Affiliated project:

Science Highlights address the Grand Challenges

GLobCoast: Estimation and analysis of the seasonal, inter-annual and decadal biogeochemical variability of the world's coastal waters by remote sensing and their impacts on higher trophic levels.

Loisel, Hubert[1]; Amara, Rachid[1]; Artigas, Luis Felipe[1]; Beaugrand, Gregory[1]; Birol, Florence[2]; Dessailly, David[1]; Duforêt-Gaurier, Lucile[1]; Gardel, Antoine[1]; Gensac, Erwan[1]; Goyens, Clémence[1];Jamet, Cedric[1]; Lefevre, Jean-Pierre[2]; Lesourd, Sandric[1]; Martinez, Jean-Michel[4]; Mériaux, Xavier[1]; Monsterleet, Bruno[3]; Ouillon, Sylvain[2]; Ramon, Didier[3]; Sentchev, Alexei[1]; Schmmitt, François[1]; Steinmetz, François[3]; Vantrepotte, Vincent[1]; Wandrebeck, Laurent[3].

[1] **LOG 32,** Wimereux, avenue Foch, 62930, France;
[2] **LEGOS**, Toulouse, Midi-Pyrénées, 31400, France;
[3] **HYGEOS**, Lille, Nord, 59000, France;
[4] **GET**, Toulouse, Midi-Pyrénées, 31400, France;

Abstract

Satellite remote sensing now allows for the collection of various physical and biological parameters at regional and global scales and at different temporal resolutions which are not accessible to other sampling methods. The first objective of GlobCoast (www.foresea.fr/globcoast/) is to assess and analyse the seasonal, inter-annual, 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 (IOPs), chlorophyll a (Chl), as a proxy for phytoplankton biomass and suspended particulate matter (SPM) concentrations) as well as more innovative products (particulate and dissolved organic carbon POC and DOC) 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, 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 preferentially performed over three highly contrasted areas covering a great variety of environmental, biological and bio-optical conditions encountered in coastal areas: the English Channel and the North Sea, some major coastal upwelling systems, the Vietnam coastal waters, and the Amazon-influenced coast (mainly French Guiana).
Besides its fundamental role in marine biogeochemical cycles, phytoplankton, which is at the basis of the marine food web, transfers energy to higher trophic levels and its dynamics influences directly and indirectly the biodiversity of some trophic groups such as zooplankton, fishes and marine mammals. The third main objective of GlobCoast 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 (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. This last part will be performed over the English Channel and the North Sea, and some major coastal upwelling systems.

Recent advances obtained in the frame of GlobCoast are presented in this paper. These results mainly focused on methodological development and data acquisition.

I- The GlobCoast project in the context of the coastal ocean global survey

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. Phytoplankton is highly sensitive to environmental perturbations (such as nutrient inputs, light, and turbulence). The abundance, biomass and dynamics of phytoplankton in coastal areas therefore reflect the prevailing environmental conditions and is used in the assessment of ecological conditions, and water quality. Coastal waters also host diverse ecosystems and important fisheries that support industry and provide livelihood to coastal settlements. The food chain in the coastal ocean is generally short (especially in upwelling systems, having as low as three trophic levels) whereas the open ocean food web presents up to six trophic levels (Wollast, 1998). As a result, when compared to the open ocean, a relative lower fraction of the primary production gets respired in the coastal ocean while a higher fraction reaches the uppermost trophic level (fish, Naqvi and Unnikrishnan, 2009) or is exported to adjacent areas (coastal or open sea).

The objective of GlobCoast is to conduct research aimed at resolving some limitations and discrepancies in our understanding and prediction of the coastal ecosystems dynamics and their associated biogeochemical cycles. Large unknowns and uncertainties still remain for a better knowledge of the coastal environment due to the strong coupling between aquatic and terrestrial systems and due to the pressure of large natural and anthropogenic forcing. Good assessments of suspended particulate matter (SPM) concentrations and of the phenomena controlling its temporal variability are essential for many fields of research in coastal areas. For instance, SPM which encompasses organic (living and non-living) and inorganic matter controls the penetration of light into the water and brings new nutrients into the system, both key parameters influencing phytoplankton primary production. Concentrations and availability of SPM are also known to control rates of food intake, growth and reproduction for various filter feeders (Riisgard et al. 1996). The potentially large fluxes of carbon in the coastal ocean underscore its significance to the global carbon cycle; however, because of the extreme heterogeneity of coastal environments, it is also difficult to know whether these systems are net authorophic or heterotrophic (Gattuso and Smith 2007). The assessment of the temporal variability of SPM, POC, DOC, and Chl in coastal areas over long time periods and along with physical forcing parameters will provide valuable insights for improving our knowledge on the biogeochemical cycle in coastal waters.

