not funded until the 1989-1990 winter and the first data set from the improved system was not acquired until May 1990. This delay necessitated the use of conservative estimates of AOCI performance in early discussions with prospects for system purchase. The unexpected difficulties encountered in transforming AOCI measurements into geocoded image products has had a much more serious impact on marketing the AOCI system as a product.

It was originally envisioned that data processing software and output devices existed that would permit near-real-time production of fishery support products with only minor modifications. The major technical work was expected to be in the development of new algorithms for the AOCI spectral bands and lower altitude operations. However, it turned out that processing the data in 12 hours or less and producing geocoded products that could be easily transmitted to users were much more difficult than first imagined. Moreover, it was hoped that there would be a relatively direct correlation between high chlorophyll content of water and successful menhaden catch data. While it now appears that there is a good correlation between high chlorophyll and menhaden location, there also seems to be a good correlation with sechhi depth and perhaps a composite chlorophyll/turbidity measurement would be a better predictor of best fishing location. Limited time to compile and analyze complex data sets has hampered our ability to close in on these parameters.

Finally, it was originally planned that phase three would consist mostly of the demonstration of the developed technique of using the AOCI in an operational menhaden fishery support role, and transfer of the technology to a commercial service organization. However, Spectro Scan's difficulties in raising capital coupled with the above technical problems prevented this from occurring. As a result, the example materials and financial data on operational procedures and costs were not generated by this program.

The overall impact of these administrative and technical problems has caused Daedalus to take a considerably modified approach to the development of the AOCI instrument product market. Because of the small number of data products from the menhaden demonstration phase, advertising brochures and sample data sets directly applicable for fisheries could not be created. Thus, the market analysis has been confined to attempting to define a market need without using market stimulating advertising and promotion materials. Instead, general materials describing the goals of the project and some preliminary data products have been used to try to measure market interest. In addition, details have been gathered on target fisheries and current operating techniques to determine how an AOCI fishery support system might fit a particular fishery. Finally, market information has been gathered on competing techniques so that potential competitive advantages of the AOCI system might be assessed.

It is now clear that most of the actual market development and promotional activities will have to take place in the post-EOCAP I time frame using the best materials that can be culled from the large amount of data acquired during EOCAP I. It is also likely that the early sales prospects for the AOCI instrument product may be users whose primary interest is in acquiring oceanographic information with fisheries as a secondary interest. The market development plan is now aimed at a two-pronged approach dealing with the AOCI instrument for both oceanographic and fishery applications and this will probably entail two different instrument packages.

3.2.2 Information service product– The original approach to developing AOCI data for delivery to commercial fishing interests on a routine basis was hampered by an early realization that no commercial fishing concern in the USA was willing, or probably able, to assume the responsibility of guarantor for a market. The expense of operating an aircraft with an AOCI sensor, a dedicated computer system for manipulating and delivering the data, and a dedicated receiving system for the data was too great for one user or even a small base of users. The alternative to paying commercial users would be a government subsidy. CAPT SAM has become accepted as a receiving system, but a delivery system dedicated solely to the task of delivering the AOCI data appeared to be too costly. The operation of sufficient aircraft with AOCI sensors to cover the Gulf of Mexico also would be too costly. Aircraft operations may be possible on a directed basis, i.e., directing the aircraft to probable locations using AVHRR satellite data.

The proper approach to commercialize an AOCI data distribution service, in Spectro Scan's opinion, requires coupling the AOCI data delivery with other information delivery services that are compatible enough to be incorporated into a single delivery system. A single delivery system that would deliver information to a computer on board a boat would be ideal. Possible combinations include weather data, AVHRR data, AOCI data and other valuable information to the boat operator. Such a delivery system would be valuable not only to the commercial fishing operators but to recreational boaters as well, and it would provide a much larger potential market base. Spectro Scan expects to pursue this approach with a test market in the Southeast Florida area.

3.3 Product Description

Development of both products is still in a state of flux and their final configuration will depend on the particular implementation chosen for hardware and software which will, in turn, depend on each customer's requirements. The AOCI instrument is fixed but even it could be tailored to specific requirements if necessary. Each product will be described as it currently exists and the major options will be explained.

3.3.1 AOCI product– The AOCI product consists of the AOCI instrument itself, a digital recording system, an inertial navigation system with a TACAN update, a navigation data recorder, and a software system which provides calibration, atmospheric correction, bio-optical products, geo-location, and georeferencing. Individual components of the AOCI product will be described in this order.

The AOCI instrument consists of an AOCI spectrometer mated to the Daedalus Enterprises multispectral electro-mechanical scanner Model AADS-1268. The ten spectral bands with their bandwidths and radiometric sensitivities (expressed as signal to noise ratios) are given in table 1. The signal to noise ratios use radiances expected at the top of the atmosphere over oceanic waters as the signal. Bands 1 through 8 are recorded at ten bits resolution while bands 9 and 10 are recorded at eight bits resolution. The high sensitivities provide good sensitivities even after atmospheric correction removes 90 95% of the original signal in the blue region. A ten bit resolution is required to record the high sensitivity properly. The eight most significant bits of each ten bit band are recorded in the normal positions for channels 1–8 in the AADS-1268 electronics system while the two least significant bits of each ten bit band are multiplexed and stored in the normal positions for channels 10 and 11 in the AADS-1268 system. Reconstruction into ten bit data requires software. The AOCI instrument has an 85 degree field of view with a 2.5 milliradian instantaneous field of view. From 41,000 feet, maximum ceiling for a Learjet Model 23, the field of view becomes 12 nautical miles or 22 km and the instantaneous field of view becomes 31 meters. It would be better to fly at higher altitudes for additional coverage rather than lower altitudes for better resolution.

Table 1. Spectral and radiometric characteristics of the AOCI

Band number	Band center, nm	Band width, nm	Sensitivity	SNR
1	444	23	450	(181)
2	490	20	1,010	(305)
3	520	21	915	(461)
4	565	20	615	(377)
5	619	21	440	(303)
6	665	21	350	(217)
7	772	60	360	(609)
8	862	60	250	(446)
9	1012	60	120	(236)
10	10,395	3,900	–	

where the original signal-to-noise ratios are given in parentheses.

The AOCI data recorder used has been either a Sangamo Sabre Model 80 or a Bell and Howell Model 1414LT; both are 14 track, PCM instrumentation recorders run at 3.75 inches per second with a recording density of 10 kilobits per inch. A decommutation system is required to transfer the data to computer disk or tape. The inertial navigation system used has been a Lytton Model LTN-72R which was updated by an aircraft navigational aid, TACAN. The essential information provided by the navigation system is latitude, longitude, heading, pitch and roll. The navigation data was recorded by a separate, custom recorder on digital cassette tape.

A clock was used to synchronize the AOCI data with the navigation data. Unfortunately during the demonstration periods, it was necessary to rely on a clock in the custom recorder which drifted. To minimize the error, the clock was set just prior to flight to conform with the AOCI's time code generator. This configuration was dictated by existing equipment and is not recommended for a commercial implementation. A better configuration would use an Exobyte Model EXB-8500 recorder which would capture both the AOCI and navigation system data in the same data stream; it could be read directly to computer disk and eliminate the decommutation system. Latitude and longitude updates from the Global Positioning System (GPS) would be preferred to TACAN updates; A Lytton Model LTN-92 inertial navigation system would be required to use GPS updates.

The software system begins with a program, FIT5LATLONG, to smooth the latitude and longitude data with a second order regression; only straight flight line data should be submitted to the program so any data taken during aircraft turns should be excluded. The program PROCESS uses the smoothed navigation data and the AOCI data to calculate atmospherically corrected imagery for all bands requested and also calculate bio-optical output products (total pigment concentration and diffuse attenuation coefficient). Both programs were written in FORTRAN and have been implemented on several computers: a VAX 11/780, a SUN 4, a MicroVAX II/III, NASA Stennis Coherent computer and even an IBM 486 PC.

Two georeferencing procedures were employed: one used the public domain ELAS (Earth Resources Laboratory Analysis System) modules available from NASA Stennis and the other used a set of stand-alone programs initiated by Spectro Scan and implemented by NASA Ames. A detailed description of the ELAS procedure with approximate timings for a parallel processing environment is included as Appendix A. Briefly, the GR-series module MGAOCI appended navigation data to the end of AOCI scan lines, EDAOCI smoothed the navigation data, GRKNOW calculated the known correction factors for the AOCI, GRRMAP geo-referenced the bio-optical products from each flight line, and a combination of ECOPY and ROTF inserted and mosaicked each flight line into a geographical data base. The stand-alone program NAV used the smoothed navigation data to calculate latitude and longitude for each pixel in an image. The stand-alone program RESAMP used that information to resample the image in question into a data base of equal latitude and longitude cells such that north was at the top. It was possible to mosaic flight lines together using RESAMP. The stand-alone program TRACE wrote the outline of the coast into the data base for reference. The ELAS modules and the stand-alone programs produced equivalent data sets. Both could specify the cell size and starting latitude and longitude of the upper left corner, resample the bio-optical output data into a geographic data base, mosaic flight lines together, and overlay coastal boundaries.

3.3.2 Information service product– The information service product, as it currently exists (i.e., without other information delivery services), uses the AOCI system product and then carries on from the georegistered, bio-optical total pigment concentration database at 60 meters spatial resolution (0.00054 degree). The database is resampled down to a 512 × 512 image of a selected area; the sampling factor that is used to represent a 2.5-degree-square area was nine (i.e., 0.00486 degree per cell). The 512 × 512 image is reformatted for the CAPT SAM software display system on a personal computer. The CAPT SAM system displays the image using a pseudo-color table and permits display of latitude and longitude and pixel value under cursor control. Depth contours and locations of bottom obstructions can also be displayed. Previous fish catch locations, if available, can replace the file of bottom obstructions and can be overlaid on the total pigment concentration image. Either the 512 × 512 image or the CAPT SAM version of it can be sent over phone lines to remote CAPT SAM systems for local use.

The CAPT SAM system was developed by the State of Mississippi for the National Marine Fisheries Service at Stennis. It is the subject of a separate commercialization venture. The State of Mississippi, the commercializing agency, has a copyright and is considering various avenues for privatization including license requirements and royalty payments. An alternative approach for the functions served by CAPT SAM would not be difficult to develop; the advantages of CAPT SAM are that it exists now and that it has proven to be user-friendly with fishermen.

4.0 Results

4.1 Technical Results

The technical results include those related to the improvement of the AOCI itself, the development of atmospheric correction algorithms and bio-optical algorithms, the implementation of geo-referencing procedures, and the demonstration projects including the relationship between fish locations and the bio-optical products.

4.1.1 Improvement of the AOCI– Table 1 shows dramatic improvement in the signal-to-noise ratios for the visible bands (1–6), particularly in the blue region. These bands are very important for the bio-optical algorithms. A degradation seems to have occurred in the near-infrared despite the replacement of the grating in the near-infrared spectrometer. Some degradation would be expected for band 7 because the notch filter eliminates 90% of the incoming light in the 758-767 region. The degradation of band 7 is very similar to that of bands 8 and 9 so a common cause should be suspected. Daedalus Enterprises now advocates a regular replacement schedule for both gratings as well as a regular recoating of the optical surfaces. Fortunately, the near-infrared bands are used only in the atmospheric correction for aerosols so their sensitivity is less critical than for the visible bands.

Degradation of the fore-optics has been a continual problem, particularly for the shorter wavelength bands, due to cold soaking of the instrument at high altitudes and returning it to the lower atmosphere where water vapor and numerous contaminants condense on the fore-optics. A regular optical cleaning and recoating program is recommended to keep the radiometric calibration close to measured values. Appropriate portions of Daedalus Enterprises' Final Report dated April 27, 1990 are enclosed as Appendix B along with their test results from December 3, 1990 after recoating of the imaging lens and replacement of the near-infrared grating. Note that the spectral response curve for band 7 in the Final Report contains a notch to reduce response in the 757–768 nm region.

Perhaps the biggest improvement of the AOCI was the marked improvement in the quality of the image for band 1. Although the original signal to-noise ratio of 181 was good by normal standards, band 1 looked so noisy over featureless waterbodies that it was unacceptable. After the AOCI improvement, band 1 appeared very crisp and sensitive. Its improvement permitted its use in bio-optical algorithms, particularly the diffuse attenuation coefficient algorithm which required bands 1 and 4. Since band 1 is even more important in measurements of clear waters of the open ocean, this improvement in band 1 is even more important for future AOCI sales where it might be used in such waters.

Although it is not part of the AOCI improvement, band 9 at 1013 nm was found useful because it does not have much response to subsurface phenomena such as suspended sediment. This fact permitted use of band 9 for atmospheric aerosol correction in areas of very turbid water such as the demonstration areas off the Louisiana coast. Band 8 at 865 nm showed substantial response to suspended sediment in these areas and could not have been used for aerosol correction. The sensitivity of band 9 appears to be adequate for detecting aerosols but future versions of the AOCI should devote special attention to increasing its sensitivity if a primary use of the instrument will be for turbid water areas. Some attention should also be given to calibrating band 9 at high radiometric gains; calibration with the present integrating sphere requires lower gains than desirable to keep the signal from saturating.

4.1.2 Algorithm development– One of the major drawbacks to using the AOCI for either scientific or commercial purposes was the lack of software to process its data. Since the atmosphere can contribute up to 90–95% of the signal received at the sensor and can vary significantly from area to area and from day to day (particularly over the Gulf and East Coasts), programs for atmospheric correction were considered essential. Previous work by NASA on the Coastal Zone Color Scanner (CZCS) had developed the methodology for doing so. It is possible to calculate the atmospheric effects due to Rayleigh scattering by molecules in the air because their composition and concentration are known. Because the particles in the air vary greatly in composition and concentration both in time and in space, some data acquired at or near the time of the overpass were required. The approach developed for the CZCS data was to find a band that had no light coming from below the water's surface, correct that band for Rayleigh scattering, and use the result as a measure of the light scattered by the particles. This approach provided a contemporaneous means of estimating the particulate atmospheric effects in one band, but it required other information to estimate the particulate atmospheric effects in other bands. The preferred method used an area of clear water where the total pigment concentration was less than 0.25 mg/m^3 and the underwater radiances could be estimated with confidence and the spectral dependence of the particulate scattering could also be determined. That spectral dependence was applied throughout the area. A less desirable method, but one more often used, simply assumed a flat spectral response after accounting for solar spectral input and ozone transmittances. The CZCS band used for estimating the effects due to particulate scattering was band 6 at 670 nm in the red region, and it is known to violate the assumption of no light coming from below the water's surface in turbid water (high total pigment concentration or suspended sediment). The CZCS approach failed under those conditions and it was recommended that future instruments employ sensitive near-infrared bands to extend the approach to turbid water. The AOCI has three sensitive near-infrared bands for that purpose.

The atmospheric correction algorithm developed for the AOCI used the aircraft inertial navigation system to provide aircraft heading and pitch as well as locational information to calculate the solar zenith and azimuth angles. After the AOCI data is calibrated radiometrically, the Rayleigh scattering contribution at each pixel in each band is calculated (knowing the extraterrestrial irradiance, the Rayleigh optical depth, the ozone transmittance and the zenith angle from the pixel to the sensor). After subtracting the Rayleigh contribution, the algorithm used band 9 to estimate particulate atmospheric effects and subtract them from all shorter wavelength bands. It is possible to specify the spectral dependence of the particulate scattering effects if they can be estimated, but the algorithm assumes a flat spectral response as the default. In actuality, any band can be specified as the one to be used to estimate the particulate scattering effects. It would be possible to estimate the spectral dependence but this process has not been automated. The atmospheric correction algorithm was developed in the public domain and can be provided to users. It has been modified for use with fewer bands in the demonstration projects to minimize data handling. Program documentation is given in Appendix C.

The bio-optical algorithms for total pigment concentration take the form Log [pigment] = A × Log [L/L'] + B where L and L' are upwelling radiances from the water for two different bands calculated by the atmospheric correction program. The bio-optical algorithms developed for CZCS processing used data from Dennis Clark's underwater spectroradiometer cruises with simultaneous measurements of total pigment concentration (Clark, 1981).

After extracting the spectroradiometer measurements convolved with the spectral response of each CZCS band, a linear regression provided the constants A and B for the bands selected along with appropriate statistics. William Broenkow of Moss Landing Marine Laboratory performed the analysis for the CZCS algorithms and he did the same for the AOCI algorithms developed here. The CZCS algorithms used the ratios of the radiances at 443 nm and 550 nm as well as at 520 nm and 550 nm. The AOCI algorithms used ratios of the radiances at 444 nm and 565 nm, at 490 nm and 565 nm, as well as a three band ratio:

$$[L(444) + L(520)]/L(565)$$

Separate algorithms were developed from data restricted to Case I water types and data including both Case I and Case II water types. Case I water types are those where the optics are controlled by phytoplankton, their detritus, and the water itself. Case II water types also contain terriginous materials such as suspended sediment and humic acids. These bio-optical algorithms are listed in Appendix C as well.

In addition to the bio-optical algorithms for total pigment concentration, a bio-optical algorithm for the diffuse attenuation coefficient of the water was implemented. This coefficient quantifies the exponential attenuation of radiance as a function of depth according to the equation, $L = e^{-kz}$, where k is the diffuse attenuation coefficient and z is the depth in meters. The coefficient k is related to other measures of light penetration such as turbidity and Secchi depth but the relationships are not simple. A data base developed for the CZCS diffuse attenuation coefficient algorithms exists, but it was not possible to access it due to monetary constraints. Instead, the CZCS algorithm derived by Austin and Petzold (1981) was implemented directly although the spectral bands that it used, CZCS bands 1 and 3 with band centers at 443 nm and 550 nm, were not exactly the same as the centers of the comparable AOCI bands, 444 nm and 565 nm. The algorithm was found to be fairly robust in the CZCS case, so the shift of the band center from 550 to 565 nm was deemed to have a minor impact. The diffuse attenuation coefficient algorithm implemented was

$$k = 0.0883 \times [L(444)/L(565)]^{-1.491} + 0.022$$

where the correlation coefficient was 0.946. Any or all of the bio-optical algorithms could be selected for calculation after the atmospheric correction was completed.

4.1.3 Geo-location and georeferencing– In the original proposal, geo-location of the imagery was required not only for the atmospheric correction algorithm but for enabling fishermen to locate features of interest by latitude and longitude. For the purposes of the atmospheric correction algorithm, geo-location using the aircraft inertial navigation data proved adequate because the solar angles, aircraft heading and pitch had an error tolerance of one degree in the program (i.e., the program would not recalculate the geometry unless one of the angles changed by more than one degree). Such a wide tolerance for locating features in the data could result in errors of 60 miles. The original approach to calculate and inscribe latitude and longitude lines onto flight lines and overlay coastal boundaries for reference and error evaluation was abandoned in favor of using ELAS georeferencing modules developed by NASA Stennis for the AOCI. These modules appended the inertial navigation data to the AOCI data, corrected for the known geometric distortions of the AOCI, and resampled the AOCI bio-optical product into a geographical data base. For the size of the study area to cover both menhaden and recreational fisheries, the data base consisted of an array of 8600 elements and 4600 lines for 60 meter pixels (0.00054 degrees/pixel). The ELAS modules permitted moving the resampled flight lines to match either shoreline features observed in the data to the coastline for fine tuning the georeferencing or to match common water features between flight lines when no shoreline appeared in the data. The inshore flight lines were fairly well registered but registration of the offshore flight lines suffered because the common features between flight lines were diffuse and subject to misinterpretation. (For the same reasons, offshore registration was less critical.)

Although it was not used in the demonstrations, the original approach of using stand-alone programs for georeferencing was pursued by Spectro Scan and implemented by NASA Ames. The programs used the inertial navigation data to calculate the latitude and longitude of each pixel; the information allowed resampling the flight line data into a geographical data base using core memory for random access (a significant constraint). These programs do not permit fine-tuning the geo-referencing process by shifting the observed features in the data to match either the coastline or common features between flight lines. These programs were provided by Spectro Scan to NASA Ames for their use, but Spectro Scan retains proprietary rights to them.

A big advantage of using the ELAS modules was that the resulting data base could be resampled for use with the CAPT SAM software on IBM-like PCs. An ELAS scene file consisting of 512 lines and 512 elements (or less) with an ELAS header was ingested into the CAPT SAM system using a modified PCFISH module. CAPT SAM was developed by the State of Mississippi for NMFS Stennis to display AVHRR data for fishermen at remote locations since the 512 × 512 array can be transmitted over (often poor) phone lines in a reasonable amount of time. For use in the demonstration projects, two subareas were defined. The western, or menhaden, area covered 90.5 to 93 degrees west by 27.5 to 30 degrees north. The eastern, or recreational fishery area covered 91 to 88.5 degrees west by 27.5 to 30 degrees north. These subareas had a resolution of 0.00486 degrees per cell and required the data base to be sampled by a factor of nine in each direction. Areas within these subareas could be selected from the data base and sampled into 512 × 512 scenes to display features of interest at higher resolution, but the two subareas given above were the standard scenes. With the coastline and latitude and longitude lines at one degree increments superimposed on the data, CAPT SAM provided good visual references as well as cursor control to interrogate latitude and longitude at any pixel. The limitation to a 512 × 512 array was severe but usable. Hardware and software enhancements might relax the limitation particularly as 1024 × 1024 displays become more common.

4.1.4 Demonstration projects– The purposes of the demonstration projects were two-fold. The first was to demonstrate that the entire system would work—from data acquisition through data processing through data dissemination to fishermen in a timely manner. The time requirement was set at 2 a.m. the day following acquisition because the recreational fishermen began leaving the docks at 4 a.m. and the spotter pilots for the menhaden fleet went up at dawn. Originally, the second purpose was to transfer use of the system to Spectro Scan and allow them to determine the actual commercial prospects for supplying near-real-time information to fisheries. Since Spectro Scan did not obtain the required capital to participate at that level, the second purpose was modified to obtaining as much information as possible to permit that determination to be made. Interaction with fishermen or spotter pilots for their evaluation of the utility of the results was implicit in the second purpose (but it was not explicitly stated in the original proposal).

The principal operational objective of the demonstration projects was to provide timely data products and demonstrate techniques for near-real-time dissemination in support of fisheries operations. This task was accomplished through the establishment of collaborative activities with organizers of selected tournaments of sport fishing clubs and menhaden fleet operations to support the demonstration projects. Fisheries personnel participated in data collection and critiquing of remotely sensed products, including distribution techniques and time frames pertinent to the operational requirements of their respective fisheries.

Three demonstrations were conducted to exhibit progress in developmental capabilities and address complexities or requirements special to a variety of fishery interests. Dissemination of remote sensing products was accomplished by electronic transfer from a host computer at Stennis to receiving computers located at distant sites via cellular telephones and/or land lines. The automated distribution capability was attained through development of basic software and a sequence of events for AOCI data manipulation. ELAS scene files of 512 × 512 elements of total pigment concentration data produced by Lockheed contractors at NASA Stennis (described in section 3.1) were received by NMFS, converted into CAPT SAM format, compressed to minimize the time required for transmission, and placed on the host computer. Similarly, computers stationed at demonstration sites were affixed with telephone hardware (cellular or land lines) and programmed to dial up the host computer, transfer, unpack, display and manipulate scene files as required.

The initial demonstration was conducted at the 1990 Invitational Billfish Tournament of the New Orleans Big Game Fishing Club in Port Eads, Louisiana. A variety of satellite and airborne sample images were transferred including first generation products of AOCI chlorophyll distribution supplemented by satellite turbidity and sea surface temperature. The informational products were collectively presented to depict high probability fishing areas for pelagic recreational gamefish based on the location of oceanic frontal boundaries (color and thermal) identified in remotely sensed data. Three successful AOCI flights were conducted on successive days, June 12, 13 and 14, 1990. Processing problems at NASA Stennis permitted only a portion of the June 14 AOCI raw data of band 6 (665 nm) to be downlinked.

The second demonstration was held in collaboration with the 1990 Grand Isle Tarpon Rodeo and repeated at the New Orleans Big Game Fishing Club. A major remote sensing display (fig. 1) was constructed and integrated into scheduled events held at tournament headquarters to reach an expanded number of fishermen with varied fishing interests as well as to inform the general public. Hence, presentations and demonstrations of fisheries remote sensing applications were conducted in conjunction with coastal and pelagic recreational sport fishing clubs at Grand Isle and Port Eads, Louisiana respectively. Three successful AOCI flights were conducted on July 23, 25 and 26, 1990. Despite intense efforts by NASA Stennis programmers to overcome processing problems, the demonstration of near-real-time delivery techniques was limited to restricted AOCI data products from the July 26th flight. However, interaction and comments from fishing participants proved highly successful for customizing the development of AOCI products and ancillary information to be included therein.

AOCI developments pertaining to the commercial fishing industry were presented at an executive meeting of Zapata Haynie Corp. in Pascagoula, Mississippi. The June 14th AOCI data had been processed at NASA Ames and geo-referenced at NASA Stennis. Initial analyses of the June 14th total pigment concentration data revealed that menhaden fish catch data seemed to correlate with a narrow range of total pigment concentrations. Figure 2 shows a CAPT SAM display of the total pigment concentrations for the western area where the menhaden fishing fleet was operating. Fish catch locations for that day have been overlaid on the AOCI product as crosses. Total pigment concentrations at the crosses were determined and used to make the histogram in figure 3 showing the number of fish catch locations as a function of the total pigment concentration. With one exception, menhaden were caught only in the range of 4 to 7 mg/m^3. It was decided that the format of AOCI products supporting menhaden fisheries in nearshore, turbid waters should highlight distributions of preferred total pigment concentrations as opposed to the location of color boundaries produced for pelagic species in oceanic waters. Figure 4 shows a CAPT SAM display of the eastern area; it can be seen that the total pigment concentration manages to delineate the boundary of coastal and oceanic waters well.

Subsequent data processing by Lockheed at NASA Stennis produced CAPT SAM products for the AOCI flights on July 23rd and 25th. Figures 5 and 6 show, respectively, the western area with menhaden fish catch locations superimposed and the eastern area where the recreation fishing activity concentrated. A histogram of the number of fish catch locations versus total pigment concentration is shown in figure 7 for July 23rd. Again the range of total pigment concentrations was narrow but it had shifted slightly to 2 to 4 mg/m^3. Figures 8–10 show the results corresponding to figures 5–7 for July 25th where the range was quite similar to July 23rd.

