Large-scale infragravity wave-resolving flood hazard modelling

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INTRODUCTION

Coastal communities worldwide are under threat of flooding due to hazards such as (extra-) tropical storms, spring tides, wind sea and swell waves, high river discharges and heavy rainfall events (Mousavi et al., 2011). In some coastal areas, waves can be the dominant driver of extreme water levels (e.g. Parker et al., 2023), but for regional to continental scales these are often not included in coastal flooding assessments, due to the high computational expense of numerical models (e.g. XBeach; Roelvink et al., 2009). Recent literature has shown that it is possible to model large coastlines in fast reduced-complexity compound flood models (e.g. SFINCS; Leijnse et al., 2021), for instance for thousands of kilometers of Australia in an early warning system (Leijnse et al., 2022). However, to be able to include dynamic wave runup and overtopping in such a system, we need to derive nearshore infragravity (IG) wave conditions in a fast way, without relying on computationally expensive advanced numerical models. Recent advancements in SFINCS and a coupled fast stationary wave spectral model, called SnapWave, have the potential to solve this. In this study we combine many of these advancements and show how to include IG waves as boundary conditions in SFINCS. Afterwards we demonstrate that one can now finally include dynamic IG wave-resolving runup and overtopping processes in large-scale flooding assessments.

METHODOLOGY INCLUDING WAVES

To model waves at large scales efficiently, we:

1) use a wave model (SnapWave) to compute incident wave heights and wave forcing inducing setup.
2) estimate IG wave conditions nearshore using a parametrization in SnapWave (Leijnse et al. 2023), see Figure 1.
3) generate IG wave time-series based on an assumed spectrum.
4) force these in the surf zone along a depth contour using a wave maker boundary condition (Van Ormondt, et al. 2023), see Figure 2.
5) compute the overland flooding with a SFINCS model with enough resolution to resolve the wave motion.

To locally refine the SFINCS model, the new quadtree approach is used (Van Ormondt, et al. 2023). This allows for a high resolution in the nearshore, while keeping the resolution inland coarser for a lower computational demand. Using this methodology, one can simulate dynamic IG waves that run up and down the beach and can thereby model hazardous flooding situations, based on water depth and velocity.

QUESTIONS RELATED TO THE FORCING OF INFRAGRAVITY WAVES

However, in linking these different steps, several research questions remain:

a) What is the optimal depth to locate the wave maker boundary condition?
b) How to account for time-varying offshore water levels due to e.g., the tide and storm surge?
c) How to account for IG wave dissipation due to friction and wave breaking in the nearshore IG estimate?
d) How to estimate the nearshore IG spectrum shape?
e) What is the resulting skill in modelling wave runup compared to a model like XBeach?

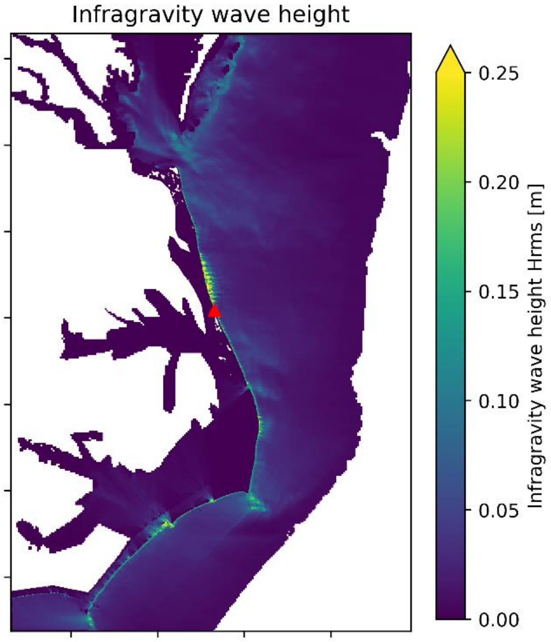

Figure 1 - Example of large-scale modelling of infragravity waves using SnapWave (Leijnse et al. 2023).

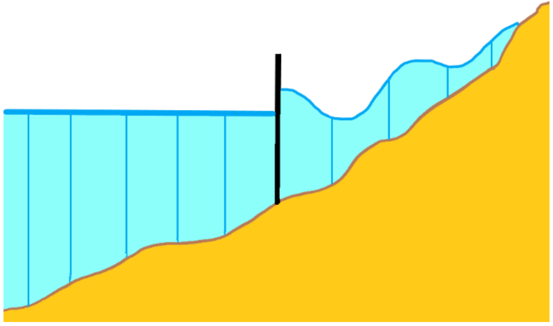

Figure 2 - Example of the nearshore wave maker boundary condition in SFINCS (van Ormondt et al. 2023).

METHODOLOGY

We use 280 configurations of coastal profiles and extreme offshore wave conditions by Van Ormondt et al. (2021). For each of the 280 profiles, a SFINCS model is made, and forced using the above approach. The wave propagation is analyzed (see Figure 3), and wave runup characteristics are compared to the original XBeach results (Figure 4). Hereby, in a systematic way, the remaining questions regarding the forcing of IG waves are investigated and answered.

