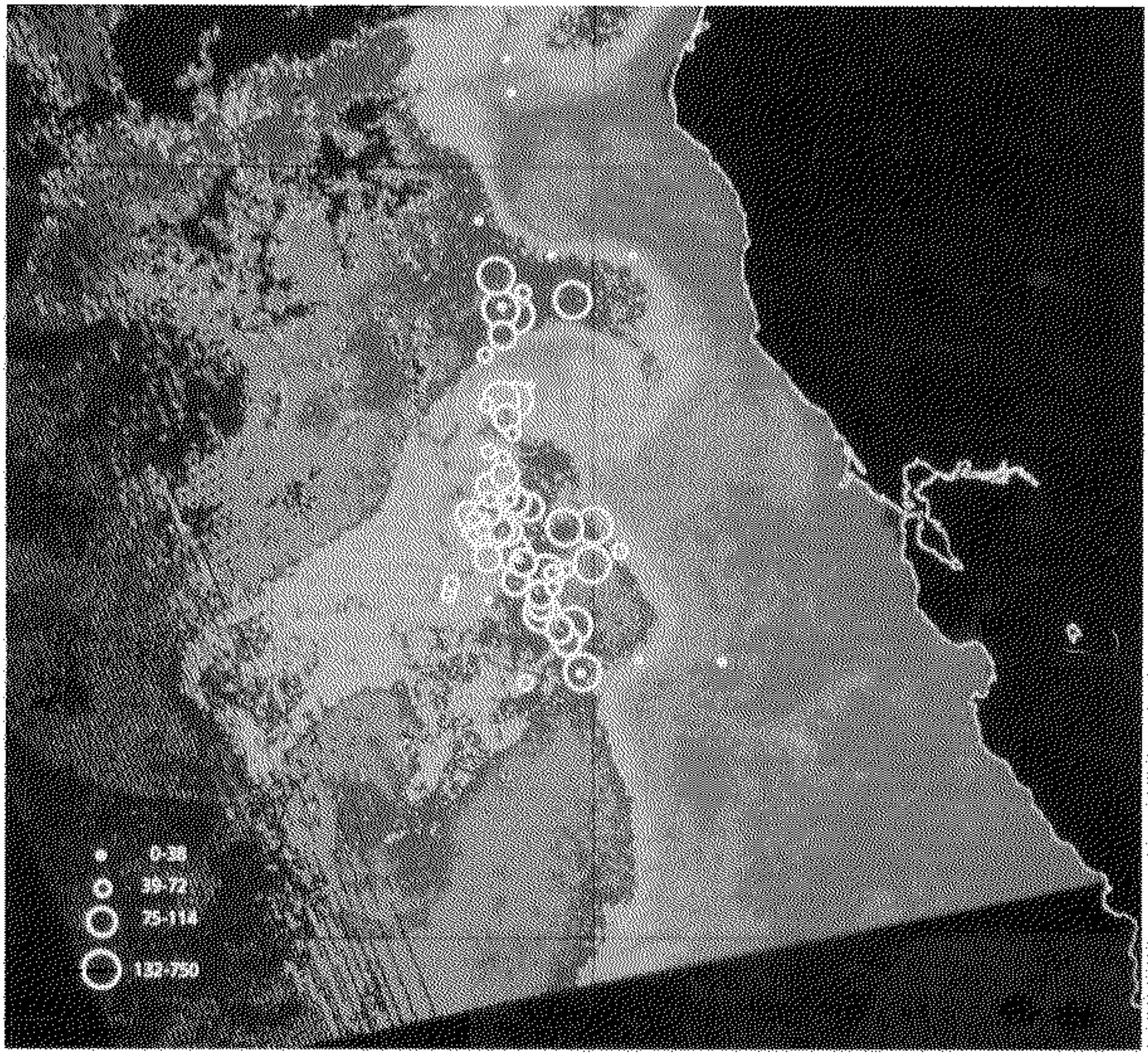
APPLICATIONS OF REMOTE SENSING TO FISHERIES AND COASTAL RESOURCES

REPORT OF A CALIFORNIA SEA GRANT WORKSHOP



A CALIFORNIA SEA GRANT
COLLEGE PROGRAM PUBLICATION

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The California Sea Grant College Program is a statewide, multiuniversity program of marine research, advisory services, and educational activities administered by the University of California Institute of Marine Resources. Through the research it sponsors, Sea Grant contributes to the growing body of knowledge about our coastal and oceanic resources and helps solve contemporary problems in the marine sphere. Through its Marine Advisory Program, Sea Grant transfers information and technology developed in its research efforts to a wide community of users in California, the Pacific region, and the nation. Sea Grant also supports a range of educational programs for students, teachers, and the general public to promote the wise use of our coastal and oceanic resources by this and future generations.

On the cover: This image shows gradations in ocean color off central California with locations of albacore tuna catches superimposed. The ocean color data were obtained on September 21, 1981 with the Coastal Zone Color Scanner (CZCS) on board NASA's *Nimbus-7* satellite. The CZCS data were enhanced to reveal oceanic features and show a transition from coastal waters (red, orange) to offshore regions (blue). The superimposed circles show the size and location of albacore tuna catches during the period of September 19 to 24, 1981. A comparison of ocean color variations with fish catch data indicates that most of the albacore were caught along the seaward side of the boundary between offshore and coastal waters. (Photo courtesy NASA. From Laurs, R.M., Fiedler, P.C., and Montgomery, D.R. 1984. Albacore tuna catch distributions relative to environmental features observed from satellites. *Deep-Sea Res.* 31: 1085-1099.)

APPLICATIONS OF REMOTE SENSING TO FISHERIES AND COASTAL RESOURCES

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NOVEMBER 30, 1983

SCRIPPS INSTITUTION OF OCEANOGRAPHY,
UNIVERSITY OF CALIFORNIA,
SAN DIEGO

EDITOR, ROSEMARY AMIDEI

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PREFACE

ELLEN WEAVER, San Jose State University

The Remote Sensing Workshop, held on November 30, 1983, was hosted and sponsored by the California Sea Grant College Program. Workshop organizers were James Hardwick of the California Department of Fish and Game, Michael Laurs of the National Marine Fisheries Service, Frank Mason of the Western Fishboat Owners Association, and myself. The meeting was attended by more than thirty people representing various state and federal government agencies, the fishing industry, and academia.

The purposes of the workshop were as follows:

1. To determine how remote sensing information is being applied to problems of fisheries and coastal resources; and
2. To assess opportunities that remote sensing might provide in the future, particularly to the development, enhancement, and management of fisheries.

A synopsis of the presentations follows.

Oceanic color and temperature have been related to albacore distribution and availability. Laurs suggested that ocean clarity, enabling albacore to see prey, is more important than temperature in determining their preferred location in the vicinity of upwelling boundaries. Svejkovsky and Lasker found that albacore catches by commercial fishing vessels were related to thermal fronts that remain stable for several weeks.

Hauschildt, Nolten, and Wittenberg reported on an investigation being conducted in Monterey Bay, where flatfish and rockfish catch data provided by cooperating fishermen are being correlated with Coastal Zone Color Scanner (CZCS) imagery over an 18-month period. It appears that the fish catch may be related to high productivity over a seamount in the Monterey Bay area.

El-Sayed and Trees related CZCS data to the menhaden fishery and to *in situ* chlorophyll determinations in the Gulf of Mexico. The CZCS data are proving useful in delineating the structure of water currents, both in the Gulf of Mexico and the eastern Mediterranean.

A panel on the operational aspects of remote sensing was led by Michael Laurs (substituting for Donald Montgomery), who described various ways in which fishermen can be informed of water color (chlorophyll distribution) and sea-surface temperature data. Charts can be transmitted by radio facsimile, photographs distributed to points where fishermen aggregate, and descriptions and interpretations of satellite data transmitted by marine radio.

Products are targeted to those fishing salmon and tuna but are used by others as well, e.g., hake, swordfish, and shark fisheries and recreational fishermen.

Daghir described the sea-surface temperature (SST) data that he compiles twice weekly from all sources (buoys, ship reports, AVHRR, etc.) for the area from 28° to 40° latitude. He is moving toward a reporting system that corresponds to that of the National Ocean Service Center in Seattle.

Timeliness of the data is a problem. Mason and Perkins described the functioning of the Western Fishboat Owners Association, an essential link between remote sensing data, the researcher, and the working albacore and swordfish fisherman. They reported favorable results when fishing boats have responded to information derived from satellite information, and they endorsed continued efforts toward cooperation between researchers and users.

Hovis illustrated complex oceanic features revealed by satellite, and solicited the cooperation of oceanographers in compiling an atlas of CZCS images that would illustrate the usefulness and range of this type of instrument.

Arvesen reported on the capabilities of NASA's U-2 aircraft.

Most of the attendees participated in a final panel discussion on the future options and applications of remote sensing. It was reported that plans for a follow-on satellite to the CZCS were not clearly delineated. Various constraints were outlined and the prediction was made that future satellite sensors would be improved.

The fisheries people in attendance made a strong case for the adoption of a system for transmitting information derived from satellites to fishermen in a consistent way, in a comprehensible and unchanging format. They need to be assured that they can receive usable products on a regular basis before they are willing to invest in instrumentation. However, they expressed enthusiasm for the potential of operating more efficiently with the help of satellite information.

There was discussion of what additional capabilities in remote sensing would be most useful to the oceanographic community, including private industry. Oil companies, for example, might be interested in projecting the extent and trajectory of oil spills. Governments are interested in lowering the costs of water quality control. Academic scientists have found good agreement between shipboard productivity analyses and those derived from satellite data, with the latter taking 0.2% as much time.

Possible strategies for assuring continued capabilities for ocean color sensing by satellite and effective means for distributing data were discussed.

The workshop closed with a consensus that a Pacific regional meeting of wider scope addressing the same issues should be planned.

Publisher's note: This report was generated from transcripts of tapes made during the workshop sessions. Because many of the speakers had organized their presentations around slides and other visual aids and because of ongoing developments in the field, participants were later given the opportunity to clarify or update their remarks.

OPENING REMARKS

JAMES J. SULLIVAN, Program Manager, California Sea Grant College Program

I would like to say a few words about how this meeting came about. In 1982, the California Sea Grant Committee indicated its desire to see strong proposals suggesting how remote sensing could be used in fisheries and for coastal resource development, use, and management. We knew, of course, that the National Weather Service and the Sea Grant Marine Advisory Service had cooperated to get temperature information to fishermen. However, most of the proposals we had received relating to remote sensing had been of dubious practicality. So we went back to the proposers and said, "Look, here are some specific problems; and here are some techniques that work. Why don't you recast your proposals to show us whether these techniques can be useful in coming up with solutions to these problems?" Using this approach, we generated five valuable research projects in 1983: four at University of California campuses, and one at the University of Southern California.[1]

After the projects were underway, we decided it would be a good idea to bring the various principal investigators together with a few agency people and representatives from the fishing community to see how things were going and what midcourse corrections people might want to make. As we were setting up the meeting, we kept receiving more and more requests from people who wanted to attend. We were delighted, and eventually set up the workshop for an entire day. Because we were afraid the workshop was going to get too long, we decided to use panel discussions for the last part of the meeting rather than individual presentations. That explains the format. Our purpose has remained the same: to assess the progress of Sea Grant projects that involve the use of remote sensing techniques and to discuss the directions being taken in this field.

I hope that a good exchange of information and ideas will come forth from this workshop. We have looked forward to having

[1] "Use of the *Nimbus 7* CZCS to Evaluate Circulation and Productivity Processes Along the Central California Coast," R. W. Austin and W. W. Broenkow; "Phytoplankton Dynamics in Eutrophic Coastal Waters," R. C. Smith; "Development of a Remote Sensing-Aided Procedure for Water Quality Monitoring," R. N. Colwell and A. W. Knight; "The Effects of Climate and Weather on Albacore Migration and Distribution in the Northeastern Pacific," R. Lasker; and "A Time Series of Satellite Thermal Imagery and Its Use in Evaluating Ocean Features and Variability on Small-Spatial Scales," Gary Kleppel.

you. Before beginning I want especially to thank Ellen Weaver from San Jose State University, the chairperson of the organizing committee for this workshop, and the other members of the committee: Frank Mason of the Western Fishboat Owners Association; James Hardwick of the California Department of Fish and Game, who was unable to attend the meeting; and Michael Laurs of the National Marine Fisheries Service, who is also going to chair this morning's meeting. I also want to thank my assistant, Lindy Nagata, for coordinating the workshop.

PART I

STATUS OF REMOTE SENSING APPLICATIONS TO FISHERIES AND COASTAL RESOURCES

APPLICATIONS OF SATELLITE REMOTE SENSING TO FISHERIES*

R. MICHAEL LAURS
National Marine Fisheries Service, Southwest Fisheries Center, La Jolla California

The use of satellite remote sensing to provide synoptic measurements of the ocean is becoming increasingly important in fisheries applications. Variations in ocean conditions play key roles in natural fluctuations of fish stocks and in their vulnerability to harvesting. Information on the changing ocean, rather than on average ocean conditions, is necessary to understand and eventually to predict the effects of the marine environment on fish populations. The evolving capabilities of satellite sensor and data-processing technology, combined with conventional data collection techniques, provide a powerful tool toward ensuring the wise use of living marine resources.

I would like to review some of the recent studies involving the use of satellite remote sensing in fisheries that we have been conducting at the Southwest Fisheries Center. These are collaborative efforts involving a number of people including myself, Dr. Reuben Lasker, Dr. Paul Fiedler, Jan Svejkovsky, and previously José Pelaéz. I will not attempt to describe everything that we are doing or have done, but will give some examples of how remote sensing can be used in fishery research and fish harvesting.

