Ocean color remote sensing in coastal waters of French Guiana: application of the ANR GlobCoast project

Vantrepotte, V, Loisel., H, Mériaux, X., Dessailly D., Gardel, A., Gensac, E

INSU-CNRS, UMR 8187, LOG, Laboratoire d'Océanologie et des Géosciences, Université Lille Nord de France, ULCO, 32 avenue Foch, 62930 Wimereux, France

Abstract.

Remote sensing data now allow for an accurate description of a variety of physical and biological parameters at global scale with a temporal resolution hardly available from other measurement methods. The ANR GlobCoast first objective is to analyze, for the first time, the seasonal, interannual and decadal variability of the global coastal waters in term of biogeochemical composition using various descriptors available from ocean color remote sensing (i.e. Chlorophyll a, suspended particulate matter, dissolved and particulate organic carbon concentration). In the frame of GlobCoast, the latter parameters will be, in a first step, assessed through innovative approaches allowing to face the challenge represented by the development of inversion algorithms in optically complex waters such as the coastal waters. In the second step, time series for the latter biogeochemical parameters will be analyzed conjointly with various physical forcing parameters as obtained from remote sensing (wind, sea surface temperature, altimetry), in situ measurements, and modelling outputs. French Guiana coastal waters represent one of the coastal domains that will be particularly investigated in the context of GlobCoast. First results have emphasized the interest of classifying these coastal waters for better characterizing of the dynamics of French Guiana coastal ecosystems and potentially improving the accuracy of the SPM retrieval from space. Further, the analysis of the SPM time series computed for the MODIS archive over the French Guiana coastal domain has allowed to characterize the dynamics of local geomorphological processes (mud banks migration) and regional hydrodynamical forcings (north Brazilian retroflection current) on these coastal waters.

Keywords: ocean color, coastal waters, French Guiana, ANR-GlobCoast .

1. Introduction

Knowing that coastal areas concentrate about 60% of the world's population (within 100 km from the coast), that 75-90% of the global sink of suspended river load takes place in coastal waters in which about 15% of the primary production occurs, the societal and economical benefits of this project are potentially huge: fish resources, aquaculture, water quality information, recreation areas management, etc. Large uncertainties remain on the evaluation of the stocks of the main biogeochemical parameters in coastal waters and their seasonal, inter-annual, and decadal evolutions. In that context, satellite Remote Sensing of ocean colour is a very powerful tool for the management of resources and activities of continental shelf waters. However, the exploitation of these data in such a complex environment, where the optical properties do not necessarily covary with phytoplankton, requires the development of specific inverse methods to assess the required bio-optical and biogeochemical parameters. While some recent progress has been achieved, challenges still remain (IOCCG, 2000, 2006).

The French national ANR GlobCoast project (ANR Blanc, 2011-2013, http://www.foresea.fr/globcoast/, Partners: LOG, ULCO-Wimereux, GET-Toulouse, LEGOS-Toulouse, Hygeos-Lille) has been built in that context and is based on three main objectives.

The first one is to assess and analyse the seasonal, year-to-year, and decadal evolution of the global coastal waters in terms of biogeochemical composition as revealed from satellite ocean colour observations, for the very first time. Basic (inherent optical properties, chlorophyll a, as a proxy for phytoplankton biomass and suspended particulate matter concentrations) as well as more innovative products (particulate and dissolved organic carbon) will be assessed from new approaches developed in the frame of GlobCoast.

In the second part of the project, time series for the latter biogeochemical parameters will be analysed conjointly with various physical forcing parameters as obtained from remote sensing (wind, sea surface temperature, altimetry), in situ measurements, and modelling. This will help to gain a better understanding of the origins of the temporal variability of biogeochemical parameters over the coastal ocean. This part will be performed over highly contrasted areas covering a great variety of environmental, biological and bio-optical conditions encountered in coastal areas.

