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Reanalysis of the Hamburg Storm Surge of 1962

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Abstract

In February 1962, Hamburg experienced its most catastrophic storm surge event of the 20th century. This paper analyses the event using the Twentieth Century Reanalysis (20CR) dataset. Responsible for the major flood was a strong low pressure system centred over Scandinavia that was associated with strong north-westerly winds towards the German North Sea coast – the ideal storm surge situation for the Elbe estuary. A comparison of the 20CR dataset with observational data proves the applicability of the reanalysis data for this extreme event.

1. Introduction

Storm surges are the main geophysical risk along the German North Sea coast (Petersen and Rohde, 1977; von Storch et al., 2008). The amplitude is largest if high tides coincide with storms. The latter affect the water level depending on the wind duration, direction and speed (Gönnert, 1999; Müller-Navarra et al., 2012). In case of the German Bight the backwater effect produced by onshore winds is of great importance for the development of storm tides (Müller-Navarra et al., 2012; Koopmann, 1962).

The city of Hamburg is situated at the end of the Elbe estuary approximately 140 km upstream of the North Sea. The northwest-southeast orientation of the estuary and its well-developed condition as inland waterway favour storm tides during north-westerly wind conditions that occur concomitantly with a gravitational high tide situation (Müller-Navarra et al., 2012; von Storch et al., 2008).

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Figure 1. Broken dyke after the storm surge in Hamburg in February 1962. Source: Hamburger Morgenpost, reprinted with permission.

The Hamburg storm surge of 16 February 1962 was the most deadly (>300 persons died, *Hamburger Abendblatt,* 15 February 1992) and costly (damages of 0.82 billion DM, corresponding to 1.6 billion EUR, see MunichRe, 2012) natural disaster affecting the city in the 20th century and is even considered the biggest natural disaster of Germany in this period. With its highest water level of 5.7 metres a. m.s.l. (above mean sea level) it caused numerous dike breaks (Fig. 1, see also Koopmann, 1962; Müller-Navarra et al., 2012; von Storch et al., 2008). In addition to the many casualties, 20,000 people lost their homes, 6,000 buildings were destroyed and thousands of farm animals perished (*Hamburger Abendblatt,* 15 February 1992).

The event has been well studied in the past. Shortly after the surge, Koopmann (1962) included it in his study on oscillation and swell processes in the German Bight. More recently many publications on storm surges in the German North Sea and Hamburg refer to the 1962 event due to its high relevance. Von Storch et al. (2008) as well as von Storch and Woth (2011) analysed the change in storm surge risk due to human induced climate change. The 1962 storm surge event and its aftermath were used as an example for storm surge mitigation planning. For the same reason, Hofstede (2009) included the event in his study about coastal protection measures. In 2012, the year of the 50th anniversary of the storm surge, the German Federal Maritime and Hydrographic Agency released a comprehensive comparison between today's storm surge research and the situation in 1962 (Müller-Navarra et al., 2012). In addition, reanalyses and reforecasts have been conducted using the ECMWF Integrated Forecasting System (Jung et al., 2005).

Here we analyse the meteorological situation responsible for the Hamburg storm surge of 1962 using the Twentieth Century Reanalysis (20CR). In Section 2 we give an overview of data and methods used. Section 3 provides a description of our results and the nature of the flood which is then discussed in Section 4. Finally, conclusions are given in Section 5.

