TU Delft   Deltares

Master project: Unstructured graph based AI model for storm surge forecasting

Location: external master project at Deltares (Delft) [1].

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§1 Project background

The field of machine learning is developing rapidly and has an increasing number of applications. One of these fields is sometimes called surrogate modeling, where deep learning networks are trained on model output to mimic the output of an existing numerical model with the aim of making the runtime (much) smaller. Until very recently Convolutional neural networks (CNNs) were considered to be the most efficient network type for this type of application, but very recent deep learning developments are more and more based on Graph Neural Networks (GNNs), where the connection structure of the network is based on a graph.

2023 was a good year for several new artificial intelligence (AI) empowered weather models that are based on GNNs, such as Google's GraphCast [2] and Huawei's PanguWeather [3]. The European Centre for Medium-Range Weather Forecasts (ECMWF) is now running an experiment with several AI models, including these two [4]. These models have shown that models based on GNNs can be computationally competitive to CNNs even on evenly spaced nodes.

At the same time, the hardware for deep learning models is being rapidly developed. The quick uptake of the large language models such as ChatGPT is driving NVIDIA to further improve the performance of the Graphics processing units (GPUs). In 2024, Deltares will get access to the latest NVIDIA Hopper generation GPUs [5] that promise even better performance for GNNs.

In this thesis project, the main purpose is the development of a fast surrogate for a storm surge model. Currently, Deltares' Global Storm Surge Forecasting and Information System (GLOSSIS) [6] uses the Delft3D Flexible Mesh (Delft3D FM) [7] software, which employs traditional numerical methods, e.g. solving shallow water equations by a finite volume method on an unstructured grid. An example of the unstructured grid is shown in Figure 1. To speed up

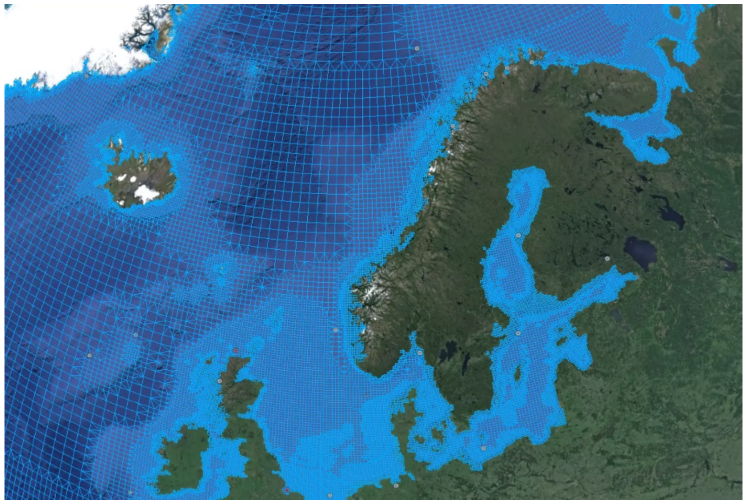

Figure 1: Using the Delft3D FM, the unstructured grid which covers the Northern Europe of the Global tide and storm surge model, which is the basis of the GLOSSIS. [10]

the computation, we would like to develop a GNNs based AI model for the forecasting of storm surges.

Some research has been done on storm surge forecast using an AI method, e.g. in [8] where a convolutional recurrent neural network method was developed. In this master project, we are especially interested in GNNs methods. The unstructured grids of Delft3D FM can be mapped to a graph structure with little effort, and it should be possible to train these networks to forecast storm-surges and tides, given the similarities between the equations for weather and storm-surges. In fact, it has been showed that flooding can be simulated with these types of networks (e.g. [9]). Still, there are many challenges with this method ranging from boundary conditions to generalization for uneven spacing.

For this project we want to make use of the Julia programming language, since it allows to include arbitrary computations as part of the network to be used a full speed both on CPU and GPU. Deep learning and GNNs are supported in Julia with the Flux [11] and GeometricFlux [12] packages.

