Patterns of Climatic Variation in Argentina and Chile—II. Temperature, 1931–60[1]

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ABSTRACT

A 30-year data set of monthly means of the daily mean temperatures at a selected network of 50 stations in Argentina and Chile has been analyzed. Eigenvector analysis reveals that the first three patterns of year-to-year variability account for 42, 14 and 7% of the total variance, respectively. The most dominant pattern shows temperature anomalies of the same sign over practically the whole area, but these are highly seasonal, being correlated negatively with the east-west pressure difference across the tropical Atlantic in fall and winter, and positively in early summer. This seasonal reversal is found to be due to the seasonal reversal in land-sea temperature difference off the central Argentine coast. The second eigenvector of the temperature variations is most strongly correlated with the pressure difference between the Tasmanian and Falkland Islands regions, while the third eigenvector is associated with variations in the latitude of high pressure belt along the coast of Chile.

These results confirm those found for precipitation in Part 1 (Pittock, 1980) in that a few dominant circulation anomaly mechanisms appear to account for a major part of the climatic variations over Argentina and Chile. Clearly, these circulation mechanisms should be studied further, as should the relationship between Argentinean climate and sea surface temperature fluctuations in the southwest Atlantic.

1. Introduction

In Part I of this study (Pittock, 1980) the spatial patterns of variation contained in a 30-year data set from a network of 87 precipitation stations in Argentina and Chile were described. Maps of the first three eigenvectors of the correlation matrix of annual precipitation were presented and the time series of their amplitudes were found to be significantly correlated with various indices of the general circulation of the atmosphere. Patterns were also presented which were derived by mapping the correlation coefficients between each of the circulation indices and individual station precipitation time series. The correlation patterns were found to be broadly consistent with the eigenvector patterns and the correlations of the time series of amplitudes of these eigenvectors with each of the circulation indices. Monthly and seasonal patterns were also discussed.

In this paper results of an essentially similar analysis procedure are presented for the related 30-year set of monthly and annual means of the daily mean temperatures for a somewhat less dense network of stations in Argentina and Chile. Coughlan (1979) has done a somewhat similar analysis of Australian temperature data.

2. The data

Chilean temperature data for four stations for the years 1931–60 were extracted from *World Weather Records* (Clayton and Clayton, 1947; U.S. Dept. of Commerce, 1959, 1966). Data for Argentina came from an unpublished tabulation by the Argentine Meteorological Service for 79 stations for the years 1931–60.

The data were tested for inhomogeneities by plotting cumulative differences between pairs of neighboring stations. On the basis of homogeneity, completeness and uniformity of spatial coverage, a network consisting of the four stations in Chile and 46 in Argentina was chosen. No adjustments were made to the data for remaining inhomogeneities. Missing data totaling 386 station-months (~2% of the network data set) were filled in by interpolation using stepwise linear regression from two to four surrounding stations. The temperature data were much more nearly normally distributed then the precipitation data.

3. Methods

The same methods were used for temperature as for precipitation, as described in more detail in Part I (Pittock, 1980). Eigenvectors of the correlation matrix of annual mean temperatures and of monthly data (e.g., 30 sets of January data for the 50 stations) were derived. Correlations between the time series

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[1] This work was performed while the author was on leave at the Laboratory of Tree-Ring Research, University of Arizona, Tucson 85721.

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of amplitudes of each eigenvector and corresponding time series of various circulation indices were computed. The four circulation indices used initially were the same ones used in the precipitation study, *viz.*, the abbreviated Southern Oscillation Index (S_I), a similar index of the east-west pressure difference across the tropical Atlantic (S_A), the mean latitude of the sub-tropical high pressure belt along the coast of Chile (L_{SA}), and the Trans-Polar Index (TPI) which is the MSL pressure anomaly difference between Hobart (43°S, 147°E) and Stanley (52°S, 58°W).

Other MSL or station-level pressure data series published in *World Weather Records* were also used, along with sea surface temperature data series supplied by Drs. A. Bunker and R. Goldsmith of Woods Hole Oceanographic Institute, in a search for parameters which might correlate with the first eigenvector of temperature. These will be discussed below.

