7A.4 INFLUENCE OF AN OCEANIC WARM ANOMALY ON THE INTENSITY OF TROPICAL CYCLONE DORA (2007) IN THE SOUTH WEST INDIAN OCEAN

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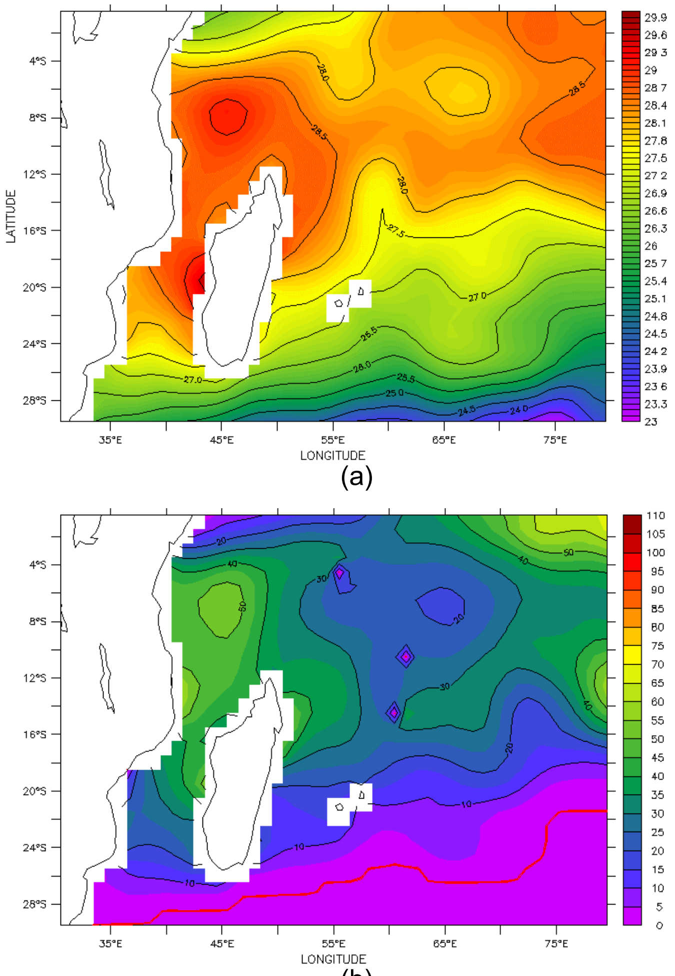
1. INTRODUCTION

Significant improvements concerning the forecast of tropical cyclones (TCs) intensity have been recently achieved by coupling atmospheric models with oceanic models (Bender and Ginis 2000) and by using an accurate description of the initial oceanic state (Yablonsky and Ginis 2008). First, these improvements permit to represent the cooling induced by a TC on the upper ocean and its feedback on the atmosphere. Secondly, the thermal structure of the upper ocean described by oceanic models is a more accurate indicator of the energy available to a TC than the sea surface temperature (SST). More precisely, the tropical cyclone heat potential (TCHP) defined as the oceanic heat content integrated between the depth of the 26° isotherm and the surface (Leipper and Volgenau 1972) has been shown to be a good indicator of TC intensity changes for the North Atlantic and the North West Pacific basins (Goni and Trinanes 2003).

The present study focus on a TC which occurred in the South West Indian Ocean (SWIO) and aims at determining if the coupling of an atmospheric model with an oceanic model can improve the intensity forecast of TCs given the characteristics of this basin. To explore this question, a detailed analysis of the recent cyclonic seasons has been conducted. It reveals the presence of an important and large oceanic warm anomaly during the 2006-2007 season. To determine if this warm anomaly played a role on TCs intensity during this season, TC Dora (2007) and its interaction with the upper ocean are examined in details by using the Meso-NH atmospheric research model (Lafore et al. 1998) coupled to a simplified 1D-ocean model (Gaspar et al. 1990).



