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Evaluation of two Eta Model versions for weather forecast over South America

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RESUMEN

En este artículo se compara el desempeño de dos versiones del modelo regional Eta utilizado en el CPTEC. La segunda variante, que es una actualización de la empleada en forma operativa hasta el momento, presenta un dominio de integración mayor, un tope más elevado e incluye una representación del suelo y la vegetación. El modelo de suelo/vegetación posee dos capas subterráneas y una canopia vegetal. La evaluación del modelo se llevó a cabo comparando los errores medios y cuadráticos medios de diversas variables sobre un conjunto de 15 situaciones meteorológicas. Esta comparación se realizó utilizando los análisis del NCEP y datos aerológicos y pluviométricos de algunas estaciones de América del Sur. Los pronósticos de precipitación fueron evaluados por medio del bias (BIAS) y el equitable threat score (ETS).

Los errores medios no difieren notablemente para ambas variantes del modelo durante las primeras 24 horas de previsión, excepto por la temperatura de superficie que es pronosticada con mayor acierto por la versión actualizada. Sin embargo las diferencias se hacen mucho más notables para los pronósticos mayores de 48 horas, donde la nueva versión logra un grado de verificación mucho mayor para la temperatura y la humedad. Estas diferencias se amplían sobre las grandes áreas forestadas de la América del Sur subtropical. Los contrastes son menores para la altura geopotencial y prácticamente nulos para las componentes zonal y meridional del viento. Los pronósticos de precipitación mostraron que durante las primeras 24 horas la nueva versión del modelo produce ETS ligeramente más elevados y BIAS similares, pero que luego de 48 horas éste tiende a sobrestimar en mayor medida la precipitación, sin alterar su verificación espacial.

PALABRAS CLAVE: Meteorología, modelado regional, desempeño, procesos superficiales, Sudamérica.

ABSTRACT

A comparison of performance of two versions of the Eta/CPTEC model is presented. The new version is an update of an earlier operational one and includes representation of soil and vegetation types. The soil/vegetation model contains two underground layers and a canopy layer. Evaluation was carried out by comparing the mean and root mean square errors of several variables for an ensemble of 15 meteorological situations, using the NCEP analyses, upper air soundings and precipitation data over South America. Precipitation forecasts were evaluated by the equitable threat score (ETS) and the bias score (BIAS).

The mean errors from both versions show similarities during the first 24 hours of forecast, but surface temperature is more accurately predicted by the updated model. After 48 hours, temperature and humidity forecasts show better skill in the new version too. Over subtropical South America differences are more evident in temperature and humidity, less so for geopotential heights and practically nonexistent for horizontal winds. The precipitation forecasts for the updated version have equitable threat scores slightly higher and similar bias scores during the first 24 hours. After 48 hours this version tends to overestimate the rainfall, while its spatial distribution remains unaffected.

KEY WORDS: Meteorology, regional modeling, performance, surface processes, South America.

1. INTRODUCTION

The Eta model has been used operationally at the Brazilian Center for Weather Forecasts and Climate Studies (Centro de Previsão de Tempo e Estudos Climáticos, CPTEC). It provides weather forecasts over most of South America since late 1996. Over the past five years the quality of the model forecasts has been continuously evaluated for identifying and correcting model failures. After changes, the evaluation needs to be repeated.

Chou and Justi da Silva (1999) verified the skill of precipitation forecasts after 24, 36, 48 and 60 hours for different regions of South America and for the one-year period of February 1997 to January 1998. The amount of precipitation generated by Eta over South America tended to be overestimated for low rainfall and underestimated for high rainfall. Precipitation forecasts showed higher accuracy at extratropical latitudes and over the Amazon region. Bustamante *et al*. (1999) studied a shorter period, April 1999, and found similar results.

Seluchi and Chou (1999) compared two Eta model versions that differed by the size of the integration area and the horizontal resolution. Through a series of sensitivity experiments they emphasized the importance of the domain size, as the forecast errors from runs using larger domain and 80-km horizontal resolution were comparable to the errors from 40-km runs.

More recently Seluchi and Chou (2000) identified some Eta model systematic biases over South America. The Betts-Miller convective scheme was identifid as the major model component responsible for those errors. This parameterization causes a spurious cooling at mid-tropospheric levels that increases the convective instability. The model also has problems in forecasting accurately the temperature at upper levels and near the ground. Raising the model top could reduce the first problem, but the second issue would probably require a more realistic representation of surface fluxes. It is widely accepted that surface processes are very important to improve the quality of simulations in general circulation models (Mintz 1981, Rowntree 1983), and in limited area models (Rowntree and Bolton 1983, Avissar and Pielke 1989, Chen and Avissar 1994). These processes are particularly important over South America which includes the world's most important hydrological basin.

An attempt to represent more suitably the exchanges between the ground and the atmosphere leads to some new land-surface parameterization schemes (e.g. Avissar and Verstraete, 1990; Garratt, 1993). Canopy effects on evapotranspiration are modeled either in implicit (Entekashi and Eagleson 1989, Wood *et al*., 1992) or in explicit form (Deardorff 1978, Pan and Mahrt, 1978, Dickinson 1984, Xue *et al*. 1991) with different levels of complexity.

Selecting land-surface models for operational use purposes involves a compromise between completeness of the physical processes and computational resources. Chen *et al*. (1996) selected the Oregon State University (OSU) land-surface scheme which can simulate the daily and seasonal cycles of evaporation, ground humidity, sensible heat fluxes and surface temperature, without a high degree of complexity.

In order to improve the quality of CPTEC weather forecasts an updated version of the Eta model was introduced. It differs from the previous one by

1) The integration domain was extended about 10° to the south and about 5° towards the east and the north (see Figure 1).

2) The model top was raised from 50 mb to 25 mb.

3) The land surface model was changed from a bucket to an OSU scheme. Some details of both schemes are given in section 3.

In this work we compare the performance of both versions of the Eta model at CPTEC at some atmospheric levels and different forecast times. The relative impact of model changes on the forecasted fields is discussed.

In section 2 the data and methodology are presented. In section 3 a brief description of the Eta/CPTEC model and the land-surface schemes is given. Section 4 evaluates both model versions. The discussion and the conclusions are given in section 5.

2 DATA AND METHODOLOGY

The performance of two Eta model versions was evaluated by comparing the mean and root-mean-square forecast errors for an ensemble of 15 meteorological situations. The cases are distributed throughout the year and represent different types of classical weather events. The dates and description of the cases are given in the Appendix I. The mean and root-mean-square errors have been obtained by comparing the predicted fields with NCEP daily analyses and with the available sounding data over South America. The same analyses are also used as initial conditions for Eta model runs. The skill of precipitation forecasts was measured by the equitable threat score (ETS) and the bias score (BIAS).

The ETS (Mesinger and Black, 1992) is found from

$$ETS = \frac{(H - CH)}{(P + O - H - CH)}, \tag{1}$$

$$CH = \frac{P \cdot O}{N}\ , \tag{2}$$

where P and O is the number of points in the integration domain with predicted or observed precipitation above a threshold. H is the number of hits, when observed and predicted precipitation occur above a certain threshold. CH is the number of hits at random, and N is the number of points within the verification area. Thus ETS compares the areas of predicted and observed precipitation. When the areas coincide, P=O=H and ETS is equal to unity; else it will be smaller than one.

BIAS is defined as the ratio between the number of points in the integration domain with predicted precipitation above a threshold P, and the number of points with observed precipitation above the same threshold O. Thus,

$$BIAS = \frac{P}{O}\ . \tag{3}$$

This calculation requires interpolating the observed rainfall data at grid crossings. BIAS>1 means that the prediction overestimates the observed precipitation, and con-

