1st International Workshop on Waves, Storm Surges, and Coastal Hazards

# M1:Estimating past and recent extreme wave and surge conditions in the southwestern Baltic Sea

Nikolaus Groll, Lidia Gaslikova and Ralf Weisse

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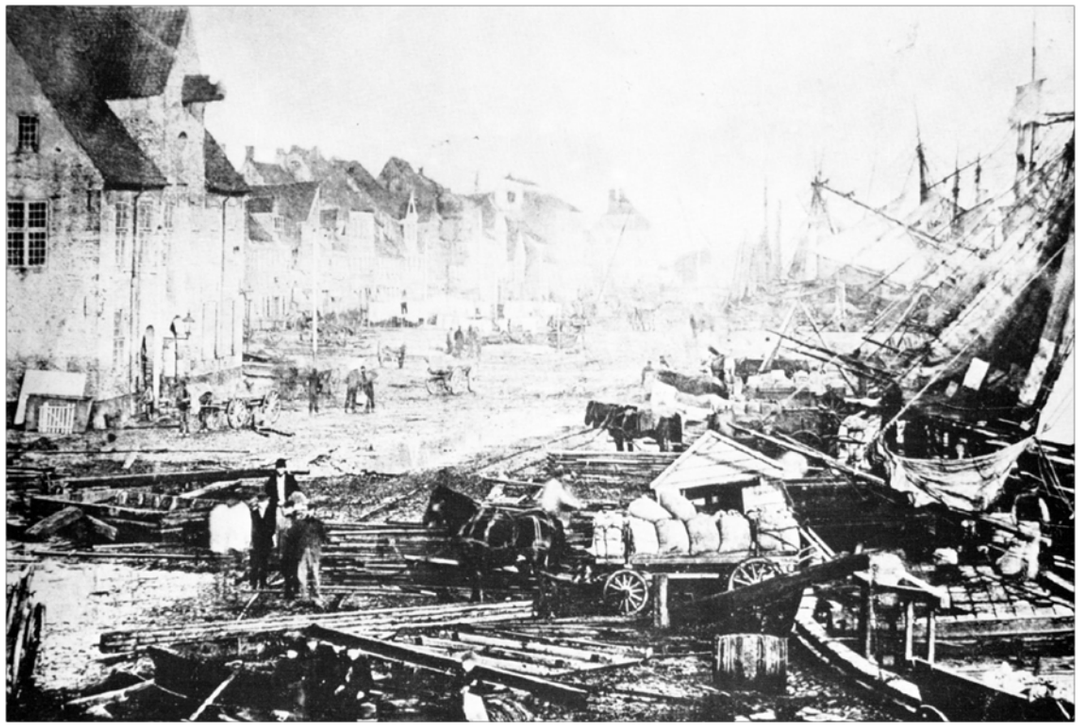
Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

# Background

- Early this year (3.1.to 5.1.) the extratropical storm Axel lead to extended flooding along the south western Baltic Sea coasts and associated damages to infrastructure and coastal erosion. This event caused a lot of attention in the media.
- While the recent event was an event that occur every 10 to 20 years, a storm in November 1872 led to the most extreme flooding in the SW Baltic Sea in centuries. The flooding led to severe damages along the coasts and many victims had to be mourned.

Flensburg Harbour after Baltic Sea storm event in 1872

*source: commons.wikimedia.org*



Strom Axel headlines:

“Storm Axel floods Germany with strongest surge in 10 years” *source:* weather.com

“German Baltic coast hit by storm surge flooding”

*source: www.bbc.com*

“Land unter an der deutsche Ostsee”

*source: www.welt.de*

“Sturmtief Axel hat schwere Schäden verursacht,..”

*source: www.spiegel.de*

# Overview

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Part 1: Storm Axel in a hindcast simulation
(Describing and comparing the storm event Axel)

Part 2: Storm Axel in a climate perspective
(Comparison with storm events in a long hindcast simulation)

# models and model data

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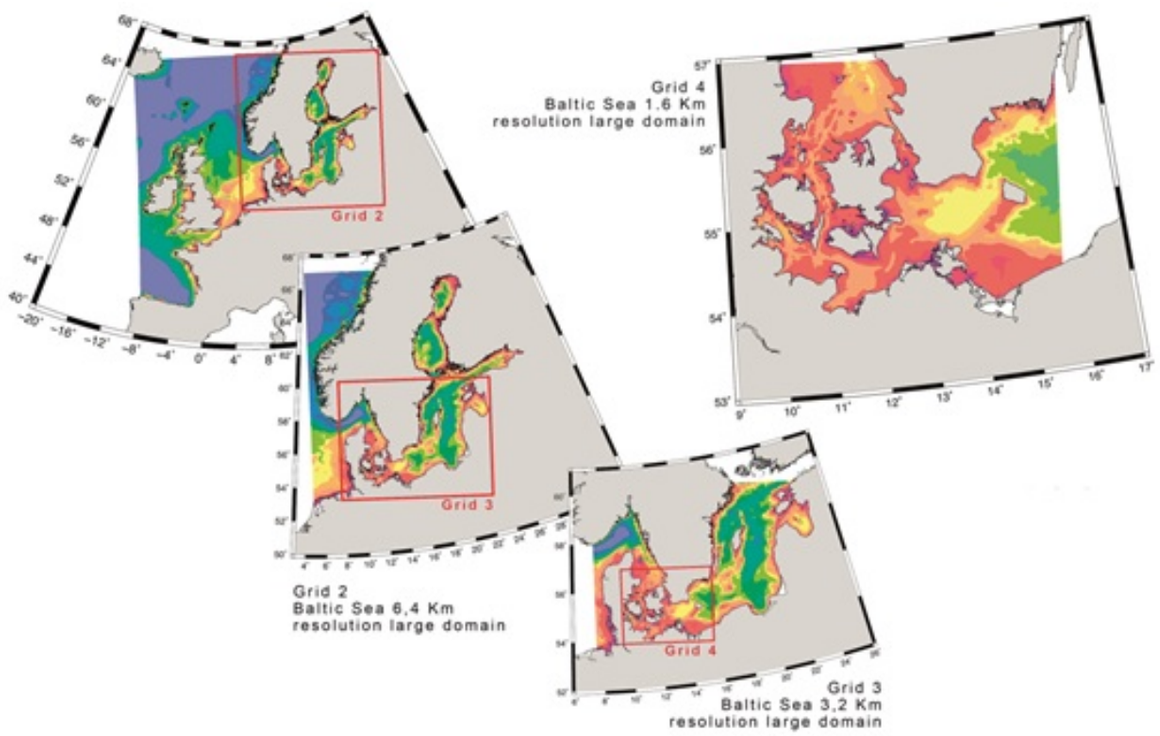
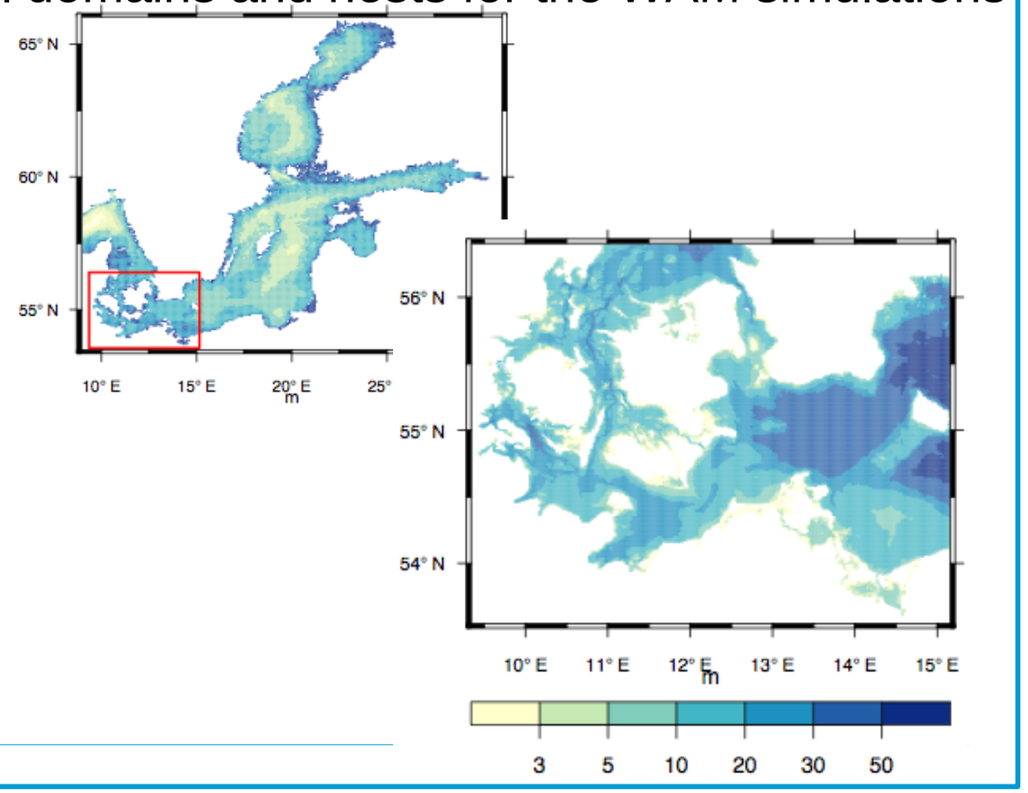
We use the **2D-hydrodynamic model TRIM-NP** for the water level simulation and the **wave model WAM** for the wave simulation. Both model are run with several nested simulations, with a spatial resolution of about **1,6km** at the finest simulation.
Both models are forced with hourly atmospheric conditions from a regional hindcast with a spatial resolution of **about 22km** with the CCLM regional model with spectral nudging (coastDat2) using the NCEP/NCAR reanalysis.
Both water level and wave hindcast cover the period from 1958 - 2012.
The same setups is used to simulated the recent storm event starting December 2016 to January 2017