The third main objective of this project is to analyse the potential link between the variability of the environmental parameters as assessed in the first parts of the project, and the variance in the recruitment and stocks of higher trophic level organisms (i.e. fishes). While fishing pressure has a strong impact on recruitment and stocks, the contribution of environmental fluctuations to the variability in recruitment is now clearly demonstrated, especially thanks to remotely sensed data from satellite.

The achievement of the different objectives proposed in the frame of GlobCoast will hopefully lead to a better understanding of coastal biogeochemical cycles, and their relationship with physical forcing occurring in coastal areas, and the evolution of productivity and fish resources. The results of this project obtained over the global coastal ocean and over long-term observations, could help to distinguish non-systematic natural variability from trends and regime shifts in coastal ecosystems that have often been related to eutrophication or anthropogenic disturbances. In the same way, the spatio-temporal scales considered in this project, as well as the diversity of the data, will facilitate the assessment of the role of environmental conditions in the variability of stocks and recruitments of fishes. The data set generated in this project from ocean colour satellite observations is also of great interest for the validation of coupled biogeochemical-physical models designed for coastal waters. Significant discrepancies still remain between models and observations, and a number of key processes are still poorly quantified. The chlorophyll (Chl), suspended particulate matter (SPM), and particulate (POC) and dissolved (DOC) organic carbon products are particularly relevant for such models especially through the use of assimilation schemes.

French Guiana (and more largely regions influenced by the Amazon river outputs) coastal waters represent one of the coastal domains that will be specifically investigated in the context of GlobCoast especially regarding the two first objectives of this project. This coastal area which is one of the most dynamic coast in the world, especially due to the influence of the immense discharge of the Amazon river, which influences on the biogeochemical cycles and ecosystems functioning over the whole Guianese coastal area still remain to be better constrained. This works aims to present some of the applications that will be developed in the context of GlobCoast over the the French Guiana coastal waters illustrated in the present paper through first results obtained within this coastal region.

2. Methods

2.1 Inversion of ocean color products from a classification-based approach.

The development of inversion algorithms needed for relating satellite radiometric measurement to bio-optical (IOPs: particulate backscattering coefficient, b_{bp}, its spectral slope, g, or other descriptive parameters of the flocsize distribution, the absorption coefficients of phytoplankton, dissolved and non algal particles a_{phy}, a_{cdom}, and a_{nap}, respectively, diffuse attenuation coefficient K_d) and biogeochemical (e.g. Chlorophyll a, POC, DOC SPM concentrations) products of interest needed to develop specific inversion approaches allowing to face the different issues related to the optical complexity of coastal ecosystems.

