Hydrodynamic inundation modelling for disaster risk management

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Introduction

Modelling the effects on the built environment of natural hazards such as riverine flooding, storm surges and tsunami is critical for understanding their economic and social impact on our urban communities. Geoscience Australia and the Australian National University are developing a hydrodynamic modelling tool called AnuGA to simulate the behaviour of water flow from such hazards.

The core of AnuGA is the fluid dynamics module, called pyvolution, which is based on a finite-volume method for solving the shallow water wave equation. The study area is represented by a mesh of triangular cells and water depths and horizontal momentum are tracked over time by solving the governing equation within each cell.

A major capability of pyvolution is that it can model the process of wetting and drying as water enters and leaves an area. This means that it is suitable for simulating water flow onto a beach or dry land and around structures such as buildings. Pyvolution is also capable of capturing hydraulic jumps due to the ability of the finite-volume method to handle discontinuities.

To set up a particular scenario the user of the system specifies the geometry (bathymetry and topography), the initial water level, boundary conditions such as tide, outputs from other models, and any forcing terms that may drive the system such as wind stress or atmospheric pressure gradients. Frictional resistance from various terrains and gravity are present in the model as predefined forcing terms.

A mesh generator, called pmesh, allows the user to set up the geometry of the problem interactively and to identify boundary segments and regions using symbolic tags. These tags may then be used to set the actual boundary conditions and attributes for different regions (e.g. the Manning friction coefficient) at run time.

Most AnuGA components are written in Python, an object-oriented programming language known for its clarity, elegance, efficiency and reliability. Software written in Python can be produced quickly and can be readily adapted to changing requirements throughout its lifetime. Computationally intensive parts are written in small efficient C routines working directly with the Numerical Python structures. The animation tool developed for AnuGA is based on OpenSceneGraph allowing high level interaction with sophisticated graphics primitives.

Validation

The process of validating the AnuGA application is in its early stages, however initial indications are encouraging.

As part of the Third International Workshop on Long-wave Runup Models, four benchmark problems were specified to allow the comparison of numerical, analytical and physical models with laboratory and field data. One of these problems describes a wave tank simulation of the 1993 Okushiri Island tsunami off Hokkaido, Japan (Matsuyama and Tanaka, 2001). A significant feature of this tsunami was a maximum runup of 32 m observed at the head of the Monai Valley. This runup was not uniform along the coast and is thought to have resulted from a particular topographic effect. Among other features, simulations of the Hokkaido tsunami should capture this runup phenomenon.

The wave tank simulation of the Hokkaido tsunami was used as the first scenario for validating AnuGA (Third International Workshop on Long-wave Runup Models 2004). The initial dataset provided bathymetry and topography, along with initial water depth and the wave specifications. The dataset also contained water depth time series from wave gauges situated offshore from the simulated inundation area.

Figure 1 compares the observed wave tank and modelled AnuGA water depth (stage height) at one of the gauges. The plots show good agreement between the two time series, with AnuGA modelling the initial draw down, the wave shoulder and the subsequent reflections very well. The discrepancy between modelled and simulated data in the first 10 seconds is due to the initial condition in the physical tank not being uniformly zero. Similarly good comparisons are evident with data from the other gauges. Additionally, AnuGA replicates exceptionally well the 32 m Monai Valley runup, as shown in Fig. 2, and demonstrates its occurrence to be due to the interaction of the tsunami wave with two juxtaposed valleys above the coastline. This successful replication of the wave tank simulation of a tsunami on a complex 3D beach is a positive first step in validating the AnuGA modelling capability.

Conclusion

AnuGA is an elegant modelling system that simulates hydrodynamics by solving the shallow water wave equation in a mesh of triangles. It can take as input bathymetric and topographic datasets and simulate the behaviour of riverine flooding, storm surge and tsunami. Initial validation using wave tank data supports AnuGA's ability to model complex scenarios extremely well. Further validation will be pursued as additional datasets become available.

AnuGA is already being used to model the behaviour of hydrodynamic natural hazards. This modelling capability will form a centrepiece of Geoscience Australia's ongoing research effort to model and understand natural hazards prevalent in Australia in order to reduce their impact on Australian communities (Hitchman and Nielsen 2005).

