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Trajectories associated to regional and extra-regional pollen transport in the southeast of Buenos Aires province, Mar del Plata (Argentina)

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Abstract Long range transport of airborne pollen has been seldom studied in South America. Backward trajectories of *Celtis* and *Nothofagus* pollen grains trapped over a meteorological station outside Mar del Plata City were calculated in one-hour steps using the regional hybrid model developed by the NOAA (HYSPLIT 4.5) and the data of the NCEP filed in the NOAA server. Results showed that the observed trajectories agree with the location of vegetation sources of the collected tree species. In the case of *Celtis*, the transport was associated to anticyclones located east of the city, generating winds with a N-NE component, which produce pollen cloud advection from the *Celtis* forests located some tens of kilometers to the N and NE of the city. The sources of *Nothofagus* pollen correspond to a narrow strip on the Andes slopes between 39° and 55°S, at least 1100 km to the SW of Mar del Plata. The transport was associated to eastward displacement of the troughs corresponding to the Westerlies circulation and the presence of an anticyclone system that brings back *Nothofagus* pollen towards Mar del Plata area.

Keywords Argentina · *Celtis* · Long range transport · *Nothofagus* · Pollen · Trajectory

Introduction

Aerosols comprise a great number of particles of anthropogenic or natural origin. Within the last type, airborne pollen is of great importance due to its interest for many fields of science, from paleoecology to allergology. Early evidence showed that, like many other particles, pollen grains are able

to travel thousands of kilometers, even reaching isolated islands or remote continents (Hafsten 1960; Bortenschlager 1969; McAndrews 1984; Linskens et al. 1993).

Numerous authors on aerobiology have studied large-scale transport of different pollen types in Europe, USA and Japan, (Johansen and Hafsten 1988; Johansen 1991; Hjelmroos 1991; Hjelmroos and Franzén 1994; Cabezudo et al. 1997) using air concentration samples or meso-scale dispersion process modeling (Kawashima and Takahashi 1995). Despite the source of data or the applied methodology, there is general consensus that the characteristics of air movement in the lower atmosphere determine the dispersion capabilities of airborne pollen.

Suspended particles are usually transported by the wind and dispersed by the existing turbulence within the atmospheric boundary layer. Once emitted, the particles are subject to dispersion processes on the micro-, meso- and synoptic scales that, within the boundary layer limit, are produced by thermal or mechanical turbulence or by the presence of mesoscale systems. Deep convection breaks the barrier imposed by the boundary layer bringing up particles to free atmosphere, where the defined puffs or plumes lose their identity and end up suspended in an air mass moved by synoptic systems. Depending on the altitude reached, they could be transported and deposited at great distances.

Long range transport is generally dominated by synoptic systems (Arya 1999). It is expected that macro-scale systems like general circulation, the semi-permanent systems, and jet streams also affect the transport of particles, especially those which have crossed the top of the boundary layer. Within this context, Machta (1958) suggested that general and synoptic circulation was responsible for the uniform distribution of contaminants through the Northern Hemisphere while Lovelock et al. (1973) and Pendergast (1984) confirmed this hypothesis at tropospheric level.

Studies of pollen transport in South America are still lacking. Particularly in Argentina, long-range transport was claimed to be the main process responsible of the atmospheric presence of extralocal and extraregional (sensu Prentice 1985) pollen types in the urban and rural areas of Mar del Plata City (Bianchi 1994; Pérez 2000; Pérez et al.

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2001). Nevertheless, relationships between source and sink areas, the atmospheric pathways and favourable synoptic conditions are still unknown.

The aim of this paper was to analyze the long-range pollen transport in the southeast of Buenos Aires Province (Argentina) from an experimental point of view. Backward trajectories of pollen samples taken in Mar del Plata City were studied. Results are then analyzed considering location and distance of the source areas and the synoptic characteristics of the atmosphere during transport.

Materials and methods

Area description

Mar del Plata (37.59°S, 57.33°W) lies on the coast of Buenos Aires Province. A detailed description of the city and the surrounding area can be found in Gassmann et al (2002). In winter, westerlies predominate with frontal passages from the sub-polar zone, while in summer the southward displacement of the South Atlantic high-pressure system, produces an increase in the frequency of the N-E wind direction. Vegetation of the area comprises cultivated trees and native grasses. Trees are the main source of airborne pollen in the urban area. The most frequent species are: *Prunus ceracifera* var. *athropurpurea* (Jaeg) Rehd., *Ulmus pumila* L., *Lagerstroemia indica* L., *Populus* spp., *Fraxinus americana* L., *Fraxinus excelsior* Boiss., *Robinia Pseudo-acacia* L., *Platanus acerifolia* Willd., *Acer negundo* L., *Tilia cordata* Mill. and *Cupressus* spp. On the rural outskirts herbaceous vegetation predominates, mainly composed of grasses (Poaceae) and some weeds like *Carduus acanthoides* Linn., *Conium maculatum* L., *Plantago major* L., *Melilotus alba* Desr. and *Medicago lupulina* L. Exotic trees such as *Eucalyptus globulus* Labill., *Acacia melanoxylon* R. Br. and several *Populus* species are planted as windbreaks.

Data

Airborne pollen trajectories of *Celtis* and *Nothofagus* were studied because they are native species which do not grow in the sampling area, but are detected in the air of Mar del Plata from spring to summer (Latorre and Pérez 1997; Pérez and Paez 1998). There are two possible sources for *Celtis* pollen: *Celtis tala* Gilles ex Planch. and *Celtis australis* L. According to Nitiu (2003), the flowering and pollination period of *Celtis tala* lasts from September to December with peak concentration in October. Considering the phenology of this species and the time when the pollen samples were taken, the source of *Celtis* pollen was the “Tala” (*Celtis tala* Gilles ex Planch.) (Latorre 1997; Pérez 2000; Pérez et al. 2003a). These trees grow some tens of kilometers to the N and NE of Mar del Plata, in the southernmost distribution limit of the Tala Sub-District (Cabrera 1976) which extends in a narrow strip that encompasses the coast of Buenos Aires province (Fig. 1).