Figure 1. Interactive remote sensing display used for AOCI demonstration at the 1990 Grand Isle Tarpon Rodeo.

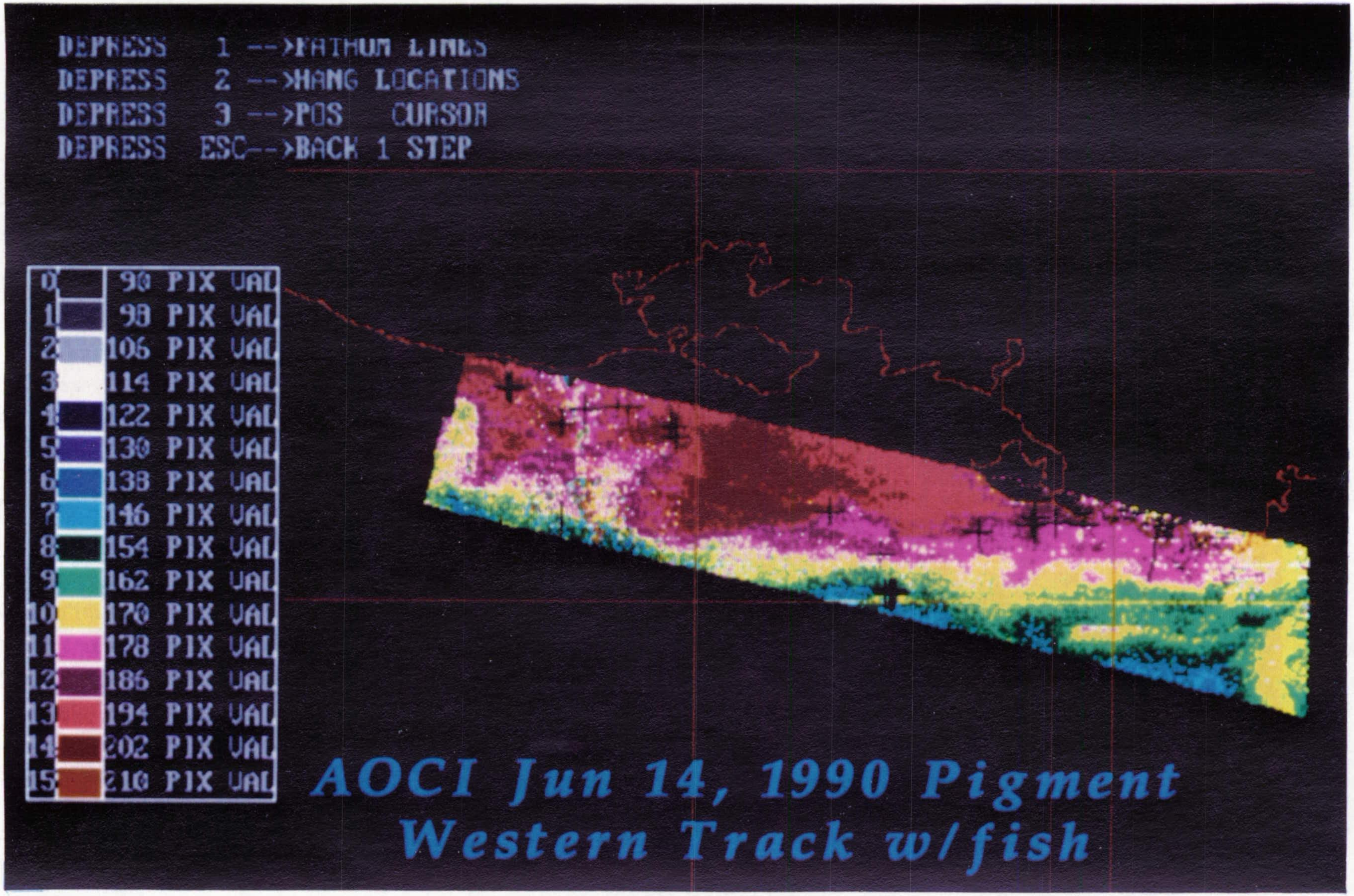

Figure 2. CAPT SAM display of AOCI-derived total pigment concentration for the western study area on June 14, 1990, with concurrent fish catch locations overlaid.

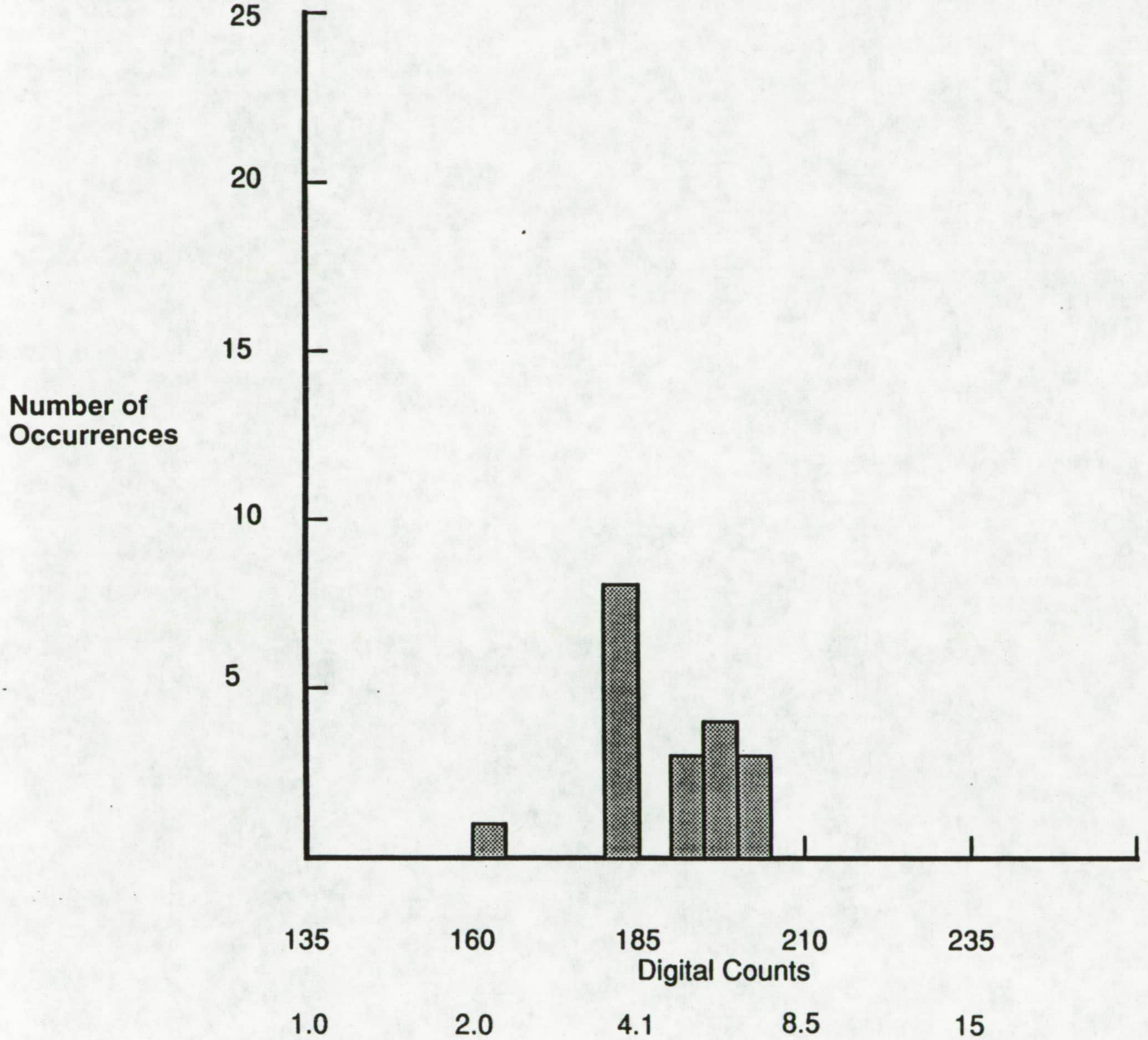

Figure 3. Histogram of the number of fish catch locations on June 14, 1990, as a function of total pigment concentration.

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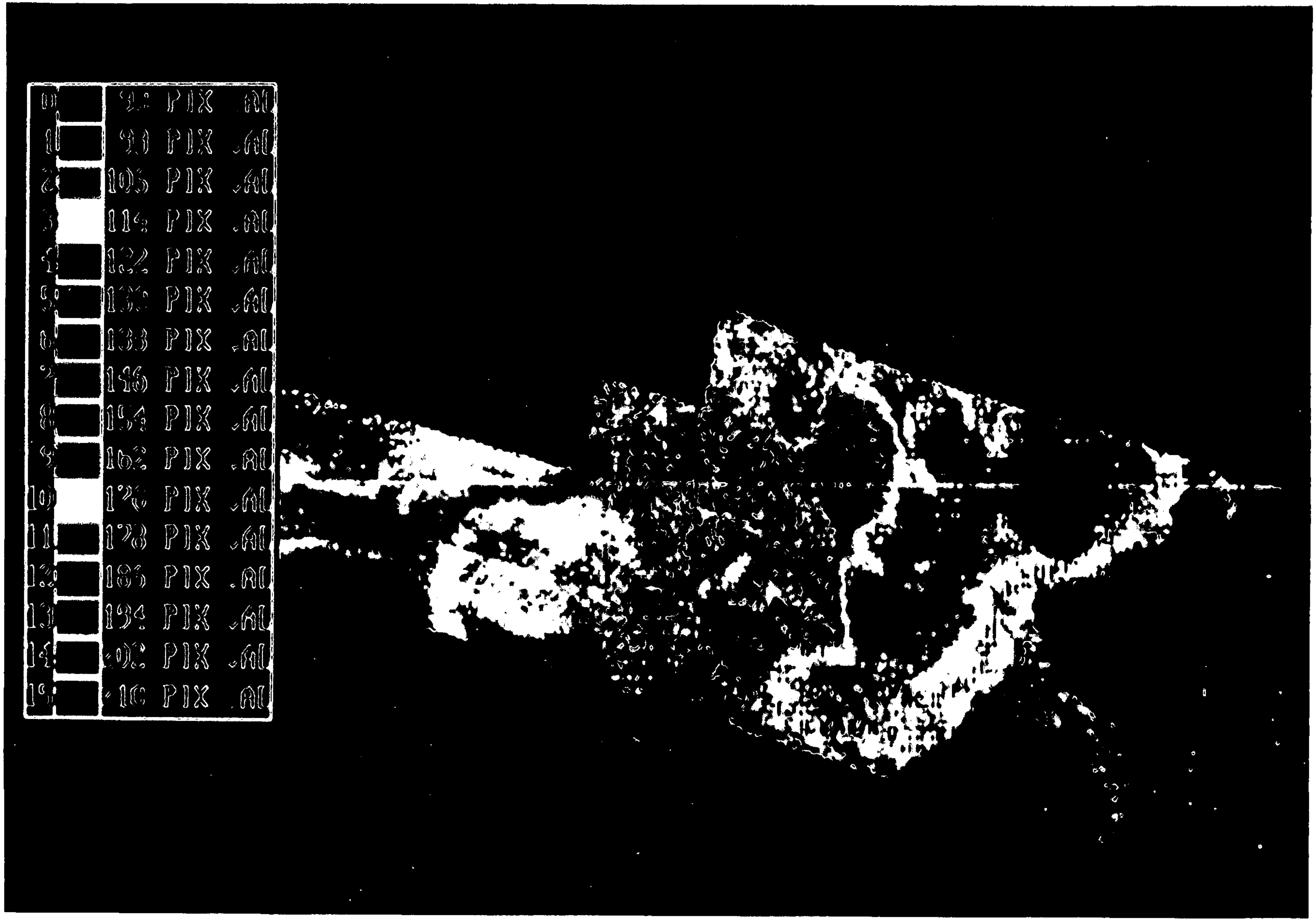

Figure 4. CAPT SAM display of AOCI-derived total pigment concentrations for the eastern study area on June 14, 1990.

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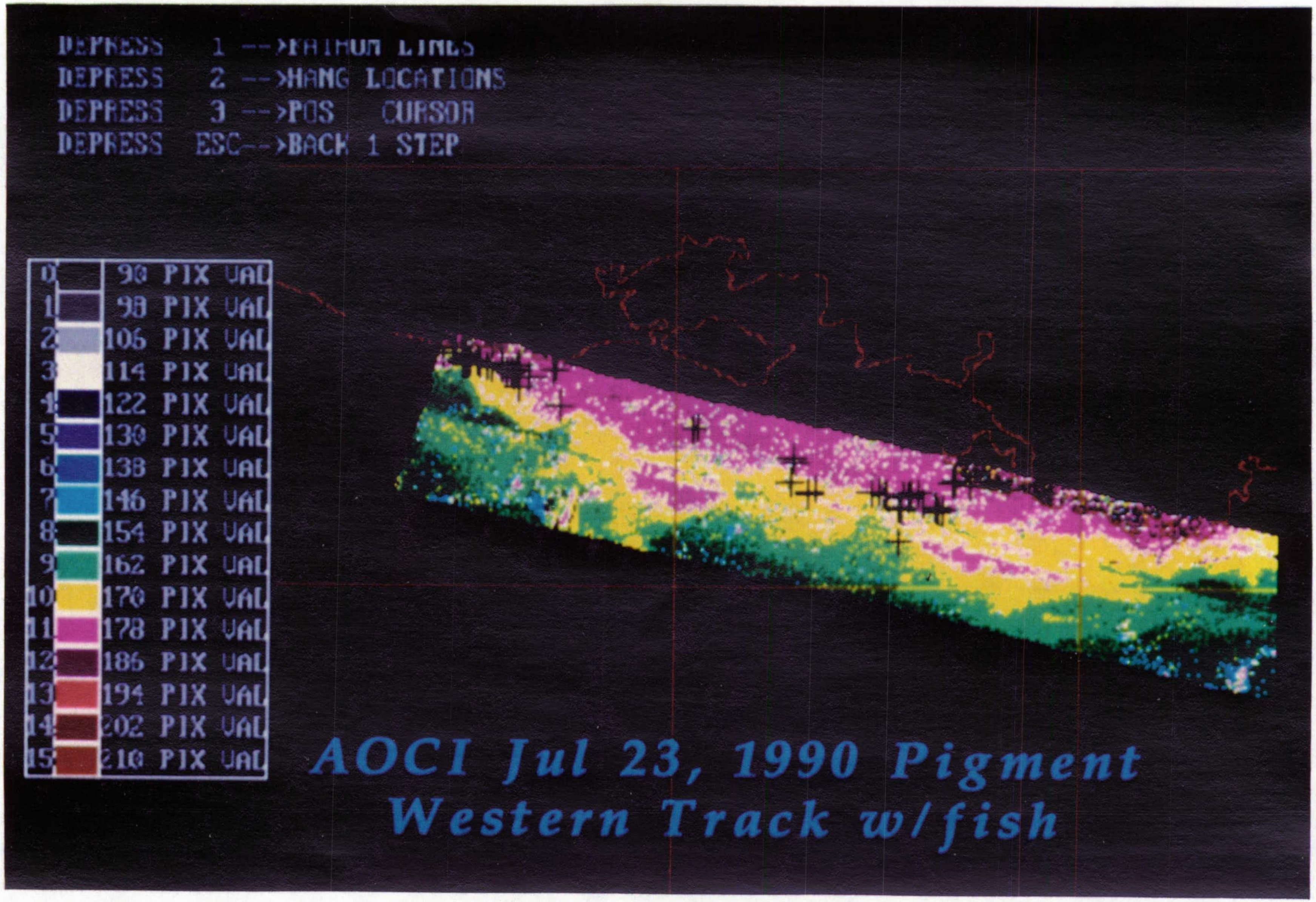

Figure 5. CAPT SAM display of AOCI-derived total pigment concentrations for the western study area on July 23, 1990, with concurrent fish catch locations overlaid.

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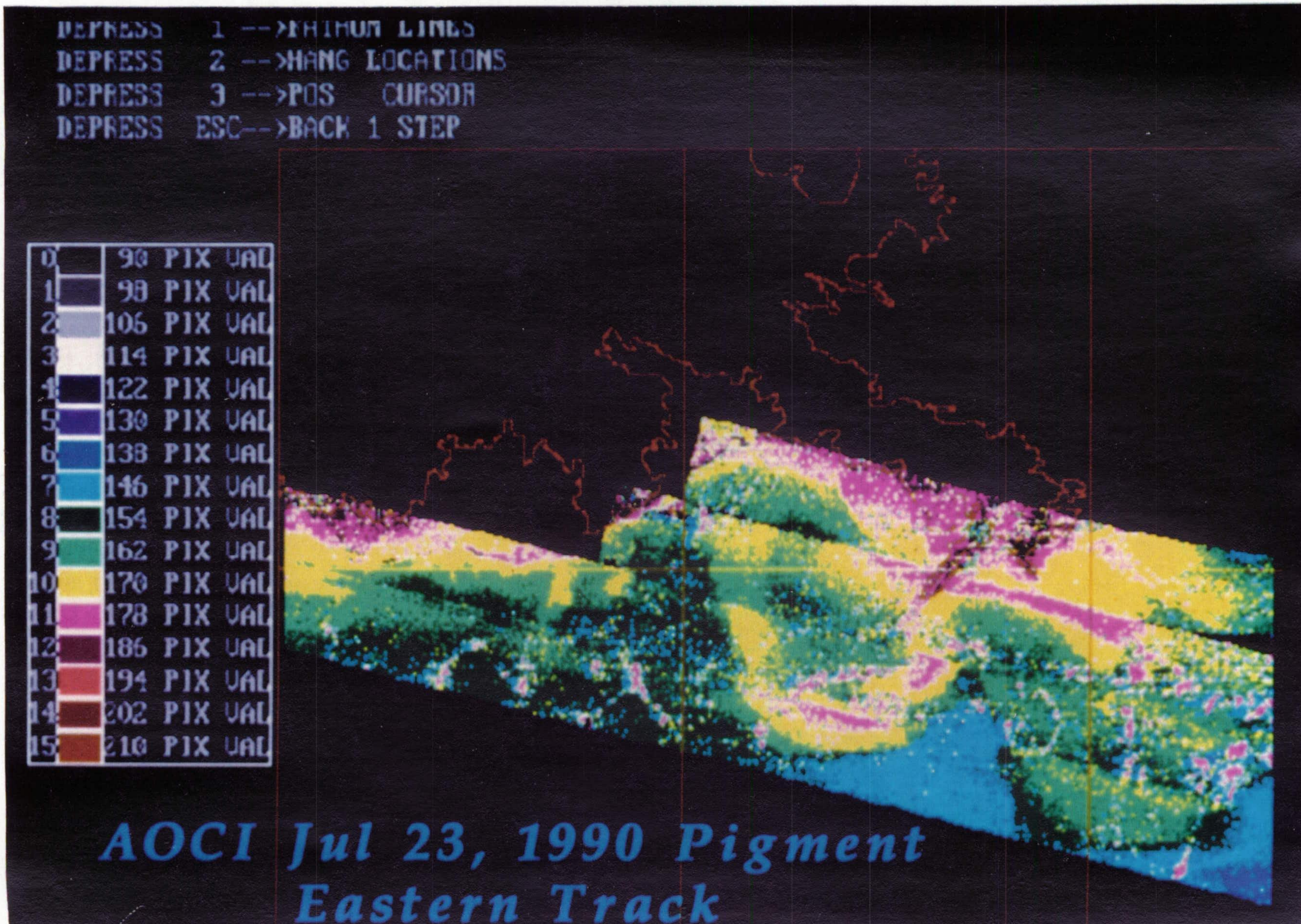

Figure 6. CAPT SAM display of AOCI-derived total pigment concentrations for the eastern study area on July 23, 1990.

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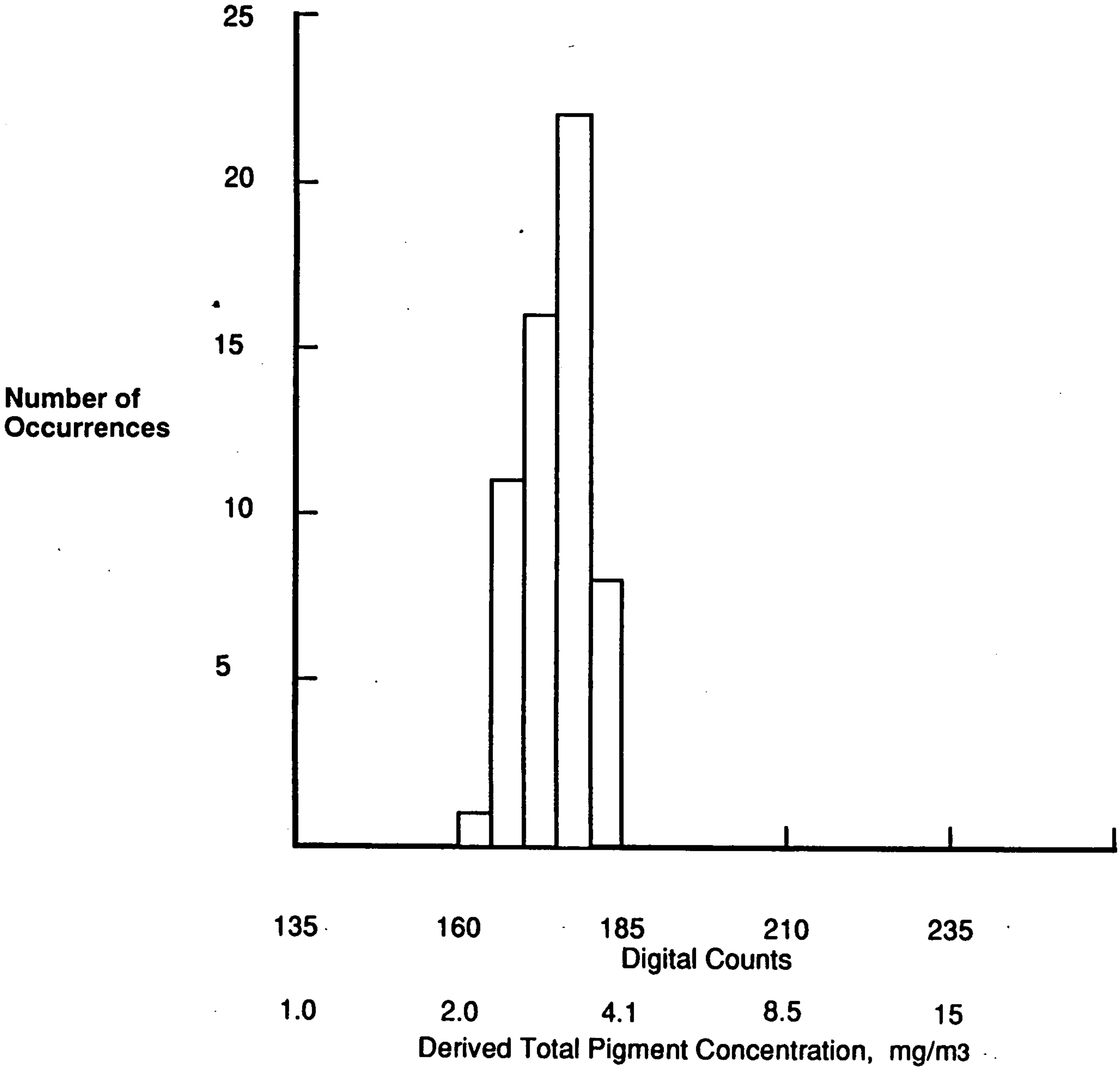

Figure 7. Histogram of the number of fish catch locations on July 23, 1990, as a function of total pigment concentration.

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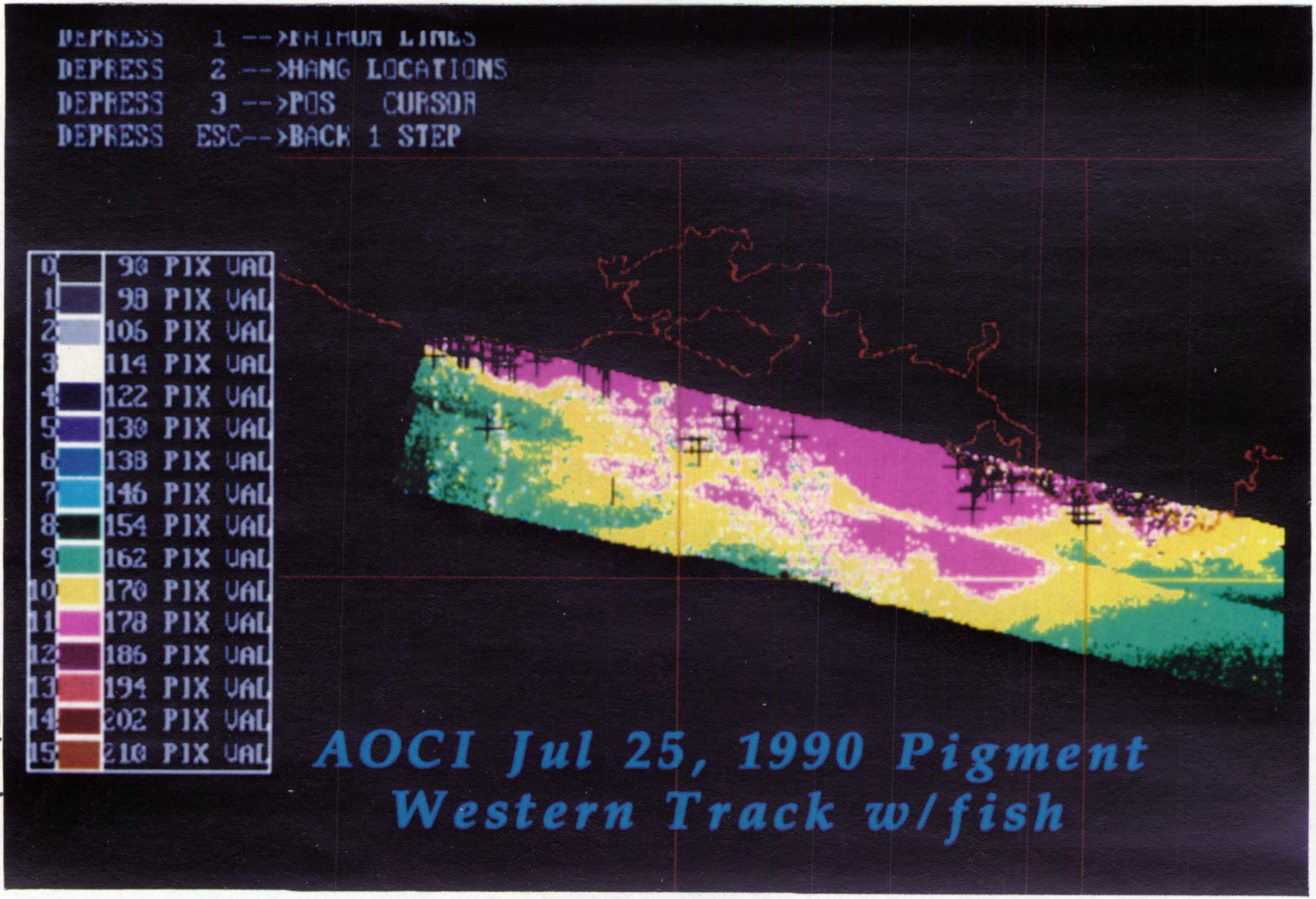

Figure 8. CAPT SAM display of AOCI-derived total pigment concentrations for the western study area on July 25, 1990, with concurrent fish catch locations overlaid.

