5.6a AN OBSERVED TREND IN CENTRAL SOUTH AMERICAN PRECIPITATION

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1. INTRODUCTION

In South America east of the Andes Mountains, pronounced trends in seasonal precipitation are observed in two regions. During summer, a positive trend is centered in Southern Brazil, and a negative trend is centered slightly north of, but roughly parallels the precipitation maximum associated with the South Atlantic convergence zone (SACZ). This paper presents analyses of the trends in both these regions.

2. DATA

This analysis utilizes daily records of precipitation from stations, which in some cases has been averaged onto grids. The many sources of data are listed in the Acknowledgments. Gridded daily precipitation fields for South America are available at 1° and 2.5° resolution by visiting *http://www.cdc.noaa.gov/people/brant.liebmann/s_america_rain.html*. This study also uses fields obtained from the National Centers for Environmental Prediction Reanalysis Project.

3. RESULTS

Figure 1 shows a 24 year climatology for January - March (JFM). There are maxima in the southern Amazon Basin, along a southeastward diagonal known as the SACZ, and on the east coast near the Equator. The latter is associated with the intertropical convergence zone (ITCZ), which extends well into the Atlantic. The JFM total is qualitatively similar to the December - February total (DJF - not shown), although during DJF the ITZC is weaker than during JFM, as it is strongest in March and April.

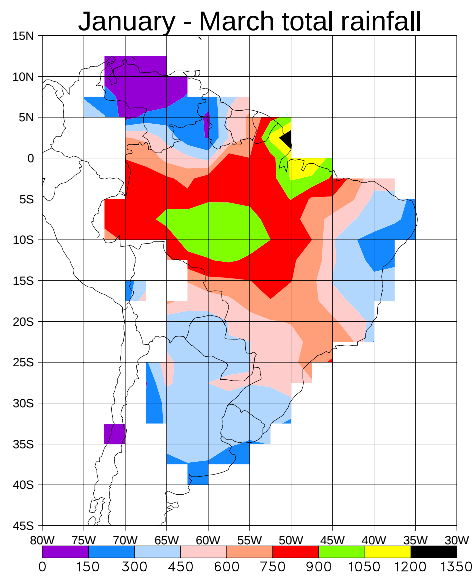

Fig. 1. January - March total precipitation, averaged for the years 1976-1999. Resolution is 2.5°. Values are in mm.

The JFM trend for the same 24 year period is shown in Fig. 2. There is a positive trend in Southern Brazil, and an elongated region with a negative trend, centered on the northern fringe of the SACZ. During DJF the Southern Brazil trend is slightly smaller, while that flanking the SACZ is marginally larger. These are the only two areas of South America with statistically relevant trends (in the regions with data), and they are evident only during the summer season.

Figure 3 shows the trend for each of the 110 stations within a radius of 2° of 25°S, 50°W with at least 20 years of data for the 1976 -1999 period.

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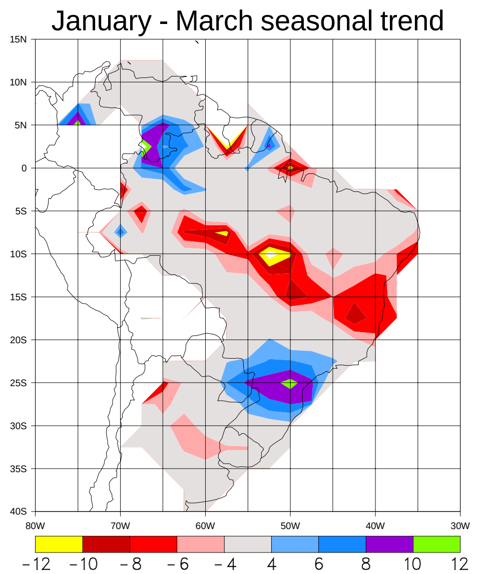

Fig. 2. Linear trend of January - March precipitation for period 1976-1999. Values are in mm season^{-1}.

All except 4 exhibit a positive trend. A JFM index is computed by averaging all values on a 1° grid from 23°S - 29°S, 47°W - 53°W. This index has a positive trend of 10.89 mm yr^{-1}.

