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A LOCAL PRECIPITATION DOWNSCALING APPROACH

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Abstract

In the context of climate change it is useful to downscale low-resolution large-scale features of models towards the high resolution small-scale features of environment and ecosystems which are modulated and driven by weather and climate. In this work, we address the problem of deriving local weather in terms of precipitation and the sensitivity to be well-described in different areas of Argentina, through a fairly simple transfer function.

The performance of the dynamical-statistical approach derived, that is based on a synthesis of significant anomaly circulation features linked to precipitation occurrence, is assessed by means of examining frequency distributions of results with two purposes: validate the diagnostic study, and give a representation of model uncertainty in geographic terms through examining the spatial variability as well as the interseasonal variability. From these results, western and southern areas are better predictable than the humid pampas and the Chaco region. Therefore, the latter may be considered as more vulnerable from the point of view of a downscaling approach or forecast. In seasonal terms, wintertime and summertime have a very similar level of predictability.

The downscaling transfer functions developed in this study may be also considered able enough to carry out future studies of precipitation vulnerability in view of potential scenarios coming from hypothetic climatic changes.

1. INTRODUCTION

As it is known, synoptic climatology investigates relationships between large-synoptic-scale atmospheric circulation conditions and local-scale surface environment (Barry and Perry 1973). The methods used in synoptic climatology usually employ one of two different approaches: the circulation-to-environment approach, which classifies and clusters circulation data in some way and afterwards looks for links with local-scale environment, and environment-to-circulation approaches, which structure circulation data based on a criterion defined by the local-surface variable (Yarnal 1993). When applying the circulation-to-environment techniques, the map-patterns are obtained independently of the variable to be connected. Then, predicted local variable conditions associated with each map pattern must be estimated subsequently. Model verification statistics between observed and expected values of the environmental conditions can be utilized to calculate the performance of the circulation-to-environment approach and to evaluate the goodness of the relationship. When using the environment-to-circulation approach, this predictive way cannot be employed, since the obtained map-patterns are conditioned by the variable of interest (Cannon et al 2002). By this reason, though circulation-to-environment and environment-to-circulation approaches are most commonly used, methods that jointly consider circulation and environmental variables have been developed. The study carried out in this work follows this line of investigation. Pioneer work by Klein (1965) examined specification models to search for relationships between synoptic-scale atmospheric flow and variables related to the surface environment. More recently, Hewitson and Crane (1996), von Storch et al. (1993), Ruiz (2002) and Ruiz and Vargas (1998) applied other forms of empirical downscaling with the same purpose. With specification or empirical downscaling techniques regression equations are used to relate gridded circulation data to values of an environmental variable (Klein 1985, von Storch et al 1993). Even though the selection of grid-points and parameters in the specification equations are not independent of the surface variable, i. e. it could be considered as an environment-to-circulation approach, the

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resulting downscaled equation can be used to predict values of the environmental variable only from values of the circulation ones; so, predictive properties are present in this method.

Models show difficulties in describing properly the variability at scales of high frequency precipitation. Moreover, precipitation exhibits large spatial variability as well as non-normality. Additionally, it exhibits large spatial variability as well as non-normality. In addition, the coarser the resolution, as in a general circulation model, the higher loss of accuracy. Statistical techniques developing a concurrent relationship between the upper-air circulation and the surface weather variables may help in diagnosis/forecast problems (Klein 1965). The objective of this work is to downscale results from a synoptic climatological study of precipitation in some regions of Argentina based on 500-hPa geopotential vorticity fields (Ruiz 2004, Ruiz and Vargas 1998) by applying empirical downscaling and statistical prediction techniques to vorticity pattern predictors exclusively, to obtain daily probabilities of occurrence of precipitation. It is of main interest in this work to focus on a sole variable that concentrates and captures the essential characteristics and physics of the circulation and, at the same time, involves direct implications on precipitation. Likewise, it is important to count on a variable with adequate reliability level when dealing with predictions in the southern hemisphere (Hoskins et al 1989). Another purpose of the downscaled variable climatology is to provide a minimum threshold of precipitation predictability for different regions of Argentina as well as background for the evaluation and skill of numerical model downscaling.

