The atmospheric water cycle over South America as seen in the new generation of global reanalyses

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The Atmospheric Water Cycle Over South America as Seen in the New Generation of Global Reanalyses

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Abstract. In this study the main features of the hydrological cycle over the South American region are documented with three reanalysis datasets and two observation-derived precipitation products. Rather than attempting to "close the water balance" that requires additional terms, many model dependent, we focus on the individual terms of the water cycle. An additional analysis is also presented in this work to investigate the role of the transport of moisture over the La Plata Basin (LPB) and South Atlantic Convergence Zone (SACZ) in the precipitation regimes from 1979 to 2007.

Keywords: Hydrological cycle, Precipitation, Reanalysis, South America.
PACS: 92.60.Jq

INTRODUCTION

Much of the current climate knowledge has been gained from studies using global reanalysis. A reanalysis system, or retrospective-analysis, consists of a background forecast model and a data assimilation routine. As the input observations are irregular in space and time, the data assimilation merges the available observations with the background model forecast to generate uniform gridded data. Observations assimilated into reanalysis systems and the model parameterizations can affect the subsequent forecast precipitation output from the system, because there is a complex interaction between the model and observations. The first global reanalysis were produced in the 1990s, and many studies have already examined their quality as well as assessed their biases. Two recently developed global reanalyses are employed. They are: (a) the Modern Era Retrospective-Analysis for Research and Applications (MERRA) developed at the Goddard Space Flight Center (GSFC/NASA) with a particular interest on applications for hydroclimate studies [1]; and (b) the Climate Forecast System Reanalysis (CFSR) developed at the National Centers for Environmental Prediction (NCEP) to provide the best estimate of the state of the coupled atmosphere-ocean-land surface-sea ice system [2]. For reference, the NCEP/Department of Energy (NCEP/DOE) Reanalysis II (NCEP-2) is included in the analysis [3]. Two sets of observed precipitation products were used for evaluation purposes in this study. The first data set is the Climate Prediction Center (CPC) unified global daily gauge analysis [4], which is prepared using 30,000 stations collected from the Global Telecommunications System (GTS) daily reports and additional reports provided by many hydrographic and agricultural agencies in countries around the world. This product will be used as the reference dataset for evaluation of the reanalyses, however, in an effort to assess the uncertainties in the observations themselves, another dataset is included. It is precipitation included in the forcing terms of the Global Land Data Assimilation System (GLDAS) [5]. For this dataset, data assimilation techniques are employed to merge satellite-based estimates and rain gauge observations.

In this analysis, the SACZ was divided into two regions by presenting different characteristics (see Fig. 4). Tropical SACZ (TSACZ) presents the maximum convective activity and small sub-seasonal variability, while Subtropical SACZ (SSACZ) presents sub-seasonal variability in terms of transient systems in the region [6]. The LPB region (Fig. 4), while also presenting two different regimes of precipitation in the north through the South American Monsoon System (SAMS) and the south by the Mesoscale Convective Systems (MCSs) and frontal systems, has been treated in this study as a single region [7]. The moisture budget components for several regions of South America were assessed from multiple Reanalysis data products and observations. The uncertainties in the

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observations were first estimated by examining diverse observational datasets generated from rain gauge measurements and/or satellite estimates.

RESULTS

The basic features of the South American precipitation patterns and their annual cycle are analyzed first. Then, the austral summer months are discussed due to the large contribution of summer precipitation to the annual precipitation in large areas of the tropics and subtropics (i.e., the Monsoon region and the South Atlantic Convergence Zone) [8]. Regional biases and the model skill to reproduce the spatial distribution of the annual precipitation are also discussed. Figure 1 presents the differences between mean annual precipitation of reanalyzes with respect to the CPC observed product. In general, there is a resemblance of the precipitation pattern among all products and the observed precipitation (figure not shown). However, considerable biases are found over some specific regions. Over Colombia, all reanalysis products present above-normal rainfall; over the Andes region only the CFSR (Fig. 1b) represents the average annual rainfall while both the NCEP-2 (Fig. 1a) and MERRA (Fig. 1c) exhibiting positive biases. In the central region of the continent, the MERRA reanalysis has a large scale negative bias precipitation compared to the CPC data. In general, the smallest biases are found in the CFSR reanalysis, even over the Andes Mountains, which is a region where typically most models have large biases.