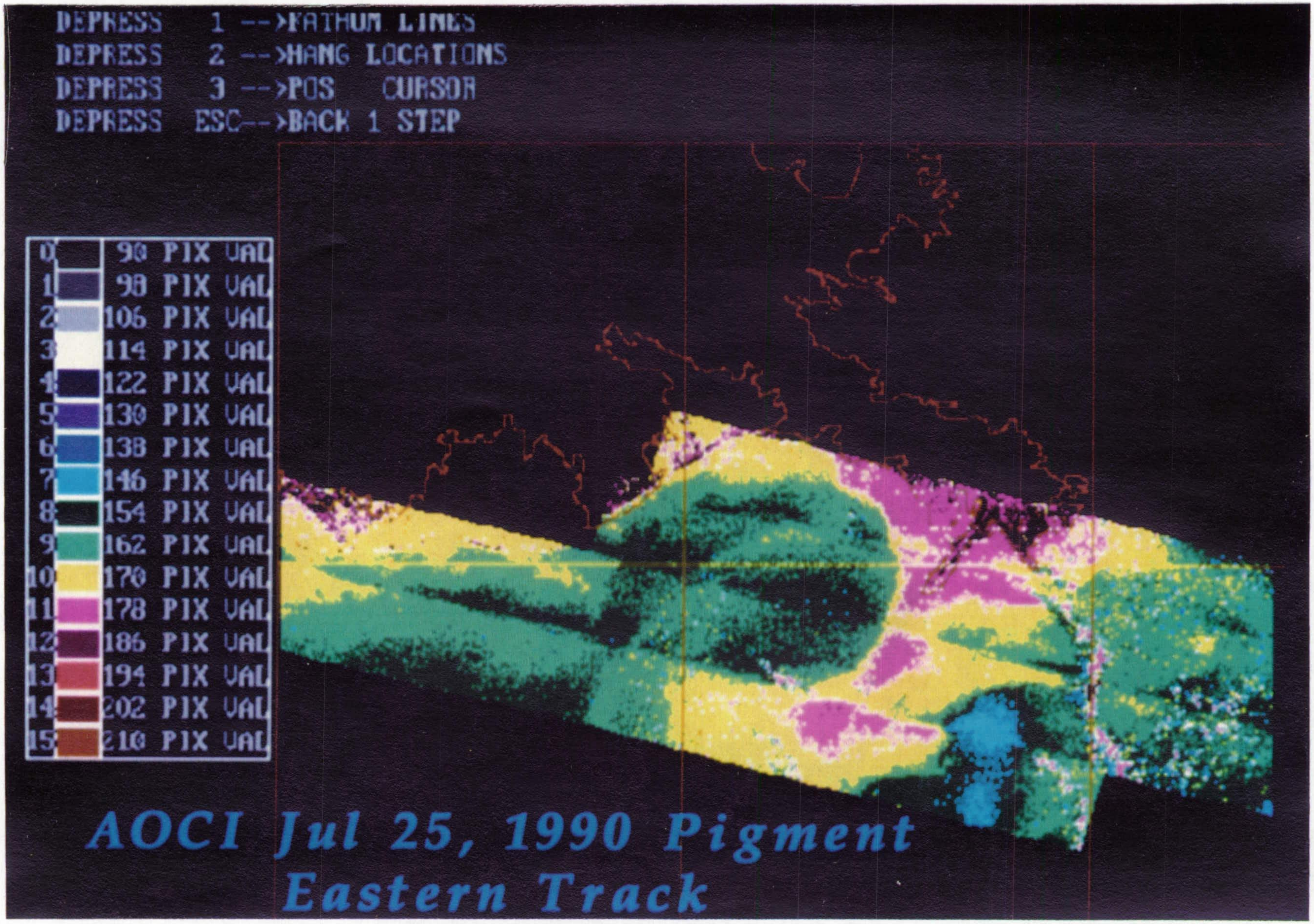

Figure 9. CAPT SAM display of AOCI-derived total pigment concentrations for the eastern study area on July 25, 1990.

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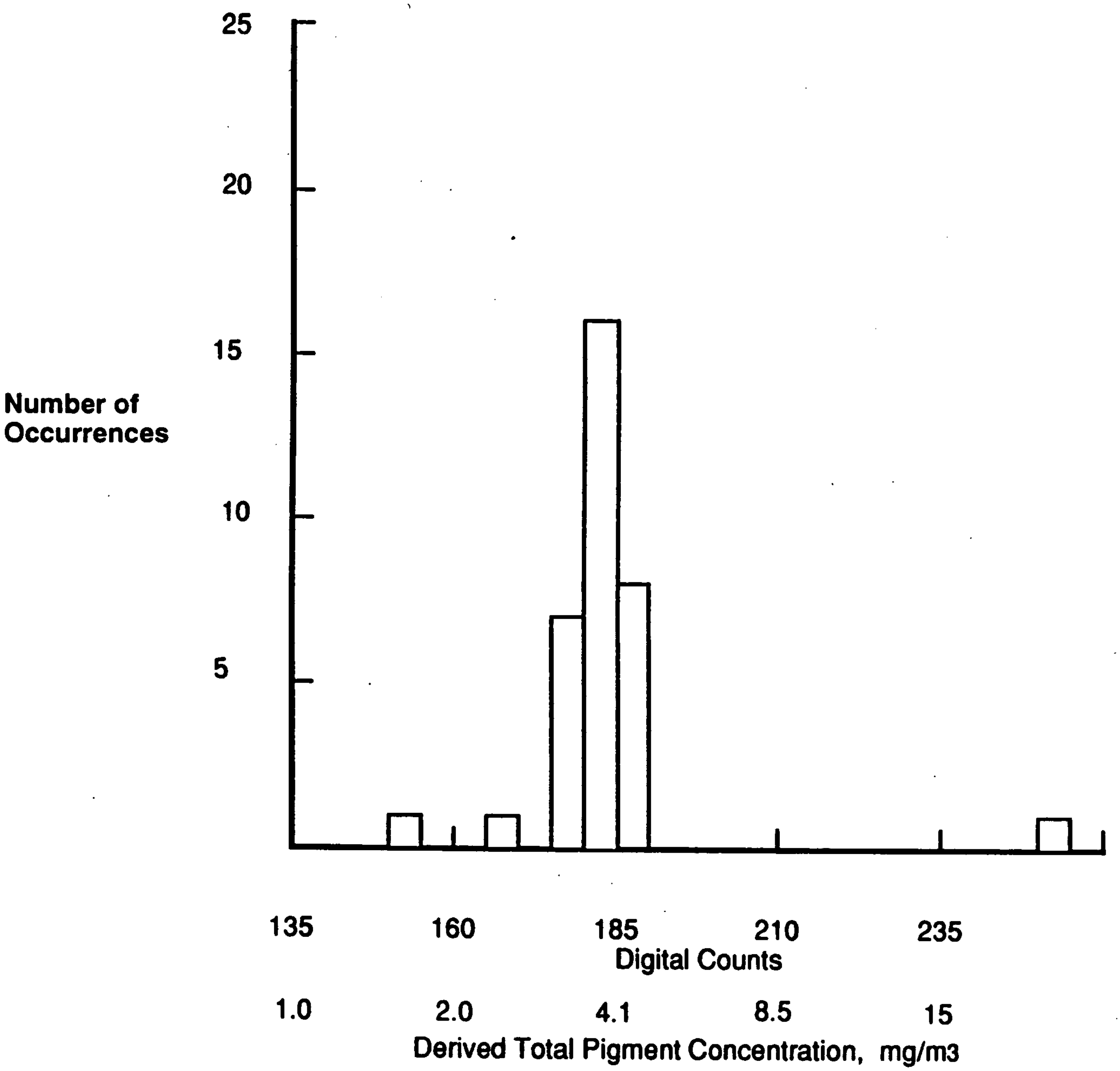

Figure 10. Histogram of the number of fish catch locations on July 25, 1990, as a function of total pigment concentration.

The main thrust of the third and final demonstration was to support coastal menhaden operations, as efforts for recreational gamefish were repeatedly thwarted by cloud cover in the offshore fishing area. Only two AOCI flights occurred due to weather limitations, June 19 and 20, 1991. The flight lines were modified to accommodate the westward movement of the menhaden fishing fleet by deleting a flight line over the Mississippi delta and adding the flight miles to the western end. The longer flight lines occasioned some system limitations on June 19th which were resolved on June 20th.

The near-real-time demonstration of AOCI capabilities was enhanced by incorporating changes in product formats suggested during the second demonstration and implementing collaborative activities with Zapata Haynie to operationally derive and depict high probability fishing areas based on preferred total pigment concentration at fish observation sites determined by spotter pilots. During routine flight operations, aircraft spotter pilots recorded the size and Loran-C navigation coordinates of menhaden schools. NMFS Stennis personnel located at airport facilities in Abbeville and Sulphur, Louisiana used telephone facsimile equipment to transfer copies of daily flight records to NMFS Stennis where the data were entered, processed, and compiled for interrogation of AOCI imagery.

The image processing and data analysis was conducted at NMFS Stennis on a super mini-computer and micro-computers that were linked together to enable the efficient transfer of data and programs. The communication link between machines was essential to complete the demonstration in a timely manner given the complexity of the task and number of required processing steps (fig. 11). The image processing software used throughout the project was ELAS (Beverly and Penton, 1989).

A Statistical Analysis System (SAS) program was used to reformat the data and help create an ELAS command stream (macro) to extract information from the total pigment concentration image. The ELAS macro was designed to convert the latitude and longitude coordinates of each reported sighting to vector (point) data, assign unique numeric codes to each observation, and digitally encode the information into a mask file that was co-registered to the total pigment concentration image. The mask file was then used as a template to digitally extract data values and the corresponding location coordinates from the image. The image data were transferred to an ASCII index file and reformatted for storage in a SAS data base.

An experimental predictive product to be used for menhaden operations the following day was produced through the development of a histogram plot (fig. 12) and look-up table (table 2) to equate fishing information with total pigment concentrations extracted from AOCI imagery acquired on June 20, 1991. The predictive product had a resolution of 540 meters with a coastline and a latitude/longitude grid. To indicate a range of fishing success from low to high, predictive values in the image were scaled from 1 to 100, respectively.

The predictive image was reformatted for display on microcomputers equipped with VGA graphics and transferred to the host computer at NMFS Stennis. NMFS Stennis field personnel were then able to download the image, print and distribute color copies of the product to spotter pilots the following day (fig. 13).

The predictive image was transferred to two field locations for display to Zapata Haynie spotter pilots, Abbeville and Sulfur, Louisiana. The image was successfully displayed at Abbeville but all the spotter pilots had moved to Sulfur. The predictive image was improperly reformatted by the equipment at Sulfur. Consequently, no spotter pilots saw it in time to be useful to them.

4.1.5 Reconciliation with expectations– Given present knowledge, expectations were always high. Complex tasks were oversimplified in the original proposal. The simpler ones such as improving the AOCI or developing atmospheric correction and bio-optical algorithms took longer than expected due to procurement practices and contractor availability, respectively, but they were accomplished in time for the demonstration projects. The loss, which proved minor, prevented proper analysis of the results of the 1988 and 1989 flight data in conjunction with the 1989 environmental data from ships and the 1989 fish catch data. The demonstration projects provided a wealth of example data products obtained in support of fisheries operations. This had been a significant lack when Daedalus Enterprises attempted to market the AOCI instrument worldwide. One of the major objectives of the original proposal was to provide such products to Daedalus Enterprises and that has been accomplished. More such products can be generated if Daedalus needs them.

Running complex tasks on unfamiliar computers and analysis systems at another NASA center proved far more troublesome than ever imagined. Local systems analysts and data processing analysts struggled mightily to revamp systems and software processing approaches that had not been tried for our particular application. The assumption that decommutation procedures were in place for AOCI data, when they were not, doomed the success of the June 1990 demonstration period. Crash attempts to decommutate a single band of raw data (the 665 nm band) and use the data as an analog of turbidity led to other problems such as: ELAS AOCI georeferencing programs had been

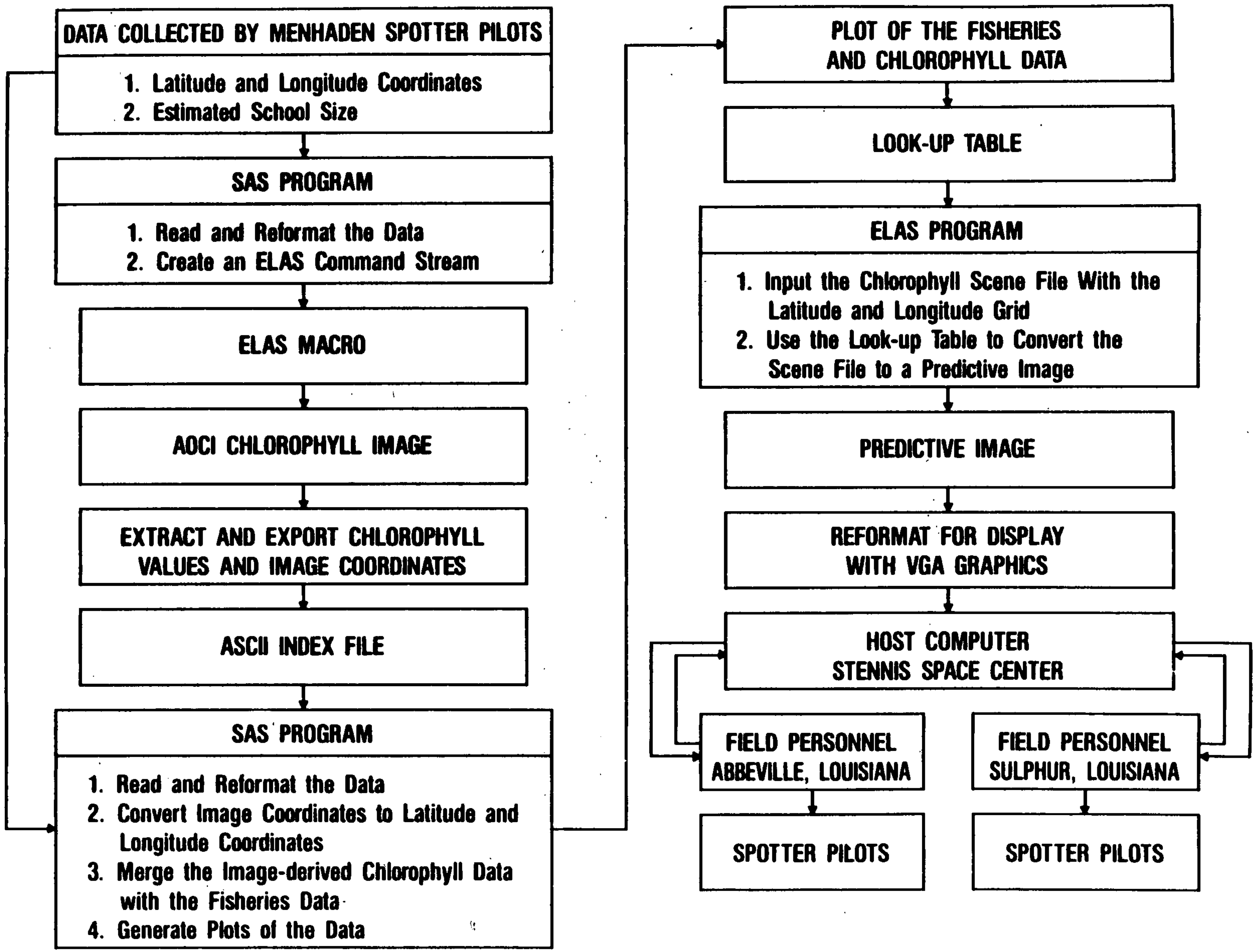

Figure 11. Flow diagram of processing protocol developed for near-real-time AOCI demonstration to the menhaden industry.

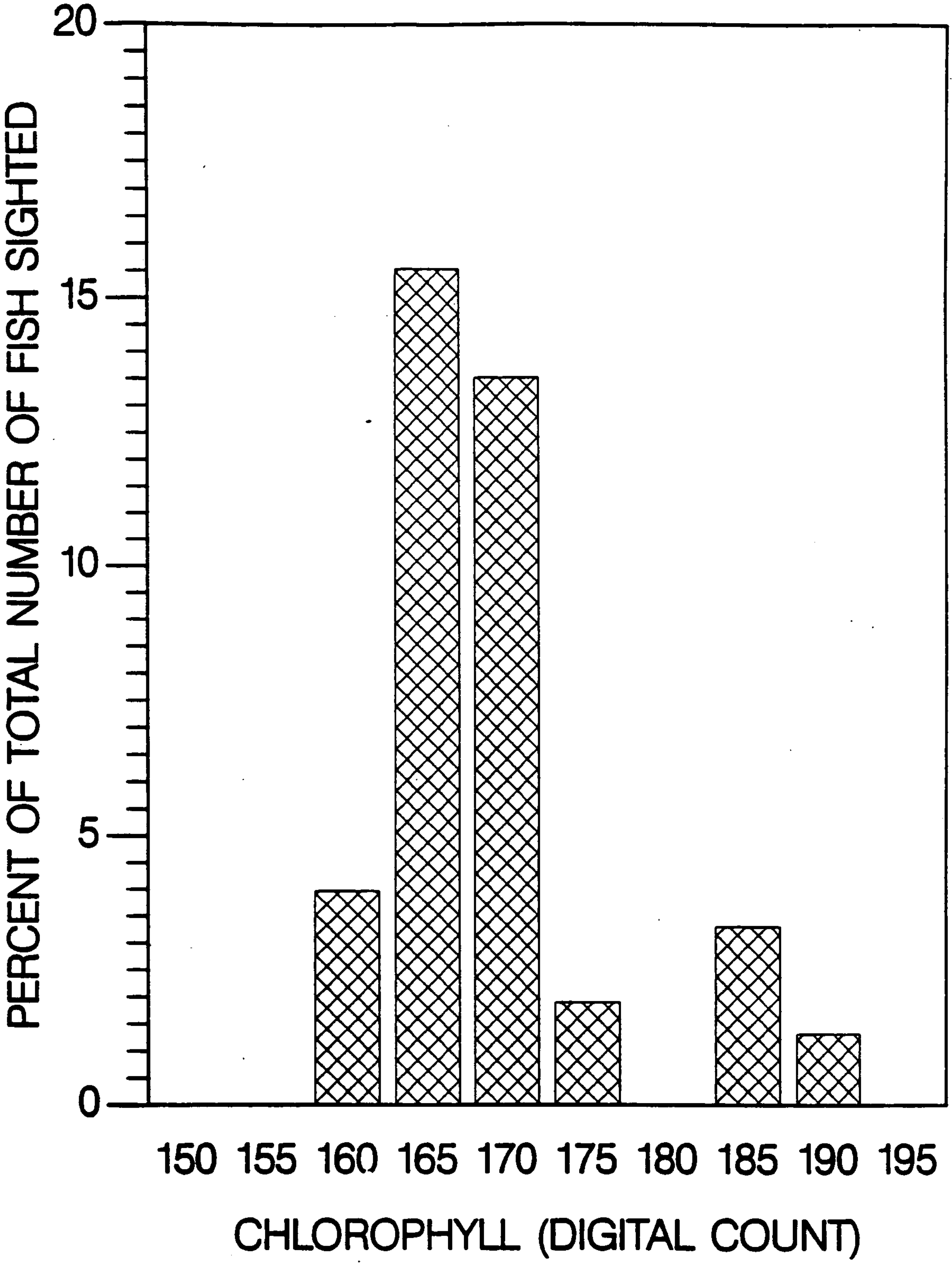

Figure 12. Catch histogram used to establish the look-up table for total pigment (chlorophyll) concentrations preferred by menhaden in the Gulf of Mexico.

Table 2. Input and output values of the look-up table derived from figure 12 used to generate the predictive image from the total pigment concentration image acquired on June 20, 1991

	Predictive image	
Range of total pigment concentration	Range of input values output values (digital count)	Identity of pixels
0	0	Background
1–155	1	Predictive data
156–160	2–26	Predictive data
161–165	27–100	Predictive data
166–170	99–87	Predictive data
171–175	86–13	Predictive data
176–180	12–1	Predictive data
181–253	1	Predictive data
254	254	Coastline, lat/long
255	255	Background

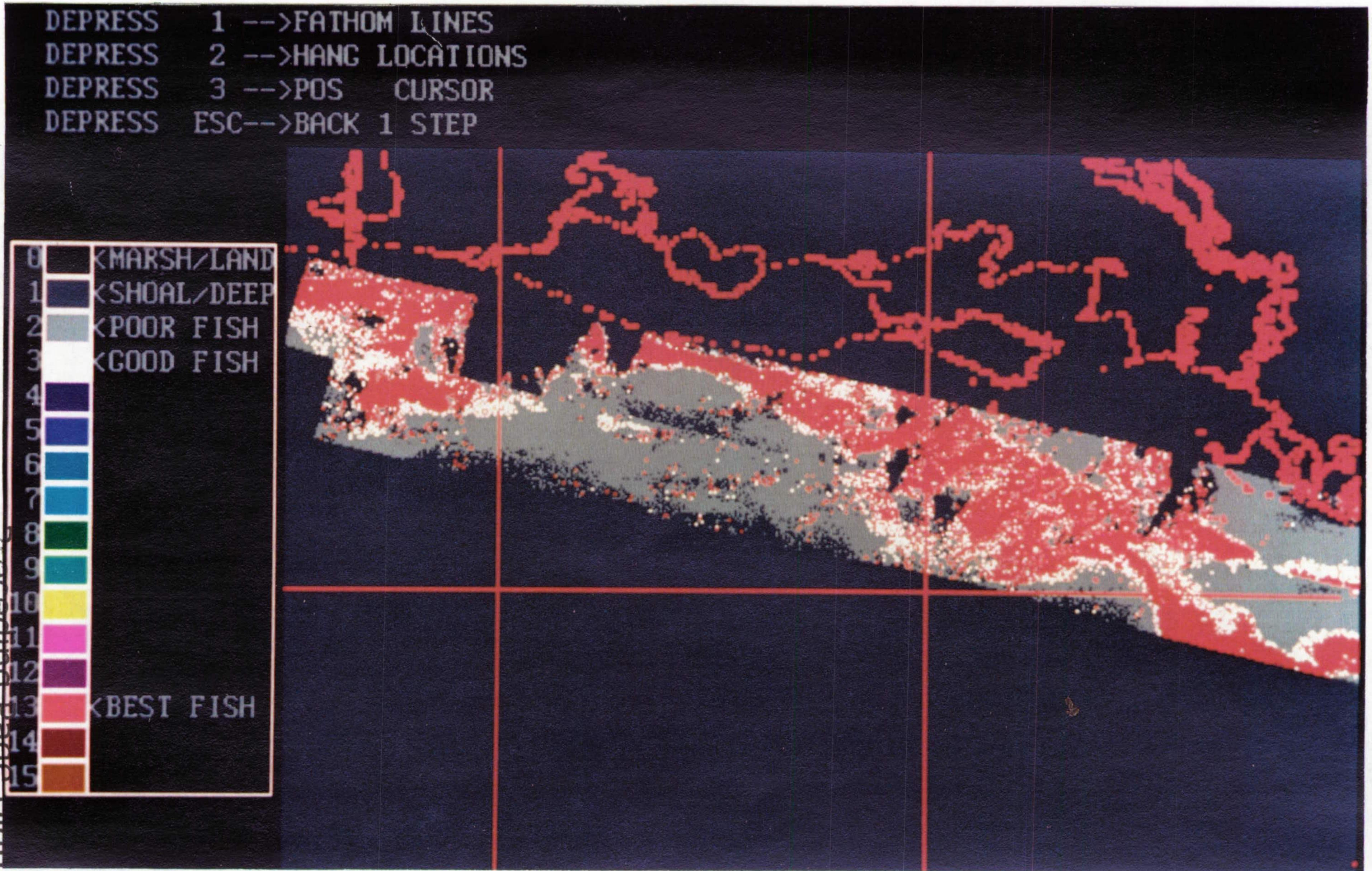

Figure 13. Model prediction of menhaden fishing conditions for June 21, 1991, based on AOCI data obtained on June 20, 1991. Red indicates best fishing areas, white indicates good fishing areas, and light gray indicates poor fishing areas.

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written for 16-bit data and NASA Ames algorithms output byte data to save disk space, the georeferencing programs were written to accept only 10-band AOCI data with housekeeping information whereas Ames output a variable number of bands without the housekeeping data, and mismatches in time between AOCI data and the navigation data caused large errors in georeferencing. Most of these problems were resolved before the July 1990 demonstration project, but rewriting the decommutation programs proved more difficult than Lockheed Stennis expected and they were not ready even at the end of the July demonstration project. To say the least, it was a major disappointment not to transmit any useful data to the CAPT SAM systems in remote locations. Scheduling a third, unanticipated demonstration project for June 1991 permitted a successful test of the entire process from beginning to end and included the development of a prediction model based on current fish locations. Unfortunately, the spotter pilots were forced to move to a new location where the computer display system did not work.

On a more positive note, it appears that our approach of defining the environmental conditions where fish should be found is appropriate. The fish catch data suggests strongly that menhaden are caught within a relatively narrow range of what is calculated as total pigment concentration. Also, the use of the ELAS georeferencing modules greatly improved the usability of the final data products because flight lines could be mosaicked together, north was always at the top of the display, and the CAPT SAM system could be used to transmit and display a good representation of the data at remote locations over cellular phones.