## model domains and nests for the TRIM-NP simulations




## model domains and nests for the WAM simulations



# observational data from Dec.2016 to Jan.2017

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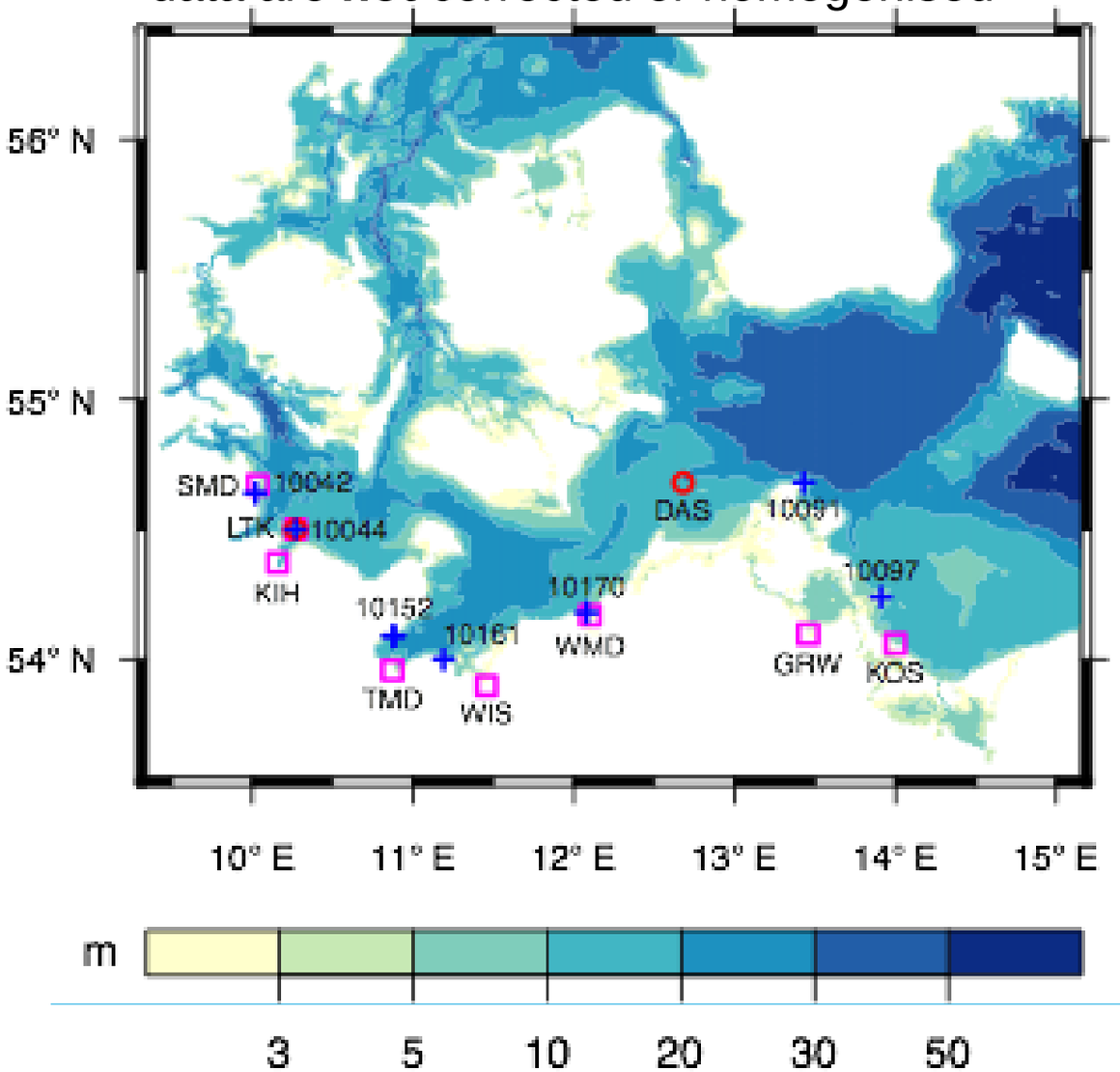
- wind observations: raw data kindly provided by the German Weather Service (DWD)
- water level data: raw data kindly provided by pegelonline.de and the Federal Maritime and Hydrographic Agency (BSH)
- wave observations: raw data kindly provide by the Federal Maritime and Hydrographic Agency (BSH) and the Helmholtz-Zentrum Geesthacht (HZG)
- data are **not** corrected or homogenised




| wind<br>blue crosses | water level<br>magenta squares | waves<br>red circles |
|---|---|---|
| 10042-<br>Schönhagen | SMD-<br>Schleimünde | |
| 10044-<br>Leuchturm Kiel | LTK-<br>Leuchtturm Kiel | LTK-<br>Leuchtturm Kiel |
| | KIH-<br>Kiel-Holtenau | |
| 10152-<br>Pelzerhaken | TMD-<br>Travemünde | |
| 1061-<br>Boltenhagen | WIS-<br>Wismar | |
| 10170-<br>Warnemünde | WMD-<br>Warnemünde | |
| 10091-<br>Akrona | | DAS-<br>Darsser Schwelle |
| 10097-<br>Greifswald Oie | GRW-<br>Greifwald | |
| | KOS-<br>Koserow | |