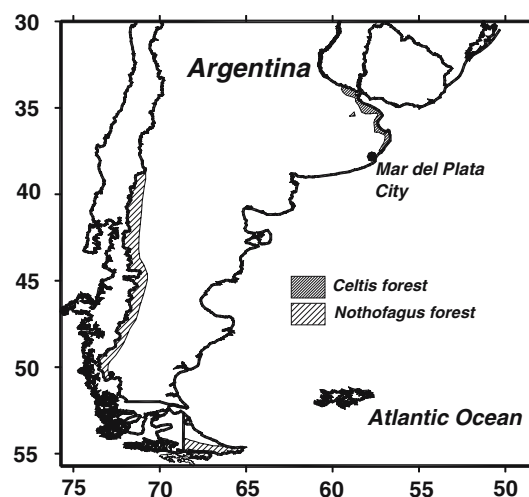


Fig. 1 Location map of Mar del Plata city. Shaded areas correspond to *Celtis* and *Nothofagus* forests according to Parodi (1940) and Cabrera (1976), respectively

In the case of *Nothofagus*, the emission sources were the “Lenga”, *Nothofagus pumilio* (Boepp. & Endl.) Krasser, the “Coigüe” *Nothofagus dombeyi* (Mirb.) Oerst. and *Nothofagus antarctica* (G. Forst.) Oerst. which grow at the eastern foot of the Andes from 39°S to 55°S in the Sub-Antarctic Province (Cabrera 1976), 1,110 km distant from Mar del Plata city at their northernmost geographical distribution (Fig. 1). These trees grow at an altitude that ranges from approximately 1,400 m in the north to 600 m in the south. Phenological studies of *Nothofagus* reported that the flowering period lasts from September to December (Palma et al. 1996).

The concentration data of these pollen types were taken from the Mar del Plata University Palinology Lab database.

The meteorological data used for the trajectory model were NCEP reanalysis data for the period October–December 1995 provided by the NOAA-CIRES Climate Diagnostic Center, Boulder, Colorado, U.S.A. stored at their web site <http://www.cdc.noaa.gov/>. The data come at grid points with a spatial resolution of 2.5° every 6 h (00, 06, 12, 18 UTC). On the vertical, data are distributed in 17 levels of pressure (1,000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 19 hPa). Backward trajectories were calculated starting at Mar del Plata (37.59°S, 57.33°W). The same data were used to map the daily synoptic sea level pressure fields and the 925 hPa wind field.

Methodology

Trajectory model description

In the Eulerian description of the fluid movement in a turbulent flow, the behavior of pollutants is described relative to a fixed point of space or coordinate system. This does not turn out to be the most appropriate methodology to describe the dispersion of air pollutants, such as gases or particles, in a

turbulent flow. More appropriate for dispersion studies is the Lagrangian approach that follows a specific particle of fluid as in the case of particle trajectories.

The trajectory of particulate matter, in this work pollen clouds emitted at far places of the monitoring site, was simulated using the HYSPLIT 4.5 regional model developed by the National Oceanic and Atmospheric Administration (NOAA) (<http://www.arl.noaa.gov/ready.html>). The *HY*brid *S*ingle-Particle *L*agrangian *I*ntegrated *T*rajectory model (Draxler and Hess 1997, 1998) computes both trajectories simulations as much forwards as backwards, and concentration fields driven by gridded meteorological data from the reanalyses archives obtained at ARL-NOAA main server.

Once the pollen is released by the sources, it will be advected by the mean wind in a Lagrangian framework. The meteorological profiles at each horizontal grid point are linearly interpolated to an internal terrain-following coordinate system dispersion model. The advection of particle is computed from the three-dimensional velocity fields interpolated in both space and time. Trajectory calculation is carried out considering a variable time step so that the particle displacement remains less than the grid spacing and depends on the maximum speed over the previous hour (Draxler 1996). The trajectories finish if they leave the superior limit of the model (10,000 m), but the advection continues throughout the surface if the trajectory intersects the ground. The particle path or the time variation of the vector position ($\vec{P}$) is expressed like:

$$\vec{P}(t + \Delta t) = \vec{P}(t) + 0.5 \left[\vec{V}(\vec{P}, t) + \vec{V}(\vec{P}(t) + \vec{V}(\vec{P}, t) \Delta t, t + \Delta t) \right] \Delta t$$

Where $\vec{V}(\vec{P}, t)$ is the three-dimensional mean velocity vector and Δt is the time step. The velocity vector is represented by the average of the velocities at the initial location and time and the velocity at the first-guess position

at time $t + \Delta t$. The velocity at a point is linearly interpolated from the values at the adjacent grid points and time periods. The integration time step can vary between simulations and is based upon the requirement that $u_m \Delta t / \Delta L < 0.5$, where u_m is the maximum expected velocity and ΔL is the horizontal grid length. The trajectory path is computed in both the horizontal and vertical direction such that the vertical integration of the position vector is computed in a manner similar of the horizontal component.

Pollen sampling

Pollen samples were taken at 10 m above ground level, on the roof of the Mar del Plata Airport meteorological station (MdPA) located approximately 8 km to the north of Mar del Plata City. Burkard type aerobiological traps, changed weekly, were used to obtain the samples. The observation period started in mid-October 1995 and ended in February 1996. The sampling methodology was continuous, volumetric and isokinetic as designed by Hirst (1952) with Burkard's modification (1984). At present, this technique has the highest level of resolution for the atmospheric sampling of aerobiological particles, determining the pollen content of a known volume of air taken at a given hour independently from the original direction of the wind. To prepare the samples, standard techniques were used and the count was made with optic microscopy at regular 2-h intervals (Käpylä and Penttinen 1981).

Results

Celtis pollen

Atmospheric content of *Celtis* pollen showed different peaks during the sampling period ranging from 103.6 grains/m³ to 262.7 grains/m³ (Fig. 2). Particularly on 31 October, 1, 2, 14, 20, 23 and 29 November, daily pollen sums reached values at

