Abnormal Winter Weather in Japan during 2012 Controlled by Large-Scale Atmospheric and Small-Scale Oceanic Phenomena

YUTA ANDO
Climate and Ecosystems Dynamics Division, Mie University, Mie, and Arctic Environment Research Center, National Institute of Polar Research, Tokyo, Japan

MASAYO OGI
Centre for Earth Observation Science, University of Manitoba, Winnipeg, Manitoba, Canada

YOSHIHIRO TACHIBANA
Climate and Ecosystems Dynamics Division, Mie University, Mie, and Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology, Kanagawa, Japan

(Manuscript received 27 January 2014, in final form 18 August 2014)

ABSTRACT

Negative Arctic Oscillation (AO) and western Pacific (WP) indices persisted from October to December 2012 in the Northern Hemisphere. For the first time, the monthly AO and WP were both negative for three consecutive months since records have been kept. Although in general negative AO and WP phases cause Siberia, East Asia, and Japan to be abnormally cold, Japan was relatively warm in October 2012 even though both the AO and WP were strongly negative. The temperature of the Sea of Japan reached a record-breaking high in October 2012, and it was found that heating by these very warm waters, despite the small size of the Sea of Japan, overwhelmed the cooling effect of the strongly negative AO and WP in October. Linear regression analyses showed that Japan tends to be warm in years when the Sea of Japan is warm. Consequently, the temperature over Japan is controlled by interannual variations of small-scale oceanic phenomena as well as by large-scale atmospheric patterns. Previous studies have ignored such small-scale oceanic influences on island temperatures.

1. Introduction

During the winter of 2012/13, surface air temperatures (SATs) in the northern midlatitudes were abnormally cool over Europe, the Eurasian continent, and North America, and abnormally cold winters have continued over East Asia and Japan for the last three winters (2010/11, 2011/12, 2012/13). Commonly variations of the large-scale atmospheric circulation are mainly responsible for year-to-year variations of SATs (e.g., He and Wang 2013). In this paper, we demonstrate oceanic control over variations of air temperatures over Japan, focusing on the anomalous cold winter of 2012/13 in the Northern Hemisphere.

One of the most important components of atmospheric circulation in the winter over the Northern Hemisphere is the Arctic Oscillation (AO) as defined by Thompson and Wallace (1998). The winter AO is strongly coupled with SAT fluctuations over midlatitudes (Thompson and Wallace 2000). The negative phase of the AO directly influences the occurrence of cold surges over East Asia as a result of changes in the mid- and high-latitude atmospheric circulation systems, including the Siberian high, upper-level trough, and westerly jet stream (Jeong and Ho 2005; Park et al. 2008, 2011).

Another important mode of variability associated with SAT over East Asia is the western Pacific (WP) pattern identified by Wallace and Gutzler (1981). The negative phase of the WP affects the East Asian...
monsoon and leads to abnormally cool temperatures over East Asia and eastern Siberia in winter (Gong et al. 2001; Linkin and Nigam 2008; Zhang et al. 2009).

Temperatures were abnormally cold during the winter of 2012/13 over East Asia, and the SAT over Japan was especially cold. In December 2012, for example, Japan experienced temperatures more than 3°C below normal (normalized interannual SAT index was $-1.70$) because of a strong cold-air inflow. A winter cold wave has social, economic, psychological, and political impacts in Japan because of the post-Fukushima closure of Japan’s nuclear power plants. Unfortunately, abnormally cold winters create more demand for electricity. Thus, there is more attention being paid to winter weather in Japan and its prediction. The recent consecutive cold winters in East Asia are consistent with the reported reamplification of the East Asian winter monsoon in the mid-2000s (Wang and Chen 2014b; Takaya and Nakamura 2013). In this study, we examined whether the extremely cold weather in Japan during the winter of 2012/13 was associated with changes in large-scale atmospheric circulation, specifically, negative phases of the AO and WP. In addition, we investigated whether small-scale changes in oceanic temperatures also contributed to the cold winter temperatures of 2012/13 in Japan.