Laurs and Brucks (1985) review fisheries applications of satellite oceanic remote sensing in the United States. Examples of recent and potential uses of satellite imagery in U.S. fisheries in the eastern North Pacific are given in Fiedler et al. (1985). Yamanaka (1982) describes the utilization of satellite imagery in Japanese fisheries. Gower (1982) gives an overview of the different kinds of remote sensing data relevant to fisheries science and oceanography, and Montgomery (1981) discusses the utility of satellite imagery to ocean industries, including fisheries.

Satellite Data Used in Fisheries

Satellite remote sensing applications in U.S. fisheries have concentrated on the measurements of ocean temperature and color, and computation of ocean transport based on satellite measured wind stress.

*Portions have been updated from a presentation prepared for the Ocean Space '85 Conference, Tokyo, Japan, June 1985.

Ocean Temperature

Virtually all fisheries studies employing satellite ocean temperature measurements have utilized imagery from thermal infrared sensors. The advanced infrared sensors, notably the Advanced Very High Resolution Radiometer (AVHRR) aboard the TIROS orbiting meteorological satellites, are characterized by high sensitivity in narrow wave lengths, fine ground resolution, and an extensive data archive. These sensors yield high quality data which, except for some limitations, meet the requirements for most fishery investigations.

There have been a very limited number of attempts to apply ocean temperature measurements made from microwave instruments aboard satellites to fisheries studies. These attempts have been only marginally successful, mostly because of the large footprint of the measurements and the contamination of the data in the vicinity of land. However, an adequate evaluation of the utility of satellite microwave ocean temperature measurements in fisheries problems has yet to be conducted. Efforts to do so have been hampered because of difficulties in obtaining microwave temperature data and lack of high speed data processing capabilities to process it.

Ocean Color

The Coastal Zone Color Scanner (CZCS) on board the *Nimbus-7* satellite, launched in October 1978, is the only sensor in orbit that is specifically designed to study living marine resources. The CZCS is capable of measuring very subtle variations in water color resulting primarily from variations in phytoplankton concentrations. Ocean color measurements from the CZCS are being used in fishery resource applications to determine the locations of oceanic fronts, effluents, and water masses; to determine circulation patterns; and to make quantitative measurements of chlorophyll and sestonic concentrations.

Ocean Winds

The scatterometer (SASS) aboard the *Seasat-A* satellite provided data which demonstrate the importance to fisheries of high resolution surface wind stress measurements made from space. Wind stress measurements made by satellite can be used to calculate ocean surface layer transport, which controls the distribution of larval stages and the subsequent recruitment and harvests of many marine fishes and shrimps (Brucks et al. in press). Satellite measurements of winds are also important in the detection of wind conditions that affect the safety and performance of fishing vessels at sea. Although the data record of satellite measured winds is very limited as a result of the unfortunate premature failure of *Seasat*, extensive global coverage of oceanic surface winds will be made by satellite systems planned for launch in the late 1980s.

Data Limitations

The major inadequacy of present satellite sensors that make measurements in the visible and infrared bands is that they can measure sea surface temperature and ocean color only through a cloud-free atmosphere. This has hampered the utilization and acceptance of satellite technology in fisheries research and fish harvesting applications because many important fisheries are located in areas which have dense cloud cover much of the time. Off the coast of Baja and California from latitude 30° to 38° N the most favorable conditions for remote sensing are from October through April, whereas a dense layer of low stratus clouds covers the coastal waters during the summer upwelling season. Off the coast of northern California, Oregon, and Washington from latitude 40° to 50° N the best conditions for remote sensing occur from August to October. North of latitude 50° N mean cloud cover increases and is consistently 70% or greater in the Gulf of Alaska, although March and April may be relatively clear.

Another drawback to satellite infrared temperature and ocean color measurements is their restriction to the uppermost skin of the ocean surface. Although AVHRR measurements are often representative of general temperature conditions in the upper mixed layer, many important species live below the thermocline or on the bottom, where temperature patterns are not necessarily apparent at the surface. Another shortcoming of infrared imagery is that its use to detect fronts in open ocean areas may be limited to periods prior to the onset of seasonal warming. The use of ocean color imagery from the CZCS can often circumvent this problem.

In spite of the limitations noted, data from the CZCS and advanced infrared sensors on satellites meet the general needs for many fisheries applications. The development of reliable microwave radiometers that can measure sea surface temperature with high resolution through clouds, along with advanced infrared sensors, however, is required to make full utilization in fisheries of ocean temperatures measured from space.

Use of Satellite Measurements in Fisheries Research

Variations in environmental conditions affect the recruitment, distribution, abundance, and availability of fishery resources. It is not possible to measure remotely from satellites the entire spectrum of information needed to assess changes in the marine environment. However, knowledge of important oceanographic conditions and processes affecting fish populations may often be deduced using ocean measurements made by satellite, e.g.,

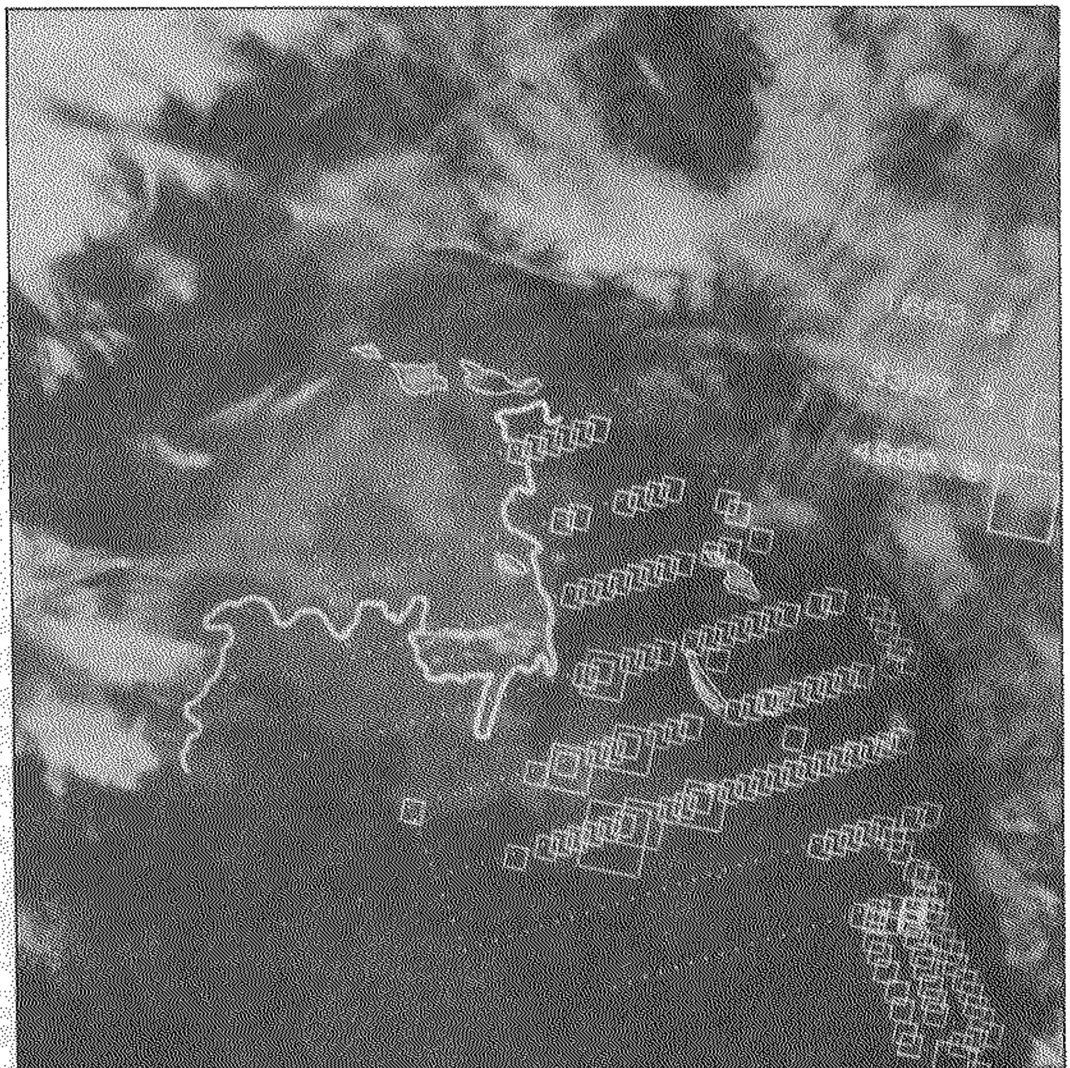

Figure 1. Distribution of anchovy eggs superimposed on the thermal image of the Southern California Bight taken 6 April, 1980. The 14 °C isotherm plotted from satellite gray-scale calibration has been drawn in. Feathery white objects are clouds. Squares indicate number of anchovy eggs under one square meter of sea surface (from Lasker et al. 1981).

distribution of surface isotherms, locations of oceanic frontal boundaries, information on currents and circulation patterns, regions of upwelling, and so on.

Ocean measurements made by satellite remote sensing can be extremely useful in defining the distribution of marine fish habitats. Lasker et al. (1981) and Fiedler (1983) have demonstrated that the northern boundary of northern anchovy spawning habitat in the Southern California Bight may be delimited using AVHRR imagery from NOAA polar orbiting satellites. In general, the northern extent of spawning in the Bight

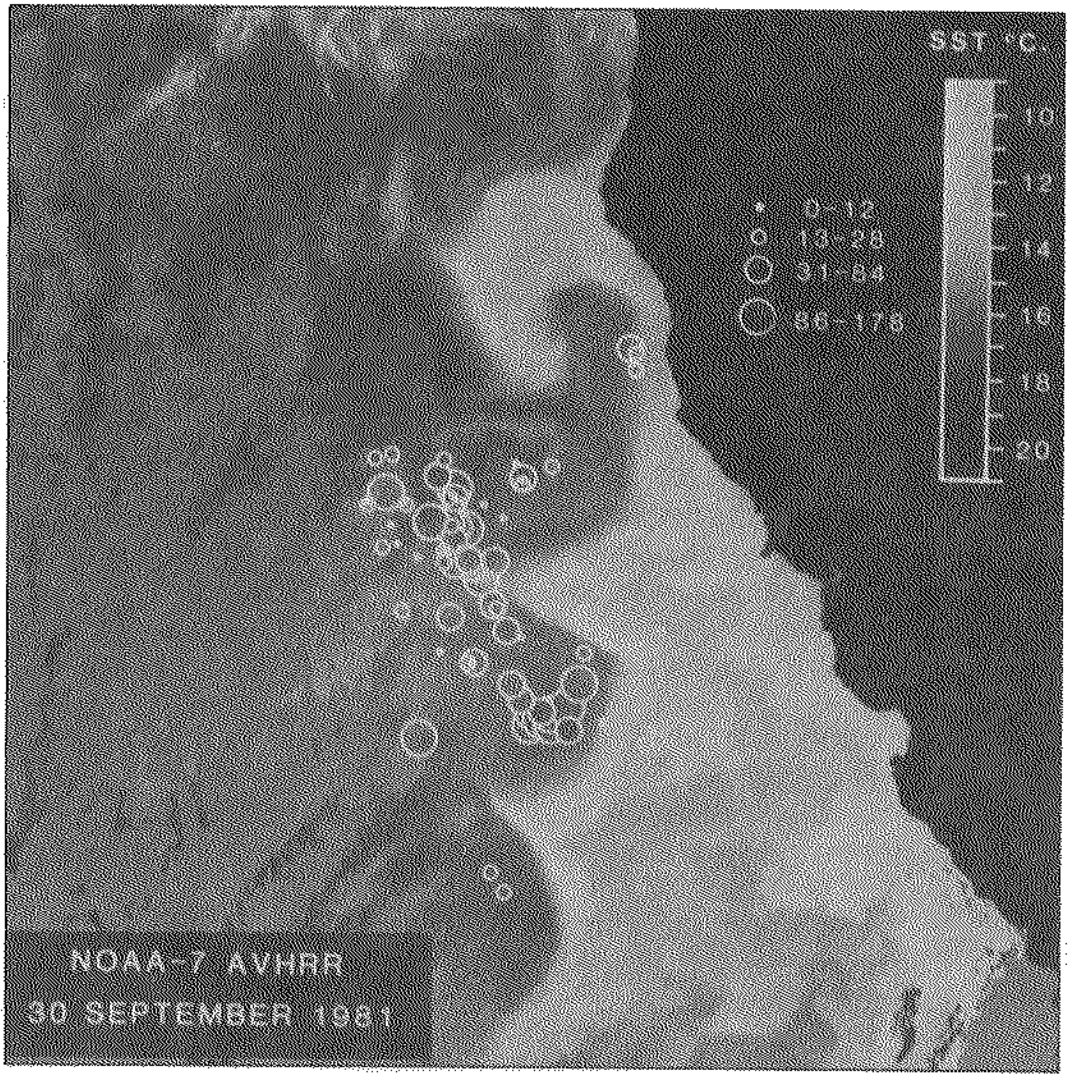

Figure 2. Central California daily albacore catches, Sept. 27 to Oct. 2, 1981 and NOAA-7 AVHRR sea surface temperatures, Sept. 30, 1981 (from Laurs et al. 1984).

and the offshore extent of spawning north of Santa Catalina Island are limited by cold, upwelled waters advected south of Point Conception. The cold waters are readily evident in satellite infrared imagery of the region. The southern limit of spawning may be defined using ocean color measurements made by the CZCS aboard the *Nimbus-7* satellite showing low chlorophyll concentrations (Fiedler 1983).

