# Application of Satellite Remote Sensing to U.S. Fisheries

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## ABSTRACT

Satellite oceanic remote sensing is beginning to play important roles in fishery research and fish harvesting. Spaceborne sensors are being used to make synoptic oceanic measurements for use in determining variations in ocean conditions which play key roles in causing fluctuations in stocks of fishes and in their vulnerability to harvesting.

## INTRODUCTION

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 to eventually 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.

Laurs and Brucks (1985) review fisheries applications of satellite oceanic remote sensing in the U. S. 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.

### 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 archival (Fiedler et al. 1985). 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 (Hovis et al. 1980). 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 (a) to determine the locations of oceanic fronts, effluents, and water masses, (b) to determine circulation patterns, and (c) 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. Winds 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. 1984). Satellite measurements of winds are also important in the detection of wind conditions that affect the safety and performance of fishing vessels at sea (Hawkins and Black 1983). While the data record of satellite measured winds is very limited due to 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 1980's (Li et al. 1984)

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

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 (Figure 1). In general, the northern extent of spawning in the Bight 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 U. S. have been found to be related to oceanic fronts seen in AVHRR infrared and CZCS imagery (Laurs et al. 1984) (Figure 2). 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 U. S. (Roeffer 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.

## 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 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 (Breaker 1981) (Figure 3). Fishermen use these charts to save time in searching for productive fishing areas associated with oceanic frontal features (Short 1979 and Breaker 1981). 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 (Chamberlain 1981). Of particular interest to fishermen these charts show (a) the outer limit of the shelf water mass, in which many fishery resource species reside, and (b) the numbers, sizes and persistence of warmcore Gulf Stream rings, which can markedly alter conditions on the fishing grounds. These charts have been particularly useful to lobster fishermen in reducing loss of fishing pots due to 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 (Lowry and Leaky 1982).

Experimental ocean color boundary charts based on CZCS imagery are distributed to U. S. west coast fishermen (Montgomery 1981). These charts show four categories of ocean color---green coastal, transition green, transition blue and deep ocean blue (Figure 4). They are produced at almost weekly intervals depending on cloud conditions, and cover coastal areas up to 700,000 km$^2$ between Guadalupe Island and Vancouver Island. NIMBUS-7 CZCS passes along the Pacific coast are collected and processed in near-real time, and transmitted by radio facsimile the following day to fishing boats at sea. Color photographs of the satellite images are also distributed by express mail to various fishing ports and to Sea Grant marine advisors in daily contact with fishermen. The color boundary charts and photographs are used primarily by commercial albacore and salmon fishermen, and recreational fishermen in southern California.

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.

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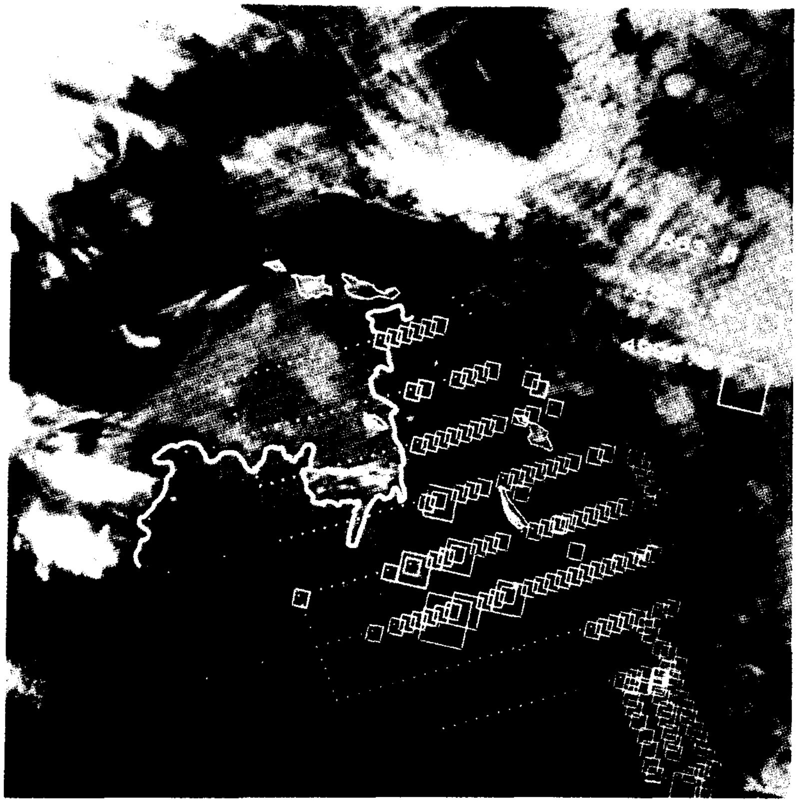

Figure 1. Distribution of anchovy eggs superimposed on the thermal image of the Southern California Bight taken 6 April, 1980. The 14$^{o}$C isotherm plotted from satellite gray-scale calibration has been drawn in. Feathery white objects are clouds. Squares indicate number of anchovy eggs under one square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

