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Review of Palaeobotany and Palynology 141 (2006) 277–286
Review of Palaeobotany & Palynology
www.elsevier.com/locate/revpalbo

New evidence of long distance pollen transport to southern Greenland in late spring

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Received 2 January 2006; received in revised form 12 May 2006; accepted 18 May 2006

Abstract

New observations of long-distance pollen transport to southern Greenland are recorded during the last 2 weeks of May, 2003. The results indicate northeastern North America as the source area of the transported pollen grains as shown in earlier investigations. Backward trajectories indicate that transport occurred twice during the first week corresponding to a time of maximum pollen flux emitted to the atmosphere in the source area. A large percentage of exotic pollen grains were identified, about 11% of the total counted. However, transport during the second week appears to have occurred during a single day at a time of reduced pollen emission into the atmosphere, which was subjected later to severe washout. As a result, only 1% of the total pollen spectra was identified as exotic grains. The back trajectories modeled by the HYSPLIT application differ somewhat from those previously identified in 2002. Although in both years air passing over southern Greenland at 3000 m carried out the main transport, additional transport could have occurred at a much lower altitude in 2003.

Keywords: Long distance transport; Greenland; pollen; Arctic domain

1. Introduction

The ongoing “EPILOBE” project, which monitors pollen transport to coastal Greenland, utilizes several stations where filters trap pollen grains present in the air throughout the year (Rousseau et al., 2001). They are located next to meteorological or radiosonde stations located on the western (Qaanaaq, Kangerlussuaq, Narsarsuaq) and eastern (Ittoqqortoormit) coasts of Greenland. Although attempts to trace spore or pollen movement backwards has been previously undertaken (Nichols, 1967; Ritchie and Lichti-Federovich, 1967; Janssen, 1973; Ritchie, 1974; Andrews et al., 1980; Short and Holdsworth, 1985; Bourgeois et al., 1985; Jacobs et al., 1985; Ritchie et al., 1987; Franzen et al., 1994; Hjelmroos and Franzen, 1994; Gajewski, 1995; Campbell et al., 1999; Bourgeois, 2000; Bourgeois et al., 2001; Hicks et al., 2001; Hicks and Isaksson, 2006), none of these studies proposed the complete trajectory from source to deposition. A previous record of long-distance pollen transport to southern Greenland, at Narsarsuaq, was documented in

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doi:10.1016/j.revpalbo.2006.05.001

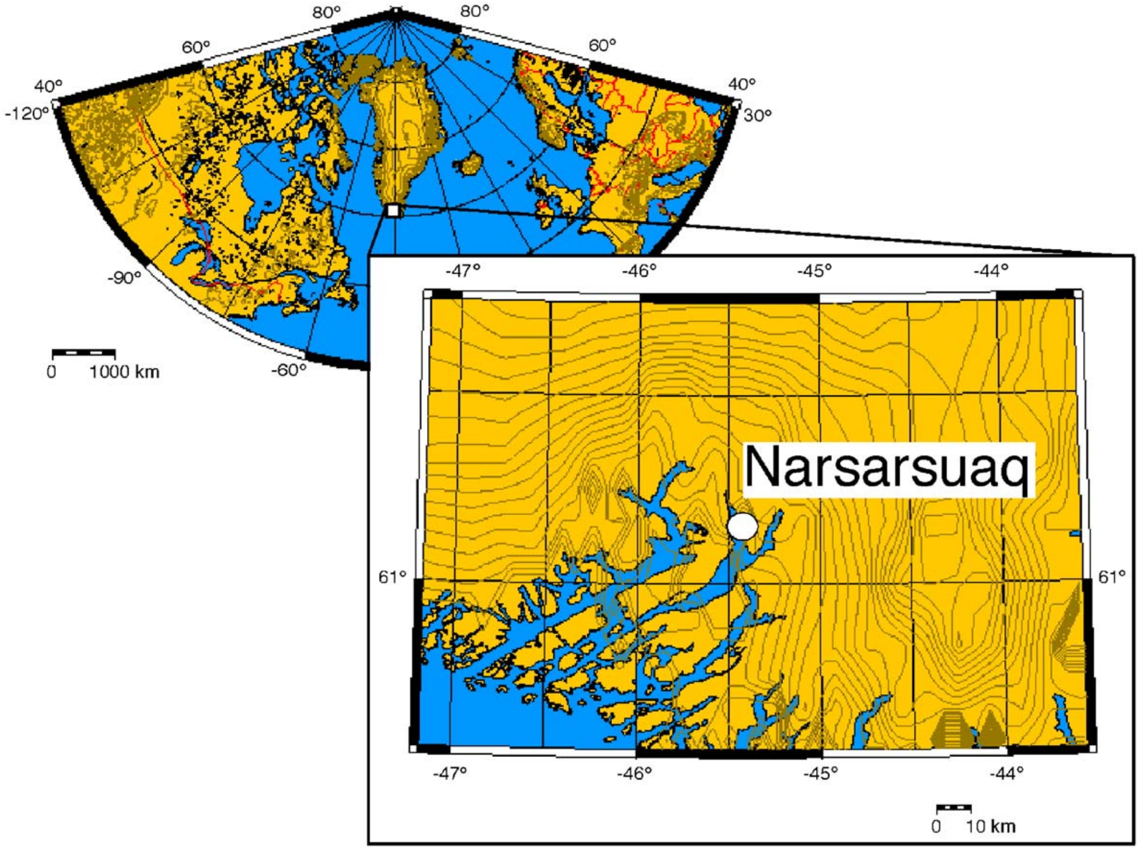

Fig. 1. Location of the pollen trap at Narsarsuaq in southern Greenland.

