CHAPTER 55

STORM SURGE PREDICTION BY COMBINED WIND AND TIDE DATA

by

Hermann Christiansen*) and Winfried Siefert*)

ABSTRACT

The authors suggest a storm tide forecasting method that allows high water predictions for a coastline 3 to 4 hours in advance with an accuracy of ± 30 min in time and ± 20 to 30 cm in height. It is based on actual (not on predicted) data, i.e. exact wind velocity and direction data from a reference station and tide data from two gauges. The method was developed by analysing storm surge curves and wind data of those 50 storm tides that occurred since 1965 in the German Bight. Another 50 storm tides back to the year of 1930 were taken into account, though without exact wind data.

The method was proved at all storm tides since 1965 and applied with good success to the events during fall and winter 1977/78 for the coastline off Cuxhaven.

*) Dr.-Ing. Hamburg River and Port Authority
Coastal Engineering Research Group "Neuwerk"
2190 Cuxhaven, F.R. Germany

INTRODUCTION

Storm tide forecastings and quick propagation of warnings are of high importance for people living at coastlines and tidal rivers behind the dykes. This yields to the demand, that a storm tide forecasting method must satisfy the highest level of scientific solidity that can be reached. Methods that are developed by hindcasting 5 to 10 special storm tides are not serious enough. Our investigations show that we have to live with at least 20 different surge types.

Lots of forecasting methods often remain insufficient as they are based on weather forecasts and these weather forecasts - mainly wind speed and wind direction developments - are not accurate enough.

The other reason for unsatisfactory predictions are the methods in itself, as usually only the peaks of storm tides are taken into consideration, and that is only one point on a curve. Characteristics of tide and surge curves are not developed, and tide/surge interactions are not evaluated.

To exclude such difficulties the presented storm tide forecasting method was developed

1. by analysing storm surge curves of those 100 storm tides that occurred since 1930 at several tide gauges on our coastline. A storm surge curve is defined as the differential curve between storm and mean tide curves;

2. by taking into consideration wind data of 50 storm tides back to 1965 (data from earlier events were not available);

3. by using only exact (not predicted) tide and wind data

STORM TIDE CONDITIONS IN THE GERMAN BIGHT

Fig. 1 shows the situation with the German North Sea coast. In the German Bight the astronomical tide is progressing anti-clockwise. Wind at storm tides comes from western directions like the storm surge wave. By this, a forecast for a point B on this coastline needs informations from a location westward of it. We found this point with the tide gauge A at the Island of Borkum. This gauge A is the so-called input gauge for the forecast gauge B.

Fig. 2 shows in the upper part the storm tide curves for one event at A and B. High water level at A occurs 2 to 3 hours earlier than at point B. A comparison of high water levels at A and B (Fig. 3) shows that there is allready a remarkable trend. On the other hand single deviations up to 1 m show that a use only of this trend is not exact enough to forecast high water levels at B. That means that water level informations merely from an input gauge are not sufficient.

FORECASTING METHOD I

Further investigations showed that an explanation for the runaways of Fig. 3 can be given if wind speed and wind direction development in the last 3 hours before high tide at A (Borkum) are taken into account. The wind development in this 3 hours intervall (about 3 hours before the expected high water level at B) is the best indicator for what will happen with the water level changes in the following 3 hours after high tide at A. The conclusion is, that about 3 hours before high tide at B no further wind informations are needed to forecast the highest level at B. These conditions are in agreement with results at the Dutch and British coast.

