Vol. 37 N°2 (2012) 57-65

Meteorologica

MESOSCALE FORECASTING OF AN EVENT OF NOVEMBER 2008 IN SANTA CATHARINA

Lia Martins Costa do Amaral[1], C. T. Homann[1], V. Pinho[2] y Y. Yamasaki[1]

[1] Federal University of Pelotas, Pelotas, RS, Brazil
[2] Federal University of Alagoas, Maceió, AL, Brazil

(Manuscrito recibido el 17 de marzo de 2010, aceptado el 7 de junio de 2011)

ABSTRACT

The large availability of water vapor at low levels of the atmosphere, advected into the coastal region of Santa Catharina State by the Atlantic Ocean semi-stationary anticyclone, provided the frequent and copious rainfall during the November, 2008. One of the most extreme event occurred in Santa Catharina coastal zone, when a quite strong blocking formed at high levels of the atmosphere is explored processing both, the MM5 and WRF mesoscale models. These models were processed with very high spatial resolution domains, covering the entire region affected by the severe event. The sea surface temperature field revealed that there was a large core on Atlantic waters with quite high temperatures along the coast of Santa Catharina, which enhanced the vertical integrated latent heat supply into the continental region by the winds. The models forecasting results showed consistent results with the observations, as well as an indication that coherences are directly related to the horizontal resolution of the models configurations.
Keywords: Mesoscale, MM5, WRF

PRONÓSTICO DE MESOESCALA DE UN EVENTO DE NOVIEMBRE DE 2008 EN SANTA CATARINA

RESUMEN

La gran disponibilidad de vapor de agua en los niveles inferiores de la atmósfera, advectada sobre la costa de la provincia de Santa Catarina por el anticiclón semi-estacionario del Océano Atlántico, favoreció períodos frecuentes de lluvia durante el mes de noviembre de 2008. La exploración del evento extremo ocurrido en Santa Catarina, que se caracterizó por un intenso bloqueo en niveles altos, se realizó con pronósticos de los modelos del mesoescala MM5 y WRF. Estos modelos fueron procesados con muy alta resolución espacial, abarcando toda la región afectada por el evento severo. La temperatura de la superficie del mar presentaba anomalías positivas de temperatura a lo largo de la costa de Santa Catarina, favoreciendo la transferencia de calor latente hacia la atmósfera, con su posterior advección hacia la zona continental. Los resultados obtenidos con los modelos son consistentes con las observaciones, aunque fuertemente dependientes de la resolución horizontal de los mismos.
Palabras clave: Mesoescala, MM5, WRF.

dirección electrónica: lia.meteorologia@gmail.com

1. INTRODUCTION

The topography plays a large influence on the rainfall distribution not only by forcing upward movements, but also by thermal and frictional effects (Browning, KA, 1980). The thermal effects manifest triggering the convective precipitation by the intense heat sources as well as by the organized mesoscale circulations. On the other hand, the frictional effects cause an increase in the precipitation by the local convergence, which occurs in the boundary layer, resulting from differences in the friction, such as those that occurs along the mountainous shorelines of the Santa Catharina State of Brazil. Although these types of precipitation may cause great damage, especially to economic and productive societies, many countries have a large dependence of these types of precipitation (India, China, and Japan). The difficulty of exploring this problem is mainly related to the topography of the complexes shaped mountainous region, besides the difficulties of taking the accurate measurements of rainfall over areas of these natures. Bergeron (1965) indicates a very close relationship between the maximum rainfall and the height of the mountains - implying that most of the topographic precipitation originates from very low levels of the atmosphere (about 500 m), otherwise, would be removed, far away, from higher altitudes regions. Even using mesoscale numerical models, to characterize, as accurately as possible, these topographic effects - it is necessary to process them with very high space resolution, in order to incorporate a part of the large topography variations of a mountainous region.

The heavy rains which occurred in Santa Catharina, during November 2008, were due to the combination of various meteorological factors. They were caused by the simultaneous occurrence of two main phenomena: an anticyclone, which remained semi-stationary over the South Atlantic Ocean near the coastal region of Santa Catharina - producing moderate winds toward the coast - and the presence of a cyclonic vortex that, in addition to topographic effects, caused a further ascent of air mass. On November 22, after a hot and sultry afternoon, with temperatures up to 29 ºC, the clouds presented a strong vertical development during the day, and rapidly expanded, extending toward the West and Midwest of continental area and causing severe storms. According to the surface observations registered in Itajaí city, the accumulated rainfall, during November, was 670 mm, well above the average normal. About 85% of this city was flooded and 41 thousand people were left homeless. The November month was also, the one with the highest amount of rain ever recorded in Florianopolis city since 1961 (Brazilian National Institute of Meteorology - INMET).

According with Civil Defense of the Santa Catharina State report, the rainfall has affected, during November, about 60 cities and more than 1.5 million people. Eight counties become isolated, 10 enacted/ into state of public calamity and several were completely flooded. According to reported surveys, the event caused 133 deaths, 22 missing and more than 78,000 people were forced to abandon their homes. The rain banned sections of major highways, closed the port of Itajaí city and disrupted gas supplies in Santa Catharina and Rio Grande do Sul States. Industries estimated losses of R$ 358 million and the state government predicted the loss of 15% in annual incomes.

