Paper_Draft

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Introduction

Individually both extreme rainfall and storm surge pose a flood risk. If these events co-occur, they create a compound event (**???**) and the risk may be magnified compared to if either event occurred individually. To reliably assess the flood risk from rainfall and surge events, the dependence relationship between these events must be accurately modelled (Zheng et al. 2014, Zscheischler and Seneviratne (2017)).

The same is true for weather forecasts. To ensure communties aren't caught unprepared, the accuracy of the joint forecast of must be considered. These joint forecasts are needed to provide advance warnings, so that the flood impacts are mitigated and water can be released in advance from devices, such as sluces or pumps.

Weather processes however, are highly chaotic and complex. Therefore forecasts from numerical weather models (NWP) can only serve as our best, most-informed guesses of what the future weather will be. Even at the high resolutions, these models contain systematic errors due to simplyfing assumptions in their equations and compuational capacity limits the number of future possible forecasts, so the full predictive distribution can not be simulated. Statistical post-processing is therefore needed to improve upon the reliabilitiy and accuracy of the forecasts by reducing systematic errors, such as bias or dispersion errors ((**???**), (**???**)).

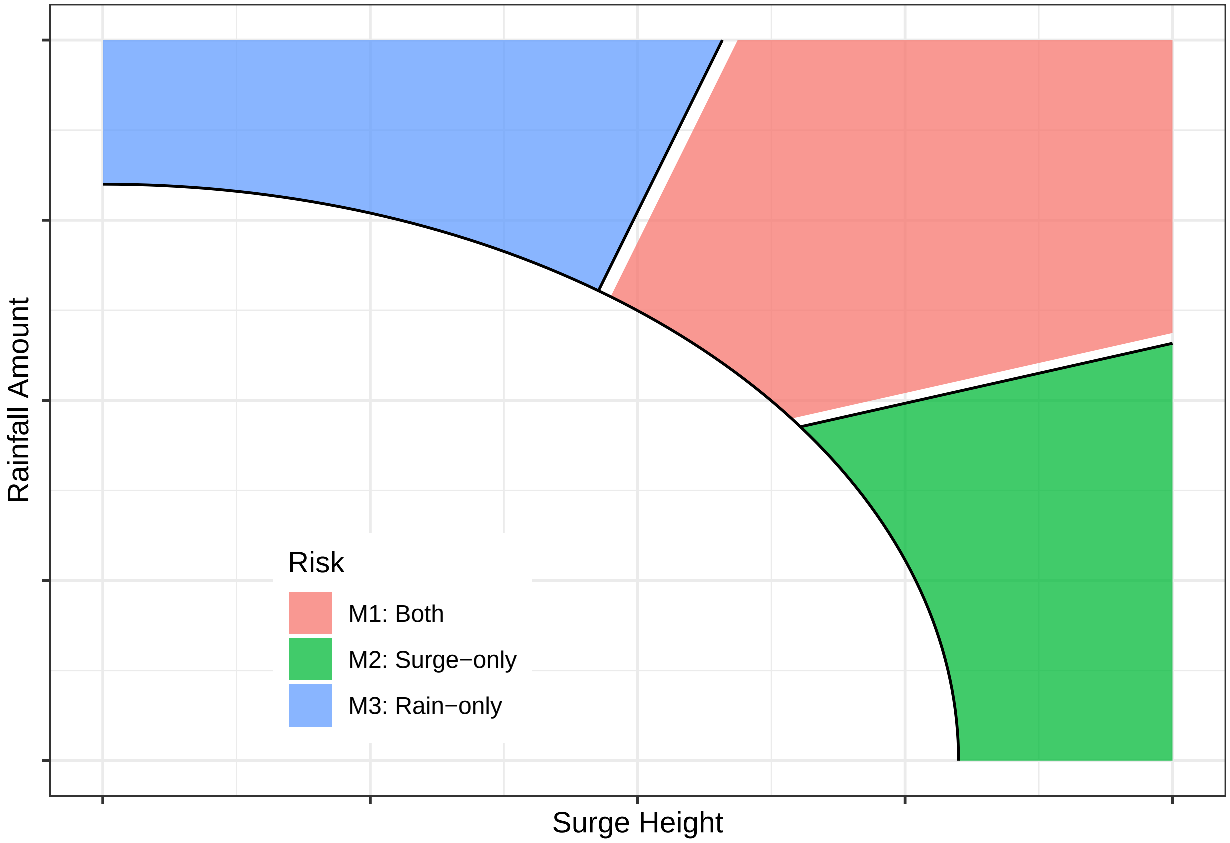
Provide a post-processing summary and fill the gap

