Determining baroclinic storminess in the European/Atlantic Sector in the 20th century

Hans von Storch, Institute for Coastal Research, GKSS, Geesthacht, Germany

Abstract: The present review describes first the inhomogeneity problem which hinders a straight forward analysis of changes in windiness related to baroclinic wind storms not only in Europe and the Atlantic sector; an option to overcome is to apply proxies, in particular proxies based on air pressure readings; results from applying such proxies are discussed – which result in the finding that in the areas considered so far, a clear tendency towards more, or less, baroclinic wind storms does not exist – but variations from decade to decade. The validity of the findings based on proxy data is confirmed by shorter time series derived from re-analysis and their downscalings with limited area models

Storms represent the dominant weather hazard in Northern Europe and across the North Atlantic. They are associated with abundant rainfall and excessive wind force. Wind storms cause different types of damages on land and on sea; on land, houses and other constructions may be damaged; also trees may break in larger numbers in forests. In the sea, wind pushes water masses towards the coasts, where the water levels may become dangerously high, overwhelm coastal defense and inundate low-lying coastal areas; also the surface of the sea is affected – wind waves are created, which eventually transform into swell.

We review two questions related to windstorms in the North East Atlantic and Northern European region, namely

1. *How to determine decadal and longer variations in the storm climate?* This issue has been dealt with in great detail in the European WASA project (WASA, 1998). The methodical problem is that many variables, which seem to be well suited for this purpose, are available only for a too short period or suffer from *inhomogeneities*, i.e., their trends are contaminated by signals related to the observation process (instrumentation, practice, or environment). Air pressure readings at weather stations and characteristics of water levels at a tide gauge useful indicators may serve as useful proxies.
2. *How has the storm climate developed in the last few decades and last few centuries?* It turns out that an increase in storm activity over the NE Atlantic and N Europe took place for a few decades since about the 1960s, which had replaced a downward trend since about 1900. When considering air pressure readings at two stations in Sweden since about 1800 no significant changes could be found. Other analyses have been made for the N Atlantic and other regions in Europe.

1. How to determine decadal and longer variations in the storm climate?

A major problem with determining changes in windiness represents the homogeneity, or more precisely the lack of homogeneity, of observed time series. The term “inhomogeneity” refers to the presence of contaminations in a data set, so that the meteorological data, which are supposed to describe the meteorological conditions and their changes over time, are actually a mix of the looked-after signal and a variety of factors reflecting changing environmental conditions, changing instruments and observation practices (e.g., Karl et al., 1993). In many cases it is possible to correct for these inhomogeneities – the process is called homogenization (Alexandersson and Moberg, 1997; Peterson et al., 1998). Often this process involves the comparison of parallel recording at neighbouring stations - first examples can already be found in the late 19th century, in Brückner (1890).

In case of windiness, however, homogenization hardly ever works, because of too few stations and too many inhomogeneities. Thus, it is advisable to refer to proxy data, which are thought to reflect changes in wind statistics, at least changes of wind associated with baroclinic storms. Air pressure readings may be used to construct such proxies

For instance, pressure readings usually depend not very much on the specifics of the location (apart of the height) and have been recorded over long periods of time with rather similar instruments, namely the mercury barometer. A rather different example represents wind measurements which depend very strongly on the details of the surrounding, in particular the exposition and obstacles. Also instruments and observation practices have changed frequently. This is in particular so with wind observations and wind estimates over sea.

Figure 1 displays two examples:

1) The first example shows frequency distributions derived from visual estimates of wind speeds in the English Channel – on distribution is derived from reports of ships without an anemometer, the other from reports of ships with an anemometer. Obviously, the presence of an instrument to measure the wind speed has a significant impact on reporting visual assessments – in the former case the median is 3 or 4 Bf, whereas for visual reports from ships with instrument the median is 5 Bf.
2) The second example shows annual 99%-iles of daily wind reports at six locations along the German North sea coast. All stations are close to each other, 100 km distance, or so. Three are from island stations, the other three are reports from coastal cities. Obviously, the records show jumps, even in most recent years. The relevant point is that these changes which are not synchronously happening at the neighbouring stations – they represent effects of changing observation practices and environments – inhomogeneities. These data are quality controlled, but even scrupulous efforts by a professional weather service can not help when the immediate environment of the instrument is changing.

