Evaluation of April 1999 rainfall forecasts over South America using the Eta model

Josiane F. Bustamante.; Jorge L. Gomes; Sin Chan Chou and José R. Rozante

Centro de Previsão de Tempo e Estudos Climáticos - CPTEC
Instituto Nacional de Pesquisas Espaciais - INPE

Cachoeira Paulista, SP, 12630-000, Brazil

Abstract

On April 1999 an excessive amount of rainfall over northern South America was predicted by the regional Eta model in the 24-h forecasts. This error was detected during the routine monthly forecast evaluation. In this study the error is described and compared with surface observations, images and precipitation estimates from satellites and global model precipitation forecasts. Large scale atmospheric conditions were characterized by anomalous northerly displaced position of the Intertropical Convergence Zone in the proximity of the continent. The excessive rainfall error is reduced with model integration period. This is shown by the equitable threat score and the bias score estimated at different forecast lead times. The error was not influenced by the global model forecasts, as the latter started with smaller amount of rainfall and increased with model integration. Forecast error profiles of model variables such as specific humidity and wind show that the errors increase with forecast lead time despite the improvement in the precipitation forecast errors. The model relaxes the lower troposphere toward a drier atmosphere with weaker trade winds. This fact may suggest an inadequacy of the current global model analyses as initial conditions to the regional model.

1. Introduction

Outputs from numerical atmospheric models are considered the major guidance used by the meteorologists to elaborate their weather forecast bulletins. Numerical models, however, have limitations in representing realistically the complex structure and temporal evolution of the atmosphere. The limitations are related to numerical schemes, truncation errors, simplifications of the physics, etc., and can cause systematic errors in model integrations. A numerical model used for operational forecast purposes also contains errors, and the knowledge of these errors can help the forecasters to correct their reports and the modellers to introduce corrections/implementations to the models. A routine evaluation of model forecast is necessary for detection of the errors. Different weather systems can prevail from one season to another, from month to month, and from year to year. Model can show high skill in forecasting some events, and low in others, therefore, model errors contain variability as weather systems do.

CPTEC provides numerical weather forecasts twice a day at medium range, up to seven days, and at short range, up to 60 hours, on global and regional scales, respectively. The global model uses spectral formulation in which triangular truncation is applied to retain 62 horizontal waves. The regional model is formulated in finite differences on a 40-km resolution grid mesh.

The present work focuses on the regional model outputs. Rainfall is the model output variable most required by the general public and it is routinely evaluated subjectively and objectively against surface observations, satellite images and rainfall estimates from satellite. During April 1999, an excessive amount of precipitation was forecast by the regional model for the Northern South America, particularly over the Amazon region. The objective of this work is to describe the forecast errors and to investigate the possible sources which may cause the excessive rain.

In the next section, brief descriptions of the model and the methodology applied in this study are given. The 1999 climatological conditions are presented in Section 3. Model errors and comparison with observations are shown in Section 4, and suggestions for the error source are in the Conclusions.

2. Methodology

The regional Eta model (Mesinger et al., 1988; Black, 1994) is used at CPTEC to produce short-range forecasts daily at 00 and 12 UTC. It is a grid-point, limited area model set up in a domain that covers most part of South America. The model resolution is 40 km in horizontal and 38 layers in vertical. The post-processed model outputs are available within approximately 45^{o}S-10^{o}N and 83^{o}W-29^{o}W, and 19 pressure levels, at 50-hPa interval.

The initial and lateral boundary conditions are taken from National Centers for Environmental Predctions (NCEP) analyses and CPTEC global model forecasts, respectively. The lateral boundary conditions are input to the regional model every 6 hours. Both conditions are provided at the resolution T62, and 28 levels.

The regional model uses the eta vertical coordinate in which orography is represented in form of steps (Mesinger, 1984), higher resolution are found in the boundary layer and near the tropopause level. The prognostic variables are surface pressure, temperature, horizontal wind, specific humidity, turbulent kinetic energy, and cloud water content. The model is integrated in a split-explicit fashion, using a modified the forward-backward scheme (Janjic, 1979) to treat the adjustment terms and a modified Euler-Backward (Janjic, 1979) for the advection terms. The radiation package was developed at Geophysical Fluid Dynamics Laboratory and includes shortwave and longwave radiative transfers (Lacis and Hansen, 1974; Fels and Schwarztkopf, 1975). Model rainfall is produced through the modified Betts-Miller scheme (Betts and Miller, 1986; Janjic, 1990) and Zhao cloud scheme (Zhao and Carr, 1997; Zhao et al., 1997). Turbulence in the free atmosphere is treated by the Mellor-Yamada 2.5 scheme (Mellor and Yamada, 1974) and at the surface layer, by the Mellor-Yamada 2.0 scheme (Mellor and Yamada, 1974). Ground water is solved by the "bucket" model (Manabe et al., 1965) with soil capacity of 1.5 meters.

Rainfall is evaluated graphically and objectively through statistical indices. 24-hour accumulated precipitation forecasts are retrieved at four different forecast lead times: 24, 36, 48, and 60 hours. These amounts are summed up in the period from 1 to 30 April 1999, resulting in monthly rainfall totals for different forecast lead times. Surface observed precipitation data are provided by the Instituto Nacional de Meteorologia (INMET) for the same period, however, this dataset exhibit low density in various parts of the continent, particularly over the Amazon region. An alternative observed rainfall estimate can be obtained from satellite data provided by the National Environmental Satellite, Data, and Information Service (NESDIS) and available at http://www.nesdis.noaa.gov. Monthly mean brightness temperature obtained from satellite is shown to corroborate the forecast rainfall patterns. Forecast rainfall amount is evaluated by the equitable threat score (ETS) and the bias (BIAS) score which are defined as (e.g., Mesinger and Black, 1992):

$$\mathrm{ETS} = \frac{\mathrm{H} - \mathrm{CH}}{\mathrm{F} + \mathrm{O} - \mathrm{H} - \mathrm{CH}} \text{ , and} \qquad (2.1)$$

$$\mathrm{BIAS} = \frac{\mathrm{F}}{\mathrm{O}} \qquad (2.2)$$

where :

$$\mathrm{CH} = \frac{\mathrm{F} \times \mathrm{O}}{\mathrm{N}} \qquad (2.3)$$

H is the number of hits, F the number of forecast, O the number of observations above a certain threshold and CH the random number of hits above a certain threshold.

