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Statistical models for sediment/detritus and dissolved absorption coefficients in coastal waters of the northern Gulf of Mexico

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ABSTRACT

We developed statistically-based, optical models to estimate tripton (sediment/detrital) and colored dissolved organic matter (CDOM) absorption coefficients (a_{sd}, a_g) from physical hydrographic and atmospheric properties. The models were developed for northern Gulf of Mexico shelf waters using multi-year satellite and physical data. First, empirical algorithms for satellite-derived a_{sd} and a_g were developed, based on comparison with a large data set of cruise measurements from northern Gulf shelf waters; these algorithms were then applied to a time series of ocean color (SeaWiFS) satellite imagery for 2002–2005. Unique seasonal timing was observed in satellite-derived optical properties, with a_{sd} peaking most often in fall/winter on the shelf, in contrast to summertime peaks observed in a_g. Next, the satellite-derived values were coupled with the physical data to form multiple regression models. A suite of physical forcing variables were tested for inclusion in the models: discharge from the Mississippi River and Mobile Bay, Alabama; gridded fields for winds, precipitation, solar radiation, sea surface temperature and height (SST, SSH); and modeled surface salinity and currents (Navy Coastal Ocean Model, NCOM). For satellite-derived a_{sd} and a_g time series (2002–2004), correlation and stepwise regression analyses revealed the most important physical forcing variables. Over our region of interest, the best predictors of tripton absorption were wind speed, river discharge, and SST, whereas dissolved absorption was best predicted by east–west wind speed, river discharge, and river discharge lagged by 1 month. These results suggest the importance of vertical mixing (as a function of winds and thermal stratification) in controlling a_{sd} distribution patterns over large regions of the shelf, in comparison to advection as the most important control on a_g. The multiple linear regression models for estimating a_{sd} and a_g were applied on a pixel-by-pixel basis and results were compared to monthly SeaWiFS composite imagery. The models performed well in resolving seasonal and interannual optical variability in model development years (2002–2004) (mean error of 32% for a_{sd} and 29% for a_g) and in predicting shelfwide optical patterns in a year independent of model development (2005; mean error of 41% for a_{sd} and 46% for a_g). The models provide insight into the dominant processes controlling optical distributions in this region, and they can be used to predict the optical fields from the physical properties at monthly timescales.

1. Introduction

As a dynamic river-dominated margin, northern Gulf of Mexico shelf waters play a significant role in mediating the large flux of terrestrial materials from north America into coastal and deep ocean waters. The Mississippi River is the seventh largest in the world by freshwater and sediment flux, and drains a vast region (41%) of the continental United States (van der Leeden et al. 1990). High concentrations of dissolved nitrate from the river ($>100\,\mu mol\,L^{-1}$; Dagg and Whitledge, 1991) support significant phytoplankton growth on the shelf (e.g., Lohrenz et al., 1999) and one of the United States' most productive fisheries. Over the last 50 years, high primary production due to increased riverborne nutrients is considered responsible for the large zone of summertime hypoxia that forms on the Louisiana–Texas shelf, currently the second largest zone of coastal hypoxia in the world (Rabalais et al., 2002). In addition to nutrient availability, phytoplankton growth on the shelf is also strongly controlled by light availability (e.g., Lohrenz et al., 1999), as large inputs of suspended sediments and dissolved materials enter the shelf from a variety of sources and attenuate light. The Mississippi River alone delivers 2.0×10^{11} kg of suspended sediments and

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3.1×10^9 kg of dissolved organic carbon (DOC) to the Louisiana shelf annually (Meade, 1996; Bianchi et al., 2004). The coastal zone of Louisiana contains ~41% of the nation's coastal wetlands, and these regions are also sources of terrestrial organic matter to the shelf (e.g., Engelhaupt and Bianchi, 2001), in addition to numerous smaller rivers.

An improved understanding of the environmental controls on dissolved and suspended particulate materials (including detritus and sediments) on the shelf is requisite to our understanding of light limitation on phytoplankton growth, as well as to the overall cycling of terrestrial materials introduced from rivers and shallow coastal environments. A variety of biological and physical mechanisms can impact sediment/detrital and dissolved distributions in surface waters of the northern Gulf of Mexico. Physical mixing of freshwater inputs and high salinity Gulf waters strongly influences surface property distributions, with both particulate and dissolved concentrations generally decreasing in the offshore direction away from riverine sources (e.g., Trefry et al., 1992; Benner and Opsahl, 2001). Seasonal variability in river discharge and wind speed also affects surface property distributions. For example, time series analyses of satellite-derived suspended particulate matter (SPM) concentrations on the shelf demonstrated strong positive correlations with both river discharge and wind speed (Walker, 1996; Salisbury et al., 2004). In some shelf regions, increased wind speeds can lead to particle resuspension and seaward transport, resulting in increased particulate concentrations in surface waters (e.g., Walker and Hammack, 2000). Fluorescence measurements have shown that several factors control colored dissolved organic matter (CDOM) distributions on the shelf. At short time scales (daily), CDOM concentrations appear to be largely controlled by conservative mixing between freshwater and marine endmembers, with inputs from both rivers and coastal wetlands (Hitchcock et al., 2004). Significant in situ biological input of CDOM has also been observed, along with some evidence of flocculation and minor photobleaching effects (Chen et al., 2004). Certainly numerous other factors will likely contribute to particulate and dissolved matter variability on the shelf, including physico-chemical processes such as aggregation and desorption, as well as biological uptake and release processes related to microbial transformations, primary production, and grazing (for review, see Dagg et al., 2004).