(a)

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Figure 1: (a) Climatological SST (°C) and (b) TCHP (kJ.cm^{-2}) for January
Source: World Ocean Atlas 2005

A description of the ocean structure and of TC Dora life-cycle is given in Sections 2 and 3. Models configuration, experiments and the initial conditions description are given in Section 4. Preliminary results presented in Section 5 show that the coupled model is able to simulate realistically the first deepening phase of TC Dora and the oceanic cooling underneath.

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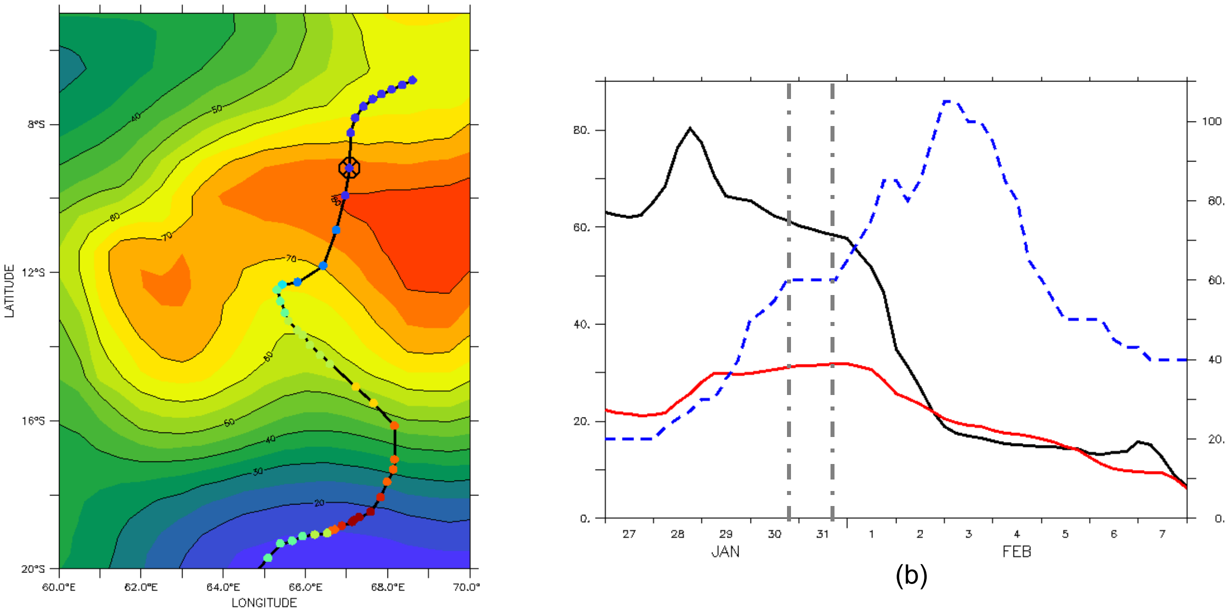
2. OCEAN DESCRIPTION

The SWIO represents about 12% of the global tropical storms (TS) and cyclones activity. This corresponds to 8 to 15 TSs per year or 20 days of cumulated cyclonic days per season. The cyclonic peak activity takes place during January and February and is strongly linked with Madden-Julian Oscillation events (Bessafi and Wheeler 2006). Furthermore, the cyclonic activity in the SWIO is modulated by sea surface temperature (SST) anomalies: anomalously warm SST in this region is associated with increased cyclonic activity (Xie et al. 2002).

Even if the climatological SST is greater than 26°C over most of the basin (Fig. 1a) during the cyclonic season, the oceanic heat content remains relatively weak compared to other basins with climatological values lower than 50 kJ.cm^{-2} (Fig. 1b). This can be considered as a limiting factor for TCs to reach high intensities. A large zone with TCHP lower than 30 kJ.cm^{-2} centered around 10°S and 60°E can also be observed. It corresponds to the “Seychelles Chagos Thermocline Ridge”. This oceanic structure is a large zone of upwelling mainly induced by the large-scale wind stress curl and is characterized by a thermocline very closed to the surface, a shallow mixed layer and consequently a low TCHP (Hermes and Reason 2008). But during the season 2006-2007, this thermocline ridge almost disappeared and a large-scale warm anomaly formed in this region. The cause of its formation remains unclear but it seems to be linked with a wind anomaly associated with the Indian Ocean Dipole (Vialard et al. 2008). As a consequence, the SST was roughly 1°C higher than normal over this large region and the TCHP associated with the warm structure reached 100 kJ.cm^{-2}, ie a 300%-increase compared to climatological values during this season.