4.2 Evaluation of Technical Results for Commercialization

Despite the problems experienced in the three demonstration projects, the technical results show the technical objectives were largely achieved.

1. The AOCI instrument was improved as planned, if not as scheduled.

2. The atmospheric correction algorithm was implemented and it processed AOCI data at approximately one scan line per second for all bands on a one MIPS computer (either the VAX 11/780 or the Concurrent).

3. The bio-optical algorithms for total pigment concentration were reformulated for the AOCI bands using the CZCS underwater spectroradiometer data base while the CZCS algorithm for diffuse attenuation coefficient was implemented directly.

4. Geo-location using the aircraft INS data appeared to work satisfactorily provided the times were synchronized before flight.

5. The georeferencing procedures were greatly improved from the original ones by the use of either the ELAS georeferencing modules or the stand-alone programs written by Mark Carle of Spectro Scan and implemented by NASA Ames.

6. The data product delivery using the CAPT SAM system was also a very great improvement over original ideas which proposed using FAXed charts with hand-drawn information on them.

7. Sufficient experience and example data products were generated to enable Daedalus Enterprises to market the AOCI for fisheries and oceanographic applications.

8. The fact that the whole process finally worked in July 1991 shows the basic technical objectives were achieved.

Wrigley et al. (1992) provided an overview of the technical aspects of the whole effort and used data from the demonstration data sets to illustrate the sequence from raw data through atmospheric correction, bio-optical products, geo-location and georeferencing. They used Carle's stand-alone for geo-location and georeferencing because ELAS was not available to them.

The original proposal also was based on the assumption that the initial commercialization of the AOCI and the data processing system would be carried out by Spectro Scan. It was intended that Spectro Scan would buy an AOCI, buy or lease a Learjet, follow the software development, take over flight responsibility for the final demonstration project, and evaluate the commercial prospects of the entire system. Since Spectro Scan has not yet obtained capital funding to purchase the equipment and begin operations, it has not been possible to achieve these objectives. It is one of the realities of the marketplace that remote sensing is considered a risky business, so it is not surprising that Spectro Scan had such difficulty. Nonetheless, it was a great disappointment that they were not able to participate as intended. Spectro Scan originally offered 100 hours of Learjet flight time to further develop and evaluate the commercial market. Analysis of the data produced by those hours and the subsequent interaction with fishermen would have provided a great deal of information on the marketing parameters for the AOCI data products. In the absence of that information it will be important to fully use the data that we have. Geo-referenced total pigment concentration data exist for June 14, July 23, July 25 and July 26, 1990, as well as for June 19 and June 20, 1991. Fish catch data exist for all those dates and environmental data exist for the 1990 dates. Non-georeferenced, diffuse attenuation coefficient and thermal data exist for all dates. Atmospherically corrected data for bands 1–4 and 9 exist for the July 1990 and June 1991 dates while atmospherically corrected data for bands 1-9 exist for the June 1990 dates. Analysis of these data should be accomplished to develop relationships between dates to answer the critical question of whether real time data are required. For marketing purposes, fishermen would want assurance that yesterday's data would be adequate. Preliminary examination of the sequential data sets indicates a coherence between successive days but that the coherence is poor by the third day. The analysis should also develop the relationships between fish location, the environmental data and the processed AOCI data.

To summarize this evaluation, the acquisition, processing and delivery of AOCI data products worked and example products were generated for Daedalus Enterprises, but the commercial utility of the AOCI data products still needs to be developed. We have some information to aid that development which will be discussed later.

Of equal importance to product delivery and demonstration activities conducted in collaboration with commercial and recreational fishery user groups, information transfer of AOCI remote sensing capabilities was commonplace throughout the period with participation in numerous presentations and sponsored events including video documentation and media broadcasts. Salient examples were:

President's Report to Congress – 1991 NMFS Stennis submission

International Work Boat Show – New Orleans, LA

America Seas Symposium – New Orleans, LA

MS State Officials	Senator Margaret Tate Senator Gene Taylor Representative Ezell Lee
NASA/SSC	Historical and Public Affairs personnel Educational program officers

Telebit Electronics – Dallas, Texas

NASA Aeronautics and Space Report

Television Broadcast via	WLOX – Biloxi, MS
	WDAM – Hattiesburg, MS
	KPIX – San Francisco, CA

NOAA's Nutrient Enhanced Coastal Ocean Productivity Program (NECOP)

1990 Grand Isle Tarpon Rodeo Magazine

4.3 Business Results for the AOCI Instrument Product

4.3.1 Overview of commercial and public sector need for the AOCI instrument product– During the past several years, Daedalus has received expressions of interest in an AOCI-type instrument product from potential customers in Argentina, Australia, Brazil, Chile, Iceland, Italy, Japan, Mexico and the Seychelles. While most of these inquiries were stimulated by the possible use of the instrument to support fisheries, some were related to biological oceanography studies as well. Most of the inquiries originated from government agencies but some represented companies in the fishing industry or service organizations desiring to support fisheries.

The establishment of the 200 mile Exclusive Economic Zones (EEZs) has stimulated most nations to be more concerned about the exploitation and protection of their marine resources. Because of the vast areas represented by the EEZs, airborne and satellite sensors are now regarded as necessary tools for every nation for at least surveillance of their areas of responsibility. This need then leads to consideration of what other sensor capabilities might be added to support the use and management of marine resources such as fish. It is estimated that more than 200 million people earn their living from marine biological resources and that almost 30 percent of all marine activities are associated with the fisheries business. The world-wide annual fish catch is estimated to be 80 million tons and represents one of the most important sources of animal proteins.

Some nations, such as Japan and the Soviet Union, have vast world-wide fishing fleets that are supported by national institutions. For example, Japan supplies ocean temperature data to its tuna fleet through a program operated by Japanese Fisheries Center using U.S. satellite data from the AVHRR sensor. Other countries with large far-ranging tuna fleets include the U.S., Canada, France, Spain, Portugal, and Italy. Some of these receive national support while others, such as those in the U.S., are privately owned businesses.

Much of the recent interest in using remote sensing as a fisheries support tool is economically driven. There is more world-wide competition for a smaller fish resource and costs of labor and fuel have escalated. In addition, the EEZs have made some good fishing grounds off-limits to all but indigenous fishermen and governments have instituted seasons and catch limits as conservation measures. All of these factors have combined to create a demand for "science" to be incorporated in fisheries. Little is known about the controls for fish production and movement in the seas. It is known that fish populations exhibit highly nonuniform distributions with major changes occurring over periods of years and areas of millions of square kilometers. Thus, there is a need for remote sensing instruments to assist in studying marine resources, establishing sound management programs, and improving the efficiency of catching fish. Some of these needs can be best met by future satellite sensors such as the U.S. SeaWiFS, Japanese OCTS, or ESA MERIS. Other needs are better met with airborne sensors and real-time or near-real-time processors which can be operated and controlled by individual nations or companies. It is this remote sensing instrumentation market that Daedalus intends to penetrate.

4.3.2 Market verification– Daedalus has verified the market for the AOCI instrument during the course of the EOCAP program through both its general international remote sensor marketing programs and special efforts related to the AOCI commercialization. During the past five years, Daedalus has sold 24 airborne multispectral imaging systems for maritime applications in eight countries world-wide. Five of these systems have been equipped with the CZCS simulator array specifically for oceanographic studies. The rest of the systems are used primarily for pollution surveillance and oil spill mapping, as well as for the inspection of fishing operations within EEZs.

Final pricing has been submitted to a European customer for an AOCI system for which Daedalus expects to negotiate a contract in 1991. This will be the first production AOCI system based upon the NASA SBIR development program and will be used for oceanographic studies in the Mediterranean. Daedalus is also involved in proposing a complete AOCI-based fishery support system for a South American customer who needs to support a fleet of ten ships involved in anchovy, sardine and horse mackerel fisheries. This sale will probably require six to nine months to close.

There is no doubt of the existence of an international market for an AOCI fishery support system. However, since the complete data processing and delivery package has not been possible to develop under the EOCAP program, it is not yet certain at what price such a system must be sold in order to capture a significant world-wide market. Further verification of the market will be accomplished as soon as a set of realistic data products can be generated for display to prospective customers.

4.3.3 Marketing plan– The AOCI instrument marketing plan developed by Daedalus consists of the following six major steps:

1. Definition
2. Analysis of competition
3. Positioning AOCI in the market
4. Market penetration strategy
5. Marketing schedule
6. Budget and pricing

4.3.3.1 Market definition: It is clear from preliminary AOCI marketing activities that a market exists for at least two different configurations of an AOCI instrument. One is needed for bio-geochemical oceanographic applications primarily conducted by government agencies throughout the world. The second is needed by fishing firms or their service suppliers to operationally assist in improving the efficiency of fish catch. The oceanographic version should have all of the current AOCI spectral channels and high sensitivity to provide data for understanding bio-geochemical processes and to assist in fishery management applications. This system does not require real-time or near-real-time data processing capabilities. Moreover, most potential customers for this system already have digital image processing capabilities, but may need AOCI specific atmospheric correction and bio-optical algorithms for processing the data. The fishery support version needs to be relatively small and rugged, with integral real-time or near-real-time data processing capabilities and a reliable method for delivering geocoded data products to fishing vessels or ground-based fleet directors. This system probably requires only four spectral channels including one thermal infrared channel for sea surface temperature mapping.

4.3.3.2 Analysis of competition: Preliminary assessments of competition indicate that there are only a few competing techniques for either the oceanographic or fisheries support market segments. Data from the now defunct CZCS satellite and TMS and SPOT are the sources for most of the current oceanographic work. However, a number of national governments are working with new experimental sensors, both passive and active, that may represent local competition in the future. In addition, a number of satellite sensors such as the U.S. SeaWiFS, Japanese OCTS, and ESA MERIS are in various stages of development and are all aimed at providing ocean color measurements. It is believed that the re-visit schedule and cloud cover problems faced by these sensors will still provide a niche for an airborne sensor.

Fisheries support techniques range from simple aerial observation platforms such as those used for menhaden and tuna to airborne radiometers used to measure sea surface temperatures for the south Pacific tuna fishery. An exception is a well developed Japanese program that provides sea surface temperature data to the Japanese fishing fleet from the AVHRR satellite data. Most fisheries still depend upon the experience of the fishermen or luck to determine effectiveness. However, labor and fuel cost increases are driving fishing companies to be more receptive to new technology aids. Sports fishermen appear to be particularly receptive to any new technique which might offer a competitive edge. Some success in marketing subscriptions of forecasts to sports fishermen has been achieved by organizations such as Roffer's Ocean Fishing Forecasting Service.

4.3.3.3 Positioning AOCI in the market: The positioning of the AOCI instrument in each market segment is an important step in developing a marketing strategy. It requires that we determine what most of the prospective buyers expect in the way of capabilities and price and also requires that we realistically design the package to have advantages over competing techniques. In the case of the oceanographic version, the positioning is complicated by the fact that a variety of satellite ocean color sensors are in development, will offer global coverage, and will probably come on line in the next few years. Therefore, the AOCI instrument must be positioned to either be a complimentary technique to these satellite sensors or to provide a niche capability that cannot be matched by the satellite sensors. Positioning studies are under way, but more information is needed about the potential capabilities of the competing sensors and how users will get access to their data products. A window of opportunity for AOCI exists before these new sensors come on-line but it will probably last no more than three or four years. Positioning the AOCI instrument as a near-shore sensor capable of dealing with pollution events such as red tides and algal blooms may make it more appealing.

Positioning the AOCI fisheries support instrument is primarily an economic issue. It must be shown that the investment in such an instrument can produce an equivalent payback in reduced costs or higher profits in a reasonable period of time. This requires obtaining some performance data based upon the EOCAP I or follow-on demonstration programs or believable promises of such economics based upon projected performance. The instrument package must be configured to fit the types of aircraft currently owned and operated by fisheries organizations or affordable by such organizations either through ownership or by purchasing services. It is likely that the appeal to service organizations may entail identification of other uses for the instrument during non-fishing seasons in order to make the economics of purchase more reasonable. Positioning the fisheries support package must also take into account new potentially competing techniques so that an ongoing analysis of competition is necessary.

4.3.3.4 Market penetration strategy: A strategy for penetrating the market segments for AOCI instrument packages includes promotional activities, marketing and sales activities, and development of a distribution network. Since the goal is to market these instruments internationally, the market penetration strategy must be global. Daedalus plans to use several forms of advertising to draw attention to the existence of the AOCI instruments. For the oceanographic version, Daedalus already does business with many of the institutes and other government agencies in the world who should be interested in such an instrument. Direct contact with international representatives via technical papers and EOCAP reports may be the best method of communicating with these organizations. For the fishing industry, there are a number of international publications that can be used for either purchased advertising or feature stories about the fishery support package. In addition, there are many sports fishing publications such as Marlin and Salt Water Sportsman that can be used to generate interest.

Marketing and sales activities require the generation of summary brochures and detailed proposals outlining the characteristics of the instruments as well as examples of their applications. These materials will be used by Daedalus marketing personnel and international representatives to pursue individual sales targets. Daedalus will generate the instrument brochures and proposals and hopes to be able to devise suitable applications materials from the data acquired and processed during EOCAP I.

Daedalus is in the process of providing preliminary materials to international representatives so that they can measure interest and develop a target list of prospects in each country. Initially, the AOCI instrument distribution network will consist of Daedalus marketing personnel and international representatives. Current representatives are located in Argentina, Chile, France, India, Indonesia, Italy, Japan, Korea, Portugal, Spain, Taiwan, Thailand, and Venezuela. Depending upon how the market develops, Daedalus may enter into marketing agreements with one or more firms involved in the supply of equipment to the fisheries industry in order to expand the distribution network.

4.3.3.5 Marketing schedule: To date, the Daedalus AOCI marketing activity has been mainly aimed at gathering information on the potential market in oceanography and fisheries, current and planned competitive techniques, and characteristics desired by potential customers. Exceptions to this general marketing approach have been a customer in Europe who plans to purchase an AOCI instrument for oceanographic applications and a customer in South America who wishes to buy an AOCI instrument to support anchovy, sardine, and horse mackerel fisheries as a flight services operation. These two customers are being pursued as test cases to help determine what types of instrument packages are needed and what sales approach must be utilized. It is expected that the sale of the oceanographic version will be accomplished in the next few months, but the fisheries version requires better applications data and a complete turn-key data processing package that has not yet been created. Therefore, the fisheries support package may take six to nine months to develop.

Based upon these early indications of market interest and completion of the EOCAP I program, Daedalus plans to begin marketing in earnest about January 1992. In the meantime, efforts will be devoted to creating advertising and marketing materials and gathering more details on prospective customers. International representatives will be supplied with AOCI summary descriptive materials and budgetary pricing in early 1992 to begin to develop individual sales prospects. A full-scale AOCI marketing campaign will probably be in place by mid-1992.

4.3.3.6 Budget and pricing: The budget for marketing the AOCI instrument, sales pricing for the oceanography and fisheries versions, and projected revenues are all being developed. The marketing budget will include the costs of developing sales brochures and proposals, advertising and promotion costs, domestic and international travel costs, and the support costs for international representatives. The cost for a typical four-color brochure for a Daedalus imaging system is $5,000 to $10,000. Advertising in a single periodical averages about $10,000 per year based on monthly issues. Travel costs for AOCI marketing will probably be about $25,000 per year if a full-scale campaign is initiated. Including salaries of marketing personnel devoting part of their time to AOCI marketing and representative support costs, an estimated AOCI marketing budget might be on the order of $75,000 to $100,000 per year. This does not include the engineering cost to document the AOCI packages and generate detailed technical proposals.

Pricing is a combination of cost analysis and market sensitivity. Daedalus has a good idea of the cost and price sensitivity for the oceanography version of the AOCI. Current selling price will probably be about $1.1 million including recording equipment, spares, training, etc. This does not include the price of a decommutation system, which will not be required with a future system.

Pricing of the fisheries support version of the AOCI instrument is difficult at present because a real-time data processing and delivery system has not been designed and costed. However, the system should have a selling price of $1 million or less. This may be difficult to achieve, but Daedalus has designed a lower cost data acquisition system so that it may be possible to produce a complete system for this price. It is not assumed that there will be sufficient market volume to have any impact on production costs in the foreseeable future.

4.3.4 Possible product changes for marketing– Based upon the experience gained from EOCAP I, available new technologies, and the preliminary marketing results, it is now likely that two versions of the AOCI instrument will be offered to the market. One version will be aimed at ocean science needs and will be similar to the AOCI used for EOCAP I. The second version will be aimed at the operational fishery support market and will probably be configured much differently than the current AOCI instrument.

The ocean science version of the AOCI instrument will incorporate the 10 channels of the existing AOCI, but will utilize a new digitizer being developed by Daedalus that provides 12-bit precision and outputs a single serial bit stream for recording on a helical scan cassette recording system. This has the advantage of eliminating the need for a decommutation system, because the cassette tapes can be read directly to disk or computer memory. This version of the AOCI instrument will be marketed for oceanography and fishery management applications where real-time data processing is not an important issue. Most of these users have current image processing systems so they are not interested in purchasing special purpose data processing equipment.

The operational fishery support version of the AOCI instrument will be designed to be smaller, lighter, and less expensive than the ocean science version, and will probably incorporate a stabilized mount to reduce geometric correction computation. This version will also incorporate data processing software and hardware to process data in real time and provide geocoded output. It is likely that this version will only use four spectral channels, two for bio-optical algorithms, one for atmospheric correction, and thermal infrared for water temperature measurements. Moreover, many fishermen believe that highly accurate chlorophyll data are not necessary for fishing use so that a smaller optical system with somewhat reduced signal-to-noise ratios may be acceptable. This will result in a less expensive data acquisition system so that the total price of a system including data processing and output may be less than the ocean science sensor system.

4.3.5 Projected revenues– Projecting commercial sales revenues for the AOCI instrument product is difficult at present because the EOCAP I program did not result in the development and demonstration of a complete fishery support system in a ready-to-market form. The EOCAP I program did provide a solid foundation upon which to make good system capability and packaging requirement decisions as well as a good base of market and customer data from which to develop market penetration strategies. Moreover, the marketing efforts conducted during the EOCAP program have revealed that a market exists for two versions of the AOCI instrument—one for ocean science and another for fishery support.

Table 3 presents a five-year forecast of estimated AOCI instrument revenues based on current market size estimates and customer assessments. It is expected that the ocean science instruments will be sold primarily to government agencies while the fishery support systems will be sold primarily to aerial service companies or directly to large fishery companies. It is further estimated that a complete fishery support system will require another year of development before it is ready for market and therefore no revenues are predicted until late 1992.

This revenue projection takes into consideration that one or more satellite sensors with ocean color capabilities will probably be launched successfully within the next three years. Therefore, the market for AOCI ocean science instruments is believed to be relatively small and primarily related to coastal applications requiring good spatial resolution and/or times of coverage not compatible with planned orbits. The forecast also takes into account that economical use of the fishery support system dictates a platform such as a Learjet and a high value fishery which can justify communications equipment suitable for recovering AOCI data products. Therefore, we have assumed a relatively restricted market in coastal waters that will take considerable time and effort to develop.

Not included in the forecast are two streams of revenue related to the sales of AOCI instruments. The first is system support revenues which are likely to amount to 10% of system cost per year for operational systems. The second revenue stream would be the revenue generated by a service company which purchases an AOCI for fishery support and sells services to the fishing industry. It is estimated that this revenue stream would be $2 to 3 million per year per system. Since it is not known at this time how many systems might be sold to service companies instead of to fishery companies or government agencies, it is not possible to forecast the total size of this revenue stream.

4.3.6 Reconciliation with expectations– Daedalus had hoped that Phase 3 of the EOCAP I program would have accomplished a full-scale commercial demonstration of the AOCI fishery support system with transfer of the technique to Spectro Scan as a commercial service provider. Unfortunately, this did not occur due to a variety of technical problems coupled with Spectro Scan's inability to acquire the capitalization needed to set up the service operation. As a result, the EOCAP I program is ending without a firm definition of a real-time data processing system and no commercial demonstration experience upon which to develop a marketing program.

On the positive side, a great deal has been learned about the difficulty of acquiring, processing, and delivering fishery support data. Use of the CAPT SAM software has at least permitted a product to be produced that can be transferred relatively quickly to users. The atmospheric correction and bio-optical algorithms work at the lower altitudes available to commercial survey aircraft. The experience gained by working with Zapata Haynie has provided valuable insight into the operational and economic factors that are important to a commercial fishery business. Also, the resources and capabilities that National Marine Fisheries Service brought to the program will provide a continuing source of valuable marketing information to Daedalus.

Daedalus believes that the EOCAP I program has provided the basis for developing an AOCI instrument market along with valuable insights into both technical and economic problems that must be solved to make this an area of future business for the company.

4.4 Business Results for Information Service Product

4.4.1 Overview of commercial sector need for information service product– The occurrence of phytoplankton revealed by the chlorophyll *a* concentrations is a good indicator for the location of feeding grounds for fish. Brucks et al. (1977) employed Landsat images to map the distribution of menhaden in the Mississippi Sound and off Louisiana in the Northern Gulf of Mexico using ocean color as the main criterion. Landsat flies every sixteen days and images from Landsat are available from one week to one month after flyover. The infrequency of Landsat image availability makes it unsuitable for the fishing industry. An AOCI mounted in an aircraft is the best available way to supply ocean color data to fishermen on a when- and where-needed basis.

The menhaden industry employs spotter aircraft to locate menhaden. One menhaden fishery employees approximately 40 aircraft to locate fish for its fishing fleet with an approximate operating cost per aircraft of $100 per block hour. A total daily operating cost of approximately $16,000 is currently being paid by this fishery, assuming one hour for positioning and three hours on station.

An AOCI sensor mounted in a high speed aircraft, deployed when and where needed, may be a means to make the spotter aircraft more efficient. To be of value as a new management tool by the commercial fishing industry, sensor data must be supplied to management in a timely and cost effective manner. Near-real-time delivery is essential; real-time data sent directly from aircraft to fishing vessel would be ideal.

4.4.2 Capital acquisition and the Florida Agricultural Demonstration—future extension to fisheries– In February 1990, at the request of Florida Congressman Bill Grant, Florida A and M University and Spectro Scan, Inc., wrote a grant request for funds to implement a remote sensing application demonstration in the State of Florida. A bill was introduced and passed authorizing the funds for the demonstration. The grant funds are to be administered by the Department of Agriculture. Unfortunately, the bill authorized the project but not the funds. Spectro Scan is currently working with Florida Senator Connie Mack, to have the funds for this project made available.

4.4.3 Market verification– The value of AOCI data to commercial fishermen as a management tool in finding fish is not in dispute. The near-real-time availability of such data could aid the fisherman to find the catch faster, more consistently, and with less fuel used in search time. At the request of Spectro Scan, Donald Sweat, Extension Agent for Marine Services, Florida Agriculture Extension Service, University of Florida, conducted a survey of commercial fishermen operating along Florida's Gulf Coast and found an overwhelming acceptance of the idea of such a service. On the matter of cost to the fishermen, the general attitude seemed to be that this should be a service provided by the National Marine Fisheries, the State of Florida, or some other government agency, without cost to the fisherman. Most stated they would pay $50 per day for this data if the use of the data would save them more than $50 per day, would result in a larger catch, or would save them time. The matter of capital cost to purchase equipment to receive the data in real time was also discussed. Capital equipment purchases are difficult at the present time due to limited funds available for bank loans. The opinion expressed by Don Sweat, based on long association with fishermen, is that fishermen are difficult people to sell to unless you can prove the value up front.

The value of AOCI data to sport fishermen is not based on money but on time. The owner of a sport fishing boat will spend what he can afford to catch fish. The investment in equipment is based on discretionary funds available. There are 650,000 recreational power boats over 16 feet registered in the State of Florida. Of these, 140,000 are based from Palm Beach County to Key West. More than 20% of these boats are suitable for operation in the Gulf of Mexico or in the Gulf Stream and represent a large investment by the owners, strictly for recreational use (Florida Department of Natural Resources, private communication, 1988). In Florida, there are 130,000 recreational vessels large enough to put to sea and which represent a capital expenditure sufficiently large to justify an additional expenditure that would allow more time to fish and less time for searching.

4.4.4 Marketing plan– Initially, Spectro Scan plans to conduct a test marketing effort in South Florida directed toward the recreational boater. We believe the recreational boater will be less reluctant to make the initial capital investment in on-board equipment necessary to make real-time delivery of the data product.

Spectro Scan intends to combine the marketing of AOCI data with AVHRR data utilizing CAPT SAM, developed by the State of Mississippi. The marketing effort will require access to AVHRR satellite data, the fabrication of point-of-sale terminals and the fabrication of on-board terminals for the remote receipt of data.

Spectro Scan intends to market three products:

1. The equipment necessary to receive the image data directly on the vessel.

2. The real-time data received from the AOCI sensor and AVHRR satellite data.

3. Near-real-time color prints of AVHRR and AOCI IMAGES at point-of-sale terminals located at marinas and commercial fishing ports.

4.4.4.1 The equipment: Spectro Scan, in collaboration with Diginetics Inc., plans to offer a Modgraph portable PC with a color monitor incorporating a Magnavox 5-channel GPS. This equipment will allow position accuracy in three axes, within centimeters of true. Additional on-board sensors will monitor ocean temperature and engine readouts. The computer will register true speed, course, position and ocean topography, will control the autopilot and will have the ability to calculate drift, current flow rate and current direction. The computer will have the ability to receive radio, radio telephone or cellular telephone transmissions of digital data from the weather service, AVHRR and AOCI. Spectro Scan expects to offer this equipment for $10,000 per unit. Customers are expected to be found among the 20% of registered boat owners having vessels with deep sea capabilities.

We believe the commercial fishermen will follow the lead to purchase the product when the utility of the product is demonstrated by the recreational boater user.

4.4.4.2 Real-time data: Spectro Scan, in collaboration with Roffer's Fishing Service, expects to offer the boat owners AVHRR data, possibly using the CAPT SAM format. The Company also expects to offer the boat owner the AOCI data. This real-time data will be transported by radio, radio telephone, or cellular telephone.

4.4.4.3 Near-real-time data: Spectro Scan expects to install and maintain point-of-sale terminals with color printers at marinas and commercial fishing ports. These terminals will be licensed to the marina operators. The point-of-sale operators will purchase data wholesale and re-sell the data in image format to boat owners and operators.