Maps of the correlation coefficients between time series of each of the four circulation indices and corresponding time series of mean temperature data at individual stations were also constructed for annual and seasonal data. These patterns of correlation were then compared with the eigenvectors of temperature taking into account the correlations of the time series of amplitudes of the eigenvectors with the corresponding circulation indices.

4. Results and discussion

a. Annual data

Figs. 1a, 1b and 1c are the patterns represented by the first three eigenvectors of the annual means of the daily mean temperatures. These account for 41.8, 14.4 and 7.1% of the total variance respectively, i.e., cumulatively for 63.3% of the total variance. The correlation coefficients of the amplitude series $a_i(t)$ [see Pittock (1980) for this notation] of each of these eigenvectors with each of the four circulation indices S_I, TPI, L_{SA} and S_A are given in Table 1. The numbers in parentheses are the number of data pairs in each paired series.

After allowing for the autocorrelations (see Quenouille, 1952) in the eigenvector amplitudes and circulation indices (which are significant in the third eigenvector and in S_A), several of these correlation coefficients are statistically significant. The amplitude of the first eigenvector, however, is not significantly correlated at the 90% confidence level with any of the four circulation indices. This point will be returned to below.

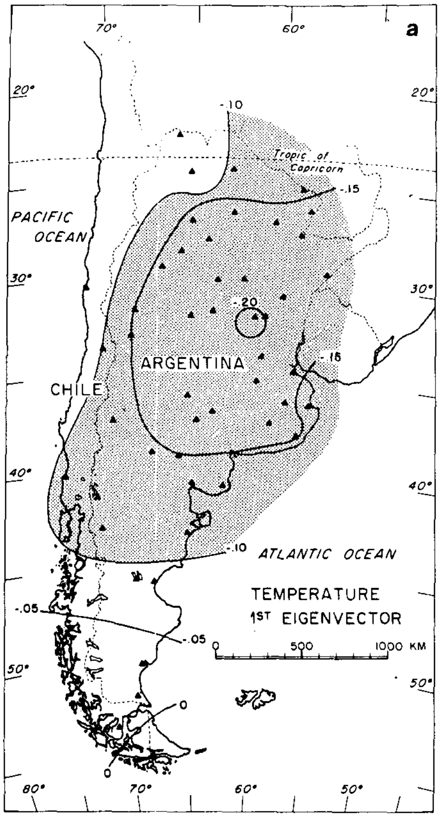
The amplitude of the second eigenvector, as in the case of precipitation, varies significantly with TPI. It also correlates at better than the 95% confidence level with L_{SA}. The third eigenvector has significant correlations with both L_{SA} and S_A, again as is the case with precipitation. Note also, from Pittock (1980), that L_{SA} and S_A are positively correlated, which is consistent with their correlations with a_3. The significant autocorrelation of a_3 (0.68 at lag 1 and 0.60 at lag 2) is due to an increasing trend over the 30 years of data.

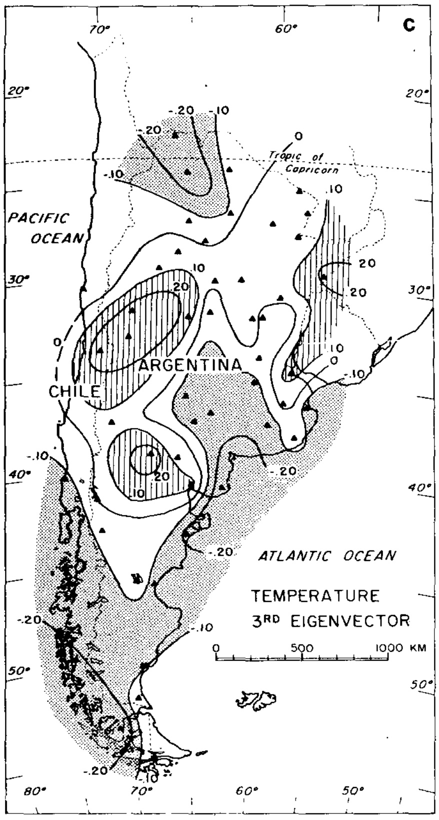
Figs. 2a, 2b, 2c and 2d are the patterns of correlation coefficients between the individual annual temperature records at each of the 50 stations in the network and S_I, TPI, L_{SA} and S_A, respectively. The number of years of data and the confidence levels are indicated in the captions. Stations are indicated by triangles.

