GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 14, 1765, doi:10.1029/2003GL017539, 2003

Long distance transport of pollen to Greenland

Denis-Didier Rousseau,[1,2] Danielle Duzer,[1] Geneviève Cambon,[1] Dominique Jolly,[1] Ulrik Poulsen,[3] Jackie Ferrier,[1] Patrick Schevin,[1] and Robert Gros[1]

Received 16 April 2003; revised 23 May 2003; accepted 2 June 2003; published 26 July 2003.

[1] Four pollen traps were recently placed at coastal sites in East and West Greenland in order to assess long distance transport of pollen to the Arctic domain. By identifying potential vegetation source areas associated with air mass pathways we were able to produce the first detailed record of pollen transport from eastern North America to Narsarsuaq, southern Greenland. The record is based on observations and on a transport and dispersion model used to calculate back trajectories of the air masses. The evidence points to the pollen being transported northward by the air mass over Newfoundland and the Labrador Sea before reaching Narsarsuaq. At this point, the air mass was at an altitude of 3000 m. Deposition of pollen grains occurred with downward air movements associated with a 0.5 mm/h rain. The source areas for these pollen grains differ from those of dust and certain other aerosols that reach the summit of the Greenland Ice Sheet. The results demonstrate the need for continued maintenance and analysis of the Greenland pollen trap data in order to improve our understanding of atmospheric circulation and transport to high northern latitudes. *INDEX TERMS:* 0315 Atmospheric Composition and Structure: Biosphere/atmosphere interactions; 0305 Atmospheric Composition and Structure: Aerosols and particles (0345, 4801); 3322 Meteorology and Atmospheric Dynamics: Land/atmosphere interactions; 3349 Meteorology and Atmospheric Dynamics: Polar meteorology; 1620 Global Change: Climate dynamics (3309). **Citation:** Rousseau, D.-D., D. Duzer, G. Cambon, D. Jolly, U. Poulsen, J. Ferrier, P. Schevin, and R. Gros, Long distance transport of pollen to Greenland, *Geophys. Res. Lett.*, *30*(14), 1765, doi:10.1029/2003GL017539, 2003.

1. Introduction

[2] Although dust and other aerosol tracers have been used to infer both present and past atmospheric circulation patterns [*Biscaye et al.*, 1997; *Bory et al.*, 2002; *Goto-Azuma and Koerner*, 2001; *Kahl et al.*, 1997], other attempts have been made to use pollen as an air mass tracer. Studying the modern pollen deposition in the Canadian Arctic and subarctic, *Ritchie and Lichti-Federovich* [1967] indicate the occurrence of long distance pollen transport of anemophilous trees growing in the temperate North American zone, of Canada and Alaska. *Andrews et al.* [1980], *Bourgeois et al.* [1985], *Gajewski* [1995], *Jacobs et al.* [1985], *Nichols* [1967], *Ritchie* [1974], *Ritchie et al.* [1987], and *Short and Holdsworth* [1985] show different transports according to the distance traveled from local, extralocal, regional to extraregional as defined by *Janssen* [1973]. However, most of these examples correspond to transport of not more than about 500 km. More recently, while sampling snow and ice in the Canadian Arctic, Bourgeois [*Bourgeois*, 2000; *Bourgeois et al.*, 2001] identified the occurrence of seasonal long distance pollen transport along NS transects starting from the Canadian boreal forest zone to the North Pole. In Europe, pollen transport to the Scandinavian Arctic was characterized through an annual survey of pollen sedimentation [*Hicks et al.*, 2001].

[3] Most of these studies lack a regular and quantified survey of the pollen dispersion. With the exception of rare events such as those reaching Northern Europe [*Franzen et al.*, 1994; *Hjelmroos and Franzen*, 1994], or the High Canadian Arctic [*Campbell et al.*, 1999], pollen grains marking long distance transport are generally in very low number. The analysis by *Bourgeois et al.* [2001] of the Arctic Ocean ice supports this interpretation as she determined pollen grains from oak, elm, maple, ash, typical of deciduous forest south of the North American boreal forest but in very low concentration.