Thus, direct observations of wind are almost never helpful to assess changes in windiness across decades of years. As an alternative, a number of proxies, which are thought to be representative for the strength of windiness or storminess in a season or a year, have been suggested and used. They are mainly based on pressure readings. Specifically spatial and temporal pressure differences are in use, but also the frequency of low pressure occurrences.

Schmidt and von Storch (1993) have suggested the calculation of geostrophic winds from triangles of pressure readings; in this way, one (or possibly more) geostrophic wind-speed per day is obtained for given location. Time series of annual percentiles of geostrophic wind speed, i.e., separately for each year, are considered as proxies of wind- and storm conditions change in the course of time (Schmidt and von Storch, 1993; Alexandersson et al., 1998, 2000). Typically used percentiles are 95% or 99%.

The performance of this approach has been examined in the framework of simulated data by Krüger and von Storch (2010): Daily geostrophic wind speeds were derived from a triangle of surface air pressure simulations from a from a multi-decadal regional model run and used to build yearly frequency distributions, and compared with yearly statistics of high wind speeds from the same model run. The correlations between quantiles of simulated geostrophic and of real wind speeds demonstrate that the two distributions are linearly linked, with best results for triangles over sea, with typical lengths of no more than 300 km (Figure 2).

An alternative proxy based on spatial differences of pressure readings is the annual frequency of days, when the geostrophic wind is larger than, say, 25 m/s. Two other proxies are based on local pressure observations, reflecting the experience that stormy weather is associated with low pressure and a fall of the barometer reading (Kaas and Schmith, 1996). This proxy has the advantage that it is available for very long time at some locations (Bärring and von Storch, 2004).

A totally different proxy is derived from short-term water variations at a tide gauge. Water levels at tide gauges are often changed by local water works but also by slow variations related to geological phenomena. Therefore, first the annual mean height tide is determined, and then the variations of the high tide relative to this mean high tide are considered (von Storch and Reichardt, 1997).

With these proxies, an assessment of past regiunal storminess is possible (see next chapter). The different indices are mostly consistent among each other, with the exception of the number of deep pressure readings, which correlated only little with the other proxies.

For historical times, when barometers where not yet available, historical accounts help to assess wind conditions, for instance repair costs of Dikes in Holland during the 17th century (de Kraker, 1999) or sailing times of supply ships on pre-determined routes (e.g., Garcia et al., 2000).

2. How has the storm climate in the Atlantic/European sector developed in the last few decades and last few centuries?

Serious efforts to study changing storminess on the NE Atlantic began in the early 1990s, when meteorologists noticed a roughening of storm and wave conditions. Wave observations from light houses and ships (Hogben, 1994; Cardone et al., 1990; Carter and Draper, 1988) described a roughening since the 1950s, and an analysis of deep pressure systems in operational weather maps indicated a steady increase of such lows since the 1930s (Schinke et al., 1992). Unfortunately, these analyses all suffered from the problems described above, namely either an insufficient length of data series or compromised homogeneity. The skill of describing weather details in weather maps has steadily improved in the course of time, because of more and better data reported to the weather services and improved analysis practices. For instance, for the case of global re-analysis the improvement related to the advent of satellite data on Southern Hemisphere analysis is described by Kistler et al. (2001). Examples on the effect of better data coverage are provided by Landsea et al. (2004) and by von Storch et al. (2010) for the case of tropical cyclones.

The breakthrough came when the proxies defined in the previous section were introduced, mostly in the EU project WASA (1998). Alexandersson et al. (1998, 2000) assembled homogenized series of air pressure readings from 1880 for a variety of locations covering most of Northern Europe. They calculated 99%iles of geostrophic winds from a number of station triangles. After some normalization and averaging they derived proxy time series for the greater Baltic Sea region and for the Greater North Sea region. According to this proxy, the storm activity intensified indeed between 1960 and about 1995, but from the beginning of the record until about1960 there was a long period of declining storminess, and since about 1995 the trend is in most areas of the NE Atlantic reversed.

