20th Century North American Snow Extent Trends: Climate Change or Natural Climate Variability?

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EXTENDED ABSTRACT

The purpose of this analysis is to test the null hypothesis that continental scale variations in North American snow cover extent (NA SCE) can be explained by atmospheric circulation alone, without need to invoke additional explanatory factors such as climate change. We test the null hypothesis by (1) presenting what is known about decadal scale variations in twentieth century continental scale NA SCE, and (2) examining historical variations in surface climate, tropospheric and stratospheric circulation, as well as corollary evidence from arctic sea ice variations, to determine whether the available evidence supports or refutes the null hypothesis. In this presentation, preliminary results are presented focusing on snow extent during spring (i.e., March). The full report is being prepared for submission for publication elsewhere.

METHODS AND DATA

In order to test the null hypothesis, we utilize data sets that extend back to, and beyond, the mid twentieth century. Variations in snow depth, surface temperature and precipitation rate, as well as upper tropospheric and mid stratospheric geopotential heights and wind speeds are examined using time series, composite, and correlation analyses. Time series analyses are used to identify climatic features in these fields that covary over interannual and decadal time scales. To evaluate decadal changes, time series were smoothed using 9-year running means as a low pass filter in order to focus on decadal and longer scale variations. The results and conclusions are robust with regards to changes in the smoothing window size. Observations of snow extent are taken from the NOAA visible based satellite product (Ramsay 1998; Robinson et al. 1999; Helfrich et al. 2006); reconstructed snow extent is from two sources (Brown 2000; Frei et al. 1999); snow depth is from a new gridded product (described in Dyer and Mote 2006); climatological fields are from the NCEP/NCAR Reanalysis project (Kalnay and co-authors 1996); and teleconnection indices are from the NOAA Climate Diagnostic Center, the Climate Research Unit of the University of East Anglia, and the National Center for Atmospheric Research.

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Time series of NA SCE and AO

During spring, the AO appears to contribute significantly to the variance in snow extent at both interannual and decadal scales (table 1). Neither the PNA nor the PDO are significantly correlated to snow extent individually, but at interannual time scales they do appear to contribute in the multiple correlation analysis. The smoothed (i.e. decadal scale) correlation between AO and snow extent is very high (r_{smooth} = –0.93), explaining ~86% of the variance, while neither of the other two indices contribute to the explanatory power. Note that a correlation of this magnitude (r_{smooth} =–0.93) is not significant (p=0.05) in this analysis because of the diminished number of effective degrees of freedom due to autocorrelation in the time series. Figure 1 shows smoothed time series that have been normalized so that units are comparable. March snow extent (inverted), including values from satellite observations and an historical reconstruction, are shown along with AO variations and two historical NAO time series derived from station observations. March snow extent and the AO appear to vary inversely, and the reconstructed snow and NAO time series indicate that this relationship holds as far back as the mid 1940s; prior to that time the relationship appears to weaken. It is not clear whether the pre-1940s deterioration of the snow-circulation relationship is real, or due to (1) the difference between the EOF-based AO and the station-based NAO time series, or (2) to possible inaccuracies in one or more of the historical data sets.

Table 1. Pearson correlation coefficients, and multiple correlation coefficients, between North American snow extent based on satellite observations and atmospheric circulation indices for annual (r_{annual}) and 9-year running mean (r_{smooth}) time series. Values marked with an asterisk are statistically significant at p=0.05. Sample sizes for annual and smoothed time series are n_{annual} = 39 and n_{smooth} = 31, respectively. However, effective sample sizes are smaller due to temporal autocorrelation.

		r_{annual}	r_{smooth}
SPRING January–February–March Indices versus March Snow Extent	AO	–0.45*	–0.93
	PNA	–0.26	–0.25
	PDO	0.00	–0.25
	AO/PNA	0.54*	0.93
	AO/PDO	0.46*	0.93
	PNA/PDO	0.38	0.25
	AO/PNA/PDO	0.60*	0.93

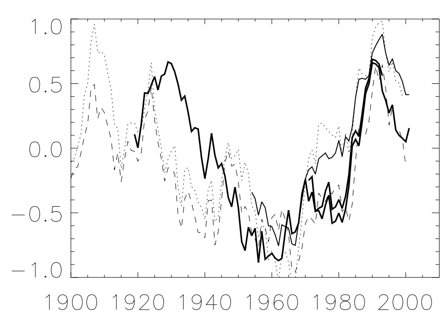

Figure 1. 9-yr running mean values of JFM AO (solid), extended NAO from station observations (from the Climate Research Unit at the University of East Anglia) (dashed), extended NAO from station observations (from the National Center for Atmospheric Research) (dots), March snow extent from satellite observations and reconstructed March snow extent from (Brown 2000) (asterisks) which have been inverted for easier comparison. All time series have been normalized to fit on the same scale.

Spatial distributions of changes in snow extent, snow depth, temperature, precipitation, and atmospheric circulation

The differences in snow extent between periods of more extensive and less extensive snow cover occur at the southern boundary of the snow pack. This is in contrast to the differences in snow depth, which are shallower across wide swaths of the continent. These variations in the March snow pack are associated with changes in surface climate during March and/or preceding months. Mean temperature differences on the order of 1–2 C across wide swaths of the continent are observed, and moderate precipitation changes on the order of 0.5 mm/day primarily are found near the southern boundary of the snow pack. The spatial distribution of these surface changes suggests that they might be caused by a southward displacement of the mean polar front and jet stream. Composite difference maps of the same atmospheric fields for positive versus negative AO years show that the upper tropospheric and stratospheric changes associated with the AO are similar in character, and greater in magnitude, than changes associated with snow cover.

Links to sea ice variability

In light of the well-studied impact of the AO on Arctic sea ice extent, and in conjunction with the results of the analyses presented in the previous sections, one would expect to find a signal in the sea ice record that is correlated to both the winter–spring AO and to march NA SCE. However, recent reports of decreasing sea ice suggest a possible discrepancy. Results of an EOF analysis of arctic sea ice extent shows that the record of sea ice extent appears to be consistent with our null hypothesis. Winter – spring AO variations do appear to be influencing both NA SCE and arctic sea ice. The arctic sea ice signal is regionally dependent, exerting opposite effects in different regions, and therefore dampened in the spatially integrated signal for the entire arctic.

DISCUSSION AND CONCLUSIONS

Evidence presented here suggests that these variations are manifestations of decadal scale variations in the position of the polar front and jet stream, partially influenced by some of the primary modes of atmospheric variability. Statistically significant relationships are found between March North American snow extent / snow depth / surface climate and the winter AO since the mid-20th century. These relationships are stronger at decadal than at interannual time scales, and appear to weaken prior to mid century. Further supporting evidence is provided by the dominant EOF of Northern Hemisphere winter sea ice extent, which displays decadal scale variations that are also correlated to historical variations in both the AO and snow extent, as would be expected under the null hypothesis. Results from climate models are consistent with the empirical results presented here. Current-generation coupled atmosphere–ocean climate model results suggest that decadal scale variability of the magnitude discussed here is likely due to internal climate variability and not to external forcing. Thus, evidence examined in this analysis leads to the conclusion that we can not presently reject our null hypothesis, and that changes observed thus far in the continental scale snow extent record over North America can not be attributed to anthropogenic forcing.

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