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Scandinavian storminess since about 1800

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[1] We study the history of storminess in Northern Europe, as derived from local pressure observations in Lund since 1780 and Stockholm since 1820 (Sweden). At both stations barometer readings were made three times per day, morning, midday and evening, and after about 1850 at fixed observation hours. We use four common storminess indices: annual number of deep lows ($p < 980$ hPa), the annual 95th and 99th percentile of pressure changes between two observations, and the annual number of fast absolute pressure changes ($|\Delta p|/\Delta t > 16$ hPa/12 h). It turns out that the 1980's–mid 1990's were a period of enhanced storminess, mainly seen in the Stockholm record, but his period is within the natural variability of the records. Thus, there are no robust signs of any long-term trend in the storminess indices. Storminess is during the entire historical period remarkably stable, with no systematic change and little transient variability. *INDEX TERMS:* 1620 Global Change: Climate dynamics (3309); 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3364 Meteorology and Atmospheric Dynamics: Synoptic-scale meteorology. **Citation:** Bärring, L., and H. von Storch (2004), Scandinavian storminess since about 1800, *Geophys. Res. Lett.*, *31*, L20202, doi:10.1029/2004GL020441.

1. Introduction

[2] Windstorms are one of the meteorological phenomena with the potential for high impact damage, both by direct wind force which may cause wide spread erosion and damage to forests and housing, but also the more indirect effect through storm surges and wind waves. The public and ecosystems in storm-prone areas, in particular in the westerly wind zones of Europe are well adjusted to the continuous stream of passing windstorms. However, every now and then extreme windstorms cause severe damage. Together with the perspective of anthropogenic climate change, such extreme events create the perception that the storm climate would change; that the storms lately have become more violent, a trend that may continue into the future.

[3] The question is, of course, whether this perception is essentially caused by certain deeply routed cultural notions about the relationship between man and nature, or whether such changes are real. In fact, analysis have claimed to have documented ongoing intensification of the storm climate in both the North Atlantic and Pacific [*Schinke*, 1992; *Graham and Diaz*, 2001], but a more careful analysis of the data used lead to serious doubts as to whether the found changes were due to real changes or were related to changing quality of monitoring the state of the atmosphere [*WASA Group*, 1998; *Harnik and Chang*, 2003]. In fact, the WASA project came to the conclusion that changes in storminess could not be found in homogenous storm proxies representative for the area Northeast Atlantic, North Sea and Baltic Sea [*WASA Group*, 1998]: Its main conclusion is that the storm- and wave climate in most of the Northeast Atlantic and in the North Sea has undergone significant variations on time scales of tens of years; it has indeed roughened in the past decades, but the present intensity of the storm- and wave-climate seems to compare with the intensity at the beginning of this century. Part of the variability is found to be related to the North Atlantic Oscillation. A similar conclusion was presented by *Chang and Fu* [2003].

[4] The most obvious parameter to measure the intensity of storms is the impact wise relevant wind speed. However, almost all if not all, multi-decade wind speed time series are compromised by inhomogeneities, stemming from different instrumentation and changing local environmental conditions. Thus, any assessment based on local wind data is endangered of showing trends due to such non-climatic factors. The situation is similar with visual assessments according to the Beaufort scale. Also, analysis of historical weather maps and modern re-analyses [*Harnik and Chang*, 2003] suffers from potentially serious inhomogeneities, due to changing densities of observations and analysis practices. Therefore, indirect "proxy" data were suggested – such as intra-annual statistics of daily geostrophic winds derived from a triangle of pressure readings [*Schmidt and von Storch*, 1993; *Alexandersson et al.*, 1998, 2000]. Comparisons with quality controlled multi-year wind data have shown [*WASA Group*, 1998] a good correlation of the intra-annual percentiles of geostrophic wind and local wind, so that changes in real wind percentiles should be describes reasonably well by changes in geostrophic wind percentiles. An alternative proxy is annual percentiles of local temporal (6 hourly, 12 hourly) pressure changes [*Kaas et al.*, 1996].

[5] In the following we will analyze long time series of pressure readings for Lund and Stockholm in Sweden, whether they provide evidence of a roughening of the storm climate in Northern Europe. These readings extend back to 1823 (Stockholm) and 1780 (Lund) – thus we present for the first time estimates based on homogenized meteorological instrument readings of the variability of storm climate for as long as 200 years.

