COMPARISON BETWEEN ETA VS SIGMA COORDINATE MODEL RUNS OVER SOUTH AMERICA

Sin Chan Chou
Centro de Previsão de Tempo e Estudos Climáticos/INPE
Cachoeira Paulista, SP, Brazil

Christopher A. Peters
National Centers for Environmental Prediction/NOAA
Camp Springs, MD, USA

Abstract

Vertical coordinate in the Eta model is redefined to sigma coordinate allowing comparisons between the eta and the sigma coordinate forecasts using the same model formulation. The comparisons are applied over the steep Andes mountains for two different period cases. Run differences are located in the vicinity of the mountains. While sigma mode runs show more structure in the fields, the eta runs show more intense features. Upper level jet lags behind in sigma runs.

1. **Introduction**

The Andes mountain runs longitudinally along the west coast of South America. It exhibits heights that generally exceed 4000 m, and width that reaches the maximum of about 600 km at about 17°S, forming the Bolivian Plateau. It is likely that numerical models produce errors in the atmospheric fields in the vicinity of these mountains due to their geometry. The use of sigma vertical coordinate leads to possible errors in the calculation of the pressure gradient force (Mesinger and Black, 1992). The objective of this works is to compare the forecasts from the same regional model using sigma and eta vertical coordinates over the steep and narrow Andes mountain chain.

2. **The coordinates**

The sigma coordinate, also known as terrain-following coordinate is defined as (Philips, 1957):

$$\sigma = \frac{p - p_t}{p_s - p_t}$$

where *p* is the air pressure, and the subscripts *s* and *t* refer to the surface and top of the model.

The advantages of this coordinate are: 1. never intersects the ground, 2. uses simple boundary conditions, and 3. the boundary fluxes are resolved at constant and thin depths. The disadvantages are: 1. the coordinate surfaces slope steeply to follow steep mountains, 2. horizontal derivative calculations yield errors in the vicinity of mountains, particularly for pressure gradient force, and 3. errors increase as model resolution increases with mountain slopes being better represented.

The eta coordinate was defined by Mesinger (1984) as:

$$\eta = \frac{p - p_t}{p_s - p_t} \frac{p_r(z_s) - p_t}{p_r(0) - p_t}$$

where the first term is the sigma definition and the second term is a correction based on a reference atmosphere. The surfaces of this coordinate are approximately horizontal and therefore errors in obtaining quantities from space derivatives such as pressure gradient force, diffusion or horizontal advection, are practically removed, and consequently there is no increase of errors with resolution. The simple boundary conditions are kept. However, this coordinate also presents disadvantages which is the coarse vertical grid as mountain height increases. The boundary layer fluxes are not resolved properly as Mellor-Yamada level 2.0 closure scheme used in the model works best with a surface layer resolution on the order of tens of meters; over high orography this requirement is difficult to meet. Another disadvantage is the internal boundary condition which is introduced where *u=0.*

3. **The model**

The Eta model used in these experiments covered most of South America continent and part of adjacent oceans. The resolution used was 80 km and 38 layers with model top at 50 mb. The initial conditions were taken from T062L28 NCEP Global Model Analyses and the lateral boundary conditions were taken from T062L28 CPTEC/COLA Global Model Forecasts and updated every 6 hours. Model details are given in Black (1994).

In the eta coordinate definition, by setting the second term to 1, the model is configured to run in sigma mode.

4. **The comparison**

Two runs are shown here. A summer condition which starts from 12UTC, on 04 February 1997 and a winter condition from 12UTC, on 11 June 1996. In the first case, there was cold front on the lee side of the mountain, whereas in the second case, a cold front is transposing the mountains at about 35^{o}S.

24-h forecast of 500-mb geopotential heights (Figure 1 a,b) show that the largest differences between sigma and eta runs can occur on both leeside and upstream of the Andes. The contours are smooth over the Andes on the eta runs, but noisy in the sigma runs.

Cross section of isentropic surfaces (Figure 2 a) for the summer case show these surfaces practically horizontal above the Andes. Larger differences in temperature are found in the layers adjacent to the mountain, and also in regions of stronger static stability. On the other hand, in the winter case for the eta run (Figure 2 b) a wavy feature on the isentropic surfaces is seen approaching the Andes and diving on the leeside. In the sigma run, however, these surfaces are noisier on the top of the mountains and waves have smaller amplitude. Downstream and away from the mountain the differences in the run are still small at 24-hour forecast.

Cross sections of the zonal wind for the summer case (Figure 3 a) show stronger upper level jet in the eta run. This jet lags behind in the sigma runs. These features were also found in the winter case. Vertical velocity (not shown) tends to be weaker in the sigma run. Errors in the calculation of pressure gradient may be causing these differences.

