Chapter

Strong Rainfall in Mato Grosso do Sul, Brazil: Synoptic Analysis and Numerical Simulation

Sergio H. Franchito, Manoel A. Gan and Julio P. Reyes Fernandez

Abstract

Heavy rainfall and strong winds occurred in the South of Mato Grosso do Sul State, Brazil on 5 December 2015. In this study the synoptic conditions responsible for the storms and their social consequences are analyzed. Also, the state-of-art model (WRF) was used to simulate the atmospheric conditions in this severe event. The results showed that the storm had harmful consequences both in the cities of the region and in the interior of the state, with floods, threw down trees and impacts on the energy distribution. The synoptic analysis showed that over the Mato Grosso do Sul State at high levels occurred a region of wind difluence which was associated with convective clouds of large vertical development. This event was responsible for the heavy rainfall and strong winds in the region. The model results showed that the simulations were in good agreement with the observations. Thus, numerical weather forecast using the model may be extremely useful to obtain important information to mitigate the possible adverse effects of future severe weather events. This study forms part of a cooperative Project between National Institute for Space Research and Energy Power Company aimed to mitigate the impacts of severe events.

Keywords: heavy rainfall in Mato Grosso do Sul state, Brazil, impact of severe weather conditions, numerical model simulation

1. Introduction

The distribution and transmission of electric energy sectors are greatly affected by the climatic changes due to the global warming. Climate (and its change) is the main external agent that affects the electric energy distribution and transmission in all the world. The situation is aggravated by the increase of frequency of extreme events like tornadoes and severe storms associated to heavy rainfall, windstorms and high lightning incidence rate. Thus, studies providing useful information of the atmospheric conditions in extreme situations are essential not only for the electric energy sector but also for the national economy and people welfare. In this sense, recently the National Institute for Space Research (INPE), Brazil, and Energy Power Company developed a cooperative project aimed to mitigate the impacts of severe events. This is the first project of the Research and Development Program of the National Agency of Electric Energy (ANEEL) aimed to identify, monitoring and anticipate the occurrence of atypical severe storms that may cause climatic disasters

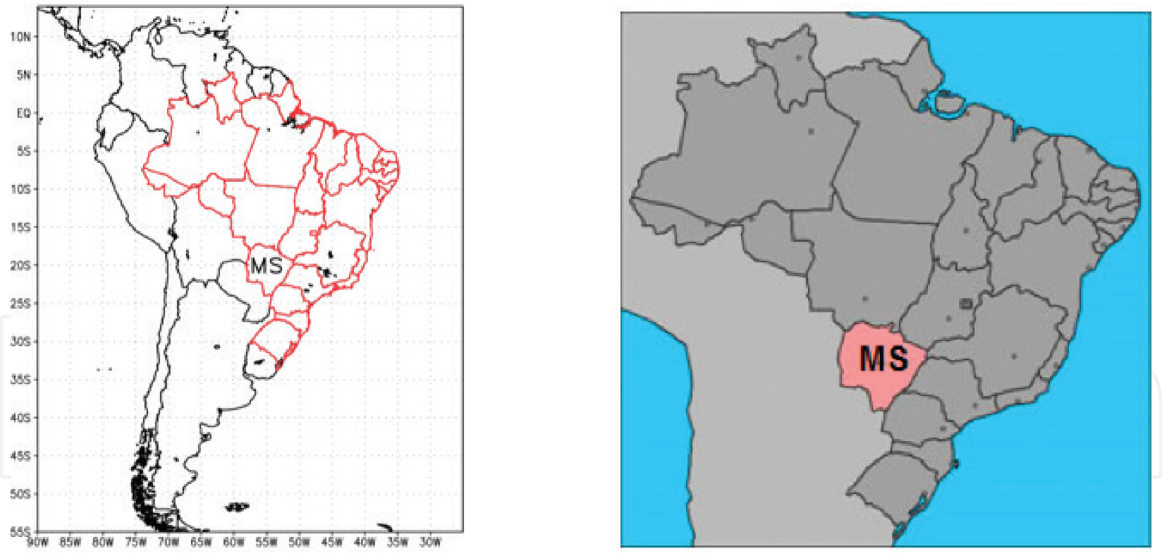

Figure 1.
Model domain of the WRF-NMM 9 km. MS in the figure indicates the location of the Mato Grosso do Sul state.

of high impact on the electric energy distribution and socioeconomic sector. One of the project components is to identify the atmospheric conditions responsible for the severe storm events and the use of a high resolution regional numerical model to obtain the meteorological variables (for example, temperature, winds, pressure, precipitation) that describe in an adequate way the atmospheric conditions favorable for the occurrence of severe storms. The study to be presented here makes part of the above project. In this chapter the event of storms in Mato do Grosso do Sul State, Brazil that occurred on 5 December 2015 is studied.

Episodes of intense rainfall and strong winds affected the south of Mato Grosso do Sul State, (**Figure 1**) during December 2015. Events of severe weather conditions can have harmful impacts on the people life since they cause floods, damage residences, interrupt the vehicles traffic and affect the energy distribution and agricultural actives [1, 2]. This chapter has a two-fold objectives: (1) to analyze the synoptic conditions and social impacts of the rainstorm that occurred on 5 December 2015; (2) to simulate the atmospheric conditions that caused this severe event using a state-of-art regional climate model. The use of a numerical model can give useful information on the evolution of synoptic systems responsible for severe events, which will occur in future and thus can be used to forecast these events. This study is not concentrate on the evaluation of the impacts on people, i.e. it is focused on the predictive model about the meteorological aspects of the storm. The chapter is organized as it follows: Section 2 presents the Data and Methodology; An analyzes of the synoptic conditions and social impacts are shown in Sections 3 and 4, respectively; Section 5 show the numerical simulations and the conclusions are presented in the final of the chapter.