The 1960-1995 increase in NE Atlantic storminess appears also as non-dramatic, when an even longer time window is considered, namely homogenized local air pressure readings at two locations in Sweden, Lund and Stockholm, which have been recorded since the early 1800s and earlier (Bärring and von Storch, 2004;). The number of deep pressure systems (Figure 3a) as well as the number of pressure falls of 16 hPa and more within 12 hours (not shown) is remarkably stationary since the beginning of the barometer measurements. This is remarkably because at the same time the regional temperatures, e.g., the winter mean temperatures for Denmark, rose markedly by almost 2K since 1874 (Figure 3b).

In the past, sometimes the argument was put forward that a general warming would lead to an increase of water vapor in the atmosphere, thus a warming would provide more “fuel” for the formation of storms. This hypothesis was examined in the framework of a millennium simulation with a state-of-the-art climate model, which was run with reconstructed natural and anthropogenic forcing since the year 1000, and extended until the year 1990. It turned out that the hypothesized link could not be detected, even if significant temperature fluctuations were simulated. These hemispheric temperature fluctuations did not co-vary with the intensity or the location of the mid-latitude storm tracks (Fischer-Bruns et al., 2005).

Indeed, there is no evidence that the Little Ice Age, and particularly the Late Maunder Minimum were storm-poor times; also, the cold season is the storm season and not the warmer summer. Clearly, not the mean level of temperature is the key parameter but the spatial gradients of temperature control the statistics of the formation of storms.

Proxies have also derived for other regions, for NE Canada (Matulla et al., 2010a), Central Europe (Matulla et al., 2008) and Northern Italy and the Adriatic Sea (Matulla et al., 2010b). Figure 4a shows the result for a triangle across the Adriatic (Matulla et al., 2010b), Figure 4b one for Northern Canada (2010a). In all these case, considerable variability from decade to decade is found, but no systematic change. Similar results were reported by BACC (2008) for the Baltic Sea, consistent with scenarios of changes of strong wind speeds in that region.

Using proxies, as described in the previous sections, indicates that a systematic roughening of storm-related risks has not happened in the past 200 years, or so. On the other hand, decade-long trends towards stronger and weaker storms have been revealed by these analyses. These shorter time periods can be studied using re-analyses, raw (e.g., Wang et al., 2006) or downscaled with a limited area model (Weisse et al., 2005).

Such a downscaling exercise, which used spectral nudging to ensure a similarity of large-scale patterns throughout the simulation 1958-2001, allowed counting of the annual number of gales per grid-box (Weisse et al., 2005). In most parts of the Northeast Atlantic, this measure of storminess increased until the early 1990s, whereas south of about 50°N there was a decrease (Figure 5). This pattern reversed almost completely in the early 1990s albeit somewhat decelerated towards the end of the period. Later, the simulation was continued so that data are now available from 1948 until 2008. The finding of reduced storminess in recent was corroborated by the additional data.

References

Alexandersson, H., and A. Moberg, 1997: Homogenization of Swedish temperature data. Part I: A homogeneity test for linear trends. Int. J. Climatol. 17, 25-34

Alexandersson, H., T. Schmith, K. Iden and H. Tuomenvirta, 1998: Long-term trend variations of the storm climate over NW Europe. The Global Atmos. Oc. System 6, 97-120

Alexandersson, H., T. Schmith, K. Iden and H. Tuomenvirta, 2000: Trends of storms in NW Europe derived from an updated pressure data set. Clim. Res. 14:71-73

BACC author team, 2008: *Assessment of Climate Change in the Baltic Sea Basin.*, Springer Verlag Berlin - Heidelberg; ISBN 978-3-540-72785, 473 pp

Bärring, L. and H. von Storch, 2004: Northern European storminess since about 1800. Geophys. Res. Letters 31, L20202, doi:10.1029/2004GL020441, 1-4

Brückner, E., 1890: *Klimaschwankungen seit 1700 nebst Bemerkungen über die Klimaschwankungen der Diluvialzeit*. Geographische Abhandlungen herausgegeben von Prof. Dr. Albrecht Penck in Wien; Wien and Olmütz, E.D. Hölzel, 325 pp.

