Intraseasonal Teleconnections between South America and South Africa

ALICE M. GRIMM

Department of Physics, Federal University of Paraná, Curitiba, Brazil

C. J. C. REASON

Department of Oceanography, University of Cape Town, Rondebosch, South Africa

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ABSTRACT

Teleconnection of climate anomalies between various parts of the tropics and extratropics is a well-established feature of the climate system. Building on previous work showing that a teleconnection exists between the South American monsoon system and interannual summer rainfall variability over southern Africa, this study considers intraseasonal variability over these landmasses. It is shown that strong teleconnections exist between South African daily rainfall and that over various areas of South America, with the latter leading by 4–5 days, for both winter and summer, involving regions with strong rainfall in these seasons. During the summer, the mechanisms involve both a modulation of the local Walker cell as well as extratropical Rossby wave trains. For winter, the latter mechanism is more important. While in summer tropical convective anomalies over South America play an important role, in winter the subtropics become more important. In both cases, these modulations lead to regional changes in circulation over southern Africa that are favorable for the dominant synoptic rainfall-producing weather systems such as cutoff lows and tropical extratropical cloud bands.

1. Introduction

Situated in the subtropics, South Africa mainly receives rainfall during austral summer (Fig. 1) except in the southwest (winter rainfall) and the south coast (all-season rainfall). Characteristic of southern African climate is marked variability on intraseasonal (e.g., Pohl et al. 2007; Mapande and Reason 2005), interannual (e.g., Lindesay 1988; Mason and Jury 1997; Reason et al. 2006), interdecadal (e.g., Tyson et al. 1975; Reason and Rouault 2002; Allan et al. 2003), and longer time scales.

Grimm and Reason (2011) suggested an interannual teleconnection between Brazilian and southern African rainfall during summers when there are Benguela Niño (Niña) events, anomalous warm (cool) sea surface temperature (SST) in the South Atlantic near Angola and Namibia. This teleconnection involves anomalous rainfall during particular South American monsoon seasons, which generate Rossby wave trains across the Atlantic and, hence, affect southern African circulation and rainfall.

Here, we focus on intraseasonal time scales, less well studied over South Africa than interannual variability, and on teleconnections between South American rainfall and that in South Africa, although it is recognized that there are other important influences such as ENSO. There is significant intraseasonal variability over South America and the Pacific (e.g., Paegle et al. 2000) that can modulate synoptic-scale variability. The enhanced synoptic anomalies can then produce teleconnections that perturb weather and circulation over Africa. Evidence is given of such teleconnections during summer (December–February) and winter (June–August) for those parts of South Africa that receive significant rainfall during these seasons.

2. Data and methods

Observed daily gauge precipitation data for 1970–99 are gridded to 1° resolution for South America and 2.5° for South Africa. At each grid point, anomalies of daily
FIG. 1. (top) Selected regions and annual cycles of precipitation in South Africa. (middle)–(bottom) The 1° boxes in South America with precipitation significantly correlated to the lagged precipitation (5 days) in each selected region in South Africa. Dark squares (triangles) indicate confidence levels higher than 90% for positive (negative) correlation; open squares (triangles) are for confidence levels between 85% and 90%. Ellipses indicate the regions with maximum correlation. White areas are void of data. The highest correlation coefficient for box 1 is 0.48, and for boxes 2 and 3, it is 0.42.
precipitation are calculated and submitted to a bandpass Lanczos filter to isolate intraseasonal oscillations in the 20–90-day band. For each season, the filtered precipitation anomalies for the South African grid boxes are correlated with filtered precipitation anomalies in the grid boxes over South America. Lags from 0 up to 12 days are applied to the South African data, in order to investigate convection anomalies over South America that could produce atmospheric perturbations associated with South African precipitation anomalies. The significance of correlation between the filtered data takes autocorrelation into account and uses an effective sample size calculated according to Dawdy and Matalas (1964).