2. Data and methodology

Mato do Grosso do Sul State is located in the Center-West Region of Brazil (**Figure 1**) It occupies an area of 357.125 km^2 with a population of more than 2,5 million of habitants and has a tropical climate. Three vegetation types are present in the region: pasture (east), swampland (west) and tropical forest (south).

In order to analyze the synoptic systems responsible for the severe event on 5 December 2015 data of meteorological variables obtained from the global forecast system (GFS—http://nomadis.ndc.noaa/data/gfsanl) analysis are used. To identify the synoptic conditions on 5 December 2015 GOES satellite images are used (http://satellite.cptec.inpe.br/home/novoSite/index.jsp). The state-of-art numerical model used is the Weather Research and Forecasting-Nonhydrostatic Mesoscale Model (WRF-NMM) [3]. The damage effect of the rainstorm was illustrated using information of news agencies.

The Non-hydrostatic Mesoscale Model (NMM) core of the Weather Research and Forecasting (WRF) system is a next-generation mesoscale forecast model. The NMM model was developed by the National Oceanic and Atmospheric Administration (NOAA)/National Centers for Environment Prediction (NCEP) based on the Eta model and replaces it in 2005. The model has been designed to be an efficient and flexible mesoscale modeling system for use across a broad range of weather forecast and idealized research applications, with an emphasis on horizontal grid sizes in the range of 1–10 km. although the NMM is a fully compressible, nonhydrostatic mesoscale model it has a hydrostatic option [3]. The model uses a terrain following hybrid sigma-pressure vertical coordinate. A version of WRF-NMM tailored for hurricane forecasting, HWRF (hurricane weather research and forecasting), became operational in 2007.

The WRF/NMM model with 9 km of horizontal resolution was introduced in 2015 in the team of models of the Center of Weather Prediction and Climate Studies (CPTEC) from INPE. The model domain cover the entire South America, with 615X1392 WE/SN grid points.

In the simulation presented in this study, the model was integrated for a period of 84 h, starting from 1200 UTC 04 December 2015 (with spin-up of 12 h). A single domain with 9 km horizontal spatial resolution was configured. Initial and boundary conditions are derived from 6 h global analysis and forecast at 0.25° × 0.25° grids generated by the National Center for Environmental Prediction (NCEP)'s global forecast system (GFS). Analysis fields, including temperature, moisture, geopotential height and wind are interpolated to the mesoscale grid. These derived fields served as initial conditions for the present experiments. The domain is configured with vertical structure of 38 unequally spaced sigma (non-dimensional pressure) levels. The physical parameterizations used in this study are Geophysical Fluid Dynamics Laboratory (GFDL) [4, 5] for

Horizontal spatial resolution	9 km
Simulation duration	84 h
Initial and boundary conditions	0.25 × 0.25 GFS Operational Model
Integration time step	15 s
Map projection	Rotated latitude and longitude
Grid points WE/SN	615 × 1392
Center domain	58.234 W, 21.633S
Horizontal grid system	Arakawa E-grid
Vertical co-ordinate	38 hybrid levels
Radiation parameterization	GFDL/GFDL
Surface layer parameterization	Janjic similarity scheme
Land surface parameterization	Noah Land surface scheme
Cumulus parameterization	Betts-Miller-Janjic scheme
PBL parameterization	Mellor-Yamada-Janjic.
Microphysics	Ferrier scheme

Table 1.
The WRF model configuration used in the simulations.

long and short wave radiation, Noah Land surface scheme [6] for land surface, Mellor-Yamada-Janjic (MYJ) scheme [7] for planetary boundary layer, Ferrier scheme [8] for microphysics, and Janjic similarity scheme [9] for surface layer. **Table 1** shows the model configuration of the present study.

The use of the WRF model for studies of severe storms can be seen for example in [10–12].

Recently, a comparison of the results of the three operational models (WRF, Eta, BRAMS) of CPTEC was made. Tests of accuracy applied to the model results indicated that the WRF model has a better skill and computational performance (not published yet). So, in the present study a subjective (visual) method is used to analyze the WRF simulation of the storm.

The methodology used in the present study makes part of the cooperative project INPE-Energisa Company. Particularly, the use of the high resolution WRF model to predict severe storms is unique. So, the results obtained here may contribute to a better understanding of severe storms conditions and their prediction.

3. Analysis of the synoptic conditions

Figure 2a–**f** show satellite images for the day 5 December 2015 at 0600 UTC, 0900 UTC, 1200 UTC, 1500 UTC, 1800 UTC and 2100 UTC, respectively. As can