# Part 1:
# Storm Axel in a hindcast simulation

# Sea level pressure during storm AXEL (3.1.-5.1. 2017) in coastDat2

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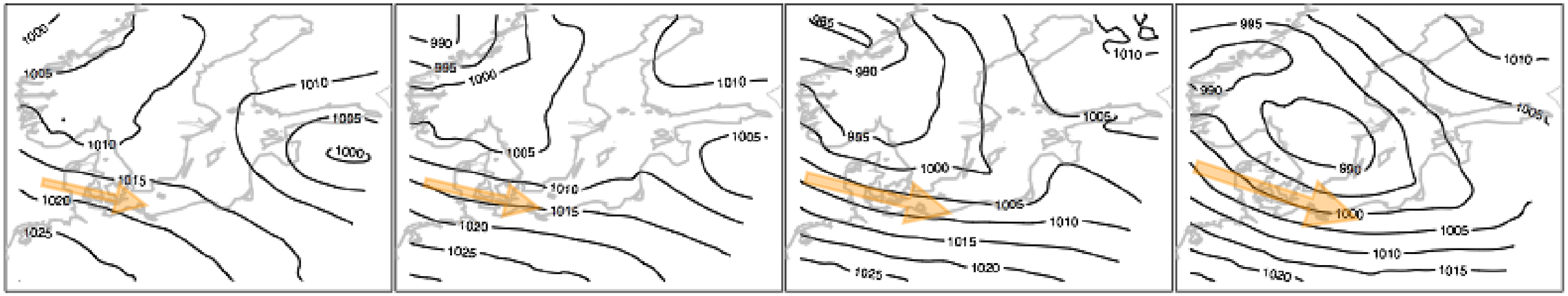
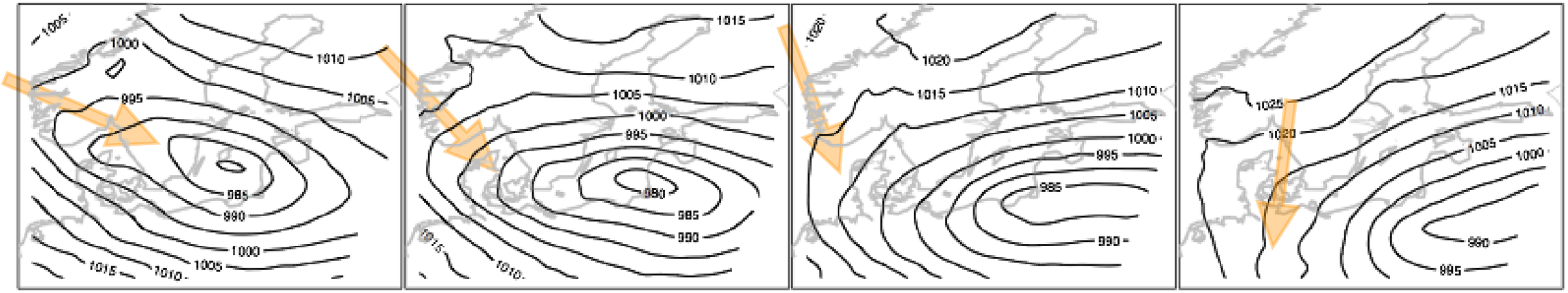
00:00 | 06:00 | 12:00 | 18:00