The examination of causal relationships between hydroclimatic factors and fisheries resources has been the subject of at least one century of research. Strong variability of marine populations with economic impacts for the fisheries exploiting them has been observed for a long time. By comparing shrimp (Pandalus borealis) egg hatching times and satellite-derived phytoplankton bloom dynamics throughout the North Atlantic, significant correlations have been identified between hatching and the timing of the phytoplankton spring bloom (Zein-Eldin and Renaud 1986; Ouellet et al. 2007; Koeller et al. 2009). 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 (Platt et al. 2003; Beaugrand et al. 2003; Koeller et al. 2009). Here we will examine these links over the English Channel and the North Sea, and some major coastal upwelling systems.

II- Challenges for the satellite observation of coastal waters

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). For that purposes new specific inverse methods will be developed and compared to traditional ones. Due to the high variability of the physical and biogeochemical processes occurring in coastal areas, traditional approaches based on oceanographic cruises and in situ time series, although essential, are very time-consuming, expensive and sometimes uncertain to yield meaningful results on the studied phenomena, especially at a large-scale synoptic scale. In this context, remote sensing of biological and physical parameters is a very powerful tool. Satellite data are not as accurate as in situ measurements and are limited to the surface layer. However, the latter limitations are largely compensated by the spatial and temporal coverage offered by the satellite observations. In situ data remain obviously necessary to validate the satellite products, in terms of absolute value, but also in terms of temporal variability in areas where long in situ time series are available. The main problems to overcome in order to have accurate observations of coastal areas from ocean colour remote sensing are the presence of highly diffusing suspended particles (mineral) as well as high concentrations of particulate organic matter (phytoplankton, detritus) which may bias atmospheric corrections, and bio-optical algorithms. Different atmospheric correction schemes have been developed over the last few years for the inversion of the marine remote sensing reflectance, Rrs, in coastal waters from the top of atmosphere reflectance measured by the satellite (see references in Jamet et al. 2011). Based on a consistent in situ data set of Rrs obtained through the AERONET-OC network (Zibordi 2009), a recent study has led to intercomparison of four of these different schemes and of their respective accuracy for the SeaWiFS sensor. The main results of this study are that the new standard algorithm (Bailey et al. 2010) shows the best overall retrievals, and that Rrs should be inversed simultaneously to obtain a better accuracy for the short visible wavelengths. A new atmospheric correction procedure, based on Steinmetz et al. (2011), for ocean colour remote sensing over coastal areas taking advantage of these different findings will be developed in the frame of this project.

Accurate assessment of the differences in water bio-optical components from ocean colour measurements in coastal areas is largely controlled by: (i) our ability to understand and to account for the origin of the variability in Rrs, and (ii) the realism of the parameterizations used between the inherent optical properties (IOPs) and the biogeochemical component (BC). Regional approaches are generally adopted to limit the impact of such variability through the development of algorithms specifically built from data collected in the studied regions. However, while such regional algorithms may reduce the variability in the IOPs-BC relationships, they are highly dependent on the dataset used for their development. Moreover, even for a local area and a given season, the regional algorithms may also be largely inadequate due to the numerous high frequency processes occurring in coastal waters. Finally, development of regional algorithms is not appropriate when dealing with the whole coastal ocean. In the frame of GlobCoast, we propose to adopt another original approach based on classification techniques which can be used in all coastal waters (Lubac and Loisel 2007). Besides traditional evaluations based on comparison with in situ measurements, this approach will be compared with results obtained over some specific coastal regions for which regional approaches are developed, or with more standard methods. Last but not least, in situ data collected in the frame of this project will enhance our knowledge on different fundamental bio-optical considerations: i.e. the relationships between coloured dissolved organic mater (CDOM) and DOC, and between the particle size distribution (PSD) and the spectral dependency (γ) of the particulate backscattering coefficient.

