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LOW-FREQUENCY OSCILLATIONS IN THE ATMOSPHERE INDUCED BY A MID-LATITUDE SST FRONT

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1.INTRODUCTION AND MOTIVATION

The most recent and famous dramatic effect of Sea Surface Temperature (SST) on the atmosphere is the intensification of Hurricane Katrina (2005) passing the warm Loop Current, [*Scharroo et al.* 2005]. [*Wu et al.* 2007] using a simple hurricane-ocean coupled model found different parameters to explain the origin of such an intensification: it depends on both oceanic structure and properties of the tropical cyclone. We now focus on mid-oceanic thermal fronts that are permanent features of the mid-latitude ocean circulation. What impact do they have on low-frequency atmospheric oscillations? [*Warner et al.* 1991] tested the sensitivity of the atmospheric marine boundary layer (AMBL) to a steady state of the Gulf Stream (GS) SST using a smooth and a high-resolution version of the SST forcing. Their AMBL develops a front near the GS's north wall that is much stronger with the high-resolution forcing. In both simulations, responses to the surface forcing extended upward to about 1200 m. Very recently, [*HaiMing et al.* 2008] using satellite observations reveal a more significant positive SST-wind correlation when strong meanders occur along the Kurushio Extension. [*Tokinaga et al.* 2005] with both satellite observations and in situ measurements found a difference in the stability in the AMBL between the warm Brazil Current (destabilization) and the cold Malvinas Current (stabilization).

Numerical models help to point out the importance of midlatitude oceanic fronts for the tropospheric circulation. [*Nakamura et al.* 2008] use a 150 km grid spacing and 48 vertical levels "aqua-planet" model. The removal of the SST front in their model leads to a weakening of the dominant mode of westerly jet variability in winter. With the Mesoscale Model named MM5 and scatterometer data, [*Song et al.* 2006] conclude that the perturbation pressure gradient is the main force modifying the air flow across the front. The effects that will be analyze in our paper are those due to a purely steady oceanic front and not those due directly to the variability of that front.

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A novel point of view of the impact of a permanent oceanic front of SST on the atmosphere has been developed by [*Feliks et al.* 2004, 2007], hereafter FP for Feliks Papers. They studied the long-term behavior of the free atmosphere as a function of SST anomalies. They used a hierarchy of models: from a highly idealized, linear AMBL to a quasi-geostrophic free atmosphere, first barotropic [*Feliks et al.* 2004] and then baroclinic [*Feliks et al.* 2007]. They linked the SST with the vertical wind w at the top H_e of the troposphere via the equation:

$$w(H_e) = -\int_0^{H_e} \left(\frac{(\partial u)}{(\partial x)} + \frac{(\partial v)}{(\partial y)} \right) dz = \Upsilon \nabla^2 \psi - \alpha \nabla^2 T \quad (1)$$

Here $T = T(x,y)$ is the SST field, (x,y) longitude and latitude, (u,v) the horizontal wind components, ψ the horizontal streamfunction, α and Υ are constants.

The first term corresponds to the mechanical component and the second to the thermal component of the surface forcing. This latter term implies that, over cold SSTs, air descends and there is a cyclonic flow in the free atmosphere, while over warm SSTs, air ascends and the free-atmospheric flow is anticyclonic. Their SST front spins up an eastward jet in the free atmosphere, Figure 1 summarizes that mechanism.

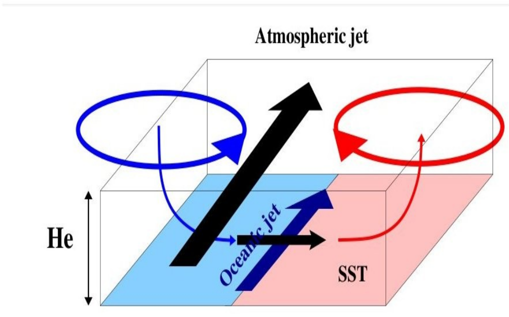

Figure 1: Feliks's mechanism; the oceanic jet in blue gives a jet stream with a double-gyre circulation up of troposphere.

With a Multivariate Singular Spectrum Analysis (MSSA), they obtained three kinds of unstable oscillatory modes: one symmetric due to barotropic instability, with a period of 30 days; one antisymmetric due to baroclinic instability, with a period of 6–8 months, and one with a northward-propagating mode; the spatio-temporal evolution of this mode resembles the observed 70-day mode of [*Plaut & Vautard* 1994]; the latter has an antisymmetric and a symmetric component, and a period of 2–3 months. A major point found by FP is that these effects depend on the atmospheric model's having a sufficiently high resolution of at least 50 km x 50 km.

The first goal of this paper is to extend the mechanism of FP to a variable-resolution Global Circulation Model (GCM). We describe the GCM parameters in the section 2. In section 3, we present our results. In the section 4, we compare its with previous papers. We affect he second goal of this paper that is to precise the origin of the SST front effect on troposphere in section 5.