2002 and included arboreal pollen (hickory, hemlock, oak, beech, hornbeam, and walnut) originating from northeast North America (Rousseau et al., 2003). This transport was supported by the dates of pollen production measured in the Toronto area, southern Canada, at the northern range of the common distribution of these trees (Cambon et al., 1992; Cambon, 1992, 1994). In addition, another experiment using the same protocol was carried out the same year on sea ice at the North Pole during the “Banquise 2002” expedition between January and July. Two previously unrecorded long-distance transport events were reported from this area. The first consisted of birch, willow, alder and pine pollen grains originating from Western Europe, and was followed by pollen from eastern Siberia 2 weeks later (Rousseau et al., 2004). The patterns of transport were described based on the HYSPLIT model (Hybrid Single-Particle Lagrangian Integrated Trajectory) from NOAA (HYSPLIT4Model, 1997; Draxler and Hess, 1998), which allows the determination of backward trajectories. The North Pole record is exceptional because access to that

Table 1
Precipitation data provided by the NASA GPCP V1DD program for the source area when the air parcels passed over the growing area in northeastern North America and Narsarsuaq, Greenland (see Figs. 4–6). Data from daily (1DD) version of precipitation estimates from NASA’s Global Precipitation Climatology project (GPCP)

Date of arrival in Narsarsuaq and rate of precipitation	Date of crossing the growing area	*X–Y* coordinates	Rate of precipitation (mm/day)
May 20, 0.4 mm/day	May 14	38°N, 82°W	0
	May 16	43°N, 75°W	7.4
May 21, 2.1 mm/day	May 13	36°N, 80°W	0
	May 17	43°N, 75°W	0
May 27, 2 mm/day	May 16	47°N, 87°W	0
	May 24	60°N, 101°W	0

region is rather rare, but the question of regular of the pollen transport from North America to southern Greenland remains. Because the pollen traps at different locations do not cover the same time interval we focus here on the 2003 season and compare results with those of 2002 at Narsarsuaq, southern Greenland.

2. Methods

Pollen data were collected from a trap consisting of two 20 cm × 20 cm filters (Cour, 1974), labeled respectively A and B, installed at 1.5 m elevation on a vane-holder positioned close to the radiosonde station at Narsarsuaq

Table 2
List of identified pollen grains, counts and percentages for A10, A10B1 and A10B2 filters (respectively, weeks 21–22, 21 and 22)

Weeks	W(21–22)		W(21)		W(22)	
Pollen types	Count	Percentage (%)	Count	Percentage (%)	Count	Percentage (%)
Acer	24	0.35	21	0.72	3	0.08
Alnus	105	1.54	90	3.07	17	0.43
Ambrosia	0	0.00	0	0.00	1	0.03
Artemisia	0	0.00	1	0.03	0	0.00
Asteraceae (liguliflorous)	3	0.04	0	0.00	0	0.00
Asteraceae (tubuliflorous)	1	0.01	0	0.00	1	0.03
Betula	5827	85.57	2133	72.65	3533	89.40
Botrychium	2	0.03	0	0.00	1	0.03
Brassicaceae	0	0.00	0	0.00	0	0.00
Carpinus	1	0.01	0	0.00	5	0.13
Carya	1	0.01	0	0.00	3	0.08
Caryophyllaceae	0	0.00	0	0.00	0	0.00
Chenopodiaceae–Amaranthaceae	1	0.01	0	0.00	0	0.00
Cyperaceae	105	1.54	37	1.26	81	2.05
Equisetum	175	2.57	77	2.62	96	2.43
Ericaceae	124	1.82	192	6.54	44	1.11
Fagus	3	0.04	3	0.10	2	0.05
Fraxinus (cf.)	154	2.26	162	5.52	12	0.30
Galium	1	0.01	0	0.00	0	0.00
Gramineae	47	0.69	6	0.20	40	1.01
Huperzia	0	0.00	0	0.00	2	0.05
Juglans	0	0.00	1	0.03	0	0.00
Juniperus	4	0.06	17	0.58	10	0.25
Lycopodium annotinum	1	0.01	3	0.10	4	0.10
Lycopodium lucidulum	7	0.10	6	0.20	3	0.08
Monolete spore	3	0.04	1	0.03	2	0.05
Moraceae	0	0.00	1	0.03	0	0.00
Myrica	6	0.09	10	0.34	0	0.00
Picea	0	0.00	2	0.07	0	0.00
Pinus	1	0.01	3	0.10	2	0.05
Plantago	0	0.00	0	0.00	2	0.05
Platanus	0	0.00	2	0.07	1	0.03
Populus (cf.)	29	0.43	65	2.21	1	0.03
Quercus	21	0.31	42	1.43	5	0.13
Rumex	16	0.23	0	0.00	14	0.35
Salix	108	1.59	39	1.33	60	1.52
Saxifragaceae	2	0.03	2	0.07	1	0.03
Sphagnum	16	0.23	0	0.00	2	0.05
Taxus	1	0.01	18	0.61	0	0.00
Thalictrum	5	0.07	1	0.03	2	0.05
Triglochin	7	0.10	0	0.00	0	0.00
Tsuga	2	0.03	0	0.00	1	0.03
Ulmus	1	0.01	0	0.00	0	0.00
Urticaceae	1	0.01	0	0.00	0	0.00
Viburnum	0	0.00	1	0.03	0	0.00
Damaged grains	4	0.06	0	0.00	0	0.00
Unidentified grains	1	0.01	0	0.00	1	0.03
Total	6810		2936		3952	

