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Evaluation of the sensitivity of China's next-generation ocean satellite sensor MWI onboard the Tiangong-2 space lab over inland waters

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ABSTRACT

The Moderate-resolution Wide-wavelengths Imager (MWI) is the next-generation ocean-color sensor independently designed by China and was successfully launched on September 15, 2016 onboard the Tiangong-2 (TG-2) Space Lab. It is currently urgent to assess the capability and data quality of the MWI sensor to determine its future applications. In this study, we first assessed the signal-to-noise ratio (SNR) and the radiometric sensitivity of the MWI. With this goal, we chose the third largest freshwater lake in China, Lake Taihu, as our test area and assessed the capability of the MWI to monitor the turbid inland waters by comparing its consistency with that of Moderate Resolution Imaging Spectroradiometer (MODIS) data and Geostationary Ocean Color Imager (GOCI) data. Our results show that (1) the SNR values of the MWI are greater than 400 in the visible band and are sufficient to effectively avoid ocean-color data errors caused by the sensor noise; however, the SNR values of the MWI are below 200 in the near-infrared (NIR) band and are lower than the theoretical expectation for the design of ocean-color sensors; (2) on the one hand, the MWI-derived remote sensing reflectance (R_{rs}) data have large errors in the blue band ($R^2 < 0.20$, MAPE < 50%) but reduced errors in the red and NIR bands with a high correlation ($R^2 > 0.90$, MAPE < 10%) compared with in situ R_{rs}; on the other hand, the MWI-derived R_{rs} data are generally consistent with the MODIS- and GOCI-derived R_{rs} data ($R^2 > 0.90$, MAPE < 10%); and (3) the MWI-derived concentration distributions of cyanobacterial algal blooms and suspended particulate matter (SPM) in Lake Taihu exhibit high spatial resolutions and good accuracies and are in good agreement with the corresponding distributions yielded by the MODIS and GOCI satellites ($R^2 > 0.90$, MAPE < 10%). However, the MWI cannot detect signals at the important 700–710 bands and consequently has a relatively weak capability to detect chlorophyll-*a* (Chla) concentrations in inland waters. In summary, as the Chinese next-generation ocean-color sensor, the overall performance metrics of the MWI approach the present international level. Meanwhile, we suggest that the band of the MWI can be further optimized to improve the derived SNR values in the near-infrared band in order to satisfy the requirements of satellite observations over inland waters.

1. Introduction

Inland waters, such as rivers, lakes, and reservoirs, interact directly with human society and thus play an indispensable role in recreation, the food supply, commerce, transportation, and human health (Guo, 2007; Palmer et al., 2015). The assessment and monitoring of inland waters are crucial to our ability to understand and disentangle the effects of environmental changes on freshwater ecosystems and to model their future changes. Satellite remote sensing has been widely applied to monitor inland waters over the past decade, and a number of ocean-color sensors have been used for lake surveys (Duan et al., 2014a; Kutser et al., 2005; Matthews, 2011), including the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), the MODerate resolution Imaging Spectroradiometer (MODIS), the MEdium Resolution Imaging Spectrometer (MERIS), the Korean Geostationary Ocean Color Imager (GOCI), the Visible Infrared Imaging Radiometer Suite (VIIRS) and most recently, the Ocean and Land Color Instrument (OLCI). These mainstream ocean-color sensors are equipped with typical spatial resolutions of 300–1000 m, approximately daily data acquisition rates, typically 8–18 spectral bands, and high signal-to-noise ratios (SNRs) for accurate radiometric performances over water targets (Ruddick et al., 2016). However, the optically active constituents (OACs) of inland lakes are quite complex, often vary at a fast speed and thus independently require improved spectral and radiometric resolutions, as well as improved spatial and temporal resolutions with respect to those of currently existing satellites (IOCCG, 2012; Mouw et al., 2015; Palmer et al., 2015).

Tiangong-2 (TG-2) is a Chinese space laboratory and part of the Project

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921-2 space station program. On September 15, 2016, the newest-generation Chinese ocean-color sensor, the Moderate-resolution Wide-wavelengths Image (MWI), onboard the TG-2 Space lab, was successfully launched, which prepares China for loading ocean-color satellite sensors onboard ocean series satellites (HY-1E and HY-1F) in the future and provides more satellite data for aquatic remote sensing of the Earth. The MWI sensor has 14 programmable visible and NIR bands (400–1040 nm), two shortwave infrared (SWIR) bands (1243–1252 nm and 1630–1654 nm), and two thermal infrared bands (8.125–8.825 μm and 8.925–9.275 μm), whose designed spatial resolutions are 100 m, 200 m, and 400 m, respectively, at the ground surface, an instantaneous field of view (IFOV) angle of 42°, and a swath width of 300 km (Wei et al., 2017). Since the MWI is similar to the mainstream ocean-color sensors, such as MODIS and MERIS, the MWI is expected to be a new source of ocean-color remote sensing data of inland waters. In particular, the MWI has many visible and NIR bands that can be applied to ocean-color observations, and its spatial resolution (100 m) is also higher than those of current mainstream ocean-color sensors. Thus, the MWI, in theory, can effectively provide ocean-color remote sensing data for inland waters, especially for those with severe eutrophication, highly turbid waters, and small lakes and reservoirs.

There have been some preliminary assessments on the accuracy of the MWI ocean-color products (He et al., 2017), which have shown that MWI-derived L_{wn} values agree quite well with in situ L_{wn} and GOCI-derived L_{wn} values, and the corresponding correlation coefficients are all greater than 0.90. Specifically, the errors are all within 10% in the range of 443–750 nm and are approximately 20% at 413 nm and 865 nm; additionally, MWI-derived Chla concentrations are also in good agreement with the corresponding MODIS- and VIIRS-derived concentrations. However, unlike ocean waters, the optical properties of inland waters, such as lakes, are more complex and are severely affected by human activities. So far, the capability of the MWI to monitor these regions has not yet been assessed.