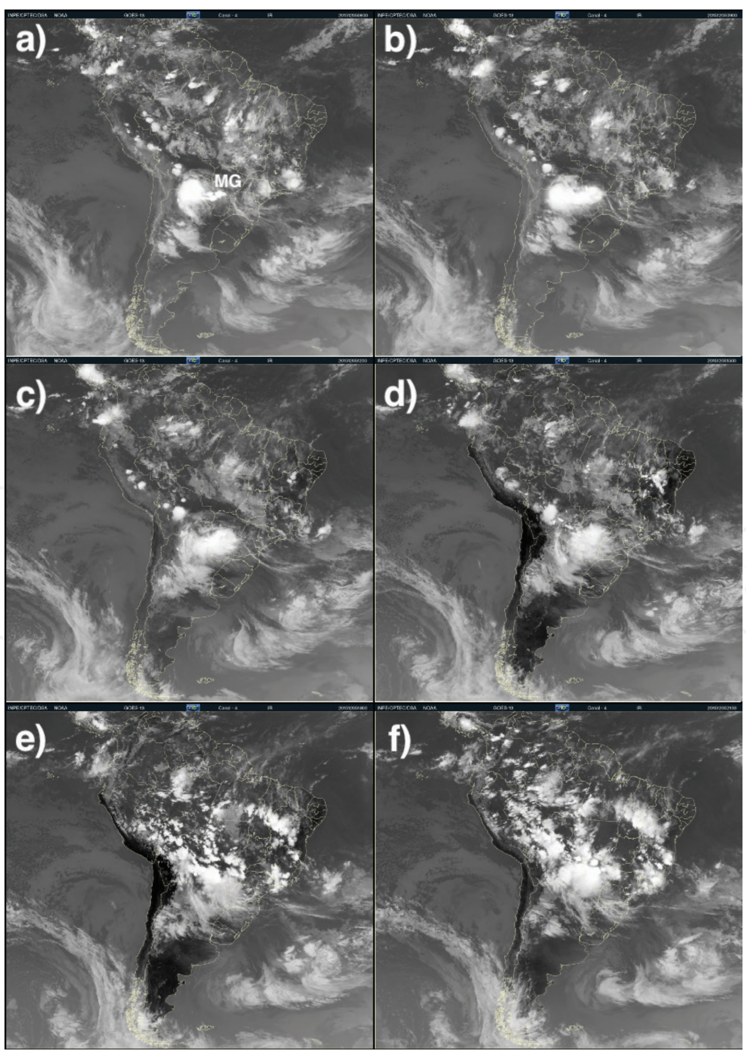

Figure 2.
Satellite images for day 5 December 2015 at (a) 0600 UTC, (b) 0900 UTC, (c) 1200 UTC, (d) 1500 UTC, (e) 1800 UTC, and (f) 2100 UTC (source: . (http://satellite.cptec.inpe.br/home/novoSite/index.jsp). MS indicates the position of Mato Grasso do Sul state.

be seen, strong convective activity started to develop in the south of Mato Grosso do Sul State during the dawn of day 5 December (**Figure 2b** and **c**). In the afternoon many convective clouds developed in most of the state (**Figure 2e** and **f**). These convective clouds were associated with the occurrence of heavy rainfall and strong wind in the region. The values of the Convective Available Potential Energy (CAPE) [13] (**Figure 3**) indicate that the atmosphere became unstable between 0600 UTC and 1200 UTC (**Figure 3a** and **b**, respectively) remaining unstable during the afternoon (**Figure 3c**). This atmospheric instability was caused by the onset of a weak cold front, as shown in **Figure 2a** and **b** and **Figure 4a** and **b**.

The presence of the cold front in the south of Mato do Grosso State provoked the change in the direction of low level winds, as can be seen in **Figure 5**. As can be noted in this figure, northwest strong winds (around 20 m s^{-1}) over Bolivia (come from Amazon region) were directed to the north of Argentina. As the cold front advanced, the direction of the winds over Bolivia changed towards the east and a convergence of mass was created due to the reduction of the magnitude of the strong northwest winds and the confluence with the south winds associated with the high pressure system behind the cold front.

At high levels (at 350 hPa) northwest winds, which come from Amazon region, were also noted (**Figure 6**). These winds rotated in a counter-clockwise direction when they reached Bolivia. It is noted that over the Mato Grosso do Sul State a region of difluence of winds occurred during the day which was associated with convective clouds of large vertical extension. This provoked the heavy rainfall and low level strong winds in many regions of the state.

