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# CLIMATIC VARIABILITY AND TENDENCIES IN CENTRAL CHILE IN THE 1950-2010 PERIOD BY DETERMINATION OF THE JENKINSON Y COLLISON SYNOPTIC TYPES

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## I. INTRODUCTION

Synoptic climatology has become an effective tool for classifying different weather types, as it enables us to attribute to these weather types determined meteorological and climatic characteristics. Synoptic classification methods can be used to establish how the different types of atmospheric circulation are statistically and temporally distributed. Lamb developed a subjective classification that uses 27 types (Lamb Weather Types), adapted in an objective and automatic manner by El-Dessouky and Jenkinson (1975) for Egypt, using 9 points of atmospheric sea level pressure, and subsequently applied by Jenkinson and Collison (1977) for the British Isles, using a total of 16 points, the names of the latter authors ultimately being given to this classification. The Jenkinson and Collison (J&C) method is one of the objective classifications most commonly used due to its simplicity and effectiveness for generating climatic series of weather types.

Numerous studies have made use of the J&C method. On the Iberian Peninsula it was applied by Spellman (2000), Trigo and DaCamara (2000), Martín-Vide (2002), etc. The case of the Iberian Peninsula is of particular interest to our study as it has the Mediterranean-type climates and based upon this, it is possible to compare the tendencies of the atmospheric circulation types in both cases. In Chile, there are two applications of the J&C method: one by Frias (2008) and Frias *et al.* (2009), making use of two grids (one centred at 35ºS and another at 55ºS) of 16 points each, and based upon the data on atmospheric pressure from the ECWMF ERA-40 Reanalysis project, and the second one, applied by Sarricolea *et al.* (2011)

for central Chile and making use of 9 points and the data from the NCEP/NCAR Reanalysis project, for the 1950-2010 period. A significant result is that no type undetermined is presented, this being due to the circulation and geographic conditions governing central Chile, which are different from those in the western Mediterranean, where there is a predominance of type undetermined, caused by barometric swamp situations (27.2%, particularly in summer) and followed by anti-cyclonic situations (20.7% of the days).

The atmospheric circulation accounting for the climatic characteristics of central Chile is controlled by the Southeast Pacific Subtropical Anticyclone (SEPAC) and the sub-polar low-pressure belt, which together affect the zones falling between 30ºS and 55ºS, thus the second one favouring the development of the frontal systems causing most of the rainfall in this area. It is interesting to note how the patterns of atmospheric circulation are modulated by different teleconnection patterns such as El Niño Southern Oscillation (ENSO), by means of the Southern Oscillation Indices (SOI), the El Niño Multivariate Index (MEI); the Pacific Decadal Oscillation (PDO), related to the ENSO (Zhang *et al.,* 1997), and the Antarctic Oscillation (AAO). In this respect, Quintana and Aceituno (2006) point out that there is clear interdecadal variability in central Chile's precipitation regime, which appears to be related to changes in the PDO and the SOI. Thus, tendencies towards less precipitation coincide with significant intensification of the SEPAC, a positive SOI and a cold phase of the PDO. On the contrary, a weakening of the anticyclone causes an increase in precipitation, a negative phase of the SOI (El Niño events) and a warm phase of the PDO (Quintana and Aceituno, 2012). Consequently, decadal behaviour of the J&C types is to be expected.

## II. METHODOLOGY

The J&C synoptic classification is an automatic method that reveals the type of atmospheric circulation based upon atmospheric pressure reduced to sea level of a minimum of 9 points, whose values were obtained from the NCEP/NCAR Reanalysis project, at daily resolution and from 1950 to 2010.

