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Pollen dispersal and long distance transport: the case of thermophilic pollen in subarctic Canada

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Abstract

At Kuujjuarapik, on the eastern coast of Hudson Bay (Canada), thermophilic tree pollens, all of long distance origin, are found in low concentrations, but throughout the pollen season. A Cour impaction pollen trap has allowed us to obtain statistically significant concentrations. The analysis of the origins of synchronous air masses by back-trajectories shows that the weekly variations of thermophilic pollens can be linked to air masses coming either from northern regions (Alaska or Beaufort Sea) for minima, and southern regions (Gulf of Mexico) for maxima. © 1997 Elsevier Science Ireland Ltd.

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1. Introduction

Pollen flux is a complex reality, notably because it has its origin in many competing sources of different geographic scales (Comtois, 1983). Although, in the interpretation of pollen analysis results, we generally apply the concept of 'black box' (or 'box model') to the pollen rain—i.e. that we consider only the consequences, not the causes—a separation of the different sources is often necessary for the elimination of the filtration effects (Tauber, 1974), or for the determination of the nature of the paleo-ecological fluctuations, climatic changes or plant succession (Comtois, 1982).

One of the most often discussed pollen fluxes is the long distance dispersal (also called extra-regional flux). Indeed, it either constitutes a nuisance to a regional interpretation, or it constitutes the basis of a sparse local flora interpretation, notably in the post-glacial period (Richard, 1977). From an aeropalynological point of view, long distance transport is often used as an indicator of origins of air masses, especially of the North American cells that bring pollutants from a south-west source to a north-east deposition (Comtois and Schemenauer, 1991).

Pollen concentrations, once their dilution have been taken into account, reflect, in large part, the composition of emission at the source. With a view to better determine the nature and the sensibility of these fluxes, spatially and temporally, we have chosen a semi-experimental conjuncture, where the premises and limits of the study are well delimited: the case of thermophilic pollen in the subarctic.

The subarctic constitutes an excellent set-up for long distance transport: its large open spaces are exposed to sedimenting pollen of southern origin, and a relatively small in situ pollen production does not interfere with the visualization of long distance transport (see, in particular Ritchie and Lichti-Federovich, 1967 and Ritchie et al., 1987; and on a more conceptual scale, Prentice, 1985).

2. Materials and methods

The site chosen for our study was Kuujjuarapik (55°22′N; 77°41′W), where the meridional limit of the subarctic reaches eastern Hudson Bay in Northern Canada (see Figs. 3–10 for localisation). Larch (*Larix*

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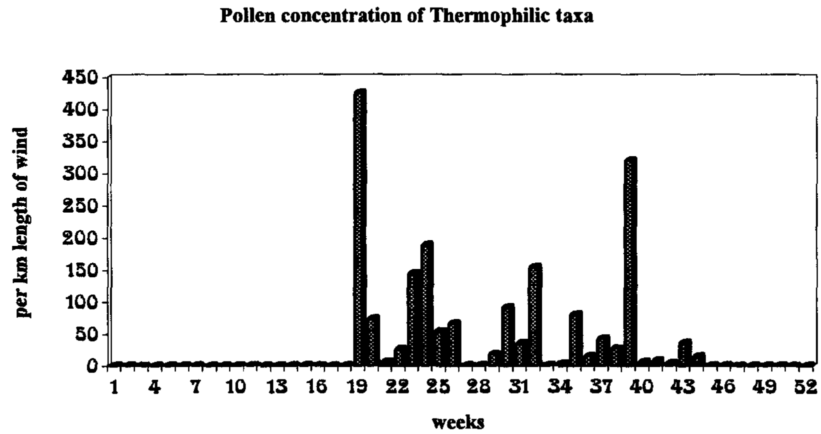

Fig. 1. Weekly concentrations (/km length of wind) of thermophilic tree pollen at Kuujjuarapik, for the year 1986, as estimated with a Cour pollen trap.

