Black Swans and Risk – Assessing Consequences of Extreme Events for the German Bight

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IN A COLLABORATIVE PROJECT WITH

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EXTREMENESS

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Background and Introduction

- Westerly and north-westerly storms regularly hit the German North Sea coast causing surges of several meters at the dikes.
- In the past, severe **storms did not lead to physically possible maximum water levels**:
  - Total water level components (i.e. mean sea level, surge, and tide) were not at their observed maximum during past extreme events *(Dangendorf et al., 2016).*
  - Earlier research suggests: Water levels may likely exceed historical events by at least 1.40 m *(Jensen & Müller-Navarra, 2008).*
- Project **EXTREMENESS** was initiated to examine the meteorological potential to find extremely **large and unlikely but physically possible storm surge events**, which we refer to as "**black swans**". Furthermore, sea level rise (SLR) impact will be investigated.
  - Sub-projects EXTREMENESS-A/B identify possible extreme meteorological events. Sub-project EXTREMENESS-C simulates the resulting storm surges in the German Bight.
  - Sub-project **EXTREMENESS-D** (presented here) **assesses the consequences of the storm surges** for a model region at the German Bight, with regard to following questions and tasks:

? How large is the damage potential and which are the most important and most vulnerable sections in current state coastal protection?

? Are there possibilities to make the region more resilient?

! Provide information to increase public awareness and to improve disaster management preparedness.

Study Area: Emden & Krummhörn

- **Model region** for the German Bight (see *Fig. 1*)
- Different **challenges**: The region is located at an estuary (River Ems), low-lying with large parts below mean sea level requiring drainage with tide gates and pumping stations, and various objects/infrastructures at risk:
  - Large agricultural areas: ~320 km², mixed use: pasture/crops (see yellowish areas in *Fig. 2*)
  - Residential development: ~50,000 people in Emden + ~20,000 people in the surrounding Krummhörn region (see red areas in *Fig. 2*)
  - Industrial areas: i.a. harbor of Emden, large car factory (see purple areas in *Fig. 2*)
  - Important infrastructures (i.a. gas terminals, offshore wind energy)
- Dike heights between 6.50 m and 8.40 m ASL
- **44.6 km primary dike line** in the study area (see black line in *Fig. 2*)

Fig. 1: *Krummhörn region (red area) with the city of Emden (white dot) in Lower Saxony at the north-western German North Sea coast.*