Although significant correlations are revealed for several regions, the results shown represent the best correlations for different precipitation regimes: the Limpopo (summer), southwestern Cape (winter), and South Coast (all-season) (Fig. 1). The correlation maps show the South American grid boxes with significant correlation, to confidence levels of 85% and 90%. The isolines of correlation coefficients are not shown, to keep the figures cleaner. The correlation coefficients may be slightly affected by different quantities of data at each grid point, since there may be different missing daily data at each grid point and each season. On the other hand, the significance levels take into account the actual number of data in each grid box and therefore are comparable. Nevertheless, it is convenient to give an idea of the magnitude of the correlation coefficients corresponding to given confidence levels, and their maximum value for each case. It may vary a little for each grid box (because of different autocorrelations). When using around 2500 data points, the correlation coefficients corresponding to confidence levels of 85% and 90% are 0.19 and 0.23, respectively. The maximum correlation coefficient for box 1 (summer) is 0.48 and for boxes 2 and 3 (winter) it is 0.42.

NCEP–NCAR reanalyses (Kalnay et al. 1996) are used to composite intraseasonal anomalies in OLR, 200-hPa streamfunction, and vertically integrated moisture flux associated with South African positive filtered precipitation anomalies above one standard deviation (positive phases). The OLR composite anomalies are also calculated for 5 days before the days of the positive phase, in order to capture the previous OLR anomalies over and near South America. The statistical significance of the composite analysis is calculated with a t test. Since the daily anomalies are filtered, they have some serial dependence, and therefore, the effective sample size must take into consideration the autocorrelation of the series (Wilks 1995).

The possible origin of the atmospheric circulation anomalies associated with those positive phases is determined using influence functions (IFs) of a vorticity equation model with a divergence source (Grimm and Silva Dias 1995a, b). The model is linearized about a realistic basic state and includes the divergence of this state and vorticity advection by divergent wind:

\[
\frac{\partial \zeta}{\partial t} + \nabla \phi \cdot \nabla \zeta + \nabla \phi \cdot \nabla \zeta + \nabla \zeta \cdot \nabla \zeta + \zeta \nabla^2 - A' = F',
\]

(1a)

where

\[
F' = -\zeta D' - V' \cdot \nabla \zeta.
\]

(1b)

Here \( F' \) depends only on the anomalous divergent flow. In these equations, \( \zeta \) is absolute vorticity; \( D \) is divergence; \( V' \) and \( \nabla \psi' \) are the divergent and rotational components of the wind, respectively; and \( A' \) is the damping term, including linear damping and biharmonic diffusion. The model is applied at 200hPa, near the level of maximum divergence associated with convective outflow in the tropics and an equivalent barotropic level in the extratropics. Its stationary version may be written as

\[
M \psi' = D',
\]

(2)

where \( M \) is a linear operator and \( \psi' \) is the anomalous streamfunction. Then the IF based on divergence forcing is defined by

\[
G_D(\lambda, \phi, \lambda', \phi') = M^{-1} [\delta(\lambda, \phi, \lambda', \phi')],
\]

(3)

where \( \delta(\lambda, \phi, \lambda', \phi') \) is the delta function. Thus, the IF \( G_D(\lambda, \phi, \lambda', \phi') \) for a target point with longitude and latitude \((\lambda, \phi)\) is, at each point \((\lambda', \phi')\), equal to the model response at \((\lambda, \phi)\) to an upper-level divergence located at \((\lambda', \phi')\). Maps with contours of IF for a given target point indicate the regions in which the anomalous upper-level divergence is most efficient in producing streamfunction anomalies around that target point. Upper-level anomalous divergence (convergence) in regions with positive values of the IF produces positive (negative) streamfunction anomalies around the target point, and the opposite is true for negative values of the IF. More information about the model and the IFs, their usefulness and drawbacks can be found in Grimm and Silva Dias (1995a, b). This model is also used for simple simulations of the observed streamfunction anomalies at 200hPa in response to anomalous convection over South America.

Here, the IFs are shown only for the action centers of circulation anomalies directly associated with
anomalous convection in southern Africa, usually cyclonic anomalies southwest of the analyzed regions. Before the IF analysis, selection of regions whose upper-level anomalous divergence might contribute to generate streamfunction anomalies leading to anomalous South African precipitation is primarily based on the correlation patterns in Fig. 1 (regions within the ellipses). The OLR composite anomalies calculated for 5 days before the days of positive phase in South Africa (Figs. 2b, 3b, and 4b) are used only to confirm the results of the correlations, and to add information about regions within or nearby South America (e.g., the Atlantic) where precipitation data are not available and anomalous convection might be important for the teleconnections. It is convenient to remark that these OLR anomaly composites for 5 days before also show enhanced convection in South Africa because the anomalies are filtered (smoothed) by a 20–90-day bandpass filter.

