NUMERICAL STORM SURGE FORECASTING

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Abstract

The present state of the development of an operative storm surge prediction system in Germany is described. It is based on numerical models of the atmosphere and the North Sea. First simulations of the storm surge on Jan. 3, 1976 yield the result, that the observed water levels along the North Sea coasts can be recalculated quite well using a meteorological input derived from observations, whereas the forecasted water levels, using the predicted geostrophic winds of the atmospheric model, are too low since the pressure gradients are too weak.
A series of storm surge recalculations with observed and predicted meteorological data shall answer the question, wether parameter fits, applied to the predicted wind stress, lead to satisfying results, suitable for practical applications.

Introduction

After the severe storm surge of January 3, 1976, the German Hydrographic Institute, being responsible for warnings, arranged a meeting with the aim to bring together all people working on numerical modelling of storm surges in Germany.
Meanwhile the Sonderforschungsbereich "Meeresforschung" - special research organisation "Marine Research" - of the University of Hamburg had started a program for the development of a storm surge prediction system. On this

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meeting it was concluded that the different activities of numerical modelling of storm surges should be coordinated by a Model Group North Sea. Some of its intentions, its work and some preliminary results shall be discussed in the following. Although e.g. in our institute many storm surge calculations, yielding encouraging results for different events with different models, have been carried out during the past 20 years, it was felt that for the development of a prediction system as a first step it is necessary to get a consistent set of storm surge hindcasts on the basis of observed meteorological data with only one model. Therefore a first goal of the Model Group was the recalculation of a certain number of storm surges.

For this purpose our Sea Weather Office reanalyses very carefully threehourly weather maps, the surface pressure and additionally the air-sea temperature differences.

Parallel to this work the meteorological fields for every of these analysed events are hindcasted with a hemispherical prediction model, developped by the Meteorological Institute of the University of Hamburg.

Both data sets are used for storm surge calculations and following analyses of the results.

When these tests are done and when possible improvements of the presently used models are finished, and if it can be shown that the predicted storm surge heights are closer to the observed ones than the conventionally estimated predictions, then we hope that a data link between the German Weather Service in Offenbach , running the meteorological model, and the German Hydrographic Institute, computing the water elevations, will enable us to give better storm surge warnings earlier than it is possible nowadays.

