APPLICATION OF THE Meso-Eta MODEL TO PREDICT A FLASH-FLOOD IN BAURU

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Abstract: The severe storms observed on 8 February 2001 by the Bauru radar, resulting in a flash flood in urban Bauru, causing the death of 8 people, provided an ideal opportunity to test the forecasting ability of the Meso-Eta Model in order to extend the nowcasting range of the radar observations from a couple of hours to about two days. As expected, the operational Regional Eta model is too coarse to capture such extreme local rainfalls. However, the Meso-Eta model could predict the accumulated precipitation reasonably well up to 48 hours ahead and also provide good estimates of the region where extreme convective development would take place, when considering the various dynamic and thermodynamic predictors. Accumulated areal radar-measured and actually observed rainfall were used for varying periods to verify the model-generated rainfall estimates. For this test all model parameters were set to defaults. Thus, based on more case studies, some fine-tuning will still be required, which could lead to improved forecasting capabilities.

Key Words: State of São Paulo, radar observations, flash-flood, Meso-Eta model

Resumo: As tempestades severas observadas em 08 de fevereiro de 2001 pelo radar de Bauru, resultando em enchente repentina na área urbana de Bauru, causando a morte de 8 pessoas, é uma oportunidade ímpar para se testar a destreza do modelo Meso-Eta, de maneira a estender o nowcasting na área de alcance dos radares de algumas horas para até dois dias. Como esperado, o modelo Regional Eta tem uma resolução em grade que não permite capturar tais extremos localizados de precipitação. Entretanto, o modelo Meso-Eta pode prever a chuva acumulada relativamente bem com até 48 horas de antecedência e também proveu boas estimativas da região onde o desenvolvimento da convecção aconteceu, quando se considerou os vários parâmetros termodinâmicos como previsores. A chuva acumulada em área observada pelo radar e a medida por pluviômetros foi usada para verificação dos vários períodos das estimativas geradas pelo modelo. Para esse teste todos os parâmetros do modelo foram usados os defaults. Portanto, baseado em mais estudos de casos, e algum fine-tuning necessário poderá certamente resultar numa melhora da capacidade de previsão do modelo.

Palavras Chave: Estado de São Paulo, observações de radar, Enchente repentina, modelo Meso-Eta,

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INTRODUCTION

Severe convective storms frequently cause local flooding in towns and/or devastation of crops and property due to hail or wind storms (microbursts) in the State of São Paulo, resulting in many millions of US Dollar damage annually, loss of lives and leave many persons injured (Gomes *et al.*, 2000; Held *et al.*, 2001). Therefore, it is of prime importance to develop an effective alert system for the occurrence of these severe storms, ranging from a couple of days (based on model outputs) to one to three hours ahead (nowcasting, using radar information) of these events. The Instituto de Pesquisas Meteorológicas (IPMet) of the Universidade Estadual Paulista (UNESP), located in Bauru, operates a network of two S-band Doppler radars for continuous precipitation monitoring in the State of São Paulo, which provided the ideal tools for this pilot study.

The Bauru radar is located at Lat: 22° 21’ 28” S, Lon: 49° 01’ 36” W, 624 m amsl, while the second radar is in Presidente Prudente, 240 km west of Bauru (275° azimuth), at Lat: 22° 10’ 30” S, Lon: 51° 22’ 22” W, 460 m amsl (Figure 1). Both have a 2° beam width and a range of 450 km for surveillance (0° PPI every 30 min), but when operated in volume-scan mode every 15 minutes (or less) it is limited to 240 km, with a resolution of 1 km radially and 1° in azimuth, recording reflectivities and radial velocities. The reflectivity threshold for this study was set at 10 dBZ.

