

Mechanisms for Precipitation Variability of the Eastern Brazil/SACZ Convective Margin

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(Manuscript received 10 September 2010, in final form 11 January 2011)

ABSTRACT

The present study examines the mechanisms for the connection between the precipitation variability in eastern Brazil and the South Atlantic convergence zone (SACZ) convective margin (eastern Brazil/SACZ convective margin) and the variability of low-level inflow on interannual time scales during austral summer. The authors' methodology is based on the analysis of observational datasets and simulations by the University of California, Los Angeles (UCLA) atmospheric general circulation model (AGCM) coupled to the Simplified Simple Biosphere Model.

It is demonstrated that the inflow variability is associated with the leading mode of wind variability over subtropical South America, and the connection is established through the mechanism of an analytic prototype for convective margin shifts proposed in previous studies. Over the eastern Brazil/SACZ convective margin, the weaker (stronger) convection tends to occur together with stronger (weaker) low-level inflows in reference to the mean easterly trades. By changing the "ventilation" effect, stronger (weaker) inflows with low moist static energy from the Atlantic Ocean suppress (promote) convection. The causal relationship is verified by AGCM mechanism-testing experiments performed in perpetual-February mode, in which low-level, nondivergent wind perturbations are imposed in a region overlapping eastern Brazil and the western Atlantic Ocean. With solely the imposed-wind perturbations acting on the moisture advection in the model equation, the AGCM can reproduce the precipitation variability in the eastern Brazil/SACZ convective margin. The capability of the AGCM in capturing such precipitation sensitivity to the low-level inflow variability also suggests that the mechanism can be applied to other regions of convective margins or to other time scales.

1. Introduction

Key features of the summertime precipitation in South America include strong monsoon convection in central Amazonia and the northwest–southeast-oriented band of convective activity known as the South Atlantic

convergence zone (SACZ), which extends from eastern Brazil into the adjacent Atlantic Ocean. Along the eastern edge of the strong convection zones is a transition toward the low-precipitation region of the southern tropical Atlantic trades. On interannual time scales, summertime precipitation in South America shows strong variability from the eastern Brazil to La Plata Basin (Paegle and Mo 2002). Such variability can result in drought and flood events, which have significant impact on human activity and economy. The better understanding of the mechanism that produces such variability is crucial to improve predictions of those important hydrological events.

The review article on American monsoon systems by Vera et al. (2006) outlines the consensus view that several factors can influence the variability of precipitation

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over the eastern Brazil and SACZ region: sea surface temperature (SST) anomalies, local land surface conditions, the strength of the tropical convergence zones, moisture transport, and large-scale circulations. Previous modeling studies by Mechoso et al. (1990) and Giannini et al. (2001) demonstrate that SST anomalies in the tropical Atlantic have significant influences on tropical South America rainfall through trade wind-induced moisture convergence anomalies. Marengo (1992), Hastenrath and Greischar (1993), and Uvo et al. (1998) further find that the gradient of SST anomalies across tropical Atlantic can have significant impacts on precipitation in northeastern Brazil and north central Amazonia. The intertropical convergence zone (ITCZ) can be modulated by SST anomalies in the tropical Atlantic and in turn impact rainfall over northeastern Brazil (Paegle and Mo 2002). Precipitation variability over southeastern South America has also been related to SST anomalies in the adjacent Atlantic Ocean (Díaz et al. 1998; Doyle and Barros 2002; Chaves and Nobre 2004). ENSO-induced large-scale circulation changes through wave dynamics can also modulate precipitation in the tropical and subtropical South America (e.g., Aceituno 1988; Kousky and Kayano 1994; Grimm et al. 1998, 2000). Based on general circulation model (GCM) experiments, Kalnay et al. (1986) suggest that the variability of SACZ is closely linked to the variability of tropical convection in the western Pacific as well as the South Pacific convergence zone (SPCZ) through Rossby wave activity propagating from the South Pacific. In regard to the land surface conditions, Grimm et al. (2007) argue that peak precipitation in eastern Brazil is negatively correlated with soil moisture in the antecedent spring season.

Of high relevance to our study, Robertson and Mechoso (2000) using the National Centers for Environmental Prediction (NCEP)–National Center for Atmospheric Research (NCAR) reanalysis dataset (Kalnay et al. 1996) link the variability of SACZ precipitation with the leading mode of variability in large-scale flows over South America. This mode is represented by an equivalent barotropic stationary vortex centered over the Atlantic coast and is accompanied by a dipole in anomalous vertical motion. An anomalous cyclonic (anticyclonic) vortex is associated with intensified (weakened) SACZ, with anomalous descent (ascent) to the southwest. At upper levels, the tendency for the vortex to be advected downstream by the westerly jet is balanced by meridional advection of planetary vorticity and stretching associated with vertical motion. At low levels, the cyclonic circulation advects warm and moist air from central Amazonia all the way to the southern part of SACZ (near 30°S, 30°W), which maintains the ascending motion.

A suite of recent studies by Lintner and Neelin (2007, 2008, 2010) examines the processes that control the variability of the margin of tropical convection zones using a combination of theory and observational datasets. These studies suggest that by the influence of low-level inflow winds, certain regional precipitation anomalies are due to shifts in the position of a convective margin (i.e., a boundary separating convecting and nonconvecting regions), the behavior of which is sensitive to inflow from neighboring nonconvective regions. The effect of inflow from nonconvective region into a continental convection zone is also referred to as “ventilation” of the convective margin (Chou and Neelin 2001). An analytic prototype for convective margin shifts is developed to illustrate the dynamic and thermodynamic factors (i.e., low-level inflow wind speed, top-of-atmosphere radiative heating, moisture of the inflow air mass, and a moisture threshold condition at which deep convection occurs) that set where the convective margin occurs (Lintner and Neelin 2007). Lintner and Neelin (2010) further examine the relationship between low-level inflow and precipitation variability along the margins of tropical convection zones in the tropical South America/Atlantic sector in austral summer using NCEP–NCAR reanalysis data (Kalnay et al. 1996) and Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP; Xie and Arkin 1997) datasets. The results indicate that convection along the eastern margin of the SACZ can be suppressed due to modification of the moisture field by inflow air with low moist static energy (MSE) from the Atlantic Ocean because the level of moisture becomes subcritical for convection. Modification of the air mass by low-level convergence and diabatic effects eventually reaches the threshold for the onset of convection, but for stronger inflow wind this tends to occur further downstream. Such inflow-related precipitation variations may account for up to 80%–90% of the precipitation variability in sectors of eastern South American convective margin. Robertson and Mechoso (2000) and Lintner and Neelin (2010), therefore, both point to low-level wind anomalies as crucial to the moisture advection in the production of important modifications in convection along the convective margins of the South American region.

