Interannual oscillations and trend of snow occurrence in the Andes region since 1885

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Using documentary sources, a series of the annual number of snow days in the Mendoza area of Argentina has been constructed. Analysis of the series using Singular Spectrum Analysis (SSA) and the Maximum Entropy Method (MEM) showed that the number of snow days exhibits interdecadal and interannual oscillations with periods of about 28 and five years. Furthermore a positive trend was detected. This temporal pattern is consistent with studies of the variability of global surface temperature, indicating a strong relationship between temperature and snow occurrence in the climate system and the potential for using snow occurrence as an indicator of climate change.

Introduction

The global average temperature has risen between 0.3º and 0.6º since the last half of the nineteenth century (IPCC 1996). Whether this temperature increase is related to greenhouse gas emissions or is due to a manifestation of natural climate variability is a continuing concern of governments and the scientific community. The global surface temperature displays variability on a number of time-scales during this period, together with a secular trend since 1930. Using a single method of analysing this variability, such as Singular Spectrum Analysis (SSA) (Broomhead and King 1986; Vautard and Ghil 1989), and a single set of data, such as time series of annually averaged temperatures from 1854 to 1988 produced by the Climatic Research Unit of the University of East Anglia (Jones et al. 1986), three main time-scales of oscillations have been found. Ghil and Vautard (1991) identified interannual oscillations with periods of five to six years, probably related to the ENSO phenomenon and interdecadal oscillations with periods of 21 and 16 years, probably related to changes in the circulation of the extratropical ocean. Schlesinger and Ramankutty (1994) identified an oscillation of period 65-70 years using the same series, but with the trend removed. This last finding does not have general consensus, however, and Yiou et al. (1996) consider that the oscillation could be an artefact generated by the general trend in the dataset.

Other climatic variables are sensitive to temperature changes and can be used to increase our confidence in this variability. Snow occurrence is one such indicator. Recent studies (Diaz and Graham 1996) have observed changes in freezing-level height (the altitude of the 0ºC isotherm), which suggests a related variation in the snow occurrence. The intuitive relationship between snow occurrence and temperature is one of decreased snow-days during times of increasing warmth, but this intuitive relationship may not be valid. Warmer air may actually lead to an increase in the number of snow days due to the higher saturation vapour pressure of the air and hence a greater supply of moisture for snow events (Leathers et al. 1993). Also, the increase in annual precipitation

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over the past few decades noted by Diaz et al. (1989) and Karl and Knight (1998) may be associated with an increase in snowfall. So, a priori, the evolution of snow occurrence is uncertain.

In this study we analyse the annual number of snow days in the central Andes region (33°S), a region influenced by ENSO and for which an historical series of snow days beginning in 1887 is available.

Data

Instrumental data of snow occurrence in the study area (Fig. 1) are sparse and discontinuous. The first meteorological stations were installed at Cristo Redentor and Puente del Inca in 1942 and removed in 1977. Furthermore, the 1942-1960 data are incomplete, and the only continuous instrumental record is the series of monthly snow occurrence at Puente del Inca from 1961 to 1976.

In order to extend this poor series, information from *Los Andes* newspaper was used. This newspaper has been issued regularly at Mendoza since 1885 and contains daily information about the snow occurrence in the study area, especially in the main four towns in the area: Las Cuevas, Puente del Inca, Punta de Vacas and Polvaredas (Fig. 1).

We are confident of the quality and continuity of the information summarised in the newspaper because of the tremendous importance that the occurrence of snow has on the economy of the area. Since the time of European conquest until the present, the main road connecting Santiago de Chile with Buenos Aires has crossed this area. The occurrence of snow can close the road and this is one of the most important pieces of information published in the newspaper. Thus, the newspaper has always used the best available source of information throughout the period and it is very unlikely that the completeness of the record has varied due to changes in editorial policy.