The distribution and availability of albacore tuna off the west coast of the United States have been found to be related to oceanic fronts seen in AVHRR infrared and CZCS imagery (Laurs et al. 1984). Commercially fishable aggregations of albacore are found in warm, blue oceanic waters near temperature and color fronts on the seaward edge of coastal water masses. These oceanic boundary features, which are believed to result primarily from coastal upwelling, are clearly observable in satellite imagery collected along the U.S. Pacific coast. The distribution of albacore during winter time in regions hundreds of miles off the coast has also been related to sea surface temperature fronts, believed to mark the outer boundary of the California Current, observed in AVHRR imagery (Laurs et al. 1981).

Satellite infrared measurements have also been used to trace the development and duration of the various bluefin tuna fisheries along the east coast of the United States (Roffer et al. 1982). These fisheries follow the movement of seasonal warming of near-surface waters which are monitored by observing the northerly progression of the 19–20° C isotherms in satellite infrared imagery. Limited success has been achieved during winter months in relating the distribution of tuna longline fishing in the Gulf of Mexico with the position of the Loop Current deduced from temperature frontal patterns observed in Geostationary Orbiting Earth Satellite (GOES) infrared imagery (Leming, Internal Report, NMFS). In summer months after seasonal warming has occurred, it is not possible to resolve temperature frontal structure in the GOES infrared imagery of the Gulf of Mexico.

Satellite remote sensing has been an especially important tool during the recent El Niño for monitoring anomalous ocean conditions along the U.S. Pacific coast (Fiedler 1984a). The satellite imagery contains invaluable information for use in assessing the effects of the El Niño conditions on U.S. west coast fisheries. Virtually all of the fisheries were affected in varying degrees, with some fisheries showing benefits from the El Niño, and others being harmed substantially. Many fish populations experienced changes in their distribution and centers of abundances. For example, there were shifts in the usual distribution of anchovy spawning which Fiedler (1984b) found could be delineated using AVHRR infrared imagery.

Another area where satellite data are being used is to assist in the design of fisheries research field studies and to guide research operations on fishery research vessels. This has been an extremely important use of satellite data at the SWFC. We have the very great advantage of having direct access to ocean infrared thermal and ocean color data that are collected and processed in quasi-realtime at the Scripps Satellite Facility. We use these data in planning sampling patterns and cruise tracks, to make adjustments in cruise operations while at sea, and to assist in the interpretation of cruise results. The use of satellite measurements has markedly enhanced our sampling ability, enabling us to sample the right places at the right times.

There are a number of fishery research situations where satellite data can potentially play an important part. For example, satellite measurements can provide vast amounts of oceanographic data for use in evaluating the status of fish stocks as advanced models for fishery stock assessment are developed which incorporate environmental information. Investigations concerned with determining interactions between fisheries and pollution are prime candidates for the use of satellite ocean measurements. Ocean color and other imagery have already been used to determine dispersion patterns of waste dumped at sea. Satellite measurements of ocean chlorophyll may be extremely useful in studies to model ecosystem energy budgets to estimate potential fish stock production. This application of satellite-data is being attempted by some researchers in Canada and on the east coast of the United States.

Use of Satellite Measurements in Fisheries-Aid Products for Fishermen

Several projects and programs have used or are using satellite-derived ocean data in fisheries-aid products which are distributed to U.S. fishermen by a variety of mechanisms, including radio facsimile transmission, voice broadcast, U.S. mail, and telephone telecopier. A prime motivation leading to the expanded use of satellite observations in fisheries-aid products was provided by the *Seasat* Commercial Demonstration Program

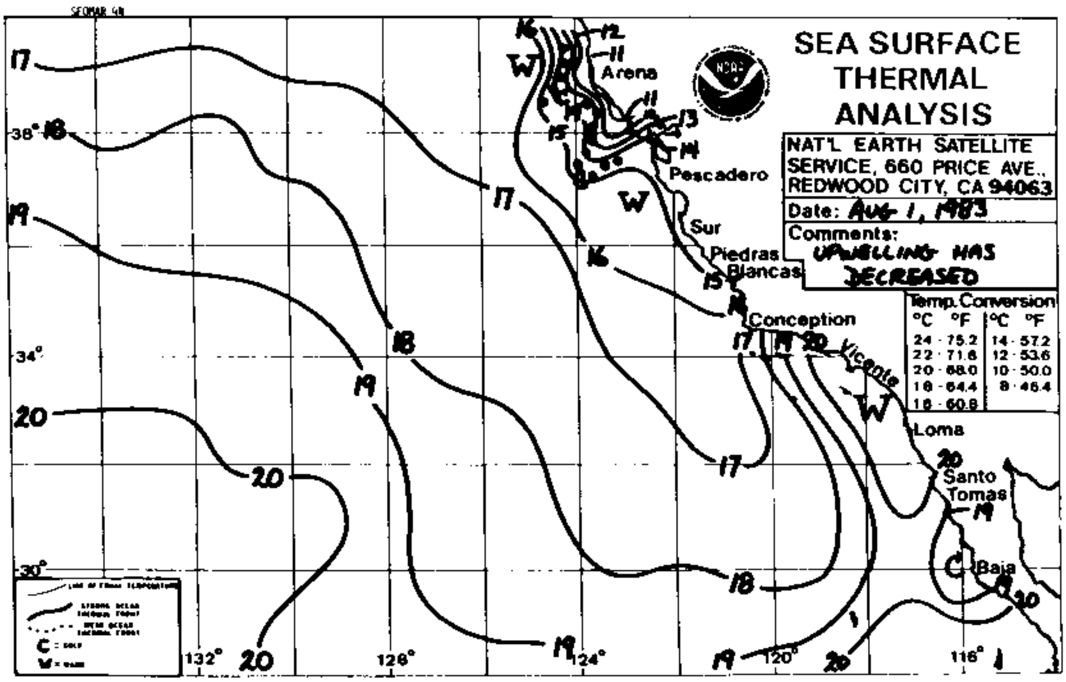

Figure 3. Sea surface temperature charts based on satellite infra-imagery and ship reports issued by U.S. National Weather Service (from Fiedler et al. 1985).

sponsored by the National Aeronautics and Space Administration/Jet Propulsion Laboratory. This program led to the development of an operational Satellite Data Distribution System used to distribute oceanographic products to ocean users (Montgomery 1981).

Charts showing the locations of oceanic thermal boundaries are derived from AVHRR infrared imagery from polar orbiting satellites and are provided to commercial and recreational fishermen for use in locating potentially productive fishing grounds along the Pacific coast from central Baja California to British Columbia, Canada. Fishermen use these charts to save time in searching for productive fishing areas associated with oceanic frontal features. (Ernie Daghir will talk more about these satellite-derived products later.) High resolution infrared images from the *GOES* satellite and ship reports are used in the preparation of charts for waters off the Atlantic Coast, which are distributed to fishermen and other interested users. Of particular interest to fishermen, these charts show the outer limit of the shelf water mass, in which many fishery resource species reside, and the numbers, sizes, and persistence of warmcore Gulf Stream rings, which can markedly alter conditions on the fishing grounds.

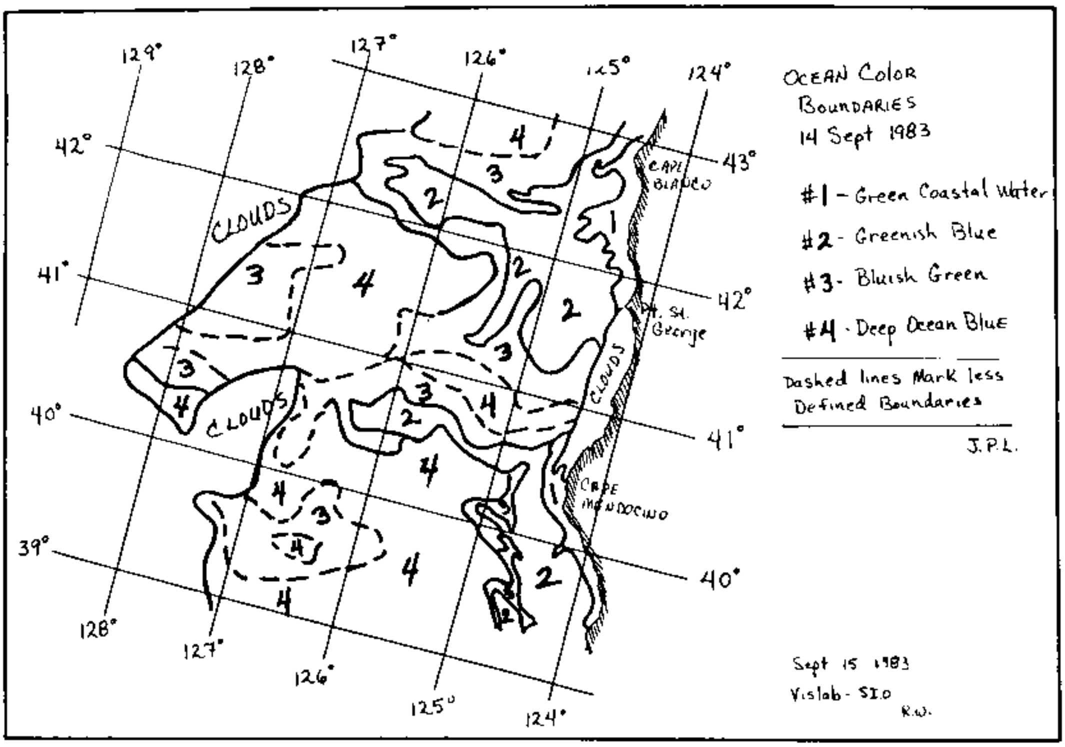

Figure 4. Ocean color boundary chart off northern California and Oregon (R. Wittenberg-Fay, Scripps Institution of Oceanography, Visibility Laboratory).

These charts have been particularly useful to lobster fishermen in reducing loss of fishing pots as a result of strong currents of the Gulf Stream warmcore eddies. Charts based on *GOES* infrared imagery are also prepared to show the path of the Loop Current in the Gulf of Mexico and are used mostly by recreational fishermen.

Experimental ocean color boundary charts based on CZCS imagery are distributed to U.S. west coast fishermen (Montgomery 1981). (These will be discussed further in Don Montgomery's talk.)

Sea ice forecast charts derived from *Nimbus-7* Scanning Multichannel Microwave Radiometer (SMMR) and AVHRR infrared imagery are prepared for regions of Alaska and transmitted by radio facsimile to fishermen and other marine users.

In summary, I am an enthusiastic proponent of the use of satellite oceanic remote sensing in fisheries. I believe that it offers great potential for being a very powerful, useful tool and that use of satellite measurements will become increasingly important in fisheries research and fish harvesting.

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EFFECTS OF THERMAL STRUCTURE ON ALBACORE TUNA DISTRIBUTION

JAN SVEJKOVSKY AND REUBEN LASKER

Scripps Institution of Oceanography, University of California, San Diego

Svejkovsky: Our work deals with the effects of atmospheric forcing and sea-surface temperature (SST) gradient patterns on the variability of albacore tuna abundance. Reuben Lasker and I are trying to delineate some relationships between the patterns in a thermal field and atmospheric forces on that field and the distribution of albacore within the U.S. fishery. Our technique has been devised to estimate the stability of SST gradients using NOAA's Advanced Very High Resolution Radiometer (AVHRR) data.

In the area to which we are restricting our study, the coastline is at a fairly constant angle. Therefore, one can use atmospheric pressure fields from which it is possible to calculate Ekman transport; this should simplify analysis in this area. The Southwest Fisheries Center has been collecting data in the form of catch reports from fishermen's logbooks for more than a decade. There are thousands of these reports per year for this region. Earlier someone questioned whether the fishermen are scattered enough to show an unbiased estimate of the fish's distribution. In the cases I have looked at, if we take the 1°-square grid as maximum resolution, there are always many reports from most squares within this area during the season. Although the fishermen do communicate with one another often, never do all of them congregate in one place at any time.

I want to point out that most of the time the lowest catch is found in turbid water close to shore. (However, the data set is not complete for those regions because fewer fishermen go there; they know they will not find many fish there.) The upwelling process along the coast causes greater biological production to occur in those waters. Hence water temperature and color are closely related. For the purposes of this study it is much easier at this stage to use temperature data because the time series is much more complete.

A typical infrared image of the region shows obvious frontal boundaries; it is an upwelling ground and quite a complex field. There are many of these frontal zones throughout the region. Close inspection of the catch data shows that not all the boundaries that have the albacore's preferred temperature range show good catches. For any given time, many of these boundary regions show low catch or no catch at all. Thus, water temperature alone does not adequately explain or predict the distribution of albacore throughout the season.

The California Current region is the feeding ground for the albacore when they migrate here, and it is reasonable to assume that the presence of forage plays an important part in determining where these fish congregate. As Michael Laurs mentioned, albacore tend to be visual feeders and are therefore limited to feeding in clearer water, close to the thermal fronts.

During a large upwelling condition when upwelling plumes shoot out, many strong frontal boundaries are formed between the upwelling waters and the warm water offshore. High chlorophyll concentrations from phytoplankton blooms allow one to see the fronts with the CZCS as well. But the albacore don't feed directly on phytoplankton, and one would think that there would be a time lag in the area before the whole food-chain cycle took place, all the way from plankton through primary and secondary consumers and finally to the food organisms that can support large fish such as albacore. Thus, it would seem that the best areas for high concentrations of tuna are those that are stable in their position, in other words, where the frontal features remain long enough for the biological cycle to take place and for the albacore to finally congregate.