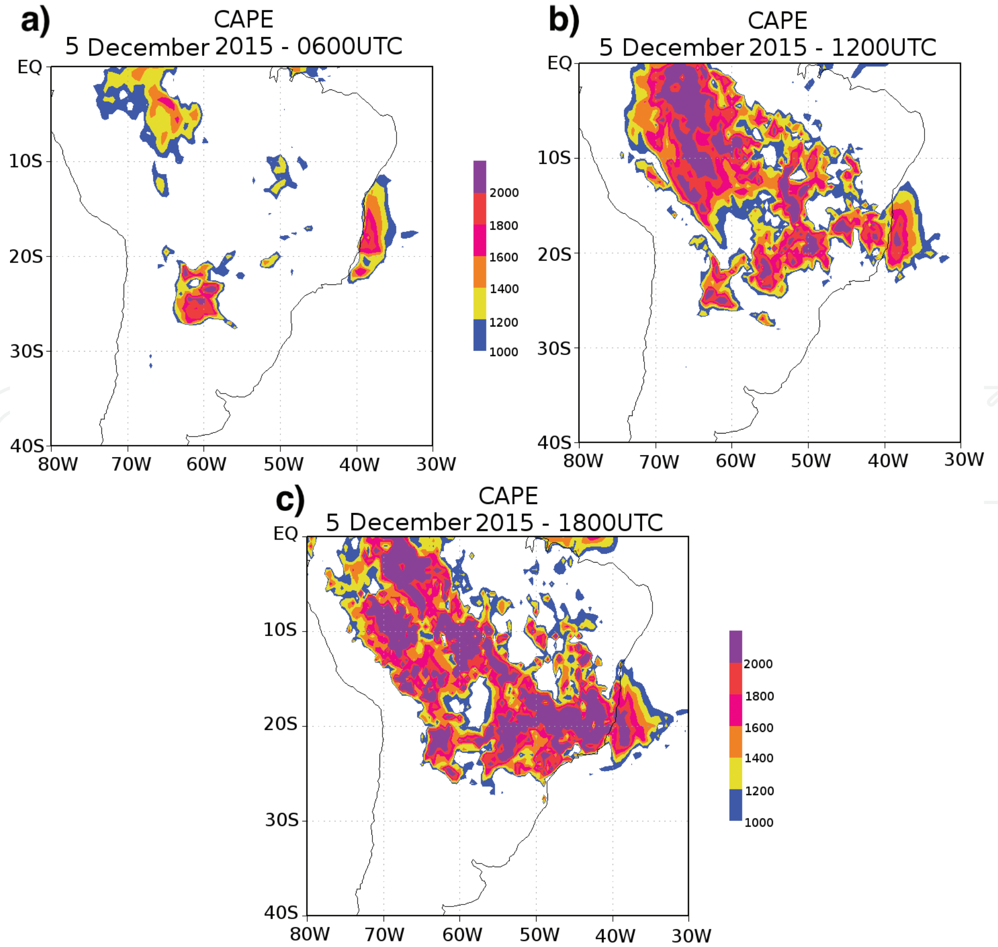

Figure 3.
Values of CAPE for day 5 December 2015 at (a) 0600 UTC, (b) 1200 UTC, and (c) 1800 UTC (source: http://nomads.ncdc.noaa.gov/data/gfsanl).

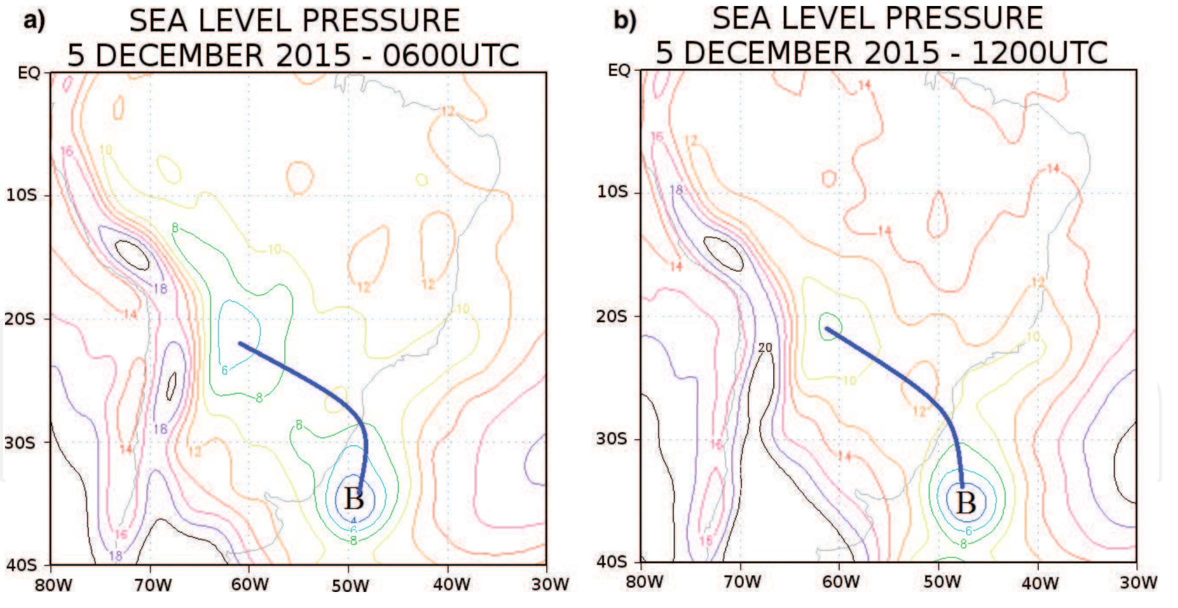

Figure 4.
Sea level surface pressure at (a) 0600 UTC and (b) 1200 UTC for day 5 December 2015. The blue line indicates the position of the cold front. B refers to the position of an extratropical cyclone.