[4] A network of four pollen traps have been established at coastal sites in East and West Greenland during the last two years as part of the (EPILOBE Project [*Rousseau et al.*, 2001]) (Figure 1). We present here results for Narsarsuaq (61.15° N, 45.43° W, 1 m asl) (Figure 2A) in southern Greenland whose modern soil samples have yielded allochtonous pollen taxa such as *Pinus* (pine), *Picea* (spruce), *Quercus* (oak) and *Olea* (olive). Greenland is very sparsely

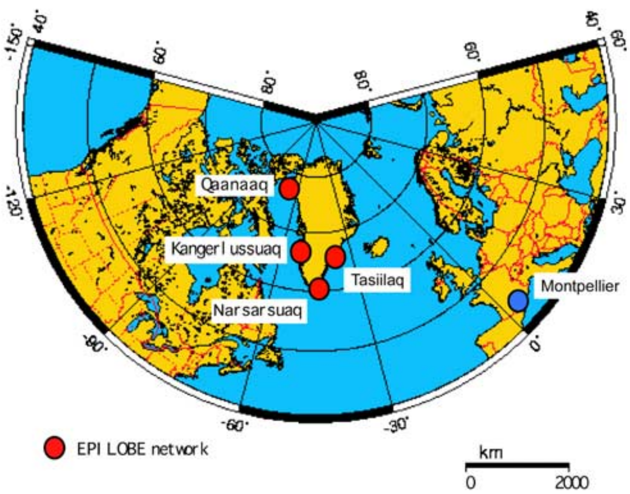

Figure 1. Location the EPILOBE network pollen trap sites, Greenland.

[1]Université Montpellier II, Institut des Sciences de l'Evolution, Montpellier cedex 05, France.
[2]Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY, USA.
[3]Danish Radio-Sonde Station, Narsarsuaq, Greenland.

