Dear Dr. Peter Neff and two Anonymous Reviewers,

Thank you very much for your comments to our manuscript. Following to your comments, we added supplemental explanations to the text and described some answers for your questions as below.
We hope that our answers clarified your questions.
Revised Table and Figure show are attached at the end of this letter.

Sincerely yours,

Akane Tsushima

Response to Dr. Peter Neff.

Many thanks for your comments to our manuscript. Your comments have helped us to improve the paper significantly.

The Aurora Peak ice core is a very intriguing addition to the growing archive of alpine ice cores from Kamchatka, Alaska, the Yukon and British Columbia. From information presented in this manuscript, the Aurora Peak record appears well-dated for the 20th century, contributing valuable records of water stable-isotopes, major-ion chemistry, and snow accumulation to considerations of regional climate in the recent past.

Exploration here of relationships between the ice core record and instrumental climate data is not entirely clear. While a meaningful relationship appears to exist between deuterium, regional temperature data, and the Pacific Decadal Oscillation Index (an index which is not broadly discussed or even introduced in this manuscript), only basic correlations are presented and for relatively long-term averages. For instance, 6-year average correlations between deuterium and weather station data are presented, and average values over often-discussed multi-decadal "shifts" in the PDOI.
This work would benefit greatly by exploring synoptic climate data available for the past 30-50 years from reanalysis efforts (e.g. NCEP or ERA-Interim) to support assumed physical mechanisms driving recent increases in accumulation rate and regional temperatures.

Considering that the PDOI is a measure of N. Pacific sea surface temperature, investigating correlations between ice core data and reanalysis SST would certainly prove valuable.

Spatial correlations between sodium and geopotential heights, may also provide insight into whether or not increasing storminess is the cause of observed increases in sodium since the 1970s at Aurora Peak.

This is likely associated with the Aleutian Low, the well-known center of low-pressure that strongly influences winter storms along the west coast of North America (see Rodionov et al., 2007). Similarly, relationships between deuterium and geopotential height may clarify the effects of temperature and changing moisture source regions on deuterium values seen at Aurora peak.

Moisture source effects on water stable-isotopes are currently not discussed in the manuscript.

Again, this ice core record represents a very valuable contribution to climate research in the North Pacific, and will be interesting to compare with developing records such as that recently retrieved near Denali (Alaska). Careful work must be done to better understand physical mechanisms driving the relationships described in this discussion paper.

Response: As you mentioned above, comparison between ice core data and reanalysis meteorological data is important to interpret the chemical signals in the ice core. However, in this paper we consider that it is extremely important to compare ice core record with surface observation data sets. Fisher et al. (2004) assumed that moisture source has been changed along with altitude, which were known by comparison of stable water isotope of PR Col (5340 m a.s.l.), King Col (4135 m a.s.l.) and Eclipse ice field (3017 m a.s.l.). Since Aurora Peak is located at lower altitude (2825 m a.s.l), compared to Eclipse ice field (3017 m a.s.l.), we considered that stable water isotope from Aurora Peak may reflect the local surface climate condition better than Eclipse ice field. Therefore, in this paper, we focus on comparison between ice core record and surface observation data sets. We would like to present the discussion with reanalysis data in the next paper.

Specific comments:

Section 1. The introduction here is generally thorough and clear, but could better in- corporate contributions to research in the North Pacific from additional cores drilled at Mt. Logan, Eclipse Icefield, etc. These records have been exhaustively examined, especially with respect to temperature, precipitation, water stable-isotopes and snow accumulation.

Response: Following to your comments, we added supplemental explanation about ice core studies in the North Pacific region (p. 1423, line 3) as follows;

"In the northern North Pacific region, several ice cores have been drilled to study preoclimate change: e.g., Mt. Logan, Eclipse ice field and Mt. Wrangell (Holdsworth et al., 1992; Moore et al., 2001; Yalcin and Wake 2001; Goto-Azuma et al., 2003; Shiraiwa et al., 2003; Fisher et al., 2004; Zagorodnov et al., 2005) (Table 1). For example, annual accumulation rates and the seasonal variation of Na^+ concentration have been reported from Mt. Logan ice core (Holdsworth et al., 1992; Shiraiwa et al., 2003). The chemical variation have been reported from Eclipse ice field snow pit observation and ice core drillied in 1992 and 2002, respectively (Yalcin and Wake 2001; Yalcin et al., 2006). Especially, Fisher et al. (2004) mentioned that moisture source has been changed along with altitude, which were known by comparison of stable water isotope of PR Col (5340 m a.s.l.), King Col (4135 m a.s.l.) and Eclipse ice field (3017 m a.s.l.). Aurora Peak is located at lower altitude (2825 m a.s.l) relative to Eclipse ice field (3017 m a.s.l.), therefore we considered that stable water isotopes of Aurora Peak has reflected the local surface climate condition better than Eclipse ice field." To reconstruct ~

Section 2. The methods here are well described and clear. -What is the assumed pore close-off density reported here at 55m?

-Are all samples reported here at 0.1 m resolution? The deuterium data looks like higher-resolution, but this is unclear.

Response: We added vertical profile of the density of ice core (Fig. 2). We defined the ice core density of 0.85 g cm^{-3} as the closed-off depth. The average density from 55-m to 180-m was 0.90 g cm^{-3}.

Chemical species and stable hydrogen isotope were also analyzed at 0.1-m resolution and shown on Fig. 2. In Fig.2, we showed the position of reference horizon for determining the ice core dating.

Section 3. 3.1 The ice core chronology is generally clear and quite robust. Wintertime minima (maxima) in deuterium (sodium) values are clear, and supported by melt features for the section presented in Figure 2. Forest fire, bomb, and volcanic markers are convincing.

3.2 The extreme increase in snow accumulation is interesting, and possibly worth closer examination here to better demonstrate that it is not an anomaly due to any part of the density correction, ice flow calculation, or any other unforeseen cause.

-Why was a flank flow value chosen for the critical depth in the Dansgaard-Johnsen model? This would not make a very large difference, but divide flow may be more appropriate for the Aurora Peak site considering the small measured horizontal motion from Fukuda et al., 2011.

-It would be good to state or show how well the modeled depth-age relationship matches that observed from the ice core chronology, especially considering that snow accumulation rate, which relies on a good ice flow correction, is a fundamental aspect discussed in the rest of the paper.

Response: It might be the best way to calculate of the ice flow by a sophisticated new flow model for this glacier. However, it is difficult to develop the new model with limited since it is known to be applied not only to ice sheets but also to blow line of a glacier available data at present. Therefore, we used D-J model (Dansgaard and Johnsen, 1969).

We think critical depth "h" is important to calculate vertical strain with D-J model. However, it is very difficult to decide the value of "h" correctly at present. Therefore, we re-calculated accumulation rate with h=0.25H, 0.40H, and 0.60H to evaluated the effect of "h" value on the accumulation rate time-series. The results show that the differences of calculated annual accumulation rate with various "h" values are negligible after 1900, but are quite large before 1900. Therefore we set the "h" to 0.25H and discuss the accumulation rate only after 1900 in this paper. To discuss the bottom part of the ice core, we need to develop an appropriate flow model for this glacier in the further studies.