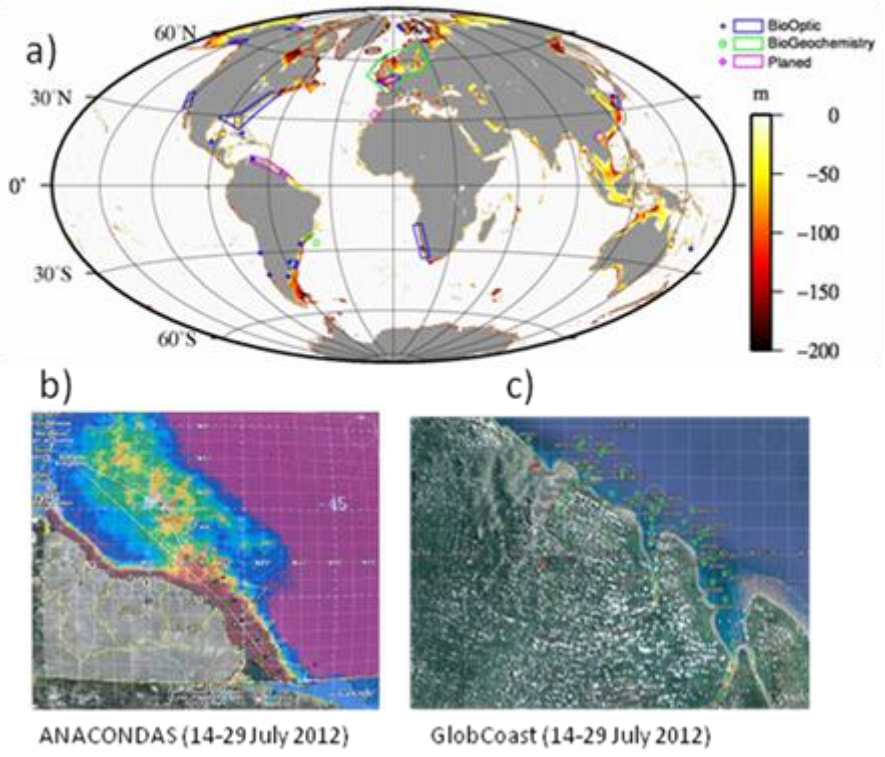

Figure 1: a) Location of the in situ data used in GlobCoast. These data are from various LOG, LEGOS, and GET cruises, the NASA/NOMAD data set, and other cruises performed in the frame of international collaborations involving some of the GLOBCOAST partners. b), c): Maps of the recent field campaigns already performed in the frame of GlobCoast and in collaboration with other research projects in French Guyana (GlobCoas), and from the Barbados to the Amazone River (ANACONDAS cruise, WHOI).

While existing inversion methods will be compared in the first steps of the project (e.g. Loisel and Stramski, 2000; Loisel et al., 2006; Lee et al., 2002; Maritorena et al., 2002; Morel and Gentili, 2009), the development of innovative approaches (Jamet et al., 2010, Vantrepotte et al., 2012) will also be considered in the context of GlobCoast. In particularly, the inversion of

IOPs and biogeochemical products will performed using an approach based on the optical classification of the coastal domain. In practice, prior to the inversion of bio-optical parameters in such complex environments, each satellite pixel will be classified according of its optical characteristics (Figure 2). Then class-specific algorithms will be applied for improving the accuracy of the different inverted parameters. Considering such a classification approach within the inversion scheme should allow to reduce the dispersion usually found in the IOPs-Biogeochemical Components (BC) relationships, and then to significantly improve the retrieval of biogeochemical components.

For that purpose, mean specific IOPs values and reflectance spectral shape for each class should be established. This will be performed from an optical and biogeochemical data base gathering existing measurements which will be supplemented through dedicated cruised planned in the frame of GlobCoast including some cruises in the French Guiana Coastal waters (Figure 1). This would also help to better characterize this coastal domain at both an optical biogeochemical point of view as well as to validate the products developed in the frame on this ANR project.

