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A statistical study of *Weinmannia* pollen trajectories across the Andes

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Abstract. Recent airborne pollen records data from Northern Patagonia (San Carlos de Bariloche, Argentina, Lat. 41.1435° S, Long. 71.375° W, 800 m elevation) suggest that pollen transport takes place from the west to the east slope of the Andes. However, the atmospheric characteristics responsible of this transport have not yet been studied. The aim of this paper is to assess potential source areas and to describe the involved atmospheric mechanisms of the trans-Andean pollen transport. Methodology relies on the analysis of backward trajectories of air masses calculated with the HYSPLIT 4.9 regional model for particular days where airborne pollen of *Weinmannia trichosperma* Cav. was detected east of the Andes. This pollen type was selected because it is found regularly at localities in eastern Patagonia beyond its present-day distribution. *Weinmannia*'s substantial presence during early Holocene times would also benefit from better knowledge of its transport mechanisms. Correspondence between atmospheric trajectories and the position of sources was checked using GIS maps. Mode T, Principal Component Analysis (PCA) with Varimax rotation was used to identify the main spatial structure of geopotential height anomalies producing the calculated trajectories. Eighty-eight cases showed that the calculated directions of trajectories trended from the Northwest to Southwest passing over the Chilean region of *W. trichosperma* distribution. PCs results showed two patterns of negative anomalies over southern Patagonia. The prevailing circulation pattern which drives airborne transport is the presence of a trough located south of 37 to 40° S with its axis over western Patagonia. The synoptic situations for two cases highly correlated with principal component scores were described.

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1 Introduction

How far pollen types are transported from their source region is an important question in Palynology. Airborne pollen and spores as well as air flow directions have been monitored during experiments conducted on the land, across the sea and in the low atmosphere (Raynor et al., 1972; Pérez et al., 2001; Waisel et al., 2008). Long range transport of pollen grains is generally dominated by synoptic systems but local circulations induced by terrain in-homogeneities can also affect it. Trajectories associated to regional and extra-regional pollen transport have been studied in Buenos Aires province (Argentina) showing that depending on the geographical location of the plant source in relation to the position of the sampling station, the transport of different pollen taxa was associated either to N-NE wind direction related to the South Atlantic Anticyclone or to a SW direction, related to the Westerlies circulation (Gassmann and Pérez, 2006). Recent airborne pollen data from Northern Patagonia (San Carlos de Bariloche, Argentina, Lat. 41.1435° S, Long. 71.375° W, 800 m elevation), suggest that a significant pollen transport takes place from the western to the eastern slopes of the Andes. To evaluate this aspect of atmospheric transport mechanisms, we choose *Weinmannia trichosperma* Cav. *(tineo)*, whose pollen grains are small (ca. 10 μ) and thus aerodynamically adapted to long distant transport. Air masses trajectory calculation is a common methodology applied to pollution

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studies (Liu and Seinfeld, 1967; Stohl, 1996, 1998; Jaffe et al., 1999) and has been applied to the study of biogenic particles such as pollen and spores (e.g. Rantio-Lehtimäki, 1994; Campbell et al., 1999; Adams-Groom et at., 2002). As an example, Sofiev et al. (2006) applied numerical models to analyze the predictability of airborne transport of *Betula* pollen and van de Water et al. (2003) to *Juniperus ashei* in the Great Plains of the United States. Both authors state that owing to the aerodynamical characteristics of the pollen grains, the trajectories can be related with source areas (van de Water and Levetin, 2001; van de Water et al., 2003). However, to further increase the understanding of pollen transport, the phenology of the pollen sources remains a critical aspect that needs to be investigated (Pasken and Pietrowicz, 2005).

The aim of this paper is to study airborne pollen transport across the Andes applying the trajectory methodology in the case of *Weinmannia trichosperma* collected in San Carlos de Bariloche and to describe the synoptic mechanisms involved in the process.

