# Dendroclimatic Research in the South American Sector of the Southern Ocean: Indicators of Atmosphere-Ocean Climate Variability

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## Abstract

A tree-ring chronology network recently developed from the subantarctic forests provides an opportunity to study long-term climatic variability at higher latitudes in the South American sector of the Southern Ocean. Based on the longest pressure records available in the South American-Antarctic Peninsula (SAAP) sector of the Southern Oceans, zonal and meridional indices have been developed for the region. Temperature records in southern South America and the Antarctic Peninsula are strongly affected by the strength of the meridional flow, whereas precipitation variations along the Pacific coast in southern South America are more related to changes in the zonal circulation at higher latitudes. We employed dendroclimatic techniques for reconstructing both the zonal (ZSAAP) and the meridional (MSAAP) circulation indices over the past four centuries. The ZSAAP reconstruction shows dominant modes of variation at around 4.4 and 5 years, which may be associated with the proposed Antarctic Circumpolar Wave in the Southern Oceans. Contrasting patterns in meridionality during the past two centuries are observed in the MSAAP reconstruction. Since the mid 1950s the northerly flow has steady increased, reaching unprecedented levels during the 1980s in the context of the past 400 years.

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## 1. Introduction

The Antarctic sea ice region, which fluctuates dramatically in albedo and heat exchange with the atmosphere, strongly influences the oceanic and atmospheric circulation in middle and lower southern latitudes (Budd 1991, Carleton 1992). In spite of major climatic role of the Antarctic continent in the Southern Hemisphere, the scarcity and shortness of the available meteorological records at high southern latitudes have hampered any study of long-term changes in the atmospheric circulation over Antarctica and the Southern Ocean.

No tree-ring based climate reconstructions exist for the high latitudes (>55°S) of the Southern Hemisphere. Indeed, the continuity of the Southern Ocean between nearly 50 and 65°S, and the extreme climate conditions prevailing in Antarctica limit the distribution of forests south of Tierra del Fuego, and consequently the availability of tree-ring records.

Recent developments in chronology networks have occurred in mid- to relatively high-latitudes (35-55°S) in southern South America (Boninsegna 1992; Boninsegna and Villalba 1996; Villalba 2000). With the increasing number of tree-ring collections from climatically sensitive areas in southern South America, the use of a spatial approach to study large-scale atmospheric variations connecting mid- to high-latitude climatic changes appears now to be feasible. A key incentive for this exercise is the documented existence of teleconnections relating climatic variations between middle and high latitudes in the Southern Hemisphere (Pittock 1984; Carleton 1992; van Loon et al. 1993; Karoly et al. 1996).

In this contribution we reviewed the most recent dendroclimatological research intended to evaluate the atmosphere-ocean climatic changes at high latitudes in southern South America over the past centuries. Instrumental records were used to characterize the patterns of zonal and meridional flow at high latitudes in the South America-Antarctic Peninsula sector of the Southern Ocean during the 20th century. Next, we combine these data with high-resolution tree-ring records to provide a long-term perspective for the climatic variations that have occurred more recently. Tree-ring based reconstructions of pressure gradients are used to infer changes in the zonal and meridional flows during the past 400 years across the southern South America-Antarctic Peninsula region.

## 2. High latitude indices of the atmospheric circulation in the Southern Hemisphere

Differences in sea-level pressure between pairs of stations have traditionally been used as indices of the large-scale atmospheric circulation (Lamb 1977). The Trans-Polar Index (TPI), defined as the difference in sea-level pressure between Hobart, Tasmania (43°S 147°E) and Stanley, South Atlantic Ocean (52°S 58°W), was proposed by Pittock (1980) to measure the eccentricity of the polar vortex around the South Pole (Fig. 1). The selection of these two sites may not be optimal, however. It has been noted that the strength of atmospheric teleconnections between the South American and Australasian sectors depends on seasonality as well as the time interval considered (Carleton 1989;

Villalba et al. 1997). An alternative index, the Summer Trans-Polar Index (STPI, Fig. 1), was developed by Villalba et al. (1997). STPI is defined as the difference between the normalized averages of five stations over New Zealand (Wellington, Christchurch, Hokitika and Dunedin on the South Island and Chatham Island) and three stations in the southwestern Atlantic (Grytviken on South Georgia, and Orcadas and Signy on the South Orkney Islands). Selection of these two sets of stations was made based on a correlation analysis of sea-level pressure records from 50 stations in the Southern Hemisphere located between 15† and 65†S. During summer, the strongest spatial teleconnection in the mean sea-level pressure (MSLP) field occurs between the southern South America-Antarctic Peninsula and New Zealand sectors of the Southern Hemisphere (Villalba et al. 1997).