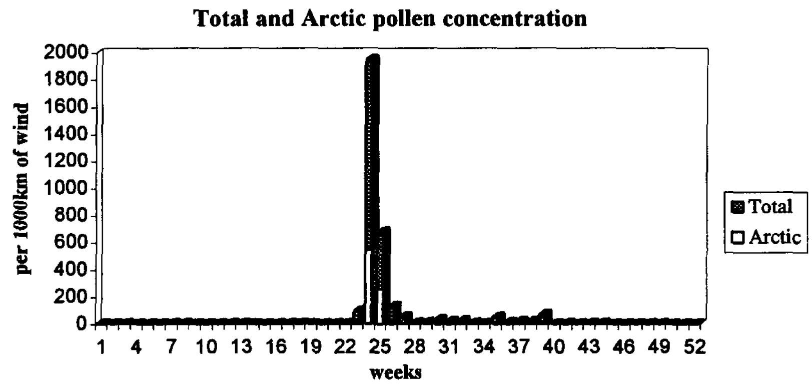

Fig. 2. Weekly concentrations (/km length of wind) of total and arctic species pollen at Kuujjuarapik, for the year 1986, as estimated with a Cour pollen trap.

laricina), white and black Spruce (*Picea glauca* and *Picea mariana*), and Aspen (*Populus balsamifera* and *Populus tremuloides*) constitute the sole arborescent vegetation, which takes the form of a forest-tundra landscape.

2.1. Pollen sampling

A Cour (1974) impaction pollen trap allowed us to register weekly airborne pollen content for all of 1986. However, the present paper will only present data for the length of the meridional pollen season, i.e. from May to October. The Cour methodology use siliconed and sterile filters of 400 cm^2, which are laborious for treatment and analysis, but which allow a qualitatively and quantitatively (by the use of an anemometer) representative sample of the weekly air pollen content to be obtained, notably because it uses a diversity curve (number of pollen grains counted/number of taxa identified), which specifies a determined counting effort (see Durand, 1986 for more methodological details).

The pollen sum of thermophilic trees is the one that is of interest in our analysis. It is defined as the sum of all deciduous arboreal species minus *Betula* (birch) and *Populus* (aspen). It is made up of *Acer* (maple), *Castanea* (chestnut), *Celtis* (hackberry), *Fagus* (beech), *Fraxinus* (ash), *Juglans* (walnut), *Ostrya* (hophornbeam), *Quercus* (oak), *Tilia* (linden) and *Ulmus* (elm). The nearest source of these specific pollen fluxes is the Great-Lakes and St.-Lawrence region (located 1000 km to the south of the studied site). In this study, the thermophilic tree species were chosen because they constitute a flux easy to identify at the genus level, and because the height and amplitude of their emission made it possible for a significant part of their pollen to be transferred to the synoptic scale level.

2.2. Back-trajectories

The origin of the pollen flux was estimated by the synoptic back-trajectories method. Synoptic maps at 850 Mb (a height of ± 2000 m) were used, so that trajectories disturbed by turbulence caused by friction between air layers would not be included in our analysis. The distance between two estimations was calculated as follows: the approximate scale of a synoptic map at the 60°N parallel can be estimated at 1:16 000 000. The mean wind velocity and direction

Table 1
Origin of air masses at 850 Mb (i.e ±2000 m) arriving at Kuujjuarapik in summer of 1986. The approximate scale at the 60°N parallel can be estimated at 1:16 000 000. The mean wind velocity and direction measured at the neighbouring stations of La Grande, Schefferville and Inukjuak allows the determination of the distance between two estimations, and the general direction of the air masses movement. The estimation error is of ±10 km for distance and ±10° for direction. Seven pathways were established for each week (i.e. 1/day). The table shows the % of air masses originating from each source region for each week of the study

Weeks/Origin	Gulf of Mexico	Mid-West	Labrador Sea	Arctic Archipelago	Beaufort Sea	Mississippi Valley	Great Lakes
19	**50**	**25**	**25**				
20	15			70	15		
21		**15**			**85**		
22	**45**	**15**	**25**		**15**		
23		**60**	**40**				
24	55	35					
25					**55**	**45**	
26		55	30			15	
27		30			55		15
28		**15**			**85**		
29		**55**	**15**		**15**		
30	15	55	15	15			
31		**55**		**45**			
32		30		70			
33		30			70		
34		30	30				40
35				100			
36		60		40			
37	40	60					
38	40				45		15
39		60		40			
40		30		70			
41		50		50			

The weeks represented in Figs. 3–10 are highlighted in bold.

measured at the neighbouring stations of La Grande, Schefferville and Inukjuak allows the determination of the distance between two estimations, and the general direction of the air masses movement. The estimation error is ±10 km for distance and ±10° for direction. This operation is repeated every day for the weekly sample.