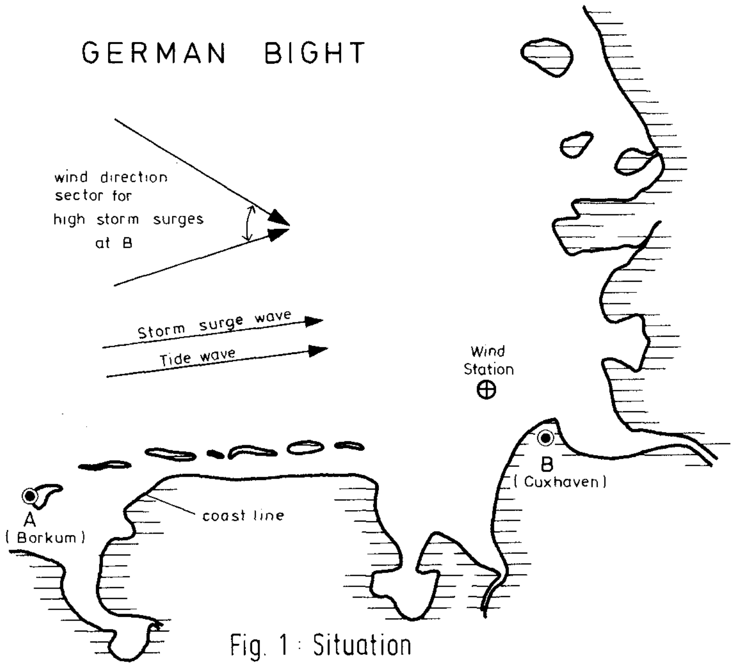

Fig. 1 : Situation

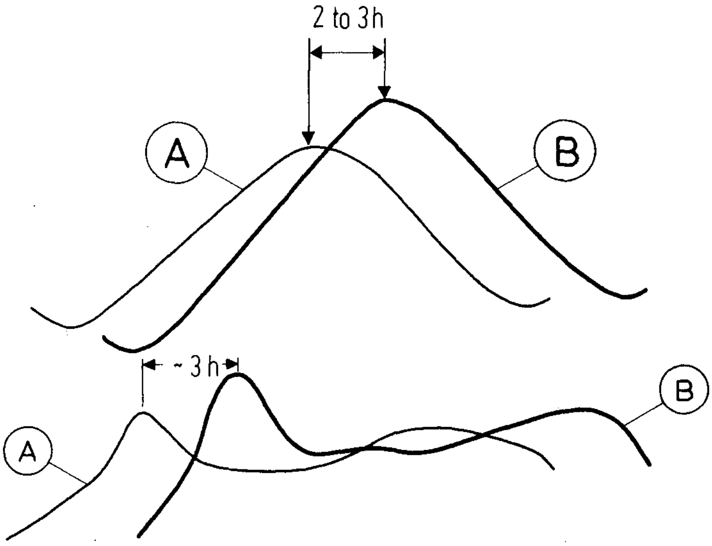

Fig. 2 : Tide- and Storm Surge Curves at A and B

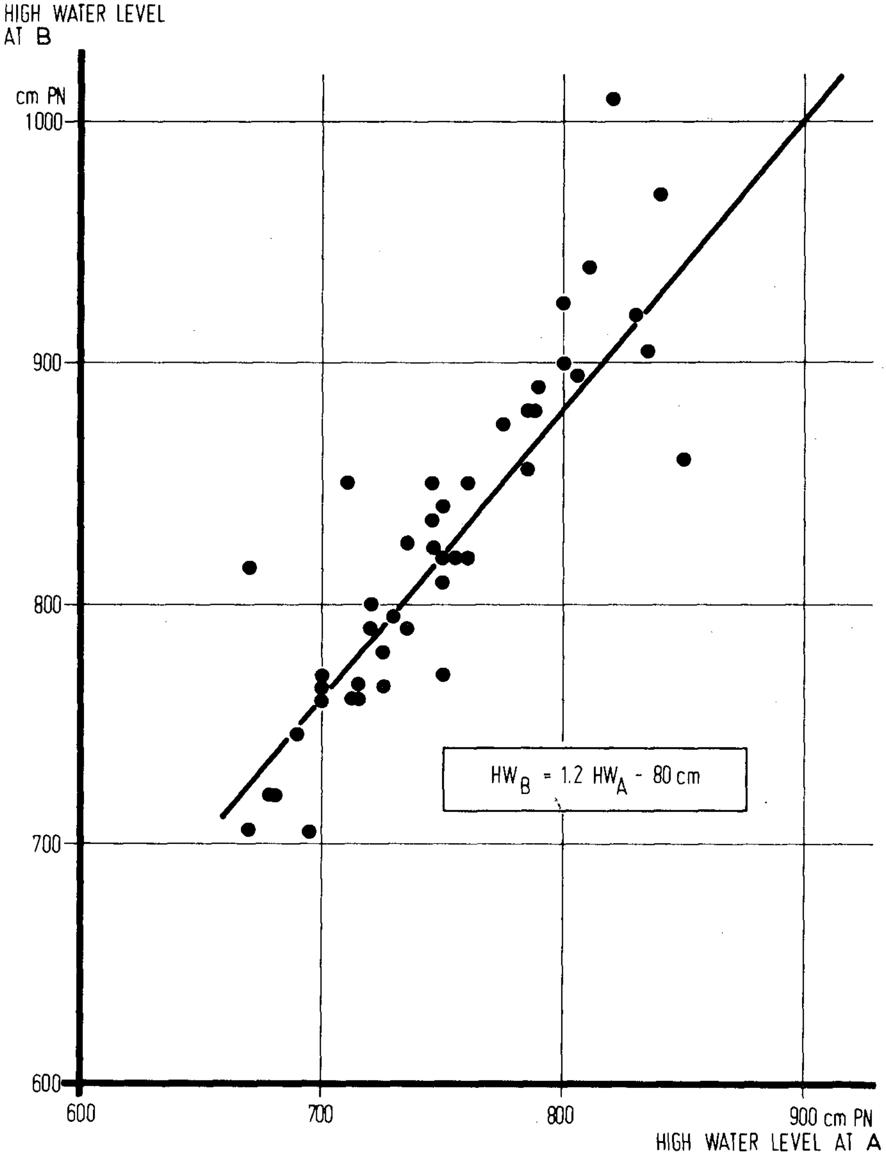

Fig. 3: Comparison of High Water Levels at A and B

The high water level at B (HW_B) can be calculated by the simple formula:

$$HW_B = 1.2 \cdot HW_A + \Delta v + \Delta R - 80 \text{ cm}$$

where

- $1.2 \cdot HW_A - 80$ cm gives the trend of high water level comparison at A and B (Fig. 3) and
- Δv (Fig. 4) and ΔR (Fig. 5) are the partial amounts for wind speed and wind direction developments within 3 hours before forecasting time

The wind data is needed with an accuracy of 1 m/s in speed and 10° in direction. The example in Fig. 4 demonstrates the neccessity of exact wind speed data. A change in wind speed from 20 to 24 m/s over the 3 hours intervall gives a positiv amount of $\Delta v = + 40$ cm. A change of only 2 m/s more (to 26 m/s) doubles this amount to $\Delta v = + 80$ cm.

Fig. 5 shows that highest amounts for wind direction developments are given by changes from other directions to 280°, what is the most effective wind direction for high storm surges at Cuxhaven. Direction changes further northward give high negative amounts, up to $\Delta R = - 80$ cm.

FORECASTING METHOD II

There is at least a second chance to forecast high water levels at B to control the first method mentioned above. This possibility is given by analysing the surge curves at A and B. The surge curve (see Fig. 6) is defined as the difference curve between the storm tide curve and the mean tide curve. This curve includes all deviations from the mean tide, such as wind influence, astronomical disproportion, external surges, temperature, atmospheric pressure etc.