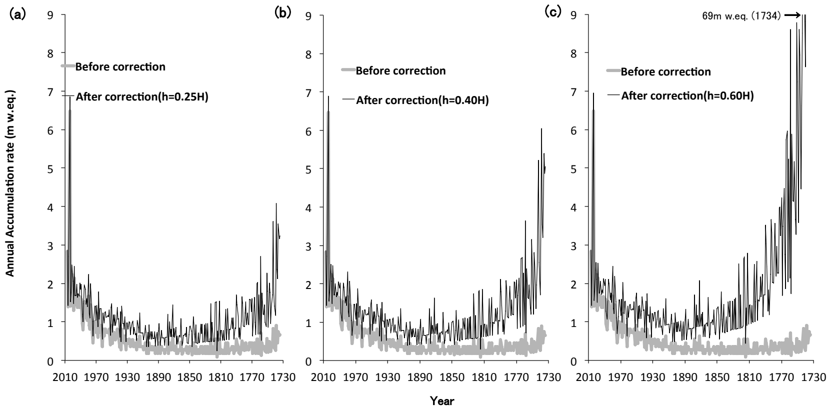

Fig. a Annual layer thickness of the Aurora Peak ice core (heavy gray line) and annual accumulation rate corrected by the Dansgaard-Johnsen model (black line). (b) critical depth “h” is 0.25H, (b) critical depth “h” is 0.40H, and (c) critical depth “h” is 0.60H.

Section 4. -Why were 6-year averages chosen for comparing deuterium and snow accumulation to regional climate observations? What do the correlations look like for 1- year? 3-years? Presumably the correlations will increase as you average over greater lengths of time. . .

-What might cause areas of southeast Alaska to show the highest correlation between temperature and deuterium (Figure 5)?

-There is a wealth of information about temperature and precipitation trends in Alaska, most recently Bienek et al. (2014) in Journal of Climate (and references therein).

http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-13-00342.1

This analysis of regional and temporal trends for Alaska does not necessarily illustrate a clear influence of the PDO on Alaskan climate, but does support some state-wide co- herence in temperature trends as opposed to highly spatially- and temporally-variable precipitation. The applicability of this data to mountainous regions, however, is not clear and represents a major challenge of interpreting alpine ice core records.

-The PDOI is not well-discussed or introduced. Simply referencing literature possibly does not provide enough of a foundation for the reader’s understanding. The PDOI is the first principal component of N. Pacific sea surface temperature variability (poleward of 20N). This impacts how one considers PDO impacts on temperature and precipitation.

Response: The age of the Aurora Peak ice core has dating error of ±3 years. Therefore we chose 7-year running averages. We then revised figures 5, 6 and Table 2.

In northern North Pacific region, there are many studies on relation between PDO and climate change. In Alaskan region, it was reported that climate condition (e.g. air temperatures and precipitation amounts) and glacier mass balance have reflected PDO (Walter and Meier, 1989; McCabe and Fountain, 1995; Mantura et al., 1997; Papinea, 2001; Rodionov at al., 2007; Bienek at al., 2014). Our results suggest that stable hydrogen isotope and annual accumulations of Aurora Peak ice core reflect surface air temperatures and precipitation amounts of Alaska, respectively. We consider that stable hydrogen isotope and annual accumulations of Aurora Peak ice core also might have a relationship with PDO. This is the reason why we compared Aurora Peak ice core record with PDOI.

We added supplemental explanation about relationship between PDO and Alaskan climate condition and definition of PDO index (p. 1429, line 19) as follows;

"In northern North Pacific region, there are many studies on relation between PDO and climate change. In Alaskan region, it was reported that climate condition (e.g. surface air temperatures and precipitation amounts) and glacier mass balance have reflected PDO (Walter and Meier, 1989; McCabe and Fountain, 1995; Mantura et al., 1997; Papinea, 2001; Rodionov at al., 2007; Bienek at al., 2014). The Pacific Decadal Oscillation index (PDOI) was introduced by Mantua et al. (1997) and is based on an empirical orthogonal function (EOF) analysis of sea-surface temperature (SST) in North Pacific, north of 20°N. In an analysis of an ice core from Mount Logan (5343 m a.s.l.), Moore et al. (2002) found that annual accumulation increased slightly from 1850 to 2000, and sharply from 1976. They suggested that the sharp increase in annual accumulation after 1976 was associated with a shift in the Pacific Decadal Oscillation index (PDOI). Our results suggest that stable hydrogen isotope and annual accumulations of Aurora Peak ice core reflect surface air temperatures and precipitation amounts of Alaska, respectively. We consider that stable hydrogen isotope and annual accumulations of Aurora Peak ice core also might have a relationship with PDO. This is the reason why we compared Aurora Peak ice core record with PDOI."

-Figure 7 is problematic. A linear regression of three data points is not incredibly useful, and an R-squared of 1.0 in a natural system of any kind should not be expected. What would this plot look like if annual values of deuterium and the PDOI were plotted? There may still be a linear relationship. One must be careful with averaging. What would 2- year, 5-year, or 10-year averages look like? There does seem to be a meaningful relationship between deuterium and the PDOI, so don't average it away. The next challenge is exploring the physical mechanism behind correlation of the

Bienek PA, Walsh JE, Thoman RL and Bhatt US (2014) Using climate divisions to ana- lyze variations and trends in Alaska temperature and precipitation. Journal of Climate, Vol. 27, 2800-2818.

Rodionov SN, Bond NA and Overland JE (2007) The Aleutian Low, storm tracks, and winter climate variability in the Bering Sea. Deep-Sea Res. II, 54(23–26), 2560–2577 (doi: 10.1016/j.dsr2. 2007.08.002)

PDOI and water isotopes at Aurora peak.

Response: As noted above, we chose 7-year running averages by considering the dating error. Then we revised Fig.5 and we removed Fig.7.

■■

■■

Response to Reviewer#1.

Thank you very much for your comments to our manuscript. Your comments have helped us to improve the paper significantly.

Review of Tsushima et al., "Reconstruction of recent climate change in Alaska from the Aurora Peak ice core, central Alaska"

For *Climate of the Past* May 7, 2014 General comments

The authors present a new ice core record from central Alaska, and attempt to interpret changes in stable isotope ratios and accumulation rate primarily in terms of the Pacific Decadal Oscillation. Overall, I applaud the authors for their work in developing this dataset; there is a great need for additional ice core records from the North Pacific region that can be used accurately to reconstruct ocean/atmosphere variability over the past millennium. Alpine ice cores such as these are a significant logistical and analytical challenge. The data the authors present appears to have been collected and analyzed with great care; I have no serious concerns about data quality or the laboratory analytical techniques used. I do have several fundamental problems with the author's data interpretation (namely time scale construction, layer thickness correction for ice flow, climate correlation analysis) such that I do not believe that the conclusions reached are sufficiently justified by the data analysis. I will detail each of the catagories below.

Specific comments

Time scale

- One of my significant concerns is the impact of melt on the isotope and chemical stratigraphy of the core, and hence the time scale development. Although they mention it in the abstract, the authors present no evidence of understanding the melt process itself (i.e., caused by sensible heat or radiation, or both), and the extent to which isotope/chemical homogenization or migration occurs. Please confirm how the melt feature percentage was calculated. In general, I do not see how melt and melt percolation can occur to the same depth every summer; thus, it seems difficult to use it as an accurate guide. In Fig. 2, there are several instances of large

(100%) melt events in winter snow, suggesting significant percolation or incorrect interpretation. Also, there are many isotope minima that are not considered winters, yet are of equal magnitude to other winter peaks. Also, Figure 2 clearly shows an increasing trend in melt percentage, yet only a small 30-50 m) portion of the record is shown in detail. Does the increasing melt amount have a differential effect on isotope/chemical stratigraphy?