3. Results

Pollen concentrations of thermophilic tree species are presented in Fig. 1. This pollen curve has a general saw-toothed profile, with a wavelength of 2–3 weeks, and an amplitude of 0.4 pollen grains/m^3. This may seem very little, but it must be remembered that the Cour methodology encompasses the sampling of thousands of cubic meters of passively moving air, so that even small concentrations are significant. In addition, it must be remembered that the local arctic-alpine flora contribute only, on average, 16 pollen grains/m^3 (Fig. 2). Thus, these weak foreign concentrations correspond to an appreciable 3% of the local pollen sum. This sum was dominated by Ericaceae (19%), Rosaceae (14%) and Tubuliflo-cae (7%).

The local pollen sum was dominated by shrub pollen (92%), for which *Betula* and *Alnus* were the dominant taxa (with 48% and 46%, respectively, of the shrub pollen sum), while *Salix* contributed a mere 6%. Local tree pollen (4%) where largely dominated by *Picea*, which accounted for 99% of the tree pollen sum, leaving less than 1% for both *Larix* and *Populus*. The herb sum, on the other hand, was more equilibrated with Cyperaceae accounting for 65% and Graminaceae for 45% of the herb pollen sum.

The thermophilic tree sum was dominated (at 83%) by four taxa: *Quercus* (42%), *Fraxinus* (23%), *Juglans* (23%) and *Ulmus* (7%). All other taxa accounted on average for 2.5% each of the total thermophilic pollen sum, the most abundant of the these less important taxa being *Acer* (4%). An interesting contribution was that of *Pinus*. There is only one *Pinus divaricata* individual in the region of Kuujjuarapik, at about 8 km to the south-east of the sampling site. It can, therefore, be considered either as a local or a foreign pollen. In our study, it was neither considered a thermophilic species nor as a component of the local tree sum. Its contribution to the pollen sum (on average, 5/m^3) was more important than the sum of all the local trees.

For each studied week, the origin of air masses could be linked to one of seven locations: three northern sources (Labrador and North Atlantic, Alaska and Beaufort Sea, or Canadian Arctic Archipelago) and four southern sources (Gulf of Mexico, Mississippi Valley, Canadian West and American Mid-West, or Great-Lakes and St.-Lawrence lowlands).

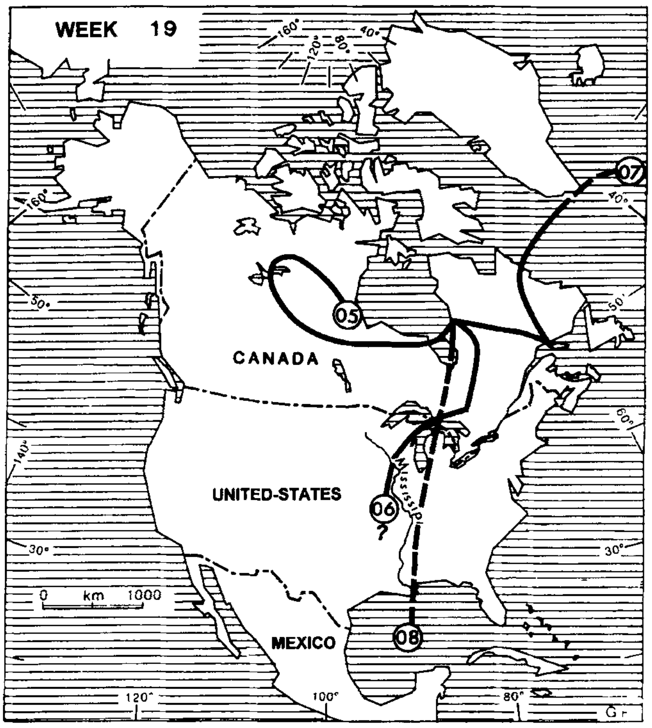

Fig. 3. Back-trajectories from Kuujjuarapik of air masses at 850 Mb for the 19th week of 1986.

