Appel à projet, PRC 2015
« Gestion sobre des ressources
et adaptation au changement climatique »

Projet: CAOCS
Coupling of Atmosphere and Ocean
at Climatic Scales :

I) Pertinence et caractère stratégique du projet

The present project relies on a new vision that has emerged about the interactions between the atmosphere and the ocean. Before 2000, it was thought that the ocean did not have a real impact on the low-frequency variability, i.e. with timescales above 2 weeks. This explained why standard General Circulation Models (GCM) of the coupled ocean-atmosphere system could not have a predictive impact at seasonal timescales. Since 2000, some breakthrough has been obtained when reconsidering our vision about what ocean processes matter in the ocean-atmosphere interactions. It is not the Sea Surface Temperature anomalies (SST) that matter for the coupling, but the SST fronts, such as in the Gulf Stream where we can have a difference of 3K in temperature over 300km across the front. The importance of these fronts have been put in evidence for the atmospheric boundary layer and for the general circulation since the last ten years.

Our preceding project (ANR ASIV) built over these facts and studied the impacts of fine-scale oceanic structures (fronts such as the Gulf Stream, or mesoscale oceanic eddies about 200km of diameter) on the atmosphere. A large response in the atmospheric boundary layer temperature and vertical velocities was shown in both idealized models, down to kilometer-scale, and in more realistic simulations of the Gulf Stream region. A large-scale response to shifts of the position of the Kuroshio front (along East coast of Japan) was also found in observational data (Révélard and Frankignoul, submitted). Experiments performed using realistic GCMs revealed that the simulated response strongly depends on the atmospheric resolution. These different results, obtained during the ASIV project, strongly suggest that frontal-scale (50-100 km) circulations within mid-latitude storms are key in understanding the remote influence of SST fronts.
Western boundary currents such as the Gulf Stream and Kuroshio, and the associated oceanic eddies, are also part of the ocean circulation that transports heat towards the pole. Their impact can therefore be usefully seen from an energy budget perspective. Indeed, it was shown during ASIV that an imposed northward heat transport by the ocean, even restricted to the Atlantic, could have global climate impacts including shifts of the storm tracks and tropical precipitations. These shifts could be explained by a compensating atmospheric energy transport, and its links with the hydrological cycle.

It is now time to go one step further to examine how climate processes (such as the North Atlantic Oscillation or even the Atlantic Multidecadal Oscillation) responds to such SST anomalies using high resolution numerical models. This is still challenging since we are at present just at the limit of resolving the important scales due to computer limitation, but programs such as PRACE (http://www.prace-ri.eu) make things possible. This project is based in large part around the use of

idealized models of the ocean and atmosphere: either in their geometry, physics, or both. This will help to bring together the French community using these simple models to study the atmosphere or the ocean, and the project indeed proposes to build several new modeling tools designed to understand air-sea interactions. The results from these idealized experiments will help climate modelers to interpret and to guide them in their effort to represent ocean-atmosphere processes and validate their results concerning atmospheric variability.
More practically, it will serve to the training of a PhD student and a postdoc and the computer resources that will be obtained thanks to its label will help to perform the numerical simulations.

