4D.2 ANALYSIS OF A RESONANT-LIKE REGIME IN THE OCEANIC MIXED LAYER INDUCED BY A MOVING HURRICANE

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1. INTRODUCTION

The ocean upper layers provide heat energy to hurricanes and in turn receive a large amount of kinetic energy. The strong currents generated by hurricanes in the oceanic mixed layer (OML) are partially converted into turbulence which entrains cold waters from the thermocline into the OML. This cooling can reduce the turbulent surface heat and moisture fluxes that influence the hurricane evolution (Emanuel 1999). Consequently, the transfer of momentum at the air-sea interface can be considered as a key index because it governs both the dynamical and the thermodynamical responses of the OML. Such transfer depends on strong winds but also on the hurricane scales (spatial distribution of the wind and translation speed). The wind-current energy flux is expected to be maximum when the frequency of the surface forcing associated with the hurricane fits well the oceanic inertial scale (Price et al. 1994). The aim of this paper is to investigate how the OML response to idealized moving hurricanes is modified by variations of the translation speed.

2. NUMERICAL EXPERIMENT SETUP

2.1 *Numerical Model*

To achieve this goal, a 2-layers reduced gravity model based on the full primitive equations integrated over the OML depth is used. The entrainment velocity is an improved version of the Gaspar (1988) parametrization which takes into account the mechanical production of turbulence explicitly. This model was tested and validated with the hurricane Frances (2004). The simulated sea surface temperatures (SSTs) are in good agreement with the satellite data, with the measurements performed during the CBLAST campaign and the ocean-wave-atmosphere coupled simulation obtained by Chen et al. (2007). The cold wake documented by profiler floats by Sanford et al. (2007) is quite well simulated as shown in Fig. 1. We conclude that the integral model used is able to simulate realistic OML responses to moving hurricanes during the forced stage.

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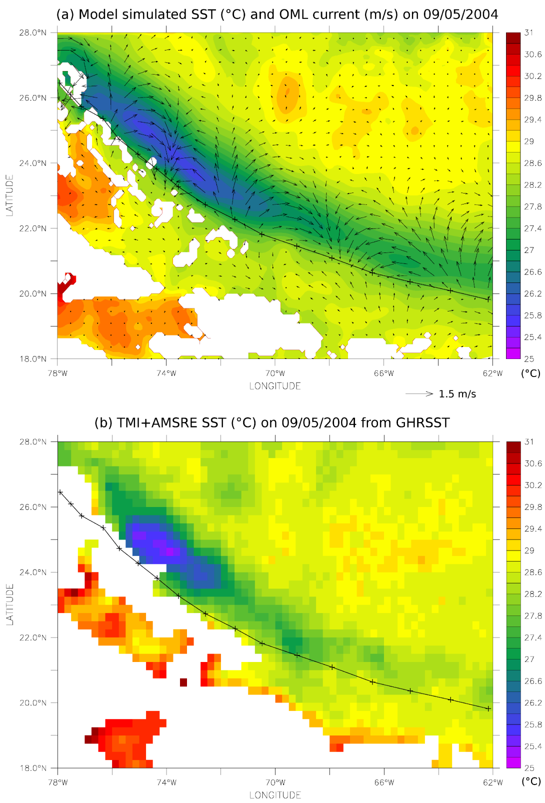

Fig. 1 (a) Model simulated SST and currents (b) TMI+AMSRE analysed SST

2.2 *Experimental design*

In order to study how the hurricane translation speed (U_h) influence the OML response, an idealized framework is used. The atmospheric and oceanic parameters are fixed except U_h which ranges from 2 m/s to 12 m/s. A Holland (1980) wind profile is used for the surface forcing, with a radius of maximum wind (RMW) of 60 km and a maximum wind speed of 50 m/s. The hurricane moves from the East to the West at a fixed latitude (30°N). Climatological temperature and salinity profiles were used to initialize the ocean model.