Fig. 2 *Celtis* pollen concentration (grains/m³) observed in Mar del Plata City

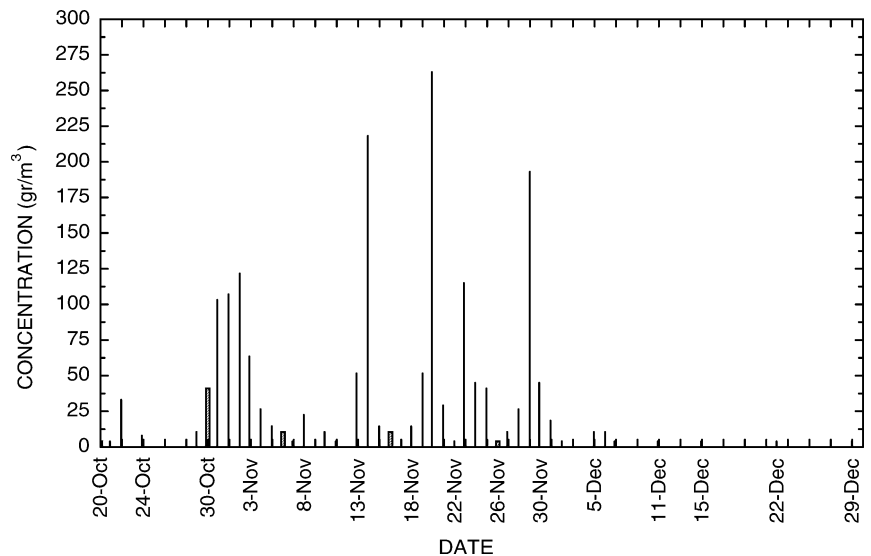
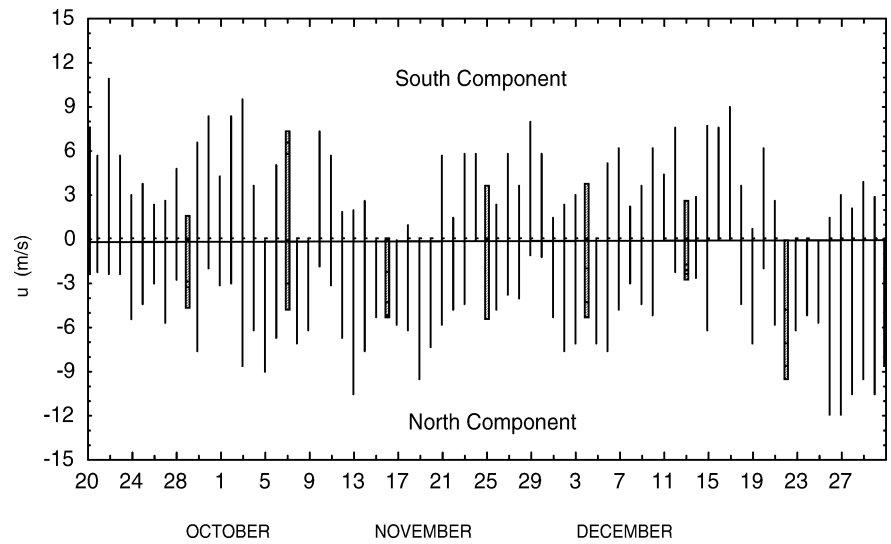


Fig. 3 Daily mean meridional component of wind at Mar del Plata City during the monitoring period



least three times higher than the mean for the entire period. These events were associated with a predominantly northern component of meridional wind (Fig. 3). Accordingly, these days were specially studied.

The calculated backward trajectories using the HYSPLIT model showed different patterns, corresponding to north (Fig. 4a), northeast (Fig. 4b) and loop (Fig. 4c) transport. Corresponding trajectories for 31 October, 1 and 2 No-

vember reach the northeast coast of Buenos Aires Province describing similar meridional transport directions that end at Mar del Plata city thus results were only shown for 31 October. On these days there was a trough in the center west of the country. An anticyclone located to the east caused winds with N-NW component entering the NE of Buenos Aires Province (Figs. 5a and 6a). The transport in these cases could come from sources located as far as 400 km

Fig. 4 *Celtis* pollen backward trajectories (dot: 6-h time step) and location of the vegetation sources. **a** North pattern of transport; Represented trajectories correspond to 31 October and 23 November. **b** Northeast pattern; represented trajectories for days: 14, 20 November. **c** Loop trajectory from 29 November. **d** Trajectories for days without *Celtis* pollen in the air; represented trajectories for 10, 12, 22 and 28 November. Shaded area corresponds to the distribution of Tala forests according to Parodi (1940). Trajectories start at 37.59°S, 57.33°W

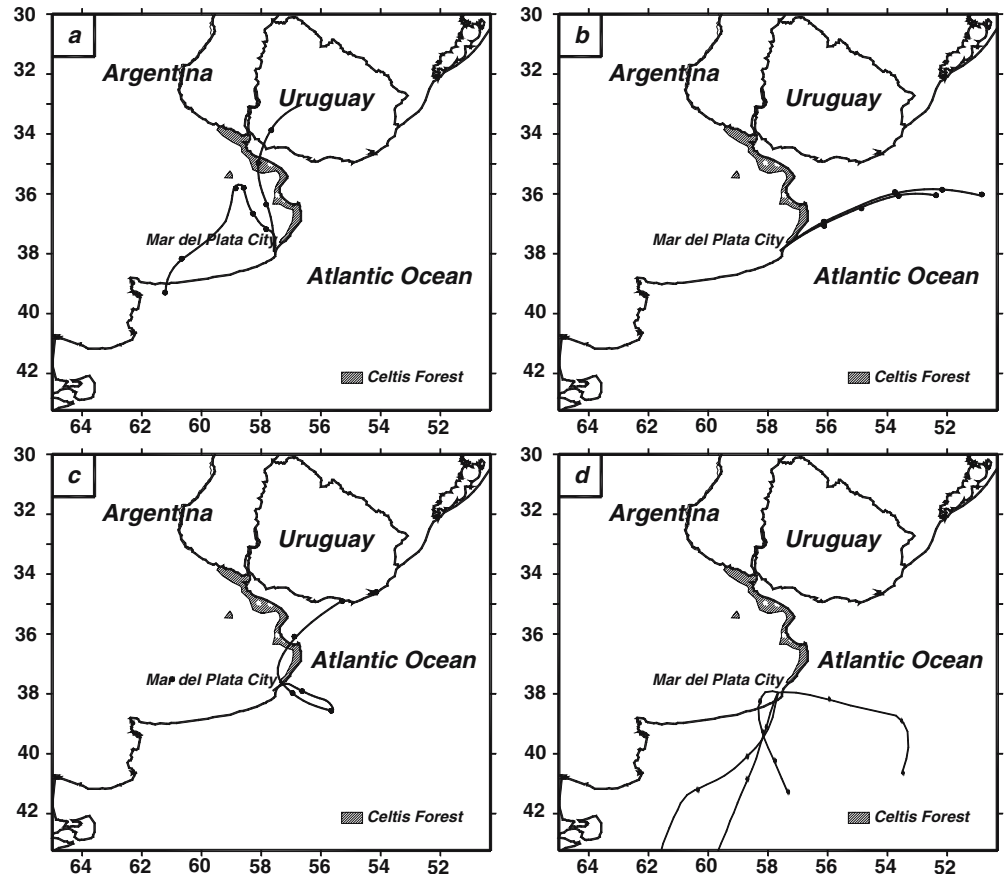


Fig. 5 Daily mean sea level pressure fields (in hPa) at selected days during the period: 31 October – 29 November 1995

