INVESTIGATION OF SOUTH AMERICAN LAND/ATMOSPHERE INTERACTIONS USING THE REGIONAL ETA/SSIB MODEL

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The NCEP Eta model coupled with a biosphere model, SSiB, was set up over the South American continent to study the role of land/atmosphere interactions in the South American hydrometeorology and regional climate predictability.

NCEP Reanalysis and NCEP GCM output were used as initial and lateral boundary conditions for the simulations. Sea surface temperature, sea ice concentration and snow cover were updated daily during the simulation. Results were compared to GCM and Reanalysis data as well as to observation to evaluate the dynamic downscaling of the regional climate model in regional hydrometeorological study. To understand the predictability, a series of sensitivity studies has been designed to explore the role of variety of factors in water cycle simulations. These factors include domain size, horizontal resolution, different lateral boundary conditions (NCEP reanalysis and GCM outputs), sea surface temperature, and land conditions. The first part of this study is shown herein.

Preliminary results indicate the regional model was able to capture most of the features of precipitation distribution over South America when compared to the GCM results and Reanalysis data. Improvement was greater for the dry and transition seasons. Eta improvement was less significant in the wet season when the model underestimated precipitation over much of the Amazon Basin, ITCZ and southern Brazil.

The study shows the importance of a regional model and the proper land surface processes representation in the South American rainfall simulation and the role of more realistic boundary condition description in predicting its regional climate.

1. INTRODUCTION

One of the major goals of the large-scale biosphere experiment in Amazonia (LBA) is to understand the seasonal-to-interannual precipitation cycle in South America and how land use/land cover influences it. The spatial and temporal distribution of precipitation in the Amazon Basin largely depends on convective activity (Peagle, 1987). Horel et al. (1989) using a 15-year record of outgoing longwave radiation from satellite observations to describe the annual cycle of large-scale convective activity in central South America, have shown that the circulation of the upper atmosphere over tropical South America during the austral summer is associated with a large region of intense convection centered over the Amazon Basin. In a more recent study based on the Data Assimilation System (DAS) of the Goddard Earth Observing System-1 (GEOS-1) and satellite-derived-rainfall, Zhou and Lau (1998) inferred that the austral spring, summer, and fall rainfall activity in South America has characteristic features of a monsoon climate system.

Previous modeling studies on South America focused on the interaction between regional climate and Amazon deforestation (Nobre et al., 1991, Xue et al., 1996). The use of the Eta model with a bucket scheme at the surface was tested in a South American study by Tanajura (1996). Chou et al (2000) using the Eta model coupled to the biosphere model SSiB concluded that the coupled model improved surface temperature and enhanced precipitation simulation in the interior of the continent due to a better representation of land surface sensible and latent heat fluxes when compared to non-coupled model results.

The mechanisms that govern the development of the South American summer monsoon (SASM) are poorly understood, despite its importance in providing water for agriculture and for the replenishment of that continent's major rivers (Amazon, Parana and Paraguay). The lack of in-situ measurements over most of central and northern South America, as well as along the high elevations of the Andes make the use of atmospheric model a key instrument in better understanding the main forcings and constrains on the processes that govern the SASM.

In this study we analyze the use of the NCEP regional atmospheric Eta model coupled to the biosphere SSiB (hereinafter Eta) in the attempt of improving the results obtained from the NCEP GCM/SSiB (hereinafter GCM) coupled model simulation of the 1987 SASM event. The GCM simulation outputs were used as boundary and initial conditions for the Eta simulations to evaluate the dynamic downscaling of the regional climate model.

This paper presents the first part of the study where we focused on precipitation results. Simulated and observed average precipitations are compared to assess improvements associated with each model simulation. Reanalysis precipitation is also used in the comparison as a reference. The impact of the regional

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model domain size is also analyzed by running the same periods on three different domain sizes.