4.4.5 Market development– Spectro Scan, in collaboration with Diginetics Inc., and Roffer's Fishing Service, will conduct a test market of the equipment and real-time data and near-real time data images in marinas and ports from Palm Beach south to Key West. Depending upon the results of this test marketing program, the Company will expand marketing efforts to the Gulf Coast, up the east coast of the United States and to the west coast of the United States for the sale of equipment and AVHRR data. When sufficient numbers of boat owners have equipment on board and sufficient marina operators and equipment suppliers at ports located on the Gulf Coast have point-of-sale terminals, the Company will begin supplying and marketing the AOCI data.

4.4.6 Projected revenues– Table 4 shows projected gross and net revenues for AOCI for both the test market area from Palm Beach south to Key West as well as an expanded marketing area covering all of Florida and other Gulf Coast states.

4.4.7 Reconciliation with expectations– Spectro Scan Inc. began EOCAP I with the expectation of acquiring a stand-alone commercial business of supplying AOCI data to commercial fisheries. It is now apparent that this goal cannot be achieved . However, the software that Spectro Scan has developed allows the near-real-time delivery of data that we can use in other remote sensing commercial areas. This development alone makes this EOCAP program worthwhile from Spectro Scan's point of view.

Table 4. Projected gross and net revenues for AOCI

Gross sales 1% market	Test market	Florida and Gulf
Equipment	$3,360	$14,000
Real time data		
AVHRR	51	219
AOCI		54
Near-real-time images		
AVHRR	5,100	21,900
AOCI	5,475	
Gross sales	$8,521	$45,408
Cost of sales:		
Equipment	n/a	n/a
Real time data		
AVHRR	n/a	n/a
AOCI	n/a	n/a
Near-real-time		
AVHRR	n/a	n/a
AOCI	n/a	n/a
Cost of sales	n/a	n/a
Net revenues	n/a	n/a

Test market – Palm Beach to Key West.

Assumptions

28,000 boats over 27 feet
1% market penetration per year
140,000 boats over 16 feet
$50 per image at point-of-sale terminal
365 possible operating days per year
$32 cost per AVHRR image at point-of-sale terminal

Major concern

We have been unable to obtain any information on the average percentage of boats operated daily. This is a significant factor and is expected to be an important finding of the test marketing plan.

5.0 Post-EOCAP I Activities

5.1 Airborne Ocean Color Imager Product

Daedalus' plans for the AOCI instrument in the Post EOCAP I time frame are outlined in table 5. As indicated previously, a market has been identified for two versions of the AOCI instrument. The ocean science version is marketable in its current configuration. Materials are needed for advertising and promotion of this version and they will be generated in the next few months based on the data created during the EOCAP I activities. In addition, future definition of the scope of the market, target customers, and impact of competing techniques is required and will be an ongoing effort over the next several years.

The fishery support version of the system requires considerable work to define, design, and implement a real-time or near-real-time hardware/software data processing and information delivery system. It is estimated that this effort will require an additional year of development time and probably a partnership or joint venture arrangement. Therefore, marketing of the fishery support version will be limited initially to the concept or a prototype system followed by vigorous marketing of a complete package upon completion of the development phase.

It is expected that the market for AOCI instruments will be impacted by promised and real capabilities of the several satellite ocean color sensors that are planned for launch over the next several years. Therefore, effective marketing of the AOCI instruments will require careful definition of their market niche and will consume a good deal of Daedalus' marketing effort.

5.2 Information Service Product

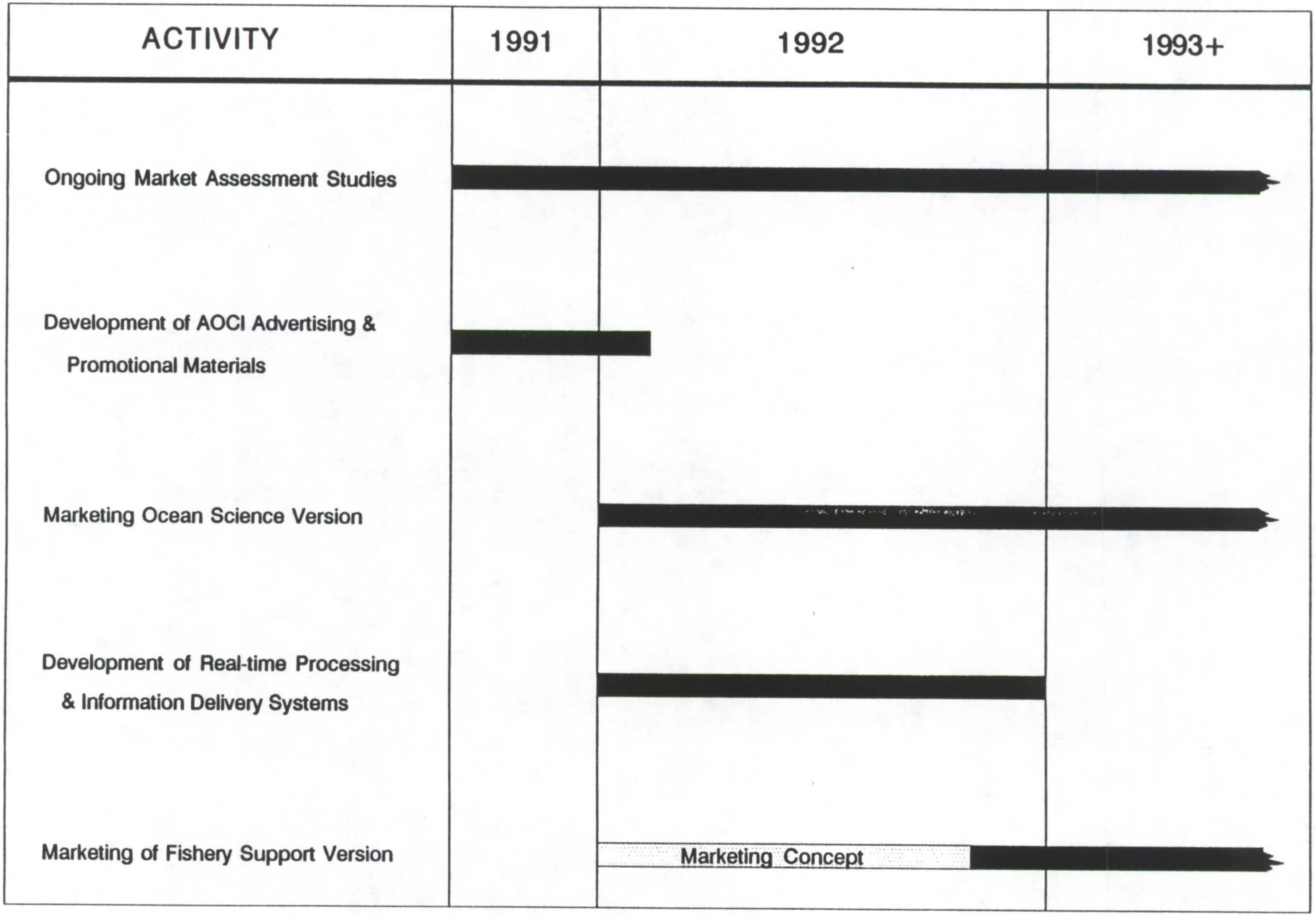
The information product Spectro Scan believes can be developed using the results of EOCAP I will be the swift delivery of multiple ephemeral products to all segments of the fishing industry. Spectro Scan further believes the results will be of value to all areas of the remote sensing industry.

5.3 Data Processing by NASA Ames and NMFS Stennis

Section 4.2, Evaluation of Technical Results for Commercialization, indicated that considerable data exist that could be used for aiding in answering some questions important for the commercialization of the system: Is near-real-time data (i.e., next day) sufficient or does the data have to be supplied within a couple of hours at most? What is the relationship between the environmental data and fish locations? What is the relationship between the environmental data and the AOCI data products for total pigment concentration, diffuse attenuation coefficient and temperature? Can better bio-optical algorithms be developed between the atmospherically corrected AOCI bands and fish location (i.e., instead of going through the environmental data)? To accomplish these tasks, the appropriate AOCI data must be georeferenced and it was beyond the scope of the original proposal to do that. Given the events, it is now important for the commercialization prospects to answer some or all of these questions.

Georeferencing the appropriate AOCI data through Lockheed at NASA Stennis would probably be quite expensive but Lockheed certainly has the capability. Both NASA Ames and NMFS Stennis either have or shortly could have the capability. Neither have resources to accomplish these tasks in the near future. NASA Ames is continuing to develop the stand-alone georeferencing programs and NMFS Stennis could acquire the AOCI georeferencing modules from NASA Stennis since they have the same kind of computer.

Table 5. AOCI instrument—post EOCAP I activities



6.0 Lessons Learned from EOCAP I

6.1 NASA Ames Perspective

Perhaps the main lesson learned from the NASA Ames perspective is that true commercialization should be placed in the hands of businessmen, not scientists. While much research was needed and much still needs to be done, a more commercial emphasis probably would have resulted in getting closer to a true product. Businessmen want to simplify the product and scientists want to make it do more. For instance, Daedalus' suggestion to use simple band ratios which can be calculated on the fly may be appropriate, but the apparent necessity for atmospheric correction will probably preclude that approach. Another example would be simpler geo-location which Daedalus uses for oil spill detection instead of the geographic database/CAPT SAM approach. Spectro Scan has long advocated real-time data but we avoided the issue due to technical difficulties and lack of equipment. Had they been in the driver's seat, Spectro Scan or Daedalus might have found a workable approach.

Another lesson learned on the technical side was the difficulty of processing data with complex programs at another site. Operational considerations dictated that data be processed at NASA Stennis but any commercial implementation should strive to have complete control of the equipment and software configuration. Lesser considerations include (1) using more accurate navigation data (i.e., GPS updates), (2) including adequate navigation data in the AOCI data stream, (3) eliminating the decommutation step, and (4) using faster computers.

6.2 Zapata Haynie Perspective

The ability to use remote sensing technologies to predict the possible location of menhaden is very interesting to Zapata Haynie. The possible increase in productivity of our fishing operations and the corresponding reduction in unit cost could increase the profitability of the company.

Zapata Haynie became interested in remote sensing technology in the 1970s when we participated in a project using Landsat. Even with a limited amount of data, we found some correlation of fish location and turbidity. We already know that chlorophyll indicates the presence of food and some species of fish prefer temperature changes. The AOCI, with its ability to measure all three of these parameters, seemed to fit well with the information we need.

There appear to be five aspects in the development of this technology for use in our business:

6.2.1 AOCI– The advantages of the AOCI over a satellite-based system are its much greater resolution and the ability to collect data at times and locations that are not fixed as with satellites. It would be hard to judge the relative effectiveness of the two systems without having the specifications of a satellite-based system. From what we have seen during this project and from what Daedalus says it will do, we think it will provide the data which would help us.

6.2.2 Processing data collected into a usable product– Processing the large volume of collected data seems to be a realistic task. Having at least one display format (CAPT SAM), we were able to have a portion of the data for display. Processing the data in a time frame which is usable to us (closer to real time) may not be as easy. During the demonstration portion of this project, we were able to process, transmit and display only a portion of the data in 12–14 hours. This meant that the display information was ready in the morning for data collected the previous morning (about 20 hours). Again, this information only included a portion of the data collected.

Ideally, we would like to have the information in real time, i.e., display the information as it is collected, since winds and currents will be changing the water conditions continuously. However, since we would be using this information as assistance to our spotter aircraft (at least in the beginning), going to an area that looked very positive 24 hours prior might put the spotter in close enough proximity to observe any schools of fish which have moved. The effectiveness of this approach has not been tested.

6.2.3 Correlation of predictions and fish locations– The lack of correlation between predictions and fish locations has been the disappointment of this project for Zapata Haynie. The ability to correlate the location of menhaden with measured conditions of food, turbidity, or temperature (and quite possibly a combination of the three) was the prime purpose for our participation in this project. If there is no correlation, then the information would be useless to us. As with Landsat, with the small amount of information collected, there appears to be some correlation. During the project we had a very limited number of flights with which we were able to match fish catch data with the AOCI data. The part of this project which would have given us a very good chance to evaluate this was Spectro Scan's intended contribution of 100 flight hours for data collection and using that data to correlate actual fish location. Since this part of the project did not take place, we still have very little knowledge of the effectiveness and reliability of remote sensing for finding menhaden. We may be able to gain a little more knowledge if all the data which were collected can be processed and compared to the actual fish locations recorded at those times.

6.2.4 Dissemination of a product to the end user– The CAPT SAM display software is a usable display product and we are sure others could be developed if the need arises. Other communications technologies have come a long way and we think several could be used to get this information to users.

6.2.5 Economics– The capital cost of the AOCI, aircraft, and processing equipment as well as the operating costs of this system will require the sale of products to many users. We do not think there is a company in the commercial fishing industry who could cost effectively purchase and operate this type of system for its own use. A company such as Spectro Scan may be able to operate the system profitably by selling the information to Zapata Haynie, other commercial fishing interests, and sports fishermen in the Gulf of Mexico as well as parts of the Atlantic coast.

In the future, if we could determine that we did not need as much information as this system provides, maybe a scanner could be developed, as Daedalus is proposing, which would be less costly to purchase and operate.

6.3 NMFS Stennis Perspective

The primary technical lesson learned from the NMFS Stennis viewpoint is the effort required to transcend the gap between state-of-the-art technology and state-of-the-art applications development of that technology.

The fisheries commercialization project demonstrated that the AOCI remote sensing is do-able although crude and cumbersome in its present form. Not unlike most remote sensing endeavors today, activities were conducted primarily within major agencies and institutions where "the parts were developed, assembled and forced to work" through high levels of commitment in equipment and manpower. In terms of technology transfer for commercial applications, the AOCI instrumentation, the processing software and the communications system must be repackaged and integrated to support efficient operations of commercial ventures.

6.4 AOCI Product Perspective

From the perspective of the AOCI instrument product, a number of important lessons have been learned from the EOCAP I experience for both technical and market concerns.

Technical lessons include learning the importance of the near-infrared bands for atmospheric correction in turbid waters. We also learned that implementing a new computer-compatible recording scheme would help improve data processing throughput by eliminating the decommutation step which proved to be difficult with available hardware. The use of aircraft navigation data for geo-location and an efficient system of georeferencing output products were found to be critical to the throughput of final data products.

Market perspectives included the lessons learned from association with Zapata Haynie Corporation. The system must be reduced in complexity and cost for fisheries applications. The information must be timely, hopefully not more than a few hours old, and must be delivered in an easily usable form such as a map or a chart. We must be able to establish the correlation between the parameters derived (chlorophyll, turbidity and temperature) and the location of fish schools. Finally, the likelihood that no single commercial fishing company could afford to own and operate such a system for their exclusive use was driven home forcefully.

These lessons will serve us well as we proceed to complete the development and begin to market the AOCI instrument for both ocean science and fishery purposes.

6.5 Information Service Product Perspective

The lessons learned by Spectro Scan, Inc. in this investigation are simple. The service cannot be made available to a limited market base. No single fishing company can afford the cost of providing the information and no small group of companies can or will guarantee a market.

The AOCI information can be a valuable tool for commercial and recreational fishermen. The AOCI information service must be incorporated as part of a system of information services dedicated to the fishing industry as a whole.

Spectro Scan Inc. will determine if a viable market exists through a test market program in southeast Florida and provide the service if a market develops.

7.0 Conclusions

The goals of this investigation included taking a state-of-the-art instrument, the Airborne Optical Color Imager, and improving it, creating software for atmospheric correction and bio-optical output products, georeferencing the output products, and creating a delivery system to get those output products into the hands of commercial and recreational fishermen in what was defined as near-real-time. This investigation was successful in achieving all those goals. The AOCI has the highest sensitivity of all available commercial, aircraft remote sensing instruments. The data processing software works well, runs efficiently, and has been implemented on a variety of computer systems; it is available as public domain software. The georeferencing software was developed by others for other purposes but it also works well, runs efficiently, has been implemented on a number of computer systems, and is available under ELAS as public domain software. Functionally equivalent stand-alone georeferencing programs were also developed by Spectro Scan and implemented by NASA Ames but they remain under the purview of Spectro Scan. The delivery system used, CAPT SAM, was a serendipitous outgrowth of work for NMFS Stennis by the State of Mississippi which is trying to commercialize that system separately. All these achieved goals can be considered to be technical in nature but they were necessary for the implementation of the business goals.

The first set of business goals revolved around Daedalus Enterprises. To be successful in marketing the AOCI for fisheries applications, they not only needed an improved AOCI and data processing software, but a set of example data products acquired for fisheries applications to show their customers some of the capabilities of the instrument. With the example data products in hand, Daedalus could better develop their marketing plans and strategies. This goal was achieved by this investigation. Daedalus now has some hardcopy imagery to use in their promotional activities and they have requested more from the wealth of data acquired under this investigation. In addition, and as a result of this investigation, Daedalus has identified the market need for a fisheries support version of their AOCI product that is much simpler and cheaper. They have also identified the need for a better data recording system that avoids the necessity of a separate (expensive) decommutation system which will also improve data throughput. Daedalus has developed their marketing plan to include an analysis of the competition, positioning of the AOCI in the market, a market penetration strategy, and a marketing schedule, as well as budgets and pricing. They intend to proceed with marketing the current version of the instrument while engineering and marketing studies proceed during the next year for the new version. Daedalus expects to sell a current version of the instrument to a European customer within the next few months and is holding discussions with a South American customer for the new version to better define a whole turn-key package. Gross revenue projections for the next five years are: $2.1 million, $7.1 million, $9.2 million, $5.1 million, and $4.1 million, respectively.

A second set of business goals revolved around Spectro Scan, Inc. as a company to develop an information service for the fishing industry based on the AOCI. Spectro Scan was to obtain capitalization separately from this investigation and buy an AOCI, buy or lease a Learjet, buy the necessary computers, follow the software development, port the software to their computers, determine the commercial viability of the AOCI data products, and market the AOCI data products to both commercial and recreational fishermen. They have not obtained their capitalization so Spectro Scan has not been able to participate at the level envisioned. Spectro Scan's marketing studies determined that it was not economically feasible to acquire, process and deliver AOCI data alone but that if it were part of other information services to be delivered it would be more feasible. They expect to pursue this approach with a test market in southeast Florida.

Overall, this investigation achieved its technical objectives and the business objectives are being pursued by the companies involved. In particular, the business objectives were achieved with respect to Daedalus Enterprises and they are beginning to sell their systems. Spectro Scan, despite a significant setback, is exploring the marketing of a product as an outgrowth of this investigation.

Appendix A

ELAS Data Processing Flow Diagram and Description

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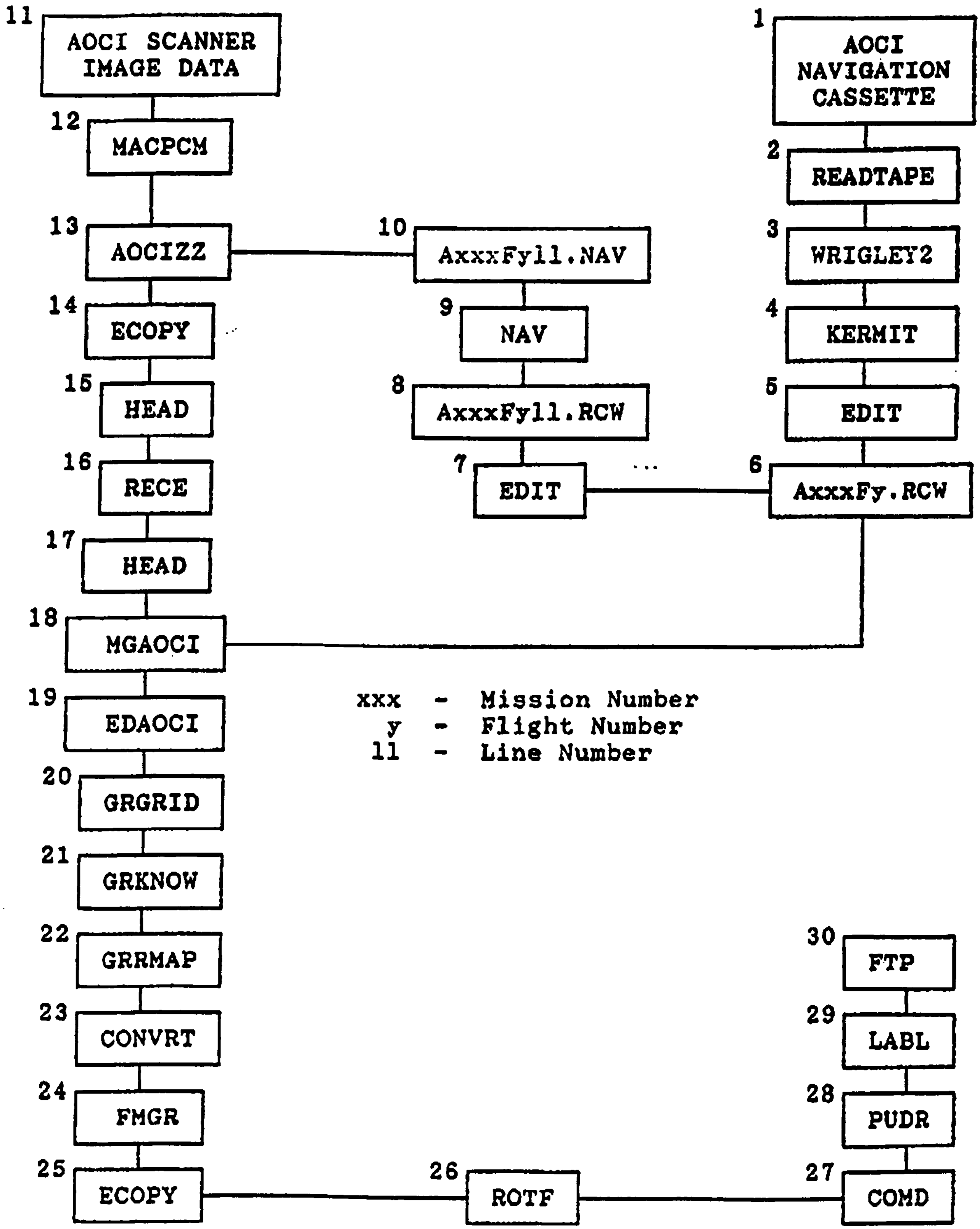
Airborne Ocean Color Imager (AOCI)
Data Processing Events



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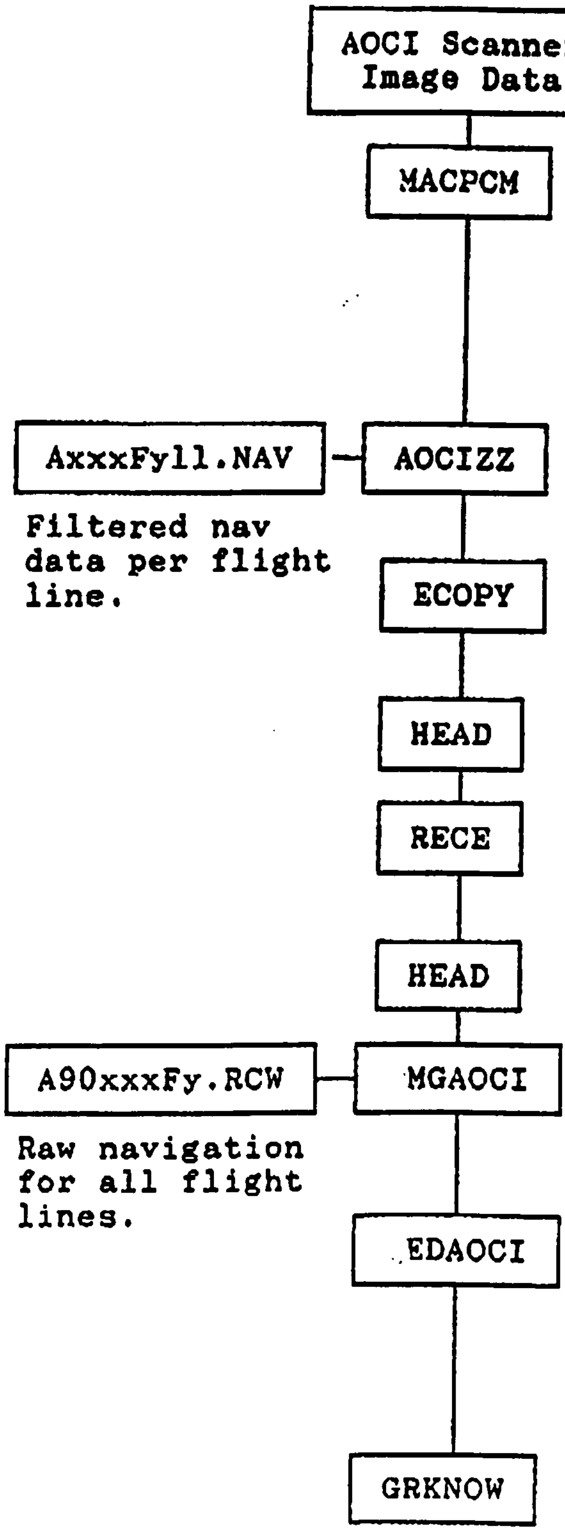
AOCI Data Processing Event Schedule				
TIME	FLIGHT LINE 4	FLIGHT LINE 3	FLIGHT LINE 2	FLIGHT LINE 1
12:00	1,11	1,11	1,11	1,11
12:30	2,3,12	2,3,12	2,3,12	2,3,12
13:00	4,5	4,5,13	4,5,13	4,5,13
13:30	6-10,13	6,7,8,9	6,7,8,9	6,7,8,9
14:00	-	10,13	10,13	-
14:30	-	-	-	10,13
15:00	-	-	14-17	-
15:30	-	-	18	14-17
16:00	14-17	-	19	18
16:30	18	14-17	20,21	19
17:00	19	18	22	20,21
17:30	20,21	19	-	22
18:00	22	20,21	23-25	-
18:30	-	22	26	23-25
19:00	23-25	-	-	26
19:30	26	23-25	27,28	-
20:00	-	26	29	27,28
20:30	27,28	-	30	29
21:30	29	27,28	-	30
22:00	30	29	-	-
22:30	-	30	-	-
23:00	Finish product downloaded to floppy disc.			

For example : Event 13 for flight line 4 would be ready for processing at 12:30 and terminate at 16:00.

