Storm surges as part of compound hazards

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Introduction

Specificity of compound events – combined effect is larger than a sum of single components.

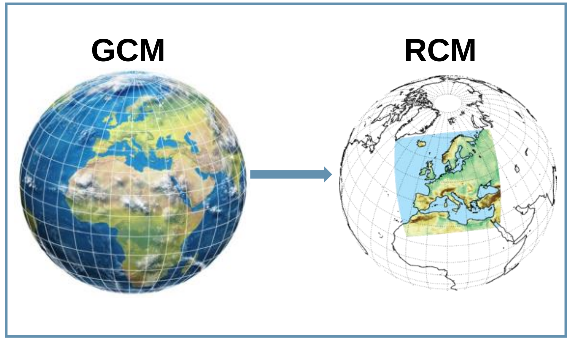
Focus regions: Northern and Central Europe and the German North Sea coast

Hazard: coastal, estuarine or hinterland flooding

Compound: near-simultaneous high water levels (storm tide) and high river runoff (heavy rain)

Two examples of how such compound events can be investigated and how their properties change in future projections.

Storm tides and SLR. Background data.

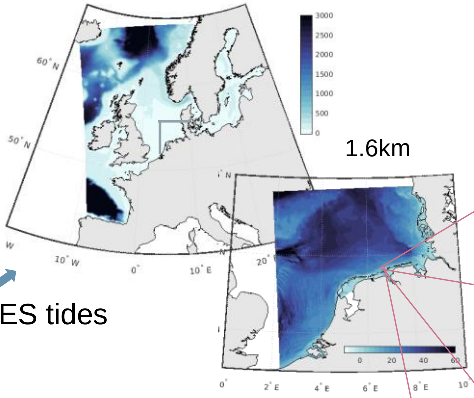


- **reanalysis** with REA6, COSMO-CLM & NCEP(1950-2022)
- CMIP5 RCP2.6 and RCP8.5 **scenarios** with REMO-MPI and REMO-HadGEM2 (1950-2100)

U10, V10, SLP

TRIM (hydrodynamics)

12.8km

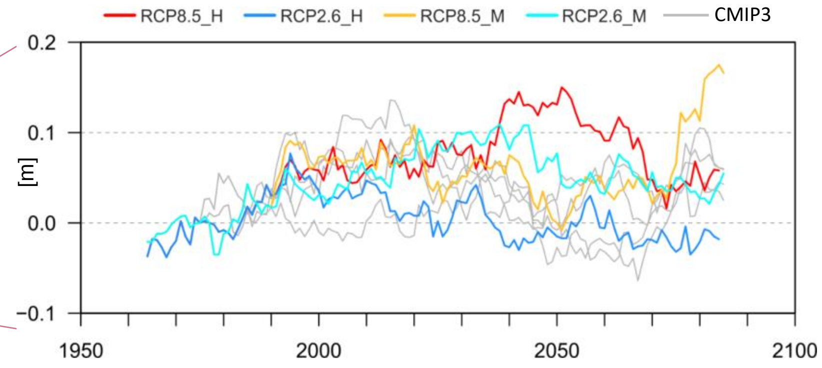


1.6km

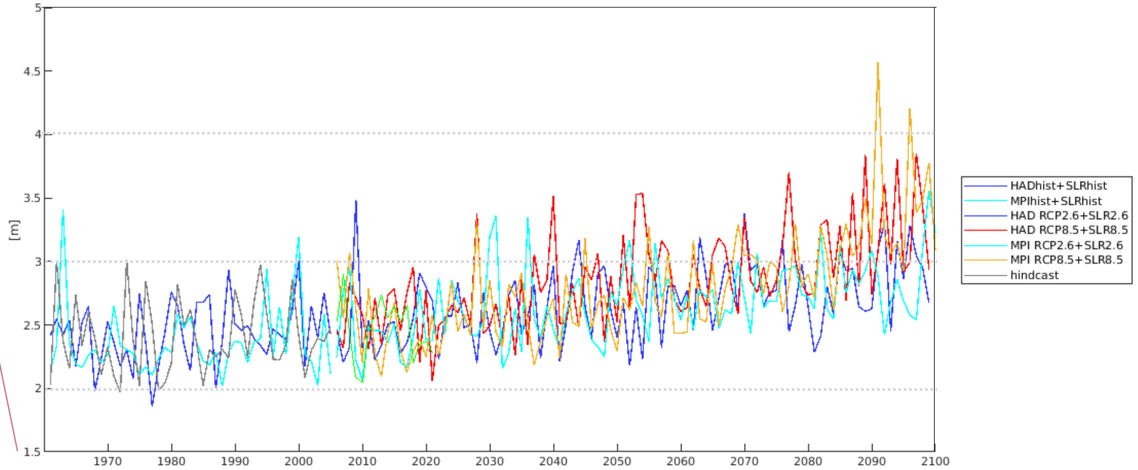
FES tides

hourly water levels

Anomalies of 30a mean of annual 99.9% of water level



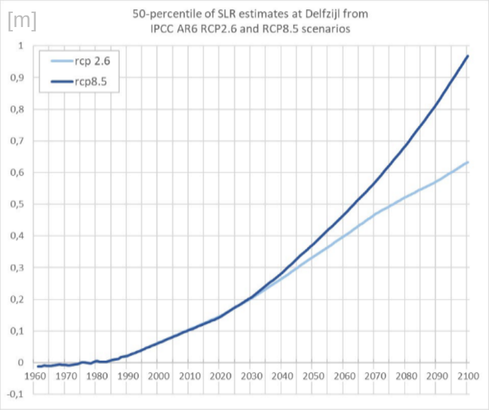
Annual 99.9% of water level + SLR



Multiple scenarios of future water level in the German Bight show a strong inter-annual, inter-model and inter-scenario variability of extremes.

Significant changes towards the end of 21st century appear only in connection with the SLR.

Mean Sea Level rise regional scenarios



sealevel.nasa.gov

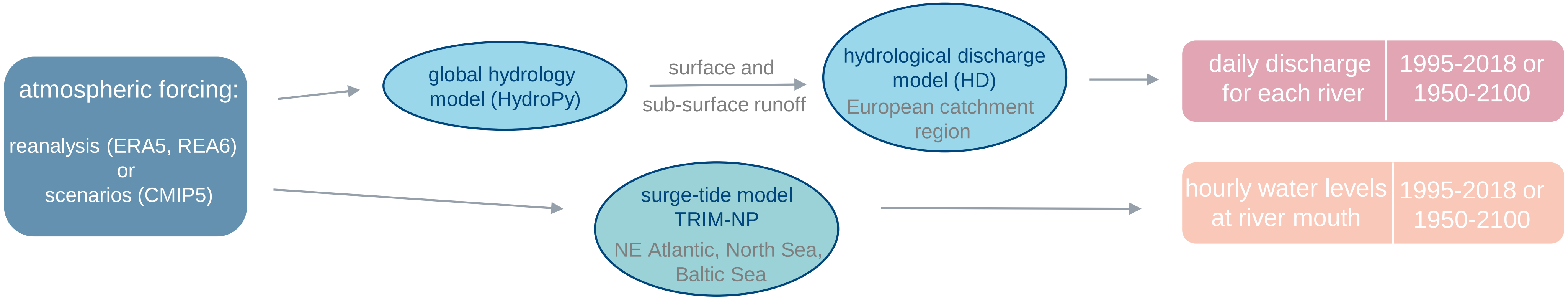
linear combination

Example 1: storm tide and extreme river discharge

Do such compound flood events occur more often than by pure coincidence?