The Models

The North Sea model is a two-dimensional vertically inte-

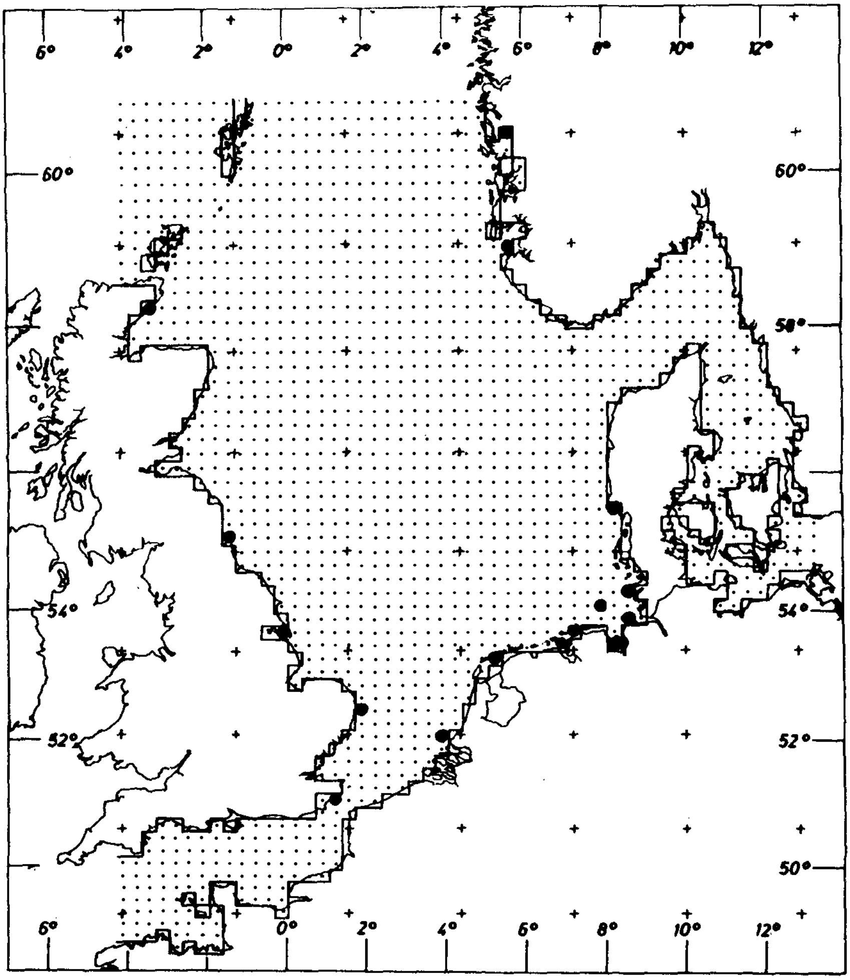


Figure 1 The HN-North Sea model
The crosses (+) denote grid points of the meteorological prediction model.
The dots (•) represent points for comparisons with tide gauge data.

grated HN - model (hydrodynamical-numerical model) with a grid point distance of about 22 km (Fig. 1). It is formulated in spherical coordinates. In addition to an earlier version it now includes parts of the English Channel. On the open boundaries the M_2 - tide is prescribed. It is intended to use later on 10 tidal constituents, but until now the results of such tidal computations are not satisfying since the boundary values are not known excactly enough.

In order to correct for meteorologically induced variations of water levels on the open boundaries a coarser model of parts of the North Atlantic is run parallel to our prediction model.

