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Warm and cold events in Argentina and their relationship with South Atlantic and South Pacific Sea surface temperatures

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[1] A Singular Value Decomposition (SVD) analysis was performed jointly on extreme temperature events in Argentina and sea surface temperature (SST) in the South Atlantic and South Pacific. Sea level pressure (SLP) patterns associated with the first SVD coupled mode were also analyzed. Winter is the season of the year that is best represented by the first mode, accounting for up to 70% of the winter covariance between temperature events and SST. The warm and cold events in Argentina are essentially a consequence of the creation of meridional atmospheric circulations over the continent. Such atmospheric patterns result from displacements and intensity changes of the subtropical anticyclones over the oceans and of the continental low-pressure center in northwestern Argentina. The temperature events in southern Argentina are also closely related to the warming and cooling of the coastal waters in the South Atlantic and South Pacific. The analysis suggests that in summer and winter, high (low) occurrence of warm events and low (high) occurrence of cold events are related to similar oceanic and atmospheric circulation situations. The temperature events in Argentina show higher correlation with the Atlantic than with the Pacific, which reflects the importance of the "orographic barrier" of the Andes Mountains in driving the atmospheric circulation. The only exception to this rule concerns the warm events in spring, for which the warming of the equatorial Pacific (the ENSO pattern) appears as the dominant mode. The temporal patterns of the temperature events in Argentina exhibit significant interannual variability in fall, winter, and spring, with periods of 3 to 5 years. The summer patterns suggest a very low-frequency variation with a period longer than 20 years. *INDEX TERMS:* 3339 Meteorology and Atmospheric Dynamics: Ocean/atmosphere interactions (0312, 4504); 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 4522 Oceanography: Physical: El Niño; 9360 Information Related to Geographic Region: South America; *KEYWORDS:* extreme temperature events, South Pacific, South Atlantic, Argentina

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1. Introduction

[2] The impact of climate variability on the environment and the economic activities mainly depends on changes in the frequency of occurrence of extreme events. Relatively few studies on regional variability of climatic extremes are found in the literature compared to the number of studies on changes in climatic means.

[3] Relatively small changes in the mean could produce substantial changes in the frequency of extreme events [*Karl et al.*, 1984; *Mearns et al.*, 1984]. The impacts of climate change will be particularly felt through changes in extreme events because they will stress or exceed our present-day adaptations to climate variability. For a variety of reasons, relatively little work has been completed on changes in high-frequency extreme temperature events such as heat waves or cold waves [*Easterling et al.*, 2000]. Nevertheless, regional variability of daily extremes was studied through the analysis of long-term variability over different regions of the world [*Collins et al.*, 2000; *Salinger and Griffiths*, 2001; *Manton et al.*, 2001; *Knappenberger et al.*, 2001; *Frich et al.*, 2002; *Yan et al.*, 2002].

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[4] The impact of cold waves can be quite extensive and regionally determined by the intensity and track of the accompanying synoptic weather systems [*Easterling et al.*, 1999]. The processes associated with the entrance of polar masses responsible for important damages in southern South America have been extensively studied. Their effects are different according to the season. Cold events in winter produce freezing events, while in summer they organize deep convections [*Garreaud*, 2000]. *Ronchail* [1989] have shown that these intense cold air advections can reach equatorial latitudes. *Ambrizzi and Pezza* [1999] present a review of studies that deal with polar events in a synoptic-climatic manner. On the other hand, the mechanisms associated with tropical air incursions into higher latitudes have been studied with a lower degree of detail, which could be explained by the fact that cold air incursions are the most relevant mode in the circulation variability [*Kousky and Cavalcanti*, 1997]. However, it is clear that both cold and warm temperature extremes are important during every season, as their effects can be beneficial or harmful for a wide range of human activities such as agriculture, human comfort, or energy consumption. The harmful health effects associated with extreme warm events can be mentioned as an example, especially when they occur outside the months of highest temperatures, affecting daily activities [*Campetella and Rusticucci*, 1998], hence the importance of understanding the mechanisms of extreme weather events and, if possible, projecting future changes.

[5] The first step in the detection of climate extremes is the assembly of high-quality time series of key variables. *Rusticucci and Barrucand* [2001] performed a detailed study on maximum and minimum temperatures in Argentina, starting with a high-quality control of the data. *Rusticucci and Vargas* [2001] were the first to study the interannual variability of the warm and cold spells in surface temperature over northern Argentina. They investigated the effect of the ENSO events on the persistence and intensity of extreme spells. They concluded that the number of extreme spells per year exhibits low frequency and biennial-scale variability, being more significant in intensity than in persistence, and in summer than in winter. In a follow-up study, *Rusticucci and Vargas* [2002] assessed the influence of ENSO on the frequency of extreme temperature events in Argentina. They found that the La Niña episodes are more homogeneous than the El Niño ones in relation to their effects on the predictability of extreme temperatures in the region, especially for the cold events. In some cases, the ENSO signal is stronger in daily temperature values than in monthly ones over Argentina. *Barros et al.* [2002] found large areas in southern South America with consistent anomalies in the monthly surface temperature field only for the winter season. *Higgins et al.* [2002] have shown that in most locations of the United States the number of daily extremes is reduced during El Niño years and increased during La Niña and neutral years. However, in several other locations of the continental United States, extreme temperature seasons may occur over a wide range of ENSO conditions. In these regions, El Niño or La Niña conditions are not necessary for the occurrence of the extreme temperature seasons [*Wolter et al.*, 1999].

[6] From the mentioned studies it is concluded that the ENSO phenomenon plays an important role on the occurrence of extreme events in Argentina. However, it may not necessarily be the only variable that influences the temperature extremes in the region. The aim of this study is therefore to investigate potential links between the occurrence of warm and cold events in Argentina and the variability of the sea surface temperature (SST) in both the South Atlantic and South Pacific Oceans.

