NAFO Sci. Coun. Studies, 4: 41-50

Application of Satellite Remote Sensing to Fishery Studies in Japan

Ichiro Yamanaka
Far Seas Fisheries Research Laboratory
1000 Orido, Shimizu 434, Japan

Abstract

The application of remotely-sensed thermal and ocean-color imagery to fisheries research in Japan is reviewed. Although the absolute accuracy of satellite-derived sea-surface temperatures is generally not high, the thermal patterns are usually in close agreement with reality. For some applications, knowledge of the location and intensity of thermal fronts is more important than absolute temperatures. For some commercially-important species, e.g. tuna and salmon, migration and concentration are associated with frontal regimes. The details and synoptic mapping of such features over large areas have been greatly enhanced with satellite-sensed infrared data.

Ocean color data from LANDSAT and NIMBUS-7 satellites have been examined for selected areas of interest to Japanese fisheries. The former, although designed primarily for land applications, is useful for near-shore larval transport and diffusion studies, but the 18-day interval between passes over a given area severely limits its usefulness. The latter, with its Coastal Zone Color Scanner (CZCS), is capable of providing synoptic data related to chlorophyll distribution over large ocean areas, with a frequency of obtaining data for a given area three times greater than for LANDSAT. Preliminary evaluation for biological application shows considerable promise, but the acquisition of color data has to date been irregular and the accompanying "sea truth" data has been sparse.

Introduction

The application of satellite data for fisheries research can be considered from two points of view, one being the use of satellite sensors to collect data and the other being the use of satellites as a communication system (e.g. the ARGOS Project). Although the latter may have great potential for various types of research, such as transmitting oceanographic data from moored and drifting buoys and the tracking of animal migrations, this paper is confined to the application of remotely-sensed data.

For the direct application of satellite technology to stock assessment, such as the detection of fish schools or individual large animals like whales or the detection of fishing vessels for both fishery surveillance and estimating the distribution of fishing effort, extremely high resolution sensors are required. At present, it is premature to expect major application of satellites for this purpose, but there has been some experience in the location of fish schools by means of the optical characteristics of ambient water, such as glittering and water color observed by eye or on color film from low-flying aircraft. For example, Cram (1977) reported on detecting fish schools off South Africa by means of bioluminescence measured by a low-light level television camera, but no such experiments have as yet been tried in Japan. Studies on the use of microwave sensors, such as Synthetic Apperture Radar (SAR), have just been initiated. However, the more prospective application of remotely-sensed data for oceanographic studies involves the use of thermal infrared data which are applied in a rather indirect way to fisheries research by giving basic and important synoptic information on the ambient environment.

Application of Synoptic Infrared Data

Among the many oceanographic parameters, the most common and basic one is water temperature, particularly surface temperature. Not only does temperature itself influence the schooling behavior of fish (Hela and Laevastu, 1961) but temperature patterns indicate the dynamic aspects of the ocean, such as oceanic circulation, fronts, upwelling, etc., which are significant to fisheries.

A regular service of acquiring surface temperature data (and subsurface data to some extent) from both commercial fishing vessels and research vessels and disseminating the data by radio facsimile has been in operation in Japan for many years. Such information is extremely valuable to commercial fishermen, particularly to those involved in the tuna fisheries of the Northwest Pacific, in the location of primary fishing areas, which have been shown to be associated with the front between the Kuroshio and Oyashio Currents and with the so-called "rings" along the front (Kawai, 1979).

Another type of application of surface temperature for fisheries is the use of temperature patterns, which provide information on the transport of eggs and larvae and thus on future recruitment to a fishery. For example, forecasting of the sardine fishery off Japan is based on the occurrence and meandering of the Kuroshio Current in relation to the mass of cold water off southern Honshu (Watanabe *et al.*, 1979).

The Japan Fisheries Service has adopted the use of infrared data for monitoring surface temperature from the National Oceanic and Atmospheric Administration (NOAA) series of USA satellites. Apart from the fundamental optometric problems associated with the conversion of data from radiance to temperature, the main problems arising from practical application of infrared data include (a) how to eliminate the effects of cloud and moisture, and (b) how relevant to fisheries are the surface-film temperatures measured by the satellite sensor. The former concerns data-processing techniques, whereas the latter involves fisheries oceanography.

As to the first problem, a number of picture elements are clustered and histograms of radiance values are obtained from open and cloud-covered areas separately. By comparing data for mixed areas with such values, the sea-surface temperatures in the mixed areas can be estimated. Furthermore, the effect of cloud cover can be diminished by overlapping some consecutive images of the same area, provided that cloud cover does not continue throughout the period