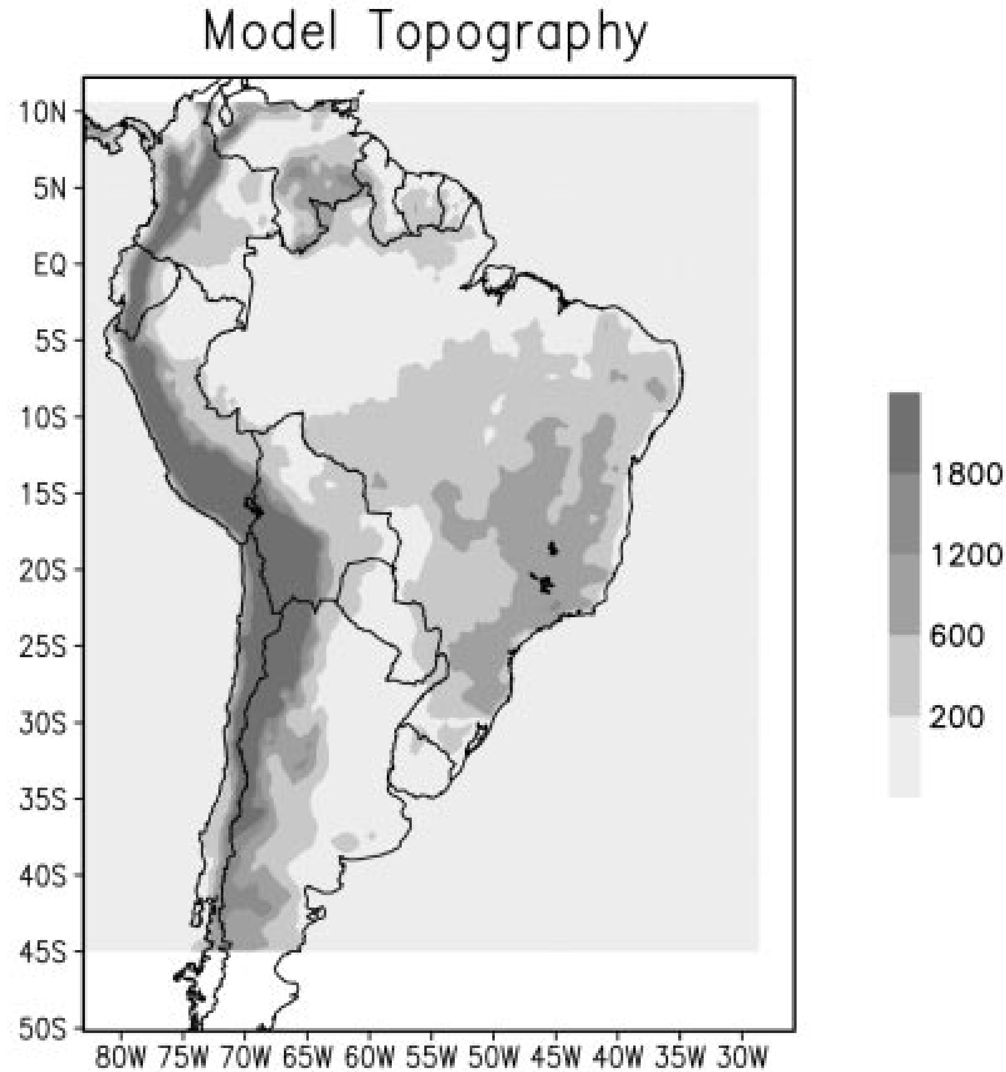

Fig. 1. Integration domain used by the Eta/OSU (outer box) and by Eta/bucket (inner shaded box). The topography employed for both versions is shown.

versely when BIAS<1. Only forecasts at 12 UTC were evaluated because of the larger amount of available information at this time.

Because the model versions have different integration domains the comparison of the forecasts was restricted to the area in common.

3 THE REGIONAL ETA MODEL AT CPTEC

3.1 General features

The Eta is a hydrostatic model, which uses the η vertical coordinate defined by Mesinger (1984) as

$$\eta = \frac{p - p_t}{p_s - p_t} \cdot \eta_s \tag{4}$$

with

$$\eta_s = \frac{p_{rf}(z_s) - p_t}{p_{rf}(0) - p_t} \ . \tag{5}$$

Here p is the pressure; the subscripts **t** and **s** stand for the top and the surface values; z is the geometric height, and $p_{rf}(z)$ is a reference pressure as a function of z.

The η coordinate improves the calculation of horizontal derivatives near steep topographic areas. This favors the use of the model over neighboring regions of abrupt slopes of the Andes in South America.

The Eta/CPTEC model has a horizontal resolution of 40 km with 38 vertical levels, tropospheric as well as stratospheric. The topography is represented as discrete at layer interfaces. It uses an Arakawa-type E grid (Arakawa and Lamb 1977) and has a complete physical package (Black, 1994) with schemes for grid-scale precipitation represented in explicit form (Zhao *et al*., 1991). Convective precipitation is according to the Betts-Miller scheme (Betts 1986, Betts and Miller 1986), as modified by Janjic' (1994). The turbulent exchanges in the free atmosphere are based on the Mellor and Yamada (1974) level 2.5 scheme, whereas the radiation model is based on the GFDL package (Lacis and Hansen, 1974; Fels and Schwartzkopf, 1975).

The initial conditions are taken from NCEP analyses. The lateral boundary conditions are updated at 6-hour intervals with the CPTEC/COLA global model forecasts (Bonatti 1996; CLIMANALISE ESPECIAL, 1996). Both initial and lateral boundary conditions are provided at spectral triangular truncation T062 and 28 sigma levels.

3.2 The soil model

In the early version of the Eta/CPTEC model, the soil water is simulated with the *bucket scheme* (Manabe 1969; Robock *et al*., 1995). The prognostic variable is the soil water content, W, which represents the humidity available for evaporation in the uppermost 1 m of soil and is calculated from

$$\frac{\partial W}{\partial t} = p - e - r \ , \qquad (6)$$

where *p* is the precipitation rate, *e* is the evaporation rate and *r* is the surface runoff. When W exceeds 75% of the maximum capacity of water storage, evaporation occurs at the potential evaporation rate.

In the updated version, the soil water treatment is based on the OSU scheme (Chen *et al*, 1996), which basically couples the Mahrt and Ek (1984) potential evapotranspiration model, the Mahrt and Pan (1984) soil model and the Pan and Mahrt (1987) canopy scheme. It has two sub-superficial layers of 5 cm and 90 cm, respectively and a canopy layer of 30 cm. The prognostic variables are soil humidity, temperature in two underground layers, water content stored in the canopy and accumulated snow at the ground. The surface temperature is determined with a linear balance equation of energy (Mahrt and Ek, 1984) that represents the combined effect of surface and vegetation. Heat fluxes are controlled by a diffusion equation, in which the heat capacity and conductivity are functions of the water content in the soil. The evaporation is the direct sum of the evaporation at the upper ground layer, the evaporation of the precipitation intercepted by the canopy and the transpiration through the canopy and the roots. Additional details can be found in Chen *et al*. (1996).

The early model version will be referred to as Eta/bucket and the new one as Eta/OSU.

4 RESULTS

4.1 Mean forecast errors

Model errors are defined as differences between forecasts and the verifying NCEP analyses. In general the differences between the error of the two model versions are negligible in the first 24 hours, except for surface temperature (Figure 2) where the error is considerably reduced in Eta/OSU. Improvements in surface temperature are seen mostly over the central Amazon region or in the southernmost Brazil and Uruguay. However, along the eastern tropical coast Eta/OSU produces higher positive temperature biases compared to the analysis fields, whereas Eta/bucket shows smaller and negative humidity errors and more accurate temperatures over this relatively small region.

Figure 3 exhibits the vertical profiles of temperature, humidity and geopotential height errors averaged over the integration domain and over the 15 selected cases. The differences between versions show up in the temperature profiles, where errors are slightly smaller near the surface and at the lower stratosphere for Eta/OSU. The specific humidity profiles indicate that Eta/bucket values are closer to observations near the surface levels but less accurate in the lower troposphere. The geopotential height error profile is smaller for Eta/OSU, especially in the lowest layers and at stratospheric levels. This is presumably due to the higher model top.

Differences between the two versions are more noticeable after 48 hours of prediction, because the model loses information of the initial conditions and responds strongly to its internal physics. Figure 4 shows the temperature errors at the surface, 850 and 500 hPa levels after 48 hours of integration. The major differences in surface temperature are found between 15°S and 35ºS, where Eta/OSU seems to be considerably better, to the extent of showing some error reduction over northeastern Brazil relative to the 24-h forecasts (Figure 2). The improved 48-hour forecasts over 24-hour forecasts may be due to some balance in the surface fluxes with integration time. Eta/OSU also shows smaller temperature errors at 850 hPa; however, the differences between both model versions tend to diminish in the middle troposphere, at the 500 hPa level, and increase again at the highest levels.