2. DATA AND METHODOLOGY

The data used consist of daily 500-hPa relative vorticity fields at 1200 UTC calculated through 500-hPa geopotential height fields (Ruiz and Vargas 1998) elaborated at the National Meteorological Service of Argentina for the study region described in Fig. 1. This dataset is compatible with the available precipitation dataset. Daily precipitation data at the following meteorological stations of Argentina are used: Buenos Aires (34º35'S, 58º29'W), Salta (24º51'S, 65º29'W), Resistencia (27º27'S, 59º03'W), Córdoba (31º24'S, 64º11'W), Paraná (31º47'S, 60º29'W), Santa Rosa (36º34'S, 64º16'W), Azul (36º45'S, 59º50'W), Neuquén (38º57'S, 68º08'W), Bahía Blanca (38º44'S, 62º10'W), Bariloche (41º09'S, 71º10'W) and Comodoro Rivadavia (45º47'S, 67º30'W). The precipitation is accumulated from 1200 UTC of day *i* to 1200 UTC of day *i+1*. The data cover the period 1983-1987.

The meteorological stations selected represent different regions of Argentina: Salta, the north-western region; Resistencia, the north-eastern subtropical region; Córdoba, the central region; Paraná, Litoral region; Santa Rosa, the semiarid pampas; Azul and Buenos Aires, the humid pampas; Bahía Blanca, the coastal humid pampas; Neuquén, the northern Patagonia; Bariloche, the mountain Patagonia and Com. Rivadavia, the coastal Patagonia.

In this study the information is separated into two samples: the austral cold semester, May to October (753 days), and the austral warm semester, November to April (603 days), to take into account the annual cycle. There are five winters and four summers in the whole data. The length of this sample satisfies the conditions proposed by Carter (1986), who shows that three seasons with six months of data each one are needed at least to be able to derive stable regression equations to evaluate precipitation probabilities.

The variable to probabilistically downscale is the occurrence of daily precipitation at a given location and it is considered categorical or non-numerical. The occurrence and non-occurrence of precipitation is defined as a binary variable. Its value is 1 if the measurable precipitation concurrent with the day of analysis is $\geq$0.1 mm and 0 otherwise. The empirical understanding of the physical and mathematical relationships between predictors and predictand may optimize the results. This knowledge has to be applied during the process of selection of predictors. For this reason, a synoptic climatology study of different tropospheric fields and their temporal-spatial patterns in relation with precipitation has been performed in previous works (Ruiz 2004, Ruiz et al 1999, Ruiz and Vargas 1998) where the analysis of some linkages between atmospheric circulation as model outputs and local/regional precipitation time series was presented. It is a purpose of the present study to estimate the capacity of the map-patterns obtained in Ruiz (2004) to distinguish occurrence of precipitation. These regional classifications are of fundamental, exclusive use in the original area of application. In a way, they characterize the region. 500-hPa fields and particularly the derived variable: relative geostrophic vorticity, as one of the parameters better linked to vertical motions and with better signal on precipitation as compared with other dynamical variables (Ruiz et al 1999), are used. It is emphasized that the focus is on vorticity in itself (though many other variables are available) as a baroclinic eddy measure and fundamental generator of precipitation processes. As in Wallace et al (1988) and Chang (1993), among others, vorticity anomaly patterns associated with precipitation as a sort of objective composites have been constructed from a regression analysis (Ruiz 2004, Ruiz 2002). The predictors are series of 500-hPa relative vorticity at grid-points, which have been examined in Ruiz (2004). The total number of predictors is reduced to only those containing significant predictive information. 500-hPa relative vorticity at three grid-points corresponding to the zones better correlated with rainfall, and at the same time independent between each other, are selected as predictors of precipitation at a specific location by using the biserial correlation model as a recursive partitioning approach of synoptic climatology. In this simple, but efficient way, enough synoptic information of mid-tropospheric dynamics is assured to be retained without obscuring results. These variables include information about the synoptic situation in the middle troposphere synthesised by three points, that are not necessarily close to the station of interest, as indicated in Ruiz and Vargas (1998). So, the map-pattern content is used rather than data over the station in itself. Because the application of regression techniques and the statistical downscaling approach can have a multiplicative effect on the total number of predictors or parameters required to be estimated, parsimonious selection is an especially important consideration (Katz and Parlange 1996). A subjective approach is commonly adopted to avoid physically non-significant predictors. The derivation of empirical downscaling transfer equations is based on two statistical techniques: a) Multiple Discriminant Analysis (MDA) (Miller 1962), and b) Regression Estimation of Event Probabilities (REEP) (Miller 1964). The downscaling model is based on optimized relationships between the predictor and the predictand fields. Klein (1985) shows that a regressive equation with only a few predictors selected on a subjective basis has better results than longer equations coming from objective selection.