Atmospheric circulation indices at mid- to high-latitudes in the Southern Hemisphere have been developed, at regional scale, over the Tasman Sea-New Zealand and South America-Antarctic Peninsula sectors. Circulation indices in the South American-Antarctic Peninsula (SAAP) sector have been less extensively studied than in the New Zealand sector. Recently, Jones et al. (1999) redefined zonal and meridional indices for the SAAP region. The zonal index (ZSAAP), originally proposed by Mayes (1985), is defined as the anomalous pressure difference between Stanley (51.46°S, 57.59°W) and Orcadas (60.70°S, 44.70°W). The meridional index (MSAAP) results from differences in anomalous pressure between Punta Arenas (53.09°S, 70.48°W) and Stanley (Fig. 1). ZSAAP is a measure of the zonal westerlies between approximately 51° and 60°S, while MSAAP measures meridionality across southern South America (58°W to 71°W).

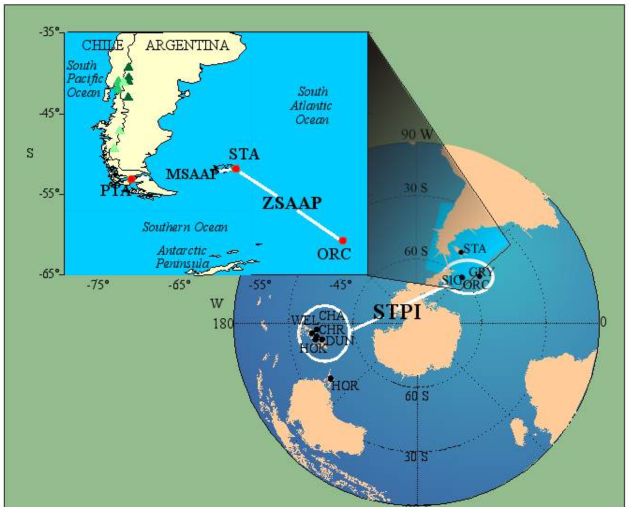

FIG. 1. Maps of the Southern Hemisphere and the southern South America-Antarctic Peninsula (upper left corner) showing the geographical setting for the Summer Trans-Polar Index (STPI), the South America-Antarctic Peninsula Zonal Index (ZSAAP), and the South America-Antarctic Peninsula Meridional Index (MSAAP). Abbreviations for meteorological stations are ORC: Orcadas, SIG: Signy Island, GRY: Grytviken, STA: Stanley, and PTA: Punta Arenas, in the South American-Antarctic Peninsula sector of the Southern Ocean, and WEL: Wellington, HOK: Hokitika, CHR: Christchurch, DUN: Dunedin, CHA: Chatham Island, and HOR: Hobart in the Australia-New Zealand region.

Locations of tree-ring chronologies across the Southern Andes are indicated by solid triangles: (s) Austrocedrus chilensis, (s) Fitzroya cupressoides, and (s) Nothofagus pumilio.

## 3. Interactions between high-latitude circulation indices

Relationships between hemispheric and regional forcings of climatic variability were explored by correlating the Trans-Polar Index with the zonal and meridional pressure gradients for the South American sector of the Southern Ocean. Significant correlations during the 20th century occur between the STPI and ZSAAP. It has been noted that changes in the circulation across Antarctic contribute to the interannual variability of the westerlies. When the STPI is positive (displaced in relation to its average position towards the South America), the westerlies intensify in the 50-60°S band across the South American sector of the Southern Ocean. Positive relationships are also observed between STPI and MSAAP in summer (Fig. 2). Positive values of STPI are associated with dominant southerly winds during summer across southern South America. This relationship was more consistent during the first half of the 20th century.