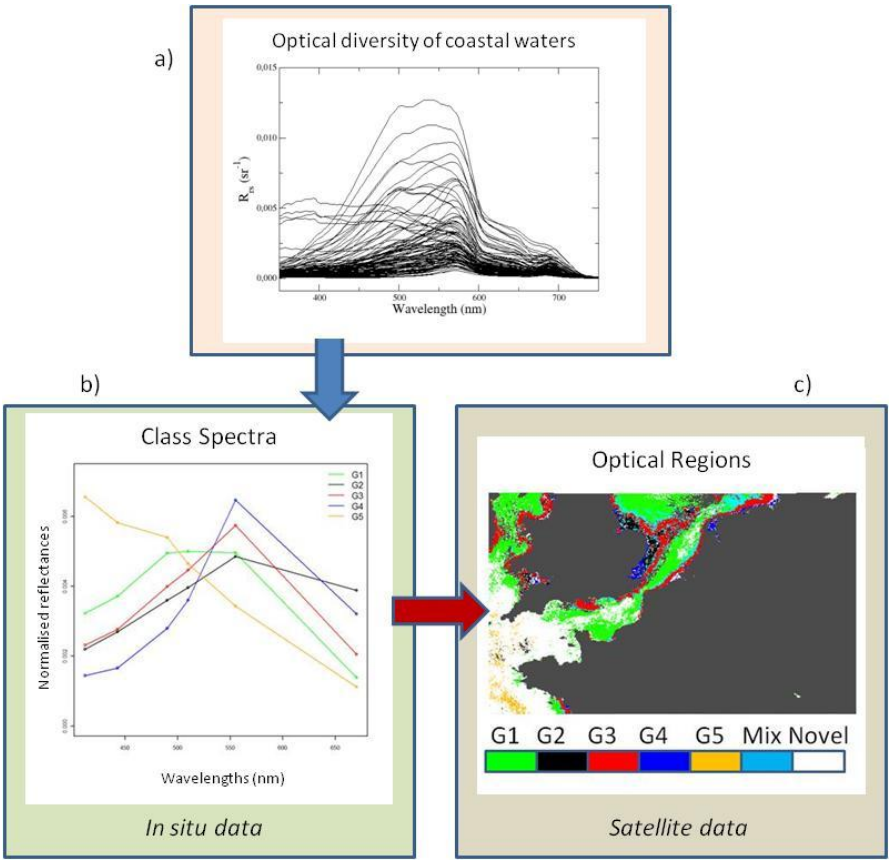

Figure 2: Methodology for the identification of optical water classes developed in the frame of GobCoast. The class-specific mean reflectance spectra (b) are obtained from classification techniques applied to a large data set of in situ reflectance (R_{rs}) spectra (a). Using novelty detection techniques, these classes will be compared to the satellite reflectance spectra to identify some homogeneous areas in terms of bio-optical properties (c).

Note that different approaches will be also used in the frame of GlobCoast for developing innovative atmospheric correction schemes in order to improve the accuracy of the normalized water-leaving radiance (nL_w) retrieval which often limit our ability to derive valuable satellite signal in coastal waters (Jamet et al., 2011). This will be for instance specifically performed through an optimization technique like the POLYMER algorithm (Steinmetz et al., 2011), developed by Hygeos.

2.2 Analysis of the inter-annual and decadal variability of the coastal ecosystems

Major patterns of temporal variability for the bio-optical and biogeochemical parameters (Task 3) as well as for sea surface temperature, wind and SSH will be described over the global coastal waters. The different ocean color products aimed in the context of the GloabCoast project will be assessed for the SeaWiFS (1997-2011, MODIS (2002-) and MERIS (2002-2012).

Temporal changes in many physical variables (e.g. river outflow, upwelling indices, tides, etc) will also be described for the various coastal test sites, the dynamics of which are supposed to be highly heterogeneous. In practice, patterns of temporal variability for the various parameters collected will be characterized considering successive time scales:

1) First, the characteristics of the seasonal cycle relevant to the general dynamics of the various coastal ecosystems will be described through the assessment of basic statistics from annual climatology (minimum, maximum, peak duration….).

2) Second, time series, when sufficiently long, will be analyzed to define the major characteristics of inter-annual temporal variability associated with the environmental and biogeochemical data in the various coastal sites.

3) Finally, variations occurring at longer time scales (i.e. decadal) will also be characterized for the selected coastal areas. The potential of comparing the chlorophyll loads provided by the Coastal Zone Color Scanner (CZCS) archive (1979-1986) to those derived from SeaWiFS (1997-2007) for characterizing changes in marine biogeochemistry over the last 2 decades will be investigated. Note that the availability of CZCS data is however too restricted for allowing p decadal analysis over the French Guiana coastal waters.

The different temporal patterns of biogeochemical parameters as well as their interactions with the various environmental forcing will be compared specifically over the Amazon-influenced coast (mainly French Guiana).

To achieve the previous objectives, advanced time series analysis techniques will be applied to the time series generated for the different ocean color optical sensors. For instance time series for the different ocean color record considered will be decomposed into terms representing a seasonal cycle, a trend and irregular variation using the Empirical Mode Decomposition methods (Huang et al., 1998) as well as the Census X-11 iterative bandpass filter algorithm (Pezzuli et al. 2005) which advantages for describing ocean colour seasonality (i.e. relative importance and year-to year stability) and non-linear long term patterns have been demonstrated (Vantrepotte and Mélin, 2011).

