CLIMATE VARIABILITY IN RIO GRANDE, RS, BRAZIL: A QUANTITATIVE ANALYSIS OF CONTRIBUTIONS DUE TO ATMOSPHERIC SYSTEMS

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ABSTRACT

The relative intensity of the atmospheric phenomena acting in Rio Grande city, RS, Brazil, is determined to investigate the local atmospheric dynamics. Data were collected from 1990 to 2001, in a conventional meteorological station located at 32°04'43"S and 52°10'03"W. The time series were analyzed using the wavelet transform as a tool. It has been suggested that several atmospheric phenomena act or have consequences in the extreme south of Brazil, such as the passage of air masses along with frontal systems, the Madden-Julian Oscillation, blocking events, and the El Niño-Southern Oscillation phenomenon. The higher variance was observed to be associated with the annual cycle in the air temperature, specific humidity, and atmospheric pressure time series, representing, respectively, 55.4%, 51.1%, and 30.5% of the total variance. For the wind meridional and zonal components and for precipitation, the highest energy is related to the passage of air masses and frontal systems. These high frequency systems assumed higher variance when the annual cycle was removed from the series. The wavelet variance analysis indicated that the annual cycle is responsible for most of the meteorological time series modulation in the extreme south of Brazil, along with the variability induced by air masses passages and frontal systems.

Keywords: atmospheric phenomena, climate variability, time series, wavelet transform

RESUMO: VARIABILIDADE CLIMÁTICA EM RIO GRANDE, RS, BRASIL: UMA ANÁLISE QUANTITATIVA DA CONTRIBUIÇÃO DOS SISTEMAS ATMOSFÉRICOS

O presente estudo determina a intensidade relativa dos fenômenos atmosféricos atuantes no município de Rio Grande, RS, com o objetivo de investigar a dinâmica atmosférica local. Os dados utilizados foram coletados numa estação meteorológica convencional localizada a 32°04'43"S e 52°10'03"W e o período em estudo compreende os anos de 1990 a 2001. As séries temporais foram analisadas utilizando a transformada de ondeleta. Verificou-se a atuação de vários fenômenos atmosféricos no extremo sul do Brasil, tais como a passagem de massas de ar e sistemas frontais, oscilação de Madden-Julian, bloqueios atmosféricos e eventos El Niño-Oscilação Sul. A maior variância observada nas séries temporais da temperatura do ar, umidade específica e da pressão atmosférica está associada com o ciclo anual representando, respectivamente, 55.4%, 51.1%, e 30.5% da variância total. Para a precipitação e componentes do vento, a maior energia está relacionada com a passagem de massas de ar e sistemas frontais. A maior energia devida a estes sistemas também é encontrada nas três primeiras séries citadas quando o ciclo anual é removido. Através da análise de variância de ondeleta, pode-se

concluir que o ciclo anual é o responsável pela maior modulação das séries temporais no extremo sul do Brasil, ao longo com a variabilidade causada pelas massas de ar e sistemas frontais. **Palavras-chave:** fenômenos atmosféricos, variabilidade climática, séries temporais, transformada de ondeleta

1. INTRODUCTION

Atmospheric systems involve distinct spatial and temporal scales whose contributions to the regional climate variability are different in intensity and occurrence. Rio Grande, which is the site of the present research, is a city located in Rio Grande do Sul state, Brazil, at 32°01'40"S and 52°05'40"W (Figure 1). Its climate is influenced by atmospheric systems with temporal scales varying from daily ones, as the sea breezes (Braga e Krusche, 2000; Krusche et al., 2002), to interannual ones, as the El Niño-Southern Oscillation (ENSO) occurrence (Grimm et al., 1998 and Grimm et al., 2000). Atmospheric systems acting over southern Brazil, Uruguay, and northern Argentina have been investigated in many studies. We will proceed to comment on some of them in order to describe the usual atmospheric phenomena in this region.

Mesoscale convective complexes are responsible for intense precipitation in those regions, mainly from November to April, according to Velasco and Fritsch (1987). Sea and land breezes are other mesoscale systems present in Rio Grande. Braga and Krusche (2000) verified their influence in all seasons which is, nevertheless, feeble. They observed, for instance, that the sea breeze reaches a maximum value of 1 ms⁻¹ in the summer.