[7] The climate variability in the South Atlantic Ocean has been previously explored by *Venegas et al.* [1997] and *Sterl and Hazeleger* [2003]. Both studies have shown that the dominant mode of variability in the South Atlantic is characterized by a dipole structure in SST with centers in the northeastern and southwestern parts of the basin, accompanied by a monopole pattern in sea level pressure (SLP) that results in a weakening and strengthening of the South Atlantic subtropical anticyclone. On the other hand, the South Pacific climate variability has been vastly investigated during the last decades due to the predominance of the ENSO pattern in both SST and SLP [e.g., *Kidson*, 1975; *Tourre and White*, 1997].

[8] This work is organized as follows. The data and the methodology are described in the next two sections. Then a Singular Value Decomposition (SVD) analysis is performed jointly on the warm/cold temperature events in Argentina and the SST in the South Atlantic and Pacific for each season of the year, in order to detect possible associations between them. The SVD spatial patterns of the temperature events and SST, and their associated SLP distributions, are analyzed and discussed separately for the four seasons, and possible mechanisms are suggested that may explain the extreme temperature events based on anomalous patterns of ocean temperatures and atmospheric circulations. A brief spectral analysis of the associated SVD time series is finally performed and the main conclusions are summarized in section 8.

2. Data

[9] The warm and cold events are derived from time series of maximum and minimum daily air temperature, measured at 24 meteorological stations in Argentina during the period 1959–1998 (see Figure 1 for stations locations) provided by the Servicio Meteorológico Nacional (Argentine National Weather Service). Daily anomalies are computed for all the time series with respect to the 40-year daily means. A cold day is defined as a day for which the anomalies of both the maximum and minimum temperatures fall into the first quartile of the respective distribution. Likewise, a warm day is a day for which both quantities fall into the last quartile. A cold (warm) event is defined as several consecutive cold (warm) days. The monthly time series are then summarized into seasonal time series (i.e., one data per season). The 3-month seasons are defined as DJF (summer), MAM (fall), JJA (winter), and SON (spring). Two seasonal variables are further defined for each type of event (warm/cold): the number of events per season (independently of the number of days involved in the definition of each event), and the number of days classified as event in each season. This last characteristic gives a measure of the intensity of the events. In the following we will refer to these two variables as WE/CE (number of warm/cold events per season) and WD/CD (number of warm/cold days classified as event per season).

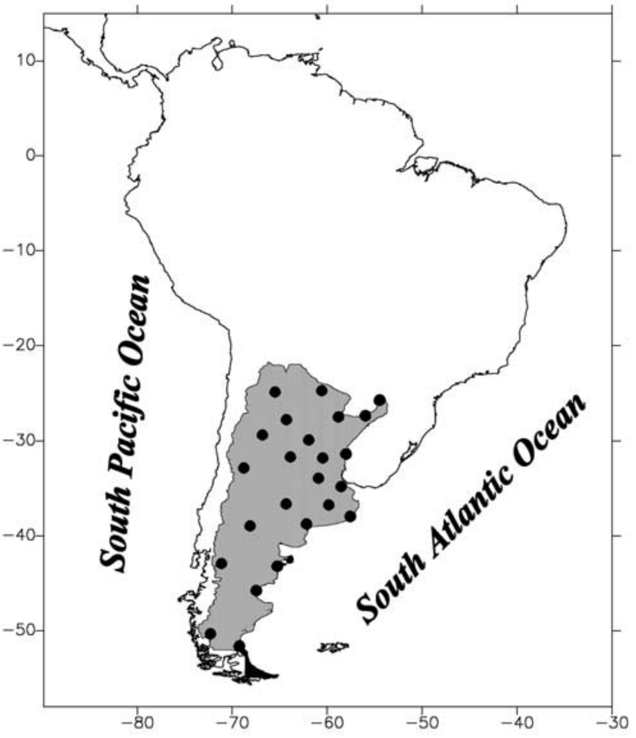

Figure 1. Stations locations.

[10] The SST data are obtained from the Global Ice and Sea Surface Temperature (GISST2.3) Data Set [*Parker et al.*, 1995], kindly provided by the Hadley Centre for Climate Prediction and Research, UK. This data set includes monthly gridded measurements of global SST from 1870 to the present. Although the quality of this data set is very heterogeneous, the SST coverage is fairly complete during the period studied here, and its quality is especially good after 1980 due to the inclusion of the available satellite observations.

[11] The SLP data are obtained from the Gridded Monthly Sea Level Pressure (GMSLP) data set [*Allan*, 1993], also provided by the Hadley Centre for Climate Prediction and Research, UK. These data consist of monthly SLP means available from 1903 to 1994, and their sparcity is most pronounced near the southern high latitudes, where some interpolation has been necessary to complete the data set. Hence we should keep in mind that the confidence in the SLP results slightly decreases near 60°S.

[12] Both the SST and SLP data have a spatial resolution of 1° latitude by 1° longitude which has been reduced to 5° by 5° (SLP) and 2.5° by 2.5° (SST) for the purposes of this study. The region of analysis comprises the South Atlantic and South Pacific Oceans, from the equator to 60°S, and from 140°W to 20°E. All monthly time series span from January 1959 to December 1998. Monthly anomalies are first computed by subtracting the 40-year monthly means from the original data, and seasonal anomalies are further obtained as the 3-month averages DJF (summer), MAM (fall), JJA (winter), and SON (spring).