Response: As indicated in the text, there were many melt-refrozen layers in this ice core, due to high temperature and/or strong insolation during summer seasons. However, the 10-m-depth temperature in the borehole was -2.2 ◦C, which corresponded to annual mean air temperature at the drilling site. Therefore, we consider that melt water failed to penetrate in previous year. Additionally this site has high accumulation rate. Thus, melt water hardly penetrates into previous layer. The average annual amplitude of δD recorded in the Aurora Peak ice core from 1735 to 2007 was 30.9 ‰. Such high amplitude cannot by maintained if intensive melting occurred in the past. Therefore, we think that homogenization due to melting process was not significant in this site (Fig. 2).

We added supplemental explanation about the ice core studies in the North Pacific region in the main text (p. 1424, line 10) as follows:

"The Aurora Peak ice core is composed mainly of firn partly interbedded with ice layers, as we will discuss later. This indicates that transformation of snow into ice proceeds in two ways: dry densification and refreezing of meltwater. It is difficult to quantify the contribution of the melting-refreezing process to the densification of firn, because the amount of melting differs from year to year. The melting occurs at the surface of the glacier; the meltwater percolates along a vertical channel and spreads horizontally on favored layers to form ice layer can be placed at the previous summer surface where size of snow grains change abruptly as mentioned in the previous section. The low temperature of the firn as will be described in the next section, however, reduces the occasion of such melting-freezing process, and the densification with depth proceeds mainly due to the dry densification processes in this glacier. Additionally as hereinafter defined, this site has high accumulation rate thus meltwater hardly penetrates into previous layer. The average annual amplitude of δD recorded in the Aurora Peak ice core from 1735 to 2007 was 30.9 ‰. Such high amplitude cannot by maintained if intensive melting occurred in the past. Therefore, we think that homogenization due to melting process was not significant in this site (Fig. 2)."

- The use of volcanic markers in the time scale development seems very limited in use. There have been hundreds of volcanic events in the region over the past 100 years, so it seems extremely difficult to ascribe one sulfate peak to a specific 1992 event. Moreover, I do not understand why Katmai shows only a Cl/Na and not a nssSO4 signal.
- There is a limited tritium profile presented, with an apparent peak. However there is no justification given as to why this has to be the 1963 peak. Without context (ie., a longer tritium record) or comparison of tritium values to other ice core records in the region, it seems a stretch to be sure this is 1963.

Response:

- The ice core age was determined by annual counts of seasonal cycles of δD and Na^+. We found a sharp peak in $nssSO_4^{2-}$ and a visible dirty layer in the layer that we estimated to be 1992 by annual counts of δD and seasonal cycles of Na^+. In 1992, a large volcanic eruption occurred in Mt. Spurr in Alaska. Then compared the depths of the dirty layers both in Aurora Peak and Mount Wrangell (Yasunari et al., 2007). Mean annual accumulation rates from 1992 to 2002 of Aurora Peak and Mt. Wrangell were 1.87m w.eq. and 2.49m w.eq., respectively. The darty layers were found at about 18.03m w.eq in Auraora Peak and 26.824-26.873m w.eq. in Mt. Wreangell. Considering the difference of mean annual accumulation rate of both site, it was located at almost equivalent depths from the surface.

Much the same is true for Mt. Katmai in 1912. We counted by annual cycled of δD and Na^+ to the year 1912 when a large volcanic eruption occurred in Mt. Katmai in Alaska.

We do not know why we did not detect a $nssSO_4^{2-}$ peak at that depth. But Yalcin et al. (2003) reported that Katmai showed the notably high peak of nssCl- (1663 ng g^{-1}) relative to Mt. Spurr (23 ng g^{-1}) despite that $nssSO_4^{2-}$ were not so much different between Mt. Katmai (349 ng g^{-1}), and Mt. Spurr (299 ng g^{-1}). Therefore we decided that the notably high peak of Cl-/Na+ near 90 m w.eq. was Katmai, 1912.

Reference:

Yalcin, K., Wake C. P. and Germani M. S.: A 100-year record of North Pacific volcanism in an ice core from Eclipse Icefield, Yukon Territory, Canada, Journal of Geophysical Res., 108, No. D1, 4012, doi:10.1029/2002JD002449, 2003

[Mt. Spurr(1992): nssSO_4^{2-}=299 ng g^{-1}, nssCl^-=23 ng g^{-1}
Mt. Katmai(1912): nssSO_4^{2-}=349 ng g^{-1}, nssCl^-=1663 ng g^{-1}]

- The value of tritium peak of Aurora Peak ice core was 333TU which was relatively close to the values found at North America ice core (>300TU) (D.L. Nafts et al. 1996) and Svalbard ice core (450TU) (L.G. Van Der Wel et al. 2011). In 1900s, there was no year showing snow a high peak than 1963-64, so we considered that this tritium peaks found at 63.3 m w.eq. and 62.4 m w.eq. corresponded to H-bomb testing in 1963.

References:

Naftz D.L., Klusman R. W., Michel R. L., Schuster P.F., Reddy M. M., Taylor H. E., Yanosky T. M., McConnaughey E.A.: Little ice age evidence from a south-central north American ice core, U.S.A, Arctic and Alpine Research, Vol. 28, No. 1, pp33-41, 1996

Van Der Wel L.G., Streurman H.J., Isaksson E., Helsen M.M., Van De Wal R.S.W., Martma T., Pohjola V.A., Moore J.C., Meijer H.A.J.: Using high-resolution tritium profiles to quantify the effects of melt on two Spitsbergen ice cores, Journal of Glaciology, Vol. 57, No. 206, 2011

Accumulation record/flow model

- The ice flow model used in this case may be overly simplistic for the glaciological situation. The Dansgaard-Johnson flow model applies to divide conditions, so if there is significant horizontal movement there can be large error induced in model results. The accumulation profiles shown in Figure 4 have a very large trend throughout the record which could very well be a result of flow conditions. The authors need to present a much more thorough glaciological analysis to convince me that the correction applied to the annual layer thickness data is accurate.

Response: It might be the way to calculate of the ice flow by a sophisticated new flow model for this glacier. However, it is difficult to develop the new model with limited since it is known to be applied not only to ice sheets but also to blow line of a glacier available data at present.

It is very difficult to decide the value of critical depth “h” correctly at present. Therefore, we re-calculated accumulation rate with h=0.25H, 0.40H, and 0.60H to evaluated the effect of “h” value on the accumulation rat time-series. The results show that the differences of calculated annual accumulation rate with various “h” values are negligible after 1900, but are quite large before 1900. Therefore we set the “h” to 0.25H and discuss the accumulation rate only after 1900 in this paper. To discuss the bottom part of the ice core, we need to develop an appropriate flow model for this glacier in the further studies.

The total ice thickness is 252±10-m (216m w.eq.) and only the surface portion (95.61m w.eq.) was used in this study. In the surface of glacier, the vertical strain rate by ice flow is quite small. We consider that we can use D-J model to reconstruct annual accumulation rates and reconstructed annual accumulations rates have not been overestimated.