Cardone, V.J., Greenwood, J.G. and M.A. Cane, 1990: On trends in historical marine data. J. Climate 3, 113-127

Carter, D.J.T. and L. Draper, 1988: Has the northeast Atlantic be come rougher? Nature 322: 494

De Kraker, A.M.J., 1999: A method to assess the impact of high tides, storms and storm surges as vital elements in climate history. The case of stormy weather and dikes in the Northern part of Flanders, 1488-1609. Climatic Change 43: 287-302

Fischer-Bruns, I., H. von Storch, F. González-Rouco and E. Zorita, 2005: Modelling the variability of midlatitude storm activity on decadal to century time scales. Clim. Dyn. 25: 461-476, DOI 10.1007/s00382-005-0036-1

García, R., L. Gimeno, E. Hernández, R. Prieto and P. Ribera, 2000: Reconstruction of North Atlantic atmospheric circulation in the 16th, 17th and 18th centuries from historical sources. Clim. Res. 14, 147-151

Hogben, N, 1994: Increases in wave heights over the North Atlantic: A review of the evidence and some implications for the naval architect. Trans. Roy. Inst. Naval Arch. W5, 93-101

Kaas, E., T-S. Li, T. Schmith, 1996: Statistical hindcast of wind climatology in the North Atlantic and northwestern European region. Clim. Res., 7, pp 97-110

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K.C. Mo, C. Ropelewski, J. Wang, A. Leetmaa, R. Reynolds, R. Jenne and D. Joseph, 1996: The NCEP/NCAR 40-Year Reanalysis Project. Bulletin of the American Meteorological Society, Vol. 77, No. 3, 437-471

Karl, T.R., R.G. Quayle and P.Y. Groisman, 1993: Detecting climate variations and change: New challenges for observing and data management systems. J. Climate 6, 1481-1494

Kistler, R., E. Kalnay, W. Collins, S. Saha, G. White, J. Woollen, M. Chelliah, W. Ebisuzaki, M. Kanamitsu, V. Kousky, H. van den Dool, R. Jenne and M. Fiorino, 2001: The NCEP/NCAR 50-year reanalysis. Bull Amer. Meteor. Soc. 82: 247-267

Krüger, O., und H. von Storch, 2010: Evaluation of an air pressure based proxy for storm activity, submitted

Landsea, C. W., C. Anderson, N. Charles, G. Clark, J. Dunion, J. Fernandez-Partagas, P. Hungerford, C. Neumann, and M. Zimmer, 2004: The Atlantic hurricane database re-analysis project: Documentation for the1851-1910 alterations and additions to the HURDAT database. In: R. J. Murname and K.-B. Liu (eds): *Hurricanes and Typhoons: Past, Present and Future*, Eds., Columbia University Press, 177-221

Lindenberg, J., and H.-T. Mengelkamp, 2010: Representativity of near surface wind measurements from coastal stations at the German Bight, submitted.

Matulla, C., W. Schöner, H. Alexandersson, H. von Storch, and X.L. Wang, 2008: European Storminess: Late 19th Century to Present, *Clim. Dyn*.31, 1125-130 DOI 10.1007/s00382-007-0333-y

Matulla, C., M. Hofstätter, I. Auer, R. Böhm, H. von Storch and M. Maugeri, 2010a: Storminess in Northern Italy and the Adriatic Sea reaching back to 1760, submitted

Matulla, C., and H. von Storch, 2010b: Changes in Eastern Canadian Storminess since 1880. submitted

Peterson E.W. and L. Hasse, 1987: Did the Beaufort scale or the wind climate change?, Journal Phys. Oceano. 17, 1071-1074

Peterson, T.C., D.R. Easterling, T.R. Karl, P. Groisman, N. Nicholls, N. Plummer, S. Torok, I.Auer, R. Boehm, D. Gullett, L. Vincent, R. Heino, H. Tuomenvirta, O. Mestre, T. Szentimrey, J. Saliner, E. Førland, I. Hanssen-Bauer, H. Alexandersson, P. Jones and D. Parker, 1998: Homogeneity adjustments of in situ atmospheric climate data: A review. Intern. J. Climatol. 18: 1493-1517

Schinke, H., 1992: Zum Auftreten von Zyklonen mit niedrigen Kerndrücken im atlantisch-europäischen Raum von 1930 bis 1991. Wiss. Zeitschrift der Humboldt Universität zu Berlin, R. Mathematik/Naturwiss. 41, 17-28

Schmidt, H. and H. von Storch, 1993: German Bight storms analyzed. - Nature 365, 791

von Storch, H., F. Feser and M. Barcikowska, 2010: Downscaling tropical cyclones from global re-analyses and scenarios: Statistics of multi-decadal variability of TC activity in E Asia. Proceeding ICCE, submitted

