Applications for mid-range forecasts
Simulations of storm surges

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1 Introduction

A possible application for mid-range and sub-seasonal forecasts is the simulation of storm surges. Storm surge is the abnormal rise of water generated by a storm, over and above the predicted astronomical tide. The main forcing for a storm surge is the wind stress from strong storms, usually tropical cyclones.

Goal: To model possible scenarios of storm surges using simulated output of winds and pressure from a mid-range weather forecast, as model forcing.

Why? Surface winds and sea level pressure are common output parameters of numerical weather prediction models. The same operational configuration can be used for further simulations, like storm surges, which are estimated to be the biggest risk of life and material loss during heavy storms in coastal regions.

2 Method

For the mid-range forecasts, input data from the *"Establishing Operational Capacity for Building, Deploying and Using Numerical Weather and Seasonal Prediction Systems in Small Island States in Africa (SIDs)"* project was used, which in part uses the Weather Research and Forecasting (WRF) model for regional scale weather simulation. In particular, this project comprises a domain covering the whole African continent (figure 1) and part of the Indian Ocean basin. This setup is mantained and developed by Belgingur[1] in Iceland. For the storm surge simulation the ADvanced CIRCulation[2] (ADCIRC) numerical model was used. ADCIRC is a system of computer programs for solving time dependent, free surface circulation and transport problems in two and three dimensions. These programs utilize the finite element method in space allowing the use of highly flexible, unstructured grids.

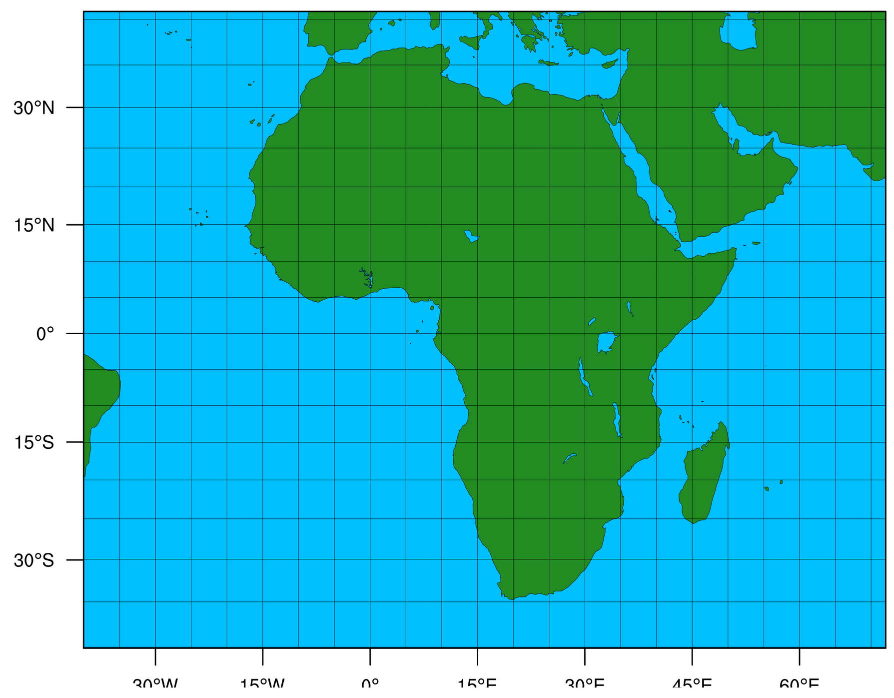

FIGURE 1: Domain for the meteorological simulation using WRF. The model resolution is 9 km, and the forecast is run daily out to 10 days.

