Estimating the spatial and temporal distributions of chlorophyll concentrations in coastal waters of Taiwan using improved MODIS-Aqua ocean color data

Chih-Hua CHANG and You-Sin WU

Abstract: This work reprocesses the standard MODIS-Aqua chlorophyll (Chl-a, mg/m^3) data for a comprehensive assessment of the coastal water quality in Taiwan. The near-infrared (NIR) and shortwave infrared (SWIR) combined method were selected to improve the availability of turbid water pixels in coastal regions. The standard MODIS OC3m Chl-a data for Taiwan's coastal waters were selected by comparing that to a matchup dataset. The spatial and temporal distributions, as well as the seasonal patterns for Chl-a in coastal regions were resolved between 2003 and 2013.

Keywords: Water quality; Ocean color products; Coastal waters; Atmospheric correction.

1. Introduction

Coastal water quality is closely associated with near-coast human activities of a region, and also reflects the level of pollution in water that is discharged from inland areas. Heavily populated cities, industry and intensive agricultural activities in Taiwan are concentrated on the western plains with distances to the adjacent shoreline being less than 40 kilometers. As shown on Figure 1, Taiwan's coastal region are divided into 17 administrative regions (isolated islands are excluded), in which water qualities are managed separately by 16 cities/counties based on seasonal or annual information provided by 89 Environmental Protection Administration (EPA) sampling stations. However, most of the sampling locations are designed to monitor water qualities near river mouths, ecological sensitive areas, or discharge/intake points of major industrial facilities and power plants, which are not spatially representative at the administrative region level.

Recently, increasing sediment and nutrient loads have gained attention based the need to comprehensively assess the eutrophication status of each

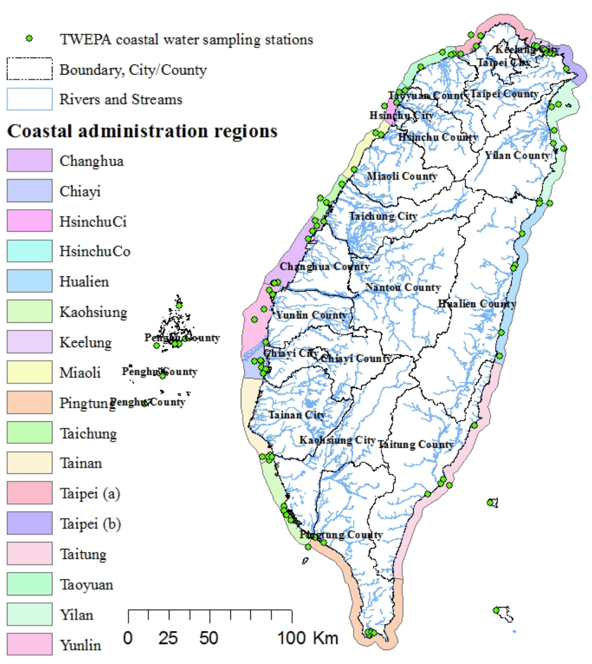


Figure 1. Taiwan's coastal administration regions

administrative region at a higher temporal frequency and a wider spatial scale. Ocean color (OC) chlorophyll products (Chl-a, mg/m^3) derived by satellite remote sensing have the potential to provide adequate data. Two important issues when applying standard MODIS (moderate resolution imaging spectroradiometer) OC data for the assessment of coastal water quality are highlighted here: (1) the standard MODIS atmospheric correction method that uses near-infrared band (NIR) only, often provides invalid results for turbid waters, leading to a significantly data loss in coastal regions, and (2) the standard MODIS OC algorithm for retrieving chlorophyll concentrations (Chl-a, mg/m^3) from ocean color might not be optimal when comparing to in-situ data collected, specifically from Taiwan's coastal waters. Therefore, this study aims to produce improved Chl-a OC product for a comprehensive assessment of the coastal water quality in Taiwan by (1) using the NIR and shortwave infrared band (SWIR) combined method to improve the availability of turbid water pixels in coastal regions, and (2) identifying the best matched retrieval algorithm through the comparisons between different Chl-a products and a matchup in-situ dataset comprising measurements from 98 EPA routine stations between 2003 and 2013. This study help equips Taiwan coastal managers with an improved assessment tool.

2. NIR-SWIR atmospheric correction algorithm

For turbid coastal waters, the NASA's standard atmospheric correction method produces error sea-surface reflectance data which are zero or negative values in the visible (blue), due to the assumption that the water pixels are black (zero ocean radiance contributions) in NIR bands (Lavender *et al.*, 2005). The black water assumption thus was examined (Wang & Shi, 2005) and is not appropriate for turbid and very turbid waters in coastal zones (Shi & Wang, 2009). Recently, Wang and Shi (2007) proposed a combined NIR-SWIR atmospheric correction algorithm for the MODIS data on Aqua, which uses the standard NIR method and the improved SWIR algorithm for the open oceans and turbid waters, respectively. The improved performance of the new NIR-SWIR approach improves the OC products, such as the diffuse attenuation coefficient (Wang *et al.*, 2009) and the Chl-a concentrations (Wang *et al.*, 2007), in coastal regions containing extremely turbid waters. The performance of two atmospheric correction methods in deriving Chl-a product from the sea reflectance is compared in our study area (Figure 2). The result shows that using the NIR-SWIR method can significantly increase the number of available Chl-a data pixels by 10% in the coastal administrative regions.