The climate over South America varies spatially. The northern region is mainly affected by deep convective systems and tropical squall lines, the latter are observed mostly along the coast. The dynamics of the Intertropical Convergence Zone (ITCZ) plays a major role in modulating weather in the Northern region. Also, the Northeastern part of Brazil is under the weather regime of the prevailing trade winds, and has distinct surface properties compared to the neighboring Amazon region. On the other hand the Southeastern part of the continent is dominated by frontal systems and organized convective systems. The scores were therefore estimated in four different regions: the whole domain, SA, within 45^{o}S-10^{o}N and 78^{o}W-29^{o}W, the North region, NO, within 15^{o}S-10^{o}N and 78^{o}W-45^{o}W, the Northeast region, NE, within 15^{o}S-10^{o}N and 45^{o}W-29^{o}W, and the Center-South region, CS, within 45^{o}S-15^{o}S and 78^{o}W-29^{o}W.

3. April 1999 conditions

During April 1999, rainfall positive anomaly of about 100 mm was observed over the Brazilian Amazon region. Positive anomaly also occurred in the South region but at smaller amounts, about 25 mm. April is one of the months of the rainy season over Northeast of Brazil, however, negative anomalies of about 100 mm were observed over most part this region. This typically occurs in El Niño year, however, 1999 was a La Niña year, with sea surface temperature (SST) anomalies over the Pacific Ocean around -1.5 ^{o}C. Along the coast of Northeast Brazil, the SST were marginally positive. The reduced convective activity in the central region is corroborated by the positive outgoing longwave radiation (OLR) anomalies, with a maximum of about 15 W/m^2 over Northeast Brazil. These monthly mean fields are available on line at *http:\\www.cptec.inpe.br/products/clima/ccprodp.html.*

4. Results

4.a Monthly total precipitation

Routine monitoring of rainfall forecasts from the regional model, revealed high amounts of accumulated rain predicted at 24 hours of lead time during April 1999 over North region. The problem is revealed by summing the 24-hour accumulated precipitation forecasts over the month at different forecast lead times. Figure 1 shows the monthly total for 24-h, 36-h, 48-h and 60-h forecasts. The 24-h forecast (Figure 1.a) shows values of approximately 1200 mm near the coastline of the North region. At longer forecast lead times, or equivalently, older forecasts, for example at 60 hours the amounts are smaller, about 600 mm (Figure 1.d). At 36 hours, the precipitation forecasts pattern has acquired more details and indicates the maximum of precipitation along the eastern coast of the Amazon region and a southward extension of the precipitation area. In subtropical latitudes, the monthly total amount of precipitation shows approximately steady values in all forecast lead times.

The excess of rain produced at the initial 24 hours of forecast is clear in the Figures 2.a and b which show the difference of total precipitation taken from the 36-hour minus the 24-hour forecasts, and the 48-hour minus 24-hour forecasts, respectively. The 24-h forecasts produced an excess of up to

500 mm over the 48-hour forecasts along the coast of the North and Northeast regions for the rest of the domain the differences are smaller.

4.b Observations

Surface precipitation observations for April 1999 (Figure 3), showed that monthly total rain reached about 450 mm along the eastern border of the North region. One can notice some zonal variability in the observed precipitation patterns, similar to the 36- up to 60-hour forecast patterns. Therefore, the 24-hour forecast largely overestimates the precipitation whereas at longer lead times the forecasts approach the observation.

Due to the scarcity of data in the North region, a qualitative comparison based on satellite estimated precipitation was added to the study. These estimates are produced daily by NESDIS at approximately 38-km x 36-km resolution in ***x*** and ***y*** directions, respectively (Figure 3.b). The April satellite total precipitation estimate exhibits localized maxima typical of tropical rains, and the magnitude are comparable to the surface observations. These values give confidence to the magnitude of the surface observed precipitation.

4.c Global model

The large adjustment of the regional model at the initial forecast times suggest that error may be introduced by the initial conditions or the lateral boundaries from the global model. The precipitation forecasts of the global model are shown in Figure 4a and b. The total monthly precipitation evaluated from the global model 24-hour forecasts (Figure 4.a) yields a pattern different from the regional model in the North region, and tends to increase the amount at longer forecast times (Figure 4-b). This distinct behavior of the global model suggests that the error is not directly input by the global model lateral boundary conditions. The large adjustment in the precipitation fields in the first 24-hours of integration is not noticed in the subtropics. The error seems to be confined to the tropics and at the initial conditions.

4.d Large scale control

The routine evaluation of the model precipitation forecast showed that similar error pattern was found in March, but largest in April 1999. In comparison to previous rainy months, such as December 1998 (Figure 5a-b) the error pattern had opposite signal. In December, rains are concentrated over the Southeast and Central part of the continent, and were modulated by the presence of the South Atlantic Convergence Zone (SACZ). This zone is clearly seen in Figure 6, where cloud bands possibly are associated with a large region of precipitation over the Central Amazon, extending southeast toward the Atlantic Ocean. During this month, the amount of forecast precipitation increased with forecast lead time. It can be noted that the monthly total precipitation at 48-hour forecasts are closer to the observed values. Although the precipitation values increased for longer forecasts, as opposed to April forecasts, the values became closer to observations, similarly to the April case. This suggest that the model corrects the forecast with integration time.

Cold cloud top temperature images shown in Figures 6.a and b for December 1998 and April 1999, respectively, represent enhanced precipitation in both periods of tropical kind, however with different large scale dynamical control. These figures suggest distinct precipitation control between these two months. During April, the ITCZ plays the major role in controlling the precipitation regime over Northern Brazil. While in December 1998 (figure 6.a) the ITCZ is positioned around 5^o N and 10^o N, with another convective band extending from northwest Amazon to southeast Brazil forming the SACZ. In April (Figure 6.b) the ITCZ over the Equatorial Atlantic is displaced southward at about 5^o S and 5^o N, and most of Amazon region is under convective activity. However, during that time, the latitudinal position of ITCZ did not reach its normal southern position, leaving most of Northeast of Brazil free from convective activity.