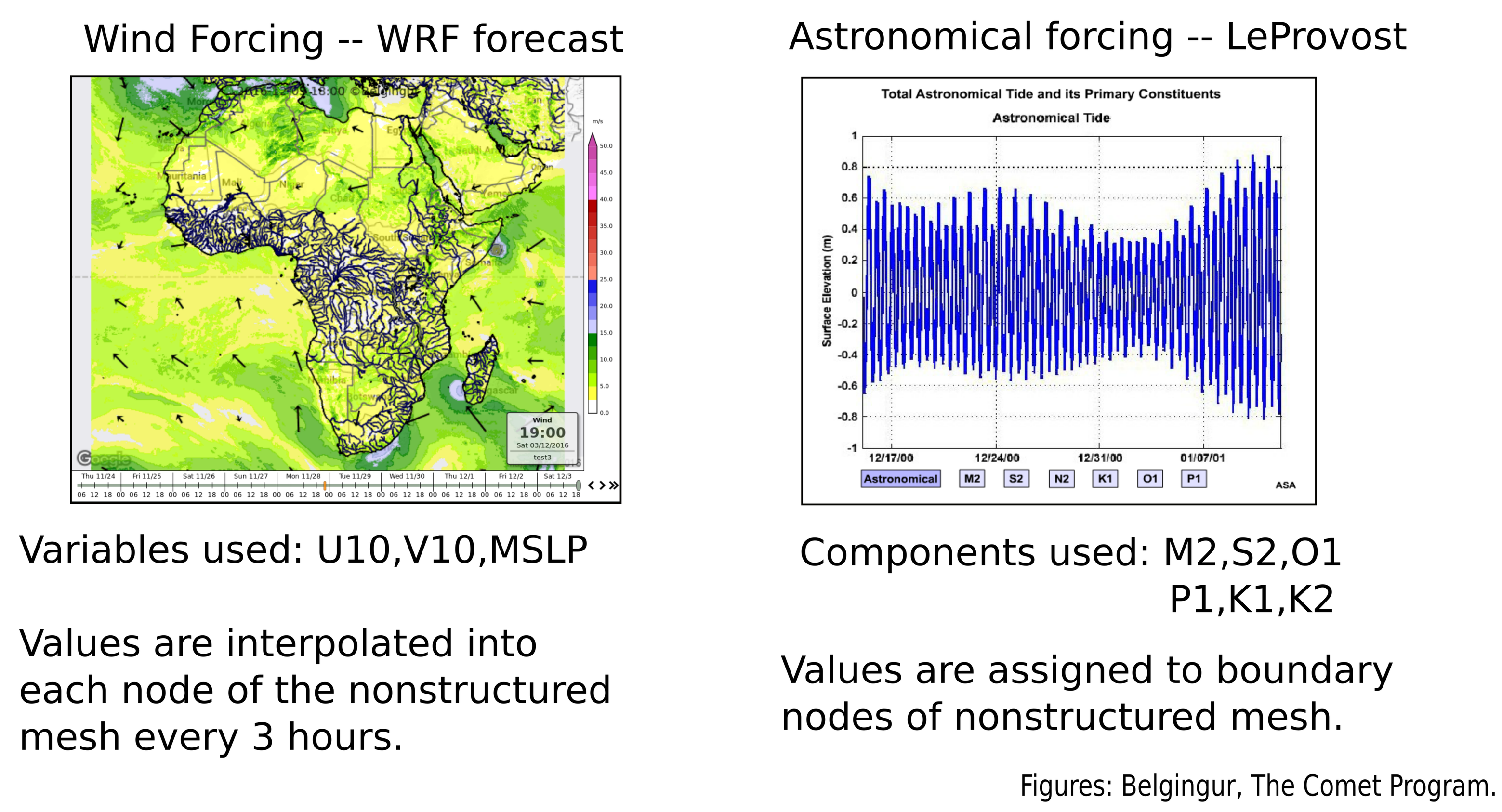

FIGURE 2: Method for surge forcing in the simulation.

3 Experimental set-up

An unstructured and non-homogeneous mesh was developed for the domain fitting inside the meteorological domain (figure 3). This mesh was made using the open source software GMSH[3] with the coastline data from the GSHHG[4] database.