(61.15°N, 45.43°W, 1 m asl) (Fig. 1). A set of filters was exposed from Monday, January 6 until Sunday December 27, 2003. The filters are made of siliconed medical gauze and held constantly at right angles to the prevailing wind by the vane-holder. The filters were processed in Montpellier using a standard method described in Cambon (Cambon et al., 1992; Cambon, 1992, 1994), and the pollen was identified by examining the pollen slides at a magnification of 600×. The "A" filters, labeled as Ax, were changed every 2 weeks, beginning at odd numbered weekly intervals. The weekly "B1" and "B2" filters were labeled AxB1 and AxB2. If the 2-week "Ax" filters, showed exotic pollen, the "B" filters were processed to determine the particular week of transport. Only half of the filter was processed making the second half available for further studies including those on dust or potentially other pollutant material. Although in the latter case, other traps or techniques are much more appropriate to perform a reliable analysis.

The HYSPLIT transport and dispersion model computes trajectories for any place in the world from archived gridded meteorological data (HYSPLIT4Model, 1997; Draxler and Hess, 1998). We used the online version of the model as a tool to determine potential backward trajectories of air parcels, which could have been the vector of the pollen transport to the filter location in southern Greenland. It is not the purpose of this study to evaluate the model, which has been assessed elsewhere (see the HYSPLIT website). Backward trajectories were examined for air parcels reaching the pollen traps at filter (ground) level, or passing over the sampling area at 1000 m and 3000 m altitude. Earlier, it was demonstrated that long-distance pollen transport to southern Greenland involved an air parcel at 3000 m altitude (Rousseau et al., 2003) while air parcels at both the 1000 and 3000 m levels were involved in transport to the North Pole (Rousseau et al., 2004).

The geographical plot of the air parcel trajectories for 2003 was compared with the distribution maps of the trees in the Northern Hemisphere (Hultén, 1964; Hultén and Fries, 1986; Thompson et al., 1999a,b), whose pollen has been identified on the exposed filters. The model also provides information on upward and downward air motion, which can contribute to enhancing or reducing the abundance of pollen that is transported and subsequently deposited on the filters. Upward movement above the pollen production area and downward movement at the Greenland station are required in making the final selection of the trajectory. We are aware of the restrictions indicated by Stohl et al. (2002) about trajectory calculations in the interpretation of atmospheric trace substance measurements, and in this paper we are using the on-line

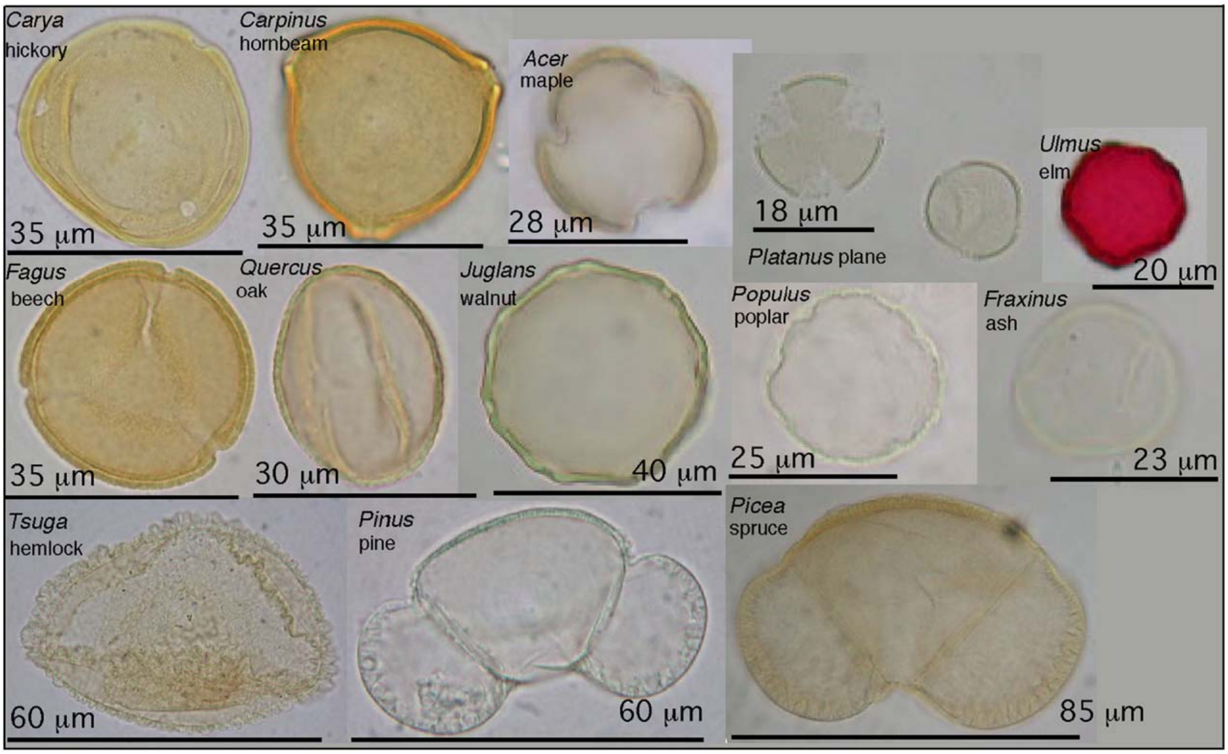

Fig. 2. Exotic pollen grains identified in the exposed filters at Narsarsuaq.