2 Methodology and data

The trajectory of airborne pollen, was simulated using the Hybrid Single-particle Lagrangian Integrated Trajectory model (HYSPLIT 4.9) developed by the National Oceanic and Atmospheric Administration (NOAA) (Draxler and Hess, 1997, 1998). The model computes both forward and backward trajectories simulations, and concentration fields driven by gridded meteorological data from either analyses or short-term forecasts from routine numerical weather prediction models at regular time intervals. The Final Run (FNL)-Southern Hemisphere (SH) Archive furnished by NOAA ARL was used as meteorological input to HYSPLIT, which provides meteorological fields with horizontal resolution of 190.5 km at 60° latitude for 00:00, 06:00, 12:00 and 18:00 UTC and includes late arriving conventional and satellite data (Stunder, 1997). Backward trajectories starting at the San Carlos de Bariloche aerobiological station (41.143° S, 71.375° W, 800 m a.m.s.l.) were calculated for specific days when *Weinmannia* pollen was detected in the air. Target days came from the airborne pollen data base collected at Bariloche aerobiological station with a Lanzoni VPPS 2000 volumetric spore trap placed at 15 m high in the urban area (Bianchi and Olabuenaga, 2006). In order to consider the meteorology of the whole day and considering that pollen records are daily sums and time of pollen arrival is unknown, HYSPLIT was started at 03:00 UTC following the target day (Argentina's time zone: −3) . Running time lasted from 24 to 30 h. Eighty eight daily records of *Weinmannia* where found during the periods October–March from 2003 to 2006 whose trajectories were calculated. Correspondence between trajectories and the position of potential sources were checked through GIS maps provided by the Laboratorio de teledetección, Instituto Nacional de Tecnología Agropecuaria (INTA), estación experimental Bariloche (Lara et al., 1999).

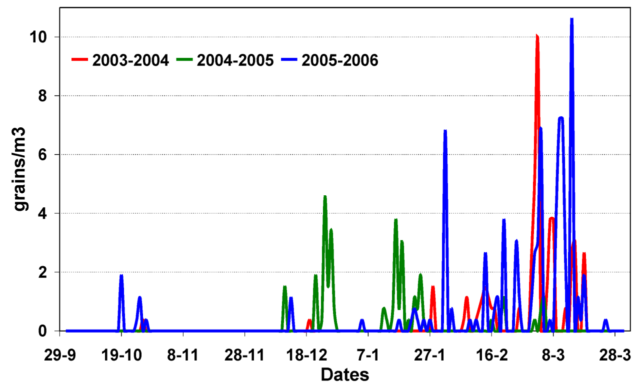

Fig. 1. Airborne pollen concentration of *Weinmannia trichosperma* in the air of Bariloche during three years of sampling.

T-Mode principal component analysis (PCA) with Varimax rotation was used in order to obtain the leading spatial anomaly patterns of geopotential height of pressure surfaces associated to the simulated trajectories. The basic definitions and concepts can be reviewed in Green (1978). The daily NCEP-NCAR reanalyses (Kalnay et al., 1996) have a 2.5° by 2.5° horizontal resolution. Three vertical levels (1000, 850 and 700 hPa) were selected in order to represent the lower troposphere. Daily anomaly fields of geopotential heights for the mentioned levels were selected for those dates when *Weinmannia* pollen was detected in the air. Time of independence was calculated to ensure independence between consecutive dates of events (Coronel et al., 2006).

PC Scores are the fields showing the primary types of anomalies and PC loadings are the time series representing the correlation between the PC spatial patterns and the observed daily anomaly fields. Explained variance determines the degree of significance of each spatial pattern in the temporal domain. According to Richman and Gong (1999), absolute values in the time series of loadings between ±0.3 are considered non-significant. 1000 hPa fields corresponding to the 2 cases that showed the highest correlation to PC patterns were selected for detailed analysis.

3 Results

3.1 Pollen record

Weinmannia pollen was detected from October to March with accumulated totals of 48, 33 and 79 grains m^{-3} for the three recording periods (Fig. 1). The mean daily concentration varies between two to three grains m^{-3}. The highest concentration was 11 grains m^{-3} on 14 March 2006. Generally *Weinmannia* pollen occurs during single days between