2. Data and methods

Ogi et al. (2004) identified seasonal variations in the Northern Hemisphere annular mode (SV NAM) from 1958 to 2002 by performing an empirical orthogonal function (EOF) analysis. They applied the EOF to a temporal covariance matrix of geopotential height fields for individual calendar months using the zonally averaged monthly geopotential height field from 1000 to 200 hPa for the area poleward of 40°N. The daily time series of the SV NAM index used in this study is obtained by projecting daily zonal mean geopotential height anomalies onto the EOF of each month. The leading mode of each month in the Northern Hemisphere is called the Northern Hemisphere annular mode (NAM) because month-to-month fluctuations of the Northern Hemisphere lower stratospheric polar vortex are strongly coupled with a wavelike pattern of geopotential height anomalies in the middle troposphere (Thompson and Wallace 1998). The SV NAM shows the seasonal variations of the NAM. In this study we used the SV NAM index as defined by Ogi et al. (2004), and all references to the AO index in this paper mean the SV NAM index (from 1 October to 31 December 2012, the correlation coefficient between the AO and SV NAM indices was $R = 0.86$). The original AO of Thompson and Wallace (2000) reflects mainly winter atmospheric variability and cannot capture the dominant atmospheric patterns of other seasons (e.g., Ogi et al. 2004; Tachibana et al. 2010; Otomi et al. 2013).

The daily time series of the WP index used in this study is defined as the following:

$$\text{WP index} = \frac{Z^*500(35.0^\circ N, 152.5^\circ E) - Z^*500(57.5^\circ N, 140.0^\circ E)}{(SD)},$$  \hspace{1cm} (1)

where $Z^*$ is geopotential height anomaly from climate value of each month during 1982–2012 and SD is the mean standard deviation during all days from 1982 to 2012.

The SV NAM and the WP indices are available online (http://www.bio.mie-u.ac.jp/kankyo/shizen/lab1/AOindex.htm and http://www.bio.mie-u.ac.jp/kankyo/shizen/lab1/earth/WPindex_index.html, respectively). We used the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis dataset (Kalnay et al. 1996) in this study. We obtained sea surface temperature (SST) data from the daily 1/4° National Oceanic and Atmospheric Administration (NOAA) optimum interpolation SST V2 (Reynolds et al. 2002). We also used daily mean SAT data, compiled by the Japan Meteorological Agency, from the 822 stations of the Automated Meteorological Data Acquisition System (AMeDAS) of Japan. The analysis period was 31 years, from 1982 to 2012. All references to interannual indices in this study mean indices normalized by their standard deviations during the periods corresponding to P1 and P2 (defined in section 3) from 1982 to 2012. Some of these datasets exhibited trends of increasing temperature due to global warming; we assumed these trends to be linear functions of time and removed them from the datasets.

3. Large-scale atmospheric control

Figure 1 shows time series of the 5-day running means of the AO index (AOI, Fig. 1a), the WP index (WPI, Fig. 1b), and the SAT anomaly index (Fig. 1c) averaged over the area of Japan (land areas only; see Fig. 3) from September to December 2012. During several time intervals between 1 September and 31 December 2012, the values of the AOI and WPI were continuously negative (Fig. 1). In addition, the time interval from October to December 2012 was the first time during 1982–2012 that the monthly means of both the AOI and WPI were negative for three consecutive months. Moreover, during these months both the AOI and WPI were continuously negative during two 2-week periods: period 1 (P1), 3–16 October; and period 2 (P2), 1–14 December (Fig. 1, red boxes). The anomalously cold SATs during
P2, which coincided with negative phases of both the AO (Jeong and Ho 2005; Park et al. 2011) and WP (Gong et al. 2001; Zhang et al. 2009), are in agreement with the findings of previous studies. Even though the AO and WP were both negative during P1, the SAT anomaly during P1 was nevertheless normal or high (Fig. 1d). This pattern is contrary to expectations based on previous studies.

Figures 2a and 2b show the estimated geopotential height anomalies at 500 hPa (Z500; contours) and air temperature anomalies at 850 hPa (T850; color shading) in the Northern Hemisphere during P1 and P2, based on the results of a multiple linear regression in which the AOI and WPI were independent variables. Figures 2c and 2d show the observed Z500 (contours) and T850 (colors) anomalies during the same time intervals.

