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THE OROGRAPHIC EFFECTS OF REUNION ISLAND ON TROPICAL CYCLONE TRACKS

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1. INTRODUCTION

Orography is well known to have significant effects on cyclone tracks (Brand and Blelloch (1973), Bender et al. (1987)). Previous studies have shown the track deflection of tropical cyclones by Taiwan among other mountain ranges (Lin et al. (2005)). Two types of cyclones passing over Taiwan have been identified: *continuous* track and *discontinuous* track.

The track deflections by the islands of the South-West Indian Ocean such as Reunion island and Madagascar still need to be objectively documented and defined. It is interesting to note that Taiwan has an intermediate mountain scale between a meso-α mountain range such as Madagascar and a meso-γ high conical-shaped one such as Reunion island.

This study focuses on the deflection of the cyclone tracks near Reunion island.

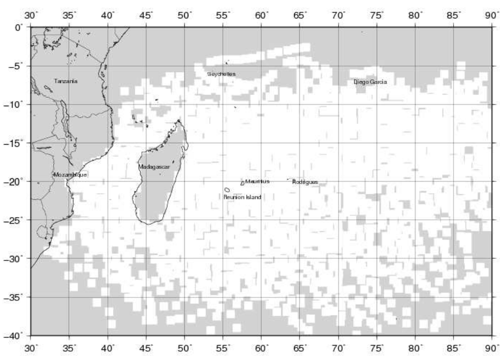

Fig. 1. Representation of SWIO basin and location area with at least one individual in a square of 1° side. The grey-shaded area represents the absence of data for population ALL.

2. STATISTICAL STUDY IN THE SOUTH-WEST INDIAN OCEAN BASIN (SWIO)

a. *Database and definition*

The database used in this study is the best-track from RSMC[1] Reunion. It focuses on the post-satellite period in order to ensure good data quality, particularly for the position of tropical cyclones. The period is from August 1981 to July 2009 for the entire SWIO basin, which covers from the East African coast to 90E and from the Equator to 40S (Fig.1).

Track deflection may be represented by two effects :

- A change in direction, for which the simplest definition is the change of direction between two consecutive postions. Although the sign of the deviation is an interesting information, the opposite types of track deflections (to the right and to left) may cancel out each other. To avoid this complication, the absolute value of this variation is used, which leads to our definition : $|\Delta CP| = |CP_{t+6h} - CP_t|$.
- A change in speed. Here again a simple definition is adopted, i.e. the absolute difference in speed between two consecutive positions $|\Delta V| = |V_{t+6h} - V_t|$. Similar to the previous definition, an absolute value is used to avoid cancellation of opposite values. This definition quantifies high or low speed changes, and not accelerations or decelerations.

Table 1 shows that in the entire basin, the fields

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[1]RSMC : Regional Specialised Meteorological Centre

population	class of intensity (Dvorak)	number of individuals	$\lvert\Delta CP\rvert$	$\sigma_{\lvert\Delta CP\rvert}$	$\lvert\Delta V\rvert$	$\sigma_{\lvert\Delta V\rvert}$
ALL	all CI	9796	19.06	24.87	4.05	4.17
MTS (Moderate Tropical Storm)	$CI = [2.5; 3]$	2635	19.70	24.40	4.00	4.01
STS (Severe Tropical Storm)	$CI = [3.5; 4]$	1592	18.95	24.68	3.79	3.56
TC (Tropical Cyclone)	$CI \geq 4.5$	1540	14.72	19.42	3.35	3.05

TABLE 1. Different populations used with the criterion of selection of coefficient intensity (CI), number of individuals and mean and standard deviation for absolute change of direction (degrees) and speed ($m.s^{-1}$).

$|\Delta CP|$ and $|\Delta V|$ have a high variability, whatever the chosen population.

From this database, four populations are defined depending on class of intensity (an individual of population is defined by a point of the track and not the whole track). This is summarized in the Table 1.

b. *Radius of influence of Reunion island*

The influence of Reunion island on cyclone tracks will be now examined. If the hypothesis that the topography of the Reunion island induced alterations on direction and/or speed is true, then the differences in the average should be significantly different in an area close to the island compared to rest of the basin. The high deflections near Reunion island (Fig.2) suggest that this assumption is true. This hypothesis should then be validated by a statistical test.
Let us define μ_0^R as the average value of a variable (deviation for absolute change of direction for example) for the population of the entire basin except for the disk of radius R centered on Reunion island (21.1S/55.5E). μ_1^R is defined similarly for the population of the disk of radius R centered on Reunion island. The hypothesis $H_0(R)$ of equal averages is that $\mu_0^R = \mu_1^R$ and the alternative hypothesis $H_1(R)$ is that $\mu_0^R \neq \mu_1^R$. Without any assumption of distribution, if $H_0(R)$ is true then the Mann-Whitney statistics follows a normal distribution (valid if both populations are more than 20). The rejection threshold is defined as $\alpha = 5\%$, $H_0(R)$ is dismissed if probability of this statistical Mann and Whitney (1947) is below α.