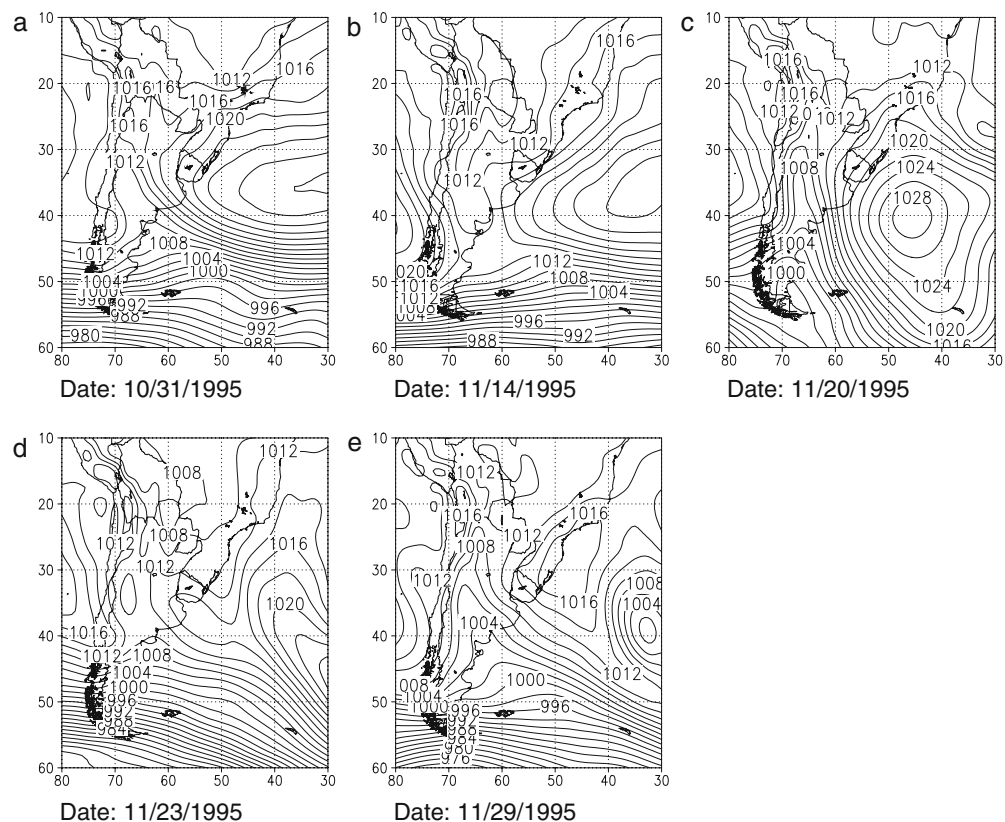


Fig. 6 Daily mean wind vectors fields at 925 hPa (in m/s) at selected days during the period: 31 October – 29 November 1995

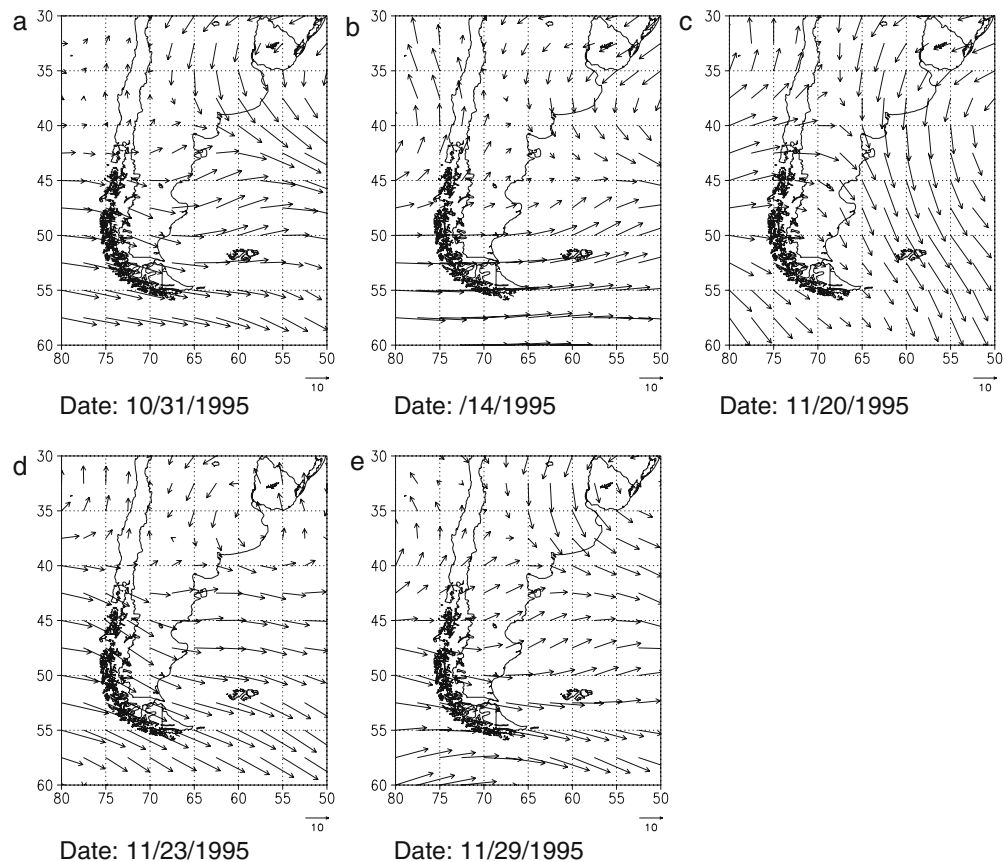
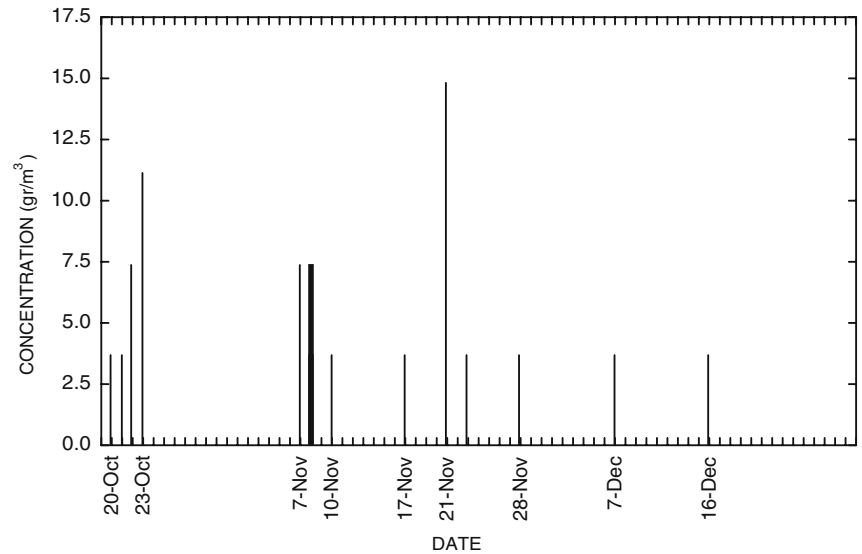


