German Bight Storminess over the Last Century

Daniel Krieger[1,2], Oliver Krueger[2], Frauke Feser[2], Ralf Weisse[2],
Birger Tinz[3], and Hans von Storch[2]

[1] Meteorological Institute, Universität Hamburg, Hamburg, Germany
[2] Institute of Coastal Research, Helmholtz-Zentrum Geesthacht, Geesthacht, Germany
[3] Deutscher Wetterdienst, Hamburg, Germany

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Motivation: Assessing past storm activity provides valuable knowledge for economic and ecological sectors, such as the renewable energy sector, insurances, or health and safety.

Issues: Long time series of wind speed measurements are often hampered by inhomogeneities due to changes in the surroundings of a measurement site, station relocations, and changes in the instrumentation. Air pressure observations are usually less affected by these factors.

Approach: We derive German Bight storminess from 1897 to 2018 by analyzing upper quantiles of geostrophic wind speeds. The geostrophic winds are calculated from triplets of three-hourly air pressure observations which span triangles over the German Bight. This method is enhanced by using up to 18 partially overlapping triangles, whose individual time series are then merged and averaged. The ensemble-like approach allows for the construction of a robust time series of German Bight storminess and provides insights into long-term variability. It also enables us to estimate the uncertainty of our method.

Data: We use air pressure data from eight stations around the German Bight (Fig. 1). Data are provided by the national meteorological services of Germany, the Netherlands and Denmark, as well as the International Surface Pressure Databank (ISPD). We reduce the data to sea-level when needed and apply existing quality flags as well as our own quality control scheme to filter out erroneous values.

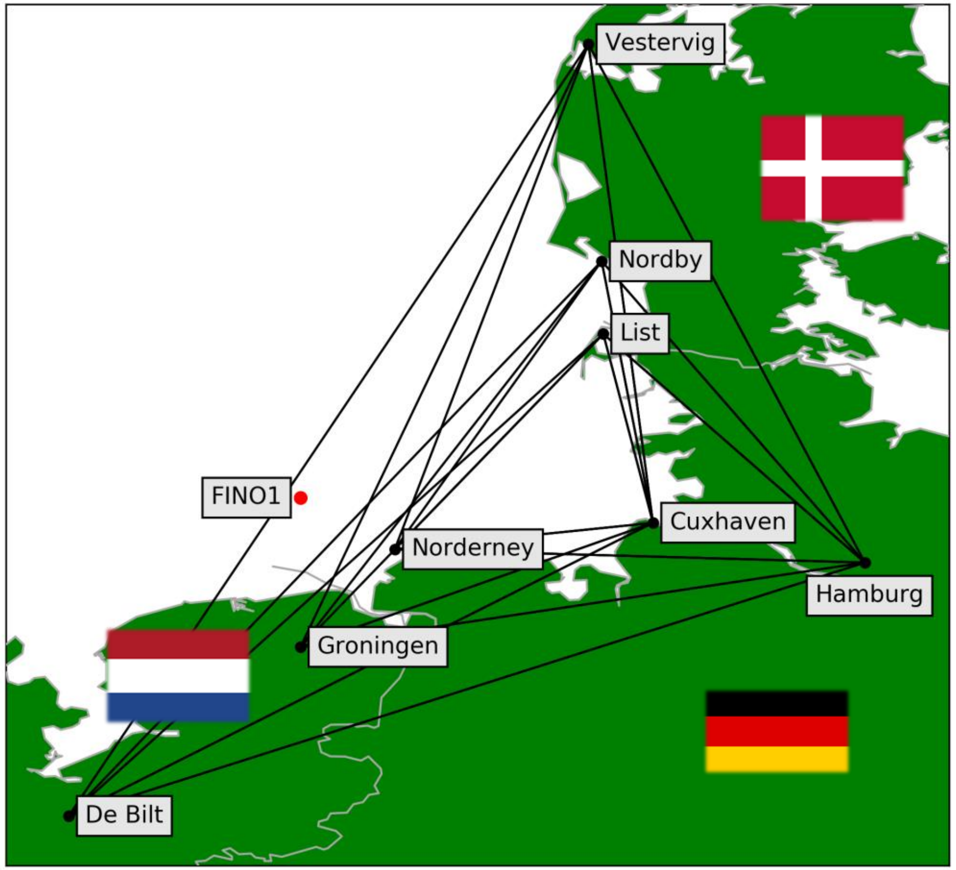

Fig. 1: *Map of eight stations from which pressure observations are used to calculate geostrophic winds and 18 triangles that are constructed based on geometric criteria. The location of the FINO1 research platform is marked in red.*

Annual and Seasonal German Bight Storminess

We define German Bight storminess as the annual and seasonal 95th percentiles of standardized geostrophic wind speeds, averaged over an ensemble of 18 triangles.