Can any changes in the amount and spatial distribution of compound events be detected in the future scenarios?

Data



Hagemann and Stacke (2021), Gaslikova (2023)

Experiment setup

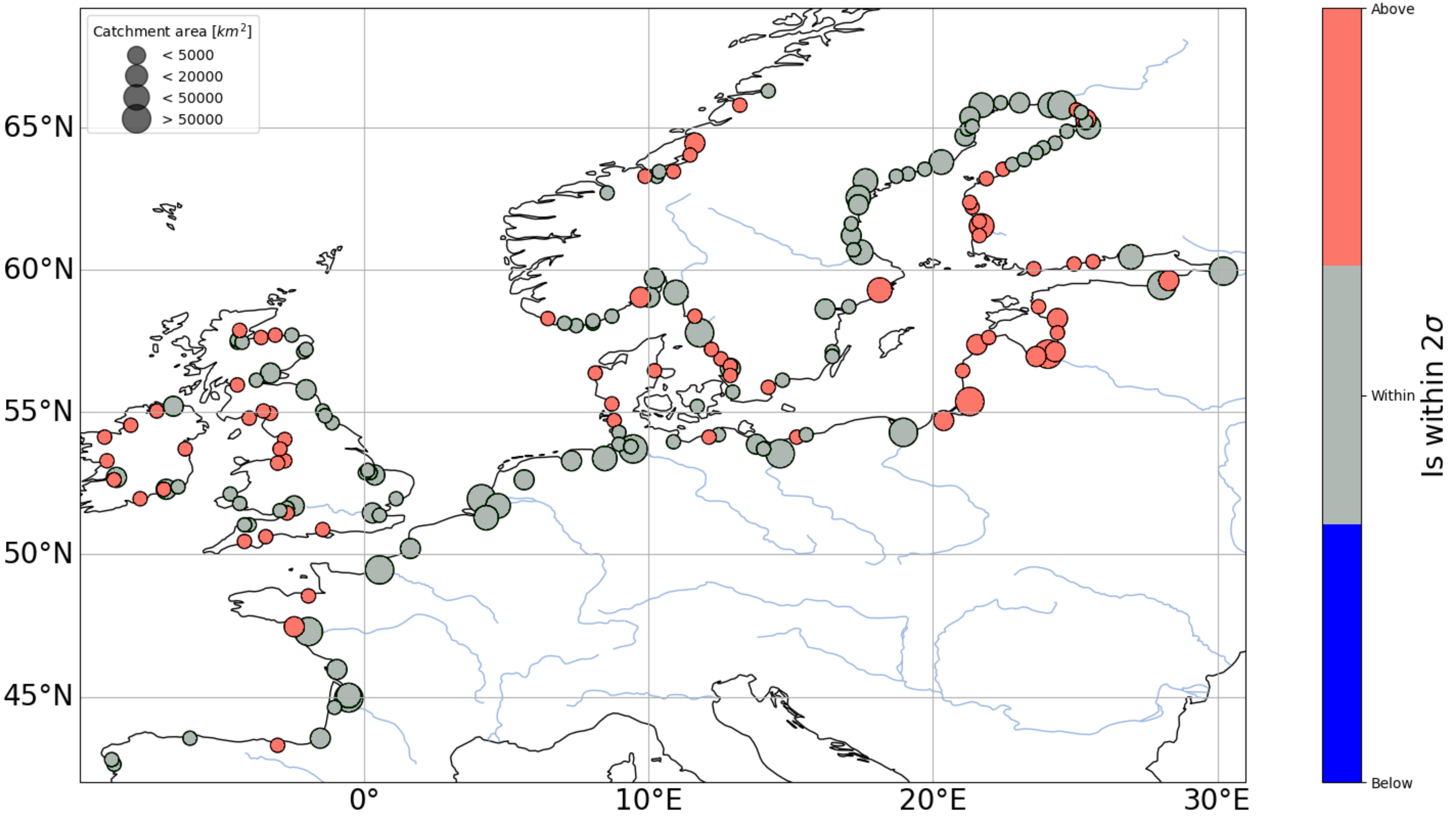
- selection of separate extreme events: Peak Over Threshold optimized to ~ 2 events per year
- compound event definition: extreme discharge and storm tide occur at the same day => number of compound events for each river
- Monte-Carlo approach: randomization of water level timeseries (re-shuffle) => new compound events =>

  => probability distribution of occasional compound events
- assess whether original number of compound events is within 95% interval of 2σ

Heinrich et al. 2023 [1]

Example 1: storm tide and extreme river discharge

compound events based on the reanalysis 1995-2018



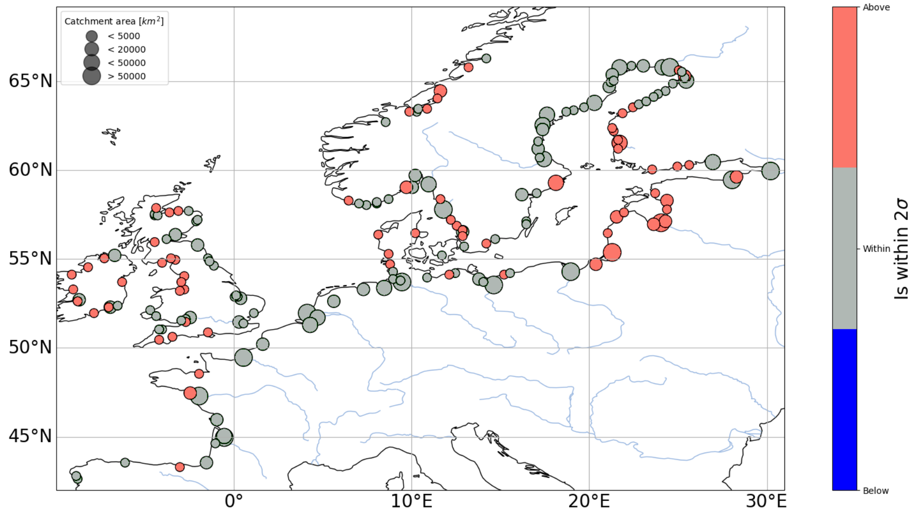
Heinrich et al. 2023 [1]