2. Data and Methods

[6] The WASA study was limited to the 20th century, since only very few data extend further back in time. In this note, we present proxy time series for the two Swedish

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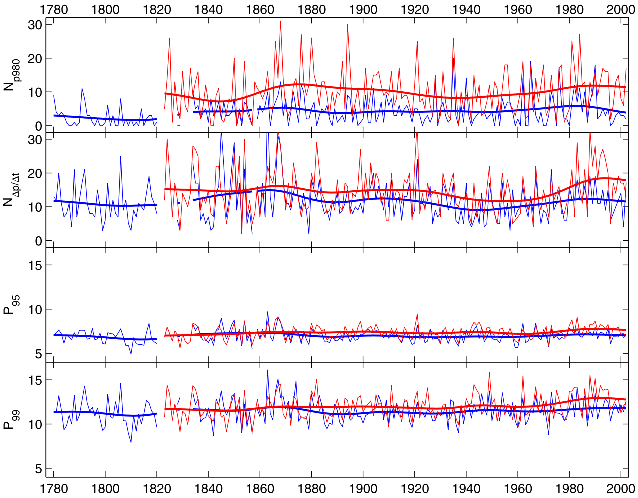

Figure 1. Time series of pressure-based storminess indices derived from pressure readings in Lund (blue) and Stockholm (red). From top to bottom: Annual number of pressure observations below 980 hPa (N_{p980}), annual number of absolute pressure differences exceeding 16 hPa/12 h ($N_{\Delta p/\Delta t}$), Intra-annual 95-percentile and 99-percentile of the pressure differences (P_{95} and P_{99}) in units of hPa. To emphasize variations on the 30-year time-scale (thick lines) the time-series were filtered with Gaussian weights ($\sigma = 9$).

locations Lund and Stockholm. These proxies are based on local station pressure readings. After a proper homogeneity check of the pressure readings [*Bärring et al.*, 1999; *Moberg et al.*, 2002], the time series of the following annual storminess indices have been determined (Figure 1) using all available (i.e., thrice-daily) pressure observations within a year

[7] • The annual number of pressure observations below 980 hPa (N_{p980}). The threshold 980 hPa was selected so as to allow comparison with previous studies in the region [*Alexandersson et al.*, 1998; *WASA Group*, 1998].

[8] • Annual number of absolute pressure tendencies $|\Delta p|/\Delta t$ exceeding 16 hPa/12h ($N_{\Delta p/\Delta t}$).

[9] • Intra-annual 95-percentile and 99-percentile (P_{95} and P_{99}) of the absolute pressure differences between two consecutive observations (6h < Δt < 18h).

[10] When calculating the pressure tendencies used in $N_{\Delta p/\Delta t}$, the different time increments in the reading pressure were accounted for by only using successive observations with a time difference Δt between 6 h and 18 h. The 12 h pressure tendency Δp was then calculated as $|\Delta p|/\Delta t \cdot 12$ h.

[11] For any year at least 85% of all three daily pressure observations had to be present to calculate a valid index. The gap during 1821–1833 in the Lund series is mainly due to no clock readings, and generally more irregular observations; see *Bärring et al.* [1998] for details about the frequency of missing data in the Lund record. We take this as a sign of less stringent observation practices and choose to omit most of this period. In such old series there is always the issue of quality and homogeneity. The same general approach towards quality control and homogenization was used for the two series. The Lund monthly pressure series were used to produce the monthly gridded dataset [*Jones et al.*, 1999] that was used as one of the reference data sets when homogenizing the Stockholm series on the monthly time-scale [*Moberg et al.*, 2002]. With respect to the quality control of the observational resolution data the Lund and Stockholm series were quality-controlled independently. For the purpose of this study the two series can thus be regarded as independently handled. Basic descriptive statistics are shown in Table 1. The correlation between the two series (Table 2) suggests that on average the two series share (based on r^2) some 25%–50% of the temporal variability. To further analyze temporal variations in the correlation between the two sites we use running correlations of length 31 years (Figure 2).