The J&C classification consists of 27 synoptic types: 8 pure advective ones (N, NE, E, SE, S, SW, W and NW), 1 cyclonic (C), 1 anti-cyclonic (A), 8 advective-cyclonic hybrids (CN, CNE, CE, CSE, CS, CSW, CW and CNW), 8 advective-anti-cyclonic hybrids (AN, ANE, AE, ASE, AS, ASW, AW and ANW) and 1 undetermined one (U). The variables to be calculated for applying the J&C method are mean sea level pressure (P), the zonal component of geostrophic wind (W) (in our case between 30º and 40ºS), the meridian component of geostrophic wind (S) (in our case between 85º and 65ºW), wind direction (D), wind speed in m/s (F), the zonal component of vorticity ($Z_W$), the meridian component of vorticity ($Z_S$) and total vorticity (Z), and the following rules are applied:

1) The direction of the flow is given by D (8 wind directions, taking into account the sign of W and S)
2) If $|Z| < F$, pure advective type, defined according to rule 1
3) If $|Z| > 2F$, cyclonic type if $Z>0$, or anti-cyclonic if $Z<0$
4) If $F < |Z| < 2F$, hybrid type, according to the sign of Z (rule 3) and the flow direction obtained from rule 1
5) If $F<6$ o $|Z| <6$, an undetermined type exists (U)

We obtained 26 types (no undetermined type U), which have also been arranged into three different grouping sets:

- 10 groups: A, C and the 8 wind directions (with the advective and hybrid types), for example, the direction [N] corresponds to the N directional N plus hybrids AN and CN. And [W] groups together the W directional W plus hybrids AW and CW.
- 5 groups: A, C, ADVA (AN, ANE, AE, ASE, AS, ASW, AW and ANW), ADVC (CN, CNE, CE, CSE, CS, CSW, CW, CNW) and ADV (N, NE, E, SE, S, SW, W and NW).
- 3 groups: ANT (A, AN, ANE, AE, ASE, AS, ASW, AW and ANW), CYC (C, CN, CNE, CE, CSE, CS, CSW, CW, CNW) and ADV (N, NE, E, SE, S, SW, W and NW).

We performed an analysis of the synoptic types for different periods and temporal resolutions: annual for the whole series (1950-2010), annual in two sub-periods (1950-1980 and 1981-2010), monthly and seasonally. We evaluated the tendencies with AnClim (Štěpánek, 2003) software, estimating changes in the J&C synoptic types in the different periods and grouping sets. We calculated the tendencies for the whole period (61 years), applying the normality and statistical significance tests. We compared the 1950-1980 and 1981-2010 sub-periods to estimate whether the changes in synoptic types were statistically significant (Z-comparison test of binomial proportions at a confidence level of 95%).

We evaluated whether relationships existed between the J&C synoptic types and the teleconnections affecting central Chile: ENSO (SOI and MEI indices), the PDO and the AAO, correlating them with the J&C types. Furthermore, we used the wind flow obtained by means of J&C to calculate the Western Index (WI), for which we grouped the wind directions into four categories: N, E (NE, E and SE), S and W (SW, W and NW), using the proportion of W for each month and year, with values ranging from 0 to 1. For central Chile the WI was normalised at the monthly level in order to establish its interannual variability because, in general terms, the winter months provide higher values than the rest of the year.

## III. RESULTS

### 1. Annual frequencies of the Jenkinson & Collison synoptic types and tendencies thereof

A predominance of ANT-group circulations can be observed, accounted for by the clear persistence of the SEPAC, with 54% of the days falling within the 1950-2010 period, followed by the ADV group, with 31%, and the CYC, with 15%. There are clear downward trends of the ANT group and an increase in the CYC and ADV groups, so changes in the atmospheric circulation in central Chile. According to different statistical significance tests (t-Student, Spearman and Mann Kendall), after verifying the normality (Kolmogorov-Smirnov), the ANT-group days show a decrease of around 10 days per decade, the CYC-group days have increased by over three days per decade and the advective ones show an increase of almost 6 days per decade.