In Fig. 2a it can be seen that only about as many stations show correlations with S_I which are locally significant at the 90% confidence level as one might except by chance, although two are locally significant at the 99% confidence level where one would expect on average between 0 and 1. Overall this correlation pattern must be considered quite likely to be by chance (which is consistent with the low correlations of S_I with a_1, a_2 and a_3), although there is a possibility of real correlations in central Chile and extreme northwest Argentina.

Figs. 2b, 2c and 2d, on the other hand, show considerably more locally significant correlations than one might expect by chance and, therefore, probably represent real associations between temperature and TPI, L_{SA} and S_A, respectively. The correlations are weaker, however, than in the case of precipitation discussed in Pittock (1980).

The spatial patterns of correlations of temperature with TPI (Fig. 2b) and S_A (Fig. 2d) each show some resemblance to the first eigenvector pattern of temperature (Fig. 1a) consistent with the weak and non-significant negative and positive correlations of a_1 with TPI and S_A, respectively. Autocorrelations in S_A (0.40 at one year lag) and individual station temperatures will slightly reduce the statistical significance of the correlations shown in Fig. 2d, where the significance levels assigned to the contours assume 18 degrees of freedom. The weak nature of the correlations of a_1 with TPI and S_A in the annual data, however, does not provide entirely convincing evidence of a relationship between either circulation parameter and the first eigenvector of temperature, especially as the latter is so dominant in the total variance of temperature. Other factors and parameters were considered but with even less success in "explaining" the first eigenvector. The spatial distribution of variance of annual temperature might be expected to resemble and account for the first eigenvector of the covariance matrix of temperature, but not of the correlation matrix of temperature. Surface pressures at stations near where the first eigenvector anomaly pattern has its largest numerical value do not correlate significantly with a_1, nor do east-west and north-south surface pressure differences across Argentina. Indeed pres-





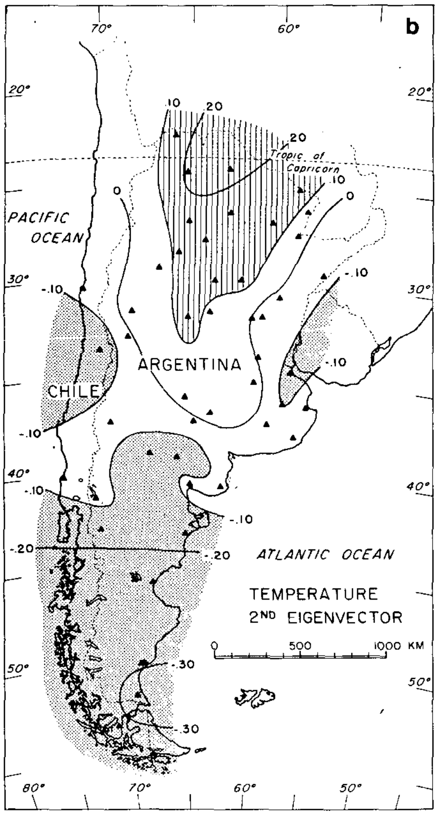


FIG. 1. The first three eigenvectors of the correlation matrix of annual mean temperature from a network of 50 stations in Argentina and Chile for the 30 years 1931–60. Stations are indicated by triangles. Eigenvectors 1, 2 and 3 (Figs. 1a, 1b and 1c, respectively) account for 41.8, 14.4 and 7.1% of the total variance, respectively.

sure anomaly maps of Argentina and Chile were constructed for the years of extreme values of a_1, but these did not provide synoptically consistent explanations for the temperature anomalies. It was only when seasonal data were examined (see below) that a consistent explanation emerged.

Fig. 2b bears a strong resemblance to the second eigenvector of temperature (Fig. 1b), which is consistent with the significant positive correlation of TPI and a_2. Fig. 2c on the other hand is consistent with a negative correlation of L_{SA} and a_2 only in southern Chile and Argentina, while in the more northerly regions L_{SA} and temperature are not significantly correlated.

Fig. 2c does, however, reflect a convincing negative relationship with the third eigenvector of temperature (Fig. 1c) over practically all of Argentina and Chile, both in the regions where the correlations of L_{SA} and temperature are large (the south) and where they are less significant. This is consistent with the significant negative correlation of L_{SA} and a_3.

