HOW WELL DO ETA CPTEC/HADCM3 PRESENT CLIMATE SIMULATIONS REPRESENT FRONTOGENESIS IN EQUIVALENTE POTENTIAL TEMPERATURE AT 850 HPA?

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ABSTRACT: This paper aims to validate the frontogenesis in equivalent potential temperature at 850 hPa produced by the ETA model forced by HadCM3 CMIP3 present climate simulations. Model's seasonal averages are compared with ERA Interim Reanalysis between 1979-90. Results show differences of the order of 100% in frontogenesis. It is shown that these stem from differences in θ_e which shows a strong cold bias between -2 to -15 K, with largest deviations at the ITCZ. Biases in humidity reach up to -4 g/kg at 850 hPa at the ITCZ and in central Brazil for some seasons, while in the northeast Argentina and center-west Brazil temperature biases reach +4 K.

RESUMO: Este trabalho faz uma avaliação da frontogênese em temperatura potencial equivalente em 850 hPa produzido pelo modelo ETA forçado pelas simulações do HadCM3 para o CMPI3. As médias sazonais dos resultados do modelo entre 1979-90 são comparados com a reanálise ERA Interim. Os resultados mostram diferenças da ordem de 100% para a frontogênese. Estas vêm das diferenças em θ_e que tem um viés negativo entre -2 e -15 K, com os maiores desvios na ITCZ. O viés na umidade específica chega a -4 g/kg em 850 hPa na ITCZ e no centro-oeste do Brasil, enquanto no nordeste da Argentina e no Brasil central o viés na temperatura chega a +4 K.

1–INTRODUCTION

Tropical air masses over South America east of the Andes that migrate southward carry away moist and heat from both the tropical Atlantic and Amazon. Midlatitude air, on the other hand, is colder and drier and strong frontogenesis in equivalent potential temperature occurs in the encounter of both air masses. Indeed, it has been found by previous studies that the South American subtropics exhibits high climatological frontogenesis in equivalent potential temperature during summer (Arraut, 2007, and references therein). Moreover, Arraut and Barbosa (2009) showed that deformation of the wind field is the main contributing mechanism and also analyzed the synoptic conditions present in high frontogenesis situations. They found the Northwestern Argentinean Low (NAL), a transient trough to its south and the Argentinean Col (AC) separating both. Barbosa and Arraut (2009) showed the AC to be a preferred spot for frontogenesis. The Andes Cordillera can enhance the NAL and hence the occurrence of the AC when a westerly jet is present in high levels over the Cordillera. The so called

Zonda wind promote extra heating via the Foehn effect. It can also block the low level zonal flow of trade winds, forcing them southwards, or serve as a barrier to northward incursions of cold air. The intent of this paper is to validate the frontogenesis in θ_e simulated by the ETA model for the 20th century.

2–MATERIAL AND METHODS

Temperature, humidity and geopotential are taken from the ECMWF ERA Interim Reanalysis (Dee et al., 2011). It has a 1.5^o horizontal resolution and 37 vertical pressure levels, provided at 6hr intervals starting in Jan/1979. As noticed by Dee and Uppala (2008), ERA Interim has a better humidity analysis, having a significantly lower bias in both total column water vapor and tropical precipitation. Chou et al. (2012) performed a dynamical downscaling of present climate over South America by driving a modified version of ETA model with HadCM3 output. Data used here are from the control run, available at 6hr intervals between 1960-90, at 0.4^o resolution and 38 vertical levels.

Equivalent potential temperature, θ_e, was calculated for both data sets according to Bolton (1980). Frontogenesis in θ_e (FG) was then computed as sum of four terms (Ninomiya, 1984) shown in the square brackets below:

$$\begin{aligned} FG|\nabla\theta_e| \quad = \quad & \left[\frac{(\nabla\theta_e\cdot\nabla)}{|\nabla\theta_e|}\frac{d\theta_e}{dt}\right] - \left[\frac{(\nabla\theta_e)^2}{2|\nabla\theta_e|}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)\right] - \left[\frac{B}{|\nabla\theta_e|}\frac{\partial\theta_e}{\partial x}\frac{\partial\theta_e}{\partial y}+\right. \\ & \left.\left\{\frac{A}{2|\nabla\theta_e|}\left(\frac{\partial\theta_e}{\partial x}\right)^2-\left(\frac{\partial\theta_e}{\partial y}\right)^2\right\}\right] - \left[\frac{\partial\theta_e}{\partial p}\left(\frac{\partial\theta_e}{\partial x}\frac{\partial w}{\partial x}+\frac{\partial\theta_e}{\partial y}\frac{\partial w}{\partial y}\right)\right] \end{aligned}$$

