A probabilistic storm surge risk model for the German North and Baltic Sea coast

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April 2010

Summary

Both the German North and Baltic Sea coast are exposed to storm surges. The North Sea region, which is mainly protected by dikes, was heavily affected by severe events in 1962 and 1976. The Baltic Sea was hit by an exceptional extreme event in 1872, but since then storm surge hazard has been more or less forgotten until now.

With the exception of a few industrial risks, storm surge is not widely insured in Germany. However Aon Benfield is developing a new risk model for this peril, commissioned by the German Insurance Association (GDV), to assess storm surge risk and generate a basis for industry discussion on future cover.

The model reflects the whole process from the meteorological origin of storm surges through to the resulting water levels at the coast. This includes wave impacts and simulating the consequences such as defense failures, followed by inundation in the coastal hinterland and damages at properties.

The model approach consists of a probabilistic event driven hazard and a vulnerability module, while an exposure interface and a financial module account for specific re/insurance conditions. This poster concentrates on the hazard module.

Event Origin – Meteorology

A storm surge event at the German coast is triggered by an extra-tropical cyclone. At the North Sea coast cyclones travelling from Northern to Western directions cause the highest surges. Wind speed and wind direction are relatively constant over space and over time (to a certain extent) as well.

Therefore a clear empirical relationship between wind and surge (where surge is defined as the wind-driven component of the sea water level) can be detected, which is described by the ATWS concept (Average Transformed Wind Speed) (Van Dyk, 2004; Van den Brink et al, 2002).

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$$V_{proj}^{k} = V^{k}\cos(\theta-\theta_0)|\cos(\theta-\theta_0)|^{k-1}$$

$$ATWS(t) = \sum_{t'=t}^{t-24} V_{proj}^{k}\, e^{-\frac{t-t'}{\Delta t}}dt'$$

$V^k(proj)$: projected wind speed on direction ϕ_0, raise to power k

exp[-(t-t')/Δt]: weighting over time before peak water level

$\sum_{t'=t}^{t-24}$: Weighted Sum over time before peak

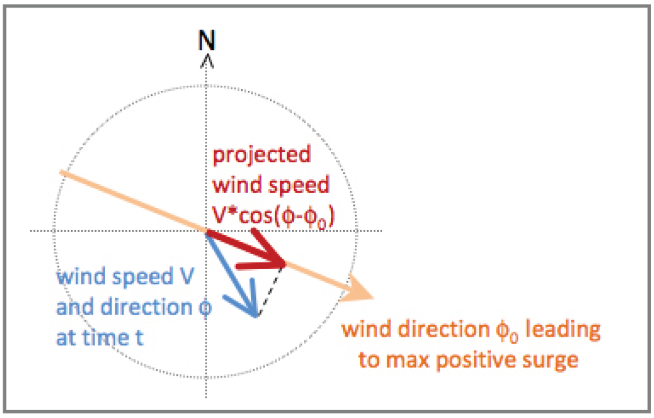

Figure 1: ATWS-concept (Average Transformed Wind speed)

The wind data was obtained from CoastDat (simulated hourly wind speed and direction from 1948 to 2006). Water level data was made available for 86 gauge stations out of which 41 were selected for the model.

Classification of historical storm surges is based on observed sea water levels at gauging stations and extended literature research (Rodda et al 2009). In total four relevant classes have been defined which include events with similar geographical distribution along the coast. An example can be seen in figure 2.

