SATELLITE-MEASURED TEMPORAL AND SPATIAL VARIABILITY OF TOKACHI RIVER PLUME

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ABSTRACT

Variations in the extent and dispersal of river plume are important in the study of coastal environment. The objectives of this study are to examine relationship between satellite detected plume area and river discharge and to clarify the temporal and spatial dynamic of plume from Tokachi River, Hokaido, Japan. We used 1.1 km spatial resolution of SeaWiFS normalized water-leaving radiance (nLw) images from 1998 to 2002. Supervised maximum likelihood classification was implemented to define classes of surface water optical properties. Satellite observed plume area was correlated to the amount of river discharge from April to October. First mode (44% of variance) of EOF analysis shows the turbid plume distribution resulting from re-suspension by strong wind mixing along the coast during winter. This mode also shows plume distribution along-shelf direction in spring and late summer. Second mode (17% of variance) shows spring pattern across-shelf direction due to strong discharge of snow melting water.

INTRODUCTION

Coastal zones are important ecosystem that includes the entire continental shelf, occupying about 18% of the surface of the globe, supplying about 90 % of global fish catch and accounting for some 25 % of global productivity (Kishino et al., 2005). Coastal waters are often characterized optically by high concentrations of suspended matter, various phytoplankton pigments and colored dissolved organic material derived from seabed re-suspension or river discharge (Binding et al., 2003; Kishino et al., 2005; Miller & McKee, 2004). River discharge is a primary source of pollutant to coastal area. Suspended material directly affects water column and benthic processes (Miller & McKee, 2004). Some materials can also have negative impact to human, ecosystem health and its productivity (Nezlin et al., 2005; Otero & Siegel, 2004).

River discharge induces river plume (Isobe, 2005). The distribution of river plume is highly variable in coastal environments and varies over a broad spectrum of time and space scale. In the past, severe under-sampling coupled with high spatial and temporal variability limited our knowledge of the coastal ocean. Now there are considerable interest in the use of remotely sensed data to provide synoptic and frequent regional overviews that enable more effective analysis of the spatial and temporal distribution of the plume using surface parameters that can be measured from space (Nezlin et al., 2005; Miller & McKee, 2004).

In this study, we focus on the Tokachi plain, in southeast Hokkaido, Japan (42°09" N to 43°38" N; 142°40" E to 144°02"E) where agriculture cultivation began with the start of 19th century settlement of the area. In general, Hokkaido is well known as the region where deforestation and agriculture land use had drastically progressed since the last 100 years (Hirakawa et al 2003). Deforestation and agricultural land use greatly influences alluvial processes, including erosion, sediment transport and deposition. Tokachi region is a representative agriculture production area in Japan that occupies 22.5 % of the total area of land. One main river system, the Tokachi River system (12 major rivers) irrigates the agriculture area and flows into the Pacific Ocean in Otsu, Toyokoro. The total catchment area of this river system is 9101 km^2. The objectives of this study are to examine relationship between satellite detected plume area and river discharge and to clarify the temporal and spatial dynamic of river plume from Tokachi River, Hokaido, Japan.

DATA AND METHODS

Level 2 (normalized water-leaving radiance at 412, 443, 490, 510, 555 and 670, chlorophyll a and k490) of SeaWiFS local area coverage (LAC) 1.1 km swaths intersecting the region 40°N-45°N, 140°E-150°E for the period of January 1 (Julian Day 1) 1998 to December 31 (Julian Day 365) 2002 were downloaded from the Goddard Distributed Active Archive Center. The study area was than subset from the images to geographic extents of 42°N-43°N, 143°E-145°E. In this study only 293 cloud free images were analyzed (52 images for 1998; 57 for 1999; 66 for 2000; 65 for 2001; 53 for 2002).

Training region polygons were manually drawn using composite images (nLw555 (red)/nLw490 (green)/nLw412 (blue) as it gives the best visual guide of optical boundaries. The mean and standard deviation of the spectral signature was computed within each training polygon for each band (nLw412, nLw443, nLw490, nLw510, nLw555 and nLw670) using GIS. Supervised maximum likelihood classification was performed using these statistics and all bands as input. The classified images were converted to polygon, projected to WGS 84 UTM zone 54N and area of each class was calculated.