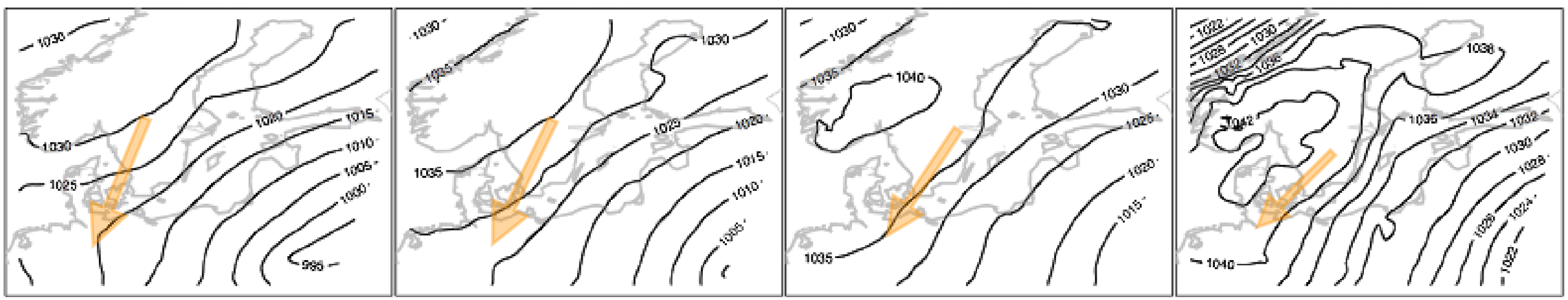
3 Jan



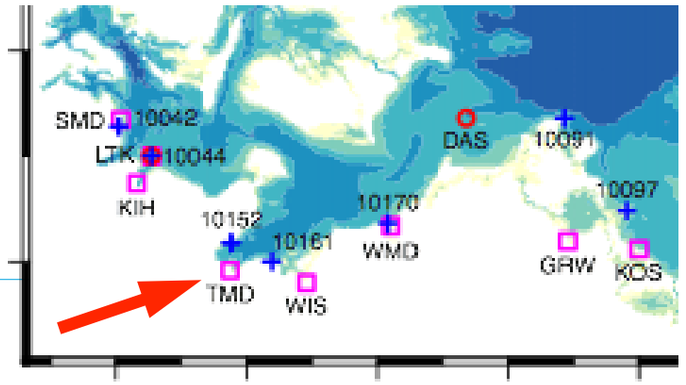
4 Jan



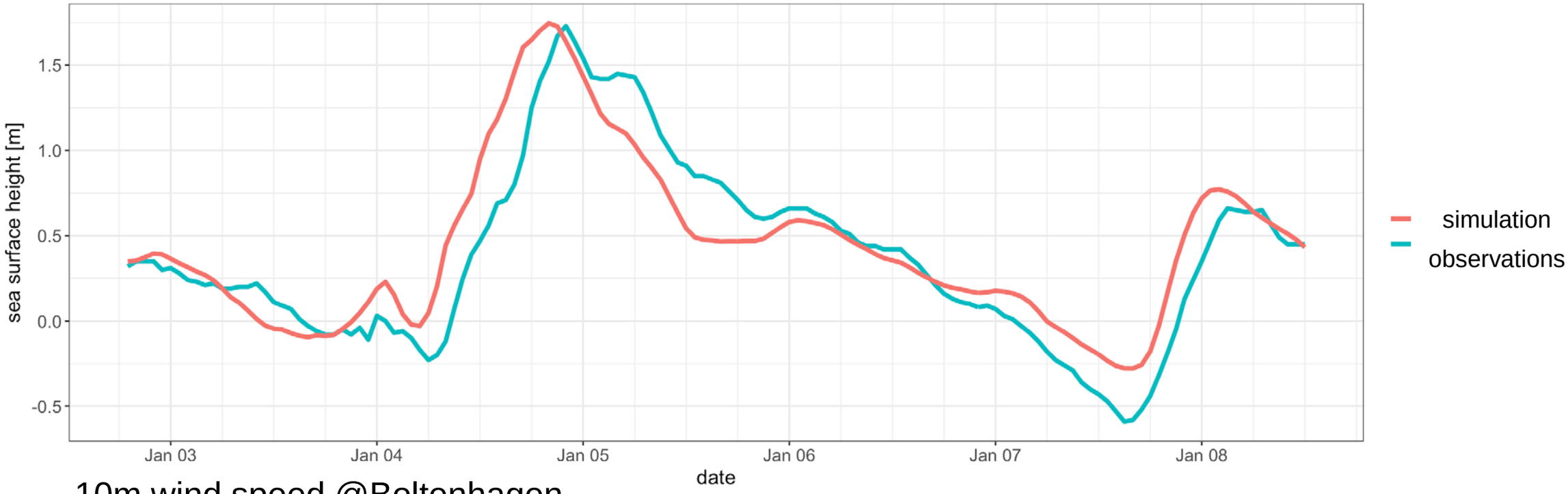
5 Jan



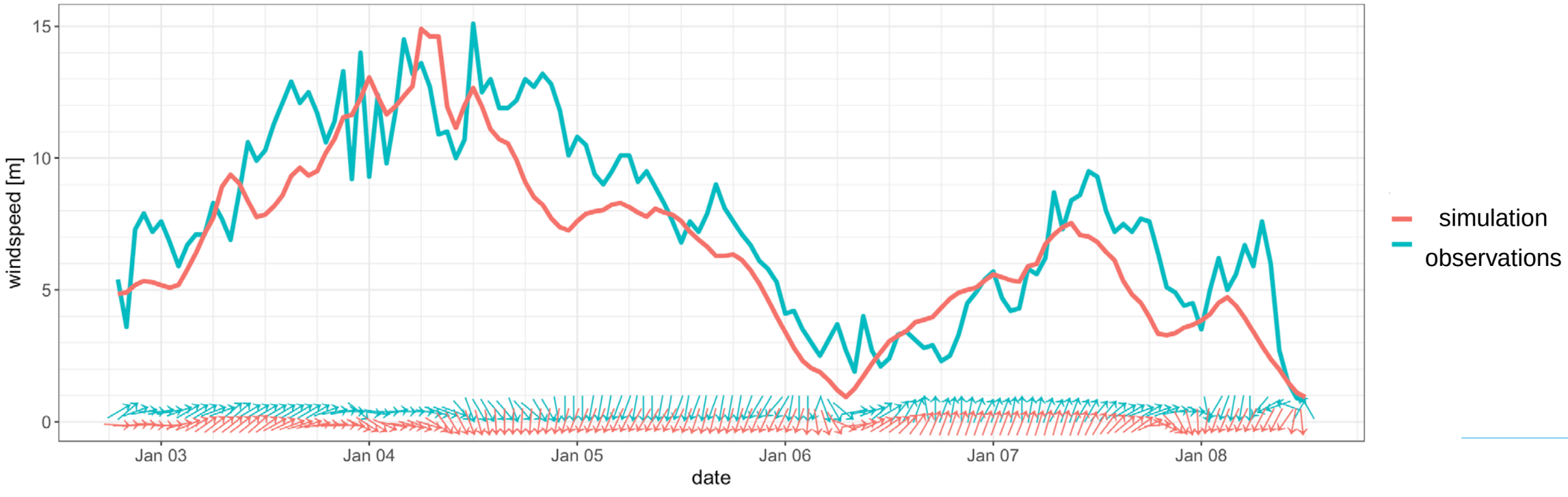
# simulated vs. observed **water level** @Travemünde and **10m wind speed** @Boltenhagen




## sea surface height @Travemünde




## 10m wind speed @Boltenhagen



# Maximum and the occurrence of the maximum for **10m wind speed**, **water level** & **wave height** between 3.1. and 5.1. 2017

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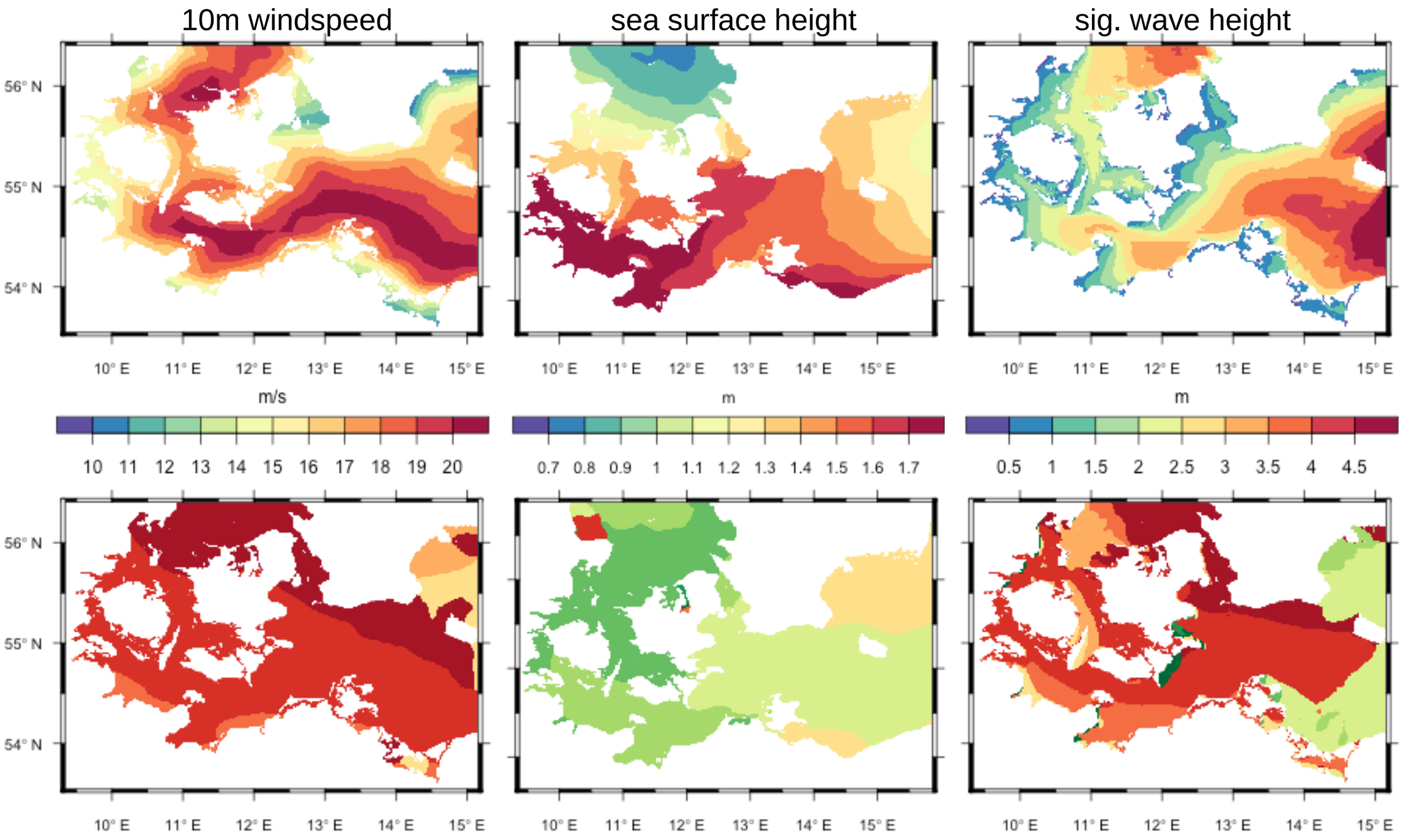

# Summary of Storm Axel

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- **good agreement** with observations
- however the timing of the maximum water level shows an offset (about 3 hours to early)
- maximum water level is about **1.75 m** above normal (western coastlines)
- maximum significant wave height range about **3-4 m** (eastern parts of the domain)
- maximum windspeed and sig. wave height occur about 12 hours earlier as the maximum water level

