Origins of Air Masses over an Alaskan Glacier and Implications for Ice Core Studies in the North Pacific Region

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Abstract

Simulations of 10-day backward trajectories of air masses from Mount Wrangell, an Alaskan ice core site, were calculated for 11 years on a daily basis. Results were analyzed statistically in order to interpret monthly air mass contributions over the ice core site and to discuss implications for ice core studies in the North Pacific Region (NPR).

Increases in tropospheric air mass transport from EA in spring suggest favorable transport conditions for Asian dust during this season. The transpacific air mass (< 300 hPa) over the ice core site increases in winter and that from East Asia (EA) to the North Pacific Ocean in late spring. The tritium peaks observed in the ice core in late spring were discussed in the context of the present results with two possibilities on the time lag of tritium transportation in the stratosphere and the seasonal variations of water vapor amount in the troposphere. Increases in air masses originating from Siberia, Alaska and Canada in summer-fall favor the transport of black carbon due to forest fires over the ice core site. These results allow advanced interpretation of the origin and transport processes of materials in the ice core proxies in the NPR.

1. Introduction

The North Pacific Region (NPR) is subject to seasonal variation in pollutants in the troposphere, such as Asian dust outbreaks in spring and black carbon from wildfires in summer in boreal forest regions such as Siberia, Alaska and Canada (e.g., Sun et al. 2001; Langmann et al. 2009). The trans-Pacific transport of aerosols including Asian dust and black carbon is well known (e.g., Darmenova et al. 2005; Hadley et al. 2007). In addition, stratospheric material intrusions into the troposphere associated with Asian dust storms in East Asia have also been discussed (Kim et al. 2002; Yasunari et al. 2007; Yasunari and Yamazaki 2009). Therefore, the NPR is an important region for understanding material circulation.

Ice cores provide direct information on past atmospheric material concentrations. Several ice cores have been drilled so far in the NPR. These ice core sites are Mount Logan (Holdsworth et al. 1992; Shiraia et al. 2003) and Eclipse ice field (Wake et al. 2002), Canada, Mount Ushkovsky and Mount Ichinsky, Russia (Shiraia et al. 2001; Matoba et al. 2007) and Mount Bona Churchill (Zagorodnov et al. 2005) and Mount Wrangell, Alaska (Shiraia et al. 2004; Yasunari et al. 2007). The ice cores at Mt. Logan, Mt. Wrangell, Mt. Bona Churchill and Eclipse ice field can be used to assess the variations in the trans-Pacific transport of materials in the NPR. The ice core sites are located close together in the synoptic weather changes may affect their sites simultaneously. However, it is difficult to directly obtain air mass and material origins from ice core proxies. Therefore, understanding the origins of transported air masses at the ice core sites in the NPR is essential, with implications for the interpretation of ice core proxies. This study focuses on the Mount Wrangell ice core site, which is considered as a representative ice core site in the NPR, to investigate and discuss monthly air mass origins in this region. Although there have been some statistical trajectory analysis studies for understanding suspended material origins in the Alaskan atmosphere (e.g., Polissar et al. 1999), there have been few focusings on the NPR ice core sites for more than 10 years. In this study, useful information is provided for understanding monthly-seasonal air mass transport patterns over the Alaskan ice core site by statistical trajectory analysis, leading to progress in the interpretation of ice core proxies in the NPR.

2. Statistical backward trajectory analysis

A 10-day backward trajectory analysis was performed on a daily basis in order to understand the air mass origins over the ice core site of Mount Wrangell from 1992–2002 (11 years), the period over which the ice core extends (Yasunari et al. 2007). This trajectory model was constructed based on the Lagrangian tracking method (Yamazaki 1986). The validity of this trajectory model was verified in the case studies (Yasunari et al. 2007; Yasunari and Yamazaki 2009). A 10-day period was chosen as long enough for Asian dust to reach the site based on the result of Yasunari et al. (2007) (see supplementary text). Three-dimensional wind data from the ECMWF operational analysis data (2.5° × 2.5° horizontally; 15 layers vertically from Jan. 1992 to Mar. 1999 and 21 layers after Apr. 1999) for 01/1992–12/2002 were used for the calculations. The top level of the data is 1 hPa. The wind was linearly interpolated in the horizontal direction and interpolated with a cubic spline function in the vertical direction over time. Initial air parcels were set in the region 143.02°W–145.02°W, 60.59°N–62.09°N and 500–700 hPa in pressure level. This initial region (Wrangell Area) covers the...
summit of the Mount Wrangell ice core site (62°N; 144°W; 4100 m above sea level, Fig. 1). A total of 125 air parcels were set in the initial region for the first time step. Then, the total number of air parcels after each 10-day calculation at each defined pressure level (> 700 hPa, 700–300 hPa, and < 300 hPa) in each defined area (Fig. 1) per month were counted. The arrival day of the air mass to the ice core site was used to classify trajectories into months. Then, the percentage of monthly air mass contributions was estimated by dividing by the total number of air parcels in each month. This method is similar to equation (6) in Polissar et al. (1999). The following days were excluded for the calculations due to model and data problems: 1992/1/1–1992/1/10; 1995/10/28; 1996/1/1–1996/1/10; 1997/2/5; 1998/9/1–1998/9/10; 1999/4/1–1999/4/10; 2001/12/31; 2002/2/9. However, the total number of calculations in each month was at least 20 days, presenting no problem for the statistical analyses in this study.