3. Results and Discussion

The following sections present some of the preliminary results obtained over the French Guiana coastal waters in the frame of GlobCoast which provide some illustrations of the applications that will be performed in the frame of this project in the latter coastal region.

3.1. Application of the classification-based approach over French Guiana coastal waters

Based on a cluster analysis applied to a wide range of coastal waters, a recent study has demonstrated that class-specific mean R_{rs} spectra significantly differ from one coastal environment to another in relation to variation in the bio-optical properties (Lubac and Loisel, 2007). This approach has been recently developed in the frame of GlobCoast (Vantrepotte et al., 2012) emphasizing the interest of performing an optical classification of coastal waters for dynamically describing changes in the optical properties and therefore in the water masses quality of the coastal waters of French Guiana (Figure 3). The four optical water types which been identified until now allow to account for about 2/3 of the optical variability of these coastal waters. Further, the advantages of the classification-based approach for improving the accuracy in the SPM concentration from satellite remote sensing techniques have also been demonstrated.

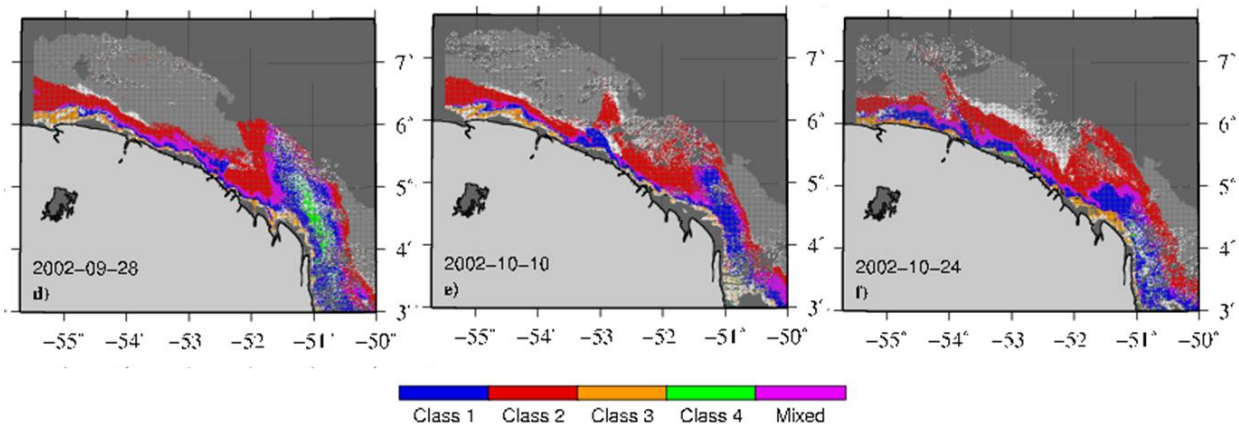

Figure 3: Daily illustration of the classification approach (from Vantrepotte et al., 2012) that will be developed and adopted in the frame of GlobCoast to assess bio-optical products from ocean color observations. Each color corresponds to a given bio-optical environment, for which specific bio-optical algorithm will be applied (Lubac and Loisel, 2007, Vantrepotte et al., 2012). This approach will allow the water masses optical quality to be dynamically monitored, and the retrieval accuracy of the marine products to be improved.

3.2. Characterization of French Guiana coastal waters dynamics as revealed from ocean color remote sensing data.

First results computed from the application of the Census X-11 decomposition method on the SPM times series derived for the MODIS archive has allowed to emphasize the impact of the north Brazilian retroflecting current system on the coastal water of French Guiana which lead to strong irregular temporal variations in the particulate matter content over this coastal region. Furthermore, the analysis of long term trends in SPM in the Guianese coastal waters has revealed the presence of peculiar alternating increasing and decreasing patterns which have been related to the impact of mud-bank migration over this coastal region (Figure 4). Further, specific results obtained over the French Guiana coast have illustrated the potential of

ocean color data for precisely monitoring the dynamics (e.g. assessment of migrations rates) of mud banks over long time scales which will potentially allow for a discrimination of the environmental forcings driving these complex geomorphological processes (Vantrepotte et al., under review).

