Progress Report

EVALUATION OF THE RELATION BETWEEN HEAVY PRECIPITATION EVENTS AND SACZ OVER SOUTHEASTERN BRAZIL

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Background

The focus of my PhD research is to investigate changes in the mechanisms related to extreme precipitation events over Southeast Brazil (SE Brazil) due to increased temperature. According to Held and Soden (2006), one of the consequences of a warmer atmosphere is an expected increase in the atmospheric moisture content with complex and non-uniform impacts on precipitation. Previous studies evaluated various precipitation indices over South America and identified positive trends in different areas, including Southern Brazil and São Paulo state (Haylock et al., 2006; Marengo et al., 2010). These positive trends were related to an intensification of the heavy rainfall rather than an increase in duration or frequency of wet days (Skansi et al., 2013). In addition to uptrends in extreme precipitation, some studies have shown an increase in the number of consecutive dry days and a decrease in the number of light rainy days (days with less than 5mm/day) in São Paulo state, indicating that precipitation is getting concentrated in fewer rainy days (Dufek and Ambrizzi, 2008). There is also evidence that the South American Monsoon System (SAMS) in getting longer, with earlier onset and later demise (Jones and Carvalho, 2013).

Our recent studies (in review) analyzed gauged and gridded daily precipitation over the past 70 years along the southeastern Brazilian coast (SE Brazil, between 20°S and 25°S), and confirmed that the increasing trend in both average and extreme precipitation described previously can be extended to the entire study area. Furthermore, our results also indicate that, during the wet season (October to March), this increased precipitation is concentrated in fewer days, especially in those stations located on the northern portion of the coast (between 20°S and 23°S), coinciding with the South Atlantic Convergence Zone (SACZ) activity area.

During the austral summer (DJF), South America is under the influence of a monsoonal circulation, responsible for the largest part of precipitation on SE Brazil (Kodama, 1992; Zhou and Lau, 1998, 2001; Liebmann et al., 2001; Jones and Carvalho, 2002). The monsoonal upper level circulation over South America is dominated by the Bolivian High, located over the Andean altiplano, and the Nordeste trough, over tropical Atlantic (Chen et al., 1999; Lenters and Cook, 1999). On lower levels, the main circulation features are the subtropical highs over both Pacific and Atlantic oceans, straddling the continent. Over the continent, the development of a heating low, centered over northern Argentina (Chaco low), increases the land-ocean temperature contrasts and favors the poleward flow along the tropical eastern coast of South America (Kodama, 1993; Zhou and Lau, 1998). The increased thermal contrast also favors the penetration of the trade winds deeper into the Amazon region. The presence of the Andes deflects the northeast flow into northerly along the eastern slope of the cordillera. Farther south, around 20°S, the Chaco Low deflects this flow counterclockwise. Episodes of intense northwesterly along the Andes are denominated Low Level Jet (LLJ) and favor the moisture transport from the Amazon toward subtropical latitudes. When the South Atlantic Convergence Zone is active, the LLJ are weaker and the moisture flow from the Amazon is diverted toward SE
Brazil (Liebmann et al., 2004). The present study investigates changes in regional circulation associated with the observed trends in precipitation during austral summer (DJF).

Progress

To investigate changes in the mechanisms associated with extreme precipitation events over SE Brazil, we analyzed daily data from National Center for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR), at 0.5° spatial resolution from 1979 to 2012, for different atmospheric variables: sea level pressure (SLP), geopotential height at 200hPa (Z200) and 850hPa (Z850), wind at 200hPa (W200) and 850hPa (W850), temperature at 850hPa (T850), precipitation (PRECIP), and precipitable water (PW). We also analyzed the sea surface temperature (SST) data from the National Ocean and Atmosphere Administration (NOAA) Optimum Interpolation Version 2 dataset (Reynolds et al., 2007). This dataset is at 0.25° of spatial resolution and covers the period of 1981 to 2012.

The first analysis is the changes in the climatological average of each variable along the period of 1979-2012. This period is divided into three intervals of 11 years each (12 for the last): 1979-1989, 1990-2000 and 2001-2012. As the SST data has a slightly different period, we considered three intervals: 1981-1990, 1991-2000 and 2001-2012. The significance of the difference between the averages for each period is accessed using a two-sided t-test, with 5% significance level and considering the samples independent. Changes in summer circulation are likely to affect the precipitation regime since this is the rainy season.