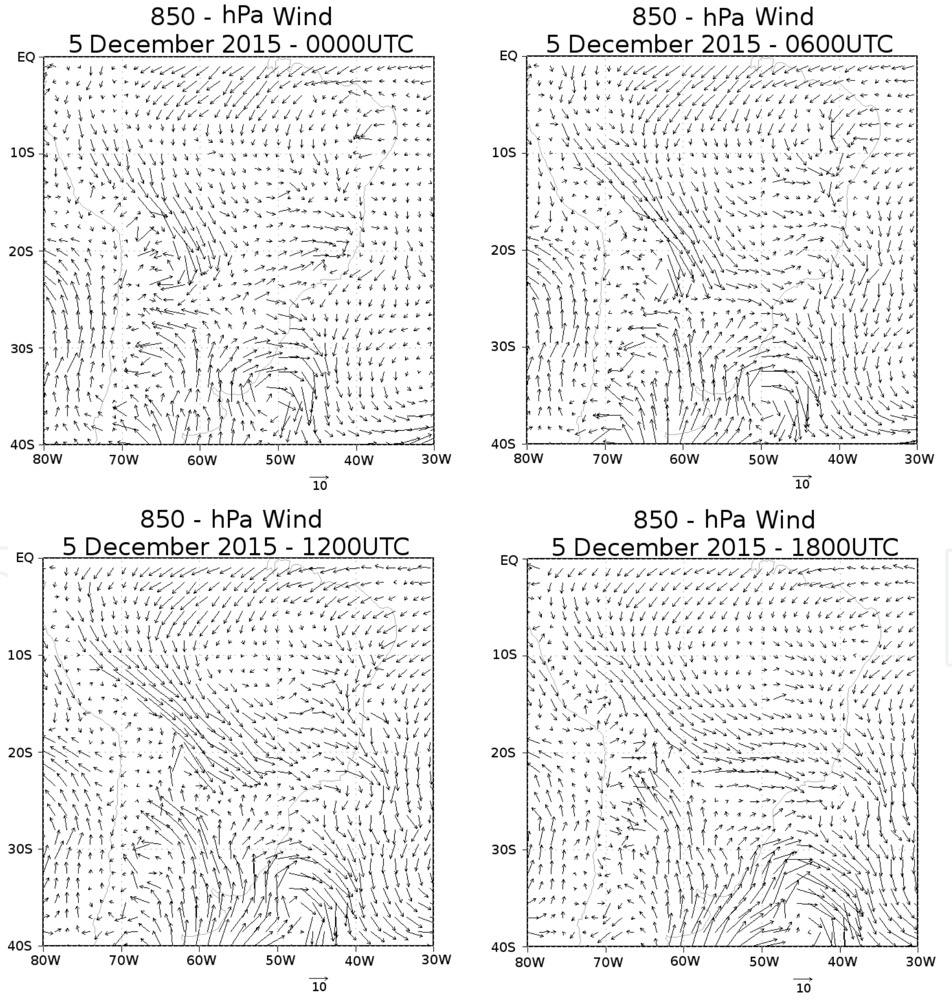

Figure 5.
Low level winds at 850 hPa at 0000 UTC, 0600 UTC, 1200 UTC and 1800 UTC for day 5 December 2015 (source: global forecast system, GFS).

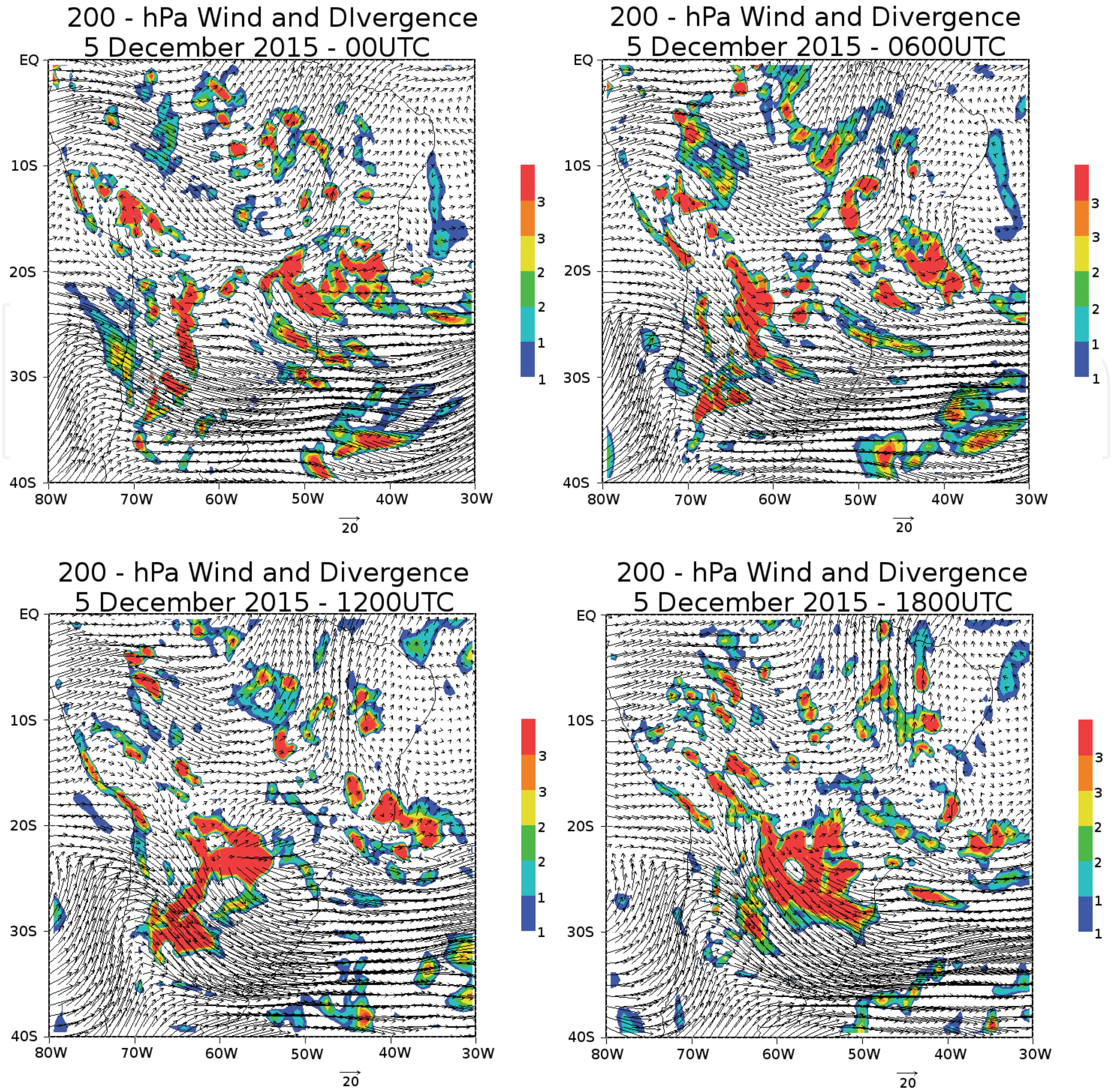

Figure 6.
High level winds and divergence of mass at 200 hPa at 0000 UTC, 0600 UTC, 1200 UTC and 1800 UTC for day 5 December 2015 (source: global forecast system, GFS).

