DISTRIBUTION OF FISHING GROUNDS IN THE EAST CHINA SEA AS A FUNCTION OF SST AND CHL-A VALIDATED BY DNB OF VIIRS

Yin SONG* and Ichio ASANUMA*
* The Tokyo University of Information Sciences

Introduction

The East China Sea (ECS) is known as the good fishing grounds because of the oligotrophic water of the Kuroshio and the eutrophic water of the Changjiang River being mixed and provided with the various levels of environments for spawning, grazing and migration of different fish species. The Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi-NPP provides the observation opportunities of the distribution of fishing boats by the intensified band of the Day-Night-Band (DNB) as the lights in the night. The distribution of fishing boats exhibited the distribution of fishing activities along the agreement boundaries among regions, where all possible fishing efforts are paid. The analysis of distribution of fishing boats as a function of the sea surface temperature and the chlorophyll-a concentration indicated their fishing activities relative to the water distributions, where fishing boats are approaching to the most productive waters.

The objective of this study is to discuss a possibility of application of satellite observation to estimate fishery resources and the migration of fishery resources in the ECS, where fishery resources are not well controlled among nations in the concept of a sustainable development of resources but only controlled as the governing regions.

Data-A

Location of fishing boats detected by Day-Night-Band of VIIRS

The fishing boats were detected by the DNB of VIIRS on the Suomi-NPP. The DNB is the band inherited band from the Operational Linescan System (OLS) on the Defense Meteorological Satellite Program (DMS-P). The DNB detects the lights of town and fishing boats in the night time, which is available as a band of VIIRS in the real-time.

Data-B

Sea surface temperature and chlorophyll-a concentration

The sea surface temperature (SST) and chlorophyll-a (Chl-a) concentration observed by MODIS and their monthly composite data were used as the reference data of locations of fishing boats detected by the DNB. Although the locations of fishing boats on one day should be compared with the nearest data of SST and Chl-a, the monthly composite data were accepted because of less number of cloud free data.

Data-C

Fishing species corresponding to the locations of fishing boats

As the fishing data of each fishing boats, including spices and amount of catch, were not available in this study, the weekly fishing data provided by the fishery office of the Nagasaki prefecture and the monthly fishing data provided by the Japan Fisheries Information Service Center were applied to determine the major fishing species caught around the locations of fishing boats for each month.

Fig. 1 Distribution of fishing boats detected by the DNB of VIIRS on Suomi-NPP on October 3, 2012.

Fig. 2 Chlorophyll-a distribution (Left) and Sea Surface Temperature distribution (Right) as the monthly composite of April in 2013.

The red line indicates the agreement line between Japan and China, and the green indicates the agreement line between Japan and South Korea with the dashed yellow line which is the northern limit of ECS.

Table 1. Major fish species caught in 3 regions

<table>
<thead>
<tr>
<th>Region</th>
<th>Species</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tsushima WC</td>
<td>Yellowtail</td>
<td>15–18</td>
<td>16–18</td>
<td>20–24</td>
<td>20–24</td>
</tr>
<tr>
<td></td>
<td>Jack mackerel</td>
<td>0.4–2.0</td>
<td>0.1–1.0</td>
<td>0.2–0.6</td>
<td>0.1–0.5</td>
</tr>
<tr>
<td></td>
<td>Jack mackerel</td>
<td>0.1–1.0</td>
<td>0.01–0.6</td>
<td>0.2–0.6</td>
<td>0.04–0.2</td>
</tr>
<tr>
<td>Kuroshio</td>
<td>Yellowtail</td>
<td>22–24</td>
<td>20–25</td>
<td>24–26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Horse mackerel</td>
<td>0.06–0.2</td>
<td>0.1–0.5</td>
<td>0.06–1.5</td>
<td></td>
</tr>
</tbody>
</table>

1. Japanese Flying Squid or Surumeika: Todarodes pacificus
2. Yellowtail: Japanese amberjack, or Bun: Seriola quinqueradiata
3. Jack mackerel, Horse mackerel, or Ajii: Caranginae

Results

The locations of fishing boats were observed and extracted from the DNB of VIIRS on the ECS. The distributions of fishing boats were analyzed with SST and Chl-a observed by the MODIS, of which data were composed for month. The fishery reports, which give the major spices of catch on the ECS by regions, were combined to analyze the locations of fishing boats.