Daily river discharge data were obtained from the River Environment Engineering Division, River Bureau, Ministry of Construction. Relationship between the signal (river discharge) and the response (plume area) was analyzed using linear correlation analysis. 1-day lag river discharge data prior to the plume area was used as it results in the best correlation.

In this study, we also examined the seasonal and spatial change of spectral signatures along-shelf and across-shelf directions from the mouth of Tokachi River. Empirical Orthogonal Function (EOF) analysis is a useful method for expressing the spatial and temporal variability of time series datasets. This analysis was applied to the anomaly of nLw555 monthly averaged images.

RESULTS AND DISCUSSION

Relationship between Satellite Measured River Plume and River Discharge

Tokachi River with 156 km in length is the second largest river after Ishikari River in Hokkaido. Discharge of freshwater from the river flow to the coastal zone at Otsu, Toyokoro, Nakagawa-gun to the Pacific Ocean with flow volume of 7 billion tons per year, with average discharge of 233 m^{3}s^{-1} from 1998 to 2002 (Ministry of Construction, 1998 - 2002). Freshwater discharge from this river is bimodal with a spring peak driven by snow melting with average of river discharge at 307 m^{3}s^{-1}. The second peak is in late summer and early autumn because of high rainfall (Figure 1). However medium discharge occurs in summer and lowest discharge in winter. Large amount of discharge was observed in 2000, followed by 1998 and 2001, while relatively small amount of discharge in 1999 and 2002.

Analysis of statistical relationship between the signal (river discharge) and the response (plume area) was done to evaluate the time lag between the river discharge and the plume. The linear correlation coefficients were calculated between river discharge and plume, testing 0-3 days lag of river discharge prior to the plume. 1-day lag river discharge and the plume area showed no correlation for each year from January to December. However there is a significant correlation ($P<0.01$) in the months of April to October for the 5 years with correlation coefficient (R) of 0.58. The best correlation was observed at 1-day time lag, i.e., the day immediately following the river discharge event. As the time lag increased, the correlation gradually decreased. In 1998 and 2001, strong correlation was observed with correlation coefficient of 0.76 and 0.67 respectively. However the relationships are minimal with correlation coefficient of 0.46 and 0.40 in 2000 and 2002 respectively. Meanwhile lowest correlation of 0.36 was obtained in 1999.

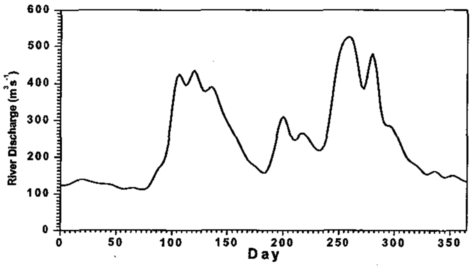

Figure 1. The climatological mean Tokachi river discharge volume, calculated from the 5 year mean of 8 day periods

This study showed that there are inter annual variation of correlation coefficient. The inter-annual variation of correlation coefficient occurs due to difference in volume of discharge water. Figure 2 shows clearly the relationship between plume area and freshwater discharge. During April to October, the graph showed that when volume of river discharge was high, satellite measures plume area relatively large. The analysis of linear correlation between total plume area from April to October and correlation coefficient of each year shows that river discharge influences plume area (R^2=0.91).

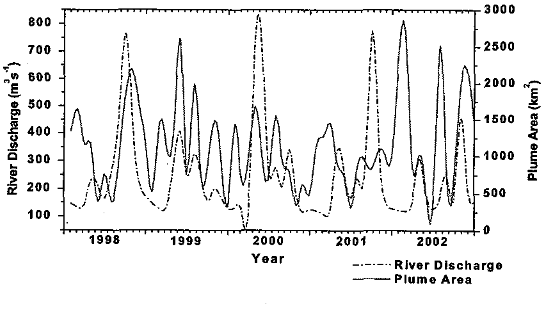

Figure 2. Relationship between plume area and freshwater discharge

However there was no correlation in the winter period for the 5 years. During this period, low water discharge was observed with high extent of plume area. These results suggest that satellite observed plume area is correlated to the amount of river discharge from April to October.