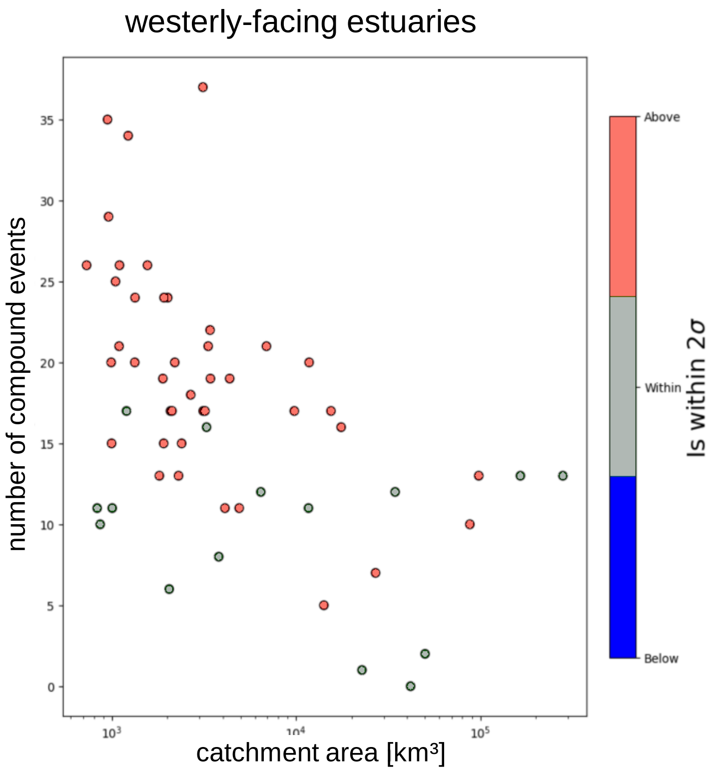
red – amount of compound events is significantly beyond the coincidence

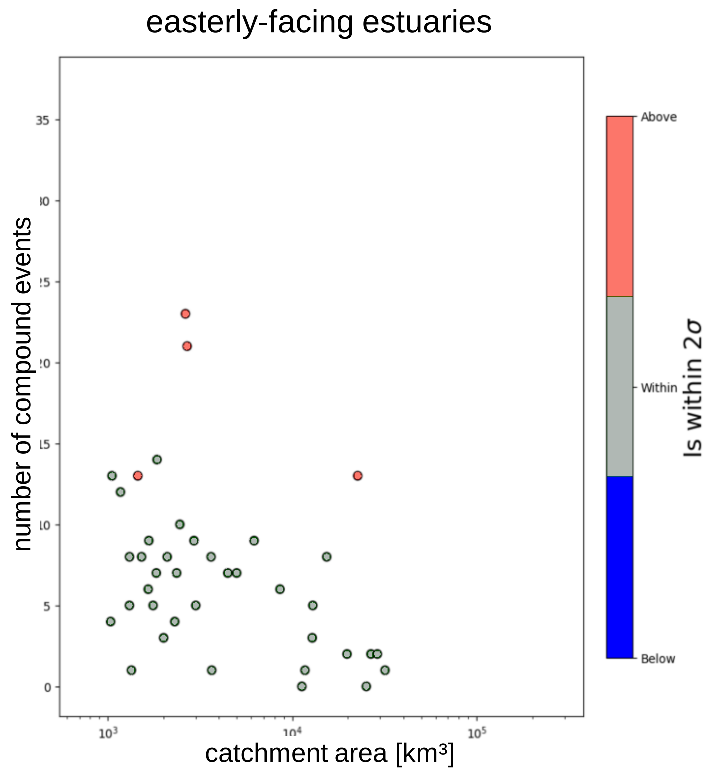
Mostly the rivers along the west-facing coasts have significantly different number of compound flood events

Compound events associated with the cyclonic westerly Grosswetterlage: ~ 90% for the North Sea west coast and Sweden, ~ 60% for the western Baltic Sea and >50 % for the Great Britain

Example 1: storm tide and extreme river discharge





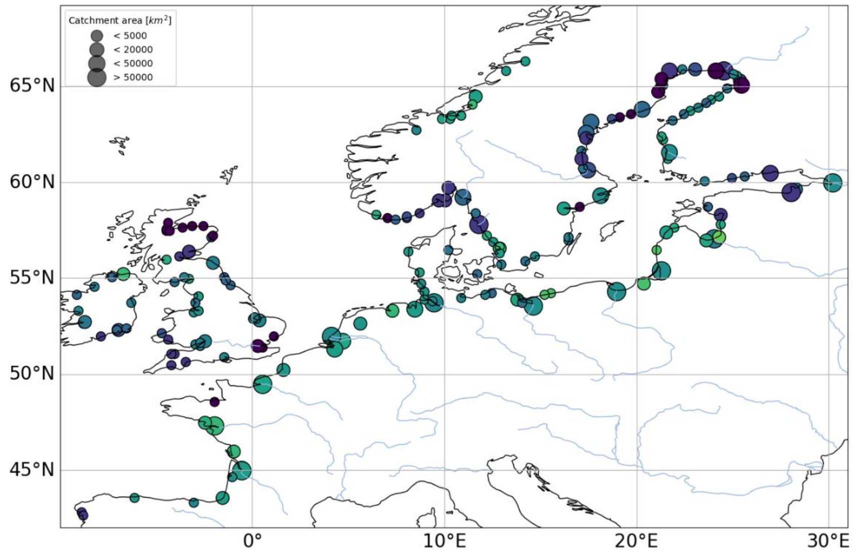


The number of compound flood events declines with increasing of catchment area

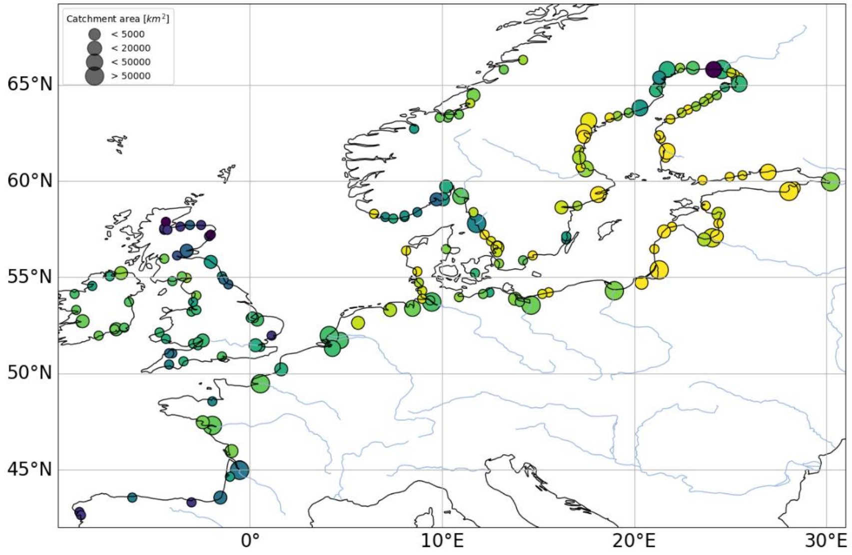
Heinrich et al. 2023 [1]