HYSPLIT application only to trace the pollen transport. However, in order to corroborate data from the model, we collected independent precipitation data at both the source and destination areas. NASA provides one-degree-daily global precipitation data extracted from satellite observations that are available on the IRI-Lamont website (NASA GPCP V1DD-IRI/LDEO, 2005) (Table 1).

3. Results

3.1. Pollen occurrence

Among the primary (A) filters collected, (A10) provided abundant pollen, corresponding to the time interval May 19–June 1 (Table 2). Out of a total of 6810 grains counted, 154 ash (*Fraxinus*), 29 poplar (*Populus*), 24 maple (*Acer*), 21 oak (*Quercus*), 3 beech (*Fagus*), 2 hemlock (*Tsuga*), 1 each of hornbeam (*Carpinus*), hickory (*Carya*), spruce (*Picea*), pine (*Pinus*), yew (*Taxus*), and elm (*Ulmus*) grains were recorded (Fig. 2). The total of 239 grains represents 3.49% of the total number of identified grains. As none of these trees grow in Greenland, long distance pollen transport is indicated. The local tundra vegetation surrounding the station is represented by birch (*Betula*), horsetail (*Equisetum*), willow (*Salix*), alder (*Alnus*), Ericaceae, Cyperaceae (6444 grains counted, i.e., 94.63% of the total identified). To narrow our time investigation, the weekly exposed filters were subsequently processed.

From a total of 2936 identified grains on the A10B1 filter corresponding to week 21 (May 19–May 25), 162 ash (*Fraxinus*), 65 poplar (*Populus*), 42 oak (*Quercus*), 21 maple (*Acer*), 18 yew (*Taxus*), 3 beech (*Fagus*), 3 pine (*Pinus*), 3 hemlock (*Tsuga*), 2 hornbeam (*Carpinus*), 2 plane (*Platanus*), 2 spruce (*Picea*), 1 walnut (*Juglans*), and 1 hickory (*Carya*) grains were counted. A total of 325 represents 11.06% of all identified grains, which is a significant proportion of exotic pollen. Native Greenland pollen grains (2568) of birch (*Betula*), alder (*Alder*), horsetail (*Equisetum*), Ericaceae, and Cyperaceae made up 87.47% of the total. From the second B