On the annual scale, German Bight storminess exhibits multidecadal variability with a period of 3-4 decades. Notable phases of below-average storm activity are present around 1930, 1970 and 2010, whereas above-average phases occur around 1910, 1950 and 1990 (Fig. 2). Despite the dominant variability, there is no significant long-term trend.

On a seasonal scale, winter (DJF) storminess bears the closest resemblance to annual storminess. This results from the high frequency of storm events in winter and generally higher wind speeds compared to the remaining seasons. In general, the winter seasons contributes most to the annual storminess index.

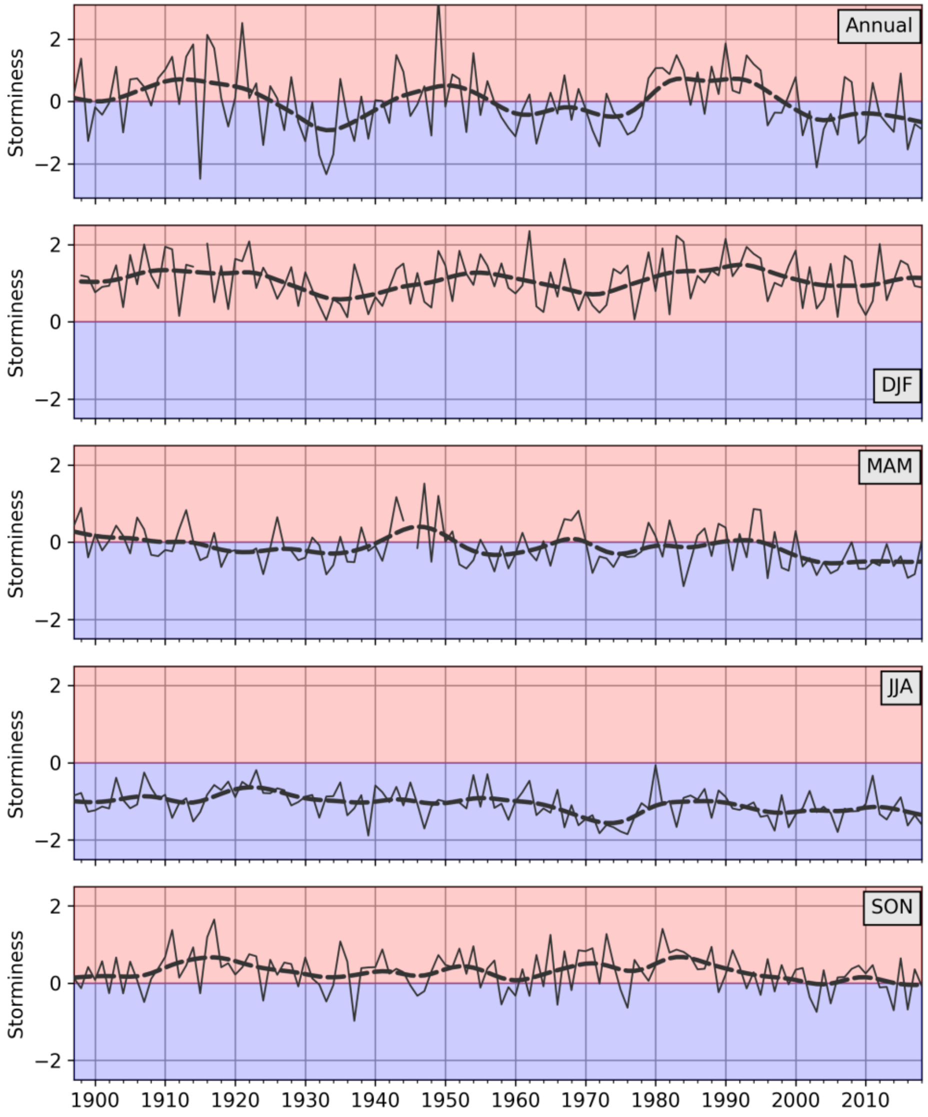

Fig. 2: *Annual and seasonal German Bight storminess. Thin solid lines indicate annual values, thick dashed lines show Gaussian low-pass filtered data. The red area indicates storminess above the long-term average (1961-2010), the blue area shows below-average storminess.*

The Large-Scale Circulation

In order to evaluate the connection between German Bight storminess and the large-scale circulation, we compare annual values of storminess to the North Atlantic Oscillation (NAO)[1], and the Scandinavia Pattern Index (SCAND)[2]. The NAO is based on surface pressure anomalies between Iceland and the Azores, whereas the SCAND index is derived from geopotential height anomalies over Scandinavia. Both indices are representative for the large-scale synoptic setup over central and northern Europe.