5. **Final Comments**

Important differences were found between these two coordinate runs using the same model configuration. Some features of differences have also been noted in GCM comparisons (Wyman, 1996). These results are preliminary, as more work is necessary in validating either forecasts. However, validation of these runs are difficult due to the lack of observed data. Currently only global model analyses are available for validation, however, those data are biased to the first guess fields which use sigma coordinate.

The main error source in the eta coordinate can be reduced by increasing vertical resolution, in the sigma coordinate, however, the main error source is numerical.

Further investigation is continued on the waves, speed of the zonal wind and on the need of representing gravity wave drag in the eta mode runs.

6. **References**

Black, T. L., 1994: The new NMC Mesoscale Eta Model: Description and Forecast examples. *Weather and Forecasting*, **9**, 265-278.

Mesinger, F. and T. L. Black, 1992: On the impact of forecast accuracy of the step-mountain (eta) vs. sigma coordinate. *Meteorol. Atmos. Phys.*, **50**, 47-50.

Mesinger, F., 1984: A blocking technique for representation of mountains in atmospheric models. *Riv. Meteor. Aeronaut.*, 44, 195-202.

Phillips, N. A.,1957: A coordinate system having some special advantages for numerical forecasting.*J. Meteor.*, **14**, 184-185.

Wyman, B. L., 1996: A step-mountain coordinate General Circulation Model: description and validation of medium-range forecasts. *Mon. Wea. Rev.*, **124**,102-121.

Fig.1 (a) 500–mb Heights
97020412 + 24h

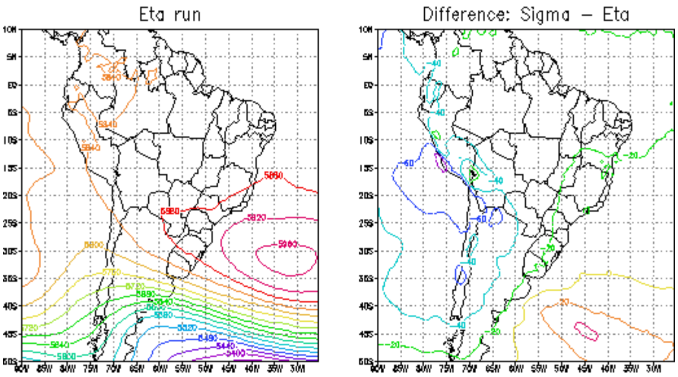
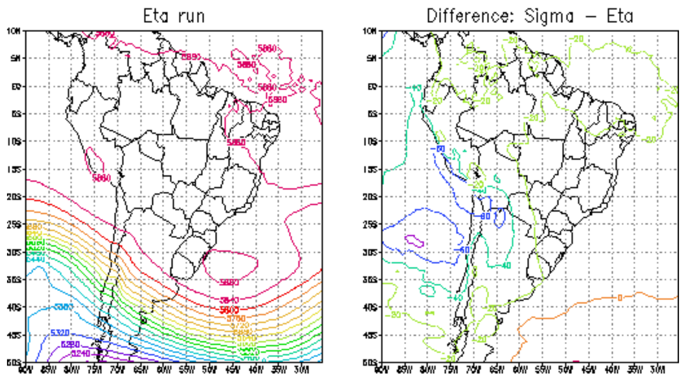


Fig.1 (b) 500–mb Heights
96061112 + 24h



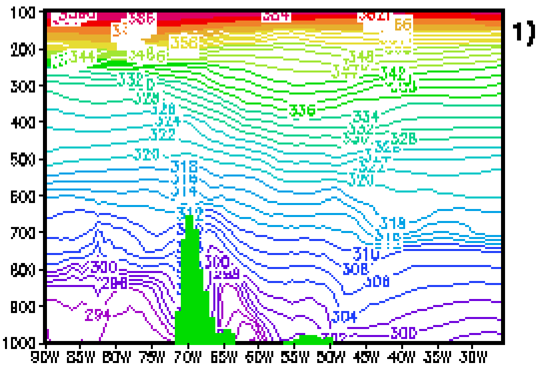
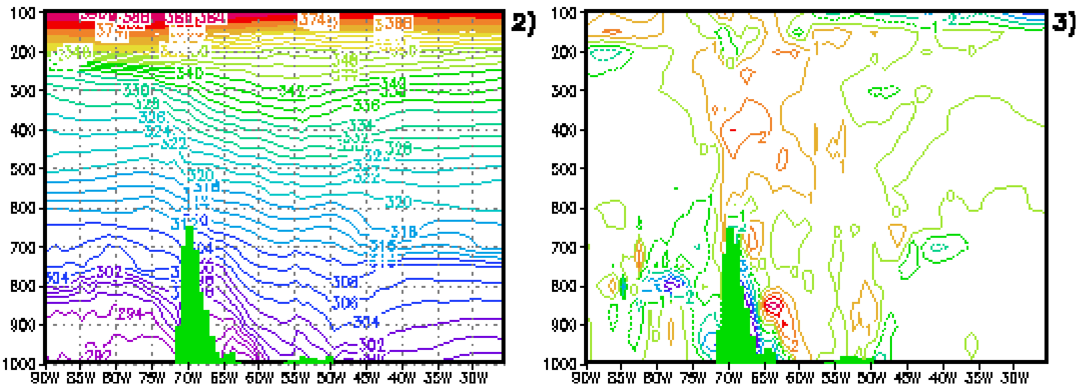
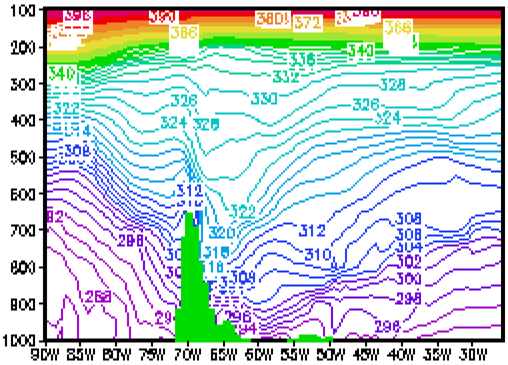


