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# The Use of Remotely Sensed Data for Operational Fisheries Oceanography

*Armando F.G. Fiúza*

## Abstract

Satellite remote sensing data are used under two contexts in fisheries: as a tool for fisheries research and as a means to provide operational support to fishing activities. Fishing operations need synoptic data provided timely; fisheries research needs that type of data and, also, good short-term climatologies.

A description is given of several experiences conducted around the world which have employed or are using satellite data for operational fisheries problems. An overview is included of the Portuguese program for fisheries support using remotely sensed data provided by satellites and in situ observations conducted by fishermen.

Environmental products useful for fisheries necessarily combine satellite and in situ data. The role of fishermen as a source of good, near- real-time in situ environmental data is stressed; so far, this role seems to have been largely overlooked.

## 1 Introduction

Satellite observations of the sea, with their synopticity, repeatability, adequate resolution, and increasing availability, are particularly suitable for supporting fisheries. Satellite data are used in fisheries under two different but strongly interconnected contexts: as a tool for fisheries research, and as a means for providing operational support to fishing activities. Fisheries research aims at understanding the response of fish and marine mammals to their environment, at ensuring the maintenance of sustainable fish (and marine mammal) stocks while obtaining yields as high as possible, and at avoiding that harmful pollutants reach man through the marine food chain. On the other hand, the operational support to fishing activities aims at providing timely information to minimize search time and to direct fishing vessels to areas of optimal availability of desired species, based on knowledge of the marine environment and of fish behavior under different environmental conditions.

It seems that progress towards the quantitative understanding of the roles of biotic and abiotic factors and of their relative importance in fisheries oceanography has been slow. This is mainly due to a lack of multidisciplinarity in the field. According to Leggett (1989), more specific reasons are: (i) the failure to integrate basic knowledge of life history of target species with analyses of potential biotic and abiotic factors; (ii) the failure to fully integrate studies of physical and biological factors and their interactions; (iii) the failure to recognize the importance of temporal and spatial scales on the design of experiments and field surveys; (iv) the limitations imposed by sampling and analytical techniques available. The development of the use of satellite remote sensing of the ocean will surely contribute to overcome some of these problems.

Fiúza (1990) has recently reviewed the oceanographic, meteorological, chemical and biological parameters of interest for fisheries research and fishing operations, as well as the pertinent capabilities of satellite remote sensors, so these will not be repeated here. Amongst the advantages of satellite remote sensing over in situ methods are their large areal coverage, synopticity, long-term monitoring capability, lack of interference with the ocean processes under observation, and speed of availability, although the latter is unfortunately not always true. Satellite data also have some limitations, like being frequently limited to surface phenomena, their spatial and temporal resolution being somewhat limited and lacking flexibility, and their accuracy being often less than that attainable with in situ data.

Obviously, there is no antagonism between satellite and in situ data. As scientists and users become progressively more aware of the capabilities of satellite remote sensing, they increasingly take both methodologies as mutually complementary. This is true both in oceanography and fisheries and also in the context of the Earth climate system.

## 2 Scales

Satellite remote sensing provides space-time sampling rates adequate for many fisheries applications.

Typical time and horizontal length scales associated with phytoplankton are in the range 1 day-1 week and 1-10 km and, apart from solar radiation diel and seasonal cycles, relate with convergence- divergence mechanisms, stratification and turbulence ("frontal scales"). Zooplankton variability scales lie in the ranges weeks-months and 10-100 km, which are apparently related with mesoscale dynamical phenomena like semi-permanent fronts and long-lived eddies. The scales associated with fish aggregation (and marine mammals) are generally larger, ranging from months to years and from tens to thousands of km, and seem to be determined by large fronts, eddies and ocean current systems, as well as by their feeding habits.

The existing sensors of oceanographic interest onboard research or operational polar orbiters cover typically space-time scales from half-a-day or few days to years, and from 1 km or a few tens of km to several thousand km. The geostationary satellites have a coarser spatial resolution but sample enormous regions in the tropics and subtropics every half-an- hour. These sampling characteristics of the satellites make them exceptional tools for measuring ocean parameters at scales compatible with those of fish, of zooplankton and even, to some extent, of phytoplankton.

In what concerns longer time scales of relevance for fisheries, like those related with interannual variability or short-term climate fluctuations (decadal time scales), it should be remarked that operational space platforms like the NOAA-X spacecraft and the geostationary meteorological satellites have already provided time series of consistent data (i.e., measurements with similar sensors) exceeding 10 years. These "historical" worldwide data sets deserve at least as much attention and analysis as the existing multi-year series of in situ observations at several points on the Earth's surface.