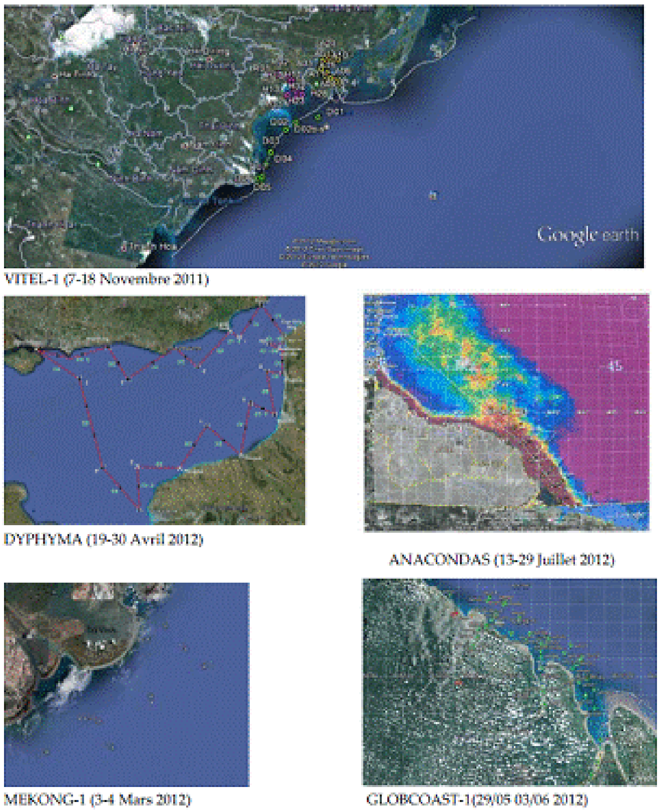

Figure 1. Maps of the recent field campaigns performed in the frame of GlobCoast and in collaboration with other research projects (TOSCA/VITEL and WWF-Mekong in Vietnam; GlobCoast in French Guyana; Interreg4A"2"Seas/Dymaphy in the English Channel, and the ANACONDA cruise from the Barbados to the AMAZONE river).

III- Recent advances in the frame of GlobCoast

The bio-optical data base. The development and validation of the different inverse methods proposed in the frame of GlobCoast require the availability of a large data set gathering radiometric, optical, and biogeochemical measurements performed in various and contrasted bio-optical environments. Besides data originating from international databases (NASA/NOMAD, Helcom, ICES, Seadatanet, SOMLIT, ANTARES ChloroGIN, etc), new specific cruises are conducted in the frame of GlobCoast in order to cover a wider range of natural variability, and to specifically characterize some poorly documented relationships (Figure 1).

Evaluation of four atmospheric correction algorithms for MODIS-Aqua images over contrasted coastal waters. This study has allowed 4 MODIS-Aqua atmospheric correction algorithms for turbid waters to be validated. The performances of the algorithms as a function of water type (Vanterpotte et al. 2012) have also been investigated. Overall, the NASA standard algorithm showed the best results. However, the performances of the algorithms appeared to be water type specific (Figure 2). This study is complementary to the work done by Jamet et al. (2011) performed for the SeaWiFS sensor.

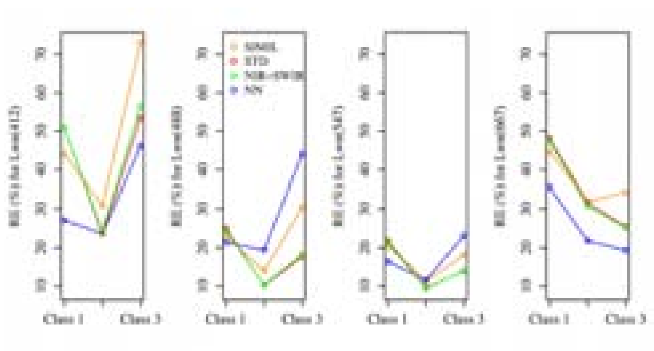

Figure 2. Relative Error (RE) using four different atmospheric correction algorithms per water type (dominated by detrital and mineral material (Class 1), presenting optical properties significantly influenced by phytplankton (Class 2), and mainly influenced by phytoplankton and CDOM (Class4)) at 412, 488, 547, 667 nm.

