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Use of Landsat 8 data for characterizing dynamic changes in physical and acoustical properties of coastal lagoon and estuarine waters

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Abstract

This study intends to develop methodologies that use high resolution satellite data from Landsat 8 (Operational Land Imager) OLI and (Thermal Infrared Sensor) TIRS sensors for characterizing spatial and temporal changes in physical and acoustical properties of coastal lagoon and estuarine waters. It employs multiple steps to achieve this possibility: a novel atmospheric correction algorithm is applied to OLI spectral data to retrieve water-leaving radiances which are key inputs for the applied models; appropriate parameterizations are developed for the OLI bands and used in conjugation with a hybrid model to produce the spectral absorption coefficients of coloured dissolved organic matter (a_{CDOM}) and to derive surface salinity fields which inversely correspond with the a_{CDOM} values; an efficient algorithm is employed to estimate surface water temperature using thermal infrared bands, and well-known models are employed with the satellite-derived products to determine the acoustical properties (sound attenuation and speed). Results from the above methodology were evaluated using in-situ data and Landsat 8 OLI matchup data acquired over the coastal lagoon systems (e.g., Chilika Lagoon on the coast of Bay of Bengal) during monsoon and non-monsoon seasons. The uncertainties associated with the derived products such as CDOM, salinity, temperature, sound attenuation and speed were found to be within the desirable mission goal. Recognizing the importance of the salinity gradient that plays a unique and fundamental role in defining a transitional ecosystem, spatial and temporal patterns in the structure of the salinity gradient were examined together with the CDOM patterns. High resolution OLI products exhibited a general horizontal gradient with salinity decreasing from the lagoon mouth in the eastern and central sectors to the river mouth in the northern sector and a near uniform gradient with moderate salinity in the adjacent locations (southern sector) of the lagoon. The time-series of OLI products further showed that spatial and temporal structures of the salinity are modulated by the terrestrially delivered freshwater inputs, tidal forcing at the lagoon mouth, mixing of these two waters sources, and local geomorphology. Surface water temperature products derived from the TIRS sensor for the lagoon and its adjoining locations depicted a well pronounced seasonal cycle with warmer temperatures modulated by reduced mixing and increased solar heating and stratification during non-monsoon, summer months and cooler temperatures during monsoon, winter months. The effect of salinity and temperature on the sound attenuation and sound speed was prominent in the locations of the freshwater discharge and tidal mixing regimes, where the salinity exerted a greater influence on both sound attenuation and speed despite the opposing effects of surface water temperatures. In areas of surface heating and stratification, both salinity and temperature increased causing an increase in sound attenuation and speed over the ranges found in the lagoon. These results are important for sonar performance modelling and operation of acoustic devices in such shallow water environments impacted by the terrestrial and ocean forcing factors.

Keywords: Remote sensing; Coastal lagoon; Salinity; Temperature; Sound attenuation; Landsat 8 data

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1. Introduction

Coastal lagoons and estuarine systems are typically shallow, turbid productive, transitional ecosystems between the terrestrial environment and ocean, exhibiting a variety of distinct characteristics in their physical and ecological properties such as salinity structure, tidal range, sedimentological and biological organization and supporting a range of natural services such as storm protection, tourism and fisheries productivity. Recent studies have noted that coastal lagoon/estuarine environments are the most dynamic and diverse systems that are intrinsically affected and altered by direct and indirect climate factors operating over a range of temporal (daily, weekly, monthly, seasonal, inter-annual) and spatial (sub-catchment, catchment, regional) scales (Anthony et al., 2009; Glamore et al., 2016). The physical changes brought about by these factors especially in tidal variability, water exchange and mixing, and salinity and temperature gradients – which are important in defining the structural and functional characteristics of the lagoon systems – are the dominant cause of ecological patterns and have a significant impact on sediment distribution and deposition, organic matter production, pollution, localized loss of native communities, species composition and diversity, eutrophication and disease, hypoxia, harmful or toxic algal blooms, acidification, recruitment-survival-growth of carbs and fish, and search and recovery operations (Cloern et al., 2017; Glamore et al., 2016; Kwei, 1977; Mohanty and Adhikary, 2015; Netto and Fonseca, 2017). This implies that an understanding of the physical nature and dynamics of the coastal lagoons has many scientific, economic and ecological implications. The salinity and temperature are two important water physical properties affected by changes in flushing rate, freshwater inputs, and evaporation, which not only greatly influence ecological patterns (geophysical and biological) but affect the performance of acoustic devices (sound attenuation and speed) in dynamic lagoon waters. For that reason, characterization of spatial and temporal changes in the physical and acoustical properties – such as salinity, temperature, sound attenuation and speed – may be of great interest to coastal engineers, environmental managers, designers and operators of acoustic devises for quantitative investigation of the dynamic environment and the sonar parameters. This requires quantitative tools that provide data products at different temporal and spatial scales for supporting coastal researchers and managers to better understand the physical and ecological processes. In the recent years, satellite remote sensing technology has been recognized as an important tool that provides an advantage over the other methods to obtain the physical properties rapidly and inexpensively from spectral data gathered by new generation space-borne sensors.