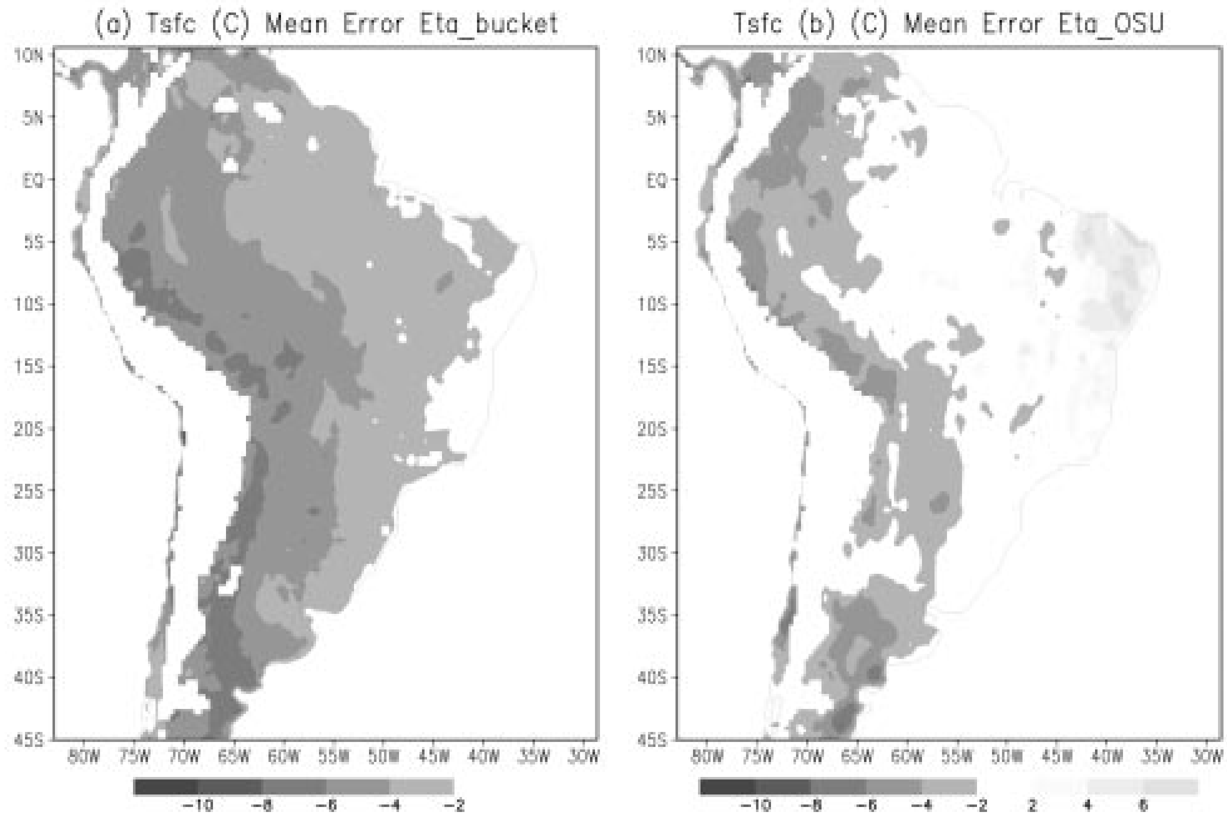

Fig. 2. Mean errors of surface temperature (ºC) corresponding to (a) Eta/bucket and (b) Eta/OSU model versions. Forecast lead time is 24 hours. Values outside the -2° to 2° range are shaded.

The specific humidity near the surface (Figure 5) is more accurately forecast by Eta/OSU, especially over the Amazon region. At extratropical latitudes, where the water vapor contents is smaller and the continent narrow, the errors are comparable for both versions.

4.2 Root-mean-square errors

The mean errors discussed above can be interpreted as a measure of systematic model inaccuracies. However, individual errors of either sign can eventually produce negligible mean biases, which will not strictly reflect the forecast performance. Moreover, area-averaged values, as in Figure 3, may hide large errors of opposite signs. In order to emphasize the error magnitude, the root-mean-square error (RMSE) was calculated at each grid point as

$$RMSE = \frac{1}{N}\sqrt{\sum_{i=1}^{N}\left(F_i - A_i\right)^2} \quad , \qquad (7)$$

where F_i is the forecast value, A_i is the NCEP analysis, and N is the number of cases (N=15). The average of RMSE over the domain to gives an idea of the magnitude of the mean inaccuracy in a concise format.

Figure 6 shows the vertical profiles of RMSE temperature averaged over the same domain, for the 24-h, 48-h and 60-h forecasts, and both Eta versions. Eta/OSU shows smaller forecast errors at almost all levels and forecast times. These differences are clearer after the first 24 hours of integration, especially at levels near the upper and the lower model boundaries, showing the positive improvements of the Eta/OSU version. In general Eta/OSU produces smaller errors in the tropical continental region (Figure 7) where vegetation cover is important. In contrast, larger temperature errors are found in the midlatitudes. The RMSE tend to increase faster with forecast time in the Eta/bucket version, especially over tropical latitudes.

The profile of RMSE of specific humidity (Figure 8) shows that Eta/OSU errors are lower at all times compared

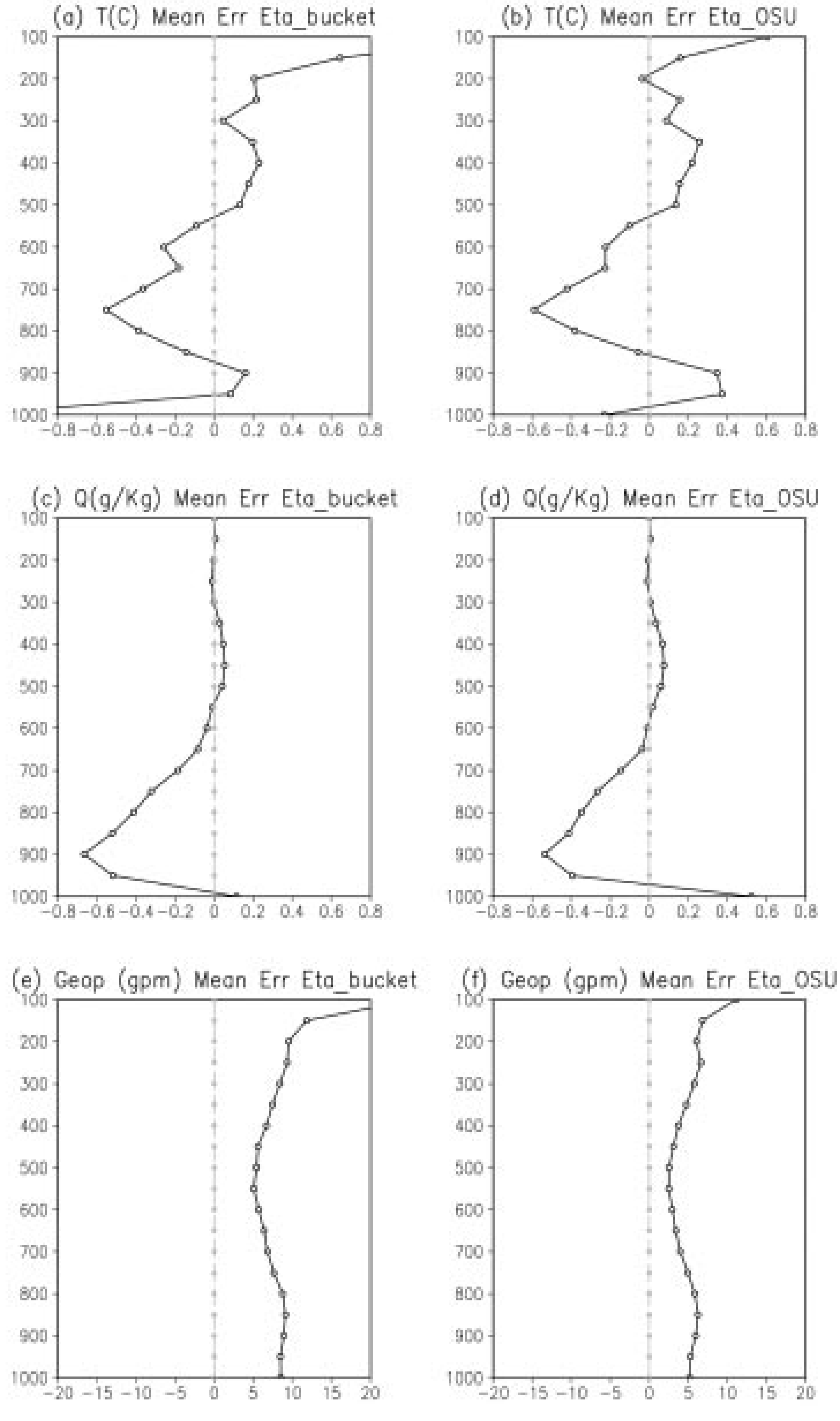

Fig. 3. Vertical profiles of temperature (ºC) (above), specific humidity (g/kg) (center) and geopotential height (gpm) (below) mean errors averaged over the whole integration domain and over the 15 selected weather situations. Left (right) column corresponds to the Eta_bucket (Eta/OSU) model version. Forecast lead time is 24 hours.

