Summer Snow Extent Heralding of the Winter North Atlantic Oscillation

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ABSTRACT

Winter climate over the North Atlantic and European sector is modulated by the North Atlantic Oscillation (NAO). We find that the summer extent of snow cover over northern North America and northern Eurasia is linked significantly ($p < 0.01$) to the upcoming winter NAO state. Summers with high/low snow extent precede winters of low/high NAO index phase. We suggest the linkage arises from the summer snow-associated formation of anomalous longitudinal differences in surface air temperature with the subpolar North Atlantic. Our findings indicate the seasonal predictability of North Atlantic winter climate may be higher and extend to longer leads than thought previously.

DATA

1) Monthly northern hemisphere snow extent records for January 1972 - February 2002 from the Snow Data Resource Center at Rutgers University. After recent processing corrections these comprise the most up-to-date snow cover records available.

2) December-February (DJF) NAO indices from the Climatic Research Unit (CRU) at the University of East Anglia UK, the US Climate Prediction Center (CPC) and the first principal component of mean sea level pressure (MSLP) over the North Atlantic (20.N-70.N, 40.E-90.W) for 1950/1-2001/2.

3) Monthly 2m air temperature and MSLP data on a 2.5..x 2.5..grid for 1950-2002 from the NCEP/NCAR global reanalysis. Monthly 2m air temperatures 1950-2002 from the CRUTEM land temperature dataset compiled by the University of East Anglia.

SUMMER SNOW EXTENT LINK TO WINTER NAO

Upcoming winter (DJF) NAO is found to be associated with, and predictable from, the prior summer northern hemisphere snow cover. Our analysis uses linear detrended time series corrected for autocorrelation throughout. This approach minimises the influence of time series trends and multi-year-to-decadal signal variability on the strength and significance of the computed correlations and the deduced NAO_{DJF} predictability.

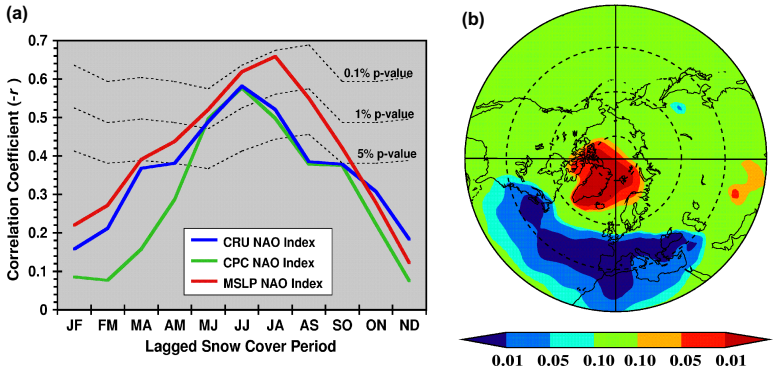

Figure 1. The link between summer northern hemisphere snow extent and the coming winter NAO 1972/3-2001/2. **(a)** The correlation between lagged northern hemisphere snow cover and winter NAO_{DJF} indices for bi-monthly snow cover periods ranging from JF (January-February) through to ND (November-December). The negative correlations from detrended time series are plotted. Dashed lines display the confidence levels of non-zero correlation between snow extent and the *MSLP NAO_{DJF} index* assessed using a 2-tailed Student s *t*-test after correction for autocorrelation with lags out to 15 years included. **(b)** The correlation pattern significance between detrended time series of June-July northern hemisphere snow extent and the following winter (DJF) northern hemisphere gridded sea level pressure. Significances are corrected for autocorrelation as in **(a).** Colour shading also denotes where the correlation is either positive (orange through red) or negative (light through dark blue).