where $A = \partial_x u - \partial_y v$ and $B = \partial_x v + \partial_y u$ are deformation terms. The first is the frontogenesis due to diabatic changes of θ_e. The second is the effect of divergence and the third (FG_3) that of deformation. The last accounts for vertical advection of θ_e.

For the current study, twelve years from January 1979 to December 1990 were analyzed focusing of the fields at 850 hPa. Vertical derivatives were computed using ancillary levels at 900 hPa and 800 hPa that exist in both data sets. Monthly means were computed from 6hr data and climatological averages were calculated. For computing the differences, the ETA model data was regridded to the lower horizontal resolution of ERA Interim data.

3–RESULTS AND DISCUSSION

Figure 1 shows the total frontogenesis and the deformation term. For all seasons there is a negative bias north of 20S and a strong positive bias south of 20S for the total frontogenesis. Values reach as much as $\pm 3\ K/100\ km/day$, which is of the same order of magnitude as the total frontogenesis itself (not shown). A comparison of the upper and middle panels indicate that the source of the bias is the FG3 term. Moreover, the excessive frontogenesis by deformation over the southeast in the ETA simulations resemble a SACZ (South Atlantic Convergence Zone) pattern semi-permanent between September to March. A strong positive (negative) bias is also found on the eastern (western) sides of the Andes. This is not related to topography as the light green color in the figure masks out the regions where the 850 hPa level lies below the topography. An analysis of the individual terms (not shown) indicates that the divergence term (FG2) is the larger contributor to this bias.

These large systematic errors in the frontogenesis must come from the calculated equivalent potential temperature and this is shown in third line of figure 1. There is a strong cold bias between -2 K and -15 K in all seasons, except for southern Brazil where a somewhat positive bias is found from April to October, and part of the Amazon from July to October. The strong cold bias seems to be correlated with the convergence zones, reaching its most negative values on the ITCZ (Intertropical Convergence Zone). There is a strong ocean to continent gradient in the differences shown in θ_e particularly where the ITCZ encounters the continent. This gradient must be forcing and changing large scale circulation, but this was not investigated here.

The differences in θ_e must come from the temperature and humidity fields, and this is shown in figure 1. From all seasons, the least close to ERA Interim is Sep-Oct where up to +4 K and -4 g/kg are found in central Brazil. For the other seasons, the dry bias in ETA simulation is less than -2 g/kg, except for the ITCZ where it reaches -8 g/kg in Apr-Jun. For the temperature, the differences stay between +4 K and -3 K, over central South America and eastern Pacific ocean respectively.

4–CONCLUSIONS AND FUTURE WORK

Large systematic differences were found between the ETA simulations and ERA Interim data set regarding the frontogenesis in θ_e which were shown to stem from differences in θ_e which in turn stem from differences in both temperature and humidity fields. Differences in the total frontogenesis are of the same order of magnitude of the total field from ERA Interim. The excessive frontogenesis the southeast Brazil in the ETA simulations indicates a semi-permanent SACZ pattern between Sep-Mar.

Biases in humidity are negative east of the Andes. In case the ETA model is correctly simulating the magnitude of the wind field, then the southward moisture transport will be underestimated by roughly the same amount as the humidity, which is of the order of 20% (analysis not shown). For the temperature, biases are generally positive over land and negative over ocean. Interestingly, on regions of permanent cloud clover the model has different behaviors. On deep convective regions (e.g. ITCZ) it is much dryer than ERA Interim, while on the Pacific deck of stratus clouds, much colder.