The present study will focus on the ability of climate models to represent the sensitivity of precipitation to the low-level anomalous flows and the associated moisture advection over the convective margin in eastern Brazil and eastern edge of the SACZ on interannual time scales. For brevity, we will refer to this region as the eastern Brazil/SACZ convective margin. The climate model we used in this study is the University of California, Los Angeles (UCLA) atmospheric GCM (AGCM). Our approach is based on the analysis of AGCM simulations

and observational datasets. The hypothesis is that low-level inflow variability in association with the leading mode of interannual variability identified by Robertson and Mechoso (2000) is responsible for the precipitation variability over the eastern Brazil/SACZ convective margin according to the mechanism proposed by Lintner and Neelin (2007, 2010). We also analyze three AGCM mechanism-testing simulations specially designed to examine our hypothesis.

The remainder of the text is organized into five sections. Section 2 provides a brief introduction to the observational datasets and the UCLA AGCM. Section 3 demonstrates the sensitivity of SACZ variability to the low-level inflows from observational datasets and AGCM simulations. Section 4 examines the AGCM mechanism-testing simulations. Section 5 presents a summary and our conclusions.

2. Datasets, model, and methodology

a. Observational datasets

We use the global dataset from the NCEP–NCAR reanalysis (Kalnay et al. 1996), which covers the period from 1948 to the present date. We also use monthly-mean global precipitation fields from CMAP (Xie and Arkin 1997). CMAP, which merges observations from rain gauges and estimates from several satellite-based algorithms (infrared and microwave), covers the period 1979–2006. We interpolate the fields in both datasets into a 2.5° longitude by 2.0° latitude grid to match the horizontal resolution of the AGCM.

b. Atmospheric model: UCLA AGCM

The UCLA AGCM includes advanced parameterizations of the major physical processes in the atmosphere. The parameterization of cumulus convection, including its interaction with the planetary boundary layer (PBL), follows the prognostic version of Arakawa and Schubert (1974) (see Pan and Randall 1998). The parameterization of radiative processes is based on Harshvardhan et al. (1987, 1989), and the parameterization of PBL processes is based on the mixed-layer approach of Suarez et al. (1983), as revised by Li et al. (2002). Surface heat fluxes are calculated following the bulk formula proposed by Deardorff (1972) and modified by Suarez et al. (1983). The model also includes the parameterizations of prognostic cloud liquid water and ice (Köhler 1999) and the effects of cumulus clouds on the radiation calculations. A more detailed description of the model can be found in Arakawa (2000) and Mechoso et al. (2000) or online (at <http://www.atmos.ucla.edu/~mechoso/esm/agcm.html>). The most recent versions of the AGCM are coupled to the first-generation Simplified Simple Biosphere model (SSiB; Xue et al.

1991). In this model, several sources of data (Dorman and Sellers 1989; Xue et al. 1996a,b) were used to determine the vegetation types that specify monthly climatological land surface properties (e.g., leaf area index, green leaf fraction, and surface roughness length).

In the present study, we use AGCM version 7.1 with a horizontal resolution of 2.5° latitude and 2° longitude, and 29 layers in the vertical. The distributions of greenhouse gases, sea ice, and ocean surface albedo are all prescribed corresponding to a monthly observed climatology. The prescribed SST fields are taken from National Oceanic and Atmospheric Administration (NOAA) Extended Reconstructed monthly SST V2 (Smith and Reynolds 2004). SSiB has three soil layers and one vegetation layer. More model details, and the highly realistic AGCM performance on South American warm season climate, are reported in Ma et al. (2011). The AGCM simulation analyzed in this study covers the period from January 1948 to February 2005.

c. Methodology

Figure 1 displays the monthly mean precipitation and its variance for December, January, and February from both CMAP and AGCM simulation. The patterns of monthly mean precipitation or variance are very similar in the three summer months. The distributions from CMAP show strong convection in central Amazonia, the Atlantic ITCZ, and the SACZ. Large precipitation variance is found over the western to central Atlantic ITCZ and the eastern sector of the SACZ between 60° and 30° W and 10° and 20° S. In the simulation, the Atlantic ITCZ is weaker, and the precipitation variance shows large values only over the eastern Brazil/SACZ convective margin, with smaller amplitude than in CMAP. The smaller amplitude of the precipitation variance in the simulation is mainly due to the limitation of conventional GCMs in reproducing all scales of convective systems (e.g., Xiao and Mechoso 2009). According to Lintner and Neelin (2010), as reviewed in the introduction, the precipitation variability over the eastern Brazil/SACZ convective margin reflects shifts in the position of the convective margin (i.e., the boundary separating convecting and non-convecting regions), the behavior of which is sensitive to land region moisture inflow from a neighboring ocean region. Figure 1 confirms that the precipitation boundary is collocated with the large precipitation variance over the eastern Brazil/SACZ convective margin in both observations and simulation. Since monthly mean precipitation shows similar patterns in the three summer months, we will concentrate on February for detailed analysis of precipitation variability along a mean low-level inflow trajectory from both observational datasets and model simulations.

