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Comparison of Selected Storminess Indices Based on Point Pressure Measurements

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1. Introduction
A long-term variability in extra-tropical cyclones frequency and strength is one of key issue in studies on potential climate changes in Baltic region. Beside theoretical considerations and numerical simulations, valuable information on recent changes in cyclone activity can be extracted from observed data. The most common approaches to the problem cover individual cyclone counting (Schinke 1993, Stein and Hense 1994, Lambert 1996), analysis of the real wind data and geostrophic wind calculated from pressure data (Alexandersson et al. 1998), or studies on the pressure fluctuations on selected stations (Schmith at al. 1996, Bärring and von Storch 2004). Application of real wind measurements or weather maps is limited because of inhomogeneity in data sets (von Storch et al. 1993, WASA Group 1998). The quality of pressure data since the beginning of 19th century is much better. However, before this date high quality data exist for a few stations only, which restricts a triangle method used to calculate geostrophic winds. Instead Eulerian statistics like the variance in frequency bands or other indices can be evaluated to extend knowledge on deep cyclone activity further back in time. However, there exists no standard method and different proxies are used. The main goal of the present work is to compare eight different storm indices derived from pressure readings in Lund (1780-2005) in order to analyse long-term changes in storminess in southern Scandinavia.

2. Data and methods
The analysis is based on the long series of pressure observations from Lund, southern Sweden (55°24’N, 13°12’E). Pressure readings from the period January 1780- May 1997 were compiled and homogenised by Bärring at al. (1999). Data consist of three observations per day, but time of the observation has varied during the whole period. The observation period was extended to the end of 2005 with data from Falsterbo meteorological station (55°23’ N, 12°58’E) with the same methodology as used before. In this work we use eight different storminess indices. The first four belong to the most intuitive and widely used proxies; by counting events when pressure exceeds a fixed threshold or calculating percentiles:

1) annual number of pressure observation below 980 hPa (\(N_{980}\))
2) intra-annual 1-percentile of the pressure data set (\(P_{98}\))
3) annual number of absolute pressure tendencies exceeding 25 hPa/24 h (\(N_{pt25}\))
4) intra-annual 99-percentile of the absolute pressure differences in 8 h (\(P_{99}\))

Thresholds were set so as to allow comparison with previous studies (Alexandersson et al. 1998, WASA Group 1998, Bärring and von Storch 2004). These indices are easy to calculate but they suffer for several limitations. For example, \(N_{980}\) does not take into account the background pressure field. Relatively shallow cyclones embedded in a larger scale low can be taken into account by this index, whereas it is possible to miss a deep vigorous cyclone in a general high pressure situation. \(N_{pt25}\) can ignore gradually developing deep cyclone with tendencies between individual observations only slightly lower than the threshold.

Next two indices are based on the pressure variance in selected frequency bands. Instead of digital filtering of the data, classical spectral analysis is used to find the variance in specific spectral bands for creating two proxies:

5) annual pressure variance in the frequency band 0.3-0.6 day\(^{-1}\) (\(S_{0.3-0.6}\))
6) ratio of the annual pressure variance in the frequency band 0.3-0.6 day\(^{-1}\) to the pressure variance in the frequency band 0.1-0.3 day\(^{-1}\) (\(R_{0.3}\))

Variance in the frequency band 0.3-0.6 [1/day] (period 1.7-3.3 day) shows fast synoptic transients. Second spectral index, \(R_{0.3}\), gives information on relative changes in the spectrum shape. An increase of deep, fast moving cyclones together with reduction of total cyclonic activity imply a shift to higher frequencies in the power spectrum (changes in spectrum colour).

Applicability of classical spectral analysis is limited to the evenly sampled data, which is not a case in Lund pressure time series. To avoid this problem the original data were linearly interpolated to fixed measurement hours; 7, 13, and 21 GMT (8h time step). Errors introduced in this way are small in comparison to the typical amplitude of waves being analysed.