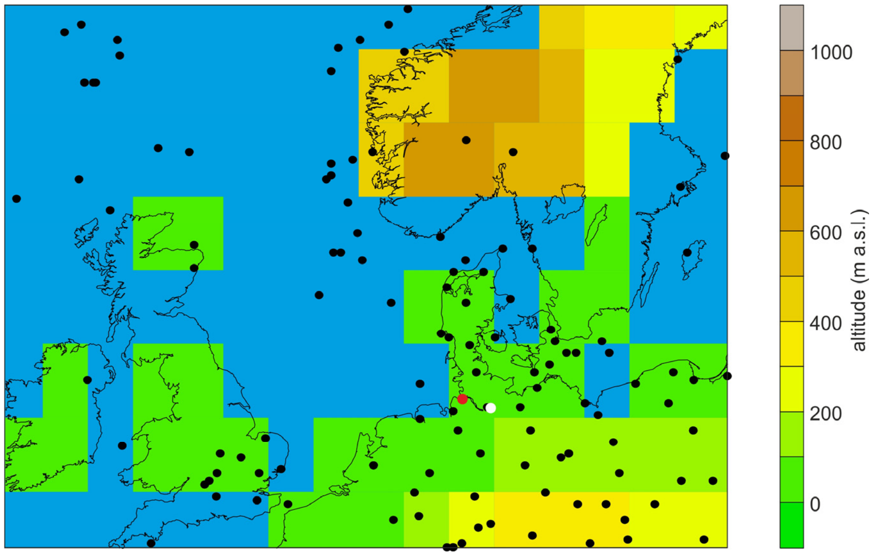

Figure 2. Map showing the surface and sea-level pressure measurements assimilated into 20CR on 16 February 1962, 12 UTC. Colours indicate the orography in 20CR and the land-sea mask as depicted in the Gaussian grid (192 x 94 cells). The red and white dots mark the locations of Cuxhaven and Hamburg, respectively.

2. Data and methods

20CR is an international reanalysis project that developed an atmospheric dataset based on the assimilation of only surface and sea-level pressure (SLP) observations (Compo et al., 2011). Monthly sea-surface temperature and sea ice conditions (Rayner et al., 2003) are used as boundary conditions for the model based (NCEP Global Forecast System, GFS see Compo et al., 2011) data assimilation. The assimilation used a variant of the Ensemble Kalman Filter with 56 members. The second version of the 20CR is used for this report. It includes 3-dimensional and 6-hourly data from 1871 to 2008 and has a 2° x 2° spatial resolution (T62 spectral truncation) and 28 levels. Figure 2 shows the locations of air pressure data (stations and ships) that were assimilated into 20CR on 16 February 1962, 12 UTC. Also shown is the orography of 20CR and the land-sea mask.

Our interest is focused on sea-level pressure, geopotential height, and wind at different levels. To a lesser extent we also consider precipitation as it, too, might have played a role for the flooding. For all analyses the ensemble mean is used. We further analysed sea level measurements for Cuxhaven (Fig. 2) from the German Federal Maritime and Hydrographic Agency's website (Bundesamt für Seeschifffahrt und Hydrographie, www.bsh.de, Pegelstandsdaten der Messstation Cuxhaven, updated on 13 February 2012, accessed 25 April 2012).

Furthermore we use meteorological station observations from Hamburg for a comparison with the 20CR data. Measurements of wind speed and gust were taken from the European Climate Assessment and Dataset (ECA&D, Klok et al., 2009) and from the German Weather Service (Deutscher Wetterdienst - DWD: Wind Data available online at http://www.dwd.de/, accessed 24 April 2012). For comparison of meteorological fields we also used daily weather maps from the German Weather Service, accessed online through the Environmental Data Rescue Program of the National Oceanic and Atmospheric Administration (NOAA), as well as two other reanalyses, namely NCAP/NCAR (Kistler et al., 2001) and ERA-40 (Uppala et al., 2005).