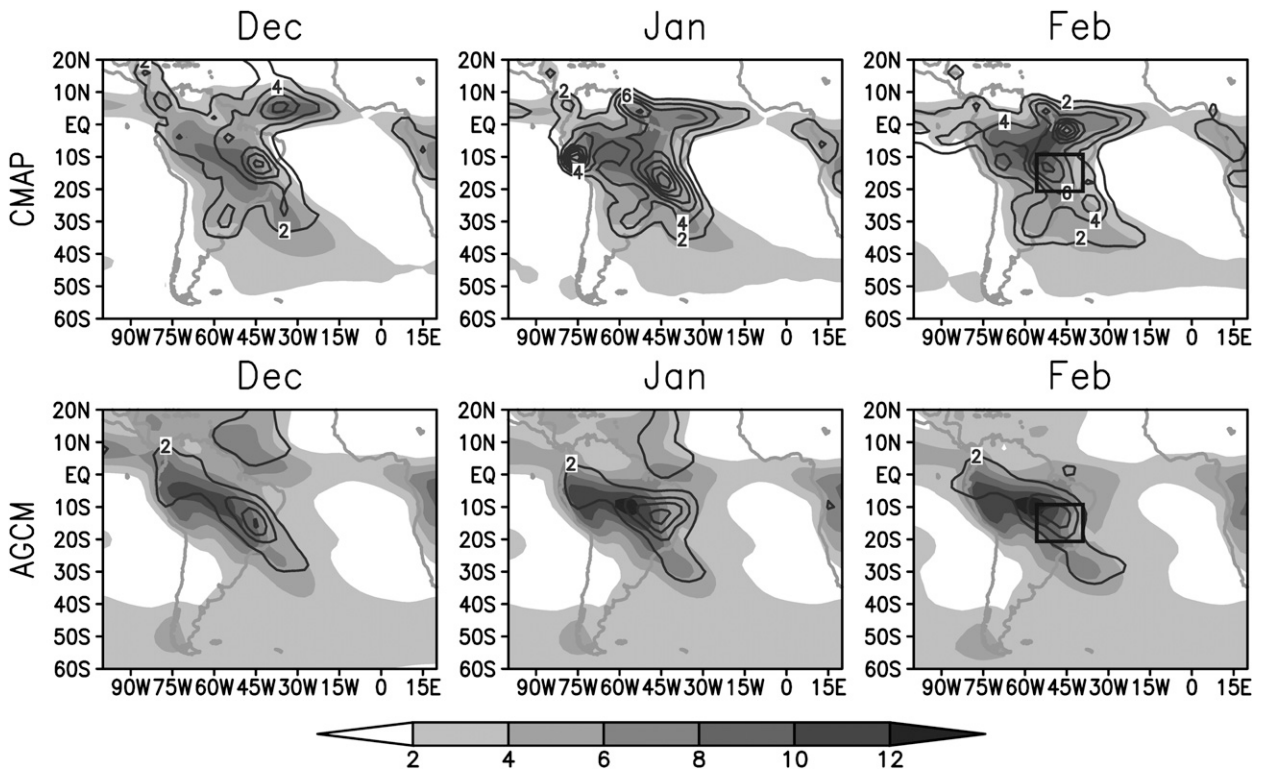


FIG. 1. Mean precipitation (mm day^{-1} , shaded) and its variance ($\text{mm}^2 \text{day}^{-2}$, contours) for (left to right) December, January, and February from CMAP and the simulation. The contour interval is $2 \text{ mm}^2 \text{day}^{-2}$. The boxes (20° – 10° S, 55° – 40° W) in the plots for February mark the regions selected for calculation of 850-hPa wind indices.

We start by constructing a wind index for the investigation of the inflow-related precipitation variability. First, we identify the region of large precipitation variability. The region marked by the box in Fig. 1 (20° – 10° S, 55° – 40° W) lies in the eastern Brazil/SACZ convective margin where large precipitation variability is found in both the observation and simulation. In this region, the direction of mean 850-hPa zonal flows is approximately perpendicular to precipitation contours (i.e., along the precipitation gradient). The wind index is defined as the 850-hPa zonal mean wind averaged over the box marked in Fig. 1 and normalized by the standard deviation of its time series for the entire period of study. Figure 2 shows the time series of wind indices for both the observation and simulation. We define “positive phase” and “negative phase” of the wind index to the periods in which this is either greater or smaller than one or minus one, respectively. Note that the wind index for the observation (NCEP–NCAR reanalysis) is plotted from 1979 to 2005 only, which corresponds to the period covered by CMAP.

We identify three positive and five negative phases from the observations, and six positive and seven negative phases from simulations. In the following

we concentrate on the composite plots for those two phases.

3. Precipitation variability in the eastern Brazil/SACZ convective margin

Figures 3a and 3b show composites of precipitation from CMAP and of 850-hPa wind anomalies from the NCEP–NCAR reanalysis during the two phases. The

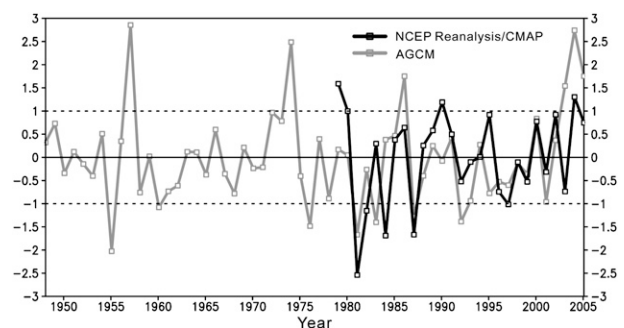


FIG. 2. Time series of February 850-hPa wind index from NCEP–NCAR reanalysis (black curve) and the AGCM (gray curve). See text for the definition of wind index, and Fig. 1 for averaging region.