3. OML MEAN KINETIC ENERGY BUDGET

3.1 *Wind-Current Energy Flux*

The local coupling between surface winds and OML currents is strongly affected by U_h (Fig. 2). Note that positive and negative energy transfer

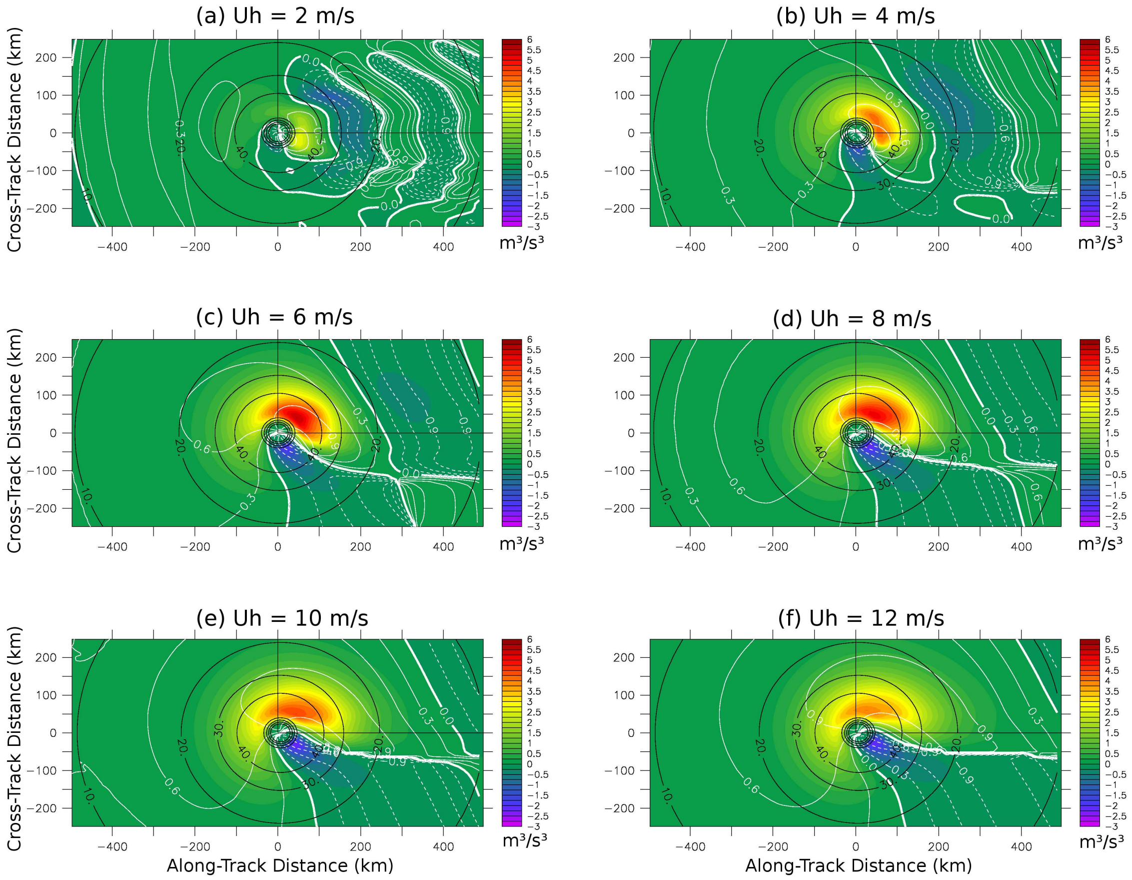

Fig. 2 $\vec{\tau}.\vec{U}/\rho_{water}$ for U_h ranging from 2 m/s to 12 m/s. White contours represent the cosine of the angle between the wind and current vectors and black contours indicate the 10m/s-isotach of the idealized hurricane. The hurricane moves from right to left

areas move with U_h. They are symmetrically opposed with respect to the hurricane center and display an anti-clockwise rotation with U_h.