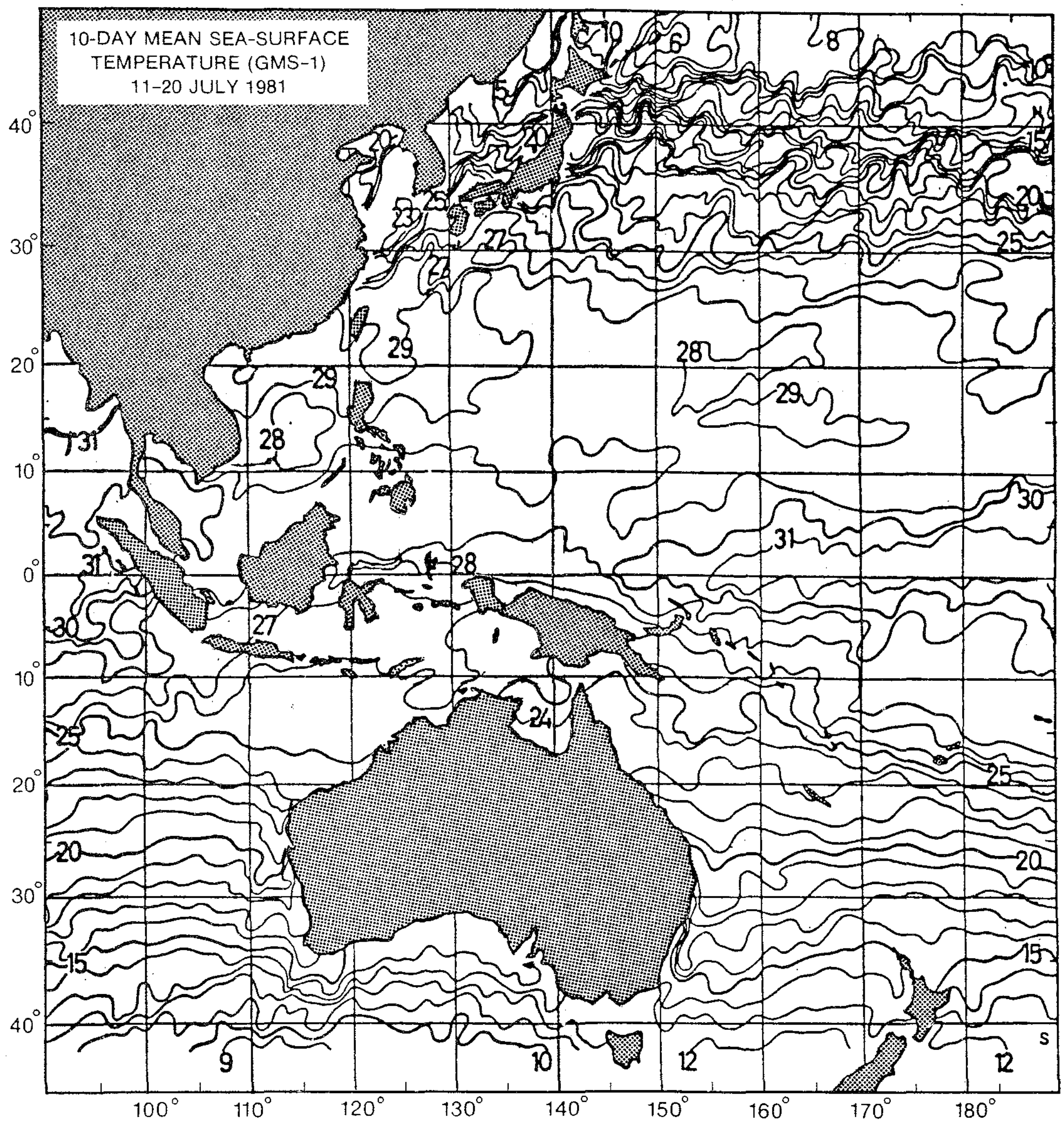

Fig. 1. Composite 10-day map of GMS-1 sea-surface temperatures for the western Pacific Ocean.

of overlapping. Such synthesized pictures were found to be very useful for locating oceanic fronts, but the method cannot eliminate the effects of continuous cloud cover. At present, a major problem involves the development of an effective system of acquiring, processing and disseminating the information quickly in a form adequate to answer the requirements of fishermen and scientists.

A regular service of providing surface temperature data from the Geostationary Meteorological Satellite (GMS-1) has been operated by the Japan Meteorological Agency, which broadcasts by radio facsimile surface temperature maps (10-day average) with 1°C contours. The time lag between the reception of the last day's data and broadcasting is 5 days. For this service, the data are grouped for 1° x 1° grids, and the grouping over 10 days tends to reduce the effects of cloud cover. The grid cover is somewhat too large to distinguish detailed patterns of oceanographic conditions, particularly in coastal areas, but the maps are still quite useful for general purposes because they cover a very large area of the Western Pacific Ocean (Fig. 1).

Infrared Data for Fisheries Oceanography

Comparison of GMS-1 and *In situ* data

Discrepancies of several degrees Celsuis usually exist between the surface-film temperatures measured by the GMS-1 satellite sensor and *in situ* measurements of surface temperature. Correction for vapor absorption is not sufficient to account for the difference. Notwithstanding such anomalies, the correction between satellite-measured surface temperatures and *in situ* measurements from vessels was found to be very high along meridianal lines in the North Pacific (Fig. 2), and good agreement was found in the vicinity of fronts and also in regions of warm and cold patches larger than 100 km in diameter (Yamanaka and Furukawa, 1980).

Putting aside the problems of estimating absolute temperature, the sea-surface temperature maps composed from GMS-1 infrared data appear to well reflect *in situ* temperature patterns. It is such temperature patterns as fronts, upwellings, and warm and cold water masses, rather than temperature itself, that have more significance for fisheries. Moreover, such synoptic maps provide important information on some oceanic features, sporadic in time and space, which are missed in vessel data. As noted previously for tuna in the Northwest Pacific, the fishing areas of skipjack tuna, *Katsuwonus pelamis*, in the tropical Western Pacific were also found to be associated with steep gradients of surface temperature, as seen in GMS-1 maps (Fig. 3).