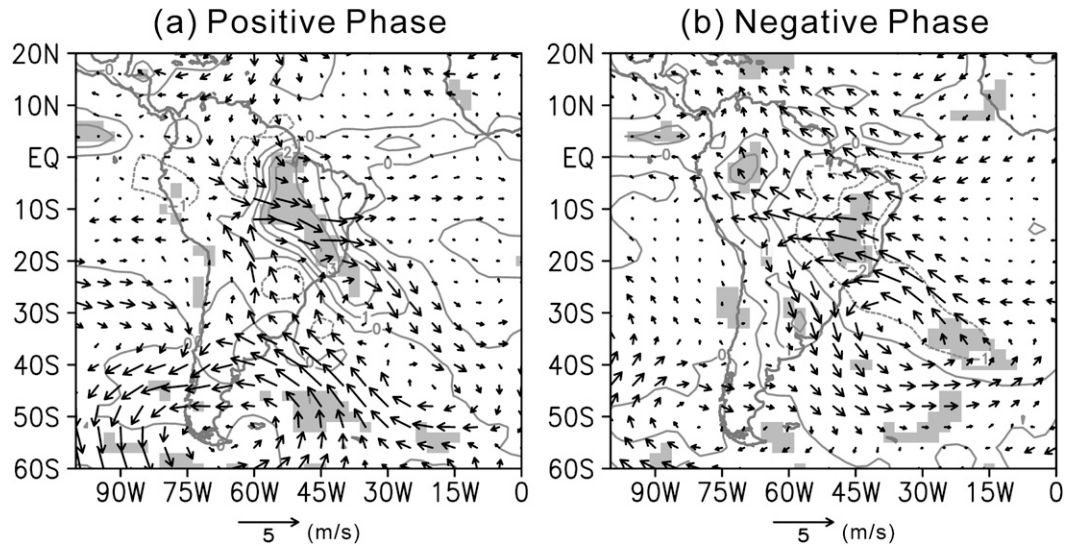


FIG. 3. Composites of February anomalies in precipitation (mm day^{-1} , contours) and 850-hPa wind (m s^{-1} , arrows) from CMAP and the NCEP–NCAR reanalysis, during the (a) positive and (b) negative phases based on the 850-hPa wind index. The shaded regions correspond to values of precipitation anomalies that are significant at the 95% confidence level. The contour interval is 1 mm day^{-1} .

shading indicates values that are statistically significant at the 95% confidence level according to a Student's t test (Wilks 2006). Anomalies are defined in reference to the overall February mean. During the positive phase, precipitation anomalies are positive over central Brazil and SACZ, and 850-hPa wind anomalies show a northwest–southeast elongated cyclonic circulation centered around 30°S , 35°W . During the negative phase, precipitation anomalies are negative over eastern Brazil, and 850-hPa wind anomalies show a northwest–southeast elongated anticyclonic circulation centered around 30°S , 35°W . The precipitation anomalies in both phases are nearly collocated with the large precipitation variance of the SACZ (Fig. 1). The anomalous circulation is equivalent barotropic, and this vortex resembles the leading mode of variability on interannual time scales over South America during austral summer identified by Robertson and Mechoso (2000).

Figure 4 shows composites of precipitation and 850-hPa wind anomalies from the simulation during the two phases. Precipitation anomalies form a dipole pattern with one pole over the eastern Brazil/SACZ convective margin and another over the La Plata Basin. The wind anomalies show a more distinct vortex. There is an overall consistency between anomalous precipitation and winds in the observation and simulation. The precipitation anomalies over the SACZ in both cases show large values over the eastern Brazil/SACZ convective margin. The difference in maximum precipitation in the two phases can be as large as 8 mm day^{-1} in magnitude.

The general tendency of stronger (weaker) precipitation over the eastern Brazil/SACZ convective margin to occur with weaker (stronger) inflow in reference to mean easterly trades can be interpreted in the context of the convective margins prototype (Lintner and Neelin 2007). Figure 5 shows composites of MSE in the PBL (lowest AGCM level) and anomalous winds at 850 hPa from the simulations during the two phases. The MSE (h_m) is defined as

$$h_m = c_p T + gz + Lq, \quad (1)$$

where c_p is specific heat capacity of dry air at constant pressure, T is temperature, g is gravity, z is geopotential height, L is latent heat of vaporization, and q is specific humidity. (Note that the units of MSE in Figs. 5, 7, and 9 have been converted into K by multiplying by c_p^{-1}). The MSE patterns are similar during both phases and show large values in the western portion of the Amazon basin. The MSE values decrease eastward gradually on the Brazilian highland and then decrease significantly away from the coast of South America. Figure 6 further shows composites of simulated advection of MSE by the anomalous flows ($-\mathbf{v}' \cdot \nabla h_m$) in the PBL. Anomalous winds at 850 hPa during the positive phase over the eastern Brazil show strong westerly anomalies that are approximately across the MSE contours (i.e., along the local MSE gradient). This suggests that weakening of the easterly trades facilitates the development of higher MSE values over eastern Brazil/SACZ convective margin. During the negative phases, on the contrary, anomalous

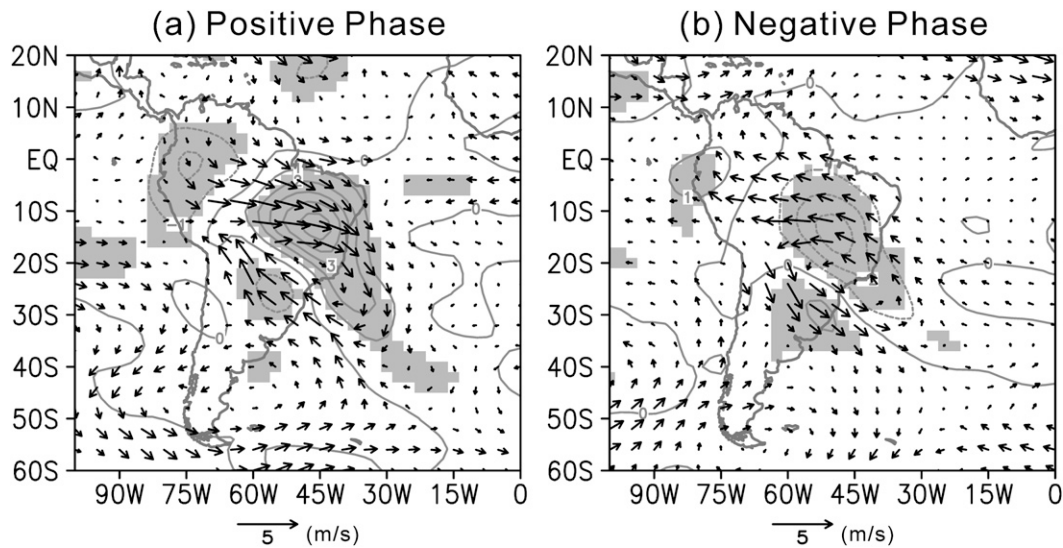


FIG. 4. As in Fig. 3, but for the simulation.