4.e Rainfall forecast scores

Objective evaluation of precipitation forecasts was carried out based on the equitable threat scores (ETS) and bias scores (BIAS). These indices were obtained following the procedure presented in Methodology. A further description of the indices is found in Chou and Justi da Silva (1999). Different thresholds refer to different rainfall intensities. In moderate rain thresholds, above 6.3

mm, Figure 7.a and b show that despite the reasonable values of ETS for the North region, the combined BIAS scores are large at 24-hour forecasts, indicating that precipitation was overestimated at those thresholds. Figure 7.b shows that the bias score has dramatically reduced approaching 1 at longer forecast lead times. These results have reasonable confidence level, as scores were based on a sufficient amount of observed precipitation points despite the poor space data coverage. Due to the magnitude of the errors, the quality of the forecasts over the North region affects largely the quality over the whole domain, SA. This is seen by comparing scores over SA and the other regions: NE and CS. CS is the region where model forecasts produced high scores, whereas NE showed lowest scores. The conclusions from these objective scores are in agreement with the evaluation obtained by comparing the observed and forecast field patterns.

4.f Forecast errors

Figure 8 a-b show the profile of forecast errors of specific humidity and zonal wind over NO at different times. The errors are computed by interpolating model variables to the analysis grid, at five vertical levels: (200, 300, 500, 850 e 1000 hPa). The errors show that the model exhibits a dry bias at low levels, and becomes marginally moist at upper levels. At 24-h forecast, the errors are smallest at low levels, and increase with forecast lead times.

The zonal wind errors show a positive bias at low levels and a negative bias at upper levels. Over NO, the easterlies predominate, and the error sign suggests that the forecast easterlies are weaker than the observations. At upper levels, winds turn westerlies, and the negative errors indicate weaker westerlies, as the integration progresses the profile wind shear is reduced and these winds are weaker compared to the analyses.

The errors suggest reduction in the model low level convergence and upper level divergence with forecast time. The reduced moisture convergence at low levels result in reduced both convective activity and precipitation.

5. Conclusions

The model tendency for overestimating rainfall in the first 24 hours of integration in the Northern South America was detected in March 1999, being more evident in April 1999 forecasts. During these months the ITCZ is typically displaced to the south of the equator. Total April rainfall forecasts were evaluated against surface observation and satellite estimates of precipitation, equitable threat scores and bias score for precipitation were calculated. The errors are not induced directly from the global model forecasts since the results showed that the global model error behaves differently from the regional model. All results showed that the regional model produced improved forecasts in longer forecast lead times, particularly after the first 24 hours. This model correction was also observed in December 1998 rains. However, in April 1999 there was an initial wet bias, as opposed to December 1998 when there was an initial dry bias. Despite the increase of errors in the humidity and wind fields with the forecast time, the precipitation forecasts improved. This fact suggests the inadequacy of using the current global analyses as an initial condition to the regional model in the tropics.

The errors investigated in this work are related to a particular weather regime in the tropics. The detection of these errors suggests two directions toward reducing them: the first one is the quality of the initial conditions which result in large adjustments at initial integration time; and the second one is the treatment of the model physics through improvement of rainfall parametrization schemes, either convective or stable. Continued work are ongoing to identify the causes of error and to improve the model forecasts.

6. References

Betts, A. K., and Miller, J., 1986: A new convective adjustment schemes. Part II: Single column model test using GATE wave, Bomex and arctic air-mass data sets. *Quart. J. Roy. Met. Soc.*, **112**, 693-709.

Black T. L., 1994: NMC Notes: The New NMC mesoescale Eta model: description and forecast examples. *Wea. Forecasting*, **9**, 256-278.

Chou, S. C., and M. G. A. Justi da Silva, 1999: Objective evaluation of Eta model precipitation forecasts over South America. Climanalise, 1, vol. 14, INPE, Cachoeira Paulista, SP, Brazil .

Fels, S. B., and Schwarztkopf, M. D., 1975: The simplified exchange approximation. A new method for radiative transfer calculations. *J. Atmos. Sci*., **32**, 1475-1488.

Janjic, Z. I., 1979: Forward-backward scheme modified to prevent two-grid interval noise and its application in sigma coordinate models. *Contrib. Atmos. Phys*., **52**, 69-84.

Lacis, A. A., and Hansen, J. E., 1974: A parametrization of the absorption of solar radiation in earth's atmosphere. *J. Atmos. Sci*., **31**, 118-133.

Mellor, G. L., and T. Yamada, 1974: A hierarchy of turbulence closure models for planetary boundary layers, *J. Atmos. Sci*., **31**, 1791-1806.

Manabe, S., J. Smagorinsky, and R. F. Strickler, 1965: Simulated Climatology of a general circulation model with a hydrological cycle. *Mon. Wea. Rev.*, **93**, 769-798.

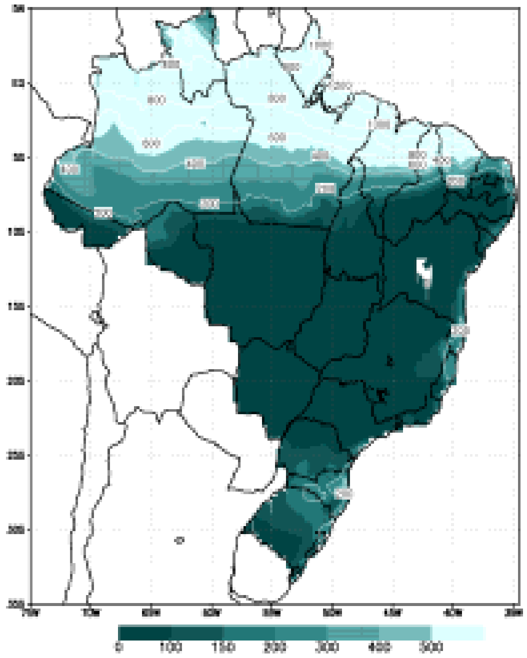
Mesinger, F., 1984: A blocking technique for representation of mountains in atmospheric models. *Rivista di Meteorologia Aeronautica*, **44**, 195-202.

Mesinger, F., Z. I. Janjic, S. Nivckovic, D. Gavrilov, and D. G. Deaven, 1988: The step-mountain coordinate: model description and performance for cases of Alpine lee cyclogenesis and for a case of an Appalachian redevelopment. *Mon. Wea. Rev.*, **116**, 1493-1518.

