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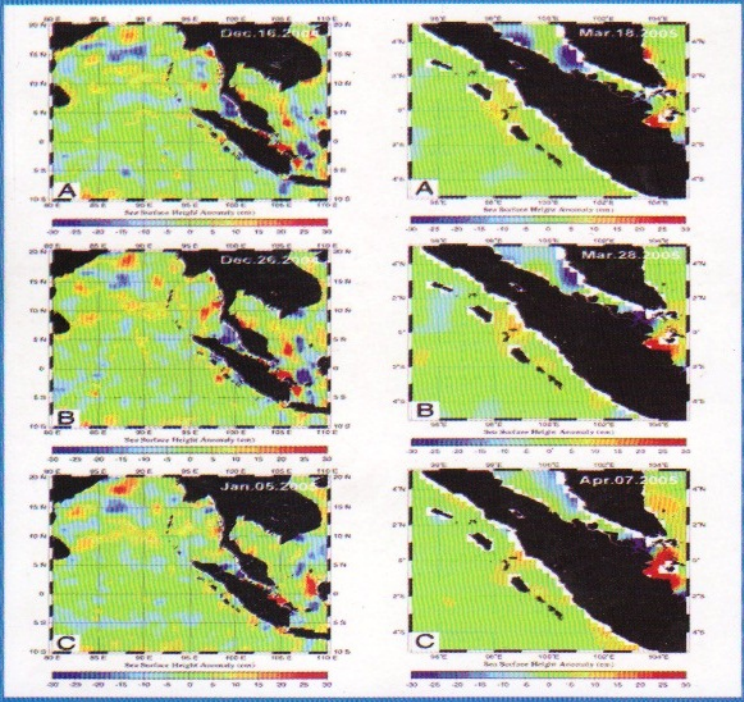

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ESTIMATION OF TUNA FISHING GROUND IN LOW LATITUDE REGION USING SEA SURFACE HEIGHT GRADIENT DERIVED FROM SATELLITE ALTIMETRY: APPLICATION TO NORTHEASTERN INDIAN OCEAN

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Abstract

In order to improve the method for prediction of tuna fishing ground, the modification of the analysis about satellite altimeter data was made as a trial. In this study, we focused on the satellite altimeter, TOPEX/POSEIDON series, to improve the method of fishing ground prediction. Fishery data were supplied as "hook rate" by local fishing information around Indonesia and hearing information. The gradient of sea surface height is calculated between the neighbor grid which has the maximum gradient. Results showed that the fishery data with hook rate over 0.8 are grouped in a zone from 1.0E-06 to 2.0E-06 of sea surface height gradient. These indicate that this method has not only possibility for the prediction of fishing ground quantitatively, but also reasonable accuracy as shown in the change in the standard deviation. This method can be utilized for the effective fishing plan with the resource protection and the economy in the fishing operation in near future.

Keywords : sea surface altimeter, sea surface gradient, remote sensing, fishing ground search, hook rate, fishery resource management.

I. Introduction

Several attempts have been tried to estimate fishing ground from satellite imagery and utilized for fishing plan and fishery resource management. The front corresponding to the interface of the water mass which has different physical properties, gathers the phytoplankton, zooplankton, and their predators as fishes. It is well known that the fronts formed between the different water mass are good locations for haul fishing ground and can be detected as the fronts of sea surface temperature or chlorophyll by optical sensors. In recent days, sea surface height is utilized to estimate and predict a fishing ground for each species of the fish, because the sea surface height reflects the phenomena of not only sea surface but also interior of the ocean. For example, horse mackerels are caught in the area with high sea surface height, while the fishing ground of mackerel pike is formed in low sea surface height area. These kind of methods are based on the decision that depends on qualitative standard for the simple and easy procedure to determine the fishing ground. On the other hand, there are few reports on locating the possibility of fishing grounds quantitatively, but no or few assurances or warrant that these locations are exactly haul fishing ground. In addition, the optical sensors can not be utilized under the ceiling of the cloud, and the horizontal gradient of sea surface temperature is not significant in the low latitude region due to