The application of this technique is performed for the meteorological stations of Argentina during the austral warm and cold semesters. The transferred solutions obtained capture the baroclinic disturbance conditions independently for each location.

3. RESULTS

To evaluate the discriminatory power of the new transferred variables, say discriminant functions *Y* (Ruiz and Vargas 2005), with regard to the cases of occurrence and non-occurrence of precipitation, the biserial correlation coefficients (Panofsky and Brier 1965) between *Y* and precipitation and their respective t-Student statistics are calculated and displayed in Table 1 (the critical value of t-Student is 2.56 to the 99% confidence level). The biserial correlation between the optimized discriminant time series and the observed precipitation is a measure of the downscaling model skill. The error of the biserial correlation coefficients is 0.05 everywhere. The model skill for all the stations, i. e. biserial coefficients listed in Table 1, are statistically significant to the 99 % level.

Station	**winter**		**summer**	
	r_{bis}	t	r_{bis}	t
Buenos Aires	0.42	9.0	0.44	8.8
Salta	0.50	9.2	0.42	8.6
Resistencia	0.40	8.5	0.42	8.4
Córdoba	0.38	7.0	0.51	10.5
Paraná	0.45	9.4	0.48	9.5
Santa Rosa	0.47	9.4	0.42	8.2
Azul	0.42	8.8	0.41	7.8
Neuquén	0.44	8.6	0.60	10.4
Bahía Blanca	0.35	7.1	0.34	6.4

Bariloche	0.53	12.7	0.57	10.4
C. Rivadavia	0.37	7.4	0.39	6.5

Table 1. Biserial correlation coefficients between the discriminant function and the precipitation (r_{bis}) and t-Student statistic (t) for each station and semester.

In wintertime, the location that better discriminates the events of occurrence and non-occurrence of rainfall is Bariloche. This station, situated in the mid-latitude regime, is not greatly affected by the subsidence leeward produced by the Cordillera de los Andes. Its precipitation is highly associated with synoptic perturbations at 500-hPa, and hence the high performance of this downscaling approach. The seaside stations, such as Bahía Blanca and Comodoro Rivadavia on Atlantic Ocean coast, exhibit lower biserial correlations for the discriminant function *Y*. This is due to the fact that precipitation in these zones is somewhat affected by maritime circulation features. Córdoba also presents a low biserial correlation coefficient with respect to other stations. A reason for this behaviour may be some days with light precipitation connected to south-eastern circulation in the lower levels (the anticyclone at surface is centred to the south of Córdoba), which are not associated with a geopotential trough at 500-hPa, during the austral cold season over this region. On the other side, it is seen that, except for Salta and the coastal locations, the biserial correlation coefficient increases southwards indicating that the transient disturbances are more important and stronger with increasing latitude, and in consequence, they hold responsible of precipitation in a greater extent.

In austral summer, the biserial correlation coefficients increase in nearly all sites, meaning a better prediction skill of the discriminant function *Y*. In this time of the year the water vapour required for the production of precipitation is climatologically present, and it is only necessary an ascent mechanism provided by the cyclonic vorticity advection in the middle troposphere.

3. 1 Relative frequency distribution of the Y functions for the cases of occurrence and non-occurrence of precipitation.

The respective relative frequency distributions are compared to visualize the degree of separation of the discriminant function evaluated for the precipitation and non-precipitation groups, Y_{yes} and Y_{no}, respectively. The strength of the environment-to-circulation relationship is so estimated. The means, $\overline{Y_{yes}}$ and $\overline{Y_{no}}$, and the respective standard deviations for both groups, for each location and time of the year are shown in Table 2. All the means are statistically different between categories, as pointed out above (see Table 1). As the biserial correlation coefficient is a measure of how far apart the means of both groups are, $\overline{Y_{yes}}$ and $\overline{Y_{no}}$ are more separated at the locations where the coefficient becomes greater in summer than in winter. Standard deviations of *Y* increase in summer, especially at Neuquén and Bariloche.