3. Summer teleconnections

There are significant correlations for a lag of few days between filtered daily precipitation anomalies in several summer rainfall regions of South Africa and South America [for precipitation regimes in South America, see Grimm (2011)]. As an example, we use box 1, in the north of the country (Fig. 1).

For box 1, the strongest correlation is at a 4–5-day lag with rainfall over parts of northeastern and central Brazil. The OLR anomalies for positive phases in box 1 show a northwest–southeast (NW–SE)-oriented connection of negative values between tropical southern Africa and the southwestern Indian Ocean (Fig. 2a), consistent with the formation of tropical-temperate troughs (TTT), the main summer synoptic rainfall system (Harrison 1984; Hart et al. 2010, 2013). Over South America 5 days before (Fig. 2b), they are predominantly negative (positive) within the ellipse with positive (negative) correlations in Fig. 1, coherent with enhanced (suppressed) precipitation associated with positive phases in box 1.

The 200-hPa streamfunction cyclonic (anticyclonic) anomalies behind (ahead) box 1 are coherent with a TTT (Fig. 2c), being part of a wave train that originated from the strongest South American convective anomalies. In the tropics, there is also a Walker cell–like pattern across the South American–African sector (pairs of anticyclones/cyclones either side of the equator). Although the filtered data do not contain isolated synoptic rainfall systems, their positive phases occur when these systems are more intense and frequent, and therefore, the anomalies during these phases are representative of them. The moisture flux anomaly (Fig. 2d) shows increased inflow of moist marine air from the southwestern Indian Ocean over Mozambique toward South Africa. Anomalous moisture flux also occurs from the Atlantic, through Angola/Namibia, consistent with Cook et al. (2004). Relative convergence occurs over South Africa, Zimbabwe, and Botswana, including the TTT region. The cyclonic moisture flux anomaly over western southern Africa and the southeastern Atlantic favors both increased uplift over subtropical southern Africa and inflow of warm tropical air from the tropical South Atlantic toward the TTT source region, the Angola low (Reason et al. 2006). An enhanced cloud band is evident in the negative OLR anomaly band (Fig. 2a) that stretches southeastward from southeastern Angola, across the Limpopo box to the Agulhas Current region where it joins with another band of relative uplift. TTT formation is triggered by the arrival of an upper-level trough over southern Africa and associated planetary waves (Hart et al. 2010), which may originate from South America.

A first indication of South American influence is the wave train visible in Fig. 2c, originating south of the Brazilian precipitation anomalies (Fig. 1). As a second indication, the IF for the action center 4 of this wave train (Fig. 2e) shows clearly that the anomalous upper-level divergence and convergence in the ellipses in Fig. 1 are in the right position to produce cyclonic anomalies around point 4. The IF is positive (negative) in the region with anomalous upper-level divergence (convergence) over central-eastern (southeastern) South America, indicating that both positive and negative divergence anomalies are able to produce cyclonic anomalies (positive streamfunction anomalies) around point 4. Although there are also OLR anomalies in the Pacific and the Atlantic, either they are in regions with weaker IF or the associated upper-level divergence does not have the correct sign, according to the IF, to produce a cyclonic anomaly around point 4. No other regions with strong OLR anomalies have such strong IF values with such coherent signs. A third indication of the influence of South America anomalous convection is the upper-level streamfunction response (Fig. 2g) to upper-level divergence anomalies in the marked ellipses (Figs. 1 and 2f). The wave trains in Figs. 2c and 2g are similar, although complete agreement is not possible with such an idealized experiment.

Our results are also consistent with Macron et al. (2014), who showed that not all extratropical waves produce a TTT; Rossby waves leading to TTT systems are already stronger and show associated enhanced convection over the subtropical southern Atlantic and eastern South America prior to the TTT development over southern Africa, indicating the contribution of a wave train that originated in the tropics.
4. Winter teleconnections

Western South Africa receives mainly winter rainfall (Fig. 1). The only other region in southern Africa that has significant winter rainfall is the south coast. Both these regions have a significant relationship on intraseasonal scales with rainfall upstream over certain South American regions.

