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Characterization of Suspended Particulates in the Northern Gulf of Mexico from Ocean Color Remote Sensing

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ABSTRACT

The ecosystem in the Northern Gulf of Mexico (NGOM) is composed of fresh waters from coastal run-offs and the Mississippi River as well as clear-salty waters from the gulf. As a result, the composition of water constituents, as well as their spatial and temporal distributions, is complex and heterogeneous, with severe hypoxia events constantly happening in the NGOM region. In this study, using properties derived from measurements of ocean color radiance by a satellite sensor, the nature of the suspended particulates was characterized. In particular, not only the concentrations (and their spatial distributions) of suspended particulate matters were derived from satellite images, but also the organic/inorganic nature of these particulates were characterized with derived inherent optical properties. These results could help us better understand the dynamics of coastal ecosystems and the development of hypoxia.

INTRODUCTION

The northern Gulf of Mexico is not only economically important, but also dynamic in ecosystem structures. It receives freshwater discharges and material export through Mobile Bay estuarine and river plumes from the Mississippi River and Atchafalaya River, the largest river system in the North America. The interactions between these river discharges and the relatively clear open gulf waters nurture the largest seafood industry [*Ache et al.*, 2008] in the United States, and form one of the most severe hypoxia region [*Rabalais et al.*, 2002b; *Walker and Rabalais*, 2006]. Indeed, the NGOM ecosystem is sensitive to environmental and climate changes [*Burkart and James*, 1999; *Rabalais et al.*, 2002a; *Raymond et al.*, 2008], and is experiencing profound influences by nutrients and particulate matter loadings from river runoff and coastal erosion, causing hypoxia, eutrophication, other potential environmental problems [*Brunner et al.*, 2006; *Rabalais et al.*, 2002a], and the enormous impacts from the Deep Water Horizon tragedy. On the other hand, because of the complex composition of various constituents, NGOM waters also post enormous challenges to propel the advancement of ocean color remote sensing. Any techniques/algorithms developed and proved working with NGOM waters will have significant impact on ocean color remote sensing of global coastal waters.

One important parameter for ecosystem studies is the concentration of suspended particulate matters, as it not only affects subsurface light field (then photosynthesis), it could also be a tracer of pollutant transport and an indicator of shoreline erosion. Adequate information of the amount, nature, and spatial variation of suspended sediments is highly desired for marine biology and geology, and for coastal management. Ship survey generally provides detailed information of discrete sampling locations. But for broad coastal areas, remote sensing by satellite sensors is the only feasible means to obtain synoptic information of the distribution of suspended sediments.

Traditional remote sensing studies of suspended particulates, however, have been focused on the estimation of total suspended sediments (or total suspended solids; practically particles collected on a filter pad) from remotely measured water reflectance [*D'Sa et al.*, 2007a; *Dekker et al.*, 2002; *Stumpf*, 1988]. This satellite product, however, does not separate mineral sediments from biogenic materials (such as phytoplankton), consequently little is known about the quality of such suspended particulate matters in coastal ecosystems. Note that suspended particulate organic and inorganic matters have different residence time, turnover rates and pathgeons, thus contribute differently in carbon cycling, nutrient and phytoplankton bloom dynamics, and toxic metal transport in coastal ecosystems [*Baskaran et al.*, 1996; *Buesseler et al.*, 1992; *Dagg et al.*, 2008; *Sridhar et al.*, 2008 ; *Trefry et al.*, 1994; *Wang et al.*, 2004]. Therefore, it is not only desired but also important to measure both the loading of suspended particulate matters and the quality (or class) of such materials [*Balch et al.*, 2005; *Gould and Arnone*, 2003; *Stramski et al.*, 2008].

Here, with measurements made by MERIS over the NGOM waters, we present products that measure the concentration of SPM and the nature (characteristics) of such particulates, and briefly discuss their interactions with currents in coastal regions.

Fig. 1. Northern Gulf of Mexico.

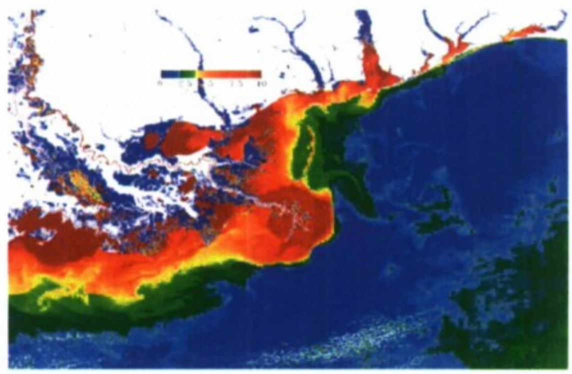

Fig. 2. Spatial distribution of [SPM]. Derived from MERIS (Feb. 6, 2007) Rrs(665) and Rrs(560).

CONCENTRATIONS AND CHARACTERISTICS OF SUSPENDED PARTICULATES FROM REMOTE SENSING

For NGOM waters, Fig. 1 shows a true color image of MERIS measurements (~300 m spatial resolution) of Feb. 6, 2007, with Level 1 (calibrated top-of-atmosphere radiance) data obtained from ESA. Remote sensing reflectance (Rrs, defined as the ratio of water-leaving radiance to downwelling irradiance just above the surface) was derived by applying the Case-2 atmosphere correction algorithm developed by Doerffer and Schiller [2006].

