WIND, WAVE, AND STORM SURGE HINDCASTS AND SCENARIOS AND RELATED COASTAL AND OFFSHORE APPLICATIONS: THE COASTDAT DATA SET AT THE GKSS INSTITUTE FOR COASTAL RESEARCH

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1. INTRODUCTION

Mid-latitude storms represent a major environmental threat. At sea and at the coasts they are associated with severe sea states and storm surges.

Hindcasts and scenarios have become common tools to investigate long-term changes in the marine wind, wave and storm surge climate. While hindcasts are frequently used as reality substitute in face of limited or insufficiently sampled observational data, scenarios are commonly used to elaborate potential future changes such as those caused by changing greenhouse gas concentrations.

At the GKSS Institute for Coastal Research in recent years major efforts have been put into the development of consistent and high-resolution meteo-marine hindcasts and scenarios for future conditions. (Here consistency refers to the fact that the different variables are in agreement according to the principal physical laws.) While initially strongest emphasis has been placed on the North Sea region, the approach is now extended to other areas such as polar or tropical regions and the Baltic Sea.

This paper sketches the underlying approach and provides a brief introduction to the available data sets. It discusses exemplarily for the North Sea region observed and potential future long-term changes in the wind, wave and storm surge climate and concludes with a brief overview on existing commercial and non-commercial coastal and offshore applications.

2. METEO-MARINE HINDCASTS AND SCENARIOS FOR THE NORTH SEA: THE COASTDAT DATA SET

A major obstacle in analyzing marine long-term changes is represented by the often incomplete and insufficient spatial coverage of the observational record. In a process called analysis such observations may be blended with dynamical models in order to obtain gridded and dynamically consistent data. Initially such analyses have been used to provide gridded atmospheric data from which weather forecast models have been initialized. Because of their consistency and gridded nature they have been used later also to derive climatologies and to assess long-term climate trends. For these purposes however, the analyses had originally not been designed: As models and analysis techniques had been constantly improved in the course of time, these improvements introduced artificial signals (in-homogeneities) into the analysis data that may later be interpreted as climate trends or changes.

The situation was improved significantly when major re-analysis projects were initiated a few years ago. In these projects the old weather data were re-processed using frozen state-of-the-art dynamical models and data assimilation schemes thereby significantly reducing in-homogeneities present in the weather analyses. Presently the longest available weather re-analyses are those produced by the ECMWF (Uppala et al. 2005) and by NCEP/NCAR (Kalnay et al. 1996). The latter meanwhile covers a period from 1948-present providing a rather long record for assessing long-term weather changes and variability.

While the situation has improved with the availability of these global weather reanalyses their spatial coverage (about 210 x 210 km in the case of the NCEP/NCAR re-analysis) remains limited for coastal or continual shelf sea applications. Also smaller scale or intense synoptic features (such as polar lows or tropical cyclones) may not be adequately resolved (e.g.

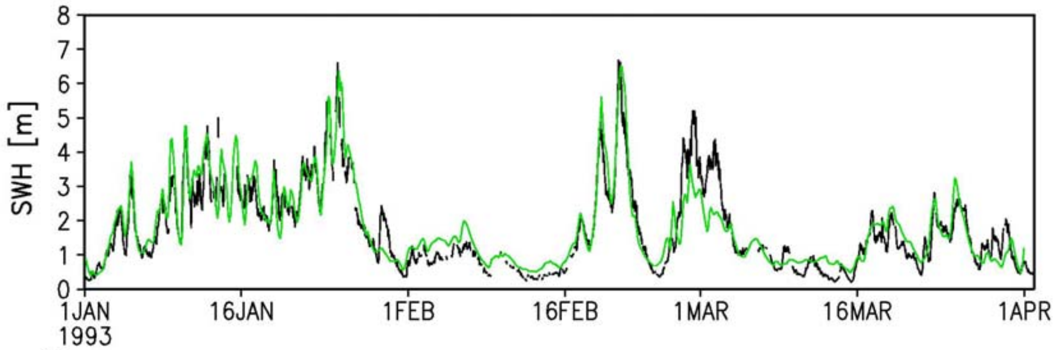

Fig. 1: Time series of significant wave height [m] at K13 for a three months period 01 January 1993–31 March 1993; observations, black; model results, green (from Weisse and Günther 2007).