0094-8276/03/2003GL017539$05.00

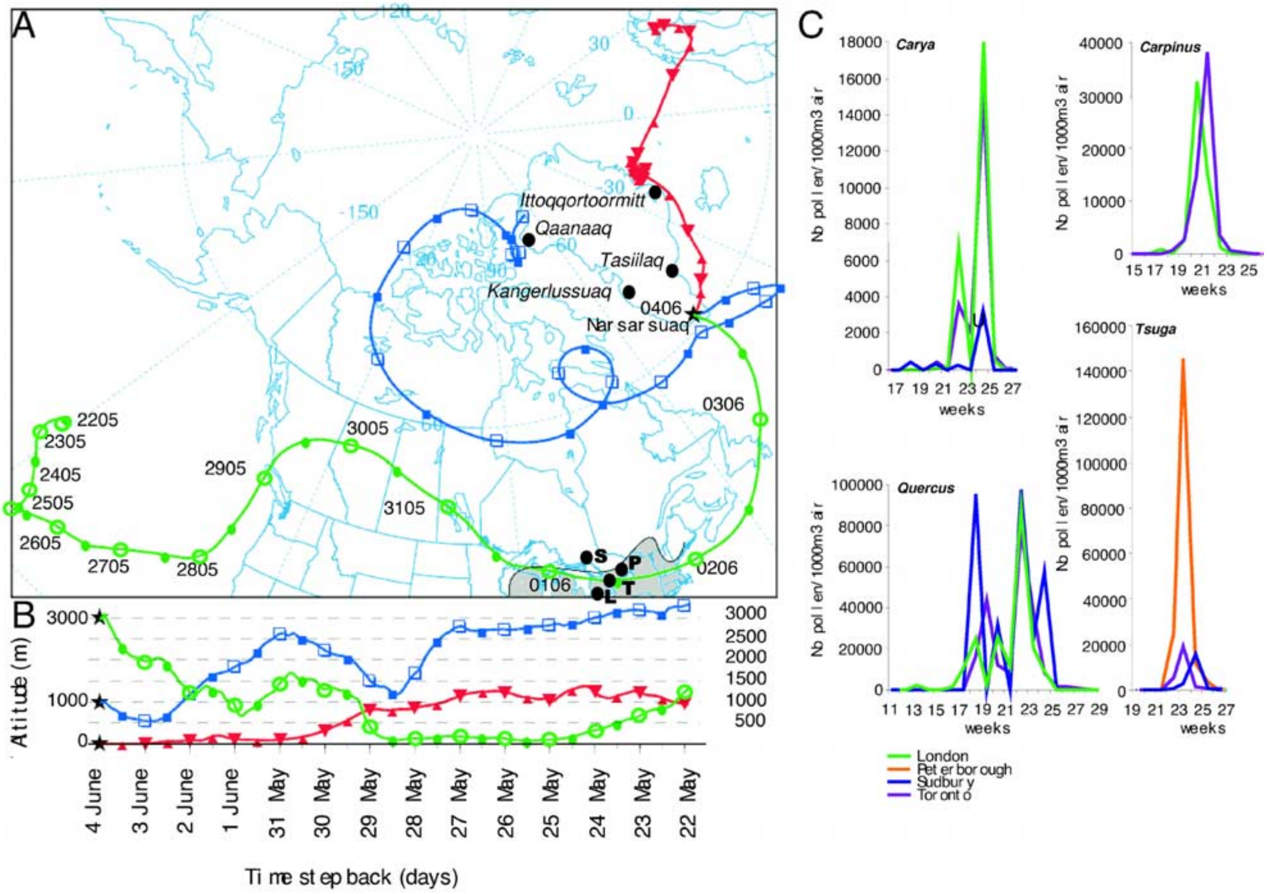

Figure 2. Long distance transport to Greenland. (a) Backward trajectories provided by the HYSPLIT model [*HYSPLIT4Model*, 1997] of air masses reaching Narsarsuaq (61.15° N, 45.43° W, 1 m asl) at different altitudes: ground level (red), 1000 m (blue) and 3000 m (green) on June 4th of 2002.The grey area in eastern USA and south-eastern Canada represents the zone where *Quercus* (oak), *Fagus* (beech), *Carpinus* (hornbeam), *Tsuga* (hemlock) and *Carya* (hickory) are all growing [from *Thompson et al.*, 1999a; 1999b]. The "3000" m air mass passed over this area. L: London, P: Peterborough, S: Sudbury, T: Toronto. (b) Altitude variation of the three air masses used in the backward trajectories analysis. The "3000 m" air mass over Narsarsuaq on June 4th, 2002, was at a lower elevation on June 1st, when it passed over the area where *Quercus*, *Fagus*, *Carpinus*, *Tsuga* and *Carya* are growing. (c) Number of pollen grains captured per thousand of cubic meters of air versus weeks expressed by their yearly occurrence number at four pollen stations located in southern Ontario, Canada (London 43°N, 81.25°W; Peterborough 44.33°N, 78.33°W; Toronto 43.65°N, 79.33°W; Sudbury 46.50°N, 81°W) for *Carya*, *Carpinus*, *Quercus* and *Tsuga*. Week 17 started on April 23, 18 on April 30, 19 on May 7, 20 on May 14, 21 on May 21, 22 on May 28, 23 on June 4, 24 on June 11 and 25 on June 18. [from *Cambon*, 1994; *Cambon et al.*, 1992].

vegetated [*Fredskild*, 1983; *Pennington*, 1980] and has a low pollen productivity compared to North American [*Cambon*, 1994; *Cambon et al.*, 1992] and European [*Cambon*, 1981] regions which simplifies the identification of long distance input. In Narsarsuaq, the local vegetation is composed of shrubs and dwarf shrub of *Betula* (birch), *Salix* (willow), *Juniperus* (juniper), with associated grasses and sedges, typical of low and mid arctic tundra.