3. Methodology

[13] Several Singular Value Decomposition (SVD) analyses are performed jointly on the extreme temperature events in Argentina and the SST over the South Atlantic and South Pacific in order to explore the co-variability between the two fields and provide insight into the possible mechanisms that may relate the extreme temperature events with the ocean temperatures. The joint analysis allows for the identification of pairs of spatial and temporal patterns that account for as much as possible of the covariance between the two variables. Detailed descriptions of the SVD method are given by *Bretherton et al.* [1992], *von Storch and Navarra* [1999], and *Venegas et al.* [1997].

[14] The four seasons are analyzed separately. For each season, four different SVD analyses are in turn performed, respectively relating WE, CE, WD, and CD with SST. All fields are normalized by their respective standard deviations prior to the analysis, so that they contribute equally to the results. The time series of expansion coefficients associated to each SVD spatial pattern (hereinafter called SVD time series) are further normalized so that they have unit variance. Correlation maps are used in this study to represent the SVD spatial patterns of the different variables. These are maps of grid point correlation coefficients between a time series and a given field. Homogeneous correlation maps are constructed as correlations between the SVD time series of a given variable (in this case WD, CD, and SST) and the grid point anomalies of the same variable. Heterogeneous correlation maps are constructed as correlations between the SVD time series of a given variable (in this case WD and CD) and the grid point anomalies of a different variable (in this case SLP). All correlations exceeding ±0.27 are significant at the 95% significance level.

4. Number of Events or Number of Days?

[15] The four variables defined in section 2 as characteristics of the warm/cold events (that is WE/CE and WD/CD) are analyzed independently for each season in combination with the Atlantic and Pacific SST. The percentage of the squared covariance accounted for by the first SVD mode in each case is given in Table 1.

[16] The first mode explains a high percentage of the squared covariance in all cases (ranging from 26% to 68%). The spatial patterns associated with the first SVD mode of the WE/CE turned out to be very similar to those of the WD/CD, respectively. Hence only the results for the number of days classified as events (WD/CD) are shown in the following, as they explain the highest percentages of the covariance between the two fields in all seasons. Winter is the season of the year that is best represented by the first SVD mode, since it accounts for up to 68% of the covariance in some cases. The individual fraction of the variance of the extreme events explained by the SST field

Table 1. Percentage of the Squared Covariance Accounted for by the First SVD Mode Between SST in the Atlantic and Pacific and WD, WE, CD, and CE, Respectively[a]

	WD	WE	CD	CE
Summer	34	33	60	55
Fall	47	34	44	34
Winter	48	43	68	65
Spring	41	37	34	26

[a] For summer (DJF), fall (MAM), winter (JJA), and spring (SON).

lies between 19% and 37% for WD and between 32% and 43% for CD, the highest values corresponding to winter in each case. On the other hand, the respective fractions of SST variance explained by the temperature events in Argentina barely reach 4–7%. This suggests that the SST plays a fundamental role as a prediction factor for the occurrence of days with extreme temperatures in Argentina, especially during winter. The respective fractions of SST variance explained by the temperature events in Argentina lie between 4% and 7%, since it was not expected that the temperature events would strongly influence the SST field. Furthermore, the occurrence of cold days is better represented by the first SVD mode than that of the warm days, in all seasons. This may be explained by the shape of the continent that induces a mainly maritime path of the cold air masses that reach Argentina, as opposed to the warm air masses that have an essentially continental path.

5. Warm Days Versus Cold Days

[17] During the summer and winter seasons, the spatial distributions of WD and CD exhibit very similar but opposite-signed patterns. The SST and SLP patterns associated with WD also resemble those associated with CD. This suggests that similar oceanic and atmospheric circulation situations are related to more (less) WD than normal and to less (more) CD than normal in these two seasons. A similar characteristic is observed in the fall, but the resemblance between WD- and CD-related patterns is slightly less striking in this season, and a few differences are seen, especially in the SST patterns. In spring, however, this is not true, and the spatial distributions of WD and CD are rather different. Such characteristic is also revealed by the correlation coefficients between the SVD time series of WD and CD, and between those of SST associated with WD and CD, for each season (see Table 2).

[18] Highly significant correlations (at the 99% significance level) between the SVD time series of WD and CD are observed during summer and winter. This may be due to the fact that the meridional flows related to the temperature events are best defined during these seasons. A less significant correlation (at the 95% significance level) is found in the fall, and no significant correlation at all appears in spring. On the basis of these results, the patterns associated with WD and CD are discussed together for summer, fall, and winter, and separately for spring in the following subsections.

5.1. Summer

[19] More WD than normal in central and eastern Argentina (Figure 2) are associated with warm SST in the western South Atlantic (SA) south of 30°S and in the eastern South Pacific (SP) between 10°S and 40°S. An almost identical SST pattern is related to less CD than normal in a similar region around central Argentina. The presence of warmer than normal waters along the coasts of South America, with centers of action around 20°S and 40°S in the SP and 40°S in the SA contributes to temperate the climatic conditions in Argentina and partially explains (34% to 60%) the high WD and the low CD in most of the country, owing to weak circulation conditions over the continent. This results in an increase of the temperature persistence that favors the generation of warm days.

Table 2. Correlation Coefficients Between the First Mode WD and CD Time Series and Between the SST Time Series Associated With WD and CD, for Each Season[a]

	WD Versus CD	SST WD Versus CD
Summer	**−0.69**	**0.89**
Fall	−0.34	0.41
Winter	**−0.72**	**0.91**
Spring	−0.28	0.15

[a]Coefficients in bold are significant at the 99% significance level. Fall coefficients are significant at the 95% significance level.

