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DeepWaive: Probabilistic 2D Flood Forecasts using a Generalized Hybrid Model

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Abstract:

The increasing risks associated with hydro-meteorological events necessitate innovative and flexible forecasting tools for effective flood risk management. FloodWaive addresses this challenge with DeepWaive, a pioneering generalized Deep Learning (DL) model for probabilistic 2D flood forecasting. Our approach overcomes the limitations of traditional hydrodynamic models, offering rapid, accurate, and scalable impact-based flood forecasting across diverse geographical domains.

In fast-responding catchments and urban areas, rapid translations of meteorological and hydrological forecasts into their hydraulic impacts and spatial consequences are crucial. Existing flood forecasting and warning systems often limit themselves to hydrological discharge hydrographs for 12-18 hours without simulating horizontal wave propagation for flood modelling. The primary reason lies in the computational challenges posed by dynamic prediction of horizontal flood propagation using hydrodynamic modelling methods.

DeepWaive integrates in-house developed DL architectures with hydrodynamic 2D models, enabling ad-hoc simulations of pluvial and fluvial events of varying intensities and durations over extensive areas. A key aspect of the model is its ability to capture long-range spatiotemporal dependencies in hydrological-hydraulic systems and catchments. This is achieved through specialized deep learning architectures designed to learn non-linear relationships and spatial-temporal data patterns. The training algorithm identifies relevant parts of the input data for a particular simulation, regardless of their spatial or temporal distance, which is particularly important in catchments where events in one location (e.g., intense precipitation in the upper reaches of a river) can have significant impacts at distant locations (e.g., flooding in the lower reaches).

Unlike conventional AI models that require retraining for each new domain, DeepWaive generalizes across different topographies and regional characteristics, eliminating the need for domain-specific retraining and enhancing scalability. This generalization offers several advantages: firstly, it allows the model to be applied without retraining in variable areas; secondly, it ensures free scalability given sufficient data availability. Consequently, after initial training, the DeepWaive model can be applied to previously unknown heavy rainfall events in different regions with a computation time of just a few seconds.

With a speed-up factor of up to 10^6 compared to classical hydrodynamic models, DeepWaive can translate precipitation or discharge values into spatial hydraulic flooding processes within seconds, without significantly compromising model quality. This substantial reduction in computation time enables real-time simulations relevant for operational applications in flood prevention and defence. The hybrid model structure also maintains high scalability, supporting deployment in various geographical and infrastructural contexts.

This capability facilitates the processing of several ensemble rainfall forecasts into impact and probability-based forecasts and warnings. The model's applications extend to dynamic risk analyses, real-time evaluation of flood protection measures, and dam break simulations.

While still in development, DeepWaive represents a significant leap in flood forecasting technology. Our goal is to offer a universally deployable and comprehensible, real-time flood prediction tool, empowering crisis and flood risk management to make informed decisions quickly, potentially saving lives and reducing economic losses worldwide.

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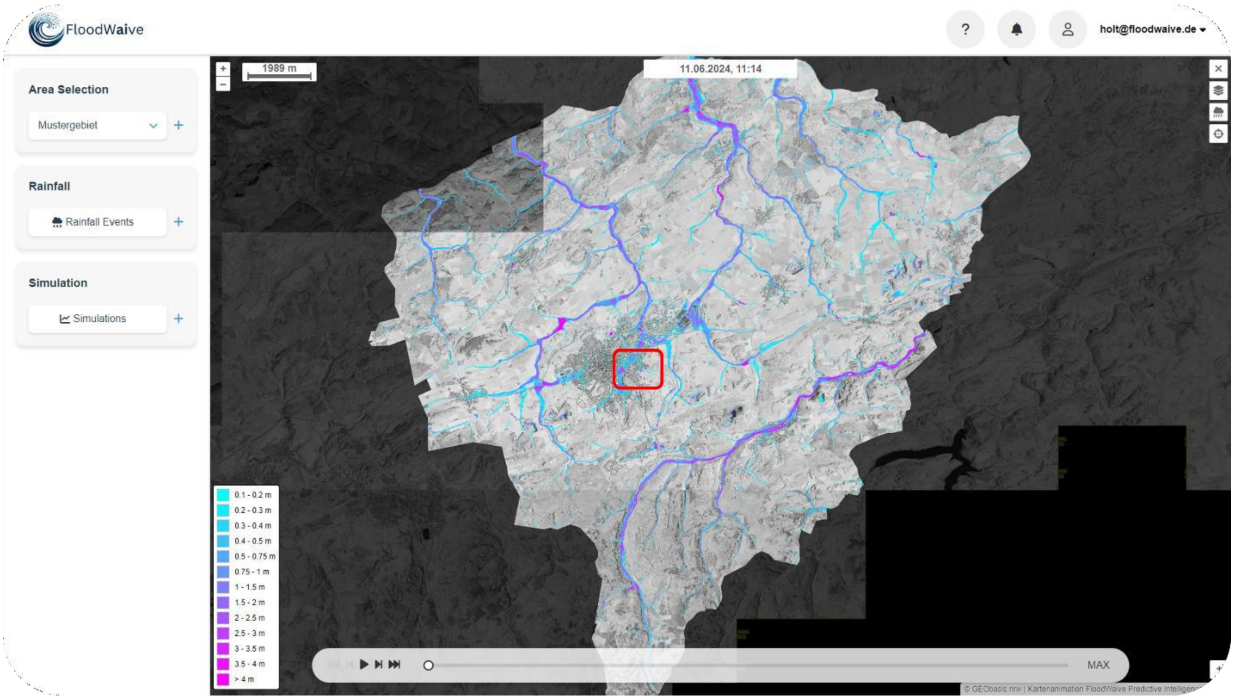

Figure 1. FloodWaive platform: Adhoc simulations of pluvial and fluvial flooding processes for large areas