Example 1: storm tide, extreme river discharge and SLR

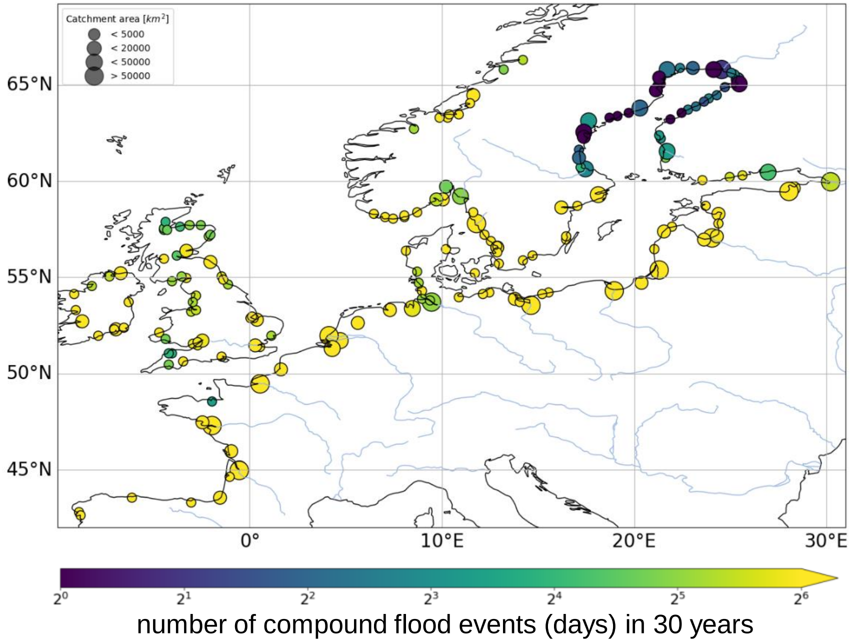
historical (1976-2005)



RCP8.5 scenario, **only atmosphere** (2070-2099)



RCP8.5 scenario, **atmosphere + SLR** (2070-2099)



For future scenarios, the number of compound events increases almost everywhere, mainly due to changes in the discharge and is still more increased with SLR included.

However, there are no changes in the area of "significance", where the number of compounds exceeds the number of coincidences by chance.

Heinrich et al. 2023 [2]

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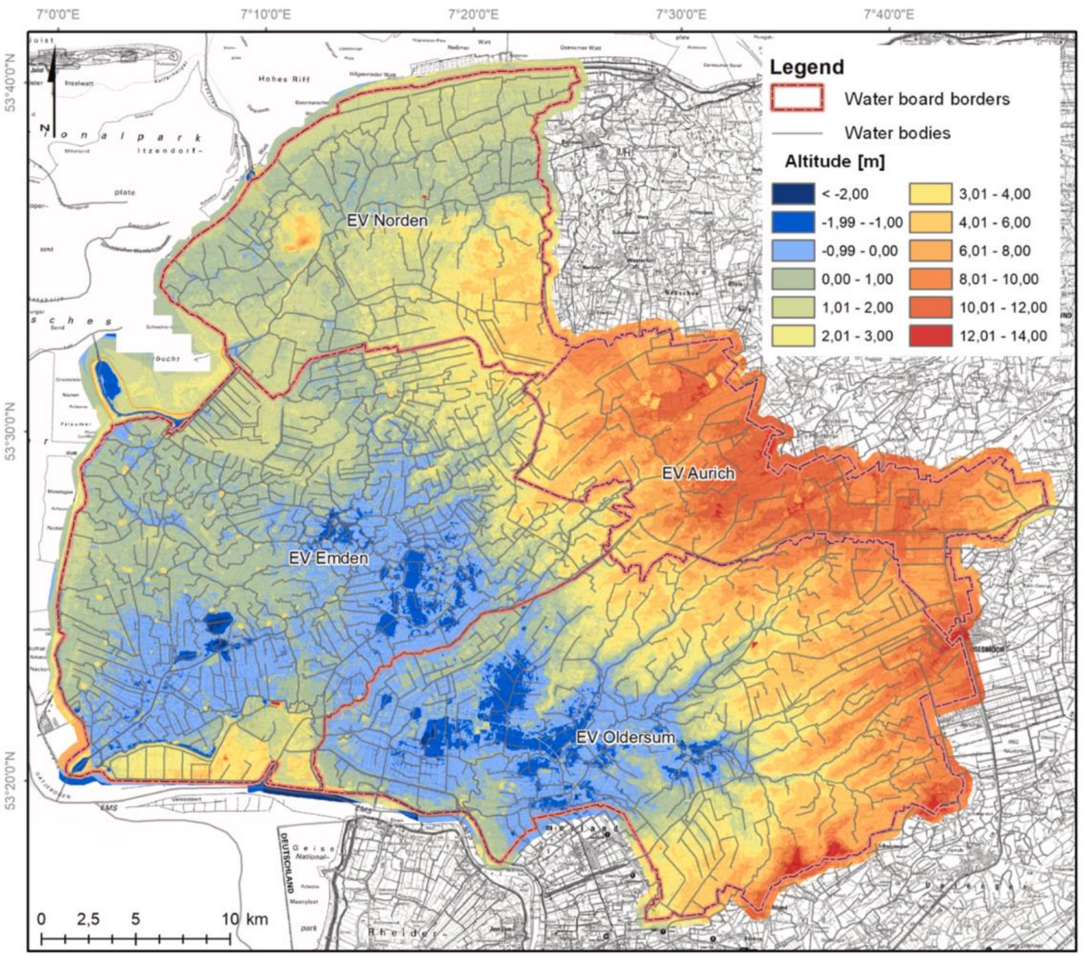
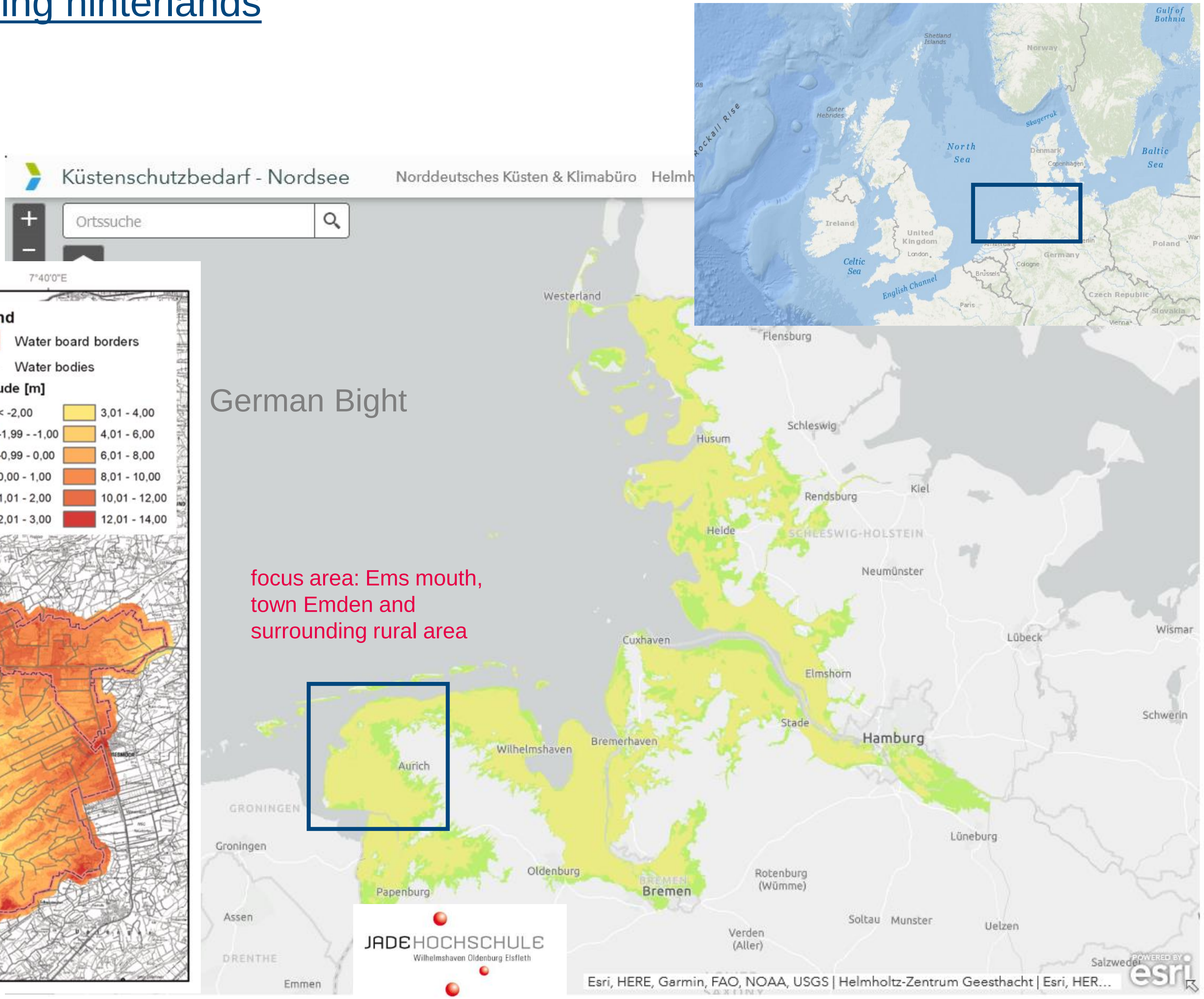
Example 2: drainage of the low-lying hinterlands





