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Storm climate and related marine hazards in the Northeast Atlantic and the North Sea

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Abstract

Storms represent a major environmental threat. At sea, wind pushes water masses towards the coast where water levels may become dangerously high eventually overwhelming coastal defences and inundating low-lying coastal areas. Also, the sea-surface is affected where wind waves and swell are generated and obviously represent a threat to offshore navigation, shipping and coastal defence. We review a number of questions related to windstorms in the Northeast Atlantic and the North Sea, in particular: (1) How to determine decadal and longer variations in the storm climate? The methodological problem is that many variables suffer from inhomogeneities or are available for too short periods only. Proxies are suggested from which useful information can be derived. (2) How has the storm climate developed in the recent past? It is shown that an increase from about the 1960s has replaced a downward trend since about 1890. Storm activity is decreasing again since about 1990-1995. (3) How did storm surges and ocean waves develop in the recent past and what may happen in the expected course of anthropogenic climate change? The issue is examined using detailed regional reconstructions and climate change scenarios.

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

When analyzing long-term changes in storm activity long and homogeneous time series at high spatial detail are required. Usually such time series are hardly available. Often a major obstacle is represented by the lack of homogeneity of observed data (inhomogeneities). Here the term inhomogeneities refers to the presence of signals in a data set that are not related to changes in storm activity but reflect contaminations such as changes in measurement techniques, instrumentation or other non-meteorological signals. Figure 1 shows an example for wind observations in the Pacific Ocean. Although both data sets more or less reflect measurements of the same phenomena in the same area, inferred long-term variability differs considerably. While the ship data seem to indicate an upward trend in mean wind speed, the measurements from the ocean weather ship indicate variable but relatively stationary conditions. Obviously, there must be signals (contaminations) present in the data that are not related to changes in the meteorological conditions. Similarly, problems may arise when long-term changes (trends) are assessed from too short or spatially too scattered time series.

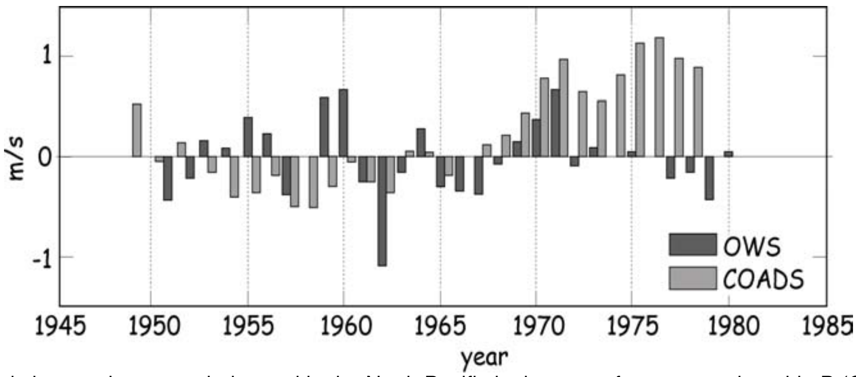

Figure 1: Estimated changes in mean wind speed in the North Pacific in the area of ocean weather ship P (OWS P). Data from ships of opportunity in the vicinity of OWS P are marked as COADS. (After Isemer, pers. communication)

While the problem may occur generally for any type of meteorological data it is particularly severe for wind measurements over the oceans. Therefore a number proxies have been suggested and tested (e.g. Schmidt and von Storch 1993; Kaas et al. 1996). The principal idea is to analyze data that represent the observed changes of storminess but are less influenced by inhomogeneities. Such data are for instance pressure derived storm indices such as upper intra-annual percentiles of geostrophic wind speed (e.g. Schmidt and von Storch 1993; Alexandersson et al. 1998), the number of strong pressure tendencies, or the number of deep pressure readings at a station (e.g. Bärring and von Storch 2004). For coastal locations another alternative are proxies derived from tide-gauge data (e.g. Pfizenmayer 1997; von Storch and Reichard 1997; Woodworth and Blackman 2002). Analyzing long-term changes from such proxy records allows an assessment of the variability of the storm climate of the Northeast Atlantic and the North Sea. The results of such analyzes are reviewed in the next section.