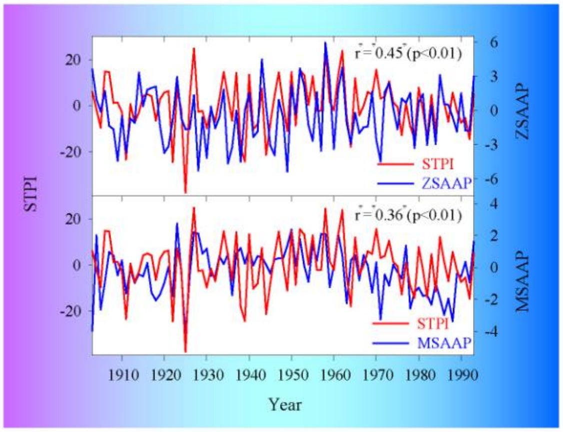

FIG. 2. Comparison of interannual variations in summer (December to February) departures of the Summer Trans-Polar Index (STPI) with zonal (ZSAAP) and meridional (MSAAP) pressure gradients in southern South America-Antarctic Peninsula.

To assess the importance of the high-latitude atmospheric circulation on climate variability in southern South America, we correlated the ZSAAP and MSAAP circulation indices with temperature and precipitation records south of 15°S. Temperature records in southern South America and Antarctic Peninsula are strongly affected by the strength of the MSAAP, whereas regional precipitation variations are more related to changes in the ZSAAP (Fig. 3).

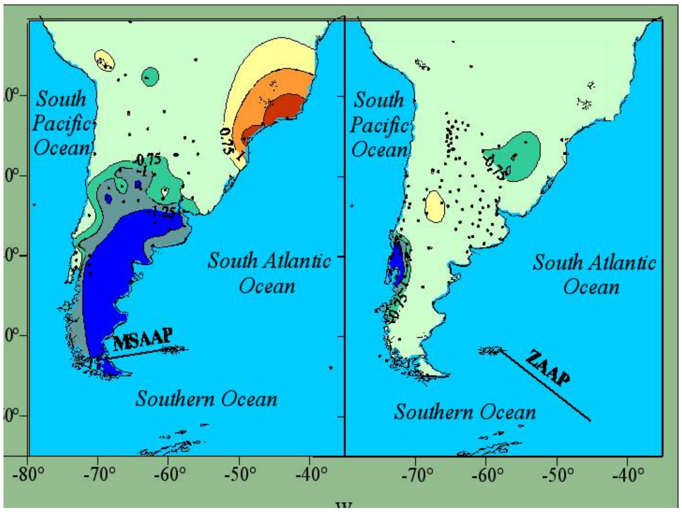

FIG. 3. Spatial patterns of correlation ratios between individual annual mean temperature (left) and total annual precipitation (right) records in Argentina, Chile, Brazil, Bolivia, Paraguay and Uruguay, and the circulation indices MSAAP and ZSAAP, respectively. The correlation ratios result from the ratio between the correlation coefficient (r) and the corresponding critical value of r for a confidence level _ = 0.05. Ratios greater than 1 correspond to significant correlations at 95% confidence level between indexes and stations. Data used include 64 and 136 records for temperature and precipitation, respectively. Meteorological stations are indicated by dots(•).

## 4. Tree-ring records

Tree-ring predictors of the zonal and meridional pressure gradients were selected based on the current relationships between circulation indices and regional climate. The spatial correlation patterns between circulation indices and regional climate shown in Figure 3 were instrumental in our setting the strategies for selecting tree-ring records sensitive to fluctuations in the zonal and meridional indices. The tree-ring records used for reconstructing the zonal index (ZSAAP) include a combination of eight precipitation-sensitive chronologies from the tree species Austrocedrus chilensis and Fitzroya cupressoides along the northern Patagonian Andes. On the other hand, the set of predictors used for reconstructing past variations in meridional circulation includes three upper-elevation Nothofagus chronologies located in Patagonia south of 40°S.