[20] The atmospheric circulation associated with increased WD (and to a lesser extent with decreased CD) shows an intensified continental low-pressure system in northwestern Argentina (near 30°S, 65°W). It also exhibits a high-pressure anomaly on the western side of the SA subtropical anticyclone, accompanied by a low-pressure anomaly on its eastern side, suggesting a westward shift of the anticyclone toward the American coast. This, in combination with the deep continental low, leads to a strong SLP gradient between the two pressure systems. The resulting stronger-than-normal northeasterly winds persistently bring anomalous amounts of warm tropical air to central/eastern Argentina and contribute to the high (low) occurrence of WD (CD) in that region.

[21] The patterns associated with WD and CD show lower values toward southern Patagonia, indicating relatively less WD (more CD) than in the rest of the country. This appears to be related to colder-than-normal SST conditions in the SP at those latitudes resulting in a stronger SST gradient. The SP subtropical anticyclone is also intensified south of 35°S near the coast, which results in strong westerlies to the north of the subpolar low belt around Antarctica (around 50°S), that bring relatively cold conditions from the SP to southern Patagonia. The WD in northern Argentina (north of 30°S) cannot be explained by this analysis since this region exhibits subtropical to tropical characteristics during summer.

5.2. Fall

[22] Similarly to the summer situation, high occurrence of WD in central/eastern Argentina (Figure 3) and low occurrence of CD in nearly the same region are associated with warm SST in the western SA south of 25°S and in the eastern SP between 20°S and 40°S. Some differences between these two SST patterns, however, are seen in the western SA south of 40°S, in the equatorial SA, and in the central SA and SP farther away from the American continent. As before, the associated atmospheric patterns show an intensification of the continental low pressure in northwestern Argentina and a positive SLP anomaly on the western side of the SA anticyclone, leading to a shift of the anticyclone toward America. The increased SLP gradient between the continental low and the SA anticyclone is again responsible for stronger-than-normal northeasterly winds around 30°S, 50°W–60°W that bring warm and humid tropical air to central/eastern Argentina (slightly farther north than in the summer situation). This results in warmer-than-normal conditions in that region, reflected by the high (low) occurrence of WD (CD).

[23] A center of cold SST south of 40°S in the eastern SP may be associated with the significantly reduced WD in

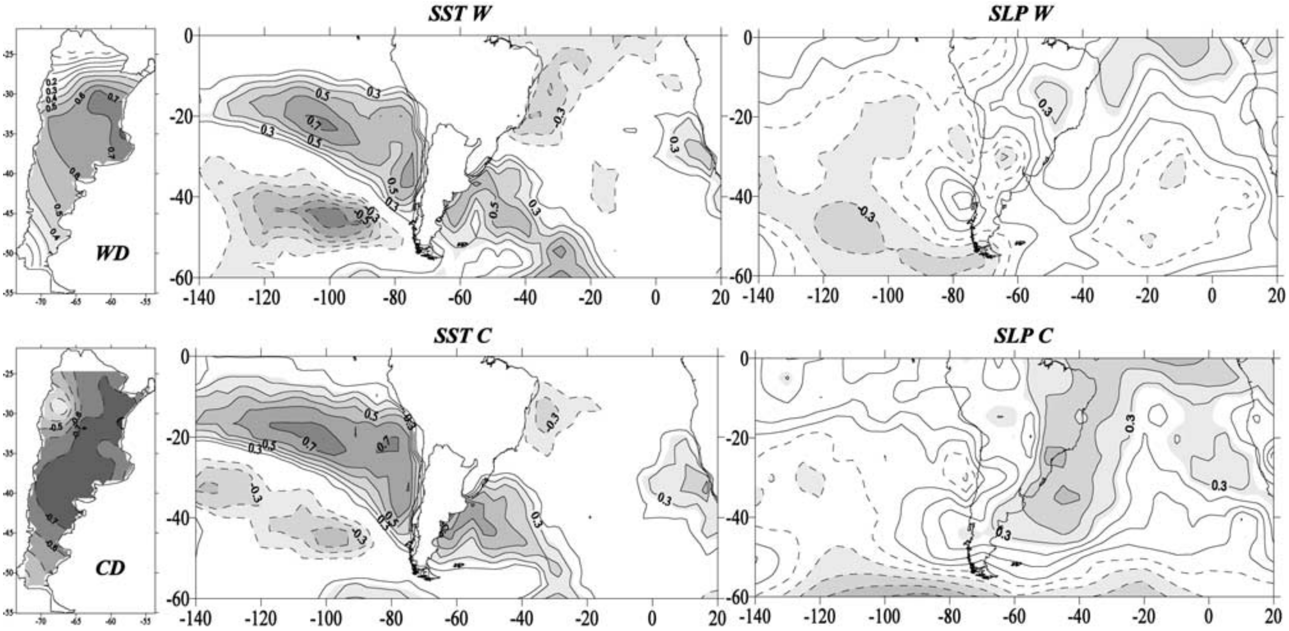

Figure 2. Summer. (top left) Correlation map between the SVD time series of WD and the WD grid point anomalies over Argentina. Positive (negative) values show regions with more (less) WD than normal. (top middle) Correlation map between the SVD time series of SST (associated with WD) and the SST grid point anomalies in the SA and SP. (top right) Heterogeneous correlation map between the SVD time series of WD and the SLP grid point anomalies over Argentina, the SA, and SP. (bottom left) Correlation map between the SVD time series of CD and the CD grid point anomalies over Argentina. (bottom middle) Correlation map between the SVD time series of SST (associated with CD) and the SST grid point anomalies in the SA and SP. (bottom right) Heterogeneous correlation map between the SVD time series of CD and the SLP grid point anomalies over Argentina, the SA, and SP. Correlation maps show correlation coefficients between −1.0 and 1.0 and have no units. Centers with correlations higher that ±0.27 are significant at the 95% level and are shaded.