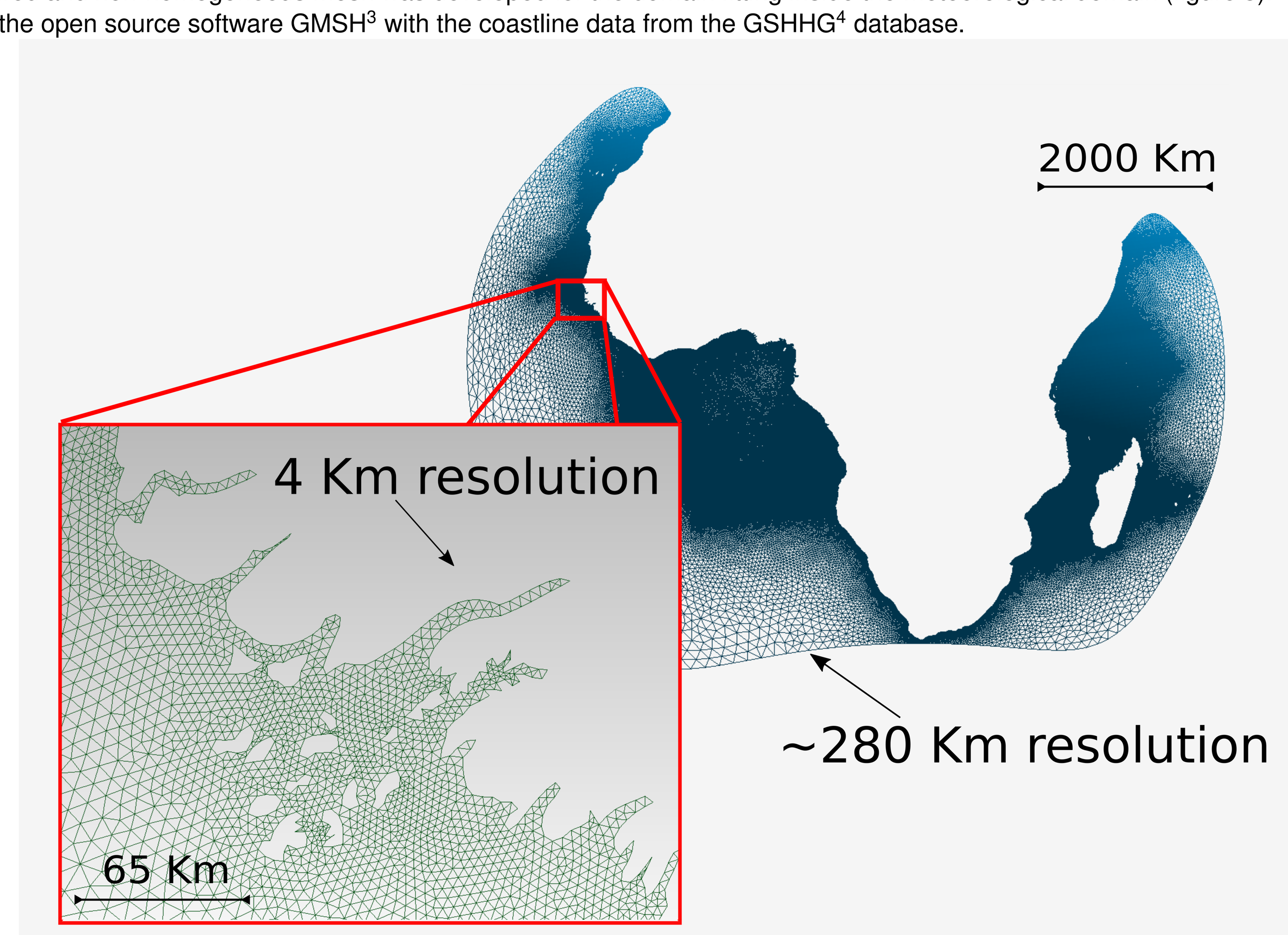

FIGURE 3: Unstructured mesh developed for the surge simulation. The mesh starts with a 4 km resolution near the coast, and becomes coarser as it moves away to the open boundaries in the ocean.

Following the mesh generation, bathymetry from the GEBCO[5] database was interpolated into each node in the domain using a bi-linear nearest neighbor interpolation (figure 4). The resulting mesh for the simulation has approximately 800.000 nodes and 1.600.000 elements.

[1]http://www.belgingur.is
[2]http://adcirc.org/
[3]http://gmsh.info/
[4]https://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html
[5]http://www.gebco.net/