Wang, X., V.R. Swail and F.W. Zwiers, 2006: Climatology and Changes of Extratropical Cyclone Activity: Comparison of ERA-40 with NCEP–NCAR Reanalysis for 1958–2001, J. Climate 19, 3145-3166

WASA, 1998: Changing waves and storms in the Northeast Atlantic? - Bull. Amer. Met. Soc. 79, 741-760

Weisse, R., H. von Storch and F. Feser, 2005: Northeast Atlantic and North Sea storminess as simulated by a regional climate model 1958-2001 and comparison with observations. J. Climate 18, 465-479

Fig 1:

(a) Frequency distribution of wind estimates on the Beaufort scale, derived from voluntary ship reports in the English Channel after 1949. The solid dots are derived from reports from ships without an anemometer, whereas the open dots stem observations made when an instrument was available. All reports are visual assessments of the sea state. Peterson and Hasse (1987).

(b) Annual 99%iles of daily wind reports at 6 locations along the German North Sea coast. Helgoland, List and Norderney are island stations, whereas Cuxhaven Emden and Bremerhaven are from coastal towns. Known inhomogeneities are marked by hatching. (Lindenberg and Mengelkamp, 2010.)

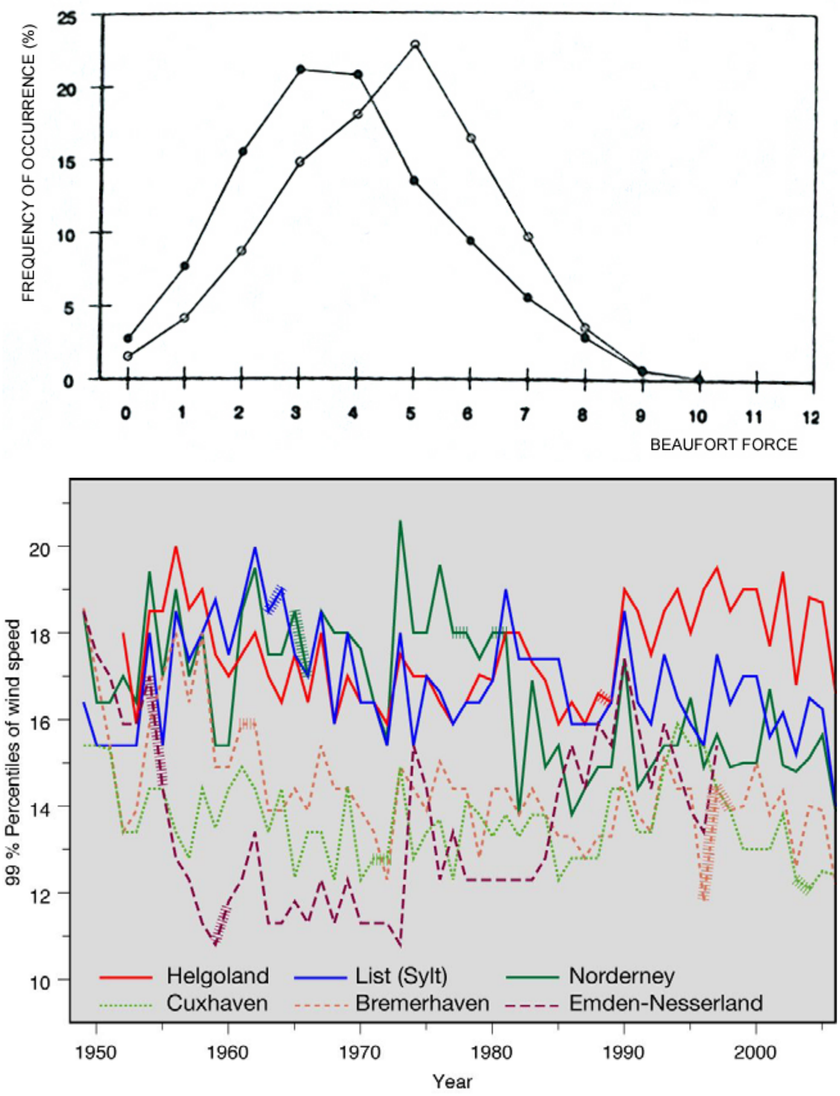


Fig 2 – Correlations of 40-year time series of 99th percentiles of geostrophic wind and surface wind speed. Shown group means for sets of land (solid circles) and sea (open triangles) triangles, as well as small (< 300 km), medium, and large (> 800 km)sized triangles. (Krüger and von Storch, 2010)

