South American rainfall impacts associated with inter-El Niño variations

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1 The impacts of inter-El Niño events on South American circulation during austral summer are investigated using observations and an atmospheric general circulation model (AGCM). The AGCM was forced with sea surface temperature (SST) anomalies in the tropical Pacific for the two El Niño events of 1997/1998 (EN97) and 2002/2003 (EN02). The strong eastern Pacific SST anomaly of EN97 resulted in a typical displacement of the Walker circulation, causing a decrease in precipitation across the north of South America. A strengthened low-level jet (LLJ) east of the Andes during EN97 enhanced the moisture transport from low latitudes to the subtropics, leading to intensified precipitation over southeastern South America. The simulated circulation in EN02 reveals a weakened LLJ and anomalous convergence of moisture over eastern South America, which can be attributed to a displacement of the Pacific-South American (PSA) mode in response to the different location of the heat sources along the tropical Pacific Ocean. Citation: Hill, K. J., A. S. Taschetto, and M. H. England (2009), South American rainfall impacts associated with inter-El Niño variations, Geophys. Res. Lett., 36, L19702, doi:10.1029/2009GL040164.

1. Introduction

2 The tropical Pacific Ocean’s leading mode of variability, namely the El Niño Southern Oscillation (ENSO), impacts South American rainfall via atmospheric teleconnections [Ropelewski and Halpert, 1987; Grimm, 2003]. Within the ENSO mode there is a level of inter-event variability, most notably characterised by variability in the location of peak sea surface temperature (SST) anomalies along the equatorial Pacific. In 1997, the near record strength El Niño (EN97) exhibited a “classic” structure (Figure 1a) and evolution, with the largest anomalies located in the eastern Pacific. In contrast, the 2002 El Niño (EN02) event was much weaker, with the largest SST anomaly located further west in the central equatorial Pacific (Figure 1b) and virtually no anomaly in the eastern Pacific. The mild EN02 event had its maximum anomaly located near 160°W, extending across the dateline. Although the warm anomalies during EN97 did extend as far west as the anomalies seen in EN02, the SST anomalies during EN02 were larger over the Niño 4 region (Figures 1a and 1b). Despite the lower intensity in SST, some climate impacts were stronger in the 2002 El Niño event; for example, there were more severe droughts over Australia [Wang and Hendon, 2007] and South Africa [Reason and Jagadheesha, 2005]. The difference in the position of the SST anomaly along the equatorial Pacific is thought to be responsible for distinct rainfall responses associated with warm ENSO events across Australia [Wang and Hendon, 2007; Taschetto and England, 2009], driven by shifts in the Walker circulation [Ashok et al., 2007] and anomalous moisture fluxes [Taschetto et al., 2009].

2 During the positive phase of ENSO, anomalous warmer waters across the eastern Pacific modify the Walker circulation by increasing convection in the east and reducing it over the west and Indonesian region. Over South America, enhanced subsidence east of the anomalous Walker circulation suppresses rainfall across northeast Brazil [Ropelewski and Halpert, 1987]. ENSO also remotely impacts the South American extratropical climate via the quasi-stationary Rossby wave trains often referred to as the Pacific South American (PSA) pattern [Karoly, 1989; Mo, 2000]. El Niño events are commonly associated with precipitation anomalies in a dipole-like pattern over South America. Rainfall is reduced over southeastern Brazil and increased to the south of this region [e.g., Grimm, 2003; Ropelewski and Halpert, 1987]. During El Niño events, warm moist air from the Amazon basin is transported from the tropical latitudes to the subtropics along an enhanced low-level jet (LLJ) east of the Andes. This configuration is conducive to rainfall over the La Plata basin and a weakening of the South Atlantic Convergence Zone (SACZ) over southeastern Brazil [e.g., Herdies et al., 2002].

4 The SACZ is a common feature of the South American climate seen in austral summer months (Dec–Feb; DJF). The SACZ appears as a convective band characterised by the convergence of warm, moist air extending from the Amazon Basin to the subtropical South Atlantic Ocean [Kodama, 1992; Carvalho et al., 2002]. Recently, Silva and Ambrizzi [2006] showed observational evidence that the El Niño event of 2002/2003 displaced the position of the South American LLJ, resulting in less moisture transport to the south compared to the 1997/1998 event.

5 Motivated by the observational study of Silva and Ambrizzi [2006] and with no previous model studies with such an experimental design available, we investigate here the impact of the 1997 (EN97) and 2002 (EN02) El Niño events on the climate over South America, using not only observations but also AGCM ensemble experiments. We focus our analyses on the South American monsoon season, i.e., DJF. The SST anomalies for both the EN97 and EN02 events were also at a peak during DJF, further
supporting the choice of this season as the focus of the present study.