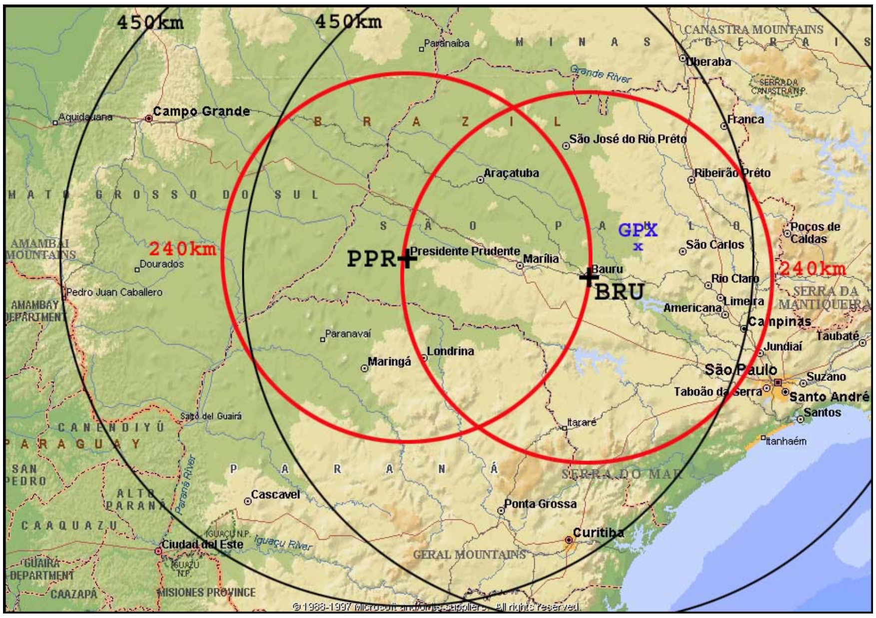

Figure 1. IPMet’s Radar Network (PPR & BRU), showing 240 and 450 km range rings, as well as the location of Gavião Peixoto Airport (GPX).

The operational Eta model (Black, 1994) is run by the Center for Weather Forecast and Climatic Studies (CPTEC) twice daily (00 & 12 UTC) for the South American continent and initiated with the NCEP analysis (resolution T62L28; ca 200x200 km). On the boundaries it is updated with the CPTEC Global Model forecasts. The output has a resolution of 40x40 km, for every 6 hours up to 72 hours ahead. The Meso-Eta model (Staudenmaier, 1996), running in nonhydrostatic mode, is also initialized with the NCEP analysis, but the boundary conditions are updated with the CPTEC/Eta operational model (resolution 40x40 km). Its domain is 1300x840 km and can be centered over any point. The output resolution is 10x10 km, with variable output intervals up to 96 hours ahead. For this case study, the model domain was centered over Bauru with output every 3 hours.

SYNOPTIC SITUATION IN FEBRUARY 2001

The beginning of February 2001 was characterized by synoptic situations typical for summer in the State of São Paulo. In broad terms, it can be summed up by a high pressure system situated off the coast between the State of São Paulo and southern Brazil and ridging in over the continent, with a weak cold front extending along its northern flank across Rio de Janeiro into Minas Gerais. The other component was a large cyclone initially centered over north-western Argentina from where a tongue of moist air extended across Paraguay, Parana and the State of São Paulo into Mato Grosso do Sul. Another important fact was the strong confluence of wind in the 700 hPa level over the State of São Paulo, overlaid by an exceptionally strong divergence at levels from 500 hPa upwards. The deep cyclone, which had developed over the southern part of the continent on 6 February had drastically intensified while moving south-eastwards, pushing the anticyclone eastwards off the central part of the continent and towards the ocean. Held and Nachtigall (2002) provide a more detailed description of the synoptic situations building up to the 8 February 2001. On 8 February 2001, 00 UT, an extremely strong confluence of moist maritime air was observed near the surface over the State of São Paulo at the 850 hPa level, overlaid by a very strong inflow of tropical air at 500 hPa (Figure 2), and topped by significant divergence at 300 hPa.