Applying this method to the variable $|\Delta CP|$ and $|\Delta V|$ for a radius ranging from 100km to 1800km on populations of Table 1 leads to Table 2. Distances of influence of Reunion island reported in Table 1 are therefore the threshold value of the radius for which the hypothesis $H_0(R)$ is rejected. It should be noted that for the TC population, there is no distance of influence.

population	Distance for $\lvert\Delta CP\rvert$	Distance for $\lvert\Delta V\rvert$
ALL	420	360
MTS	390	380
STS	310	none
TC	none	none

TABLE 2. Distance of influence (km) of Reunion island

c. *Track change due to the orography of Reunion island*

Therefore, the orography of Reunion island has an effect on the track changes, either in direction or speed, without being able to define the sign of these changes. So it is possible to quantify a distance of influence of the island which depends on the intensity of the disturbances. Whatever the parameter (direction or speed) and intensity, this distance is less than 420km. In the influence area of Reunion island (and therefore function of intensity), the difference of averaged absolute value of the direction change and speed change is represented by Fig.2, showing only the regions where the differences are significant.

By subjective analysis, Fig.2 allows to define a more restrictive limit area affected by the relief of Reunion island. Variations of direction and speed are significatly more important (red areas) for a 250km radius. In contrast, the outer limit of the zone of influence is dominated by rectilinear tracks more than average (blue areas). Thus, the direction and speed vary more if the distance from Reunion island is smaller than 250km.

3. CONTROL PARAMETERS AND NUMERICAL SIMULATIONS

a. *Case studies*

According to the limit of 250km for significant influence and to the period (from 01/01/1989 to

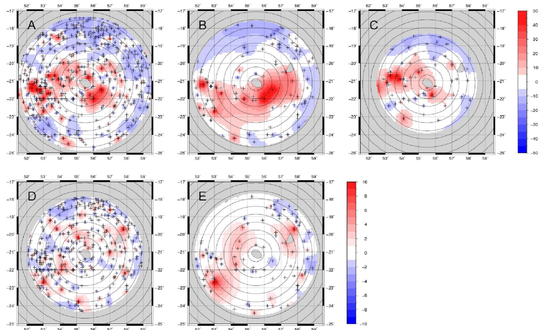

FIG. 2. Field of difference from the mean of A) $|\Delta CP|$ for population ALL, B) $|\Delta CP|$ for population TTM, C) $|\Delta CP|$ for population FTT (in degrees), D) $|\Delta V|$ for population ALL and E) $|\Delta V|$ for population TTM (in $m.s^{-1}$). The shaded area defines the limit of influence of the Reunion island where the hypothesis $H_0(R)$ is accepted. The crosses represent the location of a tropical disturbance. The circles are drawn in steps of 50km from the center of Reunion.

nowaday) of ERA-Interim (used to calculate the Brunt-Vaisala frequency in control parameters), only 12 cases of tropical cyclonic systems are considered. Table 3 presents these 12 cases.

December	January	February	March
Daniella(96)	Firinga(89)	Hollanda(94)	Kylie(95)
Celina(07)	Colina(93)	Eline(00)	Davina(99)
	Christelle(95)	Hondo(08)	
	Connie(00)		
	Dina(02)		

TABLE 3. Tropical cyclonic systems in the 250km area from Reunion island since 01/01/1989.

Following Lin et al. (2005), we can use 6 nondimensional numbers to quantify the direction change and speed change. For the case of Reunion island, the mountain horizontal scale L_x and L_y are the same and according to the limit area of influence of Reunion island, we can define an other nondimensional number such as the ratio between this distance of influence and the radius of maximum wind. The 6 numbers V_{max}/NH, U/NH , U/fL, $V_{max}/fR_{V_{max}}$, $R_{V_{max}}/L$, $D/R_{V_{max}}$ define the control parameters where V_{max} is the maximum wind speed of the cyclone, N the Brunt-Vaisala frequency, H the mountain height, U the basic flow speed (approximatively the cyclone translation speed), f the Coriolis parameter, L the mountain scale (circular form for Reunion island case), $R_{V_{max}}$ the radius of V_{max} and D the distance between the TC center and Reunion island. V_{max}, $R_{V_{max}}$, U, D and f are obtained from the Best-Track while N is calculated using the fields of ERA-Interim in an $10° \times 10°$ domain centered to Reunion island and from the surface to 3000m. $L = 40km$ and $H = 3000m$ are chosen for our cases.
Fig.3 and Fig.4 represent respectively absolute value of direction change and speed change depending on control parameters. Regression lines are calculated from these 12 cases and althought correlation coefficient are small, we can estimate a maximum of direction or speed change in relation with control parameters. The objective is to be in conditions of maximum of deflection and then to define environmental and cyclonic parameters to configure idealized numerical simulations.