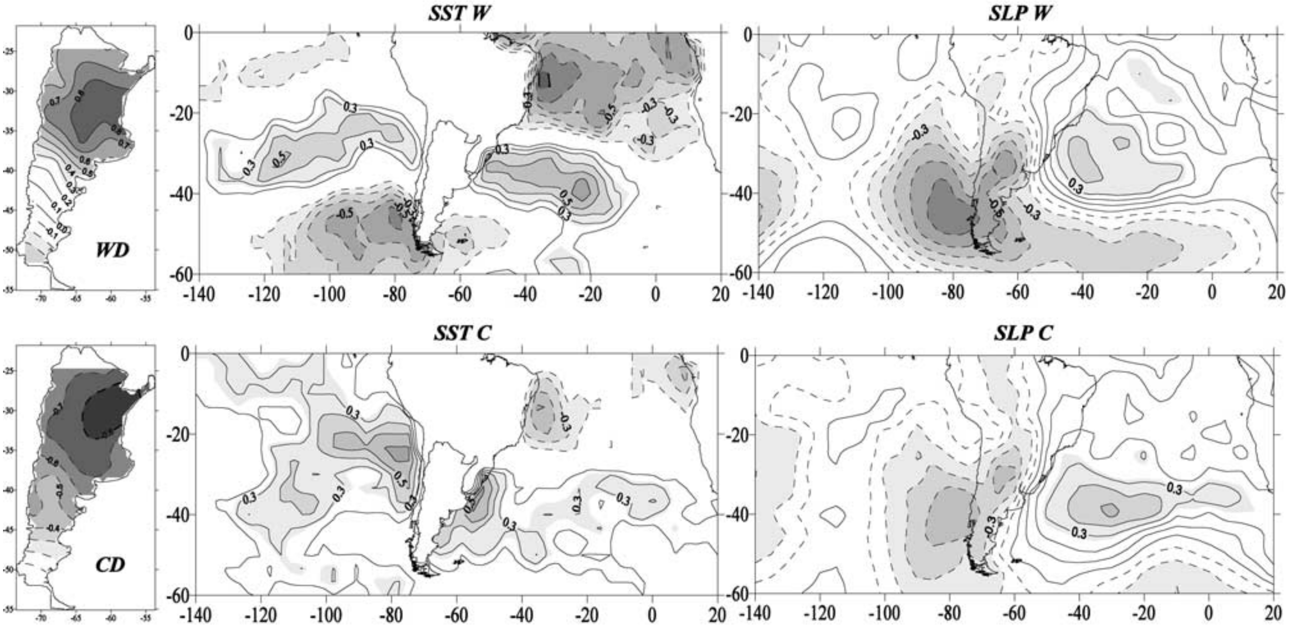

Figure 3. Same as Figure 2 but for fall.

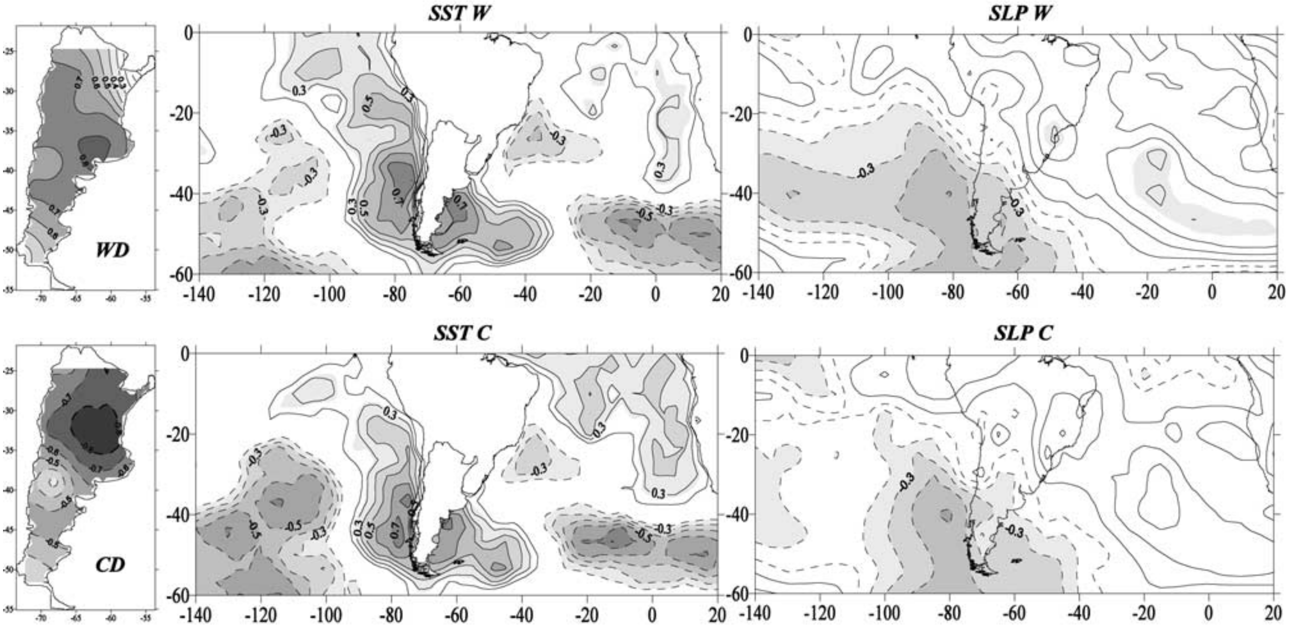

Figure 4. Same as Figure 2 but for winter.

southern Argentina. As in summer, these cold conditions in Patagonia result from westerly winds that blow from the relatively cold waters into the continent.