winds at 850 hPa over eastern Brazil show strong easterlies nearly along the MSE gradient, which indicates a strong downstream flux of low MSE from the Atlantic Ocean to eastern Brazil. These features are consistent with the positive (negative) advection of MSE by the anomalous flows over eastern Brazil during the positive (negative) phase in Fig. 6. Higher MSE favors stronger convection and is consistent with increased precipitation at the SACZ. Inflow of air with lower MSE suppresses convection until other effects such as evaporation or radiatively driven convergence increase the air moisture above the convective threshold (Lintner and Neelin

2010). We can also see in Fig. 5 the shifts in convective margin (the boundary between shaded and nonshaded areas) over the eastern Brazil/SACZ due to the anomalous advection of MSE. The physical interpretation of the choice of 4 mm day^{-1} as a proxy for identification of convective margin is presented in Chou et al. (2009) and Lintner and Neelin (2010).

This analysis suggests that anomalous precipitation in the eastern Brazil/SACZ convective margin is associated with anomalous advection of MSE at lower levels in the troposphere. Since MSE patterns in the PBL are similar in both phases of our wind index, we conjecture

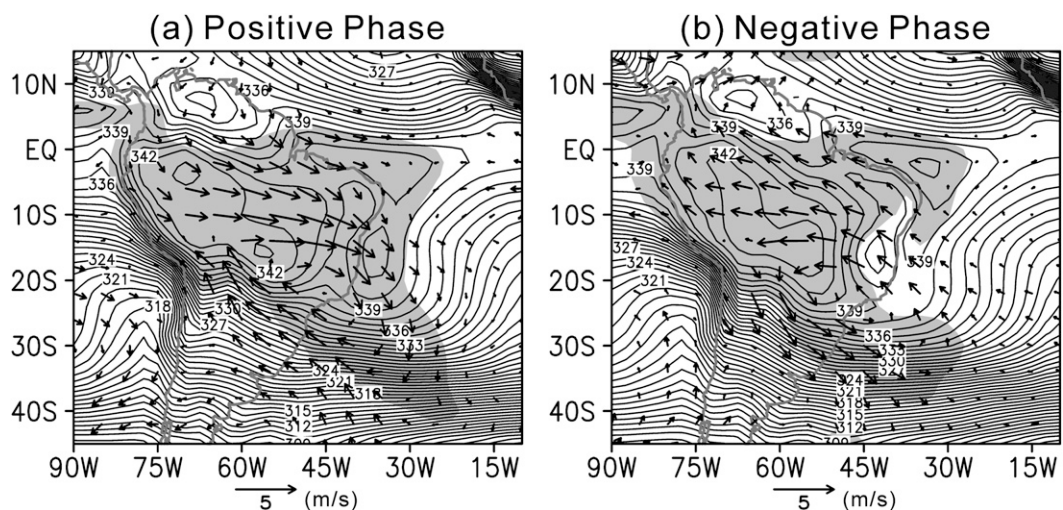


FIG. 5. Composites of simulated February mean moist static energy (K, contours) in the PBL and 850-hPa wind anomalies (m s^{-1} , arrows) during the (a) positive and (b) negative phases based on the 850-hPa wind index. Also plotted in (a) and (b) are the shaded areas where composites of simulated February mean precipitation are $>4 \text{ mm day}^{-1}$. The boundary is used as a proxy for the identification of convective margin.

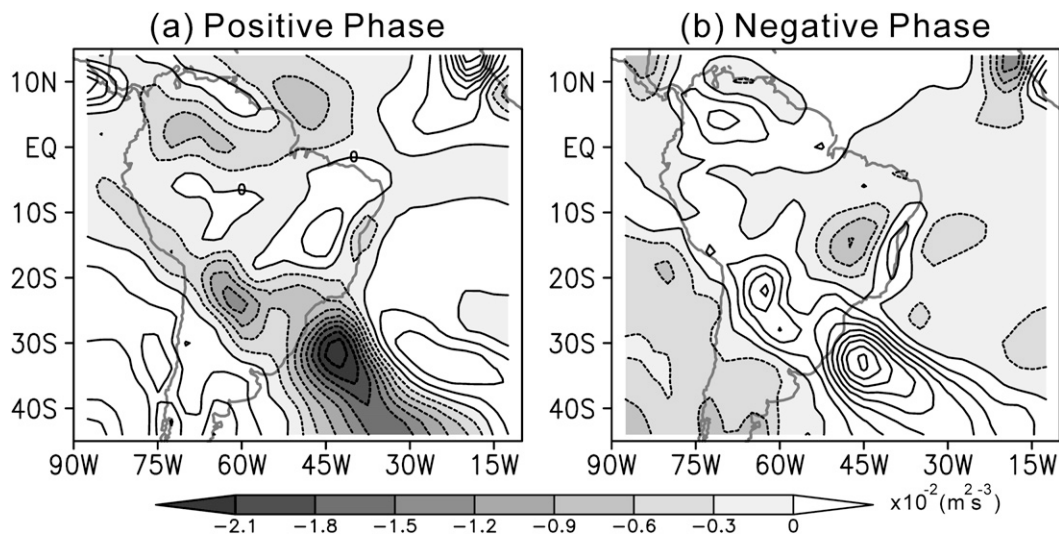


FIG. 6. Composites of simulated February advection of moist static energy by the anomalous flows ($-\mathbf{v}' \cdot \nabla h_m$) in the PBL during the (a) positive and (b) negative phases based on the 850-hPa wind index. The contour interval is $0.003 \text{ m}^2 \text{ s}^{-3}$.

that the main mechanism for interannual variability of precipitation along the eastern Brazil/SACZ convective margin is ventilation by circulation anomalies associated with the leading mode of circulation variability over South America in summertime. To support this, we aim to show that the wind anomalies have a causal impact on the precipitation via the advection of low MSE air into the convective margin.