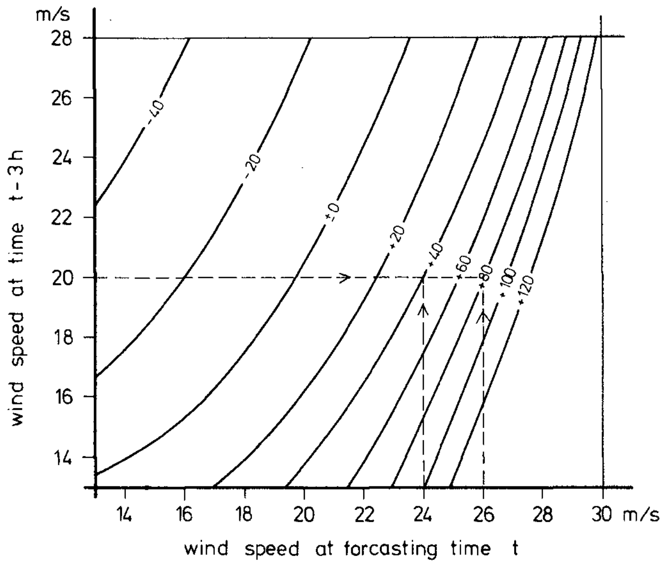

Fig. 4: Wind Speed Development Value Δv in cm

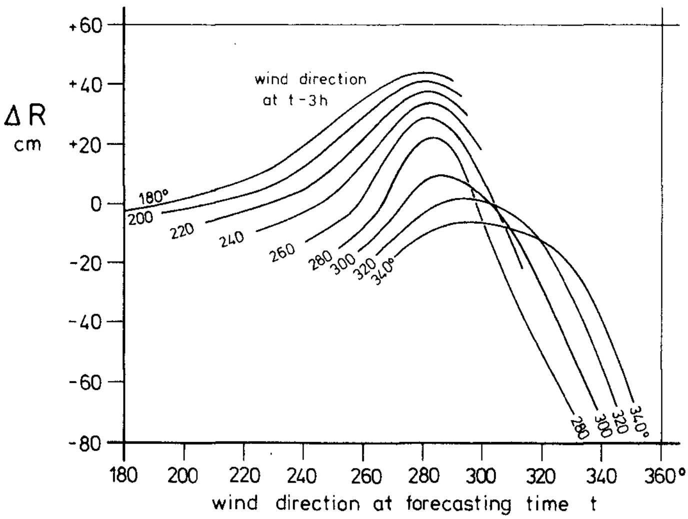

Fig. 5: Wind Direction Development Value ΔR

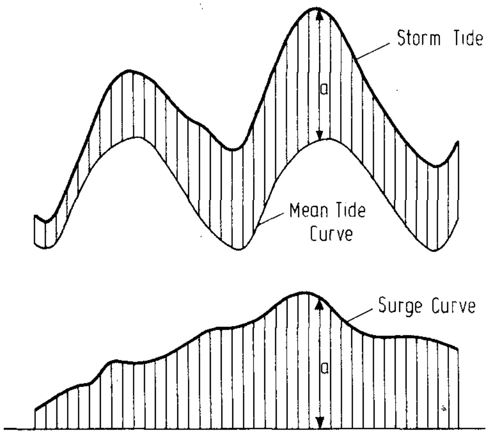

Fig. 6 : Definition Sketch Surge Curve

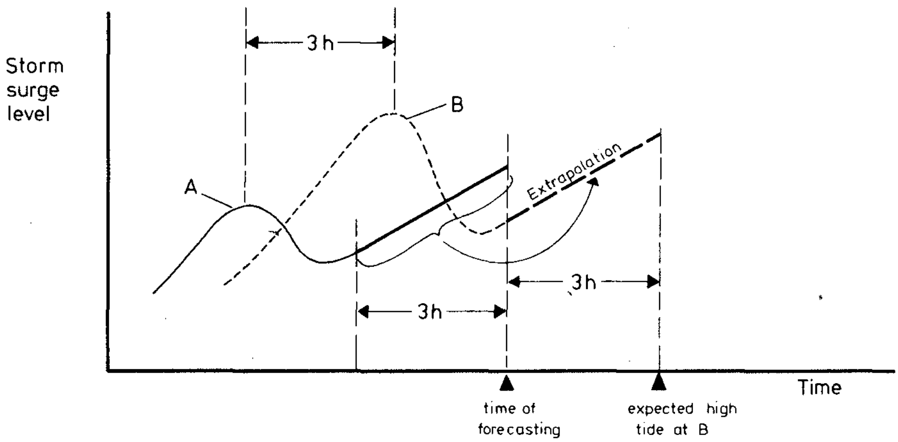

Fig. 7 : Extrapolation of Storm Surge Curve B by the Shape of Curve A

Fig. 2 shows in the lower part, that surge curves of the same event at neighbouring gauges are not only very similar, but there is also a phase lag of about 3 hours between these curves. That means, that what happened in the last 3 hours with the surge curve at A, will happen qualitatively in the same way within the next 3 hours at B. So it is possible to extrapolate the surge surve at B by the trend of A 3 hours in advance (Fig. 7). Addition of the extrapolated surge curve and the attached part of the known mean tide curve gives the expected storm tide curve at B, including the highest peak.