3. Results and discussions

3.1 Monthly origins of transported air mass

Monthly transported air mass frequency to the Mount Wrangell ice core site from each origin and altitude level was calculated as a percentage of the total number of air masses in each month (Fig. 2). Firstly, the results were checked for each defined area (not shown). Then, areas were combined into groups for easy comparison. Hereafter, we refer to the areas containing SI+ER+OB+RU as Group Russia (GrRU), NP1+NP2 as Group North Pacific (GrNP), NAO1+NAO2+NAO3+MC+AM as Group Atlantic (GrAT), EU+NE as Group Europe (GrEU) and IS+NA+OA as GrLess.

Air masses were mainly transported from adjacent sectors of the NPR (EA, GrRU, AL, GA, GrNP, JP, CA and AO) except for SEA, NA and MC in the troposphere (> 300 hPa). The contributions from GrAT and IS were relatively low (Fig. 2). Air masses were mostly transported to the ice core site from the middle troposphere (700–300 hPa) (Fig. 2b). The least contribution came from the upper troposphere to the stratosphere (< 300 hPa; Fig. 2a).

In spring, air masses from EA in the lower and middle troposphere increase and can easily transport Asian dust to the Mount Wrangell ice core site if Asian dust outbreaks occur (Figs. 2b and 2c). In fact, Asian dust outbreaks occur most frequently in spring (March, April and May) in EA (e.g., Sun et al. 2001; Kurosaki and Mikami 2003), suggesting that Asian dust may often suspend in the atmosphere in spring. Therefore, spring is considered to be the most likely season for transport of Asian dust to the North Pacific ice core sites.

In summer-fall, air mass contributions from many areas decreased, but those from the North Pacific Ocean (GrNP and GA) increased (Fig. 2c). This indicates that sea-salt aerosols from the North Pacific Ocean may be easily transported to the ice core sites at this time of year. In a case study, sea-salt (sodium) was transported from GA to the King Col. ice core site Canada (Yalcin et al. 2006). However, for determining the factors affecting seasonal peaks of sea-salt proxies in ice cores, it is also important to consider snowfall amount and sea-salt scavenging processes on the way to the ice core sites. For instance, in the Eclipse ice core, Na+ decreases were mainly seen in summer (Wake et al. 2002). The sodium data for the Mt. Wrangell ice core has not been published and its seasonality is as yet unknown. The rainy season in southern Alaskan areas is summer-fall and then the snow accumulation at the Wrangell ice core site increases too (Manley and Daly 2005; Kanamori et al. 2008). The large amount of snowfall may dilute sea-salt proxies in summer in the ice cores in the NPR. Further discussion of the relationship between sea-salt peaks in the ice cores and amount of snowfall is required in future studies.

In summer-fall, wildfires in boreal forest regions such as SI, AL and CA are active (e.g., Langmann et al. 2009). The mean 1000–700 hPa air mass contributions from these areas (Fig. 3) increased in summer-fall. This implies that air masses from areas of wildfire in SI, AL or CA may easily reach the Mount Wrangell ice core site and other such ice core sites in the NPR in summer-fall. This supports the case of the transportation of soot from Alaskan wildfires (Kim et al. 2005). In conclusion, forest fire proxies such as black carbon are most likely to impact on ice cores in the NPR in summer-fall.

In fall-winter, air masses of various continental origins contributed to the ice core site, including EA,
In this study, air mass origins at an Alaskan ice core site and their seasonal variation were modeled. Simulations of 10-day backward trajectories of air masses were conducted to understand the transport of aerosols and tritium to the ice core site. The results suggest that there are two main sources of aerosols: one from the lower stratosphere and another from the troposphere. The lower stratospheric source is mainly influenced by Asian dust outbreaks, while the tropospheric source is influenced by both Asian dust and local sources.