The general features of the estimated and observed Z500 and T850 anomaly patterns were similar during both P1 and P2. The temperature anomalies were negative over Eurasia and positive from eastern Siberia to Greenland. However, during P1, the observed and estimated T850 anomaly patterns differed over the central Pacific and Japan. During P2 the reconstructed and observed T850 patterns in the region encompassing East Asia (20°–90°N, 90°E–180°) were highly correlated ($R = 0.80$), whereas during P1 the correlation was lower ($R = 0.45$). The estimated anomalies during P1 were negative (Fig. 2a), whereas the observed anomalies were close to zero (Fig. 2c). Thus, although large-scale cold atmospheric anomalies associated with the negative phases of both the AO and WP may have influenced the temperature of the lower troposphere over Japan, during P1 the impacts may have been offset by other factors. We, therefore, examined in detail the distribution of temperature over Japan associated with the AO and WP. Figures 3a and 3b show the SAT and SST anomalies during P1 and P2, respectively, in 2012, estimated by a multiple regression with the AOI and WPI as independent variables. Figures 3c and 3d show the observed SAT and SST anomalies during P1 and P2, respectively, in 2012. Over the Japanese islands, the observed SATs during P1 were positive almost everywhere (Fig. 3c), in contrast to the expectation based on the regression analysis (Fig. 3a). Only in a few narrow areas in southern Japan were weak negative SATs observed (Fig. 3c). This result suggests that other factors overwhelmed the cooling influence of the AO and WP during P1. By contrast, during P2 the estimated SAT anomalies (Fig. 3b) were less extreme than the observed anomalies, which were strongly negative (Fig. 3d). This result also suggests that other factors contributed to the increased intensity of the cold SATs.

4. Small-scale ocean control

As we suggested in section 3, although large-scale cold atmospheric anomalies associated with both the negative AO and the negative WP may have influenced the T850 and SATs over Japan, during P1 their impacts may have been offset by other factors. Observed SSTs around northern Japan during P1 were several degrees above average (ocean area of Fig. 3c); in fact, anomalously high SSTs persisted from late August to mid-September 2012. In particular, around northern Japan, the observed SSTs were the highest among all years since 1985. We, therefore, investigated the relationship between local SSTs around Japan and SATs over Japan. SSTs over much of the Sea of Japan were significantly positively correlated with the SAT anomalies over Japan during both P1 and P2 (ocean areas of Figs. 4a and 4b). We emphasize that the simultaneous correlation between the estimated SST around Japan and the AOI or WPI during periods corresponding to P1 and P2 was
not significant on an interannual time scale (Figs. 3a and 3b), a result that implies that neither the AO nor the WP determine the SST.

Therefore, we examined in detail the distribution of SAT over Japan and its association with the area-averaged SST in the Sea of Japan. The averaging area was 36.0°–43.5°N, 130.0°–140.0°E (Figs. 4a and 4b, the ocean area in the orange box). The Sea of Japan is located climatologically upstream of Japan during the winter monsoon season. Thus, conditions in the Sea of Japan should affect wintertime SATs in Japan. Moreover, the East Asian winter monsoon is intensified during periods of negative AO and WP. We estimated SAT anomalies in 2012 (Figs. 4a and 4b, island areas) from regressions performed with the SST index as the independent variable, calculated separately for P1 and P2. During P1 the estimated SAT anomalies were positive everywhere over Japan, whereas during P2 the estimated SAT anomalies were negative, because observed SST anomalies in the Sea of Japan changed...
from positive to negative between P1 and P2 in 2012. The residual SAT anomalies (the observed SAT anomalies in 2012 minus the SAT anomalies estimated from the AO and WP shown in Figs. 3a and 3b) during P1 and P2 (Figs. 4c and 4d, island area) isolate the SAT pattern that is not accounted for by the AO or WP. The residual SAT patterns were everywhere similar to the SAT patterns estimated from the SST (Figs. 4a and 4b, island area). This result suggests that SST primarily controls the SAT pattern. To facilitate comparison of the distribution of the residual SAT with the observed SST distribution around Japan, we plotted the observed SST distribution during P1 and P2 in 2012 (see Figs. 3c and 3d) again in Figs. 4c and 4d (ocean areas). It can be seen that positive residual SAT anomalies over the Japanese islands (reddish island areas) tend to be surrounded by positive SSTs in the oceans (reddish ocean areas). This pattern also suggests that SSTs primarily control the SATs over Japan. This relationship is discussed further in the next section.