Zahn et al. 2007). Further, information on marine conditions such as sea states, storm surges, ocean temperatures, salinity etc. are usually not available (an exception is the ECMWF ERA-40 re-analysis, for which sea states are available). The problem can be addressed with a chain of dynamical regional models in combination with observational data.

In the following we illustrate such an approach for the North Sea. Here a regional atmosphere model with focus on Europe and adjacent seas was driven by the global NCEP/NCAR re-analysis in combination with some simple data assimilation (Feser et al. 2001) in order to obtain a better representation of near-surface marine wind fields (von Storch et al. 2000). From this regional simulation, near-surface marine wind-fields and other parameters have been stored hourly. They have been used subsequently to drive storm surge and wind wave models for the North Sea. This way a high-resolution and consistent meteo-marine hindcast for the past 50 years has been generated. Here consistency refers to the fact that the output fields from the different models (wind, waves and storm surges) are in physical agreement, a fact that is frequently ignored e.g., when waves and surges from different sources are analysed jointly.

The capabilities and limitations of the hindcast in simulating changing statistics of meteo-marine conditions in the North Sea have been demonstrated in a number of studies (e.g., Weisse et al. 2005; Weisse and Plüß 2006; Weisse and Günther 2007). An illustrative example is provided in Figure 1. It shows a time series of significant wave height for a three months period at a location in the Southern North Sea. Generally, a rather good agreement between measurements and hindcast can be inferred. However, closer inspection reveals that individual extreme events (such as those after 16 February and around 01 March) may or may not be reproduced by the hindcast. Regardless of this, when the statistics of such events are considered, the situation is much better as these are usually reproduced within error bounds (Weisse and Guenther 2007). In other words, while such multi-decadal hindcasts provide high-resolution meteo-marine data sets and are perfectly suited to study the statistics of events, their variability and their-long term changes, they are not necessarily useful to study individual extreme events as these may or may not be reproduced by the hindcast.

The meteo-marine hindcast is complemented with a set of scenarios for future wind, wave, and storm surge conditions. Scenarios for future wind conditions have been derived by several groups. The most useful possibly is the set of simulations with the model of the Swedish Rossby Centre, which features not only an atmospheric component but also lakes and a dynamical description of the Baltic Sea (Räisänen et al. 2004). This model was run with boundary conditions provided by two global climate models; also, the effects of two different emission scenarios were simulated. This way not only climate change induced signals, but also model uncertainties and uncertainties caused by different assumptions about the future economic developments (greenhouse gas emission scenarios) could be investigated. From these simulations, near-surface wind and atmospheric pressure fields have been used to drive regional storm surge and ocean wave models and to derive projections of future storm surge and sea state extremes for the North Sea.

Figure 2 shows an example of climate change signals (here annual maximum storm surges) and uncertainties obtained from such simulations. The differences between the two rows represent differences due to the choice of different state-of-the-art climate models (model uncertainties) while the differences between the