§2 Project target and contents

In this project, we aim to develop a prototype approximation to an existing storm-surge model (Delft3D FM model), and investigate the generalization of the model to other areas and other forcing.

This target could be achieved by the following steps:

- We would like to adapt the GNNs model, which was developed in [9], to forecast the storm surge.
- We will provide the student with the data for training the GNNs model. So the student does not need to generate the data. (The data will be obtained by running existing numerical models with different forcings and boundary conditions, using Delft3D FM. These models are available in Deltares.)

- The development of the GNNs model will be based on the excellent Julia libraries: Flux.jl [11], and GeometricFlux.jl [12].
- The available GPUs include DelftBlue (TU Delft), Snellius (SURF) and Deltares new GPUs.
- The first experiment will be on a square domain with structured grid, then we will do further experiment on more complicated domains and with unstructured grid.

§3 Useful documents for this project

Below is a list of useful documents, including online courses for this project. It might be enriched during the project.

- For instruction of installing Julia, we refer to [13].
- For a book about SciML, including writing fast program in Julia, we refer to [14].
- For a quick introduction of the deep learning, we refer to the first 3 videos of the ETH course [15].

§4 More about this project

Below gives more information about this master project:

- This project could be started as soon as possible.
- The duration of this project will be around 9 months, depending on the concrete situation.
- This project is sponsored by Deltares. The student will get monthly allowance depending on the concrete situation, e.g. the study credits, etc. Moreover, the student will work at Deltares. It is also possible to work part-time from home or the university over VPN.

References

[1] Deltares is an independent knowledge institute, it works on innovative solutions in the field of water and subsurface, see `https://www.deltares.nl/en`

[2] Google's GraphCast, see `https://deepmind.google/discover/blog/graphcast-ai-model-for-faster-and-more-accurate-global-weather-forecasting/`

[3] Huawei Cloud Pangu-Weather Model, see `https://www.huawei.com/en/news/2023/8/pangu-weather-forcast`

[4] ECMWF, products from various AI Models, see `https://charts.ecmwf.int/catalogue/packages/ai_models/`

[5] The latest NVIDIA Hopper generation GPUs, see `https://developer.nvidia.com/blog/setting-new-records-at-data-center-scale-using-nvidia-h100-gpus-and-quantum-2-infiniband/`

[6] Global Storm Surge Information System (GLOSSIS), see `https://www.deltares.nl/en/expertise/projects/global-storm-surge-information-system-glossis`

[7] Delft3D Flexible Mesh, see https://www.deltares.nl/en/software-and-data/products/delft3d-flexible-mesh-suite

[8] E. Adeli, et al. "An advanced spatio-temporal convolutional recurrent neural network for storm surge predictions." Neural Computing and Applications (2023): 1-17.

[9] R. Bentivoglio, et al. "Rapid Spatio-Temporal Flood Modelling via Hydraulics-Based Graph Neural Networks." EGUsphere 2023 (2023): 1-24.

[10] M. Verlaan. "Global tide and storm-surge model with Delft3D Flexible Mesh", presentation at Delft Software Days 2014 (2014), see https://www.slideshare.net/Delft_Software_Days/dsd-int-2014-symposium-next-generation-hydro-software-nghs-global-tide-model-martin-verlaan-deltares

[11] Julia package Flux.jl (2023). See https://github.com/FluxML/Flux.jl.

[12] Julia package GeometricFlux.jl (2023). See https://github.com/FluxML/GeometricFlux.jl.

[13] The Julia Programming Language, official website. See https://julialang.org/.

[14] Parallel Computing and Scientific Machine Learning (SciML): Methods and Applications (2023). C. Rackauckas. See https://book.sciml.ai/.

[15] ETH Zürich, Deep Learning in Scientific Computing (2023). B. Moseley and S. Mishra. See https://www.youtube.com/watch?v=y6wHpRzhhkA&list=PLJkYEExhe7rYY5HjpIJbgo-tDZ3bIAqAm.