Infrared (IR) data allow us to look at this kind of environmental stability in space and time. However, the information is difficult to quantify and to put into a model that would help explain the different distribution of fish along the coast. I devised a digital image processing technique that should allow us to do that. This image is basically an approximation of the spatial derivative of the original IR image. In it every pixel element represents the difference in temperature from the pixel elements surrounding it. Thus I have been able to look at spatial thermal gradients. In the gradient image the dark pixels show a low gradient, a small spatial change in the temperature field, and the white pixels represent large change. In one place, a strong front produced a gradient of about 2°C over a 7 km distance. What we see is the gradient intensity, which in this case is only gray shades but in the actual analysis is in degrees per kilometer. The gradient goes from high to low. There are a very large number of pixels having low-gradient intensities, which show up as white. Those are areas that do not have much spatial temperature change.

Another way to look at these data is to use a histogram. A histogram shows all the pixels in a selected area and shows the fractional composition of the frontal gradient field. The only thing one has to watch for is cloud cover, and I tend to limit myself as much as possible to daytime data, which allows me to use the visible channel to compute the albedo value, an indication of cloud contamination. It is possible to take this histogram composition and divide it into, for example, three groups: one representing a low-intensity background, one somewhere in the middle, and one representing the very high grade. Using this technique, it is possible to observe the temporal change within each region and to look for areas that show very little change throughout time. Using the hypothesis that those would be the best places to find congregations of albacore, I can then look at the actual catch and compare the two.

A composite image shows two gradient images that were filtered so that the lines remaining show only the strongest gradients; most of the middle tones and the low gradients are filtered out. One such composite was made to show the typical conditions in July 1981—for the beginning of the season along the coast. Within the period of a week, many changes took place both in the formation of new frontal boundaries and in the movement of old ones. The reason for this is that the gradient between the high atmospheric pressure over the ocean and the low pressure closer to shore was very intense, and there were periods of strong, active upwelling. In two images taken a week apart in August, we see a slightly different picture. There are still areas where conditions are changing and moving very rapidly, but there are also other areas, such as a large, warm water eddy, where there was very little change during the week. The frontal boundaries of the eddy changed very little in character during that time.

When I looked at the catch records for the same period, I found that the highest catch rates were associated with the features that had changed very little, while areas that had changed quite a bit showed low catch rates. That seems to support the hypothesis I set forth earlier.

During the second week in September, 1981, the entire area was affected by atmospheric disturbances. Two frontal systems moved through, and there were offshore winds that caused some upwelling. The original area where the fish had congregated and where catch rates had been high in the north was totally changed. A strong frontal boundary formed, and the old boundary was destroyed. But this did not happen farther south, where the fronts passed inland around San Francisco; the features changed very little down there. The gradients were not as sharp as the ones farther north, and they changed only slightly within a month. And as expected, the highest catch rates were around this persistent feature. In the north, the originally good region was no longer productive as a result of the changes caused by the high winds.

My analysis indicates that to develop a model on a fine scale (a 1°-square grid) that explains the distribution of albacore and its variations, one must use more than surface temperature and frontal boundary location information. It appears that spatial and temporal stability of frontal zones is important in concentrating albacore. Wind forcing directly affects surface thermal features and thus also influences local albacore abundance. Using atmospheric and AVHRR SST information may make it possible to explain and predict some of the short-term variability in albacore distribution within the U.S. fishery. Such a model could be helpful not only to the tuna industry but also in the management of the resource.

APPLICATION OF THE COASTAL ZONE COLOR SCANNER TO A COASTAL FISHERY

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Nolten: The Visibility Laboratory at Scripps Institution of Oceanography, in conjunction with Moss Landing Marine Laboratories, has a Sea Grant project to use the Coastal Zone Color Scanner (CZCS) to do a detailed study of fisheries in a small area fairly close to the coast in the Monterey Bay area of Central California. The area includes Point Sur to just south of San Francisco. The participants in our study represent those interested in physical oceanography as well as fisheries. We are going to be studying some transport and circulation data as well as productivity and fishery processes. Fishery data have been collected to see if any correlations can be made with bathymetry and sea-surface chlorophyll and temperature. We are just completing the data gathering phase of the project, and now we can begin to see whether any patterns are forming out of the data set we have assembled.

What we have put together so far is a collection of 52 images of the Monterey Bay area. Because our study area is small, we can collect a lot of imagery. The period of the study was from April 1981, through November 1982; we will try to go into 1983 if we can.

We intend to examine these images in a time series—that is, in a succession, to trace changes through time. We want to look at monthly and seasonal persistence and change in oceanographic features and productivity processes. We would like to start out by comparing images on successive days to see how quickly things are changing, then perhaps go to weekly or bimonthly coverage if it seems sufficient. All of the images have been digitally realigned so that the coastline always lies in the same place, and pixels can be compared for location from one image to the next. We are intrigued with the data set because with it we will be able to trace features as they move and to get an idea of the transport rates.

In an example image is shown the ratio of blue (440 nm) water color to green (520 nm) color. The complex water structure of the study area is evident. The bright or white colors indicate the more opaque waters and the darker colors indicate clearer waters. In this image upwelling flow shows up as very clear water; in fact, it is the clearest water in the image. For some of our imagery we have coincident fishery data for which we know the quantity of catch and the species that were caught. For example, in this image we have highlighted the location of several fishing trawls occurring on the same day this image was taken. The trawl locations tend to be along visible ocean color frontal boundaries. The fishermen involved here did not have access to color boundary charts or to CZCS images with which to navigate.

Hauschildt: All available CZCS images from Central California since 1981 have been processed at the Scripps Visibility Laboratory. Color enhancement and analysis is conducted at Moss Landing Marine Laboratories. The study area, located between San Francisco Bay and Point Sur, is centered around Monterey Bay, California. This study, funded by California Sea Grant, is attempting to correlate commercially important fisheries with data obtained from the CZCS. Real-time CZCS imagery may eventually aid fishermen in locating productive fishing grounds. The persistence and variability of phytoplankton distributions and circulation patterns are presently being analyzed.

Three capes were noted as upwelling areas from the CZCS images. Pt. Montara, south of San Francisco Bay, Pigeon Pt., north of Santa Cruz, and Pt. Sur, south of Monterey Bay. It is thought that high concentrations of suspended sediments originating from San Francisco Bay are responsible for the apparent high chlorophyll concentrations in the water surrounding the two points north of Monterey Bay (Pt. Montera and Pigeon Pt.). Pt. Sur, however, appears to be a persistent upwelling area throughout the year. A characteristic plume of high chlorophyll water mimicking the bathymetry was observed in most of the images analyzed so far. Other areas of upwelling are yet to be investigated. Upwelling areas at seamounts are known sites of fish, bird, and mammal aggregations. The head of the Monterey Submarine Canyon is another site of possible persistent upwelling as hypothesized by Lasley.

The California Current System is highly variable—with meanders, eddies, and plumes occurring throughout the year. The San Francisco eddy reported by Hickey and noted by Broenkow and Broenkow and Smethie is thought to be a semipermanent cyclonic eddy located west of Monterey Bay. This eddy has been noted within the CZCS images during the winter months (non-upwelling). The San Francisco eddy appears to be bathymetrically controlled by the Monterey Submarine Canyon. The northern edge of the eddy appears to parallel the northern shelf break of the canyon (also noted by Broenkow and Smethie).

As with most studies attempting to correlate fish populations to oceanographic parameters, a pelagic fishery was targeted. The northern anchovy (*Engraulis mordax*)—a commercially important fishery in the area—was expected to yield positive relationships with surface chlorophyll concentrations as estimated by the CZCS. Problems were encountered in obtaining these data in 1983. Minimal fishing effort for pelagic fish was expended during the 1982–1983 El Niño. The data available consisted mainly of groundfish. These catches consisted of rockfish (*Sebastes*) with incidental catches of Lingcod (*Ophiodon elongatus*), flatfish (Order Pleuronectiformes), Blackcod (*Anoplopoma fimbria*), and Hake (*Merluccius productus*). The fishermen willing to cooperate in this venture recorded date, location, type, and amount of fish caught.

Fish catch locations were overlayed on CZCS images. Initially, catch locations were categorized into observable oceanographic features. Preliminary results indicate that fish may aggregate on fronts. Other categories under consideration are temperature fronts, high or low chlorophyll regions, upwelling areas, specific chlorophyll concentrations, and bathymetry.

Care must be used when working with fish catch data. When "no fish caught" is reported in an area, this does not necessarily indicate that no fish are there. Net avoidance, improper net setting, and net hang ups are a few of the possible reasons for not catching the fish when they are, in fact, there. Since fishermen do not randomly select fish sites, but set their nets where they believe the fish are located, sites of no catch may need to be discarded or lumped into one category.

False color images can be deceiving; therefore numerical analysis of the image should be concurrent with observed features. For example, a front observed in a false color CZCS image is characterized by a change in color. If no change in color occurs, a front is not observed even though one may be there. Detection depends on the color representation of the chlorophyll ranges. A front can be numerically identified by a rapid horizontal change in chlorophyll concentrations. Transect lines will intersect the point of interest (fish location) at varying angles. These transect lines describe the horizontal variability in chlorophyll. Position and chlorophyll concentrations will be regressed along each transect. If the slope of that line is significantly different from zero, then it will be considered a front; if not it will be considered a homogeneous area.

Most fishermen will not readily divulge where they have been fishing or how much they have caught unless required to by law. It is generally believed that if this information is given to a scientist, it will eventually lead to more restrictions on the fishery, making it more difficult for fishermen to make a living. Many of the cooperative fishermen either forget to record the data or do not have time to during the trawl. The most reliable data were received from fishermen who were keeping accurate logs for their own use and interest.

In conclusion, preliminary results indicate that rockfish may be correlated with chlorophyll fronts. We will continue working with rockfish this coming year and hope to add anchovy information to the data set. Oceanographic features indicate that the California Current System is variable and highly productive. Eddies, offshore plumes, and upwelling areas occur throughout the year.

SOME REMOTE SENSING ACTIVITIES IN THE GULF OF MEXICO

SAYED EL-SAYED AND CHARLES C. TREES
Texas A&M University

El-Sayed: Menhaden (*Brevoortia patronus*) supports the largest bulk fishery in the United States, with most of the fish being distributed from southern Florida to the Mexican border. Since 1970, the annual yield from the Gulf of Mexico has averaged 564,000 metric tons. In 1982, the menhaden fishery had the largest recorded catch in the United States (711,000 metric tons) for a single fishery. Menhaden is an ideal fishery for analysis by satellite imagery because of its surface schooling nature. As adults, the fish are filter-feeders, feeding mostly on diatoms and dinoflagellates, although some bottom feeding also may occur.

The menhaden fishery season is from mid-April through October; fishing normally is done in the daylight. Generally, the fishery is within 15 km of the coast. Although menhaden can occur in a wide range of temperatures and salinities, it was found that the fish preferred lower salinity waters (25 ppt). Kemmerer (1977) postulated from *Landsat* and ground truth data that menhaden exhibit a daily behavior and movement pattern in the Gulf of Mexico. Light intensity was assumed to be the controlling factor, with the fish moving offshore into relatively turbid waters during the day and small schools coalescing into larger ones. In the evening, the school aggregations break up and start moving inshore. According to Kemmerer, the quality of light, and hence the type of turbidity, is important; these color fronts can be remotely sensed by the Coastal Zone Color Scanner (CZCS). The average seasonal distribution in the northern Gulf of Mexico is shown in Figure 1.