2. Data Analysis and Atmospheric Model

In this study we analyse the rainfall data from the Climate Prediction Center Merged Analysis of Precipitation (CMAP) [Xie and Arkin, 1996] and SST from the Hadley Centre climatology (HADISST1) [Rayner et al., 2003]. To assess the importance of inter-El Niño SST variability in modulating South American rainfall, perturbation experiments were conducted using the National Centre for Atmospheric Research (NCAR) Community Atmosphere Model (CAM3) which has a T42 horizontal resolution (approximately 2.8° latitude-longitude) with 26 hybrid sigma/pressure vertical levels. For a detailed description of this model see Collins et al. [2006].

A 50 year integration forced by the 12-month climatology of SST was taken as the control experiment (CNTRL). The EN97 and EN02 ensemble sets consist of 50 integrations of the model run over 28 month periods; forced by observed SST conditions during the periods September 1996 – December 1998 and September 2001 – December 2003, respectively. The anomalous monthly varying SST perturbations were applied over the region 15°S–15°N tropical region. Rainfall difference during DJF between EN97 and EN02 (shown as EN97 minus EN02) for (c) the observations and (d) the simulations. Units are in degrees Celsius (Figures 1a and 1b) and mm day⁻¹ (Figures 1c and 1d) respectively. Colour shaded regions are statistically significant at 95% confidence level according to a two-tailed student t-test.

3. Results

To assess the different impact of EN97 and EN02 events on precipitation over South America, the difference between these two events is shown (EN97 minus EN02) for the observations (Figure 1c) and the mean of the ensemble set of El Niño experiments (Figure 1d). The observed and simulated ensemble rainfall differences both show a similar spatial distribution, with the three main features from EN97 and EN02 reproduced; namely (1) increased precipitation over the eastern equatorial Pacific in EN97 relative to EN02; (2) reduced rainfall over the northern half of South America in EN97 relative to EN02; and (3) enhanced precipitation over the southeast of the continent in EN97 relative to EN02. The higher rainfall across the northwest coastline of South America and over the east Pacific Ocean in the EN97 case compared to the EN02 is the response to the large SST anomaly located in the east Pacific during EN97, while the peak anomaly is much more remotely located during EN02. Drier conditions over the northern half of the continent in EN97 is a response to the stronger Walker circulation anomalies during the 1997/1998 case compared to 2002/2003. The increase in rainfall in the southeast during EN97 compared to EN02 is associated with a shift in the position of the SACZ and a consequent enhanced southward moisture transport via a strengthened LLJ during the canonical EN97.

The anomalous Walker circulation response in EN97 relative to EN02 is illustrated in Figure 2 by vectors of anomalous vertical velocity and the divergent zonal wind.
component averaged over $10^\circ$S – $10^\circ$N. During the EN97 experiments (Figure 2a), anomalous uplift is located between 170°W and 90°W. Regions of descent are located over the South American continent and west of the date line. In comparison, the anomalous region of uplift in the EN02 case (Figure 2b) is shifted west to the central Pacific Ocean, while it is flanked by two weaker descending branches. This is a direct consequence of the maximum SST anomaly being located further west in EN02 and there being virtually no SST anomaly along the west coast of South America (Figure 1b). Although the location of the anomalous eastern subsiding branch of the Walker cell remains unchanged between EN97 and EN02, it is stronger in EN97 compared to EN02 around 60°W (see Figure 2c).

The distribution of moisture flux and its convergence at 850 hPa over the continent (Figures 2d–2f) reveals a difference in the low level moisture flux anomalies between these two events. The EN97 ensemble (Figure 2d) has a strong and well organised northwesterly anomaly extending from $10^\circ$S to 30°S. Under this region of strengthened moisture flux there is significant convergence in EN97 which would be conducive to unstable convective conditions leading to higher rainfall, as seen in the ensemble experiments (Figure 1d). This northwesterly low-level moisture flux anomaly is weaker over the southeast in the EN02 case (Figure 2e), wherein stronger moisture flux convergence is located further north near 15°S. The difference between these two El Niño events shows anomalous divergence of moisture over northern South America and an intensification of the northerly low-level moisture flux anomaly to the La Plata Basin in 1997/1998 relative to 2002/2003 (Figure 2f).

Following Ambrizzi and Hoskins [1997] we use 200 hPa meridional winds as an indicator for the ENSO teleconnection strength and pathways. When examining these meridional wind anomalies for the EN97 and EN02 cases (Figure 3) we see wave trains characteristic of a PSA pattern. During EN97 (Figure 3a), over 30°S and 50°W, there is a strong negative (northerly) wind anomaly flanked diagonally by positive (southerly) wind anomalies. During EN02 (Figure 3b), the meridional wind anomalies are smaller in magnitude over the same region. The wave train is also seen clearly in the difference plot of EN97-EN02 meridional wind anomalies (Figure 3c).

