Seasonal predictability of wintertime storminess over the North Atlantic

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[1] Interannual variability in winter storminess over the North Atlantic and Europe causes significant risk and uncertainty. Attempts to seasonally predict winter storminess levels have identified little skill to date. However, recent statistical studies of observational data indicate the presence of marginal but useful skill in predicting the winter North Atlantic Oscillation (NAO). This predictability arises from a significant ($p < 0.01$) link between northern hemisphere summer snow extent and the coming winter NAO state. We apply this link to assess the seasonal predictability in winter storminess 1972/3–2000/1 at a given point. The correlation skill for predicting, by early September, the numbers of winter gale days and storm force days in the main North Atlantic winter storm track region is between 0.5 and 0.6. Our finding suggests the seasonal predictability of North Atlantic winter storminess may be higher and extend to longer leads than thought previously. *INDEX TERMS:* 3319 Meteorology and Atmospheric Dynamics: General circulation; 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 4215 Oceanography: General: Climate and interannual variability (3309). **Citation:** Qian, B., and M. A. Saunders, Seasonal predictability of wintertime storminess over the North Atlantic, *Geophys. Res. Lett.*, *30*(13), 1698, doi:10.1029/2003GL017401, 2003.

1. Introduction

[2] European windstorms caused damages of US $ 2.9 bn per year 1990–1999 and rank as the second highest cause of global insured loss after US hurricanes. While satellites and numerical weather models provide warnings of strong winds out to ∼1-week ahead, the ability to skillfully predict activity at longer range would bring significant socio-economic benefits by reducing the risk, uncertainty and financial volatility associated with the year-to-year variability in storminess levels. Beneficiaries would include the insurance industry, the offshore oil industry through improved rig operation planning, power and energy companies and maritime operators through cost effective ship routing and scheduling. However, attempts to seasonally predict North Atlantic winter storminess; namely, to anticipate the number of gales, strong gales and storms over the 3-month winter period December–January–February (DJF) have identified little skill to date [*Palutikof et al.*, 2002].

[3] Interannual variability in North Atlantic winter storminess is associated with year-to-year variability in the strength and sign of the winter North Atlantic Oscillation (NAO), the dominant mode of boreal winter atmospheric variability over the North Atlantic [*Walker and Bliss*, 1932; *Rogers*, 1997]. Correlations between surface windspeed and the NAO reach 0.8 ($p < 0.001$, 1948/9–1999/2000) at certain locations [*George and Saunders*, 2001]. This strong association suggests that winter storminess predictability is likely to be linked to winter NAO predictability. Research has related autumn (September–October–November) Eurasian snow cover extent to upcoming boreal winter climate variability [*Cohen and Entekhabi*, 1999; *Cohen et al.*, 2001; *Saito et al.*, 2001]. However, recent work shows that it is summer, rather than autumn, snow cover which is related more strongly and robustly to the upcoming NAO_{DJF} [*Saunders et al.*, 2003; *Bojariu and Gimeno*, 2003; *Saito and Cohen*, 2003]. Based on the most up-to-date snow cover records available, there is a significant covariance ($p < 0.01$) between North American and Eurasian summer snow extent and the coming winter NAO state [*Saunders et al.*, 2003]. This covariance permits the NAO_{DJF} to be anticipated in early September with a correlation of ∼0.6 for a range of NAO indices 1972/3–2001/2. *Saunders et al.* [2003] suggest the dynamic link between summer and winter might arise through the influence of snow cover on subpolar North Atlantic circulation which couples to North Atlantic sea surface temperatures. Anomalies in the latter then persist through to winter [*Wu and Gordon*, 2002; *Saunders and Qian*, 2002].

[4] In this paper we use the NCEP/NCAR global reanalysis project data [*Kalnay et al.*, 1996] to present a climatology for wintertime storminess over the North Atlantic. We link this climatology to summer northern hemisphere (NH) snow cover extent to assess the predictive skill of the latter for wintertime near gale, gale, strong gale and storm force days 1972/3–2000/1.