Detection of spatial and temporal changes in physical and acoustical properties from satellite remote sensing data requires accurate atmospheric correction and especially the accurate estimation of the aerosol radiance contribution to the total signal recorded at the top of atmosphere (TOA). Many satellite multispectral sensors, including Landsat 8 Operational Land Imager (OLI), record these signals at multiple wavebands in the visible, near-infrared and shortwave infrared regions (Singh and Shanmugam, 2016; Vanhellemont and Ruddick, 2015). The atmospheric correction schemes are applied to these spectral data in order to remove the major portion of atmospheric contribution of scattering by molecules and aerosols (commonly referred to as the path signal, which constitutes 80–90%) from the TOA signal and retrieve the desired water-leaving radiances for the quantitative applications. While the molecular scattering contribution at visible and NIR bands can be accurately assessed based on surface atmospheric pressure and wind speed without the use of the remotely sensed data (Gordon and Wang, 1992), there are constraints for deriving the optical properties of aerosols from the TOA signal due to their spatial intensity and diversity and the black pixel assumption (i.e., negligible water-leaving radiance signal in the NIR or SWIR bands) associated with the traditional aerosol correction schemes. For instance, the NIR scheme was successful in clear oceanic waters but produced large errors in turbid and productive waters due to the invalid assumption of zero water-leaving radiance signal for the NIR bands. The SWIR scheme was effective when applied to the MODIS-Aqua and Landsat 8 OLI data in turbid coastal and estuarine waters (e.g., Vanhellemont and Ruddick, 2015; Wang and Shi, 2007). However, water colour products derived from the SWIR scheme were either noisy (Bailey et al., 2010) or erroneous (negative radiance values in many visible bands) in turbid productive waters (Singh and Shanmugam, 2014). There was a possible cause of non-zero SWIR radiances due to algal blooms and sediment plumes which were difficult to take into account when deriving the aerosol optical properties. Other schemes estimated the turbid water contribution at NIR bands through the empirical methods (Ahn et al., 2012; Ye et al., 2017), which showed potential for turbid coastal waters despite the difficulty of extending these empirical functions for algal bloom and productive waters. Recently, a novel aerosol correction scheme was developed and successfully tested on several MODIS-Aqua data (Singh and Shanmugam, 2014) and HICO data (Varunan and Shanmugam, 2017) from coastal and inland waters. This scheme uses a dimensionless coefficient κ which is calculated based on specific radiance ratios to account for non-zero NIR contributions of both turbid and productive waters. When employed with an independent extrapolation technique, it allowed for a robust atmospheric correction while providing accurate water-leaving radiances in estuarine and turbid waters. This scheme makes use of no predefined aerosol models and ancillary data and can be applied to any Landsat 8 OLI data regardless of the observed water types and atmospheric conditions.

Recent studies have shown successful application of remote sensing data in estimating biogeochemical parameters, such as chlorophyll (Chl), turbidity, suspended

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