Seasonal Variation of Surface Water Optical Characteristics

Seasonal variability in surface water optical characteristics was observed between spring to early autumn and winter period. During spring to early autumn period, lower reflectances were observed from the lower band. Meanwhile in winter (November to March), spectral signatures were characterized with high reflectance in the whole visible wavelength (Figure 3). However there was no correlation between river discharge and satellite observed plume area.

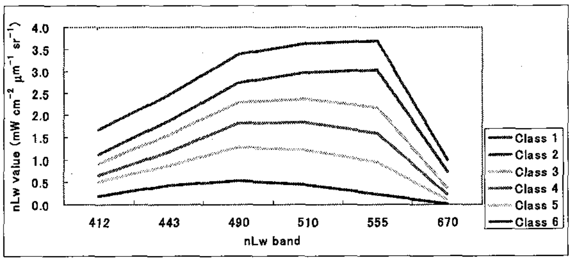

Figure 3. The mean spectral signature of each of the six optical classes during winter

Using the statistics of spectral signature, we obtained six classes. Class 1 and 2 (representing plume area) were combined, class 3 (peripheral to plume area), class 4 (resuspension) and combination of classes 5 and 6 which characterizes offshore waters. The result showed four classes were obtained in winter due to occurrences of resuspension but only three classes in spring to early autumn (Figure 4). Separation of each spectral classes implemented in this study had classification accuracy of 84 %. These results suggest that turbid water along shelf direction may be generated due to re-suspension by strong wind mixing along the coastal zone.

Interannual Variability of Plume

Time series of 5-years anomaly of monthly images sequence of nLw555 can be used to summarize the spatial and temporal variability of the plume using empirical orthogonal function (EOF) (Otero & Siegel 2004). In this study, the first 2 modes of the EOF represent 61 % of the total variance (Figure 5).

The first EOF mode explains about 44 % of temporal and spatial variability. Temporal modulation indicates negative value in January to March in 1998, January to February (1999), February to March (2000) and January (2001) but in 2002, the amplitude shows strong positive in January to March in winter season. This occurs due to high value of radiance in January and February (2002) exceeding 3.5 compared to the same period during the other years (1998 to 2001). Monthly average of wind stress in this period was also strong, however the discharge of freshwater was small. This pattern indicates the turbid water distribution due to re-suspension by strong wind mixing along the coast (along-shelf direction) in winter.

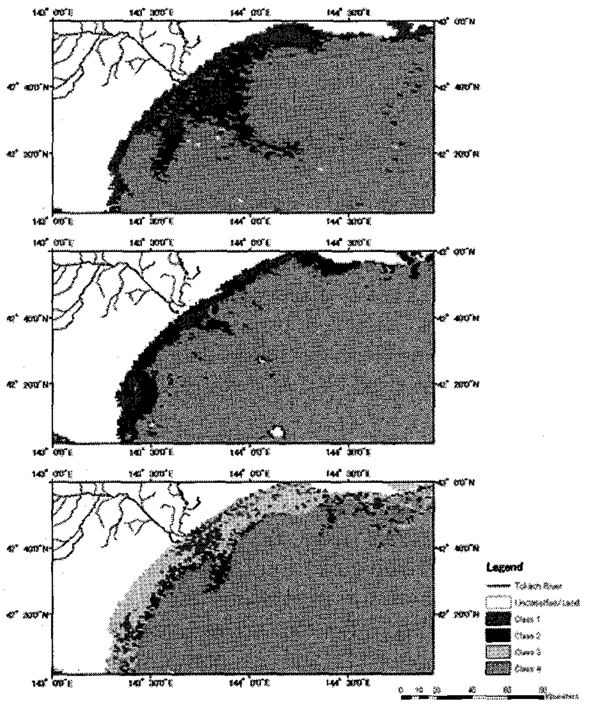

Figure 4. Application of the supervised maximum likelihood classification method revealed, plume induced by river discharge during spring, April 26, 2002 (top), during summer, July 26, 2002 (middle) and turbid water caused by resuspension (occurrence of class 3) during winter period, January 26, 2002 (bottom)