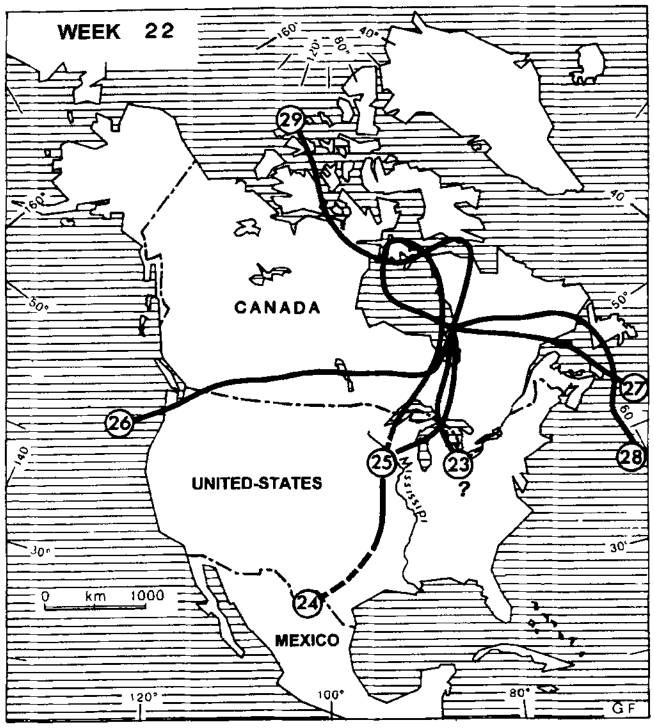

Fig. 5. Back-trajectories from Kuujjuarapik of air masses at 850 Mb for the 22nd week of 1986.

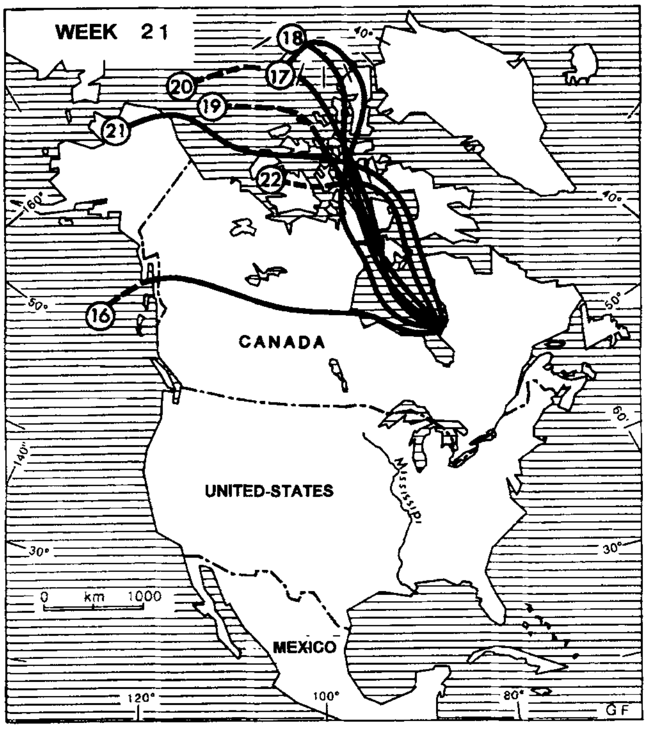

Fig. 4. Back-trajectories from Kuujjuarapik of air masses at 850 Mb for the 21st week of 1986.

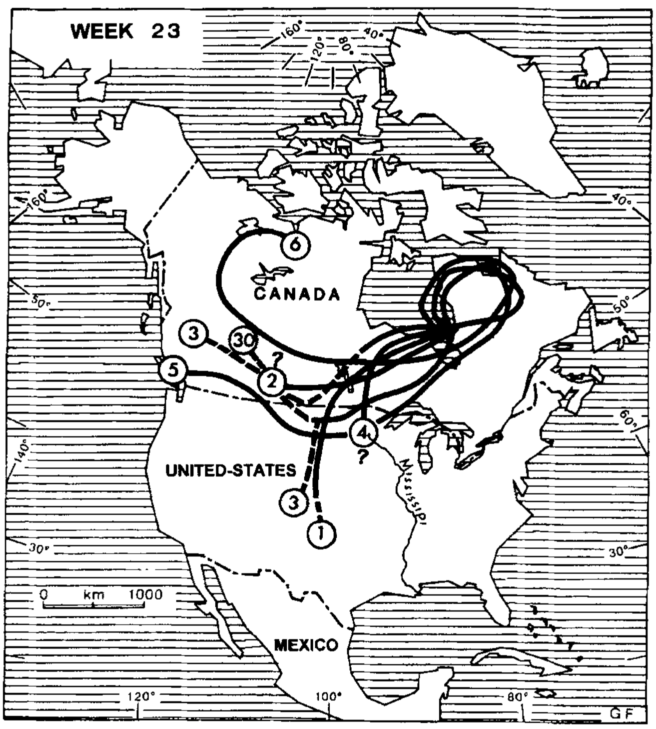

Fig. 6. Back-trajectories from Kuujjuarapik of air masses at 850 Mb for the 23rd week of 1986.