## 3 Examples of the use of satellite data in operational fisheries

### 3.1 Sea Surface Temperature, Ocean Color and Tunas

Early studies using fish catch data and contemporary in situ measurements of sea surface temperature (SST) have led to good correlations between average catches and well defined temperature ranges, particularly for several tunas (e.g. Hela and Laevastu, 1970). This result has taken to an exaggerated belief on the importance of "preferred temperatures" on the aggregation of tunas, leading to such extrapolations as, for instance, to think that, given the "appropriate" isotherm, the "corresponding" tunas would follow it like a tramway on its rails ...

Tuna, like other living beings, obviously have preferential temperature ranges, and this has been justified in physiological grounds. However, those temperature ranges surely cannot determine by themselves the concentrations of tunas as they cover huge areas of the ocean at any given time and strong fish aggregations are commonly found outside those ranges. Studies where individual tunas were tracked acoustically for a few days have shown that they made frequent vertical excursions through strong vertical temperature gradients and spent most of the time in waters within or below the thermocline where temperatures were considerably below those believed to be within their "preferred" range (Laurs et al., 1984). Indeed, it appears that there is not such a thing as an "average" fish following a "mean" isotherm.

More recently, satellite-based studies on the tunas of the North Pacific, mainly concerning the albacore and the skipjack, have demonstrated that they concentrate near color (phytoplankton) fronts and that this aggregation is determined by the availability of food. This is revealed by the highest catches being near high phytoplankton values (derived from CZCS data), but not necessarily along thermal fronts, when these are not associated with color transitions (Laurs et al., 1984; Fiedler and Bernard, 1987). It thus appears that the combined use of satellite-derived SST and color information, together with oceanographic and biological knowledge, should provide a good basis for an operational system for supporting tuna fisheries. This is exactly what was attempted during the existence of the CZCS, under the "NASA/JPL Satellite Data Distribution System and Demonstration Program to the US West Coast Fisheries". Under this program, satellite thermal (AVHRR) and color (CZCS) data were used in conjunction with more traditional marine and weather forecasts (mixed-layer depths, sea state conditions, wind speed and direction) for preparing near-real time support products for the albacore fishery, based on the scientific knowledge of the aggregation and feeding behavior of that tuna (Montgomery et al., 1986).

### 3.2 Ocean Color and the Menhaden Fishery

Data from the Multi-Spectral Scanner (MSS) on the LANDSAT-1 (originally called ERTS-1) satellite were used 20 years ago by Kemmerer et al. (1974) in an experiment concerning the menhaden fishery off the Mississippi coast, in the Gulf of Mexico. This study was later extended to other areas of the Gulf of Mexico by Brucks et al. (1977).

Many in situ measurements were conducted under these investigations in connection with this pelagic fishery: ocean color (Forel), surface chlorophyll, water turbidity (Secchi disk), sea surface temperature and salinity. Menhaden concentrations correlated significantly with 0.6-0.7 m MSS channels radiances and with in situ observations of ocean color, chlorophyll content and turbidity; no correlation was found with sea surface temperature and salinity. These results were used to provide tactical support to that menhaden fishery based on LANDSAT/MSS data.

### 3.3 Fronts and the Butterfish Fshery

Satellite-derived thermal (AVHRR) and color (CZCS) data were employed in combination with fish catch information and with in situ temperature profiles (XBT) in an investigation on the butterfish fishery in the northeastern Gulf of Mexico (Herron et al., 1989). The butterfish is a small demersal which is abundant in that region. Significant correlations were found between butterfish aggregation and SST distributions and SST gradients (in this case, with an exponential regression), color, turbidity, bottom topography, and the time evolution of oceanographic fronts. More specifically, large schools of butterfish were found to concentrate at or near fronts between warm, low-chlorophyll offshore waters and cooler, high-chlorophyll shelf and slope waters, mainly when these fronts were fully developed; when the fronts receded offshore and disappeared, the fish schools dispersed. Herron et al. (1989) indicate three mechanisms for the aggregation of butterfish near fronts: thermo-regulation, increased availability of food, and spawning selectivity.