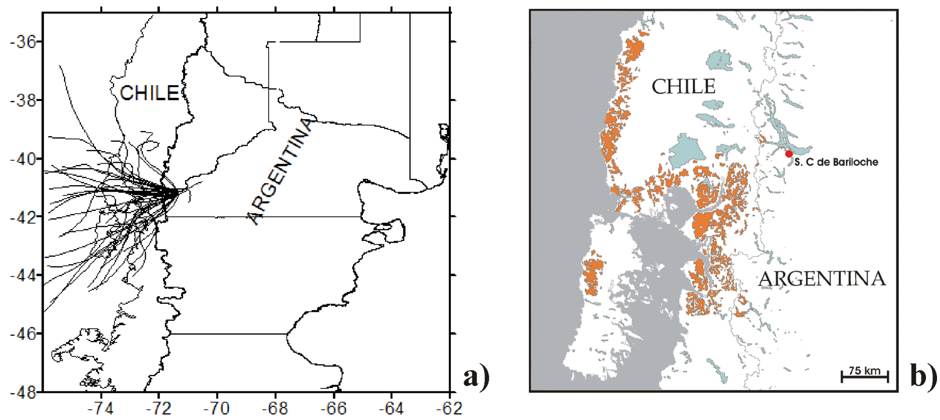

Fig. 2. HYSPLIT 4.6 backward trajectories calculated for the days when *Weinmannia* pollen was detected in the air of San Carlos de Bariloche. **(a)** Calculated trajectories. **(b)** *Weinmannia trichosperma* source locations.

mid-December to mid-March and only occasionally on consecutive days as registered from 11 to 17 February 2004.

3.2 Calculated trajectories and potential source location

Figure 2a shows an example of 45 trajectories for those days when *Weinmannia* concentration was higher than its mean daily concentration. Although not represented, the 88 cases registered showed similar trajectories coming from different directions ranging between NW and SW which are in accordance with the area of the potential pollen source areas (Fig. 2b). The trajectory for 24 February 2006 which comes from the E, is discussed in detail in a following section.

3.3 PCA and associated circulation patterns

The spatial structure of the geopotential anomalies can be described in terms of the first two PCs. They account for 61.3% of the total variance at 1000 hPa, 65.2% at 850 hPa and 57.3 %at 700 hPa.

The first PCs (31.0%, 33.4% and 31.2% of the total variance for 700, 850 and 1000 hPa, respectively) show a pattern of negative anomalies at high and mid latitudes and of positive anomalies extending towards the tropics (Fig. 3a, b, c). Negative anomalies show the presence of cyclonic systems or troughs located in southern Patagonia. The associated circulation to these geopotential fields is responsible of the observed western trajectories.

The second PCs (30.3%, 31.8% and 26.1% of total variance for 700, 850 and 1000 hPa, respectively), show the presence of an anticyclone centered at 40° S, 68° W (Fig. 3d, e, f). Meteorological situation shows a pattern similar to PC Scores 1 but shifted slightly towards the east, suggesting that the second score represents a later situation. However, the synoptic circulation is quite different over the study area. In that case mid and high latitudes are dominated by a trough located over the Atlantic and an anticyclone over Patagonia.

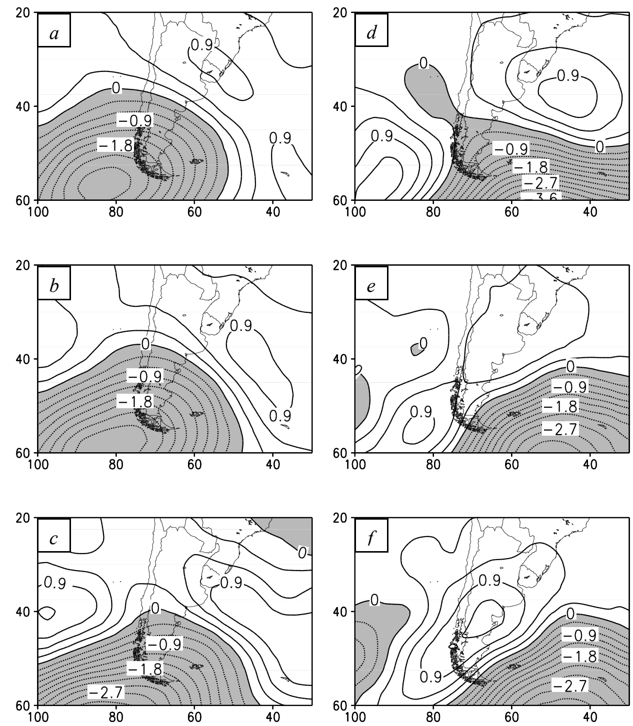

Fig. 3. Main aspects of the PCs. The left panel shows the first PC score spatial pattern, contour values are every 0.3 with shaded areas for negative score values for 700 hPa **(a)**, 850 hPa **(b)** 1000 hPa **(c)**; the right panel shows the second PC score spatial patterns – 700 hPa **(d)**, 850 hPa **(e)** 1000 hPa **(f)**.