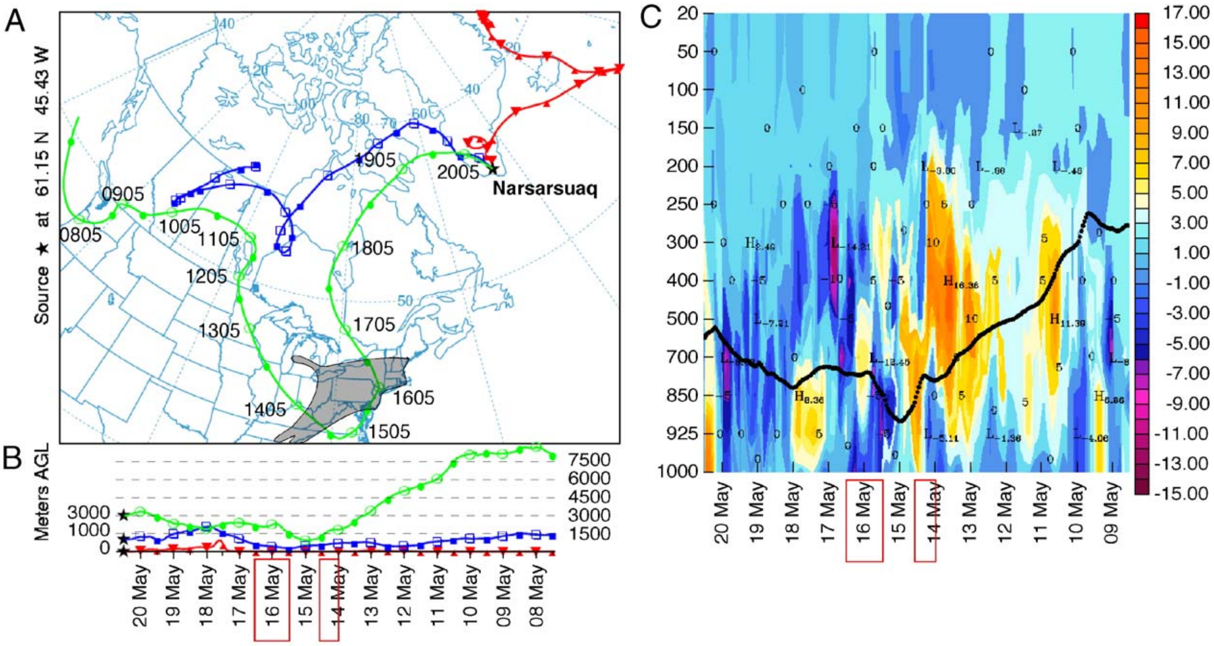

Fig. 3. Long distance transport to Narsarsuaq on May 20, 2003. (A) Backward trajectories provided by the HYSPLIT model (HYSPLIT4Model, 1997) of air parcels reaching Narsarsuaq (61.15°N, 45.43°W, 1 m asl) at different altitudes: ground level (red), 1000 m (blue) and 3000 m (green) on May 20, 2003. The grey area in northeastern North America represents the source of "exotic" trees (from Thompson et al., 1999a,b). The "3000 m" air parcel passed over this area. (B) Altitudinal variation of the three air parcels used in the backward trajectory analysis. The "3000 m" air parcel over Narsarsuaq on May 20, 2003, was at a lower elevation on May 14 and 16, when it passed over the area where "exotic" trees grow. The red box indicates the time span when potential uplift of the pollen was possible. (C) Updrafts and downdrafts in the atmosphere. Velocity of the air parcel passing over the growing area in northeastern North America which reached Narsarsuaq at 3000 m on May 20, 2003 versus time (see Fig. 2A for the geographic trajectory). Yellow to brown values indicate upward movements, whereas light blue to purple indicate downward movements. The dark line corresponds to the selected air parcel. The light colored red box characterizes the timing of the uplift of the pollen within the potential interval corresponding to the selected air parcel passing over the growing area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

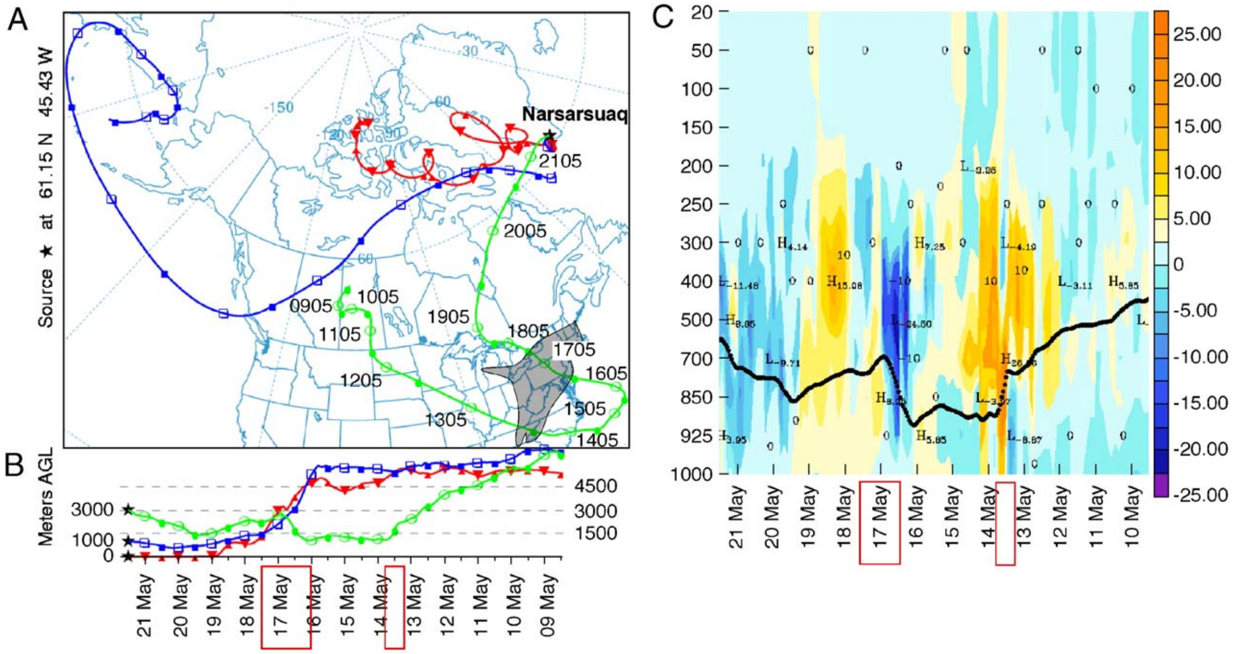

Fig. 4. Long distance transport to Narsarsuaq on May 21, 2003. (A) Backward trajectories for May 21, 2003 (see Fig. 3). (B) Altitudinal variation of the three air parcels used in the backward trajectory analysis. The “3000 m” air volume over Narsarsuaq on May 20, 2003 was at a lower elevation on May 13 and 16, when it passed over the area where “exotic” trees grow (as in Fig. 3). (C) Updrafts and downdrafts in the atmosphere (as in Fig. 3).