4. Social impacts

The heavy rainfall and strong winds that occurred in the south of Mato do Grosso do Sul State on 5 December 2015 caused damage effects in the region. In the city of Campo Grande (capital of the state) the heavy rainfall persisted by 1 h and 30 min, causing threw down trees and floods in many places. In Jardim, a city at 270 km far from Campo Grande, the strong winds of 42 km h^{-1} also caused harmful effects. Many trees fell down, inclusively over cars, and a circus tumbled due to the intense winds. After the windstorm many residences remained with lack of electric energy by almost 2 h. On 7 December around 100 domiciles retained without electric energy in some places of the city of Jardim. In the highway MS-289, between Amambai e Coronel Sapucaia (two cities of Mato Grosso do Sul State), there was an overflow of a stream let so that the vehicle traffic was interrupted. The storm provoked the interdiction of 14 cities in the south of the state. **Figure 7** illustrates the damage effects in the region.

Figure 7.
Damage effects caused by the storms on 5 December 2015 in Mato do Grosso do Sul state. Source: http://g1.globo.com/mato-grosso-do-sul/noticia/2015/12/temporal-derrubou-pontes-arvores-e-comprometeu-agua-e-luz-em-jardim.html; http://g1.globo.com/mato-grosso-do-sul/noticia/2015/12/chuva-e-ventania-de-56-kmh-causam-novos-estragos-em-dourados-ms.html).

5. Numerical simulations

In this section the WRF model is used to simulate the atmospheric conditions during the rainstorm on 5 December 2015. We used the WRF-NMM version 3.6.1 [3, 14, 15]. Details of the physical parameterization and model integration were given by [2].

As can be seen in **Figure 8a** and **b**, the sea level surface pressure field is well simulated by the model. There is good agreement between the position of the low pressure center associated with the cold front in the model and observations (point B in **Figure 4**). The change in the direction of low level winds due to the cold front is captured by the model (**Figures 5** and **9**). The model is able to simulate the region of divergence of mass in upper levels over the study region (**Figures 6** and **10**).

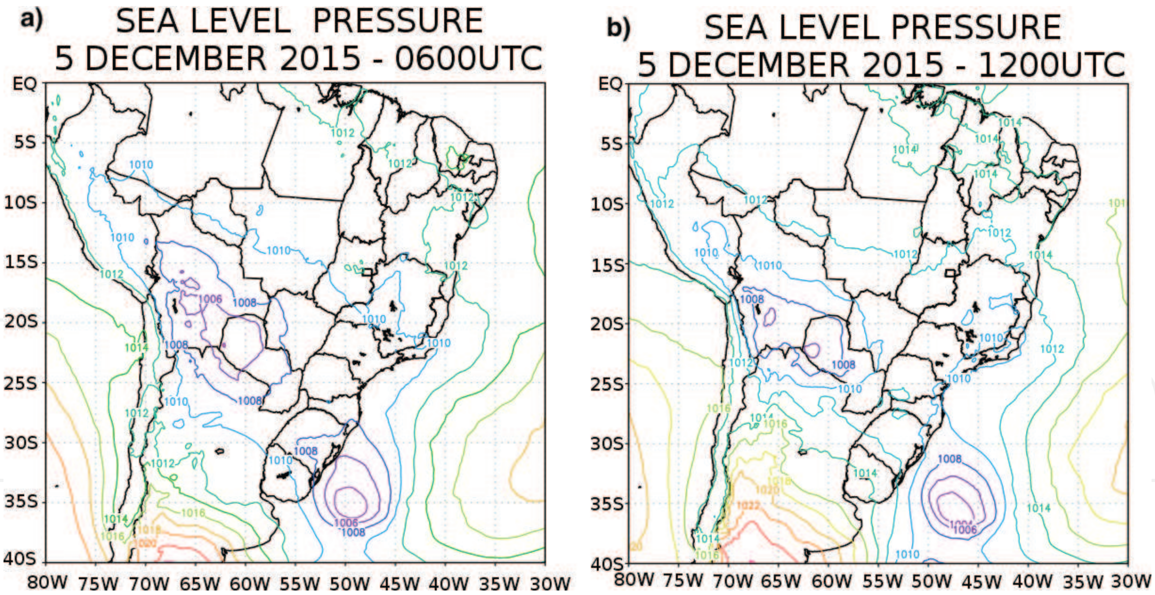

Figure 8.
Simulated sea-level pressure on day 5 December 2015 at (a) 0600 UTC and (b) 1200 UTC.