The 'Southern Brazil' index is then correlated simultaneously with sea surface temperature

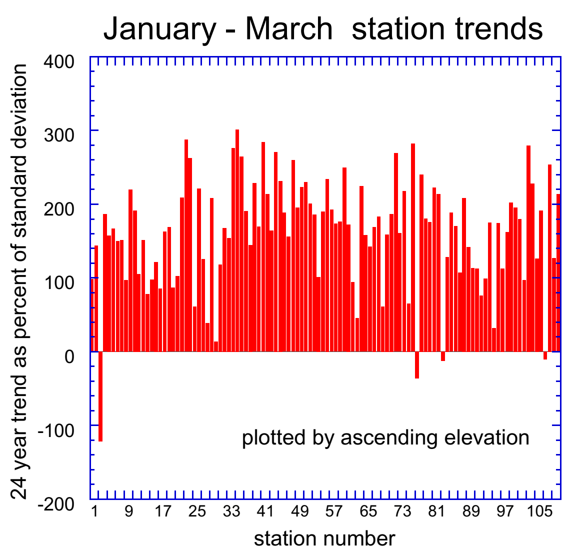

Fig. 3. January - March trends at individual stations for the period 1976-1999, expressed as a percent of 24-year trend divided by its standard deviation. Each station has at least 22 years of data during the period, and lies within 2 degrees of 25°S, 50°W.

(SST). The correlation is shown in Fig. 4a. In Fig. 4b is the trend in SST for the same period shown previously for rainfall. An area off the east coast of Brazil with a positive correlation is coincident with one of positive trend. It is possible that the positive correlation is a result of trends in both the Sothern Brazil index and in SST, effectively reducing the degrees of freedom to one.

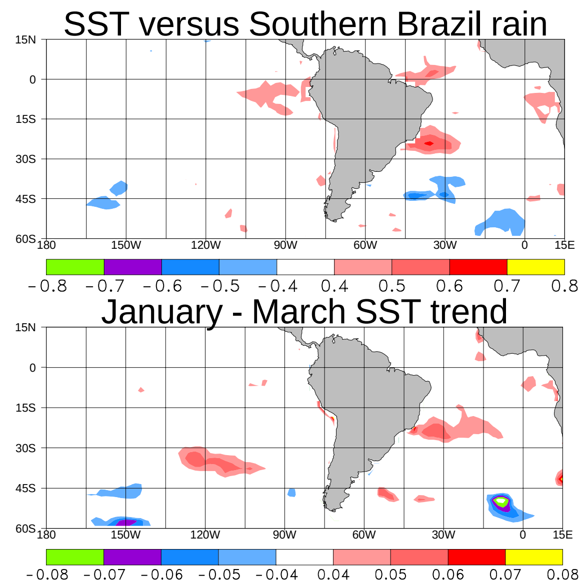

Fig. 4. a) Simultaneous correlation of Southern Brazil January - March rainfall index (see text) with SST for the period 1976-1999. b) Trend of January - March SST for the same period. Units are C per year.

Fortunately, this area of South America (and in general, most of Brazil near the coast) has a relatively high density of stations and a well-established historical rain gauge network. 41 stations, with an average record length of 50 years, have data for at least 48 years between 1948 and 1999. A JFM index made by averaging these stations correlates at 0.97 with the original index over the overlapping period.

The 1976-1999 trend is 7.5 mm yr^{-1}, while that from 1948-1975 is 2.4 mm yr^{-1}. A similar changing trend is observed in Iguazu River (located under the point of maximum trend) flow, except that while rainfall has increased along the trend line from 1976-1999 by 35%, flow has increased by 161%.

Indices of SST are computed as an average of the points from 27.6°S - 21.9°S, 28.2°W - 41.2°W. The JFM index also shows an increase in the post-1975 period from 0.022 C yr^{-1} to 0.045 C yr^{-1}.

One can argue that if there is an interannual relationship aside from the trend, and then if there is a trend in the causal field, it should result in a trend in the respondent field.Running correlations between each 21 year segment of SST and Southern Brazil rainfall are computed after first removing the trend from each segment. The correlations are computed for the simultaneous series and for JFM rainfall with DJF and February-April SST.

The running correlations are shown in Fig. 5. The largest detrended correlations occur with SST lagging by 1 month. Although each of the correlations is not independent, it is interesting that almost every detrended segment passes a 2-sided *t*-test for statistical significance at the 95% level.