Fig. 7 *Nothofagus* pollen concentration (grains/m³) observed in Mar del Plata City



away, as indicated by the calculated backward trajectories. Observed daily pollen concentrations for *Celtis* vary from 103.6 to 122.1 grains/m³ (Fig. 2).

On 29 November, meteorological conditions change slightly, with the trough located to the east of its previous position while the anticyclone weakened and moved to the south of Brazil (Fig. 5e). Accordingly, backward trajectories initially come from the southern region of Buenos

Aires Province (Fig. 4a). The wind field at 925 hPa indicates an intense N component with an anticyclone rotation in the northeastern sector of the Province (Fig. 6e). Unlike the previous days analyzed, pollen sources should be nearer to Mar del Plata due to the observed change of direction in the trajectories (Fig. 4a). Airborne pollen content matches these results with a higher pollen concentration (192.4 grains/m³) (Fig. 2).

Fig. 8 *Nothofagus* pollen backward trajectories (dot: daily time step) and location of the vegetation sources. **a** SW continental transport pattern; starting dates for represented trajectories are: 20, 21 and 23 October. **b** SW oceanic transport; trajectory started on 22 October. **c** Zonal transport; starting dates are: 8, 10 November, 16 December. Shaded area corresponds to the Sub-Antarctic Province sensu Cabrera (1976). Trajectories start at 37.59°S, 57.33°W

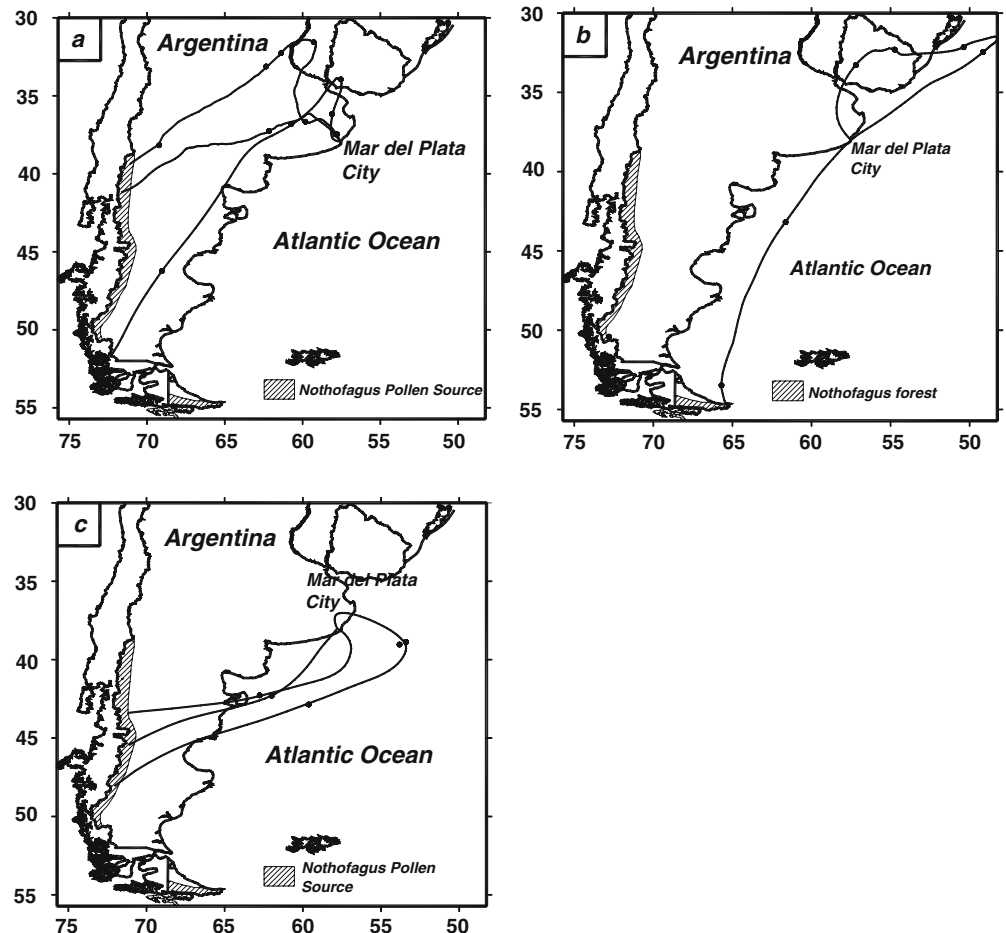


Fig. 9 Daily mean sea level pressure fields (in hPa) at selected days during the period: 16 October – 16 December 1995