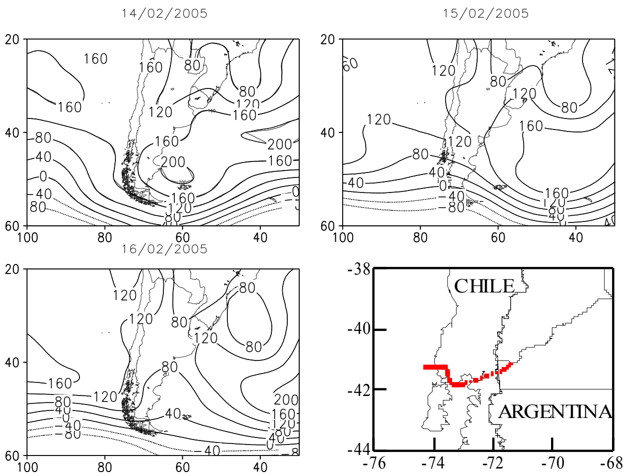

Fig. 4. Daily mean geopotential height fields of 1000 hPa pressure surface for the day of *Weinmannia* pollen capture and 48 hours before. Bottom right panel: 48 h backward trajectory started at 24:00 h local time 16 February 2005 in San Carlos de Bariloche.

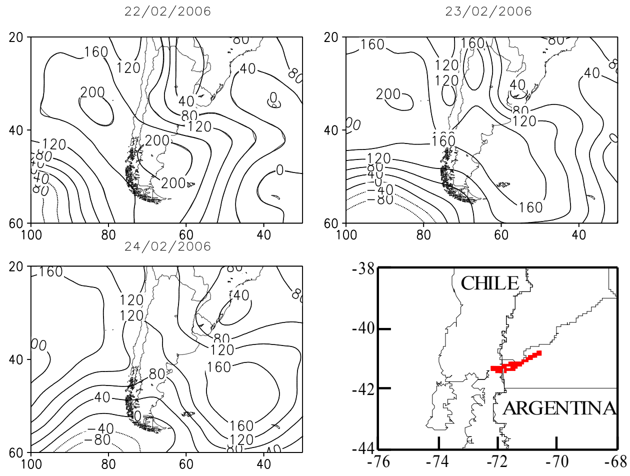

Fig. 5. Daily mean geopotential height fields of 1000 hPa pressure surface for the day of *Weinmannia* pollen capture and 48 h before. Bottom right panel: 48 h backward trajectory started at 24:00 h local time 24 February 2006 in San Carlos de Bariloche.

4 Case studies

Given the similarity between the patterns described in Sect. 3.3 we discuss those cases that are highly correlated with PC scores 1 at the three analyzed levels.

4.1 16 February 2005 (Fig. 4)

The trajectory shows PC 1 loadings of 0.86, 0.82, 0.51 at 1000, 850 and 700 hPa, respectively. On 14 February a trough was located south of 37° S towards the west of Chile. The trough axis reached the Patagonian region on 15 February with a NW-SE orientation. On the final day when *Weinmannia* was found, the trough was positioned over the eastern coast of Patagonia while an anticyclone is positioned to the west of the continent.

4.2 24 February 2006 (Fig. 5)

The southeastern trajectory on 24 February 2006 shows PC 1 loadings of 0.91, 0.88, 0.38 at 1000, 850 and 700 hPa, respectively. On 22 February an anticyclone centered south of 40° S in southern Patagonia combined with a low pressure center located to the north of Argentina, driving a highly meridional circulation which could explain the obtained trajectory. The appearance of a trough with NW-SE direction to the west of Patagonia shows the strong association with the circulation pattern described by PCs1. The rapid eastward drift of the trough on 24 February take air masses leeward from the Andes which explains the capture of *Weinmannia* pollen from Chilean sources even though the modeled trajectory starts at eastern Patagonia.