2. Results and Discussion

2.1. Pollen Occurrence

[5] Our pollen traps [*Cour*, 1974], unlike the more commonly used Tauber trap, consist of sticky filters mounted on a weather vane, which allows them to be constantly exposed to the wind. The filters are replaced every two weeks at this southern site. In addition to the local vegetation, five taxa, allochtonous to Greenland, have been identified for the period June 3–16, 2002 (23rd and 24th weeks). This is the only time since the installation of the pollen trap, in June 2001, that pollen grains, not indigenous to Greenland, have been found. Among the 5514 counted pollen grains, three are identified as *Quercus* (oak), two as *Fagus* (beech), two as *Carya* (hickory), one as *Tsuga* (hemlock) and two as *Carpinus* (hornbeam) and one as *Juglans* (walnut). Eight grains of *Pinus* (pine) were also found. However, because *Pinus* is so widely distributed and easily transported from different northern areas, we did not include it in our analysis. The shape of the transported pollen grains is severely altered indicating long distance (>1000 km). A replicate analysis of the sample provides similar results.

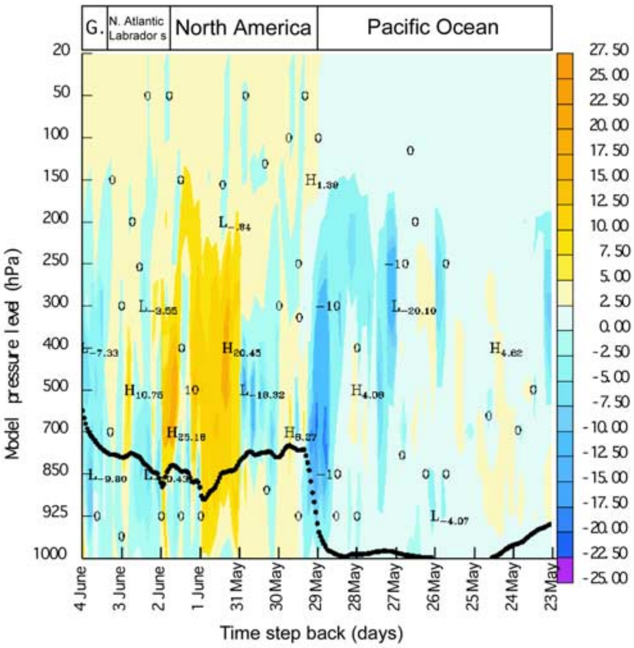

Figure 3. Updrafts and downdrafts in the atmosphere. Velocity of the air mass passing over *Quercus* (oak), *Fagus* (beech), *Carpinus* (hornbeam), *Tsuga* (hemlock) and *Carya* (hickory) growing area in North America and reached Narsarsuaq at 3000 m above the station on June 4, 2002 versus time (see Figure 2 for the geographic trajectory). Yellow to brown values indicate upward movements whereas light blue to pink indicate downward movements. The dark line corresponds to the air mass.

[6] The simultaneous occurrence of *Carya* and *Tsuga* in the same pollen sample suggests that eastern North America is the most probable source of these allochtonous pollen grains. These trees do not grow in Europe but are found in the eastern USA and south eastern Canada [*Thompson et al.*, 1999a; *Thompson et al.*, 1999b] (Figure 2a). Moreover, the pollen emission of oak, beech, hickory, hemlock, hornbeam and walnut pollen grains has been observed in the Ontario region of Canada (in London, Peterborough, Sudbury and Toronto) in 1983 and 1984 by Cambon [*Cambon*, 1994; *Cambon et al.*, 1992] using the same pollen trap system (Figure 2c). The mean monthly temperatures is not significantly different in 2002. The pollen emission data from the four Canadian sampling sites [*Cambon*, 1994; *Cambon et al.*, 1992], are then used to identify the time interval when pollen is emitted to the atmosphere (Figure 2c). It is expected that this region is also representative of the northeastern USA.