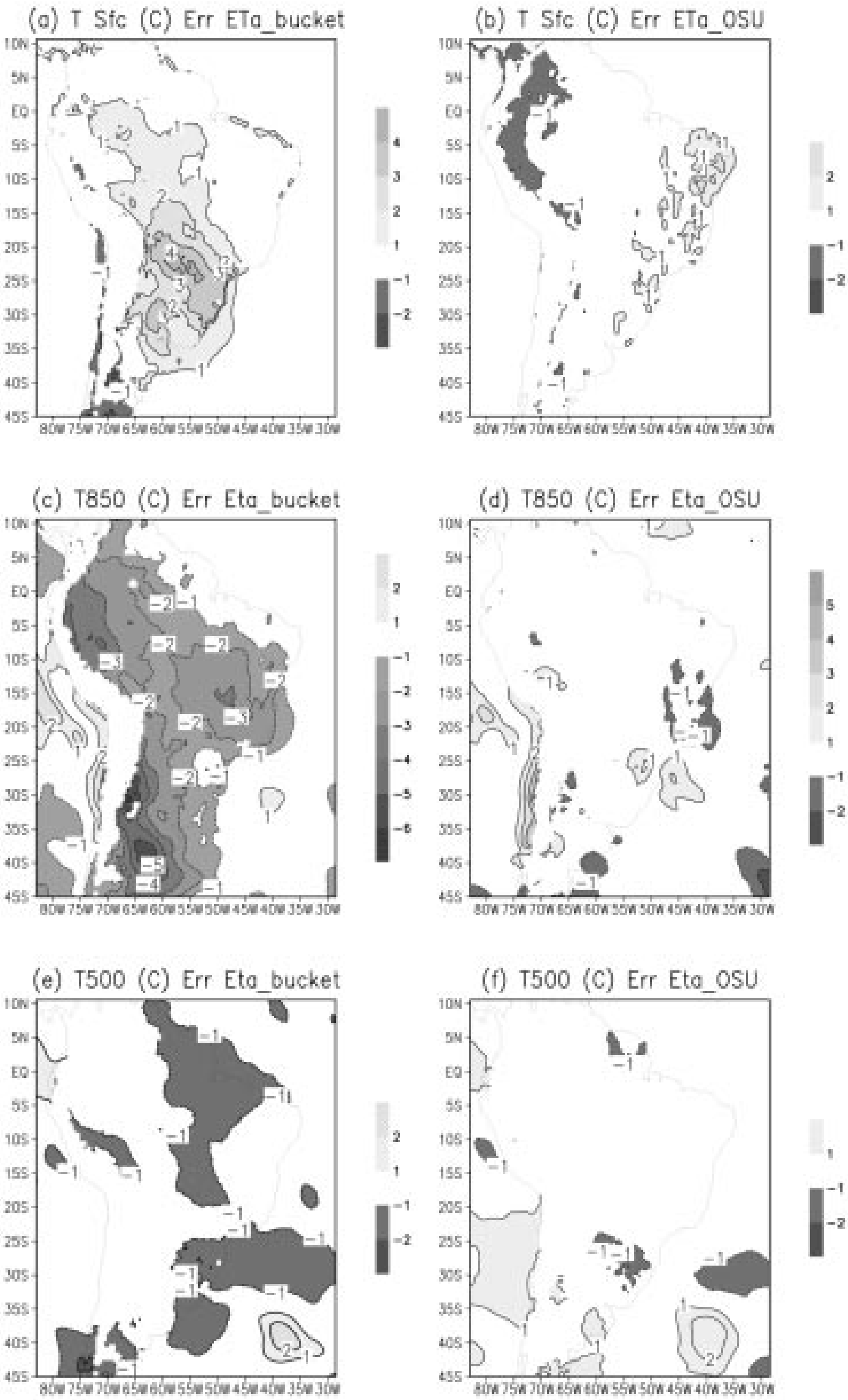

Fig. 4. Mean errors of temperature (ºC) for 48-hour forecasts at the surface (above), 850 hPa (center) and 500 hPa (below) levels. The left (right) column corresponds to the Eta/bucket (Eta/OSU) version. Values outside the -1° to 1° range are shaded.

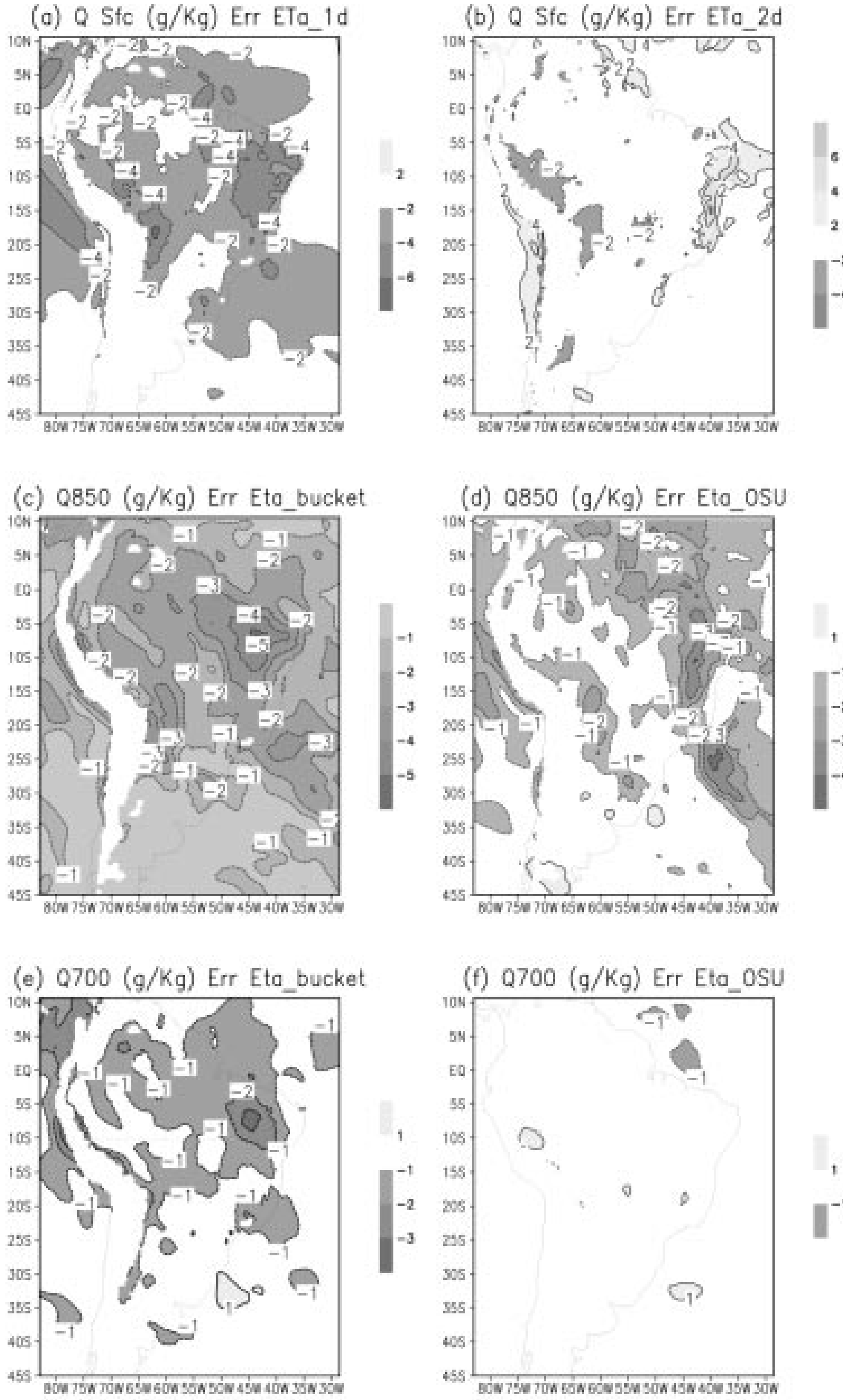

Fig. 5. Mean specific humidity errors (g/kg) at the surface (above), 850 hPa (center) and 700 hPa (below) levels. The left (right) column corresponds to the Eta/bucket (Eta/OSU) version.