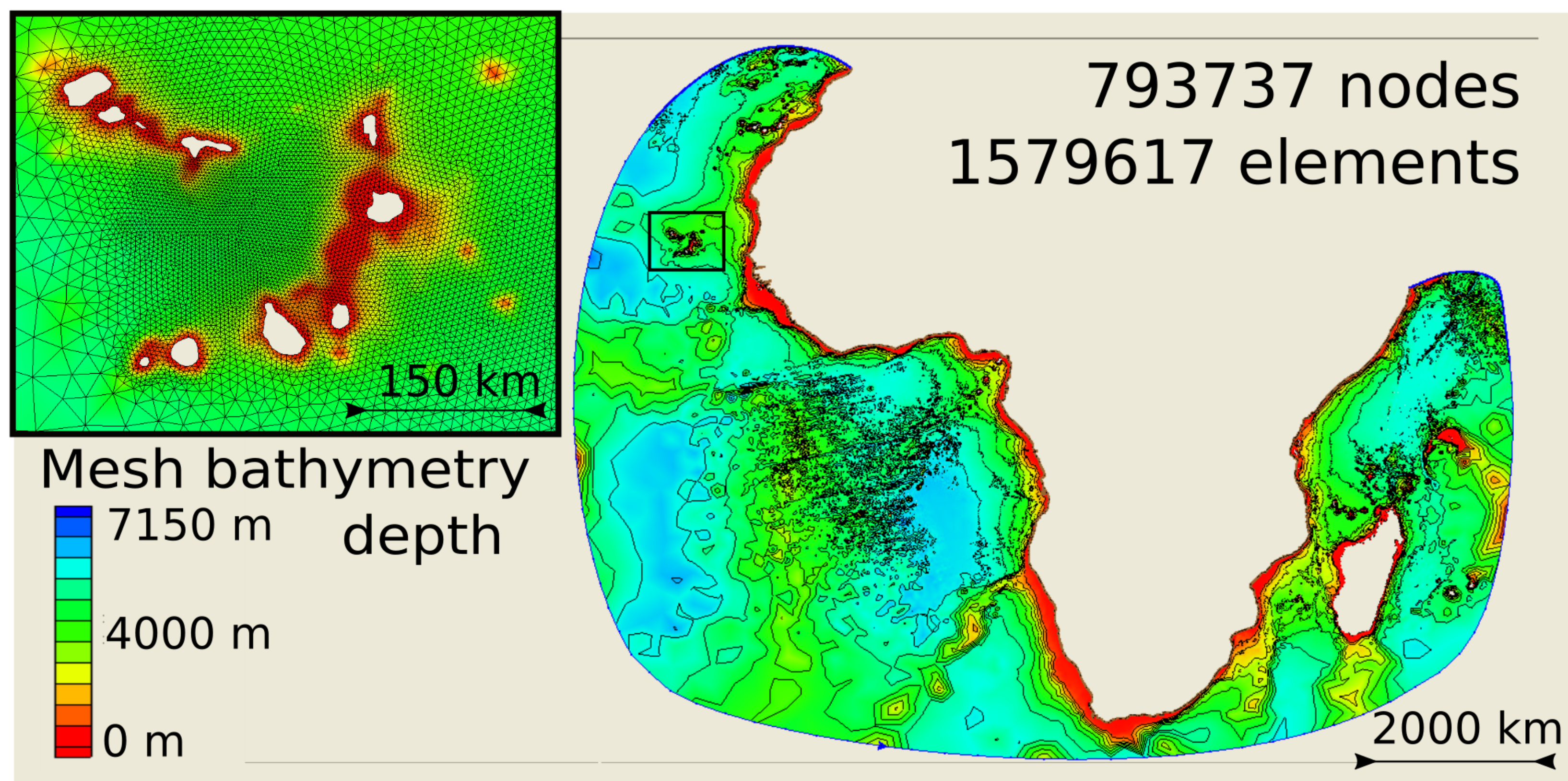

FIGURE 4: Unstructured mesh with the bathymetry interpolated into each node. A zoom comprising Cabo Verde shows the level of detail for the interpolation and the mesh as one moves closer to the coast. Elements are not shown for the complete domain to emphasize the bathymetry.

For this experiment a ten day simulation, starting at 00 UTC 21 November, was set using a 2D run with no advection, astronomical tide forcing along the open boundary, and wind forcing along every node in the domain. Meteorological input was interpolated from the WRF 10 meter height wind and sea level pressure fields. A five day ramp function was used to spin up the model. The computation for this configuration took approximately 2.5 hours using the same resources as the meteorological forecast.

4 Results

Figure 5 shows the free surface water elevation for day 8 of the simulation, showing the effect of both astronomical and wind forcing along the coast.