The cold air masses, which advance from high latitudes towards low latitudes in the Southern Hemisphere, cross over

the south of South America. Since Rio Grande is located in this region, there are often changes in the weather associated with the invasion of cold air masses or the movement of frontal systems. According to Satyamurty and Mattos (1989), the south of Brazil presents frontogenetic conditions all year round. In July, frontogenesis might be more intense and it might occur more often (Seluchi and Marengo, 2000). Britto and Saraiva (2001) estimated that the average number of cold fronts passing over Rio Grande in winter is four per month. They suggested that the precipitation rate is mostly frontal-originated in this season.

Cold air outbreaks are events related to the presence of an anticyclonic perturbation off the coast of Chile. During the winter, they may drive cold advection over southern Brazil (Marengo et al., 1997). Escobar et al. (2004) proposed an objective classification of sequence patterns of 1000 hPa and 500 hPa geopotencial heights associated with cold surges over Central Argentina, because polar outbreaks, from May to September, might cause severe damage to the regional agriculture and may also affect energy supply. The typical situation, related to colds surges over Central Argentina and, therefore, southern Brazil, shows an intense upper level ridge west of the Pacific coast and a lower level post-frontal anticyclone, producing cold air advection in the abovementioned region. Sometimes, the cold air outbreaks are so intense that extensive freezes affect southern Brazil along with considerable cooling in central and northern Amazon (Vera and



Figure 1 - Location of the Rio Grande city in relation to South America and Brazil.

Vigliarolo, 2000; Marengo and Rogers, 2001). Although these systems have synoptic characteristics, they seldom occur, since they require the dynamic support mentioned above. Vitorino (2002) studied the cases with energy maximum in the sea level pressure associated the 30-90 days band in the winter in the south and southeast of Brazil. The author concluded that the maximum can be associated with the occurrence of the cold air outbreaks.

The extratropical cyclones affect Rio Grande because it is located near the cyclogenetic region in the Uruguay coast (Gan and Rao, 1991, Reboita et al., 2005). It is also in the transient activity zone, which is the main region of cyclone strengthening in the Southern Hemisphere, approximately between 30° and 60° (Pezza and Ambrizzi, 2003). The extratropical cyclones exhibit a wide variety of subsynoptic scale organization, which is important for weather forecasting, such as frontal rain and snowbands, line convection, and comma clouds (Thorpe, 1999). Vera (2003) suggested that there is a frequency variation of the atmospheric synoptic-scale variability of 2-10 days, during the austral winter, in the Southern Hemisphere.

Blocking events that occur in the South Pacific also influence South American weather. There is a higher frequency of this phenomenon in fall and winter, and it lasts up to 10 days (Renwick and Revell, 1999). Although blocking events are synoptic systems, they occur with intraseasonal frequency. Blocking occurs when the main mid-latitude westerly flow acquires a wriggled meridional pattern which interrupts the upstream eastward moving cyclones and anticyclones, with a persistent surface anticyclone on the polar side of the block. These episodes are some of the major synoptic-scale phenomena causing regional persistent weather conditions (Kayano, 1999). Migratory lows, when near a blocking situation, remain stationary or dislocate around a subtropical high and can cause heavy precipitation. Nascimento and Ambrizzi (2002) studied a blocking event that occurred between July 5th and 10th, 1995 in the South Pacific at about 60°S. In the mature stage of this system, a classic dipole pattern was observed. During its life cycle, the blocking moved from 160°W to 120°W along a parallel situated near 55°S. This blocking was responsible for the increase in the precipitation rates in Rio Grande in July, 1995.

In the intraseasonal scale, the influence of the Madden-Julian Oscillation (MJO) can be cited (Kiladis and Mo, 1998). Over South America, this oscillation has been associated with variations in the position and the intensity of the South Atlantic Convergence Zone (Casarin and Kousky, 1986; Kousky and Kayano, 1994). A weak signal of the oscillation in the band from 25 to 87 days in the summer was observed in the south of Brazil by Kayano and Kousky (1996), through the analyses of long wave radiation and sea level pressure. Grimm and Silva Dias (1995) showed that MJO could cause substantial changes in the circulation of mid-latitudes in the Southern Hemisphere. Gonzáles and Barros (1996) carried out a spectral analysis for precipitation rate series in several stations in the east and in the northeast of Argentina. They have found oscillations with variable periods between 23 and 45 days, which may be related to MJO. Zhang and Dong (2004) reported the MJO seasonality in terms of its components in low-level zonal wind and precipitation. The authors verified a peak in the boreal winter (December - March), which corresponds to the austral summer. Strong seasonal activities of MJO seem to prefer mean westerlies or weak zonal winds at the surface and low level (850 hPa), and mean lower-level moisture convergence in the west Pacific. The mechanism for the seasonal variation in MJO remains unknown. It is convenient to assume that the sea surface temperature (SST) is responsible for the seasonal migration of MJO.

