FINAL REPORT PROGRAM LEFE

Program LEFE/ BIOHEFECT	Project Title ***Combined GEOchemical and MODelling approaches for an improved understanding of the water cycle in the Bay of Bengal (GEOMOD)***	Years 2015-2016

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Context: The northern Indian Ocean is home to the most powerful monsoon system on Earth. Monsoonal rains over the Bay of Bengal induce some of the lowest salinities in the tropical belt, which are thought to play a key role in the regional climate. Despite these implications, the water cycle in the Bay of Bengal, and particularly the origin of salinity fluctuations (continental runoffs vs oceanic rain) and its impact on the regional climate is still not well understood.

Objectives / scientific questions: This proposal aims at estimating the respective contribution of continental runoffs and oceanic rain to the Bay freshening through a multidisciplinary approach combining geochemical analyses of seawater samples with physical ocean modelling. It also tests the hypothesis that salinity stratification in the Bay of Bengal has a first-order impact on the regional climate through sensitivity experiments with a regional coupled model.

Main results: A lagragian approach allowed us assessing the observed pathways of the freshwater transport from the major river systems into the BoB. These results are illustrated on Figure 1 for the case of the Gange-Bramaputra and shows that most of these freshwater are transported along the western boundary of the Bay. Our results further demonstrate that mesoscale eddies strongly contribute to export these transport waters offshore (Fig. 1ab) and that these waters are exported further south during negative Indian Ocean Dipole events compared to their positive counterparts (Fig. 1cd). We also collected and analyzed water samples (~100) from major river estuaries and coastal and offshore stations for trace elements displaying high concentrations in the Indian rivers (Ba and U) and isotopic signatures very different from those of seawater (234U/238U activity ratio). Our results confirm that most freshwater along the east coast of India originate from the Gange-Bramapoutra outfow, with a contribution from peninsular river at specific locations. Open ocean fresh water are a mixture of oceanic rainfall and estuarine waters, with a larger contribution from estuarine water when approaching the coast.

A tracer model embedded into oceanic simulations allowed us to precisely quantify the respective influence of each of the three main sources (Ganges–Brahmaputra, Irrawadi and oceanic precipitation falling into the Bay) to the surface freshwater distribution observed during and right after the monsoon. Our results indicate that the freshwaters originating from the Ganges-Bramaputra dominate the freshening in the northern and northeastern head of the Bay, while the Irrawadi controls the eastern freshening and the oceanic rainfall dominates 500km off the shore. These results are currently quantitatively compared with our geochemical analysis. Our modeling results further indicate that salinity variations in the Bay are strongly influenced by the remote forcing from the Indian Ocean Dipole, with SSS variations of opposite polarity along the east coast of India and in the Southern Andaman Sea.

Finally, results from our from a 25-km resolution regional coupled climate model demonstrates that salinity stratification indeed tends to warm the mixed layer through vertical mixing (Figure 2a), but that this effect is entirely compensated by changes in the mixed layer heating rate by air-sea fluxes (Figure 2b), hence resulting in a negligible climatological surface temperature (Figure 2c) and rainfall change (Figure 2d) at all seasons. During and shortly after the southwest monsoon, the slight increase of the mean surface temperature and wind variance lead increased upward latent heat fluxes that cool the ocean, i.e. atmospheric thermodynamics exert a negative feedback on surface temperature. During winter, salinity enhances the atmospheric cooling by allowing negative air-sea fluxes to act over a thinner mixed layer. Because of compensating effects on the upper ocean heat budget, salinity hence does not seem to influence the Bay of Bengal climatology in our simulations.