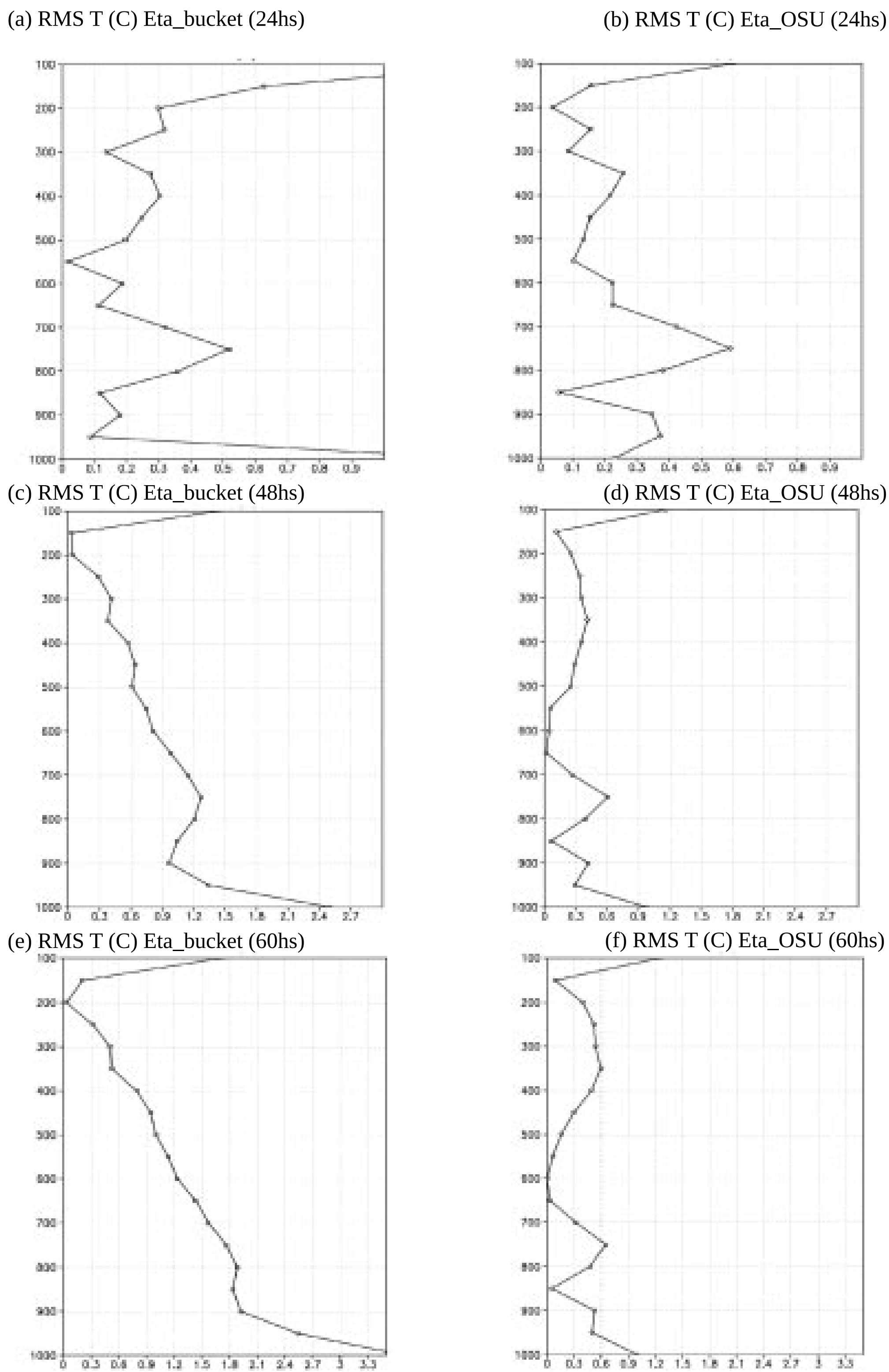

Fig. 6. Vertical profiles of root mean square temperature errors (ºC) averaged over the whole integration domain for the 15 selected weather situations. Forecast lead times are 24, (a and b) 48 (c and d) and 60hs (e and f). The left (right) column corresponds to the Eta/bucket (Eta/OSU) version.

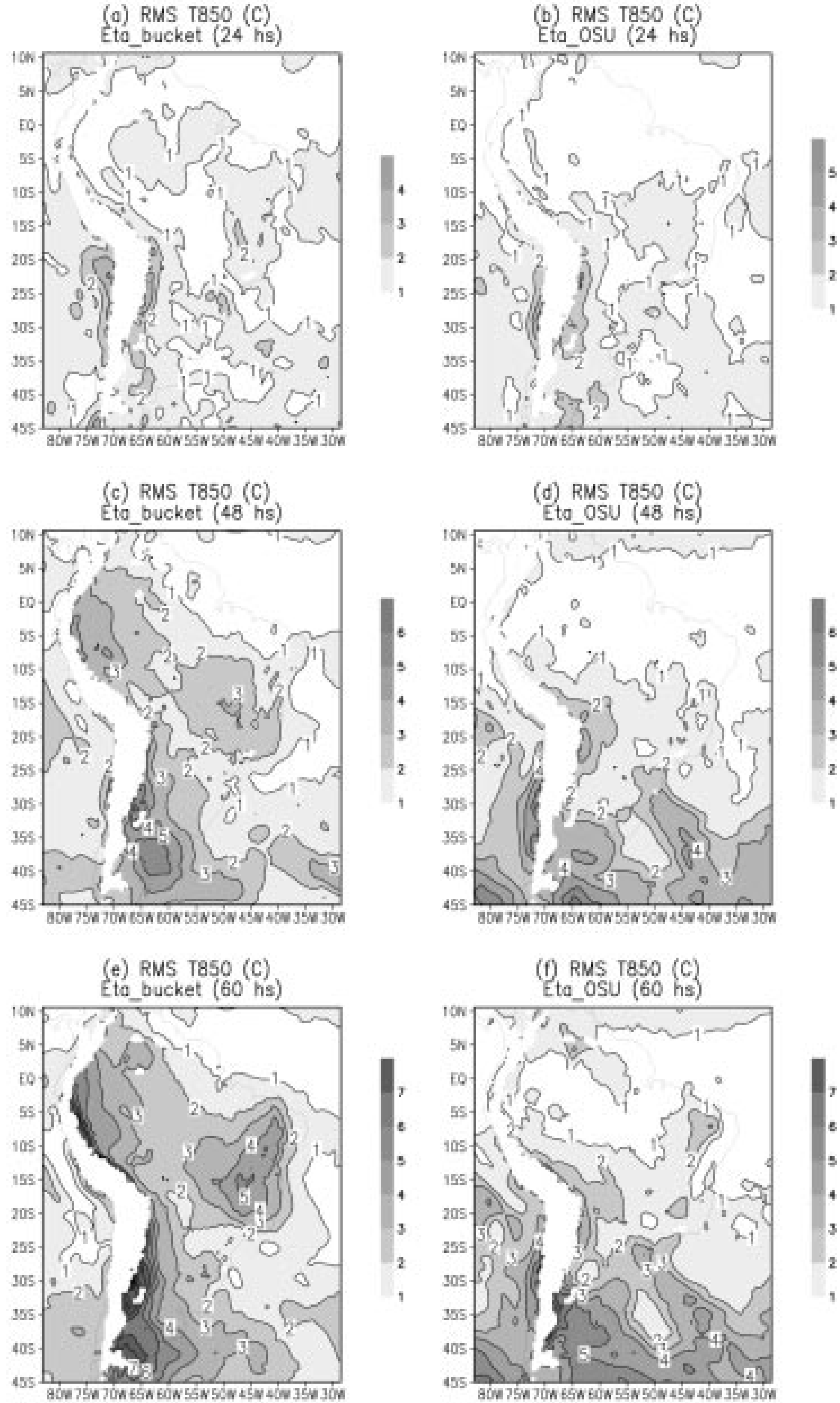

Fig. 7. Root mean square errors of temperature (ºC) for 24-h, 48-h and 60-h forecasts at 850 hPa. The left (right) column corresponds to the Eta/bucket (Eta/OSU) version.

to Eta/bucket, particularly for 48-hour and 60-hour forecasts. The old version has smaller errors only at 24-hour forecast and near the surface. Single level maps (not included) show that the differences between both model versions are stronger over the Amazon rainforest.

The geopotential height shows a different behavior, as the RMSE of 24-hour forecasts display minor discrepancies between the two model versions. After 48 hours of integration a slight improvement can be noted in the Eta/OSU forecasts. This behavior is consistent with the wind component errors, which do not exhibit significant differences for both versions.

4.3 Verification against upper-air soundings

In regions of sparse observations, e.g. over the Amazon, the Andes or the ocean, the analysis approaches the model forecasts. Moreover, models have some dependence on the initial conditions even after 24 hours of forecast. Here broad similarities can be found between the two versions. It is important to evaluate numerical predictions using observations, despite their small number. Some upper-air soundings of temperature and geopotential height were used for comparison with numerical forecasts. Since few aerological stations report at 00 UTC over South America these comparisons were carried out for 24-hour predictions starting at 12 UTC, and for all 15 selected meteorological situations. Table I lists the RMSE of temperature and geopotential height forecasts averaged over the 15 selected situations, at levels 850, 700, 500, 300, 200 and 100 hPa, for stations São Paulo (23.62°S, 46.66°W), Santa Rosa (36.57°S, 64.27°W), Quintero (32.78°S, 71.52°W), Porto Alegre (30.00°S, 51.18°W), Manaus (3.15°S, 59.98°W) and Belém (13.80°S, 48.48°W).

Sometimes the temperature and geopotential height forecast errors at some stations (especially Manaus, Santa Rosa and Quintero) are too large. These observations may have been rejected by the NCEP analysis. Table I confirms that Eta/OSU produces smaller errors in both variables and for most stations and levels, during the first 24 hours of integration except for Quintero on the Pacific side of the Andes. The error differences between the two versions favor Eta/OSU especially at Belem and Manaus, suggesting the importance of vegetation representation over these two Amazon stations.

4.4 Precipitation forecast skill

The precipitation forecast skill of both model versions

Table 1

Root mean square errors of (top) temperature (ºC) and (bottom) geopotential height (gpm) forecasts averaged over the 15 selected situations and calculated at the model grid point closer to the indicated upper-air stations.