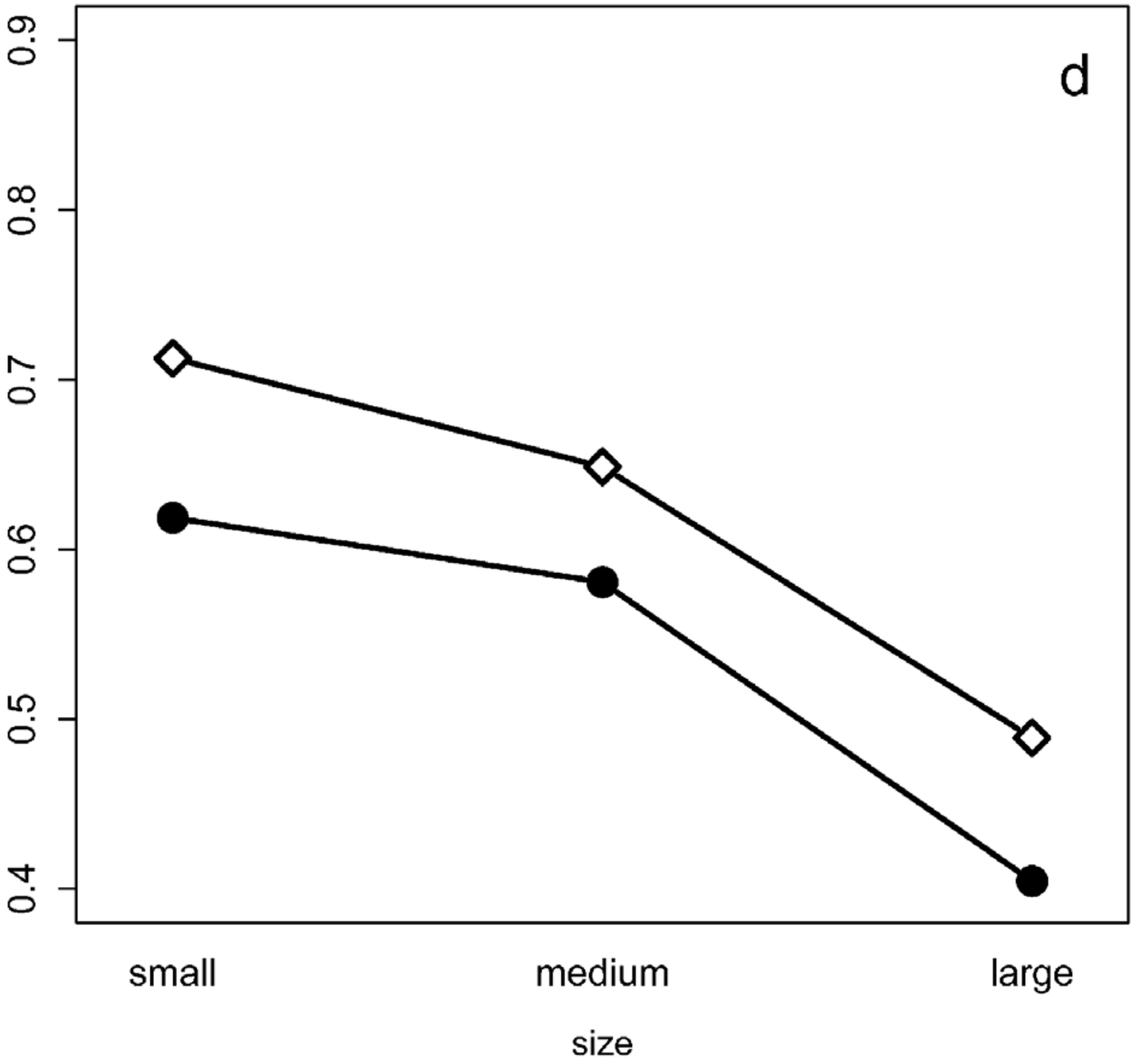