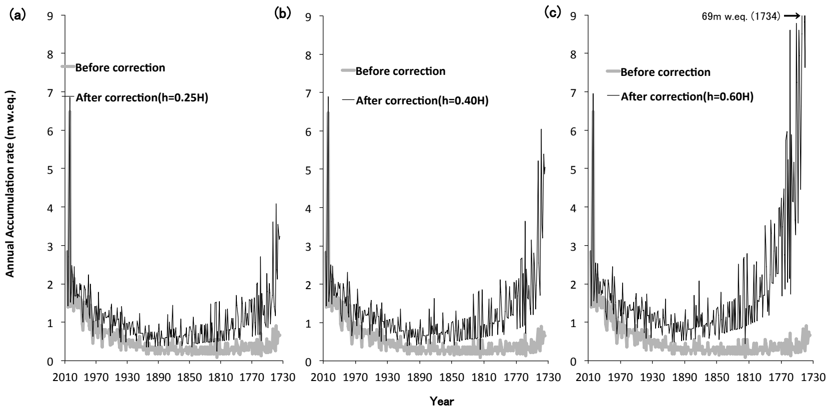

Fig. a Annual layer thickness of the Aurora Peak ice core (heavy gray line) and annual accumulation rate corrected by the Dansgaard-Johnsen model (black line). (b) critical depth “h” is 0.25H, (b) critical depth “h” is 0.40H, and (c) critical depth “h” is 0.60H.

Climate analysis

- Given my above concerns with the time scale development and ice flow correction to the accumulation record, it is difficult to move towards comparison of the isotope/chemical timeseries with climate data. In any paleoclimate record, chronology is the fundamental component of any subsequent comparison.

- Isotope/temperature correlations – why did the authors choose 6 year running means for correlation analysis? This will necessarily increase any correlation coefficient, such that in their case there are significant correlations with every station (Fig. 5). This does not appear to be physically plausible, as coastal and interior sites have much different temperature histories. If annual averages are used, what do the correlation statistics look like? The correlation between accumulation (disregarding my concerns above) and precipitation also are difficult to interpret – why a correlation only between Aurora Peak and coastal sites? It is a large logical leap, and incorrect in my opinion, to go from these correlation analyses to interpreting the ice core record in a broader climatological context.
- Comparison of accumulation trends in the ice core record to station data is not supported by the accumulation record construction, in my opinion.
- Correlation between the PDO index and isotopes is weak at best, and shows no obvious features in common. There is no discussion as to why this would be the case in the first place – is there a significant link between interior temperatures and the PDO? Precipitation on the coast and PDO?

Response: The age of Aurora Peak ice core has dating errors of ±3-year according to our analyses mentioned above. Therefore we chose 7-year running averages for further discussion. We revised Figs. 5, 6 and Table 2.

During Positive PDO periods the Aleutian low develops in the south of Alaska, which increases the precipitation amount and temperature by the southerly wind in Alaska (Minobe, 1997; Minobe et al., 2002; Nakanowatari et al., 2005). As shown in Fig.5, delta-D and annual accumulation rates have high correlation with air temperature and precipitation amount of Alaska, respectively, we therefore consider that δD and annual accumulation rates can be good indicators of PDOI.

As the reconstructed annual accumulation rates have high correlation with precipitation amount only in the coast area, we suppose that precipitation might have been blocked by high mountain range in contrast to air temperature. Moisture from south hardly penetrates into central Alaska (e.g. Fairbanks, BigDelta). Aurora Peak is located at higher altitude than weather station sites, so, annual accumulation rate estimated from Aurora Peak might have reflected the precipitation in the coastal area.

References:

Minobe S.: A 50-70 year climate oscillation over the North Pacific and North America,

Geophysical Res. Letters, 24, 6, 683-686, 1997
Minobe S.: Global structure of Bidecadal precipitation variability in boreal winter, Geophysical Res. Letters, 29, 10, doi:10.1029/2001GL014447, 2002
Nakanowatari T. and Minobe S.: Moisture Balance For Bidecadal Variability of Wintertime Precipitation in the North Pacific Using NCEP/NCAR Reanalysis, Journal of the Meteorological Society of Japan, 83, 4, 453-469, 2005

- The analysis presented in Figure 7 I do not understand. It seems that the authors have simply reduced a nearly 100 year temperature and isotope record to three points, found a correlation of the three points, and then are using that to argue for a relationship for the whole record. The logic of this approach is not clear to me.

Response: Following to two reviewer comments, we removed Figure 7.

Introduction

- a more thorough summary of previous work, state-of-the-art, present gaps in knowledge, and what specific contribution this paper intends to make would be helpful. The description presented is very much limited to previous work by Japanese groups, and ignores the wealth of data and interpretation that has occurred from ice cores and other paleoclimate records in the eastern North Pacific.

Response: Following to your comments, we added supplemental explanation about ice core studies in the North Pacific region in the introduction (p. 1423, line 3) as follows:

"In the northern North Pacific region, several ice cores have been drilled to study preoclimate change: e.g., Mt. Logan, Eclipse ice field and Mt. Wrangell (Holdsworth et al., 1992; Moore et al., 2001; Yalcin and Wake 2001; Goto-Azuma et al., 2003; Shiraiwa et al., 2003; Fisher et al., 2004; Zagorodnov et al., 2005) (Table 1). For example, annual accumulation rates and the seasonal variation of Na^+ concentration have been reported from Mt. Logan ice core (Holdsworth et al., 1992; Shiraiwa et al., 2003). The chemical variation have been reported from Eclipse ice field snow pit observation and ice core drillied in 1992 and 2002, respectively (Yalcin and Wake 2001; Yalcin et al., 2006). Especially, Fisher et al. (2004) mentioned that moisture source has been changed along with altitude, which were known by comparison of stable water isotope of PR Col

(5340 m a.s.l.), King Col (4135 m a.s.l.) and Eclipse ice field (3017 m a.s.l.). Aurora Peak is located at lower altitude (2825 m a.s.l) relative to Eclipse ice field (3017 m a.s.l.), therefore we considered that stable water isotopes of Aurora Peak has reflected the local surface climate condition better than Eclipse ice field." To reconstruct ~

Specific comments

- the value of Table 2 is not clear to me – how does this add to the discussion, and where/how is it used?

Response:To calculate the correlation coefficients shown in Fig. 5, we used the number of data and observation periods shown in Table 2. Here we revised Fig.2 by adding detail information of observation sites.

- Table 3 – the value here is also not clear – what is the time period before 1900 used in the analysis? Is it consistent?

Response: Following to your comments, we revised Table 3.

As we mentioned above we use the annual accumulation rate data after 1900 (from 95.61m w.eq. to top) only for discussion in this paper. Additionally, as there are no meteorological observation data before 1900 in Alaska.

Response to Reviewer#2.

Thank you very much for your comments to our manuscript. The comments have helped us to improve the paper significantly.

The paper concerns climate variability in Alaska between 1912-2008, relating temporal variations in ïA d'D and accumulation from an ice core from Alaska Range to Pacific Decadal Oscillation index (PDOI). There is a lack of climate records from this area and thus is a potentially very valuable data that deserves to be published. The paper is rather short and too general in many respects and therefore it is difficult to fully evaluate the presented results. However, I feel that one very important aspect; the ice core chronology is convincingly presented. The fact the paper only concerns the part between 1912-2008, where there are reliable dating reference horizons available makes me believe that the data is of good quality. Maybe the most serious discussion I miss is about the effect of high summer temperatures on the glacio-chemistry. This is specifically mentioned in the abstract but is not really followed up in the paper. If the authors want to be convincing using the ice core data for climate reconstruction the melt issue has to be thoroughly discussed in its own section of the paper.
Available weather station data from Alaska are also used is the evaluation of influence of PDO and this part of the paper is less convincing to me. Many fundamental data about the weather stations are lacking.