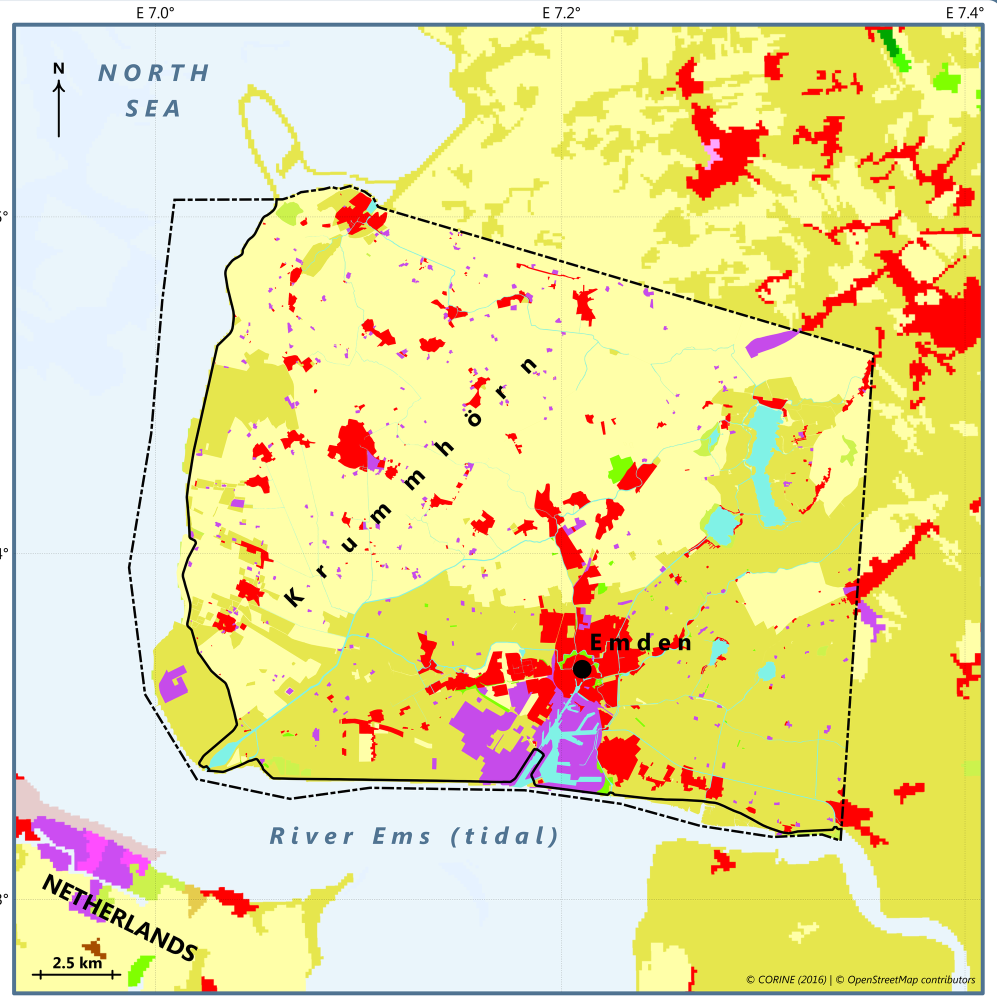

Fig. 2: *Study area (within black dash-dotted line) and neighboring regions color-coded by land use: residential (red), agricultural (yellowish), industrial (purple), water (bluish), dike line (black).*

Methods and Data

- **Simulation** of hinterland flooding due to dike failures during extreme storm surges with a two-dimensional hydrodynamic-numerical model (using DHI MIKE 21 FM).
  - **Water-side forcing**: Storm surge water levels along the axis of the tidal river Ems (output from EXTREMENESS-C simulations)
  - **Bed roughness**: Spatially varying based on eight land use categories. Land use is derived from *CORINE (2016)* and OpenStreetMap data (see *Fig. 2*)
  - **Bathymetry/topography**: DEM and bathymetry with 5 m resolution, used on an unstructured computation grid with cell edge lengths between 10 m and 75 m
  - **Assumed dike failures**: Simulation of each storm surge scenario with a breach in the center of one of 20 dike sections. Each section is approx. 2 km long. Breaches are simplified as trapezoidal openings in the dike line with a toe/top width of 90/150 m, based on observations after the storm surge 1962 *(Kramer et al., 1962)*.
  - **Reference Flood**: Water levels from Nov. 1st 2006 storm surge, which did not cause flooding in reality but is remembered as a "close call" by locals and authorities.
- **Mapping** of flooded areas for each dike failure scenario.
  - Identification of flood-prone areas and affected (critical) infrastructure. How would flooding slow down or obstruct disaster relief?
  - Estimation of damage potential based on affected land use and buildings. Which type of extreme storm surge would lead to the most severe damages?