Table 1 is the summary of fish species on the Kuroshio, the Kuroshio Branch and the Tsushima Warm Current for March to June with the range of SST and Chl-a concentration. As indicated on Table 1, the fishing fields of the Yellowtail moved northward from the Kuroshio in March to the Tsushima warm current in June, where SST is around 24 deg-C and Chl-a concentration is around 0.1 mg m$^{-3}$. In contrast, the Japanese Flying Squid was limited in the water around the Tsushima warm current in March and April, where SST is less than 18 deg-C and Chl-a is around 1.0 mg m$^{-3}$. Smaller fishes like the Jack mackerel were distributed in the water of which SST was between 18 and 24 and Chl-a concentration was between 0.2 and 1.0 slightly higher than that of the Kuroshio from March to May.

Although details of amount of catches were not available, the locations of fishing boats, which have the intentions to shift to the water where certain amount of catches are expected, suggest the rough and best estimate of standing stocks of fishes. The ranges of SST and Chl-a concentration for a group of fishing boats exhibits the spices of fishes which have the specific favorites of environment to survive.

Fig. 3 Scatter diagram of locations of fishing boats as a function of Chl-a and SST in March (Top-left), April (Top-right), May (Bottom-left) and June (Bottom-right) of 2013.

The circles were marked for the group of fishing boats at the certain regions with the name of major spices of fishes being caught. The water body on the Kuroshio is located at a high SST and a low Chl-a concentration through all seasons with catches of Yellowtail. The water body corresponding to the Tsushima warm current is located at a low SST and a high Chl-a concentration with catches of Japanese Flying Squid in March, and April and Jack mackerel in May and June. The intermediate water affected by the water from the Changjiang River exhibited the different catches of fish by months.
**Introduction**

The East China Sea (ECS) is the main route of the Kuroshio, the western boundary current, running along the continental shelf, and the Kuroshio experiences the release of the water from the Changjiang River (CR) as the diluted water on the continental shelf. Although the distribution of the diluted water from the CR could be monitored from the satellite observation as a distribution of water color like chlorophyll-a (Chl-a) concentration as a biological parameter, the distribution of diluted water could be explained in traditionally by the water temperature and the salinity as physical parameters. The water from the CR exhibits the maximum runoff in July to August with low salinity water and could be observed on the surface because of the stratification in the summer time. In contrast, the Kuroshio with the warm temperature and the high salinity through all seasons enters to the ECS and interacts with the water from the CR. As a phytoplankton exhibits the seasonal blooming, of which phase is different from the physical and seasonal changes, the Empirical Orthogonal Function (EOF) is introduced to discuss the special and temporal interaction and distribution of waters in the ECS.

**Method**

1. **EOF analysis of physical parameters**

   The water temperature and salinity data observed and combined by the Japan Oceanographic Data Center were used for the EOF analysis. The data is a climatological dataset for each month from 1906 to 2003. Fig. 1 indicated the locations of samples on the ECS for EOF analysis.

2. **EOF analysis of biological parameter**

   The Chl-a distribution derived from the MODIS were used for the EOF analysis the biological parameter, where Chl-a data is only for 2012. Fig. 2 is the Chl-a distribution in January of 2012. The Chl-a data are resampled as Fig. 1.

**Results 1: EOF analysis of water temperature**

Fig. 3-a to 3-f are the results of EOF analysis of water temperature in surface with the spatial distribution of major components and the temporal changes. The first components are located on the western side of the ECS (Fig. 3-a) with the clear seasonal change (Fig. 3-d), which is the diluted water from the CR and is the water body cooled in winter by the westerlies and heated in summer by the stratification. The second components are located along the slope of the continental shelf (Fig. 3-b) with the less seasonal change (Fig. 3-e), which is corresponding to the Kuroshio. The third components are located in the south of the Cheju Island and the Tsushima straight (Fig. 3-c) with the intermediate temporal change between Fig. 3-d and 3-e (Fig. 3-f), which is considered to be the mixed water between the CR water and the Kuroshio.