First classification schemes for bio-optical applications. Prior to the inversion of bio-optical parameters in such complex environments, we propose to classify each pixel as a function of its optical characteristics and then to apply class-specific algorithms to improve the inversion of the different parameters. The retrieval accuracy of biogeochemical parameters is indeed sensitive to the variability of inherent optical properties (Loisel et al. 2010). Based on a data set collected in contrasted turbid coastal areas of the eastern English Channel, southern North Sea and French Guiana at different seasons, four optical classes have been defined using a clustering approach performed on the spectrally normalized reflectance spectra (Vantrepotte et al. 2012). Applying this optical typology to the SeaWiFS daily reflectance data, we emphasized the high representativeness of these 4 optical water types which allow to describe about two thirds of the reflectance spectra found within the development sites whatever the season, and about 40% of the global coastal waters (Figure 3). Field measurements planed in the frame of GlobCoast in other bio-optical water types will allow to greatly increasing this percentage for global applications. The potential for class based inversion algorithms for improving ocean color products retrievals, has been illustrated from the estimation of the suspended matter concentration (Vantrepotte et al. 2012).

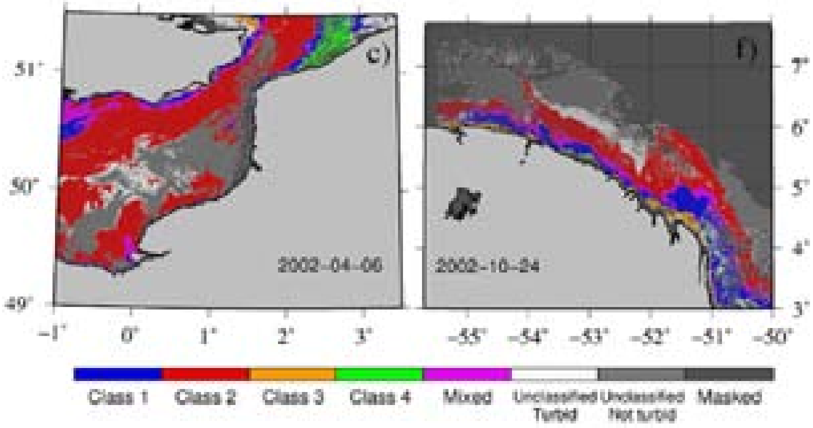

Figure 3. Short time evolution of the 4 reference water type distributions observed from the SeaWiFS reflectance data in the eastern English Channel and Southern North Sea (left) and in the French Guiana (right) coastal waters. White pixels correspond to unclassified turbid waters, light and dark gray show non-turbid and masked regions, respectively. Figure from Vantrepotte et al. (2012).

The temporal evolution patterns. The present project is based on the exploitation of data from different origins and on the use of various statistical approaches and mathematical tools to assess the relationships (causal or not) between environmental forcing parameters and biogeochemical parameters, as well as higher trophic level organisms. To describe their temporal patterns we will compare two different approaches. The time series will be first decomposed into a seasonal, an irregular and a trend-cycle term using the Census X-11 procedure which is based on an iterative band pass filter algorithm that explicitly allows the consideration of inter-annual variations in the seasonal cycle shape (Pezzulli et al., 2005). An example of application of this approach is given in Figure 4. The second method is the Empirical Mode Decomposition which is a method developed by Huang et al. (1998) to decompose a time series into a sum of modes, each mode being itself a new time series with a specific characteristic frequency, larger for increasing mode number. The modes are determined by an algorithm which is data-driven, with no a priori basis