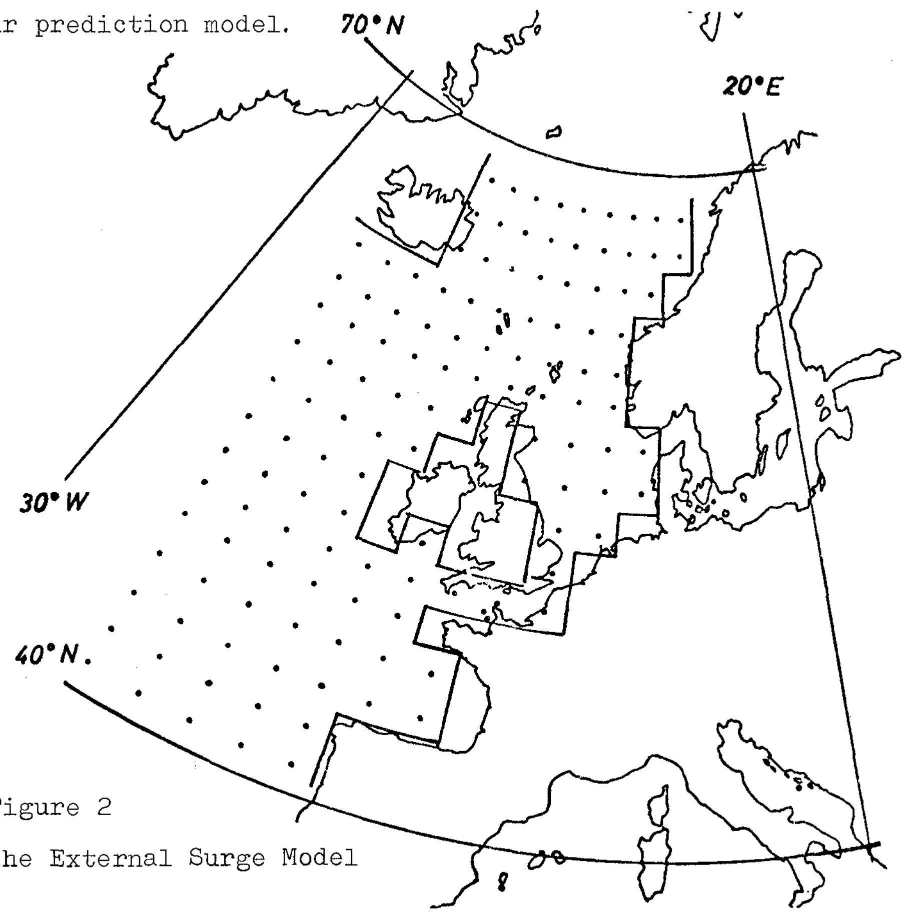


Figure 2

The External Surge Model

The water levels of this model, driven by wind and atmospheric pressure alone, are taken along the open boundaries of the finer model and are added there to the M_2-tide water levels. It is known that sometimes storm surges are significantly influenced by external surges, yielding contributions to the water levels in the German Bight up to the order of magnitude of one meter.

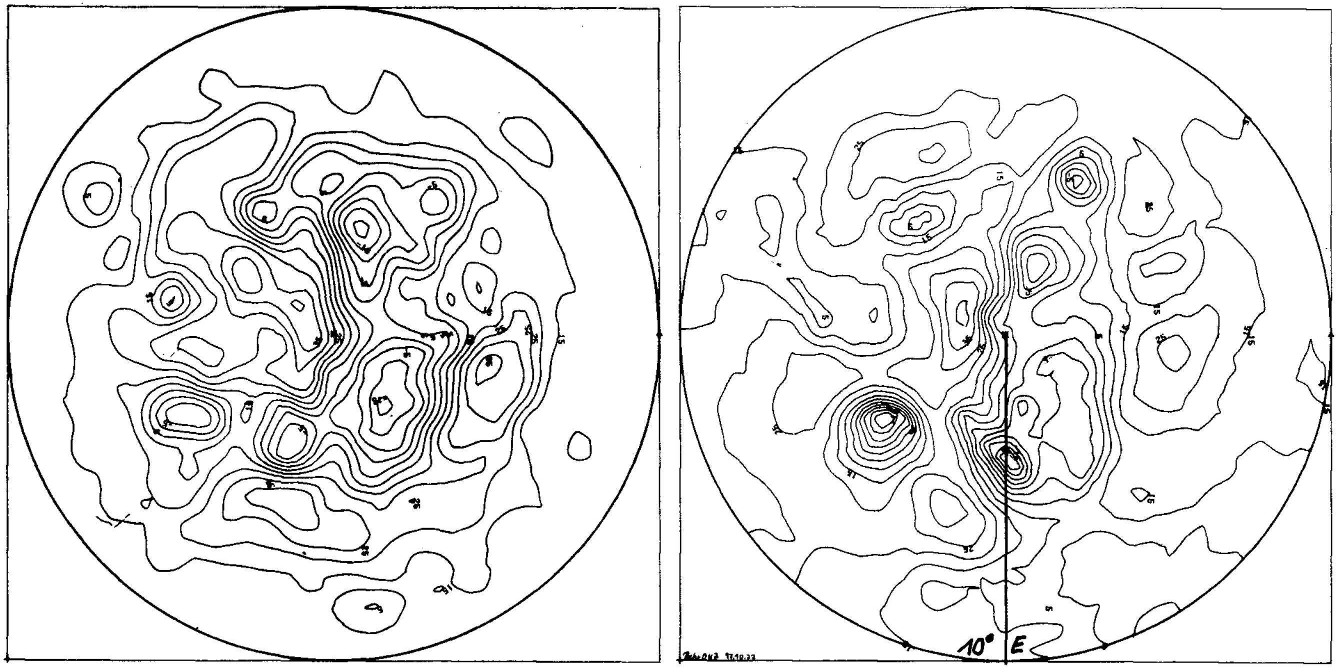
The meteorological model is an 8-layer baroclinic model of the northern hemisphere with an horizontal resolution of 1.4^{o} meridionally and 2.8^{o} zonally, i.e. about 150 km in the North Sea area. The lowest computation layer for wind velocities lies at about 500m height. It predicts wind, pressure, temperature and humidity. Bottom friction is assumed to be different over land and sea areas.