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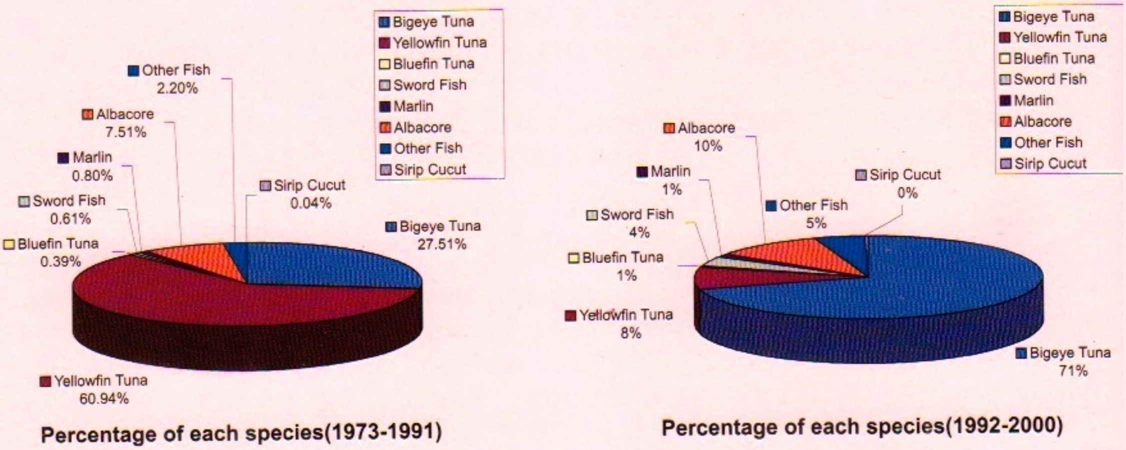

Fig. 1. Percentage of the fishes caught in the Indian Ocean from 1973 to 1991 (left) and from 1992 to 2000 (right).

the strong solar radiation.

The Indian Ocean is one of the large fishing grounds in the world. However, the detailed analysis has never been carried out between the in-situ fishing data and satellite imagery. Considering the above facts, the horizontal gradient of sea surface derived from the satellite-borne altimeter data and the actual fishery data obtained from the local tuna fishing boats are compared and analyzed to estimate the potential fishing ground and their quantitative relationships.

This method will be utilized for the effective fishing plan with the resource protection and the economy in the fishing operation, because if the fishing ground can be predicted reasonably, the over fishing in particular local area will be avoided.

II. Data

Two kinds of data are used for this study; the fishery data for tuna species to estimate the potential fishing ground in the study area and the satellite altimeter data to estimate the sea surface height anomaly in the fishing ground. The reason in selecting tuna as the fishing species is as follows; (1) it is one of the most count fishes toward fishing operation and fool culture, (2) it is one of the major species of fish caught in the Indian Ocean as shown in Fig. 1, and (3) its migrating layer and internal information are required to predict the fishing ground.

Fishery data were supplied from the local fishing information around Indonesia and hearing information. Most of the data were provided by PT. PERIKANAN SAMUDRA BESAR, the fishery company located in Benoa harbor, Bali, Indonesia. This fishery company is one of large ones operating for tuna fishing in the Indian Ocean and it has a lot of fishing boat and wide spatial coverage of the fishing area to secure the accuracy of analysis about the catch of tuna. The fishery information is converted to a "hook rate", that is how many tunas are hooked in one hundred hooks equipped in a unit "haenawa" trawling line. If the total catch of the tuna is used for the analysis, the error derived from the difference in the operational capacity of fishing for each fishing boat interferes. This suggests the possibility about the different estimation of the fishing potentiality for each fishing boat which has