3. TC DORA LIFE-CYCLE

On January 28, an area of disturbed weather west of Diego Garcia (-10°S; 67°E) was designated as a tropical disturbance by the RSMC La Réunion. The system was upgraded to a tropical depression on January 29, and later that day to a moderate tropical storm. The system named Dora meandered southward over the next two days while it was subject to a significant westerly wind shear constraint. Early on February 1, Dora straightened and RSMC La Réunion upgraded it to a TC. Although forecast to weaken, Dora continued to strengthen against expectations before weakening slightly because of an eyewall replacement cycle. The storm then became annular and intensified further, peaking at 105 kts (over 10 minutes) with a central pressure of 925 hPa on February 3. It then started to weaken as it curved to the southwest and became fully extratropical on February 9. Dora track is presented in Fig. 2a.



(a)

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Figure 2: (a) Dora track and initial TCHP from CORIOLIS (kJ.cm^{-2})

(b) TCHP from CORIOLIS (black line), climatological TCHP (red line) and maximum wind intensity over 10 minutes (kts) along Dora track
The dotted black lines indicate the wind shear period

TC Dora starts its life and intensified over the warm oceanic anomaly presented in Section 2 (Fig. 2b). This region was at the same time the place of the oceanic and atmospheric field campaign Vasco-Cirene (Vialard et al. 2008; Duvel et al. 2008) during which 12 ARGO floats and 2 Aeroclippers have been released and one ATLAS mooring has been installed as a part of the RAMA project (McPhaden et al. 2008). Finally, a total of 34 ARGO floats were located nearby Dora track which enables to get a relatively good description of the oceanic environment beneath TC Dora. Temperature and salinity fields are deduced from ARGO profiles by using the objective analysis method. These analysis are produced every week at 0.5° resolution in the frame of the CORIOLIS project and are used as a reference in this study to calculate the TCHP fields and to check the 1D-ocean model skills.

4. NUMERICAL EXPERIMENT SETUP

4.1 *Numerical Models*

A full two-way coupling has been developed between the Meso-NH atmospheric model and the Gaspar et al. (1990) 1D-ocean model in turbulent kinetic energy equations (Lebeaupin et al. 2008). The two models have the same horizontal resolution (10 km) and exchange every 10 minutes the SST, the air-sea surface momentum and heat fluxes according to the ECUME bulk parameterization (Weill et al. 2003; Belamari et al. 2005), the fresh water and the radiation fluxes. For surface winds greater than 30 $m.s^{-1}$, the exchange coefficients used in the ECUME bulk parameterization are defined following Powell et al. (2003) for the momentum flux calculation and are kept constant for the heat flux calculation. This coupled model indicates good skills to simulate heavy rainfall events and severe air-sea interactions under high winds (Lebeaupin et al. 2008). The atmospheric model has 35 vertical level concentrated in lower and upper troposphere with a maximum altitude of 19 km. The oceanic model has 40 vertical levels with a 5-m resolution in the mixed layer and a 10-m resolution in the upper thermocline. The domain extends from (4.7°S; 54.9°E) to (24.2°S; 75.1°E) which largely includes Dora track. The simulation is run during 60 hours (from the 01/28/07 12UTC to the 01/31/07 00UTC). This period corresponds to the first deepening phase of TC Dora and to the wind shear constraint event.

4.2 *Initial and Boundary Conditions*

Meso-NH is initialized and forced at the domain boundaries every 6 hours with analysis produced by the operational limited area model ALADIN-Réunion (Montroty et al. 2008). It covers almost of the SWIO and has a horizontal resolution of 10 km. The model uses a 3D-VAR data assimilation scheme which includes 3D wind bogus pseudo-observations. Compared to the best-track (BT) data of the RSMC La Réunion, ALADIN-Réunion analyses the storm 5 hPa deeper than the estimated one with a localization error of 50 km.