The correlation between annual German Bight storminess and the annual NAO index is low at 0.36. The correlation between German Bight storminess and the SCAND index is -0.31 for annual values. Both correlations increase, however, when only the winter months are considered (0.52 for NAO, -0.52 for SCAND). This increase suggests that, especially during the winter months, the large-scale circulation is a major driver of the variability of German Bight storminess.

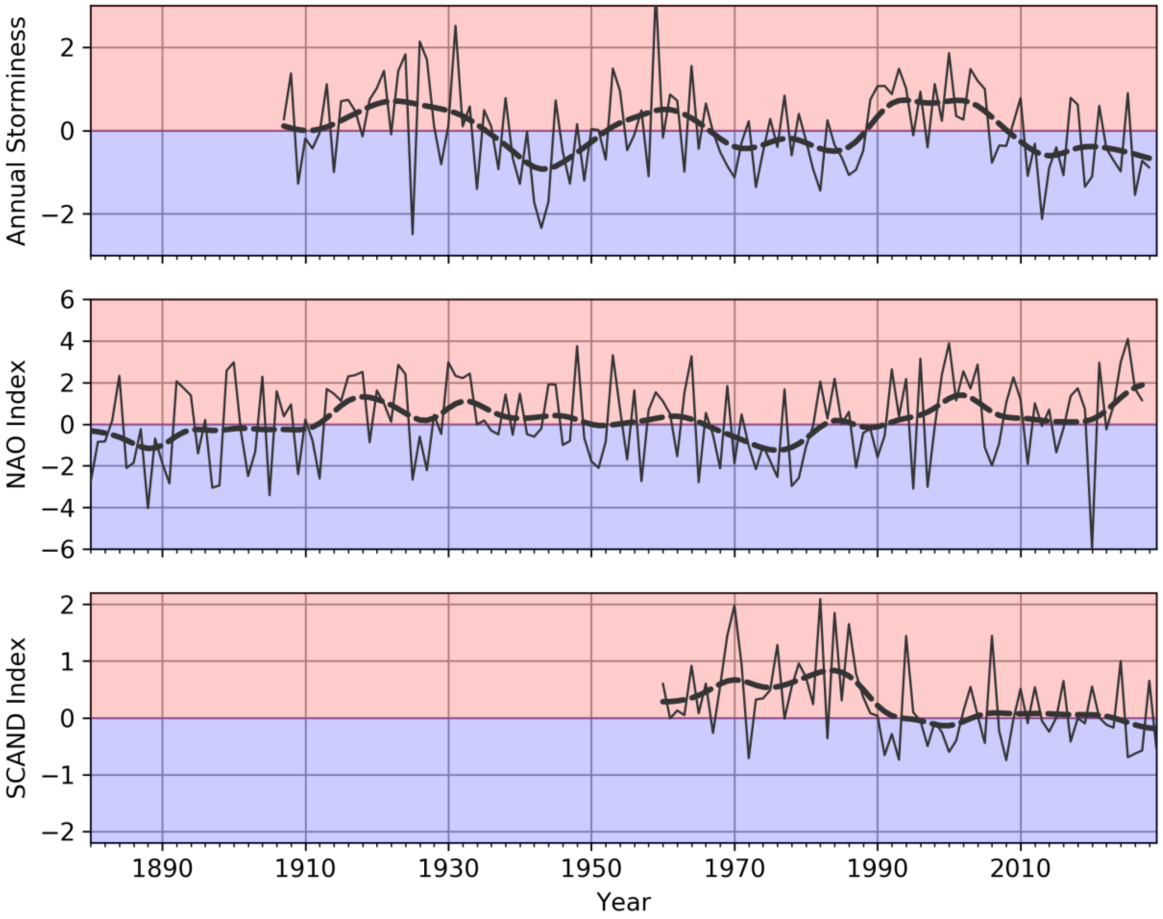

Fig. 3: *Annual German Bight storminess (top), North Atlantic Oscillation (NAO) index (middle) and Scandinavia Pattern (SCAND) index (bottom). Thin solid lines indicate annual values, thick dashed lines show Gaussian low-pass filtered data.*

Validating the Reconstruction

In order to show the validity of our approach, we compare three-hourly geostrophic wind speeds from our reconstruction (non-standardized absolute wind speeds) with wind measurements taken at the FINO1 research platform in the German Bight (marked in Fig. 1) [3].