5 Discussion

Weinmannia trichosperma, is a small, 2 to 10 m high evergreen, shade intolerant, successional tree in the Cunoniaceae family, endemic in temperate rainforest in Chile and Argentina, distributed from 35° to 47° S and growing up to 1000 m altitude (Lusk, 1999). *Weinmannia* pollen in airborne records from the Bariloche station are found mainly from December to March outside the reported blooming season which in Chile extends from October to December, while in Argentina it starts a month later. This pattern could be indicative that *Weinmannia* became airborne from pollen grains retained in the forest canopy thus being resuspended by gusty conditions on clear days. Pollen grains could be then uplifted and transported in upper layers. Markgraf (1980) also observed an increase in pollen concentration after the flowering period in Tauber traps that was explained by reflotation.

In all registered cases airborne concentrations were low indicating long distance transport. The relative abundance of trees in the station's surroundings are *Maytenus boaria* (28.5%), Rosaceae (18.5%), *Pinus* sp. (16.2%) and *Betula*sp. (8.7%) while no individuals of *Weinmannia trichosperma* grow in the local area (Bianchi et al., 2004). *Weinmannia* trees grow approximately 89 km to the W of the station and 127 km to the SW along the Argentinean border. According to Prentice (1985) presence of *Weinmannia* pollen at the Bariloche station can be defined as representing regional source. In general, *Weinmannia*'s main distribution is on the Chilean slopes of the Andes (Donoso, 2005). Calculated backward atmospheric trajectories agree with the location of the main tree sources. All this evidence lead us to conclude that *Weinmannia* pollen in the air of San Carlos de Bariloche is due to airborne transport across the Andes from primary extra-regional sources with some input from regional sources east of the Andes. Statistical analysis indicates that the prevailing circulation pattern which drives the airborne transport is the presence of a trough located south of 37–40° S with its axis over western Patagonia. The associated wind direction supports the transport from windward to leeward across the Andes, which at these latitudes takes place at a mean altitude up to 500 m above ground level. Several observed trajectories also support the hypothesis that valleys oriented longitudinally facilitate the eastward transport of this pollen type, although more detailed analysis is needed. Correlation coefficients between the study cases and the patterns associated to PC scores 1 are higher at 1000 and 850 hPa showing that the circulation patterns are better represented at lower levels, which owing to the low altitude of the southern Andes, generally represent air movements within the Atmospheric Boundary Layer. The turbulence of this layer facilitates the suspension of aerobiological particles and the transport of substances over great distances. Our results let us indicate that 850 hPa is the appropriate level to study the transport of airborne particles in this region.

The application of this methodology to different pollen types is not only potentially useful to Aerobiology, but also to other studies. The identification of underlying meteorological patterns related to occurrence of airborne pollen could help conceive preventive measures to minimize polinosis symptoms in a region with high incidence of respiratory allergy (Bianchi and Olabuenaga, 2006). Understanding atmospheric transport mechanisms would also greatly contribute to improve interpretation of fossil occurrence of pollen types. Records of mid-latitude in Chile show high amounts of *Weinmannia* pollen together with other entomophilous taxa during the early Holocene (Moreno et al., 2001; Haberle and Bennett, 2004) indicative of those taxa's expansion after disturbance by fire under warm climatic conditions. Increased amounts of *Weinmannia* together with increase in steppe taxa in records from Argentina for the same period have been interpreted to indicate open forest allowing increased long distance transport from the Chilean sources under comparable climate conditions (Markgraf, 1984; Jackson, 1996). These interpretations are supported by our findings. Moreover, at the eastern Andean flanks *Weinmannia* is an element of the lower tree stratum of the forest. The pollen transport beyond the forest margin is very poor, due to low wind velocity and the foliage filtering under the highest tree stratum (Bianchi and Olabuenaga, 2006). Therefore, the contribution of the easternmost localities to the airborne pollen concentration of *Weinmannia* outside the forest boundaries is negligible. The findings in this paper support with new empirical evidence the interpretations of Late Qaternary pollen records, as well as, provide a powerful tool to understand the role of *Tineo* in the present environment.

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