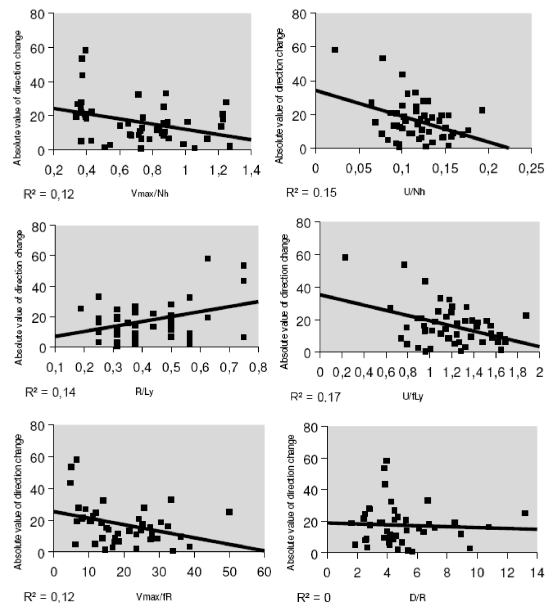

FIG. 3. $|\Delta CP|$ depending on control parameters for the 12 realcases. Regression lines and correlation coefficient are noted for each control parameters.

b. ***Numerical simulations***

Jolivet (2008) demonstrated than the orography of Reunion island has an important effect on intensity of TC DINA(2002) but no conclusions can be done about track change because of environmental contribution. So to verify the distance of influence of Reunion island ans its dependence on intensity and to understand the processes that are responsible for track deflection linked with the orography, it is necessary to performe idealized numerical simulations.

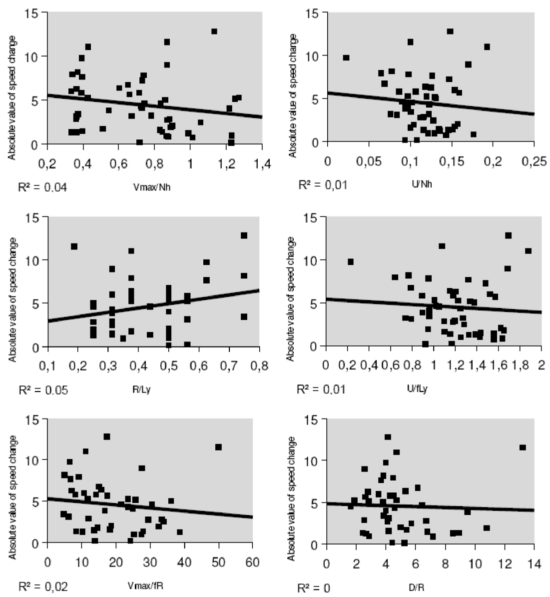

FIG. 4. Same as Fig.3 but for $|\Delta V|$.

Meso-NH, a non-hydrostatic model using the gridnesting method at 4km resolution (Lafore et al. (1998)), is used to integrate the cyclone during 84h. A simulation without orography (only sea) define the reference. To quantify the effect of orography, a conical-shaped island such as Reunion island is located at 5 different locations (D=0km, 48km and 144km at north and south) relative to the reference track. First, we focus on the difference of track and intensity to assess the distance of influence.
Concerning the track, the orography always induces a deceleration and the deviation to the right relative to the track is preferred. There is a non-zero optimal distance inducung maximum variations. About the intensity, the cyclone weakens faster and earlier if the distance D to the island is small. Coarsely, the distance of influence for all simulations is between 200 and 300km.

4. CONCLUSION AND FUTURE WORK

First, the objective climatological study is performed in the South-West Indian Ocean (SWIO) basin about the direction change and speed change of cyclones. Near Reunion island and when these direction changes and speed changes are significantly different from the mean of the SWIO basin, we can define a radius of influence of Reunion island that depends on cyclone intensity. The map of direction change and speed change in the influenced area of Reunion island allows us define a limit of 250km for significant influence.

The environment can influence the track, even mask the effect of the orography of Reunion island, so idealized simulations are necessary to verify the orographic effect and to understand processes. The control parameters that explain track deflections in the case of Taiwan are also applied to the case of a smaller island, such as Reunion island, showing different results. First results show that a small island such as Reunion island has a real effect on cyclone track deflection and on intensity change.

More simulations must be conduced to verify concluding remarks obtained by the statistical study and to propose a mechanism which explain processes gouverning the interaction between orography and cyclone. Different parameters are worth exploring, such as the distance between the island and the centre of the tropical cyclone. The effect of extending various thresholds wind (and not only the radius of maximum wind) will be also considered.

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