5.3. Winter

[24] Increased WD in central Argentina (around 35°S–40°S) and decreased CD in central/northern Argentina (around 30°S–35°S) are associated with warm SST near the coasts of Argentina south of 30°S in both ocean basins (Figure 4). The SLP distributions related to these conditions present an elongated negative anomaly close to the continent in the SP, which indicates that the SP anticyclone is weakened and slightly shifted to the northwest and the subpolar low-pressure belt is enhanced and shifted to the north in that region. This implies a northward displacement of the climatological storm-track that normally lies between the SP anticyclone and the low-pressure belt south of 60°S. In this situation, weather systems entering the continent from the SP come from the warmer-than-normal waters related to the positive SST anomaly there, which generates relatively warm winter conditions over all Argentina, in particular in the central part.

[25] In the opposite situation, the SLP pattern responsible for increased CD and decreased WD in central Argentina (Figure 4 with opposite signs) exhibits a strengthening of the climatological ridge of high pressure in southern Argentina that favors a meridional circulation of cold subpolar air and an excessive loss of radiation during clear nights. The positive SLP anomaly in the SP may be related to persistent high-pressure centers in block situations and to an enhanced number of high-pressure ridges forming on the trailing side of cold fronts. Both phenomena would favor an increase in the CD.

5.4. Spring: Warm Days

[26] As mentioned, the spring patterns for WD and CD are not opposite to each other as in the other seasons and are discussed separately. A dipole structure between northern and southern Argentina is observed in the distribution of WD in spring (Figure 5, top). The associated SST pattern is clearly dominated by the El Niño phenomenon. Warm ENSO events in the equatorial Pacific are related to a high (low) occurrence of WD in northern (southern) Argentina. This result is in agreement with the conclusions reached by *Rusticucci and Vargas* [2002]. The Atlantic SST pattern seems to have very little relevance in the WD distribution in Argentina during spring.

[27] The atmospheric pattern presents an increased southward circulation toward southeastern Brazil and northeastern Argentina, which may explain the accumulation of water vapor and the subsequent increase of rainfall in those regions during the El Niño events [*Grimm et al.*, 2000]. During La Niña, more (less) WD in the south (north) are associated with a SA subtropical anticyclone weakened in its northern part, an atmospheric circulation with an easterly component near the coast around 30°S, and a weakened low-pressure center in northwestern Argentina.

5.5. Spring: Cold Days

[28] A structure similar to the winter situation is observed, with low occurrence of CD over all Argentina and particularly in its central/northern part (Figure 5, bottom), accompanied by warm SST in the western SA and southeastern SP. The associated atmospheric circulation indicates that high occurrence of CD in spring is related to the establishment of an anomalous ridge of high pressure over the continent. This results in an anomalous wind component from the south that advects cold subpolar air from the anomalously cold waters in the southern SA into the continent. Warm SST anomalies along the SA coast help temperate the climate and inhibit the occurrence of CD in the southern and coastal regions of Argentina.

[29] Interestingly, the patterns obtained when analyzing CE or WE in spring (as opposed to CD or WD) both show the El Niño structure in the first SVD mode (not shown) as in the analysis of WD described above. Hence only the first

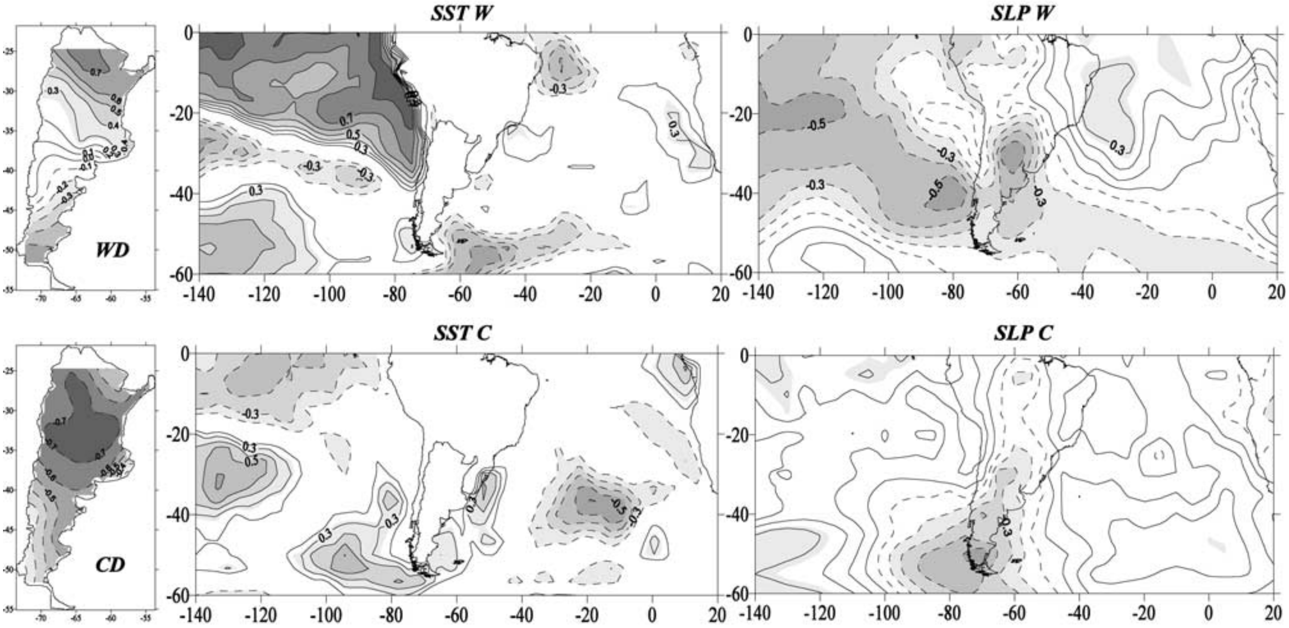

Figure 5. Same as Figure 2 but for spring.