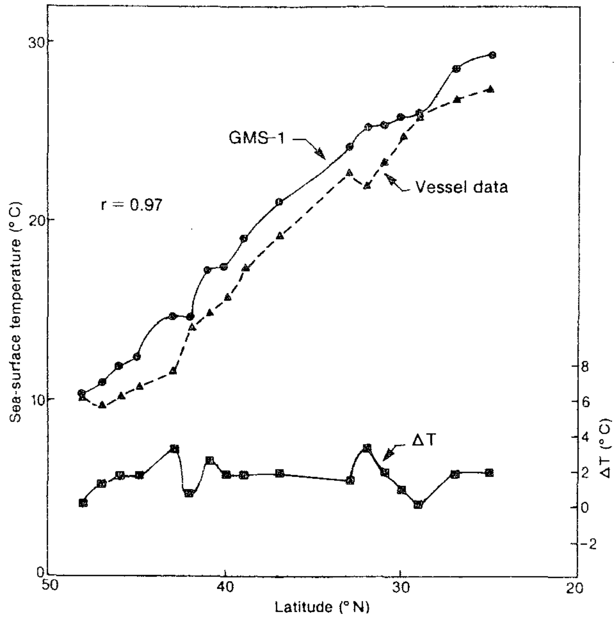

Fig. 2. Comparison of sea-surface temperature data from GMS-1 (10-day map) and vessel observations at 175°E longitude during 21-31 October 1978. (From Yamanaka and Furukawa, 1980.)

Current pattern in the South Pacific

From the good correlation of satellite-derived 10-day surface-temperature maps of the North Pacific with *in situ* vessel data, it can be inferred that similar coincidence would be indicated for surface temperature patterns in the South Pacific. The southward-flowing Eastern Australian Current is a well-known feature of the region, but a recent interesting find is a warm current flowing southward on the western coast of Australia. This current is the recently named Leeuwin Current (Creswell and Golding, 1980), the discovery of which can be traced back only to the last decade. As the waters off northwestern Australia include the spawning area of the southern bluefin tuna, *Thunnus maccoyii*, biologists have supposed that there must be a southward current along the western coast of Australia because the larvae and juveniles of this species occur in the waters off southern Australia. The monitoring of this current by satellites will therefore help to increase knowledge of the transport of eggs and larvae and provide information on fishable concentrations of the species (Fig. 4).

Depicting oceanic fronts

The surface pattern of ocean fronts can be detected by the density of isothermal lines on the maps, but the drawing of such lines is somewhat subjective when they are based on sporadic observations from vessels. Satellite data compiled on convertible computer tape (CCT) can be effectively used as an alternative way of computing vector patterns of temperature gradients to produce better information on the frontal patterns.

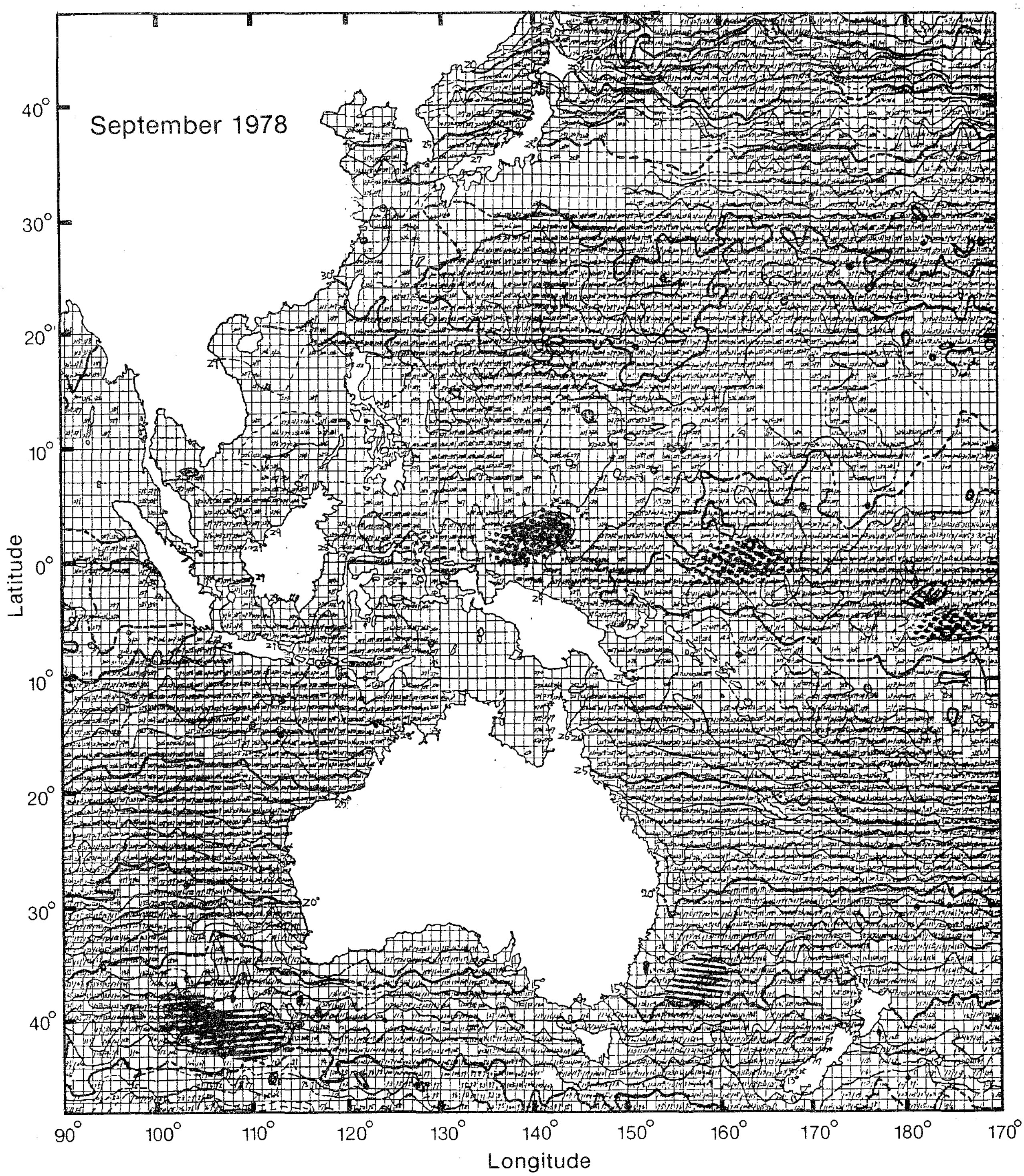

Fig. 3. Ten-day map of sea-surface temperature showing fishing ground formation of skipjack tuna (dotted) and southern bluefin tuna (hatched).

