

# A Model of Coastal Flooding Using Linearized Bottom Friction and Its Application to a Case Study in Caorle, Venice, Italy

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**This paper presents a recently developed flood propagation model. In order to use graphics processing unit (GPU) acceleration, (i) the domain shallow water equations are simplified by linearizing bottom friction and neglecting advection, and (ii) an appropriate vectorization method is implemented. The model solves the finite difference scheme for each pixel of large-scale raster maps (i.e., regional or national ones). It was initially tested against a well-known benchmark and was then applied to a coastal flooding event in the Caorle area, Venice, Italy, which occurred in December 2008.**

## INTRODUCTION

Many available studies (e.g., Hinkel et al., 2014; Weisse et al., 2014), including the most recent assessment by the IPCC (2015), show that European coasts are threatened by rising sea levels and climate change. Coastal areas are subject to the risks of both flooding and erosion. The vulnerability stemming from these hazards needs to be adequately investigated in order to mitigate the risk to human health, economic activities, cultural heritage, and the environment.

Therefore, under the EU Floods Directive, stakeholders need to establish flood maps to determine the risk of present and future levels of inundation. This issue is particularly relevant to the Northern Adriatic coast, where local managers require tools, possibly integrated to geographic information system (GIS), to simulate the complex problem of a coastal flood caused by waves overtopping in an urban area at regional level. This gave impulse to major EU projects, such as THESEUS (Zanuttigh, 2011), MICORE (Ciavola et al., 2011), and RISC-KIT (Armaroli and Duo, 2017).

The available models vary in complexity, they are able to produce regional-scale storm surge flood maps, and they may be subdivided into static or dynamic.

Static models, also called “bathtub models,” present the simplest way to map storm-surge flooding. The predicted flooded areas are those hydraulically connected to the coast and lower than the elevation of the storm surge. Because of the algorithmic simplicity of these models, the computational demand is low. A static model can be used to estimate simply and quickly storm-surge flooding and impact over large regions at hyper-resolutions (Torresan et al., 2012). The model simplicity meets the stakeholder needs for a fast result and is therefore very popular (Teng et al., 2013; Kovanen et al., 2018). However, static models do not replicate some important processes of coastal flooding (Bates et al., 2005). The most important ones are the conservation of mass for flows and the effect of landscape roughness on floodwa-

ter spread. The extent of inundation, which is calculated on the basis of static models, is often substantially overestimated when compared to the extent of real flood observations (Gallien et al., 2014; Vousdoukas et al., 2016).

Dynamic models, also called “hydrodynamic models,” include a more detailed physical process representation (e.g., TELEMAC-2D, TUFLOW, DIVAST, BreZo). These models can be directly linked to hydrological and river models to provide flood-risk mapping, flood forecasting, and scenario analysis, and they require flow hydrographs and their source locations as the input dataset. Martinelli et al. (2010) applied a procedure based on a phase-resolving model to develop coastal flooding risk maps for the Emilia Romagna coast (Italy), although the maps cover a very limited area. The risk did not take into account the breaching hazard, which is a critical aspect in coastal flooding. The XBeach model (Roevelink et al., 2009) couples the nonlinear shallow water equations with a morphodynamic model that has the potential to simulate both breaching and subsequent flood propagation; however, it is computationally intensive and limited by the uncertainty related to knowledge of dune/dike resistance.

Le Roy et al. (2015) compare observations of a flooding event with numerical predictions and show the advantages of a time-dependent phase-resolving model that includes an explicit representation of buildings and streets over a simulation based on a more conventional approach (a digital terrain model with no buildings, and a representation of the urban area by increased soil roughness).

As pointed out by Teng et al. (2017), dynamics models are computationally expensive and are considered unviable for areas larger than 1,000 km<sup>2</sup> when the grid resolution is less than 10 m. The time taken to run simulations for these large domains may be prohibitively long.

Several models have been developed in a bid to reduce computational costs by taking into account water mass conservation only (Breilh et al., 2013; Hunter et al., 2005), or some aspects of flooding hydrodynamics (Dottori et al., 2016).

With advances in computing science, the performance of flooding models has improved exponentially. A recent approach to improve computational speed involves parallelizing the source code (e.g., LISFLOOD-FP by Neal et al., 2009; FloodMap-Parallel by Yu, 2010). The limitation of this approach is related to the available number of clusters. An alternative flood model parallelization technique utilizes graphic processing units (GPUs) to achieve a far quicker time speed when compared with central processing units (CPUs). Kalyanapu et al. (2011) proposed an

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