ATMOSPHERIC SCIENCE LETTERS
Atmos. Sci. Let. **12**: 351–355 (2011)
DOI: 10.1002/asl.348

RMetS
Royal Meteorological Society

Land–atmosphere coupling in El Niño influence over South America

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Received: 6 April 2011
Revised: 8 April 2011
Accepted: 11 April 2011

Abstract

This study addresses the role of soil moisture and its interaction with the overlying atmosphere in setting up climate anomalies over South America during El Niño years using observations as well as Atmospheric General Circulation Model (AGCM) simulations. It is found that during summertime land–atmosphere interaction is instrumental in setting the spatial pattern and sign of surface air temperature anomalies, and increases substantially the amplitude of precipitation anomalies particularly in southeastern South America. Thus, in order to improve the seasonal forecasts over South America it is necessary to represent properly not only the teleconnection processes but also the regional land–atmosphere interactions.

Keywords: **land-atmosphere coupling; South America; El Niño**

1. Introduction

Climate variability in South America is influenced by El Niño with strong dependence on the season and region considered (Ropelewski and Halpert, 1987). The atmospheric bridges that connect the equatorial Pacific with South America have been studied in detail for several decades and the main mechanisms are well understood (Grimm and Ambrizzi, 2009). That is, however, not the whole story because once the signal arrives over a certain continental region the atmospheric anomalies will be modified by the interaction with the surface, a process that only recently has received attention (Koster *et al*., 2000, 2004). Tropical areas during summertime are clear candidates for having a strong coupling between land and the overlying atmosphere, because it depends on the exchanges of energy and water in the boundary layer that will affect the development of clouds, precipitation and the atmospheric circulation. Using atmospheric models, it has been shown recently that South America is a region where the interaction between soil moisture and precipitation is important to correctly simulate the climatological fields and the South American Monsoon (Xue *et al*., 2006; Collini *et al*., 2008; Misra, 2008; Ma *et al*., 2010; Sorensson and Menéndez, 2010). On interannual time scales, Grimm *et al*. (2007) found that precipitation in central-east Brazil during peak summer is negatively correlated with soil moisture in the previous spring, and they propose a feedback between the surface and the atmosphere to explain this relationship.

In this study, we investigate the role of the interaction between soil moisture and the atmosphere in setting up the climate anomalies over South America induced by El Niño. We concentrate in the austral summer and beginning of fall, that is, in the decay phase of El Niño. The effects of La Niña during summer are less clear than those of El Niño and are not considered here (Silvestri, 2004).

2. Data and methodology

For surface air temperature we use the data set from the University of East Anglia, Climate Research Unit (CRU) which is on a global 0.5° × 0.5° grid (Mitchell and Jones, 2005) from 1949 to 2006. For southeastern South America (SESA) we also use the data set of Tencer *et al*. (2010) that provides monthly mean, maximum and minimum temperature in a 0.5° × 0.5° grid from 1961 to 2000. We use the precipitation reconstruction data set (PREC-L) of Chen *et al*. (2002) for land precipitation, which is based on gauge observations from the Global Historical Climate Network, regridded on a 2.5° × 2.5° grid from 1949 to 2006.

The model used is the AGCM from the International Centre for Theoretical Physics (ICTP AGCM), a full atmospheric model with simplified physics and an horizontal resolution of T30 (3.75° × 3.75°) with eight vertical levels (Molteni 2003; Kucharski *et al*. 2005). The model has a bias consisting in a maximum of summer rainfall in the northwestern part of SESA, instead of a more uniform observed rainfall distribution (Kucharski *et al*. 2005). This bias is also reflected in the precipitation anomalies. For example, for El Niño years the simulated anomalies are centered at about (60 °W, 24 °S) instead of at about (55 °W, 28 °S) as shown in Figures 1 and 3. The model is forced with historical global sea surface temperatures (SSTs) (ERSSTv.2, Smith and Reynolds, 2004), and we performed two experiments in order to test the impact