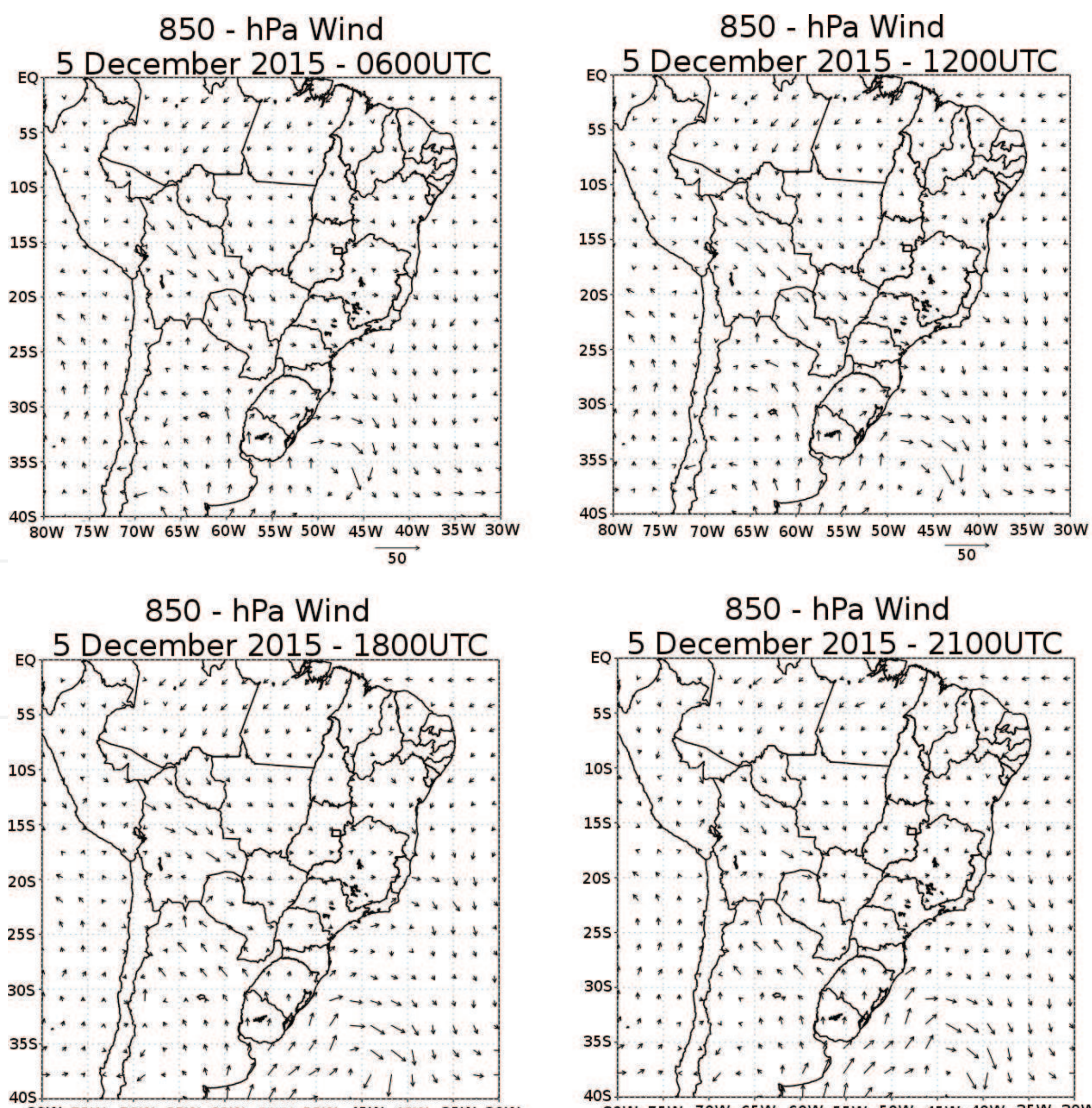

Figure 9.
Simulated low level wind at 850 hPa for day 5 December 2015 at 0600 UTC, 1200 UTC, 1800 UTC, and 2100 UTC. Units: m s^{-1}.