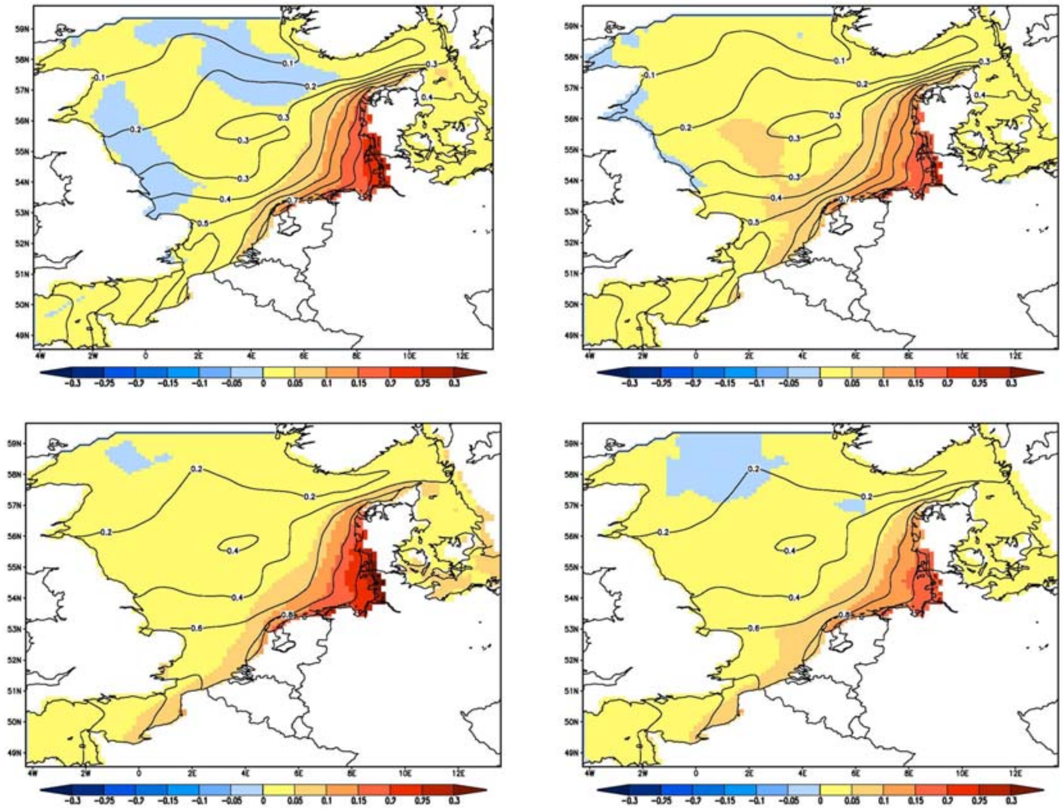

Figure 2: Simulated changes in annual maximum storm surge height in m for the North Sea. Changes are representative for the period 2071-2100 vs. today. Changes are obtained using two different state-of-the-art climate models (upper and lower row) and under different greenhouse gas forcing (lower column pessimistic scenario [A2], right column optimistic scenario [B2]) (after Woth et al. 2006).

columns represent the uncertainty due to different possible global economic developments in the future. For the case of extreme storm surges in the North Sea it can be inferred that, although the patterns differ in detail, a robust signal (namely an increase of extreme events in the German Bight) emerges despite the existing uncertainties. When the signal is compared to the variability that has been observed during the last 50 years (obtained from the aforementioned meteo-marine hindcast) it can be inferred that despite the existing uncertainties the projected future change is outside the range of natural climate variability (Woth et al. 2006). Note that signals for other variables and/or areas (e.g. sea states in the North Sea) may be less robust (Grabemann and Weisse 2007).

3. METEO-MARINE LONG-TERM CHANGES FOR THE NORTH SEA REGION

Based on analyses from the described model studies we briefly summarize the findings for recent and potential future changes in wind storms and related marine hazards and compare the results to those obtained from independent studies based on proxy data.

Storm activity over the northeast Atlantic and northern Europe increased for a few decades after the 1960s following an earlier downward trend that started in about 1900 (e.g. Alexandersson et al. 2000). A similar but regionally more detailed result was obtained from our model studies (Weisse et al. 2005). When longer periods have been considered (such as by analyzing air pressure readings at stations in Sweden since about 1800), no significant changes have been found (Bärring and von Storch 2004). Comparison with hindcast data show a good agreement between observed and modelled storm indices (Figure 3).

Changes in storm surge and wind wave climate were found to be consistent with the changes of storm activity; namely, a general increase since 1960 to the mid-1990s and thereafter a decline (Weisse and Plüß 2006, Weisse and Guenther 2007). Scenarios prepared by a chain of assumed emission scenarios, and global and regional climate models point to a future of slightly