Data from the Information Center for Environmental Resources and Hydrometeorology (CIRAM) reported that the meteorological station of Blumenau registered a record high of 283 mm of precipitation in 24 hours, between days 22 and 23.

However, the accumulated precipitation in the month, until November 24, in Joinville city was even higher; with 911 mm, while in Blumenau city recorded 878 mm.

Severe rainfall events which have been occurring in Brazil, particularly as the 2008 in Santa Catharina, reveals the importance of the researches and the constant re-structuring and improvement, not only of the forms, as well as the techniques of numerical weather prediction. The diagnostic and prognostic assessment of severe event occurred in Santa Catharina, in 2008, is studied and explored using observational data and the MM5 and WRF mesoscale models.

2. MM5 MODEL: CONFIGURATION AND SIMULATION

The MM5 mesoscale model system (Dudhia et al. 2002) has been set up for three integration domains (D01, D02 and D03) covering the states of Santa Catharina and Rio Grande do Sul and neighboring areas, as shown in Fig.1. They were set, respectively, with 80, 160, 223 grid points in the East-West direction and 60, 127 and 151 grid points in the North-South direction. The distance between the grid points was set at 18 km, 6 km and 2 km, resolutions respectively; with 24 sigma levels in the vertical and the top of the atmosphere has been set to 100hPa. The time step of integration has been set to 81 seconds for the domain D01.

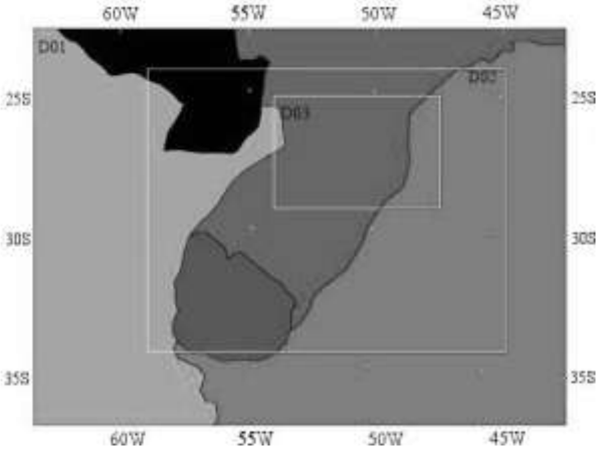

Fig. 1: D01, D02 e D03 integration domains of MM5.

The numerical simulations were processed using the Kain-Fritsch 2 (Kain, 2004) scheme cumulus parameterization for domain 1 (D01). As the model has the ability to address explicitly the convective processes for scales smaller than about 10 km, no cumulus parameterization was used for domains D02 and D03.

3. WRF MODEL: CONFIGURATION AND SIMULATION

The WRF (Weather Research and Forecast) is a numerical modeling system, developed for research of atmospheric phenomena as well as for mesoscale weather forecasting. Its continued development is a collaborative effort evolving several research centers and U.S. government agencies. Architected to be a top tool in simulating atmospheric, flexible, portable, and efficient in a variety of computing platforms, the WRF system, is of public domain and made available for free at http://wrfmodel.org.
The Fig.2 presents the configuration of the three domains of integration of WRF model, covering the state of Santa Catharina and surrounding areas. The first domain has been configured with 117 by 64 grid points; the second with 196 by 115 grid points and the third one with 349 by 205 grid points; respectively with 18 km, 6 km and 2 km horizontal grid space resolution.
The model has been configured in Lambert projection, integrated with two way nesting and time step of 54 seconds for the largest domain. The processing has been made for the 00 UTC of November 21, 2008 to 00 UTC of November 23, 2008.

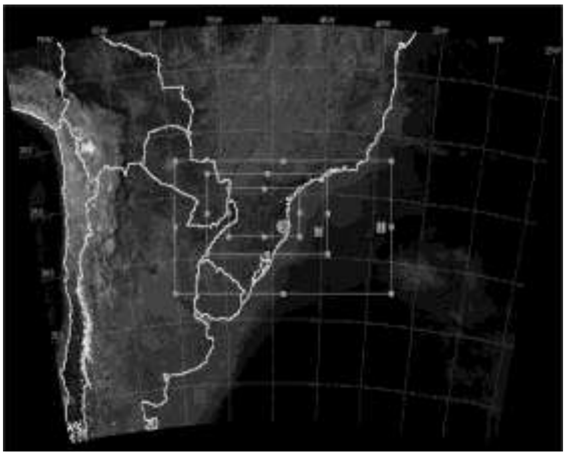

Fig. 2: Domains of WRF model integration.

4. CHARACTERISTICS OF MM5 AND WRF MODELS

The MM5 and WRF models have been processed with the global GFS/NCEP model forecasting, gathered in GRIB2 format, with 0.5 degrees space resolution, via the IDD / LDM system. These forecasts provided the analysis and global forecasts for every three hours, and provided both, the analysis and boundaries conditions to mesoscale models. The models have been processed and the forecasts stored for each hour, during the 48 hours of integration period.
The analysis of both models have been made generating plots, of meteorological fields, with GrADS (Grid Analysis and Display System) system including, among others, the rainfall, temperature and the sea surface (SST). The infrared channels GOES satellite images, for the southern hemisphere, have been also used in the analysis.