Example 2: drainage of the low-lying hinterlands

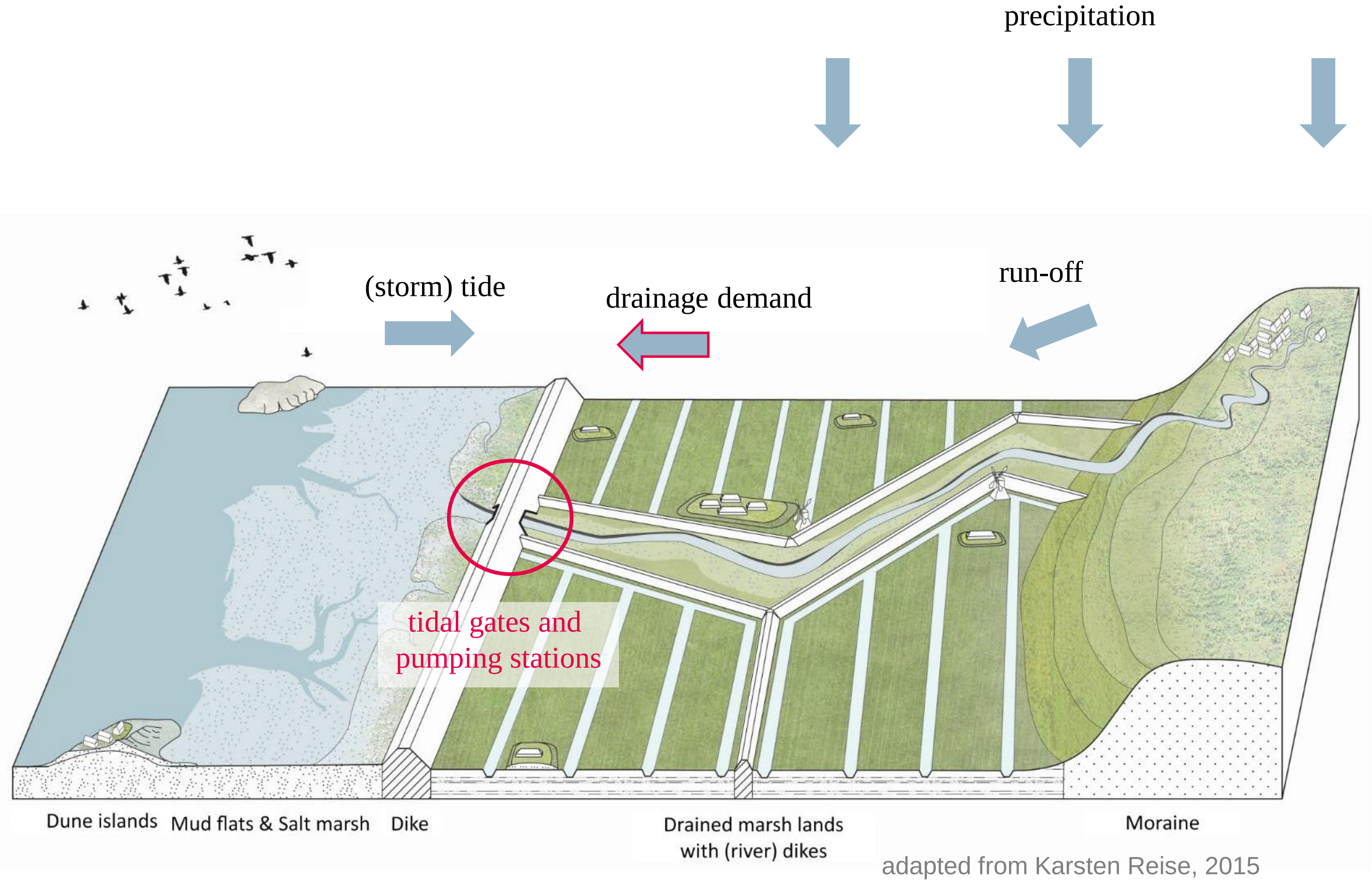
Low-lying coastal areas are protected by dykes, which generates managed hydrological systems in the hinterlands.

A generally humid climate and a positive water balance lead to necessity of drainage.

A combination of channels, tidal gates and pumping stations enables the removal of excessive water from the hinterland.

This can be (partly) impaired by the high waters at the outer side e.g. during the storm tides.