The percentage of trajectories that could be linked to theses sources for each week is presented in Table 1, and a few selected back-trajectories (julian weeks 19, 21, 22, 23, 25, 28, 29 and 31) are presented in Figs.

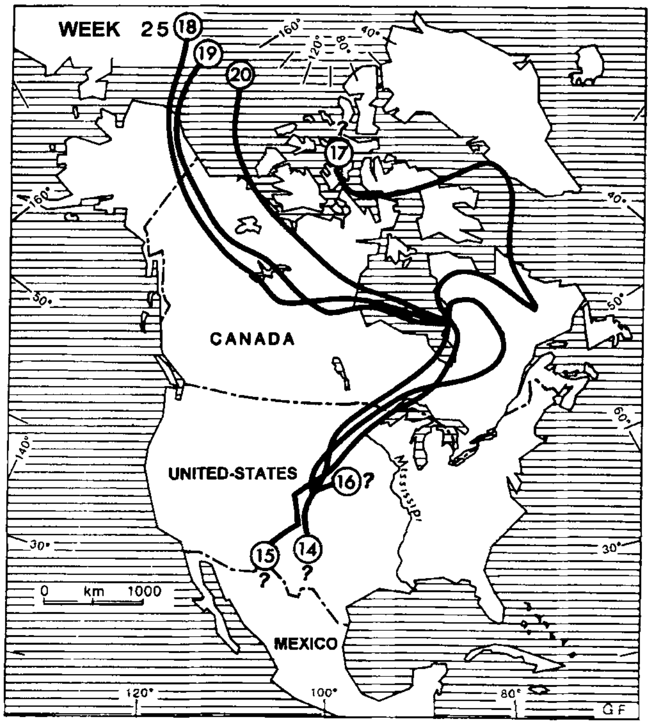

Fig. 7. Back-trajectories from Kuujjuarapik of air masses at 850 Mb for the 25th week of 1986.

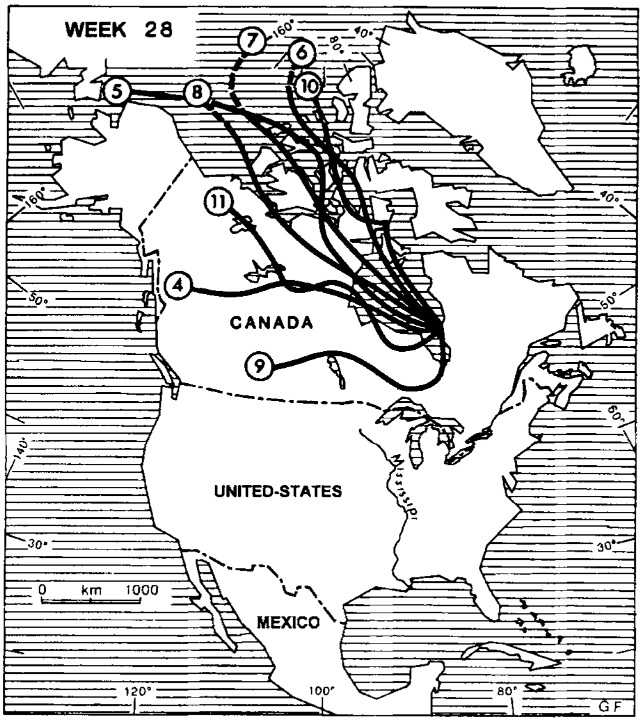

Fig. 8. Back-trajectories from Kuujjuarapik of air masses at 850 Mb for the 28th week of 1986.