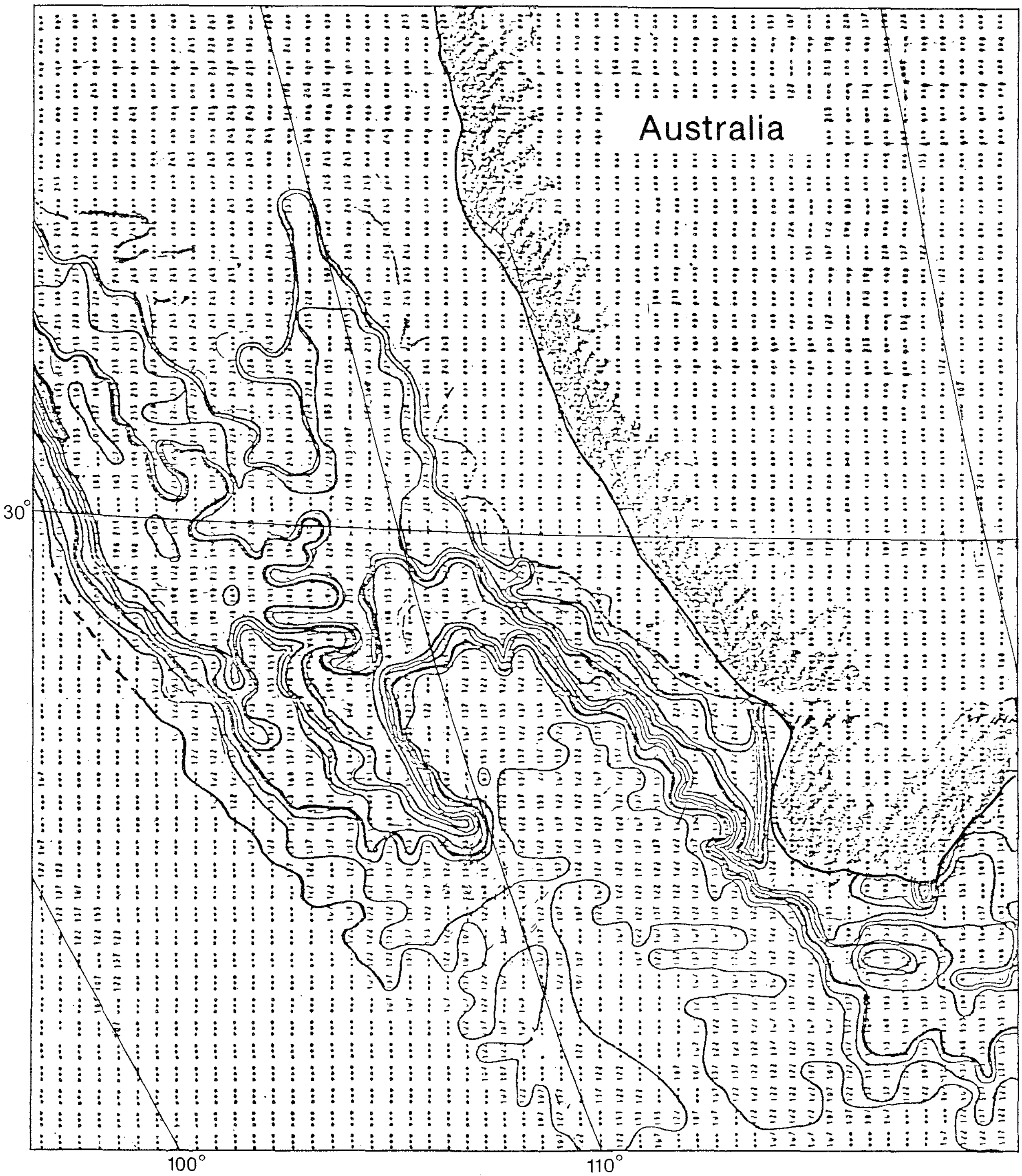

Fig. 4. Real-time infrared data from GMS-1 showing the south flowing Leeuwin Current along western Australia, 17 February 1979.

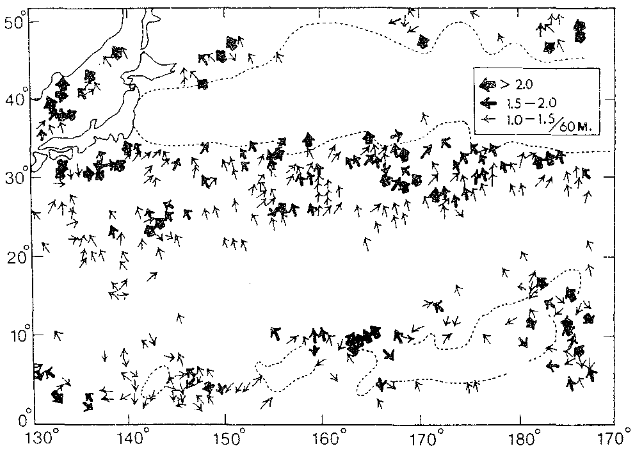

Fig. 5. Temperature gradients in the North Pacific computed from 10-day GMS-1 surface temperature data for 21-30 April 1979.

