

A SPATIAL ANALYSIS OF THE DEPENDENCE BETWEEN WAVE HEIGHTS AND WATER LEVELS USING COPULAS IN THE DUTCH DELTA

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INTRODUCTION

The Netherlands is a low-lying country with approximately 60% of its land vulnerable to flooding. An elaborated flood defense system composed of dikes, dunes and storm surge barriers was created to protect the large number of inhabitants and high value of assets (Slomp, 2012), Figure 1. To maintain the appropriate level of safety along the water-land interface, understanding the hydraulic boundary conditions, the underlying relation between the environmental variables and their evolution in time and space is essential.

In coastal and delta areas, design values for flood protection infrastructures, i.e., primary flood defenses, are mainly governed by the combination of high water levels and wave heights that in extreme conditions might exhibit a significant degree of correlation due to the, often, common origin associated with intense wind (Masina et al., 2015). A misrepresentation of the underlying relationship between these variables can potentially lead to an incorrect quantification of the forcings acting on the primary protection.

This study aims to (i) characterize the spatial dependencies of hydraulic boundary conditions along Dutch southwest delta from coastal to inland areas and (ii) to assess how accounting for these dependencies when estimating design values affect the safety assessment of the primary defense.

Both analyses will provide an overview of the spatial dependencies of extreme environmental conditions, which are essential in understanding the Dutch southwest delta system.



Figure 1 - Current safety assessment of the primary defenses at the southwest delta. The green lines are primary defenses that fulfill the current safety requirements. In yellow those that are acceptable and in orange are the primary defenses that do not satisfy safety requirements.

DATASET

Three locations along the delta protected by the Eastern Scheldt barrier are chosen for this study, see Figure 2:

1. OS4: outside the protected area;
2. KEET: Mid-way in the protected area;
3. MRG: Further in-land.



Figure 2 - Location of the two datasets.

Measurements of water level and wave height are collected every 30 minutes and provided by the Dutch Ministry of Infrastructure and Water Management.

For location 1 the observed water levels and wave heights are measured from January 1988 until January 2012. For location 2 both water level and wave heights measurements are available from October 1999 until January 2012. Location 3 starts in January 1988 until September 2020.

METHOD

To derive design values, the spatial dependence between extreme water level and the associated wave height is investigated. Extreme events are defined and identified within the dataset according to the peak over threshold method (Coles et al., 2001). The event starts when the water level exceeds a threshold value, equal to 95th quantile (Tomasicchio et al., 2021), and ends when it is below the threshold for at least four days (Caires, 2011). Due to the mainly depth limited nature of the investigated locations the water level is considered the dominant variables so that it is also used to define the event. The corresponding extreme wave height is the maximum value found two hours before or after the extreme water level.

A statistical characteristics of the extremes are obtained by fitting univariate distribution functions based on Maximum Likelihood Estimation technique. A preliminary quantification of the relationship between extreme water level and extreme wave height is assessed via measure of dependence, such as Spearman's rho and Kendall's tau. The dependence

structure between extreme water level and extreme wave height is then modeled via copula functions (Durante & Sempi, 2016).

The effect of accounting for the dependence between environmental variables when assessing the overtopping failure mechanism is found by comparing the results of overtopping failure probability under the assumption of independence. This is done for various types of structures that compose the primary protection, namely dikes and dunes.

RESULTS

The extreme conditions of all locations are found using the peak over threshold method. Location 1 has a threshold of 165 cm and 1,114 extremes are found, Location 2 has 588 extremes with a threshold of 192 cm and location 3 has 1,389 extremes with 166 cm as threshold.

The extreme events are transformed to a uniform distribution via the probability integral transformation. Figure 3 show the relationship between extreme water levels and extreme wave heights in this uniform space. In the same figure, spearman's coefficient is provided for each location. The correlation coefficient at location 1 is 0.67, at location 2 is 0.53 and at location 3 is 0.42. It is clear that outside the protected area, the correlation between water level and wave height is the highest. The more inland the lower the correlation.

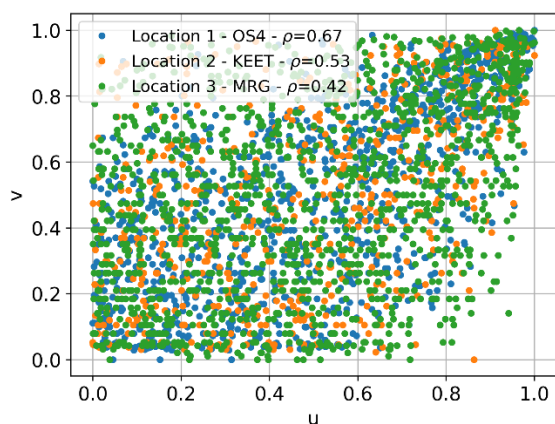


Figure 3 - Scatter plot of the transformed extreme water levels (u) and wave heights (v) in the unit square domain and corresponding spearman's coefficient.

At the conference, a complete description of the underlying dependency between water level and significant wave height is presented together with an overview on the evolution of the spatial dependencies along the Dutch delta.

Furthermore, overtopping failure probabilities are calculated according to the univariate and bivariate approach so that insights into failure probabilities and the effects of the boundary conditions on the assessment of different primary defense structures can be gathered.

REFERENCES

- Caires (2011): Extreme value analysis: Still water level. Geneva, Switzerland: World Meteorological Organization, Intergovernmental Oceanographic Commission (of UNESCO), JCOMM Technical Report, no. 58.
- Coles, Bawa, Trenner and Dorazio (2001): An introduction to statistical modeling of extreme values. Springer, vol. 208.
- Durante and Sempi (2016): Principles of copula theory, CRC/Chapman & Hall, Boca Raton.
- Masina., Lamberti, & Archetti (2015): Coastal flooding: A copula based approach for estimating the joint probability of water levels and waves. Coastal Engineering, vol 97, pp. 37-52
- Slomp (2012): Flood Risk and Water Management in the Netherlands, Rijkswaterstaat.
- Stephens (1974): EDF statistics for goodness of fit and some comparisons, Journal of the American Statistical Association, vol 69, num. 347, pp. 730-737.
- Tomasicchio, Salvadori, Lusito, Francone, Saponieri, Leone and De Bartolo (2021): A Statistical Analysis of the Occurrences of Critical Waves and Water Levels for the Management of the Operativity of the MoSE System in the Venice Lagoon. Stochastic Environmental Research and Risk Assessment, pp.1-12.