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## 1. INTRODUCTION

This study aims to explore new aspects of the case studied by Correa et. al. (2010). The case consisted of convection induced by topography over southern Brazil. According to Correa et al., the existence of Low Level Jet (LLJ) and Maximum Velocity Core (MVC) over the mountain regions of southern Brazil ("Serra do Mar" with average heights of 950 m) could induce the formation of convective cells from low-top cloudiness during the early morning hours.

The low level circulation examined by Correa et al. (2010), using the MM5 mesoscale regional model with horizontal spacing of 12 km, showed that the relief acted as a barrier to the northeasterly low level flow from the South Atlantic Ocean, leading to a southward flow along the southern Brazil coast. On the western side of "Serra do Mar", the barrier led to low level atmospheric convergence. This convergence associated to the nighttime LLJ/ MVC in the lower atmosphere explained the formation of the observed convective cells. The interaction between mesoscale circulation and orography could generate instabilities regardless the occurrence of synoptic forcings (Raymond, 1978).

Observations in subtropical regions show that the low level stratiform cloud cover is well correlated to the atmospheric stability (Wood and Bretherton, 2006). On the other hand, the variability of cloudiness between daytime and nighttime at low levels is strongly influenced by turbulence, entrainment and radiative fluxes found in the PBL. Therefore, all these factors might play a crucial role in the formation and evolution of nocturnal stratiform cloudiness related to PBL, and it can have dramatic consequences on climate models (Terra, 2004; Santanelli Jr. et al., 2005, 2007).

In numerical simulations and observational studies, the influence of orography on cloudiness and precipitation is well known (e.g., Yoshizaki, et. al. 2000). Kirshbaum and Durran (2005) suggest two important factors for convective events associated with the orography: strong vertical shear of the horizontal wind at low levels and atmospheric instability. The convective response depends on various scales: it is favored when the topographic elevations are located in a region of mesoscale convergence within a favorable large-scale circulation. Buoyancy is also an important process in PBL flows (Moeng and Sullivan, 1994), and Maddox

and Doswell III (1982) presented cases of intense convective storms that do not follow the classic synoptic model.

The effect of intense transport of heat and water vapor and strong wind shear near the surface can be ingredients for severe convection processes, such as tornadoes. O. Marcelino et. al. (2009) presented a preliminary description of the climatological occurrence of tornadoes in the state of Santa Catarina, the same geographical region of this study, and described 23 episodes (18 tornadoes and five waterspout) during the period 1976 to 2000.,

Therefore in this work, we study a case of convection induced by topography in southern Brazil by using the WRF model.

## 2. MATERIAL AND METHODS

The period analyzed is from 06 to 09-Jun-2007. To characterize the synoptic situation, we used satellite images from GOES 10 (infrared and visible channels) obtained from CPTEC / INPE ([www.cptec.inpe.br](http://www.cptec.inpe.br)).

We used Doppler S-band SIMEPAR radar data to characterize the convective structures. PPI (Plan Position Indicator) images with elevation of 0 degree were used.

For the simulations, we used the Weather Research and Forecast (WRF) model, version 3.1.1., For initial and boundary conditions, we used the analysis of the NCEP Global Forecast System (GFS) every 6 h. The domain consists of 112 by 97 grid points in the zonal and meridional directions, respectively, centered on 28° S, 50°W), with horizontal grid spacing of 10 km and 35 vertical levels (preliminary tests showed that WRF responded more skillfully when this number of vertical levels was used). The parameterizations schemes were: WSM3 class "simple ice" for explicit cloud microphysics (Hong et al., 2004), RRTM longwave radiation (Mlawer et al., 1997), Goddard shortwave radiation (Chou and Suarez, 1994), MM5 atmospheric surface layer model based on Monin-Obukhov with Carlson-Borland viscous sublayer and standard similarity functions (Paulson, 1970; Dyer and Hicks, 1970; Webb, 1970), Noah land surface model (Chen and Dudhia, 2001), 3d Grell ensemble (Grell and Devenyi, 2002) for deep convection and Yonsei University (YSU) scheme (Noh et al. 2003) for PBL. The total integration time was 72 h after 00 UTC 06-Jun-2007.