First Results

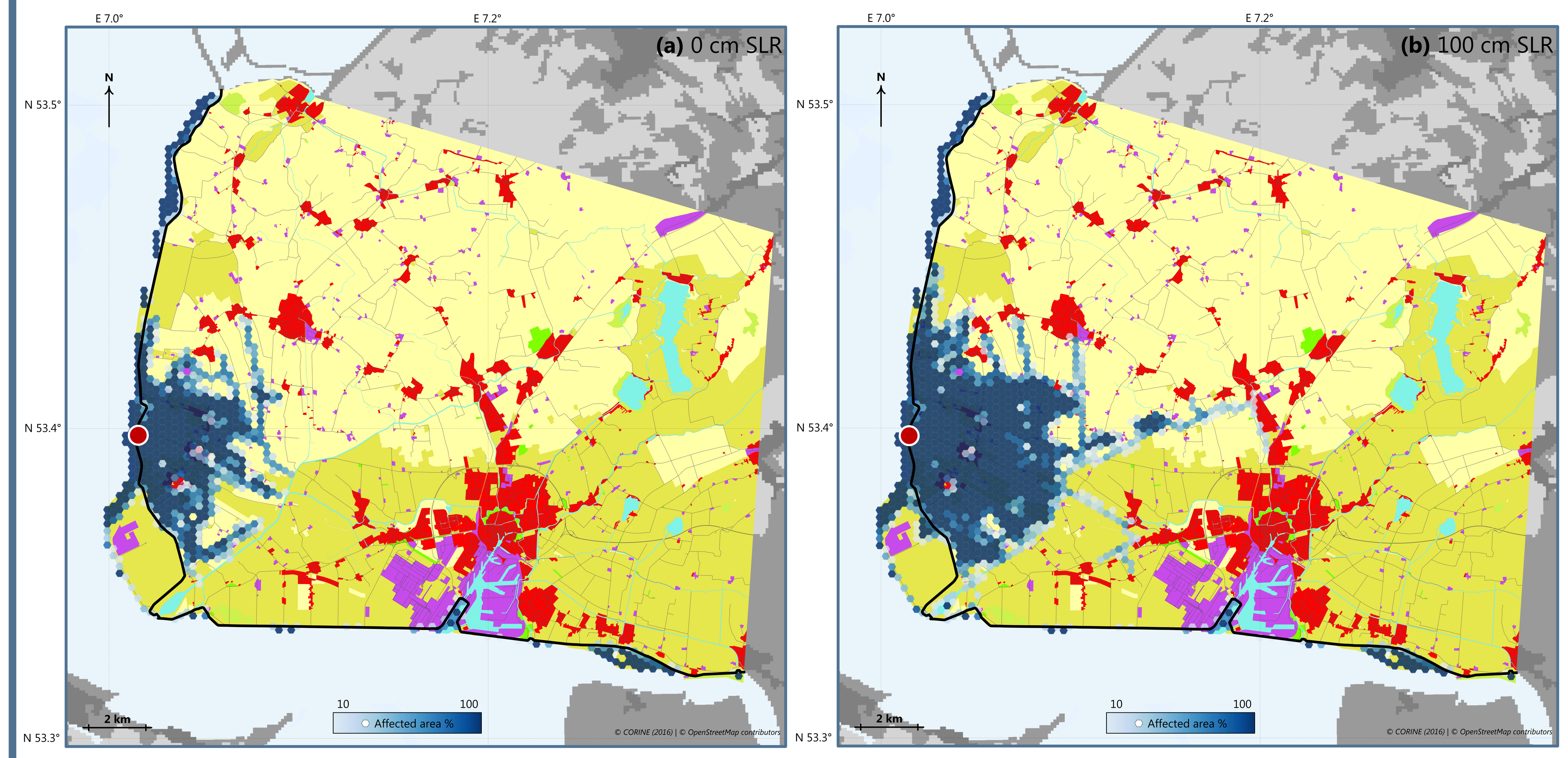

Fig. 3: *Inundation resulting from dike failure at section 6 (red dot) simulated with (a) unchanged Reference Flood and (b) with 100 cm sea level adjustment. Computation results are shown as rate of flood affected area in blue colors on a hexagonal tessellation (250 m cell diameter).*

- Peak water level of the Reference Flood (as occurred 2006) is at ~5.00 m ASL (Emden harbor). First simulations of this Reference Flood and variations with an assumed sea level rise (SLR) show **significantly larger inundation areas when SLR is considered**. *Fig. 3* shows this examplarily for a dike failure at section 6 (red dot). *Fig. 3a* shows the affected area for the Reference Flood, *Fig. 3b* considers 100 cm SLR.
- Areas affected by the dike failure are mapped on a **hexagonal grid**:
  - *Dark blue cells:* initially dry land is completely flooded after the dike failure
  - *Paler blue cells:* only some of the cell area is affected by flooding
- For a dike failure at section 6: The overall affected area is **1.68 times larger** when 100 cm SLR scenario is considered.
  At some dike sections, simulations show a **doubling of the affected area**.

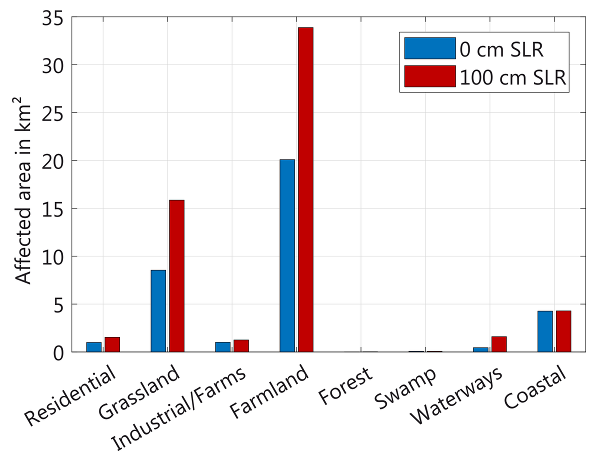

Fig. 4: *Affected land use in km² for the scenarios shown in* Fig. 3. *Considering SLR, mostly agricultural areas are additionally affected. But since largest damage potentials are in residential and industrial areas, even their small increase may lead to disproportionally larger damages.*

Conclusions and Outlook

- The Reference Flood would have caused **large inundation areas** if a dike failure had occurred. Combining this storm with SLR shows that inundation areas would significantly increase up to a doubling of the affected area.
- Extreme storm surges ("black swans") that are currently derived from climatic data by our project partners are expected to be even higher and/or with longer high water durations. **Affected areas will likely be higher**, compared to the Reference Flood.
- Damages have not been considered yet. The irregular land use distribution may lead to significantly larger damages even if the total affected area does not increase much and vice versa. The **dike failure location mostly controls the extent of damages**.
- Further steps in the project will include:
  - **Statistical classification** of the black swans (i.e. return periods based on today's observations).
  - Consideration of the affected land use and infrastructure including the **damage potential** due to inundations.
  - Discussion of the results with local authorities and disaster management to draft measures to **improve preparedness** for even extremely unlikely events.

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