In summary both the presentation of the data and discussion have to be improved. I have summarized some suggestions and concerns below (many of them the same as Ref 1). In addition, the language has to be improved. I have full understanding for the fact that none of the authors are English native speakers but many of the language items that I spot should be easily detected with the ordinary spelling/grammer checker.

Introduction I think that the paper would have benefitted from a more through presen- tation of previous work and findings from this area. For the reader not familiar with region this is crucial information. Please include information about dominating weather systems and general climate history from the area.

Response: Following to your comments, we added supplemental explanation about ice core studies in the North Pacific region (p. 1423, line 3) as follows;

"In the northern North Pacific region, several ice cores have been drilled to study preoclimate change: e.g., Mt. Logan, Eclipse ice field and Mt. Wrangell (Holdsworth et al., 1992; Moore et al., 2001; Yalcin and Wake 2001; Goto-Azuma et al., 2003; Shiraiwa et al., 2003; Fisher et al., 2004; Zagorodnov et al., 2005) (Table 1). For example, annual accumulation rates and the seasonal variation of Na^+ concentration have been reported from Mt. Logan ice core (Holdsworth et al., 1992; Shiraiwa et al., 2003). The chemical variation have been reported from Eclipse ice field snow pit observation and ice core drillied in 1992 and 2002, respectively (Yalcin and Wake 2001; Yalcin et al., 2006). Especially, Fisher et al. (2004) mentioned that moisture source has been changed along with altitude, which were known by comparison of stable water isotope of PR Col (5340 m a.s.l.), King Col (4135 m a.s.l.) and Eclipse ice field (3017 m a.s.l.). Aurora Peak is located at lower altitude (2825 m a.s.l) relative to Eclipse ice field (3017 m a.s.l.), therefore we considered that stable water isotopes of Aurora Peak has reflected the local surface climate condition better than Eclipse ice field." To reconstruct ~

And the English in our manuscript has been checked by at least two professional editors, both were native speakers of English. We revised the text again after the checking of the native speakers. For a certificate, please see: http://www.textcheck.com/certificate/KFgANs

Sampling site. . . Also in this section I miss some of the fundamental information such as various local meteorological influences. Was there any show pits sampled at the drill site? Do you have any idea of the distribution of precipitation over the year at the drill site? That would affect the interpretation of the ïA □d'D in terms of temperature. . .

Results In the abstract the authors are pointing out that this is a location with summer high temperatures producing many melt layers so a section about "impact of post- depositional processes on glacio-chemistry" is absolutely necessary. Much of the pre- sentations of the results in Tables and Figures have to be improved (see below).

Response: As indicated in the text, there were many melt-refrozen layers in this ice core, due to high temperature and/or strong insolation during summer seasons. However, the 10-m-depth temperature in the borehole was -2.2 ◦C, which corresponded to annual mean air temperature at the drilling site. Therefore, we consider that melt water failed to penetrate in previous year. Additionally this site has high accumulation rate. Thus, melt water hardly penetrates into previous layer. The average annual amplitude of δD recorded in the Aurora Peak ice core from 1735 to 2007 was 30.9 ‰. Such high amplitude, cannot by maintained if intensive melting occurred in the past. Therefore, we think that homogenization due to melting process was not significant in this site (Fig. 2).

We added supplemental explanation about the ice core studies in the North Pacific region in the main text (p. 1424, line 10) as follows:

"The Aurora Peak ice core is composed mainly of firn partly interbedded with ice layers, as we will discuss later. This indicates that transformation of snow into ice proceeds in two ways: dry densification and refreezing of meltwater. It is difficult to quantify the contribution of the melting-refreezing process to the densification of firn, because the amount of melting differs from year to year. The melting occurs at the surface of the glacier; the meltwater percolates along a vertical channel and spreads horizontally on favored layers to form ice layer can be placed at the previous summer surface where size of snow grains change abruptly as mentioned in the previous section. The low temperature of the firn as will be described in the next section, however, reduces the occasion of such melting-freezing process, and the densification with depth proceeds mainly due to the dry densification processes in this glacier. Additionally as hereinafter defined, this site has high accumulation rate thus meltwater hardly penetrates into previous layer. The average annual amplitude of δD recorded in the Aurora Peak ice core from 1735 to 2007 was 30.9 ‰. Such high amplitude cannot by maintained if intensive melting occurred in the past. Therefore, we think that homogenization due to melting process was not significant in this site (Fig. 2)."

Discussion For the discussion things like distribution of precipitation over the year at the drill site are very important i.e.is the stable isotope records biased towards one special season? There is no information about the elevation of the weather stations. This will strongly affect both the precipitation and temperature and therefore the results from the correlation analysis presented in Fig 5 are not very useful. PDOI is suddenly introduced here- it needs to be explained for the reader not familiar with this. Much of the discussion and statistics involving PDOI is weak and not easy to understand. I am not convinced that of these results. . ...

Response: At drilling site, snow accumulates mainly during autumn-winter seasons. In this paper, we did not discussed the seasonality, but we are able to discuss it because Aurora Peak ice core was analyzed with high resolution. We would like to discuss this point in our next paper.

During Positive PDO periods the Aleutian low develops in the south of Alaska, which increases the precipitation amount and temperature by the southerly wind in Alaska (Minobe, 1997; Minobe et al., 2002; Nakanowatari et al., 2005). As shown in Fig.5, delta-D and annual accumulation rates have high correlation with air temperature and precipitation amount of Alaska, respectively, we therefore consider that δD and annual accumulation rates can be good indicators of PDOI.

Table 1 Contains useful information but should be "cleaned up" ; Since all records are of the same type, i.e. ice cores that could already be stated in the Table head ("North Pacific ice core records") and use the last column for the reference instead. Please think about the number of decimals presented and be consistent- for instance one of the drill depth numbers has up to 3 decimals presented. Please be consistent with presenting the time from older to younger (i.e. 1992-2003) and don't mix as it is now is the Accum- rate column.

Response: Following to your comments, we revised Table 1.

Table 2 and 3 First of all these two table should be combined. I don't quite see the logic behind the columns. . . Important information for the reader would be elevation, length of record, annual mean data. Why is a 6th year averaged chosen?

Table 4 I don't think it is necessary to present these values in a Table. Why are these particular time intervals chosen?

Table 5 I do not see the point with this.

Response: The age of Aurora Peak ice core has dating errors of ±3-year according to our analyses mentioned above. Therefore we chose 7-year running averages for further discussion.

Table 2- We added the detail information of the meteorological data at each site.

Table 3- We combined Table3 with Table-5 to make Table3.

Table 5 shows that air temperature changes during period Ⅰ(123-1942), II(1943-1975), and III(1976-2007). Increase or decrease in the PDOI corresponded to increase or decrease in air temperature. This means that variation of air temperature reflects PDO in Alaska.

In general, PDO shifted in 1976, 1943 and 1923, so, we discuss this period Ⅰ(123-1942), II(1943-1975), and Ⅲ(1976-2007).