For forecasting the co-occurrence of bivariate events, such as rainfall and storm surge, it is important to understand the driving mechanism behind these events. (Wahl et al. 2015) breaks the compound event mechanism into three types:

- **Mechanism (1)** in estuarine regions, the joint occurrence of both may elevate water levels to a point where flooding is initiated or its impacts exacerbated.

- **Mechanism (2)** occurs when a destructive storm surge already causes widespread flooding, such that any significant rainfall on top of this—even if it is not an extreme event on its own—increases the flood depth and/or extent of the inundated area.

- **Mechanism (3)** occurs during a moderate storm surge which does not directly cause flooding, but is high enough to fully block or slow down gravity-fed storm water drainage, such that precipitation is more likely to cause flooding.



- Event based statistics
- Aggregate rainfall
- Period a sluice gate is open
- Why we need to consider temporal trajectories and dependence in the plume

Case Study

- Lake Lauwersoog (two sluices)
- Show a plot of culmulative rainfall / surge / tide
- How the sluice works (- 10)
- Mechanisms in the Netherlands
- Extremes don't necessary mean big - Duration is important
- Largest != Longest
- Define a surge period (clustering)
- Importance of scoring the whole / understand trajectory

Data

- Rainfall
- Storm Surge

- We treat tide (deterministic) and surge (random)
- Caveat of wind (ignoring at present)
- Seasonality

Statistical Post-processing Methods

Univariate Methods

- NGR

Univariate Scoring

- Rank Histograms
- CRPS
- BSS

Multivariate Methods

- ECC
- Schaake (Analogs)

Multivariate Scoring

- ES
- Variogram
- Weights
- David-Sebastiani (Not here)

Results

Surge Univariate

- CRPS
- BSS
- Rank Histograms
- Reliability (optional)

Rainfall Univariate

- CRPS
- BSS
- Rank Histograms
- Reliability (optional)

Surge Trajectory

- ES
- VS
- weights
- relaximing to climatology (loose univariate skill)
- best methods for restoring dependence

Rainfall Trajectory

- ES
- VS
- weights
- relaximing to climatology (loose univariate skill)
- best methods for restoring dependence

Combined Surge and Rainfall Trajectories

Discussion

Conclusions

Future Directions

- Wind
- Bivariate post-processing (then restore dependence)
- Lag relations (zheng/westra - explore)

Wahl, Thomas, Shaleen Jain, Jens Bender, Steven D. Meyers, and Mark E. Luther. 2015. “Increasing Risk of Compound Flooding from Storm Surge and Rainfall for Major US Cities.” *Nature Climate Change* 5 (12): 1093–7. doi:10.1038/nclimate2736.

Zheng, Feifei, Seth Westra, Michael Leonard, and Scott A. Sisson. 2014. “Modeling Dependence Between Extreme Rainfall and Storm Surge to Estimate Coastal Flooding Risk.” *Water Resources Research* 50 (3): 2050–71. doi:10.1002/2013WR014616.

Zscheischler, Jakob, and Sonia I. Seneviratne. 2017. “Dependence of Drivers Affects Risks Associated with Compound Events.” *Science Advances* 3 (6): e1700263. doi:10.1126/sciadv.1700263.