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### 3. OBSERVATIONAL ANALYSIS

Figure 1 presents the sequence of high-resolution satellite infrared images from 06 to 07-Jun-2007. In early evening (2100 UTC 06-Jun-2007), over a wide region covering the states of Parana and Santa Catarina, there is low top cloudiness [cumulus (Cu) and stratocumulus (Sc)] that is not related to any continental synoptic system. During nighttime, the cloudiness expands and show an eastward propagation (Figs. 1C and 1D). In morningtime of 07-Jun-2007, convective clouds form over the central part of Santa Catarina state (Figure 1E). Convective cloud formation occurs between 0900 and 1200 UTC inside the low-top cloudiness, which now covers a large region from Paraguay to the ocean adjacent to the coast of Parana and Santa Catarina states. From the mid to late morning, there is enhancement of the convective clouds (Figures 1E-1F).

The convective clouds formed over the western edge of the Serra do Mar in Santa Catarina (Figure 2), suggesting the mechanical ascent, induced by topography, of air parcels embedded in the westerly low level flow. But, as convective cloud formation occurred during early morning, several hours after favorable conditions for orographic lifting, additional factor(s) must have played a relevant role in the early morning convection. During late nighttime/early morning time, the PBL could contain intense LLJ/MVC, as observed in Porto Alegre city. Thus, it can be conjectured that the formation of convective clouds is due to the combined action of two mechanisms: mechanical rise due to topography and presence of LLJ/MVC.

To confirm the convective nature of the high top cloudiness in mid-morning, Figure 3 shows the mesoscale convective structures that occurred in southern Parana, Santa Catarina and northern Rio Grande do Sul, from the radar data. During the afternoon of 07-Jun-2007 (1500 to 2100 UTC), the convective cloud intensifies, expands and moves towards the east. At 2100 UTC (Figure 3D), the convection region is over eastern Santa Catarina. The propagation velocity is about  $14 \text{ m s}^{-1}$ , consistent to the values found for other mesoscale systems in the region (Kneib, 2004). During the nighttime, the regions of convection merge (0000 UTC, Figure 3E) and split (0300 UTC, Figure 3F) in two parts, one remaining over the central part of Santa Catarina (system 1) and the other following a zonal eastward path towards the ocean (system 2). At 0600 UTC (Figure 3G), system 2 almost disappears and system 1 propagates eastward. At 0900 UTC (Figure 3H), there are no convective cells over the region.

Summing up, convective clouds initiate during the morning time (07-Jun-2007), intensify during the daytime (diurnal convection), propagate eastward following the low-level circulation and weaken during night-

time. The life cycle is about 24 h. Thus, the presence of LLJ/MVC associated to mechanical orographic lifting are likely to be the fundamental mechanisms of convective triggering in the study region, and may be responsible for the organization of the mesoscale convective systems that remained active for 24 h.

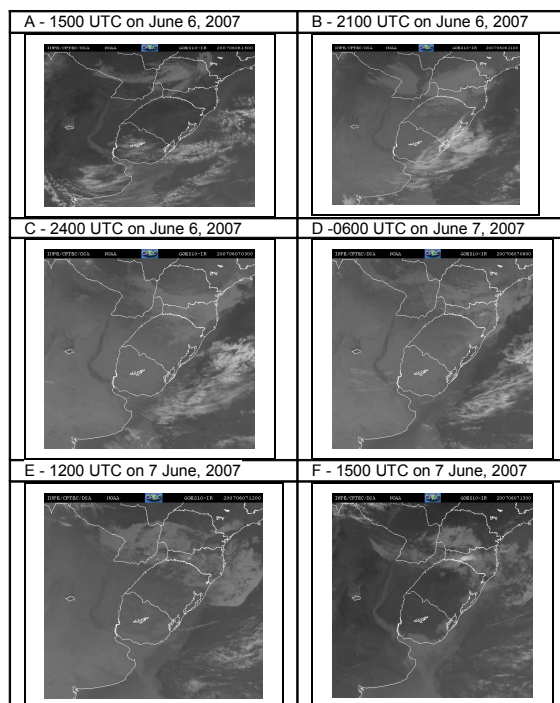


Figure 1 - High resolution satellite infrared images between 1500 UTC 06-Jun-2007 to 1500 UTC 07-Jun-2007.