5. EVENT DESCRIPTION

The event under consideration, occurred in Santa Catharina State, has been caused by the simultaneous occurrence and combination of several meteorological factors. The one of them was the high evaporation rate, of high temperature water, from the Atlantic Ocean, near the coastal region of the state. Between November 17 and 21, the coast region of Santa Catharina had a core with high temperature of the water (Fig. 3), lower than that between November 21 and 25 (Fig. 4), [http://www.fnmoc.navy.mil], i.e., a gradual increase in temperature of sea water, which allowed the fact that it becomes even higher than the air temperature.

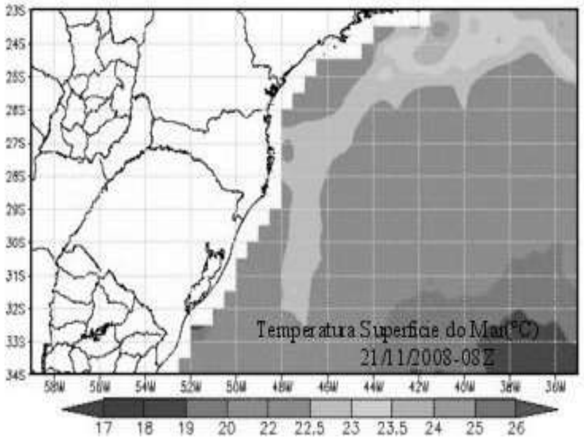

Fig. 3: Sea surface temperature – November 21 – 08:00UTC.

This fact revealed that there was an anomaly of about 1.5 °C on SST, near the coast of southern Brazil (Fig.5) as in http://www.bom.gov.au, which reflected the increased vertically integrated latent heat flow over the Atlantic Ocean, presented in Fig. 6.

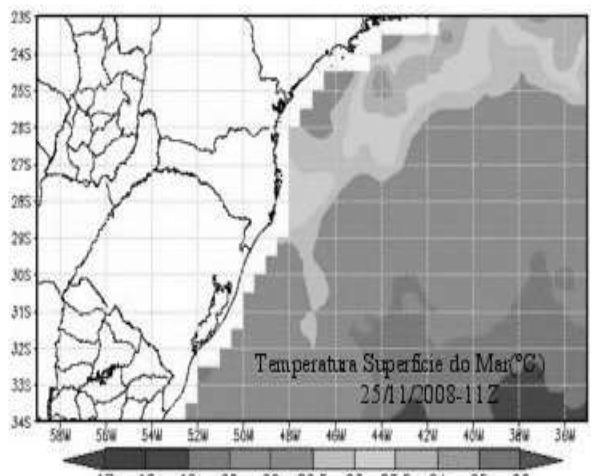

Fig. 4: Sea surface temperature – November 25, 11:00UTC.

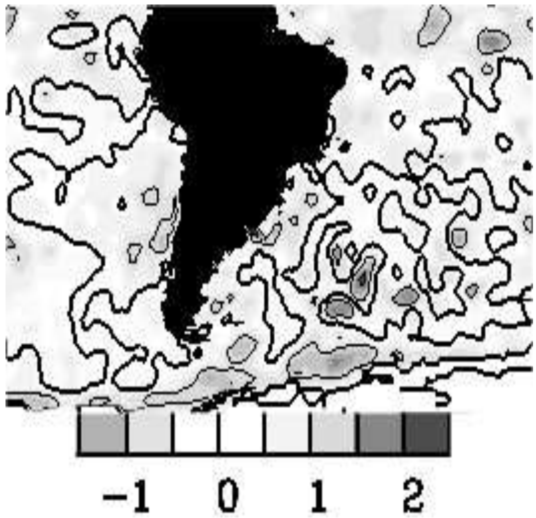

Fig. 5: Sea surface temperature anomaly - November 17 to 23

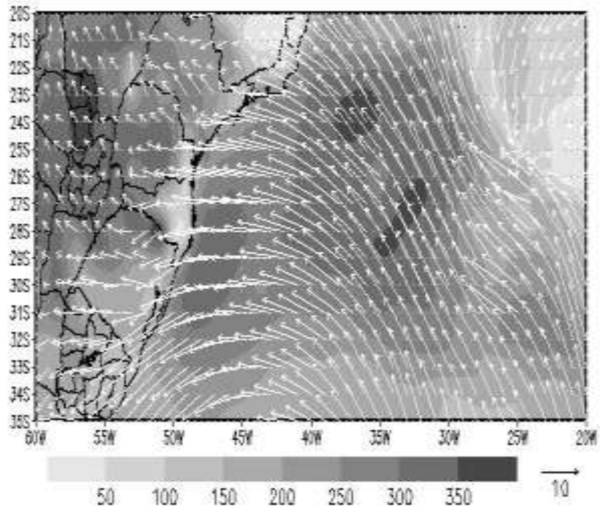

Fig. 6: Latent heat rate (W/ m^2) and wind (m/s) – November 21 – 21:00UTC.