# Part 2:
# Storm Axel in a climate perspective

# Sea surface height 1958-2012 @Travemünde in coastDat2

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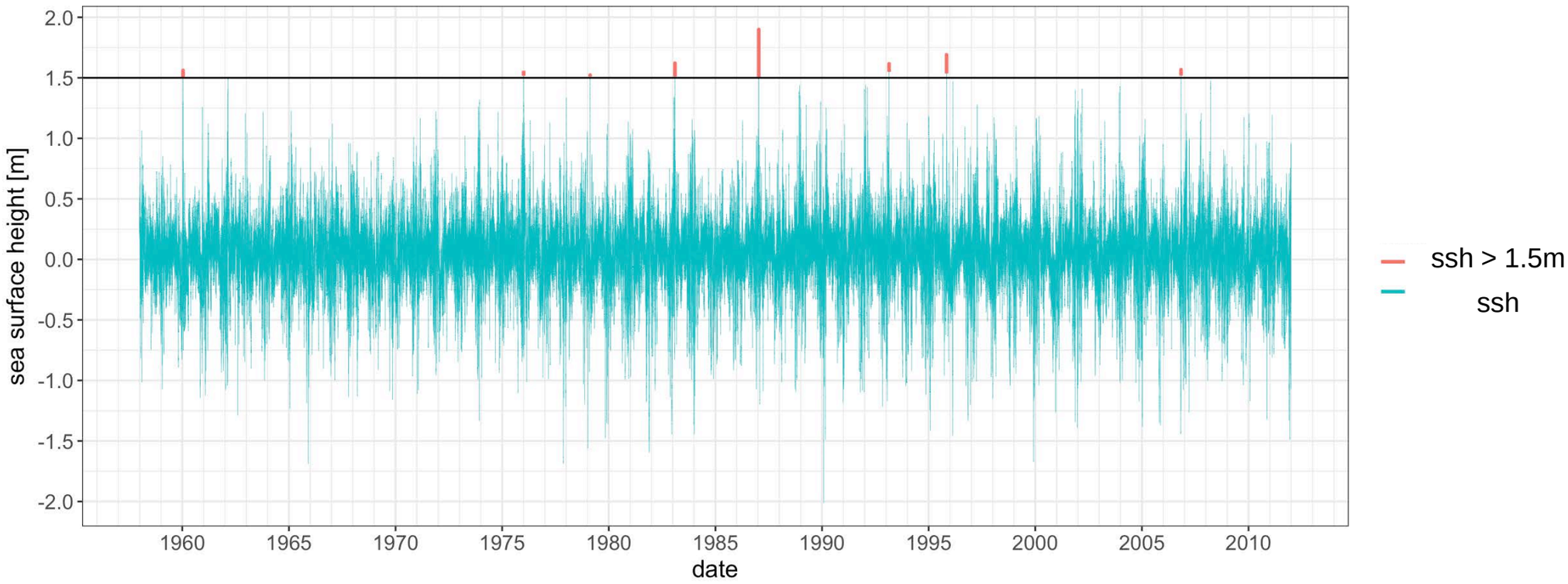


| date | duration [h] | mean [m] | maximum [m] |
|---|---|---|---|
| 14.01.1960 | 6 | 1.53 | 1.56 |
| 03.01.1976 | 2 | 1.54 | 1.56 |
| 15.02.1979 | 3 | 1.52 | 1.52 |
| 07.02.1983 | ***9*** | 1.58 | 1.62 |
| 12.01.1987 | ***15*** | ***1.73*** | ***1.90*** |
| 21.02.1993 | 3 | 1.58 | 1.62 |
| 03.11.1995 | 6 | ***1.62*** | ***1.69*** |
| 01.11.2006 | 4 | 1.54 | 1.57 |
| 04.01.2017 | ***7*** | ***1.66*** | ***1.75*** |

# Decomposition of surge height in the Baltic Sea

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surge height ~ Wind field + SLP + Filling + Seiches

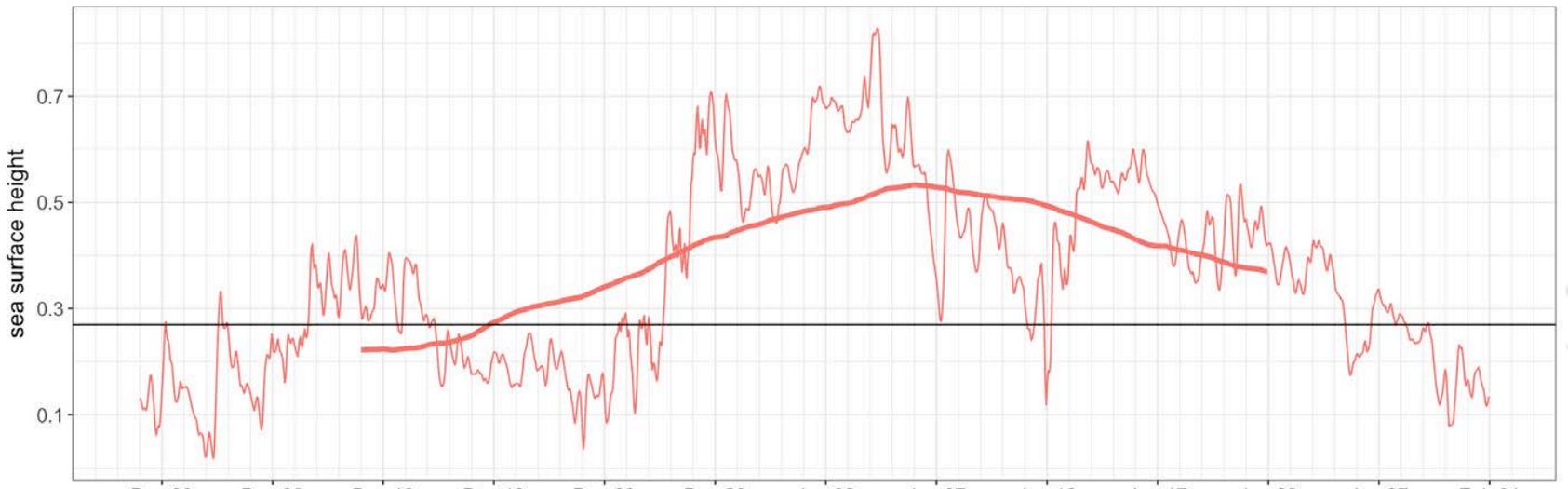
***Filling:*** prevailing westerly winds can lead to an increased inflow of water from the North Sea into the Baltic Sea and to a temporary rise of the water level.
The level of filling is defined as the 20 day mean of the sea surface height at the location Landsort (Sweden). A water level 27cm above normal (15cm above the mean sea level from 13cm @Landsort) is considered as *pre-filling* (Mudersbach and Jensen, 2010)

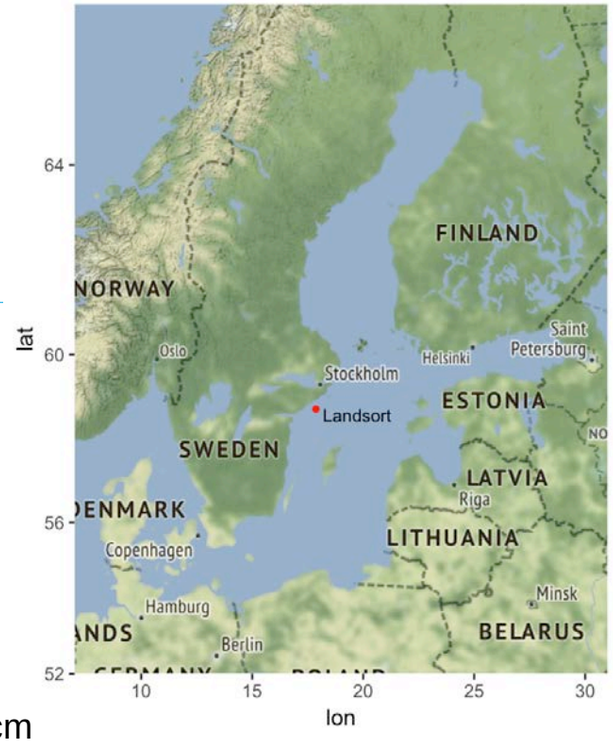
***Seiches:*** The variations in the wind field and the geometry of the Baltic Sea cloud lead to seiches. Using a harmonic analyse typical (31h, 26.4h, 22.4h, 19.8h) periods of this seiches are analyses (Wübber und Kraus 1979).