4. AGCM mechanism-testing experiments

a. Experimental design

To challenge our conjecture on the role played by low-level wind variability and the leading mode of interannual variability on the generation of precipitation anomalies over the eastern Brazil/SACZ convective margin, we perform and analyze three AGCM mechanism-testing experiments. These experiments aim to demonstrate that in a quasi-steady (i.e., with no seasonal cycle) climate state a time-independent perturbation similar to the wind anomalies from the simulation during the two phases of the 850-hPa wind index—and confined to the region where those anomalies have substantial amplitudes—will result in a quasi-steady displacement of the eastern Brazil/SACZ convective margin. The quasi-steady climate state is obtained by integrating the AGCM in perpetual-February mode. This strategy also bypasses the need for multiyear integrations otherwise needed to have statistically significant results for the southern summer season. In the perpetual-February mode, the solar declination angle and all boundary conditions including SST, ground

properties, and albedo at the ocean surface are prescribed in the AGCM to be those corresponding to 15 February and remain unchanged through the entire model integration. The steady perturbation to the velocity field is required to be nondivergent in order not to generate vertical velocity that would directly lead to precipitation. In addition, the artificial perturbation is restricted to the low levels of the troposphere where moisture transports are important and to the region overlapping the eastern to southern Brazil and western Atlantic Ocean (50°S – 10°N , 90° – 10°W). To produce an artificial perturbation with those characteristics, we start by selecting the horizontal wind anomalies (\mathbf{v}') at the lowest four AGCM levels for both the positive and negative phases of the wind index from the simulation analyzed in section 3. Next, we separate the wind anomalies into their divergent and rotational (non-divergent) components: $\mathbf{v}' = \mathbf{v}'_{\Phi} + \mathbf{v}'_{\Psi}$, where Φ is velocity potential and Ψ is streamfunction. The second component does not contribute to the divergence field. For technical reasons, this separation is done in sigma coordinate system. Thus, in regions of topographic slope there will be some imposed vertical motion that can directly impact precipitation processes. For most of the region of interest this is not an issue, but some effect at the edge of the Andes can occur and should be ignored in interpretation of the results. We perform three mechanism-testing experiments. The first is a 12-month-long integration that will provide our reference and will be referred to as CONTROL. We then conduct a pair of imposed-wind experiments in which we artificially impose wind perturbations corresponding to the positive

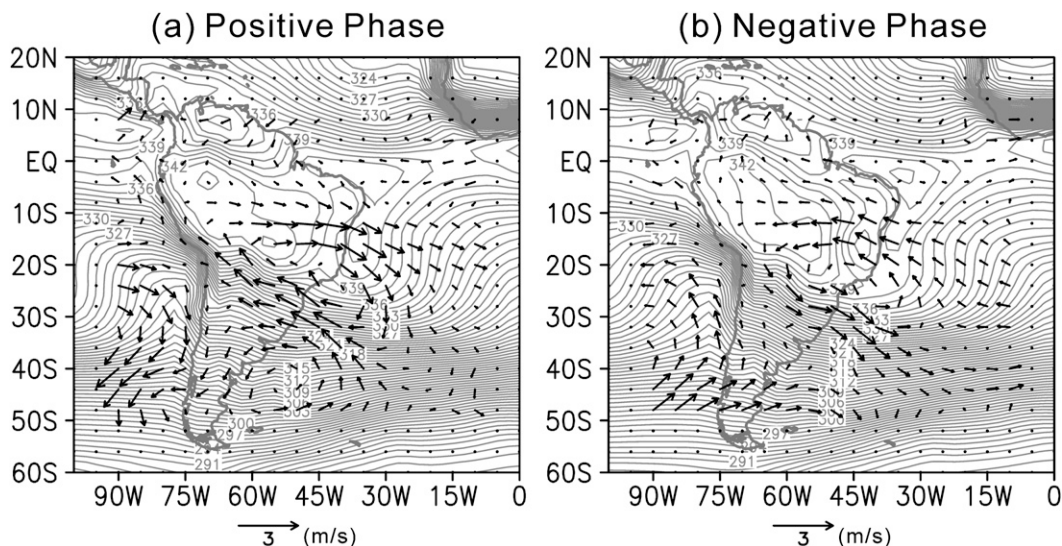


FIG. 7. Composites of simulated February mean moist static energy (K, contours) and nondivergent component of anomalous winds (m s^{-1} , arrows) in the PBL during the (a) positive and (b) negative phases of the 850-hPa wind index. See text for more information.

and negative phases, respectively, obtained according to the method described above, with the wind perturbations acting *only in the moisture advection* in the model equations. We only change the moisture advection since it is the dominant term in the MSE advection.

