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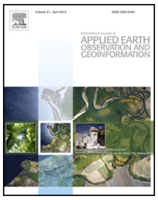

Estimation of the spectral diffuse attenuation coefficient of downwelling irradiance in inland and coastal waters from hyperspectral remote sensing data: Validation with experimental data

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ABSTRACT

A semi-analytical model is developed for estimating the spectral diffuse attenuation coefficient of downwelling irradiance ($K_d(\lambda)$) in inland and coastal waters. The model works as a function of the inherent optical properties (absorption and backscattering), depth, and solar zenith angle. Results of this model are validated using a large number of *in-situ* measurements of $K_d(\lambda)$ in clear oceanic, turbid coastal and productive lagoon waters. To further evaluate its relative performance, $K_d(\lambda)$ values obtained from this model are compared with results from three existing models. Validation results show that the present model is a better descriptor of $K_d(\lambda)$ and shows an overall better performance compared to the existing models. The applicability of the present model is further tested on two Hyperspectral Imager for the Coastal Ocean (HICO) remote sensing images acquired simultaneously with our field measurements. The $K_d(\lambda)$ spectra derived from HICO imageries have good agreement with measured data with the mean relative percent error of less than 12% which are well within the benchmark for a validated uncertainty of ±35% endorsed for the remote sensing products in oceanic waters. The model offers potential advantages for predicting changes in spectral and vertical K_d values in a wide variety of waters within inland and coastal environments.

1. Introduction

Inferring the concentrations of dissolved and particulate constituents in inland and coastal waters from remote sensing spectral reflectance or diffuse attenuation coefficient of downwelling irradiance through inverse methods is essential for monitoring the efficacy of pollution abatement efforts, categorizing water types, mapping algal blooms, and assessing biogeochemical fluxes (Jenaa et al., 2012; Song et al., 2016; Stock et al., 2015; Tebbsa et al., 2015; Oyamaa et al., 2015). However, determination of the water quality parameters is hampered by the lack of theoretical framework to predict optical properties as well as the lack of *in-situ* measurements and methods to interpret ocean color data in these waters.

The diffuse attenuation coefficient for downwelling irradiance is an important apparent optical property (AOP) that depends on both the medium (*i.e.*, inherent optical properties “IOPs”, such as absorption and scattering) and geometric structure of the ambient light field. Knowledge of its spatial, spectral, vertical, and temporal changes is needed for determination of light availability as a critical regulator of oceanic and coastal production of phytoplankton (Lee et al., 2005; Arthi and Shanmugam, 2013), classification of water types based on its spectral shape (Jerlov, 1976), assessment of water clarity and water quality and optical bathymetry (Gallegos, 2001), and target detection and diving (Trees et al., 2005; Leach and Morris, 1993). It has been recognized that in coastal and associated inland water systems, the optically significant water constituents differ widely with time and space which in turn affect the diffuse attenuation coefficient of downwelling irradiance. Eutrophication and nutrient pollution often result in enhanced growth of phytoplankton which in turn reduces water clarity and increases light attenuation in these water bodies. On the other hand, the coastal environments play a profound role in the global carbon budget (Behrenfeld et al., 2005). In spite of the potential importance of light attenuation in these waters, our current understanding of its spatial, spectral, vertical, and temporal changes is limited by the lack of predictive models that are unable to fully account for the complex interplay of light and water constituents. The prediction of light attenuation is further hampered by the lack of theoretical framework as well as the lack of *in-situ* measurements and methods to interpret ocean color data (Gallegos et al., 1990). This