	São Paulo		Santa Rosa		Quintero		Porto Alegre		Manaus		Belem	
Level	Eta/bucket	Eta/OSU	Eta/bucket	Eta/OSU	Eta/bucket	Eta/OSU	Eta/bucket	Eta/OSU	Eta/bucket	Eta/OSU	Eta/bucket	Eta/OSU
850	0.9	0.8	3.2	1.1	1.6	1.9	1.4	0.8	1.2	0.4	0.7	0.5
700	0.6	0.6	1.5	0.9	1.3	1.4	1.3	1.2	1.8	0.9	1.8	0.3
500	0.7	0.6	2.7	1.7	1.8	1.0	1.9	1.4	1.9	1.3	1.4	0.8
300	1.2	1.1	3.5	2.7	1.0	0.9	1.1	1.4	2.2	1.0	1.6	0.9
200	0.8	0.7	3.5	2.3	3.1	2.7	1.1	1.1	1.8	1.0	1.8	0.9
100	1.2	1.1	1.6	1.0	1.8	1.8	2.3	1.9	2.2	1.1	2.2	1.5

	São Paulo		Santa Rosa		Quintero		Porto Alegre		Manaus		Belem	
Level	Eta/bucket	Eta/OSU	Eta/bucket	Eta/OSU	Eta/bucket	Eta/OSU	Eta/bucket	Eta/OSU	Eta/bucket	Eta/OSU	Eta/bucket	Eta/OSU
850	18	11	25	11	12	13	22	19	21	7	23	11
700	16	10	34	19	21	22	17	12	17	6	17	13
500	9	9	31	26	20	17	23	20	12	10	17	11
300	15	10	30	28	38	31	24	19	21	18	20	18
200	22	20	29	28	39	32	27	17	50	35	42	32
100	20	18	42	39	36	35	26	19	57	37	28	21

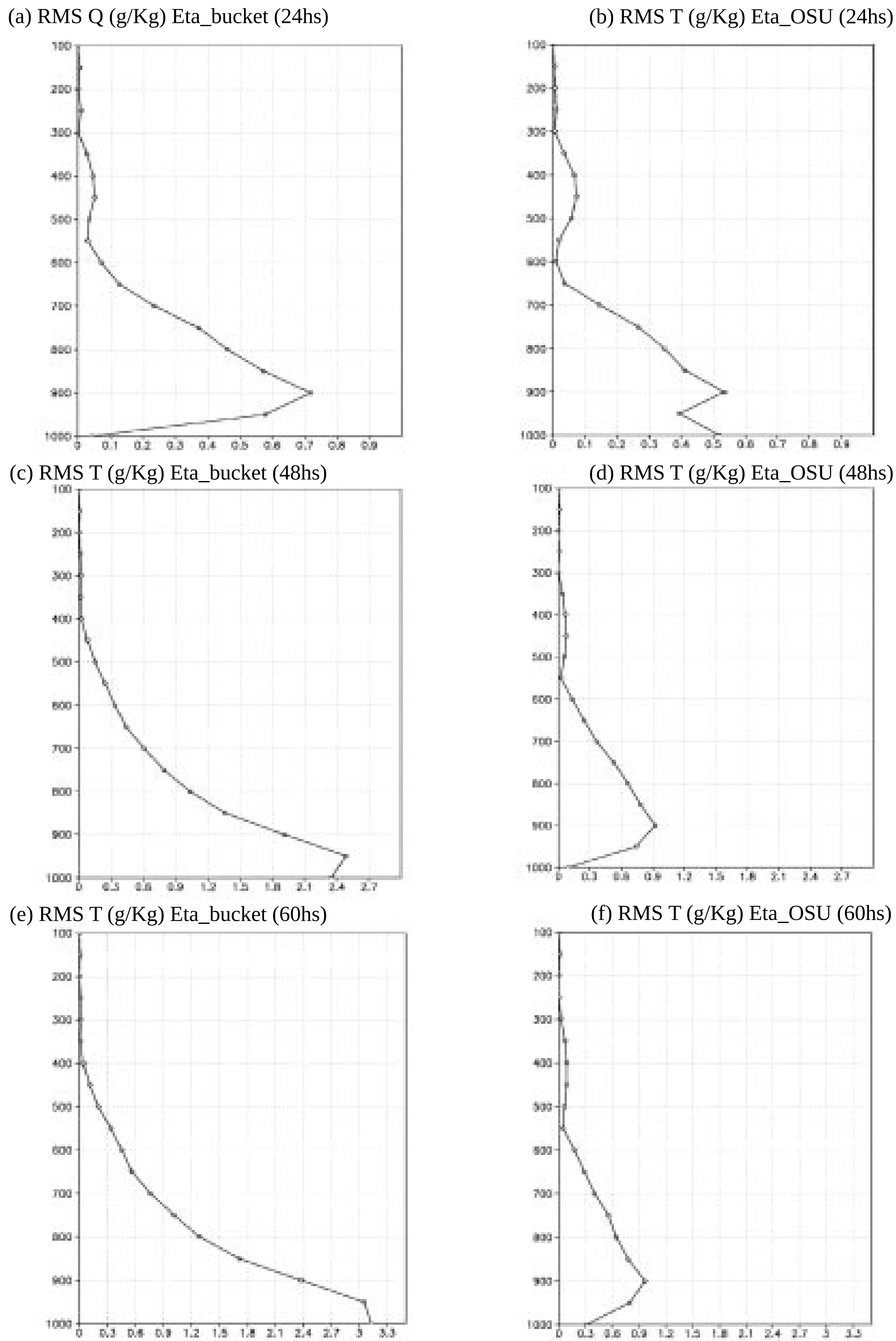

Fig. 8. Vertical profiles of root mean square specific humidity errors (g/kg) averaged over the whole integration domain for the 15 selected weather situations. Forecasts lead times are 24, (a and b) 48 (c and d) and 60hs (e and f). The left (right) column corresponds to the Eta/bucket (Eta/OSU) version.

has been evaluated objectively using the BIAS and the ETS scores. For each of the 15 meteorological situations the ETS and BIAS scores were calculated for different thresholds.

Figures 9a and 9b show that the 24-hour forecasts produced by Eta/OSU has a slightly higher ETS for all thresholds, particularly for higher ones, but has practically identical BIAS. Figures 9c and 9d indicate no significant improvement in ETS for 48-hour forecasts, but the BIAS scores show that Eta/OSU tends to overestimate the rainfall more than the Eta/bucket version. A division of the integration domain into three different regions (north, northeast and south) sugested that the most important improvements obtained by Eta/OSU took place over the northern regions in the Amazon rainforest.

The 15 weather situations were further divided into warm (November – April) and cold (May – September) to evaluate the model skill. The ETS for the Eta/OSU version is higher during the warm period, which is rainier. In these cases the ETS is slightly higher than the mean values shown in Figure 9. BIAS was improved by reducing the overestimation by about 25% for 48-hour forecasts.

Finally, in order to improve the quality of the precipitation prediction an experiment with the Eta/OSU version was carried out. the Betts-Miller convective scheme was adjusted with a new set of parameters. These coefficients were optimized for the current Eta/CPTEC version by Seluchi and Chou (2000b), with good results. The mean values of ETS and BIAS (OSUn in Figure 9) show that this new variant improves the forecast skill. The ETS were similar to the previous ones but the BIAS remained much closer to one. Thus the new set of parameters produces predictions where the rainfall is more accurately forecasted.

