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Application of least squares support vector machine regression for historical reconstruction and real-time prediction of flood inundation

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ABSTRACT

A surrogate model of the two-dimensional shallow water equations based on least squares support vector machine is applied to flood inundation modelling. Two applications are presented: (1) real-time prediction of flood inundation maps, and (2) reconstruction of long-term time series of water levels.

1 INTRODUCTION

Numerical models based on the two-dimensional shallow water equations (2D-SWE) are widely used for flood inundation simulation. However, due to their computational time, they are generally impractical for applications that require results in a very short time (e.g., real-time prediction), a large number of model runs (e.g., Monte Carlo simulation frameworks) or long-term simulations (e.g., historical reconstruction). In this work we apply a surrogate model approach based on least squares support vector machine (LS-SVM) regression for simulating flood inundation. We present two applications: (1) real-time prediction of flood inundation maps, and (2) reconstruction of long-term time series of water surface elevation.

2 METHODS AND STUDY CASES

2.1 *Real-time prediction of flood inundation*

The urban area of Vilagarcía de Arousa (Northwest Spain), a coastal town recurrently affected by flooding, was used as a test case. A high-resolution 2D-SWE model of the area was set up using the software Iber [1, 2]. A total of 100 flood events were run to generate the calibration and validation dataset for the surrogate model, each defined by the upstream hydrographs of the three main watercourses and the downstream tidal levels.

A LS-SVM model was calibrated in approximately 25,000 points evenly distributed in the study area (~ 2 km^2) using the data of 40 flood events. The maximum flood depth obtained with the 2D-SWE model constituted the dependent variable of the regression models, whereas the predictor variables were derived from the discharge and tide time series prescribed at the open boundaries.

The point predictions of the LS-SVM model were then used to derive spatial maps of water depth (Figure 1). The predictive accuracy of the proposed method was evaluated by comparing the results of the LS-SVM model and the 2D-SWE model, considering the pointwise predictions and the derived spatial patterns of flooding in the whole study area.

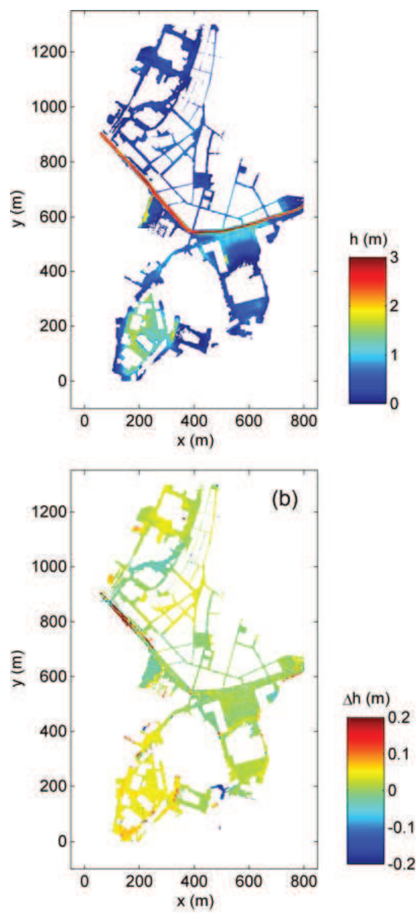

Figure 1. Example of depth raster map based on the LS-SVM predictions (up) and depth differences with respect to the corresponding 2D-SWE map (down).

2.2 *Long-term reconstruction of water level*

The coastal town of Betanzos, located at the confluence of two rivers in a macrotidal estuary in Northwest Spain, was used as a test case. In order to reconstruct long-term time series of maximum water depth at daily scale, the following predictors were selected: daily mean river discharge, daily astronomical tidal range, daily maximum surge and time lag between peak discharge and high tide. Long-term synthetic time series of these variables were generated (details in [3]) and a representative sample of 40 characteristic days was selected to calibrate and validate the regression model. These characteristic days were simulated in a 2D-SWE model of the area, set up using the software Iber [1, 2]. The predictors were introduced in the 2D-SWE model as boundary conditions, downscaled to a time resolution of 15 minutes, and the output was the daily maximum water depth at 12 control points.

A LS-SVM model was then calibrated at each control point using 26 characteristic cases, and applied to reconstruct a 500-year time series of daily maximum water levels. The performance of the LS-SVM model was quantified considering the direct predictions from the 2D-SWE at those control points, using the remaining 14 characteristic days.

3 RESULTS

3.1 *Flood inundation maps*

The LS-SVM depth maps exhibit a reasonable match with the corresponding 2D-SWE maps (Figure 1). Poor predictions are obtained only in relatively small areas scattered throughout the map. The model matches the flood extent well (average precision and recall of 0.84 and 0.94, respectively).

3.2 *Long-term series of water levels*

The LS-SVM model correctly reproduces the daily maximum depth after calibration with only 26 characteristic days (R^2 values above 0.90 in validation). It successfully emulates diverse non-linear relationships between the predictor and dependent variables (Figure 2). From the 500-year time series, the probability of exceedance of a given water level can be easily computed without the need of fitting any statistical distribution (Figure 3).

4 CONCLUSIONS

The surrogate models can emulate diverse non-linear relationships between the predictor and dependent variables, which cannot be modelled using standard regression techniques. The required calculation time is short, and the loss of accuracy is acceptable for the intended applications. This further demonstrates the great potential of machine learning techniques and, in particular, LS-SVM models for flood simulation.

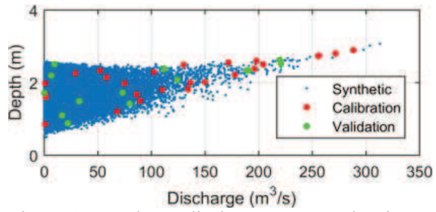

Figure 2. Depth vs. discharge at control point 1: synthetic using LS-SVM (500 years), calibration and validation data.

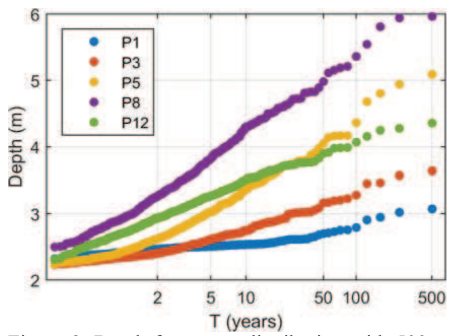

Figure 3. Depth frequency distribution with 500 years of data obtained with LS-SVM model at 5 control points.

ACKNOWLEDGEMENTS

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