2.2. Backward Trajectories

[7] The HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) transport and dispersion model computes trajectories for any place in the world from archives of gridded meteorological data [*HYSPLIT4 Model*, 1997]. HYSPLIT backward trajectories from Narsarsuaq show that an air mass passed over the northern boundary of the range distribution of the identified trees in the eastern USA on June 1st of 2002 (Figures 2a and 2b). The pollen grains would have been carried upward to about the 895 hPa level (about 630 m above ground level) (Figure 3), and then transported eastward over the USA and then northward over Newfoundland and the Labrador Sea to Greenland. They reached Narsarsuaq early in the morning of June 4th with the air mass at an altitude of 3000 m (Figure 2). The pollen grains were deposited with downward air movements associated with a 0.5 mm/h rain in the early morning (Figure 3). The analysis of the 3D backward trajectories shows that several previous downward air motions are likely to have contributed to considerably reduce the number of pollen grains being deposited at this site. The model indicates that just when the air mass passed over the growing area of oak, beech, hornbeam, hemlock and hickory, upward air movements could have lifted the pollen grains to a high altitude during a very limited interval, but long enough to begin their long distance transport.

[8] The identified transport from eastern northeastern North America to southern Greenland took three days. *Barry et al.* [1981] reported a 5 days average duration for a pollen grain to be transported, which is similar to the transport we identified. Comparing these pollen results with those of dust transport to Greenland, it appears that the source of the air masses are not the same Dust in the ice at the summit of the Greenland ice cap has been shown to have originated mostly from the Takla Makan and Gobi deserts [*Biscaye et al.*, 1997; *Bory et al.*, 2002]. However, the atmospheric dynamics for both cases are not the same. The general range in size of pollen grains ($10\ \mu < \text{Size} > 200\ \mu$) place them among the mechanically produced super-micrometer aerosol particles [*Charlson and Heintzenberg*, 1995]. The pollen grains identified at our site range between 20 and 80 μm. Pollen grains of similar size have been identified in snow deposited on the Greenland Ice Sheet and Canadian Arctic ice caps [*Bourgeois*, 1990; *Bourgeois et al.*, 2000; *Short and Holdsworth*, 1985]. Dust on the other hand ranges in smaller size and originated from areas without any vegetation.

[9] Similar to dust or chemical elements, long distance transport of pollen grains requires several conditions. First, the source area must be favorable for both the emission in the air and uplift to a sufficient altitude to be transported. Second, the pollen must remain in the air, and not sink via dry or wet deposition in route towards the sampling station. However, unlike dust, long distance pollen transport must coincide with the timing of the emission of pollen grains in the air. Our case study documents the first long distance pollen transport, from emission to capture. Ongoing analysis is expected to improve understanding of past and present atmospheric circulation and long distance transport of super-micrometer aerosol particles to the high northern latitudes.

[10] **Acknowledgments.** The EPILOBE project is supported by IPEV (French Polar Institute Paul-Emile Victor) grant A-349. We thank J. Gavin, J. Andrews, P. Biscaye, R. Cheddadi, J. Jouzel and D. Raynaud and two anonymous reviewers for comments and critical reading of the manuscript. This is ISEM contribution 2003-033 and LDEO contribution 6473.

References

Andrews, J. T., W. N. Mode, and P. T. Davis, Holocene climate based on pollen transfer-functions, Eastern Canadian Arctic, *Arct. Alp. Res.*, *12*(1), 41–64, 1980.

Barry, R. G., D. L. Elliott, and R. G. Crane, The palaeoclimatic interpretation of exotic pollen peaks in Holocene records from the eastern Canadian Arctic: A discussion, *Rev. Palaeobot. Palynol.*, *33*, 153–167, 1981.