Lake Taihu, the third largest freshwater lake in China, has a surface water area of 2338 km^2 and is located in an economically well-developed region in eastern China. In the past 40 years, because of rapid economic development in its reaches, Lake Taihu has been strongly disturbed by human activities and has suffered from severe eutrophication, with frequent occurrences of cyanobacterial blooms and high Chla concentrations (Duan et al., 2009). Moreover, algae are easily accumulated in lakes and bays, and after their deaths, decomposition occurs and produces a large quantity of colored dissolved organic matter (CDOM), which eventually leads to black water bodies (Duan et al., 2016; Duan et al., 2014b). Additionally, Lake Taihu is shallow (average water depth of 1.8 m); hence, sediments are easily re-suspended due to winds (Zhang et al., 2014b). River-water systems are well-developed, and a large amount of turbid water flows into Lake Taihu every year. Consequently, it is highly turbid, and its optical properties are controlled by suspended inorganic particles (Duan et al., 2010). Thus, as a representative of water bodies with complex optical properties, Lake Taihu is ideal for testing the capability of an ocean-color sensor to monitor inland waters.

The main goals of this study include (1) assessing the radiometric capability of the MWI sensor (SNR, radiometric sensitivity); (2) assessing its capability and performance at obtaining water quality parameters for inland waters (e.g., R_{rs}, Chla, SPM); and (3) comparing MWI-derived products with the products of mainstream ocean-water sensors, such as MODIS, MERIS and GOCI. This study aims to understand the capability and potential applications of the MWI to monitor inland waters and to give detailed suggestions in order to magnify the role of the MWI in monitoring the water quality of global inland lakes after its official satellite launch in the future.

2. Materials and methods

2.1. Data

2.1.1. Field data

A field trip was conducted on March 14, 2017 when the TG-2 space lab with the MWI sensor flew over Lake Taihu (Fig. 1), with a total of 12

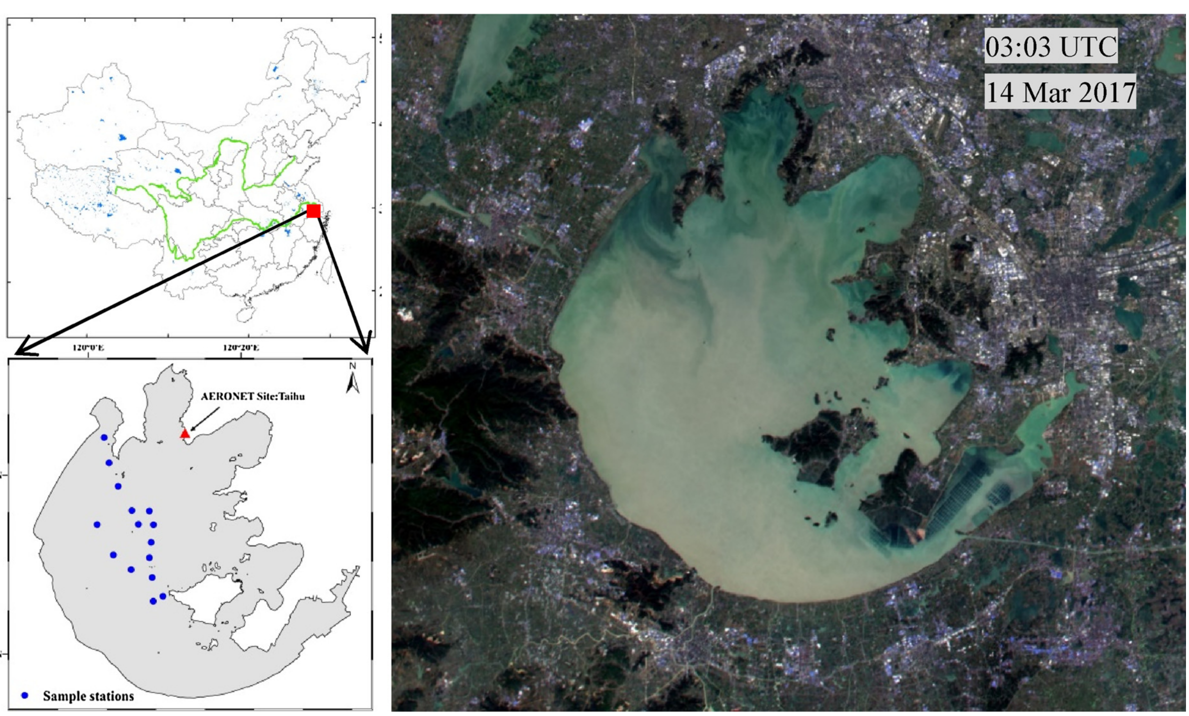

Fig. 1. Location of Lake Taihu, China. The blue symbols indicate stations where in situ measurements were collected on 14 Mar 2017, and the red triangle is the location of AERONET Taihu (https://aeronet.gsfc.nasa.gov/new_web/photo_db/Taihu.html). The right image is a view of the Lake Taihu captured by the Moderate-resolution Wide-wavelengths Imager (MWI) instrument onboard the Chinese Tian-Gong II space lab (TG-2), which was launched on 15 Sep 2016. A turbid plume of re-suspended sediment is clearly visible on the true-color Red-Green-Blue composite image (R: 665 nm, G: 565 nm, B: 490 nm), from the TG-2 MWI on 14 Mar 2017. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).