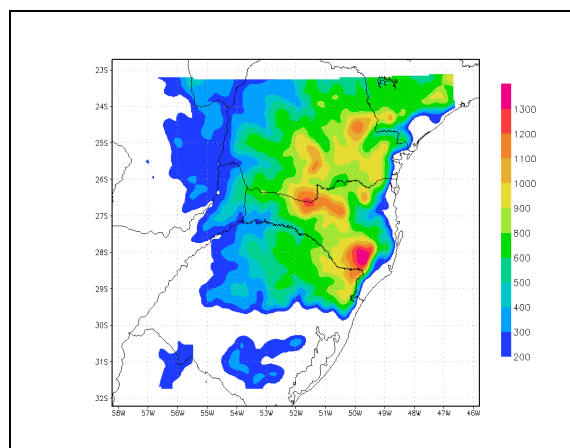


Figure 2 – Topography in southern Brazil (10 km grid spacing). Heights in meters.

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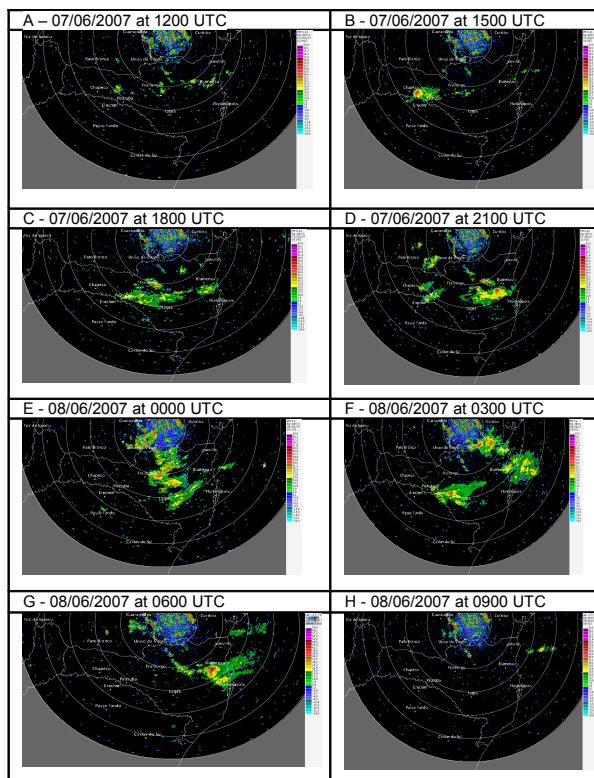


Figure 3 – Reflectivity (dBZ) images from the SIMEPAR radar. PPI with 0° elevation. Period between 1200 UTC 07-Jun-2007 to 1500 UTC 08-Jun-2007.

#### 4. SIMULATIONS

Figure 4 shows the wind field, simulated by WRF, at 970 and 950 hPa levels, corresponding to the lowest levels of 200 to 300 m. At 970 hPa, circulation on the eastern side is parallel to the relief following the coast. During the nighttime of 07-Jun-2007, the direction and intensity of the wind change. On the western side, circulation has a greater wind acceleration at 950 hPa. The flow becomes accelerated (Fig. 4F and 4H) between 0600 and 0900 UTC. Thus, the WRF model simulation show a directional shear of the horizontal wind, and the low level circulation is consistent to the topographic barrier of Serra do Mar. The influence of topography appears at 950 hPa over the western edge of Serra do Mar, where, coupled to the northwesterly low level MVC,

directional shear and mass convergence appear, and these could lead to the onset of convective clouds.