How has the storm climate of the Northeast Atlantic and the North Sea developed in the recent past?

Serious efforts to study changing storminess in the Northeast Atlantic begun when a roughening of the wind and wave climate in the area was noticed at the beginning of the 1990s (e.g. Carter and Draper 1988; Cardone et al. 1990; Hogben 1994). Unfortunately, some of these early analyses suffered from a lack of homogeneity of the analyzed data while others were based on rather short time series. A major breakthrough was achieved when analyses based on proxy data became available mostly within the EU project WASA (WASA 1998). Alexandersson et al. (1998, 2000) assembled homogeneous 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 these time series, storm activity has indeed intensified between about 1960 and 1995. However, the 1960s were characterized by rather low storm activity and storm activity has decreased from about 1890 to about 1960 with some variability superimposed. After 1960 storm activity increased again and reached levels comparable to that at the beginning of the century around 1990-1995. Afterwards again a decrease was observed (Alexandersson et al. 2000) with the later years showing the lowest storm activity on record, at least for the German Bight (Schmidt 2001). A regionally more detailed analysis of the changes after the 1960s is provided in Weisse et al. (2005).

A similar result is obtained when records of high waters at Den Helder and Esbjerg, two harbours at the Dutch and the Danish North Sea coast, are analyzed (Pfizenmayer 1997). Figure 2 displays two statistics for each of the two tide gauges, namely seasonal mean high waters and seasonal 99%iles of the deviations between the high waters and the seasonal mean. The first statistics is influenced by a number of non-storm related processes such as in particular water works or geological changes (land sinking) and global mean sea level rise. For this statistics, both locations exhibit a marked increase while the rate of increase is different at the two locations. The latter is likely to be related to different regional processes. The second statistics is believed to better reflect changes in storminess (Pfizenmayer 1997). It shows some long-term variability but no significant increase during the analysis period.

The 1960-1995 increase in Northeast Atlantic storminess also appears to be non-dramatic, when even longer time windows are considered. Woodworth and Blackman (2002) studied changes in extreme high waters at Liverpool for the period 1768–1999. They concluded that their proxies pointed in particular to increased storminess during the late eighteenth and late twentieth centuries while no longer term trends were evident. Bärring and von Storch (2004) analyzed homogenized local air pressure readings at two locations in Sweden, Lund and Stockholm, which have been recorded since the early 1800s. They found both, the numbers of deep pressure systems and of strong pressure tendencies of more than 16 hPa within 12 hours to be remarkably stationary since the beginning of the barometer measurements.