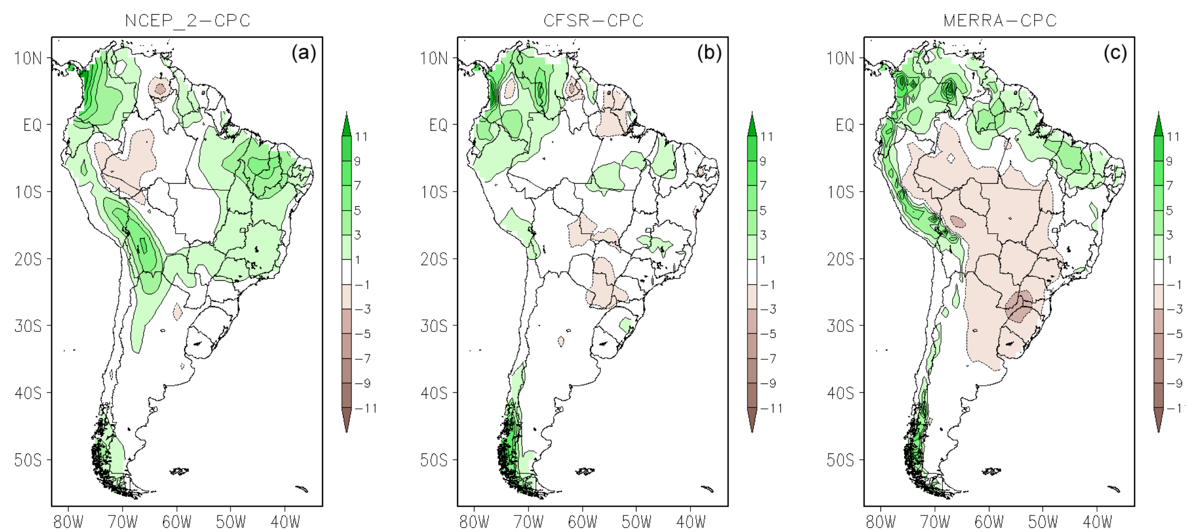

FIGURE 1. Differences between climatological precipitation (mm day^{-1}) of CPC and NCEP 2 (a), CFSR (b) and MERRA (c) for 1979-2007.

Figure 2 presents the mean annual cycle of precipitation for the three selected regions. The annual cycle is similar for all observed products, and in general, the observational-based products are very similar over all regions. However, some differences are noted between the CPC and GLDAS data over TSACZ and SSACZ regions, primarily during the warm season (October to March). The differences in the climatological values may result from the different sources of data, as the GLDAS use satellite-derived products in the process of assimilation and CPC calculate the precipitation through interpolation in the data from rain gauges only. The mean annual cycle of reanalysis precipitation depict a similar evolution as the observations for each of the regions, but some specific features can be noted. Over the TSACZ region (Fig. 2a) the reanalyses underestimate the observed rainfall during the dry season (May-September). At the beginning of the rainy season, the NCEP-2 reanalysis tends to follow the observed values, but during the austral summer (DJF), NCEP 2 underestimates the observed precipitation. On the contrary, CFSR overestimates precipitation. Interestingly, the MERRA reanalysis has the highest negative bias in this region. This will be discussed later. Over the SSACZ region (Fig. 2b) the reanalysis precipitation has a better representation of observations, particularly during the dry season. In rainy months, while the NCEP reanalyses tend to accompany the products of observation, with maxima around 8 mm day^{-1} in January, MERRA has half that amount (approximately 4 mm day^{-1}). Over the LPB region (Fig. 2c) NCEP-2 and CFSR also present a better representation of observations during the dry season of SAMS (Apr to Sep). MERRA also presents a negative bias, especially during the austral summer, where the NCEP reanalysis shows opposite signs.