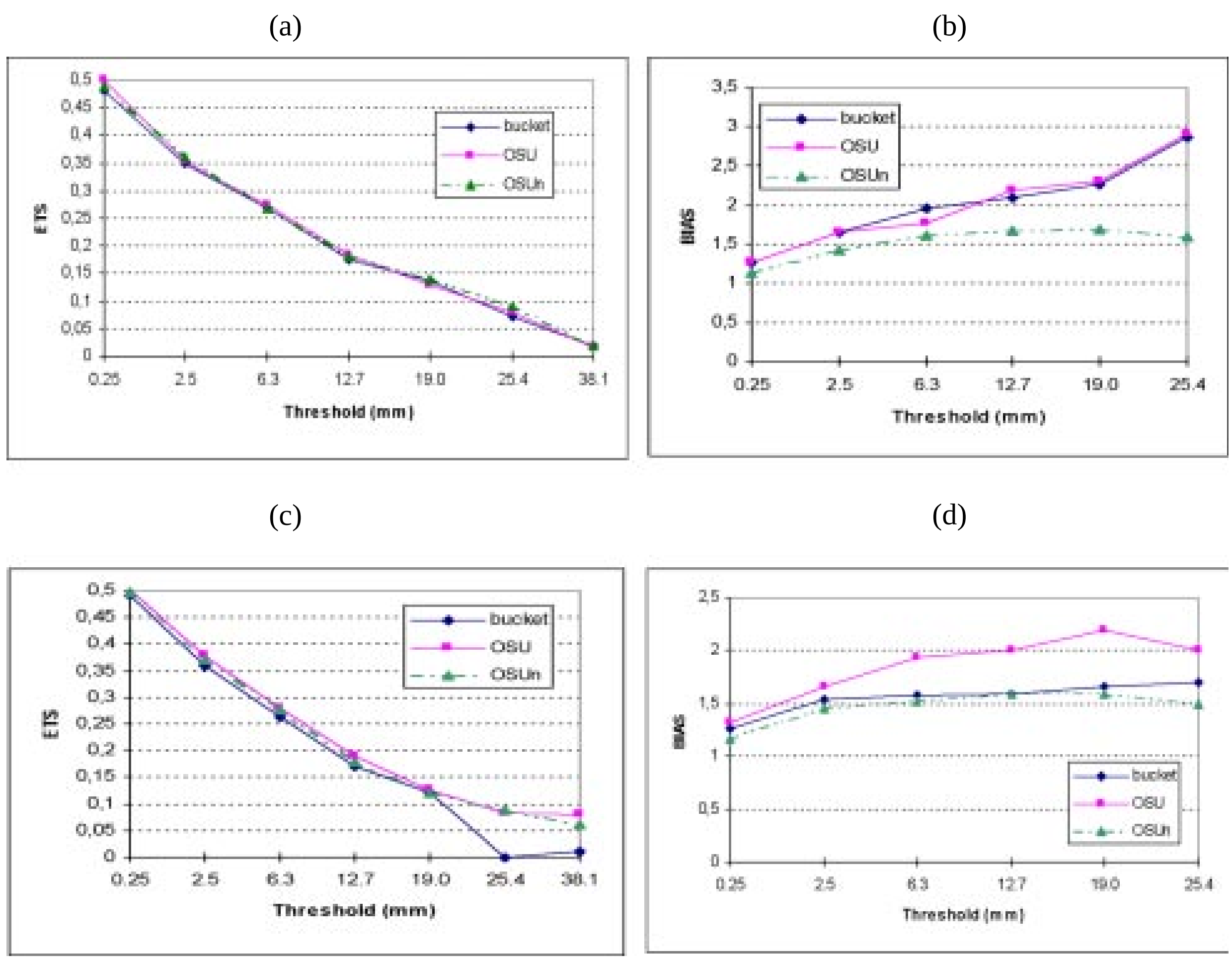

Fig. 9. Precipitation skill scores: (a) ETS and (b) BIAS obtained for 24 hour forecast for 3 Eta/CPTEC model versions (Eta/bucket, Eta/OSU and Eta/OSUn (including a new parameters set to adjust the convective scheme)). (c) and (d) Same as (a) and (b) except for 48 hour forecasts.

5 DISCUSSION AND CONCLUSIONS

An updated version of the regional Eta model used at CPTEC, the Eta/OSU, is evaluated and compared with the previous version, Eta/bucket. The Eta/OSU domain is larger, the model top is higher and the land-surface scheme includes different vegetation and soil types, whereas Eta/bucket uses the bucket model to treat land-surface processes.

The comparison was based on mean errors and root-mean-square errors of temperature, specific humidity and geopotential height forecasts for a set of 15 typical weather events during the year. Forecasts were compared with NCEP analyses and upper-air soundings.

The mean forecast errors do not differ strongly between the two model versions during the first 24 hours of forecast. Larger differences are noticed in the surface temperature, more accurately predicted by the Eta/OSU version. The most important improvement of Eta/OSU over Eta/bucket occurs in the tropical areas covered by rainforest. Surface temperatures over the semi-arid region of northeastern Brazil are not predicted as accurately, as the specific humidity at surface level is too high over this rather small region. Nevertheless Eta/OSU predicted specific humidity values closer to observations (analyses) in the lower troposphere (950-700 hPa).

The forecast error differences between both Eta versions emerge after 48 hours of integration, when the internal physics has developed and dominates over the initial conditions. At 48 hours of forecasts, Eta/OSU achieves higher skill than Eta/bucket for the temperature and the humidity fields especially over tropical forested regions.

A key question is which of the three differences between model versions is responsible for the largest impact on the predicted fields. Three additional experiments were performed for this purpose. First the Eta/bucket model was integrated over a larger domain, similar to those employed in Eta/OSU. The model top and the soil scheme remained unchanged. This sensitivity experiment (called DOMAIN Experiment) evaluated the impact of the size of the integration area on the forecast. A second experiment was carried out in order to test the influence of the model top: in the TOP Experiment the top of Eta/bucket was elevated from 50 mb to 25 mb. Finally, the SOIL Experiment analyzes the influence of the soil scheme on the model outputs. In this experiment the Eta/bucket was integrated in a domain similar (in size and top) to the one employed by Eta/OSU. In all cases the forecast lead-time is 48 hours.

Figure 10 shows the difference in temperature and specific humidity at lower and upper levels between the Domain, Top and Soil Experiment and the control Experiment (Eta/bucket). As expected, the effect of enlarging the integration domain is seen near the lateral boundaries (Figures 10a and 10b), especially near the southern border, though some humidity changes are also noted over subtropical latitudes and over the northeastern coast. Only the southern border is affected at middle and upper levels, which agrees with results obtained by Seluchi and Chou (1999). Thus, the Domain Experiment suggests that forecast improvements over the continental tropical latitudes are not essentially produced by the enlargement of the integration domain, as this region is located near the center of the grid far from the southern borders. Figures 10c and 10d show that the rise of the model top to 25 mb is mainly responsible for improvements in the upper tropospheric fields. This fact does not impact substantially the surface variables. Figures 10e and 10f suggest that the improvements of Eta/OSU over Eta/bucket are primarily due to the more complex land-surface scheme. This is in agreement with the largest impact detected over land areas, where interaction between ground, vegetation and atmosphere becomes more critical. It is thus expected that Eta/OSU performs better in the Amazon rainforest and after the first 24 hours of forecast, as the model fields become less dependent on initial conditions. The temperature increase produced by incorporation of the OSU scheme contributed to compensate the negative bias showed in Figure 2a. Eta/OSU forecasts more accurately the temperature at all model levels, particularly at the upper levels and near the surface. This shows the positive effect of raising the model top and including soil-vegetation-atmosphere interaction processes.

The geopotential height has higher skill at stratospheric levels, but no significant difference is found in the troposphere. This may be due to the fact that the geopotential height is more related to dynamic forcing (equations of motion) and less affected by the changes in the physical parameterizations.

Precipitation forecast skills were evaluated with ETS and BIAS. During the first 24 hours Eta/OSU produces similar ETS and slightly higher BIAS over Eta/bucket. After 48 hours the older version tends to produce a large overestimation of rainfall.

According to Seluchi and Chou (2000), the Betts-Miller scheme is responsible for most of the systematic errors in temperature and humidity detected in the model. This parameterization tends to generate a spurious cooling at midtropospheric levels that leads to unrealistic increases of convective instability, which contributes to overestimate the precipitation. For the 15 chosen situations the adjustment of the convective scheme with the new parameter set slightly reduced this spurious cooling, thus reducing overestimation of the precipitation rate. In general it is found that this ver-