5. Discussion and conclusions

Monthly averaged AO and WP were continuously negative from October to December 2012. When these indices are negative, Japan is typically cold (see Figs. 2a,b and 3a,b), and Japan was, therefore, expected to be cold in 2012. In October, however, Japan was warmer than expected given the strong negative values of the AO and WP (see Fig. 3c). Furthermore, in December, even though both the AO and WP were strongly negative, Japan was much colder than expected (see Fig. 3d).
Therefore, by themselves, the negative AO and WP values cannot account for the temperatures observed over Japan during P1 and P2 in 2012.

The SST in the Sea of Japan and SAT over Japan were significantly positively correlated on an interannual scale, 1982 to 2012, during P1 and P2, respectively (see Figs. 4a and 4b). Therefore, when the SST was warm (cold), the SAT tended to be high (low). In fact, the observed SST anomalies in October 2012 were high, whereas in December they were low. As noted in section 4, the AO and WP were not significantly correlated with observed SST (see Figs. 3a and 3b, ocean areas); thus, the SST variation was independent of the AO and WP. The SAT pattern that was not accounted for by the negative AO and WP (residual SAT) closely resembled the SAT pattern expected from the distribution of observed SSTs (see Fig. 4, island areas). This resemblance supports the inference that the SST was the influence on the SAT. Also, because the Sea of Japan is effectively upstream of Japan during the winter monsoon season, it is reasonable to infer that cold Siberian air masses that pass over the Sea of Japan are heated by the sea.

It is possible that some other large-scale atmospheric circulation might influence both the SAT and SST. To evaluate this possibility, we investigated indices of several large-scale atmospheric circulations that influence SATs over the Northern Hemisphere: the Eurasian, Pacific–North American, western Atlantic, and eastern

---

**Fig. 4.** SAT anomalies (island areas) estimated by a regression with the SST index in 2012 as the independent variable, and SST regression coefficients (ocean areas) estimated from a regression with the SAT index as the independent variable, during (a) P1 and (b) P2. The daily and interannual SST indices are the areaal average in the Sea of Japan part of the orange box (36.0°–43.5°N, 130.0°–140.0°E), and the daily and interannual SAT indices are the mean SAT of all stations in Japan. The contour interval is 0.2°C (solid contours, positive; dotted contours, negative), and the ocean areas significant at the 90%, 95%, and 99% levels (t tests) are shaded light green, normal green, and dark green, respectively. The residual SAT (island areas) (the observed SAT minus the SAT estimated from the AO and WP shown in Figs. 3a and 3b, respectively, corresponds to the component of temperature not accounted for by the AO or WP), and observed SST anomalies (ocean areas) during (c) P1 and (d) P2. The units are °C.
Atlantic patterns (Wallace and Gutzler 1981); the North Atlantic Oscillation (Barnston and Livezey 1987); the Pacific–Japan pattern (Nitta 1987); and the West Asia–Japan (WJ) pattern and the Europe–Japan (EJ) 1 and EJ2 patterns (Wakabayashi and Kawamura 2004). Among these indices, the value of EJ2 was 0.82 during P1, and that of WJ was −1.00 during P2, whereas the values of the other indices were close to zero during these periods. Neither the EJ2 nor the WJ index, however, was significantly correlated with SAT over Japan or SST in the Sea of Japan (figures not shown). Accordingly, we concluded that no other large-scale atmospheric teleconnection patterns strongly affected Japan during October–December 2012.

Another possibility is that other oceanic regions influenced the SAT in Japan during our focal periods. We found that SATs over Japan were weakly but significantly correlated with SSTs in some areas of the central Pacific Ocean (figures not shown). Moreover, SSTs in the Sea of Japan were significantly correlated with SATs over Japan during two periods on an interannual scale 1982–2012. Additionally, El Niño–Southern Oscillation conditions were neutral during October–December 2012. Taken together, these facts suggest that only the SST in the Sea of Japan strongly influenced SATs over Japan.

It is possible that some “unknown” large-scale atmospheric circulation pattern might influence both the SAT and SST around Japan. To evaluate this possibility, we compared large-scale atmospheric anomaly patterns estimated by linear regressions using the SAT anomaly index or the SST index as independent variables with the observed large-scale anomaly patterns in 2012. However, the anomaly patterns estimated from the regressions did not resemble the observed anomaly patterns in 2012 over East Asia (figures not shown). Accordingly, we inferred that no unknown large-scale atmospheric circulation existed from October to December 2012 that could have affected both SAT and SST around Japan. This result also suggests that SST in the Sea of Japan mainly accounted for the observed SATs over Japan.