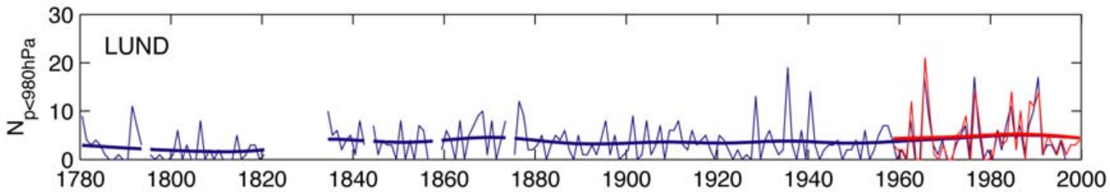

Figure 3: Comparison of observed and hindcast storm indices for Lund (Sweden). Shown is the number of deep pressure readings (< 980 hPa) obtained from homogenized station data (blue) and the coastDat hindcast (red). After Bärring and von Storch (2004) (Bärring, pers. com.)

more violent storminess, storm surges, and waves in the North Sea. For the end of the century, an intensification of up to 10% is envisaged, mostly independently of the emission scenario used. When a linear increase is assumed (resulting in an overestimation of the effect in the first decades) an increase of 1% per decade can be inferred. Compared to the natural variability this comprises a rather weak signal. It is therefore natural that presently no anthropogenic signal in strong winds can be detected. When not only the change in windiness but also the thermal expansion of the ocean is considered, increases of 20–30 cm by 2030 and of 50 cm by 2085 appear to be reasonable guesses for future extreme water levels along the German Bight coastline (Woth et al. 2006).

4. COASTAL AND OFFSHORE APPLICATIONS

The coastDat data set described above has been used for numerous coastal and offshore applications. They comprise wind- and sea state statistics for offshore wind or coastal protection facilities, applications in ship design or simulation of transports for the assessment of oil risk sensitivities and the interpretation of observational data.

Figure 4 shows an example from an oil risk assessment. Here the coastDat data set has been used to force an oil spill model with. For any particular source region (characterized for instance by dense ship traffic), hypothetical accidents were assumed to occur every 28 hours over the 1958-2002 period. The latter provides a rather reasonable sample of the different possible marine weather situations which in turn allows for the estimation of different statistics that characterize the risk and sensitivity of any target region that might potentially be influenced by the accidents. As an example, Figure 4 shows one result of such an analysis for the island of Helgoland. The analysis may be further refined taking into account for example the facts that the probability of an accident might be conditioned upon the weather situation, that different oil fighting strategies may be applied whose efficiency in turn may depend on the weather or that the vulnerability of several target regions may vary.

Figure 5 shows another example in which coastDat data have been used to compare measurements taken onboard a ferry with station data. Originally data have been collocated and compared whenever the ferry position was closest to the station yielding a relatively weak agreement among the two measurements. The agreement is partially enhanced when coastDat data have been used to collocate the two measurements.

5. SUMMARY

The coastDat data set is a compilation of coastal analyses and scenarios for the future from various sources. It contains no direct measurements but results from numerical models that have been driven either by observed data in order to achieve the best possible representation of observed past conditions or by climate change scenarios for the near future. Contrary to direct measurements which are often rare and incomplete, coastDat offers a unique combination of consistent atmospheric, oceanic, sea state and other parameters at high spatial and temporal detail, even for places and variables for which no measurements have been made. In addition, coastal scenarios for the near-future are available which complement the numerical analyses of past conditions.

The backbones of coastDat are regional wind, wave and storm surge hindcast and scenarios mainly for the North Sea. Other areas and phenomena will be included in the near future. We discussed the methodology to derive these data, their quality and limitations in comparison with observations. Long-term changes in the wind, wave and storm surge climate have been discussed and potential future changes were assessed. The data set is presently used for various coastal and offshore