Satellite remote sensing can provide the synoptic data to study surface ocean constituents at high spatial and temporal resolution, even in coastal waters. Previously, in situ cruise measurements have shown significant spatial and temporal variability in detrital and CDOM absorption in the Louisiana Bight (D'Sa et al., 2006). However, while cruise measurements are necessary for algorithm development, especially in coastal regions, satellite measurements can allow for higher temporal resolution time series analyses and for larger spatial coverage. SPM distributions have been the focus of several satellite-based studies in the northern Gulf (e.g., Walker, 1996; Salisbury et al., 2004), but there have been no similar studies of satellite-derived tripton (non-algal particle) and CDOM distributions in this region. Traditionally, ocean color remote sensing algorithms have allowed for the retrieval of total absorption and backscattering coefficients, with the further separation of total absorption into a phytoplankton and combined CDOM/tripton component (Lee et al., 2002; Maritorena et al., 2002). An expanding data set of optical measurements for northern Gulf shelf waters (e.g., D'Sa et al., 2007; Green and Gould, 2008) sets the stage for the development of regional algorithms for CDOM and tripton absorption in this paper. As well, improved techniques for processing satellite imagery in coastal regions have been developed. These include more accurate methods for atmospheric correction of satellite imagery, such as a near-infrared correction scheme for estimating water-leaving radiance at 670 nm (Arnone et al., 1998; Stumpf et al., 2003), as well as a new absorbing aerosol correction (Ransibrahmanakul and Stumpf, 2006).

In this study, our goal was to develop satellite algorithms for estimating tripton and CDOM absorption in the northern Gulf of Mexico and to apply these to development of statistically-based, predictive models for both absorption components. Predictive optical models represent an important avenue of current research in the oceanic sciences, with applications ranging from forecasting light fields for phytoplankton growth to predicting underwater visibility for naval and maritime operations (e.g., Dickey et al., 2006). Previously, we developed a predictive model for satellite-derived phytoplankton variability in Louisiana shelf waters using a host of environmental forcing mechanisms (Green and Gould, 2008). In the current study, we expanded our region-of-interest to include a larger portion of the northern Gulf (Louisiana, Mississippi, and Alabama coastal waters), and updated our physical forcing database to include several forcing fields of higher spatial resolution (e.g., winds, precipitation, and surface salinity and currents). We first develop empirical algorithms for estimating CDOM and sediment/detrital absorption coefficients (a_g, a_{sd}) from satellite measurements, and then use our algorithms to describe multi-year, satellite-derived optical variability in shelf waters. Secondly, we develop statistically based models for both a_g and a_{sd} for mean monthly imagery from 2002 to 2004 and demonstrate the predictive capability of the models in application to 2005.

2. Methods

2.1. Cruise measurements

Measurements of optical properties were made in northern Gulf of Mexico coastal waters during seven field experiments. Measurements were obtained during two cruises on the Louisiana shelf aboard the R/V *Pelican* (27 April–1 May 2006) and OSV *Bold* (6–11 September 2006). Surface water samples were collected using a conductivity–temperature–depth profiler/rosette system equipped with sampling bottles. All samples were processed onboard ship within 2–3 h of sample collection. As well, two nearshore samplings in shallower waters of the Louisiana shelf were conducted as transects out of Vermilion, Terrebonne, and Barataria Bays (17–19 May and 17–19 July 2007). Three field experiments were also conducted off the Mississippi/Alabama coasts during 20–24 May 2002, 13 December 2005, and 6 February 2007. During these experiments, samples were collected on day trips and processed that evening or the next day onshore. Sample sites were generally located inside the 50 m isobath, with the majority of stations within the 15 m isobath (Fig. 1).

Absorption coefficients for particulate material (a_p) and CDOM (a_g) in surface water samples were measured spectrophotometrically. Particulate material was collected on GF/F filters (nominal pore size of 0.7 μm), and absorption coefficients were measured using an analytical spectral devices (ASD) fiber optic-based spectrophotometer. Subsequent to the initial optical density measurements for particulates, filters were extracted for 20 min in hot methanol (to remove phytoplankton pigments) and reanalyzed to determine the residual particulate absorption by sediment and detritus (a_{sd}) (Kishino et al., 1985). We here use the subscript "sd" in a_{sd} to refer to the sum of absorption by inorganic suspended sediments and organic detritus. We will also refer to this non-living particulate pool composed of both sediments and detritus as "tripton". All particulate measurements were relative to a blank filter saturated with milli-Q water, and the optical density (OD) at 850 nm for the blank was subtracted from each