Figure 7 shows the wind perturbations in the PBL used in the imposed-wind experiments for both the positive and negative phases, as well as the composites of MSE from Fig. 5. A comparison with Fig. 5 illustrates the similarity with the wind fields except for smaller magnitudes in some regions (due to being only the purely rotational component). The imposed-wind experiments are also 12 months long and will be referred to as POSEXP and NEGEXP for the positive phase and negative phase experiment, respectively.

b. Experiment results

Figure 8 presents the mean precipitation for the imposed-wind experiments, as well as the difference between POSEXP and NEGEXP. The experiments capture the overall precipitation features of South American warm season climate relatively well: there is strong convection in central Amazonia and the SACZ. The largest differences are over the eastern Brazil/SACZ convective margin. POSEXP shows a precipitation maximum (Fig. 8b), while NEGEXP shows weaker precipitation (Fig. 8c). The impact of the imposed wind anomalies on precipitation is clear in Fig. 8: along the convective margins, weakened inflow in reference to the easterly trades from the Atlantic Ocean leads to strengthened precipitation, and strengthened inflow leads to lower precipitation. The

difference between POSEXP and NEGEXP can be locally as large as 4 mm day^{-1} (Fig. 8d). The precipitation difference here is smaller comparing to the difference shown in Fig. 4 (8 mm day^{-1}). This occurs for several reasons, and the experiment design that excludes the effects of temperature advection (part of the MSE advection) and moisture convergence is the main reason for such a difference. Nevertheless, the results suggest that moisture advection is the main contributor to the precipitation difference over the convective margin between the two phases. Figure 8d also shows negative values of large magnitude centered over the Andes Mountains around 12°S , 70°W . These features are influenced by differences in orography-induced precipitation, which should be regarded as discussed above.

Figure 9 presents the differences between POSEXP and NEGEXP with CONTROL as well as the mean MSE averaged over the lowest four AGCM levels in both phases. In POSEXP, the MSE has a maximum in central Brazil and decreases eastward over the Brazilian Highland and off the Atlantic coast of South America. With the imposed-wind perturbations, westerly anomalies are apparent over the eastern Brazil/SACZ convective margin, which suggests weaker easterly trades and reduced low MSE flux from the Atlantic Ocean to eastern Brazil. In NEGEXP, the pattern of MSE is similar except that the maximum is in western Brazil. The wind anomalies, on the other hand, increase the advection of low MSE air from the Atlantic Ocean to eastern Brazil. These results further suggest that in addition to the imposed-wind perturbations that contribute to the moisture

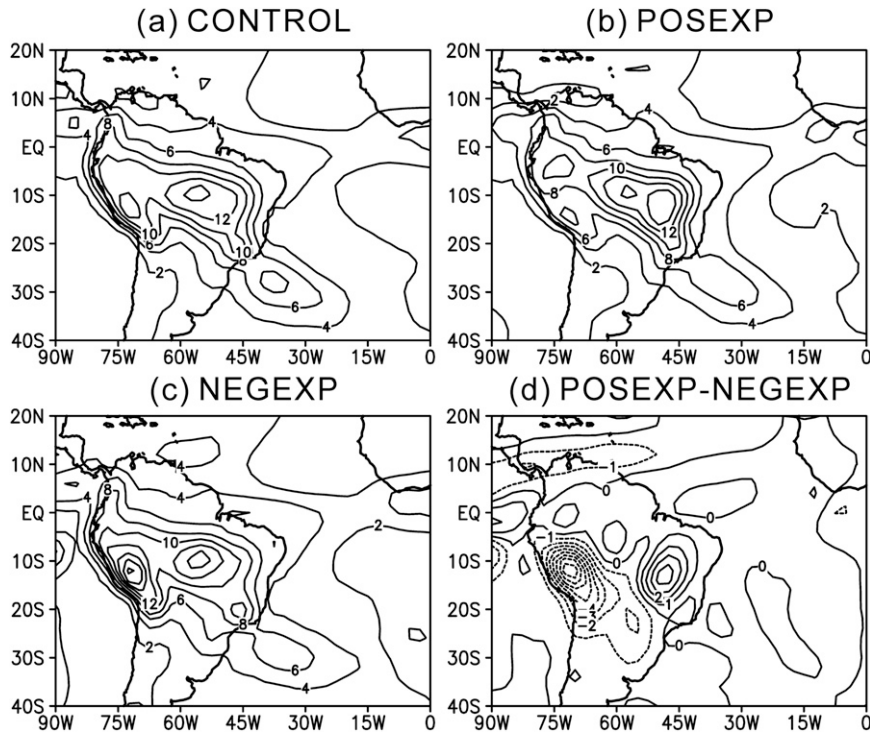


FIG. 8. Mean precipitation (mm day^{-1}) from (a) CONTROL, (b) POSEXP, and (c) NEGEXP. See text for experiment descriptions. (d) The difference in precipitation between (b) and (c).

advection, the velocity field responses in the experiments also provide additional moisture flux, which positively feeds back in precipitation fields over the eastern Brazil/SACZ convective margin.

5. Summary and conclusions

It is demonstrated that the eastern Brazil/SACZ convective margin in the austral summer is sensitive to

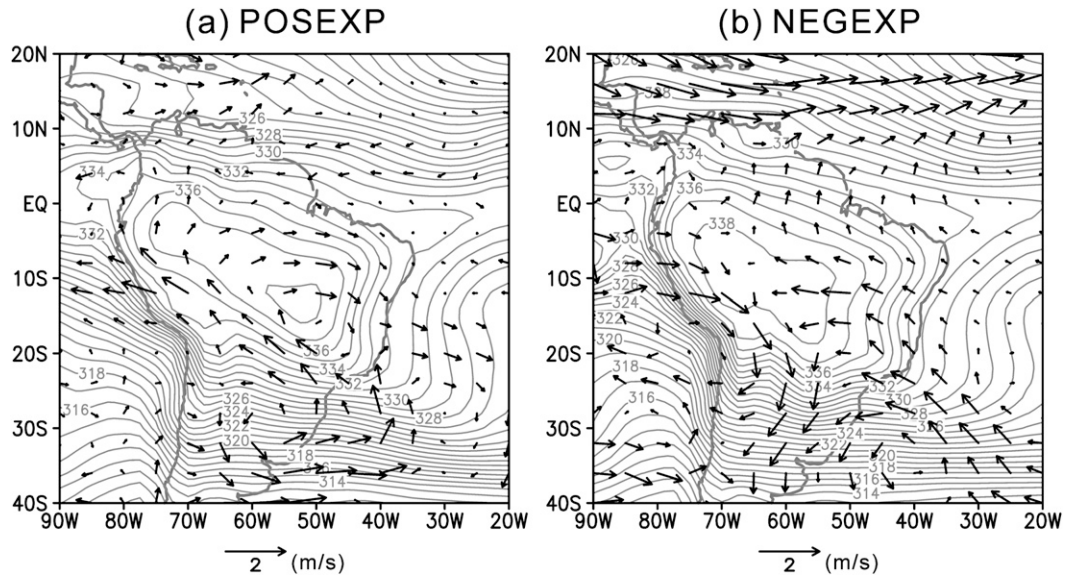


FIG. 9. Mean moist static energy (K, contours) and wind anomalies (m s^{-1} , arrows) averaged over the lowest four AGCM levels from (a) POSEXP and (b) NEGEXP.