Procedure For Obtaining Navigatiion Parameters For AOCI Scanner

AOCI Navigation Tape	Verbatim R300NH Cassette Memodyne M-80 Cassette Recorder PC serial port connect to M-80
READTAPE	Read cassette data into 80 byte hexadecimal data file.
WRIGLEY2	Convert 80 byte hexadecimal data file to 150 byte ASCII file after altitude and true air speed are modified.
KERMIT	Upload navigation data file to Concurrent System 04.
EDIT	Modify and insert takeoff/landing time/day (hh:mm/dd).
A90xxxFy.RCW	Navigation data file ready for ELAS module QMGAOCI.
EDIT	Edit navigation data into separate files for each flight line based upon roll angles.
AxxxFyll.RCW	Raw navigation file for mission xxx flight line yy.
NAV	Navigation filtering program to account for any time differential between image and navigation times and to smooth navigation parameters for use in the chlorophyll model.
AxxxFyll.NAV	Filtered navigation data ready for chlorophyll model AOCIZZ.

Procedure For Obtaining Georeferenced Chlorophyll Data From The AOCI Scanner



Data imaged in ten channels. Channels 1-8 are 10 bit and channels 9,10 are 8 bit data.

Decommutate and format on Concurrent System 04 every other scan line and put all flight lines in one long ELAS data file. Output channels correspond to input channels 1,2,3,4,9,10.

Model chlorophyll and output as 16 bit data in channel 6.

Extract chlorophyll channel as a single channel 16 bit data file.

Modify header record for ELAS module RECE .

Duplicate each scan line to account for underscan during decommutation.

Modify header record to obtain original form.

Merge navigation housekeeping data as last 50 bytes on each scan line using time to align image and navigation data.

Smooth housekeeping parameters for GRKNOW using BSP option with 5 splines for lattitude, longitude, and altitude. Use 20 splines for the true heading and the pitch angle.

Execute the known correction factors for AOCI scanner.

GRKNOW	Execute the known correction factors for the AOCI scanner.
GRRMAP	Use the GRRMAP module to georeference the chlorophyll data instead of the larger GRBMAP module. Time to process a flight path whose inclination is more than 20 degrees is about the same.
CONVRT	Convert the 16 bit georeferenced data file to a 8 bit data file due to storage requirements and limitations of ELAS module ROTF.
FMGR	Create database from -93 to -88.44 degrees longitude and 30 to 28.44 degrees lattitude at .00054 degree (60 meter) resolution.
ECOPY	Copy flight line 4 into database at proper location based on header information.
ROTF	Determine 3 tie points in each of the other 3 flight lines with their corresponding coordinates in the database and overlay each flight line into the database.
COMD	Select 512x512 pixel study areas at the various resolutions required on the final products and store as datasets.
PUDR	Overlay coastal boundaries and lattitude/longitude grid on subsampled datasets.
LABL	Store final datasets as scene files.
FTP	Download scene files to floppy diskettes for delivery to NMFS personnel.

Appendix B

Daedalus Enterprises Report on AOCI Improvement

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27 April 1990

Mr. Robert Wrigley, Technical Monitor
NASA Ames Research Center
Mail Stop N242-4
Moffett Field, Ca. 94035

RE: Final Report Contract NAS2-13088

Dear Bob:

This letter will document the work done on your scanner system by Daedalus under the above referenced contract number. Included are revised schematic drawings and parts lists, spectral response curves, and acceptance test results. Copies of the schematics and parts lists are also being sent directly to the aircraft operations group for their use in maintaining the system. The following text describes the work that was performed, and follows the sequence of the statement of work contained in the contract.

IMAGING LENS

This lens assembly was supposed to be disassembled, stripped and recoated by our lens vendor to reduce the reflective losses at each lens surface for the shorter wavelengths. This work was not done due to the long turnaround time quoted by the vendor, and the schedule commitments for using the instrument by Ames. This work should still be done at some future date, since there is some performance gain to be realized.

DIFFRACTION GRATING

A new diffraction grating for channels 1-6 is installed in the spectrometer in conjunction with a new optical layout for this port. These two changes increase the percentage of input energy diffracted into the gratings first order, which is the order used by the spectrometer.

NEW DETECTOR ARRAY

Channels 1-6 have a new detector array, matching the detector physical boundaries to the new grating and optical layout, in order to maintain the spectral band edges the same as before the upgrade.

INCREASED FIRST STAGE GAIN

The fixed electronic gain of the preamplifier was increased for channels 1-6 by a factor of two. This increase

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improves the SNR since the gain determining feedback resistor is a noise contributor, and a higher value resistance contributes less noise. This change was not done to channels 7-9 because the SNR for these channels seems to be adequate without it. The electronic bandwidth was adjusted to maintain the required system performance with the higher gain.

REDUCED DIGITIZER GAIN

This change was not implemented into the delivered system because tests showed that the performance improvement would be minimal.

VIDEO CLAMP CARD

A new 10 channel video clamp card was fabricated and installed into the system. The variable gains on this card were set to maximize the performance of the 9 AOCI bands. This card should be placed in the system at any time that the AOCI spectrometer is used.

NOTCH FILTER

A holographic notch filter is installed in the channel 7-9 spectrometer to attenuate the oxygen absorption band centered at 764 nm. Vendor data showing the response of this filter is attached to this report.

ASSEMBLE, TEST AND DOCUMENT

All of the above changes were assembled and tested in the complete system. The spectrometer was aligned and spectrally calibrated. The spectral response of channels 1-9 was measured and recorded. Printed copies of this data is attached to this report. A floppy disk containing this data will be provided under separate cover.

Note that the band edge calculation printed at the bottom of the channel 7 response is not correct. The value for the lower half power point should be approximately 740 nm instead of 767 nm. The automatic calculation done by the plotting program has been fooled by the notch filter now placed into the path of this channel.

A functional Acceptance Test Procedure identical to the one performed when the AOCI spectrometer was originally delivered was performed. A comparison of the results from these two procedures indicates that improved SNR performance for channels 1-6 has been achieved.

REFERENCE CALIBRATION LAMP

The reference calibration lamp was replaced, and the filters used to balance the spectral output of this assembly were re-selected in an attempt to maximize the response of each channel to this source. This effort was not a part of the original statement of work.

MOTOR/ENCODER REPAIR

The motor-mirror-encoder assembly was removed from the system and returned to the vendor for refurbishment. The refurbished assembly was successfully operated in our test chamber at -55°C. In conjunction with this test, the system electronic assemblies were operated successfully at -20°C. This work was accomplished under a separate purchase order.

RECOMMENDATIONS

Deterioration was observed on some of the system optical components. Specifically the primary paraboloid, and the pfund assembly optical components should be recoated at the earliest convenient time. This process requires approximately 2 months to complete, so must be scheduled during a time when the system is not needed for data collection. A further performance gain can still be achieved for channels 1 & 2 by recoating the imaging lens. The reflective coating on the diffraction grating for channels 7-9 has deteriorated. This can be corrected only by replacing the grating.

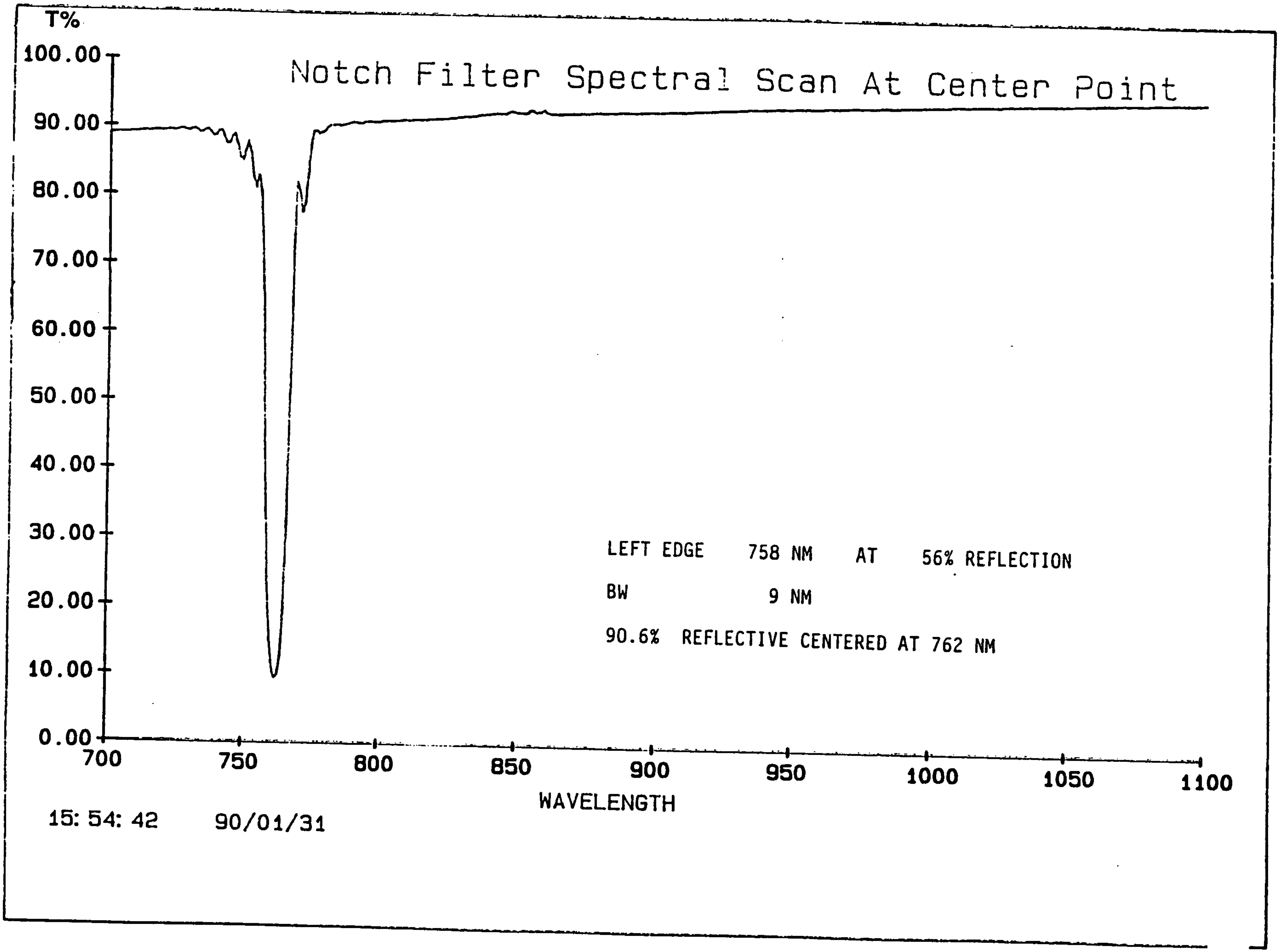
Sincerely,

Fred

Frederick G. Osterwisch
Project Engineer

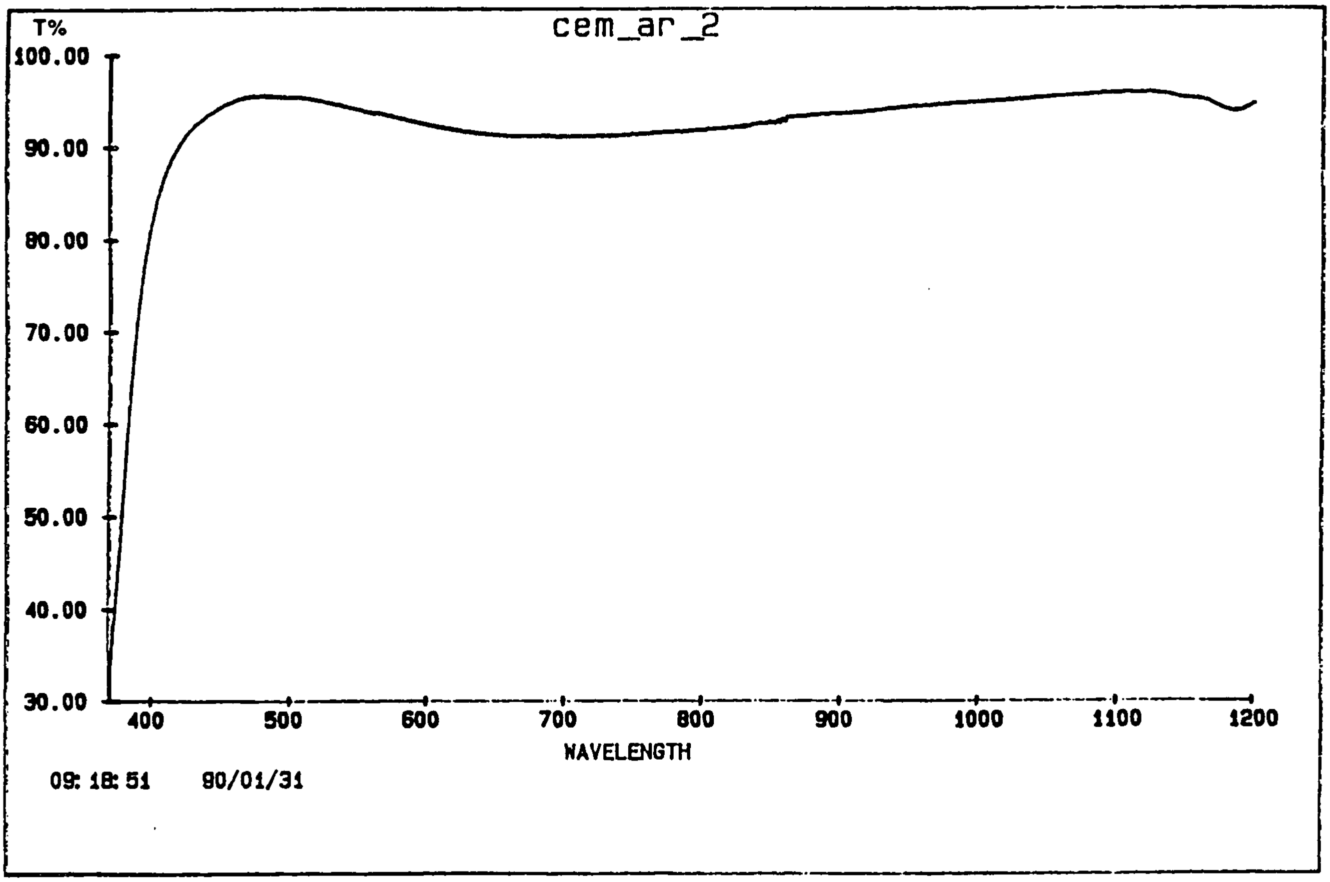
FGO:cif
enclosures:
1) Spectral response measurements
2) Notch filter response
3) ATP results
4) AD16008 Preamplifier schematic
5) AD16009 Preamplifier schematic
6) AB182B Spectrometer parts list

Distribution: Ames Research Center
Jeff Meyers, MS N240-12
John Arvesen, MS N240-6
Gary Berchem, MS N240-6



T%
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Notch Filter Spectral Scan At Center Point
LEFT EDGE 758 NM AT 56% REFLECTION
BW 9 NM
90.6% REFLECTIVE CENTERED AT 762 NM
700
750
800
850
900
950
1000
1050
1100
WAVELENGTH
15: 54: 42
90/01/31

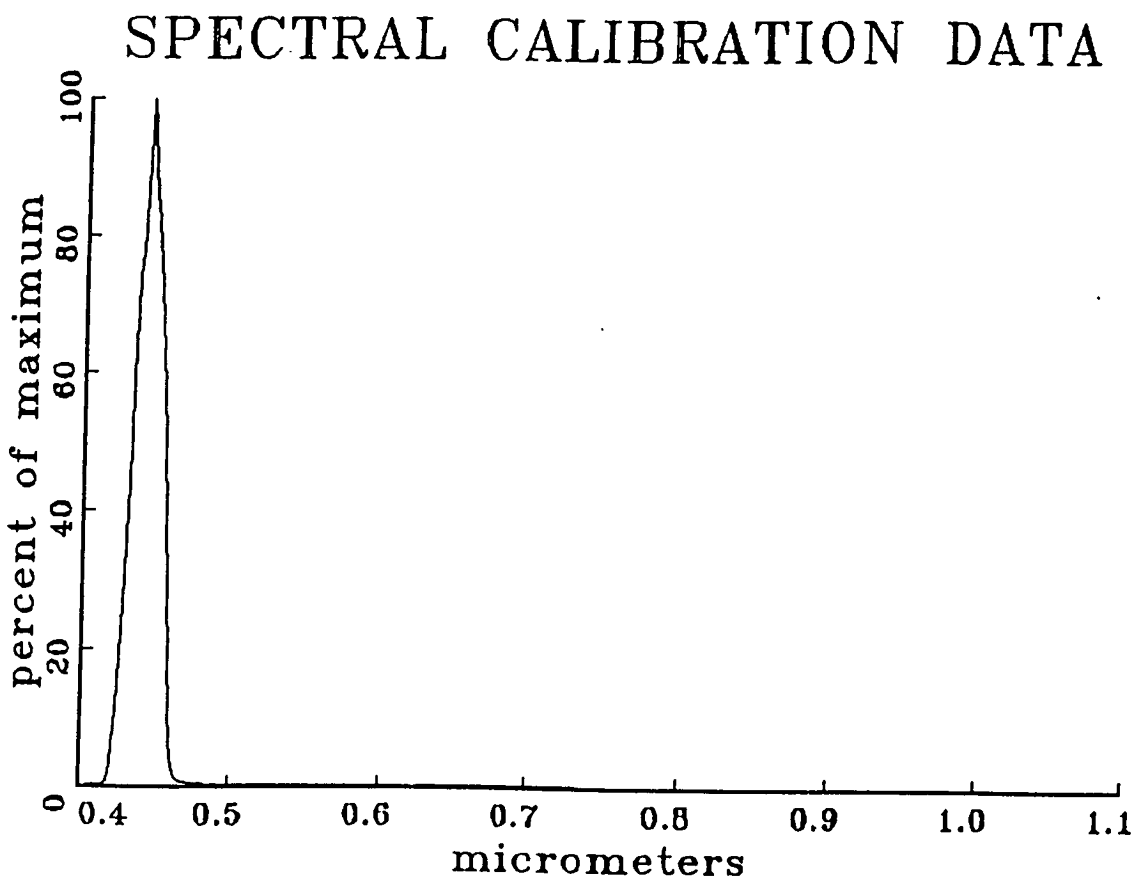
AOCI NOTCH FILTER WINDOW TRANSMISSION



SPECTRAL CALIBRATION DATA

File: N3DEC90.CH1 Mon Dec 03 09:38:26 1990

Operator Name:	JMG
Operator Comment(s):	PRE TC=1S POST TC=.1S
Operator Comment(s):	SLITS=400
Spectrometer Identification:	AOCI
Detector(s) Identification:	MT18255 SN002
Monochromator Speed:	1000
Monochromator Start Reading:	4000
Monochromator End Reading:	11000
Grating Identification:	600G 5000A
Source Identification:	TUNG90 120V
Filter(s) Identification:	At=7500 Passband=720-1350
Number of Readings:	697
File Code:	4 [4AUG86]
Raw Data File	3dec90.ch1
Normalization Data File	29aug86.rf1



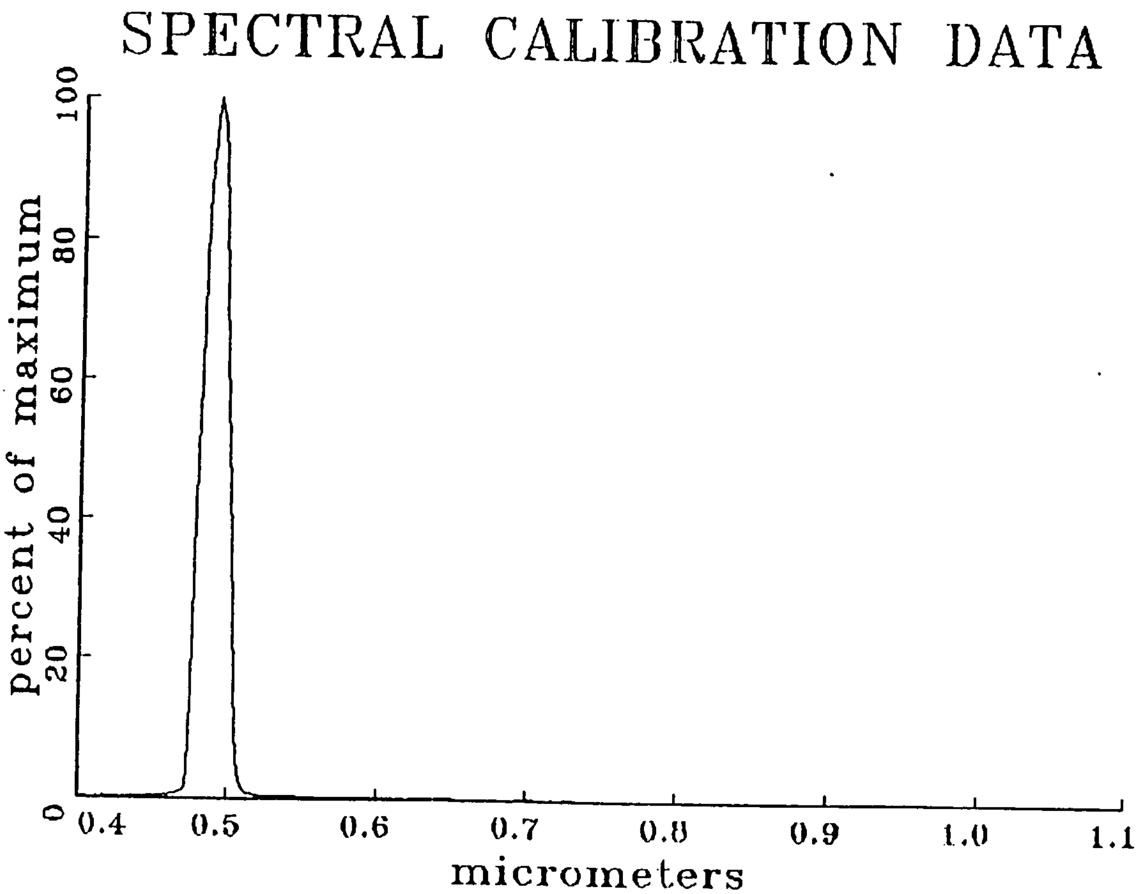
LOWER HALF POWER POINT AT 0.432 micrometers
UPPER HALF POWER POINT AT 0.455 micrometers
PEAK POWER AT 0.443 micrometers

98% of the energy is between 0.421 and 0.467 nm

File: N26MAR90.CH2

SPECTRAL CALIBRATION DATA
Mon Mar 26 15:48:39 1990

Operator Name:	JMG
Operator Comment(s):	PRE TC=1S, POST TC=.1S
Operator Comment(s):	SLITS=275 MICRONS
Spectrometer Identification:	A001
Detector(s) Identification:	MT18255 SN 002
Monochromator Speed:	1000
Monochromator Start Reading:	4000
Monochromator End Reading:	11000
Grating Identification:	600G 5000A
Source Identification:	TUNG 86 120V
Filter(s) Identification:	At=7500 Passband=720-1350
Number of Readings:	697
File Code:	4 [4AUG86]
Raw Data File	26MAR90.CH2
Normalization Data File	29aug86.rf1



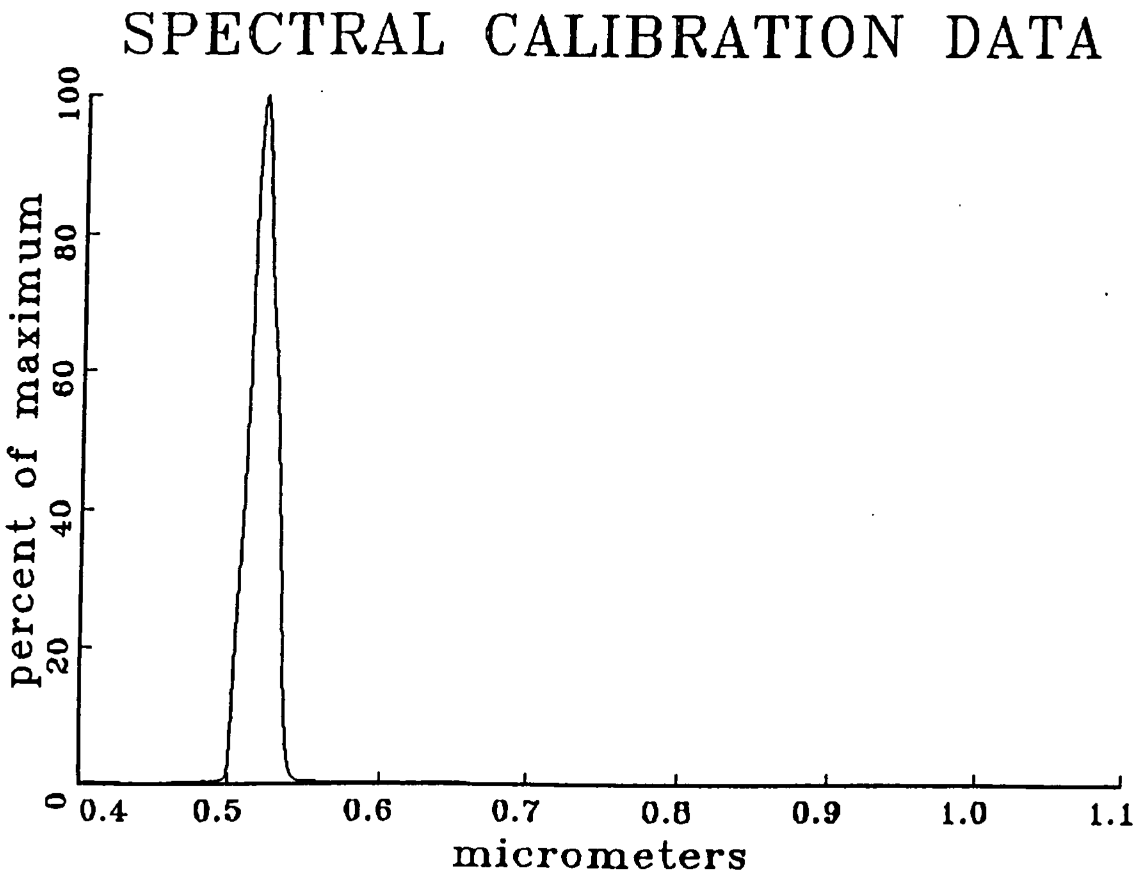
LOWER HALF POWER POINT AT 0.480 micrometers
UPPER HALF POWER POINT AT 0.501 micrometers
PEAK POWER AT 0.492 micrometers