A temperature budget analysis is also executed. The local air temperature change is given by

\[
\frac{\partial T}{\partial t} = \frac{DT}{Dt} - \mathbf{V} \cdot \nabla T - \omega \frac{\partial T}{\partial p},
\]

(2)

where \(\mathbf{V}\), \(\omega\), \(T\), and \(\mathbf{V}\) are the horizontal wind vector, vertical \(p\) velocity, air temperature, and isobaric gradient operator, respectively. The right-hand side of this equation expresses a warming or cooling of the air mass due to diabatic absorption or loss of heat (first term), horizontal thermal advection (second term), and vertical motion (third term). We examined whether the warm (cold) SST contributed to the warm (cold) SAT focusing on the horizontal thermal advection. The horizontal thermal advection term is expanded as follows:

\[
-\mathbf{V} \cdot \nabla T = -\mathbf{V}_c \cdot \nabla T_c - \mathbf{V}_a \cdot \nabla T_a - \mathbf{V}_c \cdot \nabla T_a - \mathbf{V}_a \cdot \nabla T_c.
\]

(3)

The subscript \(a\) refers to the anomaly in 2012, and the subscript \(c\) refers to the climatic values during P1 and P2. We estimated each term at 925 hPa. The area-averaged values over Japan (30.0°–50.0°N, 125.0°–150.0°E; inside the green box in Fig. 5) are listed in Table 1. Term 1 indicates the horizontal thermal advection by climatological wind and air temperature at 925 hPa (hereafter climatological thermal advection). The climatological thermal advections were negative during both P1 and P2. This result suggests it was climatologically cold advection in all years during P1 and P2. Term 4 was close to zero during both P1 and P2. Figures 5a and 5b show the horizontal thermal advection by the anomalous wind at 925 hPa (term 3, contour) and by the anomalous air temperature at 925 hPa (term 2, color shading). The thermal advections calculated in term 3 is regarded as the footprint of the temperatures due to anomalous teleconnection patterns such as negative AO and WP, and hereafter referred to teleconnection thermal advection. Term 2 is the advection by the anomalous low-level air temperature related to underlying SST, and hereafter referred to SST thermal advection. The teleconnection thermal advection in October is weaker than that in December, and more robust in winter. The teleconnection thermal advection in both P1 and P2 were negative (i.e., cold advection) over Japan (contours in Fig. 5); however, the SST thermal advection during P1 was positive over Japan (color shading in Fig. 5a), whereas the SST thermal advection during P2 was negative (color shading in Fig. 5b). These results suggest that the warm (cold) SST contributed to the warm (cold) SAT over Japan during P1 and P2.

The time series of the anomalous vertical air temperature distributions over the Sea of Japan from September to December 2012 (Fig. 1d) shows that during P1 and P2, cold air was distributed from the 500-hPa level down to quite low levels. This cold air did not reach the surface of the earth in October (during P1), however, in spite of the strong negative AO and WP values then. Anomalous positive sensible and latent heat fluxes during P1 and P2 indicate that heat from the ocean was released to the atmosphere during these periods (Fig. 1e). The negative AO and WP, which tended to cool SATs around Japan, also led to these positive heat
fluxes. During October, the record-breaking warm SST (normalized interannual SST index was +1.72) offset the impacts of the upper-level cold air associated with the AO and WP. The gradual change of the SST anomaly from positive in October to negative in December (Fig. 1f), however, may have resulted from the continuously negative AO and WP together with the continuous positive heat fluxes. Thus, the positive heat fluxes, which resulted from the negative AO and WP, cooled the SST, which in turn intensified the cooling of the surface air around Japan. This analysis suggests that although negative AOs and WPs can potentially cool Japan, their effect can be modulated by ocean temperatures.