Concerning the 1D-ocean model, it is initialized with a 3D analysis of the Mercator operational model (Bahurel et al. 2004) at 0.25°-resolution which assimilates the sea level anomalies with an optimal interpolation technique.

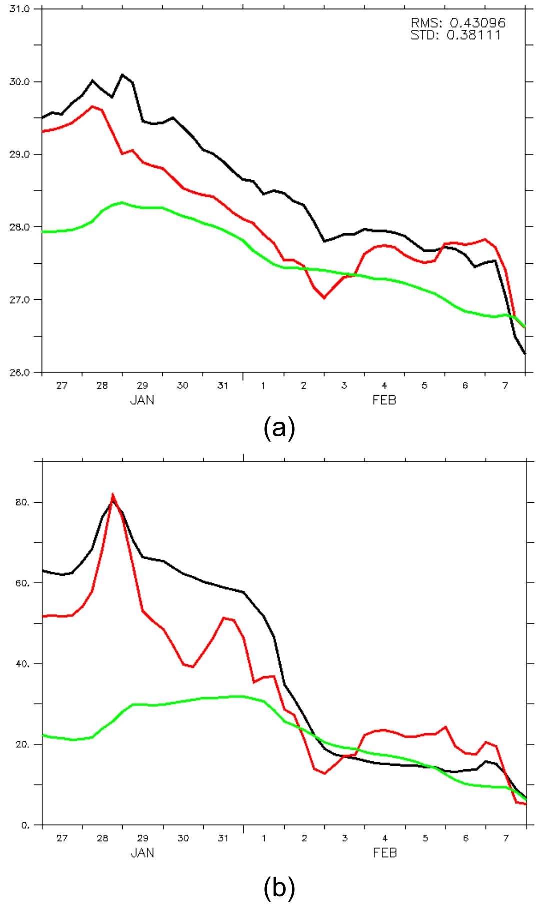


Figure 3: (a) Initial Model SST (red), observed SST from OSTIA (black) and climatological SST (green) along Dora track

(b) Initial Model TCHP (red), observed TCHP from CORIOLIS (black) and climatological TCHP (green) along Dora track

In order to estimate if the warm anomaly is realistically represented in the ocean model, the initial state is evaluated by comparison with satellite measurements for the SST (OSTIA analysis at 0.05°-resolution from UKMO) and in-situ data for the TCHP (CORA analysis at 0.5°-resolution from CORIOLIS) along Dora track (Fig. 3a and 3b). Concerning the SST, the model represents well the spatial variations of the SST along Dora path with a RMS error of 0.43°C and a standard deviation of 0.38°C. Globally, the simulated SST is slightly colder than the observed one. Concerning the TCHP, the oceanic model captures well the warm anomaly. It is well localized and has a realistic amplitude with a peak at nearly 80 kJ.cm^{-2}. Nonetheless, the warm anomaly is slightly underestimated by roughly 10 kJ.cm^{-2} in the model as it has already been observed with the SST. Furthermore, we observe more small scale spatial variations of the TCHP in the model that cannot be represented by the CORA analysis due to its lower resolution.

4.3 *Numerical Experiments*

Three experiments are conducted. The first one is a purely atmospheric simulation without coupling with the ocean and where the Mercator initial SST is used as a constant boundary condition. It is named hereafter FM (Forced Mercator). In the second experiment, the coupling with the ocean is turned on which allows a feedback between the TC and the ocean. This experience is named CM (Coupled Mercator). The third experiment is a coupled simulation where the ocean model is initialized from climatological data (World Ocean Atlas 2005). It is named CC (Coupled Climatology).