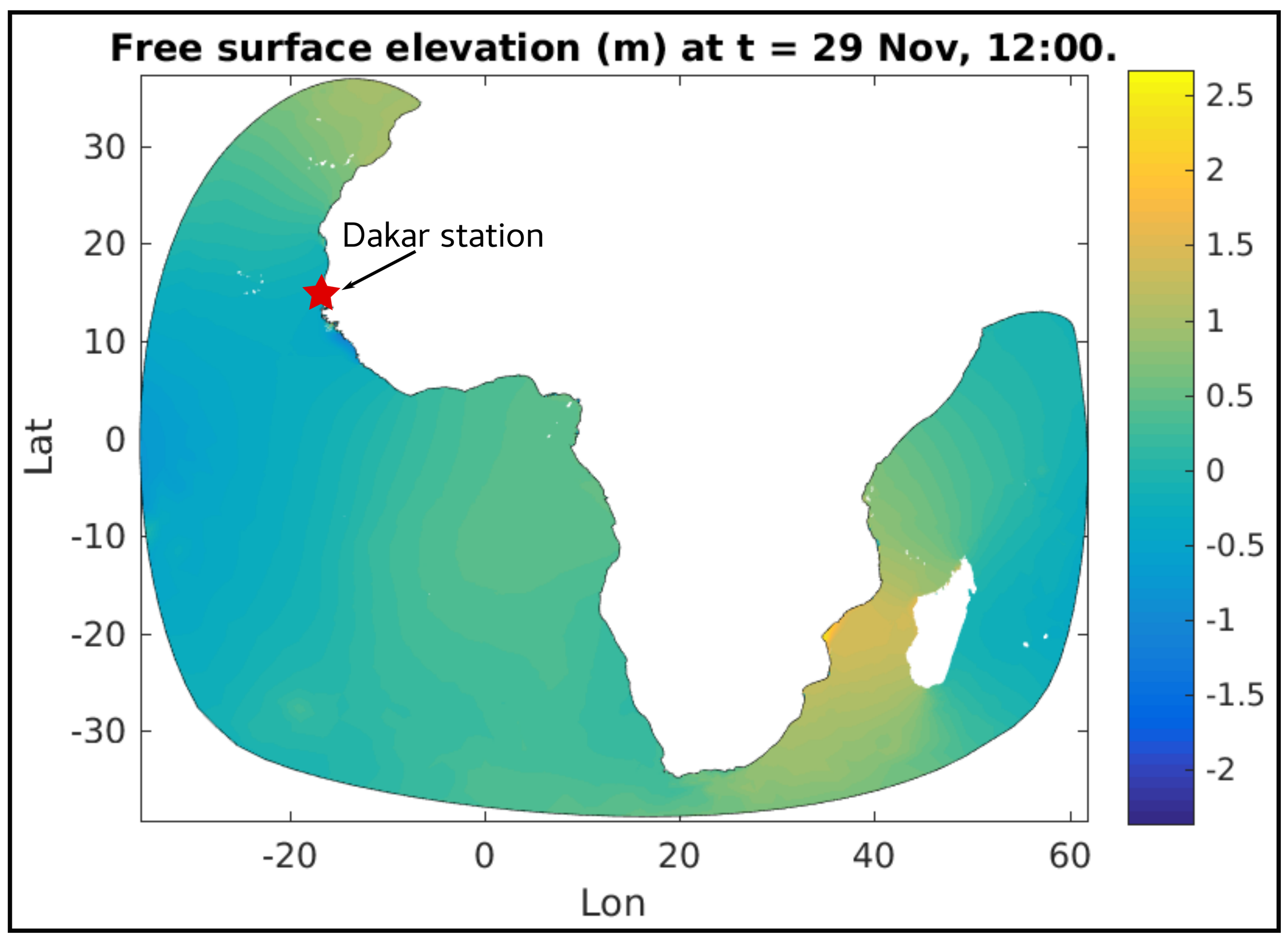

FIGURE 5: Results for the 10 day simulation. Colors indicate free surface elevation in meters.

For comparison, a sea level monitoring station in Dakar is plotted against a virtual sea level station from the model (figure 6). This shows that the model is relatively good in forecasting changes on the water level, but suffers in the amplitude of the elevation.