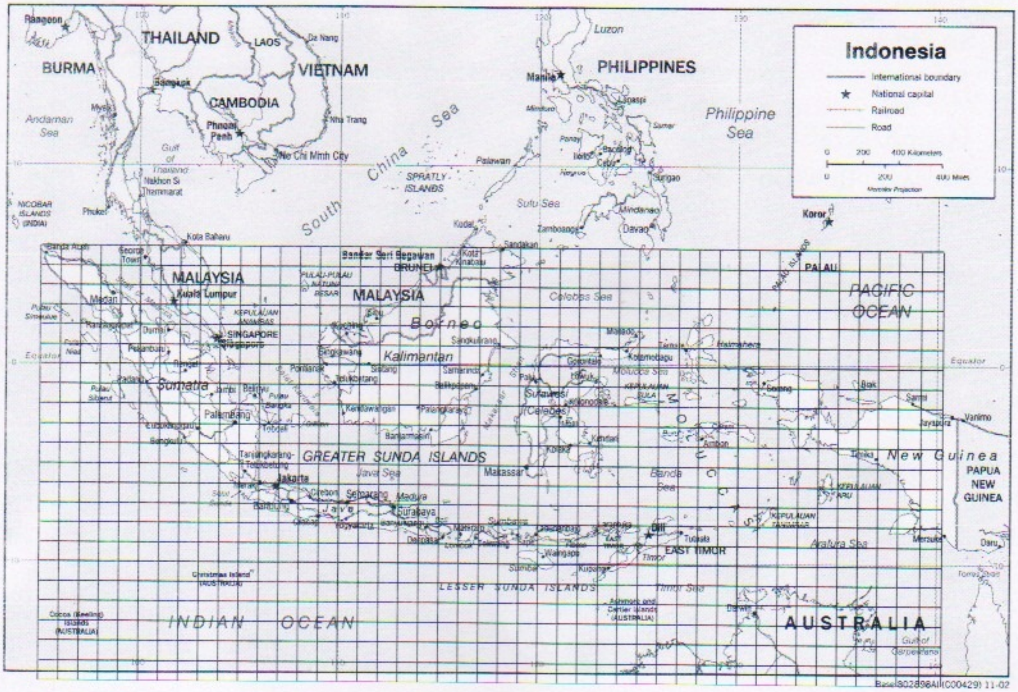

Fig. 2. Study area for the potentiality of Tuna fishing ground by satellite altimetry

individual operation ability for fishing. For example, a fishing boat equipped with the effective fishing apparatus could catch a large amount of fish, but a boat with poor fishing facility gets less catch than about with a good fishing facility even if both boats are operating in entirely the same fishing ground. Therefore, the use of hook rate is reasonable for correcting the fishery data for the analysis, and it can be referred to normalized fishery data as CPUE (Catch Per Unit Effort). The data were collected from the northeastern area of the Indian Ocean and supplied as the hook rate for each grid divided by one degree interval as shown in Fig. 2. The time scale of the fishery data covers the AD 2000 with the interval of ten days. As a result, 36 images of satellite altimetry can be compared with in-situ fishing data in each one degree grid in the study area. The grid indices referred to the hook rate over 0.8 are selected as in the fishery information and defined as a good haul fishing condition.

The sea surface height anomaly is used to the analysis and the altimetry data is provided by the satellite altimeter. The satellite altimeter measures the time required to travel from the satellite sensor which is reflected from the ocean surface and returned to the sensor for radar pulse. The speed of the radar pulse depends on the dry air between the sensor and the ocean surface, the water vapor in the atmosphere, and the electron content of the ionosphere. The distance between the sensor and the ocean surface is obtained after correcting effects with the accuracy of a few centimeters. The satellite-derived sea surface height anomaly data were collected from the archive system on the web developed by the Colorado Center for Astrodynamics Research (CCAR), Colorado, USA. The sea surface height anomaly was used in the analysis because of the reason for normalization of the absolute sea surface height in the model area. Since the swath of the satellite altimeter is not so wide, the sea surface

Table 1. Brief specifications of satellite-borne altimeter used in this study.

SATELLITE/SENSOR	SAMPLING RATE	ORBIT HEIGHT	ACCURACY
Jason	10 days	1336 km	4.2 cm
TOPEX/POSEIDON	10 days	1336 km	4.2 cm
Geosat Follow-On	17 days	800 km	3.5 cm
ERS-2	35 days	777 km	10 cm
Envisat	35 days	799 km	12 cm

height anomaly image has to be merged and compounded over the several images obtained around the objective date. Usually, the image of sea surface height anomaly is produced with the data obtained by satellite onboard altimeters, Jason, TOPEX/POSEIDON, Geosat Follow-ON, ERS-2 and Envisat processed in near real time. On the other hand, the past data is updated by the latest ten days of Jason and TOPEX/POSEIDON, seventeen days of Geosat Follow-ON, and thirty five days of ERS-2 and Envisat sampling as shown as Table 1. The 36 images have been compiled by this method. Although the error in the composition has been suggested about such a kind of case, this method can secure sufficient accuracy since the time scale of fishery data and the sampling rate of the image interpolation is almost same order.