Biscaye, P. E., F. E. Grousset, M. Revel, S. Van der Gaast, G. A. Zielinski, A. Vaars, and G. Kukla, Asian provenance of glacial dust (Stage 2) in the GISP2 ice core, summit, Greenland, *J. Geophys. Res.*, *102*, 26,765–26,781, 1997.

Bory, A. J. M., P. E. Biscaye, A. Svensson, and F. E. Grousset, Seasonal variability in the origin of recent atmospheric mineral dust at NorthGRIP, Greenland, *Earth Planet. Sci. Lett.*, *196*, 123–134, 2002.

Bourgeois, J. C., A Modern Pollen Spectrum From Dye-3, South Greenland Ice-Sheet, *J. Glaciol.*, *36*(124), 340–342, 1990.

Bourgeois, J. C., Seasonal and interannual pollen variability in snow layers of arctic ice caps, *Rev. Palaeobot. Palynol.*, *108*(1–2), 17–36, 2000.

Bourgeois, J. C., K. Gajewski, and R. M. Koerner, Spatial patterns of pollen deposition in arctic snow, *J. Geophys. Res.*, *106*(D6), 5255–5265, 2001.

Bourgeois, J. C., R. M. Koerner, and J. C. Alt, Airborne pollen: A unique air mass tracer, its influx to the Canadian high Arctic, *Ann. Glaciol.*, *7*, 109–116, 1985.

Bourgeois, J. C., R. M. Koerner, K. Gajewski, and D. A. Fisher, A Holocene ice-core pollen record from Ellesmere Island, Nunavut, Canada, *Quat. Res.*, *54*(2), 275–283, 2000.

Cambon, G., Relations entre le contenu pollinique de l'atmosphère et le couvert végétal en Méditerranée occidentale à Montpellier (France), Valencia (Espagne) et Oran (Algérie) Tome I: Texte, Thèse 3e cycle thesis, Univ. é Montpellier II, Montpellier, 1981.

Cambon, G., Modern pollen spectra and vegetation in southern Ontario, Canada, *Rev. Palaeobot. Palynol.*, *82*, 147–155, 1994.

Cambon, G., J. C. Ritchie, and P. Guinet, Pollen marqueur de transports à longue distance dans l'atmosphère du sud de l'Ontario (Canada), *Can. J. Bot.*, *70*, 2284–2293, 1992.

Campbell, I. D., K. McDonald, M. Flannigan, and J. Kringayark, Long-distance transport of pollen into the Arctic, *Nature*, *399*, 29–30, 1999.

Charlson, R. J., and J. Heintzenberg, Introduction: Aerosol Forcing of Climate, in *Aerosol Forcing of Climate*, edited by R. J. Charlson, and J. Heintzenberg, 1–10, Wiley & Sons Ltd, Londres, 1995.

Cour, P., Nouvelles techniques de détection des flux et des retombées polliniques: Etude de la sédimentation des pollens et des spores à la surface du sol, *Pollen et Spores*, *16*(1), 103–141, 1974.

Franzen, L. G., M. Hjelmroos, P. Kallberg, E. Brorstromlunden, S. Juntto, and A. L. Savolainen, The yellow-snow episode of Northern Fennoscandia, March-1991. A case-study of long-distance transport of soil, pollen and stable organic-compounds, *Atmos. Env.*, *28*(22), 3587–3604, 1994.

Fredskild, B., The Holocene vegetational development of the Godthabsfjord area, West Greenland, *Meddr Gronland, Geosci.*, *10*, 3–28, 1983.

Gajewski, K., Modern and Holocene pollen assemblages from some small Arctic lakes on Somerset Island, NWT, Canada, *Quat. Res.*, *44*, 228–236, 1995.

Goto-Azuma, K., and R. M. Koerner, Ice core studies of anthropogenic sulfate and nitrate trends in the Arctic, *J. Geophys. Res.*, *106*(D5), 4959–4969, 2001.