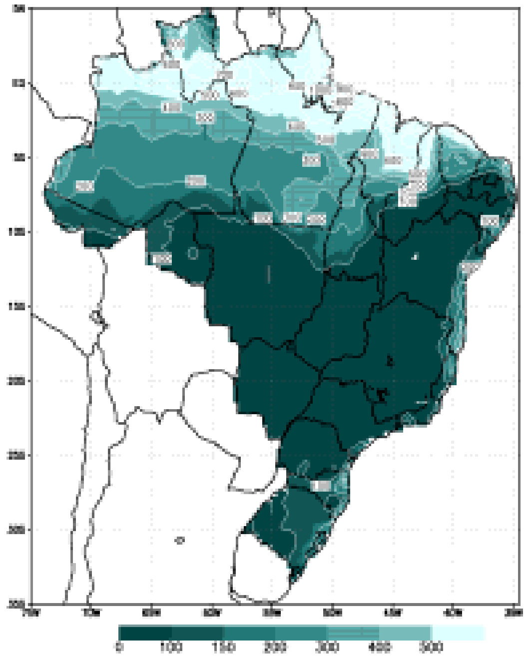
Mesinger, F., and T. L. Black, 1992: On the impact on forecast accuracy of the step-mountain (eta) vs. sigma coordinate. Special issue of Meteor. Atmos. Phys. on Meso-Alpha Scale, Numerical Techniques and Models, **50**, 47-60.

Zhao, Q., and F. H. Carr, 1997: A prognostic cloud scheme for operational NWP Models. *Mon. Wea. Rev.*, **125**, 1931-1953.

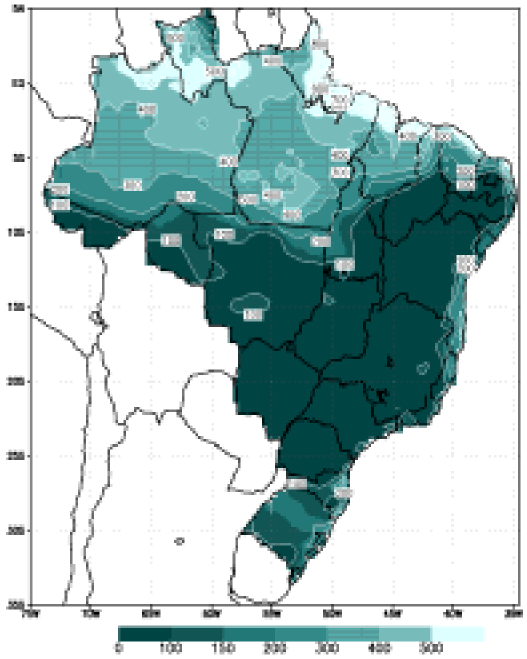
Zhao, Q., T. L. Black, and M. E. Baldwin, 1997: Implementation of the cloud prediction scheme in the Eta model at NCEP. *Wea. Forecasting*, **12**, 697-712.



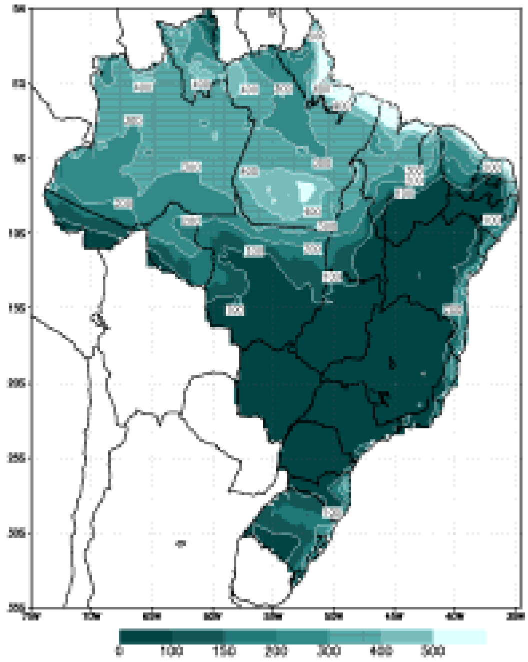
1a)



1b)

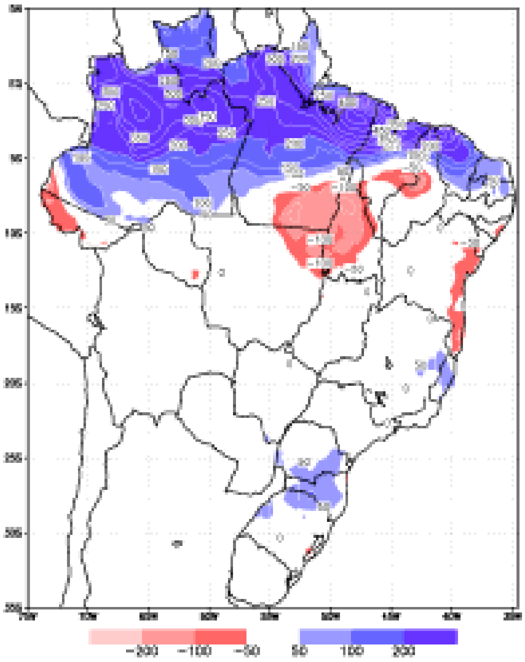


1c)

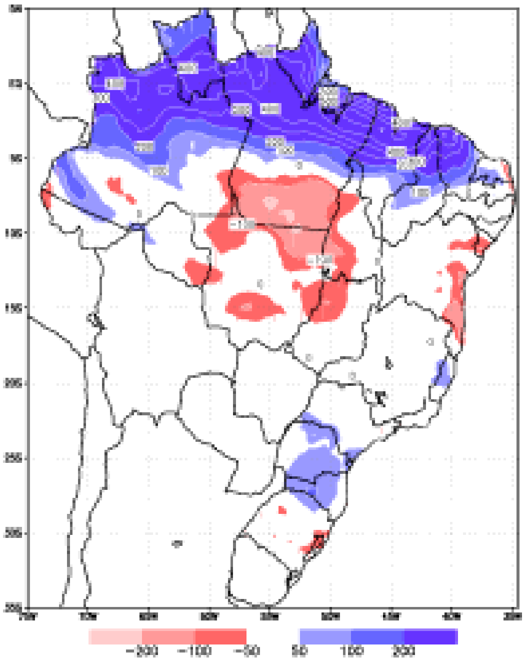


1d)

Figure 1a-d : Monthly total 24 hours accumulated rainfall (mm) of April 1999 predicted by the regional Eta model at different forecast lead times: a) 24 hours; b) 36 hours; c) 48 hours; d) 60 hours.