In a large scale, the south of Brazil is affected by the El Niño-Southern Oscillation phenomenon. There are several studies (Pisciottano et al., 1994; Grimm et al., 1998; Diaz et al., 1998; Grimm et al. 2000) that describe associations among precipitation anomalies and the extreme phases of the Southern Oscillation in the southeastern region of South America comprising southern Brazil, Uruguay, and Argentina. Pisciottano et al. (1994) analyzed data measured at a large number of rainfall stations to search for relationships among the Southern Oscillation and precipitation anomalies in Uruguay. They found out that years with El Niño events tend to have higher than average rainfall, especially from November to January. Besides, years with high values of the Southern Oscillation Index, associated with La Niña, tend to have lower than average rainfall, especially from October to December. Grimm et al. (1998) investigated the impact of El Niño and La Niña events on rainfall over southern Brazil through the use of a large dataset of monthly precipitation collected in 250 stations. The authors verified that southern Brazil has strong and consistent precipitation anomalies associated with these events. There are wet anomalies during the austral spring of the warm event year, with a pronounced peak in November. Most of the wet anomalies in spring of El Niño years are due to the intensification of mesoscale convective complexes in this region. Their intensification is probably associated with the strengthening of the subtropical jet over the region during El Niño events. Furthermore, these wet anomalies are also associated with an anomalous cyclonic circulation to the east, in the subtropics. These features favor baroclinic developments and are conducive to anomalous rainfalll over southern Brazil (Grimm et al., 1998). Compagnucci et al. (2002) analyzed precipitation series in the central-western region of Argentina. They identified oscillations with periods between 3 and 6 years associated with the El Niño-Southern Oscillation phenomenon. Rigozo et al. (2003) detected, on three ring data from southern

Brazil, variations between 2 to 5 years related to ENSO. Krepper et al. (2003) analyzed Uruguay River flow and precipitation trough spectrum analysis. They observed that approximately a 6-year and a 3.5-year ENSO signals are the two statistically significant peaks.

In the extreme south of Brazil, there are a few studies that employ harmonic analysis to identify the atmospheric systems that act in this region. For instance, Campello et al. (2004) found periods with variation from 4.5 to 13.5 days that were associated with frontal systems; periods from 17 to 28 days were related to the convection variability in the South Atlantic Convergence Zone; periods from 36 to 77 days were associated with MJO. However, the main cycle detected in the variables corresponded to 365 days, the annual cycle, except for the wind velocity components and precipitation.

We propose to perform a quantitative analysis of the contributions due to all the above-mentioned atmospheric systems, in order to evaluate the relative intensity of their influence on the climate in Rio Grande. The wavelet transform, which yields decomposition in both temporal and scale domains, will be applied to meteorological time series measured from 1990 to 2001 at a conventional station. Thereafter, an analysis of both period and season of occurrence of the most energetic oscillations will be employed to associate them with the atmospheric phenomena prevalent in the region.

In the next section, the site and the data of study are presented. The wavelet transform theory is briefly revised in the following section. The results are then described, and the conclusions are presented in the last section.

2. MEASUREMENT SITE AND DATA

Data measured in a conventional meteorological station were analyzed. The station belongs to the World Meteorological Organization network, located at 32°04'43"S and 52°10'03"W, in Rio Grande city. The variables were air temperature, relative humidity, atmospheric pressure, and wind velocity intensity and direction, measured at 12 and 00 UTC, from January 1st, 1990 to March 19th, 2001. The specific humidity was determined applying the Clausius-Clayperon equation (Wallace and Hobbs, 1977). Due to the intense influence of the annual cycle, air temperature, relative humidity, and atmospheric pressure time series were deseasonalized by subtraction of a trigonometric function that was adjusted to the signals (Chatfield, 1999).