-> see Poster 68 by Ralf Weisse for more detail on Baltic Sea seiches and filling

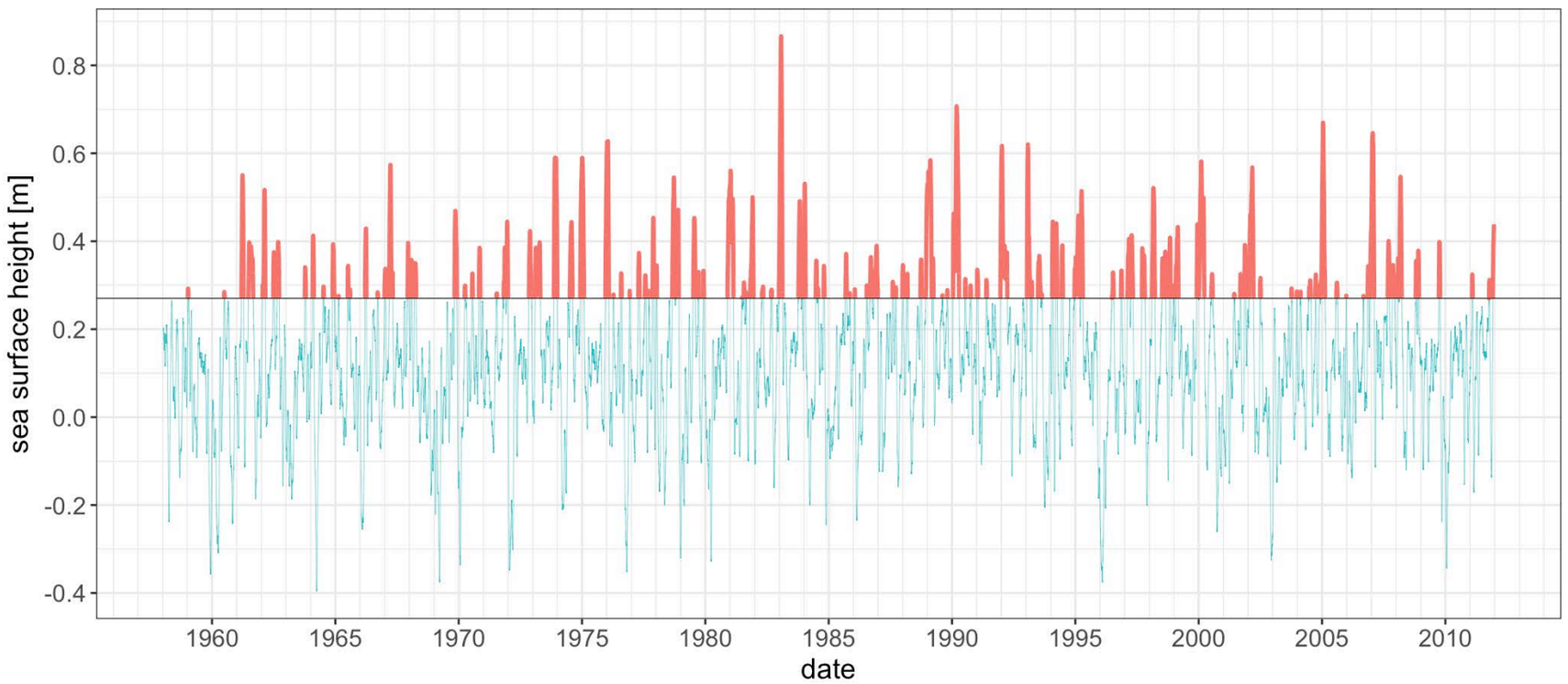
# Level of filling

water level and 20 day moving average @Landsort

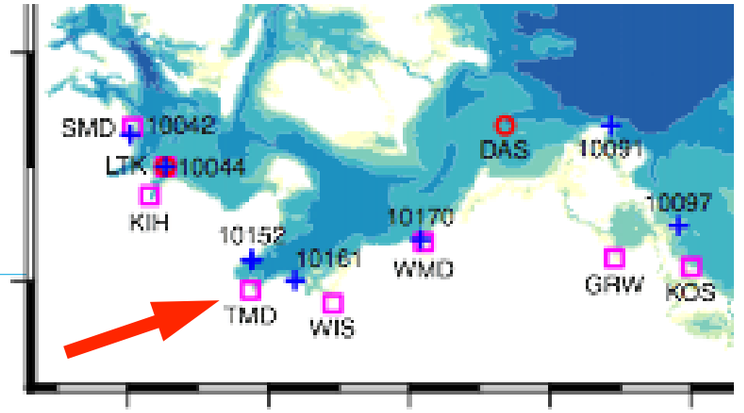


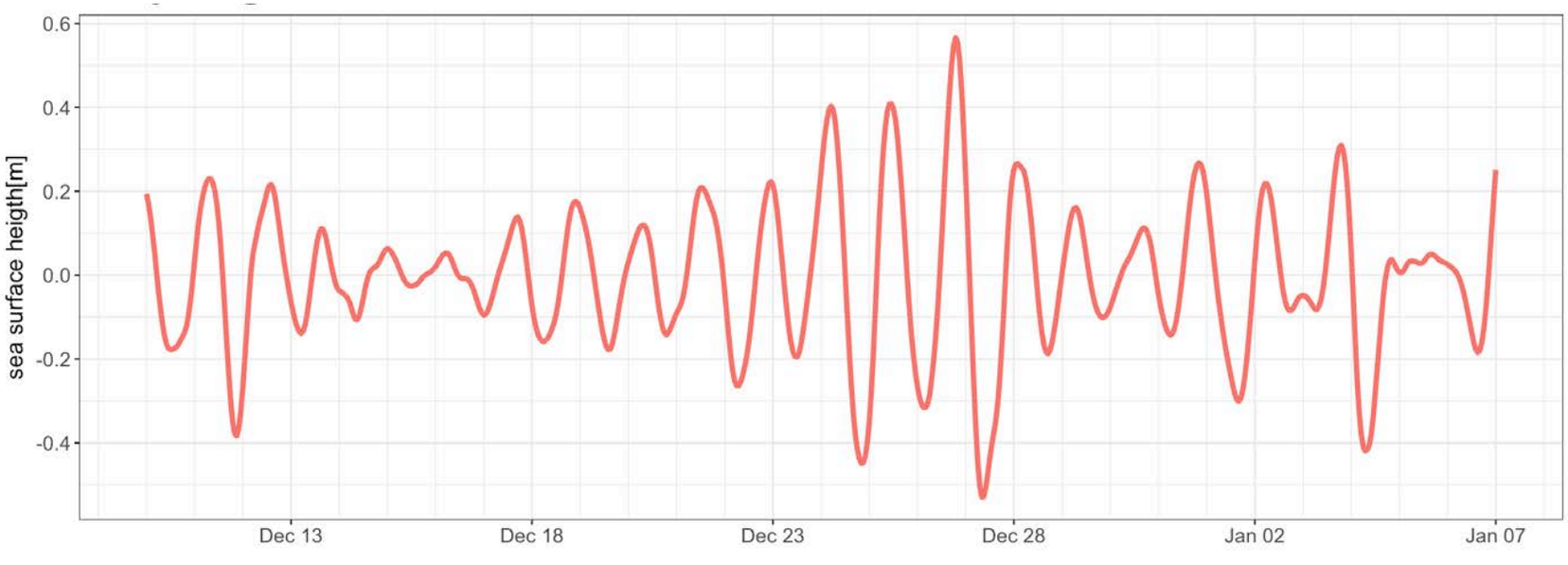

long term 20 day moving average @Landsort



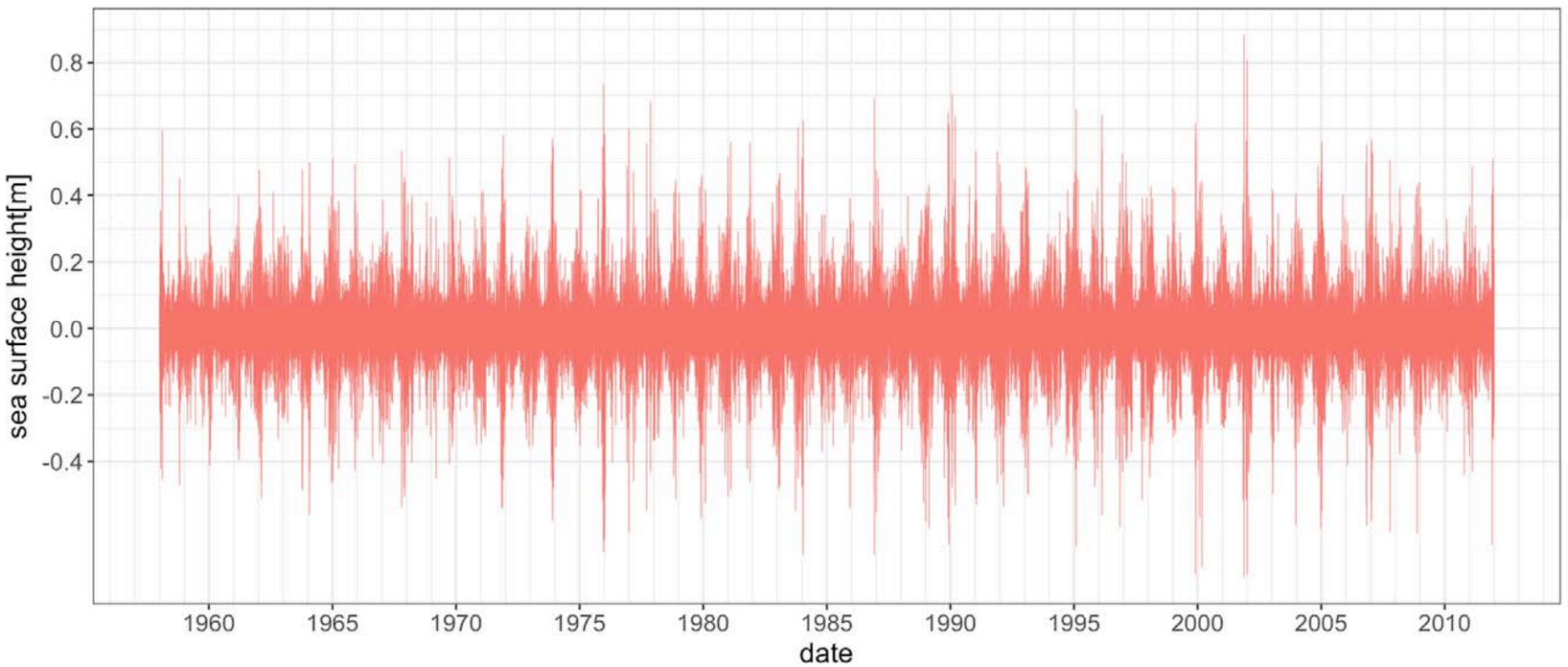
# Seiches @Travemünde



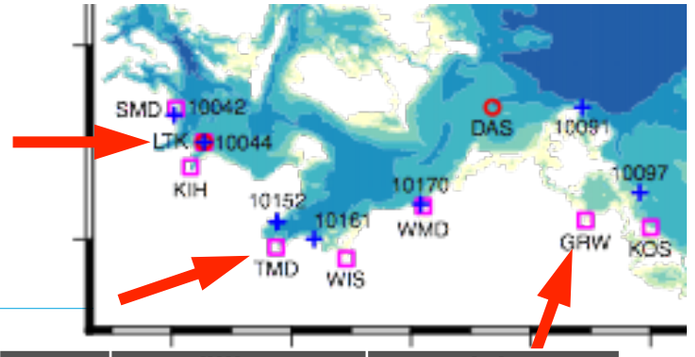

total seiches @Travemünde



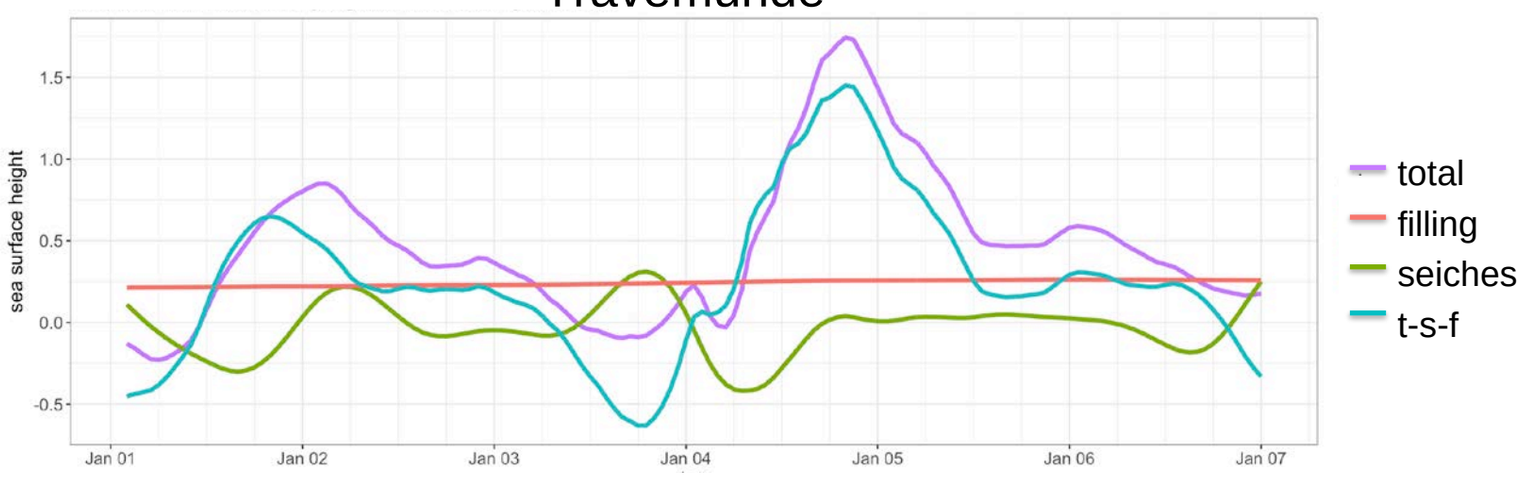

long term total seiches @Travemünde



# Decomposition of sea surface height

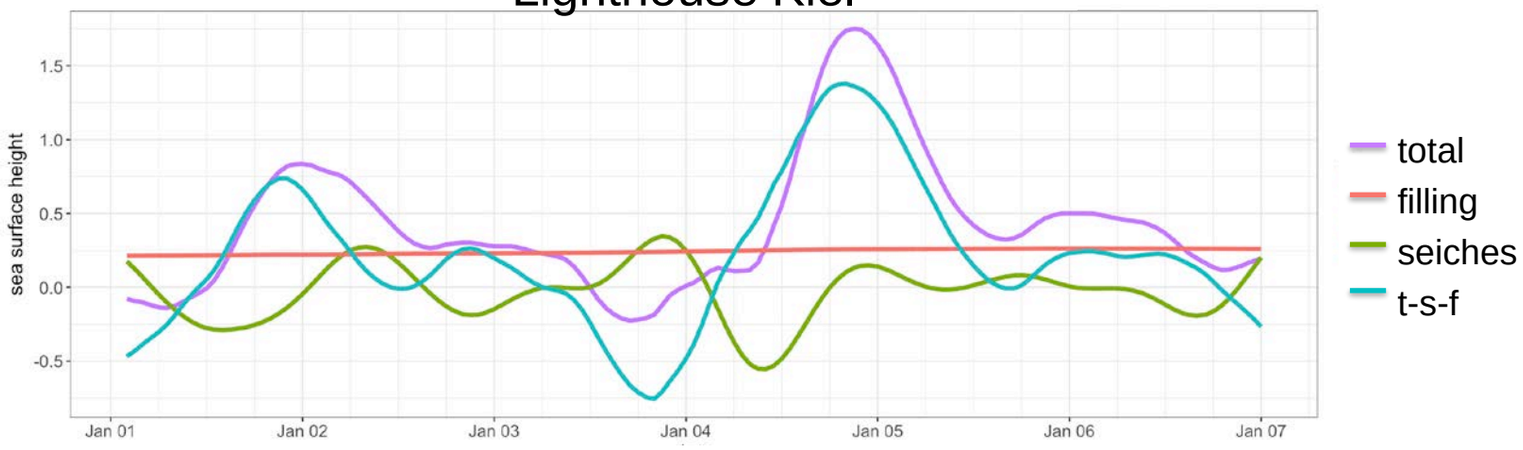



## Travemünde



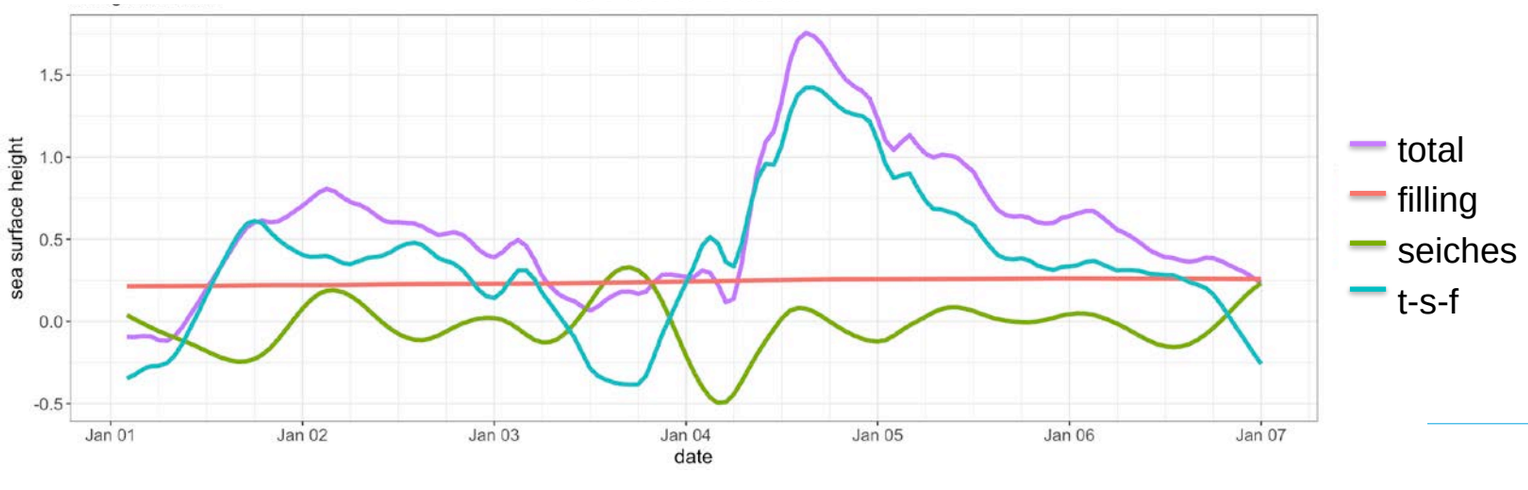

| date | max [m] | filling [m] | filling [%] | seiches [m] | seiches [%] |
|---|---|---|---|---|---|
| 14.01.1960 | 1.56 | -0.24 | -15.2 | 0.05 | 3,5 |
| 03.01.1976 | 1.56 | 0.34 | 21.5 | 0.28 | 17.7 |
| 15.02.1979 | 1.52 | -0.43 | -28.1 | 0.04 | 2.6 |
| 07.02.1983 | 1.62 | 0.36 | 22.0 | -0.02 | -1.4 |
| 12.01.1987 | 1.90 | -0.32 | -16.7 | 0.01 | 0.6 |