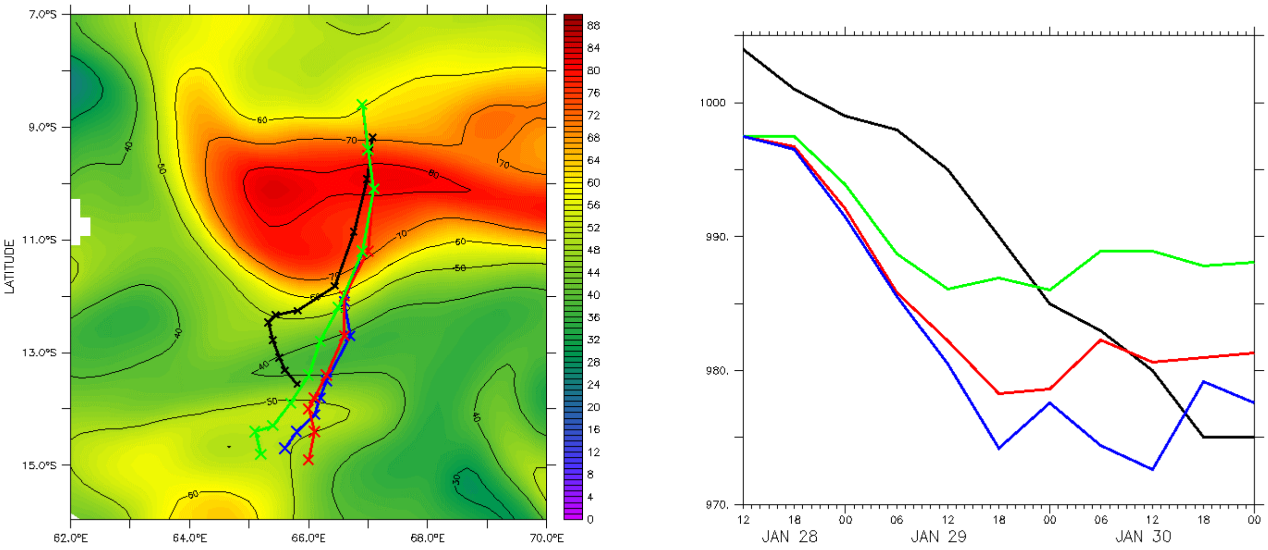
The Best-Track (BT) data from RSMC La Réunion are used as reference. These simulations will allow us to determine the influence of the coupling with the ocean on TC Dora and the role of the warm anomaly on its intensification. We will also be able to look at the simulated ocean response.

5. PRELIMINARY RESULTS

5.1 *Dora Intensity and Trajectory Changes*

Compared to Dora BT central pressure evolution, Meso-NH is able to simulate the deepening of the TC in the three experiments (Fig. 4b). We also observe that the first deepening phase ends earlier in the three simulations than in the BT data. Several reasons can explain this difference but the most credible is that the wind shear constraint period starts too early in the simulations compared with the real situation. Another possible reason is that the model errors concerning the TC track and translation speed leads the TC to a less favorable environment than it was in reality (Fig. 4a). The difference between the tracks (maximum of 50 km) increases with the difference of intensity, but the track error remains relatively small (~ 100 km) at the end of the simulations.

Differences between the FM and the CM simulations become significant after 18 hours of simulation with a slower intensification for the CM case (Fig. 4b). The maximum intensity reached in the FM case is 973 hPa while it is 978 hPa for the CM case.