Figure 3a shows the bottom pressure over the northern hemisphere on the 2nd of January at 12^{00} GMT (this information belongs to the set of initial values for the computation) and Fig. 3b gives the predicted field 24 hours later. The cyclone on the 10^{o} meridian lies over the North Sea.

On Figure 4 observations and forecasts of bottom pressure over western Europe are blown up. For a further comparison the predicted bottom pressure of the German Weather Service is added. Both models underestimate the pressure gradients. We will come back to this feature when discussing the predicted storm surge results.

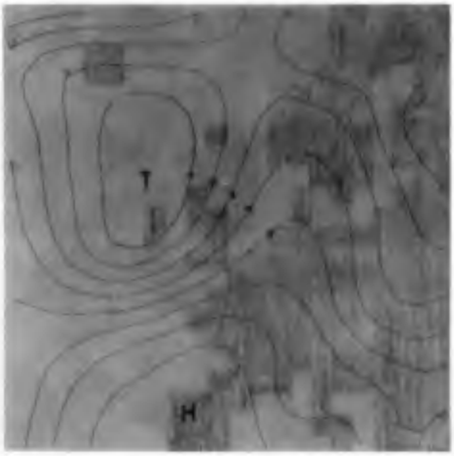
From the meteorological model the pressure is interpolated on the grid points of the North Sea model and then the wind stress is calculated. When using observed meteorological data for surge computations, the pressure information is taken from isobars of weather charts. The pressure gradients are determined as the slope of triangular planes between the isobars and thus can be used directly for stress computations in the North Sea model.

So far we have studied only the already mentioned storm

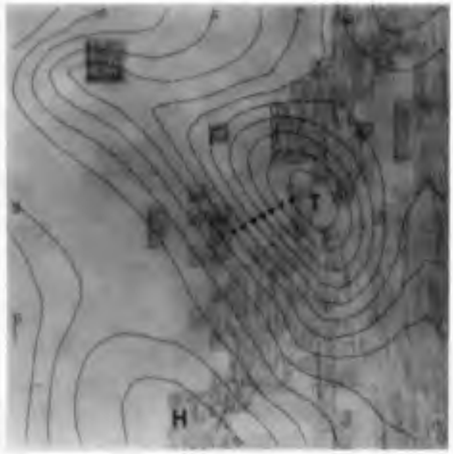


a b

Figure 3 Bottom pressure over the northern hemisphere
(a) Initial values on the 2^{nd} of January 1976, 12^{00} GMT
(b) Predicted bottom pressure field 24 hours later

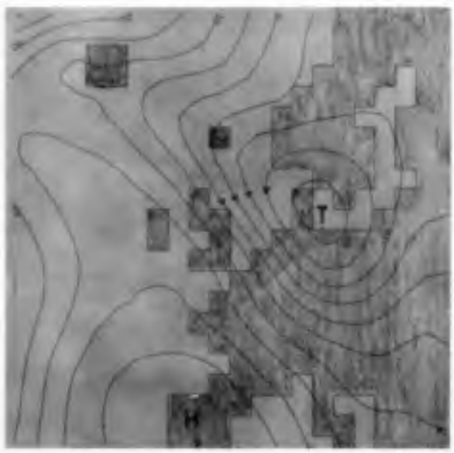


Initial bottom pressure field, 2.Jan. 76, 12^{00}GMT



24 hours forecast of the prediction system model

Observation on 3. Jan. 12^{00}GMT (24 hours later)