A combination of high cumulative precipitation in the inland and high and/or prolonged storm surges can lead to a potentially hazardous compound event.



adapted from Karsten Reise, 2015

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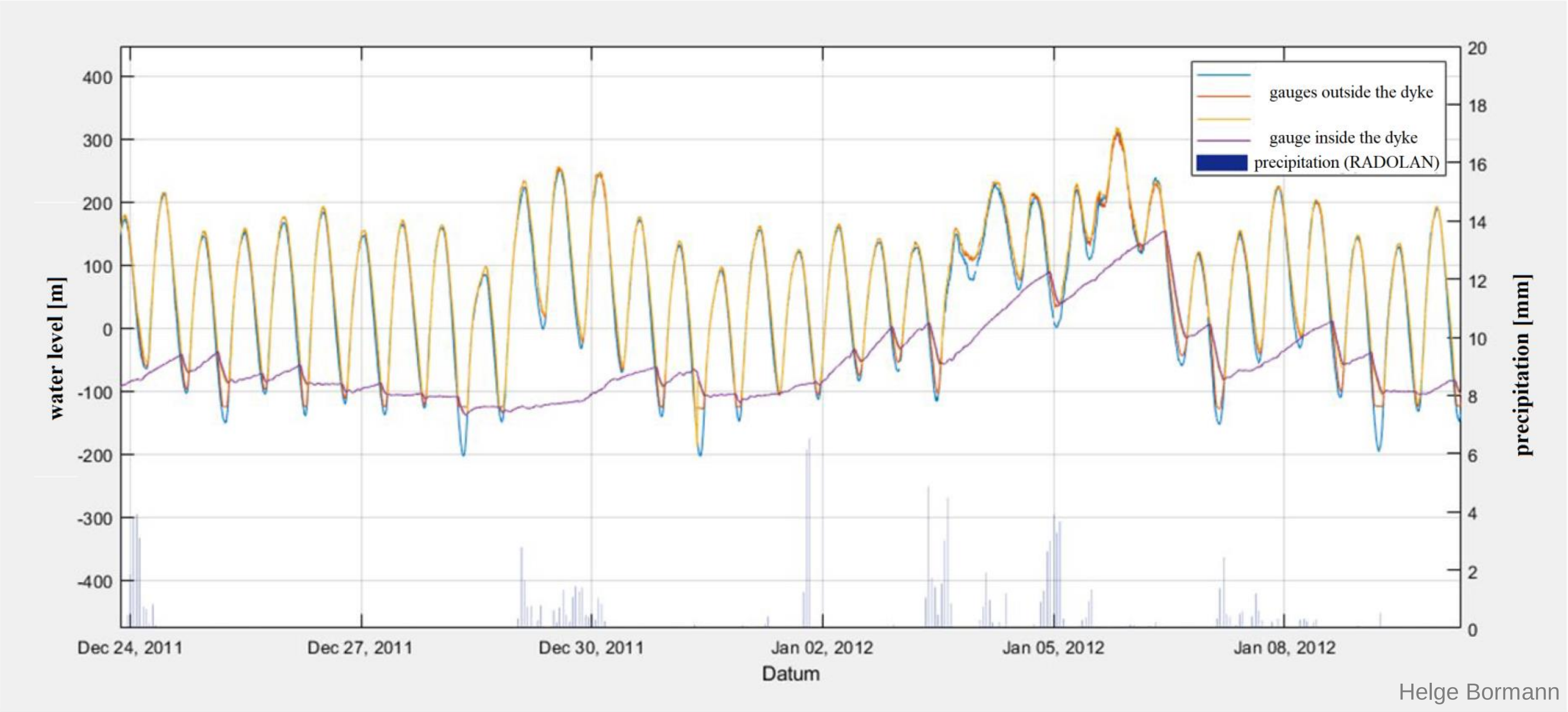
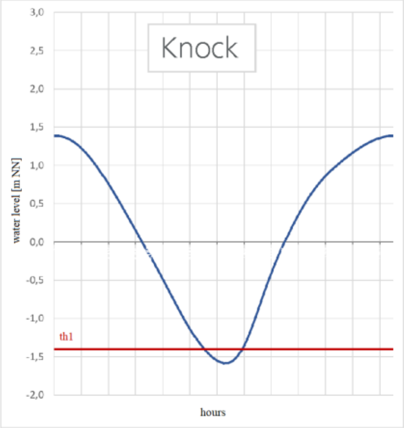
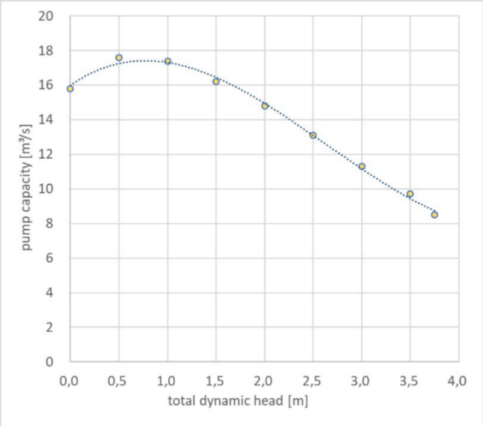


Only limited amount of water can be removed from the hinterland with the present-day infrastructure

Critical time windows to sluice water (outside water levels < th1)



Pump capacity decreases with high outer water levels

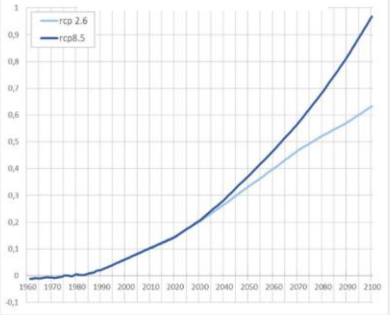


Example 2: drainage of the low-lying hinterlands

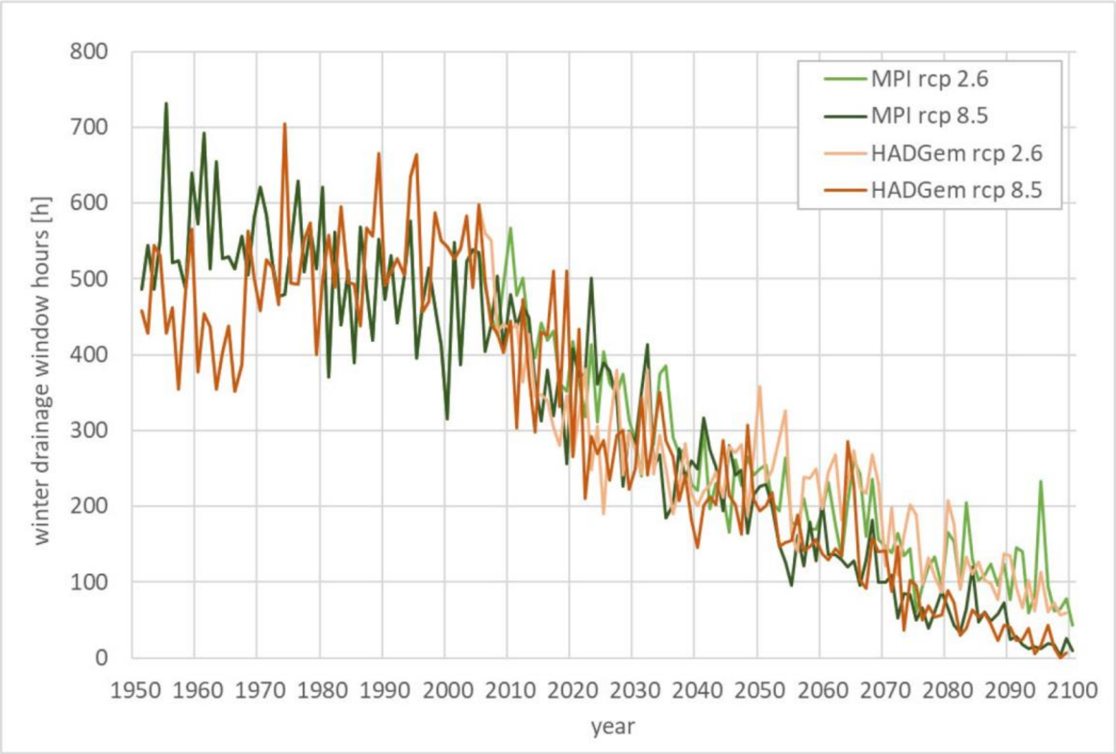
There is a loss in drainage and pump capacity towards the end of the 21st century for the future storm tide scenarios.