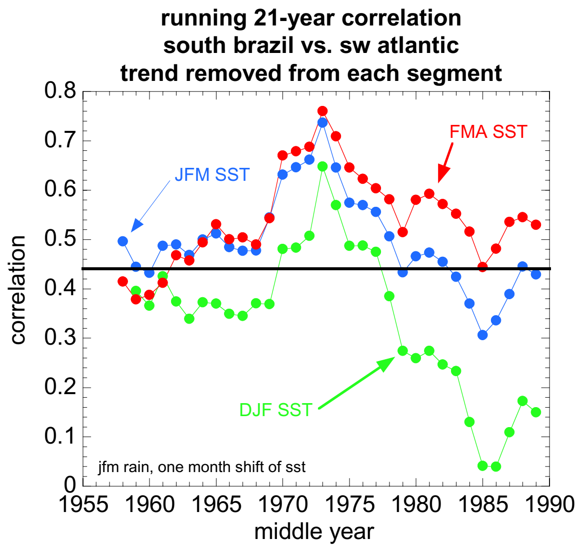

Fig. 5. 21-year running correlations between January - March Southern Brazil rainfall index and southwest Atlantic SST index. Trend has been removed from each segment. Red curve, February - April SST; blue curve, simultaneous correlation; green curve, December - February SST.

Figure 6a shows the JFM average surface winds for the period 1976-1981. Fig. 6b shows the JFM surface winds for the 6-year period from 1994-1999 minus the average from 1976-1981. One of the largest changes is in the area of the positive SST trend. It appears as though the South Atlantic high has decreased in strength from the beginning to the end of the period. This change would reduce evaporation at the surface and mixing above the thermocline. Reduced mixing will reduce entrainment at the thermocline. Both of these processes will result in warmer SSTs than in seasons with stronger mean winds. Furthermore, the mean wind is parallel to the coast, and so the net Ekman transport is away from the coast, causing coastal upwelling and surface cooling. The Ekman transport is lessened along with a reduction in mean winds, resulting in warmer SST.

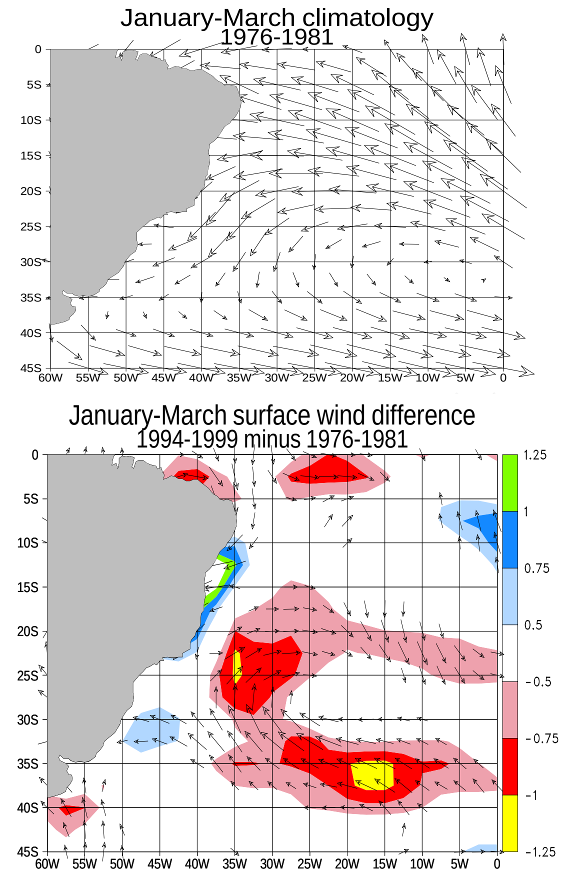

Fig. 6. a) Average surface winds for January - March 1976-1981. b) Average winds for January - March 1994-1999 minus those for 1976 - 1981. Differences in speed are shaded, with units in ms^{-1}.

The change in winds is consistent with the trend in SST. The connection between SST and rainfall appears to be real. The link between the two, however, is not obvious.

The other area that exhibits a large trend in precipitation during summer is roughly parallel to and slightly north of the line of maximum mean precipitation associated with the SACZ (Fig. 2). Here the trend is negative.