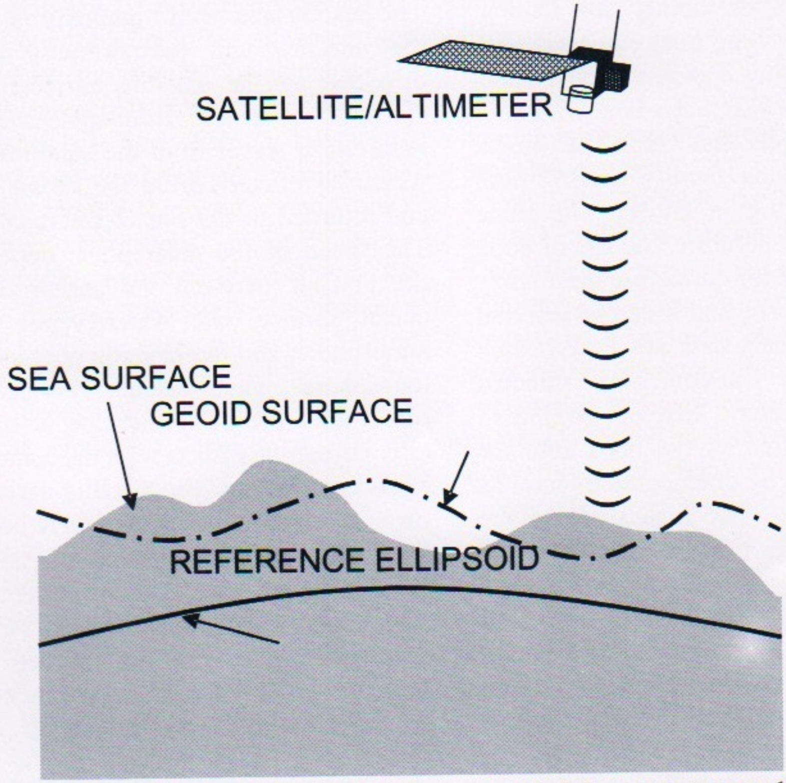

Fig. 3. Schematic representation of sea surface height measurement by satellite-borne altimeter.

III. Method of analysis

If there is no motion and no forces forcing in the ocean, then the ocean surface would coincide with the geoid. The deviations of the ocean surface from the geoid imply the horizontal pressure gradients. These gradients are related to the currents within the ocean. Therefore, it is expected that the fishing ground can be estimated by the sea surface height. But, there is a problem. Even though the location of the ocean surface may be known exactly, the exact height of the ocean surface from the geoid could not be known. There are independent estimates of the geoid retrieved by the ship gravimetric data, the simultaneous in-situ and the altimeter observations, and the satellite observations. However, the geoid accuracy on the spatial scales of a few hundred kilometers or less is not efficient. Thus, the geoid is unknown for mesoscale applications. On the other hand, generally the geoid is almost constant in time. This means that in the sea surface height measurements at a particular point on the ground, removing the mean sea surface level can remove the geoid influence. Removal of the mean sea surface level also removes any influence derived from mean ocean currents. Thus, the satellite-borne altimeter provides accurate measurements of sea surface height variations around their mean as shown in Fig. 3.

As well known, most of the utilization of sea surface height data derived from satellite altimetry focus on the flow field. But the sea surface height has been used for the fishing ground prediction not only for tuna species, but also for horse mackerel, mackerel pike and other fishing targets for the satellite imagery. An absolute sea surface height has been used in most of cases of the fishing ground prediction. In this study, the sea surface height anomaly is defined as the difference