A high pressure (anticyclone) center on 37 ° S and 40° W, which had already been presenting a steady characteristic, since few days ago (Fig. 7), was the main physical mechanism responsible for the transport of moisture, toward the coastal region of Santa Catharina, in the low levels of the atmosphere.

As a result of the high pressure center (anticyclones) there was a peculiar wind circulation behavior (in the vertical profile) in such system. The surface wind, under a high pressure center diverge in this level; rising and converging at high levels, where the atmospheric pressure is lower.

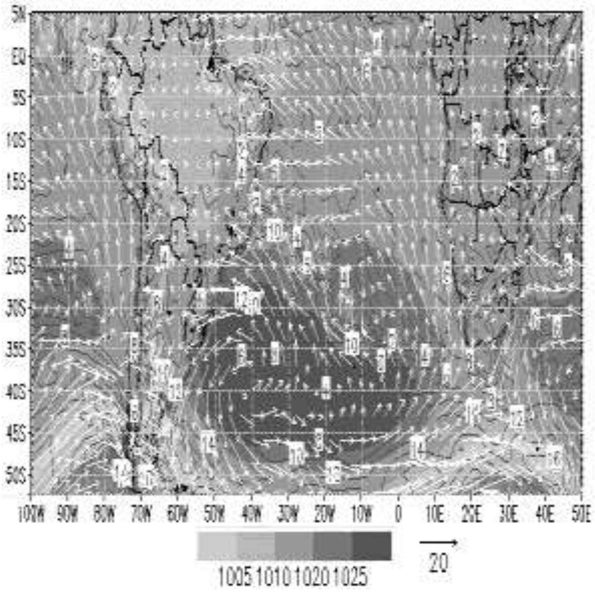

Fig. 7: Atmospheric pressure (hPa), direction and magnitude of wind (m/s) - November 21–21:00UTC.

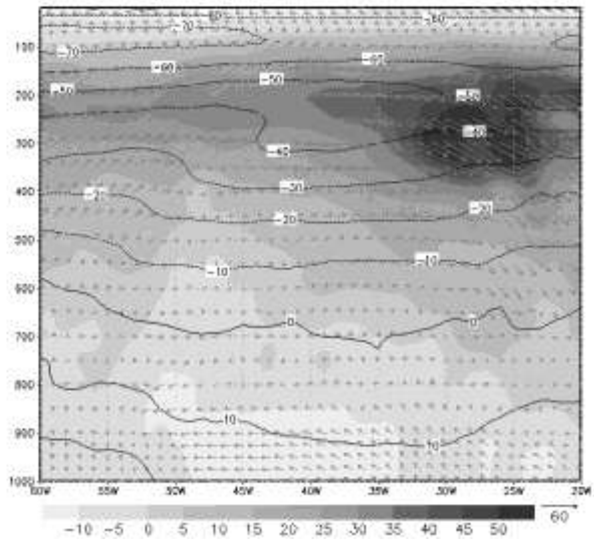

Fig.8: Cross section of atmosphere at 27°S with forecasting of horizontal wind component (u) at m/s and isothermal lines (°C) – November, 21– 21:00UTC.

In the Fig.8, presenting the vertical cross section of the atmosphere, along 27°S of latitude, covering the region between the 60°W and 20°W, illustrates this behavior; in which the horizontal surface wind component moves westward varying the magnitude between 5 and 15 m/s. At high levels, on the other hand, moves from eastward, reaching magnitudes of up to 50 m/s between 300 hPa and 200 hPa layer.

6. PROGNOSTIC ANALYSIS OF MESOSCALE NUMERICAL MODELS

According with Epagri-Ciram, between 09:00 UTC of November 21st and 09:00 UTC of November 23, the largest volumes of rain occurred in the São Francisco do Sul city (located at 26.1ºS and 48.3ºW) - with 466.6 mm and Itapoá city (26.1º S and 48.4ºW) with 408.2 mm. The region close to these cities is analyzed in the light of the simulations made by two mesoscale models. At the beginning of day 21, until 03:00 UTC, the accumulated rainfall, in 3 hours, as provided by the MM5 and WRF already indicated a rainfall of about 25 mm on the coastal region of Santa Catharina, as indicated in Fig. 9a and Fig. 9b. The accumulated precipitation, provided by MM5 (Fig. 9a), has a little bit greater area coverage with higher total rainfall.

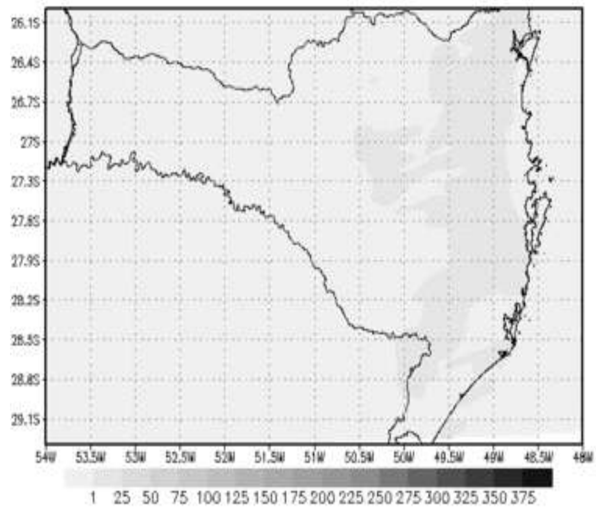

Fig. 9a: Accumulated precipitation from MM5 model – November 21- 03:00UTC.