This study on the butterfish fishery led to a satellite data-based (AVHRR) experiment designed to predict favorable fishing areas (Leming, 1990). Under this experiment, an "expert system" installed on a personal computer (PC) used bottom depth, moon phase and satellite-derived SST gradients, SST, and location of eddies and fronts (relative to local bathymetric features), to derive the best areas for butterfish aggregation. The processed satellite imagery and fish location charts were then digitally transferred to PCs onboard fishing vessels at sea via the cellular telephone system that covers a large region of the northeastern Gulf of Mexico. The provision of digital data in near-real time to a computer freely operated by the fishing master gives him considerable flexibility and constitutes one of the ways ahead in the use of satellite-derived tools for supporting fishing operations.

### 3.4 The Japanese Fisheries Forecasting System (JFIC)

JFIC constitutes, by far, the better organized and more comprehensive operational support system for fisheries. Some of its activities have recently been summarized by Yamanaka et al. (1988). Data collected from satellites (basically thermal data), fishing vessels, merchant and research ships, aircraft, and drifting or moored buoys, are gathered, processed and analyzed in near-real time by oceanographers and fishery scientists, who prepare and distribute marine environmental analysis and forecasts tailored for the needs of each fishery. These activities use extensively the existing (and continuously updated) knowledge on the structure and evolution of oceanographic features, particularly of fronts and eddies, as defined by their thermal signature on the surface of the ocean, and of their relationships with the aggregation of different species of fishes of commercial interest.

### 3.5 The Satellite-Based System for Supporting the Portuguese Fisheries

Under the NATO-sponsored SATOCEAN Project, the University of Lisbon Group of Oceanography is conducting a research and applications program for supporting the fisheries in the Portuguese Exclusive Economic Zone, which includes large areas in the northeast Atlantic around the Azores and Madeira archipels and off Continental Portugal. These activities have recently been described by Santos and Fiúza (1992).

NOAA/HRPT data directly received, processed and archived at the SATOCEAN Space Oceanography Facility at the University of Lisbon constitute the backbone of the Project. This, apart from the activities for supporting fisheries, also includes investigations on the fine temperature structure of the upper ocean, on algorithms for the retrieval of SST from satellite infrared measurements, and on the spatial structure and time variability of SST in the northeast Atlantic.

The University of Lisbon is supporting operationally the Portuguese tuna and swordfish fisheries by providing them with near-real time products based on satellite measurements of sea surface temperature and on scientific knowledge of the oceanography of the NE Atlantic. These products include charts with the distribution of isotherms and with the location of thermal fronts and comments on their evolution. Besides these operational activities, three research programmes are being carried out to investigate the relations between tuna, swordfish and sardine aggregations and simultaneous distributions of oceanographic parameters as derived from in-situ observations conducted by the fishermen and from satellite data. A preliminary finding of this research was that sardines concentrate in moderately cool, relatively "old" upwelling waters, on the inner shelf off western Continental Portugal. Another finding was that swordfish and tunas are preferentially found seaward of the semi-permanent thermal front separating coastal waters from the warmer open ocean off Continental Portugal. These activities will soon be considerably improved with the installation of computerized XBT systems with GPS positioning systems on board several sardine and swordfish fishing vessels and with the dissemination of WOCE-TOGA satellite- tracked drifting buoys with SST measuring capability in the NE-Atlantic.

## 4 Conclusion

Satellite data are of paramount importance for the operational support to fishing activities and to fisheries research. However, these data are still considerably under-used apparently because their importance is not yet widely understood. Also, the enormous potential of the fishing fleets as originators of good quality, intensive and systematic data from the sea has not been generally realized.

Another problem is that, in recent years, mainly since the demise of the CZCS, the only useful satellite-borne sensors for supporting fisheries whose data are adequately available have been basically the infra-red sensors on the NOAA-N and on the geostationary meteorological satellites, like METEOSAT and GOES. However, this situation will change considerably with the access to color data from the SeaWiFS, to be launched on the SeaStar in August 1993, with the increasing availability of passive microwave data mainly from the SSM/I sensors on the DSMP satellites, and with the radiometers and radars (scatterometer, SAR and altimeters) on the new generation of environmental satellites like the already flying ERS-1 and the soon to be launched TOPEX-Poseidon

The synergistic use of the data provided by these different but simultaneously observing systems, together with in situ observations made from automated platforms, merchant and fishing vessels, will allow the preparation of homogeneous data sets of relevant parameters like surface winds, ocean waves, ocean color, surface temperatures, currents, fronts and eddies. The combination of these observed fields with the fast increasing modelling capability of ocean processes, including physical-biological interactions, and their mutual integration with scientific understanding, will certainly lead to considerably increased meteorological/oceanographic/fishery analyses and forecasts which will provide better safety for operations at sea and improved support for fishing activities.

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