Overall, there is a good agreement between reconstructed and measured winds (correlation: r=0.83), especially in low-wind environments (Fig. 4). In high-wind environments, our reconstruction overestimates the surface winds. This is the case because the geostrophic assumptions in our approach neglect ageostrophic effects, such as friction, surface roughness, and subgeostrophic motion in cyclonically curved flow.

A correlation analysis between annual 95th percentiles of geostrophic winds from our reconstruction and near-surface winds from four different reanalysis products (ERA5, ERA-Interim, MERRA2, and CFSR) also confirms the validity of the chosen approach with correlation coefficients in the order of 0.7-0.8.

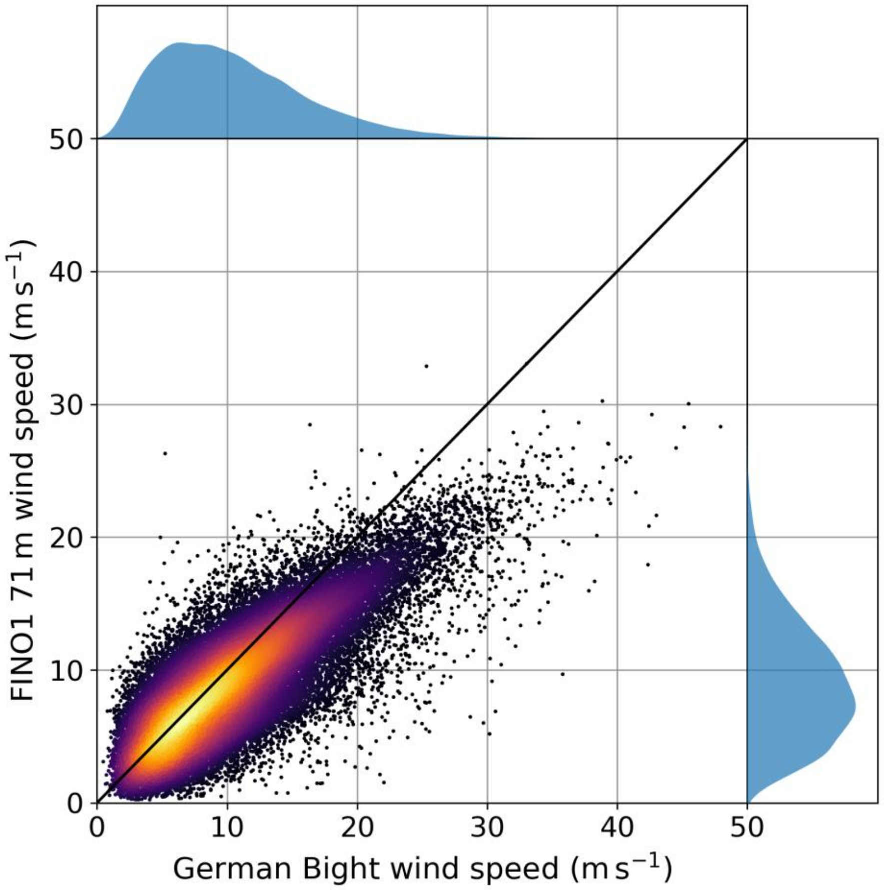

Fig. 4: *Three-hourly reconstructed geostrophic wind speeds over the German Bight vs. three-hourly 10-minute mean wind speed observations from the cup anemometer (71m above sea level) at the FINO1 site, 2004-2017. Data points are color-coded based on a bivariate Gaussian kernel density estimation, where brighter colors indicate higher probability densities. The one-dimensional histograms show probability densities of the individual time series.*

Estimating the Uncertainty

We use a bootstrapping approach to assess the underlying uncertainty in our reconstruction. The bootstrapping scheme samples with replacement from the original geostrophic wind database, so that the newly generated sample is the same size as the original dataset. This process is done for every triangle, month and year in order to generate a new set of geostrophic wind speeds, from which we can recalculate the time series of German Bight storminess. We perform this recalculation 10,000 times and define the uncertainty range as the 95% confidence intervals (difference between 2.5% and 97.5% quantiles) of the resulting distributions of annual storminess values.

