Emulation of 2D hydrodynamic flood inundation model using deep learning with spatial reduction and reconstruction

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Introduction

The computational complexity of 2D hydrodynamic models has limited their applications to real-time ensemble flood forecasting and uncertainty analysis. In this study, we introduce a novel framework using deep learning (DL) with spatial reduction and reconstruction (SRR) to emulate 2D-hydrodynamic models for flood inundation simulation. In the framework, we identify representative locations using the SRR method and simulate the water levels at these locations with DL models. The simulated water levels are then passed back to the SRR method to map flood inundation. The DL models include a built-in input selection layer and the Long Short-Term Memory architecture for time series modelling. The emulation framework is applied to a real-world river system in Australia with pre-computed 2D hydrodynamic model results.

Study area and dataset

Study area: Burnett River downstream Paradise Dam in Queensland, Australia, with a total area of 1153 km². Dataset: 74 flood events simulated using a TUFLOW 2D hydrodynamic model, including three historical events and 71 design events.

Modelling framework

The modelling framework is shown in the flowchart below. The SRR method is used with DL models to simulate flood inundation.

Application

The flood inundation surface is reduced into water level information at representative locations (RLs) using SRR method. The figure below shows the 125 RLs (out of over 3 million grid cells, covering a 1,479 km² area) for DL model development. Each DL model takes multivariate time series input of 15 flood drivers. The water levels at RLs are simulated using DL models, and then used to reconstruct the flood inundation surface with the SRR method. The figure below shows the major components of the SRR method results.

Results

The DL models developed for the estimation of water levels at RLs have an average RMSE of 0.056 m compared to the TUFLOW model. The emulation model leads to relatively low RMSEs for most of the grid cells in the model domain, with over 90% of grid cells having RMSE values below 0.8 m. It performs better during the rising period of flood events compared to the receding period of flood events. The simulated flood inundation surfaces obtained using the emulation model detect over 99% of the areal extent of maximum inundation. The emulation model also captures the flood inundation evolution during flood events. Once developed, the emulation model simulates the flood inundation at each timestep of the event in 4 s, which is over 21 times faster than a 2D hydrodynamic model.

Conclusion

The emulation model is found to provide fast time series estimates of the flood inundation without appreciable loss of accuracy. The DL models in this study are trained using pre-computed results from a 2D hydrodynamic model, which means that we are able to generate training data for a flood of any magnitude. The SRR-DL framework can thus be used to model events of any magnitude as long as the equivalent 2D hydrodynamic model results are provided. This model can potentially be used for characterising uncertainty in operational real-time forecasting or design applications where computationally efficient models are required.

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