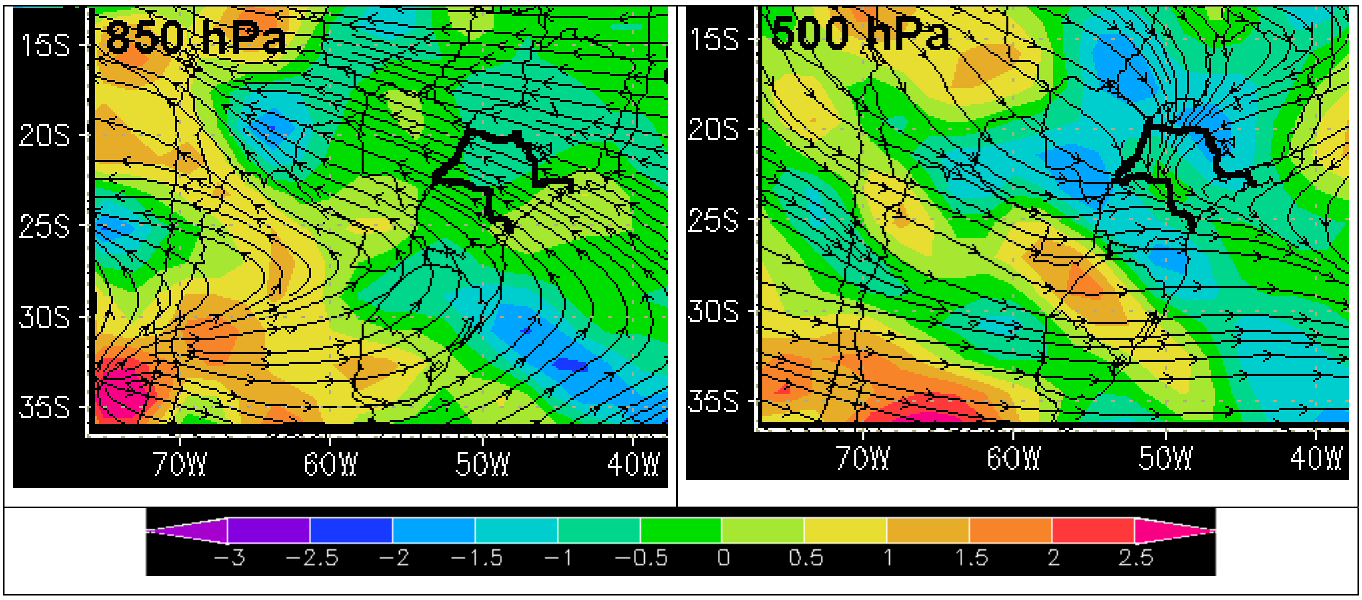

Figure 2. 08 February 2001, 00 UT: Streamflow lines and divergence at 850 hPa (left) and 500 hPa (right), with borders of the State of São Paulo shown in bold; from CPTEC Global Analysis.

On three days, relatively isolated and more or less stationary storms developed into very intense cells, accumulating vast amounts of rain and hail above cloud base for periods of about 30 minutes and longer (Held and Nachtigall, 2002). A cyclonic shear, observed in the radial velocity field of the Bauru S-band Doppler radar near ground, probably induced strong updrafts, which supported the accumulated precipitation aloft. Once these updrafts collapsed, all precipitation came down within a short period of time, resulting in parts of Bauru being flooded, due to inadequate drainage capabilities and possibly saturated catchments.

RADAR OBSERVATIONS

The most severe flood resulted from a storm that occurred on 8 February 2001, between 18:16 and 19:31 (all times in LT = UTC-3, summer time is disregarded), over the southern and western catchment of the Bauru River. Storms already began to develop within the 240 km radar range around noon, with some of them reaching reflectivities of >60 dBZ by 14:00, thereafter growing in size and intensity, with more and more cells developing and merging into large complexes, especially in the north-north-east to east-south-east sector between 60-200 km in range. At around 18:00, due to new development rapidly progressing from north and north-west within the 50 km range, the town of Bauru appeared to be threatened and a general warning for extremely heavy rainfall was issued to the local Civil Defense Authority, solely based on radar observations and automatically generated alerts. Figure 3 shows the 450 km surveillance PPI (EL=0°) at 18:30.

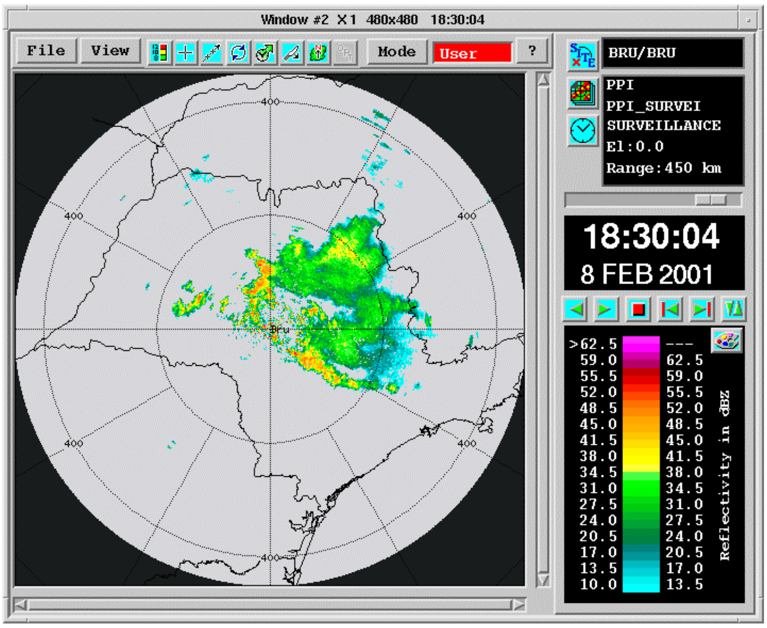

Figure 3. Surveillance PPI (EL=0°, 450 km range) at 18:30 on 8 February 2001.