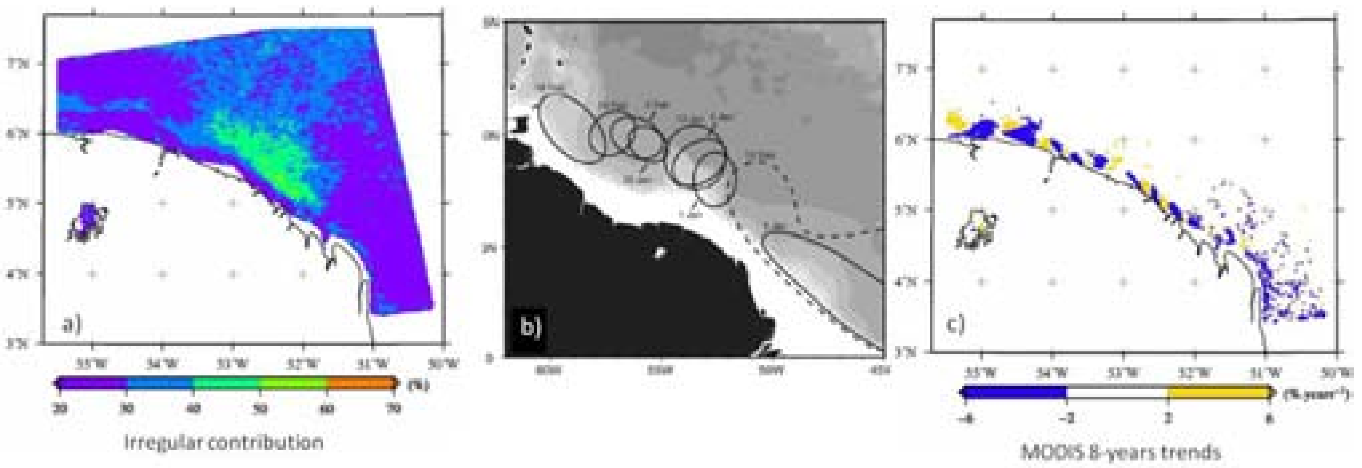

Figure 4: Application of the Census X-11 method for analyzing the temporal variation patterns of suspended particulate matter, SPM, in the French Guiana coastal waters over the MODIS period (2002-2010). The temporal variability in a large area offshore French Guiana is mainly explained by irregular variations (a) presumably associated with the formation of hydrodynamic rings (b) linked to the north Brazilian retroflection current system (Frantatoni and Glickson 2002). Significant trends in the SPM contents over this 8-yr period (c) 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.

as done for wavelet or Fourier decompositions. In order to illustrate this, we apply here the EMD to the normalised leaving radiance at 488 nm, Lwn(488), recorded at the Aeronet Venice station from 2002 to 2011 (Figure 5).

Extreme coastal variability: the case of the French Guiana coast. The morphology and sediment dynamics of the 1500 km-long coast of South America between the mouths of the Amazon and the Orinoco Rivers are largely dependent on the massive suspended-sediment discharge of the Amazon, part of which is transported alongshore as mud banks. The coastal dynamics, confronted in terms of mud bank migration, is quantified using innovative morphological data extraction methods from satellite images developed over the last five years. The use of multi-temporal set of satellite images (high spatial resolution sensors as SPOT) provides updated monitoring of variability in mud bank migration rates along the French Guiana coastline (Figure 6). It has become clear in the course of ongoing research that river mouths and river discharge patterns, initially invoked as sources of migration-rate variability, may indeed influence migration rates. The large rivers appear to generate significant offshore deflection of mud banks in transit alongshore, through a hydraulic-groyne effect. This may favour both muddy accretion on the updrift coast and downdrift mud liquefaction with probably lessened muddy deposition. Modelling of mud-bank migration rates in the future will need to take into account this river-mouth component.