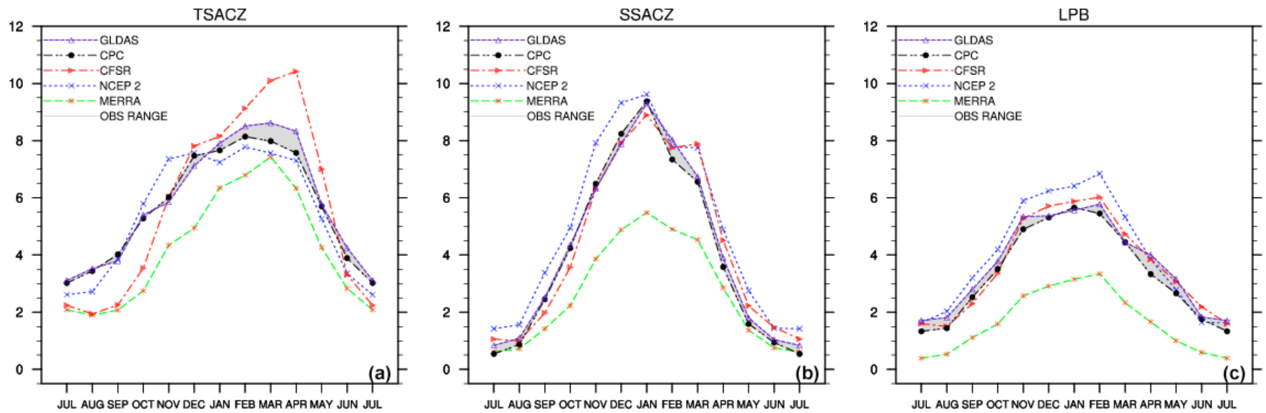

FIGURE 2. Annual average of the monthly precipitation (mm/day) of the observed-based precipitation products (CPC and GLDAS) and reanalyses (NCEP 2, CFSR and MERRA) for TSACZ (a), SSACZ (b) and LPB (c) region.

Skill of the reanalyzes precipitation relative to the reference dataset (CPC) was estimated by means of Taylor diagrams [9] (Fig. 3). The GLDAS product tends to be tightly grouped near the CPC reference point for the three regions analyzed. Over TSACZ region (Fig. 3a) NCEP-2 and MERRA exhibit the weakest correlations coefficient and largest standard deviation differences regarding to the CPC dataset. The CFSR reanalysis has correlations above 0.7 and larger standard deviation than the CPC reference. In general, the SSACZ (Fig. 3b) region presents the same pattern where MERRA and NCEP-2 have correlations lower than 0.5 and the CFSR still provides a best correlation and a standard deviation slightly greater than that CPC dataset. Finally, for the LPB region (Fig. 3c), MERRA reanalysis presents small amplitude in the variability and can be verified closer correlations between the CPC and CFSR.

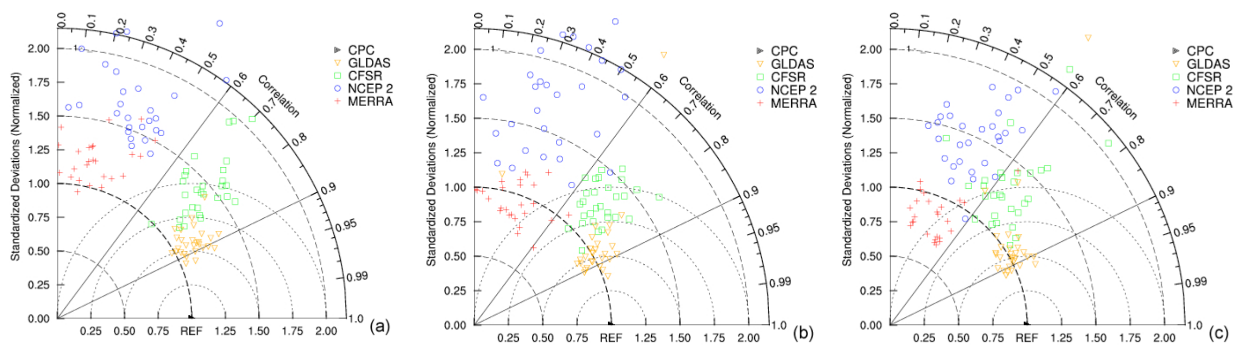

FIGURE 3. Taylor diagrams for the summer mean correlation and standard deviation of the TSACZ (a) and SSACZ (b) and LPB (c) regions, using CPC as reference.