The first indication of an extremely severe cell just north-west of the catchment, was observed at 18:16, manifested in a dramatic tilt of the echo core, with a significant vertical shear of radial velocities from +13 m.s^{-1} at cloud base to –11m.s^{-1} near the echo top (18:31), still accumulating precipitation aloft. At 18:46, a well-pronounced shear in radial velocities (up to –1.8x10^{-3} s^{-1}) could be observed near the ground along a 50 km long, radially-oriented line along the 325° azimuth, persisting for more than 30 min, still clearly visible at 19:01 (Figure 4, bottom). Figure 4 (top) shows the vast amounts of precipitation still being accumulated above cloud base at 19:01. Heavy rain only began to fall at 19:16 in the catchment, with rainfall rates of up to 200 mm.h^{-1} for at least 15 minutes, causing flash floods in tributaries, as well as in the main river, which resulted in the loss of five lives through drowning and three due to landslides and collapsing structures, with an estimated material damage of about R$ 3.5 million. Only by 20:01 had the reflectivity over the catchment dropped to ± 45 dBZ (50 mm.h^{-1}). The rain in the inundated area stopped between 20:16 and 20:31. However, other parts of Bauru still received moderate rain until well after 21:00 while the storm complex moved slowly north-westwards.

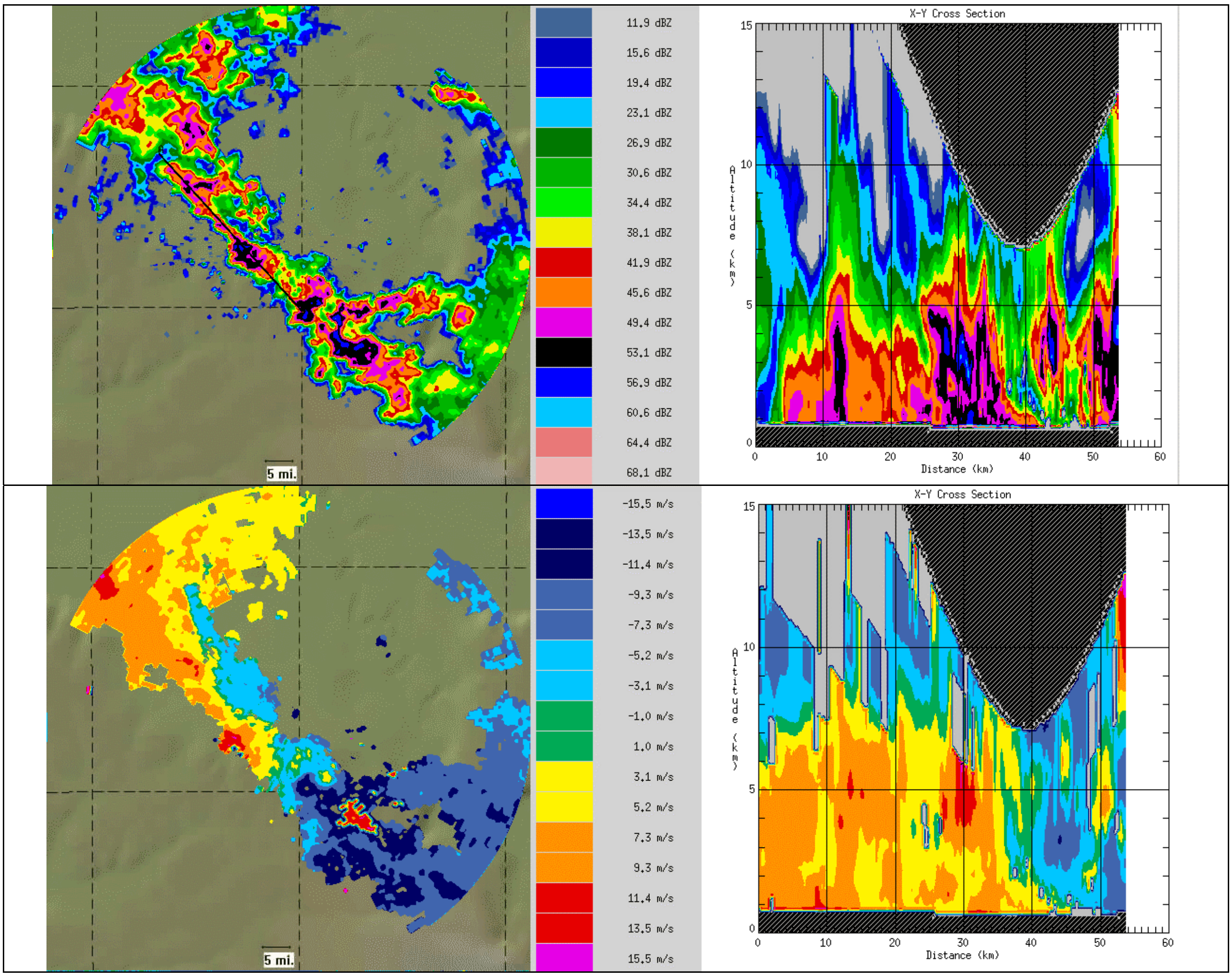

Figure 4. 8 February 2001, 19:01. **Top:** PPI with radar reflectivity at EL=1.7° (left) and vertical cross section (right) along the indicated base line.
Bottom: PPI with radial velocity field at EL=1.7° (left) and vertical cross section (right) along the base line shown above .