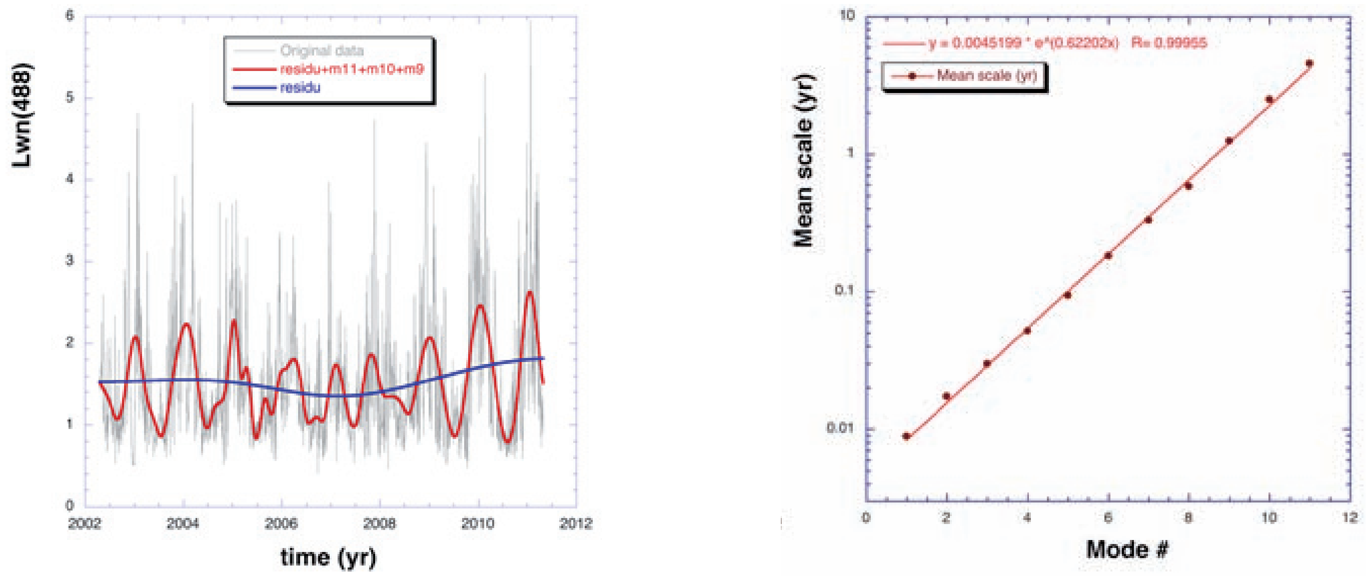

Figure 5. Residue, and larger modes, compared to the original time series. The red curve shows the residue and 3 larger modes, capturing the seasonal fluctuations (left). The relation between mode number and mean time scale, with an exponential fit, showing that each mode has a mean time scale about twice(1.86 exactly) the previous mode (right).

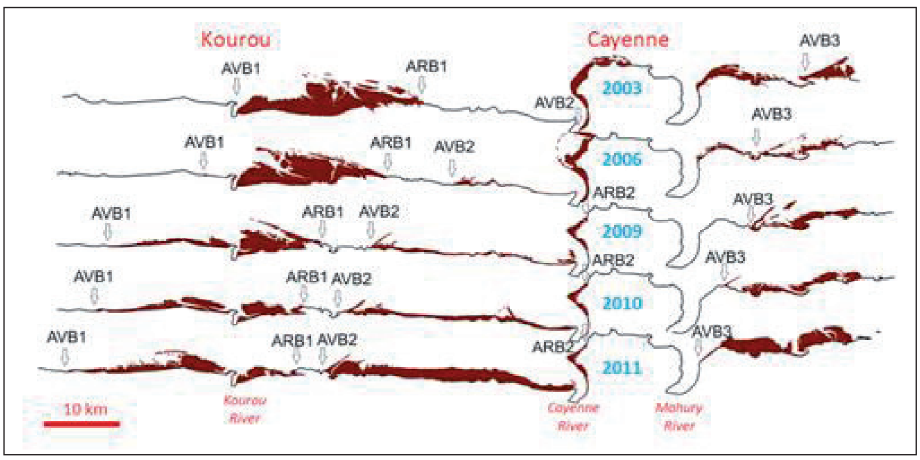

Figure 6. mud banks (in brown) position along the Cayenne Kourou coast between 2003 and 2011. AVB indicates heading edge position of mud banks (1, 2, and 3), ARB indicates trailing edge position of mud banks.

IV- Conclusions

Large uncertainties remain on the evaluation of stocks of main biogeochemical parameters in coastal waters and their seasonal, inter-annual, and decadal evolutions. The achievement of the different objectives of the GLobCoast project 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 (Reid et al. 1998). 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 (Fontana et al. 2009).

Acknowledgments

The GlobCoast project id funded by the Agence National de la Recherche (ANR-blanc, France).

References

Beaugrand G., K.M., Brander, J.A., Lindley, S., Souissi and P.C., Reid (2003). Plankton effect on cod recruitment in the North Sea, Nature, 426, 661-664.