2. EXPERIMENTAL DESIGN

The GCM was set up on a T42 horizontal resolution, 28 vertical-level configuration. While the Eta model was set up with 80 x 80 km horizontal grid and 38 vertical levels centered at 60W and 22S.
The GCM simulation consists of a 1-year long run starting on 00 UTC 01 May 1987. The NCEP/NCAR Global Reanalysis (Kalnay et al., 1996; Kistler et al., 1999), hereafter referred to simply as "Reanalysis", was used as the source of initial conditions for the atmosphere, ocean surface boundary conditions (SST and sea ice), and initial snow depth in the GCM runs. Initial soil moisture was taken from the GEWEX soil wetness project (GSWP, Dirmeyer et al., 1999).
The 1-year long run was then divided into 3 segments, namely dry, transition and wet season, each having a 3-month period (Table 1). Each season was then simulated again this time with the Eta model using the GCM results as initial and boundary condition. The boundary conditions were updated at every 6 hour of simulation. Reanalysis SST and ice cover initial condition were used on the Eta simulations.

Table 1: Eta simulation periods.

Season	Period
Dry	June-July-August 1987
Transition	September-October-November 1987
Wet	December-January-February 1987/88

The impact of Eta model domain size on the simulations was assessed by running the “transition season” case on 3 different domain sizes. The sizes of the domains are specified on table 2. The domain sizes were chosen in a way to cover more or less ocean on the simulations. All the domains have the same horizontal and vertical resolutions and were centered on the same coordinates. They differ only on their longitude span. The latitude range for all simulations was from 57.0S to 15.0N.

Table 2: Eta simulation domain sizes.

Run	Longitude span
Original	110.0W ~ 5.0E
Large	145.0W ~ 25.0E
Small	105.0W ~ 10.0W

The global land cover classification map that specifies land conditions for the NCEP GCM and Eta was developed at the Department of Geography, University of Maryland (Hansen et al, 1999) and was based on the NOAA/NASA pathfinder AVHRR 1-km land data set. The classifications were derived using a decision tree classifier with training data from a global network of high resolution Landsat data. The land cover data sets were validated with Landsat data as well as with regional data sets. The dominant vegetation type was specified for every grid point on each model according to the dominant class in the histogram of the 12 SSiB vegetation types. More detailed procedure of this type of conversion could be found in Xue et al. (2001).

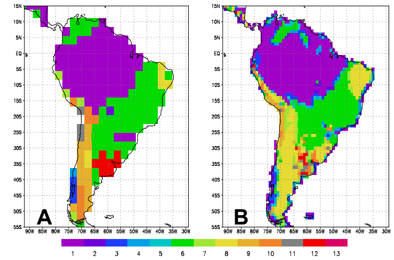

Figure 1: South America SSiB vegetation type map. A) GCM and B) Eta model (NOAA/NASA).

3. RESULTS

3.1 Rainfall simulations

Figure 2 shows the observed monthly average precipitation for each of the 3-month period in Table 1. During the dry season most of the precipitation is located in the NW portion of the continents (Figure 2a). Two other areas with significant mean precipitation in the continent are southern and northeastern Brazil and the southern Andes. The central section of the continent receives less than 2 mm of rainfall a day on average. During the transition season precipitation spreads through the central section of the continent extending from southern Central America through central and southern Brazil to northeastern Argentina (Figure 2b). Precipitation is reduced over the southern Andes and Brazilian northeast.

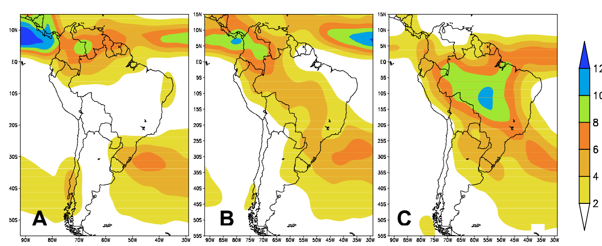

Figure 2: Average precipitation for A) June-July-August 1987 B) September-October-November 1987 and C) December-January-February 1987/88 [mm/day]. Source Xie and Arkin [1986]

Figure 2c shows precipitation during the wet season. It depicts the typical C-shape rainfall band over the continent which extends from the Intertropical convergence zone (ITCZ) in the northern part of the continent through central and southeastern Brazil and merging with the South America Convergence Zone off the southeastern Brazilian coast. Highest precipitation is found in central portion of the continent with values over 8 mm/day occupying most of the Amazon Basin and central Brazil. The figure shows that southern Brazil receives a significant amount of rainfall throughout the entire 9-month period. It also shows the SASM progression as the displacement of the high precipitation areas from northern and northwestern

South America towards the Amazon Basin and central Brazil as the dry season gives way to the wet season.
Figure 3 shows the difference between Reanalysis, GCM and Eta results and observation. It can be seen that there is a progressive improvement of the precipitation simulation from Reanalysis to GCM to Eta model. Reanalysis overestimates precipitation over northern Amazon, tropical Atlantic along northeastern Brazil and southern Andes, while underestimates it over southern Brazil and adjacent areas. GCM results (Figure 2b) show some improvement when compared to Reanalysis, especially in the Amazon area and southern Andes. However, it also underestimates precipitation over the southeaster portion of the continent and in northern Peru as seen in the Reanalysis.