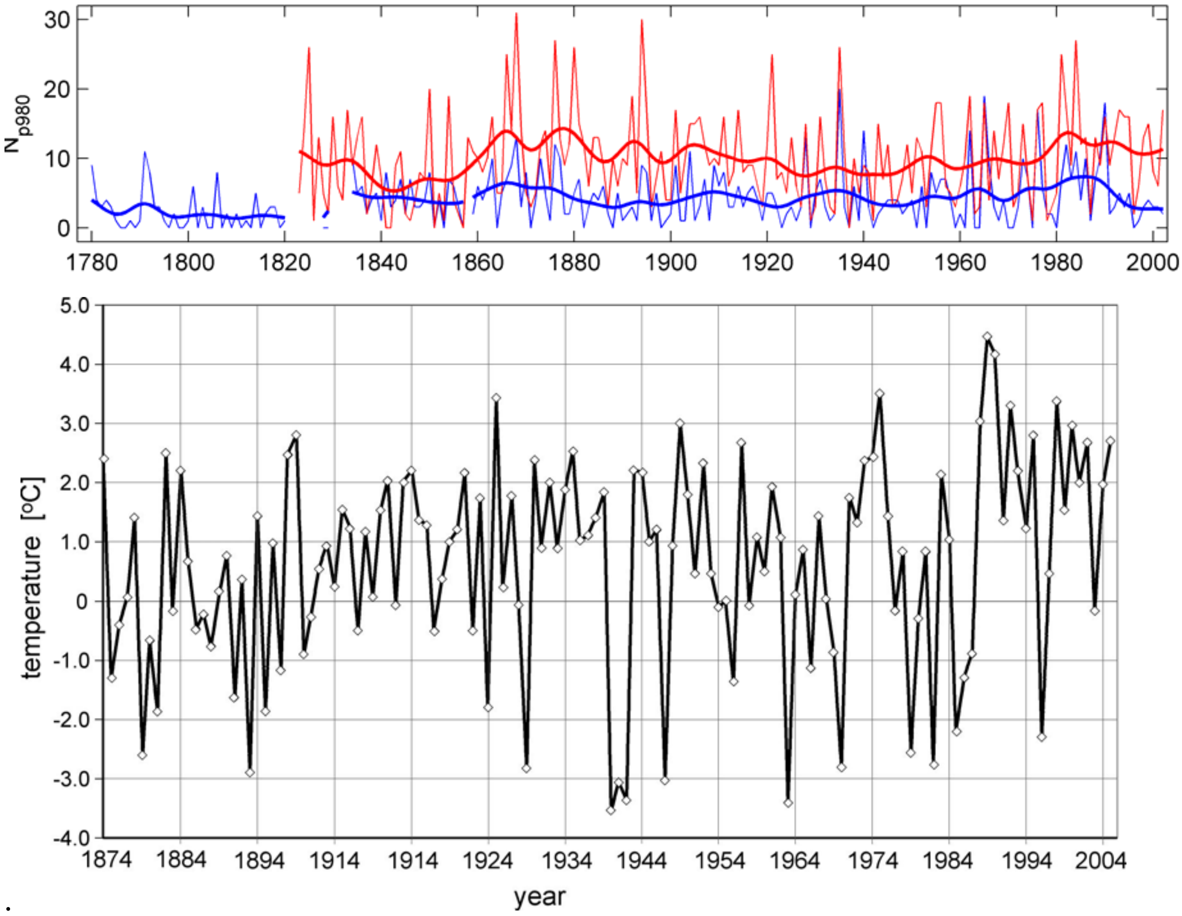