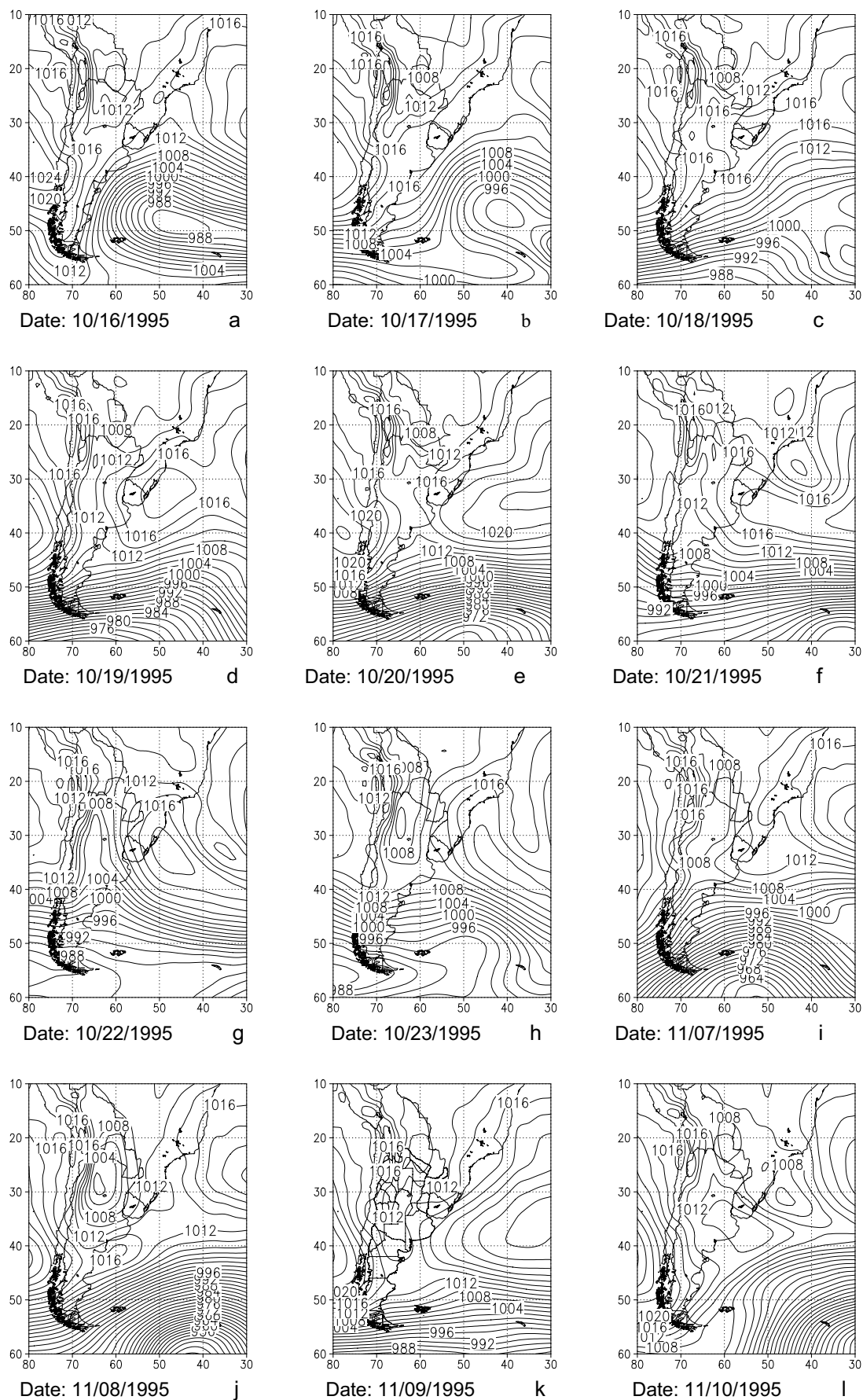
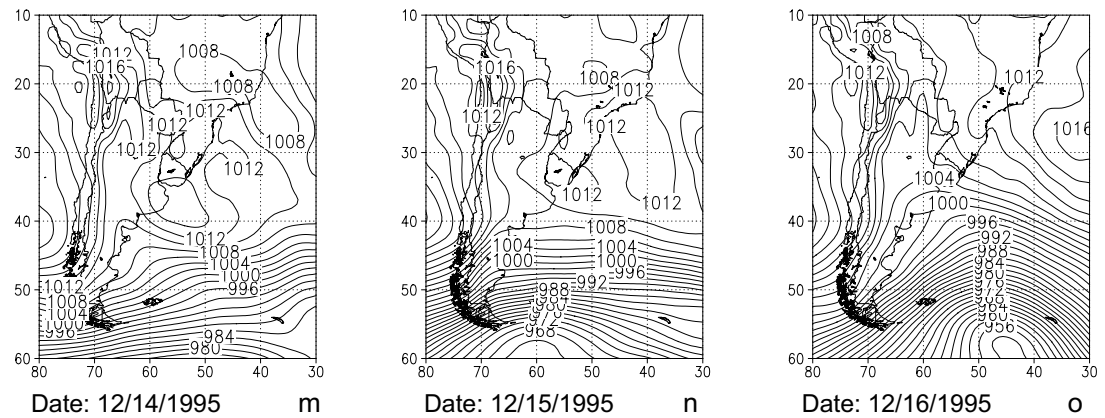


Fig. 9 (continued)



On 14 and 20 November, the anticyclone, which produced the transport from the N to Mar del Plata (Fig. 5b,c), was slightly displaced southward than in the previously described cases, producing wind with N and NE components over the E of Mar del Plata. Trajectories are then mainly maritime (Fig. 4b). In the 925 hPa wind fields (Fig. 6b,c) it can be seen how the wind reaches the Mar del Plata area passing through the sources a few kilometers to the northeast of the city. Accordingly, concentration values observed on 14 and 20 November are higher than those previously described days with 218.3 and 262.7 grains/m³ (Fig. 2).

On 23 November, there was a high pressure area located SE of the continent that was distorted by a wedge located to the SE of Brazil. The presence of this system maximized the anticyclonic curvature over Buenos Aires Province (Fig. 5d). The 925-hPa wind field shows an anticyclonic circulation with a wind speed that did not surpass 2 m/s over Mar del Plata (Fig. 6d). These conditions could lead to the possible establishment of a sea breeze system during the day, which transported the pollen from the rural areas towards the sea and then bringing it back to the city (Fig. 4c). Considering the trajectory, the covered distance and the dispersion of the pollen cloud during the run, *Celtis* sources should be close as the observed concentration was similar to that of 31 October and 1 and 2 November.

During all the simulations, *Celtis* pollen grains remained between 50 and 250 m of altitude above ground level. Although there are some other simulations at greater altitudes, they did not show trajectories reaching the city (not shown). Therefore, it is to be expected that the pollen trapped in Mar del Plata remained within the atmospheric boundary layer. According to the calculated trajectories and the location of the sources, *Celtis* pollen showed a transport time-out which vary from 6 to 18 h (Fig. 4).

Null cases, i.e. those days within the pollination period whose airborne *Celtis* pollen concentration was less than 1 grains/m³ were also considered. Four days (10, 12, 22 and 28 November) were selected for the analysis. Figure 4d showed that the calculated backward trajectories for the null cases were maritime, coming from the SW (12 and 28 November), S (22 November) and E (10 November) quadrant. None of them passed through the location of *Celtis* sources located to the northeast of the city.