2. Data

[5] We analyze wintertime storminess over the North Atlantic using 6-hourly 10m windspeed data from the NCEP/NCAR reanalysis on a 2.5° latitude by 2.5° longitude grid. The suitability of these windfields for generating a long-term wave hindcast of the North Atlantic Ocean has been confirmed by *Swail and Cox* [2000]. However, since the NCEP/NCAR reanalysis windfields are presented as averages over 2.5° latitude-longitude grid boxes, peak wind speeds are likely to be underestimated. This is particularly true for major jet streak features propagating about intense mid-latitude cyclones [*Swail and Cox*, 2000] and in coastal regions with special geographical characteristics. Due to the limitation of available snow cover, we study storminess only for the period 1971 ∼ 2001.
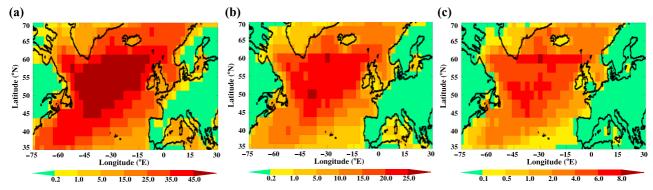
Figure 1. The climatology (1971/2−2000/1) for winter storminess over the North Atlantic sector in terms of the mean number of December−January−February (a) near gale days (windspeed reaching Beaufort Scale 7), (b) gale days (windspeed reaching Beaufort Scale 8) and (c) strong gale days (windspeed reaching Beaufort Scale 9).

[6] We define storminess as the numbers of days with strong winds reaching different force levels on the Beaufort Wind Scale/World Meteorological Organisation windspeed classification. These levels are 'near gale' force (Beaufort Scale 7, $13.9-17.1$ ms^{-1}), 'gale' force (Beaufort Scale 8, $17.2-20.7$ ms^{-1}), 'strong gale' force (Beaufort Scale 9, $20.8-24.4$ ms^{-1}) and 'storm' force (Beaufort Scale 10, $24.5-28.4$ ms^{-1}). A 'day' is counted for a particular grid cell and Beaufort Scale level if the windspeed within that cell exceeds the lower limit of the particular Scale level for any of the four 6-hourly data records during that day. For example, a 'day' is counted for near gale, gale, strong gale and storm force if the windspeed reaches 24.5 ms^{-1} at any one of the four recording times 00, 06, 12 or 18UT during that day. The total number of 'days' is then accumulated for each grid cell, Beaufort Scale level and winter (DJF) season.

[7] We employ monthly NH ground snow extent records from January 1972 through February 2001. These data are provided by the Snow Data Resource Center at Rutgers Univ. and comprise, after recent processing corrections, the most up-to-date snow cover records currently available. Values are derived from weekly snow cover charts produced by the National Oceanic and Atmospheric Administration from visible satellite images [*Robinson et al.*, 1993]. Charting improved considerably in 1972 with the satellite deployment of the Very High Resolution Radiometer having a

spatial resolution of 1.0 km. Since then the snow extent records are considered reliable for climate analysis studies [*Robinson et al.*, 1993].

3. Storminess Climatology

[8] Figure 1 shows the climatology of wintertime storminess for the North Atlantic sector 35°N−70°N. The mean numbers of days with near gales, gales and strong gales are displayed for the 30 winter period 1971/2−2000/1. It is clear that strong winds rarely extend far inland and that the mid-latitude North Atlantic Ocean between the British Isles and eastern Canada is the stormiest region. The maximum mean numbers of days with near gales, gales and strong gales are 53.3, 26.1 and 8.4 respectively. Highest interannual variability in the number of winter strong wind days is observed to the northwest of the British Isles where storminess is moderately strong. The largest standard deviations are 12.6, 9.9 and 5.1 days respectively for near gale, gale and strong gale days. Storm force winds are observed rarely; their maximum mean number and standard deviation for a grid cell being 1.4 and 1.8 days respectively. The storminess climatology in Figure 1 compares well with a climatology for winter gale frequency in the North Atlantic derived from the Comprehensive Ocean and Atmosphere Data Set (COADS) (for details visit the US Naval European Meteo-
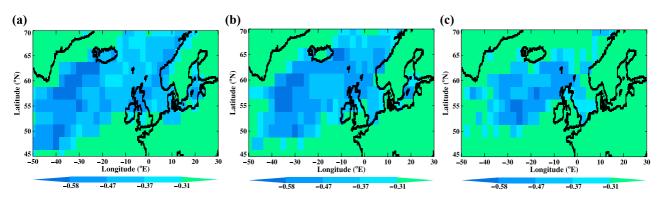

Figure 2. The correlation patterns between July−August northern hemisphere snow cover and the upcoming winter number of (a) near gale days, (b) gale days and (c) strong gale days. Correlation coefficients are computed on detrended time series. The correlation coefficient thresholds of 0.31, 0.37, 0.47 and 0.58 correspond respectively to significance levels of 0.20, 0.12, 0.04 and 0.009 based on 17 degrees of freedom.