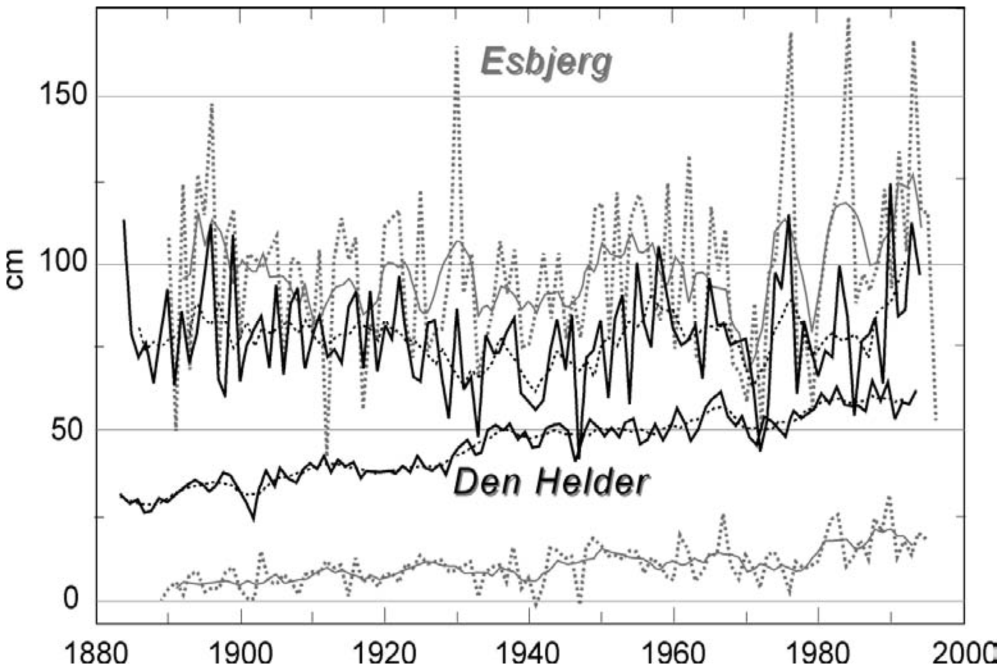

Figure 2: Changing intra-seasonal statistics of high waters at Esbjerg (Denmark) and Den Helder (The Netherlands). The lower two curves show seasonal means; the upper two curves the 99%iles of the intra-seasonal variations relative to the seasonal mean. While the seasonal means reflect all kind of climatic and other local effects, the change of the upper percentiles relative to the means represents a proxy for regional storm activity. (After Pfizenmayer 1997)

How did storm surges and ocean waves develop in the recent past and what may happen in the expected course of anthropogenic climate change?

Using proxies as described above no systematic roughening of the storm climate in the Northeast Atlantic, the North Sea and the Baltic Sea could be identified for the past about 200 years. However, a worsening has taken place within the last about 50 years or so and data during that period are good enough to examine the changes as well as those of storm surge and ocean wave (sea state) statistics in more detail. The basis to do so is provided by the so-called global weather re-analyses that have been provided in the last few years (Kalnay et al. 1996; Uppala et al. 2005). While these re-analyses represent the most homogeneous weather analysis products so far, their spatial resolution remains coarse for regional studies. Therefore, Feser et al. (2001) have used a regional atmosphere model with a simple data assimilation procedure (von Storch et al. 2000) to downscale the NCEP/NCAR re-analyses for the Northeast Atlantic, the North Sea and the Baltic Sea. In the mean time this regional re-analyses is available for 1948-2006. While from this regional re-analysis near-surface wind and atmospheric pressure data are available every hour for the past 59 years, they provide an optimal source to drive wind wave and storm surge models with and to perform detailed analyses of changing ocean wave and storm surge conditions. The latter has been done recently by Weisse and Plüß (2006) and by Weisse and Günther (2006). Similar attempts have been provided earlier using different atmospheric forcing data, for shorter periods or with less detail (e.g. Günther et al. 1998; Sterl et al. 1998; Flather et al. 1998a,b; Langenberg et al. 1999, Lowe et al. 2001, 2005). In the following we briefly summarize the major findings from the more recent analyses.

The regional re-analyses of Feser et al. (2001) have been used to examine changes in the patterns of storminess (Weisse et al. 2005). In most parts of the Northeast Atlantic storminess, given as the annual frequency of storms per grid box, increased until the early 1990s while south of about 50 N a decrease was found. This pattern reversed almost completely in the early 1990s apart from the Southern North Sea, where the trend towards more storms continued, albeit the rate of increase decelerated towards the end of the period (Figure 3). Accordingly, simulations of high tide statistics reveal an increase of water levels in the order of a few mm/year for the same period in particular along the German Bight coast line (Weisse and Plüß 2006; Aspelien 2006). Extreme wave heights have increased in the Southeastern North Sea within the period 1958-2002 by a rate of up to 1.8 cm/year while for much of the UK coast a decrease is found. The increase in the Southeastern North Sea, however, is not constant in time. The frequency of high wave events has increased until about 1985-1990 and remained almost constant since that time (Weisse and Günther 2006). This development closely follows that of storm activity (Weisse et al. 2005).