For U_h < 6 m/s, the positive energy flux area remains downstream the hurricane. For U_h > 6 m/s, this area spreads on the right side of the hurricane track. At U_h = 6 m/s, the surface energy flux reaches a maximum (6 m^3/s^3) in the rear-right quadrant of the hurricane. This corresponds to the optimal hurricane-ocean configuration for a maximized momentum transfer.

3.2 *OML Kinetic Energy Production*

The OML response is investigated by looking at the OML mean kinetic energy (MKE) budget. The nondimensional storm speed $S = 2\pi U_h / fL$ (where f is the Coriolis parameter and L = 4 RMW is the hurricane along-track length scale) is used to evaluate the correspondence between the atmospheric and oceanic scales. This parameter gives an estimation of the ratio between the oceanic inertial period and the wind inversion time span in the center of the hurricane. The translation speed corresponding to the resonant regime (i.e. S=1) is U_h = 3 m/s. Fig. 3 presents the accumulated MKE during the forced period with respect to U_h and for different cross-track distances. In the central region (0 RMW), a maximum of MKE production is found at

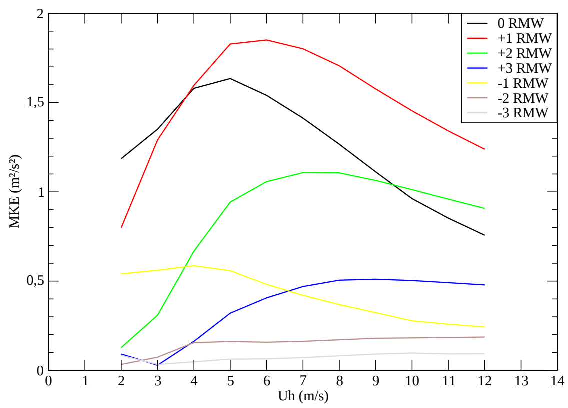

Fig. 3 MKE production variations with the hurricane translation speed U_h for different cross-track regions. Values are averaged over a 1-RMW length

U_h = 4.5 m/s. This value is slightly higher than the velocity deduced from the scaling parameter S because of the inflow angle imposed to the surface wind field.

The MKE production is a strong non-linear function of U_h with several local maxima which vary with the cross-track distance (Fig. 3). Consequently, the concept of “local resonant regime” can be generalized to different cross-track distances. As the wind rotation frequency decreases with the

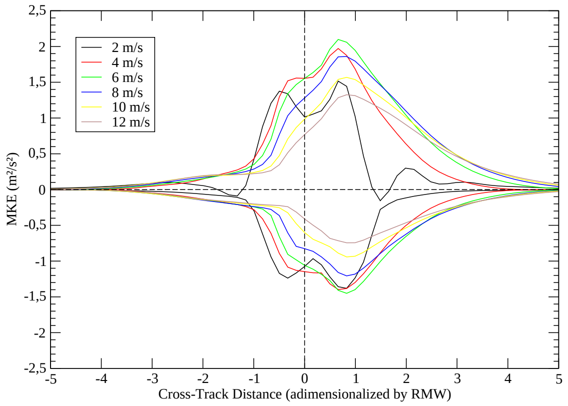

Fig. 4 Cross-track section of the MKE production and entrainment for different hurricane translation speeds

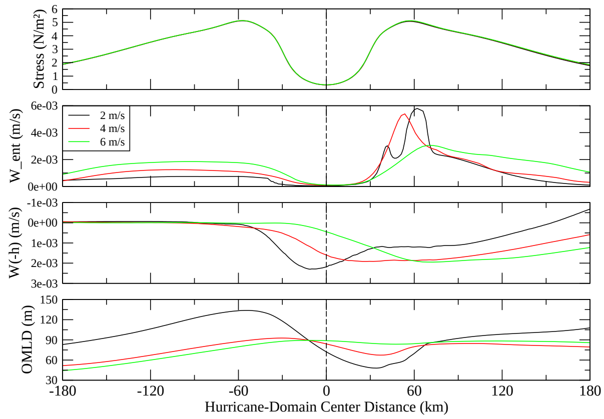

Fig. 5 The wind stress, the entrainment velocity, the vertical kinematic velocity and the OML depth (from top to bottom) in the central region as a function of the distance between the hurricane center and the budget region.

cross-track distance from the hurricane center, the position of the optimal wind-current coupling increases with the translation speed.