In recent years, there has been increasing interest in relating ocean color and thermal fronts to the trophodynamic processes occurring in the marine environment. Savidge and Foster (1978) described the increase in phytoplankton photosynthesis and pigment concentrations in frontal zones in the Celtic Sea, while others correlated the distribution of zooplankton to tidal fronts (Pingree et al. 1974). Still others correlated the horizontal distribution of fish larvae with the location of the vertical chlorophyll maximum and the 16°C isotherm off a frontal upwelling area. Adult fish, such as albacore, were concentrated near the vicinity of an upwelling front off Monterey Bay, California, as was shown by Laurs and Yuen (1977). These observations indicate a strong correlation between the vertical and horizontal distributions of phytoplankton and higher trophic levels. They also underscore the significance of frontal zones as areas of

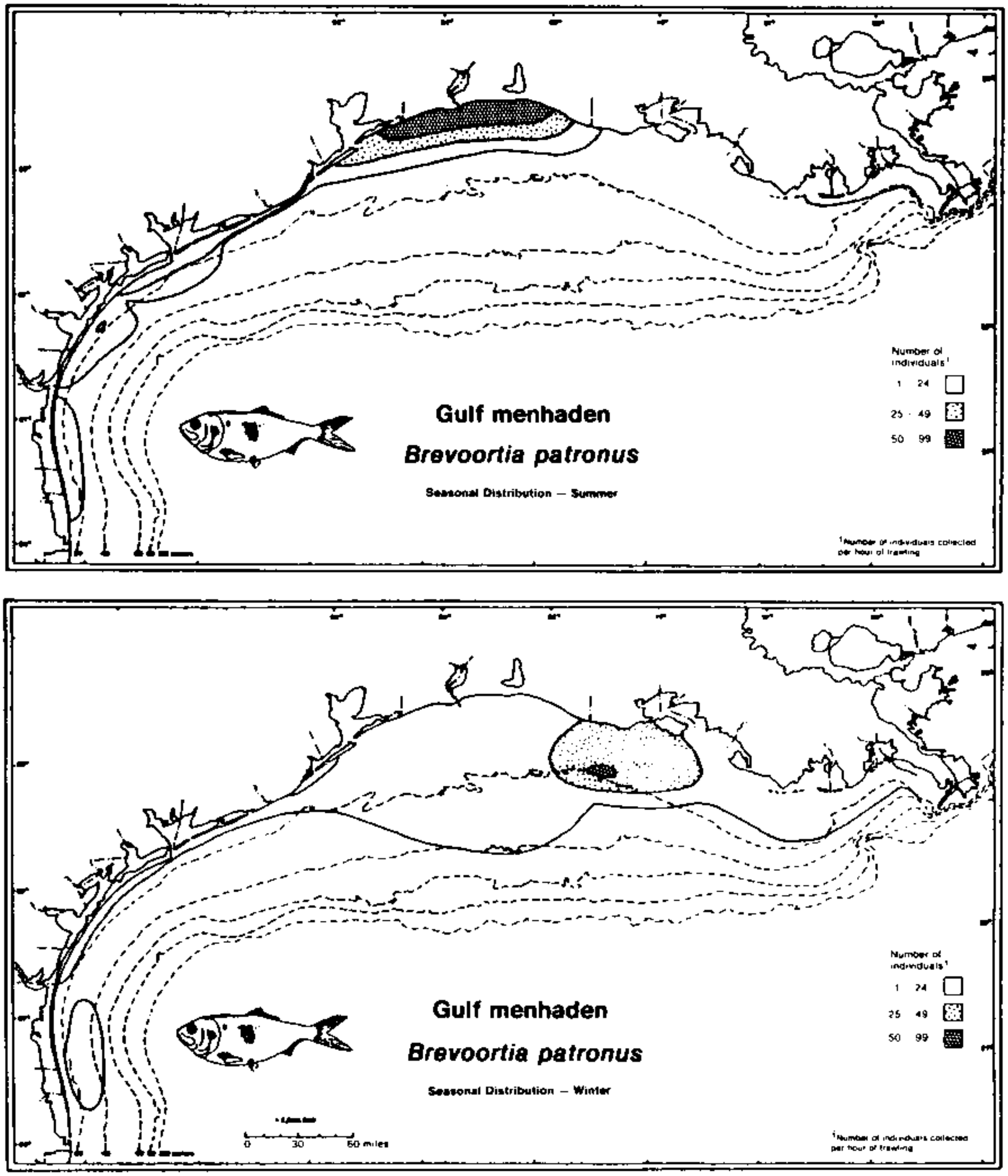

Figure 1. Seasonal distribution of Gulf menhaden in northwestern Gulf of Mexico (1961–65). (After R.M. Darnel et al., 1983. Northwestern Gulf Shelf Bio-Atlas: A study of the distribution of demersal fishes and penaeid shrimp of soft bottoms of the continental shelf from the Rio Grande to the Mississippi Delta. U.S. Department of the Interior/Minerals Management Service, Open File Report 82–04, p. 438.)

intense biological activity, as was shown by Fournier et al. (1977, 1979). These frontal areas probably serve as the major sites for energy transfer through the phytoplankton.

Fisheries resources investigators could use the CZCS data to improve sampling strategy and the resultant analysis for more accurate stock assessment. Improvement in sampling design also could be used by fishermen to improve fishing efficiency and to evaluate fleet performance. Long-term analysis of these patterns would enable fishery managers to detect perturbations within the system, whether natural or man-induced. By identifying frontal areas and focusing on these areas as locations of increased probability of higher fishery yields, fishermen could be directed in their fishing efforts. Satellite data could also be used to predict the reduction and/or increase of fishery stocks by analyzing frontal variability and intensification and by applying these results to the modelling of fishery stocks and recruitment. Once the color and thermal imagery has been produced for the northwestern Gulf of Mexico, it can be used to compare frontal areas to other important commercial fishery operations such as shrimp, tuna, mackerel and game fish.

We proposed, together with Drs. Andrew Kemmerer (National Fisheries Engineering Laboratory, NMFS) and Mitchell Roffer (University of Miami), to use historical CZCS data from 1979 covering the northwestern Gulf of Mexico to identify color and thermal frontal areas and other circulation features and to correlate the location and intensity of these fronts with the distribution of menhaden. An example of a CZCS processed image that represents the pigment (chlorophyll *a* and phaeopigments) distribution in the northern Gulf of Mexico in October 1979 is shown in Figure 2.

I am going to stop here and let Chuck Trees discuss his work on remote sensing in the Gulf of Mexico.

Trees: In general my interest is in photosynthetic pigment distributions and concentrations and their effect on remotely sensing ocean color. One approach has been to compare methodologies (standard fluorometric method versus high-pressure liquid chromatographic [HPLC] methods) for measuring pigments. Some of these results are being applied to work we have been doing on the spatial and temporal variability of pigment fronts as viewed by satellite.

Texas A&M has a state-of-the-art image-processing system.

The image processor is an International Imaging System (Model-70) which utilizes a VA 11-750 computer. It has an Advanced Color Technology printer/plotter that produces low quality prints for marking and outlining and a high quality 35 mm camera system.

We have been doing extensive remote sensing work in the Gulf

Figure 2. CZCS subscene off the Mississippi Delta from Orbit 4830, October 8, 1979, with dark areas corresponding to low pigment concentrations (chlorophyll *a* and phaeopigment). The darkened feature is an intrusion of the Gulf of Mexico Loop Current into coastal areas with the entrainment of high pigment concentrations (white) 100–200 km offshore.

of Mexico and participated on a NOAA/NMFS ichythoplankton cruise in 1980. Vertical profiles of chlorophyll *a*, primary productivity, dissolved organics, and nutrients were taken during this cruise. We also monitored continuous *in vivo* fluorescence and calibrated these traces with discrete chlorophyll *a* samples every 2 hours during the 30-day period. CZCS images were processed at the University of Miami (Otis Brown) which showed some of the structure discernible from the *in vivo* fluorescence traces. Unfortunately this cruise covered mostly offshore areas whereas our Sea Grant menhaden project pertains to the analysis of pigment and temperature fronts near shore (30–50 km).

The CZCS provided a very useful oceanographic tool for observing many physical and biological processes. Warren Hovis will be talking somewhat later about an atlas of CZCS imagery that NOAA is putting together. Some of the CZCS images which I will be showing on the menhaden project are included in the atlas.

In the first CZCS image a couple of interesting features were found. The Loop Current, which has low pigment concentration, is definitely apparent in this image of the Gulf of Mexico. It has quite a northwestward extension into the Gulf and has produced many eddy features. In this next image another cyclonic eddy was observed just southwest of the tip of Cuba. It has been hypothesized that there is a counter-current to the Loop Current along the northern part of Cuba. This theory has been difficult to test although this image shows the eddy formed from such a current. South of this eddy are vorticity structures indicating that the active current is moving in that direction. Viewing the topography one finds that these vorticity structures are centered between two topographic mounds. Therefore it is probable that there is a channeling effect on the current between those two reliefs.

In addition to the Loop Current and the Mississippi River, the other major feature in the Gulf of Mexico is the pinching off of rings from the Loop Current and the passage of these rings into the western Gulf of Mexico. During one such Loop Current intrusion, there occurred entrainment of coastal waters some 200 to 300 nautical miles offshore. The productivity of these waters is substantially higher than the surrounding waters and may serve as a food resource for organisms offshore. From talking to representatives from Sea Grant in Texas, I learned that during this same time Florida swordfish fishermen seemed to be moving farther offshore to fish. It would be interesting to see if this entrainment was prevalent when they fished in this area. In the next image, which was taken 7 days later, we see that the Loop Current is still moving coastal water offshore. Features like this will definitely affect the distribution and concentration of many of the fisheries.

In addition to the work done in the Gulf of Mexico we have also been using CZCS imagery to determine the effects of the Aswan Dam on phytoplankton biomass off the coast of Israel and Egypt. Currently we are analyzing the effects of color and temperature fronts on the fisheries in these waters.

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PART II

OPERATIONAL ASPECTS OF REMOTE SENSING

OCEAN COLOR OPERATIONS FOR COMMERCIAL FISHERIES APPLICATIONS

DONALD MONTGOMERY*
Jet Propulsion Laboratory

Laurs: I will attempt to give you an overview of what Don Montgomery has been doing recently. I think that Don is one of the people most instrumental in getting satellite products to the user, particularly to the fishing industry. Back in the days of *Seasat*, Don headed a program called Satellite Applications at the Jet Propulsion Laboratory. For that program, he devised a system for distributing what were going to be products derived from *Seasat* sensors. As we all know, *Seasat* met its demise prematurely; yet the system was in place. Other products have been distributed on this system, including some ocean color boundary products.

In the Coastal Zone Color Scanner (CZCS) project, satellite imagery is captured at the Remote Sensing Facility on the Scripps campus and processed at the Scripps Visibility Laboratory. A boundary chart is then generated and distributed by radio facsimile to fishermen on the fishing grounds. Photos (8 x 10 inches) of the boundary features shown in false color are also produced and sent out to key locations along the West Coast where fishermen aggregate. Another way this information is disseminated is through the Western Fishboat Owners Association. Frank Mason, who will speak a little later, interprets the color boundary prints and gives information to fishermen over marine radio bands.

I will quickly run through the basic process of collecting and distributing remote sensing information. After the images are collected at the Remote Sensing Facility at Scripps, the tapes are taken to the Scripps Visibility Laboratory in Point Loma (San Diego) where the atmospheric algorithm is applied, and the ratio of band 1 to band 3 is generated. The boundary features are then hand drawn on an acetate overlay. The boundary chart is transmitted by radio facsimile by radio station WWD the day after the satellite pass. Fishermen on the fishing grounds are able to obtain information on the location of ocean color boundary features. About 35 to 50 fishermen are equipped to collect these charts—they pass the information on to others.

Typically there are about 20 such charts distributed from the southern California–Baja area up to the coast of Oregon, Washington, and British Columbia. The products are targeted

*Paper delivered by Michael Laurs in Donald Montgomery's absence.

primarily for salmon and albacore fishermen. There are also other fisheries which are begining to use them. One group is the hake fisheries that are fishing in joint ventures, primarily with the Soviets, off the Pacific Northwest. There is keen interest from San Diego-based recreational fishermen, and shark and swordfish gill-net fishermen are using these charts to help locate favorable areas to fish.

SEA-SURFACE TEMPERATURE PROGRAMS AT THE NATIONAL WEATHER SERVICE IN REDWOOD CITY, CALIFORNIA

ERNEST DAGHIR
NOAA, National Weather Service

Before coming to California, I worked in Washington, D.C., for 10 years for the Satellite Service. All the Satellite Service units in the field—for example, Redwood City, Kansas City, and Miami—are now under the National Weather Service (NWS). It was felt by people at NOAA that since the satellite units were really supporting the NWS, they should all be part of the Weather Service. However, we still have the same acronym, SFSS, for Satellite Field Service Stations.

My main responsibility is to produce an analysis of West Coast sea-surface temperatures (SST). I use information from several data bases, including ship reports, buoy data, and expendable bathythermograph (XBT) data—in other words, any data that I can get. I use a base chart to plot ship reports. I also access the main computer in Washington, D.C., through a remote terminal, to obtain printouts of satellite and ship SSTs for 3-day periods, which I then plot. I also use data from buoys located along the California coast. There are seven operating buoys at present, nine during the summer, which report every hour on the hour. The high-resolution satellite temperatures, multichannel SSTs (MCSSTs) use polar orbiting AVHRR data and the McClain algorithm. The data are corrected for atmospheric attenuation, and I get 50-km and 100-km averages at every whole degree of latitude and longitude in my analysis area. The only other source of data is the actual analog AVHRR data (pictures) we get twice a day from NOAA 9, the polar orbiting satellite. I put these data into my base chart and augment the analysis with whatever kind of thermal frontal boundaries I can see on the AVHRR imagery, particularly during the upwelling season—April to October.

The Northwest Ocean Service Center in Seattle was a special project of John Byrne [then Administrator of NOAA]. Byrne wanted to set up a prototype facility in which all the major components of NOAA would be located: National Marine Fisheries Service, National Ocean Service, National Environmental Satellite Data and Information Service (NESDIS), and the Office of Oceanic and Atmospheric Research and the National Weather Service. The Northwest Ocean Service Center in Seattle produces analyses very similar to mine, but unfortunately, they are on different scales. The data bases are similar, and the scale is similar, but fishermen can't put them together to use the interface area. I'm trying now to coordinate our efforts and make our analyses similar. (Editor's note: The analyses are now the same.)

I generate these charts twice a week, on Tuesdays and Fridays, as does the facility in Seattle. Our analysis is available over national facsimile, mailing list, and received by telecopier service. We have an automatic telecopier: you can just dial a particular number, hook up a Xerox telecopier to the phone, and the analysis will automatically go to you. Most of the California Sea Grant Marine Advisors call twice a week and distribute copies to the fishermen.

I would appreciate input for the revisions I want to make to the system. Also, the fishermen need to be educated on the value of these analyses and how they are used. The charts come out looking rather complex and confusing, and consequently many fishermen don't know what is being represented. I think fishermen would have a good idea about where to fish if they could use both thermal and ocean color analysis information.