The positive value occurred in spring to early autumn (June and August to October, 1998, May and October 1999, April and June 2000, and June 2002) while negative value in July 2001. From August to October 1998, discharge water was the highest compared to other years exceeding 1000 m^3s^{-1} and this influenced the radiance value which was the highest at this time. This also was seen in May and October 1999, April and June 2000 and June 2002 where discharge influences the radiance value with correlation coefficient at 0.64. The use of anomaly clearly shows temporal distribution of plume. This pattern indicates the plume observed along shelf was influenced by river discharge. Linear correlation analysis shows the amplitude had a correlation with river discharge in April to October with correlation coefficient of 0.59 in 1998, 0.81 in 1999, 0.45 in 2000, 0.47 in 2001 and 0.24 in 2002.

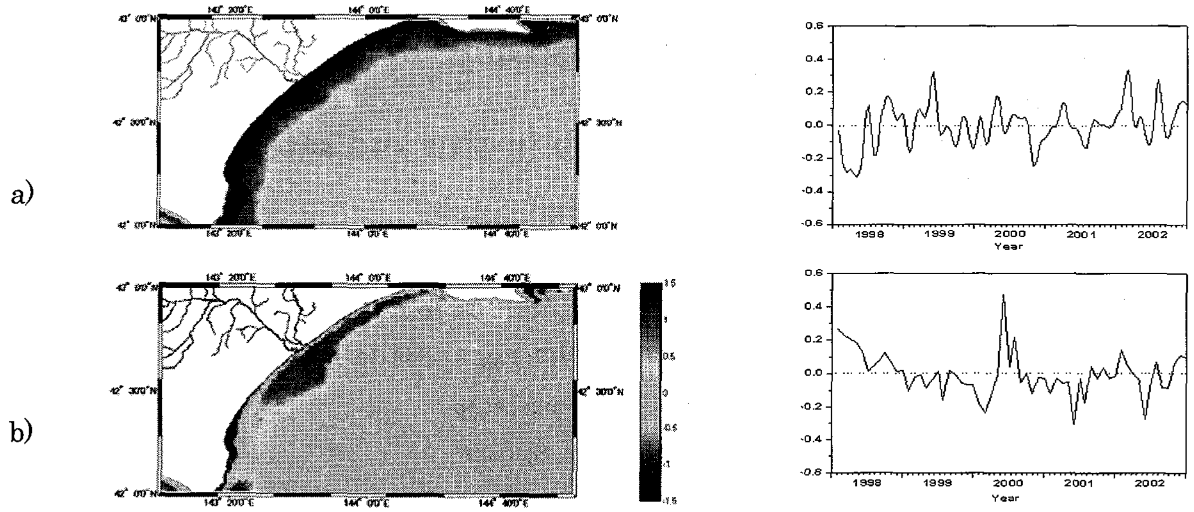

Figure 5. EOF analysis showing interannual variability, first mode (a), and second mode (b), which together explain 61% of total variance. Each mode consists of a space pattern (left) and time series (right).

The second mode of EOF explains about 17% of variance which indicates the spring pattern across-shelf direction. High signal of temporal amplitude occurred in May 2000 (positive value) because the radiance was the highest compared to other years. High signal of temporal amplitude occurred in May due to large discharge of snow melting water.

CONCLUSIONS

This study shows that ocean color satellites can be used to monitor the pattern and size of plume area on seasonal and interannual time scale. We found that correlation exist between plume area and river discharge during April to October. This happen because of high volume of river discharge corresponds to large plume detected by satellite. However there was no correlation between plume area and river discharge during winter. The results of image classification showed that satellite measured plume area due to re-suspension of suspended matter.

Overall first mode of EOF analysis indicate plume distribution along shelf direction in spring and early autumn due to river discharge and turbid water distribution resulting from re-suspension by strong wind mixing along the coast during winter. Second mode shows spring pattern across-shelf direction due to strong discharge of snow melting water.

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