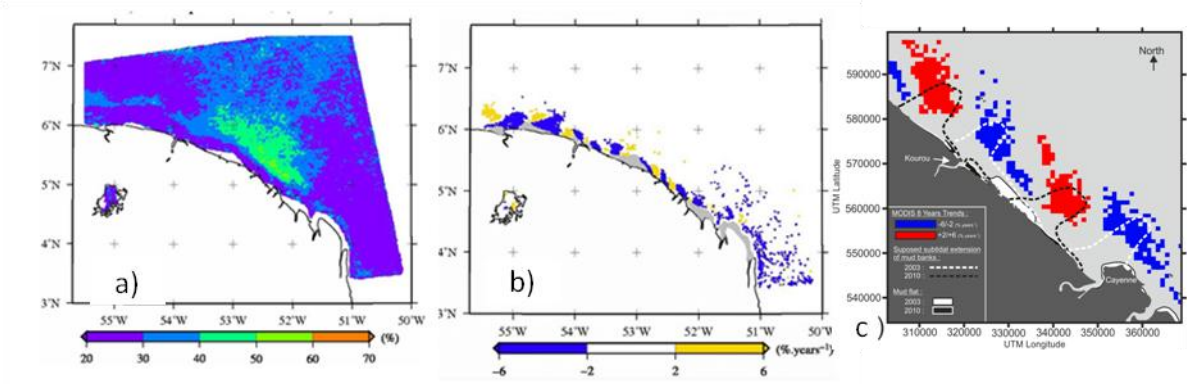

Figure 4: Application of the Census X-11 (Vantrepotte and Mélin, 2011) method for analyzing the temporal variation patterns of suspended particulate matter, SPM, in the French Guiana coastal waters over the MODIS period (2002-2010). The temporal variability in a large area offshore French Guiana is mainly explained by irregular variations (a) presumably associated with the formation of hydrodynamic rings linked to the north Brazilian retroflection current system. Significant trends in the SPM contents over this 8-yr period b) (Guianese coast) and c) (French Guiana) shows a clear alternation between increasing and decreasing areas that might be associated with the migration of mud banks particularly dynamic in this coastal region (Vantrepotte et al., under review).

4. Conclusion

French Guiana coastal waters (and more largely coastal waters influenced by the Amazon river outputs) will be specifically investigated in the frame of the ANR GlobCoast project. The different optical (IOPs, Kd) and biogeochemical (Chla, POC, DOC, SPM) descriptors which will be assessed from innovative approaches in the frame of this project will provide new and crucial information for understanding the biogeochemical processes occurring in the latter coastal domain. In particularly, the analysis of the time series generated for the various optical sensors considered in the frame of this project (SeaWiFS, MODIS, MERIS) will provide relevant insights on the dynamics of French Guiana coastal waters. The various scientific achievements planned in the context of the GlobCoast project will in particularly help to better characterize the impact of the Amazon river outputs and related hydrodynamic processes on the biogeochemical dynamics of the Guianese ecosystems. As a matter of fact, some of the GlobCoast outputs will for instance provide precise information helping to better characterize and understand the dynamics of complex geomorphological processes (i.e. mud banks migration) occurring over the Guianese coast.

References

Huang, N. E., Shen, Z., Long, S. R., Wu, M. C., Shih, H. H., Zheng, Q., Yen, N. C., Tung, C. C., Liu, H. H. The Empirical Mode Decomposition and the Hilbert Spectrum for Nonlinear and Nonstationary Time Series Analysis. **Proceedings of the Royal Society of London** A 454 (1971): 903–995. doi:10.1098/rspa.1998.0193, 1998.