I also provide climatological data to the Oceanographic Monthly Summary. I do a great deal of analysis and research to see how the actual temperatures vary from what was anticipated before I produce the monthly summary. Although this information does not go into the summary, I think it is important to see how representative temperatures differ from what was anticipated in terms of climate. I also produce a chart for the Oceanographic Monthly Summary which shows the changes from month to month—the changes in sea-surface temperature, for example, from September to October. I would like to increase our distribution of this. (Editor's note: Mr. Daghir now also produces a Pacific Ocean sea-surface temperature (SST) analysis from 50°N to 30°S and from the West Coast of North and South America out to the International Date Line (80°W). This product is produced once weekly, on Thursday. The analysis is transmitted over marine facsimile circuits WWD [La Jolla] and NMC [Pt. Reyes]. The main users are commercial fishermen, primarily those in search of tuna.)

EXPERIENCE OF ALBACORE FISHERMEN USING COLOR CHARTS BASED ON COASTAL ZONE COLOR SCANNER IMAGERY

FRANK MASON AND WILLIAM PERKINS
Western Fishboat Owners Association

Mason: Because of the earlier comments about getting information from fishermen, I thought it might be useful to tell you how our organization is set up. The Western Fishboat Owners Association (WFOA) is a marketing group that represents only about one-fourth or fewer of the boats that fish for albacore on the West Coast; however, those boats produce 80% or more of all the albacore. That means that there are a large number of boats that participate in the albacore fishery to only a very limited degree, probably because they are in some other fishery and fish for albacore for only a week or two per year.

The WFOA is probably a little more organized than most fishermen's groups and has been in operation over 12 years. We have a fairly strong organization, and the leadership is widespread. We have directors from each area along the coast, from the Canadian border to the Mexican border, so that all the members have input to the organization's management. We feel that we have more participation by our members than do most organizations.

When we negotiate the price of fish with the canners each year, we also arrange a second, completely separate agreement for the canners to collect for the organization a certain amount on every ton of albacore that is processed domestically. This money is transferred to the American Fishermen's Research Foundation. Half of the board of directors of that Foundation are from the board of directors of the WFOA and the other half are from the canners. There is one representative from each canner—so if we have four canners, they will have four members on the board and the WFOA will have four members on the board. This board of directors establishes policy for the Research Foundation. The actual operation of the Research Foundation is done under contract by the WFOA. I'm the only employee, so to speak, and our overhead is very low. We do have operational expenses, but most of the money is used to fund research charters, subsidies, etc.

We have a working relationship with the National Marine Fisheries Service (NMFS), particularly with the group that Mike Laurs leads. Our vessels go out and generate a great deal of information. Sometimes the NMFS observers are on board these vessels, and at other times the vessel operators themselves make observations. All of the data are then turned over to Mike Laurs' division.

One way we gather information is through subsidies. We pay a small fee, a subsidy, to fishermen to report certain information to us daily. We do not direct exactly where the boat is to go, but we do specify certain areas. The fishermen keep what they catch, and their sole obligation is to report to us each day where they are, what their catch is, what the weather is like, and what the water temperature is. In some cases, the NMFS furnishes us with equipment—for example, bathythermographs; the fishermen report the data to us, and we transmit the information to the NMFS.

Our first subsidies usually start in the middle of June. We may begin a little sooner in the western Pacific at the dateline because the fishing season starts a little earlier there. At that time we start a radio program. We broadcast every morning at 9:30 our time, and we operate on two different channels. We talk to these vessels every day, getting their latitude and longitude and fishing information, and passing weather, satellite, and other data to them. As the year progresses, we begin to have full charters. With charters, we pay the entire fee for the vessel and direct where it goes and what it does. The catch belongs to the Foundation, and the proceeds from its sale go back into the Foundation for further research. For example, we can tell charter vessels to leave a good fishing area and move to some other area; we couldn't do that with a subsidy or volunteer vessel.

Satellite imagery prints are rushed to me as fast as possible whenever they are available. We do our best to translate what we see on the charts into verbal descriptions to give to the fleet. It is difficult in some ways because we are limited for time, and if our description becomes too complicated, the fishermen may be unable to follow it. Often we have to disregard interesting and pertinent information because there is no vessel close enough to take advantage of it. We give the information to the vessels when there is a possibility that they will be able to use it.

I should note that vessels off the West Coast travel greater distances than do those in the Gulf. Vessels running what we call the "inshore fleet" cover 400 to 500 miles. For far-distance fisheries, vessels may travel 2000 to 3000 miles from their home port. So we are trying to cover a very large area, and the boats themselves are limited because they don't have a very high top speed (about 8 knots). We may see a good fishing area indicated on the imagery and report it to the fishermen, but it takes quite a bit of faith on their part to go there if the area is far away—it might entail their running 3 to 5 days to get to an area, and that represents a substantial expenditure of money. Also, time is lost if they are not catching anything while they're traveling.

Therefore, we have mainly reported situations occurring fairly near the fleet. When fishermen have used this information, they have had favorable results.

I charted several vessels according to date and looked to see if good fish reports coincided with our reports to the fleet. For each of the dates that we reported a feature to the fleet, the fish reports show there were catches coincident with the areas of "blue" water on the imagery. Sometimes the albacore catch is just over the boundary. We suppose this is because the food chain is already developing, and the blue, clear water enables the fish to see and come in to feed. If food is particularly abundant, the albacore will continue feeding even out of the clear area, because the food is so easy to find. When I have correlated the data exactly, I have sometimes found that there were some in the blue, clear water and others closely adjacent in the "green" water area. Nonetheless, the results have almost invariably been favorable. When we have reported something to the fishermen and they have gone to the areas indicated, they have caught fish. On other occasions, there have been vessels already in an area, and their catch coincided with the favorable signs we had in the imagery.

We think that there are about 30 facsimile machines in the albacore fleet (this number is rapidly growing), and there are about 400 vessels that are the real producers. But they exchange information a lot. They may not communicate with the entire fleet, but they do exchange information with probably 6 to 10 other boats. Thus we believe that the facsimile information is being disseminated to at least 180 to 300 other vessels, and these facsimile transmissions are certainly much better and more useful than are our verbal transmissions.

We have also been successful with thermal front analyses; in fact, these data are all we had before remote sensing. It is unfortunate, however, that we are not getting as good information as we used to. I do not know how accurate the old information was, but the graphic representation was good because it was made in degrees Fahrenheit, which gave a detailed chart because the distance between the isotherms was much less. The information we get now is in degrees centigrade, and the measurements are in 2°C increments. This is a pretty crude measurement for albacore fishing, but we still use it and it works. The individuals on their boats watch seawater temperatures closely. One temperature may be productive one day and a different temperature productive another day (although they are within a fairly narrow band). Fishermen get facsimile charts showing the isotherms, and we also transmit that information verbally. We transmit the coordinates for the area with a favorable temperature, and fishermen draw that on the chart. We follow these very closely and have found that there is a good relationship to fish production. But it takes several different factors to have good fish production: the right temperature, the right water color (which probably translates to clarity), and the presence of food. When you get all of these things occurring simultaneously, then you get fish...if the fish come.

There are times when there are strong thermal fronts but no coincident color front, in which case you can instruct people to go to the thermal front, which is all we had before satellite imagery anyway.

Let me make one comment about open-ocean sensing. It is common wisdom that there aren't many color differences, but fortunately the blue band changes very rapidly; that is, the reflectants in the blue band change rapidly with respect to chlorophyll concentrations for the low chlorophyll values. Thus, there is a marked change in the signal that we have to work with in the open ocean because of the structure in the blue band.

There are a lot of subtle and subjective things that fishermen use to make judgments about where the fishing is likely to be good: bird behavior, whether there are fish visible at the surface, the presence of jumping bait, and wave action. Fishermen may not even be able to verbalize about what cues they are picking up. It is gratifying to find out that some of the ideas held by the more productive fishermen correlate very closely with the results we are getting from this research.

Our Research Foundation has been going for 11 years now, and in the past 3 years, more than 75% of all the albacore produced on this coast has been produced in areas where the fishermen never would have fished had those areas not been developed by the Research Foundation.

To end on a political note: we are all concerned about funding. We have had fairly favorable reactions whenever we have asked for funding or cooperation from various governmental agencies. We have been outstandingly successful in obtaining Saltonstall–Kennedy funds for various projects. And of course, we've met the Reagan administration's criterion of "self help" with flying colors. We believe that the better the cooperation we have between the academic scientific community and the actual users, the more successful we are going to be in keeping programs like this going.

STATUS OF THE COASTAL ZONE COLOR SCANNER PROGRAM

WARREN HOVIS
NOAA/NESDIS

After 7 years in orbit (as of 1985), the Coastal Zone Color Scanner (CZCS) instrument is experiencing difficulty with the command that turns it on after a period of non-use. Operation over specific areas can no longer be guaranteed. The procedure at present is to send start commands until the sensor starts up properly and allow the scan motor to run all day every other day. Data are then collected over areas of interest by commanding the data system on and off. There is no problem with the data system, only in starting the scan mirror rotating. The thermal band lasted for only the first 1½ years until the cooler could no longer reach its control temperature. Power on the spacecraft is slowly dropping but is still sufficient for partial operation of all of those sensors still functioning.

The coastlines of the United States still remain the primary focus, but the new method of operation has shifted a higher percentage of coverage to deep oceans. Requests for operation in conjunction with ship operations are still accepted, with the proviso that the sensor may not function, and every effort is made by the *Nimbus* controllers to meet such requests.

The first product remains a laser quick look that is used to screen data for processing. About half of the data acquired are not processed because of excessive cloud cover or problems with the quality of the recording on the ground. Selected scenes are processed to Level 1 where all bands are shown for a two-minute scene, about 500 x 1000 nautical miles. Approximately 60,000 Level 1 scenes have been processed and are available to users from the Satellite Data Services Division (SDSD) of NOAA. The Level 1 scenes are being transferred to 35 mm microfilm rolls, segregated by geographic area, and are available, at modest cost, from the SDSD in 500-scene rolls.

The Level 1 archive that was maintained at NOAA, NESDIS, has been transferred to NASA Goddard Space Flight Center. This archive, geographically segregated, is available for observers at Goddard. It is not the same archive as maintained by the NOAA SDSD. That archive remains the proper place for purchase of imagery on film or tape.

The Atlas of CZCS data with analysis by prominent oceanographers has been completed to the prototype stage and is awaiting final government clearance for printing.

Level 2 data consist of scenes with the atmospheric correction applied and contain calculated surface upwelled radiance for

Bands 1, 2, and 3 as well as calculated pigment concentration and diffuse attenuation coefficients for 2-minute scenes. Approximately 1200 of these Level 2 scenes have been produced and are archived, together with the Level 1 data, at the NOAA SDSD. NASA has recently agreed to process a large number of scenes to Level 2 and, possibly, to add conversion to map projection if funding allows. This may number as many as 30,000 scenes.

Plans for a follow-on sensor are uncertain at this writing, although NOAA has again requested approval to fly a follow-on sensor on a NOAA satellite. NASA has stopped negotiations to fly a follow-on sensor on the French SPOT satellite. On a more positive note, NASA Ames Research Center has received funding to modify the Thematic Mapper Simulator on the ER2 aircraft to an Ocean Color Imager with the spectral bands recommended by the MAREX report. This sensor should be ready in the spring of 1986.

Degradation of the CZCS response has been noticed, especially in the blue, and a number of efforts are underway to recalibrate the sensor in orbit. One involves flying a spectrometer under the spacecraft, at high altitude, and making simultaneous measurements. This effort is somewhat hampered by the erratic operation of the sensor but has been reasonably successful. (Aircraft results were reported by Hovis, Knoll, and Smith in *Applied Optics*, Vol. 24, No. 3, 1985 p. 407).

A sensor called the MODIS T, where T is for tilt, is under consideration for the *EOS* satellite as part of the Space Station Program of NASA. This sensor would be devoted to ocean color imagery. The date of launch of the MODIS T is uncertain and dependent on funding of the space station program.

OCEAN COLOR OBSERVATIONS FROM U-2 HIGH ALTITUDE AIRCRAFT

JOHN ARVESEN
NASA (Ames Research Center)

Ames Research Center has operated two high-altitude U-2 aircraft since 1970. In 1980 Ames obtained a high-altitude ER-2, which is basically a larger U-2. These three aircraft routinely fly at 70,000 feet and carry a wide variety of equipment. The advantage to the oceanographic remote sensing community is that this altitude is close to a space environment. It is above 95% of the atmosphere and virtually all water vapor and particulate matter in the atmosphere. Except for a small amount of scattering in the blue wavelength region, the aircraft essentially provides a spaceborne platform for remote sensing of the earth. One-third of the aircraft missions are involved with air sampling, another third with electronic sensors of various types, and a final third are photographic flights for other agencies.

I personally became involved with ocean color work 15 years ago when we were attempting to correlate blue–green ratios with plankton content and to correlate variations in the blue–green ratio with sea-surface temperature variations. These flights were made at low altitude. About 10 years ago, I became involved with the U-2s, at about the same time that Warren Hovis was developing the Ocean Color Scanner (OCS) onboard the U-2. This was his initial imaging system that led to the algorithms and the spectral band determinations for the CZCS onboard *Nimbus-7*.

In 1980, we put a digital scanner system on the U-2 that was built by Daedalus Enterprises, Inc. in Ann Arbor, Michigan. The system simulates the Landsat 4 Thematic Mapper.