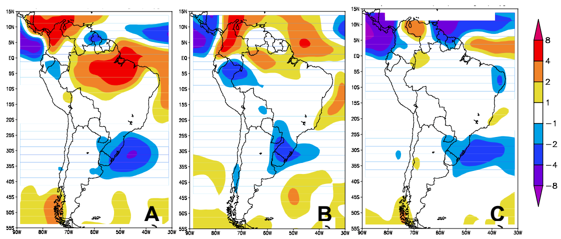

Figure 3: Average precipitation difference between A) Reanalysis, B) GCM and C) Eta results and observation for the dry season (June-July-August 1987) [mm/day].

Eta results are shown in Figure 3c. Overall, Eta results are better than GCM's. The regional model improved rainfall simulation in most of the continent, in particular over the northern Amazon Basin and southeastern Brazil. Eta results are still not good over the Atlantic off the southern coast of Brazil where rainfall is underestimated.
Figure 4 shows mean precipitation difference for the transition period. Reanalysis puts too much precipitation over northern Amazon, central Brazil and east of the Central Andes and also places the ITCZ south of its observed position. As it happens to the dry season, Reanalysis underestimates the rainfall over the Atlantic Ocean off the southeastern coast of Brazil. GCM results show a significant improvement on precipitation amounts and distribution when compared to Reanalysis. Most of the improvements take place over the Amazon Basin, the southern tip of Central America and in central Andes where the global model reduces the extra rainfall seen in the Reanalysis. However, GCM still underestimates rainfall over the Atlantic Ocean off the southeastern coast and underestimates rainfall over the western Amazon Basin and along the Brazilian-Bolivian boundary line.
To some extent Eta precipitation shows better results than the GCM. Especially over land, precipitation amounts are better simulated. Most of the difference between simulation and observation lies between the ± 2 mm/day range. Rainfall over the Amazon Basin is notably improved when compared to Reanalysis. Nonetheless, the regional model degrades rainfall simulation over the Atlantic Ocean off the southeastern coast of Brazil, as well as along the ITCZ region where Eta average rainfall is much smaller than observation.

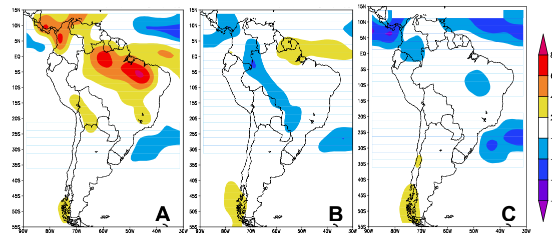

Figure 4: Average precipitation difference between A) Reanalysis, B) GCM and C) Eta results and observation for the transition season (September-October-November 1987) [mm/day].

Figure 5 presents mean precipitation difference for the rainy period. This period shows the less improvement of the three periods. Overall, Eta results are better then both Reanalysis and GCM. Reanalysis places too much rainfall over the northeastern portion of Brazil, which also happens with the GCM.
Eta simulated better the rainfall along the eastern side of the Central Andes, which was overestimated by GCM and Reanalysis. Improvement was not as great over most of the northern Amazon Basil where Eta underestimated the rainfall. GCM did better in this region. The same happens over southern Brazil; in this case Reanalysis did better.
Table 3 has the root mean square error of precipitation over land between the latitudes 40S and10N for each simulation, plus reanalysis. Overall, Eta performed better in all three seasons.