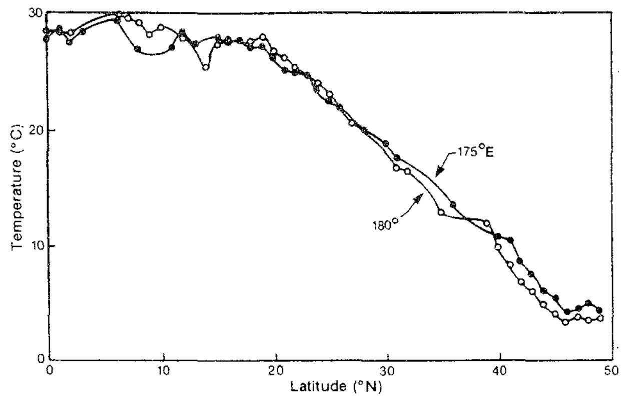

Fig. 6. Change in sea-surface temperature along the 175° and 180° E meridians from 10-day GMS-1 data, 21-31 March 1979.

In the example of temperature gradients for the North Pacific (Fig. 5), two major zones with steepest gradient are evident. One is located at about 30° N between 130° and 140° E and extends northeastward off the coast of Japan to about 45° N and 150° E. This zone corresponds to the northwest margin of the Kuroshio Current. The area between 30° and 40° N is frequently covered by cloud and the frontal pattern east of Honshu is rather obscure. Another zone lies between 20° and 30° N with some meandering. In the western part of the area considered here (130° to 140° E), the zone extends somewhat northward to about 28° N. The latter front is particularly obvious in spring (February-May), and its pattern corresponds to the subtropical frontal zone described by White *et al.* (1978). In tropical areas, the direction of the gradient vector is somewhat unstable because of the occurrence of warm and cold patches.

The trans-Pacific migration of albacore tuna, *Thunnus alalunga*, in the North Pacific is considered to be affected by the patterns of the subtopical zone of the Central Pacific. If the frontal zone is well-developed, the migration route of the tuna is relatively narrow and the aggregations of fish tend to stay offshore in the vicinity of the fronts for a longer period, with a consequent delay in their arrival to the nearshore fishing grounds (Laurs and Lynn, 1977). Thus, the monitoring of the subtropical front in the vicinity of 30° to 50° N at about 170° E was recommended by Japanese and USA scientists. As the area is too far from both countries for regular surveys, the use of satellite data has been adopted as a practical method of monitoring.

Another example, effectively shown by GMS-1 data, is the subarctic frontal boundary in the Northeast Pacific, which is located around 45° N and affects the distribution of salmon (Favorite *et al.*, 1976). At this latitude, the GMS-1 data show a slow down or inversion of the meridianal temperature gradient, which indicates the influence of the warm Alaskan Current (Fig. 6). Such phenomena cannot always be detected from sporadic data collected by vessels.

Although satellite infrared data provide only the distribution of surface-film temperature, their synopticity shows much information concerning oceanic circulartion patterns.

Synthesized Infrared Data and Real-time Imagery

The process of superimposing the data for 10 successive days by clustering into 1° x 1° grid arrays certainly provides a synoptic picture of temperature distribution and fronts, but the picture is too rough for studying the fine structure of such fronts if their pattern undergoes short-term variation. In such cases, real-time pictures provide better information, even if cloud cover is often a nuisance. For example, the front along the northern margin of the Kuroshio Current Extension, depicted in a single GMS-1 picture on 24 May 1980 (Fig. 7) is shown to consist of many small eddy-like meanders, in contrast to the pattern from the 10-day synthesized GMS-1 data for 21-31 May 1980 (Fig. 8) and to the surface-temperature pattern from 5 days of vessel observations during 21-25 May 1980 (Fig. 9). The comparison of two GMS-1 scenes on 23 May and 24 May 1980 indicates that the frontal pattern changed over a 24-hr period (Fig. 10).

Such "microscopic" eddies along the front can be detected by real-time infrared pictures from other types of satellites, as indicated in a picture from NOAA-6 on 24 October 1980 (Fig. 11). In some fisheries, schools of fish are closely associated with such eddies, and planktonic animals, such as Antarctic krill, *Euphausia superba*, behave likewise (Nasu, 1979). Thus, the shapes of such "microscopic" eddies are of great value for understanding the formation of schooling concentrations of fish and the distribution of eggs and larvae transported by currents. Because such

