Efficiently and discretely modelling shallow water flows

Computational Science Centre for Research Communities

Natural disasters involving flow such as flooding and tsunamis often lead to a loss of lives and considerable economic damage. For example, in 1993 a tsunami generated by a magnitude-7.8 earthquake inundated Okushiri, Japan causing the death of 165 people; in the UK flooding causes £1.3 billion of economic loss each year[1]. Understanding these flows is a crucial step towards mitigating their devastation, and the application of computational modelling techniques is one important method contributing to this field of research.

Dr. Jianping Meng, Dr. Xiaojun Gu, and Prof. David Emerson, (computational engineers at the Science and Technologies Facilities Council (STFC)) Mr Yunlong Fei, Dr. Peng Yong*, and Prof. Jianmin Zhang (at the State Key Laboratory of Hydraulics and Mountain River Engineering (SKLH), Sichuan University, China) developed software to simulate realistic flow problems such as a tsunami inundation.

1993 Hokkaido earthquake and tsunami: Aonae, Okushiri Island, looking southeast. Structures in the foreground were damaged by fires fueled by above-ground kerosene and propane tanks following the tsunami. The concrete steps provided a means of escape for some residents following the strong earthquake[2]

Enhancing the lattice Boltzmann method

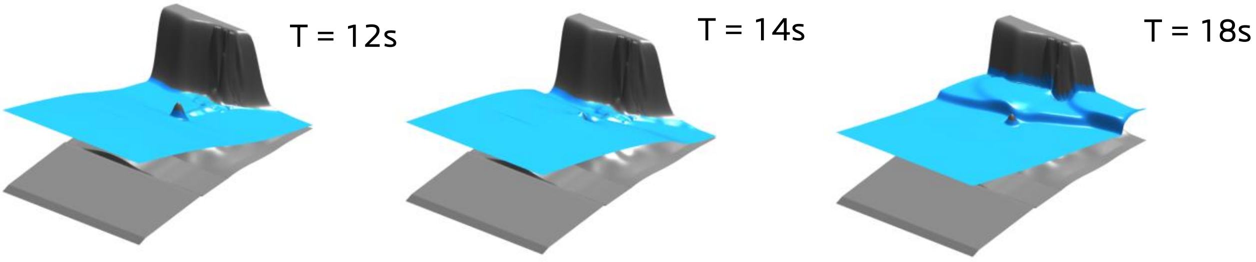
The lattice Boltzmann method (LBM) has emerged as an easy-to-understand modelling tool for fluid flows. Rooted in the kinetic theory of gases - where identical particles move in random directions – the LBM is formed by discretizing the statistical Boltzmann equation on a grid ('lattice'). Although used in the shallow water model, LBM needed further development to make it applicable to supercritical flows that occur in natural disasters[3]. To simulate these more realistic problems, e.g., tsunami inundation, it is necessary to model the drying-wetting interface that is moving during the inundation. 'Vanilla' LBM lacked this capability, and was in need of development.

[1] Flood risk and the UK Energy & Climate Intelligence Unit
eciu.net/analysis/briefings/climate-impacts/flood-risk-and-the-uk

[2] National Centers for Environmental Information
ngdc.noaa.gov/hazardimages/#/all/46

Discrete Boltzmann model (DBM)

To tackle this challenge, the team developed a type of discrete Boltzmann model (DBM) by applying a specific type of polynomial expansion i.e., the Hermite expansion approach[3] to the LBM. This extended the model's capability to supercritical flows without much loss in efficiency and simplicity. The model was then implemented into the multiple platform lattice Boltzmann (MPLB) code within STFC's general purpose mesoscale simulation package - DL-MESO.



High-resolution snapshots of a discrete Boltzmann model (DBM) simulation of a tsunami run-up onto a complex beach profile showing the 3D water height distributions at different times, (T). Grey denotes the sea bathymetry (surface of the underwater floors); and blue is the height of the surface of the water.

To simulate the drying-wetting phenomenon seen, for example, in a tsunami inundation the research team implemented various schemes based on the MPLB code and tested them over a range of benchmark problems. In particular, they compared the DBM simulations with the experimental data produced using a large-scale tank for exploring the extreme run-up of 32m height observed near the village of Monai during the 1993 Okushiri tsunami[4]. The computer simulations were conducted to model a sub-region of the tank where there are complex bathymetry (underwater floor surface profiles) and coastal topography. Preliminary testing demonstrated promising results, confirming the successful implementation and application of the MPLB code to such shallow water flows.

How to obtain DL-MESO

Follow the instructions on this page to register:
https://www.scd.stfc.ac.uk/Pages/DL_MESO-register.aspx
Then follow the instructions that are emailed to you on successful registration.
DL_MESO is one of the software codes developed by UKCOMES (ucl.ac.uk/mesoscale-modelling-consortium) that is one of the 19 communities supported by STFC scientists and engineers through the CoSeC project (cosec.stfc.ac.uk)

[3]Meng JP, Gu XJ, Emerson DR, Peng Y, Zhang JM (2018), Discrete Boltzmann model of shallow water equations with polynomial equilibria, International Journal of Modern Physics C 29: 1850080-15; [4]Liu P. L.-F, Yeh H, Synolakis C (Eds.), Advanced numerical models for simulating tsunami waves and run-up, Vol. 10. World Scientific, 2008.

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