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The LSG Model: A new approach to simulating flood inundation with high accuracy and low computational demand

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Abstract: Floods are one of the most frequent and devastating natural disasters for human communities. Currently, hydrodynamic models are commonly used for flood response management worldwide. These models can accurately simulate complex flow patterns of flood events and provide crucial information on flood risks. However, the computational demand of hydrodynamic models scales with their resolution and complexity. This means accurate high-resolution (i.e. high-fidelity) models cannot be deployed usefully for real-time flood inundation forecasting over large domains or for situations where models need to be run repeatedly to evaluate and update meteorological forecast and dam operation options (Teng et al., 2017).

We introduce a new modelling approach that supercharges hydrodynamic models for speed while maintaining high accuracy. We found that spatial-temporal patterns of flood inundation simulated using an extremely simplified (and hence super-fast) hydrodynamic (i.e. low-fidelity) model can be mathematically transformed to reproduce similar results as a high-fidelity model. The mathematical transformation consists of first using Empirical Orthogonal Function (EOF) analysis to reduce the dimensionality of the low-fidelity data to just a few key features, and secondly, using pre-trained Sparse Gaussian Process models to convert the low-fidelity feature to high-fidelity features. We call this new modelling approach the hybrid Low-fidelity, Spatial analysis, and Gaussian Process Learning (LSG) model (Fraehr et al., 2022, 2023). By basing the predictions on a low-fidelity model, the LSG model can incorporate spatial-temporal correlations and simulate the entire dynamic evolution of the flood inundation.

To demonstrate the application of the LSG model, we have simulated historic flood events for two distinctively different river reaches in Australia: the Chowilla floodplain of Murray River and Burnett River in coastal Queensland. The study sites were chosen due to their distinctive topography and flow patterns. The Chowilla floodplain has a flat and complex topography resulting in slow-moving water, whereas the Burnett River is a steep, coastal river with rapid flows. The LSG model demonstrates a significant reduction in computational demand for both sites, predicting flood inundation more than three orders of magnitude faster than a conventional high-fidelity model (i.e. computational time is reduced from days and hours to a few seconds), while still maintaining high accuracy. The high accuracy is demonstrated by a Critical Success Index of 0.98 and 0.95 for the maximum inundation extent, and a Coefficient of Determination (R^2) of 0.999 and 0.997 for the maximum water depth in the Chowilla floodplain and the Burnett River, respectfully. The results demonstrate that the LSG model can evaluate flood risk accurately, rapidly, and repeatedly as events unfold, a capability that would greatly assist active decision-making during flood emergencies to save lives and protect assets.

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