| 21.02.1993 | 1.62 | 0.06 | 3.9 | -0.22 | -13.7 |
| 03.11.1995 | 1.69 | -0.08 | -4.7 | -0.06 | -3.9 |
| 01.11.2006 | 1.57 | -0.12 | -7.7 | -0.22 | -14.3 |
| 04.01.2017 | 1.75 | 0.26 | 14.7 | 0.04 | 2.1 |

## Lighthouse Kiel




| date | max [m] | filling [m] | filling [%] | seiches [m] | seiches [%] |
|---|---|---|---|---|---|
| 14.01.1960 | 1.58 | -0.24 | -15.1 | 0.05 | 3,3 |
| 15.02.1979 | 1.63 | -0.43 | -26.3 | 0.05 | 3.1 |
| 19.01.1983 | 1.53 | 0.50 | 32.7 | -0.19 | -12.2 |
| 08.02.1983 | 1.62 | 0.35 | 21.7 | -0.25 | -15.5 |
| 13.01.1987 | 1.79 | -0.32 | -17.8 | -0.00 | -0.2 |
| 21.02.1993 | 1.58 | 0.06 | 4.0 | -0.20 | -12.3 |
| 04.11.1995 | 1.62 | -0.08 | -4.9 | -0.03 | -2.0 |
| 19.02.1996 | 1.55 | -0.53 | -34.2 | -0.52 | -33.5 |
| 01.11.2006 | 1.76 | -0.12 | -6.7 | -0.25 | -14.0 |
| 04.01.2017 | 1.75 | 0.26 | 14.6 | 0.13 | 7.5 |

## Greifswald




| date | max [m] | filling [m] | filling [%] | seiches [m] | seiches [%] |
|---|---|---|---|---|---|
| 14.01.1960 | 1.55 | -0.24 | -15.3 | -0.05 | -3.2 |
| 03.01.1976 | 1.80 | 0.34 | 18.8 | -0.15 | -8.5 |
| 12.01.1987 | 1.71 | -0.32 | -18.3 | -0.07 | -4.2 |
| 17.01.1992 | 1.72 | 0.25 | 14.4 | 0.01 | 0.5 |
| 21.02.1993 | 1.56 | 0.06 | 4.0 | -0.28 | -18.2 |
| 03.11.1995 | 1.80 | -0.08 | -4.3 | -0.10 | -5.5 |
| 22.03.2008 | 1.64 | 0.07 | 4.3 | 0.05 | 3.2 |
| 04.01.2017 | 1.75 | 0.25 | 14.5 | 0.08 | 4.5 |

# Conclusions

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- considering maximum (**1.75m**) and mean (**1.66m**) water level and the length (**7 hours**) above 1.5m, the surge event along the southwestern Baltic coast is within the range (~15-20 year return value) of the highest surge events during the simulation period of 1958-2012.
- level of filling (**0.26m**) contribute significantly to the high water level and is higher compared to other extreme surge events
- seiches contribute less to the water level, except @Lighthouse Kiel (**0.13m**)
- the surge event associated with storm Axel is not comparable to the extreme surge event in 1872 (**3.3m**) -> see Poster 42 by Elke Meyer on simulations for the 1872 storm event