TABLE 1. Site characteristics for the composite tree-ring chronologies.

| Code | Sites included | Species | Lat. (ƒS) | Long. (ƒW) | Elev. (m) |
|---|---|---|---|---|---|
| AUS1 | ‹orquinco | Austrocedrus chilensis | 39ƒ07' | 71ƒ07' | 1150 |
|  | Rucachoroi | Austrocedrus chilensis | 39ƒ15' | 71ƒ10' | 1300 |
|  | QuillÈn | Austrocedrus chilensis | 39ƒ17' | 71ƒ16' | 1100 |
| AUS2 | Collun-co Alto | Austrocedrus chilensis | 39ƒ56' | 71ƒ08' | 870 |
|  | C. La Hormiga | Austrocedrus chilensis | 40ƒ03' | 71ƒ17' | 920 |

| | | | | | |
|---|---|---|---|---|---|
| | C. Los Pinos | Austrocedrus chilensis | 40ƒ04' | 71ƒ02' | 1100 |
| AUS3 | C. Los Leones | Austrocedrus chilensis | 41ƒ05' | 71ƒ09' | 1020 |
| | C. Los Leones | Austrocedrus chilensis | 41ƒ05' | 71ƒ09' | 1020 |
| AUS4 | Est. Teresa | Austrocedrus chilensis | 42ƒ57' | 71ƒ14' | 820 |
| | Nahuel-Pan | Austrocedrus chilensis | 42ƒ58' | 71ƒ13' | 850 |
| FIT1 | RÌo FrÌas | Fitzroya cupressoides | 41ƒ06' | 71ƒ48' | 950 |
| | RÌo Alerce | Fitzroya cupressoides | 41ƒ10' | 71ƒ47' | 1100 |
| FIT2 | Los Quetros | Fitzroya cupressoides | 40ƒ50' | 72ƒ20' | 900 |
| | Puntiagudo | Fitzroya cupressoides | 40ƒ55' | 72ƒ21' | 970 |
| | V. Osorno | Fitzroya cupressoides | 41ƒ10' | 72ƒ30' | 990 |
| FIT3 | Lenca | Fitzroya cupressoides | 41ƒ33' | 72ƒ36' | 875 |
| | Patamay | Fitzroya cupressoides | 41ƒ52' | 72ƒ32' | 875 |
| | Contao | Fitzroya cupressoides | 41ƒ53' | 72ƒ38' | 975 |
| | Pichicolo | Fitzroya cupressoides | 41ƒ56' | 72ƒ25' | 700 |
| FIT4 | L. Inexplorado | Fitzroya cupressoides | 41ƒ57' | 72ƒ17' | 1000 |
| | Ayacara | Fitzroya cupressoides | 42ƒ16' | 72ƒ46' | 800 |
| COV6 | Tronador | Nothofagus pumilio | 41ƒ10' | 71ƒ48' | 1480 |
| NOT1 | C. Oportus | Nothofagus pumilio | 47ƒ08' | 71ƒ56' | 930 |
| | C. Tamango | Nothofagus pumilio | 47ƒ10' | 72ƒ30' | 1060 |
| GPB | Piedras Blancas | Nothofagus pumilio | 49ƒ21' | 72ƒ58' | 650 |

## 5. Tree-ring reconstructions of circulation indices

We used principal component regression (Cooley and Lohnes 1971) to orthogonalize the inter-correlated set of chronologies (predictors) and reduce the dimension of the regression analysis by eliminating the high-order eigenvectors that account for very little variance. Only eigenvectors showing eigenvalues >1 were retained in the model. Tree growth in any particular yr (t) can be influenced by climate in the current and previous year. This lag effect in the relationships between climate and tree growth is particularly evident in Fitzroya cupressoides. Previous studies have shown that radial growth of Fitzroya cupressoides is more strongly associated with climatic conditions in the previous than in the current growing season (Villalba 1990; Lara and Villalba 1993). Consequently, the zonal and meridional circulation indices in year t were modeled as a function of tree growth in the years t, t+1, t+2, and t+3. We used the Mallow's Cp criterion, a measure of the tradeoff between the goodness-of-fit of the regression and the number of predictors in the model (Draper and Smith 1981), to select the best-fit regression models.