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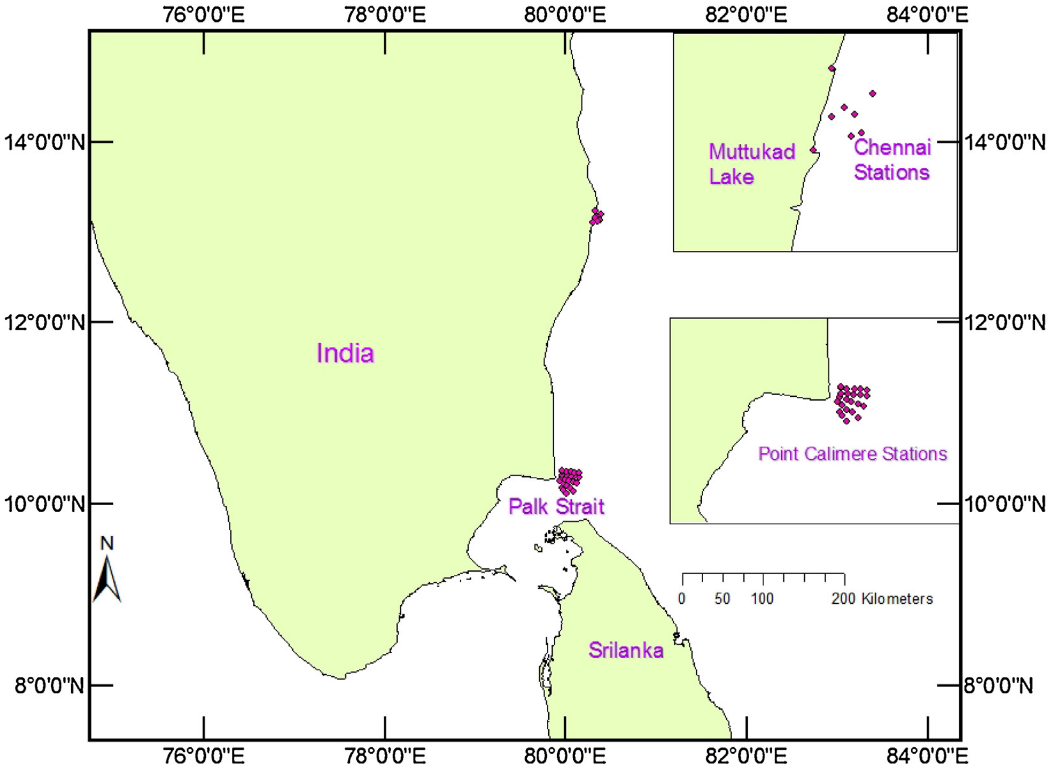

Fig. 1. Study area map showing the sample locations around Chennai (clear and moderately turbid waters), Muttukadu (turbid productive waters) and Point Calimere (turbid waters) on the southeast part of India.

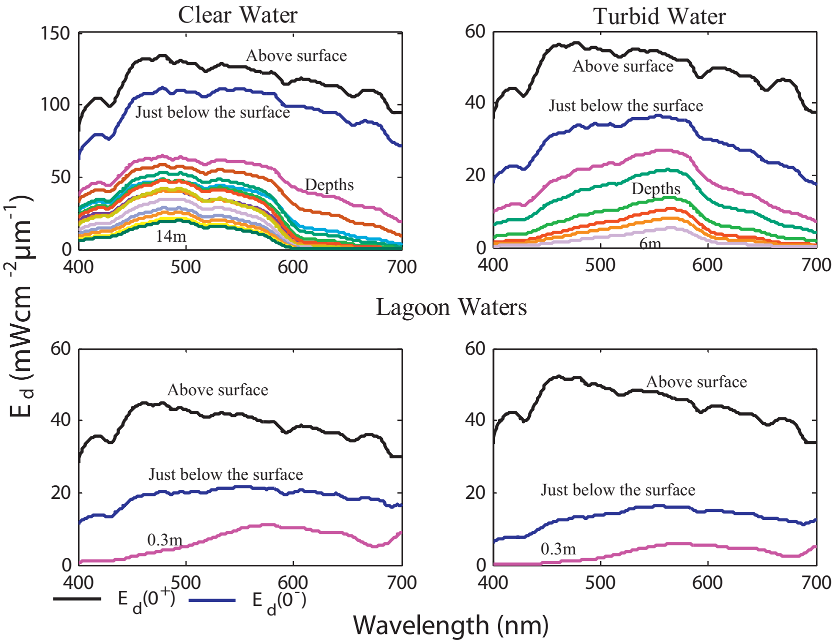

Fig. 2. Downwelling irradiances (E_d) measured at discrete depths from clear waters (0–14 m), turbid waters (0–6 m) and turbid productive lagoon waters (0–0.3 m). Black and Blue spectra represent the E_d just above the water surface and just below the water surface, and the remaining spectra represent the E_d for different depths. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

had led to reliance on semi-analytical algorithms commonly used to derive $K_d(490)$ maps from ocean color satellite sensors (further details in Tiwari and Shanmugam (2014)), although such methods are often reported to underestimate or overestimate the attenuation of light in turbid coastal waters where the backscattering by suspended sediments and the absorption by dissolved organic matter and phytoplankton tend to increase light attenuation in the water column.

Since the diffuse attenuation coefficient $K_d(\lambda)$ of downwelling irradiance is a very useful quantity for many optical analyses of