Until 12:00 UTC, both models show areas with relatively higher precipitation than at 03:00 UTC, as shown in Fig.10a and Fig.10b. The MM5 predicted, in the southern coastal region, a rainfall greater than 75mm, while the WRF predicted rainfall lower than 75mm and also over other regions located in the south mainland region.

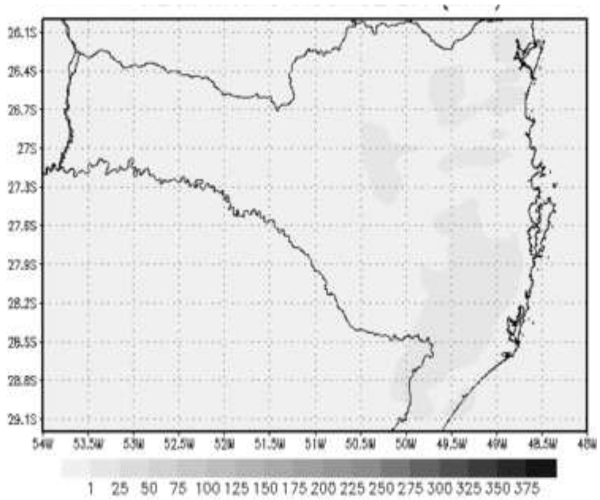

Fig. 9b: Accumulated precipitation from WRF model – November 21, 03:00UTC.

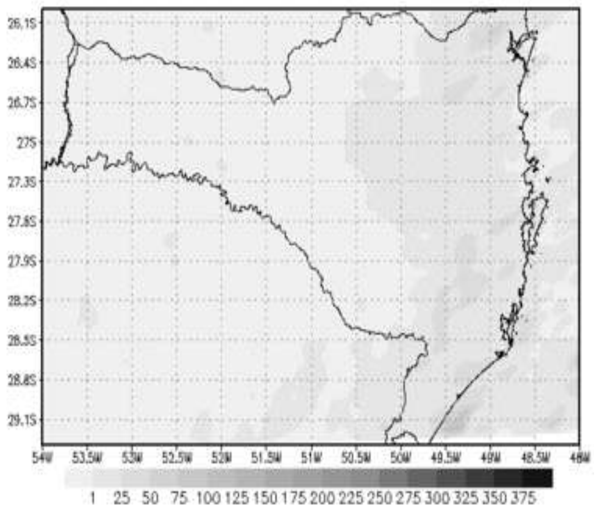

Fig.10a: Accumulated precipitation from MM5 model – November 21, 12:00UTC.

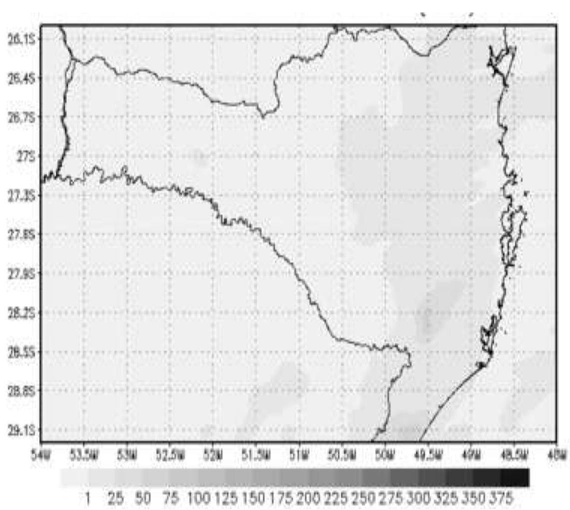

Fig. 10b: Accumulated precipitation from WRF model – November 21, 12:00UTC.

The total accumulated precipitation, up to 03:00 UTC of day 22, provided by the WRF is presented in regions with rates of up to 225 mm along both the north and the south coastal region of Santa Catharina. However, MM5 presents levels which do not exceed 200 mm, although over smaller and sparser regions. These forecasting are shown in figures Fig.11a and Fig.11b.

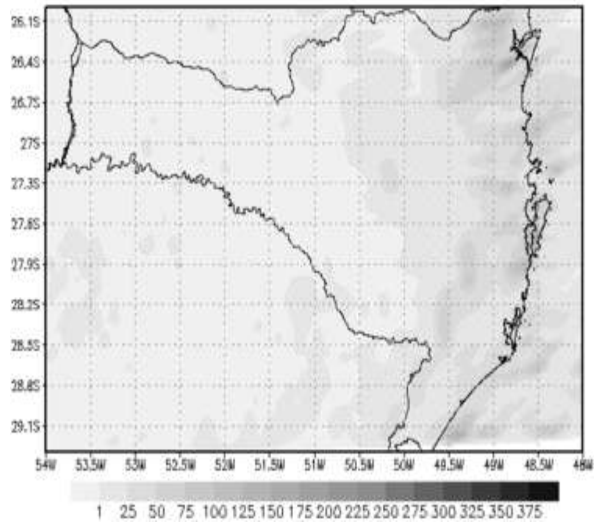

Fig.11a: Accumulated precipitation from MM5 model – November 22, 03:00UTC.