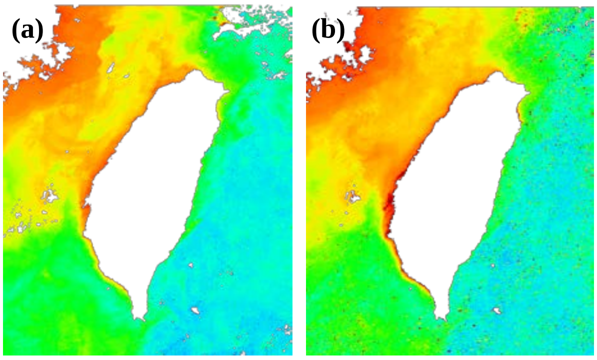


Figure 2. The OC3M Chl-a product derived from Level 2 MODIS-Aqua monthly composite imagery which is atmospheric corrected by (a) the standard NIR algorithm, and (b) the NIR-SWIR algorithm.

3. Comparisons between OC Chl-a products and a matchup in-situ dataset

We establish a matchup in-situ dataset which consists of a total of 4,300 Chl-a data points collected from 98 selected seasonal sampling stations for 11 years (2003-2013). After a comprehensive comparison of 4 OC Chl-a products (OC2, OC3, OC3C and OC3M) and the matchup in-situ dataset, the standard OC3M algorithm was selected for the processing of Chl-a concentrations in Taiwan's coastal administration regions because of the least errors (R^2=0.07). Although the OC3M Chl-a product was demonstrated to be optimal for the study area and relatively lined up well with the multi-year in-situ (Figure 3), it still requires further modification for accurately deriving Chl-a concentrations. The correction of OC3M algorithm was not included in this paper.

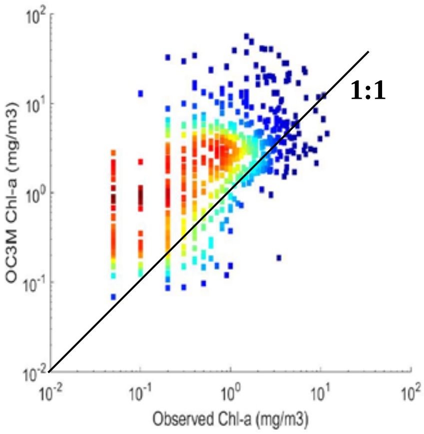


Figure 3. Comparison between the OC3M Chl-a product and the matchup in-situ dataset (N=4,300).

4. The spatial and temporal distributions of region based Chl-a concentrations

The spatial and temporal distributions of Chl-a concentrations in coastal administration regions are resolved using 506 sets of 8-day composite MODIS-Aqua images through 11 years (2003-2013).

4.1. Spatial distributions

Boxplots were used to organize the distributions of 8-day average Chl-a values for each region through 11 years. The 2003 and 2013 boxplots are shown on Figure 4a and Figure 4b, respectively, to examine the spatial relationships and their changes between 2003 and 2013. The spatial relationships show that the levels of Chl-a in western regions (10 regions between Taoyuan and Kaohsiung) are significantly higher than that in southern (Pingtung), northern (Taipei A, Keelung and Taipei B), and eastern regions (Ilan, Hualien and Taitung). In addition, the spatial relationship was not significantly changed during 11 years.

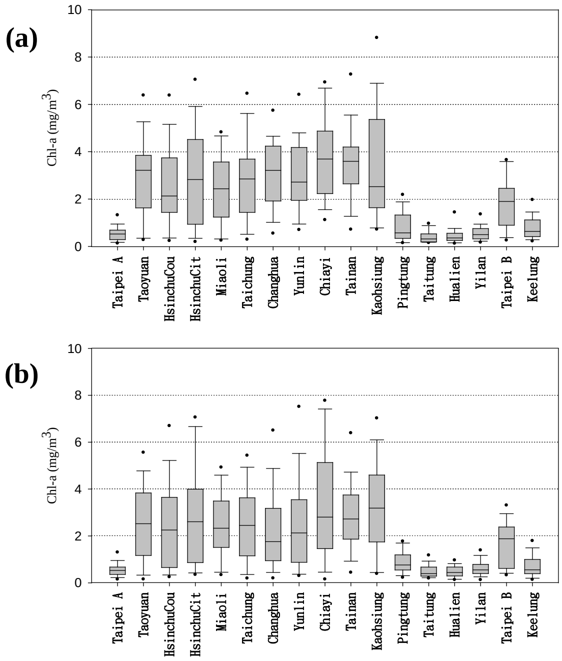
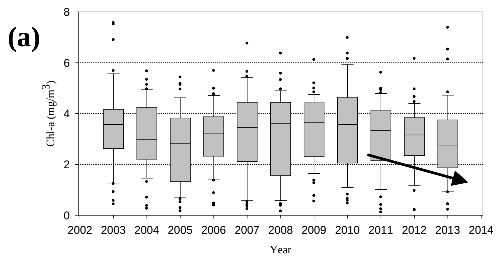


Figure 4. The OC derived 8-day average Chl-a concentrations of 17 coastal administration regions in (a) 2003, and (b) 2013.