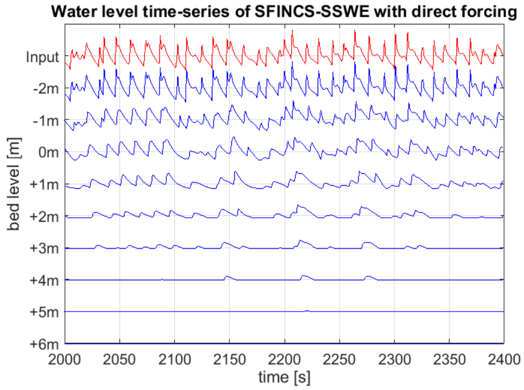

Figure 3 - Example of wave runup modelling in SFINCS.

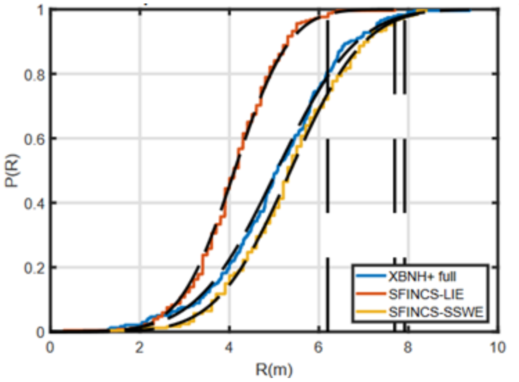

Figure 4 - Example of comparison cumulative runup distribution R between XBeach NH+ (blue) and SFINCS without (-LIE, red) and with (-SSWE, yellow) advection.

VALIDATION CASE STUDY

To investigate the ability to model wave-driven flooding measured in the field, a 2D case study is performed at Mexico Beach, Florida, during Hurricane Michael (2018). It is shown that the SFINCS+SnapWave model can hindcast the peak water levels accurately (Figure 5). By comparing a simulation with and without waves, it is shown that waves are important to capture the peak water levels at the high-water marks close to the coast. Here also the fluxes can do significant damages to houses situated close to the coast. Further inland, the influence of the wave contribution to the total flooding reduces.

LARGE SCALE DEMONSTRATION

Finally, an even larger-scale demonstration case is performed, modelling the impact of Hurricane Ian (2022) on Florida for hundreds of kilometers of coastline, and modelled in a timeframe of minutes on a local laptop.

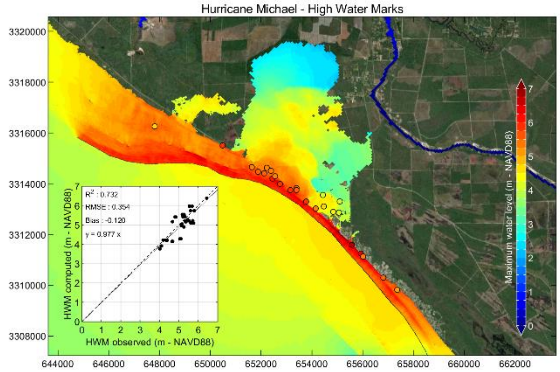

Figure 5 - Example of peak water levels modelled by SFINCS with waves for the case study of Mexico Beach, Florida, during Hurricane Michael (2018).

REFERENCES

Leijnse, de Goede, van Ormondt, Lemans, Hegnauer, Eilander, De Kleermaeker, Yenory, Maguire (2022). Developing large scale and fast compound flood models for Australian coastlines. International Conference on Coastal Engineering 2022, Sydney.

Leijnse, van Ormondt, Nederhoff, van Dongeren (2021). Modeling compound flooding in coastal systems using a computationally efficient reduced-physics solver: Including fluvial, pluvial, tidal, wind- and wave-driven processes. Coastal Engineering, 163, 103796. https://doi.org/10.1016/j.coastaleng.2020.103796

Leijnse, van Dongeren, van Ormondt, Muis, Aerts (2023). Deriving a parametrization for estimating nearshore infragravity wave energy for scaling up wave-resolving flood hazard modelling. 17th International Workshop on Wave Hindcasting and Forecasting.

Mousavi, Irish, Frey, Olivera, Edge (2011). Global warming and hurricanes: The potential impact of hurricane intensification and sea level rise on coastal flooding. Climatic Change, 104(3-4), 575-597. https://doi.org/10.1007/s10584-009-9790-0

Parker, Erikson, Thomas, Nederhoff, Barnard, Muis (2023). Relative contributions of water-level components to extreme water levels along the US Southeast Atlantic Coast from a regional-scale water-level hindcast. Natural Hazards. https://doi.org/10.1007/s11069-023-05939-6

Roelvink, Reniers, van Dongeren, van Thiel de Vries, McCall, Lescinski (2009). Modelling storm impacts on beaches, dunes and barrier islands. Coastal Engineering, 56(11-12), 1133-1152. https://doi.org/10.1016/j.coastaleng.2009.08.006

van Ormondt, Roelvink, van Dongeren (2021). A Model-Derived Empirical Formulation for Wave Run-Up on Naturally Sloping Beaches. Journal of Marine Science and Engineering, 9(11), 1185. https://doi.org/10.3390/jmse9111185

van Ormondt, Roelvink, van Dongeren (2023). Wave effects in a rapid compound flood model. 17th International Workshop on Wave Hindcasting and Forecasting.