Considering the 5 groups A, C, ADVA, ADVC and ADV, it can be seen the predominance of A (32.6%) for the whole series, over ADV (30.9%); but it is the contrary for the subperiod from 1981to2010, ADV (33.2%) and A (28.6%). On reducing the J&C types to 10 categories, A, C and the 8 wind directions (with the advective and hybrid types), the directional ones exhibit an increase in dominance, with 59%, the [S] (23%) and[SE] (16%) mainly standing

out. The frequency of A type is 32.6% in central Chile for the whole period. The A days have become less significant in the last 30 years, from 36.4% (1950-1980) to 28.6% (1981-2010). Group [S] has increased by 4.7%, from 20.4% to 25.1%. With all the days classified into the 26 J&C types, the most frequent ones are A, with 7,252 days (32.6%), S, with 2,546 (11.4%), SE, with 2,274 (10.2%) and AS, with 2,272 (10.2%). These are followed by type C (8.1%), ASW (3.7%), ASE (3.4%), CSE (2.9%) and SW (2.4%). The sum of these 9 synoptic types is 85% of all the days in the 1950-2010 period. And the 96% of the days is covered by 16 synoptic types.

The anti-cyclonic, cyclonic and advective circulations with north, northeast and east winds, and the west and northwest cyclonic situations have a very low frequency. On revising the less frequent types, we found that there are 14 which in some years were not presented, four of them being anti-cyclonic hybrids (ANE, AE, AW, AN), two advective (E and N) and seven cyclonic hybrids (CNE, CE, CS, CSW, CW, CNW, CN). The minimum annual variation coefficient is 20% for AS type, the maximum coefficients corresponding to the ANE and AE types, with189% and 110%, respectively. Moreover, the highest values of the temporal irregularity index coincide with those presenting a variation coefficient of between 44% and 68%.

As for the tendency of the J&C types, there is a notable decrease in type A, with a loss every decade of 10.5 days (64.8 days in the whole period), accompanied by an increase in the S (4.3 days/decade), C (2,2 days/decade) and ASW (1,5 days/decade).

## 2. Monthly frequencies and seasonal tendencies of the Jenkinson & Collison types

Anti-cyclonic conditions are more frequent from May to November (over 30% of the days have the A type), with a minimum in February, related to thermal lows, coinciding with the summer month presenting most cyclonic situations. The southerly and south-easterly circulations, bringing good weather, are frequent from October to April, whereas bad-weather circulations (south-westerly, westerly and north-westerly) are characteristic of the May-September period. The AS, SE and S types show a clear seasonal behaviour, with maxima in the warm half part of the year and minima in the cold one, whereas the C type has its maxima frequencies from May to September.

Reducing the J&C types to ADV, ADVA and ADVC, the first two are the most frequent circulation types in summertime, whereas the ADVC exhibits two well-differentiated maxima in the year, one between March and April and the other in the month of July. The months presenting the least amount of ADVC days are January and November, which is partly similar to what was described by Romero (1985), when he indicated that in November there is a relative decrease in cyclonic circulations, in this case of a cyclonic-advective nature.

The above mentioned also has an effect upon the regime of winds classified according to seasons. Indeed, the southerly and south-easterly winds are the most frequent ones in summer, with a similar situation in autumn and spring, but moreover with winds from SW. Winter is different, because the westerly component is the most important one in central Chile.

Continuing the analysis of seasonal trends, and comparing the two subperiods, type A shows a decrease in all seasons of the year ($p\text{-value}<0.01$). ASE days also exhibit a decrease (summer, autumn and spring). However, the types showing an increase are the AS days (sum-

mer) and ASW days (summer, autumn and spring). The cyclonic days (C) show a significant increase only in autumn, and the south-easterly cyclonic days (CSE) present a decrease in spring. Finally, the south advective type (S) has increased in the last 30 years (except in winter), and the south-west type (SW) does likewise in autumn and spring, whereas the south-east advective type (SE) decreases in summer and autumn.