For the winter rainfall southwestern region (box 2), the strongest correlation with South American winter rainfall regions is southern Brazil/Uruguay (positive),
at a 4–5-day lag (Fig. 1). The OLR anomaly composite confirms the enhanced convection in southwestern South Africa (Fig. 3a) and 5 days before in a region off of southeastern South America, an important winter cyclogenesis region (Fig. 3b). Most of the rainfall in southwestern South Africa is brought by cold fronts, with cutoff lows that are sometimes important. Figure 3c shows a wave pattern in the midlatitudes, similar to that identified by Weldon and Reason (2014) as important for southern South African rainfall, with large cyclonic features over western South Africa and southern Argentina and Chile. The latter extends over the western South Atlantic important area for cyclogenesis, and thus favors more frontal systems approaching southwestern South Africa. On the other hand, an anticyclonic anomaly is present near southeastern South America. These patterns are consistent with the positive correlations between box 2 rainfall and southern Brazil/Uruguay, and negative OLR anomaly composites off of southeastern South America (Fig. 3b). The cyclonic...
The streamfunction anomalies at 200 hPa (Fig. 4c) show a wave train between South America and southern Africa. Over South Africa, a large area of negative OLR anomalies (relative uplift) is apparent over the south coast and inland, except in the far southwest (Fig. 4a). Both the 850- (not shown) and 200-hPa streamfunction anomalies (Fig. 4c) are characteristic of cutoff low conditions since they have a large anticyclonic anomaly (center 2) to the south of South Africa and a cyclonic anomaly over the landmass (center 3) (Singleton and Reason 2006, 2007a). The fact that these patterns are similar at the lower and upper levels is consistent with the development of deep convective storms such as cutoff lows. Almost all of the flooding events in southern South Africa result from these weather systems (Singleton and Reason 2007b). Relative moisture flux convergence is evident over eastern South Africa, including the eastern part of the south coast where there are easterly onshore anomalies (Fig. 4d).

The influence of South American anomalous convection in forcing the wave train between the two continents is confirmed by the IF of center 3 (Fig. 4e), which displays strong positive values over southeastern and central Brazil, around 20°S, indicating that upper-level divergence in this region is able to produce a positive streamfunction around center 3. The IFs of the other centers (not shown) indicate that also the subtropical upper-level convergence is important in generating that wave train. Furthermore, a model simulation of the streamfunction anomalies at 200 hPa forced by anomalous divergence (convergence) within the continuous (dashed) ellipse on the correlation map for box 3 (Fig. 1), as represented in Fig. 4f, shows a wave train over the southern Atlantic (Fig. 4g) similar to the observed one (Fig. 4c).

5. Summary and conclusions

Grimm and Reason (2011) showed that a teleconnection exists between the South American monsoon and summer rainfall over tropical southern Africa on interannual scales. Here, evidence is shown that teleconnections exist between South American rainfall variability and that of various South African regions for both summer and winter on intraseasonal scales. Although not as strong as summer/winter, there is evidence of rainfall teleconnections for the transition seasons too. It, therefore, appears that the rainfall relationships between these two Southern Hemisphere landmasses can exist at any time of the year. Since there are teleconnections at both intraseasonal and interannual scales, they might appear on interdecadal scales, too, since there is strong interdecadal precipitation variability over South America (Grimm and Saboia 2015) as well as southern Africa (Reason and Rouault 2002).
The mechanisms by which these teleconnections occur involve the generation of wave trains across the South Atlantic that then impact on regional circulation and moisture flux convergence over South Africa. In summer, there is also an anomalous Walker-type circulation in the tropical Atlantic region, associated with anomalous tropical convection. While in summer tropical convective anomalies play an important role, in winter the subtropics become more important. Even when there is a wave pattern circling the globe in the subtropics and midlatitudes that could be associated with anomalous convection in South America and southern Africa some days after, it is possible to show that the anomalous convection over South America and the neighboring Atlantic region is able to influence South African precipitation.

Obviously there are other influences over southern Africa rainfall on interannual, interdecadal, and intraseasonal time scales. The focus of this manuscript is on the possible influence of the South American anomalous convection on the precipitation variability in southern Africa on intraseasonal time scales. The strongest relationships between the intraseasonal variability of

![Fig. 4. As in Fig. 2, but for box 3 in winter.](image)
South American and South African rainfall exist at lags of 4–5 days of the South African rainfall behind that over South America. This aspect then suggests that there may be some possibilities for improving forecasting of wet and dry spells over South Africa based on near-real-time monitoring of rainfall upstream over South America. Understanding and predicting dry and wet spell frequencies during the rainy season is very important for users in agriculture and other sectors of the economy (Usman and Reason 2004).

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