Nothofagus pollen

Nothofagus showed very low pollen concentration values which ranged from 3.7 to 14.8 grains/m³ (Fig. 7). Figure 8 shows three patterns of backward trajectories for the days on which airborne pollen was detected in the air of the city. Three characteristic patterns were detected: a SW continental transport (Fig. 8a), a SW oceanic transport (Fig. 8b) and a zonal transport (Fig. 8c). According to the trajectories, *Nothofagus* was transported at least 48 to 120 h before it was captured. For that reason, sea level pressure and 925-hPa wind-fields were analyzed up to 5 days before the observation (Figs. 9 and 10). Synoptic situation corresponding to the periods 16–23 October, 7–10 November and 14–16 December were studied.

From 20 to 23 October the wind direction in the Mar del Plata area was predominantly from N and NW (Fig. 10e–h) due to a high-pressure system in the mid-latitudes. Meanwhile, between 40°S and 60°S it was registered the passage of a trough associated to the low-pressure system located approximately at 60°S (Fig. 9e–h). Those days, *Nothofagus* pollen concentration varied from 3.7 to 11 grains/m³ (Fig. 7). The western portion of the trough associated to the low at 60°S (first observed on 16 October), transported pollen towards the NNE (Figs. 9a and 10a). On 17 and 18 October, the weakened trough located over Patagonia continued a slow displacement towards the NE. The wind fields modeled at 925 hPa (Fig. 10a–h) are consistent with the described transport patterns for each day. The trajectories showed that the pollen came from the southernmost Patagonia, moved slowly towards the north until it reached Uruguay on 18 October (Fig. 8a,b). On 19 and 20 October the pollen cloud moved towards Mar del Plata and reached it on 20 October (Figs. 9d,e and 10d,e).

From 6 to 10 November, pollen transport from the region of emission took 2–3 days to reach Mar del Plata. Corresponding trajectories cross Patagonia towards the NE, enter the sea and then return to Mar del Plata (Fig. 8c). Synoptic situation showed that an anticyclone which entered Patagonia on 7 November, slowly displaced an intense trough to the east transporting grains towards the city (Fig. 9i–l). Because of the presence of a low pressure system in the center north of the country, circulation was forced from the sea

Fig. 10 Daily mean wind vectors fields at 925 hPa (in m/s) at selected days during the period: 16 October – 16 December 1995

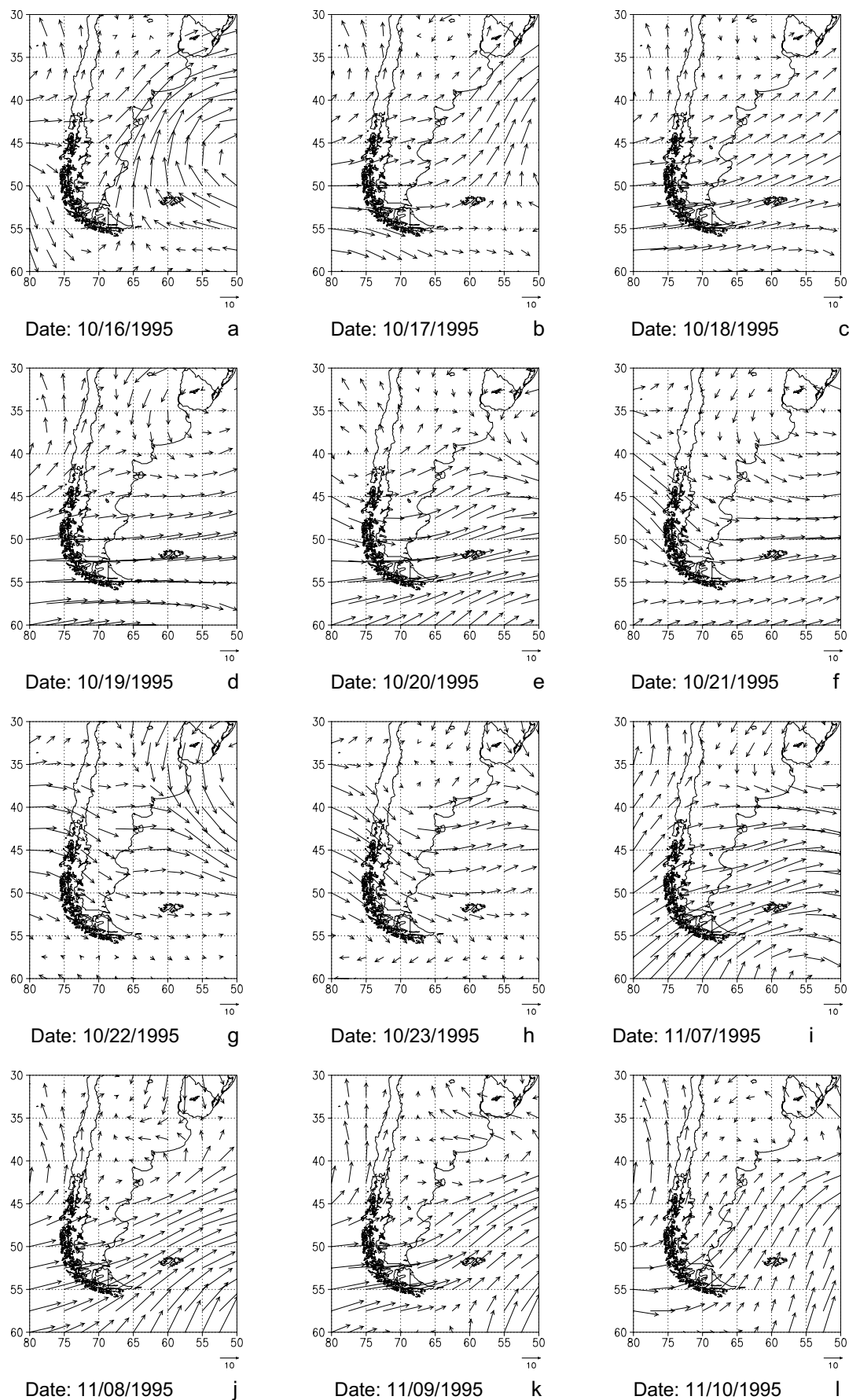
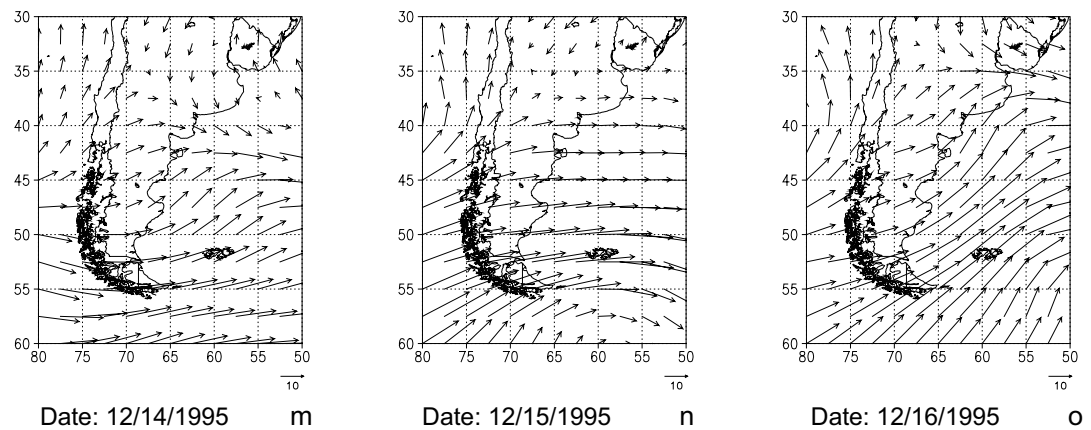