II) Objectifs scientifiques et technologiques

- *Impacts on storm development and storm tracks*

The tropospheric variability at timescales of months is affected by the so-called “storm-track”, which are regions of storm life-cycles, over the Atlantic and Pacific basin. Mid-latitude storms take their energy from the instability of the tropospheric jet at the entrance of the storm-track, transport energy eastward and retroact on the mean jet when they decay. The nonlinear wave-mean flow interactions between the fast transients (corresponding to the storms with a typical timescale of days) with low-frequency waves (timescale of several weeks, such as the North Atlantic Oscillation, corresponding to the jet variability) define the storm-track region. An emerging idea is that mid-latitude storms are an important intermediate for a large-scale influence of SST fronts on the general circulation of the atmosphere. This influence is a bottom-up process: a) the atmospheric boundary layer has a rapid response to oceanic eddies or fronts, as showed by one of our previous studies and we were able to provide some theoretical prediction of this response; b) the development of storms is dependent on the surface conditions in SST because of its effect on surface heat fluxes, as shown by several past studies; c) the final ingredient is the wave-mean flow interactions between the storms and the general atmospheric circulation when storms give their energy to the mean jet.
The project will try to identify how the oceanic mesoscale eddies impact on the characteristics of the atmospheric storm-track through these different interactions, namely, between the oceanic SST and the storm dynamics on one hand, and between the storms and the storm-tracks on the other hand. An important point is to know what oceanic scales the upper troposphere really see, and is it different for different timescales?
This can only be achieved by using very-high resolution simulations simulating both the storm-track (domain of thousands of km) and oceanic eddies (scales of hundred of km). Such simulations can be done in idealized setting, including only key processes. We suspect for instance that water vapor processes may play a crucial role, as water is evaporated from the ocean surface, is transported by the storms over long distances (thousand of km) and latent heat is released further along the storm-track. Hence, the moist processes may play a catalytic role in the air-sea coupling for low-frequency variability.

- *Mechanisms of atmospheric variability: passive or active ocean?*

Our previous studies seem to show that the coupling between ocean and atmosphere is active over the North Atlantic region and over the North Pacific boundary current regions. This was observed for the mean atmospheric response. Several paradigms apply to the decadal to multidecadal climate variability in the North Atlantic, and neither observations nor climate models allow yet to identify the most relevant. Thus, the low-frequency oceanic variability like the Atlantic Multidecadal

Oscillation may simply result from the internal atmospheric variability, or fully coupled modes. Previous works showed that an atmospheric model coupled to a mixed layer can reproduce some aspect of the El Niño Southern Oscillation. Also, idealized-geometry ocean models spontaneously generate multidecadal variability under prescribed buoyancy fluxes, due to large-scale baroclinically unstable Rossby waves. Such mechanism may still be relevant in more realistic ocean or coupled configurations.

Recent progress suggests that oceanic modes may be damped in realistic configurations, but sustained through either oceanic mesoscale turbulence or atmospheric synoptic variability: both processes result in a widening of the variability spectrum. A relevant question is what are the mechanisms responsible of the persistence of oceanic modes and how they participate to modify the air-sea interactions, in particular in the Atlantic sector. Such mechanisms could be associated with oceanic fronts or mesoscale eddies. These different processes can be analyzed through a series of linear and nonlinear numerical experiments using coupled and uncoupled models.

- *Energetics constraints and climate*

On long enough timescales, the global energy budget must be balanced everywhere. This means that a change in the radiative forcing at the top of the atmosphere, or a change in the meridional heat transport by the ocean, must be balanced by opposite changes in the atmospheric energy transport.

The atmospheric meridional energy transport is accomplished mostly by eddies (storms) in the mid-latitudes, and by the Hadley Cells in the tropics. In both cases, it is strongly coupled with the moisture budget, and changes in the meridional transport lead to changes in the storm tracks or the Inter-Tropical Convergence Zone (ITCZ).

In particular, it has been shown in a number of studies that an inter-hemispheric unbalance – caused by albedo changes, or by prescribed ocean heating anomalies – led to meridional shifts of the ITCZ, coupled to a cross-equatorial Hadley circulation. The ASIV project contributed by showing in an atmospheric GCM coupled to a slab ocean that

1. A prescribed northward heat transport in the Atlantic Ocean, as could be due to decadal changes in the meridional circulation, led to global climate impacts, irrespective of the spatial structure of the mid-latitude heating.
2. The atmospheric response included a northward shift of the ITCZ, but also of the storm tracks in both hemispheres.

All of these previous modeling studies used either an inert ocean ("slab") or an experimental setup that did not allow a quantitative understanding of the mechanisms at work (such as "hosing" experiments). An active ocean circulation may however strongly modify this classic response. Indeed, in the current climate most of the poleward energy transport in the deep tropics is done by the ocean; and changes in the Hadley circulation should drive corresponding changes in the oceanic cells.