We are also interested in identifying changes in the mechanisms associated with extreme precipitation events (EE) in each portion of SE Brazil. Our previous research, based on observed precipitation from gages located along the southeastern coast, described two different trends over the area. The southern portion is experiencing an increase in the number and intensity of extreme events and in the number of rainy days (precipitation above 1mm/day), affecting the total amount of precipitation during the rainy season. On the northern portion, the intensity of the extreme events is also increasing. However, there are fewer rainy days, indicating that the same amount of rain is now concentrated in fewer more intense events. To investigate how changes in atmospheric circulation are affecting extreme precipitation events in each portion of SE Brazil, we analyzed composites of the atmospheric fields during extreme precipitation days for each portion separately. The composites are based on days with precipitation above the 80th percentile, estimated for each station. The events were determined based on the precipitation observed on the stations: days with precipitation above the threshold in more than 50% of the stations located at each portion were considered event days. The data period is also divided in three intervals and the results are presented as the difference between the composites for the first and last interval. The significance of the difference between the periods is accessed using a two-sided t-test for independent samples, with significance level of 5%.

Seasonal changes along the decades

In upper levels (200hPa), the difference between the last (2001-2012) and first (1979-1989) intervals indicates an increase in geopotential height (Z200) over the tropics (shades in Fig 1a, representing areas where the difference in average is significant with p<0.05). The increase in Z200 is reflected in the intensification of the Bolivian High and a deepening the Nordeste trough along the three time intervals analyzed (Fig 1a, contours: 1979-1989 – solid; 1990-2000 – dashed; 2001-2012 – dot-dashed). The intensification of this circulation accelerates the southerly upper level winds over central Brazil and the northerlies over the western flank of South America (Fig 1d). The increased gradient in Z200 between the tropical and extratropical latitudes also accelerates the subtropical jet over western South America (around 30°S; Fig 1d).
Fig. 1: Summer average for all periods (contour) and significant difference (p<0.05) between first (1979-1989) and last (2001-2012) interval average. (a-c) Averages (contour) for the first (1979-1989, solid), second (1990-2000, dashed) and third (2001-2012, dot-dashed) periods and significance level (shades; p<0.05) for the difference between the first and last period: positive (negative) significant difference in dark (light) gray. (a) Geopotential height at 200hPa, contours at 12400m; (b) Geopotential height at 850hPa, contours at 1500m; and (c) Sea level pressure, contours at 1009hPa. (d-e) Difference between the summer averages for the first (1979-1989) and last (2001-2012) intervals for winds at 200hPa (d) and 850hPa (e) (only significant difference plotted, p<0.05), with scale according to the key on the upper right.
Fig. 2: As in Figure 1, for (a) Sea surface temperature, with contours at 27°C; (b) Temperature at 850hPa, contours at 18°C; (c) CAPE, contours at 900 J/kg; (d) Precipitable water, contours at 40kg/m²; and (e) Precipitation, with contours at 5mm/day.
In lower levels, the thermal low over the continent is weakening (Fig 1b) while the South Atlantic Subtropical High (SASH; Figs 1b and 1c) is deepening, slowing down the winds around it (Fig 1e). The reduction of the continent-ocean pressure gradient contributes to the weakening of the northerly winds along Brazilian east coast, between 5°S and 25°S (Fig 1e). The monsoonal circulation is also weaker, with reduced intensity of the easterlies over tropical Atlantic and the LLJ eastern of the Andes (Fig 1e), deflecting the flow from the Amazon towards SE Brazil.

The ocean along the ITCZ and the east coast of Brazil is warming (Fig 2a), as well as the atmosphere over the tropical portion of the continent and adjacent ocean (at 850hPa; Fig 2b). There is also more moisture available as precipitable water (PW) over the Amazon, central Brazil and along the SACZ and ITCZ (Fig 2d). The increase in temperature and precipitable water over Amazon, ITCZ and parts of SE Brazil is reflected in an increase in CAPE (Fig 2c) and precipitation (Fig 2e). On the other hand, areas with increased temperature and PW over central Brazil and oceanic SACZ are becoming more stable (decrease in CAPE, Fig 1c). Over central Argentina, CAPE (Fig 2c), PW (Fig 2d), and PRECIP (Fig 2e), are decreasing, probably associated with the weakening of the LLJ.

These changes observed in the South American climatology indicate that there is enough moisture to produce precipitation even in a warmer environment. However, the circulation is getting weaker, affecting the dynamical component necessary to support convection over the region.

Changes in Extreme Events (EE)

North Portion

Previous studies indicated that, over the north portion of the domain, there are fewer rainy days but extreme events are getting more intense. The increase in geopotential height observed for the climatological analysis can also be identified when comparing the composites for EE during the first (1979-1990) and last (2001-2012) intervals. The largest increase in Z200 anomalies occur north of 30°S over South America and the tropical Atlantic (Fig 3a). Over the subtropics, the cyclonic circulation related to the SACZ is weakening (positive Z200 anomalies), although the change is not significant. At lower levels, trends in Z850 are not significant, although there is a deepening of both subtropical anticyclonic circulations over the ocean, as well as a weakening of the Chaco low over the continent (Fig 3b and 3c). The wind anomalies in lower and upper levels (Fig 3d and 3e) also do not show any significant changes.