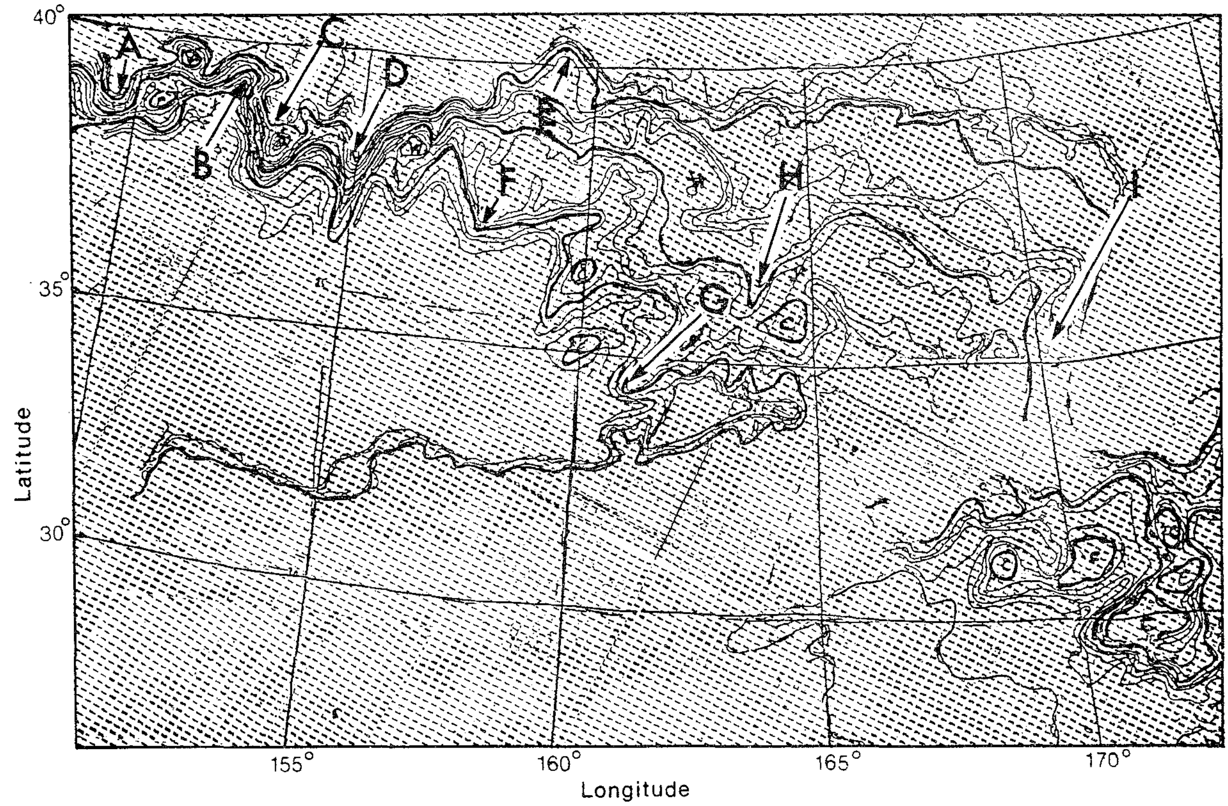

Fig. 7. Frontal pattern of the Kuroshio Current Extension in the North Pacific, based on a single GMS-1 infrared image, 24 May 1980.

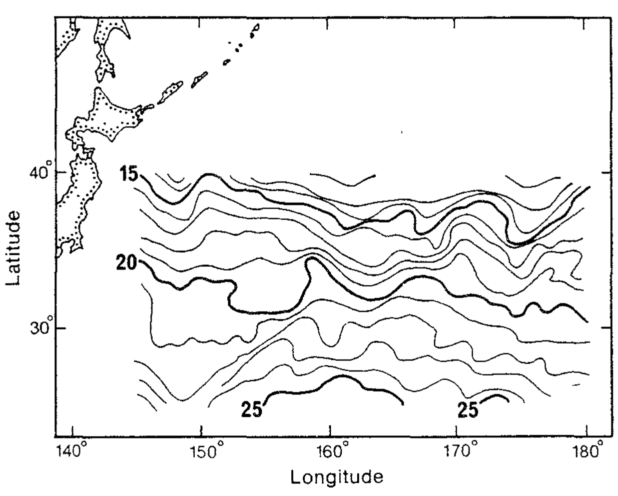

Fig. 8. Frontal pattern of the Kuroshio Current Extension in the North Pacific, based on 10-day GMS-1 temperature data, 21–31 May 1980.

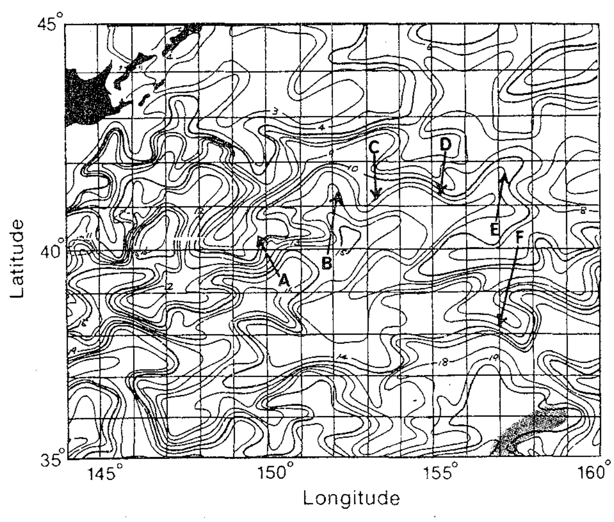

Fig. 9. Frontal pattern of the Kuroshio Current Extension in the North Pacific, based on vessel observations of surface temperature, 21–25 May 1980. (Prepared by the Japanese Fisheries Information Center.)

eddies can hardly be found by conventional oceanographic shipboard observations, remote-sensing is now considered to be a major method of oceanographic study rather than one which only supplements vessel survey data.

Some fishermen are anxious for such scenes of real-time imagery that include "microscopic" eddies to be disseminated as quickly as possible, even without digital temperatures and without interpretation by fisheries oceanographers.

Application of Ocean Color Imagery

Remote sensing of ocean color by multiple spectral scanner (MSS) sensor represents another application being undertaken for fisheries oceanography.

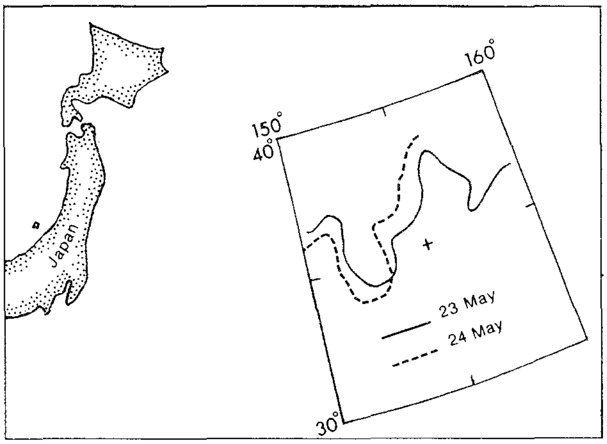

Fig. 10. Shift in the frontal position of the Kuroshio Current Extension during a 24-hr period, based on real-time GMS-1 images at 03Z on 24 May and 25 May 1980.