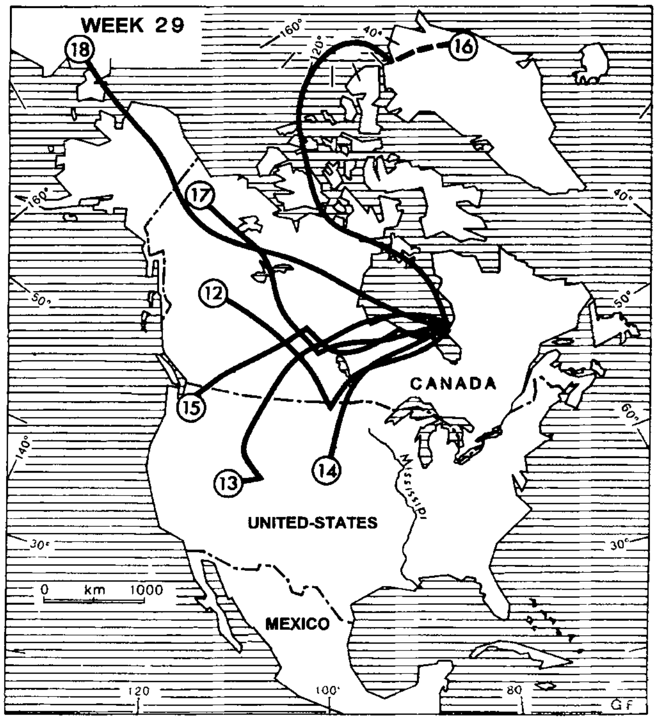

Fig. 9. Back-trajectories from Kuujjuarapik of air masses at 850 Mb for the 29th week of 1986.

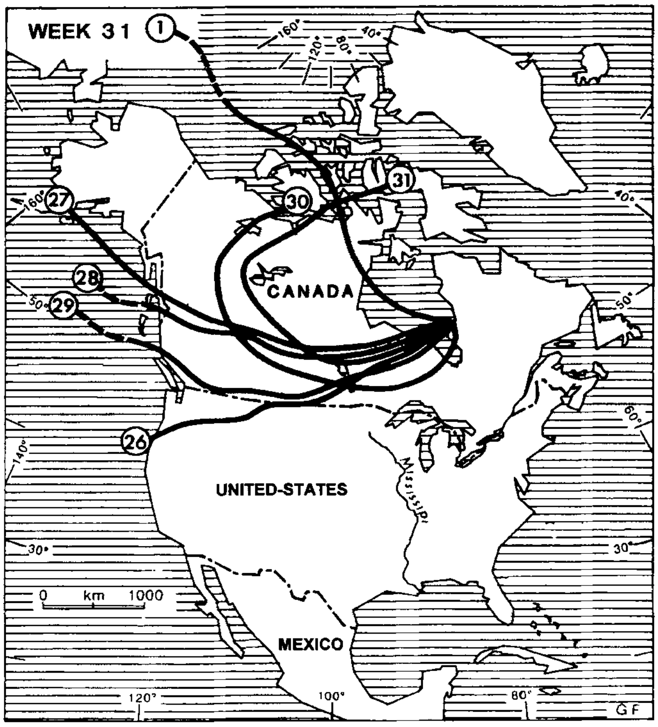

Fig. 10. Back-trajectories from Kuujjuarapik of air masses at 850 Mb for the 31st week of 1986.

3–10. In each case, the maxima of thermophilic pollen representation corresponds to a majority of air masses coming from regional sources at the south or the west of the sampling site. In cases of an absence of thermophilic pollen representation, regional sources could be pin-pointed to northern or Arctic locations.

4. Discussion

In general, thermophilic pollen concentrations are diagnostic of the regions that could be pinpointed by the back-trajectories analysis. However, all these regions do not have the same predictive power. Indeed, as our source index is made of meridional trees, meridional sources can have both a positive and a negative influence on the sum of thermophilic tree pollens. However, the northern provenances can only have, by default, a relative influence.

We believe that it is for this reason that all thermophilic maxima have more or less the same amplitude, and can be the result of less than 55% of air masses being of southern origin. On the other hand, minima need at least 75% of northern air masses to be registered as such. Moreover, the strength of each region in a common origin is not uniform. In the north, Alaska and the Beaufort Sea are truly diagnostic and this is also the case for the Gulf of Mexico in the south. It is to be noted that these two regions are the two regions located at the end of our spectra in North America. The sources in the Canadian West and American Mid-West have little influence, characterize or amplitude modulation, neither maxima nor minima.

5. Conclusions

Long distance pollen concentrations constitute not only an index of the sampled habitat opening, but they are also a powerful indicator of the origin and trajectory of the pollen flux. They, therefore, can be classified as continental scale parameters. The case of the thermophilic tree pollen in the subarctic has allowed us to determine that these fluxes can cover, on average, 2000 km for weekly samples and that the farther the sources are, the more precise will be their diagnostic.

These parameters can add to our interpretation of maxima of thermophilic species in the post-glacial period, notably in Southern Québec. Indeed, they are often observed while there is no evidence of any local vegetation at the sampling site. If the sources of the air masses are also the source of the pollen emission, they will be diagnostic even if they are in competition with other origins. This does not seem to be the case for trajectories inhibiting the long distance transport of thermophilic pollen.

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