Station	**winter**			
	yes pp		*no pp*	
	Y	s	Y	s
Buenos Aires	3.7	8.8	-3.6	10.2
Salta	6.4	11.8	-6.4	13.2
Resistencia	3.3	8.7	-3.3	9.6
Córdoba	3.4	10.6	-3.4	9.4
Paraná	4.6	10.1	-4.6	11.3
Santa Rosa	5.2	11.1	-5.2	11.9
Azul	3.8	9.2	-3.8	10.3

Station	winter			
Neuquén	4.5	11.5	-4.5	10.8
Bahía Blanca	2.5	8.0	-2.5	8.2
Bariloche	5.9	11.6	-6.0	13.2
C. Rivadavia	3.0	9.2	-3.0	9.0

Station	summer			
	yes pp		*no pp*	
	Y	s	Y	s
Buenos Aires	4.3	12.4	-4.7	11.5
Salta	4.1	10.5	-4.1	12.7
Resistencia	4.2	11.0	-4.2	12.3
Córdoba	6.6	15.4	-6.6	14.5
Paraná	6.1	13.4	-6.1	14.5
Santa Rosa	4.7	11.7	-4.7	12.8
Azul	4.3	12.5	-4.3	11.7
Neuquén	12.1	21.1	-12.1	19.8
Bahía Blanca	2.9	10.3	-2.9	9.7
Bariloche	10.1	19.0	-10.1	18.1
C. Rivadavia	4.6	11.4	-4.5	12.5

Table 2. Means and standard deviations of the discriminant function *Y* (10^{-4}) for the groups of *yes* precipitation and *no* precipitation, for each station and semester.

Relative frequency distributions of *Y* for each station and time of the year, a) austral cold semester and b) austral warm semester, are displayed in Fig. 1. For all locations studied, and particularly in winter, the frequency distributions of Y_{yes} and Y_{no} are Gaussian and significantly different, as expected since *Y* is precisely the linear combination discriminating both groups the best. The more conspicuous examples are given by Santa Rosa (Fig. 1. 6a) and Bariloche (Fig. 1. 10a) in winter. Thus, the model proposed demonstrates a satisfactory ability to derive local precipitation probabilities as a function of synoptic forcing. Excepting for Salta, all distributions are platykurtic (kurtosis <3 yielding flatter histograms) in the warm semester. This characteristic is outstanding at Neuquén (Fig. 1. 8b) and Bariloche (Fig. 1. 10b), to the point that the scale used is not strictly the appropriate as the extremes are an addition of frequencies corresponding to exterior intervals. The discriminant function reaches more extreme values, which brings to a better definition of the forecasts (probabilities are closer to either 0% or 100%) during the warm season. The underlying physical reason may be related to the wavelength of the synoptic disturbances and their relative intensity. Not only typical, mid-latitude stations evidence a good separation between *Y* distributions, ascribed directly to the dynamical predictor chosen, but also stations such as Resistencia (Fig. 1. 3) belonging to subtropical rainfall regime show a significant discrimination in winter as well as in summer, particularly. However, during the austral cold semester (Fig. 1. 3a) relative frequencies are high in the central interval (precipitation probability is about 50 %), a fact not helping to define the local environmental variable in forecast terms. In summer (Fig. 1. 3b), the latter does not happen. Upper atmospheric perturbations fairly influence in the production of rainfall even in the subtropical region of north-eastern Argentina. The discriminant function at Paraná exhibits the more acceptable predictive condition all around the year (Fig. 1. 5a and b), after Bariloche (Fig. 1. 10). Also Santa Rosa (Fig. 1. 6) shows a very good separation between distributions which tends to predict probabilities of precipitation above or below 50 % in a clear way. Forecasts may become fairly good during the austral warm semester in the central region of Argentina, as is observed for Córdoba (Fig. 1. 4b). In the province of Buenos Aires the better results appear at Buenos Aires (Fig. 1. 1), followed by Azul (Fig. 1. 7), and finally Bahía Blanca (Fig. 1. 9). $\overline{Y_{yes}}$ and $\overline{Y_{no}}$ separation is rather poor at the coastal maritime stations Com. Rivadavia (Fig. 1. 11) and Bahía Blanca (Fig. 1. 9). The distributions at Salta (Fig. 1. 2) are more separated in winter than in summer. Indeed, a particular 500-hPa circulation pattern is needed to favour the occurrence of precipitation in this region during the austral cold season (see the configuration of the vorticity anomaly pattern for Salta, Fig. 2 in Ruiz, 2004), while in summer a great deal of the precipitation component is due to upward motion forced by orography (though some influence of 500-hPa may not be neglected).