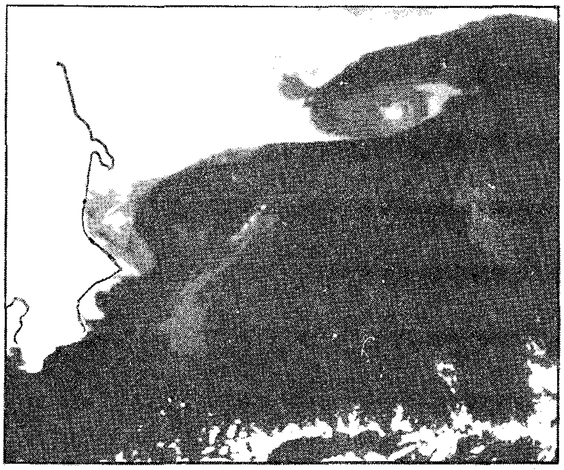

Fig. 11. Eddies off Japan shown by NOAA-6 imagery on 24 October 1980.

Fig. 12. Coastal current and eddy near Central Japan, shown by LANDSAT-3 imagery on 14 December 1979.

Among satellites providing such data are the LANDSAT series and NIMBUS-7.

LANDSAT satellites

The data from these satellites are most widely applied to biological studies on land. However, a very good example showing the coastal currents near the central part of Japan is a color picture taken by LANDSAT-3 on 22 October 1979 (Fig. 12). It shows a very clear eastward stream of the outflow of water from the Teneyu River to form an eddy just south of the Izu Peninsula. The pattern of the flow was highly correlated with *in situ* data obtained by the Prefectural Fisheries Experimental Station of Shizuoka from a large-scale experiment involving the release of pig-

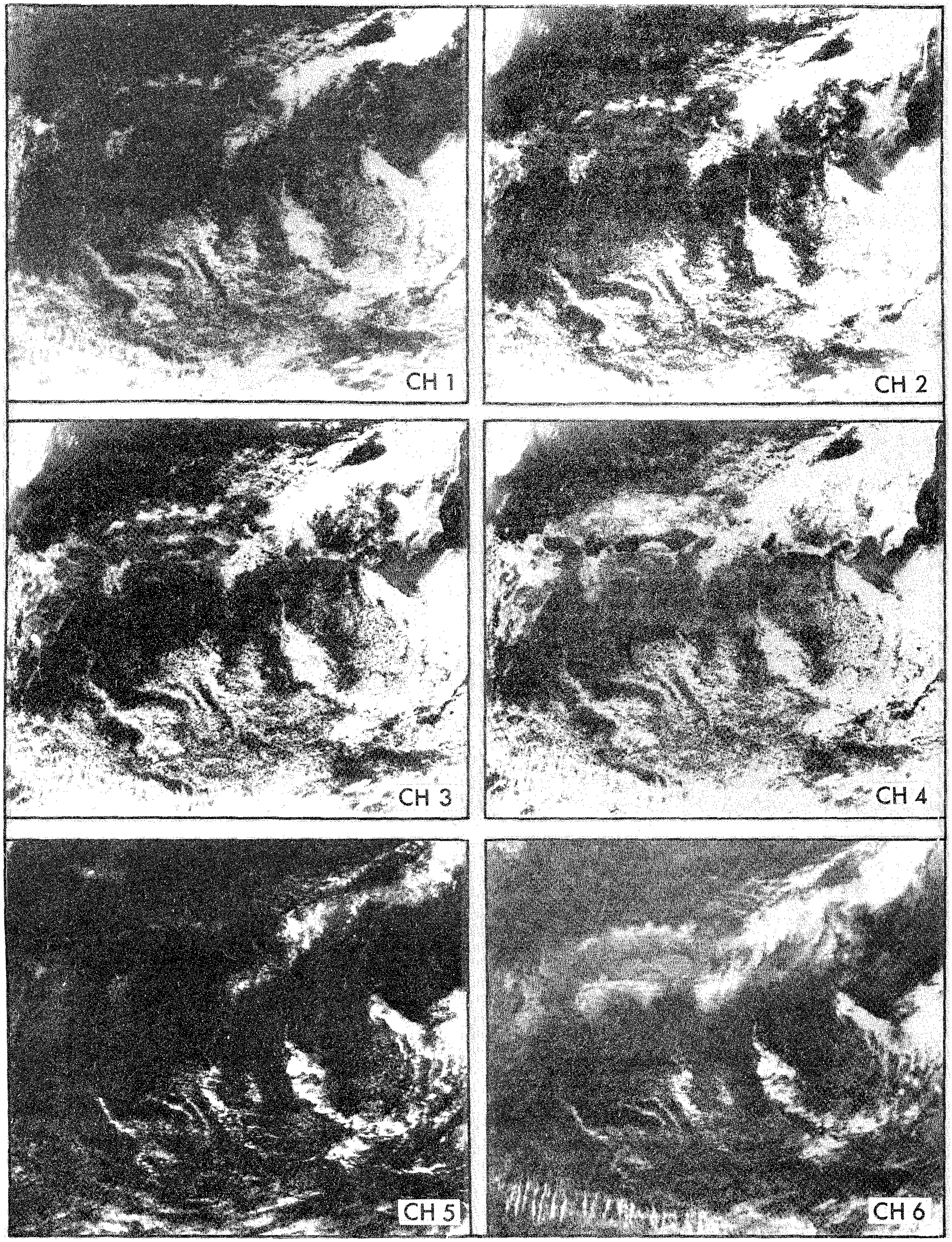

Fig. 13. NIMBUS-7 CZCS imagery of Central Japan and vicinity from channels 1 to 6, 26 January 1979.

ment into the sea and the monitoring of the current from an aircraft. The area off the mouth of the Teneyu River is the spawning ground of anchory and mackerel. The larvae are transported to the area off the Izu Peninsula and aggregate where the eddy occurs. Such information is very useful for predicting recruitment. Unfortunately, pictures of such clear contrast in water color are infrequent. One reason is that the interval between flights of the satellite over the same area is about 18 days, much too long for regular monitoring. Moreover, much of the range in the radiance histogram of a channel is occupied by land area. Therefore, the application of LANDSAT data to detecting fish concentrations from ocean color contrasts can be expected only for some infrequent cases, an example of which was reported by Kemmerer and Butler (1977).