4.2. Temporal trends

Generally, the temporal trends for the levels of the median values of region based 8-day average Chl-a during 2003 to 2013 were almost even in all coastal regions (Figure 5). The OC product is capable to obtain maximum 46 region based 8-day average Chl-a values in a year. The high frequency of monitoring helped capture that the levels of Chl-a in the period between 2011 and 2013 slightly decreasing in most western regions (Figure 5a, taking Tainan as an example), but increases in all eastern regions (Figure 5b, taking Ilan as an example). It is noted that the recent increasing trends in Chl-a for east coastal regions whereas the water quality are commonly much clear were not shown on the in-situ data monitored by EPA stations.



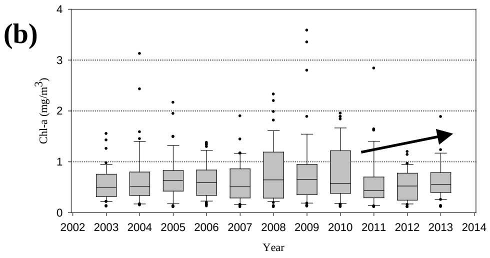


Figure 5. The OC derived 8-day average Chl-a concentrations during 2003 to 2013 in (a) Tainan, and (b) Ilan coastal regions.

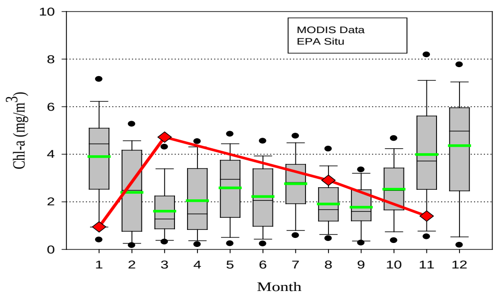


Figure 6. The seasonal/monthly levels of Chl-a distributions in Changhua coastal region during 2003 to 2013.

4.3. Seasonal patterns

Figure 6 shows the seasonal (monthly) levels of Chl-a for 11 years in Changhua coastal region using both EPA station (EPA Situ) and region based OC data (MODIS). Because many EPA stations are located near river mouths (Figure 1), the levels of station data are particularly low during dry seasons (winter, early spring, and late autumn). The OC product comprehensively assesses the Chl-a distribution for the entire region, and shows a completely different pattern to station data. Figure 7 maps the monthly distribution of Chl-a concentrations for Taiwan's coastal regions using the enhanced OC product. The cause of high Chl-a levels in Taiwan's west coastal regions during dry months is possibly due to a relatively warmer water temperature of Taiwan Strait during winter, or the influence of nutrient-rich plumes from the China south-eastern coastal region. Importantly, the contributions of external sources (from Taiwan Strait) to the Chl-a levels in Taiwan west coastal regions are relatively higher than that from internal sources (terrestrial export).

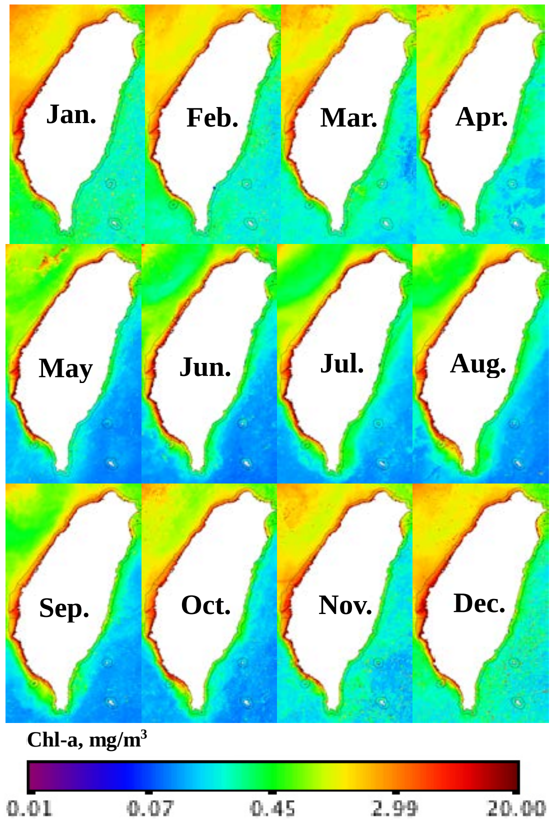


Figure 7. Mapping the monthly distributions of Chl-a concentrations in Taiwan's coastal regions.

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Chih-Hua Chang

National Cheng Kung University, Tainan, Taiwan

No. 1, University Rd., Dept. Environmental Engineering

chihhua@mail.ncku.edu.tw

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