Daily precipitation totals from January 1st, 1990 to December 31st, 2002 were also analyzed. Precipitation pentads were calculated to avoid errors which are generated when Fourier and wavelet transforms are applied to time series with many zeroes. Pentads are totals of daily precipitation for five days, and they were calculated according to the methodology described by Kousky (1988). The period for the precipitation pentads is different from the other variables to ensure that they have length next to a power of two; it improves the computational performance of the calculation of the transform. The period for all the other series corresponds to a power of two.

Monthly data of the Southern Oscillation index, obtained at the Australian National Climatic Center, in 2003, were also analyzed from January 1982 to April 2003.

The wavelet transform was applied to this study to estimate the contribution of various temporal scales to the meteorological time series. A brief description of this technique is presented next.

3. WAVELET TRANSFORM

The wavelet transform has been applied to many studies on atmospheric phenomena, because it is an effective tool that reveals the temporal and spatial structure of non-stationary time series. Weng and Lau (1994) employed this methodology to study convection organization over the tropical west Pacific. They used the Morlet wavelet in an infrared radiance dataset. As a result, they observed two regimes in the variation of the data, corresponding to the wet and dry periods. In the austral summer (wet seasons), diurnal variation of convection is stronger. Gu and Philander (1995) have emphasized the wavelet transform application to the study of El Niño-Southern Oscillation. This methodology was applied to analyze ocean and atmospheric data sets from 1870 to 1988. The amplitude of ENSO was found to be large from 1885 to 1915, to be small from 1915 to 1950, and to increase rapidly after 1960. Surprisingly, the decadal variations in the amplitude of ENSO are not matched by similar decadal variations in the amplitude of the annual cycle.

Breaker et al. (2001) employed the wavelet transform in the analysis of intraseasonal oscillations. The wavelet transform has also been successfully applied to the study of turbulence by Farge (1992) and Collineau and Brunet (1993), for instance.

In this research, the wavelet transform was applied to the original series to verify the influence of the annual cycle, along with the other components. It was also applied to the deseasonalized series to verify the influence of the other components that may be masked when the contribution from the annual cycle component to the energy spectra is too intense.

The continuous wavelet transform of a signal f(t) is defined as (Daubechies, 1988):

$$W_{\ell,t'}(f) = \left\langle f, \psi_{\ell,t'}^* \right\rangle = \frac{1}{\sqrt{\ell}} \int f(t) \psi^* \left(\frac{t-t'}{\ell} \right) dt \qquad (1)$$

where ℓ is the dilation parameter, *t*' is the translation parameter, and ψ^* is the complex conjugate of function ψ which is the mother wavelet.

The expression to calculate the inverse wavelet transform is (Lau e Weng, 1995):

$$f(t) = \frac{1}{C_{\psi}} \iint W_{\ell,t'}(f) \psi_{\ell,t'}(t) dt' \frac{d\ell}{\ell^2}$$
(2)

where C_{ψ} appears as a normalizing factor and can be defined as (Collineau and Brunet, 1993):

$$C_{\psi} = 2\pi \int_{0}^{\infty} \frac{\left| \hat{\Psi}(\omega) \right|^{2}}{\omega} d\omega < \infty$$
(3)

where $\hat{\psi}$ is the Fourier transform of ψ .

We selected the complex Morlet wavelet as a mother wavelet. According to Kumar and Foufoula-Georgio (1994), this wavelet might be expressed as:

$$\Psi(t) = \pi^{-1/4} e^{i\omega_0 t} e^{-t^2/2}$$
(4)

where the Morlet wavelet parameter ω_{θ} is 5.4. This value is the one which best ensures that the mother wavelet satisfies the admissibility condition (Melice and Roucou, 1998). This condition is necessary to obtain the inverse wavelet transform.

The wavelet energy is defined as the square modulus of each coefficient of the transform. The wavelet variance is the wavelet energy integral over the translation parameter (Collineau and Brunet, 1993):

$$\mathbf{V}_{\mathrm{f}}\left(\ell\right) = \int_{-\infty}^{+\infty} \left|\mathbf{W}(\ell, \mathbf{t}')\right|^2 \mathrm{d}\mathbf{t}' \tag{5}$$

The graph of the wavelet variance plotted against the scale is identified as the global wavelet spectra. The wavelet coefficients real part, modulus, or energy may be plotted as a function of time and scale. These graphs are called scalograms. The real part scalograms present information about the intensity and phase of the signal; modulus scalograms show the signal amplitude; and energy scalograms yield energy density (Weng and Lau, 1994). The cone of influence delimitates the significant region on a scalogram. Torrence and Compo (1998a) describe a procedure for the calculation of the cone of influence.