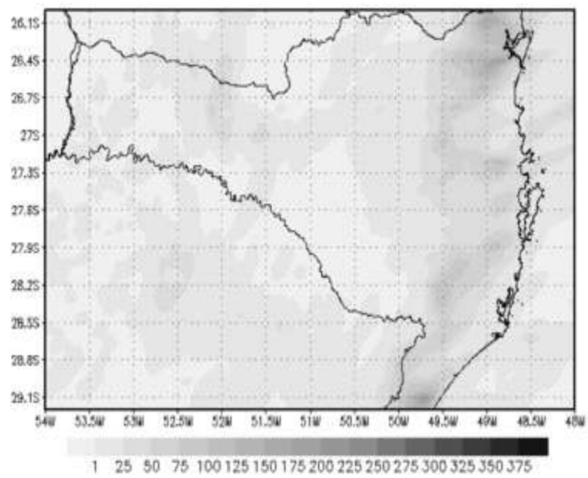

Fig.11b: Accumulated precipitation from WRF model – November 22, 03:00UTC.

The accumulated precipitation for 23:00UTC of day 22 (i.e. 48 hours integration), the rainfall of both models exceed 325 mm in the north coast of Santa Catharina. The WRF presented a relatively higher area (even though consisting largely with lower rates) than that presented by MM5, as shown in Fig.12a and Fig.12b.

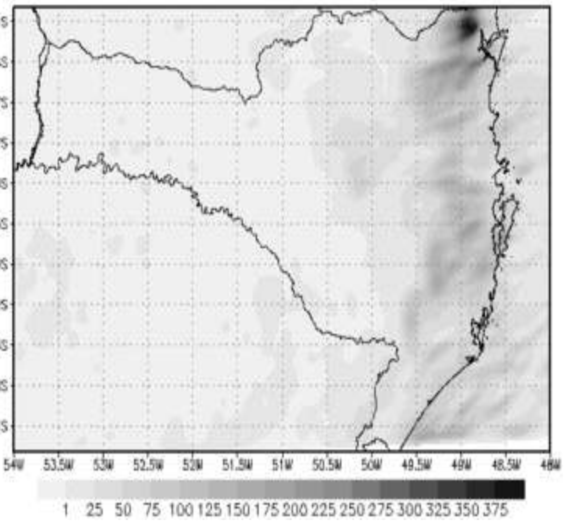

Fig.12a: Accumulated precipitation from MM5 model – November 22, 23:00UTC.

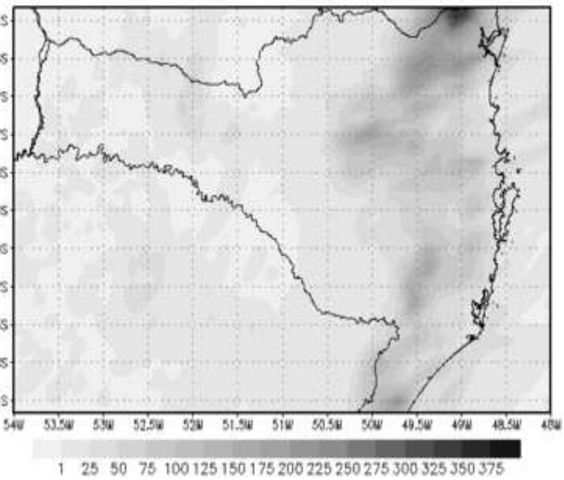

Fig.12b: Accumulated precipitation from WRF model – November 22, 03:00UTC.

The Fig. 13 and Fig. 14 show the accumulated rainfall between 00:00 UTC of 21 and 00:00 UTC on 23, on 26.1° S and 48.9° W, for the models MM5 and WRF, respectively. It is observed that, even with a small reduction of precipitation, during the afternoon of 21 and the morning of 22, there was a significant rainfall during 48 hours – with a total of more than 350 mm.

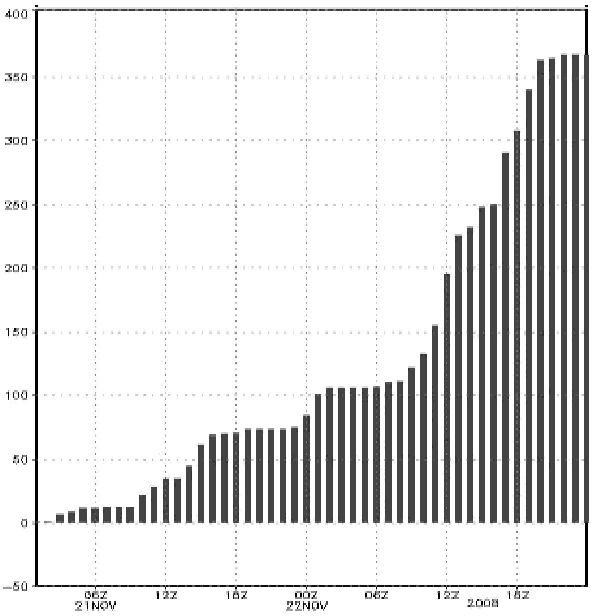

Fig.13: Accumulated precipitation between November 21st- 00:00UTC and November 23rd - 00:00UTC according to MM5 model.