Table 3: RMSE [mm/day]

Model	JJA-87	SON-87	DJF 87/88
Eta	1.58	1.56	2.72
GCM	2.01	1.82	3.07
Reanalysis	2.71	3.25	3.28

Further analysis of soil moisture and latent heat flux over land (not shown) indicates that there was continuous dry-out in the Eta simulation, especially in the some portions of the Amazon Basin and central Brazil during the transition and rainy seasons. Such phenomenon is still not well understood and is probably responsible for the rainfall underestimation in those areas.
Analyses of the average sensible and latent heat fluxes (not shown) indicate that the representation of semi-arid region in northeastern Brazil was possibly exaggerated in extent. Correct representation of land surface characteristics over that area is of great importance in the SASM simulations, since it works as a constraint to rainfall expansion during the rainy season. Too much of semi-arid land cover would probably shift the entire rainfall band eastward due to the overestimated sensible heat flux gradient between tropical Atlantic Ocean and the adjacent portions of South America.

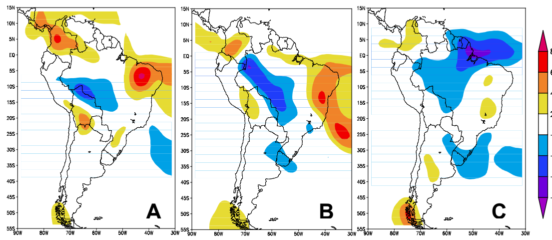

Figure 5: Average precipitation difference between A) Reanalysis, B) GCM and C) Eta results and observation for the wet season (December-January-February 1987/88) [mm/day].

3.2 Domain-size impact

Figure 6 shows the precipitation results from 3 different domain-size simulations with the Eta model. Respective root mean square errors are on table 4. All 3 panels show average rainfall for the transition period. The larger the domain the more ocean it includes, since latitudinal span was kept constant. The smaller domain does not show the low precipitation area in central Brazil, which is present in both original and larger domains. However, this domain produces a higher RMSE than the original domain, due to a few areas where rainfall is overestimated. Overall, the larger domain deteriorates rainfall simulation in central Brazil and also has a higher RMSE than the original domain size. Although this experiment is rather simple and does not cover all possible scenarios it raises a question about Eta performance when large portions of the domain are covered by ocean. Further experiments are needed to investigate this issue.

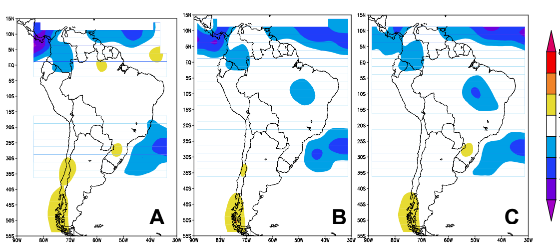

Figure 6: Eta average precipitation difference between A) small, B) original and C) large domain results and observation for the transition season (September-October-November 1987) [mm/day].

Table 4: RMSE [mm/day]

	Small	Original	Large
Eta	1.78	1.56	1.84

4. CONCLUSIONS

Results indicate that the Eta model improved the simulation of precipitation over South America for the dry, transition and wet seasons, compared to Reanalysis and GCM. Most of the improvement occurred over the Amazon Basin, Central Andes, and northeastern, southern and central Brazil. Improvement was greater for the dry and transition seasons. Eta improvement was less significant in the wet season when the model underestimated precipitation over much of the Amazon Basin, ITCZ and southern Brazil. Results showed that despite overall progress on precipitation simulation Eta inherited some GCM weakness.

A general dry-out was seen in the Eta simulation during both the transition and rainy seasons, as average soil moisture and latent heat flux steadily declined especially over the Amazon Basin and central Brazil. Such phenomenon is still not well understood and is probably responsible for the rainfall underestimation in those areas.

Analyses of the average sensible and latent heat fluxes (not shown) indicate that the representation of semi-arid region in northeastern Brazil was possibly exaggerated in extent which might have been responsible for a shift of the entire rainfall band eastward due to a overestimated sensible heat flux gradient between the continent and tropical Atlantic Ocean.

Results have also shown that there is not a simple relationship between domain size and rainfall simulation. The domain with less ocean cover produced a slightly better rainfall distribution over the central portion of the continent. However, this same domain yielded an overall higher RMSE then original domain. The larger domain simulation was in general worse then the original domain one, which possibly indicates a weakness of the Eta model over ocean. Further studies are needed to investigate this issue.

5. REFERENCES

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