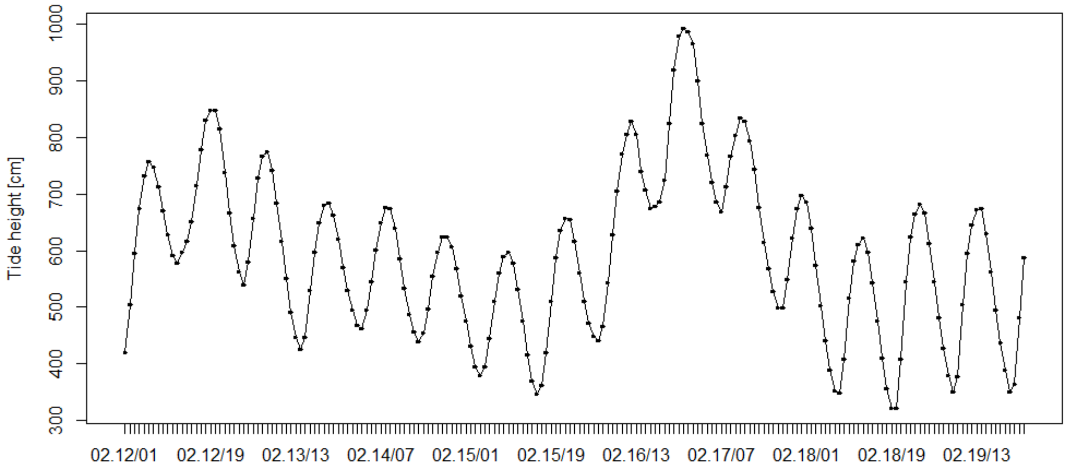

Figure 3. Tide gauge height (cm) at Cuxhaven between 12 February and 19 February 1962 (data from Bundesamt für Seeschifffahrt und Hydrographie).

3. Results

Three days prior to the storm surge event on 12 February 1962 a first deep low pressure system was located over Scandinavia which resulted in strong winds over the North Sea and a rising sea level. This is depicted in Figure 3, which shows the tide gauge height in Cuxhaven, a town situated at the mouth of the Elbe estuary (Fig. 2). However the effects of the strong winds associated with this low pressure system were weakened due to a secondary depression located south of the German Bight.

On 15 February 1962 a low pressure system was developing over the North Atlantic and rapidly gained strength while moving eastward to Scandinavia. At 0 UTC on 15 February, SLP at the centre of the system was approximately 990 hPa. Figure 4 shows the situation 24 hours later. The pressure at the centre had decreased to 955 hPa (the isobar is marked in red in Figure 4a). Accordingly, geopotential height at the 500 hPa level was also very low, around 4900 gpm. Figure 4b shows a strong jet stream at 200 hPa over the North Atlantic with a large meander reaching southward and divergence over Scandinavia.

At 12 UTC on 16 February the depression was centred over Scandinavia with a tight pressure gradient over the southern North Sea and northern Germany. Figure 5a shows this situation with a minimum pressure below 960 hPa (isobar marked in red). In parallel, Figure 5b highlights the strong north-westerly winds over the North Sea and Scotland with 10 m wind speeds of up to 30 m/s in the ensemble mean. Winds over northern Germany were initially coming from a south-westerly direction (Fig. 5b, 16 February 12 UTC) and when the depression moved eastward they turned into north-westerly winds (Fig. 5d, 17 February 0 UTC). Over the North Sea north-westerly winds were prevalent already at 12 UTC on 16 February. Twelve hours later (Figure 5c) the low pressure system started to weaken. Its centre was located further east and the minimum pressure increased to 965 hPa. Accordingly the pressure gradient over the North Sea weakened. However strong winds persisted over the German Bight with speeds up to 28 m/s and a direction perpendicular to the Elbe estuary (Fig. 5d).