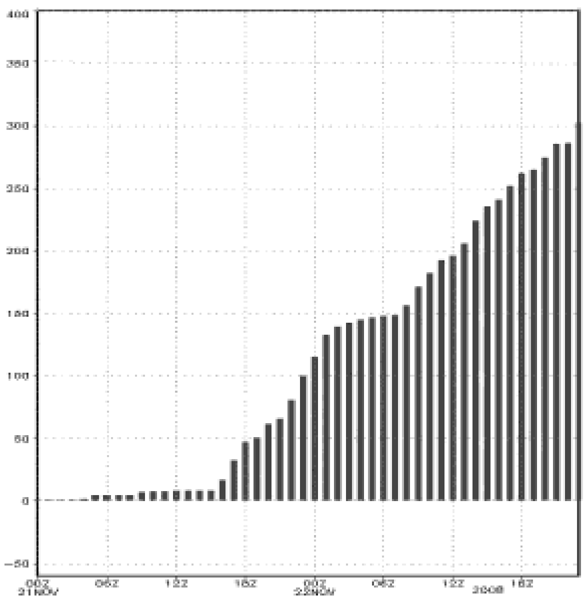

Fig.14: Accumulated precipitation between November 21, 00:00UTC and November 23, 00:00UTC according to WRF model.

There was an increase of precipitation, between 12:00 UTC and 18:00UTC of 21 and between 12:00 UTC and 00:00 UTC of 23, as it can be seen in Fig. 15 and Fig.16. These period coincide with those presented in the infrared channel image of the satellite GOES-10, which have a higher cloudiness on the coast of Santa Catharina (Fig. 15 and 16).

Fig.15: Satellite image of GOES10 (infrared channel) – November 21, 12:00UTC

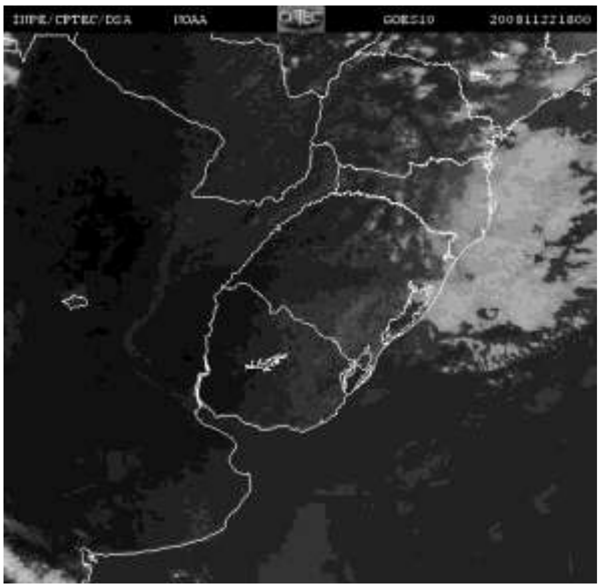

Fig.16: Satellite image of GOES10 (infrared channel) – November 22, 18:00UTC

The vertical cross sections of potential temperature, potential vorticity and the vector wind circulation, provided by MM5 for the domain D01, to be presented, refer to the one made along the horizontal line with a latitude of 20° S, which has an the order of 1500 km across the entire state of Santa Catharina, as illustrated in Fig. 17.

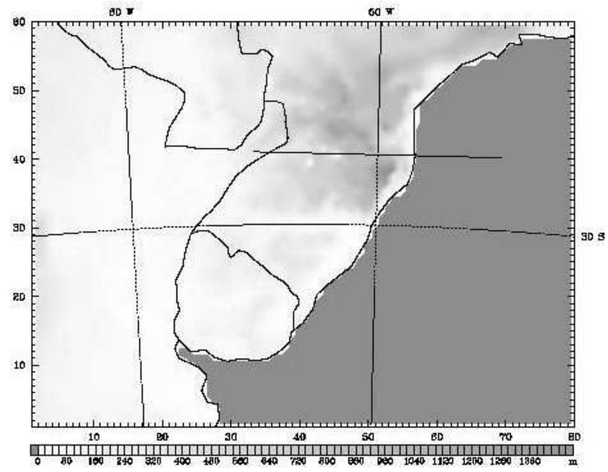

Fig.17: Cross section along the latitude of 27, 3°S

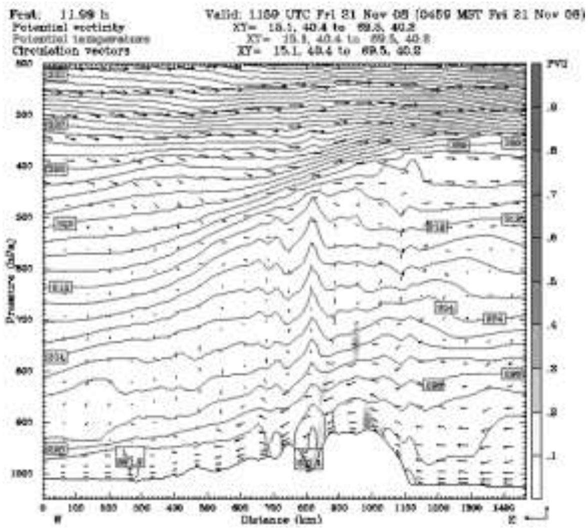

Fig. 18: Vertical cross section of potential temperature, vorticity and wind circulation vector for November 21, 12:00UTC.