Table 1. Average and Standard Deviation of the Four Storminess Indices for Lund and for Stockholm

	Lund				Stockholm			
	N_{p980}	$N_{\Delta p/\Delta t}$	P_{95}	P_{99}	N_{p980}	$N_{\Delta p/\Delta t}$	P_{95}	P_{99}
Avg	4.0	11.6	7.0	11.4	9.9	14.6	7.4	12.0
Std	3.9	5.8	0.7	1.3	6.6	6.6	0.7	1.4

Table 2. Correlation Coefficients for the Whole Period Between the Storminess Indices for Lund and Stockholm[a]

	N_{p980}	$N_{\Delta p/\Delta t}$	P_{95}	P_{99}
N_{p980}	0.57	0.43	0.33	0.36
$N_{\Delta p/\Delta t}$	0.47	0.63	0.78	0.73
P_{95}	0.41	0.78	0.71	0.74
P_{99}	0.46	0.73	0.77	0.56

[a] The triangle above the diagonal shows correlations between the Lund indices and the triangle below shows correlations between the Stockholm indices. The diagonal shows the correlation between the respective storminess index for Lund and for Stockholm. All correlations are significant at $\alpha = 0.01$ or better.

[12] To quantify any long-term trends in the storminess indices we use two linear regression methods (Table 3): the common ordinary least-squares (OLS) linear regression, and a robust regression method to avoid influence from outliers and/or non-stationary variability [*Huber*, 1981]. The robust method is the one available in Matlab Statistics Toolbox

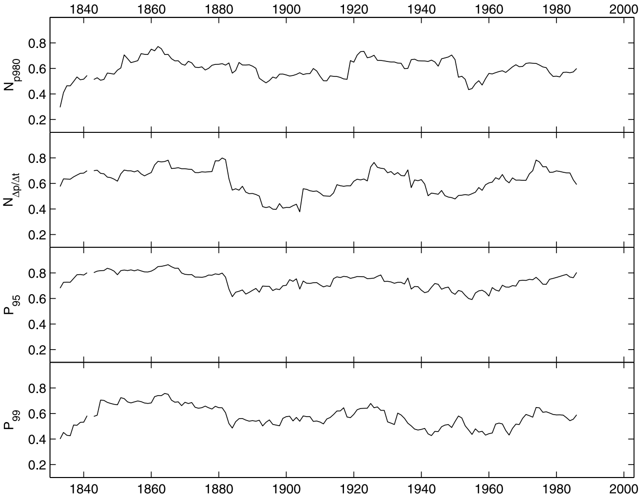

Figure 2. Running correlations of length 31 years between the Lund and Stockholm storminess indices. Before about 1850 the correlations are unreliable because of few common values, close to the beginning of the Stockholm series and several years with missing data in the Lund series.

Table 3. Linear Trend Statistics (the Slope and Its p-Value) for the Pressure-Based Storminess Indices (Figure 1)[a]

	OLS Linear Regression		Robust Regression	
	Slope	p	Slope	p
		Lund (1780–2002)		
N_{p980}	0.0115[b]	0.0055	0.0068	0.0641
$N_{\Delta p/\Delta t}$	−0.0045	0.4710	0.0001	0.9867
P_{95}	0.0002	0.7826	0.0004	0.5945
P_{99}	0.0013	0.3395	0.0017	0.2342
		Lund (1780–1962)		
N_{p980}	0.0115[b]	0.0221	0.0086	0.0657
$N_{\Delta p/\Delta t}$	−0.0082	0.3512	−0.0039	0.6165
P_{95}	−0.0004	0.7266	−0.0004	0.7188
P_{99}	0.0006	0.7689	0.0008	0.6887
		Stockholm (1823–2002)		
N_{p980}	0.0081	0.3948	0.0118	0.2095
$N_{\Delta p/\Delta t}$	−0.0015	0.8723	−0.0006	0.9516
P_{95}	0.0024[b]	0.0216	0.0025[b]	0.0190
P_{99}	0.0055[b]	0.0052	0.0054[b]	0.0086
		Stockholm (1823–1962)		
N_{p980}	0.0002	0.9893	0.0038	0.7756
$N_{\Delta p/\Delta t}$	−0.0248	0.0683	−0.0221	0.1031
P_{95}	0.0017	0.2524	0.0018	0.2494
P_{99}	0.0027	0.3460	0.0019	0.5129

[a] Two regression methods were used: ordinary least-squares regression and robust regression to avoid sensitivity to a few extreme years. To single out the influence of recent decades the analyses were carried out both on the whole time-series and on the period up to 1962.