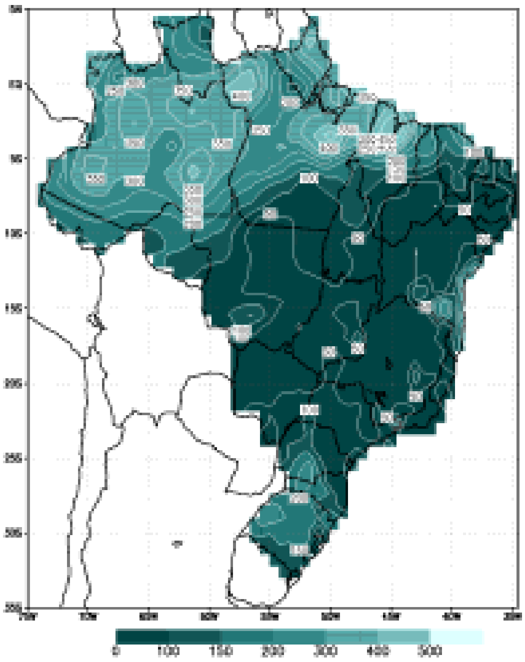


2a)

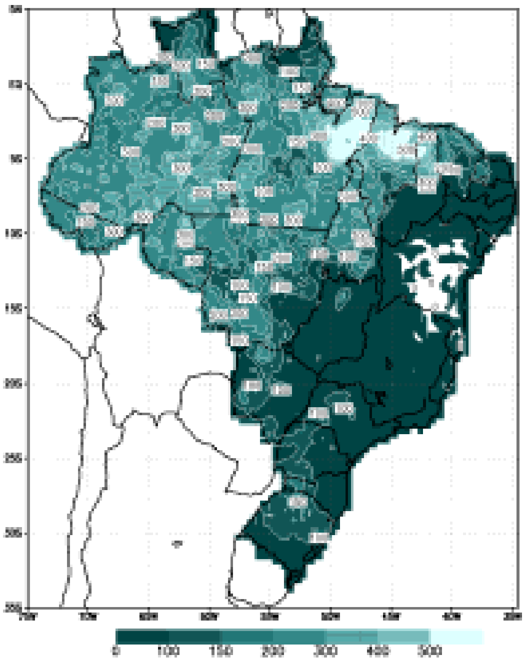


2b)

Figure 2a-b: Differences of monthly total precipitation forecast at 24 hours: a) 24 h minus 36 h forecasts; b) 48h minus 36 h forecasts

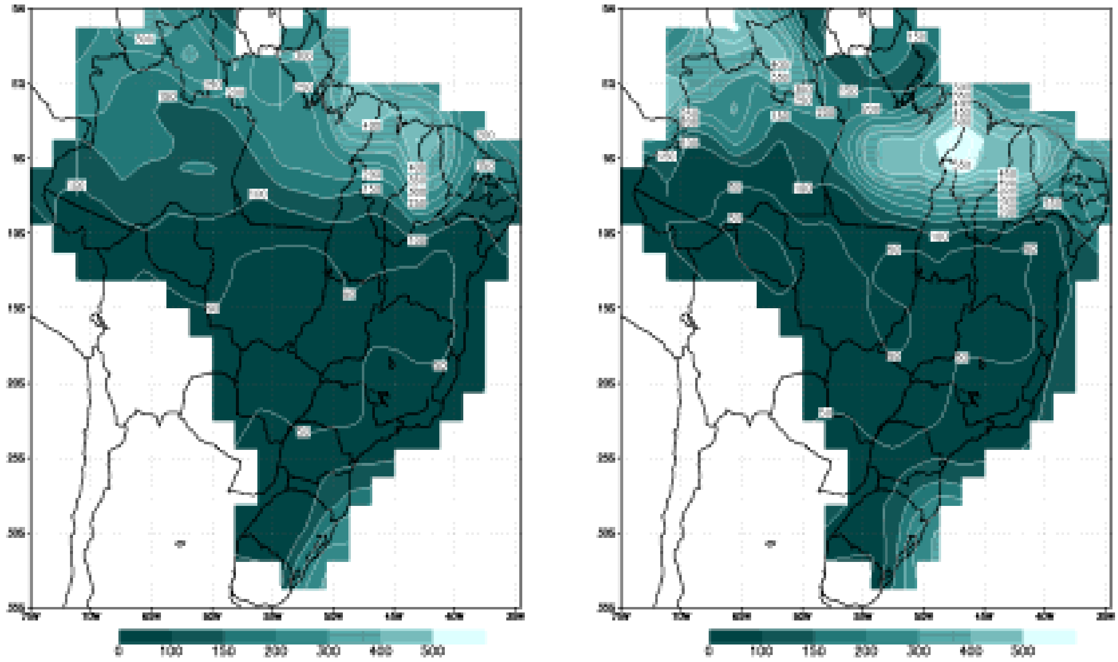


3a)



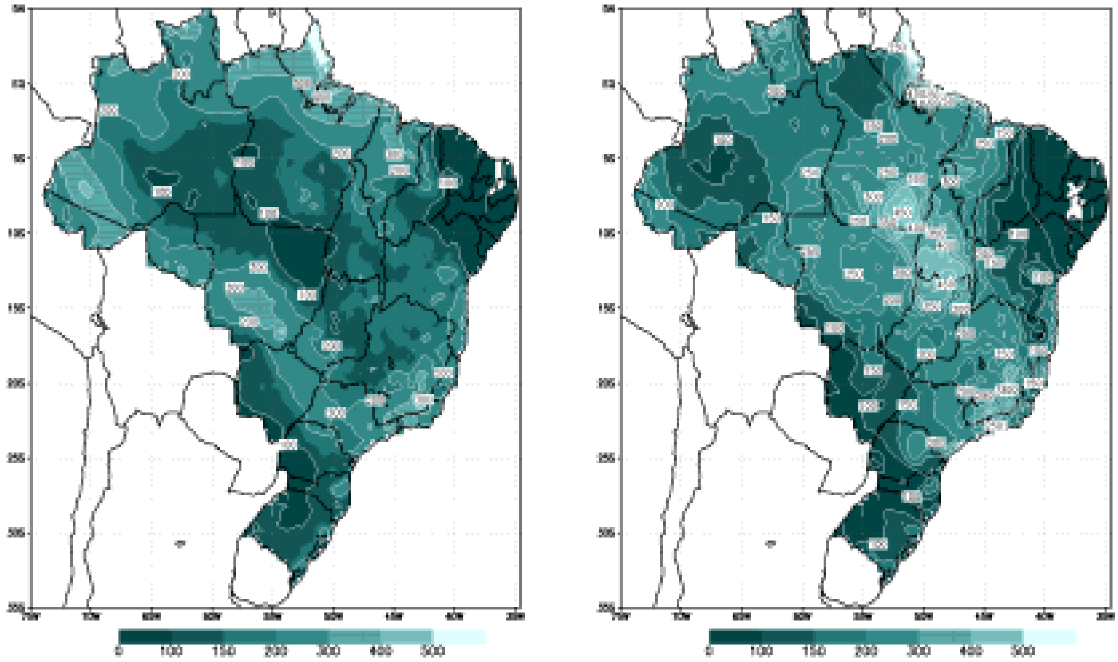
3b)