Table 1. Wintertime Storminess Climatology (1971/2–2000/1) for the High-Latitude North Atlantic Region 53.75°N–61.25°N, 46.25°W–11.25°E

	Near Gale	Gale	Strong Gale	Storm
Mean (Days)	38.3	16.6	4.0	0.5
Standard Deviation	6.2	4.0	1.5	0.3
Percent of Winter Days	42.6	18.4	4.4	0.6
Correlation to Snow	−0.58	−0.61	−0.68	−0.58
p-value	0.009	0.006	0.003	0.009

Winter storminess is defined by the number of days in December–January–February where the mean wind strength reaches near gale, gale, strong gale or storm force on the Beaufort Scale.

rology and Oceanography Center at https://www.nemoc. navy.mil:443).

4. Linking Storminess to Summer Snow Cover

[9] Our analysis uses linear detrended time series throughout to remove the influence of time series trends on the strength and significance of the computed correlations and the deduced storminess predictability. The influence of time series autocorrelation on the correlation significances is removed by computing the effective number of degrees of freedom in the cross-correlation estimation [*Davis*, 1976; *Saunders et al.*, 2003]. The use of raw (not detrended) time series gives, in all cases, links of similar or stronger magnitude and significance to those described herein.

[10] Figure 2 shows the correlation pattern between winter numbers of near gale days, gale days and strong gale days over the North Atlantic/European sector poleward of 45°N and the prior July–August NH snow extent 1972/3–2000/1. Highest correlations are observed in the stormiest region (Figure 1) with a peak (negative) correlation of −0.70. Correlations significant to 0.05 are also observed over Scotland and parts of the North Sea. The correlation sign shows that summers with high/low NH snow extent precede winters of low/high North Atlantic winter storminess poleward of 45°N.

[11] In view of the spatial variability in the strength of the correlation link in Figure 2, we have also examined the magnitude and significance of this link for a larger agglomerated North Atlantic region (53.75°N–61.25°N, 46.25°W–11.25°E), extending from southern Greenland to the Scandinavian coast. This rectangular region, which straddles the main North Atlantic winter storm track, is referred to henceforth as the *high-latitude North Atlantic* (HLNA) region. The winter numbers of near gale days, gale days, strong gale days and storm days over the HLNA region are obtained by averaging the corresponding numbers from each grid cell in the region. The wintertime storminess climatology for the HLNA region is shown in Table 1. The Table displays, for each strong wind strength category, the mean and standard deviation for the number of strong wind days over the HLNA region 1971/2–2000/1, the percentage of winter (DJF) days with strong winds occurring within the HLNA region, the correlation magnitude and p-value for the link between the strong wind time series and prior July–August NH snow cover extent. The latter shows that winter storminess over the HLNA region is correlated significantly ($p < 0.01$ for all Beaufort wind categories) to prior summer NH snow extent.

5. Prediction Skill for Winter Storminess

[12] The significant correlations shown above between July–August NH snow cover extent and upcoming winter North Atlantic storminess suggest the potential for predicting the latter from summer NH snow cover in early September. We assess the seasonal prediction skill for winter storminess using standard cross-validated hindcasts [*Michaelson*, 1987; *WMO*, 2002] for the 29 year period 1972/3–2000/1. In this scheme a univariate regressive model is calibrated for each hindcast winter by withholding the predictor and predictand of the hindcast year and constructing the model using the remaining 28 years. A hindcast for each withdrawn year is then made by placing the prior July–August NH snow cover extent from that year into the model. The cross-validated prediction model is built on linear detrended data 1972/3–2000/1. We compute the predictive deterministic skill for winter storminess using three skill measures: (a) the correlation (r) between forecast and observed storminess values; (b) the *mean square skill score* ($MSSS_{Clim}$) defined as the forecast percentage reduction in mean square error over a climatological forecast. The climatology used here is the standard 30-year 1971/2–2000/1 climate norm. $MSSS_{Clim}$ is the skill metric recommended by the World Meteorological Organisation for verification of deterministic seasonal forecasts [*WMO*, 2002]; (c) the forecast percentage reduction in mean square error over a
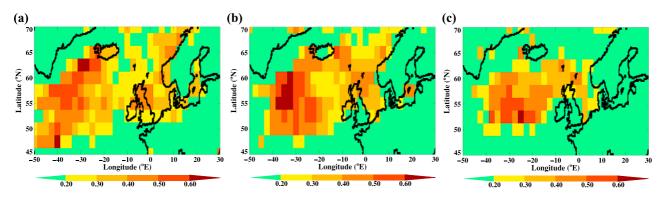