After an overall inspection of Fig. 1, it is clearly noted that there are regions better disposed to good precipitation diagnosis/forecasts, such as western Argentina region leeside of the Andes mountains and, particularly, the western Patagonia sector. Thereby, better downscaling results might be expected there. Furthermore, there are also seasons inclined to be more predictable, which is the case of summertime for some stations. On the other hand, there appear regions more vulnerable to be properly described in terms of precipitation predictability in eastern Argentina, mainly humid pampas and the Chaco region.

4. CONCLUSIONS

Synoptic-scale circulation conditions are related to local precipitation in a downscaling way using previous synoptic-climatological studies for the region and the performance of the output variables are assessed by means of examining probability distributions of results, among others. It is worth noting that each one of the regional synoptic map-pattern classifications investigated and developed in Ruiz (2004) and in Ruiz and Vargas (1998) are appropriate or of exclusive use for the corresponding surface station, then there exist separate classification systems for each variable of interest, and thereby, different responses at each station. The output variables and their distributions may be considered as indexes of the classification system in the sense of how well this system reflects synoptic-scale controls on local surface weather. Most of the synoptically relevant information for the specific predictand is synthesized in view of longer range predictions. This objective procedure relating upper-air circulation and local surface weather conditions yields a degree of probability of the event to happen, supporting the notion of uncertainty. The performance of the downscaling-regression system depends not only on the quality of the dataset used, but also on the applied methodology and selection of parameters containing valuable information about the phenomenon to downscale or predict, and ultimately on the observations themselves. Anyway, analyses provided by the National Meteorological Service of Argentina are a good measure of the real atmospheric circulation, or at least the most realistic ones available for the region.

Precipitation probability performance on timescales of a day is done for both validating the diagnostic study and giving a representation of model uncertainty in geographic terms through examining the spatial variability as also through the interseasonal variability. Western and southern areas are better predictable than the humid pampas and the Chaco region, thus the latter may be considered as more vulnerable from a downscaling forecast point of view whatever the prediction range. In seasonal terms, wintertime and summertime have a very similar level of predictability. Precipitation probability performance gives better evidence of the model response and capability. Then, it may be recognized as an integration of a fairly realistic model. Moreover, results from this study might constitute a help and guidance for a feedback of more accurate higher resolution forecast models, which could also be a major beneficiary. Verification statistics show that probability of precipitation products obtained display an acceptable skill in the region and may be also used in conjunction with direct regional model outputs, which do not seem to be adequate enough to represent convection and high frequency variability of precipitation at present.

In what regions a downscaling experiment coming from a general circulation model could be relatively more successful in terms of rainfall? It is also interesting to note to what extent a GCM downscaling experiment could yield relatively more successful results in terms of precipitation over different regions of the country and time of the year. By comparison of frequency distributions of the transfer discriminant function for occurrence and non-occurrence of precipitation, it is clearly seen that the more separated, the more probable the downscaling model could be satisfactory in precipitation diagnosis/forecast terms. It is observed that a downscaling model skill for precipitation in Argentina is strongly dependent on the region, though not so much on the season. The downscaling transfer functions developed in this study may be also considered able enough to carry out future studies of precipitation vulnerability in view of potential scenarios coming from hypothetic climatic changes, especially in a region sensitive to climate change impacts as Argentina.