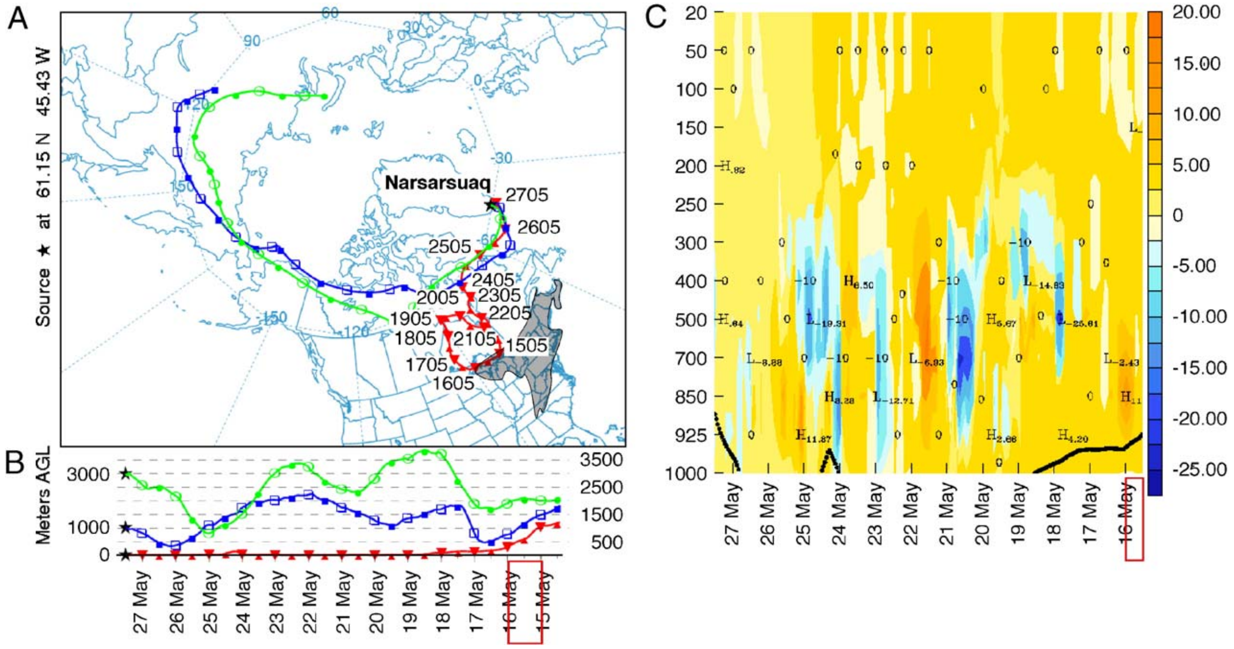

Fig. 5. Long distance transport to Narsarsuaq on May 27, 2003. First scenario: (A) Backward trajectories for May 27, 2003. The “ground to 300 m” air volume passed over this area (see Fig. 3). (B) Altitudinal variation of the three air parcels used in the backward trajectory analysis. The “ground to 300 m” air parcel over Narsarsuaq on May 27, 2003, was at a higher elevation on May 15, when it passed over the area where “exotic” trees grow (see Fig. 3). (C) Updrafts and downdrafts in the atmosphere. Velocity of the air parcel passing over the source area in northeastern North America, which reached Narsarsuaq at “ground level–300 m” on May 27, 2003 versus time (see Fig. 3).