A detailed description of the radar analysis, showing the development of the various storm complexes, eventually building up to the flood-producing cell can be found in Held and Nachtigall (2002).

Eta MODEL PREDICTIONS

The operational Regional Eta model (grid resolution of 40 km), initiated with boundary conditions from the global model on 6 February 2001 at 21:00 (07 February, 00:00 UTC), predicted 48 hours ahead virtually no rain within the 240 km range of the Bauru radar for the 6-hour period ending at 21:00 (Figure 5), but showed the rain area further north, probably linked to the cold front. However, a run initiated 12 hours later (7 February, 09:00) did predict moderate rainfall (≤10 mm accumulated in 6 hours) in the north-west sector of the radar, but only for the period 21:00 to 09:00 on 9 February, considerably later than observed.

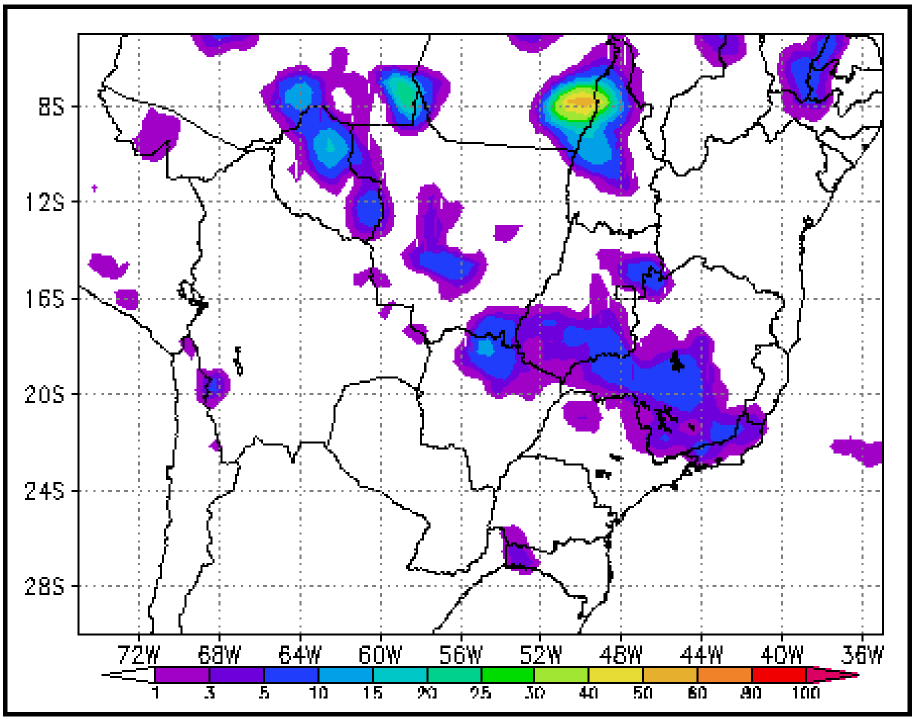

Figure 5. Operational Regional Eta model; 6-hour accumulated rainfall (mm) ending at 21:00 on 8 Feb. 2001.

Post analysis runs of the Meso Eta model with a grid resolution of 10 km, centered over Bauru, and also initiated on 6 February 2001, 21:00 (07 February, 00:00 UTC), using boundary conditions from the Eta operational model, predicted the rainfall very well 48 hours ahead, but underestimated the maximum of the 24-hour rain total by about a factor of 2-3 (Figure 6). The model runs initiated 12 hours later (7 February, 09:00) also predicted the rain field, but further out in range. Figure 6 also shows the accumulated radar rainfall (≥1 mm within 240 km of both radars) during the same 24-hour period relative to the model prediction.