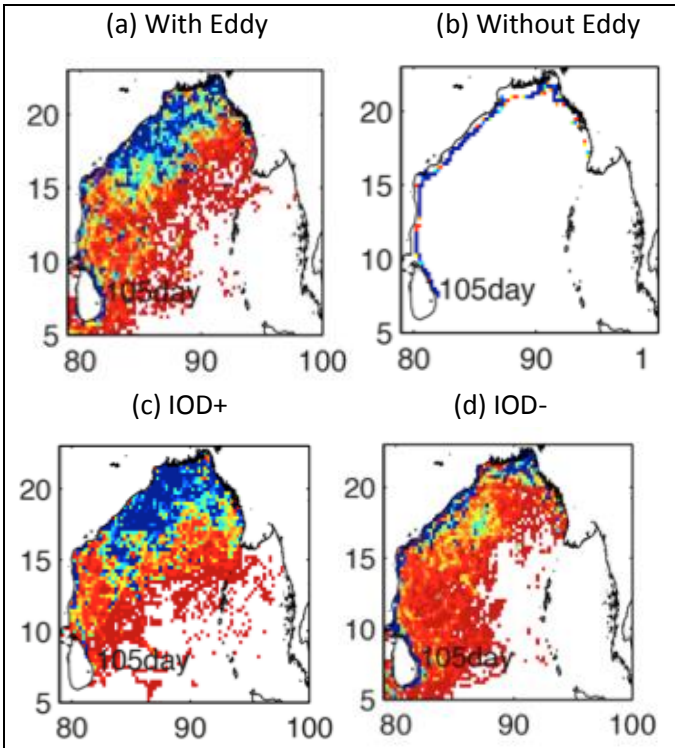

Figure 1: (Left) Distribution of particules 105 days after their release at the Ganges-Bramaputra estuary from our lagrangian model (a) in the presence of eddies, (b) in the absence of eddies, for (c) positive IOD and (b) a negative IOD,

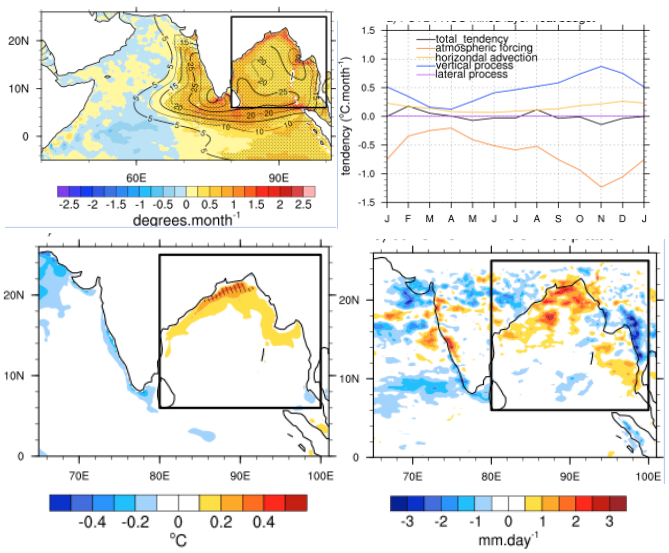

Figure 2: (Top left) Summer climatological maps of the impact of salinity stratification on the vertical mixing term of the mixed layer heat budget (°C month^{-1}) and barrier layer (contours). (Top right) Climatological impact of salinity stratification over the Bay of Bengal on the MLD heat budget (°C/month). (Bottom) Summer climatological maps of the impact of salinity stratification on SST (°C) and precipitation (mm.day^{-1}).

Future of the project: The near future of this project will be first to finalize the work and publications related to (1) the geochemical analyses, (2) the lagrangian model and (3) the tracer model within the frame of Indian PhD student involved in the project (AVS Chaitanya). On the longer term, we will pursue our collaboration with our indian colleagues on the assessement of salinity variability in the northern Indian ocean through dedicated models experiments and in-situ and satallite observations and to assess the impact of this salinity stratification on the BoB tropical cyclones by setting a very high resolution coupled ocean-atmosphere model within the Bay of Bengal.

Thèse : AVS Chaitanya (2015-…) : Assessing the origin of freshwaters over the BoB: An interdisciplinary approach

Publications :

[1] Krishnamohan, K.S., J. Vialard, M. Lengaigne, S. Masson, G. Samson, S. Pous, F. Durand, S. Shenoi, G. Madec: Is there an effect of the Bay of Bengal salinity on the Indian Ocean Climate? *Climate Dynamics*, in revision

[2] Fournier S., J. Vialard, **M. Lengaigne**, T. Lee, M.M. Gierach, A.V.S. Chaitanya, 2017: Unprecedented satellite synoptic views of the Bay of Bengal "river in the sea", *Journal of Geophysical Research-Ocean*, online first, doi: 10.1002/2017JC013333

[3] Akhil V.P., M. Lengaigne, J. Vialard, F. Durand, M.G. Keerthi, A.V.S. Chaitanya, F. Papa, V.V. Gopalakrishna, C. de Boyer Montégut, 2016: A modelling study of processes controlling the Bay of Bengal sea surface salinity interannual variability, *Journal of Geophysical Research: Oceans*, 121: 8471-8495, doi:10.1002/2016JC011662

[4] Akhil V.P., **M. Lengaigne**, F. Durand, J. Vialard, C. de Boyer Montégut, V.V. Gopalakrishna, 2016: Assessment of seasonal and year-to-year surface salinity signals retrieved from SMOS and Aquarius missions in the Bay of Bengal, International Journal of Remote Sensing, 37: 1089-1114, doi:10.1080/01431161.2016.1145362