We removed table 4.

Fig. 1. I assume that the black triangles are the other ice cores sites listed in Table 1? Please include that in the figure captions. Fig 2. Some language issues in the figure caption that makes it hard to understand. "compartmental depth of annual layers" – maybe instead "division of annual layers" ? "We shows"- should be "we show" In this case a more correct expression for "snow depth" is "drill depth"

Response: Thank you for your comments. Following to your comments, we revised the figures 1,2 and table 1.

Fig. 3. For the reader not familiar with the geography it might be good to include the locations of Katmai and Mt Spurr on the map. Why did not Katmai not leave a nssS04 trace behind?

Response: Following to your comments, we added the locations of Katmai and Spurr in figure 1.

We do not know why we did not detect a $nssSO_4^{2-}$ peak at that depth. But Yalcin et al. (2003) reported that Katmai showed the notably high peak of nssCl- (1663 ng g^{-1})

relative to Mt. Spurr (23 ng g^{-1}) despite that $nssSO_4^{2-}$ were not so much different between Mt. Katmai (349 ng g^{-1}), and Mt. Spurr (299 ng g^{-1}). Therefore we decided that the notably high peak of Cl-/Na+ near 90 m w.eq. was Katmai, 1912.

References:

Yalcin, K., Wake C. P. and Germani M. S.: A 100-year record of North Pacific volcanism in an ice core from Eclipse Icefield, Yukon Territory, Canada, Journal of Geophysical Res., 108, No. D1, 4012, doi:10.1029/2002JD002449, 2003

[Mt. Spurr(1992): $nssSO_4^{2-}$=299 ng g^{-1}, $nssCl^-$=23 ng g^{-1}
Mt. Katmai(1912): $nssSO_4^{2-}$=349 ng g^{-1}, $nssCl^-$=1663 ng g^{-1}]

Fig 7. This figure does not add anything so please remove.

Response:

Following to your comments, we removed Fig.7.

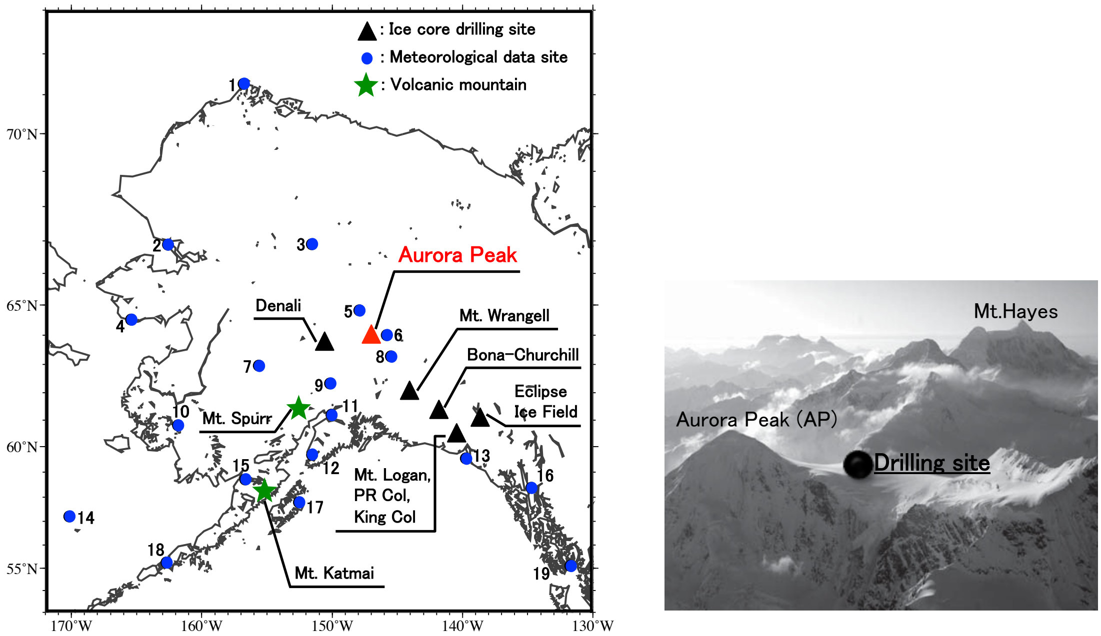

Fig. 1. Location of the study area and drilling site at Aurora Peak in the central Alaska Range and meteorological data sites. (Meteorological data sites: 1 Barrow, 2 Kotzebue, 3 Bettels, 4 Nome, 5 Fairbanks, 6 Big delta, 7 McGrath, 8 Talkeetna, 9 Gulkana Glacier, 10 Bethel, 11 Anchorage, 12 Homer, 13 Yakutat, 14 St Paul, 15 King Salmon, 16 Juneau, 17 Kodiak, 18 Cold Bay, 19 Annette).