References

Hitchman, A. and Nielsen, O. 2005. Numerical simulation of coastal inundation. *BMRC Research Report, this volume*.

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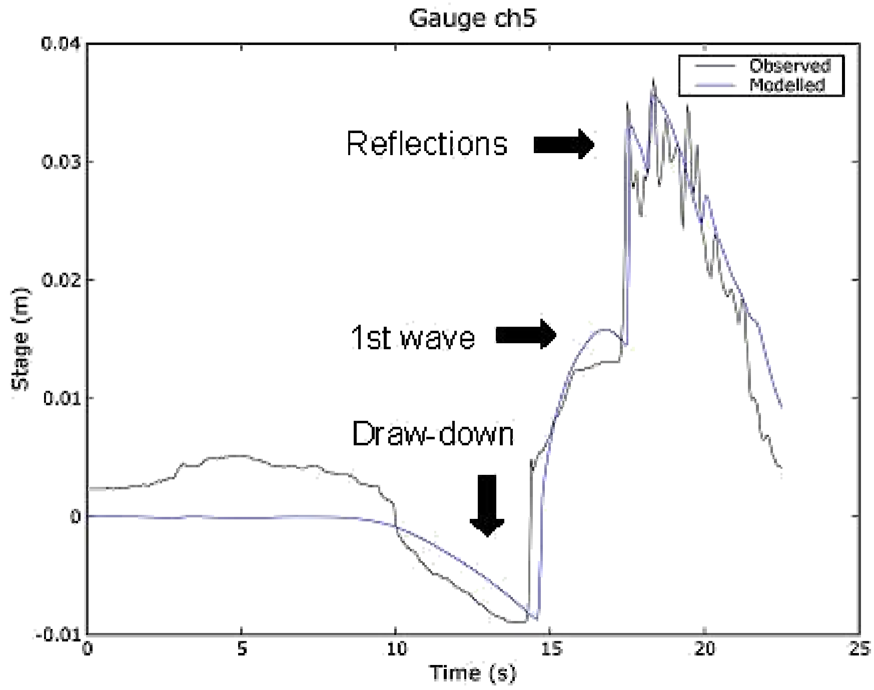

Fig. 1: Comparison of observed wave tank and modelled AnuGA water level (stage) at one of the gauges.

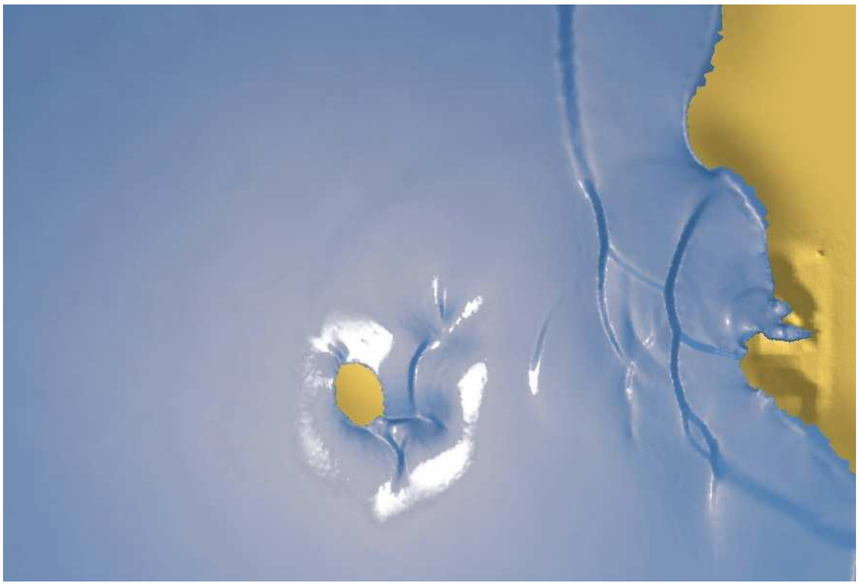

Fig. 2: The run-up in Monai Valley (right hand side of image) was captured accurately by the AnuGA model.