Fontana, C, C. Grenz, C. Pinazo, P. Marsaleix, and F. Diaz. (2009) Assimilation of SeaWiFS chlorophyll data into a 3D-coupled physical–biogeochemical model applied to a freshwater-influenced coastal zone. Continental Shelf Research 29, 1397–1409.

Gattuso J.-P. & Smith S. V., 2007. Coastal zone. In: Cleveland C. J. (Ed.), Encyclopedia of Earth. Washington D. C.: Environmental Information Coalition, National Council for Science and the Environment.

Huang N. E., Shen Z., Long S. R., Wu M. C., Shih, H. H., Zheng Q., Yen N., Tung C. C. and Liu H. H., The empirical mode decomposition and Hilbert spectrum for non-linear and non-stationary time seriesanalysis, Proc. R. Soc. London, Ser. A., 454 (1998), 903-905.

IOCCG (2000). RRemote sensing of Ocean Colour in coastal and Other Optically-Complex, Waters, Eds. S. Sathendranath, Report 3, pp. 140.

IOCCG (2006). Remote Sensing of Inherent Optical Properties: Fundamentals, Tests of Algorithms and Applications, Eds. ZP Lee, Report 5, pp. 126.

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

Koeller, P., C., Fuentes-Yaco, T., Platt, S., Sathyendranath, A., Richards, P., Ouellet, D., Orr, U., Skuladottir, K., Wieland, L., Savard and M., Aschan (2009). Basin-scale coherence in phenology of shrimps and phytoplankton in the North Atlantoic Ocean, Science, 324, 791-793.

Loisel H., Lubac B., Dessailly D., Duforêt-Gaurier L., and Vantrepotte V. "Effect of inherent optical properties variability on the chlorophyll retrieval from ocean color remote sensing : an in situ approach", Optics Express, Vol. 18, No. 20, 2010.

Lubac, B. and H., Loisel (2007). Variability and classification of remote sensing reflectance spectra in the eastern English Channel and southern North Sea, Remote Sens. Environ., 110, 45-58.

Naqvi, S.W.A.; Unnikrishnan, A.S. 2009. Hydrography and biogeochemistry of the coastal ocean In "Surface ocean - Lower atmosphere processes. eds. by: Le Quere, C.; Saltzman, E.S.", 233-250.

Pezzulli, S.; D.B. Stephenson and A. Hannachi, (2005). The variability of seasonality, Journal of Climate, 18, 71-88.
Platt, T., C., Fuentes-Yaco and K.T., Frank (2003). Spring algal bloom and larval fish survival, Nature, 423, 398-399.
Reid, P.C., M., Edwards, H.G., Hunt and A.J., Warner (1998) Phytoplankton change in the North Atlantic, Nature, 391, 546-546.

RiisgArd, H.U. (1998). Filter feeding and plankton dynamics in a Danish fjord: a review of the importance of flow, mixing and density-driven circulation, J. Environ. Manag., 53, 195-207.

Steinmetz F., P.-Y. Deschamps, and D. Ramon, "Atmospheric correction in presence of sun glint: application to MERIS", Opt. Express, Vol. 19, Issue 10, pp. 9783-9800 (2011).

Ouellet, P., Savard, L. & Larouche, P., 2007. Spring oceanographic conditions and northern shrimp Pandalus borealis recruitment success in the north-western Gulf of St. Lawrence. Marine Ecology Progress Series, 339, 229-241.

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

Wollast, R. (1998). Evaluation and comparison of the global carbon cycle in the coastal zone and in the open ocean, p. 213-252. In K. H. Brink and A. R. Robinson (eds.), The Global Coastal Ocean. John Wiley & Sons.

Zein-Eldin , Z.P. and M., Renaud (1986). Inshore Environmental Effects on Brown Shrimp, Penaeus aztecus, and White Shrimp, P. setiferus,
Populations in Coastal Waters, Particularly of Texas. Marine Fisheries Review, 48, 9-19.

Zibordi, G., B., Holben, I., Slutsker, D., Giles, D., D'Alimonte, F., Mélin, F., J.-F., Berthon, D., Vandemark, H., Feng, G., Schuster, B.E., Fabbri, S., Kaitala and J., Seppälä (2009). AERONET-OC: A network for the validation of ocean color primary products. Journal of Atmospheric and Oceanic Technology, 26, 1634-1651.