In 1985, the U-2 aircraft are going to get more involved in the ocean color field with two instruments. One is Warren Hovis' Ocean Color Spectrometer, which will be performing CZCS calibrations during aircraft underflights of *Nimbus-7* and developing more spectral data to determine spectral bands for an advanced Ocean Color Imager. Also, in conjunction with Bill Barnes at Goddard Space Flight Center, an instrument called ASAS (Advanced Scanning Airborne Spectrometer) will be applied to ocean color work. In addition, Ames Research Center will modify the U-2 Thematic Mapper Simulator to match the eight spectral bands (recommended by the MAREX Ocean Color Science working group) that have been proposed for the Ocean Color Imager.

The advantage of the U-2 aircraft is that it is a research and development tool; you can fly instruments, make modifications, then fly again and see the results of the modifications. We can choose our flight times to coincide with specific requirements. The U-2 must operate within 200 miles of the coast, unless we have an air–sea rescue aircraft working with it. I see its primary application to be for coastal zone work. The resolution is considerably higher than that available for the CZCS or AVHRR. The U-2 is capable of 100- to 200-foot (30- to 60-m) resolution. This is the same resolution as the Thematic Mapper on *Landsat*. Within one hour's flight time an aircraft can map a 400- by 9-mile swath (3600 square miles).

PART III:

FUTURE APPLICATIONS OF REMOTE SENSING

APPLICATIONS OF REMOTE SENSING TO MARINE RESOURCE DEVELOPMENT, USE, AND MANAGEMENT

JAMES SULLIVAN, Moderator
California Sea Grant College Program

Sullivan: In this session we would like to follow up previous discussions about the kinds of new scanners, techniques, and instrumentation that might either be available or desirable. We would like to get some idea how these tools might be applicable to marine and coastal resource issues, whether related to development, usage, or management. What I will do first is ask our California Sea Grant Marine Fisheries Specialist, Chris Dewees, to talk about how the advisory service uses the satellite information for the fishermen.

Dewees: The California Sea Grant Marine Advisory Program has been involved with remote-sensing data for almost 10 years. When the technology first started to appear, fishermen recognized that thermal fronts were difficult to detect otherwise, and that this new technology could enable them to see ocean temperature fronts. Fred Jurick was the first marine advisory person to get into this, about 1973 or 1974. It was actually before we had documented what we were looking at on the satellite photos, so there was some skepticism.

Over the years, we have held workshops for fishermen, informing them about the availability of the products, and showing fishermen how to use and interpret them. We have also discussed how fishermen could provide input into the system to improve the products. This has been an ongoing educational program.

The main problem we have run into over and over again is distribution. We started out distributing data through the mail, which is rather like providing a weather report 4 days after it has rained. Then we went to the Xerox telecopier. Each marine advisor receives the data, makes copies, and distributes them in his local area at fish docks or the Fishermen's Association—places where fishermen gather. Distribution is still being done this way to some degree, but we just do not have the resources to operate as a service organization—for example, actually going out to the docks. One of the problems with distributing data at the docks is that the fishermen only see the images when they are in port. So the images are of use only as a general reference. We tried television in Eureka, California. For a year, the satellite images were broadcast on the local television station early in the morning. Of course, this is not useful over a very wide range at sea, but it did provide a daily look at the images. The fishermen found it useful, but the television station did not want to keep the program going because of the expense.

Art Flechsig, marine advisor in San Diego, started to work with the Scripps Visibility Lab to provide the color information. It was almost like a subscription service for the color information, both for recreational and commercial users. We have been involved in trying to develop distribution systems, but we have not found one other than the weather facsimile machine. We worked closely with the Satellite Service (now the Weather Service). Mike Laurs has helped us with workshops, and the Jet Propulsion Laboratory is trying to get the information out to the fishermen so they can use it.

My impression of the present situation is that most fishermen view remote sensing as another tool that they can use. And I have a feeling that our perceptions of remote sensing may be different from those of the fishermen. We see a product that we think can really be used, and we know the applications. The fisherman, on the other hand, is in the business, and he has to be convinced. I don't know if many fishermen are totally convinced yet. If fishermen really perceived satellite imagery to be tremendously advantageous in their business, they probably would be using it more.

Some of the things we would need to do to get fuller utilization of remote sensing in the fishing industry take a lot of money. We need both funding from the government and more participation by fishermen; perhaps fishermen's organizations would want to participate in some satellite research. I think that we need to look at some of the other fisheries. Many fishermen are very diversified these days. The more fisheries to which we can apply the satellite information, the more likely it is that it will be considered useful by the industry. I think we have to look at more localized fisheries because fishermen are working mostly in localized areas. They need specific, detailed information to find productive fishing areas. So I think we need to look at particular species.

A hypothesis has been formulated about the relationship of albacore distribution to water clarity and temperature. These relationships are being researched for albacore, but they have not been investigated for many other economically important species. If we are going to apply satellite data, I think we need to look at some of those relationships to see if they do exist for other species. I also think we need to look at some of the barriers that are keeping satellite products from being more fully utilized. We certainly should continue educating the fishing industry about what information is available, how to use it, and how to get the most out of it.

Mason: There is a side issue I would like to comment on. The technology of marine telemetry is changing just as rapidly as it is with computers. The fishermen have had to endure changes in radio frequencies, for example, and have had to throw away radios and buy new crystals. They have become cautious. They are waiting until they feel that they can get instrumentation that will be reasonably up to date and last for a while. A few years ago we bought facsimile machines, and they are already obsolete. Now for only a little more money than we paid for those, we can get machines that automatically turn on and off, produce a better picture, and are just better all around. I think that when a good product becomes available, you will start to see many of them being used by the albacore fishermen.

Fishermen also need to be assured of having regular, usable products before they will buy the instrumentation. There are weather data available every day. If we started getting these satellite products out, I think we would need to get a regular time slot someplace and transmit every day, whether or not we have data available...tell fishermen, if necessary, that there is cloud cover or that we are having technical difficulty. At a minimum they need a message to let them know that the machines are still working.

Wilder: From my point of view, I would like to see consistent information; let us evaluate it, but don't change it on us. Keep something coming out on a regular basis. We would rather get 60% pure data regularly, than 100% pure data every 1 to 3 months. In other words, give us your best shot each day and let us work with it. Even if you can only get us general information, we have got enough common sense and instrumentation to fine-tune it.

Sullivan: What kind of data do you feel would be useful on a regular basis?

Wilder: I am going to order a weatherfax machine next year. I have learned enough from this meeting to think that I could really increase my gross income next year. I am serious about that. All I need on a regular basis is the data that you are already producing. Fishermen also need a better way to learn how to interpret the data. It is difficult sometimes to find out what some of the marks on the recordings mean. These kinds of data are important, but I don't believe most fishermen know they exist.

Sullivan: You are suggesting, then, that we initiate an operational program that is left alone long enough for you to utilize it consistently over a long time period so that you can recoup your investment in the equipment.

Wilder: Let me give you an example. Here are two images that were produced 17 days apart. The first thing you notice is that the yellow color is absent from the second image. There appears to have been a major change in the ocean. But do you know what the change was? Actually the legend was changed and that's all. There was no major change in the ocean. The legend was changed for a good reason, but when you are just glancing at the image, the first (and perhaps only) thing you see is the change. You are probably not going to look down at the legend. To repeat, it is preferable for us to get consistent information and to evaluate it ourselves.

Sullivan: Okay, are there other suggestions? Mike (Laurs), what might be done from the university perspective to help you in your interaction with the fisheries? We have heard that the fishing community needs timely information for the specific areas that they are going to be in, information that is not too sophisticated in terms of data reduction or interpretation. On the other hand, there is the need to do long-term fisheries planning. We have to consider the large variations in oceanic conditions. It seems to me that we have to deal with both of these issues. Can you tell us what you think the university people might be doing that would be of assistance to us in both of these ways?

Laurs: One of the best things that the academic community could do would be to further the programs they have to educate fishermen and other marine users on how to use these products. Fishermen and other marine users should also be informed about how they can help us to evaluate the products. The technology is there but two big problems are money and not having a broad base of users. I think one of the reasons we don't have a broader base of users is that not enough people are familiar with these products—what they are, how they can be used, and how important they are. Conversely, it's important that the users provide input or evaluation to scientific researchers and agencies.

Sullivan: Are there any other suggestions, comments, or questions about the potential use of imagery for the fisheries?

Participant: I have started to think about the importance of trends. If there is any way to report trends in what we are already recording, that would be a tremendous help. The researcher has the ability to use Mylar overlays but the fisherman at sea does not have that option. He's lucky if he can save the piece of paper that he got in the morning, let alone save reports for 4 or 5 days and overlay them.

Participant: On a day when there is cloud cover and there are no new data to report, we could present a summary instead. For example, we could show the last three report overlays. We wouldn't have to draw any particular conclusions, but it would be nice to see an overlay.

Participant: It's not just an operational program. One thing that is different in this project is that the user community, and not a management agency, stands to gain from the program. It's much more difficult to convince a management agency to use new methods when all they have to gain is a change in technology. In this case, though, an industry stands to gain increased productivity and financial benefits. I think in many ways the technology transfer could be much easier because of this, but the users still need continuity in the data products.

Sullivan: I would like now to open another area for discussion and to ask Gary Kleppel to discuss our need to know in real time, the direction and speed at which an oil spill is moving.

Kleppel: I have spoken to a representative of a major oil company who is interested in remote sensing. He told me that most oil company experts are seeking to improve models of oil spill trajectories. Their major concern is that while the trajectory models are predicting water movement at the surface, the water below the surface may actually be moving in another direction. I know there is interest from that part of the private sector in using imagery to predict water movements.

Participant: Can you evaluate that for us? Can imagery be used for that purpose?

Kleppel: No, I am not able to evaluate it at this time; I haven't used imagery enough for this purpose to know if it can be done. It is interesting to note though that one can look at a single image and make all sorts of predictions. We have all done it in an offhand way, such as making projections about where fronts are coming from and where they are going. And there is a function at a Scripps facility called WINDS, which actually generates a flow field from sequential images. So the belief is that it can be done. To my knowledge, it has not been tested using actual data, but I think Drew Vastano at Texas A&M has suggested that the published flow data for certain currents are consistent with the WINDS function in the satellite imagery.

Participant: Can the images sense the oil?

Kleppel: At the moment, we do not claim that we can detect oil spills.

Sullivan: What about using aircraft platforms?

Participant: Oil spills can be detected quite well optically from aircraft. They show up as black ink spots when polarizers and red filters are used.

Kleppel: I think there are two problems involved in tracking oil spills. With satellites, the problem is in sorting out water movement. The actual tracking of the oil from space is, however, less important because the oil companies monitor the spill from aircraft. The second problem is where to put the spill abatement equipment. Here oil companies use trajectory model predictions to judge where they may be able to intersect spills before these impact resources.

The way trajectory models often work is that a theoretical spill is launched; the oil stays at the surface and moves in a straight line with a direction and velocity determined by wind field analysis. Wherever the oil hits the coast, it destroys all natural resources for some distance along the coast. That's essentially the model. The concern is to be able to make more accurate predictions and to determine if the model is working well.

Participant: This WINDS algorithm follows features and fronts?

Kleppel: I haven't used it, but what I understand about the WINDS algorithm is that you find the gradient in your image and collect two or three images over 6 to 12 hours. You measure some displacement of that gradient and the direction of that displacement. It then calculates the direction and speed of the displacement.

Sullivan: Are there other topics that people want to bring up?

Dewees: We did not hear about the new project starting up on water quality in San Francisco Bay, and there may be something on the use of waterways. Governments are asking us about the chance of lowering the cost of water quality control.

Laurs: The interesting aspect of that research is that it is utilizing a multistage approach to sampling. They are merging surface observations with aircraft and satellite imagery to make the agencies' surveys more efficient, allowing for extrapolation from both sample points to larger areas. That same approach has been historically valuable for agricultural remote sensing and classifications of very large areas with small ground truth sampling areas.

Weaver: Has anybody tried to calculate plankton biomass as a result of CZCS data and compare it with the results obtained by classic methods over any area?

Eppley: Yes, and it worked well. We looked at an area roughly 30,000 km^2 with 16 ship stations. It took the ship 6 days to cover what the satellite covered in 20 minutes. The agreement between ship chlorophyll and satellite chlorophyll was very good.

Weaver: Would it be possible to get a global picture of oceanic productivity?

Eppley: We are getting into that. We have some money from NASA to look at that possibility. There is a proportionality factor between productivity and chlorophyll near the surface. But there are large regional differences in that proportionality factor, and of course, the proportionality factor itself has a variance that is as large as the mean. For example, the Central Pacific is totally different from coastal California, which is, in turn, totally different from the Canadian Arctic.

Weaver: I would like to know if the satellite will still provide a means for a time series as well as complete global coverage of oceanic productivity, perhaps with more detail and greater validity than we have seen before.

Sullivan: Does anyone else have a comment or question?

El-Sayed: Those of us in the Gulf of Mexico do not have the data that you have on the West Coast. We would be interested in having a national symposium on these issues and in trying to get sponsoring agencies and other support. We would have to organize such an event with a lead time of at least 1 to 1½ years. That would give us time to start analyzing the data that we have or hope to have.

OPTIONS, DIRECTIONS, AND RECOMMENDATIONS (Panel Discussion)

MARK ABBOTT, Scripps Institution of Oceanography
and WARREN HOVIS, NOAA/NESDIS, Moderators

Abbott: In listening to the presentations, it occurs to me that there are several future options for us to think about. First of all, the CZCS obviously has a finite life, so we should talk a bit about what we can do to get another color scanner in orbit. Also, we might want to look ahead to a second generation CZCS. What kind of instrument would be best for our uses? What bands should it measure? What spatial resolution should it have? Another more immediate item of interest is that we are only going to continue to be able to collect CZCS data for a few more years. What sort of research plans can we envision that would help us to plan more intelligently for future color scanners?