SVD of CD presents a very different structure. However, when computing the second SVD of CD (not shown), we recover the El Niño pattern in the Pacific, as in the first SVD of the three other variables. Thus the El Niño phenomenon is slightly less important for determining the CD than for determining the three other variables (WD, CE, and WE), but is definitely a relevant component in the generation of temperature events in spring.

6. Temporal Variability

[30] A spectral analysis of the SVD time series WD and CD (Figure 6) was performed using the Multitaper Method (MTM [*Percival and Walden*, 1993]) and the significance of the spectral peaks was determined against a red-noise null hypothesis [*Mann and Lees*, 1996].

[31] The summer spectra do not reveal statistically significant peaks. However, some long-term (interdecadal) variability is found with a period longer than 20 years and is especially significant in the CD case. It does not appear as significant in the MTM spectra, however, due to the shortness of the record analyzed (40 years). This long-term variation in the occurrence of CD in summer was also shown by *Barrucand and Rusticucci* [2001] and was observed in other variables such as annual flow of the Paraná River, rainfall in northeastern Argentina and humidity advection into the continent in southern South America [*Minetti and Vargas*, 1999; *Vargas et al.*, 2002]. A marked change of sign is clearly observed in the summer CD and WD time series (and those of their associated SST) around the second part of the 1970s (results not shown), which is presumably related to the well known climatic "jump" of 1976/1977 [*Deser and Blackmon*, 1993; *Kushnir*, 1994].

[32] The fall spectra of both WD and CD exhibit a statistically significant peak (at the 95% level) on the interannual band, with period of around 3 years. The winter spectra also show significant peaks on the interannual band, with period around 3.5 years in the WD case (significant at the 95% level), and around 4 years in the CD case (significant at the 90% level). Some energy is also shown on the decadal band (period around 10 years), but such a periodicity is not significant in a 40-year-long time series. The spring spectrum for WD shows significant peaks (at the 90% level) on the El Niño frequencies, as expected, that is, periods around 4–5 years. The spring spectrum for CD shows two different significant peaks (at the 95% level): one on the interannual band with period around 3 years and the other closer to the decadal band with period around 7–9 years.

7. Relative Influence of the Atlantic and Pacific

[33] In order to assess the relative importance of the Atlantic and the Pacific influence on the extreme events over Argentina, the SVD analyses were repeated combining WD/CD with SST of the Atlantic basin alone, instead of the two basins. In summer, fall, and winter, the resulting first mode patterns of Atlantic SST remain the same independently of whether we include the Pacific SST or not. The Atlantic SST anomalies just become stronger and better defined when considering the Atlantic alone. This indicates that the Atlantic SST mainly determines the relationship between the extreme events and the SST in both oceans in summer, fall and winter. The relative dominance of the Atlantic over the Pacific is essentially determined by the presence of the Andes Mountains, an orographic factor that strongly influences the atmospheric circulation, favoring the meridional exchange of air masses and lessening the direct influence of the Pacific on the temperature in Argentina [*Seluchi and Marengo*, 2000].

[34] The Atlantic patterns of CD in spring are also identical in the two-basin analysis and in the Atlantic-alone analysis, as in the other seasons. The patterns of WD in spring, however, show substantially different distributions depend-