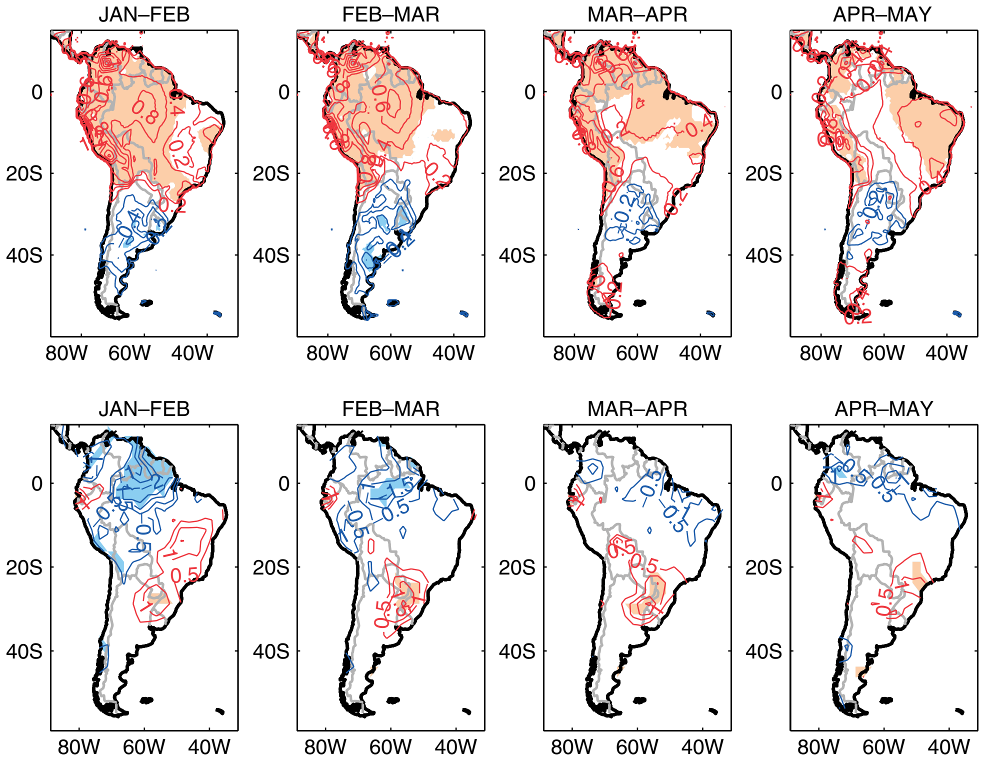

Figure 1. Composites of CRU surface air temperature (°C, above) and PREC-L rainfall (mm d^{-1}, below) for different bimesters. Composites are constructed as the average of El Niño years minus neutral years. Shading indicates significance at the 5% level calculated using a two-sided Student's *t*-test.