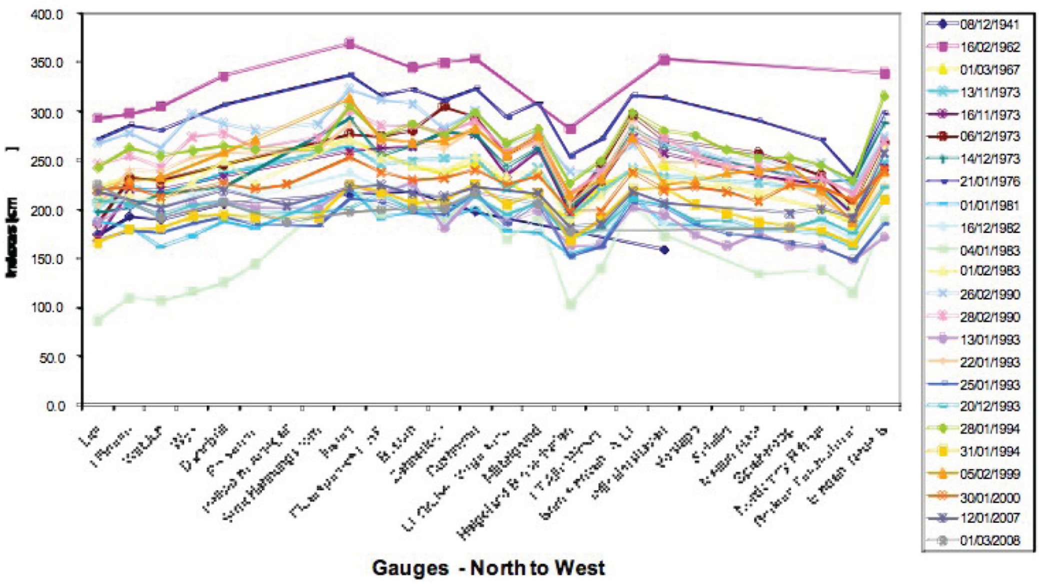

Figure 2: Example for an event type showing evenly distributed water levels along the coast

Storm Surge Simulator – Event Generation

A stochastic storm surge event simulator has been developed to simulate a large number of synthetic events based on historical conditions inherent in observed data. An event is defined by an initial ATWS value, an event type (based on the classification) with an assigned yearly mean frequency and a date, which is recorded during the simulation process, to detect events following each other in sequence. As storm surges are a winter phenomenon the, simulation year starts at 1 August and ends at 30 April. To derive water levels the ATWS value is transformed into a surge level and combined with astronomical tide and headwater influx (in estuaries).

The interdependency of water levels at the coast is simulated using the Gauss copula concept. For the marginal distributions of water levels the Laplace probability distribution was chosen providing a very good fit particularly at the right tail. An interpolation algorithm is used to transfer water levels from gauges to segments.

The coast is split into segments (a total of 1500 at the North Sea) according to defence characteristics such as heights, slopes, orientation and foreland. For each segment, defence failure and inundation is simulated based on water level and wave parameters.

Wave Conditions

Water level and wave parameters such as height, period and direction form the load at the coastal defence elements. To assess the wave characteristics at the coast the numerical model SWAN (Simulating Waves Near Shore) from TU Delft has been used (RIS, 1997). The simulations have been based on a 100m grid for ranges of relevant boundary conditions such as wind speed (8-32m/s), wind direction and water level (see figures 3 & 4) which are calculated within the storm surge event simulator for each event.

Coastal foreland can have an attenuation effect on waves which is part of the defence design at the North Sea coast. The transition of waves on a foreland has been assessed on a high resolution grid of 1m. Without access to detailed foreland profiles the calculations have been based on schematised forelands.

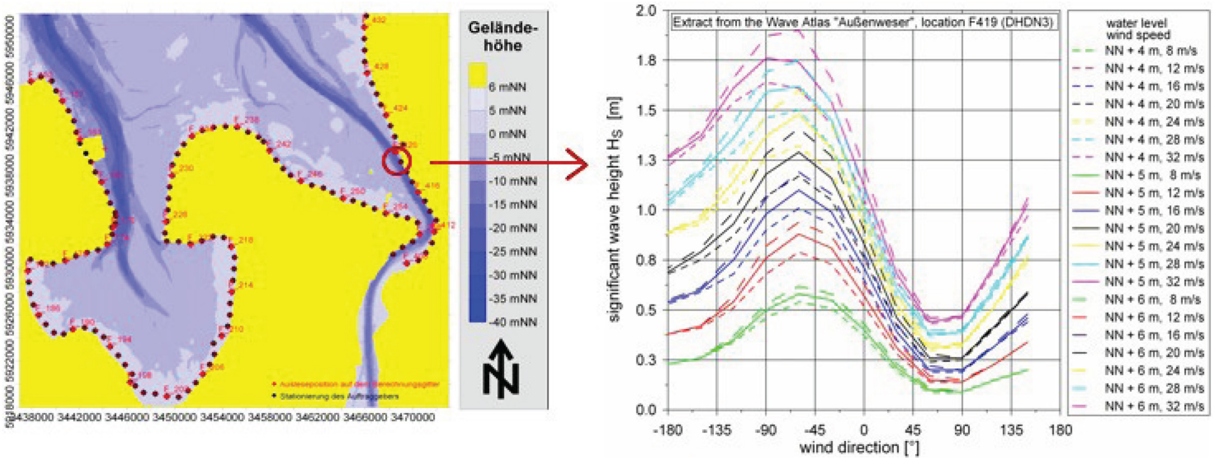

Figure 4: Mapped wave height and wave period for the Dollart area, Western North Sea coast (Source: Daemrich, Mai, Ohle 2005)