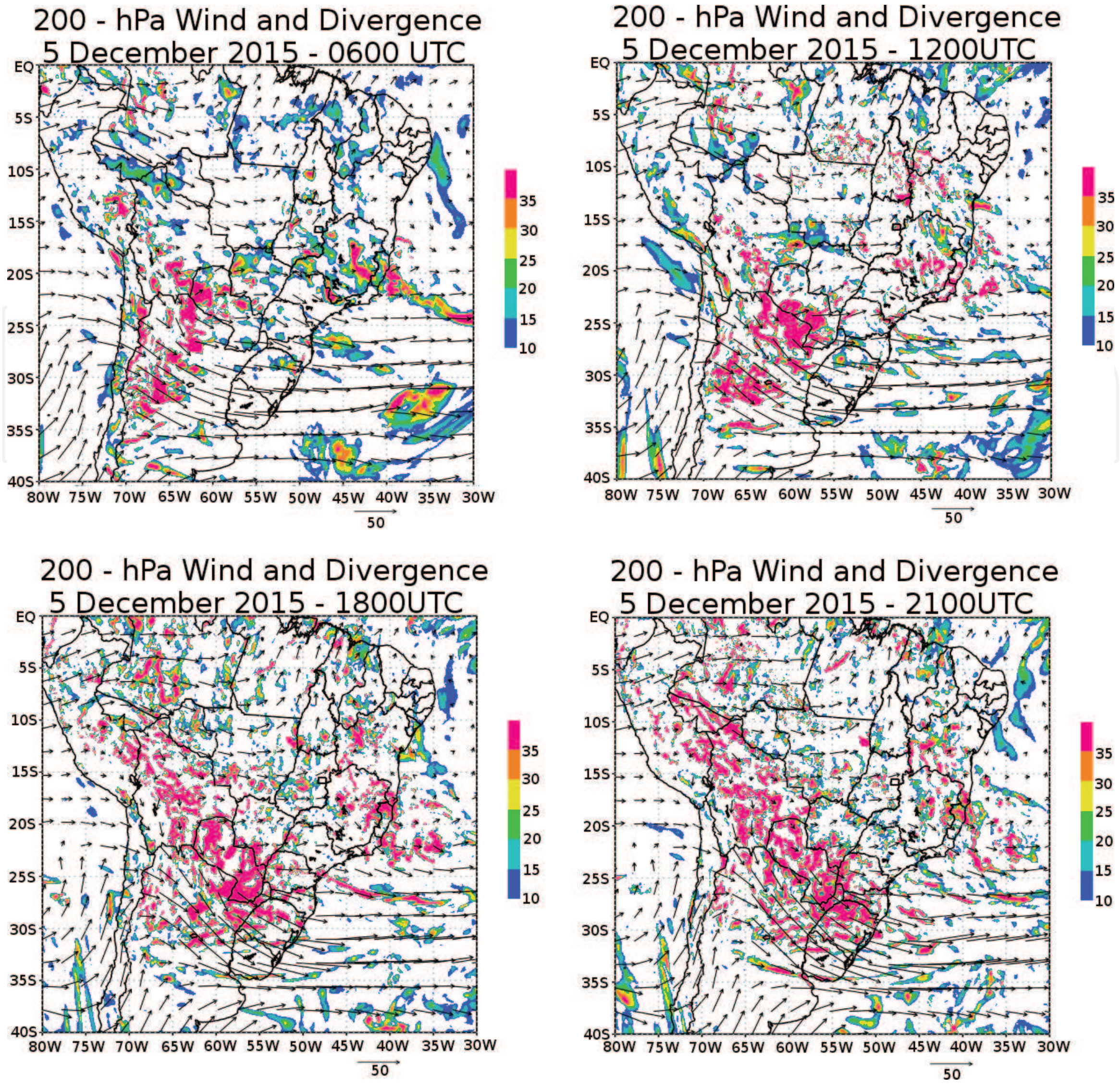

Figure 10.
Simulated divergence (×10^{-5} s^{-1}) and high level wind at 200 hPa (m s^{-1}) for day 5 December 2015 at 0600 UTC, 1200 UTC, 1800 UTC and 2100 UTC.

The results presented above suggest that the present model may be an useful tool to forecast future events of severe weather. Nevertheless, many other experiments must be performed to have a better assessment of the model simulations.

6. Conclusions

In this study the synoptic conditions and social impacts of the severe event on 5 December 2015 in the south of Mato Grosso do Sul State, Brazil were analyzed. The results showed that the heavy rainfall and strong winds caused floods, damage in several residences and affected the distribution of electric energy not only in the region but also in the interior of the state. The synoptic analyzes showed that the windstorm was caused by a region of wind difluence at high levels which was associated with convective clouds of large vertical development. The WRF model was used to simulate the atmospheric conditions in this severe event. The modeled values of some meteorological variables were in good agreement with the observations suggesting that the model may be used in future to forecast adverse weather conditions. This study makes part of a cooperative project between the National Institute for Space Research and the Energisa power company aimed to mitigate the impact of adverse weather conditions. The results obtained here may contribute to a better knowledge of the atmospheric conditions responsible for severe storms and provides subsidies for forecasting these events and thus cooperate with the management of the resources of the energy electric sector and civil defense.

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Conflict of interest

The authors declare that there is no conflict of interest.

Author details

Sergio H. Franchito*, Manoel A. Gan and Julio P. Reyes Fernandez
National Institute for Space Research, INPE, Sao Jose dos Campos, SP, Brazil

*Address all correspondence to: sfranchito@hotmail.com

References

[1] Franchito SH, Gan MA, Rao VB, Santo CME, Conforte JC, Pinto O Jr. Impacts of rainstorms during austral winter in Sao Paulo state, Brazil: A case study. Journal of Geography and Natural Disasters. 2016;**6**:162. DOI: 10.4172/2167-0587.1000162

[2] Franchito SH, Gan MA, Fernandez JPR, Rao VB, Santo CME. Rainstorms during spring in Sao Paulo state, Brazil: A case study of 27-28 September 2015. IIARD International Journal of Geography and Environmental Management. 2017;**3**:12-24

[3] Janjic ZI, Gerrity JP Jr, Nickovic S. An alternative approach to nonhydrostatic modeling. Monthly Weather Review. 2001;**129**:1164-1178

[4] Schwarzkopf MD, Fels SB. The simplified exchange method revisited: An accurate, rapid method for computations of infrared cooling rates and fluxes. Journal of Geophysical Research. 1991;**96**:9075-9096

[5] Lacis AA, Hansen JE. A parameterization for the absorption of solar radiation in the earth's atmosphere. Journal of the Atmospheric Sciences. 1974;**31**:118-133

[6] Ek MB, Mitchell KE, Lin Y, Rogers E, Grunmann P, Koren V, et al. Implementation of NOAH land surface model advances in the NCEP operational mesoscale Eta model. Journal of Geophysical Research. 2003;**108**(22):8851

[7] Janjic ZI. Nonsingular implementation of the Mellor–Yamada level 2.5 scheme in the NCEP Meso model. NCEP Office Note. 2002;**437**:61

[8] Ferrier BS, Lin Y, Black T, Rogers E, DiMego G. Implementation of a new grid-scale cloud and precipitation scheme in the NCEP Eta model. In: Preprints, 15th Conference on Numerical Weather Prediction, American Meteorological Society, San Antonio, TX. 2002. pp. 280-283

[9] Janjic ZI. The surface layer in the NCEP eta model. In: 11th Conf. on NWP. American Meteorological Society, Norfolk, VA. 1996. pp. 354-355

[10] Weiss SJ, Bright DR, Kain JS, et al. Complementary use of short-range ensemble and 455?KM WRF-NMM model guidance for severe weather forecasting at the storm prediction Centre. In: Proceedings of the 23rd Conference on Severe Local Storms, American Meteorological Society. 2006

[11] Litta AJ, Mohanty UC, Bhan SC. Numerical simulation of a tornado over Ludhiana (India) using WRF-NMM model. Meteorological Applications. 2010;**17**(1):64-75

[12] Litta J, Mohanty UC, Kiran Prasad S, Mohapatra M, Tyagi A, Sahu SC. Simulation of tornado over Orissa (India) on March 31, 2009, using WRF-NMM model. Natural Hazards. 2009;**61**(3):1219-1242

[13] Betts AK. Thermodynamic classification of tropical convective soundings. Monthly Weather Review. 1974;**102**:760-764

[14] Janjic ZI. A nonhydrostatic model based on a new approach. Meteorology and Atmospheric Physics. 2003;**82**:271-285

[15] Skamarock WC, Klemp JB, Dudhia J, Gill DO, Barker DM, Duda MG et al. A description of the advanced research WRF version 3; NCAR technical note: NCAR/TN–475+STR. 2008. Available from: http://www.mmm.ucar.edu/wrf/users/docs/arw_v3.pdf [Accessed: 4 Feb 2010]