Figure 3a-b: a) observed April 1999 precipitation (mm); b) April 1999 precipitation estimated by satellite (data avaible at http: ://www.nesdis.noaa.gov.



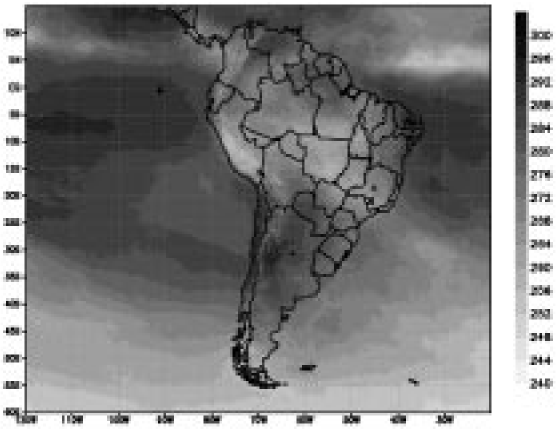
4a) 4b)

Figure 4a-b : same as Figure 1, except for CPTEC/COLA global model at: a) 24 h; b) 48 h forecast lead time.

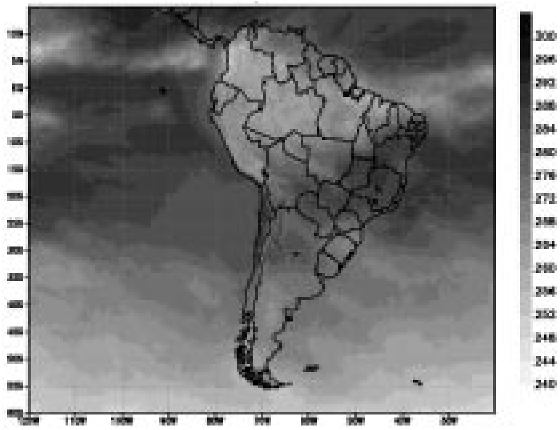


5a) 5b)

Figure 5a-b : same as Figure 1, except for December 1998, at: a) 24 h and b) 48 h forecast time.

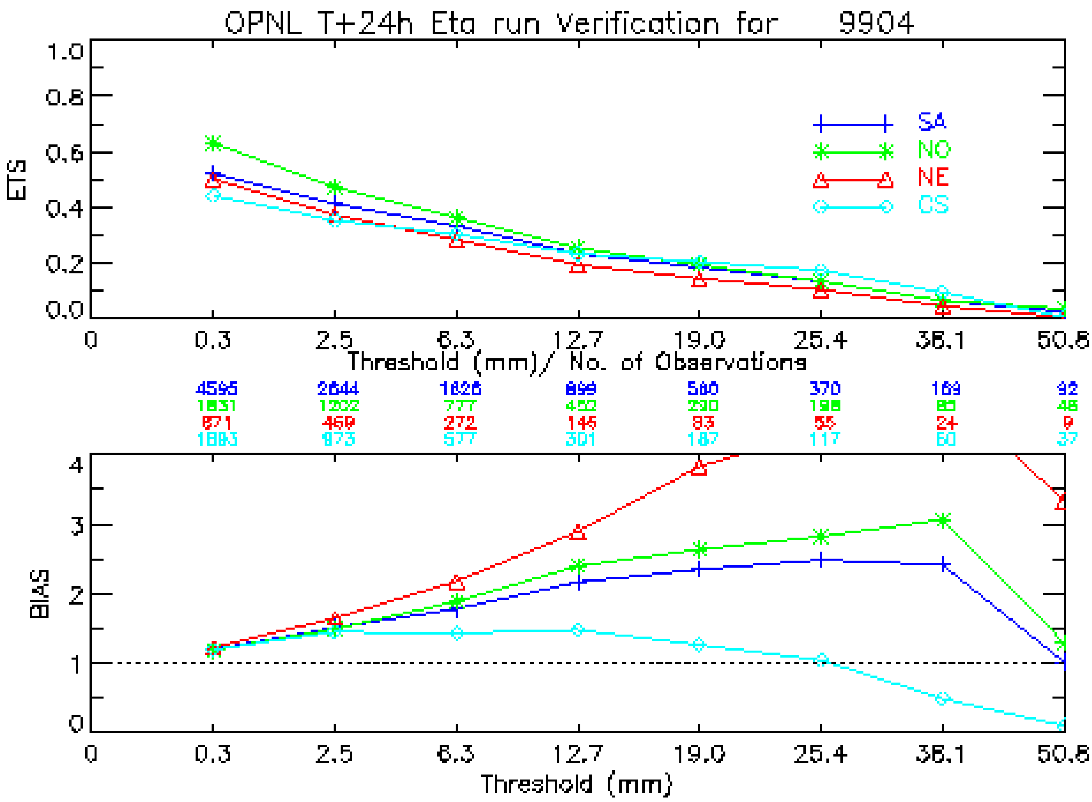


6a)