Figure 3 – Climate indicators in Southern Scandinavia –

(a) Annual frequency of daily low pressure readings in Lund (blue) and Stockholm (red) for since the end of the 18th century, showing decadal variability but no tendency towards higher storm activity in recent years. (Bärring and von Storch, 2004)

(b) Winter mean temperatures in Denmark since 1874 (Cappelen, pers. comm.) showing an increase by almost 2K.



.

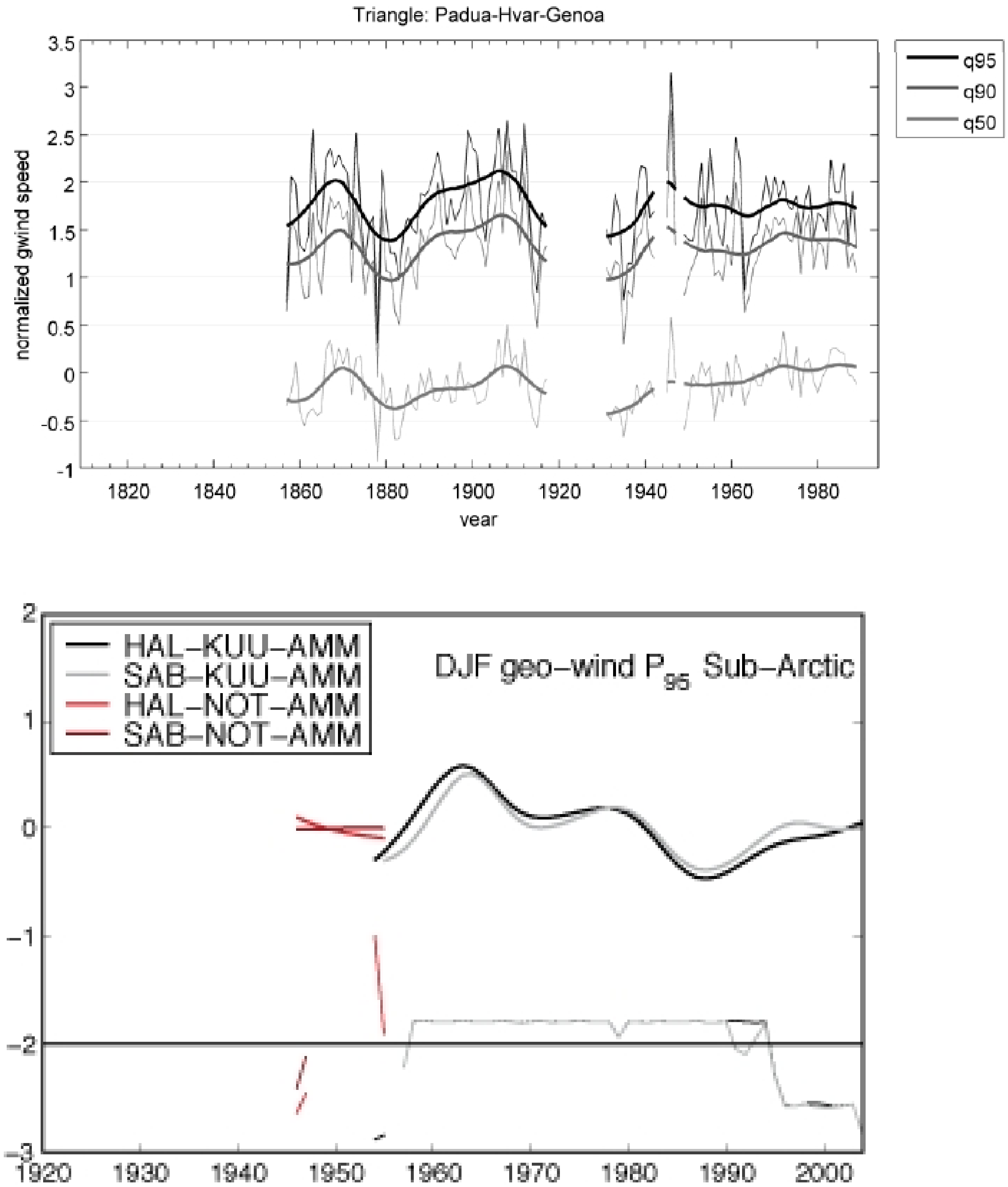


Figure 4: Geostrophic wind speed percentiles derived from a station-triangles

a) *across the Adriatic Sea (Padua, Hvar and Genoa) for the winter half year (Nov-Mar). (95%, 90% and 50% From Matulla et al., 2010b), and*

b) *in the East Canadian Subarctic (90%). From Matulla et al., 2010a)*

Figure 5: Piecewise linear trends in the total number of storms per year with maximum wind speeds exceeding 17.2 m s1. (a) Linear trend for the 1958–T period; (b) linear trend for the T–2001 period. Units in both cases are number of storms per year. (c) Year T at which a change in trends is indicated by the statistical model. (d) Brier skill score of the bi-linear trend fitting the data as compared to using one trend. (Weisse et al., 2005)