The size of the uncertainty ranges is highest near the beginning of the investigated period, and decreases until the 1950s (Fig. 5). Afterward, it stays constant at a low level. This behavior can best be explained by data availability, which is highest after 1950, and lower due to gaps in the data before 1950. In general, the uncertainty of our reconstruction is inversely related to the availability of pressure/wind data.

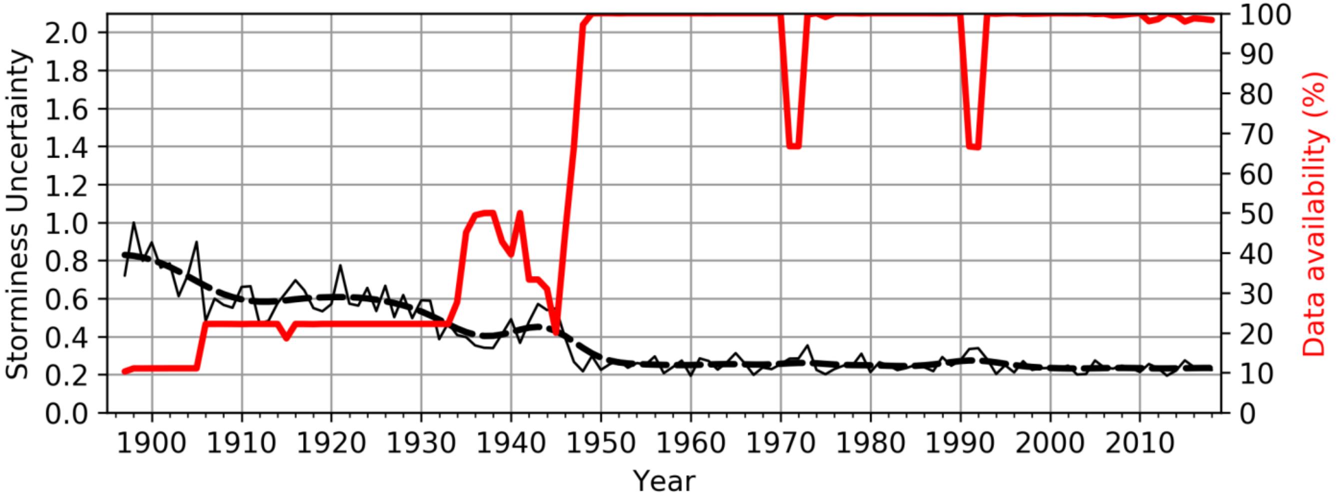

Fig. 5: *Uncertainty of German Bight storminess estimated through a 10,000-iteration-bootstrapping approach (black; thin: annual, dashed: low-pass filtered) and availability of geostrophic wind data (red). 100% data availability corresponds to 2,920 three-hourly wind speed data points for all 18 triangles in a specific year (2,928 in leap years).*

Conclusions

We reconstructed German Bight storminess from 1897-2018 from air pressure observations and enhanced the established triangle method by using an ensemble of 18 partially overlapping triangles.

We found that annual storminess is subject to multidecadal variability with a dominant period of 3-4 decades, and that annual storminess inherits most of its characteristics from winter storminess. A significant long-term trend can not be seen in the annual storminess data.

A comparison with the North Atlantic Oscillation and the Scandinavia Pattern illustrated that annual German Bight storminess shows a weak connection to the large-scale synoptic setup. However, this connection notably increases during winter, when most storms usually occur.

We showed that our reconstruction agrees well with in-situ wind speed measurements and reanalysis products, which confirms the validity of our method.

An uncertainty estimation via a bootstrapping approach demonstrated that uncertainty is inversely related to data availability, and therefore higher early in the investigated period.

References

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[3] Leiding, T., and Coauthors, 2016: Standardisierung und vergleichende Analyse der meteorologischen FINO-Messdaten (FINO123). Tech. Rep. Abschlussbericht, Deutscher Wetterdienst. https://www.dwd.de/DE/klimaumwelt/klimaforschung/ klimaueberwachung/finowind/finodoku/abschlussbericht_pdf.pdf.