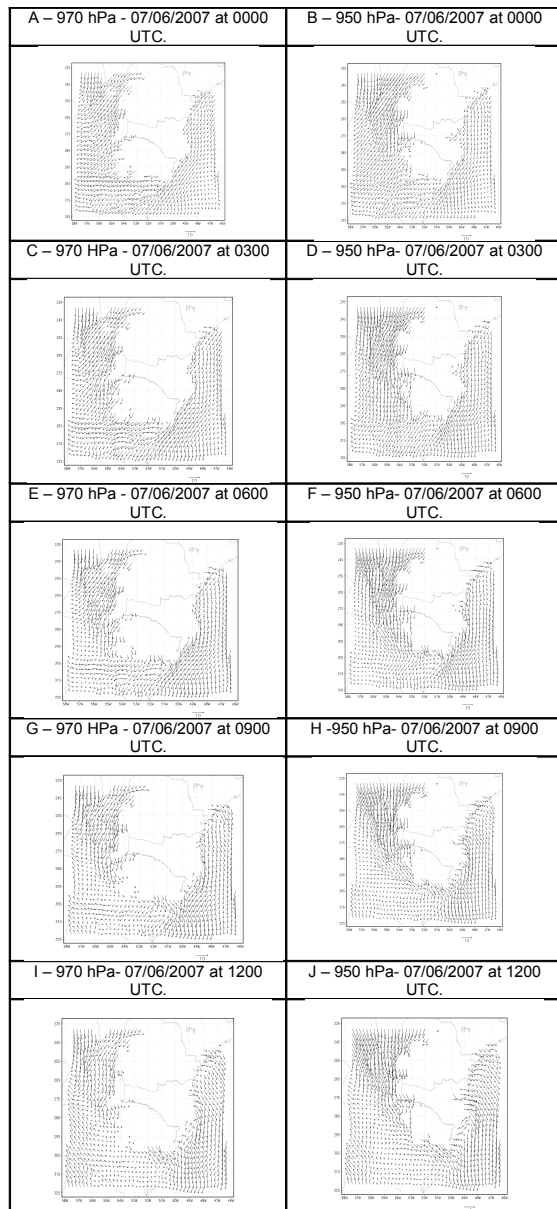


Figure 4 - Simulated wind fields at 970 hPa (fields of the left column) and 950 hPa (right column of fields) level from (A) 0000 UTC 07-Jun-2007 and (J) 1200 UTC 07-Jun-2007. Horizontal grid spacing of 10 km and units in  $m s^{-1}$ .

Figure 5 shows the wind field at 900 and 880 hPa levels from 0000 to 1200 UTC 07-Jun-2007. Comparing 970/950 and 900/880 hPa levels, a dynamic structure with strong directional shear appears. Strong mass convergence and wind field discontinuity are also found. In this structure, the circulation at 900 hPa is strongly accelerated when

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compared to the lower level circulation (970-950 hPa).

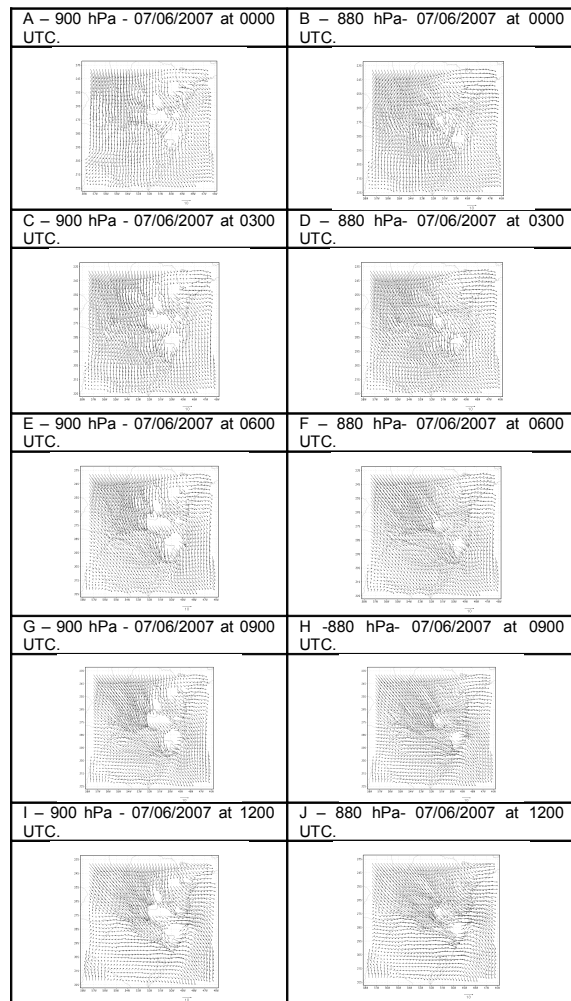


Figure 5 - Simulated wind fields at 900hPa level (fields of the left column) and 880 hPa (right column of fields) between (A) of 07/06/2007 0000UTC and (J) of 07/06/2007 1200UTC. Horizontal grid spacing of 10 km and in units  $\text{ms}^{-1}$ .