IOCCG. Remote Sensing of Inherent Optical Properties : Fundamentals, Tests of Algorithms, and Applications. Lee, Z. (ed.), **Reports of the International Ocean-Colour Coordinating Group**, No. 5, IOCCG, Dartmouth, Canada. 2006, 89 p

IOCCG. Remote Sensing of Ocean Colour in Coastal, and Other Optically-Complex, Waters. Sathyendranath, S. (ed), **Reports of the International Ocean-Colour Coordinating Group.** 2000, pp. 140.

Jamet, C., Loisel, H., Kuchinke, C.P., Ruddick, K., Zibordi, G., Feng, H. Comparison of three SeaWiFS atmospheric correction algorithms for turbid waters using AERONET-OC measurements. **Remote Sensing of Environment** 115, 1955–1965, doi:10.1016/j.rse.2011.03.018, 2011.

Jamet, C; Loisel, H. and Dessailly, D. Empirical nonlinear determination of the diffuse attenuation coefficient Kd(490) in coastal waters from ocean color images, **Proceeding SPIE** 7858, 785806, doi:10.1117/12.869730, 2010.

Lee, Z. Carder, K.L. and Arnone, R.A. Deriving inherent optical properties from water color: a multiband quasi-analytical algorithm for optically deep waters. **Applied Optics**, 41, 5755-5772, 2002.

Loisel, H., Nicolas, J.-M, Sciandra, A., Stramski, D. and Poteau, A. Spectral dependency of optical backscattering by marine particles from satellite remote sensing of the global ocean, **Journal of Geophysical Research**, 111, C09024, doi:10.1029/2005JC003367, 2006.

Loisel, H. and D. Stramski, D. Estimation of the inherent optical properties of natural waters from irradiance attenuation coefficient and reflectance in the presence of Raman scattering. **Applied Optics**, 39 : 3001-3011, 2000

Loisel, H. and D. Stramski, D. Estimation of the inherent optical properties of natural waters from irradiance attenuation coefficient and reflectance in the presence of Raman scattering. **Applied Optics**, 39 : 3001-3011, 2000.

Lubac, B., and Loisel, H. Variability and classification of remote sensing reflectance spectra in the eastern English Channel and southern North Sea, **Remote Sensing of Environment**, 110, 45–58, 2007.

Maritorena, S., Siegel, D.A .and Peterson, A.R. Optimization of a semi-analytical ocean color model for global-scale applications. **Applied Optics**, 41, 2705-2714, 2002.

Morel, A. and Gentili B. A simple band ratio technique to quantify the colored dissolved and detrital organic material from ocean color remotely sensed data. **Remote Sensing of Environement**, 113, 998-1011, doi:10.1016/j.rse.2009.01.008, 2009.

Steinmetz, F., Deschamps, P.-Y., and Ramon, D., Atmospheric correction in presence of sun glint: application to MERIS, **Optic Express**, 9(10):9783-800. doi: 10.1364/OE.19.009783, 2011.

Vantrepotte, V., H. Loisel, H., Dessailly, D., Mériaux, X. Optical classification of contrasted coastal waters. **Remote Sensing of Environment,** 123, 306–323, doi:10.1016/j.rse.2012.03.004, 2012.

Vantrepotte, V., Mélin, F. Inter-annual variations in the SeaWiFS global chlorophyll a concentration (1997-2007), **Deep Sea Research I**, 10.1016/j.dsr.2011.02.003, 2011.

Vantrepotte, V., Gensac, E., Loisel, H., Gardel, A., Dessailly, D., & Mériaux, X. Satellite assessment of the coupling between in water suspended particulate matter and mud banks dynamics over the French Guiana coastal domain, **Journal of South American Earth Sciences,** under review**.**

Acknowledgements

This research has been founded by the GlobCoast project supported by the Agence Nationale pour la Recherche (ANR, Paris).