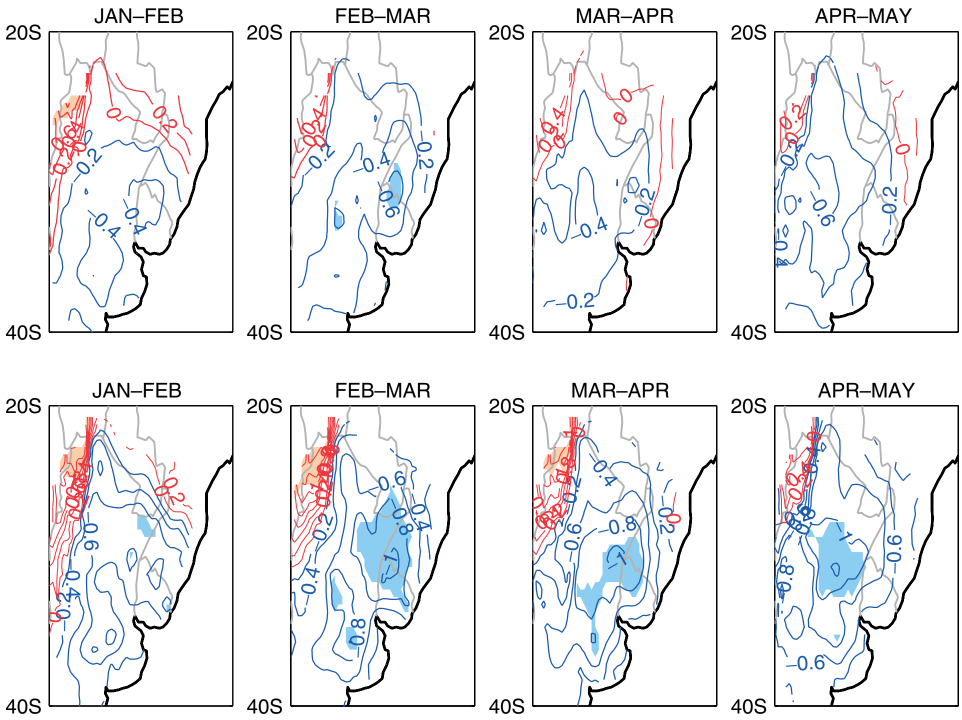

Figure 2. Composites of mean surface temperature (°C, above) and maximum surface temperature (°C, below) from the work by Tencer *et al.* (2010) data set for different bimesters during El Niño years. Since this data set comprises the period 1961–2000 the composites are constructed using only the El Niño and neutral years between these dates. Significance as in Figure 1.

of land–atmosphere coupling. In the first experiment the soil moisture climatology is prescribed, while in the second experiment the AGCM is coupled to a land surface model in order to allow land–atmosphere interaction. The land surface model assumes a single soil layer with different depths for the energy and water balance and is described by Zeng *et al.* (2000). The inclusion of interactive soil moisture improved

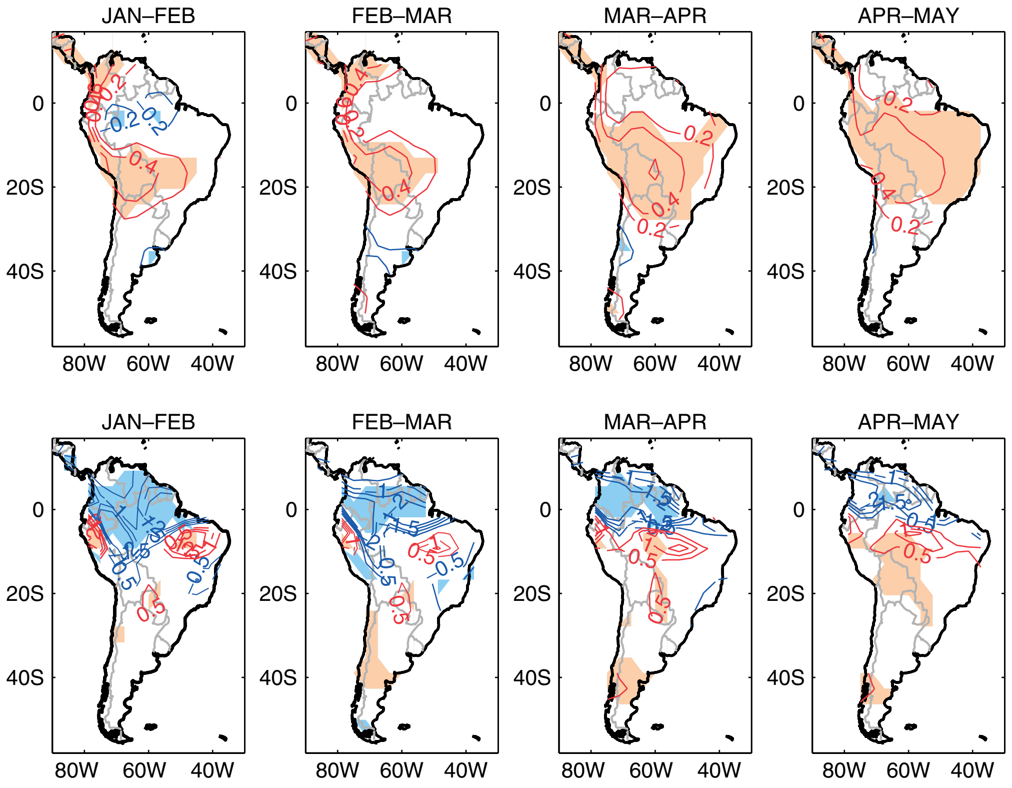

Figure 3. Composites of surface air temperature (°C, above) and rainfall (mm d^{-1}, below) for the model simulation with climatological soil moisture in different bimesters. Composites and shading as in Figure 1.

the mean climatological conditions particularly during summer (not shown) in agreement with Ma *et al.* (2010). The AGCM was integrated from 1880 to 2006, starting from different initial atmospheric conditions in order to create a ten-member ensemble for each experiment. In this study, we only consider the period 1949–2006, as for observations. Results are based on the ensemble mean.