[b] Significant trends ($\alpha = 0.05$).

version 4.1 (The Mathworks Inc., Natick, Massachusetts), which employs an iteratively reweighted least-squares algorithm employing a bi-square weighting function. To single out the effect of any changes during recent decades we analyze both the full time-series and a sub-period ending in 1962, i.e., with the last 40 years excluded. We calculate significance levels under the assumption of no serial dependence. In fact, the serial correlations of the four considered indices vary between 0.01 and 0.14, so that the effect of serial dependency is weak if not irrelevant.

3. Conclusions

[13] The main conclusions to be drawn are:

[14] ● From Table 1 we note that there are on average six more low pressure readings (N_{p980}) in Stockholm compared to in Lund, mainly because the pressure in Stockholm is on average lower than in Lund (1012.1 hPa vs. 1013.6 hPa). The inter-annual variability is also higher in Stockholm. The other storminess indices, in particular P_{95} and P_{99} are similar at the two locations.

[15] ● Although the average number of deep lows (N_{p980}) over Lund remains constant, the inter-annual variability has increased since the 1930's and is now comparable to the variability over Stockholm (Figure 1).

[16] ● The time series exhibit no significant robust long-term trends (Table 3). The increase of N_{p980} in Lund only appears in the OLS regression and is an effect of the increased variability since the 1930's. The other significant trends (Stockholm P_{95} and P_{99}) are an effect of the increase during recent decades and are not present in the period prior to 1962. This is not consistent with the result of *Dawson et al.* [1997], who instead found a significant downward trend in the number of gale-days derived from observed wind strength in Edinburgh and surrounding stations during the 1770–1988. However, they do not provide any details regarding to what extent the gale-day records from the different stations were homogenized when merged into a composite series.

[17] ● The conspicuous increase in Stockholm $N_{\Delta p/\Delta t}$ in the 1980's is evident but much less pronounced in the other storminess indices for Stockholm. This general increase in the storminess indices during this period is consistent with the findings by *Alexandersson et al.* [2000]. There are however only weak indications of this increase in the Lund indices, which instead show a return to low levels again in the 1990's. This south – north gradient in the recent storminess variation is consistent with the conclusion of *Vikebø et al.* [2003] who conclude the wave conditions of the northern North Sea has become more rough compared to the southern North Sea.

[18] ● The 1860's–70's was a period when the storminess indices showed general higher values of comparable magnitude as during the 1980's–90's. However, from Figure 1 it is also clear that the indices have returned to close to their long-term average. The increased inter-annual variability during the 1840's–60's in Lund $N_{\Delta p/\Delta t}$ is partially matched by the Stockholm series, but for a few extreme years there is no match between the two series.

[19] ● From Figure 2 it is clear that periods of stronger coupling between the two sites are followed by periods of weaker coupling. We identify the following phases that are broadly consistent in all series: strong coupling during 1850–1880, 1920–1930, and the 1970's, and weak coupling during the periods 1890–1910, and 1950–1960. As some of the largest variations occur in the modern data period we believe this variation is a result of some physical process rather than a sign of varying data quality.

[20] ● The correlation between a NAO index [*Luterbacher et al.*, 2002] and the storminess indices is low, in the range 0–0.25.

[21] ● The time series are remarkably stationary in their mean, with little variations on time scales of more than one or two decades. This is surprising to us, as we know that at the same time considerable variations in temperature have taken place, for instance during the Dalton Minimum in the first part of the 19th century or the rapid warming in North Atlantic sector in the first decades of the 20th century [*van Loon and Rogers*, 1978]. A similar result was found in a 1000 year simulation with a coupled atmosphere-ocean model forced with time variable solar input, volcanic and greenhouse gas atmospheric loading (I. Fischer-Bruns, personal communication).

[22] Thus the proxies support the notion of an amplified storminess in the 1980's, but show no indication of a long-term robust change towards a more vigorous storm climate. The fact that the Lund and Stockholm pressure series were independently homogenized and quality controlled adds to the credibility of our conclusions.

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