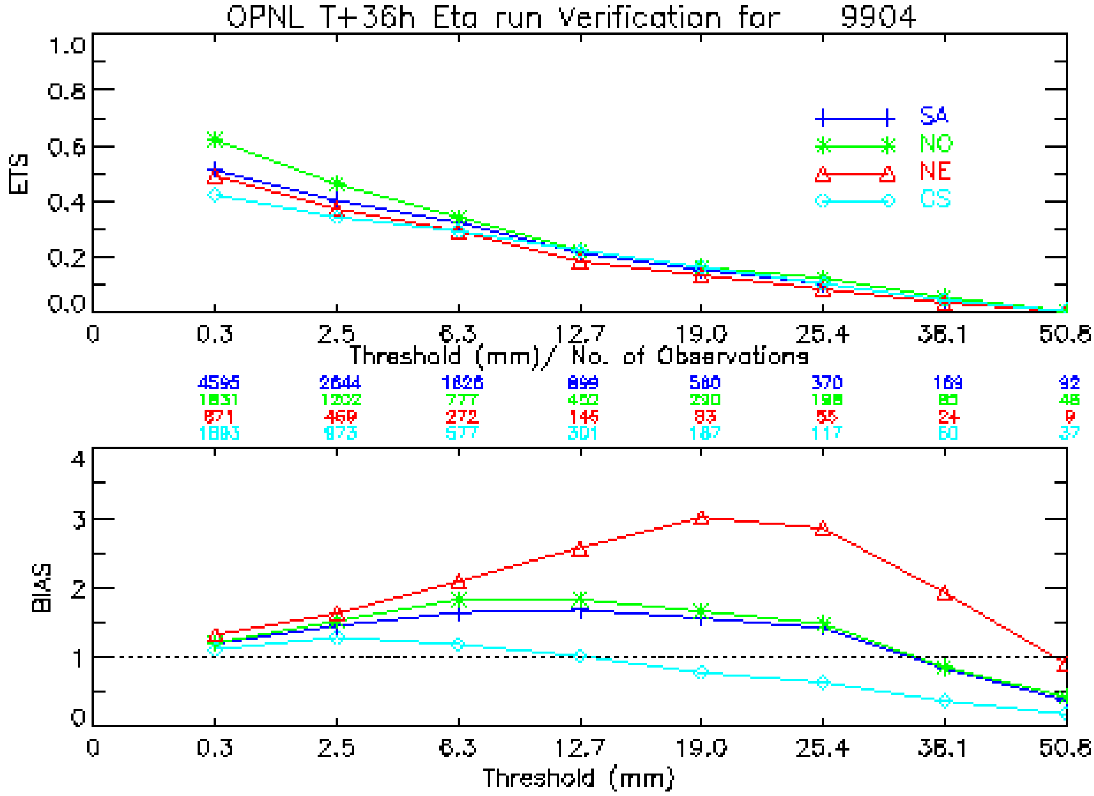


6b)

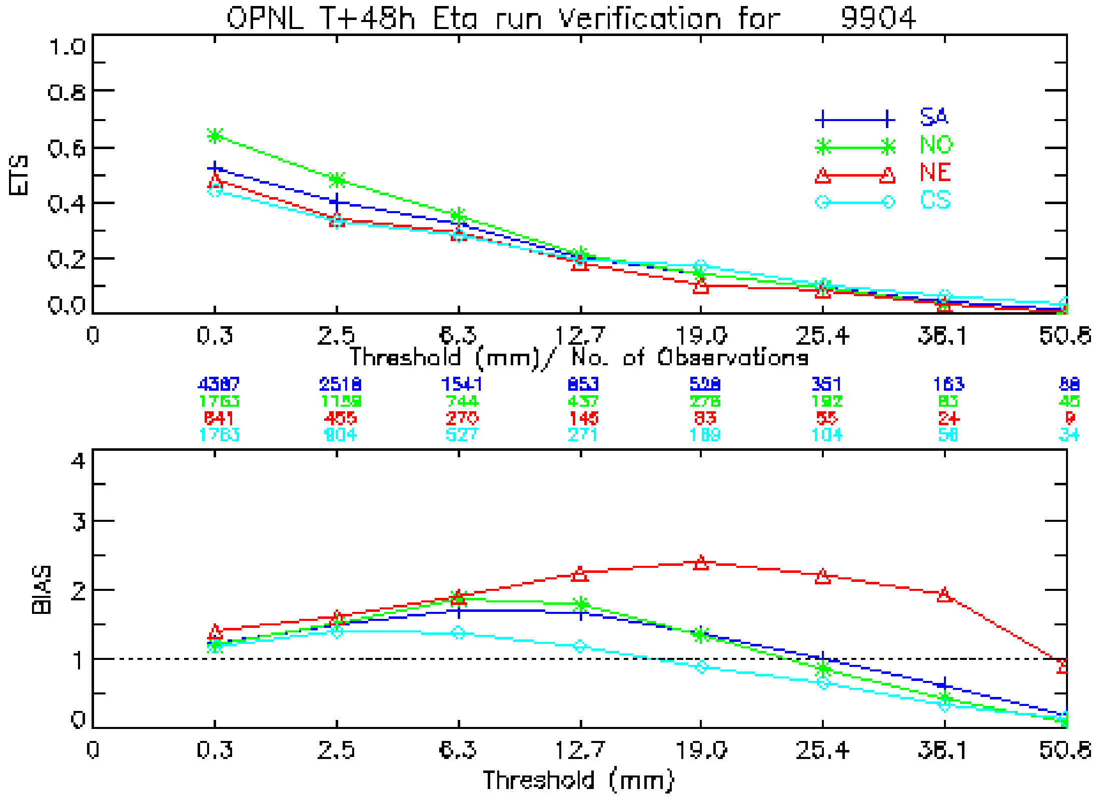
Figure 6a-b: Monthly mean brightness temperature (K), from GOES 8 satellite: a) December 1998; and b) April 1999.