Cross-validation tests for the ZSAAP and MSAAP regression models were next performed for the intervals 1910-1989 and 1913-1989, respectively. We divided the zonal and meridional records into two intervals, using the first 50 years (1910-1959 and 1913-1962 respectively) for calibration and reserving the most recent decades of each record for verification. We then reversed the process, selecting the most recent 50 years (1940-1989) for calibration and withholding the earliest years for verification. Finally, the entire common intervals between the ZSAAP and MSAAP indices and the tree-ring series were used to derive the final regression equations used to develop the ZSAAP and MSAAP index reconstructions. Utilization of the longest possible calibration interval enhances the ability of the regression models to reconstruct low-frequency variability in both reconstructions.

For the ZSAAP index, the regression equation explained 42.2 % of the total variance in the October-March pressure gradient between Stanley and Orcadas over the calibration interval from 1910-1989 (Fig. 4). Correlations between observed and predicted values for the independent, cross-validation periods were significant. The reduction of error statistics is highly positive, indicating useful skill in the regressions (Gordon and LeDuc 1981).

Regression equations for the summer (November to February) MSAAP index explained 44.4% of the total variance in the Punta Arenas-Stanley pressure gradient for the 1913-1989 calibration interval (Fig. 4). The verification statistics indicate some skill in the reconstructions of the MSAAP index during summer.

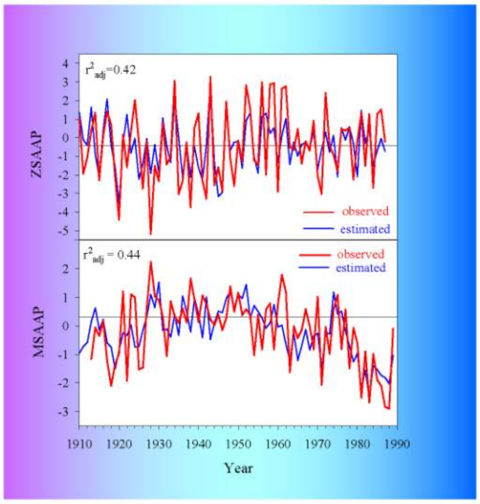

FIG. 4. Observed and estimated anomalies for ZSAAP and MSAAP in summer across South America-Antarctic Peninsula for the intervals 1910-1989 and 1913-1989, respectively.

The ZSAAP reconstruction is largely dominated by high-frequency variations (Fig. 5), however, some periods of persistent anomalies in the westerly flow between 50 and 60°S are observed. Two of the five weakest non-overlapping intervals of 25 years in the zonal flow (1918-1942 and 1963-1987) occurred during the 20th century. Conversely, none of the five 25-year intervals with the strongest zonal flow during the past four centuries was recorded in the 20th century. Based on these observations, it looks like the zonal flow at southern latitudes was, on average, weaker during the 20th century than in the three previous centuries.

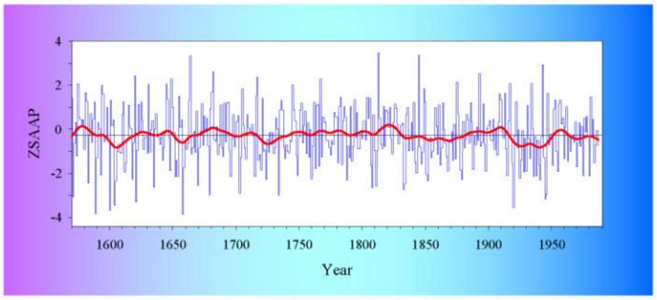

FIG. 5. Reconstructed variations in summer zonal circulation (ZSAAP) in the South America-Antarctic Peninsula sector of the Southern Ocean from 1570 to 1989.

In contrast to the ZSAAP, the MSAAP reconstruction shows remarkable long-term oscillations in meridionality across southern South America since 1630 (Fig. 6). Southerly winds were persistent since 1640 to 1670, around 1740 and most years during the 19th century. The two strongest long-term interval (25 years) of southerly flow during the past 370 years occurred during the 1800s (1850-1874 and 1808-1832). Two intervals in the 20th century, 1965-1989 and 1902-1926, represent the strongest anomalies of northerly flow over the past 4 centuries. Persistent northerly flow during the 1980s has been unprecedented in the 370-yr record.