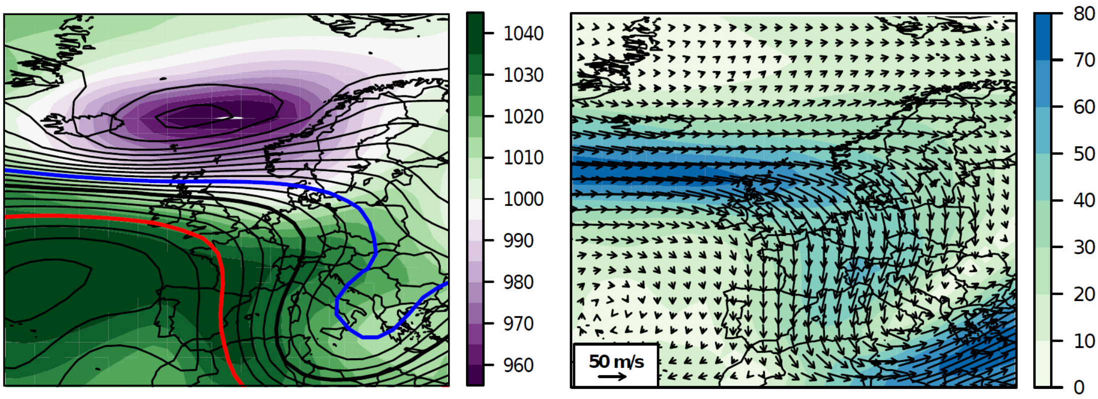

Figure 4. (left) SLP (colour shading, in hPa) and 500 hPa geopotential height (lines at 5 gpdm intervals; blue, black and red lines denote 535, 550 and 570 gpdm, respectively) on 16 February 1962, 0 UTC. (right) 200 hPa wind (vectors) and wind speed (colour shading, in m/s) on 16 February 1962, 0 UTC. All data are from 20CR.

The relation between the weather situation and the water level of the Elbe river is shown on behalf of the tide level record of Cuxhaven (Fig. 3). The figure displays the tide with amplitidues of around 2 m. On top of the regular tide, lower frequeny variations are clearly recognisable. As mentioned before, a rise of the sea level can be observed on 12 and 13 February followed by a decreasing water level. Then the level started to rise again in the morning of 16 February and reached a maximum of 9.93 m around 23 UTC the same day.

In the measurements the strongest winds were found in Hamburg on 16 and 17 February with mean speeds up to 14.3 m/s. Wind gust measurements show a maximum of 30.7 m/s on 16 February. The precipitation sum measured in Hamburg over the two days 16 and 17 February amounted to 15 mm.

4. Discussion

The results show a typical winter weather situation with a low pressure system moving eastward from the North Atlantic and affecting northern Europe. The strong jet stream exhibited a meander and divergence over Scandinavia. A strong low pressure system developed at the left exit position of the jet. Concurrent with the strengthening of the depression the pressure gradient over the German Bight tightened and the winds changed to a north-westerly direction. Even after the cyclone had moved eastward and the pressure gradient weakened the wind speed remained high and the wind direction north-westerly. With the Elbe estuary pointing in the same direction, these preconditions were ideal for a storm surge (Koopmann, 1962; Müller-Navarra et al., 2012; von Storch et al., 2008). The wind caused a so-called backwater effect, pushing the water into the estuary. The observational data (not shown) confirm this hypothesis of the wind being the main reason for surges by showing only little precipitation (15 mm summed over 16 and 17 February) which obviously cannot cause a water level rise of over 5.5 metres in 24 hours.

The time of the maximum sea-level at the tide gauge station in Cuxhaven and the storm surge in Hamburg are consistent with each other considering the time it takes for the water to reach Hamburg from the North Sea (3 hours 30 minutes, according to Müller-Navarra (2012)). Comparing the wind maxima derived from the 20CR dataset to the tide levels meas-