Figure 3. The correlation skill for predicting winter storminess from July–August northern hemisphere snow cover extent based on a cross-validation of 1972/3–2000/1 data. Skill values are shown for (a) near gale days, (b) gale days and (c) strong gale days.

Table 2. Hindcast Predictive Skill for Wintertime Storminess Over the High-Latitude North Atlantic Region 1972/3 – 2000/1

Skill Measure	Near Gale	Gale	Strong Gale	Storm
r	0.53	0.60	0.67	0.52
$MSSS_{Clim}$ (%)	28	36	45	28
$MSSS_{Pers}$ (%)	73	63	62	59

persistence forecast ($MSSS_{Pers}$). The persistence forecast used is the storminess value from the previous winter.

[13] Figure 3 shows the gridded correlation skill from cross-validation for the winter numbers of near gale, gale and strong gale days over the North Atlantic sector. As in Figure 2, largest skills are observed over the most stormy waters with the spatial distribution in skill being similar for all strong wind scales. The highest correlation skill exceeds 0.6, explaining over 40% of the observed variance and providing a 45% improvement in MSE_{Clim}. The skills from replicated real-time forecasts (not shown) display similar spatial distributions to those in Figure 3 suggesting a quasi-stable relationship between summer NH snow cover and North Atlantic winter storminess during the period 1972 ∼ 2000.

[14] Table 2 displays the predictive skill for winter storminess over the high latitude North Atlantic region defined in Section 3. The predictand is the average number of strong wind days from all grid cells within the HLNA region. Table 2 shows that irrespective of hindcast model, skill measure and Beaufort Scale, the wintertime number of high wind days within the HLNA is predictable from NH summer snow extent with a correlation skill of 0.52 to 0.67, an $MSSS_{Clim}$ value of 28% to 45% and an $MSSS_{Pers}$ value of 59% to 73%. Thus the climatology forecast outperforms the persistence forecast.

6. Conclusions

[15] Winter storminess over the North Atlantic and European sector is analyzed using the NCEP/NCAR reanalysis 6-hourly gridded windspeed data. Storminess is examined in terms of the numbers of days with windspeeds reaching Beaufort Scales 7, 8, 9 or 10 (ranging from near gale to storm force in strength). The suitability of these windspeeds for climate studies has been confirmed by *Swail and Cox* [2000] and by our deduced climatology for the number of gale days over the North Atlantic which appears consistent with that obtained from the COADS.

[16] We find that winter storminess over large parts of the high latitude North Atlantic, including the North Sea and Scotland, is linked significantly to the prior summer extent of northern hemisphere snow cover 1972/3 – 2000/1. We assess the predictive skill of winter storminess, based on September forecasts, using cross-validation. The prediction skill is found to be useable especially for the high latitude North Atlantic as a whole rather than at the individual grid square level. These results are based on just 29 years of reliable snow cover records and clearly a longer data series would provide greater confidence in the temporal stability of this predictability.

[17] The winter storminess link to prior summer snow cover is associated with the winter NAO link to summer snow extent [*Saunders et al.*, 2003; *Bojariu and Gimeno*, 2003; *Saito and Cohen*, 2003]. As described in *Saunders et al.* [2003], a plausible mechanism for this association is that

summer snow cover — which occurs over the Canadian Northwest Territories and the Siberian region adjacent to the Barents and Kara Seas - gives rise to anomalous longitudinal differences in summer surface air temperature with the subpolar North Atlantic. These temperature differences produce circulation changes which couple to North Atlantic sea surface temperatures. The latter may then persist through to winter [*Wu and Gordon*, 2002; *Saunders and Qian*, 2002]. However, another underlying root influence which forces the variability in summer snow cover as well as all associated linking variables cannot be ruled out. Numerical model experiments with prescribed snow cover conditions are required to resolve this question.

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