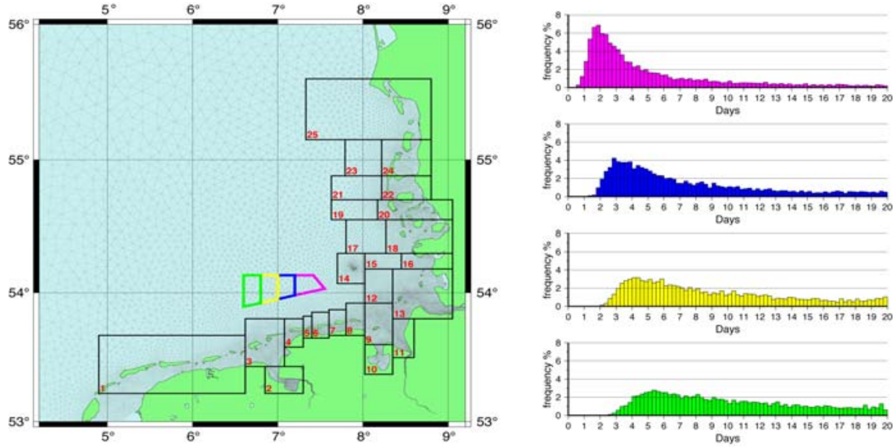

Figure 4: Use of coastDat in oil risk modeling. Left: Colored boxes show hypothetical accident regions within a traffic separation scheme. Numbered boxes are target regions for which impact statistics have been computed. Right: Example of impact statistics for target region 14 (Helgoland). Shown are the frequency distributions of travel times that are needed for the pollution caused by an accident to reach region 14. Color codes match the source regions (left). Region 14 is hit in 65%, 50%, 43% and 37% of accidents depending on source region (right panel from top).

applications demonstrating some of the potentials of the data set in hazard assessment. Examples comprise applications of coastDat in ship design, oil risk modeling and assessment, and the construction and operation of offshore wind farms.

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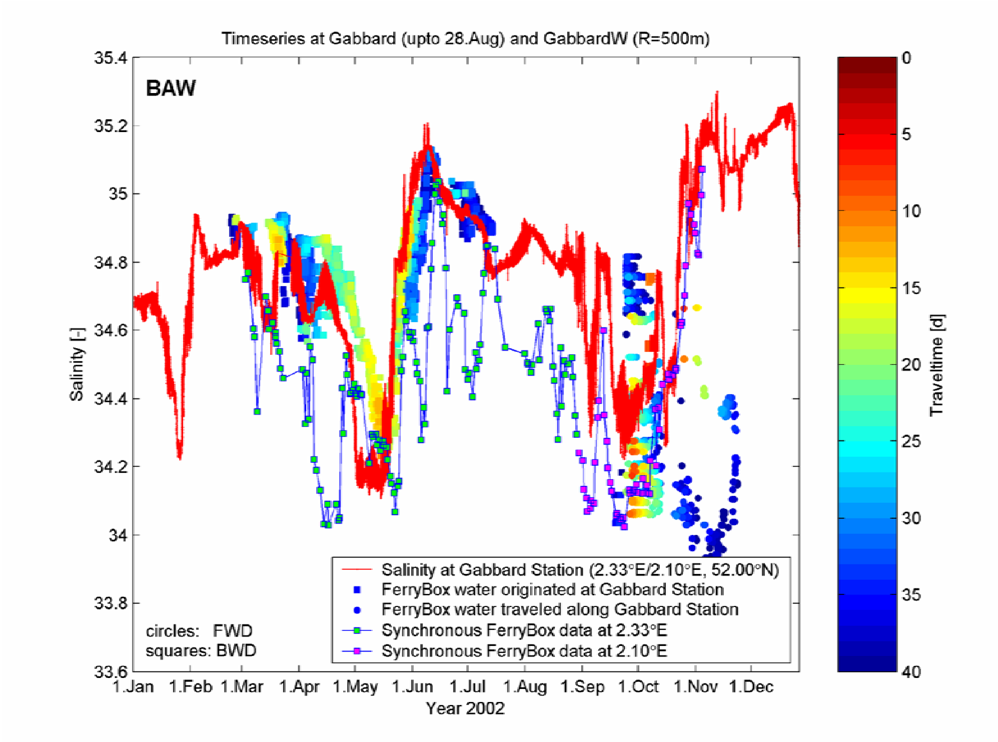

Figure 5: Comparison of measured salinity data at Gabbard in the Southern North Sea (red) and as sampled from a nearby ferry route whenever the ferry is close to Gabbard (thin green and magenta lines). Additionally adjusted data are shown (unconnected thick squares and circles). Here data are compared whenever water masses coming from (squares) or going to (circles) Gabbard intersect with the ferry route according to velocities derived from coastDat. Color code: Time needed from/to Gabbard to intersect with the ferry route.

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