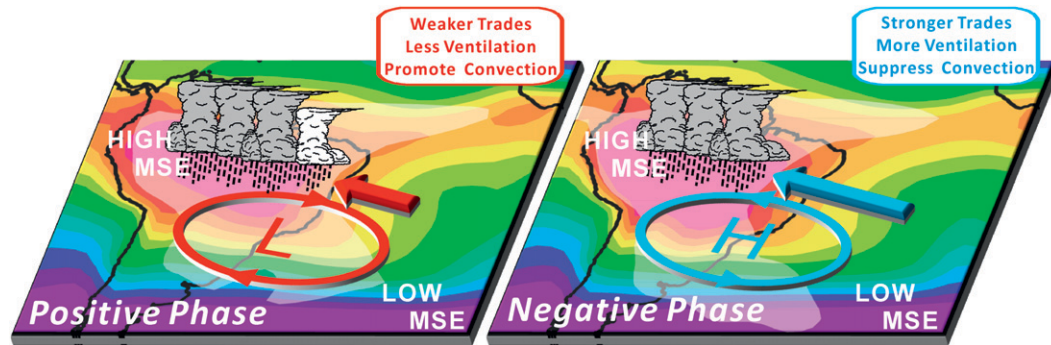


FIG. 10. Schematic diagram of the mechanism for the precipitation variability of the eastern Brazil/SACZ convective margin during positive–negative phases as defined by the intensity of low-level easterly trades. Color shades represent the MSE and white shades represent regions where deep convection occurs. Variability of the low-level easterly trades, which are associated with the leading mode of wind variability on interannual time scales, can modify the import of low MSE into the convective margin as represented by the red (blue) arrow during positive (negative) phases, and convection over the convective margin can be modified substantially through the “ventilation” effect.

the variability of low-level flows on interannual time scales. In addition to showing an association of low-level inflow and precipitation change in observational datasets and AGCM simulations, AGCM mechanism-testing experiments demonstrate a causal connection via moisture advection.

Defining a low-level wind index in a region (850 hPa; 20°–10°S, 55°–40°W) where both observed and simulated precipitation variances are large, precipitation in the selected region shows positive (negative) anomalies during positive (negative) phases of the wind index over the eastern Brazil/SACZ convective margin. Figure 10 provides a schematic diagram illustrating the underlying mechanism. During positive phases, positive precipitation anomalies are consistent with stronger convection, which is associated with weakening of the easterly trades. The weaker trades that reduce the advection of low-MSE air from the Atlantic Ocean promote convection over the eastern Brazil/SACZ convective margin. During negative phases, negative precipitation anomalies are consistent with weaker convection, which is associated with stronger easterly trades that increase the advection of low MSE air from the Atlantic Ocean. Inflow air with lower MSE suppresses convection until other effects increase the moisture of air above the convective threshold. The anomalous inflows that affect the intensity of mean easterly trades are associated with the leading mode of wind variability over subtropical South America (Robertson and Mechoso 2000). These results are consistent with the theoretical work proposed on convective margins by Lintner and Neelin (2007, 2010) and on ventilation mechanism by Chou and Neelin (2001).

AGCM imposed-wind experiments to test the causal role of horizontal moisture advection by low-level inflow

wind in creating precipitation anomalies over the convective margin are designed as follows. A steady perturbation of the horizontal velocity field is artificially imposed in the moisture equation that resembles the spatial pattern of observed wind anomalies (but non-divergent in order not to generate vertical velocities). The precipitation difference between positive and negative phase experiments can be as large as 4 mm day^{-1} . Since the MSE fields during both phases are almost identical to each other, the differences in precipitation can be attributed to the difference in low-level flows. In addition to the imposed-wind perturbations that contribute to the moisture advection, there is also a velocity field response in these experiments, which tends to reinforce the initial effect with additional moisture advection. This thus represents a positive feedback on precipitation anomalies over the eastern Brazil/SACZ convective margin.

Our analysis supports the conjecture that the connection between precipitation variability over the eastern Brazil/SACZ convective margin and the leading mode of variability over the subtropical South America (Robertson and Mechoso 2000) is established substantially via the ventilation mechanism for the variability of convective margins (Lintner and Neelin 2007, 2010). The ability of the AGCM to capture the sensitivity of SACZ precipitation to the low-level inflow variability raises the question of potential predictability. In austral summer, the leading mode of variability over South America has no strong correlation with ENSO-related SST anomalies or with the Pacific–South America mode in the South Pacific (Zamboni et al. 2010). While Robertson and Mechoso (2000) note some correlation of the vortex with southwest Atlantic SST anomalies, we have not found clear association with SST and the inflow winds

here. We thus assume that the variability is largely atmospheric internal variability. Nevertheless, the mechanism tested here, in which changes in the ventilation of the convective margin impact the precipitation, would apply on any time scale, given a perturbation to the inflow. The imposed-wind experiments provide a clear method for testing the impact of anomalous ventilation on precipitation over convective margins that can be applied to other regions.

Acknowledgments. We thank Dr. Benjamin Lintner for very helpful comments and Joyce Meyerson for graphical assistance. Computing resources were provided from the NCAR computational and information systems laboratory. This research was supported by NOAA under Grants NA08OAR4310597 and NA08OAR4310882 and by NSF under Grants ATM-0645200 and AGS-1102838.

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