And, if we are going to try again with NOAA for an Ocean Color Imager, what can people in this audience do to help? What I hear from NASA scientists is that there was not enough pressure from the scientific community to get one of these things through. We would like to have some concrete ideas about what can be done.

Weaver: The CZCS has performed remarkably well. It was launched in October 1978 and is still delivering excellent images. However, a new Ocean Color Imager should have some additional capabilities. The CZCS signal saturates in coastal waters, which are more turbid and have higher chlorophyll levels than the open ocean. Since it is these waters which are the most productive, it is essential that we be able to derive information from them. Additional spectral bands and increased radiometric sensitivity should make it possible to obtain such information. Prototype instruments with these additional capabilities are in the planning stage. However, funding for a second-generation ocean color satellite is not yet assured.

Hovis: One of the things that has been demonstrated at this meeting is the usability of the system for fisheries. People at NASA and NOAA need to receive this information so that they can discuss the system with the appropriate authorities. We cannot sell the product by keeping its usefulness under a rug out here in California. We need to demonstrate the system's practicality to the right people and provide them with more information. Presenting case histories showing that fishermen can correlate fish catch with remote sensing data seems to be more effective than writing letters.

Abbott: We need to make satellite oceanography better known. I guess one way is to put out more scientific publications.

Hovis: The atlas of CZCS imagery that is presently in preparation would be a very useful selling tool. Anything else that you can put out would help too. Although the physical oceanographers have done a better job of making satellite oceanography more visible to the public, they have not succeeded in getting a new start either.

Weaver: Has anyone done a cost–benefit analysis for a continued CZCS? It would be interesting to see what the system earns in the way of saved fuel for fishermen. I am particularly interested in basic information on the amount of productivity in the ocean. How much CO_2 is fixed, how much oxygen is evolved, and how much nitrogen is fixed? All these data are going to be accessible, or are accessible, with the CZCS to a far greater accuracy than has been possible before. If we can translate the benefits of these data into dollars, I have a feeling the scanner might turn out to be the bargain of the century. I think that is the approach we have to take: not how much it is going to cost, but how much it is going to earn.

Hovis: That kind of analysis could be done, I suppose, but we do not have the facilities to do it. We tried it with *Landsat*, using an economic analysis service. The results were never very clear. The problem is that many people don't tell you what they are doing with the data.

Laurs: I think the point that must be made abundantly clear is that satellite imagery is extremely important to understanding the marine environment. The technology is there for us to use effectively. The bottom line is that we do not have the funding to do it, and to get the funding, we need to have policy makers support us. The only way that will happen is if users or people who benefit from the technology say, "We really need these data."

Participant: How much interaction is there between industries, like the oil industry, and the scientific community? It seems to me that such interaction would be beneficial in deciding what instruments to orbit and in trying to obtain funding. It is very difficult to organize fishermen and convince them to chip in a couple million dollars to put a satellite in space when they are not that sure they will get their money's worth. But the oil industry has that kind of money and does use satellite research. Has anyone tried to involve industry users in planning for these projects?

Hovis: The answer to that is partly yes. The National Ocean Industries Association was very effective in saving the original

Seasat. In fact, it was that organization—whose members include the petroleum industry, ocean mining, transportation, fisheries, and private forecasters—that pulled the *Seasat* package off the rocks.

Weaver: I am sorry Don Walsh wasn't here because he could certainly organize a committee and get a report out to Congress and the Administration on this problem. In fact, we should do that. This is serious. Another interesting thing to consider is that the most powerful person in this whole area is the chairman of the Committee on Merchant Marine and Fisheries in the House of Representatives. I think a presentation to representatives of this committee on the importance of this technology to the fishing industry would help.

Laurs: We are really talking about the whole marine user community, and maybe that is the way the issue should be approached because many people could benefit from use of the CZCS. I think we are at the point where unless everyone contributes his support, the whole project may collapse.

Participant: I think the point about cost analysis was important. If there could be a cost analysis made that would demonstrate the benefits, then we could go to Congress and probably get some action. However, I think our first goal should be to demonstrate the cost vs. benefits for scientific applications; that would be very useful.

Hovis: I think you are right. NASA's HOPE project studies the habitability of the planet Earth. It's not trying to justify the project by economic means. We, too, should try to justify our project on the basis of scientific need for the environment of the whole Earth.

Participant: One of the problems historically has been that marine biologists do not seem to be able to coordinate their efforts, as physical oceanographers have. That's why I think we have to get some kind of organization together, working from many different sides, to promote remote sensing.

Laurs: A number of international programs are poised to undertake research on climate and global change, to provide the basis for an improved understanding of biogeochemical processes on a global scale. (See Appendix I.) Such a global perspective is necessary for understanding the role of the oceans in the CO_2 problem, for example, and for assessing the biological consequences of El Niño. But these programs will require simultaneous satellite observations of winds, currents, surface temperature, and ocean color.

We here recognize that in addition to contributing information on the global carbon cycle and the ocean's role in climate, an Ocean Color Imager (OCI)—an improved version of the CZCS—aboard a NOAA satellite would allow us to observe pollution and sediment inputs to the coastal zone; to analyze the ocean currents and eddies (for use in offshore petroleum and marine mining); and to predict fishing locations and other high productivity regions. But what has become abundantly clear at this meeting is that we, the users of satellite data, lack a unified voice with which to demonstrate our belief in the importance of remote sensing activities and in particular our support for an Ocean Color Imager.

It would certainly be useful if this meeting served as the catalyst which propelled all of us, representing the academic, scientific, fishing, and other user communities, to write a statement underscoring our strong belief in the need for this technology. Additionally, we have heard several recommendations for regional and even national meetings in order to develop the communications mechanisms that are so clearly necessary.

Weaver: The information exchanged and the enthusiasm expressed at this workshop have been enormously stimulating. I know we are all grateful to California Sea Grant for having sponsored the meeting, and it is my sincere hope that we will be able to come together at future meetings. I would urge anyone who is interested in the kind of work that was reported here, or who would like to participate in a future meeting, to get in touch with Dr. Sullivan or with me.

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APPENDIX I

Oceanography from Space: Update

The research strategy proposed by the Joint Oceanographic Institutions in their report *Oceanography from Space: A Research Strategy for the Decade 1985–1995*[1] recommends a sequence of satellite missions over the next decade. The schedule provides the opportunity for simultaneous observations over much of the period 1989–1993, which coincides with the major activities of the international Tropical Ocean and Global Atmosphere (TOGA) program and the World Ocean Circulation Experiment (WOCE). (The European Space Agency's Earth Resources Satellite [ERS-1] is also scheduled to begin a three-year mission in 1989.) Proposed missions, sensors, and scientific measurements (as of 1985[2]) are as follows.

Proposed Mission and Timing	**Primary Sensors**	**Variables of Major Research Importance**
NROSS Approved. Launch in1990.	Scatterometer, altimeter, microwave radiometer	Surface winds and temperature, ice sheet topography
TOPEX Proposed. Launch 1991 at earliest.	Precision altimeter and tracking system	Ocean surface topography for surface currents
NOAA/OCI[3] Proposed. Launch in 1990.	Ocean color imager	Ocean color for surface chlorophyll
GRM Start 1988. Launch 1991.	Satellite range rate and magnetometer	Global geoid and magnetic field

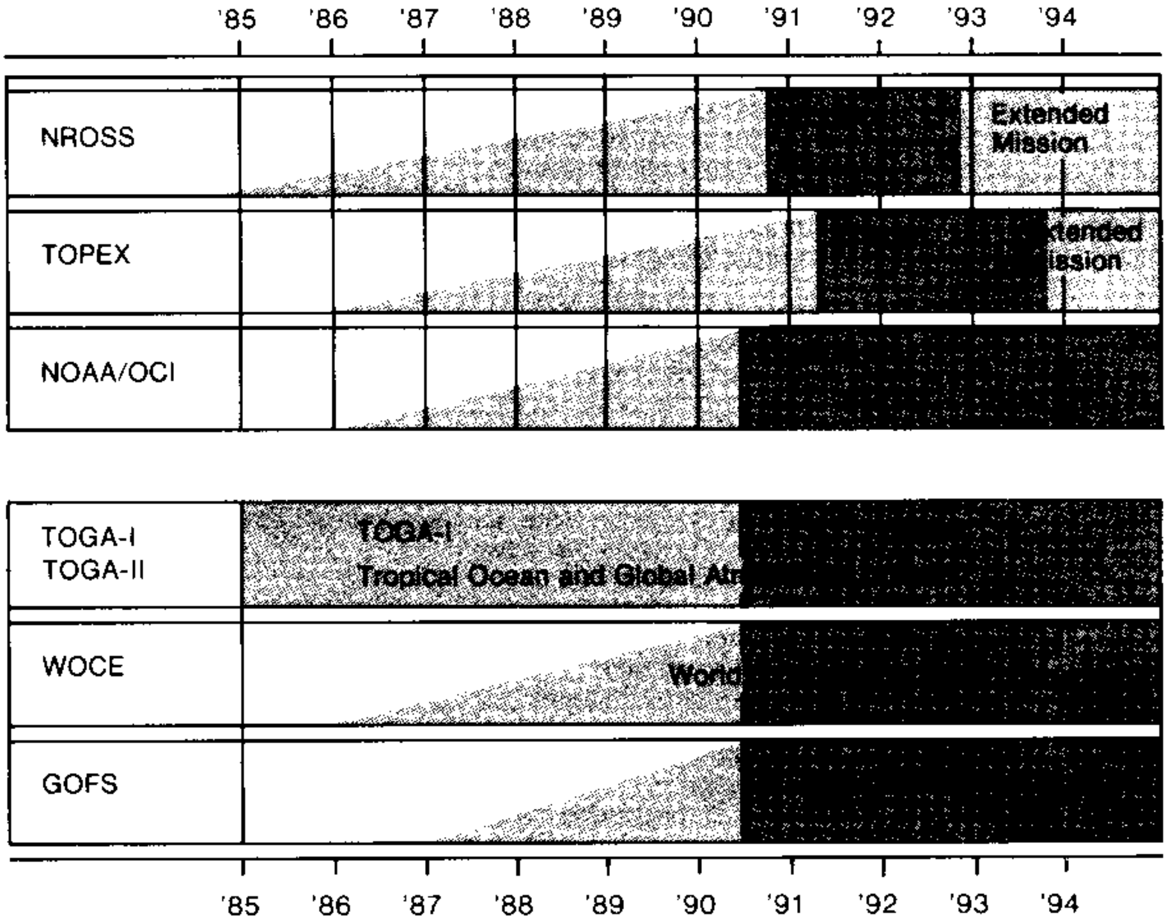
TOGA-I	Underway
TOGA-II	Starts in 1990.
WOCE	Starts in 1987. Global field effort starts in 1990.
GOFS	Starts in 1986. Global field effort starts in 1990.

[1] *Oceanography from Space: A Research Strategy for the Decade 1985-1995.* (Executive Summary, July 1984), Joint Oceanographic Institutions Inc., Washington, D.C.

[2] *Ocean Color Observations: A New Environmental Perspective* 1985. Prepared by the GOFS Executive Committee in cooperation with Joint Oceanographic Institutions Inc. Washington, D.C.

[3] OCI was identified as an essential component of the Global Ocean Flux Study (GOFS) at the National Academy of Sciences GOFS Workshop (1984).

SATELLITE MISSIONS



Adapted with permission from *Ocean Color Observations: A New Environmental Perspective.* Prepared by the GOFS Executive Committee in cooperation with Joint Oceanographic Institutions Inc.

APPENDIX II

List of Acronyms

ASAS	Advanced Scanning Airborne Spectrometer
AVHRR	Advanced Very High Resolution Radiometer
CCT	Computer compatible tape
CZCS	Coastal Zone Color Scanner
ERBE	Earth Radiation Budget Experiment
ERS	European Space Agency's Remote Sensing Satellite
ESSA	Environmental Science Services Administration
GARP	Global Atmospheric Research Program
GOES	Geostationary Operational Environmental Satellite
GOFS	Global Ocean Flux Study
GRM	Geopotential Research Mission
IR	Infrared
JOI	Joint Oceanographic Institutions Inc.
JPL	Jet Propulsion Laboratory
Landsat	Land Remote-Sensing Satellite
MCSSTs	Multichannel SSTs
MOS	Marine Observational Satellite
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information Service
NESS	National Environmental Satellite Service
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
NOS	National Ocean Service
NOSC	Northwest Ocean Service Center
NROSS	Navy Remote Ocean Sensing System
NSCAT	NASA scatterometer
NSF	National Science Foundation
NWS	National Weather Service
OOAR	Office of Oceanic and Atmospheric Research
OCI	Ocean Color Imager
OCS	Ocean Color Scanner
ONR	Office of Naval Research
SFSS	Satellite Field Service Stations
SIO	Scripps Institution of Oceanography
SPOT	Satellite Probatoire d'Observation de la Terre (France)
SST	Sea-Surface Temperature
SWFC	Southwest Fisheries Center
TIROS	Television and Infrared Observation Satellite
TOGA	Tropical Ocean Global Atmosphere
TOPEX	Topography Experiment Satellite (joint U.S./France mission)
TDRSS	Tracking and Data Relay Satellite System
USGS	United States Geological Survey
WFOA	Western Fishboat Owners Association
WOCE	World Ocean Circulation Experiment
XBT	Expendable bathythermograph