Figure 4 shows the terms of hydrological cycle through the CFSR reanalysis. The precipitation (P) field of the CFSR (Fig. 4a) shows a rainfall pattern consistent with the location of SACZ. As in MERRA reanalysis, CFSR also presents the moisture transport by the trade winds to the SACZ region (Fig. 4b). For LPB region, the northerly flow on the northern boundary evidences the moisture transport from the Amazon associated with the Low Level Jet (LLJ) east of the Andes. However, unlike the MERRA, this reanalysis shows higher values and evaporation (E) (Fig. 4c) over this region, which compensates for the deficit of precipitation, when compared to observations made by the CPC. As in the regions analyzed the CFSR reanalysis presents higher values of P and E, the runoff values are also higher, particularly over the Andes Mountain, SSACZ region and the south region of Brazil (Fig. 4d).

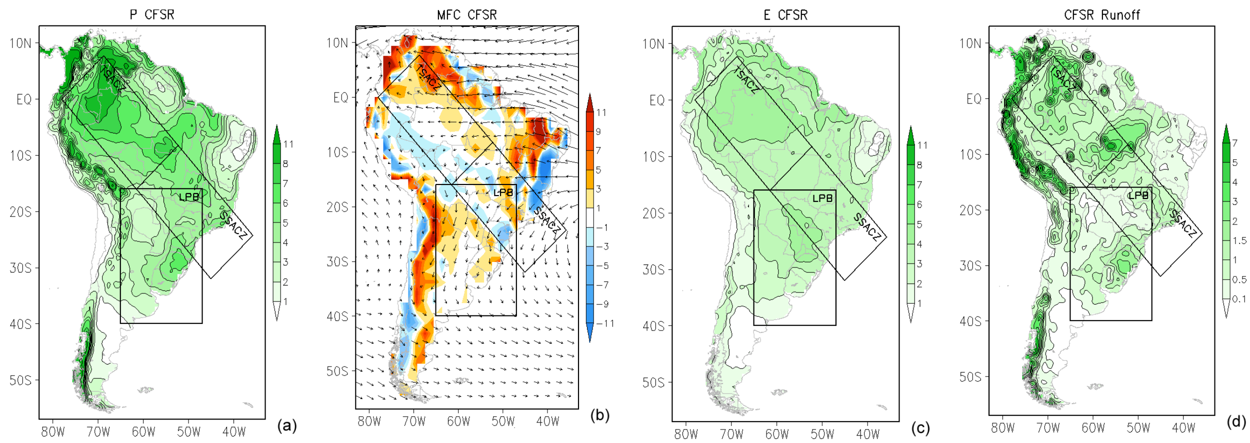

FIGURE 4. Annual mean of the precipitation (P), vertically integrated moisture fluxes convergence (MFC), evaporation (E), runoff and soil moisture for CFSR reanalysis (mm.day^{-1}).

SUMMARY

The new generation of reanalysis shows an improvement in the representation of the rainfall patterns and their magnitude. Spatial averaging for bias and the skill at reproducing the annual precipitation spatial distribution with Taylor diagrams. These diagrams show that the observed GLDAS product tends to be tightly grouped and in the vicinity of the CPC reference point. The CFSR (new generation of reanalysis) provides the best correlation for the three regions analyzed, with correlations above 0.7 and a standard deviation slightly greater than that CPC dataset, with higher standard deviation over the TSACZ region and around the reference point in the region LPB. The summer vertically integrated flux of moisture over the tropical region is strong and they are associated with moisture transport carried by the trade winds. Enhanced northerly flow evidence the moisture transport from Amazon region to LPB, associated to Low Level Jet (LLJ). The net flux in LPB is largest, resulting from a greater transport by easterly winds.

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