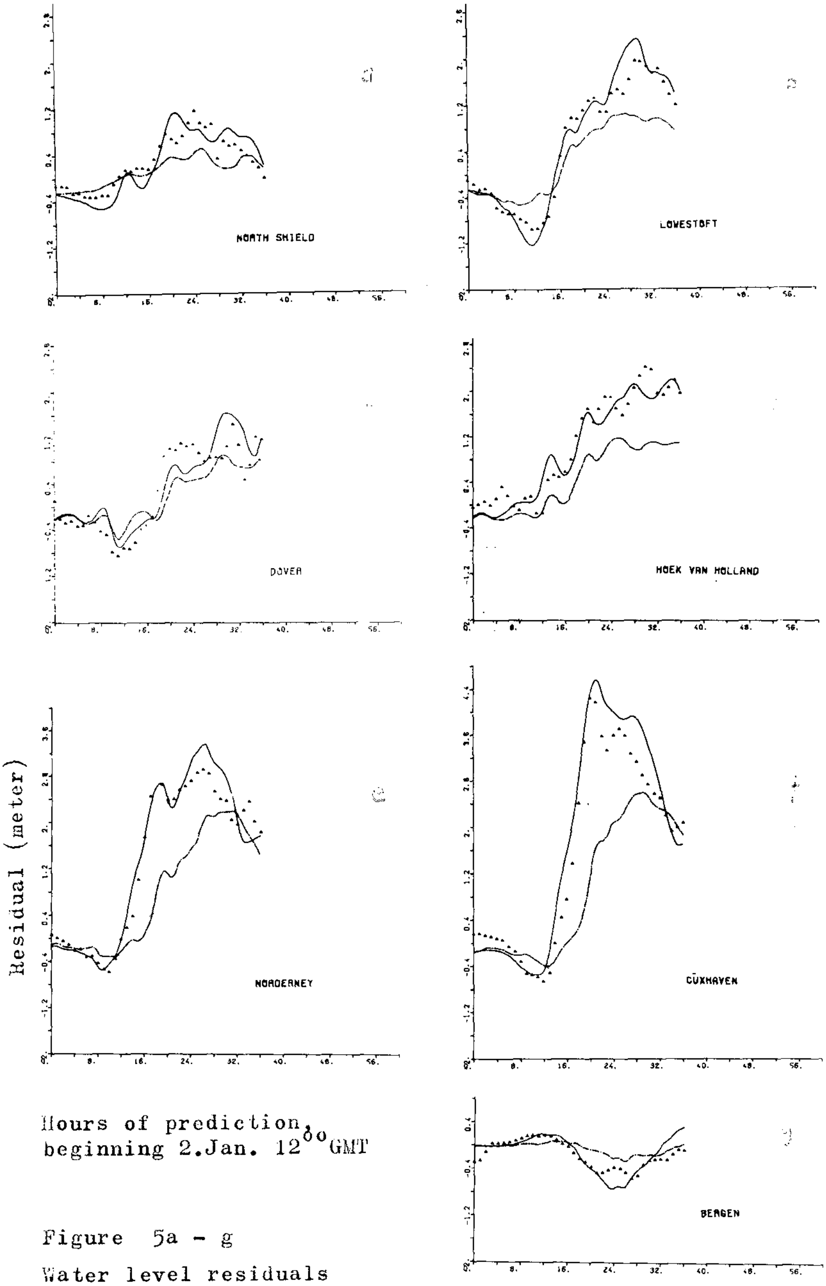
24 hours forecast of the German Weather Service

Figure 4 Observed and predicted bottom pressure fields over western Europe

surge of the 3rd of January in1976 with this system. This storm surge caused the highest water level, at least at Hamburg, which was ever observed.
Calculations of a series of storm surges from the 19th through 21st of January, 1976 are under preparation.

Results

On figures 5a-g computed and observed residuals of water levels for different locations around the North Sea are compared. The residual is defined as the difference between water levels as observed or computed with wind, pressure and tides and those which were predicted for the tide or computed in the model for the M_2-tide alone.
All plots show a much better correspondence between observed and hindcasted residuals than between observed and predicted ones. From the results at Dover one can deduce that it is necessary to extend the model into the English Channel.
These first results, yielding the largest prediction errors in the German Bight, are of course not yet suitable to demonstrate the reliability of our prediction system. The discrepancies in the residual forecasts are the direct consequence of the discrepancies of the predicted geostrophic winds, being too weak during the period of interest (Fig. 6).
Both surge computations have been carried out with the same formulation of wind stresses. Since it is a commom feature of many atmospheric circulation models to underestimate geostrophic winds, a further surge simulation using the forecasted geostrophic wind and a drag coefficient, tuned at the maximum water levels, has been carried out. The results are looking better, at least up to the maximum water level, but since the predicted low did not decay quickly enough, the following water levels were overestimated.