**Results 2: EOF analysis of salinity**

Fig. 4-a to 4-f are the results of EOF analysis of salinity in surface with the spatial distribution of major components and the temporal changes. The first components are located on the western side of the ECS (Fig. 4-a) with the clear seasonal change (Fig. 4-d) as well as the first component of water temperature, which is the water from the CR and has the maximum dilution in the summer time. The second components are located around the Cheju Island and the Tsushima Straight (Fig. 4-b) with the less seasonal change but with the clearly low salinity in summer (Fig. 4-e), which is corresponding to the mixed water between the CR water and the Kuroshio. The third components are located along the slope of the continental shelf and to the Tsushima Straight (Fig. 4-c) with the most seasonal change (Fig. 4-f), which is corresponding to the Kuroshio holding a high salinity.

**Results 3: EOF analysis of Chl-a**

Fig. 5-a to 5-f are the results of EOF analysis of Chl-a spatial distribution of major components and the temporal changes. The first components are located on the eastern side of the continental shelf (Fig. 5-a) with the less seasonal change and the low Chl-a concentration through the year (Fig. 5-d), which is corresponding to the Kuroshio. The second components are located near the coast of the China main land and the Kyushu Island (Fig. 5-b) with the higher Chl-a concentration than the third components (Fig. 5-c), which could be the typical coastal waters. The third components are located along the eastern end of the continental shelf (Fig. 5-c) with the clear seasonal change (Fig. 5-c), which is corresponding to the intermediate water between the CR water and the Kuroshio.

**Conclusion**

The three components for the water temperature, the salinity and the Chl-a were determined by the EOF analysis on the ECS. The two components were commonly extracted for all parameters, those are the water body along the slope of the continental shelf, which is corresponding to the Kuroshio, and the intermediate water mixed with the CR water and the Kuroshio.

The lowest Chl-a concentration in the Kuroshio is the first component because of the certain amount of water bodies in this EOF analysis. The second and third components of Chl-a was the higher productive waters along the coasts and the intermediate water. As the diluted waters from the CR was not extracted as the EOF component for Chl-a, the CR water body itself does not have the significant contributions to the productivity of phytoplankton in the ECS. But it is obvious that the water body from the CR has the important role physically with the maximum runoff in the summer time.
1. Introduction
Airborne lidars have been developed since 1980s and recently a new generation of airborne aquatic-terrestrial lidars is under the operational use that can penetrate water and map the submerged topography inside a stream (McKeen and Issak, 2011). As streams and rivers are arguably the most dynamic components of natural landscapes, of which physical characteristics are over a wide range of spatiotemporal scales as they respond to both natural and anthropogenic forcing (McKeen et al., 2009). Knowledge of water depth is valuable for computing river discharge and estimating bed material transports by the water surface slope (Legleiter and Overstreet, 2012). Airborne laser bathymetry (ALB) is an established operational technique which has been proven to be an accurate, efficient, cost-effective, save, and flexible method for rapidly charting near-shore water, adjacent beaches and coastal engineering structures (Gunther, 2000, Longenecker, 2002). The ALB collects bathymetry and topography over very shallow or environmentally sensitive waters that are unreachable using conventional survey methods (Irish and Lillycrop, 1999). The ALB provides accurate digital depth model in a 1 to 50 m vertical range with a 25 cm height precision (Collin et al., 2007). At water depths less than about 10 to 20 cm, laser reflections from the water surface can become convolved with channel bed reflections (McKeen and Issak, 2011). Researches are under way to explore the range of water conditions that might limit the use of the ALB over the water with entrained air bubbles in turbulent flows and sediment suspended which reduces laser penetration in the water column and some organic contaminants absorbing laser energy (McKeen and Issak, 2011).

In this study, as the diffused attenuation coefficient, K, determines the detection limit of the ALB, Kd is discussed as a function of SS, CDOM and Chl-a with traditional optical measurements. The limit of Kd for ALB is presented.

2. Lidar equation
Although ALB is a measure of a time difference between a laser beam signal penetrating water column and a volume scattered return from the water bottom (Gunther, 2000), a simple lidar equation was considered (Collin et al., 2002;2007);

\[ P_{\text{final}} = P_{\text{initial}} \exp (-2KD) \]

where \( P_{\text{final}} \) is the received power by the bathymetry system as a signal, \( P_{\text{initial}} \) the transmitted power of laser pulse, \( p \) is the bottom reflectance, \( K \) is the diffused attenuation coefficient, \( D \) is the water depth, and \( P_{\text{final}} \) is a performance of ALB detector system (Kun, 2008). K is determined as a sum of scattering parameters of SS and Chl-a as a proxy of phytoplankton, and the absorption parameter of CDOM as Eq. 2.

\[ K = K_s + K_{Chl-a} + K_{CDOM} \]

Based on this lidar equation, a limit of bathymetry measurement is discussed on the various SS, Chl-a, and CDOM from the shallow waters around Japan.