The algorithm applied to this research to calculate the wavelet transform was lent by J. L. Melice. It is similar to an algorithm developed by Torrence and Compo (1998b). Both are based on the fast Fourier transform.

When the time series have periods that are longer than one year, the annual average of the wavelet energy can be calculated (Breaker et al, 2001). It corresponds to an average, for all years, of the wavelet energy for each one of the 365 days of the year.

The wavelet variance was also integrated by bands to quantify the influence of the annual cycle and of the different atmospheric systems. According to Emery and Thomson (1998), the variance integrated by bands is defined by:

$$V_{f}(\ell_{1},\ell_{2}) = \int_{\ell=\ell_{1}}^{\ell=\ell_{2}} V_{f}(\ell) d\ell$$
(6)

where $V_f(\ell)$ is the wavelet variance.

The bands were determined according to periods of higher energy observed in the global wavelet spectrum. The less energetic periods were added as one band.

4. RESULTS AND DISCUSSION

The wavelet transform was applied to all the original series in order to verify the influence of the annual cycle and other time component contributions to their energy spectra. There is an important contribution of the annual cycle to the time series of air temperature, specific humidity, and atmospheric pressure. That contribution can mask the energy of the other oscillations. Therefore, the wavelet transform was then applied to the deseasonalized air temperature, specific humidity, and atmospheric pressure series.

The annual average of the wavelet energy was calculated to verify the seasonal behavior of the oscillations that are present in the signals, since all time series had a duration superior to a year. The wavelet variance was integrated by bands in order to quantify the influence of the atmospheric systems on the climate variability in Rio Grande. The integration bands were limited by the most energetic periods observed in the series of wavelet variance for each variable.

The global wavelet spectra were calculated to verify the periods with higher energy in the series (Figure 2). The atmospheric phenomena that occur in the region were then associated with the corresponding periods. The confidence limits were not plotted in the global wavelet spectra because the scalograms of the real part, the modulus, or the wavelet energy (Figure 3) present the cone of influence, and this fact is taken into account when the variance is calculated. The atmospheric phenomena associated with the periods of variance maxima are presented in Table 1.

One-day periods were detected in all time series under analysis. In the atmospheric pressure, air temperature and specific humidity, this period is related to the daily cycle of insolation. In the wind components, it is probably related to the sea and land breeze, since it occurs in all seasons (Braga and Krusche, 2000).

Periods that vary from 4 to 12 days were also detected in all variables, as can be observed in Figure 2a, 2b, and 2c. These periods are related to the passage of air masses and to their associated frontal systems over the region. Intraseasonal periods with variation from 30 to 100 days, which can be associated with the influence of MJO, were observed in all time series, except in atmospheric pressure (Figure 2a, 2b, and 2c). In winter, these periods can also be related to the cold air outbreaks in South America. In air temperature, specific humidity, zonal and meridional wind component, and precipitation time series,



Figure 2 – Global wavelet spectra of the variables measured in the conventional station. Variable maxima are marked with dots. The spectra is normalized by the maximum value of spectral energy for each variable.



Figure 3 - a) Temporal series of deseasonalized air temperature for January, 1990 to March 2001, b) real part of wavelet coefficients, and c) global wavelet spectrum. In c the arrow indicates a maximum that exceed the influence cone. The number of the time series data points provide just a general view of the results.

Atmospheric Phenomena	Variable	Period (days)
Diurnal Cycle	Temperature	1.0
	Specific Humidity	1.2
	Atmospheric Pressure	1.0
	Meridional Component	1.3
	Zonal Component	1.2
Air Masses Incursions and Frontal System	Temperature	6.1 9.2
	Specific Humidity	5.6 9.2
	Atmospheric Pressure	8.0
	Meridional Component	4.0
	Zonal Component	4.0 5.3
	Precipitation	12.3
Madden-Julian Oscillation or Cold Air Outbreaks	Temperature	97.6
	Specific Humidity	37.0 97.6
	Meridional Component	42.5
	Zonal Component	56.1
	Precipitation	60.4
Semiannual Cycle	Temperature	170.0
	Specific Humidity	170.0
	Atmospheric Pressure	170.0
Atmospheric Blocking	Temperature	296.0
	Specific Humidity	257.7
	Meridional Component	112.2
	Zonal Component	128.8
	Precipitation	105.1 241.6
Annual Cycle	Meridional Component	340
	Zonal Component	340
Atlantic Dipole	Atmospheric Pressure	680.0
El Niño – Southern Oscillation	Temperature	448.6 1030.7
	Specific Humidity	515.4 897.3
	Atmospheric Pressure	1030.7
	Zonal Component	1360.1
	Precipitation	637.5 1275.0