It can be mostly attributed to the SLR, which leads to (1) rising low water and (2) increasing storm tide extremes.

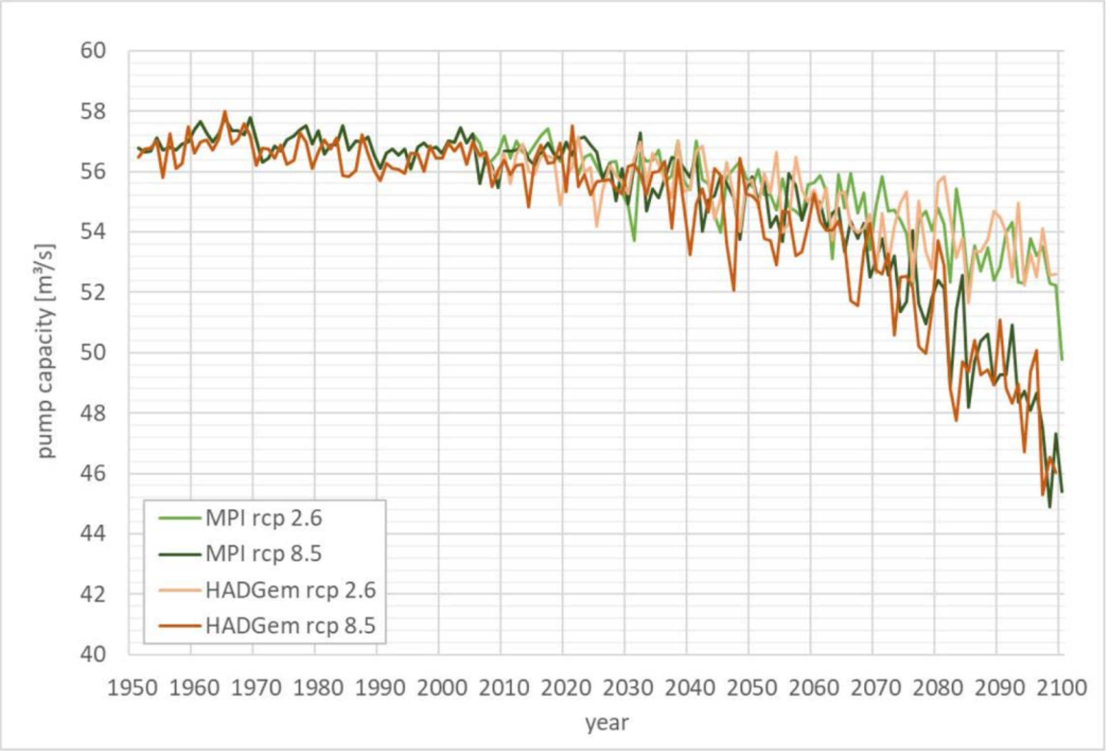
SLR regional scenarios



Loss in drainage window hours at drainage station Knock

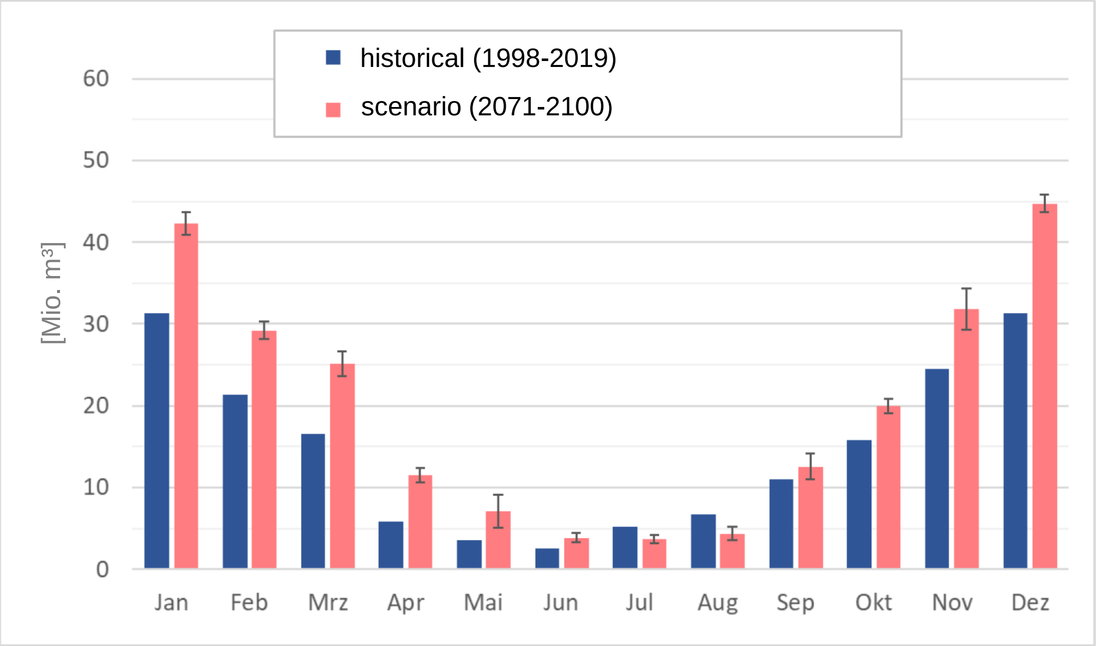


Loss in pump capacity at drainage station Knock



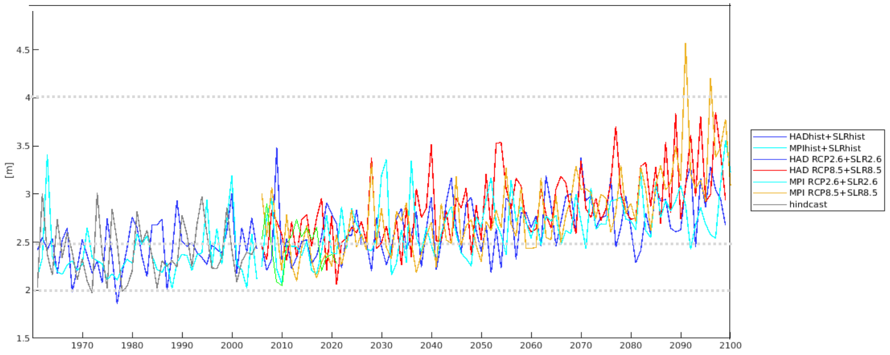
Example 2: drainage of the low-lying hinterlands

Runoff generation for EV Emden



results from the hydrological model SIMULAT (Bormann et al. 2023)

Annual 99.9% of water level + SLR

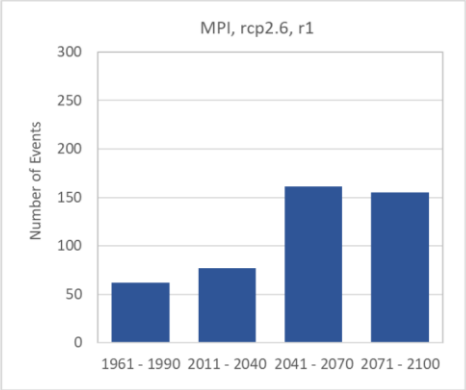


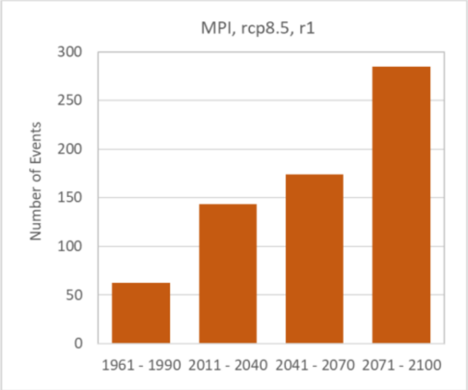
Runoff generation (similar to precipitation) increases significantly for scenario projections for wet winter season.