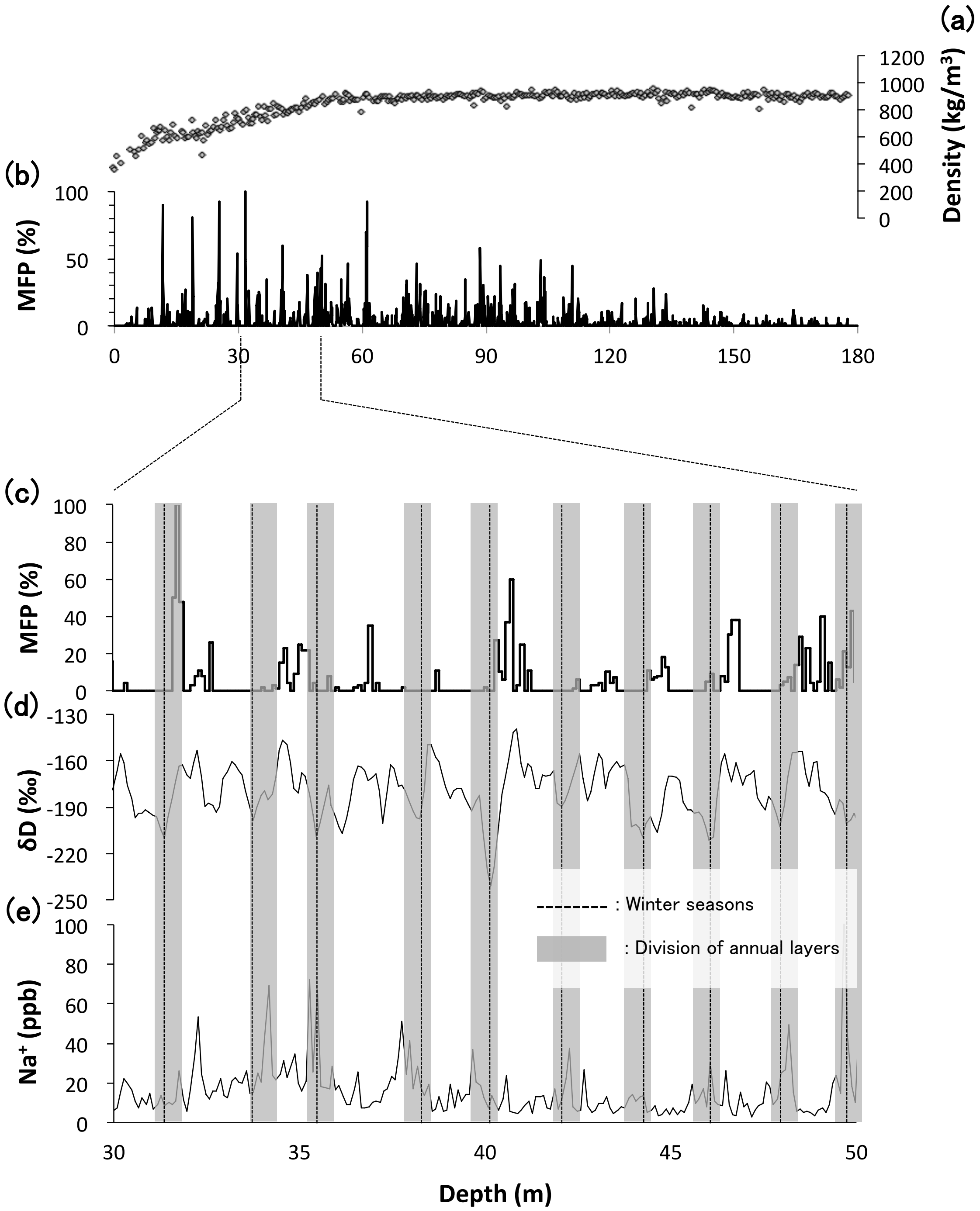

Fig. 2. (a) Ice core density and (b) Melt feature percentage (MFP) plotted against snow depth scale between 0 m and 180 m. Then, we shows the variation in snow depth scale between 30m and 50m, (c) MFP, (d) Stable hydrogen isotopes (δD), and (e) Na^+. Gray shading indicates winter seasons. The dotted lines show the compartmental depths of the annual layers.

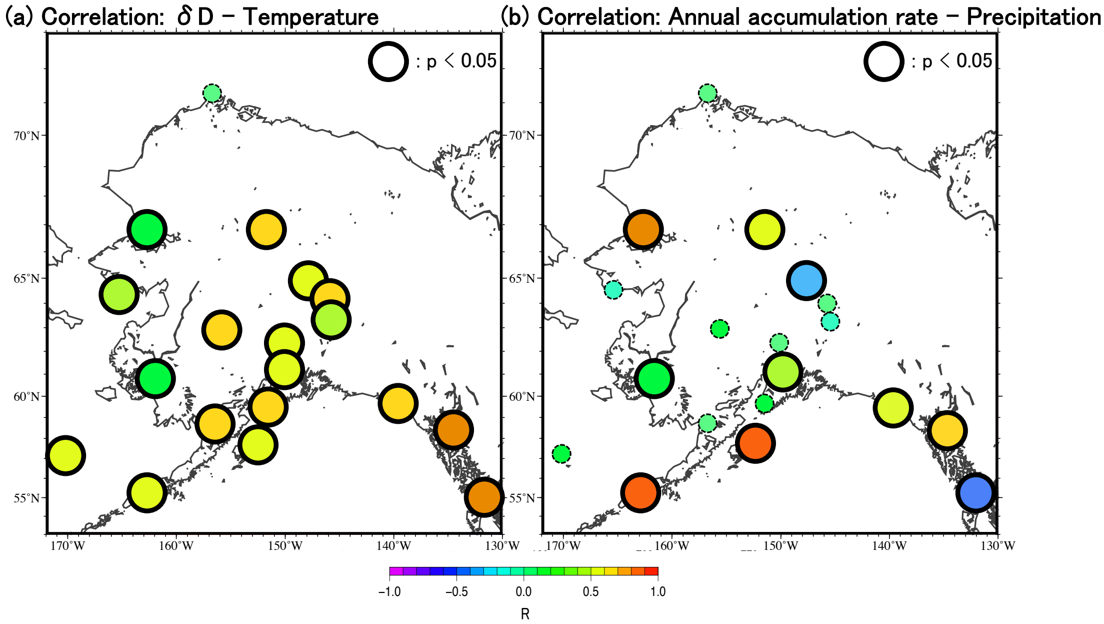

Fig. 5. (a) Correlations between 7-year running-average stable hydrogen isotope (δD) values of the Aurora Peak ice core and 7-year running-average temperatures at the weather stations. (b) Correlations between 7-year running-average annual accumulation rates estimated for the Aurora Peak ice core and 7-year running-average precipitation data at the weather stations. The heavy black circles indicate sites that were statistically significant at the 95% level.