Table 1 – Atmospheric phenomena associated with the maximum wavelet energy, for the conventional station variables. In the first column, the atmospheric phenomena are associated with maxima variance; in the second column, the variables are specified; and in the third, the periods of the maximum variance are presented.

a period between 112 and 296 days was observed (Figure 2), which is related to an atmospheric blocking, since it occurs around July 1995, when the strong blocking studied by Nascimento and Ambrizzi (2002) happened. It contributed to an intense precipitation rate in Rio Grande at that time. In Figure 4a, the modulus of the precipitation wavelet coefficients for 1995 is presented. The blocking occurrence can be observed the Figure 4a, in the band between 64 and 148 days. The rise in the precipitation rate can be observed in Figures 4b and 4c.

The semi-annual cycle was verified in the atmospheric pressure, temperature, and specific humidity noted as a maximum of energy with a period of 170 days in Figure 2a and 2b.

The influence of the ENSO phenomenon in the south of Brazil might be related to periods with variation from 2 to 4 years detected in all variables. To verify the relation between these periods and ENSO, the wavelet transform was also applied to the Southern Oscillation index data from January 1982 to April 2003. The wavelet transform detected 5 periods in the Southern Oscillation index data that correspond to 2.61 and 8 months, and to 2.3, 3.5 and 5.3 years. Periods longer than one year detected in the atmospheric pressure, temperature, specific humidity, and precipitation may be observed in Figure 5. They are compatible to the ones found in the Southern Oscillation index series, specially the 3.5-year period detected in the precipitation. Other investigators, such as Krepper et al. (2003) have also detected this period in their study of Uruguay River flows associated with ENSO.

The 1.86-year period (680 days in Figure 2a) observed in the atmospheric pressure time series might be related to the South Atlantic dipole. This dipole is characterized by an interhemispheric gradient (north/south) in the Atlantic sea surface temperature, and it has periods close to the annual and biannual scales (Servain et al., 1998).

It should be noted that the largest wavelet variance in the global wavelet spectra was associated with oscillations related to high frequency systems as the air masses passage and fronts, for all the time series under study. Thus, we concluded that these systems account for most of the climate variability in the extreme south of Brazil, along with the modulation of the annual cycle.



Figure 4 - a) Wavelet coefficient modulus of the precipitation of the year 1995, b) monthly precipitation of the year of 1995 and c) occurred precipitation in the month of July from 1990 to 2002.

We calculated the annual average of the wavelet energy to verify the behavior of atmospheric phenomena associated with energy maxima along the seasons. The annual average of wavelet energy scalograms can be observed in Figure 6. The period of highest energy in the atmospheric pressure, temperature, and specific humidity occurred in the band from 5 to 12 days. In the zonal and meridional wind component, the band with more energy was from 1 to 5 days, and in the precipitation, it was from 11 to 20 days. The Figure 6f presents vertical axis different the other due to the precipitation series to be constituted by pentads. Thus it is necessary in the minimum two points (10 days) to have an oscillation. In winter, one energy maximum in the annual average of wavelet energy for the atmospheric pressure and the temperature time series was verified. It is associated with the passage of the cold air masses. In Figures 6a and 6c, a maximum around 64 days might indicate cold air outbreaks. For the precipitation time series, a maximum in winter can also be found, but it is less strong than other maxima mentioned.

In spring, the annual average of the wavelet energy was more intense in the atmospheric pressure, however, energy maxima were also present in other variables. For the meridional and zonal wind component, the energy maximum can be related to the southward movement of the South Atlantic



Figure 5 – Wavelet coefficient spectrum for the period that is longer than one year for variables measured in the conventional station. The cone of influence is represented by a solid black line, whereas periods, longer than one year, that were detected in the variables are represented by a dashed white line.

Anticyclone which promotes change in the wind of the region under study.

In summer, the strongest energy maximum appeared in the specific humidity and precipitation, and it can be associated with the convective activity. The energy maximum observed in the wind components occurs in the 1-day period, which might be related to the breeze. A signal varying from 20 to 65 days can be observed in the atmospheric pressure, specific humidity, and precipitation. It can be an indication of MJO.