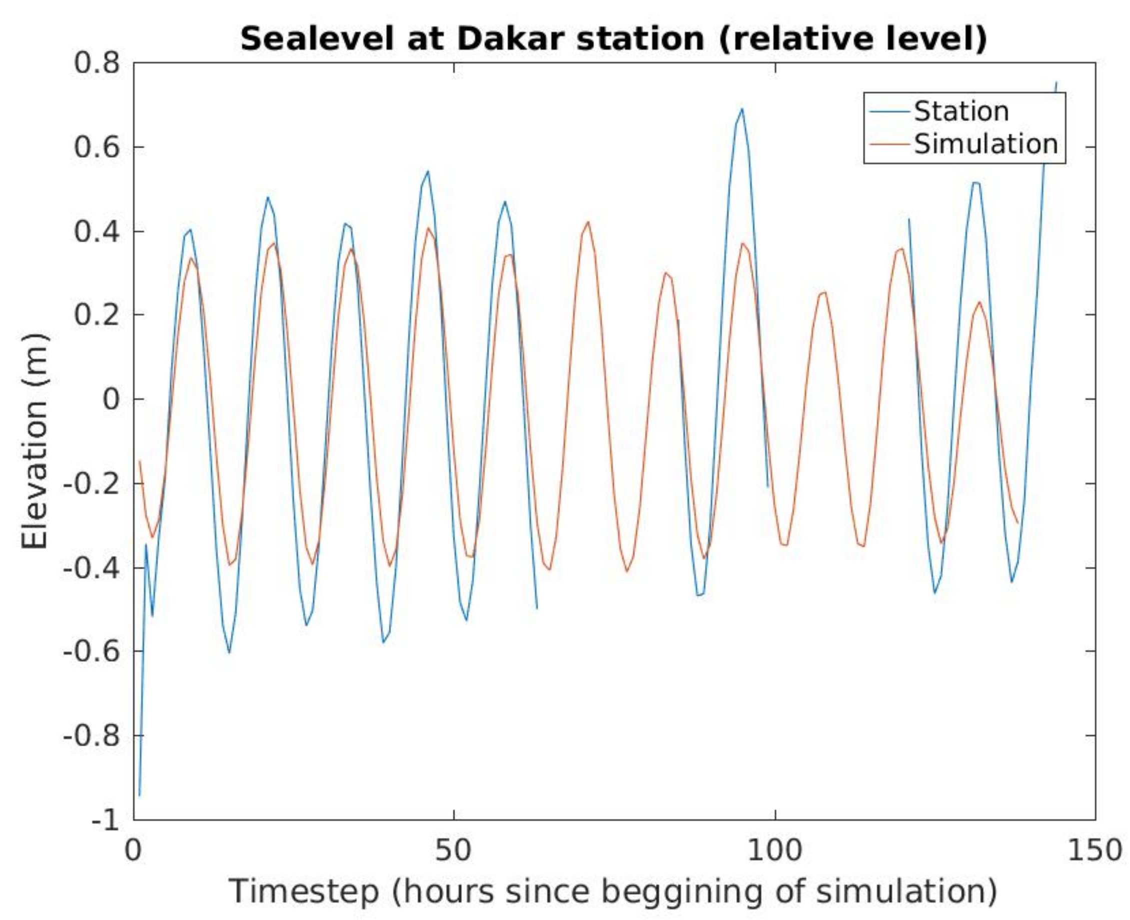

FIGURE 6: Relative sea level from Dakar station and ADCIRC simulation from 00 UTC 26 November to 00 UTC 01 December 2016. While the frequency seems to be a good match, the simulated amplitude is too low compared to observations.

5 Conclusions

- **Is it possible to forecast storm surges using mid-range weather forecasts?** We were able to use the meteorological forecast data to initialize a storm surge forecast using the ADCIRC model and a unstructured mesh developed specifically for this project, with a resolution of ~4 km along the coast. The model was able to show places with high water level, signaling where a more detailed simulation could be done.
- **What have we learned?** The results show that while the model is able to see changes in water free surface level, it has some issues with forecasting the correct amplitude change for specific locations. This could be solved by increasing the resolution along the coast, but it should be noted that bathymetry data is a big limitation for doing so in the region.
- **Future plans**. Use of sub-domains with even higher resolution could solve the issue for improving the amplitude of the surge events. Streamlining the post-processing and visualization of the simulation output is also needed in order to make this application viable for use for decision making.

6 Acknowledgements

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