97% of the energy is between 0.467 and 0.510 nm

File: N2DEC90.CH3

SPECTRAL CALIBRATION DATA
Sun Dec 02 17:01:46 1990

Operator Name:	JMG
Operator Comment(s):	PRE TC=1S POST TC=.1S
Operator Comment(s):	SLITS=270
Spectrometer Identification:	AOCI
Detector(s) Identification:	MT18255 SN002
Monochromator Speed:	1000
Monochromator Start Reading:	4000
Monochromator End Reading:	11000
Grating Identification:	600G 5000A
Source Identification:	TUNG90 120V
Filter(s) Identification:	At=7500 Passband=720-1350
Number of Readings:	697
File Code:	4 [4AUG86]
Raw Data File	2DEC90.CH3
Normalization Data File	29aug86.rf1



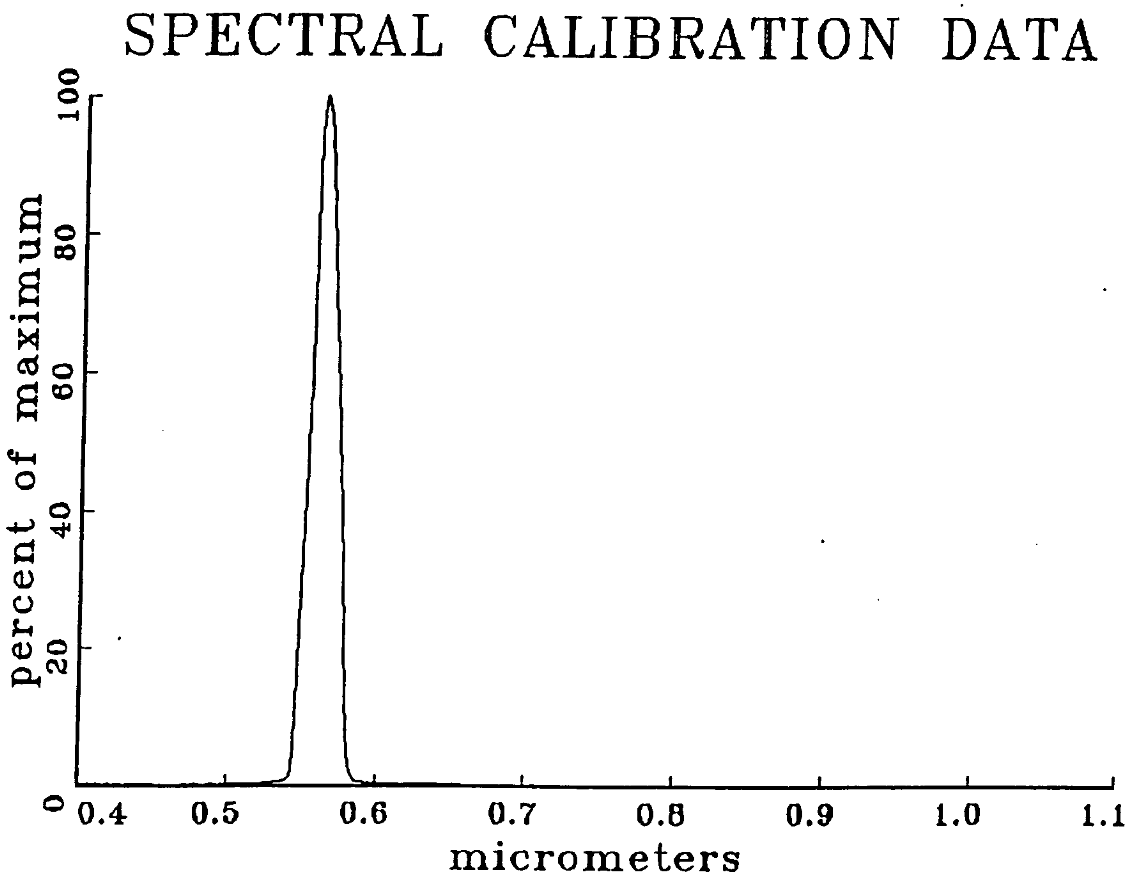
LOWER HALF POWER POINT AT 0.511 micrometers
UPPER HALF POWER POINT AT 0.532 micrometers
PEAK POWER AT 0.521 micrometers

90% of the energy is between 0.501 and 0.543 nm

SPECTRAL CALIBRATION DATA

File: N2DEC90.CH4 Sun Dec 02 17:16:51 1990

Operator Name:	JMG
Operator Comment(s):	PRE TC=1S POST TC=.1S
Operator Comment(s):	SLITS=250
Spectrometer Identification:	AOCI
Detector(s) Identification:	MT18255 SN002
Monochromator Speed:	1000
Monochromator Start Reading:	4000
Monochromator End Reading:	11000
Grating Identification:	600G 5000A
Source Identification:	TUNG90 120V
Filter(s) Identification:	At=7500 Passband=720-1350
Number of Readings:	697
File Code:	4 [4AUG86]
Raw Data File	2DEC90.CH4
Normalization Data File	29aug86.rf1



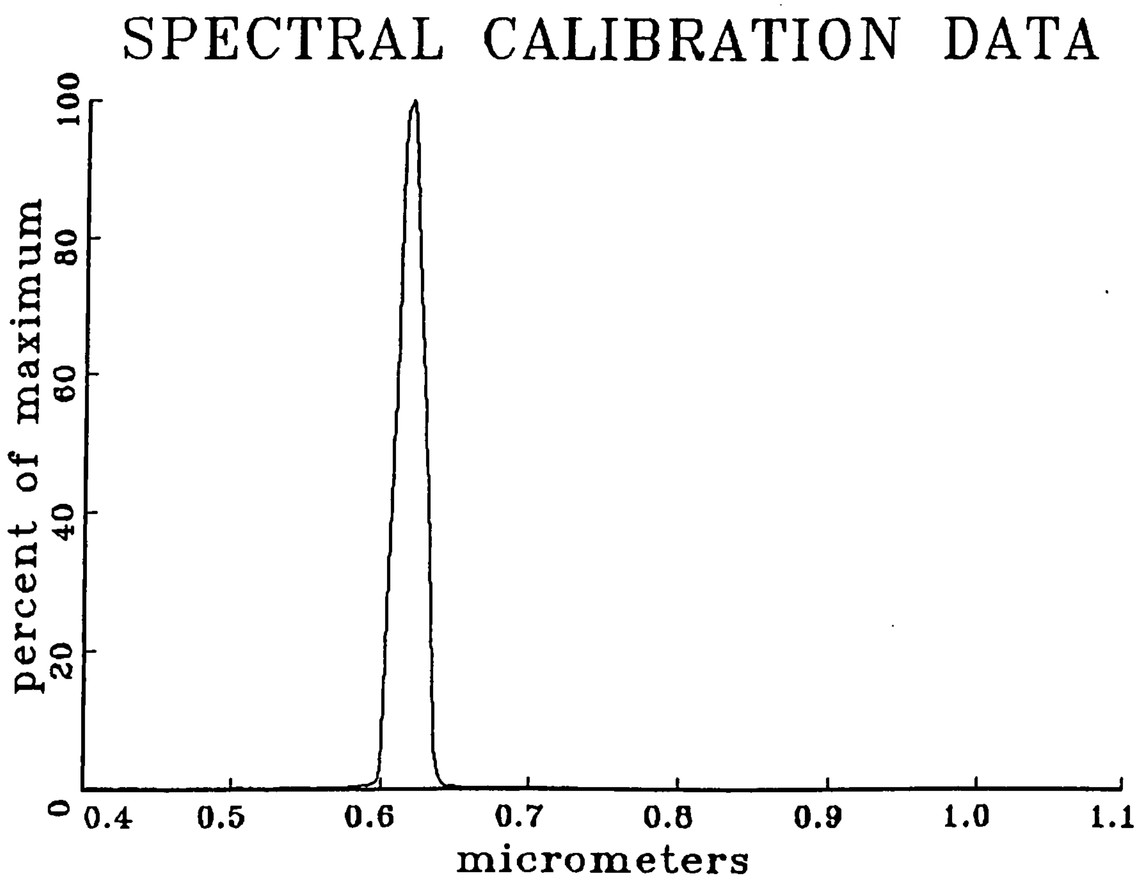
LOWER HALF POWER POINT AT	0.554 micrometers
UPPER HALF POWER POINT AT	0.574 micrometers
PEAK POWER AT	0.562 micrometers

98% of the energy is between 0.546 and 0.586 nm

SPECTRAL CALIBRATION DATA

File: N2DEC90.CH5   Sun Dec 02 17:31:14 1990

Operator Name:	JMG
Operator Comment(s):	PRE TC=1S POST TC=.1S
Operator Comment(s):	SLITS=250
Spectrometer Identification:	AOCI
Detector(s) Identification:	MT18255 SN002
Monochromator Speed:	1000
Monochromator Start Reading:	4000
Monochromator End Reading:	11000
Grating Identification:	600G 5000A
Source Identification:	TUNG90 120V
Filter(s) Identification:	At=7500 Passband=720-1350
Number of Readings:	697
File Code:	4 [4AUG86]
Raw Data File	2DEC90.CH5
Normalization Data File	29aug86.rf1



LOWER HALF POWER POINT AT 0.609 micrometers
UPPER HALF POWER POINT AT 0.630 micrometers
PEAK POWER AT 0.619 micrometers

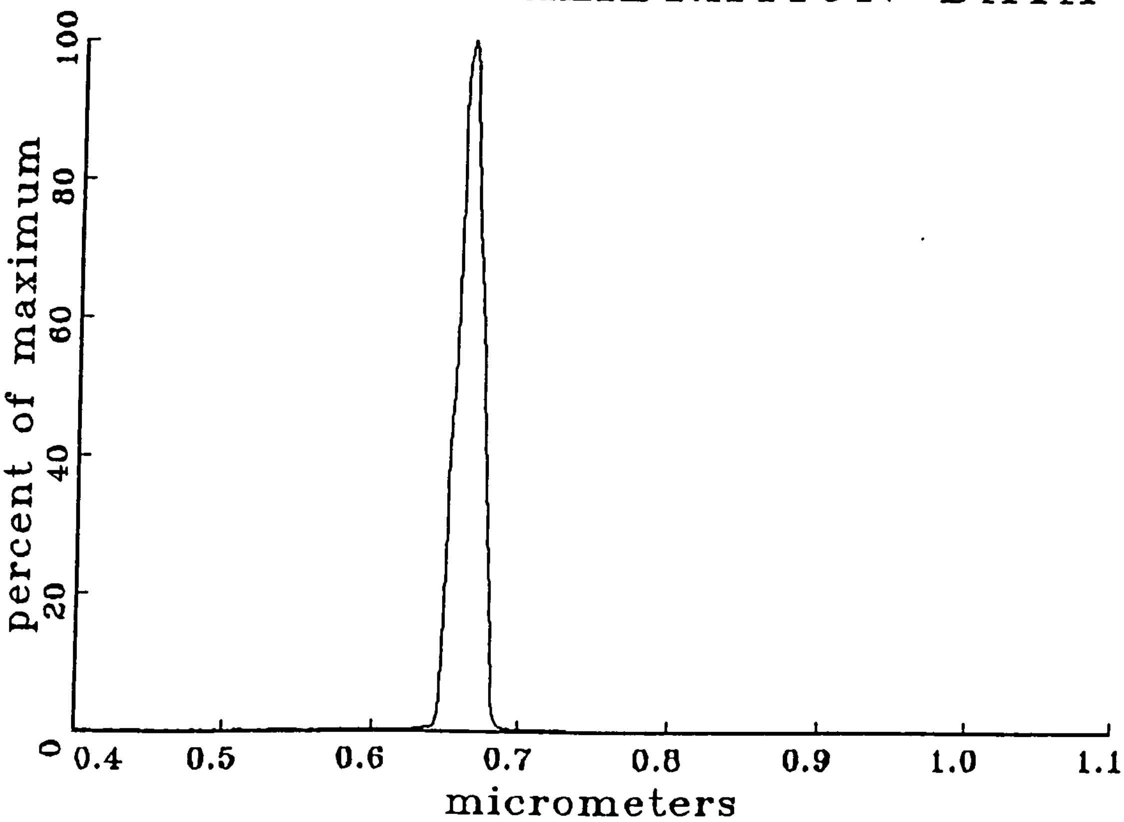
90% of the energy is between 0.599 and 0.641 nm

SPECTRAL CALIBRATION DATA

File: N2DEC90.CH6 Sun Dec 02 17:45:01 1990

Operator Name:	JMG
Operator Comment(s):	PRE TC=1S POST TC=.1S
Operator Comment(s):	SLITS=250
Spectrometer Identification:	AOCI
Detector(s) Identification:	MT18255 SN002
Monochromator Speed:	1000
Monochromator Start Reading:	4000
Monochromator End Reading:	11000
Grating Identification:	600G 5000A
Source Identification:	TUNG90 120V
Filter(s) Identification:	At=7500 Passband=720-1350
Number of Readings:	697
File Code:	4 [4AUG86]
Raw Data File	2DEC90.CH6
Normalization Data File	29aug86.rf1

SPECTRAL CALIBRATION DATA



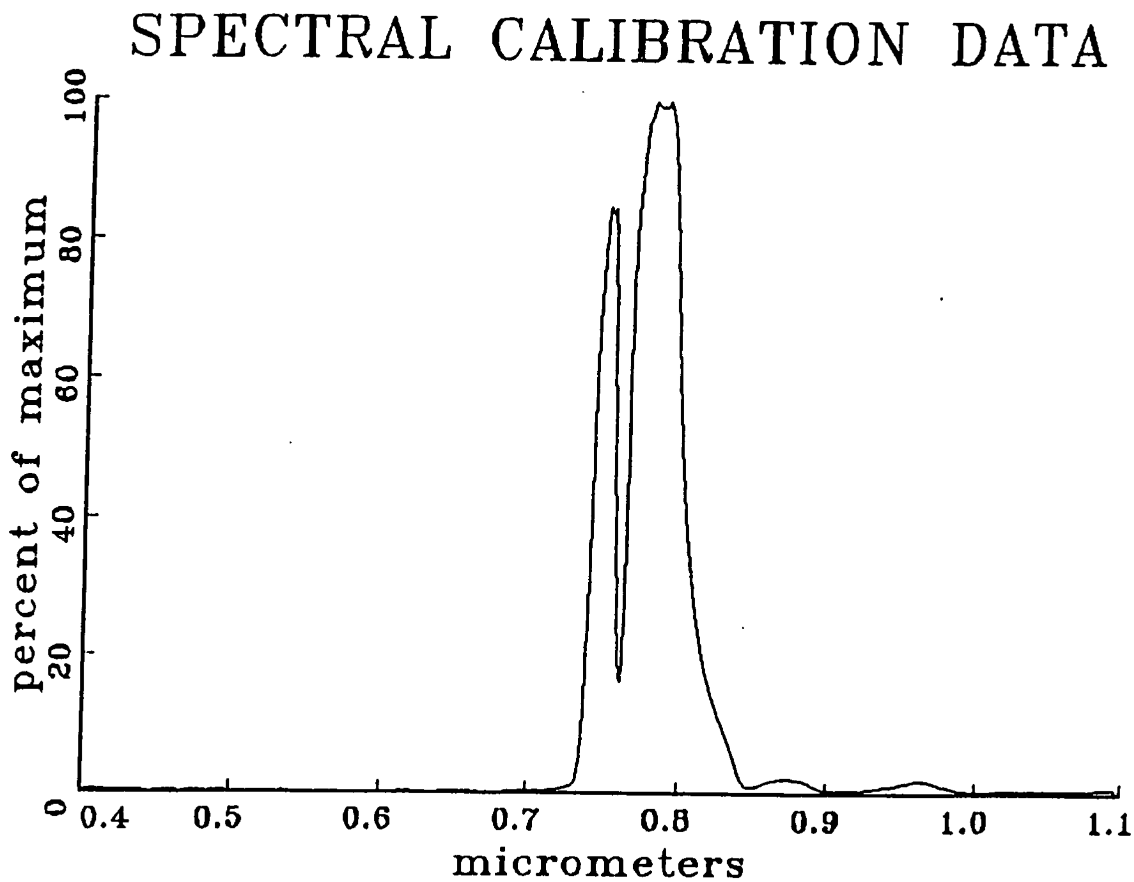
LOWER HALF POWER POINT AT	0.655 micrometers
UPPER HALF POWER POINT AT	0.676 micrometers
PEAK POWER AT	0.664 micrometers

98% of the energy is between 0.645 and 0.688 nm

SPECTRAL CALIBRATION DATA

File: N3DEC90.CH7 Mon Dec 03 12:31:00 1990

Operator Name:	JMG
Operator Comment(s):	PRE TC=1S POST TC=.1S
Operator Comment(s):	SLITS=280
Spectrometer Identification:	AOCI
Detector(s) Identification:	5404 SN001
Monochromator Speed:	1000
Monochromator Start Reading:	4000
Monochromator End Reading:	11000
Grating Identification:	600G 5000A
Source Identification:	TUNG90 120V
Filter(s) Identification:	At=6500 Passband=650-1230
Number of Readings:	697
File Code:	4 [4AUG86]
Raw Data File	3DEC90.CH7
Normalization Data File	29aug86.rf2



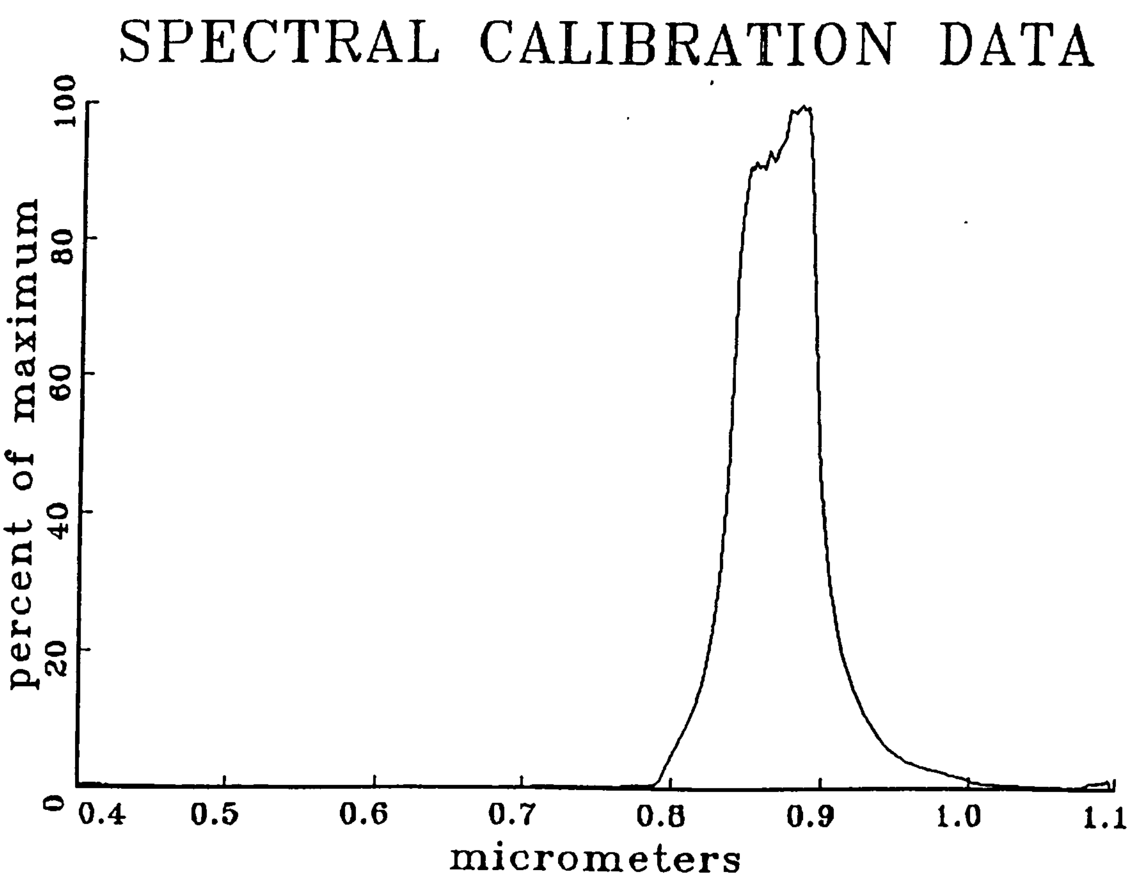
LOWER HALF POWER POINT AT 0.744 micrometers
UPPER HALF POWER POINT AT 0.802 micrometers
PEAK POWER AT 0.789 micrometers

90% of the energy is between 0.699 and 0.815 nm

SPECTRAL CALIBRATION DATA

File: N3DEC90.CH8 Mon Dec 03 12:04:53 1990

Operator Name:	JMG
Operator Comment(s):	PRE TC=1S POST TC=.1S
Operator Comment(s):	SLITS=270
Spectrometer Identification:	AOCI
Detector(s) Identification:	5404 SN001
Monochromator Speed:	1000
Monochromator Start Reading:	4000
Monochromator End Reading:	11000
Grating Identification:	600G 5000A
Source Identification:	TUNG90 120V
Filter(s) Identification:	At=6500 Passband=650-1230
Number of Readings:	697
File Code:	4 [4AUG86]
Raw Data File	3DEC90.CH8
Normalization Data File	29aug86.rf2



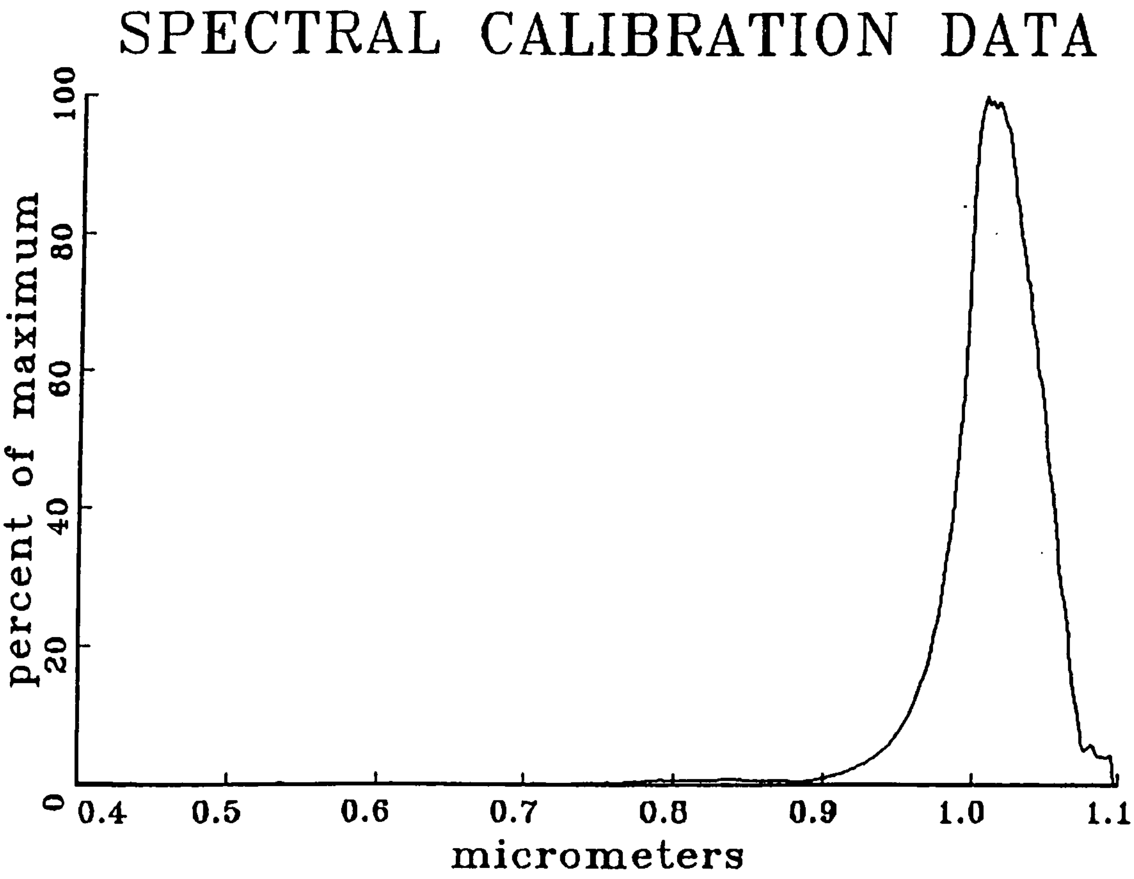
LOWER HALF POWER POINT AT	0.840 micrometers
UPPER HALF POWER POINT AT	0.900 micrometers
PEAK POWER AT	0.886 micrometers

91% of the energy is between 0.793 and 0.914 nm

SPECTRAL CALIBRATION DATA

File: N3DEC90.CH9 Mon Dec 03 12:47:00 1990

Operator Name:	JMG
Operator Comment(s):	PRE TC=1S POST TC=.1S
Operator Comment(s):	SLITS=400
Spectrometer Identification:	AOCI
Detector(s) Identification:	5404 SN001
Monochromator Speed:	1000
Monochromator Start Reading:	4000
Monochromator End Reading:	11000
Grating Identification:	600G 5000A
Source Identification:	TUNG90 120V
Filter(s) Identification:	At=6500 Passband=650-1230
Number of Readings:	697
File Code:	4 [4AUG86]
Raw Data File	3DEC90.CH9
Normalization Data File	29aug86.rf2



LOWER HALF POWER POINT AT 0.994 micrometers
UPPER HALF POWER POINT AT 1.054 micrometers
PEAK POWER AT 1.010 micrometers

91% of the energy is between 0.979 and 1.098 nm

Channel Number	A Input Radiance*	B Measured Signal @ 6.25	C Measured Noise 6.25	C Measured Noise 12.5	D SNR B/C	E Operational Radiance**	F Radiance Factor A/E	G Equivalent Operational SNR F x D	Required Operational SNR
1	3.71 E-4	375	9.4	14.0	39.9	4.2 E-3	11.3	451	320
2	6.49 E-4	1580	9.7	14.8	162.9	4.0 E-3	6.2	1010	495
3	8.69 E-4	1385	5.3	7.8	261	3.0 E-3	3.5	915	490
4	1.26 E-3	2310	6.0	8.5	385	2.0 E-3	1.6	616	425
5	1.72 E-3	3220	6.6	9.9	488	1.5 E-3	0.9	439	370
6	2.07 E-3	3710	5.3	7.5	700	1.0 E-3	0.5	350	355
7	2.56 E-3	4170	2.3	2.7	1813	5.0 E-4	0.2	363	465
8	2.95 E-3	3945	1.6	1.8	2466	3.0 E-4	0.1	247	345
9	3.32 E-3	3160	2.4	2.7	1317	3.0 E-4	0.09	119	125
	BB1-BB2 (°C)				NETD (°C) (C/B) x A				Required NETD
12	15°					--	--	--	0.1°

*W/CM^2 -um -Sr

** At 65K ft. altitude

*Calibration Source: Bands 1-9 = Model AB532 S/N 508 Date Calibrated: 4-13-87
Band 12 = Blackbody ___ or Water Bath ___ (check one)

SENSOR S/N :
Bands 1-6 002 Position ___
Bands 7-9 001 Position ___
Band 12

SYSTEM S/N: 002
SPECTROMETER MODEL:
IFOV (circle one): 1/25 (2.5) 5.0
1/2 Angle (circle one): Yes (No)

TESTS PERFORMED & VERIFIED BY:
John M. Green
DAEDALUS ENTERPRISES, INC.