Figure 7 shows trends for each 24-year segment beginning in the period 1948-1971 and ending in the period 1976-1999. The last segment is the period for which the trends shown in Figs. 2, 3, and 4b were calculated. The indices from which the trends shown in this figure were computed as an average of stations with record lengths of at

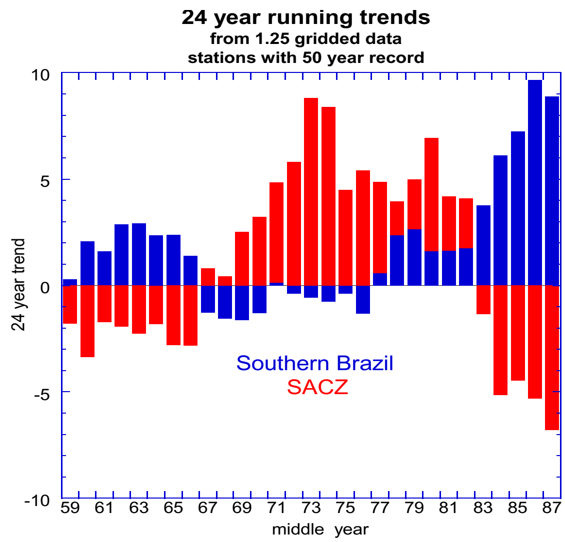

Fig. 7. 24-year running trends for January - March computed from 1.25° gridded data. Stations included in grid have at least 50 years of 81 day seasons from 1948-1999. Histogram in red denotes trends for an average of the grid points centered from 40°W-45°W, 15°S-20°S. Histogram in blue denotes trends for an average of the grid points centered from 50°W-45°W, 25°S-20°S.

least 50 years. For the area of negative trend slightly north of the SACZ shown in Fig. 2, long records are available only near the coast, which is why the index includes only grid points near the coast (see caption). It will be referred to as the SACZ index.

There are at least two interesting aspects to Fig. 7. The first is that the trends in Southern Brazil are largest during the most recent segments. The second is that the negative trends found in the SACZ are a relatively recent phenomenon, and the largest trends in that region are actually positive and occurred in the segments centered around 1973.

An inspection of Fig. 7, however, indicates a tendency for the trends to be out-of-phase (at least for 24-year segments), and in fact the trends for the segments are correlated at -0.75. Although the out-of-phase nature of the pattern shown in Fig. 2 is remniscent of the 'see-saw' in precipitation shown by Nogués-Paegle and Mo (1997), the centers are displaced to the north of those shown in that paper.

Since there is a tendency for the trends to be of opposite sign over the period of record, it again follows that interannual variability should be out of phase as well. In fact, it is difficult to conclude that there is an out-of-phase relationship between the centers shown in Fig. 2. Fig. 8 shows the running correlation for each of the 24-year segments. While the correlations for all the segments are negative, in the beginning and middle of the record they are quite low.

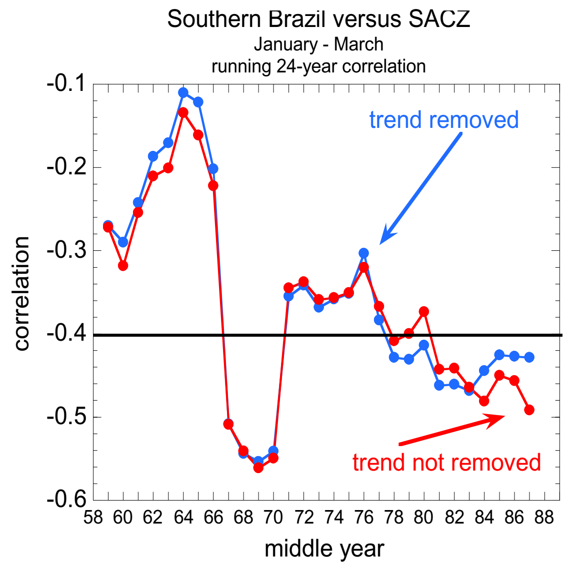

Fig. 8. Correlation between SACZ and Southern Brazil indices. Each point on graph represents correlation for 24 years of January - March totals, with year on abscissa the middle year of period. The blue curve shows the correlations after the trend for each 24-year period was removed. Horizontal black line is 95% significance level for a two-sided *t*-test for an individual correlation.

The correlation between the SACZ index and SST is of similar magnitude to that between SST and the Southern Brazil index (Fig. 4a), but as expected is of opposite sign. This is no surprise, as there is a significant correlation between that index and the SST index over the same period (rightmost point on Fig. 8).