Next, we investigated the relative influences of the AO, WP, and SST on SATs over Japan, and how they varied seasonally. We calculated the relative correlations of the AO, the WP, and SST with SAT anomalies at each AMeDAS station in Japan during P1 and P2 and plotted the results on triangular diagrams (Figs. 6a and 6b). During P1, the influence of SST was stronger than that of AO and WP over all of Japan. Additionally, the contribution of WP to the SAT of Japan was almost equal to that of AO. During P2, however, the influence of SST was weaker than that of AO in northern Japan. Moreover, the contribution of WP was relatively weaker than that of AO. Hence, the strength of the influence of local SSTs appears to depend on the basic state of the seasonal circulation. Thus, (i) teleconnections are generally stronger in winter; and (ii) the air–sea thermal contrast and, thus, surface heat fluxes may be larger in the transition seasons. We then performed the same analysis, but using SSTs from the month prior to each period (Figs. 6c and 6d). The results showed that during P1, the influence of the previous month’s SST on SATs over Japan was stronger than that of the simultaneous SST (cf. Figs. 6a and 6d). During P2, however, the influence of the previous month’s SST was weaker than that of the simultaneous SST (cf. Figs. 6a and 6c). These results indicate that the SATs over Japan in P1 could be predicted from the previous month’s SSTs.

We also calculated the relative correlations between SAT and the AO, the WP, and SST using data averaged over one-month periods (instead of two-week periods) and obtained similar results (figures not shown). Thus, our conclusion holds even when a longer period is considered.

| TABLE 1. The area-averaged values over Japan (30.0°–50.0°N, 125.0°–150.0°E; inside the green box in Fig. 5) of the horizontal thermal advection terms; $V$ is the horizontal wind vector and $T$ is air temperature. The subscript $a$ refers to the anomaly in 2012, and the subscript $c$ refers to the climatic values during P1 and P2. We estimated each term at 925 hPa. The unit is m°C day$^{-1}$. |
|---|---|---|---|---|
| (Term 1) $-V_a \cdot VT_c$ | (Term 2) $-V_a \cdot VT_a$ | (Term 3) $-V_a \cdot VT_c$ | (Term 4) $-V_a \cdot VT_a$ |
| P1 (period 1) | $-0.06$ | $+0.13$ | $-0.23$ | $-0.03$ |
| P2 (period 2) | $-3.40$ | $-0.26$ | $-0.51$ | $+0.11$ |
The results reported here were obtained by using datasets from which global warming trends had been removed. When we performed the same analysis using the datasets without removing the trends, the correlations of SST with SAT anomalies during P1 and P2 were significantly higher. Thus, global warming might intensify the influence of SST on SATs. Future research should examine this interesting possibility.

To summarize, on the basis of the results presented here, we interpret the observed SATs in 2012 as follows: the negative AO and WP tended to cool Japan during both P1 and P2, particularly southern Japan in October (P1), and the SST in the Sea of Japan strongly heated (cooled) all of Japan in October (December), thus, overwhelming the impact of the strongly negative AO and WP, despite the small size of the Sea of Japan. Thus, the observed SAT over the Japanese islands reflected the net effect of the cooling influences of the negative AO and WP and the heating (cooling) influence of the SST (Figs. 4a and 4b). In October, because the heating influence of the record-breaking warm SST overwhelmed the cooling influence of the negative AO and WP, SATs over Japan were warm, whereas December was anomalously cold owing to the combined effects of the negative AO and WP and the cold SST in the Sea of Japan.

Our findings are likely to be relevant to other island groups, to peninsular areas, and even to coastal continental areas. Because many of the Earth’s large islands and island groups have large populations, the relationship between an island’s climate and the temperature of the surrounding ocean temperature needs to be better understood. The results of this study suggest that an
island’s climate cannot be correctly predicted by numerical experiments, such as simulations of global warming, unless the surrounding small-scale ocean temperature distribution is also correctly predicted.

Acknowledgments. We extend special thanks to Dr. Kunihiko Kodera and Dr. Koji Yamazaki for their very insightful discussions. Graduate students at Mie University offered us fruitful advice. Suggestions by the reviewers, in particular those offered by Dr. Sumant Nigam, helped us to improve the paper. This study was supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) through a Grant-in-Aid for Scientific Research on Innovative Areas (Grant 22106003) and by the Green Network of Excellence (GRENE) Program Arctic Climate Change Research. The work of M. Ogi was supported by the Canada Excellence Research Chairs (CERC) Program and the Grid Analysis and Display System (GrADS) and the Generic Mapping Tools (GMT) were used to draw the figures.

REFERENCES