The wave parameters simulated with SWAN have been validated against radar based wave-buoy measurements at different locations showing good agreement for the simulated values.

Failure of Coastal Defences

About 85% of the North Sea coastline is protected against storm surges with a high level of safety. The coastal defence system mainly consists of dikes, while the Frisian islands are protected by dunes at the seaward side and dikes at the rear side. Due to its steeper and more complex topography, the Baltic Sea coastline is much less protected, mostly by dunes.

Defence failures both for dikes and for dunes are considered within the model. Dike breaches are initiated by wave run-up, wave overtopping and overflow. These processes are covered by empirical formulae (ProDeich 2002; Die Kueste 2002). The breaching process is simulated using time-dependent erosion algorithms also based on empirical formulae. The most critical parameters are modelled under consideration of uncertainty such as the final breach width.

The relevant failure modes reflected in this model are:

1. Wave overtopping
2. Overflow
3. Dike breach, initiated by:
    a. wave run-up (velocity) leading to cover-erosion (grass and clay layer) of seaward slope followed by core failure
    b. wave overtopping (flow & velocity) leading to cover-erosion (grass and clay layer) of landward slope followed by core failure

Dune failure is processed based on dune erosion simulations for which the model DUROS (Vellinga, 1986; TU Delft) has been used. The simulations have been undertaken on schematised cross-shore profiles with a typical North Sea island shape (figure 5).

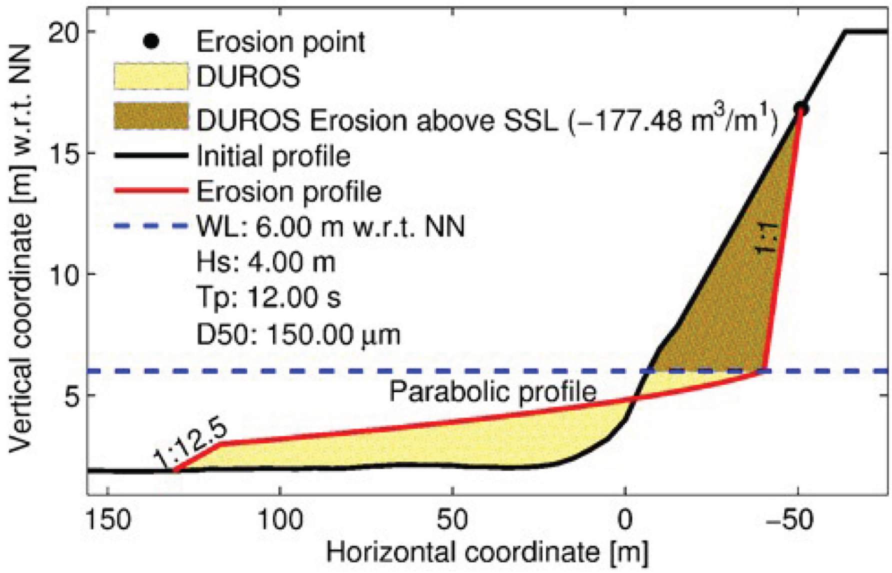

Figure 5: Schematic example of a the dune erosion assessment with DUROS (Den Heijer 2009)

Inundation of Coastal Hinterland

Widespread inundation of the land behind the defence structures can occur as a consequence of defence failures, which is the case for large areas at the North Sea coast and along the Elbe and Weser estuaries. This is realised by the hydro-dynamic 2d GIS-based tool FloodArea, developed by Geomer and Ruiz Rodriguez, Zeisler & Blank.