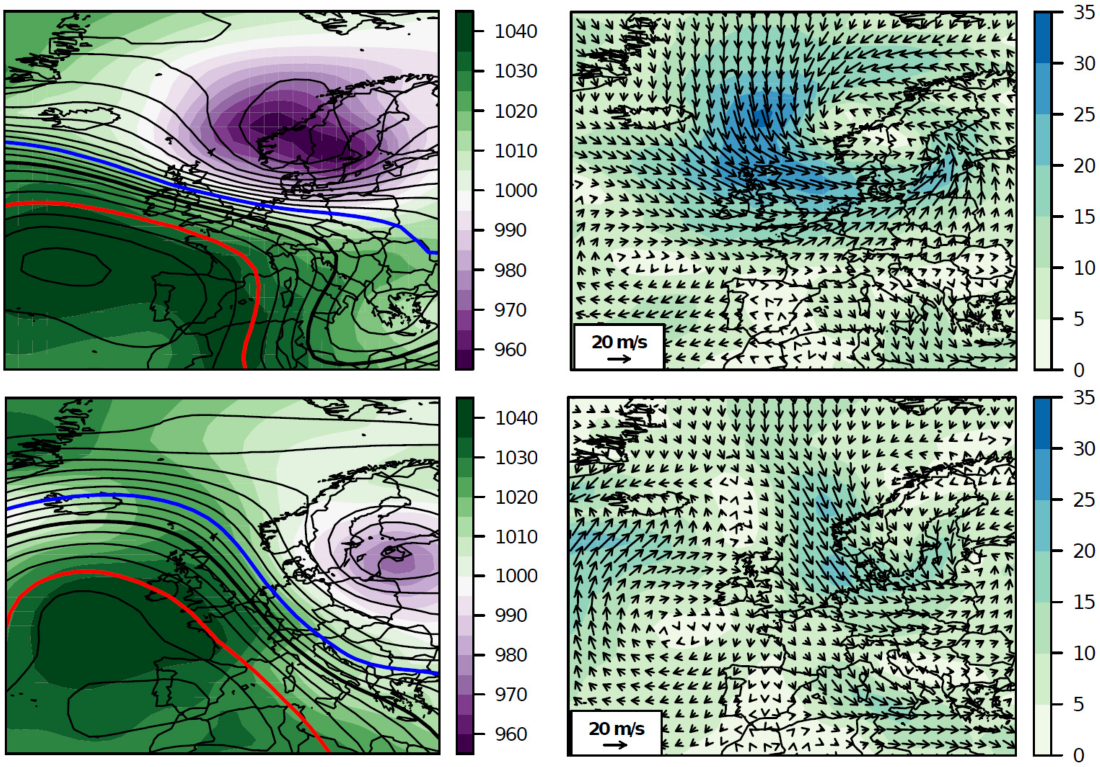

Figure 5. (top left) SLP (hPa, black lines; the red line denotes 960 hPa) and 500 hPa geopotential height (gpm, colour shades) on 16 February 1962, 12 UTC, (top right) 10 m wind (vectors) and speed (m/s, colours) on 16 February 1962, 12 UTC; (bottom left) SLP (hPa, black lines; the red line denotes 965 hPa) and 500 hPa geopotential height (gpm, colour shades) on 17 February 1962, 0 UTC; (bottom right) 10 m wind (vectors) and speed (m/s, colours) on 17 February 1962, 0 UTC. All data are from 20CR.

ured in Cuxhaven, a clear relationship to the surge in Hamburg appears. The maximum winds over the German Bight occurred between 18 and 0 UTC on 16 February. The maximum tide level measured in Cuxhaven was at 23 UTC. Taking into the account the time needed by the water to arrive in Hamburg, the storm surge maximum should have occurred around 02.30 UTC on 17 February in the city. This coincides with Koopmann's (1962) study directly after the catastrophe who reports a maximum around the same time.

The 20CR dataset is based on sparse observations (see Fig. 2) and a coarse resolution model. It is important to assess how accurately this data set describes features such as the cyclone on February 1962. We therefore compared the 20CR reanalysis data with hand-analysed weather maps from the German Weather service as well with NCEP/NCAR reanalysis and ERA-40 reanalysis for 16 February 1962, 6 UTC (Fig. 6). No significant differences can be found between the data sets. The core pressure of the surface low over Scandinavia (around 955 hPa) is very similar in all data sets, and also the position of the minimum is very similar. The same applies to the pressure gradients and the Atlantic high pressure system.

The 10 m speed in the 20CR dataset is slightly higher than the observed wind speeds. For example, a wind speed of 13 m/s was observed in Hamburg on 16 February 1962, 6 UTC while the 20CR shows 15 m/s at the same place. This difference is however considered small given the strong local dependence of wind speed and the coarse resolution of 20CR.