To assess the impact of a singular SST forcing without the confounding influences of other remote factors during the 1997/1998 and 2002/2003 El Niños, we examined the 200 hPa meridional winds from a set of idealised ensemble experiments. These were forced by a $+1^\circ$ SST warming superimposed on the seasonal cycle over the eastern Pacific (120°W–80°W, 10°S–10°N) and the central western Pacific around the date line (160°E–160°W, 10°S–10°N), hereafter referred to as the E$_{PAC}$ and CW$_{PAC}$ experiments, respectively. The meridional winds reveal a change in sign around 30°S, 50°W with a negative (northerly) anomaly in the E$_{PAC}$ ensemble and a positive (southerly) anomaly in CW$_{PAC}$ (Figure S1 of the auxiliary material), suggesting a
phase shift of the PSA over the continent. These two wind configurations generate an anomalous anticyclonic (cyclonic) circulation over southeastern South America favouring (inhibiting) the moisture transport to the La Plata basin during E\textsuperscript{PAC} (CW\textsubscript{Pac}). Interestingly, when we examine the low-level winds from the EN97 and EN02 experiments (Figures 3d and 3e) we find the same phase shift in the circulation around 30°C176S, 50°C176W, as in the idealised sensitivity experiments. This suggests that the location of peak tropical SST anomaly could be a determining factor in setting the response phase of South America atmospheric circulation to El Niño events.

4. Summary and Conclusions

[13] In order to assess the impact of inter-El Niño event variability on South American climate we perturbed the NCAR CAM3 model with observed 15°C15°N SST anomalies from the 1997/1998 and 2002/2003 El Niño events. The resulting ensemble set sufficiently reproduces the major observed rainfall differences between the two events. The significantly higher rainfall during 1997/1998 over the La Plata basin appears to be a direct result of the increased available moisture transported to the subtropics via an intensified South American LLJ. The widespread drier conditions across the northern half of the continent is shown to be a consequence of increased subsidence from the Walker circulation in the EN97 case compared to EN02. These experiments confirm that the location of the SST heat source modifies the Walker circulation by changing the region of atmospheric convection and uplift across the equatorial Pacific. The more centrally located SST anomaly during EN02 results in an upward anomaly across the dateline, while the EN97 case exhibits stronger convection in the east. During both EN97 and EN02 a secondary descending branch of the anomalous Walker circulation is located east of 90°W. These circulation responses to the position of the tropical Pacific SST anomalies impact the convection over South America. Both cases show anomalous subsidence over the continent but with important differences in magnitude, which can explain the negative difference in precipitation across the north between EN97 and EN02 (Figure 1c). The shift in the region of uplift is also seen in the 200 hPa velocity potential and divergence (Figure S2), with a slightly stronger magnitude of convergence over northern South America for EN97 compared to EN02.

[14] Investigation of the moisture flux and convergence indicated that the main difference between these two events was a weakening of the LLJ due to anomalous northward low level winds east of the Andes in 2002/2003, that is generally present during canonical El Niño events such as 1997/1998. Convergence of moisture and an increase in winds into the region of the SACZ would be conducive to an increase in rainfall. This is shifted to the south in EN97 and to the north in the EN02 ensemble set. This result corroborates the findings of Silva and Ambrizzi [2006] who observed a southward shift and strengthening of the LLJ in EN97, and a weaker and more northward located LLJ in EN02.

[15] To further explain the change over southeastern Brazil we investigated the teleconnection patterns using upper-level meridional winds. The 200 hPa meridional winds in EN97 compared to EN02 showed a stronger northerly anomaly over southeastern South America (Figure 3a), leading to enhanced rainfall over the La Plata Basin (Figure 1a) via intensified moisture transport into the region (Figure 2f). This reduction in the magnitude could explain...
the reduction in rainfall (Figure 1c) via weakening of the southward moisture transport into the region. On the other hand, the meridional wind anomaly in 2002/2003 was sufficiently weak to keep the moisture transport to southeastern Brazil.

[16] It is worth noting that, apart from the location of the maximum SST anomalies in the tropical Pacific, other factors can also influence the moisture availability and convergence over South America, which then leads to rainfall anomalies over the La Plata Basin. One such factor is the gradient across the Subtropical South-Central Pacific (SSCP), as discussed by Vera et al. [2004], who showed through observations that the sign of the SST anomaly in the SSCP modified the strength of the teleconnection to southeastern Brazil. Furthermore the amplitude and time evolution of El Niño SST anomalies could also play a large role in the variability of precipitation over this region. The present study focused specifically on the influence of changes in the location of the maximum anomaly of the El Niño SST signature.

[17] Further comparison with an idealised experiment set was used to identify the mechanism responsible for the observed climate shift in the LLJ and precipitation over the region. The meridional winds from the idealised experiments based on simplified and localised SST warming showed a significant difference between experiments forced by eastern versus central-west Pacific SST anomalies, with a clear phase shift of the PSA apparent. This phase shift in the idealised experiments is possibly the main factor responsible for the different responses in South American atmospheric circulation between the 1997/1998 and 2002/2003 El Niño events. The phase shift over southeastern South America was also seen in the low-level 850 hPa winds in the EN97 and EN02 experiments, suggesting that the PSA phase shift is responsible for the shift in the moisture transport over southeastern Brazil between the two El Niño events. In summary, the location of the maximum SST anomaly appears to be an important factor in controlling the amount of moisture transported into the SACZ region during El Niño events. This has important implications for seasonal and interannual climate variability over South America.

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References


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