2.THE ATMOSPHERIC MODEL

The previous work showed that high resolution was crucial in simulating the effect of an SST front on the atmosphere. We therefore choose to study this effect in GCM LMDZ. It is a Laboratoire de Météorologie Dynamique gridpoint global primitive equation model LMDZ, which allows a high-resolution zoom over a selected area; hence the 'Z' in LMDZ.
The core of the GCM is the hydrodynamical code dedicated to the temporal and spatial integration of the equations of hydrodynamics on a latitude-longitude grid. These dynamics corresponds to mainly horizontal exchanges on a 3D-grid, while its physics is a juxtaposition of atmospheric columns without interactions [*Bony et al.* 2004]. The model is vertically discretized on 19 hybrid sigma-pressure levels (sigma=P/Ps where P and Ps are the atmospheric and surface pressures, respectively).
The resolution considered in our present study is 120 points in longitude and 91 points in latitude that means 3° outside the zoomed area and of 0.5° inside it. This zoom allows us to resolve correctly the effects of the GS front. The zoomed area is 20° latitude x 40° longitude and it is centered at (65°W, 40°N). The new approach realized in this version of the GCM is the implementation of a perpetual forcing in order to filter out the seasonal signal. The model is forced with a perpetual day, the 15th of February that means that the ground humidity is constant.

3.NUMERICAL RESULTS

1.1Experimental set-up

To follow the FP mechanism, we study the link between the vertical velocity and the laplacian of temperature. To remove the mechanical component, we perform two simulations: a control simulation with the climatological SST field named hereafter CTLS for ConTroL Simulation and one where the SST front has been reinforced named hereafter GSS for Gulf Stream Simulation. The GSS has an additional theoretical SST centered at (60°W, 40°N) with the following formulation: $f(T)=\ 2\cos(x)*(-8)\sin(y)$ and an axis inclination of 25° (Figure 2). We look at the difference of those two simulations to study only the effects due to the thermal component of equation (1).

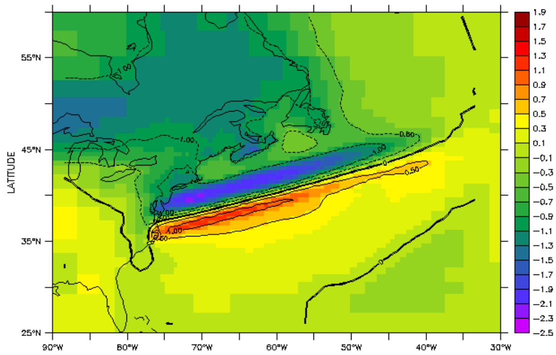

Figure 2: Difference between the temperature of the GSS and the CTLS. Unit is degrees. The blue corresponds to a colder front, the red to a warmer front. The laplacian is then intensified in the SST front-added simulation.

1.2 First results

Our anomalies corresponds to the difference between the GSS and the CTLS. We average these anomalies over the 872 days that is the length of our data. The first point to notice is the right way of the wind anomalies in the AMBL as described in Figure 1. We notice a strong near-surface southward flow for the mean meridional wind anomalies v' of 2 m/s above the SST front, between the isotherms of 288 and 294°K. By looking at the mean vertical wind anomalies w' for the first near-surface vertical levels, we can see an upward jet above the warm side of the front and a downward jet above the cold side of the front. That are in great agreement with that was waiting from the FP theory.

4.DIAGNOSTICS AND COMPARISONS

Figure 3 displays an average of the vertical wind anomalies over the longitude band 75°W and 40°W, between the latitudes 35°N and 47°N, for the 19 model levels. An upward flow can be seen on the warm side of the front (red shading), with values that reach 0.02 Pa/s, and a downward flow over the cold side (blue shading), with values that reach 0.01 Pa/s. These slanting, predominantly vertical flows develop at the top of the AMBL, as expected by FP and [*Minobe et al.*, 2008]. The impact of the zoom is considerable: without zoom, Figure 3 up, the descending flow is confined in the low atmospheric levels, and the atmosphere is stratified. With the zoom, Figure 3 middle, the ascending and descending flow are more pronounced and the velocity increases with the SST gradient, Figure 3 down.