The correlation of a_2 with L_{SA} is accounted for in Fig. 2c mainly by the significant correlations of L_{SA} and temperature in southern Chile and Argentina, while the correlations of a_3 with L_{SA} and with S_A are accounted for more by correlations of L_{SA} and S_A with temperature in more northerly regions (Figs. 2c and 2d). This suggests that the correlation of L_{SA} and S_A is related more to what happens in northern and central Chile and Argentina than with what happens in the south.

b. Seasonal variations

Eigenvector and correlation pattern analyses analogous to those using annual data have been carried out using monthly and seasonal data. The main findings are summarized below.

The first eigenvector pattern of the monthly data is similar to the annual case and does not vary greatly in shape or location throughout the year. However the percentage of the total variance which it accounts for varies considerably from a minimum of 39.2% in December to a maximum of 67.5% in July, as shown in Fig. 3a.

The correlation of the amplitude series of the first eigenvector, when the central anomaly is given the same sign (i.e., negative) as in the annual case (the sign is arbitrary), with corresponding monthly S_A time series, varies from a positive correlation of +0.70 in July to a negative correlation of −0.56 in December. Both these extreme correlations are statistically significant at the 99% confidence level for the 20 years of overlapping S_A and a_1 data available. The variation of the correlation coefficient throughout the year is shown in Fig. 3b along with the 95% and 99% confidence levels.

What could lead to this remarkable seasonal reversal of the correlation between S_A and a_1? First consider the physical significance of S_A. A positive S_A represents a positive anomaly in the surface pressure difference between the eastern tropical Atlantic Ocean and the tropical coast of Brazil. (In fact the pressure anomalies along the coast of tropical Brazil correlate well with those further inland in the Amazon Basin.) S_A is thus closely analogous to S_I in the Pacific, with positive S_A leading to an anomalous westward flow at the surface near the equator (where there is no Coriolis deflection) and deflection of this flow toward the south at more southerly latitudes. This was the interpretation put on variations of S_I over eastern Australia by Pittock (1975).

If the influence of fluctuations in S_A should extend as far south as central Argentina, as observed significant correlations attest (see Figs. 4a and 4b), this means that positive S_A should correspond in general to northerly offshore winds and negative S_A to southerly onshore winds. Seasonal variations in land-sea temperature differences could thus account for a seasonal reversal in the effect of such circulation anomalies.

Table 1. Correlations between the amplitudes a_i, of the first three eigenvectors of the correlation matrices of the South American annual mean temperature network data and the four circulation indices: the Southern Oscillation Index S_I; the Trans-Polar Index TPI; the latitude of the high-pressure belt off the coast of Chile L_{SA}; and the tropical Atlantic pressure index S_A. The figures in parentheses are the number of data pairs. Doubly (singly) underlined correlation coefficients are significant at about or better than the 99% (95%) confidence level, assuming successive annual data are independent.