Main geodata inputs for the application of FloodArea are:

1. DTM (Digital Terrain Model) with 25m resolution

2. Delineated main defence line

3. Roughness Layer based on CORINE 2000 landuse data

The flow through a dike breach is calculated using the Poleni weir overfall formula modified for dike breaching at rivers (Disse at al 2003).

$$Q = \frac{2}{3} \times \mu \times L\sqrt{2g} \times h^{\frac{3}{2}}$$

Q – discharge, μ – weir coefficient,
L – breach widths, g – gravitational constant,
h – water level at dike toe (overfall height)

A set of five different synthetic scenarios has been defined and run for each coastal defence segment (see figure 7). The scenarios are defined by an overall flood volume passing the breach. The link to the simulated defence failures per event is given by the volume.

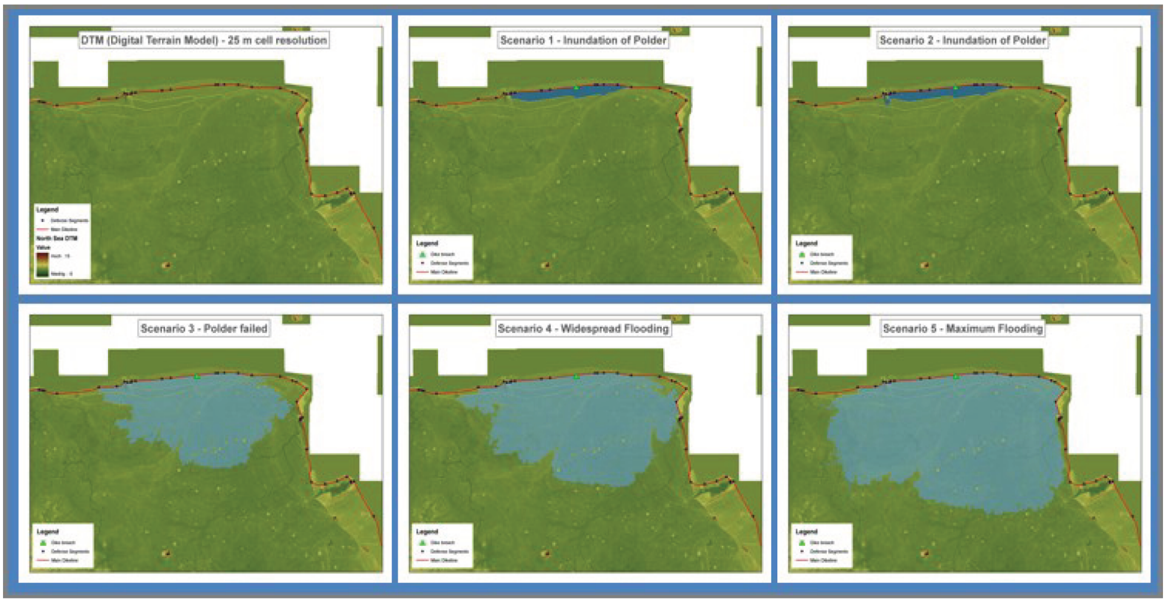

Figure 6: Inundation after dike breach scenarios; derived by FloodArea; volume based approach; 24 hours duration

Vulnerability

Risk in context of storm surges is defined as probability to receive losses. To calculate the losses a set of transfer functions is needed which relate the damage susceptibility of buildings and contents to storm surge inundation impacts. The main impact parameter is flood depth which is reflected in the common stage-damage functions widely used in the field of river flood risk.

Some sources reflect the effect of salt-water to buildings (MERK 2002, Penning-Rowsell), but no sources could be found where this parameter has been ever applied in damage calculations within risk analyses. For the presented model a consideration of salinity in damage curves is being examined.

Differences in damage susceptibility for residential, commercial and industrial buildings, as well as differences according to the height and type of buildings, should be reflected in the damage curves.

Climate Change

In addition to the present day risk the model is being designed to also account for potential changed conditions in the future due to climate change. This includes increases in sea water levels, amplification of wind speed and also possibly changes in event frequency. Therefore results of regional climate modelling studies are being incorporated.

Results/Conclusions

The final model in development aims to be an innovative approach for the German coast with a probabilistic risk model designed to assess the risk of occurrence and annual aggregate for storm surges. The model software shall enable the insurance industry and government to discuss effective cover for storm surge risk.

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