El Niño years are defined as those years in which the SST anomaly in the region Niño3.4 during November-December-January is larger than +1 standard deviation. This results in the following El Niño years: 1958, 1964, 1966, 1973, 1983, 1987, 1992, 1995, 1998 and 2003. We constructed composites of El Niño years minus neutral years (those with absolute values of Nino3.4 smaller than 1 standard deviation) and calculated the statistical significance using a two-sided Student's t-test at the 5% level.

3. Results

As shown in Figure 1 during El Niño events northern South America west of 50 °W becomes warmer than usual from January to April, a signal that has been reported before and has been explained as the adjustment of the surface to the tropospheric temperature increase that occurs during El Niño (Yulaeva and Wallace, 1994; Chiang and Sobel, 2002). In April–May, the Amazon region tends to get back to normal conditions while northeast Brazil becomes warmer. Over SESA, there is a cooling signal particularly during January–February and February–March and a tendency (but not statistical significant) during March–April and April–May. To our knowledge this cooling has not been reported before. It is usually thought that the signal of El Niño over SESA consists only of a warming during the wintertime, while during other seasons the partial balance between the effects of advection of heat and moisture (that increases precipitation and cloudiness) results in no significant temperature anomaly (Barros *et al.*, 2002).

To further look into the summertime cooling during El Niño we computed the composites of temperature using the data set of Tencer *et al.* (2010) (Figure 2). Interestingly, the new data set also shows a cooling tendency over SESA during the decay stage of El Niño with a maximum in February–March, although the significance is lower. Moreover, the composites of monthly mean maximum and minimum temperatures show that the cooling is mainly due to a reduction of the maximum temperature (Figure 2). The minimum temperature, on the other hand, shows no significant change (not shown). The decrease in maximum temperature is about 1 °C from January to May and has a very consistent pattern.

Accompanying these changes in air surface temperature there are significant precipitation anomalies. Over northern South America there is a tendency for decreased precipitation with a maximum and statistical significant reduction in January–February, while over SESA there is increased precipitation from January to

April, and to a lesser extent in April–May, in overall agreement with the literature (Ropelewski and Halpert, 1987; Grimm, 2009). Thus, northern South America and SESA tend to show opposite patterns of anomalies during El Niño: warm and dry and wet and cold, respectively. This is in agreement with the results of Trenberth and Shea (2005) who found that there is a strong negative correlation between precipitation and temperature interannual anomalies during summertime. They argue this relationship is to be expected from simple physical arguments: if the ground is wet the energy will be used for evaporation and not for warming the surface. Also, increased rain means more cloudiness that blocks the direct radiation from the sun, reinforcing the cooling.

The above results suggest an important role for the surface moisture in setting up the local response to El Niño forcing. To address this issue, we compared the two experiments with the ICTP AGCM with and without interactive soil moisture. The El Niño response over South America in the first experiment, with fixed climatological soil moisture, is shown in Figure 3. Results with interactive soil moisture are shown in Figure 4. As can be seen comparing both figures there are large changes in the response. In the experiment with climatological soil moisture the structure of the precipitation signal is similar to that in observations, but the surface air temperature anomalies are of the wrong sign in large parts of the continent. As result, the model has a tendency to generate anomalies that follow the relationship dry–cold in northern South America and wet–warm in SESA, that is, the opposite from observations.

On the other hand, the model with interactive soil moisture recovers the wet–cold and dry–warm relationships. Particularly, striking is the result over northern South America in summer. While using climatological soil moisture the model tends to induce a cold temperature anomaly, with interactive soil moisture there is a large warming with very similar characteristics as the observed one. Contrary to observations, the model warming over northern South America does not weaken in the following seasons as much as in observations, hinting to a too strong land–atmosphere coupling. The pattern of precipitation also improves with the use of interactive soil moisture as it does not show the elongated region of positive anomalies at around 5°–10°S (compare Figures 3 and 4). Over SESA the changes are also very significant. The use of the interactive soil moisture allows the model to capture the cooling signal with largest amplitude in February–March as in observations. Accompanying these changes in temperature the precipitation anomalies over SESA become substantially stronger and closer to observations (Figure 4), although the bias in the location of the maximum persists. Concordantly, soil wetness anomalies have very similar spatial structure as rainfall anomalies (not shown).