We therefore propose to study in more details the interactions between the energy transports by the ocean and the atmosphere in shaping the response to asymmetric extra-tropical heating. In parallel, we will also study the case of a CO_2 increase, which leads to more symmetric anomalous meridional energy fluxes and which is crucial to better understand climate change. We will start with the classical setup of an atmospheric GCM coupled with a simple (slab) ocean and progressively add complexity in the ocean – sea ice, which may yield additional feedbacks, Ekman heat transports due to wind, etc. The final step will be to use a global ocean model – or analyze the relevant simulations of Climate Change (CMIP5) experiments in the case of a CO_2 increase.

III) Cohérence de la pré-proposition

- ## *Personnes impliquées dans ce projet*

The project involves the Laboratoire de Météorologie Dynamique (LMD, Ecole Normale Supérieure/CNRS, Paris), the Laboratoire d'Océanographie et du Climat – Expérimentation et Approches Numériques (LOCEAN, Université Pierre et Marie Curie/CNRS, Paris) and Laboratoire de Physique des Océans (LPO, Université de Bretagne Occidentale/CNRS, Brest).
The Principal Investigator is Guillaume Lapeyre (LMD). Other scientists involved at LMD are Riwal Plougonven and Gwendal Rivière. They benefit from the modeling assistance of Lionel Guez. Francis Codron and Guillaume Gastineau participate at LOCEAN and Olivier Arzel and Thierry Huck, with the assistance of Patrice Bellec in modelling at LPO.

One important fact is that the average age of the team is around 40 years old, which means that the project mainly involves junior scientists.

Guillaume Lapeyre is a specialist of physical oceanography at mesoscales and on dynamical meteorology, using simplified models and theory. Riwal Plougonven is a specialist of storm-tracks and in realistic modeling. Gwendal Rivière is a specialist on dynamics of midlatitude storms. Francis Codron is a specialist in the atmosphere general circulation, climate variability. Guillaume Gastineau will provide his expertise in role of the ocean in decadal variability, AMOC, coupled modeling. Thierry Huck and Olivier Arzel are specialists of low-frequency variability in the ocean.

- ## *Relevant publications*

1. J. Lambaerts, **G. Lapeyre**, **R. Plougonven** and P. Klein, 2013, Atmospheric response to sea surface temperature mesoscale structures. J. Geophys. Res 118, 9611-9621.
2. Brachet, S., **F. Codron**, Y. Feliks, M. Ghil, H. Le Treut and E. Simonnet (2012). Atmospheric circulations induced by a mid-latitude SST front: a GCM study. Journal of Climate,25, 1847-1853.
3. Frankignoul, C., **Guillaume Gastineau** and Young-Oh Kwon, 2013 : . The Influence of the AMOC Variability on the Atmosphere in CCSM3. *J. Climate*, **26**, 9774–9790
4. **Huck, T.**, **O. Arzel**, F. Sévellec, 2014: Multidecadal variability of the overturning circulation in presence of eddy turbulence. J. Phys. Oceanogr., in press.

- ## *CV of PI Guillaume Lapeyre*

Education
2010 Habilitation à Diriger des Recherches (UPMC).
2000 PhD in Oceanography, Meteorology and Environment, at Laboratoire de Physique des Océans (LPO, IFREMER, Brest) under the supervision of Patrice Klein and Lien Hua
1995 Ecole Normale Supérieure (Paris)

Professional Experience
Since 2004 CNRS Associate Scientist (Chargé de Recherche) at LMD
2002-2004 Postdoctoral fellow at LPO, IFREMER (Brest)
2000-2002 Visiting Scientist, GFDL, Princeton University

Professional Activities
37 publications (see http://www.lmd.ens.fr/glapeyre).
Since 2004, 5 Phd students and 4 postdocs supervised.
Since 2003, Referee for national agencies (NSF, NSERC, NERC), AXA research fund, various scientific journals such as J. Atmos. Sci., J. Phys. Oceanog., J. Climate, Phys. Fluids
2012- Scientific Secretary of Section 19 of the "Comité National" of CNRS

Awards
2008 Journal of Physical Oceanography Editor's Award.

- *Funding*

- 40000 Euros for LMD
- 140000 Euros for LOCEAN
- 110000 Euros for LPO

1 PhD student at LOCEAN + 1 postdoc at LPO + Master students: 240000Euros
Other costs (publications, computer expenses, travel, etc.): 50000 Euros