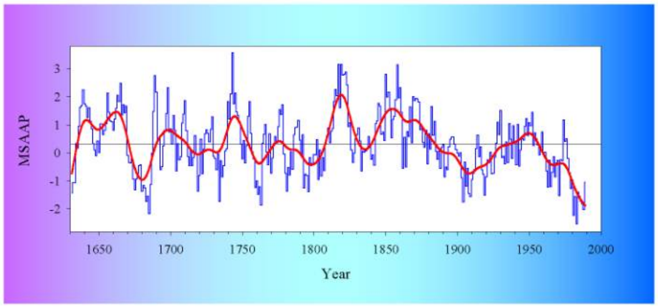

FIG. 6. Reconstructed variations in summer meridional circulation (MSAAP) in the South America-Antarctic Peninsula sector of the Southern Ocean from 1631 to 1989.

## 6. Spectral properties of the circulation index reconstructions

We used the Blackman-Tukey (BTM; Jenkins and Watts 1968) spectral technique to establish the most significant dominant periods at which variance occur in the ZSAAP and MSAAP reconstructions. The BTM spectrum for the reconstructed ZSAAP shows that large part of the spectral power is concentrated at cycles between 3.2 and 5 years in length. Low-frequency oscillations are also manifest at 6.1, 8.9 and 18 years, but they more subdued than the 2-5 years oscillations.

In contrast to the ZSAAP index, the MSAAP spectra show marked concentrations of the spectral power at low frequencies (> 30 years). A prominent peak at 66-100 years is observed in the BTM spectrum. Significant peaks (above the 95% confidence level) are recorded for oscillations centered at 11.4 and 2.5 yr (Fig. 7).

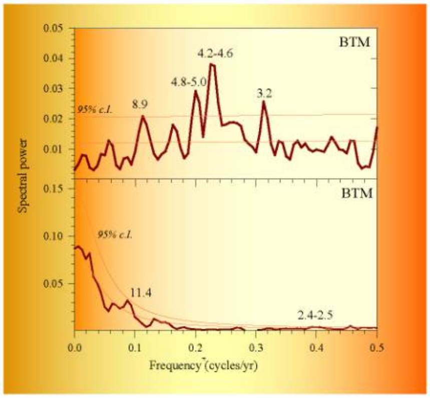

FIG. 7. Blackman-Tukey (BTM) power spectra for the ZSAAP (upper) and MSAAP (lower) reconstructions. The 95% confidence limits are based on a 1st-order Markov null continuum model. The periods are given in years for the significant peaks.

## 7. Long-term interactions between circulation indices

Decade- to century-scale interactions between major atmospheric features in the South American sector of the Southern Ocean were investigated using the tree-ring based reconstructions of atmospheric pressure gradients in the South America-Antarctic Peninsula sector. Correlation coefficients of successive subinterval of 50-yr in length between reconstructions show remarkable changes in the relationships between STPI and ZSAAP. Deteriorations during the 19th century in the relationships between extra-tropical circulation indexes emerge from most comparisons (Fig. 8). In most cases, relationships during the second half of the 18th century improve, reaching significance levels similar to those observed in the 20th century. We speculate that circulation patterns at higher latitudes during the 19th century might have been different from those recorded during the instrumental period. The strongest southerly flow across the region in the past 400 years was concurrent with the climatic anomalies in the 1800s (Fig. 8).

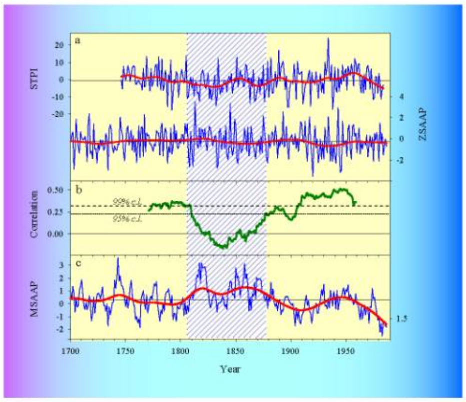

FIG. 8. Long-term interactions between regional and hemispheric circulation indexes were evaluated using (c) moving Pearson correlation coefficients between the STPI and ZSAAP plotted on the centroids of 50-year periods. Slanted lines indicate the interval, during the 19th century, characterized by changes in the correlation patterns between STPI and ZSAAP, and by the occurrence of persistently high MSAAP values (dominant southerly flow).