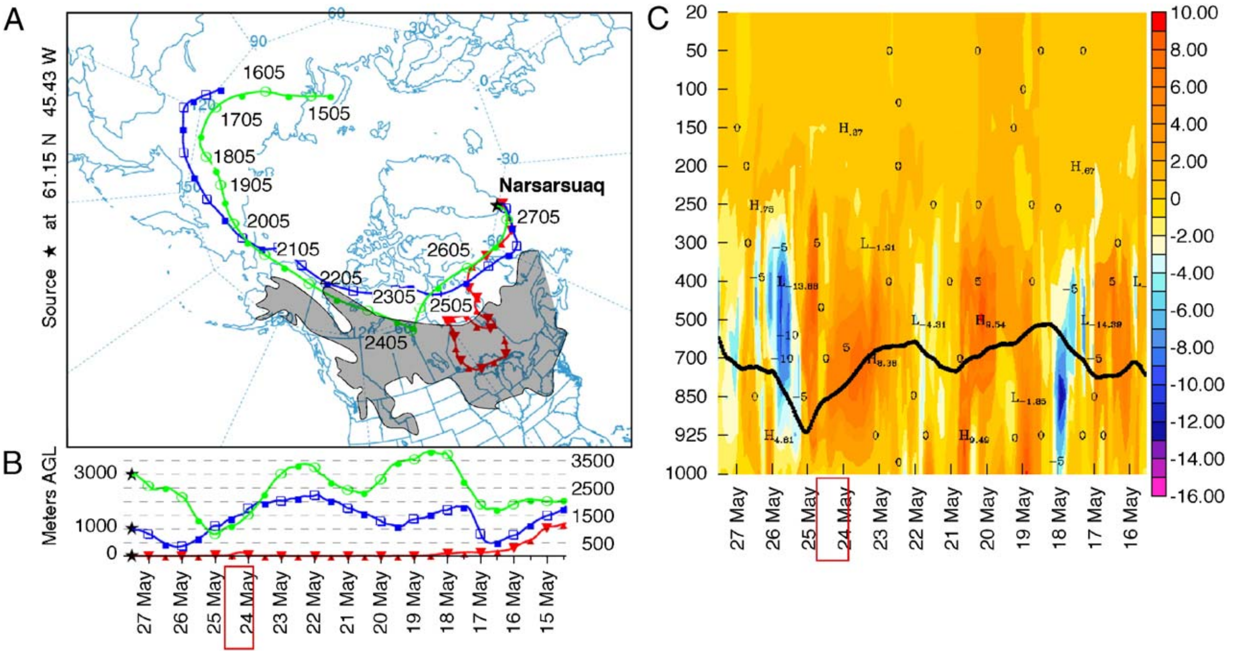

Fig. 6. Long distance transport to Narsarsuaq on May 27, 2003. Second scenario: (A) Backward trajectories for May 27, 2003. The " 3000 m" air volume passed over the northern range of pine (*Pinus*), poplar (*Populus*), and Taxaceae (see Fig. 3). (B) Altitudinal variation of the three air parcels used in the backward trajectory analysis. The "3000 m" air volume over Narsarsuaq on May 27, 2003, was at a higher elevation on May 24, when it passed over the northern range of the area where "exotic" trees grow (see Fig. 3). (C) Updrafts and downdrafts in the atmosphere. Velocity of the air parcel passing over the northern range of the growing area of exotic trees in Northeastern North America and which reached Narsarsuaq at "3000 m" on May 27, 2003 versus time (see Fig. 3).

filter, A10B2, corresponding to week 22 (May 26–June 1), a total of 3952 grains were identified. Among them, 12 ash (*Fraxinus*), 5 oak (*Quercus*), 3 maple (*Acer*), 3 hemlock (*Tsuga*), 2 beech (*Fagus*), 2 pine (*Pinus*), 1 hornbeam (*Carpinus*), 1 plane (*Platanus*) and 1 poplar (*Populus*) were counted. A total of 30 exotic grains represents 0.76% of all the identified grains. Local pollen of birch (*Betula*), horsetail (*Equisetum*), willow (*Salix*), Cyperaceae, Ericaceae, Gramineae (3854 counted grains) are 97.52% of the total.

These results clearly indicate that the exotic pollen captured on the exposed filters at Narsarsuaq was mainly transported during week 21 with some minor transport during week 22. Hemlock (*Tsuga*) and hickory (*Carya*) are solely North American taxa and thus identify this area as the source of the transported pollen. In addition to these two taxa, oak (*Quercus*), beech (*Fagus*), hornbeam (*Carpinus*), and walnut (*Juglans*) recorded in the 2003 exposed filters and poplar (*Populus*), yew (*Taxus*), ash (*Fraxinus*), plane (*Platanus*) and spruce (*Picea*) observed in 2002 grow in eastern North America (Thompson et al., 1999a,b). These trees flower between weeks 15 and 31 according to the pollen captured in the Toronto area, southern Canada, by Cambon (Cambon et al., 1992; Cambon, 1994). Therefore, it is highly likely that the air parcel responsible for the pollen transport during weeks 21 and 22 passed over the growing region when these arboreal taxa were dispersing pollen into the atmosphere.

3.2. Backward trajectories

Backward trajectories calculated once a day at 12:00 UTC from Narsarsuaq, were obtained for 14 days totaling 314 h, during weeks 21 and 22. These trajectories were compared with the compiled distribution of trees (Thompson et al., 1999a,b), in order to select the most probable candidates for pollen transport. Three altitudes were investigated: Ground level, 1000 and 3000 m.

The compilation of the HYSPLIT backward trajectories for week 21 shows that two air parcels passed over the northern limit of the distribution range of the identified trees in northeastern North America. These air parcels reached southern Greenland on May 20 and 21, 2003 (Figs. 3A,B and 4A,B) and are referred to here as AP (air parcel) 20 and AP21, respectively. According to the model, the pollen grains could have been uplifted to the 850 hPa level (about 1500 m above ground level) on May 14th and May 16th (AP20), as well as on May 13th and

16th (AP21) (Figs. 3B,C and 4B,C). The pollen grains were then transported northward to Narsarsuaq after crossing the Ontario and Quebec provinces. From the comparison of the obtained backward trajectories plotted on Figs. 3 and 4, the pollen deposited on May 20 appears to have been released at Narsarsuaq 1 day later than that recorded on May 21 because of a different trajectory inducing a longer transport. On both May 21 and 22, the pollen grains reached the filter station with an air parcel passing over Greenland at an altitude of 3000 m (Figs. 3A and 4A). The pollen was deposited with downward air movements associated with a 2-h precipitation event of 0.1 mm/h and a more intense event of 0.3 mm/h at 11:00 a.m. Analysis of the 3D backward trajectories shows that few downward air motions occurred during the transport by AP21 whereas stronger downward motions occurred during AP20 (Figs. 3C and 4C).

Because the sampling time of the pollen is weekly, a daily breakdown of when the pollen was deposited was not possible. However, for week 22, the HYSPLIT model indicates two possible scenarios for a single day of deposition in southern Greenland on May 27. In the first, the air parcel reaches Narsarsuaq between ground level and 100 m (Fig. 5A) with a light rain of 0.1 mm/h during 2 h. Upward air movements lifted the pollen grains to an altitude between 500 and 1000 m from the source area, growing region of the trees, on May 15 (Fig. 5B,C), and light downward air motion released the transported grains on the filters (Fig. 5C). The second possibility is that the source area was further north. The model shows an air parcel passing over such an area on May 23 and 24 when the pollen grains could have been released at a higher altitude than the one indicated for the ground (100 m) level (Fig. 6A). This air parcel could have transported the pollen to Greenland over the Canadian Arctic and released the pollen at Narsarsuaq at an altitude of 3000 m (Fig. 6B, C) as observed in previous analyses. Strong upward air motion occurred during the pollen emission, whereas weak downward movements associated with light 0.1 mm/h rain during 6 h in the morning could have resulted in pollen deposition over Narsarsuaq.