WITNESS: ___

DATE: 12-3-90

Channel Number	A Input Radiance*	B Measured Signal	C Measured Noise	D SNR B/C	E Operational Radiance**	F Radiance Factor A/E	G Equivalent Operational SNR F x D	Required Operational SNR
1	3.71 E-4	248	9.8	25.3	4.2 E-3	11.3	286	320
2	6.49 E-4	1005	10.0	100.5	4.0 E-3	6.2	623	495
3	8.69 E-4	930	5.4	172	3.0 E-3	3.5	603	490
4	1.25 E-3	1750	5.7	307	2.0 E-3	1.6	491	425
5	1.72 E-3	2765	8.2	337	1.5 E-3	0.9	303	370
6	2.07 E-3	3320	5.3	626	1.0 E-3	0.5	313	355
7	2.56 E-3	3600	4.3	837	5.0 E-4	0.2	167	465
8	2.95 E-3	3320	2.4	1383	3.0 E-4	0.1	138	345
9	3.32 E-3	2830	3.0	943	3.0 E-4	0.09	85	125
	BB1-BB2 (^{o}C)			NETD (^{o}C) (C/B) x A				Required NETD
12	15°	4000	8.5	.03	--	--	--	0.1°

*W/CM^2 -um -Sr

** At 65K ft. altitude

*Calibration Source: Bands 1-9 = Model AB532 S/N 508
Band 12 = Blackbody X or Water Bath ___ (check one)
Date Calibrated: 4/13/87

SENSOR S/N :

Bands 1-6	002	Position	.668
Bands 7-9	001	Position	.620 from left
Band 12	001		

SYSTEM S/N: 002
SPECTROMETER MODEL: AB182, S/N 001
IFOV (circle one): 1/25 (2.5) 5.0
1/2 Angle (circle one): Yes (No)

TESTS PERFORMED & VERIFIED BY:

John Green
DAEDALUS ENTERPRISES, INC.

WITNESS: ______

DATE: 4/13/90

Appendix C

Atmospheric Correction and Bio-Optical Algorithm Program Documentation for Processing Airborne Ocean Color Imager (AOCI) Data

Processing of AOCI Data

In order to process a typical AOCI run, two Fortran programs and two data tapes are needed. The first program smooths the navigational data, and the second program calculates the atmospheric corrections and derives chlorophyll concentrations from the corrected data. These programs should run on most computers that have sufficient disk space, but some modifications may be necessary for any given system. The removal of byte swapping that is used in the VAX version would be the most obvious example.

The first step is to copy the needed information to disk. For the navigational data tape this can be done by using a utility such as MTREAD available at Ames Research Center or by writing a simple Fortran program that will read/write 200 character ASCII files. On certain computer systems a "copy" command may also work. The AOCI scanner data requires special treatment on most systems because of the large record length and blocksize of the data. At Ames Research Center we used a Fortran program that copied the binary data to a disk file as long records.

Once the data is on the disk the next step is to decide what flight lines are to be processed. Then the navigational data should be edited to exclude all times outside of the desired flight line, but not shorter than the flight line. The beginning and end of the useful data can be determined both by looking at the times on the navigation clock and by checking the heading of the aircraft and looking for the turns. After the navigation data file has been edited, the ASCII file can be input as data into a program that uses a moving average smoothing routine over seven points to produce a new file of navigation data that contains the essential data for input into the AOCI code. This includes time, latitude and longitude, aircraft heading, pitch, and altitude, and additional data on speed that is not used by the program.

The AOCI reduction program needs three inputs: the processed navigation data, the raw AOCI data, and a namelist input. The program uses the namelist input to control the processing and produces two output files, one printed and one written in a binary format that is designed for an image display system. Also, since the program at NASA Ames was originally written to run on a VAX, the program must do byte swapping of the raw AOCI data on input and then byte swap the results (atmospherically corrected data and/or chlorophyll concentration) before writing the output file intended for the image display. Other computer systems may not require this byte swapping.

There are two versions of the program: one that uses a single scattering theory for the atmospheric correction (Gordon et al., 1983) and another that uses the Sobolev method for correcting the data. The Sobolev method (Guzzi et al., 1987) averages various quantities over azimuth in order to approximate higher order corrections due to multiple scattering. The only difference in running the two methods is in the namelist input for the atmospheric correction program. Several auxiliary programs are also available for reading the raw input data onto disk.

References

Gordon, H. R.; Clark, D. K.; Brown, J. W.; Brown, O. B.; Evans, R. H.; and Broenkow, W. W.: Phytoplankton Pigment Concentrations in the Middle Atlantic Bight: Comparison of Ship Determinations and Coastal Zone Color Scanner Measurements. Applied Optics, vol. 22, 1983, pp. 20–36.

Guzzi, R.; Rizzi, R.; and Zibordi, G.: Atmospheric Correction of Data Measured by a Flying Platform Over the Sea: Elements of a Model and Its Experimental Verification. Applied Optics, vol. 26, 1987, pp. 3043–3051.

A Guide to Running Data Reduction Programs for Airborne Ocean Color Imager Data

General Description

The Airborne Ocean Color Imager is an electro-optical multispectral scanner which was developed by NASA Ames Research Center as an aircraft instrument to simulate the sectral and radiometric characteristics of the next generation of satellite ocean color instrumentation. The Airborne Ocean Color Imager (AOCI) has six ~20 nanometer bands in the visible spectral region at 443, 490, 520, 565, 620, and 665 nm as well as three ~60 nm bands in the near-infrared region at 765, 865, and 1015 nm and a thermal infrared band at 8–12 micrometers. The visible bands are used in bio-otical algorithms to calculate hytolankton igment concentrations in surface waters while the near-infrared bands are used in atmospheric correction algorithms for the visible bands. Data processing programs have been developed for the AOCI as extensions of algorithms developed for the Coastal Zone Color Scanner for atmospheric correction and bio-otical output products. Those programs are provided in this release. The following sections provide guidance in running those programs on a VAX 11/785.

Required Data

The data required for running the programs consist of two site specific data sets and a calibration data set. The first site specific data set consists of navigational data from the host aircraft's inertial navigational data system (time, latitude, longitude, heading, pitch, roll, altitude, ground speed, etc.). The navigational data is recorded every five seconds in hexadecimal format on a digital cassette tape. A reformatting program converts the hexadecimal data into ASCII format in 200 byte records; the data is normally written to nine-track magnetic tape. The second site specific data set consists of AOCI data as 741 sixteen-bit words for each of the ten bands for each scan line. All the AOCI data for each scan line is contained in one physical record of 14,820 bytes on magnetic tape. A single flight line will consist of many scan lines, typically 5,000 to 15,000 scan lines. The first 25 words of the data for each band contain housekeeping information in a coded format and the remaining 716 words contain the video data as ten-bit binary words embedded in sixteen-bit words. The calibration data set is provided by various common blocks (e.g., aerosol.cmn, atmdat.cmn, constants.cmn, new_dat.cmn) as well as flight specific radiometric gains from the Flight Summary Report.

Reduction of the Navigational Data

The navigation data tape is first copied to disk using a tape-to-disk utility program set to read and write 200 character records. On the VAX 11/785, the VAX utility COPY can be used as follows:

allocate mfa_:

mount foreign/blocksize=200/recordsize=200 mfa_:

copy mfa_: diskname:filename

dismount mfa_:

deallocate mfa_:

Once the file is on disk, it should be edited to separate out the desired flight line. The "flight line" for a given flight is defined simply as the "straight" portion of a flight between turns. Use a text editor (EDIT on the VAX) to separate out any desired flight line; it can then be fed into the moving average smoothing program, LATLONG5. A line can be defined by the values in the navigational clock field in comparison to the AOCI scanner clock or by checking the aircraft heading field and looking for turns in the roll field (see example below for locating various fields). Caution: the AOCI data should fall completely within the times represented by the edited navigational data.

Running the Navigational Fitting Program (Illustrated for a VAX system)

VAX Commaands	Comments on these commands
run [LATLONG5]	Include the complete path name to the navigational fitting program executable on your computer system.
[program now asks for the file name of the input file]	Enter at the keyboard the complete name [including directory path if needed] for the edited input navigational data. <=40 characters
output [smoothed] appears on a file called: processed.nav_data	This file is in the proper format for input into the AOCI data reduction program.

Listed below is a sample input line from the RAW navigation data file. Since the line is long, it is split into three parts. The line just above the data indicating the number of each column is not a part of the original file. (The fives column is indicated by a "+" and the tens column by the tens digit.)

```
       time    Date     c     Lat         Long        Alt      air speed   pitch
    hh:mm:ss/DD/MM     e     degrees    degrees     feet        knot     degrees
....+....1....+....2....+....3....+....4....+....5....+....6....+....7
    13:17:30/11/05    G   29.57539 -95.15631     476.70    147.137     29.518

      roll      heading    N-S vel     E-W vel  Vert vel     speed
    degrees    degrees      knot        knot    feet/sec     knot
....+....8....+....9....+....0....+....1....+....2....+....3
       -.283    175.057   -128.400        .800 -1655.100   126.700

    G-speed   Wind Spd   Wind Ang   Vert Vel   Temperature
     knot       knot      degrees   feet/sec     deg C
....+....4....+....5....+....6....+....7....+....8
     128.402     21.724      33.14    999.000      91.07
```

The output of the navigational fitting program is a smoother version (using a moving average fit) of the original file and should be renamed using the date and flight line as an identifier. Only latitude and longitude are smoothed by the program.

Running the AOCI Data Reduction Program

To prepare the scanner data for the AOCI data reduction program, the data should first be copied to disk using the program FILE_READ (or another utility) that can read and write long records. Each data record (scan line) on the tape is 14820 bytes long and for most computer systems the tape must be mounted with an explicit request for a longer than standard record size and block size. On a VAX this would be done by:

Sample VAX Command File

$! for aoci tape only

$ allocate mfa_:

$ mount/foreign/blocksize=14820/recordsize= 14820 'tapename' mfa_:

$!enter # of files to be skipped

$ set magtape 'tapename' mfa_:/skip=files:'files'

$ run file_read

$ "enter logical unit for tape drive"

$ mfa_:(after file_read completes, enter)

$ dismount mfa_:

$ deallocate mfa_:

After copying the data to the disk, the next step is to prepare an input Fortran namelist (control file) as follows.

Extract of the Fortran Namelist for the SINGLE SCATTERING Version

NAMELIST /AOCI/ ALTSET, ANGSTROM, AOCI_DATA, APPROX_EXP, ATMOS_P,

$ ATM_AER_D, ATM_DEPTH, CALIB, CALIB_F, CALIB_S, C_SET, DOBSONS,

$ IBAND, IFLEAR, IF_AER, IF_FIRST, IF_PRINT, IF_THERM, IMAGE_1LINE,

$ IMAGE_FIXED, LSKIP, NAV_DATA, PSKIP, START_L, STOP_L, STYLE,

$ TARE, TOLERANCE, T_OFFSET, USE_BANDS, WR_BANDS

An example namelist is appended to these instructions.

Comments on the Single Scattering Version

The method runs as follows:

First calculate the flux from Rayleigh scattering expected at the sensor (for each pixel). All of the following quantities are understood to be wavelength dependent.

L(R) = tau(r)*Flux[solar - reduced by ozone absorption and Rayleigh scattering above aircraft]*Phase term/4π*cos(theta)

where

tau(r) = Rayleigh optical depth

Flux = Solar extra terrestrial irradiance x ozone and Rayleigh transmittances

Phase term = Rayleigh phase function at the scattering angle

theta = zenith angle to the sensor

L[aersol] is derived from one of the longest wavelength bands (usually band 9 at 1015 nm) after subtracting the expected Rayleigh radiance. This term is scaled for other bands using the ratio of expected solar flux and the expected change in the aerosol optical depth (but the latter is usually assumed to be wavelength independent).

The resultant water-leaving radiance is then obtained by subtracting the Rayleigh and aerosol terms (including corrections for light reflected off the surface of the ocean) and dividing by the total expected extinction between the water and the scanner (due mainly to Rayleigh scattering but may include ozone and water vapor absorption).

Comments on the Quantities in the Namelist

AMPLIFIER CALIBRATION FACTORS AND SCALING FACTORS: CALIB: CALIB_F: CALIB_S:

ALWAYS READ 9 VALUES FOR THE SCANNER CALIBRATIONS AND 9 VALUES FOR THE 'CORRECTION' FACTORS [CALIB_F]. ONE VALUE FOR EACH BAND

The scanner calibrations are derived from calibration data for the AOCI detectors. The CALIB values assume a Flight Gain of "1." The program obtains the actual Flight Gain from the housekeeping data for each band and derives the radiometric gain for each band. These numbers should be available after every flight. The CALIB_F values were included in an earlier version as "fudge" factors. They all should be set to 1 (i.e., 9*1.) in the current version (unless a comparison of results with surface measurements indicates they should be modified).

The numbers CALIB_S are used to avoid "overflowing" the scale limit of the image display device (i.e., 255). These numbers only affect the display output of the individual corrected bands, and are not used when the bio-optical relations are calculated. Set = 9*1. for no scaling, otherwise the display output is divided by CALIB_S. The program also uses a 'TARE' correction. (See discussion below.)

'ANGSTROM' is the angstrom coefficient used to describe the wavelength dependence of aerosol scattering:

$$L_a(\lambda_0)/L_a(\lambda) = (\lambda/\lambda_0)\ e^{(\mathrm{Angstrom})}$$

'IBAND' is an integer which determines the band used for the aerosol correction in Gordon's method. [Gordon et. al., Applied Optics, 1983, vol. 22, 20-36].

'T_OFFSET' is any possible offset of clock. May be in error by ±1 hour due to confusion between daylight and standard times, or may just be wrong! Read in as a real number in hours. This time is added to the time derived from the scanner's clock.

TOLERANCE: the time between recalculation of certain solar angles. Set to a default value of 1 hr in block data.

The program has several built in 'tolerance' values. Once the angle (position) of the sun or the direction (heading and/or pitch) of the aircraft has changed by a value that exceeds the tolerance for that quantity, the program GEOM is called to recalculate the geometry of the problem. Otherwise, each line is corrected using the values from the most recent call of GEOM. Tolerances are usually set to 2.5 degrees in angle and 1 Hr. in time. These can be adjusted if desired.

ATM_DEPTH: The % [number density in the vertical line of sight] of the atmosphere below the sensor. Use as a constant for the moment.

Estimate this quantity from the altitude of the plane and a model of atmospheric number density with altitude (i.e., U.S. Standard Atmosphere); enter it in the namelist. No default value.

ATM_AER_D: The % of the atmosphere between the plane and an aerosol "layer." Only relevant if the extra absorption of the atmosphere is included in the aerosol correction calculation [i.e., IF_AER = .TRUE., the default value is false]. No longer used.

A series of logical control variables (may be .TRUE. or .FALSE.) to control the correction method.

IF_AER: To include the Rayleigh absorption of incoming sunlight in the calculation of the aerosol flux ratios and the absorption of any scattered flux by the atmosphere (or some portion of it) from the water to the sensor. No longer used: preset to '.FALSE.' [Defaults to false.]

IF_PRINT: To control the printout [through 'display'] of the original tape input data. Set = .FALSE. by default. This includes the raw data, and is used to check the output. The program by default prints out details of the calculation [individual correction terms] for the first line only.

APPROX_EXP: Logical to control the use of the approximation of the exponential in the correction term [Gordon's method]. '.TRUE.' corresponds to Gordon's method. [Defaults to .TRUE.]. This uses: TAU(Rayleigh) as an approximation to: 1 - EXP(- TAU(Rayleigh)). The rationale for this is to approximately "correct" for the lack of multiple scattering in the code. See the discussion by Gordon for more details. This is missing from the Sobolev version (multiple scattering) because the Sobolev method is using another method to correct for the effects of multiple scattering and no additional approximations are involved.

'IFLEAR' and 'ALTSET' added May 1990 for data acquired using Stennis Space Center's Lear Jet because that aircraft did not include altitude in the navigation data. The Lear Jet navigation tape altitude was totally incorrect on the navigation tape. Allowed "setting" a fixed altitude for the entire flight line. 'IFLEAR' defaults to ".FALSE." and the actual altitude from the navigation tape is used. Use ".TRUE." + "ALTSET" (in feet) for Lear Jet data to enter the proper altitude.

Logical variable 'TARE' controls use of the "tare correction." Defaults to '.FALSE.' IF SET = .TRUE., would cause the 'tare' correction to be read from the AOCI scanline header. This subtracts the tare (gain*bb_1 (in counts)) from the raw counts. The tare correction is always used to correct the value of the gain entered in the calibrations.

'IF_FIRST'. Use with 'tare' to use the information in the header of the first line of data (=.TRUE.), or use the header information on a line by line basis (=.FALSE.). No default. Must be set if 'TARE' is chosen.

IF_THERM : a logical variable used to control writing of band 10—the thermal band. Defaults to '.FALSE.' (no writing). No correction or calibration is applied to this band.

ATMOS_P : The atmospheric pressure in millibars or inches of HG. Used to scale various quantities like optical depth. Defaults to one standard atmosphere.

STYLE : This is either 'new' or 'old' and refers to the pre-processing of the AOCI data. For 'old' data a correction is applied to bands 9 and 10 to correct each value back to 8 bits from 10. 'New' data would be appropriate to all runs after about 1989. Check with the Ames Aircraft Data Facility (415-604-6252) for details if all pixel values in bands 9 and 10 are multiples of four.

START_L (defaults to 1) and STOP_L (no default): Controls first and last line processed from raw AOCI data. STOP_L must be read in. On the AOCI file the first data line is simply the first line of data on the disk file, not on the original tape. These values should be chosen to avoid the turns at the end of each flight line.

PSKIP : Used to control skipping pixels across image. Default = 1. Using a value of pskip=n, the program will only compute values for pixels 1,716,n. The other pixels are skipped and are not written out. (Note: this option has caused problems and should be used with caution.)

LSKIP : Used to control skipping of entire lines. Default = 1. Using a value of lskip=n, the program will only compute values for every nth line.

DOBSONS : Ozone concentration from the ground to space. Defaults to 350 [in Dobson units]. Used to scale ozone optical depths.

'C_SET' reads in control variables for the bio-optical (or chlorophyll) algorithms. Up to MAX_CH relations allowed. Seven now currently in use. Just read in MAX_CH (7 at present) integers in free field format. To choose a relation, enter its number. Current choices are: [2 4 6 8 10 12 14]. Relations 2-12 are various bio-optical algorithms to calculate the total pigment concentration (chlorophyll *a* + phaeophyton) of the water. Relation 14 is really the relation for the diffuse attenuation coefficient of the water, not a new total pigment relation. All relations are listed below.

For example, to choose relations 2, 4 and 6 enter: C_SET = 2 4 6 0 0 0 0

Remember that you must also 'turn on' the proper bands needed for each corresponding calculation; bands 1, 2, 4, and 9 would be needed for this example. (See USE_BANDS.)

WR_BANDS (defaults to 9*1) : All bands written to fixed file. Set any band = 0 to not write that band. (But see USE_BANDS below.) If you try to write a band that has not been calculated, that band will not be written, causing an error in the header of the display file. So be careful to compare WR_BANDS and USE_BANDS; do not try to write a band that has not been calculated.

Add USE_BANDS to control actual usage of bands in the atmospheric correction procedure. This assumes that one will include any bands needed in the calculation. The user must check to see that any necessary bands are included. There are 9 bands; a non-zero number in any band position indicates the calculation of the atmospheric correction for that band.

The table below shows what bands are needed for each bio-optical relation (based on C_SET and a set of coefficients entered as block data in the program). The following relations use ratios of the form A/B where A and B represent the corrected radiance bands A and B. Case 1 and case 2 refer to water types: case 1 waters are dominated by absorption due to phytoplankton pigments and their degradation products while case 2 waters include scattering due to phytoplankton as well as scattering and absorption due to terrigenous materials (suspended sediment and gelbstoffe).

Relations of the Form (A/B)

Relation 2: Log[pigment] = 0.182 - 1.004*Log(1/4)
Case 1

Relation 4: Log[pigment] = 0.501 - 1.709*Log(2/4)
Case 1

Relation 6: Log[pigment] = 0.161 - 1.050*Log(1/4)
Cases 1 & 2 combined

Relation 8: Log[pigment] = 0.371 - 1.544*Log(2/4)
Cases 1 & 2 combined

Relations of the Form (A+B)/C

Relation 10: Log[pigment] = 0.597 - 1.261*Log((1+3)/4)
Case 1

Relation 12: Log[pigment] = 0.607 - 1.330*Log((1+3)/4)
Cases 1 & 2 combined

These pigments are then converted to pixel values using the following relations:

if 10**Log[pigment] < .042
Pixel value = 0.0

if .042 < 10**Log[pigment] < 1.0
Pixel value = 98.38*Log[pigment] + 136.

if 1.0 < 10**Log[pigment] < 32.
Pixel value = 74.17*Log[pigment] + 136.

if 10**Log[pigment] > 32.
Pixel value = 255.

Diffuse Attenuation Coefficient Relation

Relation 14: Log[diffuse att'n coeff.] = 0.022 + .0883*(1/4)**(-1.491)

Conversion of Diffuse Attenuation Coefficient to Pixel Values

Log[diffuse att'n coeff.] < .025
Pixel value = 0.0

.025 < Log[diff. att'n coeff.] < .5
Pixel value =184.46*Log[diffuse att'n coeff.] + 303.52

Log[diffuse att'n coeff.] > .5
Pixel value = 255.

Running the AOCI program

FILE NAMES: The names of the input and output files are entered as part of the namelist input.

NAV_DATA: Complete path to the smoothed navigation data.

AOCI_DATA: Complete path to the AOCI raw data.

IMAGE_1LINE: The name [and directory path] for the summary printout. Prints a summary of the run parameters and the results for the first line processed.

IMAGE_FIXED: The name [and directory path] for the final results in the image display format.

Usually the program is run in batch (or the background, depending on the operating system), but for testing purposes on a few lines of data the program can be run interactively.

NAMELIST

NOTE: Anything on a line after an "!" is considered to be a comment by VAX namelist. The comment character on another machine may be different. Try ":" or ";".

```
$aoci
!raw input data complete path name to file
aoci_data='idims4:[idims.klooster]jun14ab.raw',
! calibration, "fudge," and scaling factors in * format
! numbers always. use "1." for no scaling/fudging
calib= .0124 .0052 .0073 .0052 .0044 .0044 .0061 .0072
  .0356 ,
! radiometric units are in mW/cm^2 nm steradian
calib_f= 9*1.0 ,
calib_s = 1. 1. 1. 2. 2. 2. 1. 1. 1.,
! atmos_p angstrom Iband _offset tolerance atm_depth
!  atm_aer_d
atmos_p=1013.25,
angstrom=0.0,
iband=9,
t_offset=0.0,
tolerance=1.0,
atm_depth=.823,
! atm_aer_d=.75,
! 2 logical variables: if_aer if_print
! CAN ONLY BE T or F (.TRUE. or .FALSE.)
if_aer=F,
```

```
if_print=F,
!complete file name of printed output
image_1line='scratch4:jun14ab.out',
! smoothed nav data
nav_data='idims:[idims.klooster.nav]nav_fit.jun14ab',
image_fixed='scratch5:jun14ab.fixed',
! read in NEW for no division or OLD for band 9 division
!  by 4.
! character variable
style='NEW',
! data for bio-optical "images."
! Read in max_ch numbers (maximum of 7 at present).
!  0's or 2 4 6 8 10 12 14
c_set=0 4 0 0 0 0 14,
start_l=1,
stop_l=2048,
iflear=t,
altset=41000.,
lskip=1,
pskip=1,
tare=t,
if_first=f,
if_therm=t,
approx_exp=t,
! must correctly set use_bands for chlorophyl relations
!  and iband
! in this example: we need bands 2 4 9 at a minimum
use_bands=0 1 0 1 0 0 0 0 1,
! now set wr_bands. You could choose to not write any
!  bands and only the chlorophyl band(s) chosen would be
!  written
wr_bands = 0 1 0 1 0 0 0 0 1,
! end of namelist loop
$
```

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13. ABSTRACT *(Maximum 200 words)*

The objective of the investigation was to develop a commercial remote sensing system for providing near-real-time data (within one day) in support of commercial fishing operations. The Airborne Ocean Color Imager (AOCI) had been built for NASA by Daedalus Enterprises, Inc., but it needed certain improvements, data processing software, and a delivery system to make it into a commercial system for fisheries. Two products were developed to support this effort: the AOCI with its associated processing system and an information service for both commercial and recreational fisheries to be created by Spectro Scan, Inc. The investigation achieved all technical objectives: improving the AOCI, creating software for atmospheric correction and bio-optical output products, georeferencing the output products, and creating a delivery system to get those products into the hands of commercial and recreational fishermen in near-real-time. The first set of business objectives involved Daedalus Enterprises and also were achieved: they have an improved AOCI and new data processing software with a set of example data products for fisheries applications to show their customers. Daedalus' marketing activities showed the need for simplification of the product for fisheries, but they successfully marketed the current version to an Italian consortium. The second set of business objectives tasked Spectro Scan to provide an information service and they could not be achieved because Spectro Scan was unable to obtain necessary venture capital to start up operations.

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