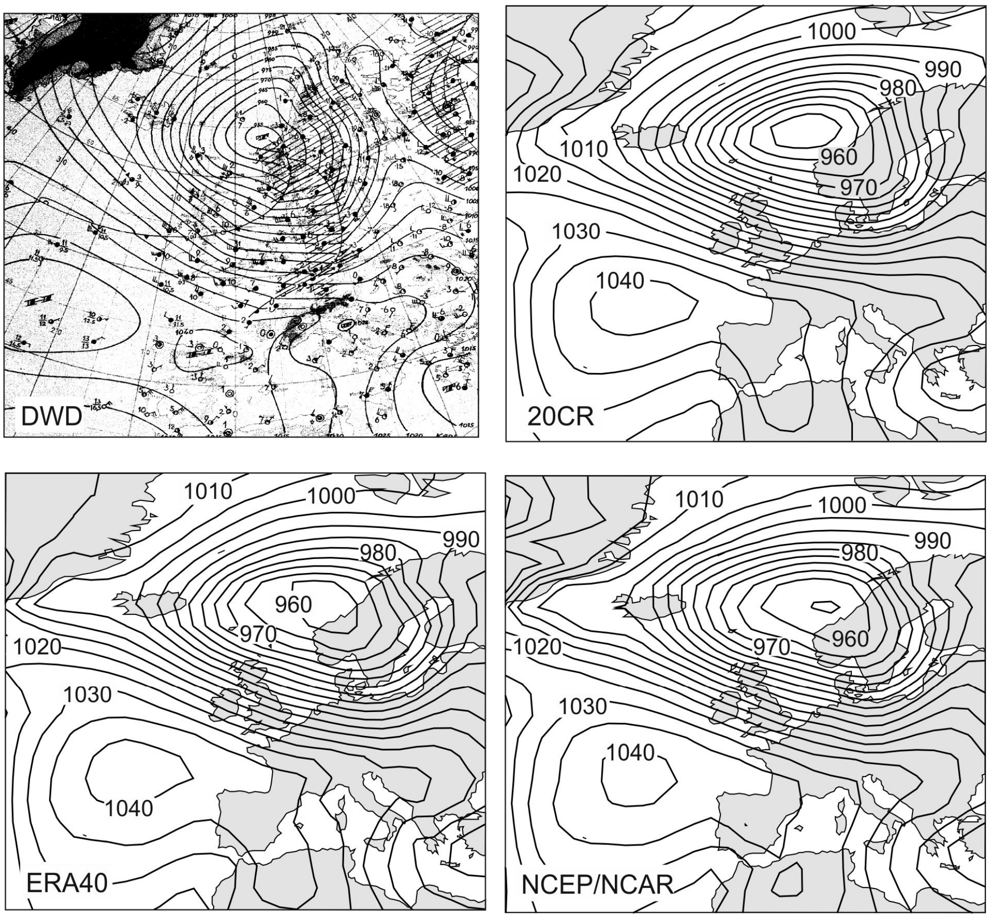

Figure 6. Sea-level pressure for 16 February 1962, 6 UTC from (top left) the German Weather Service, (top right) 20CR, (bottom left) ERA-40, and (bottom right) NCEP/NCAR.

5. Conclusions

The 20CR dataset agrees with the observational data and gives a good overview of the meteorological situation that led to the Hamburg storm surge. This includes the development of the low pressure system, its track from the North Atlantic to Scandinavia as well as the wind field during the relevant time period. The 200 hPa wind data provide a possible explanation for the formation of the low pressure system and the strong winds associated with it. It shows the divergence of the upper-level flow that can be seen in Figure 2b. The outcome of the data analysis confirms the assumption that in the case of the Hamburg storm surge, wind speed, wind direction and the backwater effect caused by it were the main reasons for the flood.

Low pressure systems and winter storms are a common phenomenon over Northern Europe and regularly cause storm surges along the coast of the North Sea, mostly without having such a strong intensity. The prevailing weather situation that led to the catastrophe was unusual in that the combination of high tide, wind speed and direction resulted in ideal storm surge preconditions for the Elbe estuary. The main damages were caused at the Elbe river dykes and not the coastal dykes that had already been reinforced after the Holland storm surge of 1953 (see Schneider et al., 2013). Today, due to higher protection levels, the same surge height would not cause large problems anymore.

Acknowledgements

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