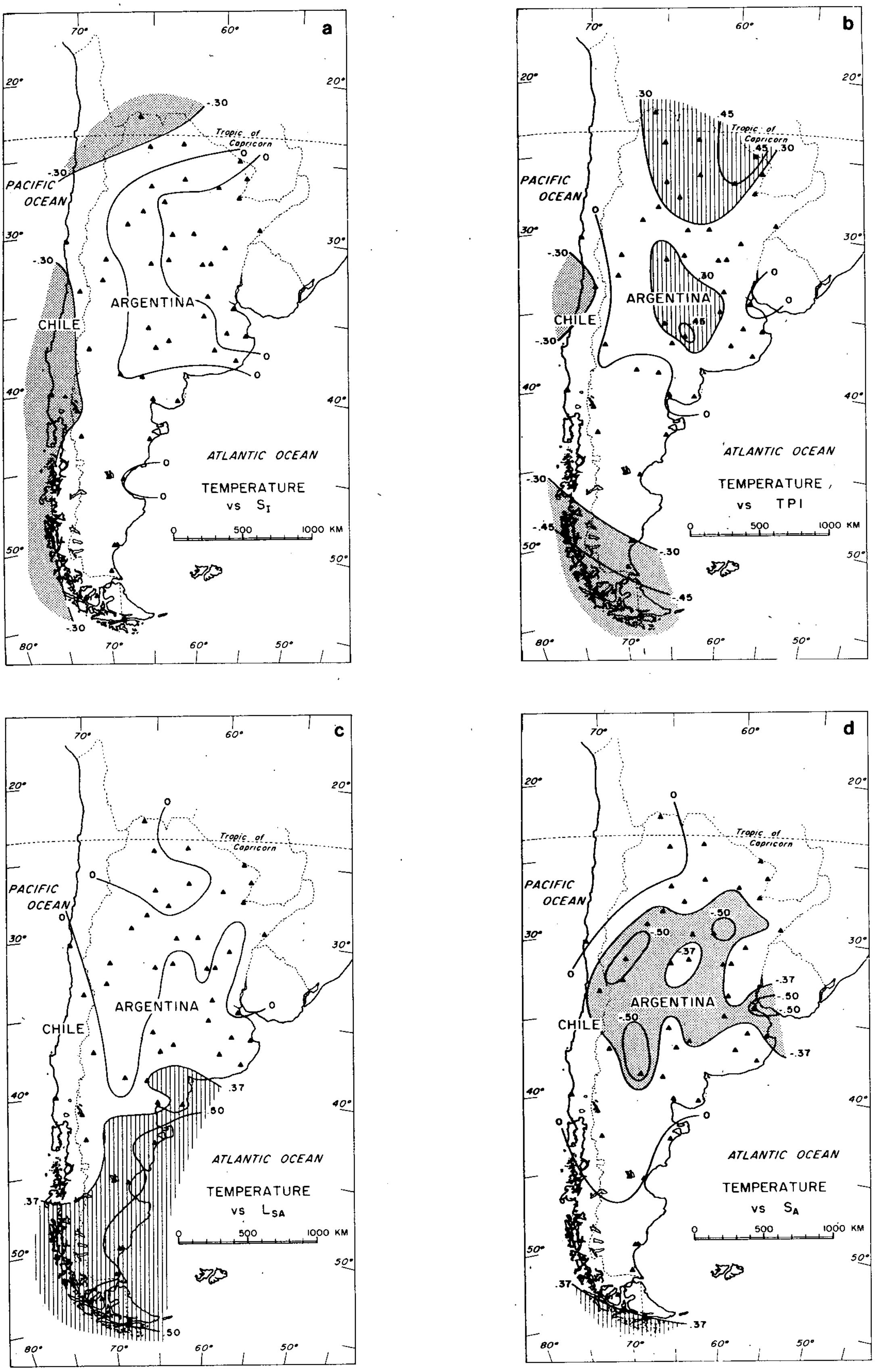
Amplitude	Index			
	S_I	TPI	L_{SA}	S_A
a_1	+0.08 (28)	−0.23 (30)	−0.11 (20)	+0.35 (20)
a_2	+0.08 (28)	+$\underline{\underline{0.56}}$ (30)	−$\underline{0.49}$ (20)	−0.10 (20)
a_3	+0.18 (28)	−0.03 (30)	−$\underline{\underline{0.61}}$ (20)	−$\underline{0.48}$ (20)

Fig. 3c shows the mean annual cycle of the surface temperature difference between Marsden square 413 (30–40°S, 50–60°W, off Buenos Aires) and Junin airport (34°35′S, 60°56′W, 81 m elevation) in the upper curve, and Marsden square 413 and Ceres (29°53′S, 61°57′W, 88 m elevation) in the lower curve. Junin is further south and east, i.e., nearer the coast, and is an average 3–4°C cooler than Ceres.

It can thus be argued as follows: When the sea surface temperature is higher than the average land temperature (as is the case at both stations in April–June) an onshore wind, which corresponds to a negative value of S_A, will produce a warm temperature anomaly over the land and thus in general a negative correlation between S_A and land temperature or a positive correlation between S_A and the amplitude of the first eigenvector of temperature (which has a negative anomaly pattern).

When the sea surface temperature is lower than the average land temperature (as is the case at both stations in November–January) an onshore wind, corresponding again to a negative value of S_A, will tend to produce a cold temperature anomaly due to advection, and thus positive correlations between S_A and land temperatures and a negative correlation between S_A and a_1.