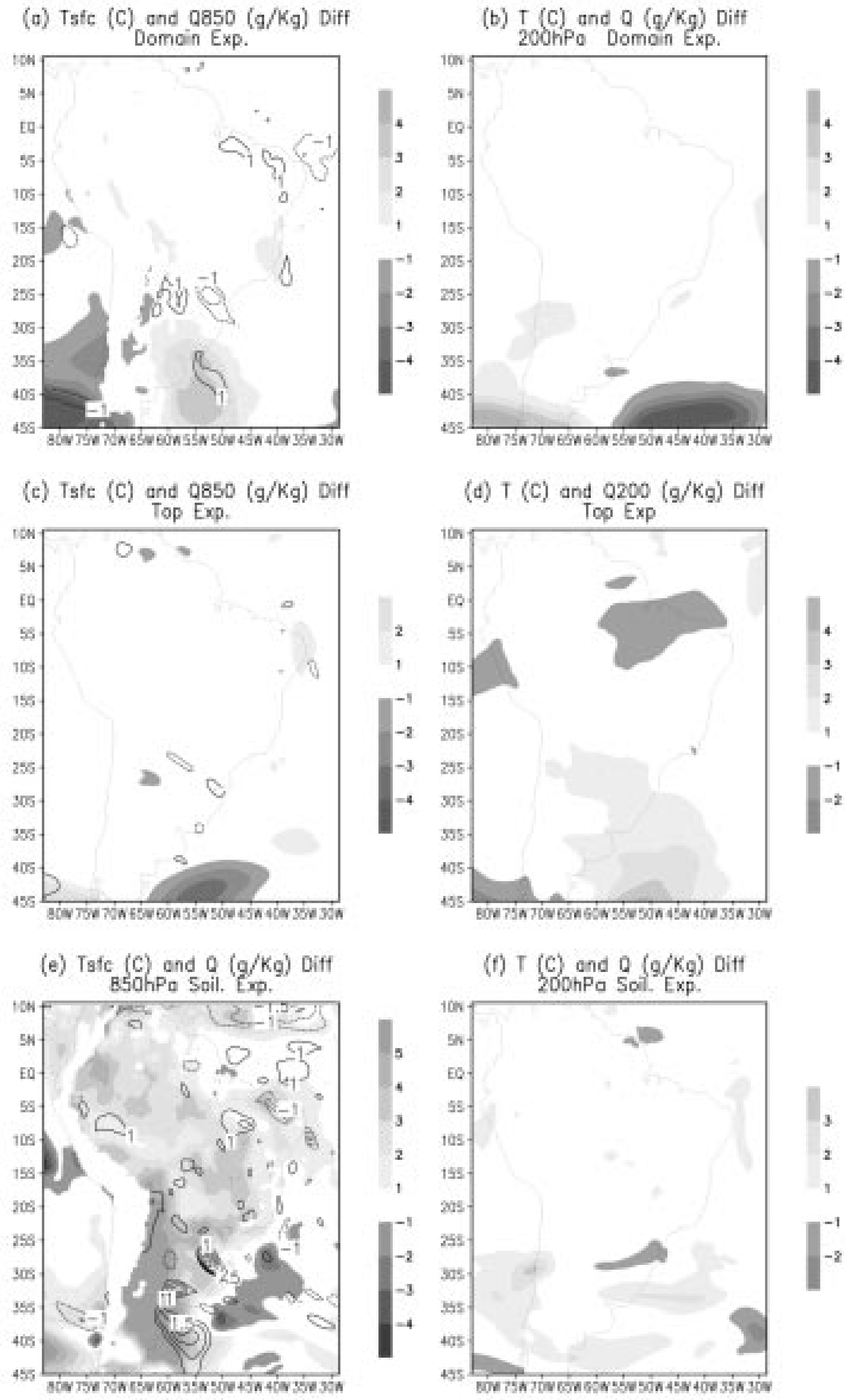

Fig. 10. (a) Difference in temperature (°C) and specific humidity (g/Kg) between the Domain Experiment and the Control Experiment (Eta/bucket) at 850 hPa. (b) Same as (a) at the 200 hPa level. (c) Difference in temperature (°C) and specific humidity (g/Kg) between the Top Experiment and the Control Experiment (Eta/bucket) at 850 hPa . (d) Same as (c) at the 200 hPa level. (e) Difference in temperature (C) and specific humidity (g/Kg) between the Soil Experiment and the Control Experiment (Eta/bucket) at 850 hPa. (f) Same as (e) at the 200 hPa level. Forecast lead time is 48 hours.

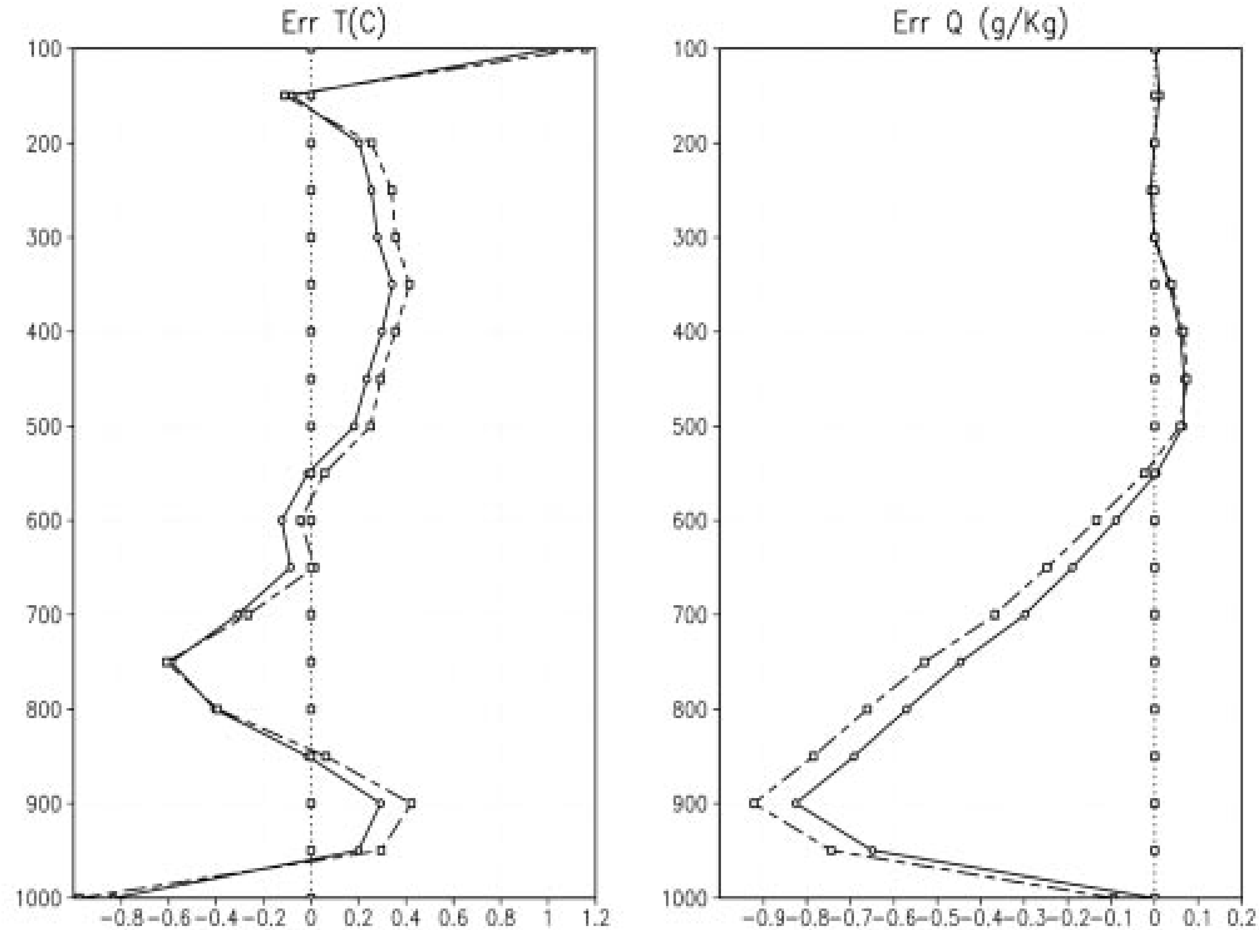

Fig. 11. Vertical profiles of mean Temperature (ºC) (left) and specific humidity errors (g/kg) (right) for the Eta/bucket (dashed line) and Eta/OSU with adjusted convective scheme (solid line).

sion yields a slight but systematic reduction of the mean and root-mean-square errors of temperature and humidity over the entire integration domain. Figure 11 shows this behavior for 48-hour forecasts.

The improvements in precipitation forecasts obtained by Eta/OSU are more significant over the Amazon region, between 83ºW and 45ºW and latitude 25ºS to 5ºN. The more accurate representation of surface processes produced higher forecast skill of the lower tropospheric temperature and humidity. Precipitation from deep convection predominates over the Amazon region, while convective instability depends on surface fluxes. This is consistent with the better performance of Eta/OSU during summer, when convective rains prevail. For both versions, the precipitation forecasts have lower skill for higher thresholds. However, at higher thresholds, the smaller number of occurrences reduces the significance of the results.

The number of cases in this study is still relatively small for statistical significance. However, conclusions are consistent in all cases.

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APPENDIX I

Meteorological cases chosen to study the performance of the Eta/CPTEC. Table includes the date and a brief description of the synoptic situation

Nº	Date	Description
1	03/06/98	Coastal cyclone over SE and S Brazil, anticyclone over mid latitudes.
2	14/06/98	Precipitation over N Brazil, warm front over Paraguay and Argentina.
3	03/07/98	Strong warm front on S Brazil and NE Argentina, depression at the NW Argentina (DNWA), precipitation over N Brazil.
4	06/07/98	Cold front over tropical latitudes, cold wave, precipitation over the northern tip of South America (SA).
5	10/08/98	Frontal wave over SE Brazil, migrating anticyclone over Argentina and Paraguay.
6	15/08/98	Frontal system over E Brazil (precipitation over Bahia State), precipitation over Colombia and Venezuela.
7	27/09/98	Cyclogenesis East of De la Plata river- strong cold front over S Brazil. ITCZ over the northern tip of the continent.
8	03/10/98	Cold front over Argentina.- DNWA development- precipitation over Colombia and Venezuela.
9	23/10/98	Strong cold front over S Brazil, anticyclone over Argentina yielding widespread frost.
10	21/12/98	Cyclone over the S Brazilian coast (precip.), anticyclone over N Argentina. Active ITCZ, precipitation over NE SA.
11	01/01/99	Anticyclone over Argentina, cold front on SE Brazil- SACZ intense precipitation.
12	05/01/99	Cyclonic center over SE Brazil (intense precip.) and blocking-type anticyclone over S Brazil.
13	20/01/99	Cold front over SE Brazil connected to an oceanic cyclone vortex, precipitation on N SA.
14	07/03/99	SACZ over E SA, cyclonic vortex over E and NE SA.
15	25/04/99	Migrating anticyclone over S coast of SA , warm front over S and SE Brazil –ITCZ.

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