Figure 6 shows the simulated vertical velocity cross sections at  $28^{\circ}\text{S}$  (left side pannels) and  $50^{\circ}\text{W}$  (right side pannels) from 0000 UTC to 12 00UTC 07-Jun-2007. From the mid to high levels, a marked persistence of negative velocities associated with the orography in southern and eastern windward

mountain formations. From 0600 to 0900 UTC, positive vertical velocities are found (east and south the negative velocity cores), and the velocities show a bottom-up increase during daytime. This fact is consistent with the organization and formation of convective cells and lines found in the radar images (Fig. 3).

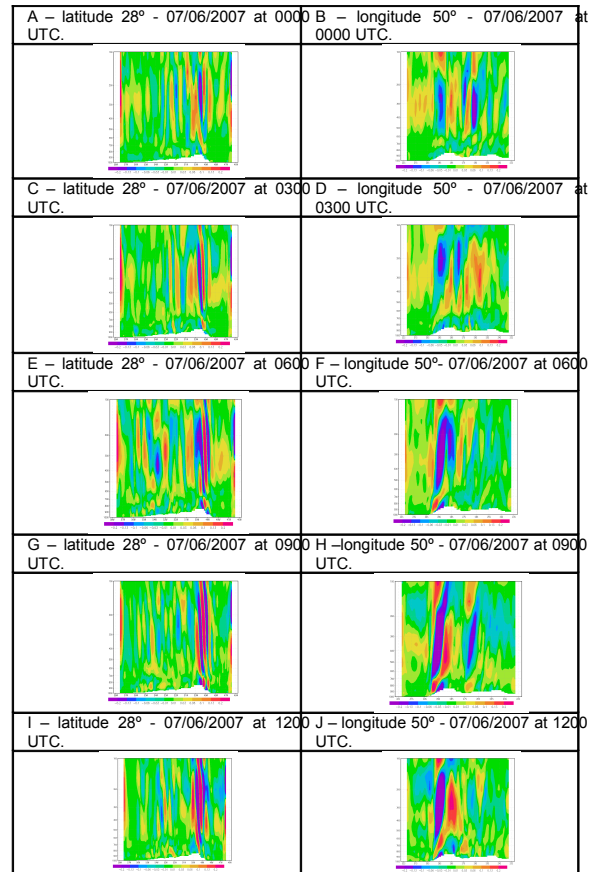


Figure 6 - Simulated vertical velocity fields at  $28^{\circ}\text{S}$  (left side pannels) and  $50^{\circ}\text{W}$  (right side pannels) from (A) 0000 UTC to (J) 1200 UTC 07-Jun-2007. Unit:  $\text{m s}^{-1}$ .

#### 4. CONCLUSIONS

This study seeks to contribute to the understanding of cases of nocturnal convection observed in southern Brazil. The case study allows us to propose a dynamic model on tropospheric lower levels that conceptually explain the emergence of physical conditions that are directly involved on the generation of nocturnal convection. The physical conditions are: topography and vertical/directional shear of the horizontal wind. The WRF model was able to represent effectively the vertical/directional shear, and vertical velocity acceleration below 900 hPa over the south-eastern region of Santa Catarina

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state and northeastern Rio Grande do Sul. That kind of wind shear profile at the lower levels induces strong confluence of mass and moisture. This behavior extends from the southern/eastern to the eastern sides of the mountains in Santa Catarina and Parana, organizing the convection over these regions. On the mesoscale level at lower levels, there was strong interaction between the planetary boundary layer (970 and 950 hPa) and lower levels (850hPa), and also influence on the mid-tropospheric levels (500 hPa).

The conclusions presented here are based on a single case. Therefore, for future work, more cases could be studied. Moreover, the sensitivity of convection to different parameterization schemes and horizontal grid spacing could be evaluated. Finally, the use of a Large Eddy Simulation (LES) could be important to resolve turbulent structures relevant to PBL evolution.

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