Hours of prediction, beginning 2.Jan. 12^{00} GMT

Figure 5a – g
Water level residuals
▲ observed ——— hindcasted —·—· forecasted

Wether such a parameter fit is suitable for our prediction system or not, this can only be decided if we have computed enough events to make a statistical analysis.
Beside this attempt, other improvements must be considered to get better meteorological input. For this purpose three projects are under investigation within the Model Group:

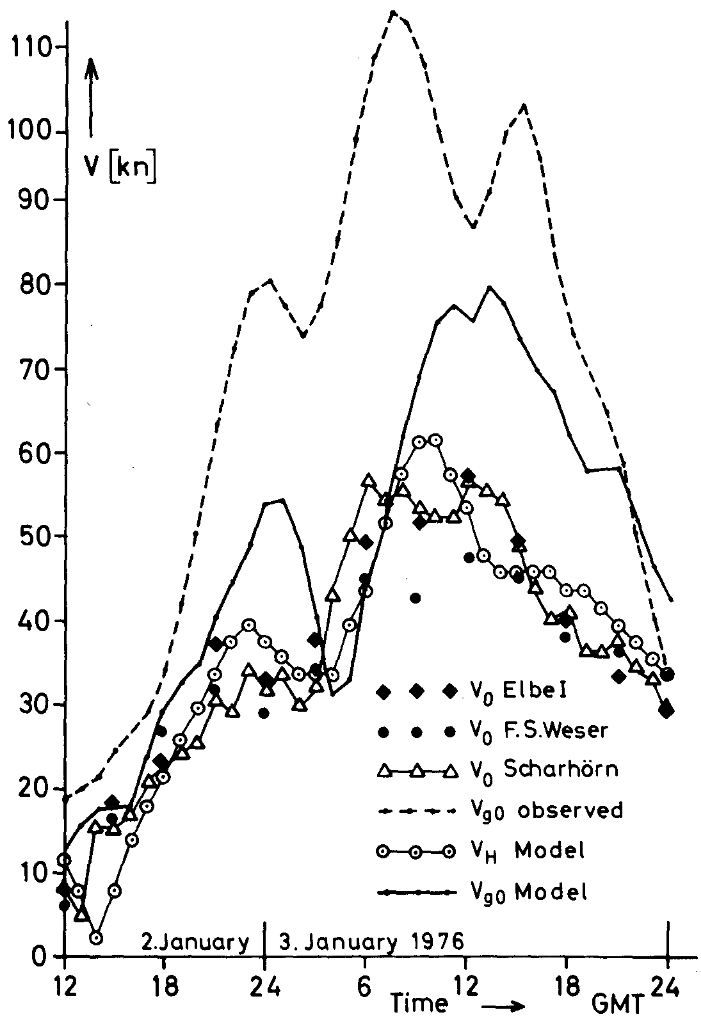


Figure 6 Comparison of observed and predicted geostrophic wind V_{go}

(a) to improve the meteorological forecast by means of a nested meteorological model of the North Sea area,

(b) to test wind stress calculations based on resistance law formulations for the boundary layer,

(c) to separate the contributions of wind and wave set-up to the storm surge water levels.

In any case it can be concluded that the meteorological data for the North Sea model must be known with high accuracy in order to get satisfying storm surge predictions within the shallow German Bight, which is very sensitive to the meteorological input in nature and in model simulations.

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References

Fischer, G.
Results of a 36-hour Storm Surge Prediction of the North Sea for January 3, 1976 on the Basis of Numerical Models
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to be published