3. In-situ measurements
Fig. 1 (Left) shows the location of in-situ measurements in Japan including the Yukari River, the Kussharo River, the Mogami River, the Tone River, the Yoshiro River, the Ibo River, the Chikugo River and the Tateyama Bay.

The bathymetry measurement by the ALB off the Tone River and on the Tateyama Bay were referred to discuss the limit of ALB measurement (Fig.1 Right).

Through the in-situ measurements, K was obtained with the measurements of down-welling irradiance using PAR sensor (Biophysical) attached to CTD (XR-620D, RBR) from surface to bottom with a linear regression in the logarithm scale of irradiance. SS was determined with the dry weight measurement of filtered particles on 1.0 and 0.2 μm pore size filter as SS and SS-a. SS is a sum as a SS of SS and SS-a in this paper. CDOM was determined as the absorption coefficient of filtered water at 350 nm by the UV spectrometer meter (U-2000, Hitachi) (Vecchio and Subramaniam, 2004). Chlorophyll-a contained in phytoplankton was extracted and its concentration was determined by the fluorometric measurement using the Fluorometer (Turner).

4. Results
4.1. Limit of depth to be measured by ALB estimated with a simple lidar model
From the typical parameters of ALB and the simple lidar model, Eq.1, the limit of depth measurements by ALB was simulated as a function of K and the bottom reflectance. The limit of depth measurement is defined as the signal detection limit by ALB as a difference between the surface and bottom return, which could be ingested by a log amplified signal.

The bottom reflectance was determined from the in-situ measurement of albedo between the down and up-welling irradiance in the Tateyama Bay. Table 1 indicates the detection limit of water depth for each K. The bottom reflectance, \( P_{\text{final}} \), exhibited a slightly lower detection limit. Although the various combination between K and water depth, K=3 could be selected as the limit of ALB measurements where the water depth is 0.9 to 1.0 m. This detection limit showed a slightly deeper depth than the ALB measurements carried out off and the Tone River.

Table 1. Simulated detection limit by ALB as a function of K and bottom reflectance.

<table>
<thead>
<tr>
<th>K (m-1)</th>
<th>Chl-a</th>
<th>CDOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>3.0</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>3.5</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>4.0</td>
<td>0.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>

4.2. Estimate of K from optical parameters
As the in-situ covers a wide range of water, SS, Chl-a, CDOM, and K, the in-situ data were ordered by K and the higher dataset of K more than 3.0 m-1 were eliminated so as to avoid a complex system of parameters. Fig.2 shows a distribution of each parameter vs. K, which were selected by K less than 3.0 m-1.

SS, Chl-a, and CDOM exhibited the correlation coefficients with K as 0.545, 0.417, and 0.625 respectively. Although SS and Chl-a work as the scattering components, a further study is necessary on the contribution of Chl-a, which partly works as the absorption component CDOM, which works as the absorption component, exhibited the most highest correlation coefficient with K, which suggests a significant contribution to K and CDOM determines the optical properties of water.

5. Discussion
The implementations of ALB to the turbid water regions including coastal waters and rivers need the cost sensitive decisions based on the scientific background to measure the bottom profiles. The diffused attenuation coefficient, K, is one criterion to decide the possibility to measure bathymetries. Two methods to estimate K were studied and the use of a nephelometric turbid unit was suggested to be one simple decision tool to decide the ALB flight.

6. Acknowledgements
This research is supported by the River Works Technology Research and Development Program of the National Institute for Land and Infrastructure Management. The ALB data were provided by the Coast Guard of Japan.

Fig.3 Scatter diagram between observed and simulated K.

TD = 244.13 NTU/3.442 - 1.3 x (3)

The in-situ data were grouped by K and NTU. K (+3.0) with blue dots and K (+3.0) with red dots could be a clear boundary for the diffused attenuation coefficients. In contrast, NTU=40.0 which is corresponding to the depth of 21 cm in the turbidity tube, could be a boundary in NTU, but with some irregular K in a lower NTU values.

Fig.4 Scatter diagram between K and Nephelometric Turbidity

K vs Nephelometric Turbidity