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Atmospheric correction of geostationary Himawari-8 satellite data for Total Suspended Sediment mapping: A case study in the Coastal Waters of Western Australia

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ABSTRACT

Recent studies in the application of geostationary satellite sensors, such as the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) onboard the European Union's meteorological satellite, and the Geostationary Ocean Color Imager (GOCI) from South Korea, to monitor the Total Suspended Sediment (TSS) in coastal waters have shown that the higher temporal dynamics in the coastal processes can be better achieved with high temporal resolution geostationary satellite sensors. The availability of the geostationary satellite, Himawari-8 carrying the Advanced Himawari Imager (AHI) sensor with visible, Near InfraRed (NIR) and Shortwave InfraRed (SWIR) bands over the coastal waters of Australia has prompted this study to test the feasibility of AHI in mapping TSS concentration. In this study, we present an atmospheric correction method for AHI data using two different aerosol correction methods, a combination of two SWIR bands, and a combination of one NIR and one SWIR band. The outcome from this study indicated that the atmospherically corrected AHI data at 10 min temporal resolution can be used to discern TSS concentrations greater than ~0.15 mg/L when solar zenith angles (θ_0) are less than 60°. The result of the cross-validation of AHI derived TSS concentration, with MODIS-Aqua and Lansat-8 Operational Land Imager (OLI) derived TSS concentration showed good correlation, with correlation coefficients $r = 0.71$ and $r = 0.91$, respectively.

1. Introduction

Monitoring the status of ocean color in the past has been mostly met by low altitude, polar orbiting satellites with either a dedicated ocean color sensor or sensors that were primarily designed for terrestrial monitoring (IOCCG, 2000). Widely used historical ocean color sensors with dedicated ocean color bands employed in mapping Total Suspended Sediment (TSS) included the Coastal Zone Color Scanner (CZCS) (Viollier and Sturm, 1984), Sea-Viewing Wide Field-of-view Sensor (SeaWiFS) (Burenko et al., 2001; Myint and Walker, 2002; Binding et al., 2003; Fettweis et al., 2007), and the MEdium Resolution Imaging Spectrometer (MERIS) (Kratzer et al., 2008; Odermatt et al., 2008; Doxaran et al., 2014). The currently operational polar orbiting sensor with dedicated ocean color bands used in TSS mapping is the MODerate resolution Imaging Spectrometer (MODIS) on board the Terra and Aqua satellites (Miller and McKee, 2004; Wang et al., 2009a; Li et al., 2010; Constantin et al., 2016) and the recently launched Sentinel-3A in February 2016 with Ocean and Land Colour Instrument (OLCI) as part of the European Commission's Copernicus programme (Donlon et al., 2012). The MODIS instruments have passed their designed life-spans (MODIS Web, 2017). Landsat based sensors, which were primarily designed for use in terrestrial monitoring, have also been extensively used in marine applications. For example, TSS mapping in coastal environments was carried out using the earliest Multispectral Scanner (MSS) and Thematic Mapper (TM) aboard Landsat satellites 1 to 5 (Klemas et al., 1973; Kim, 1980; Wang et al., 2006a; Zhou et al., 2006) and more recently using the currently operational Landsat sensors, Enhanced Thematic Mapper Plus (ETM+) (Kallio et al., 2008; Wang et al., 2009b) and Operational Land Imager (OLI) (Vanhellemont and Ruddick, 2014b; Cai et al., 2015; Vanhellemont and Ruddick, 2015; Ody et al., 2016; Zhang et al., 2016) aboard Landsat-7 and Landsat-8 respectively.

The advantage of low earth orbiting satellite sensors are numerous, and have far surpassed the spatiotemporal limitations inherent in the traditional *in situ* sampling methods used in water quality monitoring. Further, notwithstanding the availability of the high spatial resolution (~1.5–10 m) of commercial satellite sensors such as WorldView 2–4, Satellite Pour l'Observation de la Terre (SPOT) 6–7, and Advanced Land Observing Satellite (ALOS) 2, the freely accessible low earth orbiting

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sensors such as MODIS-Aqua/Terra and Landsat-7 and Landsat-8 with global spatial coverage, provide ocean color data for mapping TSS concentration at adequate spatial resolutions from 30 m to 0.25–1.0 km respectively. However, the temporal resolutions of MODIS and Landsat sensors are generally ~1–2 days and ~16 days respectively, thus data from these sensors are sufficient to differentiate, at best, daily TSS variability during cloud free periods, or seasonal variability of TSS concentration for most open ocean waters (Neukermans et al., 2009). In contrast, most coastal waters are characterized by highly energetic environments that undergo frequent horizontal advection and vertical resuspension from the influence of wind driven and tidal currents, thus the variability in biogeochemical processes occurs at relatively short timescales (Van Raaphorst et al., 1998). For instance, Thompson et al. (2011) reported that apart from the wind driven waves, the resuspension due to tidal forcing alone can account for from approximately 8% to 13% for a short (< 30 min) duration timescale. The temporal resolution needed to discern such diurnal variability from daily or seasonal variation in TSS concentration is much higher than currently afforded by low earth orbiting satellite sensors. Satellite sensors with the capability of acquiring numerous images per day, currently available only through high earth orbiting geostationary satellite sensors, can provide the high temporal resolution required for studies of coastal dynamics.