In the past decade, various algorithms [*Bukata et al.*, 1995; *D'Sa et al.*, 2007b; *Dekker et al.*, 2002; *Miller and McKee*, 2004; *Stumpf and Pennock*, 1989] have been developed to retrieve the loading of the suspended particulate matters ([SPM], unites: mg/m^3) in surface waters. Fig. 2 displays the spatial distribution of [SPM] derived with the algorithm of D'Sa et al [2007a], which uses Rrs at 670 nm and 555 nm as inputs (replaced as 665 nm and 560 nm for MERIS measurements) and was specifically tuned for the waters in the northern Gulf of Mexico. The image suggests that except the lower right corner where impacts from cirrus clouds caused falsely enhanced [SPM], higher concentrations of [SPM] are found, as expected, in coastal regions that are adjacent to land. In addition, eddies resulted from mixing of coastal currents are highlighted in the [SPM] image.

This [SPM] image, however, although shows a decrease gradient of SPM loading from nearshore to offshore, does not reveal particle features of the distinctive water patch (light blue) in the lower left corner. This patch of waters has significantly different spectral Rrs than that of adjacent waters with similar Rrs values at 665 nm (see Fig. 3). The contrast in spectral Rrs indicates that the water constituents of the two pixels (or patches) could be significantly different.

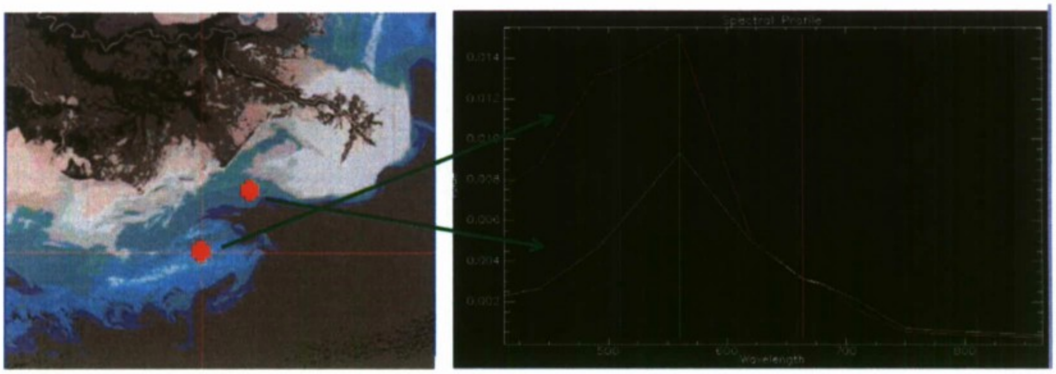

Fig. 3. Examples of spectral Rrs.

To evaluate and understand this contrast, at least to the first order, inherent optical properties (IOPs) of waters shown in Fig.1 were derived by applying the Quasi-Analytical Algorithm (QAA) [*Lee et al.*, 2002], with derived total absorption and backscattering coefficients shown in Fig. 4. Apparently, while the absorption image has some resemblance of the [SPM] spatial pattern, the backscattering image show enhanced scattering of the light-blue patch. This contrast in IOPs further indicates different characteristics of suspended particulates in the northern Gulf of Mexico.

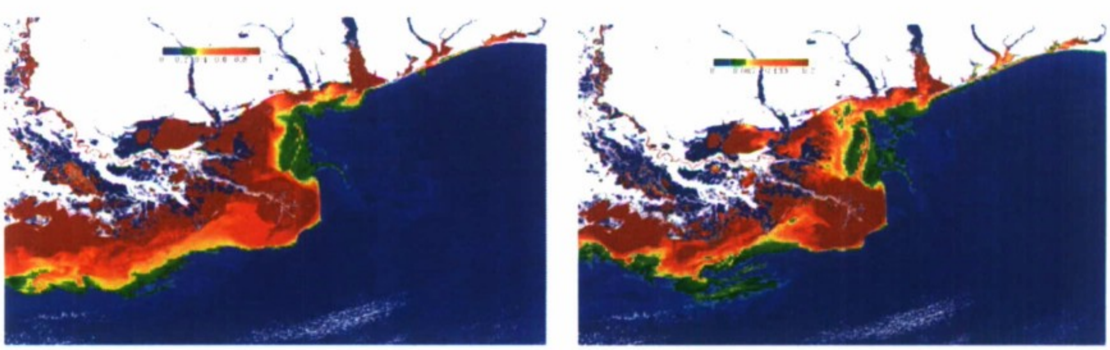

Fig. 4. Spatial distribution of absorption coefficient (left) and backscattering coefficient (right).