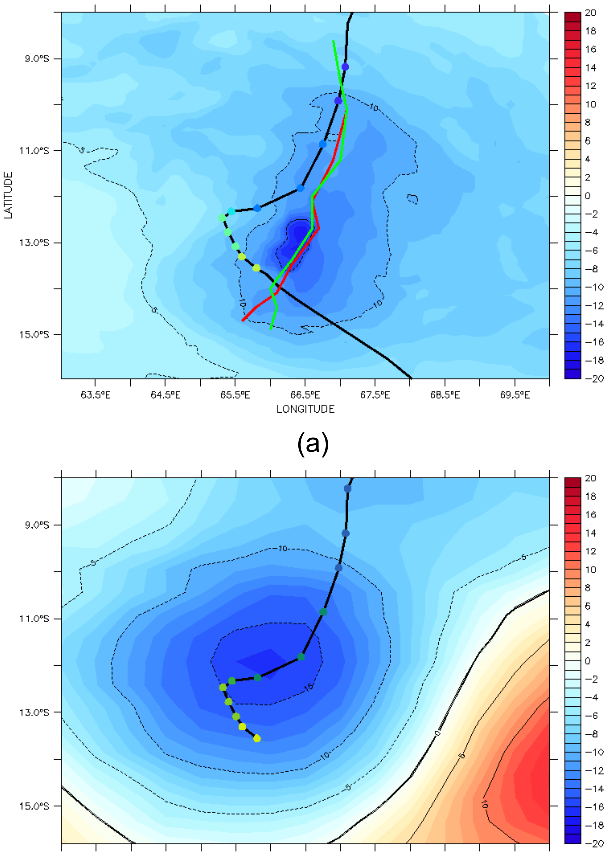


(a) (b)

Figure 4 : (a) Simulated (FM: blue, CM: red, CC: green) and Reference Tracks (black)

(b) Simulated (FM: blue, CM: red, CC: green) and Reference Sea Level Central Pressure (black) in hPa

Consequently, the coupling with the ocean has slightly reduced the intensification of the TC by 5 hPa. The intensity obtained in the CC simulation is the weakest of the three experiments with a maximum intensity of 987 hPa, ie a 9 hPa difference with the CM simulation and a 14 hPa difference with the FM simulation. The differences in terms of intensity with the two other experiments become visible only 6 hours after the beginning of the simulation. This clearly shows the strong impact of the warm anomaly on the intensification of TC Dora. The climatological upper ocean is not able to supply enough energy to the TC to permit such intensification compared to the realistic ocean.



(a)

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Figure 5: TCHP diminution in kJ.cm^{-2}
(a) simulated by the 1D-ocean model and
(b) observed by ARGO profilers
on the 01/31/2007

5.2 *Oceanic Heat Content Evolution*

The CM simulation allows us to look at the evolution of the upper ocean under the TC Dora. More particularly, it is interesting to compare the oceanic heat loss simulated by the 1D-ocean model with the one measured by the ARGO profilers at the end of the first intensification period (Fig. 5). At the beginning of the CM simulation, the TCHP diminution is about 5 kJ.cm^{-2} over a large part of the domain. As the TC becomes more intense, the heat loss increases up to 10 kJ.cm^{-2} and becomes asymmetric with a cooling more pronounced on the left side of TC Dora. This result is in agreement with previous results from Price (1994) who showed that this asymmetrical oceanic response is induced by shear instabilities of the current at the base of the mixed layer. He demonstrated that a phasing between the surface wind and the mixed layer near-inertial currents on the right-hand side of TCs is responsible of the generation of such strong currents (in the Northern hemisphere). On the left-hand side of TCs, wind and current evolve in opposite directions and lead to a less energetic response. In the Southern Hemisphere, this mechanism is reversed and leads to a more important heat loss on the left-hand side of the TC.

When the TC reaches its first intensity peak, the simulated TCHP decreases up to 18 kJ.cm^{-2}. This cooling is in good agreement with the heat loss measured by the ARGO profilers after Dora passage (Fig. 5b). But compared to the initial level of TCHP in this region (between 60 and 80 kJ.cm^{-2}), it represents only a diminution of 20 to 30% of the heat content available for the TC. It means that the intensification of Dora is not limited by the ocean. In the case of a climatological ocean, it represents up to 80% of the total energy available for the TC.

6. CONCLUSION AND PERSPECTIVES

Compared to other cyclonic basin, the SWIO has been poorly studied and needs an special attention in order to understand its characteristics and specificities. Previous studies have shown the importance of the upper ocean and of its heat content to understand and to forecast storm intensity variations. The preliminary results presented here show that the coupled system Meso-NH/1D-ocean model gives interesting insights to understand the role of the ocean on TCs in the SWIO and to study the oceanic response to a TC. The case of Dora is a good illustration of the importance to correctly represent the oceanic heat content in order to simulate realistically the TC intensification.

In the future, new simulations will be run with grid nesting technique up to 1 km resolution in order to capture the TC inner core dynamics and to study how the TC structure is affected by the ocean coupling. The length of the simulations will also be extended up to 120 hours to capture the entire deepening phase of TC Dora.

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