NIMBUS-7 (CZCS) satellite

The Coastal Zone Color Scanner carried by this satellite is a more preferable sensor than that of LANDSAT to detect ocean color in relation to biological productivity and the distribution of chlorophyll. Such a study was undertaken as one of the projects within the framework of the USA-Japan Cooperative Research and Development Program in the Field of Space Science and Technology. Unfortunately, the supply of CZCS data was irregular and the amount of data analyzed to date is rather limited, but the results are encouraging. The CZCS images, illustrated in Fig. 13, were derived from Orbit No. 1297 of NIMBUS-7 on 26 January 1979. Originally, it was planned to compare the CZCS data with sea-truth data from a cruise in the East China Sea. However, the area was covered with clouds for most of the period, and only a few sea-truth data were obtained off Honshu during January to March 1979. Of the six channels of CZCS, No. 6 is the infrared channel, and the image shows a clear meandering of the Kuroshio Current off South Honshu (Fig. 13).

Trials were made by combining the radiance values of various channels for comparison with chlorophyll *a* data, the correlation coefficients (r) for some comparisons being as follows:

log (C2/C1)	*vs*	Chlorophyll	*a*	r = 0.67
log (C5/C1)	*vs*	"	"	r = 0.68
log (C3/C4)	*vs*	"	"	r = 0.65
log (C3/C1+C4)	*vs*	"	"	r = 0.85

A color picture (not shown), based on the Channel 2/Channel 1 ratio, indicates extremely high chlorophyll content in certain coastal waters of Japan, which conforms to common knowledge of the areas, although there were no corresponding *in situ* data. The picture also appears to show high chlorophyll concentration in the central part of the Japan Sea, in contrast to the observations by Ohwada (1971) in October 1969 which indicated higher chlorophyll concentration in the northern part of the Japan Sea than in the warm Tsushima Current.

The major problems associated with studying the application of CZCS data to fisheries research are the sparsity of *in situ* data and the irregular acquisition and processing of CZCS data. Another problem is that the real-time acquisition and processing of CZCS data are not regularized. The frequency of obtaining data of a specific target area by CZCS is three times greater than that for LANDSAT, and the area covered by a picture of the former is 30 times larger than that of the latter. Consequently, the application of CZCS data for fisheries research is rather limited to providing a synoptic pattern of the biological aspect of the ocean, which is very difficult to obtain by conventional methods in parallel to the temperature pattern.

Acknowledgements

I thank the scientific staffs of the Computer Center and the Research and Information Center of Tokai University for their energetic cooperation during the preparation of this paper.

References

CRAM, D. L. 1977. Fishing surveillance and advisory system in South Africa. *FAO Fish. Tech. Paper*, **170**: 84–97.

CRESWELL, G. R., and T. J. GOLDING. 1980. Observation of a south flowing current in the southeastern Indian Ocean. *Deep Sea Res.*, **27**: 449–460.

FAVORITE, F., A. J. DODIMEAD, and K. NASU. 1976. Oceanography of the Subarctic Pacific region, 1960–1970. *INPFC Bull.*, **33**: 1–187.

HELA, I., and T. LAEVASTU. 1961. Fisheries hydrography. *Fish. News (Books) Ltd., London*, 137 p.

KAWAI, H. 1979. Rings south of the Kuroshio and their possible roles in transport of the intermediate salinity minimum in formation of the skipjack and albacore fishing grounds. *The Kuroshio IV, Saikon Shuppan Co. Ltd., Tokyo*, p. 250–273.

KEMMERER, A. J., and J. A. BUTLER. 1977. Finding fish with satellites. *Mar. Fish. Rev. U. S.*, **39**(1): 16–21.

LAURS, R. M., and R. J. LYNN. 1977. Seasonal migration of North Pacific albacore (*Thunnus alalunga*) into North American coastal waters. *Fish. Bull., U. S.*, **75**: 795–822.

NASU, K. 1979. Oceanic environment of Antarctic krill. *Mar. Sci. Month.*, **11**(7): 564–573 (in Japanese).

OHWADA, M. 1971. Distribution of chlorophyll and paeophytin in the Sea of Japan. *The Ocean. Mag.*, **23**(1): 21–31.

WATANABE, T., K. HONJO, and T. OKOTANI. 1979. Fluctuation of population size of Japanese sardine (*Sardinops melanosticta*) and the Kuroshio. *The Kuroshio IV, Saikon Shuppan Co. Ltd., Tokyo*, p. 830–848.

WHITE, W. B., K. HASUNUMA, and H. SOLOMON. 1978. Large scale seasonal and secular variability of subtropical front in the western North Pacific from 1954 to 1974. *J. Geog. Res.*, **83**(9): 4531–4544.

YAMANAKA, I., and K. FURUKAWA. 1980. Oceanographic information by infrared images of GMS-1 (Himawari) and its application for fisheries. *Bull. Airborne and Satellite Fisheries Oceanogr.*, **2**: 27–46 (in Japanese).