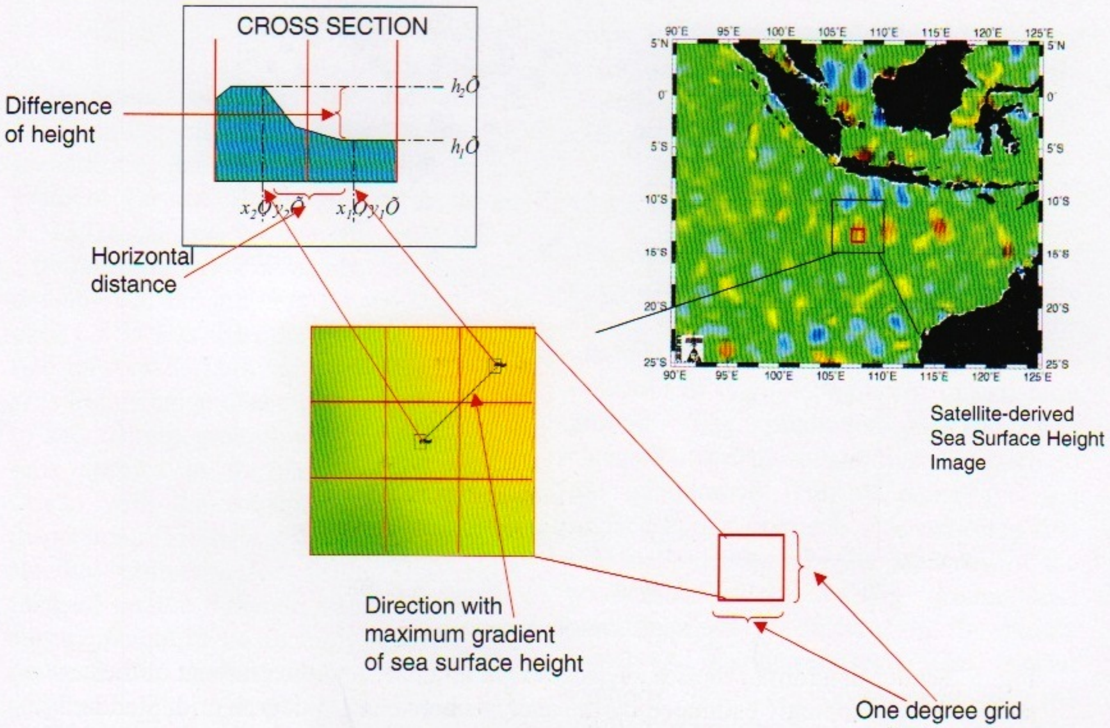

Fig. 4. Concept for the definition of the sea surface height gradient in one degree grid

between….and the mean sea surface level. It was used as the indicator of sea surface position and the horizontal gradient of that was calculated. The reason of using the anomaly is as follows; (1) it is necessary to normalize the position of sea surface based on some standards of normal position to emphasize the effect of change in sea surface height, (2) the mean flow field follows to the mean sea surface level, but the change in flow field is reflected in the change in the sea surface position from its mean sea surface and sometimes it affects on the behavior of the fishes.

The spatial resolution of the analysis is set to one degree which referred to 60 nautical miles according to the spatial scale of fishery data. First, in order to define this, the grid is divided into 9 parts by the scale of the one third degrees grid and the sea surface height anomaly is averaged in each divided part as shown in Fig. 4. Second, the sea surface height gradient is calculated instantaneously from the horizontal gradient between the central grids in the one degree one to neighbor one third degrees grid. Because the one degree grid is divided into nine square parts, eight kind of the gradients are obtained by the difference of sea surface height anomaly and the distance between neighbor grids. Finally, the gradient of the one degree grid is represented by the maximum gradient in these eight gradients. Thus, the hook rate and the gradient of sea surface height can be compared over the northeastern Indian Ocean by the ten days time scale and one degree spatial scale. Unfortunately, the data of the hook rate were collected by whether the hook rate was over 0.8 or not.

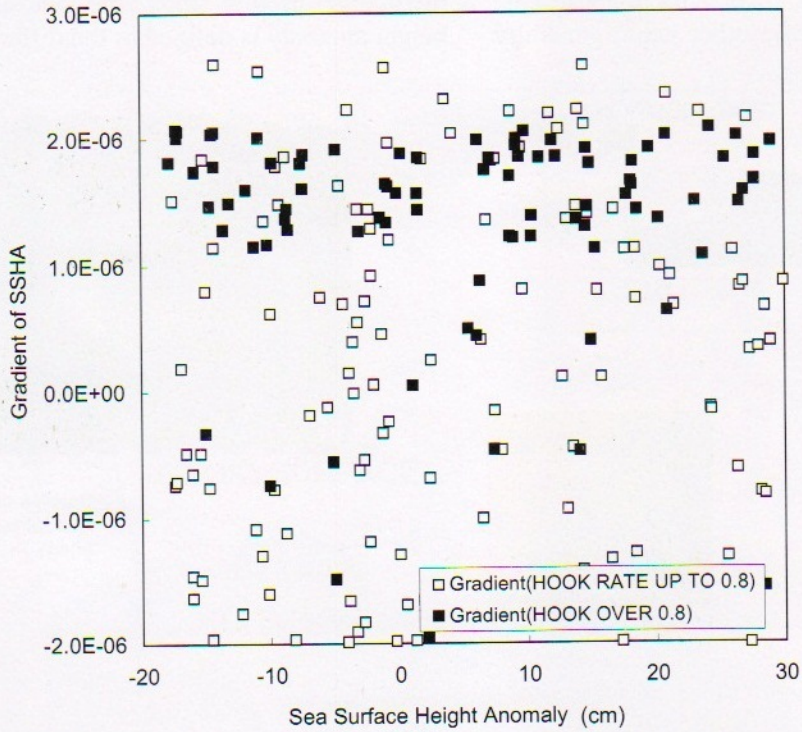

Fig. 5. Scatter diagram of the sea surface height anomaly and the gradient of the sea surface height anomaly estimated by the analysis between 1/3 degree grid. Standard deviations of the gradient for the value up to 0.8 is 1.37352E-06 and the one for the value over 0.8 is 1.00037E-06.