### Table 1. Estimated seasonal mean concentrations of fine dust and tritium from Mount Wrangell ice core flux data in 1992–2002 by Yasunari et al. (2007).

<table>
<thead>
<tr>
<th>Particle</th>
<th>ES-LS</th>
<th>LS-SU</th>
<th>SU-FA</th>
<th>FA-WI</th>
<th>WI-ES</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine dust</td>
<td>59405</td>
<td>11.92</td>
<td>42995</td>
<td>10.17</td>
<td>35794</td>
<td>(Particles/mL)</td>
</tr>
<tr>
<td>Tritium</td>
<td>11.92</td>
<td>10.42</td>
<td>35794</td>
<td>6.45</td>
<td>40235</td>
<td>(TU)</td>
</tr>
</tbody>
</table>

ES, LS, SU, FA and WI denote Early spring, Late spring, Summer, Fall, and Winter, respectively.

The result shown in Fig. 3 supports black carbon contributions due to wildfires. Although anthropogenic total black carbon emission from China has been increasing since about 1970 (e.g., Novakov et al. 2003), no clear increasing trend of fine dust concentration in the ice core of Yasunari et al. (2007) may be attributed to a lower contribution from continental regions to the ice core site, especially from East Eurasia (Fig. 2) and also the rainy season in southern Alaska (Manley and Daly 2005; Kanamori et al. 2008).

### 3.3 Implication for tritium variation

It is well known that tritium is made by cosmic rays in the stratosphere and is transported to the troposphere. The transport of air mass from the stratosphere to the troposphere shows a January maximum (Fig. 2a). However, tritium concentration in the Mount Wrangell ice core shows a late-spring maximum (Table 1). This discrepancy requires explanation.

One possible explanation is the tritium concentration just above the tropopause may peak in spring. The concentration of tritium is higher in the upper-middle stratosphere and lower in the lower stratosphere (Ehhalt et al. 2002). The tritium in dense concentration may be transported toward the tropopause during winter, likely taking about two months to reach the tropopause in spring.

Another possible explanation is related to the meridional gradient of tritium. Tritium mainly may exist in a form of water vapor (HTO) and its concentration may decrease with latitude. In winter, the stratospheric air mostly comes from high latitudes where water vapor is low and possibly ineffective at transporting tritium to the ice core site. The effective transport route is considered to be along lower-latitude East Asian storm-track. The transport of tritium from EA to the North Pacific Ocean at < 300 hPa peaks in May (Fig. 3). It may cause efficient tritium depositions by snowfall at the ice core site.

Since few observations of tritium in the lower stratosphere and the troposphere have been made, further observational and modeling studies are required to explain the seasonal variation of tritium at the ice core site.

### 4. Conclusion

In this study, air mass origins at an Alaskan ice core site and their seasonal variation were modeled. Simulations of 10-day backward trajectories of air masses were conducted to understand the transport of aerosols and tritium to the ice core site. The results suggest that there are two main sources of aerosols: one from the lower stratosphere and another from the troposphere. The lower stratospheric source is mainly influenced by Asian dust outbreaks, while the tropospheric source is influenced by both Asian dust and local sources.
made on a daily basis from 1992–2002, corresponding to the period covered by the Mount Wrangell ice core by Yasunari et al. (2007). Major air masses affecting the ice core site were found to come from the North Pacific Ocean and adjacent continental regions. However, care must be taken when discussing material origins since source intensity, distributions, seasonality and wet and dry deposition processes should also be taken into account. In addition, results depend on the period to some extent. The model does not include cumulus effects and the turbulent mixing effect and those will be future studies. Thus, the results presented in this study should be taken as a rough estimate of material origins.

This study has shown that pollutants from spring Asian dust storms in EA and summer biomass burning in SI, AL and CA can easily reach the ice core sites in the NPR. The air mass transport above the 300 hPa level increases in winter and that from the EA+JP+NP1-GA region increases in late spring. The tritium peak observed in the ice core in late spring was discussed in the context of the present results with two possibilities on the time lag of tritium transportation in the stratosphere and the seasonal variations of water vapor amount in the troposphere.

In conclusion, this study provides information clarifying the origins of ice core proxies in the NPR and is useful for understanding material circulation in the NPR.

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Supplement

1. The reason why we chose 10-day backward trajectory analysis in this study and points to notice to use the results of statistical trajectory analysis are included as supplementary text.

References


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