First of the pioneering studies in estimating TSS using a geostationary satellite sensor was carried out by Neukermans et al. (2009) using the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) onboard the European Union's meteorological satellite (EUMETSAT). Following Neukermans et al. (2009), a limited number of studies have been carried out using the SEVIRI sensor (Salama and Shen, 2010; Neukermans et al., 2012) and the dedicated ocean color sensor, Geostationary Ocean Color Imager (GOCI) (Choi et al., 2014; Doxaran et al., 2014; Huang et al., 2015), on board the Communication, Ocean and Meteorological Satellite (COMS) operated by Korean Aerospace Research Institute. The SEVIRI instrument was primarily developed for meteorological purposes with broad spectral resolution in the visible and near infrared (NIR) bands, thus it has limitations in ocean color applications. Nonetheless, SEVIRI has demonstrated its usefulness in the study of the temporal dynamics of coastal waters because of its high temporal resolution (data available every 15 min) and its ability to map TSS concentration using just a single Red or NIR band at a spatial resolution of 3.0 × 6.5 km (Neukermans et al., 2009). The GOCI sensor, primarily developed for ocean color applications with six visible (412, 443, 490, 555, 660, and 680 nm) and two NIR (745 and 865 nm) bands, has shown that it can be used in mapping the dynamics of TSS concentration in coastal waters at high temporal resolution (eight images per day) (He et al., 2013), but the absence of spectral bands in shortwave infrared (SWIR) bands has proven challenging in atmospheric correction of data collected over highly turbid coastal waters (Wang et al., 2013).

This study was prompted by the success of the SEVIRI and GOCI sensors in mapping TSS concentration in coastal waters. We explore the feasibility of the Advanced Himawari Imager (AHI) on board the Japanese meteorological agency's geostationary meteorological satellite, Himawari-8, in mapping the TSS variability in coastal waters of Western Australia. The AHI sensor has the required spectral bands in the SWIR wavelength which GOCI currently lacks for atmospheric correction of turbid coastal waters and the spatiotemporal resolution of 10 min for full earth disk needed for the detection of high temporal dynamics in coastal waters in Western Australia. Further, there are recently launched and planned missions involving series of meteorological and non-meteorological geostationary satellite sensors with bands capable of making earth surface observations. The non-meteorological geostationary sensor with dedicated earth surface observation bands are GOCI-II by South Korea, GEO-CAPE by the United States, HR-GEO by India and Geo-Oculus by Europe. The meteorological geostationary sensor with required bands and the potential for land and ocean color applications includes recently launched sensors, such as GEOS-R ABI by the United States, FY-4 AGRI by China and Himawari-9 by Japan and planned missions of Meteosat Third Generation (MTG) satellite series by Europe (IOCCG, 2012). The current geostationary sensors, and the planned missions, provide the needed incentive in conducting more studies in ocean color mapping using geostationary satellite sensors. To our knowledge, no study has been conducted using the AHI sensor in mapping TSS concentration, although ocean color product such as the chlorophyll-a (Chl-a), sea surface temperature (SST), photosynthetically active radiation (PAR) and aerosol properties are provided as an operational product by Japan Aerospace Exploration Agency using AHI observations. In this study, we describe an atmospheric correction method for the AHI sensor for ocean color remote sensing. Further, the application of atmospherically corrected AHI data to map TSS concentration in coastal waters of Western Australia is also presented, with validation using MODIS-Aqua and Landsat-8 OLI data.

2. Materials and methods

2.1. Study area

The study area chosen for this study falls along the Pilbara coast, which extends between the Exmouth Gulf (22°25′00″S and 114°25′00″E) and Onslow (21°35′00″S and 115°05′00″E) in Western

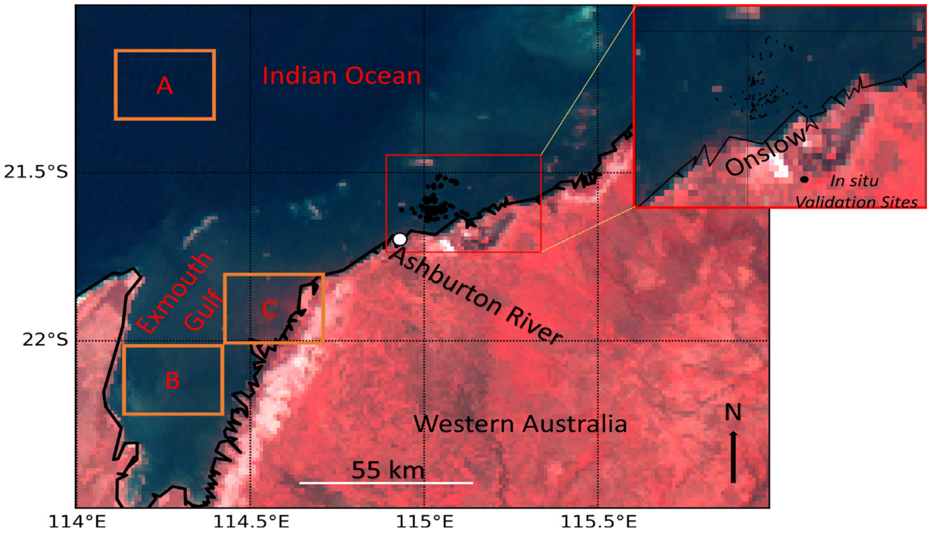

Fig. 1. True color image of the study site (RGB = AHI bands 3, 2, 1). Black filled circles indicate the locations of *in situ* validation points of the field campaign on July 4th–July 10th 2015 (shown in blow-out version on the right for greater detail). Box A corresponds to homogenous clear water area; Box B corresponds to the homogenous region within the Exmouth Gulf; Box C corresponds to turbid waters near the coast. The dimension of Box A, B and C are 66 km × 42 km.