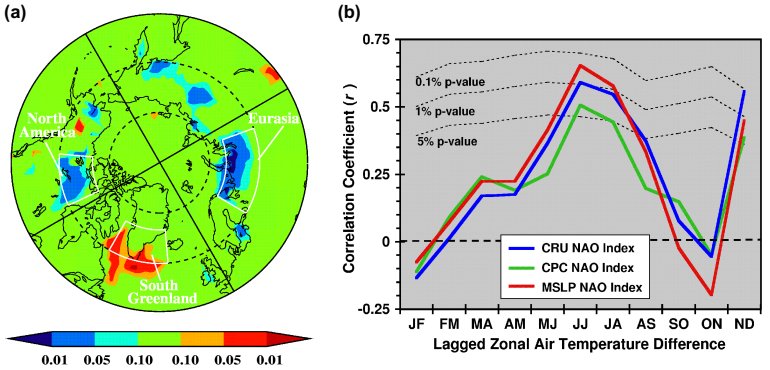

Figure 2. The associations between summer northern hemisphere snow cover, summer subpolar surface air temperature, and the coming winter NAO for the period 1972/3-2001/2. **(a)** The correlation pattern significance between detrended time series of June-July northern hemisphere snow extent and gridded June-July 2m surface air temperature. Significances are corrected for autocorrelation with lags out to 15 years included. Colour shading also denotes where the correlation is either positive (orange through red) or negative (light through dark blue). **(b)** The strength and significance of the correlation between the lagged zonal air temperature difference ˜ *T = (North America + Eurasia)/2 - South Greenland* and coming winter NAO_{DJF} indices. The correlations from detrended time series are plotted. Dashed lines display the confidence levels of non-zero correlation between ˜ T and the *MSLP NAO_{DJF} index* assessed using a 2-tailed Student s *t*-test after correction for autocorrelation with lags out to 15 years included. The bi-monthly lagged ˜ T intervals range from JF (January-February) through to ND (November-December).

PHYSICAL MECHANISM

Figure 2 suggests that summer northern hemisphere snow cover may influence winter NAO predictability through the snow cover-associated formation of anomalous zonal gradients in surface air temperature with the subpolar North Atlantic. These temperature differences would force anomalous meridional thermal winds and, over the North Atlantic, sea level pressure anomalies, a mid-latitude zonal wind anomaly and SST anomalies of the correct sign which, if persisted through to winter, would give the correct winter NAO index sign. Although this physical mechanism is plausible, our analysis can not rule out the existence of another underlying root influence which forces the variability in summer snow cover as well as all associated linking variables. Numerical model experiments with prescribed snow cover conditions will be required to resolve this question.

PREDICTION SKILL FOR WINTER NAO INDICES

Table 1. Hindcast predictive skill for the wintertime *$MSLP\ NAO_{DJF}$ index* from the prior July-August northern hemisphere snow extent.

Skill Measure	Cross-Validated Skill 1972/3-2001/2	Replicated-Real-Time Forecast Skill 1987/8-2001/2
r	0.62 (0.61)	0.60
PVE	38 (35)	35
$RMSE_{Clim\ (Prior\ 5yr)}$ (%)	34 (27)	32
$RMSE_{Clim\ (1971/2\text{-}2000/1)}$ (%)	22 (20)	25
$MAE_{Clim\ (Prior\ 5yr)}$ (%)	33 (25)	23
$MAE_{Clim\ (1971/2\text{-}2000/1)}$ (%)	23 (23)	28

Brackets indicate the cross-validated skill with the influence of time series autocorrelation minimised.

CONCLUSIONS

We find that summer snow cover over northern North America and northern Eurasia is linked significantly to the coming winter NAO state. These results are based on 30 years of reliable snow cover records. A longer data series would provide greater confidence in the temporal stability of this link. However, using summer air temperature as a proxy for snow cover we find for the extended 52 year period 1950/1-2001/2 that the summer ˜ T link to all winter NAO indices remains significant to $p < 0.01$ after correction for autocorrelation. Our finding suggests that the seasonal predictability of North Atlantic winter climate may be higher and extend to longer leads than thought previously. It also suggests that summer northern hemisphere snow extent may be relevant for longer term forced shifts in climate.

REFERENCE

Saunders, M. A., B. Qian and B. Lloyd-Hughes, Summer snow extent heralding of the winter North Atlantic Oscillation, *Geophys. Res. Lett., 30(7),* 1378, doi:10.1029/2002GL016832, 2003.