From Fig. 3c it should be expected that the negative correlation between S_A and land temperatures (and the positive correlation of S_A with the amplitude of the first eigenvector) will occur for a greater part of the year at stations nearer the coast such as Junin, than at stations further inland such as Ceres. Plots of the correlation coefficients between S_A and mean temperatures at each of the 50 stations in the network for 20 years of April–June and July–September data are shown in Figs. 4a and 4b, respectively, with the locations of Junin and Ceres indi-


a
TEMPERATURE vs S_I
b
TEMPERATURE, vs TPI
c
TEMPERATURE vs L_{SA}
d
TEMPERATURE vs S_A
PACIFIC OCEAN
ATLANTIC OCEAN
ARGENTINA
CHILE
Tropic of Capricorn
0 500 1000 KM
80° 70° 60° 50°
20° 30° 40° 50°
-.30
-.45
-.37
-.50
.30
.45
.37
.50
0

cated by an open circle and an open square respectively. Corresponding plots for January–March and October–December show generally positive correlations between S_A and temperatures in eastern central and northern Argentina but the correlations are much weaker than in winter and spring. The weakness of these positive correlations may be explained by the smaller absolute temperature difference between land and sea, at least as far inland as Junin, in spring and summer (October–March) than in fall and winter (April–September).

The second eigenvector of the monthly data again varies rather little from the annual case. It maintains a basic contrast between anomalies in the northern and southern parts of the study area, but varies in strength from explaining only ~10.7% of the total variance in July to 20.1% in November.

Eigenvector three shows anomalies of the same sign in the north and south, with opposite anomalies in central Argentina and Chile in all months, although the central anomaly is stronger in Chile and western Argentina except in summer when it is strongest in east central Argentina. The percentage variance accounted for by this eigenvector varies from 4.0% in May to 9.2% in January.

The pattern of correlations of temperature with S_1 shows overall statistical significance in winter, and to a lesser extent in fall and spring, with strong negative correlations as great as $r = -0.5$ in central Chile. A tendency toward negative correlations is also evident in this area in summer.

Each of the seasonal patterns of correlation of TPI with temperature show a consistent contrast between negative correlations in the southwest and positive correlations in the northeast. These are strongest in summer and fall and not statistically significant in winter. Opposite correlations having magnitudes as great as ± 0.66 occur in fall.

Correlations of temperature with L_{SA} are significantly positive in the extreme south during summer, fall and winter, while significant negative correlations tend to occur in northern Argentina in fall and winter. Overall, however, the correlations with L_{SA} are weak.