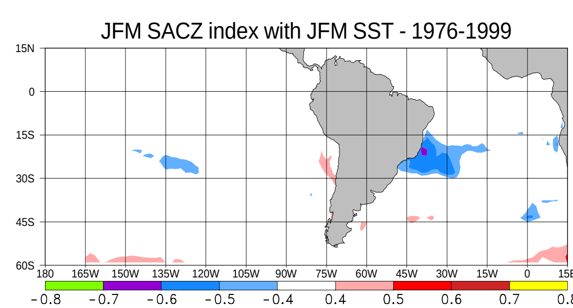

Fig. 9. Simultaneous correlation between January - March SACZ rainfall index and SST for the period 1976 - 1999.

The running 24-year correlations between the SACZ and SST indices (Fig. 10) are statistically relevant over the entire period (except 1 segment), and are largest with the trends removed. The simultaneous correlations shown here are larger than lead-lag correlations. Thus, even though rainfall in Southern Brazil and the SACZ are not strongly out-of-phase throughout the period, they both appear to be related to SST on an interannual time-scale. One cannot rule out the possibility of SST forcing SACZ rainfall anomalies, or vice-versa.

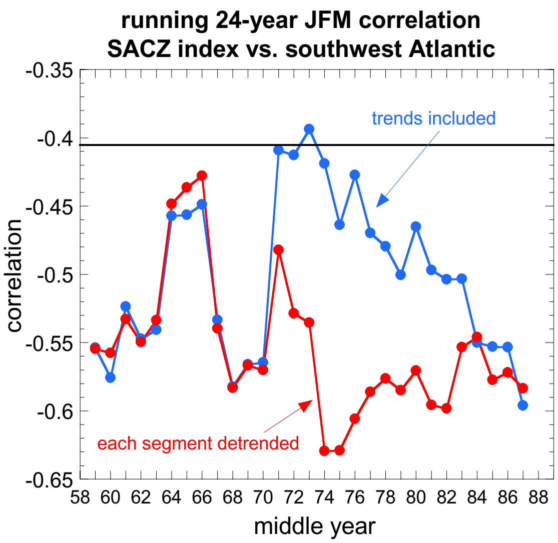

Fig. 10. Correlation between southeast SACZ and SST indices. Each point on graph represents correlation for 24 years of January - March totals, with year on abscissa the middle year of period. The red curve shows the correlations after the trend for each 24-year period was removed. Horizontal black line is 95% significance level for a two-sided *t*-test for an individual correlation.

4. SUMMARY

This study has shown that two regions of South America (in areas with data) have exhibited trends in precipitation during recent decades. Both of the observed trends have occurred in summer. Trends have been almost consistently positive in Southern Brazil since the late 1940s. There is an interannual relationship between Southern Brazil rainfall and SST near the Brazilian coast even in absence of a trend. There is also a positive trend in SST in the same area. We speculate that the relationship is not causal, but that there is a mutual cause of trends in both these regions. The cause of the positive SST trend seems to be a decrease in the strength of the South Atlantic high, which has resulted in less evaporation and less Ekman upwelling.

A negative trend was observed parallel to and slightly north of the mean position of the SACZ. Although as large as that in Southern Brazil, this trend is less robust in that if one examines trends for running 24-year segments, there are periods during which the trend has been positive with as large a magnitude as in more recent times. Running correlations between the SACZ index and the same SST region are larger with the trend removed than with it included. Thus it is possible that either the SST is forcing rainfall, or vice-versa.

5. REFERENCES

Nogués-Paegle, J., and K.C. Mo, 1997: Alternating wet and dry conditions over South America during summer. *Mon. Wea. Rev.*, **125**, 279-291.

6. ACKNOWLEDGMENTS

Thanks to Toshi Shinoda (NOAA-CIRES Climate Diagnostics Center) for help in understanding the SST-rainfall linkage. We wish to thank the following agencies for providing data that made this project possible: Agência Nacional de Águas (Brasil), Agência Nacional de Energia Elétrica (Brasil), U.T.E. Uruguay, C.T.M. Salto Grande, Servicio Meteorologico Nacional de Argentina, Servicio Meteorologico Nacional de Paraguay, Servicio Meteorologico Nacional de Uruguay, FUNCEME (Ceará, Brasil), Sistema Meteorologico do Paraná (Paraná, Brasil), DAEE (São Paulo, Brasil), Administración Provincial de Agua (Chaco Province, Argentina), Ministerio del Ambiente y los Recursos Naturales (Venezuela), Meteorologische Dienst Suriname, METEO-France, and the National Climatic Data Center (USA). We wish to thank the Inter-American Institute for Global Change Research (IAI-CRN-055) for providing funds to allow collaboration between the Argentinean and United States investigators.