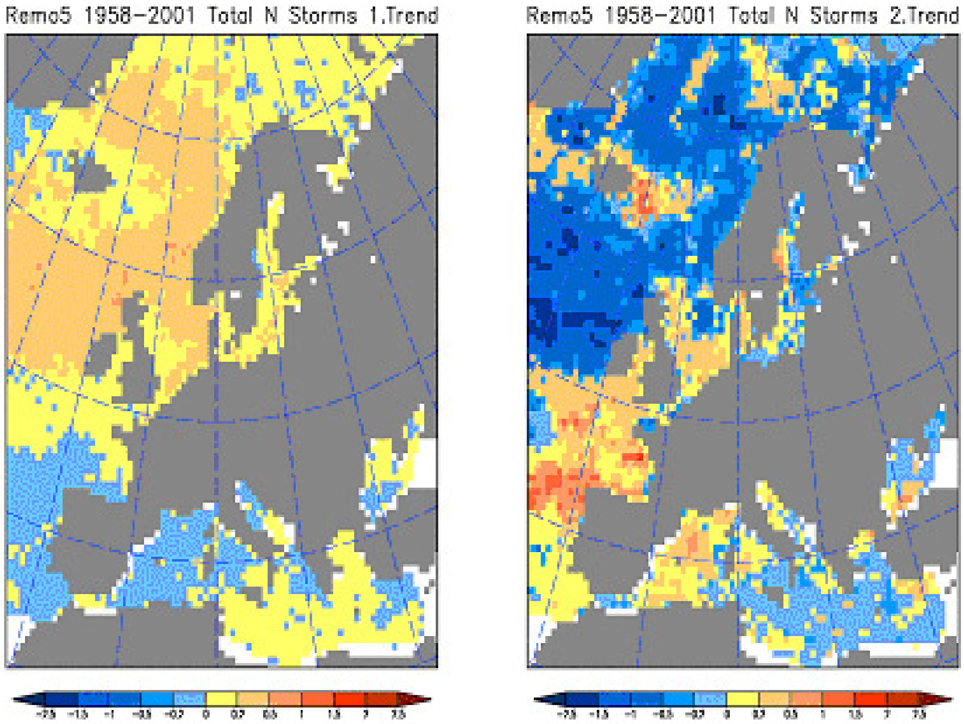

Figure 3: Piecewise linear trends in the total number of storms per year with maximum wind speeds exceeding 17.2 ms^{-1}; Left: linear trend for the 1958–T period; right: linear trend for the T–2001 period. Units in both cases are number of storms per year. For most of the area the year T at which trends change varies between 1990 and 1995. (After Weisse et al., 2005)

Scenarios of future wind conditions have been derived by several groups. One of the most comprehensive sets has been provided by the Swedish Rossby Center with their regional coupled atmosphere ocean model (Räisänen et al. 2004). Here the model was driven with boundary conditions taken from two different global climate models and the effect of two different emission scenarios (A2, B2) has been accounted for. Analysis of changing wind conditions from these experiments has been provided by e.g. Pryor et al. (2006), Woth (2005), or Woth et al. (2006). It was found that strong westerly winds over the North Sea are intensified by less than 10% at the end of the 21st century (Woth et al. 2006).

Wind fields from these scenario runs have been used to drive a storm surge (Woth et al. 2006) and a wind wave model (Weisse and Grabemann, in prep.) with. For storm surges, intensification is expected along the North Sea coast which may reach up to 30 cm towards the end of the century (Woth et al. 2006, Figure 4, top). Note that this increase represents the meteorological induced changes only and does not account for changes in mean sea level. The latter have to be added on top of the meteorological induced changes. Kauker (1998) has shown that this can be done linearly for the North Sea.

Scenarios of future wave conditions show large differences in the spatial patterns and the amplitude of the climate change signals. There is, however, agreement among models and scenarios that extreme wave heights may increase by up to 30 cm (7% of present values) in the Southeastern North Sea by 2085 (Weisse und Grabemann, in prep., Figure 4, bottom).