The 00:00 UTC of November 22 (Fig. 19), presented an ascending wind movement up to 900hPa. However, on 00:00UTC of the next day, although the movement of wind has been the same it extended up to 700hPa.

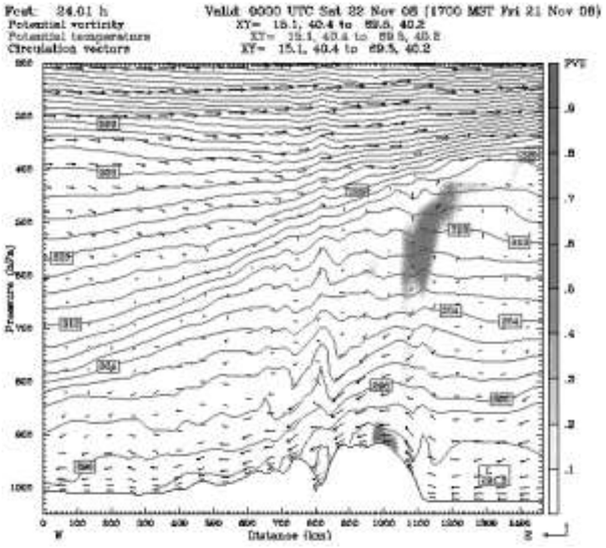

Fig. 19: Vertical cross section of potential temperature, vorticity and wind circulation vector for November 22, 00:00UTC.

7. CONCLUSIONS

The catastrophic episode mainly caused by the intermittent rainfall in Santa Catharina, during the November 2008 led to the precipitation that occurred on 21 and 22, causing bulky damage to both economic and social sectors. These events have been mainly strengthened by the enhanced availability of water vapor at low levels of the atmosphere, advected into the coast of Santa Catharina, by anticyclones which remained semi- stationary over the Atlantic Ocean during the month under investigation, providing frequent periods of copious rainfall. Some anticyclones which have also been established - although during shorter periods of time during the month, also provided a positive feedback of moisture over the Santa Catharina state. It should be mentioned that phenomena of similar nature, which has lately been more frequently occurring on the southern Brazil, have been severe - not only by the amount of rainfall in one day, but also as a result of intense rainfall which occurs in a quite short period of time.

The extreme event, occurred during the day 21 and 22, when an intense blocking at higher levels has been acting, causing a huge disaster, is explored based on MM5 and WRF mesoscale forecasting models. These models have been processed with high spatial resolution integration domains, covering the entire region affected by the severe event.

The mesoscale models processing have been made with the support of the global forecasting system (GFS) model of NCEP, to provide the necessary requirements on both initial and lateral boundaries conditions. Due to the dependencies of numerical models on the parameterizations, different parameterizations of clouds were used and the results of numerical integrations are presented and discussed for one of them.

The sea surface temperature before the occurrence of the event under investigation revealed that there was a core with higher temperatures on Atlantic Ocean along the coast of Santa Catharina - which was even above the temperature of atmospheric air and substantially facilitated the supply of water vapor into the continent of Santa Catharina.

Both models presented a reasonably consistent numerical results compared with the observed data of extreme rainfall - which reached a record of 466 mm, from November 21 - 09:00 UTC to November 23 - 09:00 UTC – against the numerical models, presenting 370 mm (from November 21 00:00UTC to November 22 00:00 UTC of day 22) in the proximity of the site of the recorded precipitation. Finally, it should also be noted that the results of models which have been processed with higher horizontal resolution (2 km) presented better results than the mothers of their domains.

Acknowledgment: To all institutions that provided the essential data and supports to carrying out the study: NCEP, UCAR, and using UFPEL.

REFERENCES

Bergeron, 1965. On the lower level redistribution of atmospheric water caused by orography. Supl. Proc. Intl. Conf. cloud Phys., págs. 96-100.

Browning, K.A. 1980. Structure, mecanism and prediction of orographicdally enhanced rain in Britain. GARP Publ.Series 23, WMO, págs. 85 114.

Dudhia, J., Dave, G., Young-Run, G., Kevin, M. Al B., Wei, W. and Cindy, B., 2002. PSU/NCAR Mesoscale Modeling System Tutorial Class Notes and User’s Guide: MM5 Modeling System Version 3.

Kain, J. S. 2004. The Kain–Fritsch convective parameterization scheme: An update. J. Appl. Meteor, 43, pp. 170 – 181.