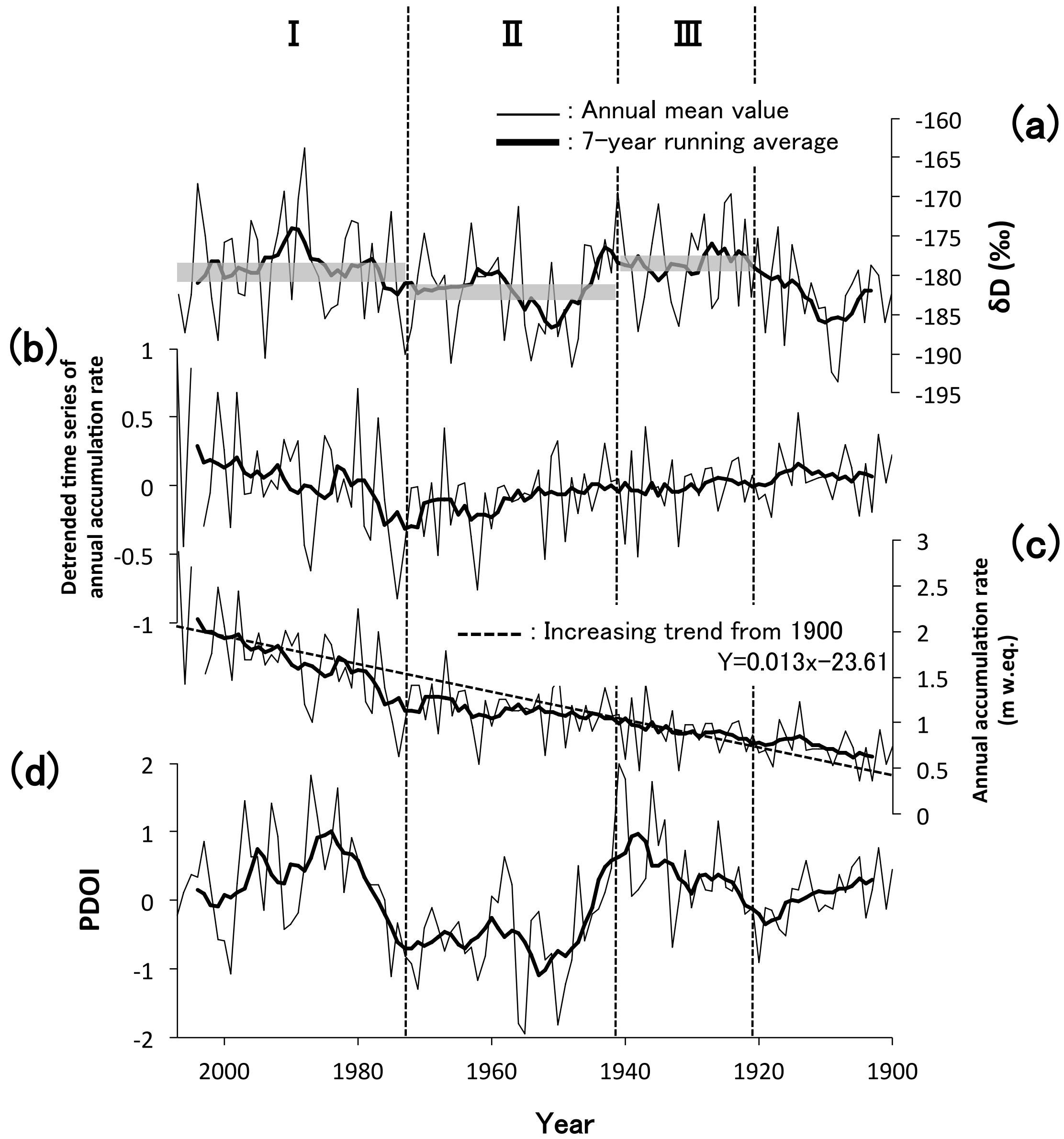

Fig. 6. (a) Temporal variation in stable hydrogen isotopes (δD). The heavy gray lines indicate average values of δD in periods I (1976-2007), II (1943-1975), and III (1923-1942). (b) Detrended annual accumulation rates, which exclude the increasing trend from the annual accumulation rates. (c) Annual accumulation rates of the Aurora Peak ice core. Dotted lines show the increasing trend from 1900. (d) The Pacific Decadal Oscillation index (PDO). Annual mean value given by the gray line, 7-year running averages given by the heavy black line.

Table 1. Information from the northern North Pacific ice core records.

Site	Drilling year (AD)	Latitude	Longitude	Elevation (m a.s.l.)	Mean temp. (°C)	Accum. rate (m w.eq.$^{-1}$)	Depth (m)	Time span (year)
North America								
Aurora Peak	2008	63.52°N	146.54°W	2825	-2.2	2.04 (1997-2007) 2.13 (2003-2007) 1.87 (1992-2002)	180.17	274
Logan*[a,b]	1980	60.34°N	140.24°W	5340	-	-	103	301
Eclipse*[c]	1996	60.51°N	139.47°W	3017	~ -5	1.38	345	~1000
PRCol*[d]	2001, 2002	60.59°N	140.50°W	5300	-29	~0.65	188	8000
King Col*[e]	2002	60.58°N	140.60°W	4135	-17	~1.00	220.5	~300
Bona-Churchill*[f]	2002	-	-	4200	-24	-	460	-
Wrangell*[g]	2003*[h], 2004*[i]	62.00°N	144.00°W	4317	-18.9	2.49 (1992-2002)*[h] 2.66 (1992-2004)*[i]	50, 212	12
Kahiltna Pass*[j]	2008	63.07°N	151.17°W	2970	-	2.43 (2003-2007)	18.77	5
Kamchatka								
Ushkovsky*[k]	1998	56.04°N	160.28°E	3903	-15.7	0.55*[l]	211.7	640-830*[m]
Ichinsky*[n]	2006	55.46° N	157.55°E	3607	-13.0	0.68*[o]	115	-

This work, a Holdsworth et al. (1992), b Moore et al. (2002), c Yalcin and Wake (2001), d Fisher et al. (2004), e Goto-Azuma et al. (2003), f Zagorodnov et al., 2005, g Shiraiwa et al. (2003), h Yasunari et al. (2007), i Kanamori et al. (2008), j Kelsey et al. (2010), k Shiraiwa et al. (1999), l Shiraiwa and Yamaguchi (2002), m Shiraiwa et al. (2001), n Matoba et al. (2007), o Matoba et al. (2011)

Table 2. Information of meteorological data sites.

No.	Weather Station Site	Latitude	Longitude	Elevation (m a.s.l.)	Since (AD)	The number of Data			
						Temperature (°C)		Precipitation (mm)	
						Annual	7 year ave.	Annual	7 year ave.
1	BARROW	71.17	156.46	9	1901	94	77	92	76
2	KOTZEBUE	66.53	162.36	3	1897	81	65	76	64
3	BETTELS	64.49	147.51	132	1951	56	51	55	51
4	NOME	64.31	165.27	3	1900	102	96	101	96
5	FAIR BANKS	64.49	147.51	132	1929	78	73	76	72
6	BIG DELTA	64.00	145.43	386	1937	67	61	67	62
7	MCGRATH	62.57	155.36	104	1941	66	61	65	61
8	GULKANA GLACIER	63.16	145.25	1480	1968	34	34	37	34
9	TALKEETNA	62.19	150.06	105	1918	89	84	88	84
10	BETHEL	60.47	161.50	38	1923	81	70	80	70
11	ANCHORAGE	61.11	150.00	34	1952	55	50	54	50
12	HOMER	59.39	151.29	27	1932	75	70	74	70
13	YAKUTAT	59.31	139.38	8	1917	87	70	86	70
14	ST PAUL	57.10	170.13	6	1892	58	53	57	53
15	KING SALMON	58.41	156.39	14	1917	87	67	84	67
16	JUNEAU	58.21	134.35	3	1936	68	62	70	66
17	KODIAK	57.45	152.30	4	1931	76	71	75	71
18	COLD BAY	55.12	162.43	29	1950	57	52	56	52
19	ANNETTE	55.03	131.34	33	1941	66	61	65	61

Table 3. Increase rates of the annual accumulation rate of Aurora Peak and annual precipitation amounts observed at 13 weather stations after 1900, and air temperature records at 15 weather stations during periods I, II, and III, which were correlated with δD of Aurora Peak.

Weather Station Site	Average (m w.eq.)	Increase rate (%)	Ave. Temp. (°C)	I*		II*[a]		III*[b]	
				PDOI Positive phase		PDOI Negative phase		PDOI Positive phase	
				Ave. Temp. (°C)	Anomaly	Ave. Temp. (°C)	Anomaly	Ave. Temp. (°C)	Anomaly
Aurora Peak	1.25	199							
BARROW	0.10	119							
KOTZEBUE	0.21	142							
BETTELS	0.36	109							
NOME									
FAIR BANKS			-3.25	-2.19	1.05	-3.60	-0.36	-4.81	-1.56
BIG DELTA	0.28	104	-1.95	-1.39	0.56	-2.81	-0.86	1.56	3.50
MCGRATH			-3.26	-2.64	0.63	-4.01	-0.75	-0.94	2.32
GULKANA GLACIER			-3.83	-3.51	0.32	-4.93	-1.09	-	-
TALKEETNA			1.07	1.81	0.75	0.19	-0.87	1.26	0.19
BETHEL	0.44	101							
ANCHORAGE	0.40	107	2.41	2.89	0.48	1.77	-0.64	-	-
HOMER	0.62	103	3.02	3.82	0.80	2.34	-0.69	2.76	-0.26
YAKUTAT	3.49	118	4.28	4.63	0.35	3.54	-0.75	4.87	0.59
ST PAUL			1.63	2.05	0.42	1.13	-0.50	-	-
KING SALMON	0.48	113	0.99	1.83	0.83	0.39	-0.61	0.77	-0.23
JUNEAU	1.38	122	5.04	5.59	0.55	4.32	-0.72	6.56	1.52
KODIAK	1.69	121	5.00	5.28	0.28	4.55	-0.45	5.47	0.48
COLD BAY	0.97	123	3.55	3.86	0.31	3.17	-0.38	-	-
ANNETTE			7.77	8.10	0.32	7.41	-0.36	8.53	0.75

1976-2007, a 1943-1975, b 1923-1942