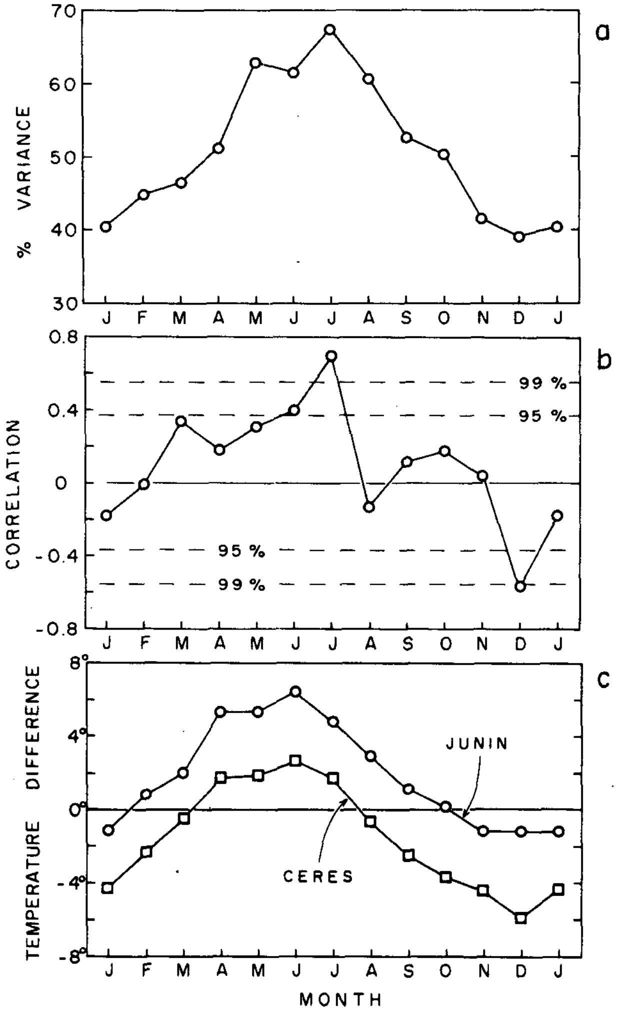


FIG. 3. Fig. 3a shows the annual variation in percentage of the total variance explained by the first eigenvector for monthly mean temperature data for the network of 50 stations in Argentina and Chile for the years 1931–60. Fig. 3b shows the annual variation in the correlation coefficient between the amplitude a_1, of the first eigenvector of monthly mean temperature data and the Atlantic Oscillation index S_A. 95% and 99% confidence levels are indicated. Fig. 3c shows the annual variation in the mean monthly temperature difference (°C) between the sea surface temperature in Marsden square 413 (30–40°S, 50–60°W) and the mean temperature at Junin airport (indicated by the open circles here and in Fig. 4) or that at Ceres (indicated by the open squares here and in Fig. 4).

5. Conclusions

Eigenvector analysis of 30 years of monthly and annual temperature data from Argentina and Chile has revealed three dominant patterns of year-to-year variability which account for more than 60% of the total variance.

The time series of amplitudes of these three

FIG. 2. Patterns of correlation coefficients between the individual annual mean temperature records at each of 50 stations in Argentina and Chile, and the circulation indices S_I (Southern Oscillation), TPI (Trans-Polar Index), L_{SA} (latitude of the high pressure belt, South America), and S_A (the Atlantic Oscillation) respectively. Data used are for the years 1933–60 (S_I), 1930–60 (TPI), 1941–60 (L_{SA}) and 1941–60 (S_A). Stations are indicated by triangles. Stippled and shaded areas have correlation coefficients which are locally significant at the 90% confidence level, positive being shaded and negative stippled. Contours within these areas indicate areas having correlation coefficients locally significant at the 98% (L_{SA} and S_A) or 99% (S_I and TPI) confidence levels.

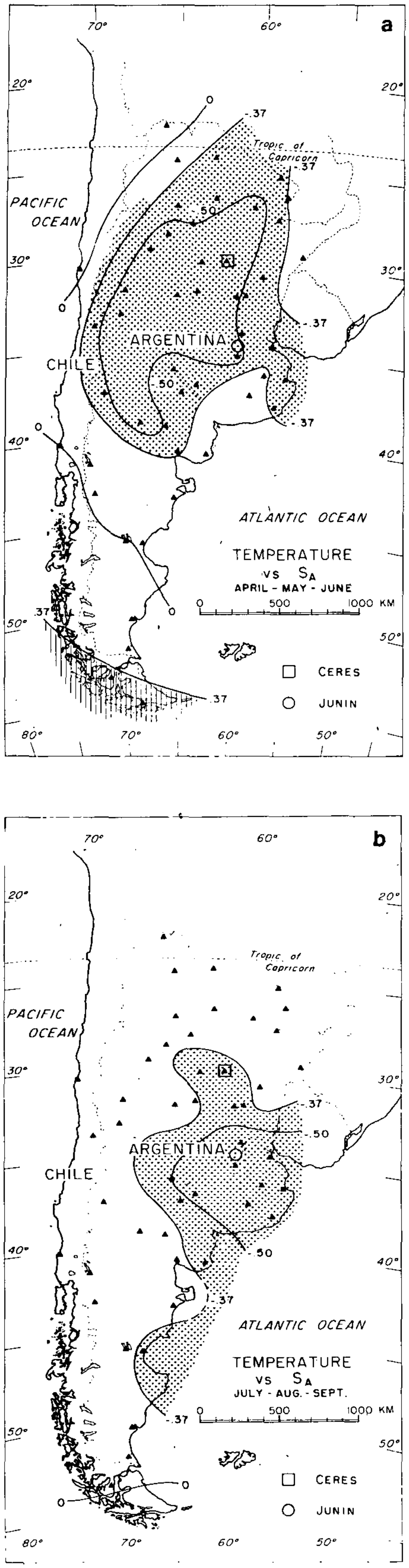


FIG. 4. Patterns of correlation coefficients between the individual mean temperature records at each of 50 stations in Argentina and Chile, and the Atlantic Oscillation index S_A, for 20 years of (a) April–May–June and (b) July–August–September data. Junin is indicated by the open circle and Ceres by the open square. Stippling and shading is as in Fig. 2.