A total of 14,600 issues of the newspaper was used to build a series of snow occurrence (annual number of snow-days) between 1885 and 1996 (Fig. 2). During this period 36 expressions were used in the newspaper to describe the occurrence of snow. We have used these expressions to classify snowfall into three categories: intermittent, moderate and heavy. The expressions and the category each corresponds to are shown in Table 1. A snow day is defined as a day (from 00:00 to 24:00 local time) when the newspaper reported the occurrence of snow, using any of the 36 expressions, in any of the main referenced towns.

To calibrate the historical series, the instrumental series from 1961 to 1976 in Puente del Inca was used. Figure 3 displays both series for the calibration period, showing good agreement between the two. The Spearman correlation coefficient between the two sets of data was 0.838, significant at the one per cent level.

Fig. 1 Map of the Mendoza area and the main towns in the region.

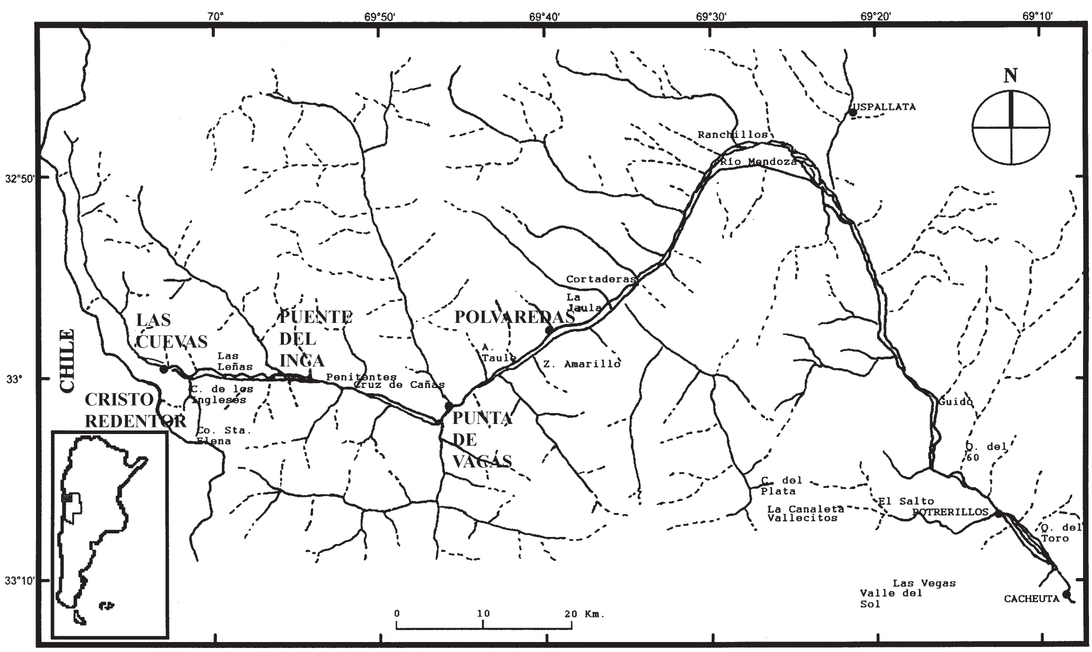
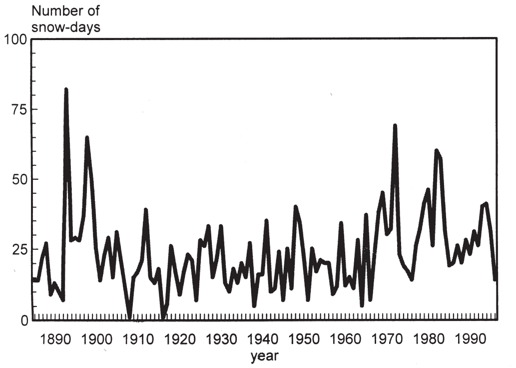


Fig. 2 The annual number of snow-days in the Mendoza area from 1885 to 1996



Both the instrumental and the historical series show a jump around 1967, suggesting that it has not been produced by any change in the reporting procedure, the ownership or the staff of the newspaper, changes in the sources of information or any other non-meteorological factor.