## 8 . Discussion

Several environmental changes have occurred in southern South America and the Antarctic Peninsula that are consistent with the increasing northerly flow during the recent decades. Abrupt warming trends have been documented in most station temperature records south of 45°S in South America (Rosenblutt et al., 1997) and in the Antarctic Peninsula (King, 1994). Extensive ablation has been observed on the Andean glaciers (Casassa et al. 1997, 2000) and on low altitude glaciers and small ice caps on the Antarctic Peninsula (Splettstoesser 2000).

The anomalous northerly flow during the past few decades may be also related to documented increase in sea surface temperature (SST) in the southern SAAP region. To assess the importance of the meridional circulation on the long-term increase in sea surface temperature around southern South America, we correlated the MSAAP index reconstructions with annual (April to March) sea surface temperature in the South Pacific and South Atlantic oceans (Fig. 9). Statistically significant correlations are observed all around southern South America southward of 40°S, reflecting the concomitant increase in SST and northerly flow during the past decades.

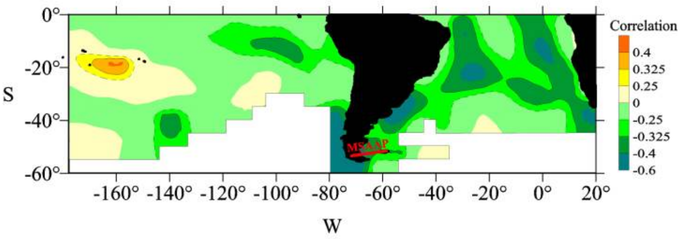

FIG. 9. Spatial correlation patterns during the interval 1930-1989 between annual SST (on 5° lat. x 5° long. grid) anomalies over the South Pacific and South Atlantic Oceans and the reconstructed MSAAP index. SST records, on 5° latitude x 5° longitude grids, were obtained from Kaplan et al. (1997).

The BTM spectrum of ZSAAP reconstruction indicate that the most significant oscillatory modes are centered at 4.4 and 5 yr (Fig. 7). Interestingly, it has been shown that local signals in fields of SST, MSLP, meridional winds, and sea ice extent around Antarctica have a periodicity of 4-5 years. This oscillation, termed the Antarctic Circumpolar Wave (ACW), is manifest by an eastward propagation signal in both oceanic and atmospheric variables of the high latitudes southern latitudes (White and Peterson, 1996). In view of the very short observational records in this data-sparse region, it may be somewhat surprising that a reconstruction of zonal flow across the southern ocean can capture a a consistent 4-5 year oscillatory mode over the past four centuries. Our results suggests that the ACW patterns observed for the 1980s and 1990s represent a stable mode of interannual variability that has not been strongly modified or supplanted by other modes, at least during the past 400 years.

The long-term perspective provide by our reconstructions have important implications in relation to our knowledge of climate variability at southern latitudes. Have the circulation modes of variability revealed by the analysis of the instrumental records prevailed during the past 400 years? Or there are other important modes of variability inherent to the higher latitudes that have not been exposed by the fragmentary and sparse network of climate records in the southern oceans? Whereas the ZSAAP reconstruction provides support for a persistent 4-5 year cycle in the westerly flow, impressive changes in meridional circulation are inferred from the MSAAP reconstruction during the past 400 years. Interactions between regional and hemispheric circulation indexes have certainly changed in the past.

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## References

Boninsegna, J.A., 1992: South American dendroclimatological records. In Bradley, R.S., Jones, P.D. (eds), Climate since A.D. 1500, Routledge, London pp. 446-462.

Boninsegna, J.A., and R. Villalba, 1996: Dendroclimatology in the Southern Hemisphere: Review and Prospect. In: Tree Rings, Environment and Humanity, J.S. Dean, D.M. Meko, and T.W. Swetnam (eds.), pp. 127-141.

Budd, W.F., 1991: Antarctica and global change. Clim. Change, 18: 271-299.
Carleton, A.M. 1989: Antarctic sea-ice relationships with indices of the atmospheric circulation of the Southern Hemisphere. Clim. Dyn., 2, 207-220

Carleton, A.M., 1992: Synoptic interactions between Antarctica and lower latitudes. Aust. Met. Mag., 40, 129-147.