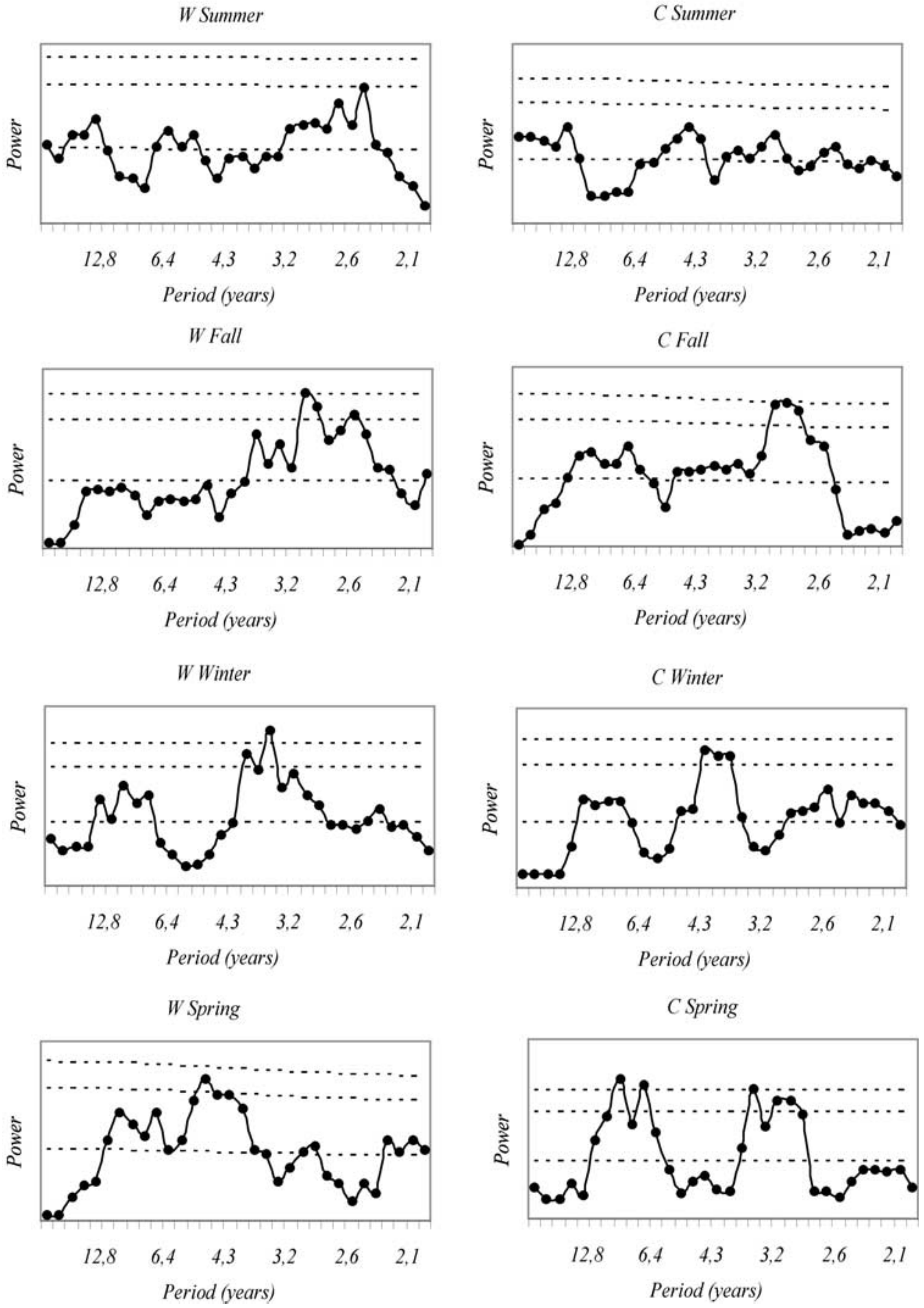

Figure 6. Power spectra of the (left) WD and (right) CD SVD time series for summer, fall, winter, and spring. The spectra are computed using the Multitaper Method and the median and 90% and 95% significance levels are shown with dashed lines.

ing on the inclusion or not of the Pacific in the analysis: the El Niño phenomenon clearly dominates the first SVD mode when including the Pacific SST. The first mode in the Atlantic-alone analysis appears as the second mode in the two-basin analysis and is very different from El Niño.

8. Discussion

[35] We have explored the first mode patterns of a joint SVD analysis between the numbers of days classified as warm/cold events in Argentina (WD/CD) and the South Atlantic and South Pacific SST. The atmospheric circulation patterns associated with them have also been analyzed through SLP correlation maps. The warm and cold events in Argentina result basically from the generation of meridional atmospheric circulations over the continent, in which anomalous northerly and southerly winds bring warm air from the tropics or cold air from the subpolar regions into the country. Such atmospheric circulation patterns result in turn from displacements and intensity changes of the

subtropical anticyclones over the oceans and of the continental low-pressure center in northwestern Argentina. The warm and cold events are also closely related to the warming and cooling of the coastal waters in the South Atlantic and South Pacific. The large percentage of the covariance explained by the first SVD mode suggests a fair degree of predictability of the warm and cold events in Argentina based on the Atlantic and Pacific SST in all seasons, although no lags are included in this analysis. This is especially true in winter, in which the first mode accounts for up to 68% of the covariance between the SST and the temperature events.

[36] In summer and winter, a clear correlation is found between high (low) occurrence of warm days and low (high) occurrence of cold days. Both types of events are related to the presence of well-defined and persistent meridional flows. Such a relationship is not so clear in the transition seasons fall and spring, in which extreme values of both warm and cold events may occur simultaneously. For all seasons, the occurrence of temperature events in Argentina shows higher correlation with the Atlantic than with the Pacific. This reflects the important role played by the Andes Mountains as an ‘‘orographic barrier’’ that strongly drives the atmospheric circulation and blocks a direct influence of the Pacific SST on the temperature in Argentina. The only exception to this rule concerns the warm events in spring, for which the warming of the equatorial Pacific (the ENSO pattern) appears as the dominant mode. The associated SLP patterns also suggest the predominance of the Atlantic over the Pacific in the generation of meridional circulations over northern Argentina, via changes in location and intensity of the SA subtropical anticyclone.

[37] The meridional circulations responsible for the extreme temperature events in Argentina have slightly different characteristics for the cases of the warm and the cold events. The occurrence of cold events is particularly dependent on the intensity of the northward flows associated with the ridge of high pressure in southern Argentina. This is especially clear in fall, winter, and spring. The occurrence of warm events is mainly related to the strength of the southward flows associated with the low-pressure center in northwestern Argentina and the SA anticyclone. This characteristic is more evident in summer and fall. In the particular case of warm events in summer, the fact that the entire country cannot be represented by a homogeneous pattern reflects the special condition of the northern region of Argentina as a transition zone between middle and subtropical/tropical latitudes.

[38] The temporal patterns (SVD time series) of the WD and CD in Argentina exhibit significant interannual variability in fall, winter, and spring, presenting oscillations with periods of 3 to 5 years. As expected, the pattern for WD in spring exhibits variability on the frequency band associated with ENSO, that is, periods around 4–5 years. The pattern for CD in spring also shows a significant signal closer to the decadal band, with periods around 7–9 years, in addition to the interannual periods. Some decadal-interdecadal variability, on a broad band of periods from 8 to 17 years, is suggested in the wintertime series for both WD and CD but this variability is not statistically significant, which could be due to the shortness of the record analyzed. The summer patterns do not show statistically significant signals, although a very low-frequency variation with a period longer than 20 years is suggested. This long-term signal has also been observed in other variables of the region, which would suggest that the SVD analysis performed has isolated the SST and the atmospheric circulation conditions necessary to produce maximum and minimum values of meridional exchanges of air masses. Such extreme situations in north-south displacements of air masses are highly responsible for the occurrence of warm and cold events.

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