The difference in particulate characteristics is further manifested with an analysis of the backscattering coefficients of phytoplankton ($b_{b\text{-Phy}}$) and non-phytoplankton ($b_{b\text{-Nphy}}$) components, both were calculated at 560 nm. $b_{b\text{-Phy}}$ is based on QAA-derived phytoplankton absorption coefficient at 442 nm ($a_{Phyt}(442)$) with the following steps:

1) Index of phytoplankton amount ([*Phyt*]) is estimated based on the absorption model of Bricaud et al [1995]

$$[Phyt] = \left(\frac{a_{Phyt}(442)}{0.065}\right)^{1/0.728}. \tag{1}$$

2) Scattering coefficient (at 560 nm) of phytoplankton is estimated based on the model of Gordon and Morel [1983] with the above [Phyt] as input

$$b_{Phyt}(560) = 0.3([Phyt])^{0.62}. \tag{2}$$

3) Backscattering coefficient (at 560 nm) of phytoplankton $b_{b\text{-}Phyt}(560)$ is estimated as 1% of $b_{Phyt}(560)$.

Further, backscattering coefficient (at 560 nm) of Non-Phytoplankton ($b_{b\text{-}NPhyt}(560)$) is derived from QAA derived particle backscattering coefficient ($b_{bp}(560)$),

$$b_{b-NPhyt}(560) = b_{bp}(560) - b_{b-Phyt}(560), \tag{3}$$

and a b_b-*ratio* is evaluated as $b_{b\text{-}NPhyt}(560)/b_{b\text{-}Phyt}(560)$, with results shown in Fig. 5. It is found that generally b_b-*ratio* is in a range of 2 - 30 for the study area, and higher values (> 50) were found around the Mississippi River delta. Stavn and Richeter [2008] found a ratio of 4-30 between the scattering coefficients of non-organic to organic particulates for waters around the Mobile Bay. The b_b-*ratio* results are consistent with those findings.

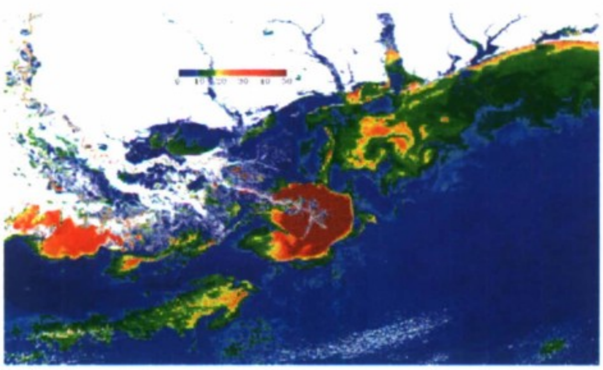

Fig. 5. Spatial distribution of b_b-ratio.

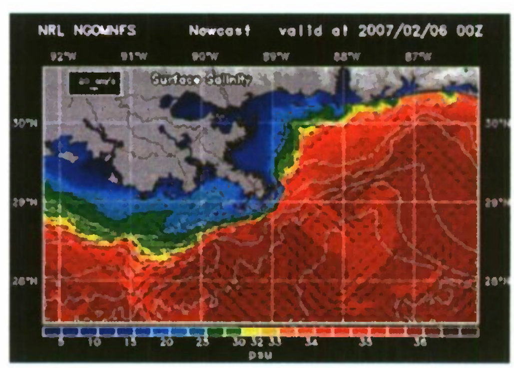

Fig. 6. NCOM results of coastal currents.

Combining the spatial distribution of $a(442)$, $b_b(442)$ and b_b-*ratio*, and comparing these patterns with that shown by the [SPM], more information about the characteristics, and spatial variation, emerge. 1) Non-phytoplankton scatterings, mainly dominated by mineral particles, make strong contributions in the coastal regions, especially the waters off Mobile Bay (Alabama). 2) Extremely strong non-phytoplankton scattering appeared in the Mississippi River plume and the Atchafalaya Bay, due likely to resuspended mineral sediments. 3) Waters in the Lake Pontchartrain show suspended particles with both biogenic and mineral characteristics. And, 4) The light-blue patch in the lower left corner of Fig.1 is dominated by particles of non-phytoplankton (or mineral) character. This detached mineral-dominant water patch could be resulted from mixings between coastal runoff and ocean currents. During winter time, coastal currents flow westward (see Fig. 6), which could effectively separate the coastal runoff water with ocean water, of which the contribution from non-phytoplankton is much less (see Fig. 5). During the mixing of runoff waters with clearer oceanic waters, likely a dilution effect, or removal of organic coatings of the particles, resulted in a reduction of the absorption coefficient (at 442 nm) in the light-blue patch, consequently enhanced Rrs in the blue-green wavelengths are observed (Fig. 3). At the same time, those particles may add nutrients in the deeper water column and eventually contribute to the occurrence of hypoxia in this region [*Rabalais et al.*, 2002a].

SUMMARY

As an example, concentration of suspended particle matters ([SPM]), along with optical properties, in the northern Gulf of Mexico were derived from a measurement of MERIS (Feb. 6, 2007). Presently [SPM] image products provide valuable spatial variations of particulates in the upper water column. Its nature of derivation, however, could not inform the characteristics of the suspended particulates. With optical properties derived from advanced near-analytical algorithms, such characteristic information could then be evaluated. Combined with circulation models we will be able to better understand and predict the dynamics of particulates and coastal ecosystems.

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