4. Discussion and conclusion

The total transported exotic grains was much greater during week 21 than during week 22. Several possibilities may explain such marked differences. First, according to previous investigations on the northern growth limit of these trees, the maximum pollen emission could have been greatly reduced in week 22 (Cambon, 1992, 1994; Cambon et al., 1992), leading to the release of less pollen to the atmosphere. Second, the meteorological conditions for pollen capture could have been less favorable during this week leading to a reduction in pollen transport (weak upward air movements). Third, even given favorable conditions for pollen capture, downward air motion at the filter location could be absent. Fourth, washout by rain during the transport to Greenland associated with turbulence effects would imply a large reduction in the number of pollen grains remaining in the air parcel reaching southern Greenland. Our results clearly indicate that during 2 consecutive weeks, from May 19th until June 1st, pollen grains originating from North America were transported by air parcels reaching southern Greenland at 3000 m. They were deposited on exposed filters at Narsarsuaq associated with washout. However, the occurrence of hemlock in the filter exposed during week 22 (May 26 to June 1), originating from northeastern North America (Thompson et al., 1999a,b), supports the occurrence of low-altitude transport not previously recorded. Thus the pollen transport from North America during the second week, while supported by two pollen grains of hemlock (*Tsuga*), is also attested by other exotic pollen grains. As the pollen trap in Narsarsuaq is exposed directly to the sea, vertical mixing of air masses or re-entrainment of previously deposited grains are difficult reasons to invoke for explaining such occurrence. Furthermore this should also be used to explain the occurrence of the other exotic grains. A similar low number was noticed during the previous year at the same place (Rousseau et al., 2003). According to the model, the air parcel reaching southern Greenland was between ground level and 100 m. Barry et al. (1981) point out that horizontal transport depends upon the differential transportability of the pollen grains, meteorological factors related to the trajectory at a particular altitude and washout probability. It could be argued that not taking into account gravitational settling compromises our interpretation. Although there are currently reliable models of pollen dispersion and transport on local or regional scales (McCartney and Lacey, 1991; Sugita, 1993; Helbig et al., 2004), modeling transport over longer (several thousands of kilometers) distances requires more sophisticated parameterizations. We rely instead on lack of precipitation over the source area during the assumed time interval of pollen capture and reported precipitation events leading to outwash at the station to support our interpretation.

The results show that the transport conditions were more favorable during week 21 (stronger upward and downward air velocity) than week 22, especially for the capture of pollen over the source area. This could partly explain the difference in pollen grains identified on the weekly filters. Figs. 3–6 all show that pollen capture by the air parcels primarily occurred at about noon when the conditions for higher emission have been found to be favorable (Cour et al., 1993). This finding also supports the numerical modeling results of pollen dispersion by Helbig et al. (2004) indicating that in a source area, the maximum pollen concentration, and thus the probability of more pollen being captured by an air parcel, is reached at 12:00 UTC. Conversely, at night, pollen emission and thus the concentration are considerably reduced. Furthermore, the greater abundance of exotic pollen grains identified at Narsarsuaq during the first week is likely to be related to the most favorable period of pollen emission during that interval, very close to the peak pollen emission for most of the identified trees. Greatly reduced pollen emission during the second week may indicate that the emissions occurred at the end of the pollen production interval in addition to the transport conditions being less favorable. The occurrence of rain during the transport reached up to 2.6 mm/h which is enough to remove most of the pollen from the air parcel (Barry et al., 1981). Thus, our results suggest two different air parcel trajectories for the transport of exotic pollen grains to southern Greenland in 2003 from northeastern North America. These air parcels are at different altitudes, which suggests a more complex pattern than previously recorded. Continuing investigations will help further define inter-annual variability in seasonal long distance transport to Greenland.

Although there are currently reliable models of pollen dispersion and transport on local or regional scales (McCartney and Lacey, 1991; Sugita, 1993; Helbig et al., 2004), modeling transport over longer (several thousands of kilometers) distances requires more sophisticated parameterizations. The general transport pattern observed today, which requires atmospheric circulation analyses, could be considered as a control for modeling the last 20,000 years and future climatic conditions affecting the distribution of North American temperate trees (Shafer et al., 2001; Overpeck et al., 2003; Williams et al., 2004). A change in the present local climate conditions in the source area would be likely to affect the timing in the pollen emission as well as the present distribution of the taxa.

Acknowledgement

This study was carried out thanks to the financial support from the French Polar Institute (IPEV). We thank Dr. A.J. Chepstow-Lusty, J. Gavin, and the Boulder 34th International Arctic Workshop participants for comments and remarks. The first author completed this paper during a stay at the University of Bayreuth thanks to a von Humboldt research award. This is ISEM contribution 2006-028 and LDEO contribution 6900. The authors gratefully acknowledge the NOAA Air resources laboratory (ARL) for the provision of the HYSPLIT transport and dispersion model on the READY web site (http://www.arl.noaa.gov/ready.html) and IRI LDEO for the NASA GPCP V1DD global precipitation data (http://iridl.ldeo.columbia.edu/SOURCES/.NASA/.GPCP/.V1DD/) used in this publication.

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