4.3 *OML Kinetic Energy Entrainment*

A cross-track section of the accumulated MKE production (top part) and MKE entrainment (low part) are shown in Fig.4. At the first order, the production and entrainment are opposite. Note that the contributions of the horizontal advection and of the pressure to the MKE budget are of second order compared to the production and the entrainment terms (not shown).

For $U_h \geq 6$ m/s, roughly 60% of the MKE is converted into TKE to supply the entrainment process. For $U_h < 6$ m/s, despite of lower MKE production than for $U_h = 6$ m/s, the MKE entrainent keeps at the same level (Fig.4).

In order to understand this behavior, the evolutions of the wind stress, the entrainment velocity (w_e), the kinematic velocity (w_{-h}) and the OML depth (h) in the central region of the hurricane are plotted in Fig. 5. A spatial x-axis is used to represent the along-track distance between x=0 and the hurricane center.

The spatial runs of w_{-h} and OMLD displayed in Fig.5 show that slow hurricanes ($U_h = 2$ m/s) trigger the first upwelling phase earlier than fast moving hurricanes ($U_h = 6$ m/s). This upwelling strongly reduces the OML depth from 130m to 50m, because it occurs with no wind (eye region) and consequently no entrainment. During the second wind peak (at +60 km), the shallow OML depths give a very favorable configuration to generate strong TKE (w_e) entrainment and deepening.

For faster hurricanes ($U_h = 6$ m/s), the maxima of upwelling and entrainment occur simultaneously downstream of the hurricane center. These maxima are phased with the second wind-maximum. Both these processes are opposite and are of the same order of magnitude. Consequently, the OML depth remains deep. In these conditions, the second wind-maximum passage does not produce as strong TKE and entrainment as for $U_h = 2$ m/s.

These results highlight how the translation speed is important for the OML because it induces or not a time-lag between the upwelling and the entrainment. Finally, the similar MKE entrainments obtained for U_h included between 2 and 6 m/s are associated with two different mechanisms: the time-lag for slow moving huricanes and the wind-current resonant regime for fast moving hurricanes.

4. OML COOLING

The OML heat content is strongly affected by the surface winds upstream the hurricane. 50% of the OML total heat loss occurs upstream the hurricane, in a region where the MKE entrainment is negligible. This cooling is produced by surface heat fluxes (30%) and by the wind-induced turbulence (70%). The upwelling-entrainment time-lag which occurs for slow moving hurricanes dramatically enhances the entrainment and thus the OML cooling. This is the result of a sharp temperature gradient generated upstream of the hurricane and of a large turbulent velocity at the OML base under the second wind peak. For fast moving hurricanes, the cold wake on the right side of the hurricane track is driven by the MKE entrainment presented in section 4.3. Surface heat fluxes have a negligible contribution to the OML heat budget and the horizontal advection acts at attenuating the cold wake.

5. CONCLUSION

The academic and simplified numerical simulations presented in this study allowed to investigate the OML response to the hurricane translation speed. They prove that the hurricane translation speed is a key parameter for the OML dynamics and thermodynamics.

For fast moving hurricanes, the OML response is totally governed by the wind-current energy flux caracteristics and the mechanism of resonance. For slow moving hurricanes, the OML displays an important sensitivity to the translation speed because it defines the elapsed time between the central upwelling and the entrainment under the eye wall winds region. In this regime, small variations of the translation speed can induce large variations of the OML currents and temperatures. The hurricane Frances illustrates well this point. Indeed, the cold patch observed around (74°W; 25°N) in Fig. 1 is induced by Frances deceleration over this region. Finally, the variations of Frances translation speeds appear to be more important to obtain a realistic OML cooling than the hurricane wind speed variations during this period.

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