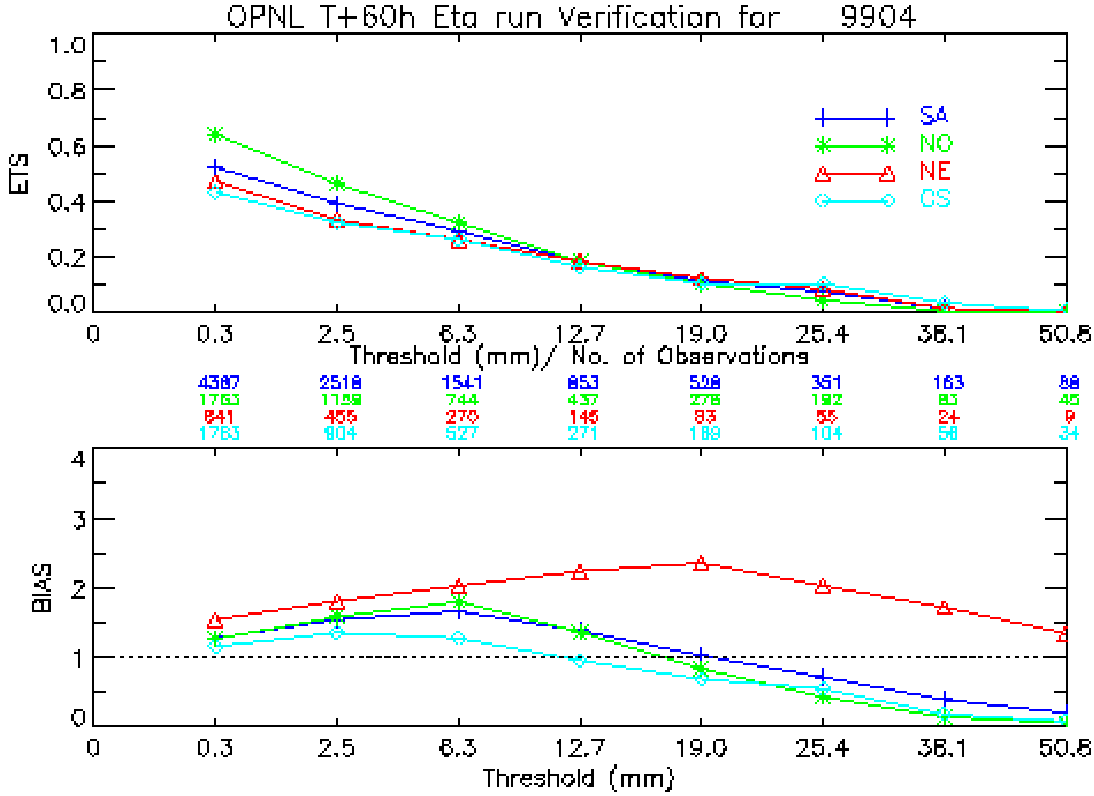
7a)


OPNL T+36h Eta run Verification for 9904
ETS
1.0
0.8
0.6
0.4
0.2
0.0
SA
NO
NE
CS
0 0.3 2.5 6.3 12.7 19.0 25.4 38.1 50.8
Threshold (mm)/ No. of Observations
4595 2644 1626 899 560 370 169 92
1831 1202 777 452 290 198 85 46
871 469 272 145 83 55 24 9
1883 873 577 301 187 117 60 37
BIAS
4
3
2
1
0
0 0.3 2.5 6.3 12.7 19.0 25.4 38.1 50.8
Threshold (mm)

7b)

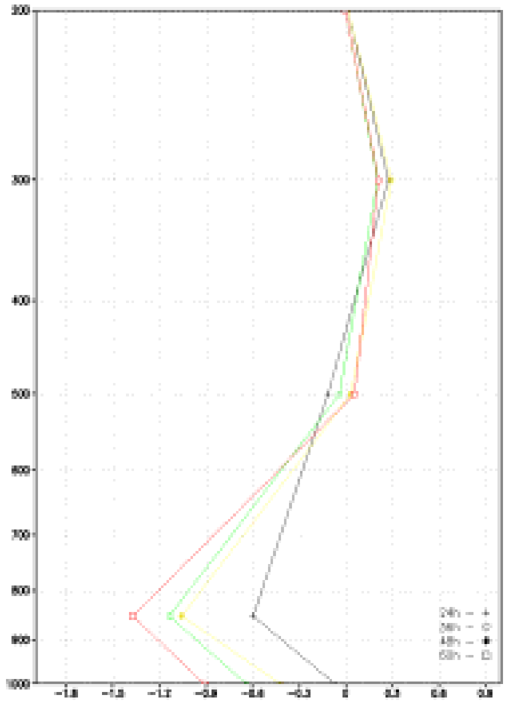

OPNL T+48h Eta run Verification for 9904
ETS
1.0
0.8
0.6
0.4
0.2
0.0
SA
NO
NE
CS
0 0.3 2.5 6.3 12.7 19.0 25.4 38.1 50.8
Threshold (mm)/ No. of Observations
4387 2518 1541 853 528 351 163 88
1763 1159 744 437 276 192 83 45
841 455 270 145 83 55 24 9
1763 804 527 271 189 104 58 34
BIAS
4
3
2
1
0
0 0.3 2.5 6.3 12.7 19.0 25.4 38.1 50.8
Threshold (mm)

7c)

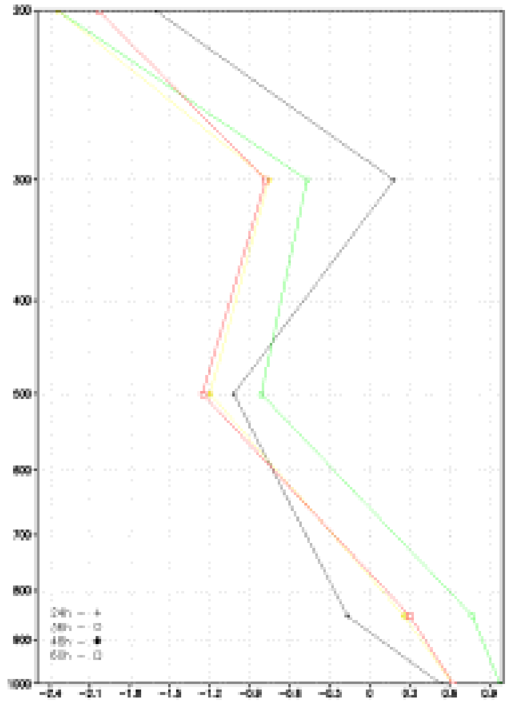


7d)

Figure 7a-d: Equitable threat score and bias score of Eta model precipitations forecast over 4 different regions: NO (north of 15.5^{o}S and west of 45^{o}W), NE (east of 45^{o}W and north of 15.5^{o}S), CS (south of 15.5^{o}S) and whole South America (SA) at 24-h forecast and at 48-h forecast times. The numbers below the axis of the ETS graph are the number of grid boxes which contained observations above each threshold, and for each region as given in the legend. These number give the confidence level of the score of each rainfall threshold.



8a)



8b)

Figure 8: Mean Eta model forecast errors of: a)specific humidity (g kg^{-1}) and b) zonal wind (ms^{-1}), at different forecast times over the NO region.