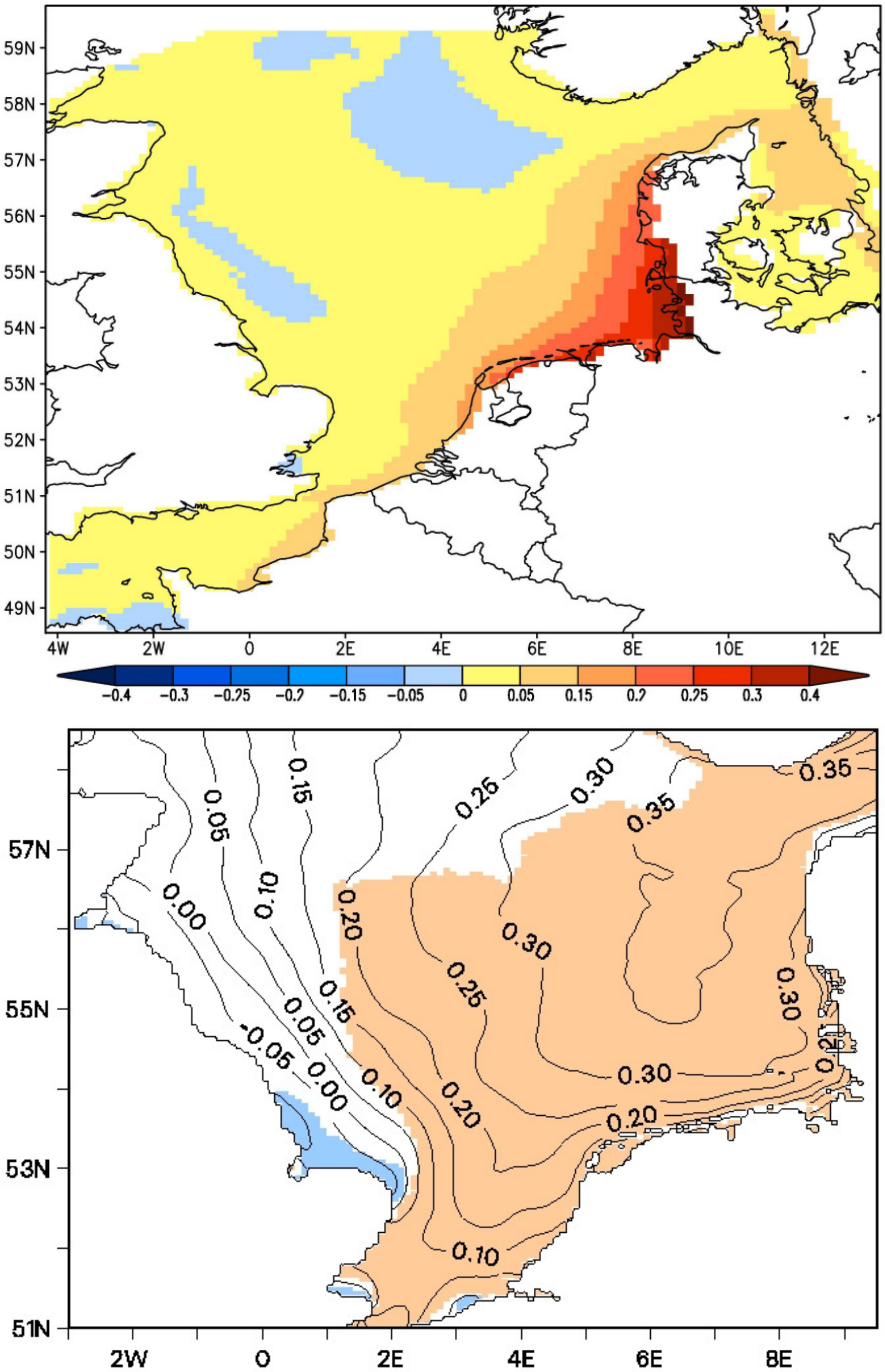

Figure 4: Expected changes 2071-2100 vs. 1961-1990 in annual maximum storm surge heights in m for the A2 emission scenario (top, after Woth 2005) and in ocean wave heights in m (bottom¸ Grabemann, pers. comm.). The latter represents changes of annual 99%-ile wave heights averaged across a series of simulations using different models and scenarios. Shading indicates areas where signals from all models and scenarios have the same sign; red-positive, blue-negative.

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