eigenvectors have been correlated with time series derived from MSL pressure data and which are indices of various aspects of the general circulation. The second eigenvector (14.4% of the variance) is correlated significantly with the Trans-Polar Index TPI and with the latitude of the high-pressure belt along the coast of Chile, L_{SA}. The third eigenvector (7.1% of the variance) is significantly correlated with L_{SA} and with S_A, which is an east-west pressure anomaly index for the tropical Atlantic analogous to the Southern Oscillation Index.

The first eigenvector of the annual data, however, is only weakly correlated with S_A. Examination of eigenvectors of the monthly data shows that in fact the first eigenvector has a significant positive correlation with S_A in fall and winter, and a significant negative correlation in late spring. This seasonal reversal is explicable in terms of the seasonal reversal in land-sea temperature differences which causes atmospheric flow anomaly patterns to have reverse effects on temperature in the opposing seasons.

Correlation coefficients of individual station temperature data with each of the abovementioned circulation indices have been calculated and mapped. These show patterns of correlations on an annual and seasonal basis which are broadly consistent with the eigenvectors of the correlation matrix of the temperature data and the correlations of the time series of amplitudes of these eigenvectors with each of the circulation indices. The consistency of these results gives added credence to the interpretations put on the eigenvectors as patterns arising from frequently occurring circulation anomalies.

The cautionary remarks made in Part I (Pittock, 1980) concerning orthogonality of the eigenvectors and bias and subjectivity in selection of the basic data set apply here also, but that about non-normality of the data is less important as temperature data tend to be more nearly normally distributed than precipitation data.

The present results confirm the importance of the circulation anomalies represented by TPI, L_{SA} and S_A, which were found to be important for precipitation in Part I. S_I appears to be of rather less importance to temperature fluctuations except in a restricted area of central Chile.

The most notable difference between the temperature results and those for precipitation discussed in Part I concerns the dominant eigenvector, which in the case of temperature is far more dominant and also related in a very seasonal manner to the tropical Atlantic pressure index and land-sea temperature contrasts. The importance of variations in the tropical Atlantic to climatic fluctuations in middle latitudes of the Southern Hemisphere has not been noted before in the literature, although Namias (1972) linked circulation changes in the Newfoundland-Greenland area with changes in the Hadley circulation and drought over northeast Brazil (see, also, Sanchez and Kutzbach, 1974). However, Rowntree (1976) has modeled the effects of sea surface temperature anomalies in the tropical Atlantic on the circulation of the Northern Hemisphere and Meehl and van Loon (1979) have noted teleconnections with the North Atlantic region. The present results suggest that it is time such links in the Southern Hemisphere were more thoroughly explored, particularly as to cause and effect if this should prove possible.

If seasonal variations in land-sea temperature differences are also important, as suggested above, year-to-year or longer term fluctuations in boundary currents and sea surface temperatures may play an important role in temperature fluctuations over land. The SST data for Marsden square 413 show year-to-year fluctuations of annual mean temperature of the order of 1–2°C which is a considerable fraction of the mean land-sea temperature difference in the vicinity of central Argentina.

The present results for temperature reinforce the remarks made in Part I regarding the use of time series of instrumental or proxy climatic data from one or more key sites in order to make inferences about climatic fluctuations over wider areas. As the characteristic spatial patterns associated with different circulation mechanisms vary with the seasons and variables considered (e.g., precipitation or temperature) great care must be taken in drawing wide inferences from data from particular sites. Widely distributed sites in different key areas are clearly desirable to distinguish between mechanism and enable reliable generalizations to be made.

Acknowledgments. These are essentially the same as for Part I, with the addition of special thanks to Drs. A. Bunker and R. Goldsmith of Woods Hole Oceanographic Institute who supplied the monthly mean sea surface temperature data for the southwest Atlantic Ocean. Funds were provided by the Climate Dynamics Program, National Science Foundation.

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