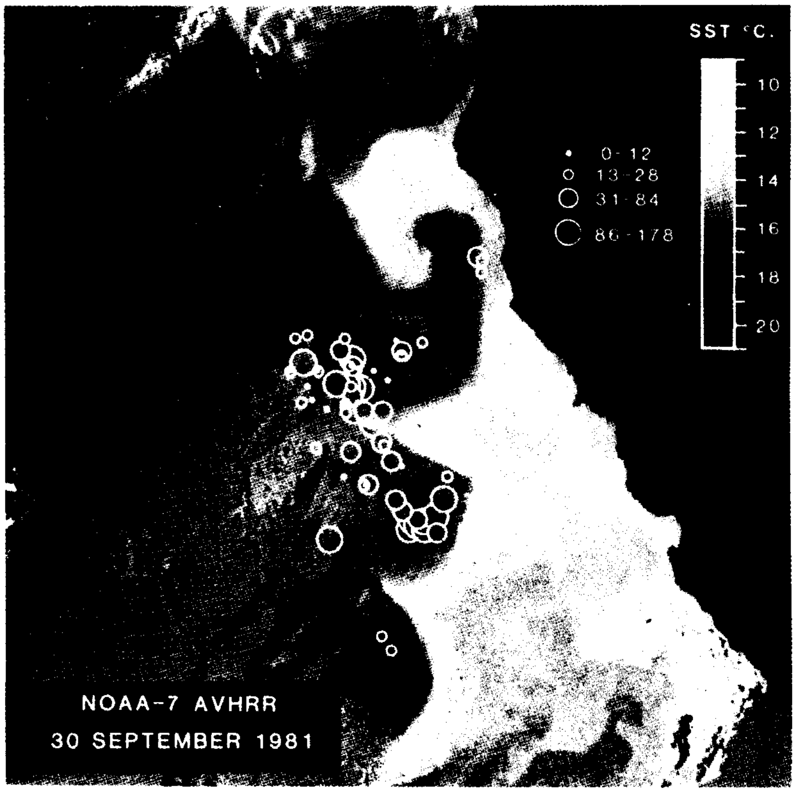

Figure 2. Central California daily albacore catches, Sept. 27-Oct. 2, 1981 and NOAA-7 AVHRR sea surface temperatures, Sept. 30, 1981 (from Laurs et al., 1984).

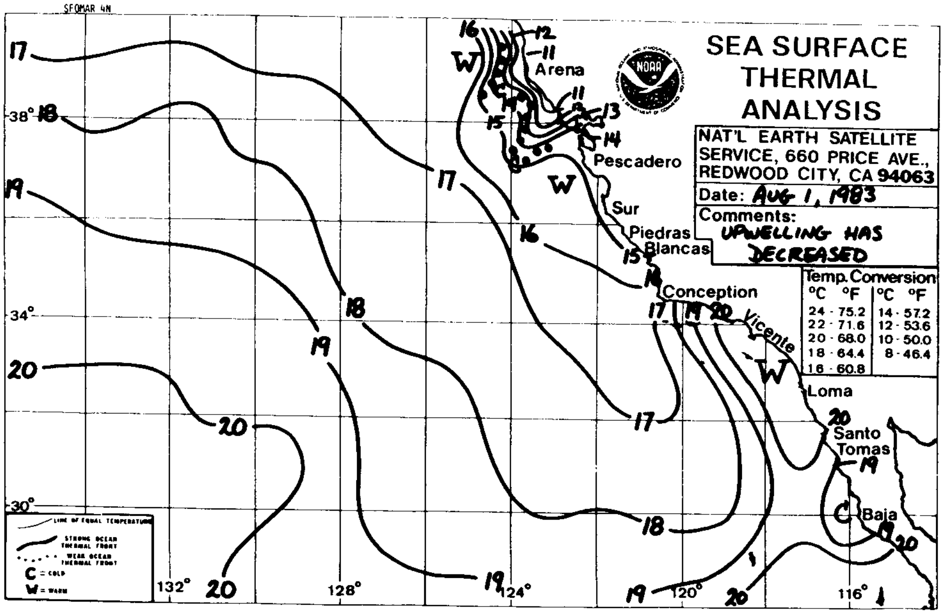

Figure 3. Sea surface temperature charts based on satellite infra-imagery and ship reports issued by U.S. National Weather Service (from Fiedler et al., 1985).

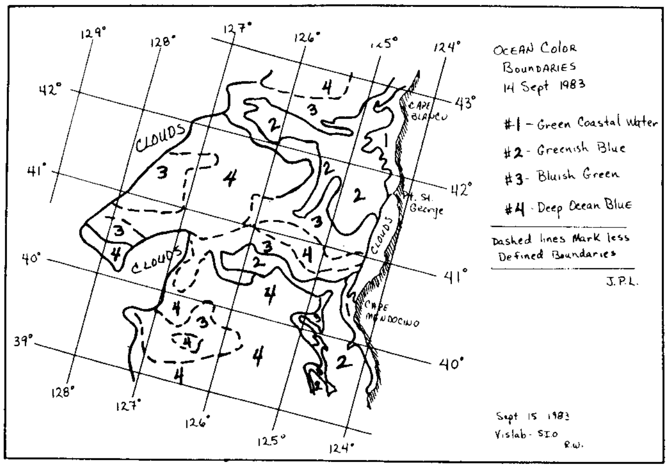

Figure 4. Ocean color boundary chart off northern California and Oregon (R. Wittenberg, Scripps Institution of Oceanography, Visibility Laboratory).