+

Storm surges are mostly associated with winter storms and high water extremes are exacerbated by SLR.

Number of compound events for CMIP5 scenarios





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JADE HOCHSCHULE Wilhelmshaven Oldenburg Elsfleth
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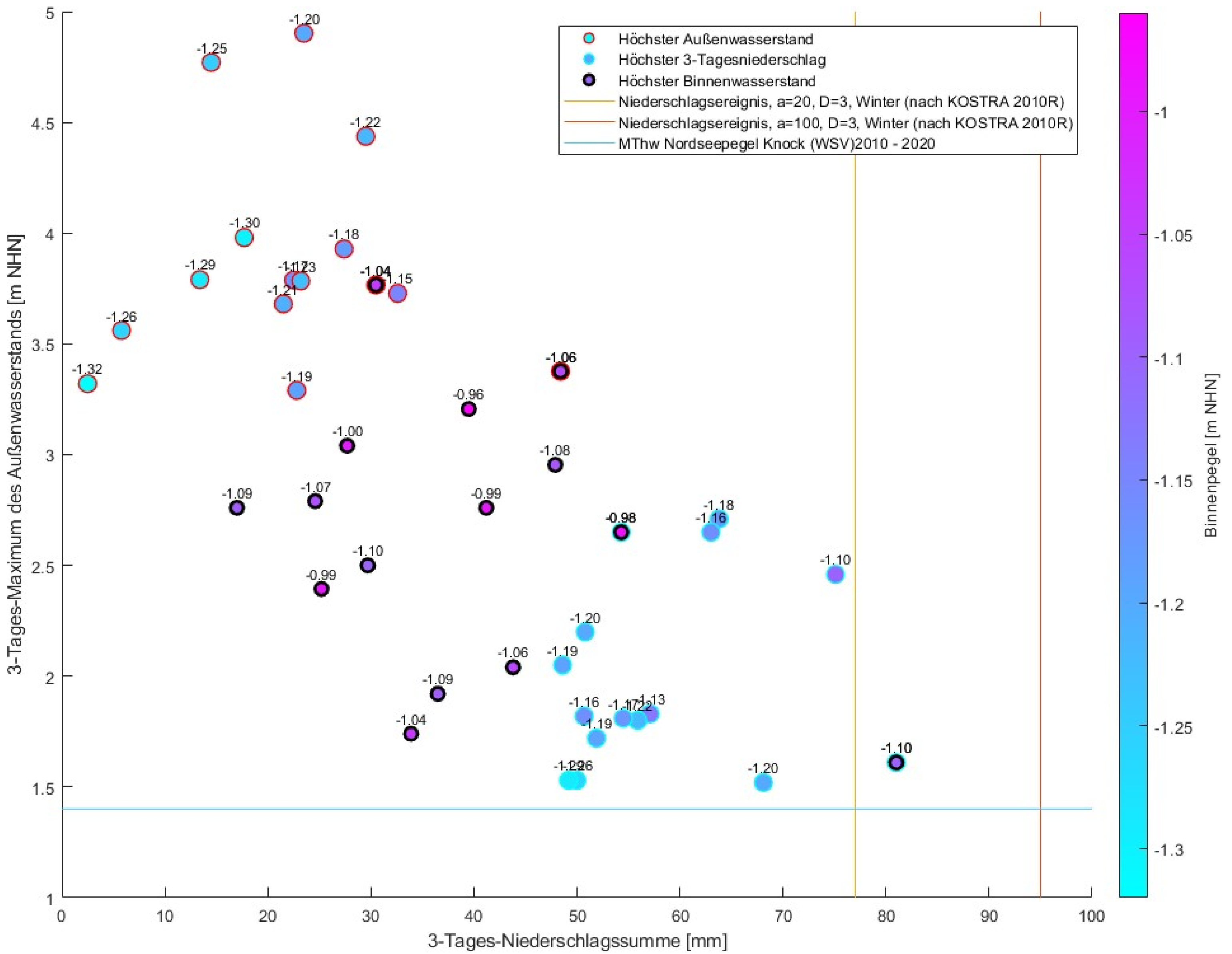
Example 2: drainage of the low-lying hinterlands

A combination of even moderate single events (here storm tide and intensive precipitation) can lead to higher drainage demand and thus an increased risk of flooding.



Summary

Two examples of storm tide / heavy rain compound events demonstrate different approaches to tackle the compound events depending on the size and detailing rate of the study area, posed questions and focus hazards.

For the future projections an increase of the flood risk due to combined effect of storm tides and heavy precipitation and consequent extreme runoff was found. It can be mainly attributed to the mean SLR and changes in the winter precipitation in Northern and Central Europe.

This is reflected in the increased frequency of compound events and increased drainage demand.

Bormann H., Kebschull J. (2023) “*Model based estimation of climate change impacts on the drainage demand of low lying coastal areas in Northwest Germany along the North Sea*”, Journal of Hydrology: Regional Studies https://doi.org/10.1016/j.ejrh.2023.101451

Gaslikova, L. (2023). ”*coastDat TRIM-NP-2d CMIP5 hydrodynamic transient scenarios for the North Sea and the Northeast Atlantic for the period 1950-2100 with REMO MPI-ESM and HadGEM2 forcing*” World Data Center for Climate (WDCC) at DKRZ. https://doi.org/10.26050/WDCC/cD_C5_sc

Hagemann, S. and Stacke, T. (2021) “*Forcing for HD Model from HydroPy and subsequent HD Model river runoff over Europe based on EOBS22 and ERA5 data*”, World Data Center for Climate (WDCC) at DKRZ [data set], https://doi.org/10.26050/WDCC/EOBS_ERA5-River_Runoff

Heinrich P., Hagemann S., Weisse R., Schrum C., Daewel U. and Gaslikova L. (2023) “*Compound flood events: analysing the joint occurrence of extreme river discharge events and storm surges in northern and central Europe*”, NHESS https://doi.org/10.5194/nhess-23-1967-2023

Heinrich P., Hagemann S., Weisse R. and Gaslikova L. (2023) “*Changes in compound flood event frequency in northern and central Europe under climate change*”, Frontiers in Climate https://doi.org/10.3389/fclim.2023.1227613

Thank you

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