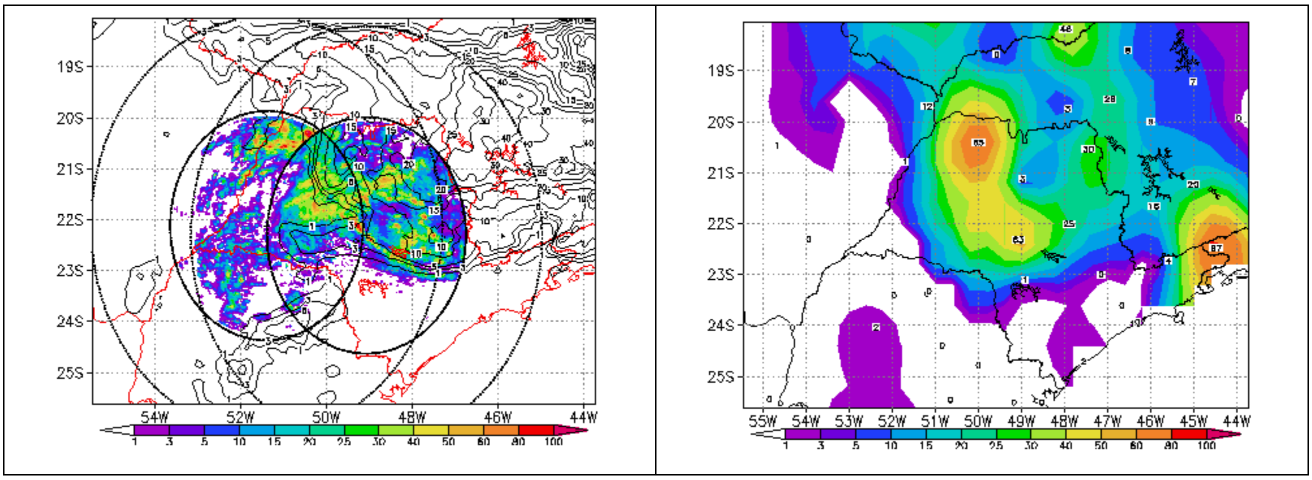

Figure 6. 24-hour accumulated rainfall on 8/9 Feb 2001. **Left:** Contours show model-predicted rainfall; shaded area indicates ≥1 mm rain observed by the Presidente Prudente (PPR) and Bauru (BRU) radars. **Right:** Observed 24-hour rainfall totals at rain monitoring stations.

Accumulated rainfall within the 450 km range had to be extracted manually from the surveillance PPIs and also confirmed the model-predicted rainfall areas, with the exception of the north-west sector, where the model failed to forecast rain.

Since most of the intense rain occurred within the 240 km range of the Bauru radar, it was decided to only use this radar for a more detailed comparison with the model outputs. The onset of the rain was well predicted when one compares the 6-hour accumulated rainfall maps for the period ending 15:00 (rain only in the north-east and north-north-west sectors of the radar). Even the most intense phase of the storms (15:00 to 21:00; Figure 7) was captured very well regionally, although the model underestimated the local peaks observed by the radar. However, some of the most intense storms responsible for the flooding just north-west of the radar occurred within a narrow region where the model did not predict any rain. After 21:00, the model predicted the decaying stage of the storms too slowly and thus overestimated the areas with rain until 03:00 slightly, also because it did not consider the westward drift.

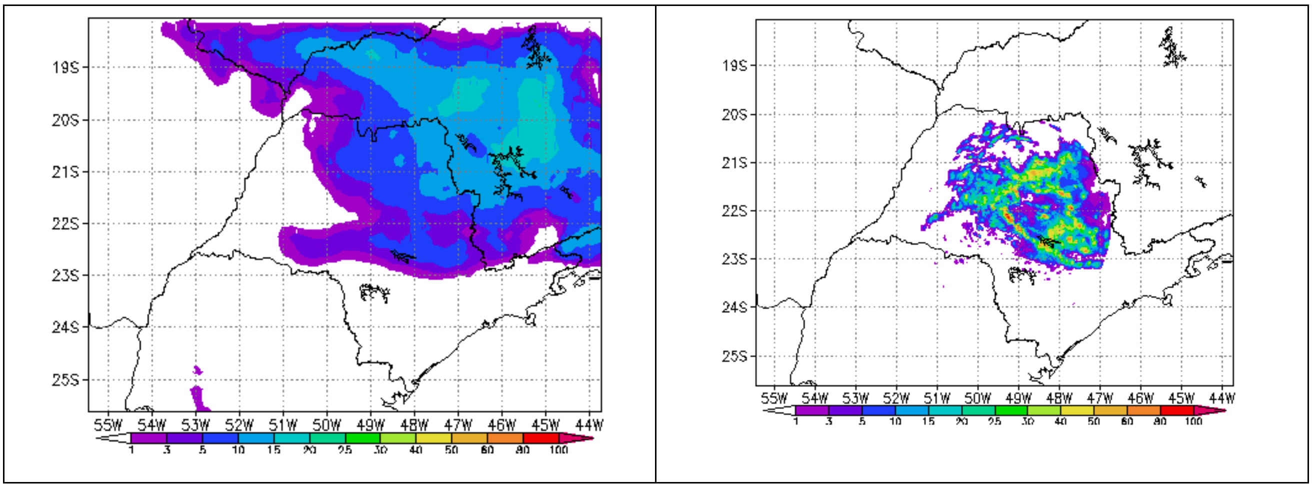

Figure 7. 8 Feb 2001, 6-hour accumulated rainfall (mm) ending at 21:00 LT. **Left:** Model-predicted rainfall. **Right:** as observed by the Bauru radar.