Method

To analyse the time series of annual snow days, we have combined two methods: Singular Spectrum Analysis and the Maximum Entropy Method.

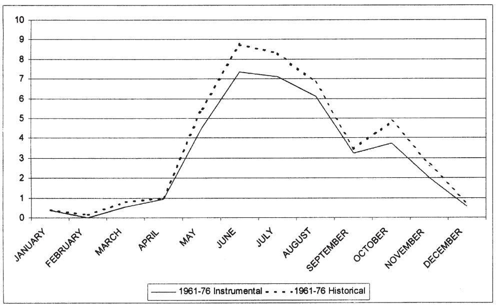
Singular Spectrum Analysis (SSA) is designed to extract as much information as possible from short, noisy time series without requiring prior knowledge of the dynamics underlying the series (Broomhead and King 1986; Vautard and Ghil 1989). The method is a form of principal component (PC) analysis applied to lag-correlation structures of time series. SSA is particularly successful in isolating periodic components and trends. It decomposes time series into oscillatory, trending and noise components and provides reconstructed components (RCs).

To analyse the periods of the reconstructed components a method of spectral analysis must be used. In this study the Maximum Entropy Method (MEM) is employed (Burg 1967). MEM differs from other spectral methods by its representation of noisy oscillatory signals as autoregressive processes, rather than as a sum of sinusoids. It has the advantage of being very efficient for detecting frequency lines of stationary time series. Its disadvantage is that, when there are a high number of autoregressive terms, it often includes spurious peaks. Since we analyse RCs, which have low noise, however, this is not a big problem. A comprehensive description of both methods (i.e. SSA and MEM) can be found in the review by Yiou et al. (1996).

Table 1. Categorisation of snowfall in the Mendoza region of Argentina based on 36 expressions used in daily snow reports in the Los Andes newspaper for the period 1885 to 1996.

Snow categories		
Intermittent	*Moderate*	*Heavy*
-nevando a intervalos	-de poca intensidad	-enorme
-con intermitencias	-escarchilla	-fuerte borrasca
	-está nevando	-gran cantidad
	-fina nevada	-gran nevada
	-nevada	-gran nevazón
	-nevadas ligeras	-gran temporal
	-nevando en poca cantidad	-mal tiempo (invierno)
	-nieva o nevó	-mucha nieve
	-nieve fina	-nevadas
	-pequeña nevada	-nevadas persistentes
	-pequeño temporal	-nevazón
	-poco importante	-nevó bastante
	-temporal de agua y nieve	-nieva copiosamente
		-nieva grueso
		-nieve fuerte
		-regular espesor
		-regular nevada
		-serio temporal
		-temporal de nieve
		-temporal general
		-violentos temporales

Fig. 3 Comparison between the instrumental (at Puenta del Inca) and historical series of average numbers of snow days between 1961 and 1976.