Last two indices are based on the idea of a wavelet transformation. In the first of them a convolution, \(W_{ab}\), of pressure time series, \(p(t)\), with a scaled and translated mother wavelet, \(\phi(x)\), is calculated as a indicator of a cyclone occurrence in time point \(h\):

\[
W_{ab} = \sum p(t) \cdot \phi\left(\frac{t-b}{a}\right)
\]

This mother wavelet is an inverted version of the classical ‘Mexican Hat’. Parameter \(b\) denotes wavelet location and parameter \(a\) scale (dilation) of the wavelet. For the Mexican Hat wavelet parameter \(a\) is related to characteristic cyclone time scale by a factor \(2\sqrt{3}\). Deep, fast moving cyclones appear as high peaks in \(W_{ab}\) for low values of \(a\). A cyclone activity index is defined as:

7) annual sum of the structures characterised by \(W_{ab}\) values higher than a fixed threshold in a chosen range of parameter \(a\) (\(N_{\phi(x)}\)).

Because of lack of an objective method for selecting a threshold it is set as 22. This gives annual number of cyclones at the same order of magnitude as \(N_{pt25}\) and \(N_{980}\). To keep the similarity to the spectral analysis the range of a scale parameter was set as: \(1 \leq a \leq 4\). For thrice-daily pressure observations, this corresponds to the cyclones characterised by a time scale (range between two maxima in wavelet function) from 1.1 to 4.6 days.

The mother function for the last index is defined as

\[
\phi(x) = |x| - 1 \text{ for } -1 \leq x \leq 1 \text{ and } 0 \text{ elsewhere.}
\]

This function does not have zero mean, so the covariance, \(\Delta_r\), with the pressure for the interval (-\(a\), \(a\)) was calculated instead \(W_{ab}\).
In similarity with the previous index, the cyclone activity index is defined as:

\[ C_{ab} = \text{cov} \left( \phi(t), \phi \left( t - \frac{b}{a} \right) \right) \]

8) annual sum of the structures characterised by \( C_{ab} \) values higher than 2.3 for the range of scale parameter from 2 to 5 (\( N_{ab,1} \))

This corresponds to a cyclone time scale of 1.3 to 3.4 days.

3. Results and discussion

Temporal changes of all 8 indices presented in Figure 1 show two main features:

1) the overall long-term variability of the indices agree, but the high frequency variability differ,

2) there is no evidence for extraordinary intensification of the cyclonic activity in last decades.

Indeed, except for \( N_{p980} \), and the highly correlated \( P_{1p} \), there no positive trend is visible. And for these two indices this trend can be a result of low values at the beginning of the 19th century. For the 19th century, the highest values in were recorded around 1870 and 1850 whereas the last two decades was a relatively calm period. For the first years of the 20th century most indices suggest a recovery of the cyclonic activity. After these first decades, there is a decreasing tendency up to the 1960’s in several indices, but amplification of cyclonic activity begins already in the 1940’s is also well pronounced in some indices. Last five decades is at the centre of interest because of potential changes related to global warming. All indices increase since beginning of 1960s to about 1990, but in general they turn down toward low values around 2000. Some indices \( (P_{090}, P_{1p}, S_{f0.3-0.6}, R_{so}) \) show quite dramatic decrease in last years whereas others suggest only slight reduction of the activity. However, in all cases variability in last few decades is within the limits of the earlier variability. All indices are highly correlated \( (p<0.01) \) except \( R_{so} \) which is rather weakly linked to the others indices, except \( S_{f0.3-0.6} \) \( (p>0.01 \) for correlation with \( N_{p980}, P_{1p}, \text{and } N_{MedHat} \)). Results show that no single index is representative for the secular changes in cyclonic activity and an analysis based on one index only can be misleading. However, general information variations in storminess can be extracted from a set of several proxies - like the 8 indices presented here - with the aid of principal component analysis. The first PC (not shown) correlates well with previous studies \( \text{e.g. Alexandersson at al. 1998} \) and can be use as a good proxy for long term changes in storminess at relatively large area.

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Figure 1. Time series of pressure-based storminess indices derived from pressure readings in Lund.