The Meso Eta Model predicts a large variety of parameters and their post analysis showed, that 36 hours after initialization (at 09:00 LT) the convergence of humidity field indicated a well-pronounced, very narrow, south-east to north-west oriented maximum of >15 [(kg/kg)/s]*10e^{7} (Figure 8) in exactly the region where the severe cells would develop about 9 hours later (Figure 4).

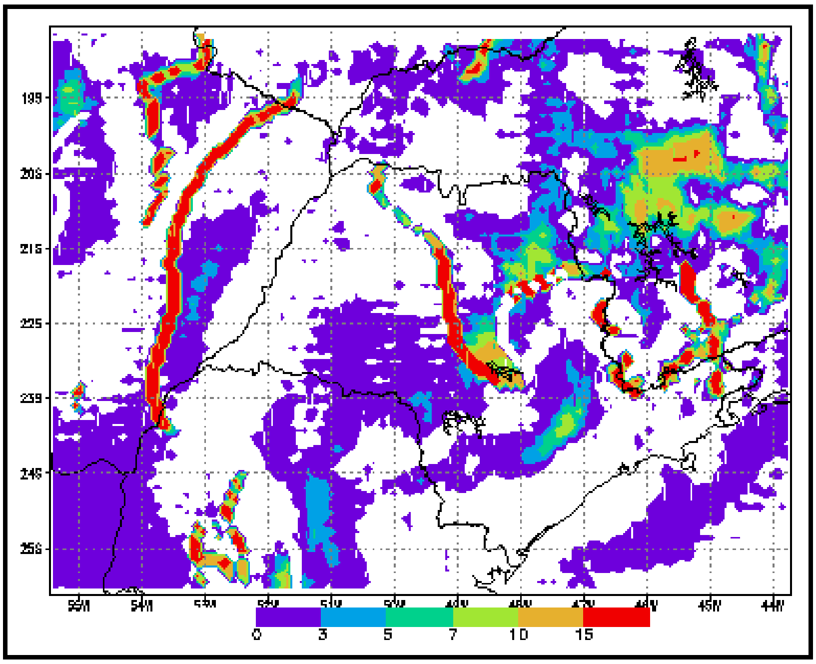

Figure 8. Model-predicted convergence of humidity in [(kg/kg)/s]*10e^{7} at 850 hPa on 8 Feb. 2001 at 09:00 LT.

Further study of dynamic and thermodynamic parameters predicted for the afternoon (15:00 to 21:00) confirmed this, such as a strong maximum of the K Index centered over Bauru (Figure 9a), together with a strong negative maximum of Omega (vertical flux >–1.6 kg.m^{-2}.s^{-2}) at 850 hPa (Figure 9d), reaching through the 500 hPa level (Figure 9e) up to 300 hPa (–1.2 kg.m^{-2}.s^{-2})

(Figure 9f). Strong divergence at the 300 hPa level was also predicted in the Bauru area (Figure 9b), together with a strong westerly jet at 250 hPa over the southern-most part of the domain (Figure 9c), where very little or no rain occurred. In the north-east sector of the Bauru radar, where the storms first developed (Figure 3), strongly converging streamlines (10-12 $m.s^{-1}$) at 200 hPa predicted the inflow of tropical air from the north-west, while at low levels (850 hPa) advection of moist oceanic air was predicted for the morning prior to the storm development, creating favorable conditions. However, it should also be noted, that none of the other maxima of humidity convergence apparent in Figure 8 were supported by any of the dynamic and thermodynamic parameters, thus leaving only the Bauru area for strong development of convection, with a good likelihood for severe storms.

CONCLUSION

The severe storms observed on 8 February 2001 by the Bauru radar provided an ideal opportunity to test the forecasting ability of the Meso-Eta Model in order to extend the nowcasting range of the radar observations from a couple of hours to about two days.

Based on the findings for this day, the operational Regional Eta model is obviously too coarse to capture the extreme local rainfalls resulting in a flash flood, as one would expect. However, it appears that the Meso-Eta model can predict accumulated precipitation reasonably well up to 48 hours ahead and also provide good estimates of the region where extreme convective development will take place, when considering the various dynamic and thermodynamic predictors. Accumulated areal radar-measured and actually observed rainfall were used for varying periods to verify the model-generated rainfall estimates. The predicted synoptic conditions match well the actual situation. However, it should be emphasized, that this model is currently not running operationally and that for this test all parameters were set to defaults. Thus, based on more case studies, some fine-tuning will still be required, which could lead to improved forecasting capabilities.