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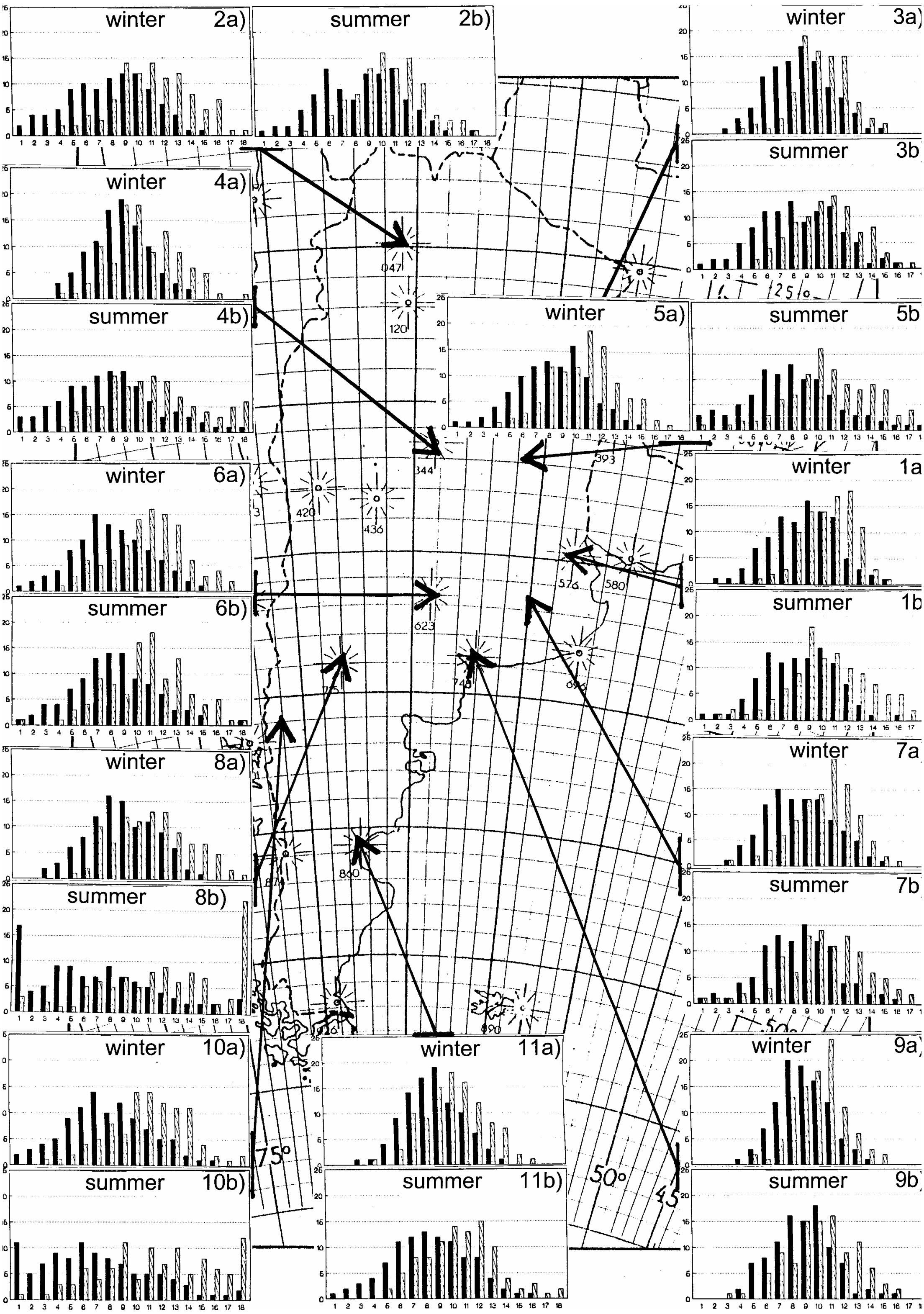

Fig. 1. Relative frequency (%) distributions of the discriminant function *Y* for the groups of *yes* precipitation (⧅) and *no* precipitation (█) for the stations: 1) Buenos Aires (34°35'S, 58°29'W), 2) Salta (24°51'S, 65°29'W), 3) Resistencia (27°27'S, 59°03'W), 4) Córdoba (31°24'S, 64°11'W), 5) Paraná (31°47'S, 60°29'W), 6) Santa Rosa (36°34'S, 64°16'W), 7) Azul (36°45'S, 59°50'W), 8) Neuquén (38°57'S, 68°08'W), 9) Bahía Blanca (38°44'S, 62°10'W), 10) Bariloche (41°09'S, 71°10'W) and 11) Com. Rivadavia (45°47'S, 67°30'W), during a) the austral cold semester and b) the austral warm semester. Rank of *Y*: $-3.4*10^{-3}$ to $3.4*10^{-3}$. Intervals of $0.4*10^{-3}$