In fall, there was an energy maximum evident in the specific humidity and precipitation, and a less intense one in the atmospheric pressure, temperature, and zonal component. In the precipitation, it can be associated with the atmospheric blocking, as this is the season with the highest occurrence of this phenomenon in South America (Renwick and Revell, 1999).

The wavelet variance was integrated by bands to estimate the influence of the atmospheric systems on the climate variability in Rio Grande. The integration bands correspond to the periods from 1 to 1.5 days, 4 to 15 days, 30 to 100 days, 100 to 250 days, 300 to 400 days, and 500 to 1500 days, except to the precipitation time series, whose first band is from 11 to 15 days. The contribution of the wavelet variance to each band in relation to the total wavelet variance may be observed in Figure 7. The annual cycle, band from 300 to 400 days, had



Figure 6 – Wavelet average energy spectra for atmospheric variables. In the Figure 6f the vertical axis starts in 11 days, since the precipitation series are formed by pentads.

stronger influence on the air temperature with 55.4% of the total wavelet variance. In the specific humidity, it was 51.1% of the total wavelet variance. In the atmospheric pressure, it was 30.5% of the total wavelet variance. In the zonal component, the influence of this cycle was 11.8%; in the precipitation, it was 2.6%; and in the meridional component, it was 1.3%.

Besides the annual cycle, the second most important component was the one associated with the systems of high frequency such as air masses and fronts, which correspond to the integration band of periods from 4 to 15 days. In the precipitation, its influence was 39.5%; in the meridional component, it was 28.3%; in the zonal component, it was 23.5%; in the atmospheric



pressure, it was 21.9%; in the specific humidity, it was 6.8%; and in the temperature, it was 4.0%.

The same methodology was employed in the deseasonalized series (Figure 8). The bands were generated as in the original series. We concluded that along with the annual cycle, the air masses and fronts are really responsible for the climate variability in the extreme south of Brazil. In the atmospheric pressure, these systems represent 41.3% of the wavelet variance total, while, in the specific humidity, they represent 31.7%, and in air temperature, 28.0%. The wavelet variance percentage was integrated to each band in relation to the wavelet variance total in Figure 8.



Figure 7 – Variance wavelet integrated by bands of the original variables measured in the conventional station. The legend in a) apply to all variables except figure f, where the first value is 11 days, since the precipitation series are formed by pentads.



Figure 8 – Variance wavelet integrated by bands of the deseasonalized variables measured in the conventional station. The legend in a) apply to all variables.

5. CONCLUSIONS

Data measured from January 1st, 1990 to March 19th, 2001, in the meteorological station located at 32°04'43"S and 52°10'03"W, were analyzed. The wavelet transform was chosen as a tool to determine the most significant times scales in the climate variability in Rio Grande. Periods associated with intense wavelet energy were selected and related to atmospheric phenomena which occur, with similar time scales, in the region under study,

The association of the results of the wavelet analysis to the typical time scale of the atmospheric systems which occur in the extreme south of Brazil indicate that the variations in the meteorological time series, in terms of energy, are largely determine by the annual solar cycle, along with the passages of air masses and frontal systems, and, to a less extent, the Madden-Julian Oscillation, blocking events, and ENSO phenomenon.

The air temperature, specific humidity, and atmospheric pressure time series presented intense wavelet variance associated with the annual cycle. When the annual cycle was subtracted from those time series, the most intense wavelet energy had periods related to the passage of air masses and frontal systems, as in the zonal and meridional wind components and in the precipitation wavelet variance. Therefore, through a wavelet variance analysis, we can infer that the annual cycle is responsible for most of the climatic variability in the extreme south of Brazil, along with the passage of air masses and frontal systems.

The annual average of wavelet energy of the time series for all variables was calculated with the purpose to analyze the seasonal behavior of atmospheric phenomena associated with energy maxima. We noted that the period of highest energy in the atmospheric pressure, temperature, and specific humidity occurred in the band from 5 to 12 days. In the zonal and meridional wind component, the band with more energy is from 1 to 5 days, and in the precipitation, it is from 11 to 20 days. The phenomena that have stronger relation to these maxima are the passage of air masses and frontal systems.

Further studies about the influence of the Atlantic dipole and MJO upon the climate variability in the south of Brazil will be conducted.

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