Fig. 10 (continued)



towards the continent at Mar del Plata latitude. Particularly, Fig. 10l shows the weak anticyclone rotation of the wind towards the south of Buenos Aires province on November 10.

The transport corresponding to 14–16 December had a similar pattern to the one observed on 6–10 November (Fig. 8c). The western portion of the trough located over Patagonia, transported pollen towards the NE directly to Mar del Plata in less than 48 h (Fig. 9m–o and Fig. 10m–o). Other cases registered during November, December and January 1996 resemble the synoptic situation described here.

Trajectory analysis showed the transport occurs at altitudes between 200 and 2,000 m without necessarily remaining within the atmospheric boundary layer (not shown). These altitudes may be easily reached by pollen particles because of convection always present in the development of diurnal boundary layers, then passing to free atmosphere by the processes previously mentioned in the introduction. Transport schedule at great altitudes allow the displacement of pollen clouds during several days reaching great distances from their sources. Accordingly, *Nothofagus* reach Buenos Aires province from sources located at least 1,100 km to the SW on the Andean slopes.

Nothofagus null cases were not analyzed considering that the absence of this pollen type in the air of Mar del Plata does not guarantee the lack of association between trajectories and pollen sources due to the distances and time lags required to reach the sink area.

Discussion

The monitoring of the airborne pollen spectrum of Mar del Plata allowed determining the presence of regional and extra-regional pollen species. Looking at the daily mean sea level pressure and 925-hPa wind-fields, it was possible to determine how the transient meteorological systems in middle latitudes in the Southern Hemisphere contributed to this long range transport.

In the case of *Celtis* pollen, transport was related to the establishment of an anticyclone system in the east of the continent. Transport time-out was less than 24 h and the pollen grains were constrained to the atmospheric boundary layer. In all the cases analyzed, trajectories match the position of

possible sources to be a narrow strip of Tala woods of the Tala Sub-District (Cabrera 1976). Analysis of positive (high concentration days) and null cases revealed that the presence of *Celtis* in the air is directly related to the synergic effect of meteorological conditions and the position of the sources. Mesoscale circulation processes were also an important factor which can alter pollen dispersal. A characteristic deposition curve has asymptotic decreasing values when moving away from a source (Lanner 1966). Results showed that depending on the synoptic conditions, it is possible the establishment of a see breeze system which could change deposition patterns by means of pollen re-entrainment. Previous results confirmed that the see breeze system is the main factor of multimodal airborne pollen concentration curves in Mar del Plata (Gassmann et al. 2002). Also, coastal breeze is postulated as responsible for some surface pollen patterns in localities near Mar del Plata (Pérez et al. 2003b).

Nothofagus pollen was transported by transient meteorological systems associated with westerly circulation, always present at mid latitudes in Patagonia. The transport starts with the passage of the western portion of a trough over the emission area, extended from 40°S to 50°S. It may be observed that this synoptic situation corresponds to a region where a relative maximum of anticyclonic vorticity advection leads to good weather condition. These conditions allow surface warming, due to incoming solar radiation, which generates strong thermal convection in the atmospheric boundary layer necessary to raise a pollen cloud at sufficient height to be transported by synoptic systems. Results showed that pollen transport takes place at altitudes higher than 1,000 m reaching the free atmosphere, with time schedules from 48 to 120 h. The shift of the trough carries the pollen cloud to the north where in most cases an anticyclone system brings *Nothofagus* pollen grains back towards the Mar del Plata area. The described conditions for transport of *Nothofagus* are similar to those reported by Hjelmroos (1991) for *Betula* pollen in Fennoscandia.

Because of sideways dispersion over such altitudes and distances, an airborne *Nothofagus* pollen cloud with peaks of 60 grains/m³ in Bariloche city (41.22°S, 71.6°W) (Bianchi et al. 2004) could be thinned to almost 4 grains/m³ at Mar del Plata. Over such distances, a *Nothofagus* pollen cloud could be thinned below detectable concentra-

tions even at favorable meteorological conditions, thus null cases are nonsense and are not analyzed for this pollen type. Besides, there are many other factors affecting the pollen arrival from distant sources from unfavorable local conditions, such as too light winds over source areas to release significant pollen amounts to occurring rainstorms on intermediate localities at regional scale.

Nothofagus and *Celtis* are widespread pollen types, present in many surface and fossil pollen samples taken throughout Buenos Aires province and Patagonia. Isopoll maps predict typical *Nothofagus* surface percentages varying from 65% at the Andes to less than 5% in the Atlantic coast of Patagonia (Paez et al. 2001). A similar analysis for *Celtis* showed values of 50% in the NE coast of Buenos Aires province which diminish to less than 1% when moving 300 km inland (Tonello, personal communication). Isopoll patterns reveal axes of maximum variation collinear with the atmospheric pathways described in this paper.

Implications of these results to the interpretation of Holocene pollen records open a field to reflect on. In this sense, aeropalynological surveys in other countries have shown that distant sources contribute substantially to the local pollen cloud if favorable meteorological conditions are met (Hirst and Hurst 1967; Raynor et al. 1972; Tampieri et al. 1977; Hjelmroos 1991; Hjelmroos and Franzén 1994). The scopes of our results show that the analysis of meteorological conditions could bring some new perspectives of interpretation for modern pollen deposition. Particularly, it is stated that the aerobiological pathway is an important signal within surface pollen assemblages that deserves more detailed investigations which in turn can give valuable insights into climate change.

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