Hicks, S., H. Tinsley, A. Huusko, C. Jensen, M. Hättestrand, A. Gerasimides, and E. Kvavadze, Some comments on spatial variation in arboreal pollen deposition: First records from the Pollen Monitoring Programme (PMP), *Rev. Palaeobot. Palynol.*, *117*, 183–194, 2001.

Hjelmroos, M., and L. G. Franzen, Implications or recent long-distance pollen transport events for the interpretation of fossil pollen records in Fennoscandia, *Rev. Palaeobot. Palynol.*, *82*(1–2), 175–189, 1994.

HYSPLIT4 Model, (HYbrid Single-Particle Lagrangian Integrated Trajectory) http://www.arl.noaa. gov/ready/hysplit4.html, NOAA Air Resources Laboratory, Silver Spring, MD, 1997.

Jacobs, J. D., W. N. Mode, and E. K. Dowdeswell, Contemporary pollen deposition and the distribution of *Betula glandulosa* at the limit of low arctic tundra in Southern Baffin Island, Nwt, Canada, *Arct. Alp. Res.*, *17*(3), 279–287, 1985.

Janssen, C. R., Local and regional pollen deposition, in *Quaternary Plant Ecology*, edited by J. H. B. Birks and R. G. West, 30–43, Blackwell Scientific, Oxford, 1973.

Kahl, J. D. W., D. A. Martinez, H. Kuhns, C. I. Davidson, J. L. Jaffrezo, and J. M. Harris, Air mass trajectories to Summit, Greenland: A 44-year climatology and some episodic events, *J. Geophys. Res.*, *102*, 26,861–26,875, 1997.

Nichols, H., Pollen diagrams from Sub-Arctic Central Canada, *Science*, *155*(3770), 1665–XX, 1967.

Pennington, W., Modern samples from West Greenland and the interpretation of pollen data from the British Late-Glacial (Late Devensian), *New Phytol.*, *84*(1), 171–201, 1980.

Ritchie, J. C., Modern pollen assemblages near arctic tree Line, Mackenzie Delta Region, Northwest-Territories, *Can. J. Bot.*, *52*(2), 381–396, 1974.

Ritchie, J. C., K. A. Hadden, and K. Gajewski, Modern pollen spectra from lakes in Arctic Western Canada, *Can. J. Bot.*, *65*(8), 1605–1613, 1987.

Ritchie, J. C., and S. Lichti-Federovich, Pollen dispersal phenomena in Arctic-Subarctic Canada, *Rev. Palaeobot. Palynol.*, *3*, 255–266, 1967.

Rousseau, D. D., D. Duzer, G. Cambon, J. Ferrier, R. Gros, and D. Jolly, La pluie pollinique au Groenland, *Rap. activité IPEV*, 51–58, 2001.

Short, S. K., and G. Holdsworth, Pollen, oxygen isotope content and seasonality in an ice-core from Penny Ice Cap, Baffin Island, *Arctic*, *38*, 214–218, 1985.

Thompson, R. S., K. H. Anderson, and P. J. Bartlein, *Atlas of relations between climatic parameters and distributions of important trees and shrubs in North America; harwoods*, 423 pp., Geological Survey, U.S., Denver, 1999a.

Thompson, R. S., K. H. Anderson, and P. J. Bartlein, *Atlas of relations between climatic parameters and distributions of important trees and shrubs in North America; introduction and conifers*, 269 pp., U.S. Geological Survey, Denver, 1999b.

D.-D. Rousseau, D. Duzer, G. Cambon, D. Jolly, J. Ferrier, P. Schevin, and R. Gros, Université Montpellier II, Institut des Sciences de l'Evolution, UMR CNRS 5554, case 61, pl. Eugène Bataillon, 34095 Montpellier cedex 05, France. (denis@dstu.univ-montp2.fr)

U. Poulsen, Danish Radio-Sonde Station, DK-3923 Narsarsuaq, Greenland.