Fig.2 (a) Potential Temperature (K) along 30S

97020412 + 24h

1) Eta run
2) Sigma run
3) Diff: Sigma – Eta



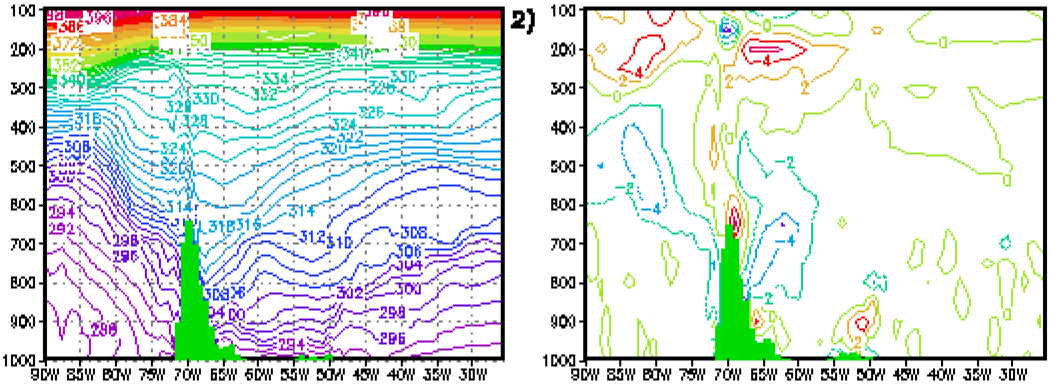


1)

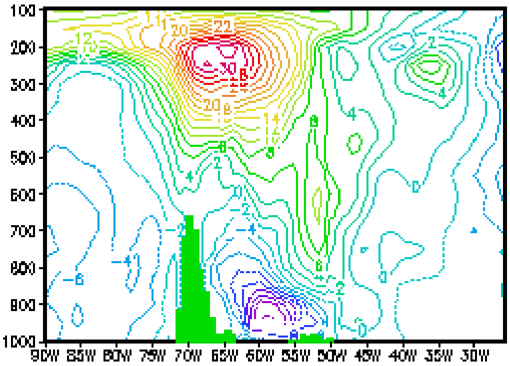
Fig.2 (b) Potential Temperature (K) along 30S

96061112 + 24h

1) Eta run
2) Sigma run
3) Diff: Sigma − Eta



2) 3)

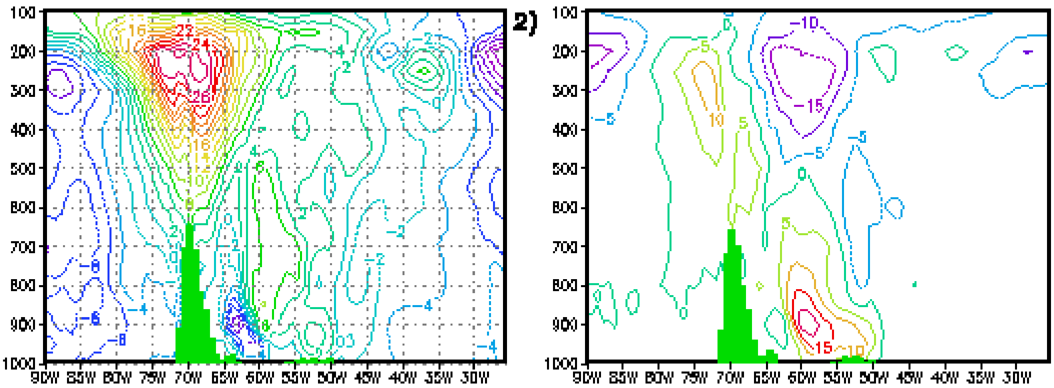


1)

Fig.3 (a) Zonal Wind (m/s) along 30S

97020412 + 48h

1) Eta run
2) Sigma run
3) Diff: Sigma − Eta



2) 3)