In practice we found, that the mean value of methods I and II gives the best result for the high water level forecast. The comparison of computed and observed HW data for Cuxhaven is given on Fig. 8.

WHAT CAN WE DO IN FUTURE?

To improve and to reform the presented forecasting method, first of all we have to include all informations that can be reached by further storm tides.

While the hight accuracy in forecasting is satisfactory we should try to find a way to give the forecasts earlier than 3 or 4 hours in advance. We believe that this is only practicable if we get exact wind forecasts for the next 2 or 3 hours. For better, i.e. earlier storm tide forecastings it would be greatly helpful if programs could be started to research not only in the development of wind conditions for the next 2 or 3 days but also for this short interval we are interested in.

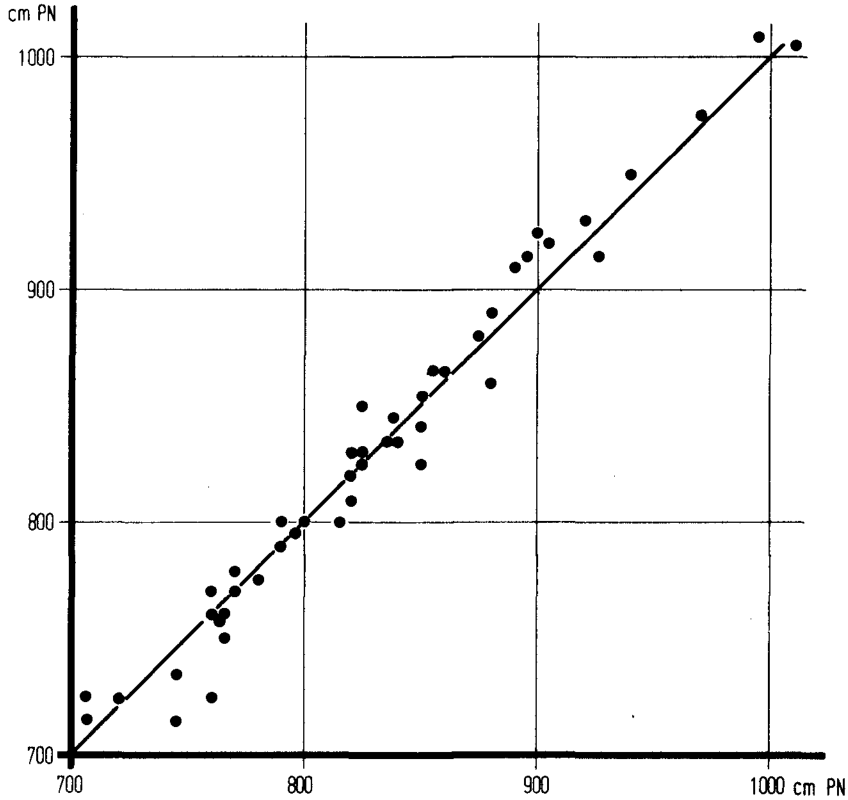

Fig. 8 : Comparison of computed and observed HW-Data Cuxhaven

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REFERENCE

SIEFERT, W.
CHRISTIANSEN, H.: Development of a New Storm Tide Forecasting Method for Cuxhaven. Cuxhaven 1977 (unpublished)