Changes in SST are stronger over the Tropical Atlantic, with areas of increased SST anomalies also over subtropical Southwest South Atlantic (Fig 4a). Over land, the increase in temperature (at 850) is stronger over central Brazil and the ITCZ (Fig 4b). Trends in moisture available as PW and CAPE are larger over the Amazon and ITCZ (Figs 4c and 4d). Over subtropical southwest Atlantic, a warmer ocean (Fig 4a) and cooler atmosphere (not significant; Fig 4b) increases the stability (Fig 4c).

Despite the increase in Z200 over the tropic, other dynamic variables have not shown significant changes during EE events over the North portion. Thus, when the dynamic conditions to sustain extreme events are present, the increased amount of precipitable water in the atmosphere favors the occurrence of more intense precipitation.
Fig. 3: Differences between composites for the first (1979-1989) and last (2001-2012) periods during extreme events on North portion of the domain for summer. (a-c) Solid (dashed) contour: positive (negative) difference between anomalies for the first (1979-1989) and last (2001-2012) periods; dark (light) shades: positive (negative) significant differences. (a) Geopotential height at 200hPa, with contours each 15m; (b) Geopotential height at 850hPa, contours each 6m; (c) Sea level pressure, contours each 1hPa. (d-e) Difference for the wind anomalies at 200hPa (d) and 850hPa (e) (only significant difference plotted, p<0.05), with scale according to the key on the upper right.
Fig. 4: Same as Figure 3, for (a) Sea surface temperature, with contours each 0.3°C; (b) Temperature at 850hPa, with contours each 0.5°C; (c) CAPE, with contours each 60 J/kg; (d) Precipitable water, with contours each 1.5kg/m²; and (e) Precipitation, with contours each 3mm/day.
South Portion

Over the south portion of the domain, precipitation is increasing and the rainy days are getting more frequent. In upper levels, the changes in Z200 anomalies (Fig 5a) are similar to those observed for the climatological analysis, increasing the equator-pole pressure gradient. In lower levels, the Chaco low is weakening (Fig 5b and 5c). Although not significant, the thermal low over the continent is also weakening while the SASH is deepening (Fig 5b and 5c). This reduces the land-ocean contrast and weakens the northerly winds along Brazilian east coast (Fig 5e). There is also a weakening of the trade winds along the equator, indicating a weakening of the monsoonal circulation (Fig 5e). Although similar to the changes observed for the climatology, the changes for the south portion of the domain are weaker.

The anomalies in SST are more intense over Tropical Atlantic, along the Brazilian eastern coast and over subtropical western South Atlantic (Fig 6a). Over land, the temperature anomalies at 850hPa and the moisture available as precipitable water are increasing over tropical areas, mainly over Amazon, SE Brazil, and along the ITCZ and SACZ (Fig 6b and 6d). The increase in CAPE is spatially more restrict, occurring mostly over equatorial Amazon, SE Brazil and Paraguay (Fig 6c). Additionally, CAPE is reducing over the oceanic portion of the SACZ (Fig 6c), where the SST and T850 anomalies are increasing (Fig 6a).

As for the north portion, the differences in composites for EE over the south portion of SE Brazil indicate that the thermodynamic forcing is present as increased moisture and instability. The dynamic forcing show some changes similar to those observed for the climatological analysis, however less intense. One interesting result is the large increase in CAPE over Paraguay. This region is associated with the formation of Mesoscale Convective Complexes which propagates eastward and can be associated with extreme precipitation events over São Paulo (Rickenbach et al., 2011).

Final Remarks and Future Work

The difference in climatology analysis indicated an increase in atmospheric thermodynamic forcing during the summer, with warmer, moister and more instable conditions over tropical South America, including SE Brazil. On the other hand, the dynamic forcing related to the occurrence of precipitation is getting weaker, with reduced land-ocean pressure gradient slowing down the northerly flow along Brazilian east coast and weakening the moisture convergence over the area. However, when analyzing the conditions related to extreme precipitation events over the North portion of the study area, both the dynamic and thermodynamic conditions favoring intense precipitation are present. This helps explaining the observed changes, with the number of rainy days is decreasing and the precipitation is getting more concentrated in more intense events. Thus, for the north portion of the domain, the observed changes in precipitation are related to a weakening of the monsoonal circulation, reducing the dynamical support for the precipitation. Whenever these dynamic conditions are favorable, the increased instability and precipitable water favors the occurrence on extreme precipitation events.

For the EE occurring over South portion of the study area, where the precipitation is becoming more intense and frequent, both the dynamic and thermodynamic conditions are similar to the changes observed for the climatology, however less intense. Thus, the changes in precipitation observed over this area could be linked to local factors favoring the convection. To better investigate this hypothesis, it is necessary a more in depth analysis of the vertical structure of the atmosphere. In addition, the analysis of longer time series and relation of the observed changes with global atmospheric modes would allow a better understanding of the climatic variability affecting on the region.
Fig. 5: Same as Figure 3, for extreme events on South portion of the domain.
Fig. 6: Same as Figure 4, for extreme events on South portion of the domain.
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References


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