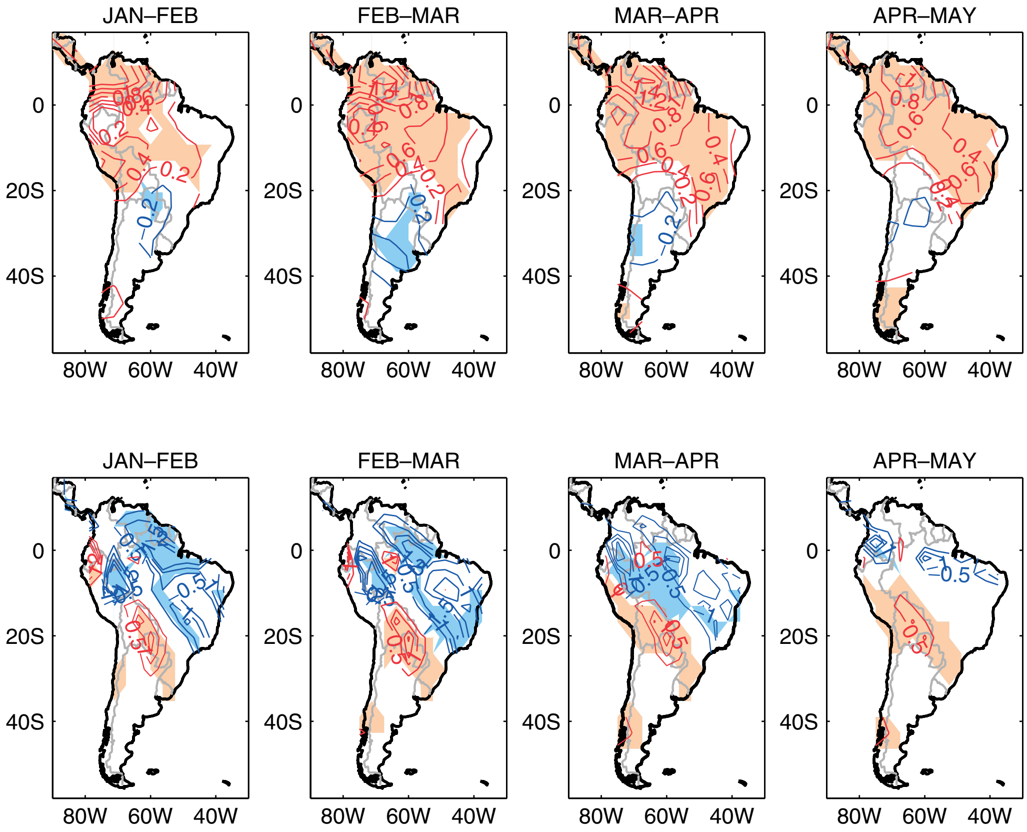

Figure 4. As Figure 3, but for the model simulation with interactive soil moisture. Note the large similarity with the observed anomalies shown in Figure 1.

4. Summary

The study shows that during summer and the beginning of fall the influence of El Niño over South America is controlled by the interaction between the soil moisture and the overlying atmosphere. This is particularly true for the surface air temperature anomalies, which acquire the right sign only if the model includes the land–atmosphere coupling. The structure and sign of the precipitation anomalies are less affected, but the amplitude increases particularly over SESA. As a result, with interactive soil moisture, the model is able to capture the warm–dry and cold–wet relationships that are observed in northern South America and SESA, respectively.

While the precipitation anomalies associated with El Niño during summertime in South America were reported before, the findings of this study show for the first time a cooling signal over SESA mainly due to a decrease in the maximum temperature, which is consistent with the physical arguments used above to explain the wet–cold relationship.

These results have clear consequences for the seasonal forecasts of temperature and precipitation. According to our results, the pattern of the precipitation anomalies are mainly dependent on the large-scale atmospheric anomalies associated with El Niño, and thus a model that represents the atmospheric teleconnections correctly will tend to locate the anomalies in the right place with the correct sign. On the other hand, the amplitude of precipitation anomalies, as well as the pattern and sign of surface temperature anomalies are controlled not only by the large-scale atmospheric circulation, but also by the local interaction between the soil moisture and the atmospheric anomalies. Thus, in order to improve the seasonal forecasts over South America it is necessary to represent properly not only the teleconnection processes but also the regional land–atmosphere interactions.

Acknowledgements

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under Grant Agreement N° 212492 (CLARIS LPB. A Europe-South America Network for Climate Change Assessment and Impact Studies in La Plata Basin).

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