Casassa, G., H. Brecher, A. Rivera, and M. Aniya, 1997: A century-long record of Glaciar O'Higgins, Patagonia. Annals of Glaciology, 24, 106-110.

Casassa, G., A. Rivera, and J.F. Carrasco, 2000: Glacier variations in the Southern Patagonia Icefield and their relation with climate, Proceedings of the Sixth International Conference on Southern Hemisphere Meteorology and Oceanography, Amer. Met. Soc. 3-7 April 2000, Santiago, Chile, 312-313.

Cooley, W.W., and P.R. Lohnes, 1971: Multivariate data analysis. Wiley, New York, USA.

Draper, N.R., and H. Smith, 1981: Applied regression analysis, John Wiley and Sons, New York. 2nd edition.

Gordon, G.A., and S.K. LeDuc, 1981: Verification statistics for regression models, In:

Preprints Seventh Conference on Probability and Statistics in Atmospheric Sciences, Am. Meteorol. Soc., Monterey, pp 129-133

Jenkins, G.M., and D.G. Watts, 1968: Spectral analysis and its applications. Holden-Day, San Francisco. pp. 525.

Jones, P.D., M.J. Salinger, and A.B. Mullan, 1999: Extratropical circulation indices in the Southern Hemisphere based on station data. Int. J. Climatol. 19: 1301-1317.

Kaplan, A., M.A. Cane, Y. Kushnir, B. Blumenthal, and B. Rajagopalan, 1997: Analyses of global sea surface temperature 1856-1991. J. Geophys. Res., 101, 22599-22617.

Karoly, D.J., P. Hope, and P.D. Jones, 1996: Decadal variations of the Southern Hemisphere circulation. Int. J. Climatol., 16, 723-738.

King, J.C., 1994: Recent climate variability in the vicinity of the Antarctic Peninsula. Int. J. Climatol., 14, 357-369.

Lamb, H.H., 1977: Climate: Present, Past and Future, Vol. 2, Methuen, London.
Lara, A., and R. Villalba, 1993: A 3,620-year temperature reconstruction from Fitzroya cupressoides tree rings in southern South America. Science, 260, 1104-1106.

Mayes, P.R. 1985: Secular variations in cyclonic frequencies near the Drake passage, Southwest Atlantic. J. Geophys. Res., 90, 5829-5839.

Pittock, A.B., 1980: Patterns of climatic variation in Argentina and Chile. I. Precipitation, 1931-1960, Mon. Weather. Rev. 108, 1347-1361.

Pittock, A.B., 1984: On the reality, stability, and usefulness of southern hemisphere teleconnections. Aust. Meteor. Mag., 32: 75-82.

Rosenbluth, B., H.A. Fuenzalida, and P. Aceituno, 1997: Recent temperature variations in southern South America. Inter. J. Climatology, 17, 67-85.

Splettstoesser, J., 1992: Antarctic global warning?, Nature, 355, 503.

van Loon, H., J.W. Kidson, and A.B. Mullan, 1993: Decadal variation of the annual cycle in the Australian dataset. J. Climate, 6, 1227-1231.

Villalba, R. 1990: Climatic fluctuations in Northern Patagonia during the last 1000 years as inferred from tree-ring records. Quaternary Research, 34, 346-360.

Villalba, R. 2000: Dendroclimatology: a Southern Hemisphere Perspective. In: Paleo- and Neoclimates of the Southern Hemisphere: the state of the arts. P. Smolka and W. Volkheimer (eds.). Springer. pp. 105-143.

Villalba, R., E.R. Cook, R.D. D'Arrigo, G.C. Jacoby, P.D. Jones, M.J. Salinger, and J. Palmer, 1997: Sea-level pressure variability around Antarctica since A.D. 1750 inferred from subantarctic tree-ring records. Clim. Dyn., 13, 375-390.

White, W.B., and R. G. Peterson, 1996: An Antarctic circumpolar wave in the surface pressure, wind, temperature and sea-ice extent. Nature, 380, 699-702.