During the recently conducted TroCCiBras campaign (Held *et al.*, 2004), the Meso-Eta model was specifically run by CPTEC as part of the international joint activities. It was also centered on Bauru and with the same grid-resolution as in this study, but the outputs were 3-hourly. This set of outputs for an almost seven week period of intensive observations will provide an excellent opportunity for verification studies, with the possibility to also test any improvements by adding the Bauru radiosoundings and also affect some fine-tuning.

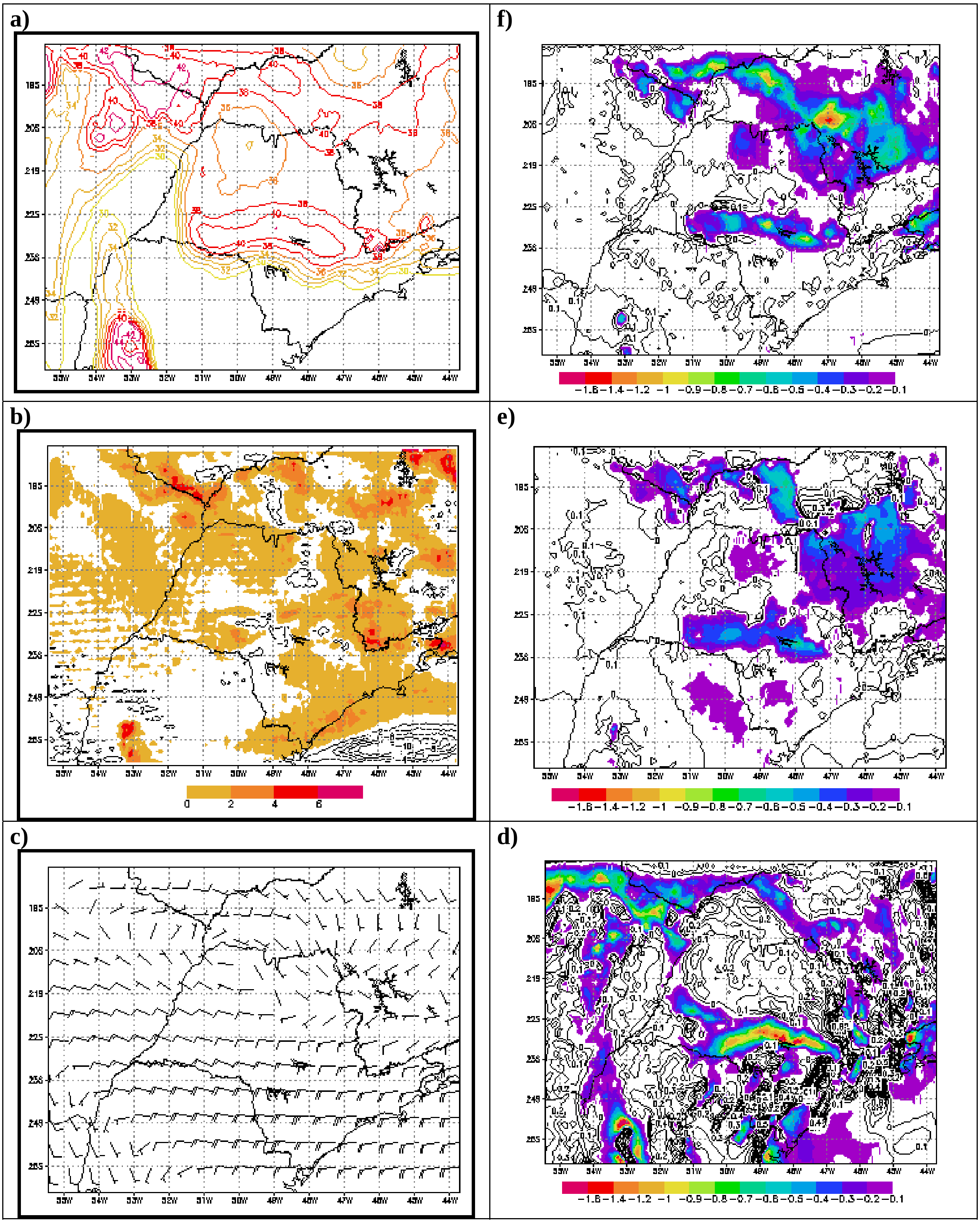

Figure 9. a) Model-predicted K Index on 8 Feb. 2001 for 6-hour period ending at 21:00 LT.
b) Model-predicted Divergence on 8 Feb. 2001 for 6-hour period ending at 21:00 LT at 300 hPa
c) Model-predicted Divergence on 8 Feb. 2001 for 6-hour period ending at 21:00 LT at 300 hPa
d) Model-predicted Omega ($kg.m^{-2}.s^{-2}$) on 8 Feb. 2001 for 6-hour period ending at 21:00 LT at 850 hPa (bottom), **e)** 500 hPa (middle) and **f)** 300 hPa (top)

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