Results

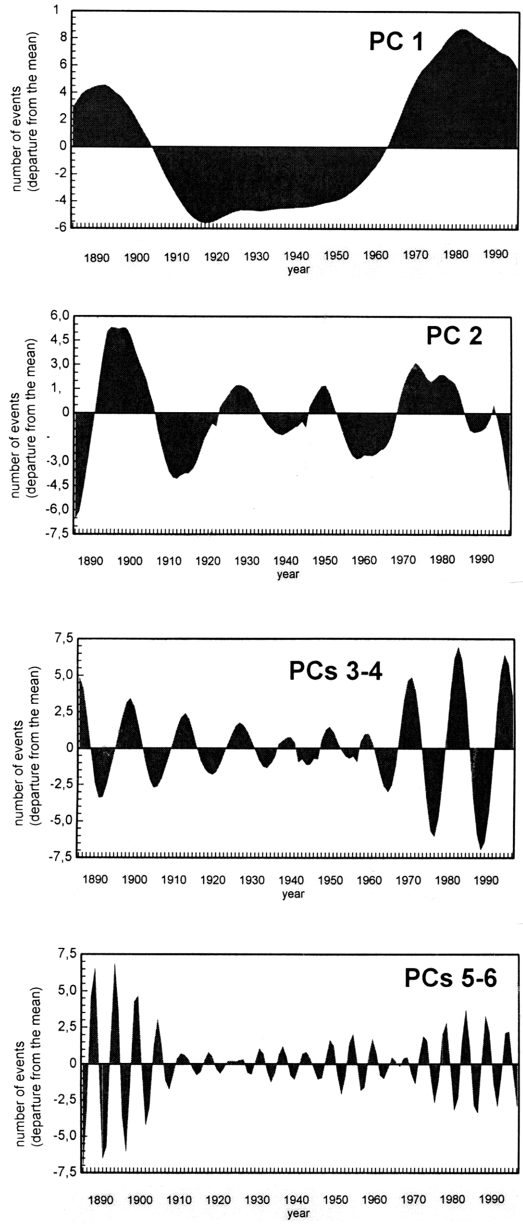
The series of annual snow-days is given in Fig. 2. SSA has been used to investigate the oscillatory component. SSA considers a number of lagged copies of a central time series sampled at equal intervals and calculates the eigenvalues and eigenvectors of their covariance matrix. By analogy with nomenclature from other climatic analysis, the eigenvectors are usually called empirical orthogonal functions (EOFs) and the coefficients involved in the expansion of each lagged copy of the temporal series, principal components (PC). It is important to notice that an oscillatory phenomenon could be sometimes represented by one eigenvalue but sometimes by pairs of eigenvalues (Vautard and Ghil 1989). In the latter case both EOFs and PCs are in quadrature with each other.

The first six eigenvalues account for 75.53 per cent of the total variance. The first eigenvalue accounts for 22.69 per cent of the variance and the following five together for 52.84 per cent of the variance.

If we reconstruct the temporal series using the first six principal components (PC-1 to PC-6, Fig. 4), we find a positive trend together with a very low frequency oscillation of about 80 years (PC-1), which is considered to be an artefact caused by the general trend rather than the 65 to 70-year oscillation described by Schlesinger and Ramankutty (1994). The second to sixth components can all be related to components found by Ghil and Vautard (1991) in their analysis of the global temperature time series.

The second component (PC-2) represents an oscillation with period about 28 years that can be related to the bidecadal oscillation of the global surface temperature associated with changes in the thermocline. The third and fourth components (PC-3 and PC-4) represent an oscillation with period 11 years that is consistent with the 9.1-year oscillation in the global surface temperature.

Fig. 4 Reconstructed series for the first six components, PC-1 to PC-6.



The fifth and sixth components (PC-5 and PC-6) represent an oscillation with a period of about five years that is consistent with an oscillation in the global surface temperature with a period of 4.8 years and which is related to the ENSO phenomenon.

To test the influence of ENSO on snow occurrence, we have split the original series into three categories according to the classification by Quinn et al. (1992): warm phase ENSO events, cold-phase ENSO events and normal years. The difference between snow occurrence in warm-phase ENSO events and cold-phase ENSO events was statistically significant at the five per cent level. Furthermore, the ENSO influence on snow occurrence seems to be especially important for very strong warm-phase ENSO events. Thus, 1925-1926 and 1982-1983 were very strong warm-phase ENSO events and were accompanied by a significant increase in snow occurrence in the area.

Concluding remarks

Two main conclusions can be drawn from the present study. First, the more intense ENSO events are accompanied by high snow occurrence in the central Andes region and second, variations of the global surface temperature observed in other studies are also present in variables related to temperature such as snow occurrence.

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