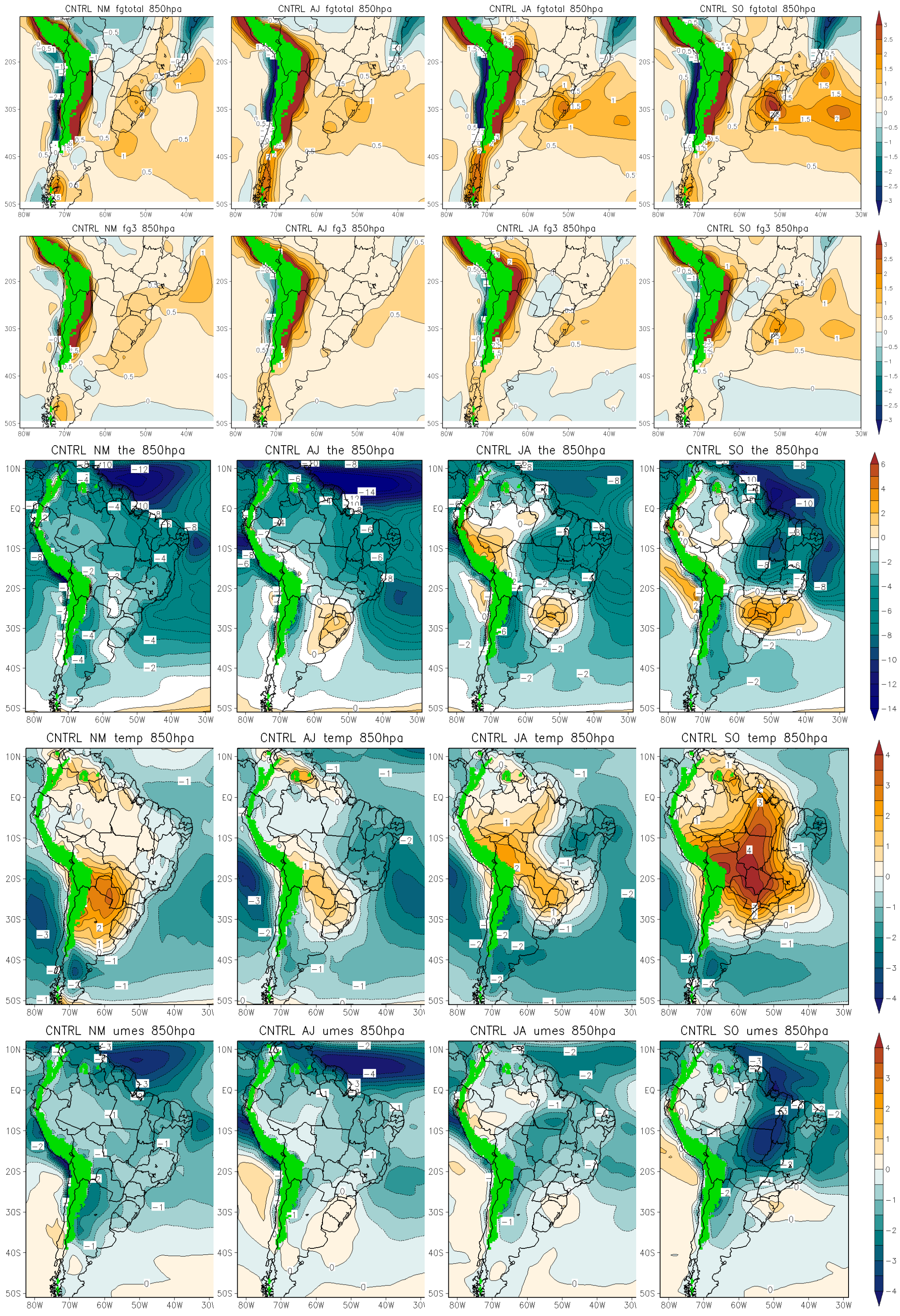

Figure 1: Differences between ETA control run and ERA Interim are shown. From top to bottom: FG and FG3 given in K/100km/day, θ_e and temperature in K, and specific humidity in g/kg. Columns give seasonal averages: Nov-Mar (NM), Apr-Jun (AJ), Jul-Aug (JA) and Sep-Oct (SO).

To understand the origin and confirm these biases, further analysis will need to be taken. Surface fluxes, clouds and radiation balance will have to be verified, and other reference data sets such as NCEP Reanalysis and satellite data must be compared.

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