Furthermore, we observed the anomalies of the Western Index (WI). This index exhibits a winter regime, with maxima from May to August, summer being with the lowest number of days with this circulation. Application of spectral analysis shows that the frequency of the WI is 0.083, which confirms a maximum every 12 months. A second maximum in the potency spectrum is observed at a frequency of 0.166 (6 months), which provides evidence of the WI winter regime. The WI anomalies, however, present evident index phases which reveal, for instance, that from 1950 to 1958 the tendency was towards a positive phase, whereas in the 1959-1980 period, the anomaly was negative. Performing a spectral analysis, we detected that these anomalies possess a cycle of 146.4 months, corresponding to 12.2 years. There is therefore a need to establish whether this is correlated with low-frequency variability patterns, whether with the El Niño Southern Oscillation, with the Pacific Decadal Oscillation or with the solar cycles.

### 3. Relationship between the J&C types and the SOI, MEI and PDO teleconnections

We correlated the 9 most typical Jenkinson and Collison types with the teleconnections influencing central Chile, that is, the Antarctic Oscillation, the El Niño Southern Oscillation (ENSO, measured with the SOI and MEI indices) and the Pacific Decadal Oscillation.

The results indicate that, for type A of the J&C classification, there is a significant (p-value<0.000) and inverse relationship with the Antarctic Oscillation, which suggests that during a negative phase of the AAO, central Chile presents more anti-cyclonic days. The statistic $R^2$ indicates that the adjusted regression model accounts for 36.48% of type A's variability (correlation coefficient is equal to -0.60). The standard deviation of the residuals is 22.32 days/year. The remaining indices (SOI, MEI and PDO) do not present statistically significant relationships with anti-cyclonic days.

The hybrid southerly anti-cyclonic days (AS) are not significantly related to any of the teleconnection patterns, but the south-easterly anti-cyclonic (ASE, inverse relationship) and south-westerly anti-cyclonic (ASW, direct relationship) types are statistically related to the Antarctic Oscillation.

The cyclonic type is also significantly correlated with the AAO, with a p-value of 0.009, and there is a direct relationship between the development of cyclonic activity in central Chile and the positive phase of the AAO, which is noteworthy because in this phase the polar front retreats, which implies that cyclonic activity in central Chile has probably another origin during the positive phase of the AAO. The $R^2$ indicates that the model accounts for 11.01% of variability of cyclonic days (correlation coefficient of 0.33).

The S and SW advective types are correlated with the AAO, both with a positive sign and an $R^2$of 21.67% and 6.41%, respectively. Type S, besides, is positively correlated with the SOI. This might indicate that in positive phases of the SOI (La Niña), there is a higher frequency of advective circulations from the South, traditionally associated with "good weather".

## IV. CONCLUSIONS

There is a predominance in the complete series of 61 years (1950-2010) of anti-cyclonic days, with a higher frequency thereof in the winter months, when the SEPAC is in a more centred position in relation to the grid used in the analysis, and greater negative vorticity is induced in the synoptic types occurring on a daily basis. Days with anti-cyclonic vorticity reach a percentage of 54% in relation to the total, which is due to the persistence of the SEPAC at these latitudes. The tendencies analysis, however, shows a decrease in the A type in all seasons, whereas the ADVA days exhibit a significant increase.

The AS type is more frequent in the austral summer and do not present a significant relationship with any of the teleconnections studied. Types ASE and ASW, however, present a significant relationship with the AAO, in an inverse and direct manner, respectively.

Type C is more frequent from March to September as a result of the advance of the subpolar low-pressure belt at the expense of the SEPAC, which had a blocking effect during the summer. This type is directly related with the AAO, coinciding with its positive phase when the polar front retreats. The southerly and south-easterly circulations are more frequent in summer, from October to April, whereas the circulation presenting a westerly component occurs more from May to September. Of these, the S type presents a direct and significant relationship both with the AAO and with the SOI, as occurs between the south-westerly advective type and the AAO.

Considering the WI for central Chile, that possess a cycle of 12.2 years, the days with a westerly component are more frequent from May to August.

It should be pointed out that no case has been recorded as undetermined (U), this being due to the inexistence of situations presenting a weak atmospheric pressure gradient.