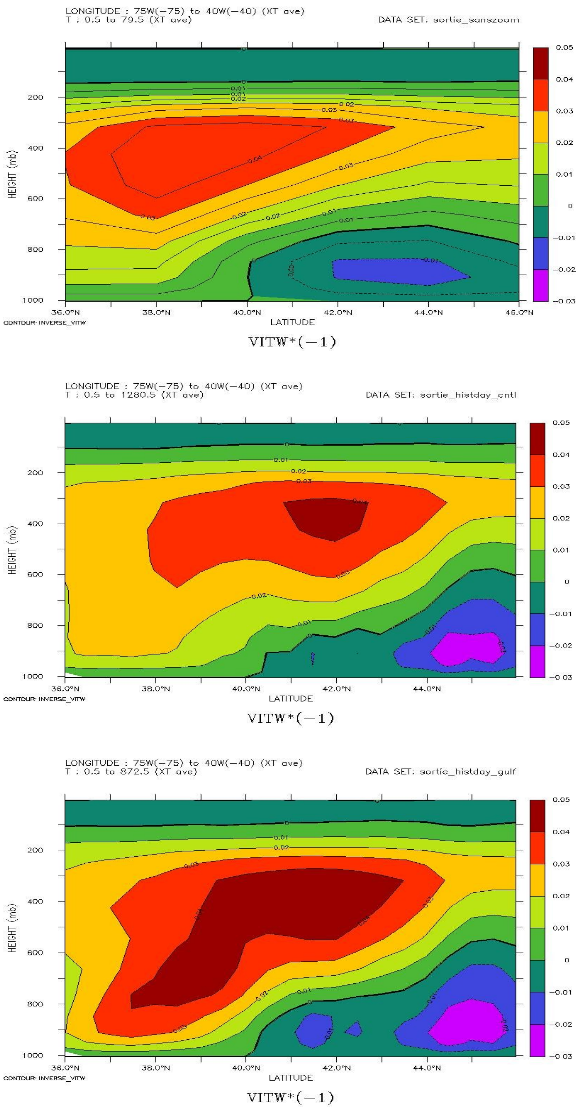

Figure 3: Mean *w* averaged from 70°W to 40°W. Height *vs*. latitude cross-section; red/blue means +ve/–ve upward velocity. Up: Without Zoom & without SST front; middle: With Zoom & without SST front; With Zoom & with SST front. Units are Pa/s.

5.CONCLUDING REMARKS

The mean difference between our work and previous works is that we take into account the two components that determine the vertical velocity above a thermal oceanic front as described by FP. Such an approach of the analysis of the thermal oceanic front impact on the atmosphere is a major novelty. [*Minobe et al.*, 2008] link the divergence of the vertical wind directly to the laplacian of the pressure. They make an assumption of the tropical mechanism [*Lindzen & Nigam*, 1987] (LN hereafter) to mid-latitudes by finding a high correlation between laplacian of SST and laplacian of SLP. However, they do not take into account the winds in the AMBL that have a strong influence with the geostrophic pressure gradient. This term is missing in the LN theory that concerns only the Tropics. When this mechanical component is significant, laplacian of pressure is no more proportional to the laplacian of temperature as claims by [*Minobe et al.,* 2008]. It is why in our analysis we focus on the thermal component by subtracting the GSS to the CTLS. Our result is in agreement with [*Minobe et al.,* 2008] and [*Song et al.,* 2006] but for SST forcing only (not SLP more SST).

REFERENCES

Bony, S., J.-L. Dufresne, H. Le Treut, J.-J. Morcrette, and C. Senior (2004), On dynamic and thermodynamic components of cloud changes, *Clim. Dyn.s*, **22**, 71–86**.**

Feliks, Y., M. Ghil, and E. Simonnet (2004), Low-frequency variability in the midlatitude atmosphere induced by an oceanic thermal front, *J. Atmos. Sci.*, **61**, 961–981.

Feliks, Y., M. Ghil, and E. Simonnet (2007), Low-frequency variability in the midlatitude baroclinic atmosphere induced by an oceanic thermal front, *J. Atmos. Sci.*, **64**, 97–116.

Lindzen, R. S., and S. Nigam (1987), On the role of sea surface temperature gradients in forcing low-level winds and convergence in the tropics, *J. Atmos. Sci.*, **44**, 2418–2436.

Minobe, S., A. Kuwano-Yoshida, N. Komori, S.-P. Xie, and R.J. Small (2008), Influence of the Gulf Stream on the troposphere, *Nature*, **452**, 206–209.

Nakamura, H., T. Sampe, A. Goto, W. Ohfuchi, and S.-P. Xie (2008), On the importance of midlatitude oceanic frontal zones for the mean state and dominant variability in the tropospheric circulation, *Geophys. Res. Lett.*, **35**, L15709.

Plaut, G., & R. Vautard (1994), Spells of oscillations and weather regimes in the low-frequency dynamics of the Northern Hemisphere. *J. Atmos. Sci.*, **51**, 210–236.

Scharroo, R., W. H. F. Smith, and J. L. Lillibridge (2005), Satellite altimetry and the intensification of Hurricane Katrina, *EOS, Trans. Amer. Geophysic. Union,* **86**, 366–367.

Song, Q., P. Cornillon, and T. Hara (2006), Surface wind response to oceanic fronts, *J. Geophys. Res.*, **111**, C12006.

Tokinaga, H., Y. Tanimoto, and S.-P. Xie (2005), SST-inducedsurface wind variations over the Brazil-Malvinas Confluence: satellite and in situ observations,

J. Climate, **18**, 3470–3482.
Warner, T. T., M. N. Lakhtakia, J. D. Doyle and R. A. Pearson (1990), Marine atmospheric boundary layer circulations forced by Gulf Stream sea surface temperature gradients, *Mon. Wea. Rev.,* **116**, 358–367.
Wu, C.-C., C.-Y. Lee, and I.-I. Lin (2007), The effect of the ocean eddy on the tropical cyclone intensity, *J. Atmos. Sci.*, **64**, 3562–3578.
Xu, H., L. Wang, and J. He (2008), Observed oceanic feedback to the atmosphere over the Kurushio Extension during spring time and its possible mechanism, *Chinese Science Bulletin,* **53**, 12, 1905–1912.