Therefore, the relationships between the hook rate and the gradient can not be analyzed numerically. Then, the relationships between them are analyzed by the scattering diagram of the sea surface height anomaly and its gradient.

IV. Results and Discussion

The relationships between sea surface height anomaly and the gradient of sea surface height anomaly are plotted and shown in Fig. 5. Figure 5 shows a scattering diagram of the sea surface height anomaly from the fishing location grid and the gradient of sea surface height anomaly obtained by the method explained before. The symbol is referred to just only two classes; (1) data obtained in the grid without the hook rate up to 0.8, (2) one in the grid where there was haul catch of tuna referred to the hook rate over 0.8, as shown in the legend. It is clearly shown most symbols referred to the hook rate over 0.8 are grouped in the range of the gradient of the sea surface height anomaly from 0.001 to 0.002 in the vertical axis. However, there are no significant trends in the relationships between the sea surface height in horizontal axis and the hook rate. In addition, the standard deviation of the gradient for the hook rate up to 0.8 is 1.37352E-06 and the one for over 0.8 is 1.00037E-06. In other words, the standard deviation of the gradient for the hook rate over 0.8 is less than the one for the hook rate up to 0.8. This fact suggests that the area in this range of the gradient is referred to the fishing ground with good haul of tuna species in the northeastern Indian Ocean with the statistical trend in data dispersion. In past, the utilization of satellite altimetry for fishing has been focused on the dynamic value of the sea surface height or its anomaly. Comparison between the dynamic value of the sea surface height and the catch sometimes showed an efficient agreement in the trend of the dynamic value and the catch. But this conventional method is based on the qualitative analysis of sea surface height as high or low values and involves a possibility of the blank for the prediction of fishing ground, because the judgment of the possibility has been always estimated by the psycho – physical decision of the operator. The method proposed in this study showed the suitable value of the gradient of sea surface height anomaly in the narrow range and few reflective trends in the sea surface height anomaly for tuna fishing ground with the quantitative approach.

It is well known that the fishing ground of the tuna species is formed in the area where the sea surface height changes significantly in the horizontal scale. But the prediction has been performed by the sea surface height itself or flow field estimated by the theory of the geostrophic flow. Of course, many results succeed in predicting the fishing ground for mackerel, horse mackerel, and mackerel pike. But the tuna species is located in the top of the food chain of the migratory fish and they are predators for previous species of fish. Therefore, the feeding location might be different from them.

Conclusions

The relationships between the gradient of sea surface height and the hook rate were analyzed. The specific range of the gradient was shown as the quantitative indicator of the potentiality of tuna fishing ground. The prediction method was changed from the qualitative approach to the quantitative one by using the sea surface height gradient. It is expected that this method improves the accuracy of the prediction of the fishing ground and contributes to the fishery in the Indian Ocean and the adjacent areas. The efficient methods or the improvement of the prediction are sometimes misunderstood as an encouragement of overfishing because they are sometimes thought as just the increase in the catch and drain of the fishery resource. But when we think about the fishing resource preservation, one of the most important matters is the avoidance of intensive fishing in both time and spatial scales in the ocean. For example, if a lot of fishing boats are dispatched to the same location in a short period, it will sometimes result in overfishing. On the other hand, the supply of the information on good fishing ground in the wide area, large number of fishing boats can share the good fishing ground and the catch is averaged over the wide area of the ocean. This means the averaging of the catch over the wide area of the ocean and prevention of the too much catch and the drain derived from overfishing in narrow area or point. Thus, the improvement and effectiveness of the prediction do not always result in the overfishing, and it can be preservation rather than resource drain in most of case.

The results obtained here are just the application to the data compiled for the northeastern Indian Ocean in 2000. Further trial of the method is necessary for another location and period to check the capability of this method in wide range of both spatial and time scales. This method can be utilized for the effective and reasonable fishing plan and contributed to the fishing operation and the ocean resource management after the verification of these capability.

Acknowledgement

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