Bathymetry improvement and high-resolution tidal modelling at regional scales

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Introduction

Coastal processes (tidal currents, storm surges, waves) are highly dependent on bathymetry and directly impact offshore and coastal activities. Many studies and applications rely on a growing ocean-modelling effort, but the limited accuracy of bathymetry, especially on the continental shelves, contributes to limit the numerical modelling performance, despite significant use of in-situ and satellite measurements assimilation. In particular, tidal models are very sensitive to the bathymetry accuracy on the shelves, where the ocean tides show the largest amplitudes and are strongly non-linear. This directly impacts the quality of the altimetry sea surface heights as the tide correction is one of the largest corrections on the shelves, ranging from several centimeters to several meters. Improving tidal models in these regions is thus of prime importance for the current and future satellite altimetry missions that already or will enable to retrieve high-resolution coastal observations of the sea surface height, such as Sentinel-3, Sentinel-6 and SWOT.

The increase in the grid resolution, combined with local model tuning, is one of the means to improve the tidal model performance in the coastal regions and large improvements have been achieved thanks to this approach. However, increasing the resolution of the model grid implies consistent bathymetry quality and accuracy, which is today the main limiting factor to accurate high-resolution tidal modelling. In this context, CNES recently funded a project that aimed to improve the bathymetry and the tides in the North-East Atlantic Ocean, the Mediterranean Sea, the Arctic Ocean and around Australia, and thus pave the way for the implementation of the new global tidal model, FES2022.

Bathymetry improvement

Inventory of existing/freely available bathymetry datasets:

- Raw data from single-beam or multi-beam soundings
- Digital Elevation Models (DEM)

Data processing: vertical reference, editing, sub-sampling…

Merging of the bathymetry datasets into the global reference database (FES2014).

Assessment and iterations (removal of dubious datasets):

- Visual quality check: seamless boundaries, small scale features, realistic isobaths lines...
- Hydrodynamic modelling: impact of the new bathymetry on the tidal simulation performance, iterative process.

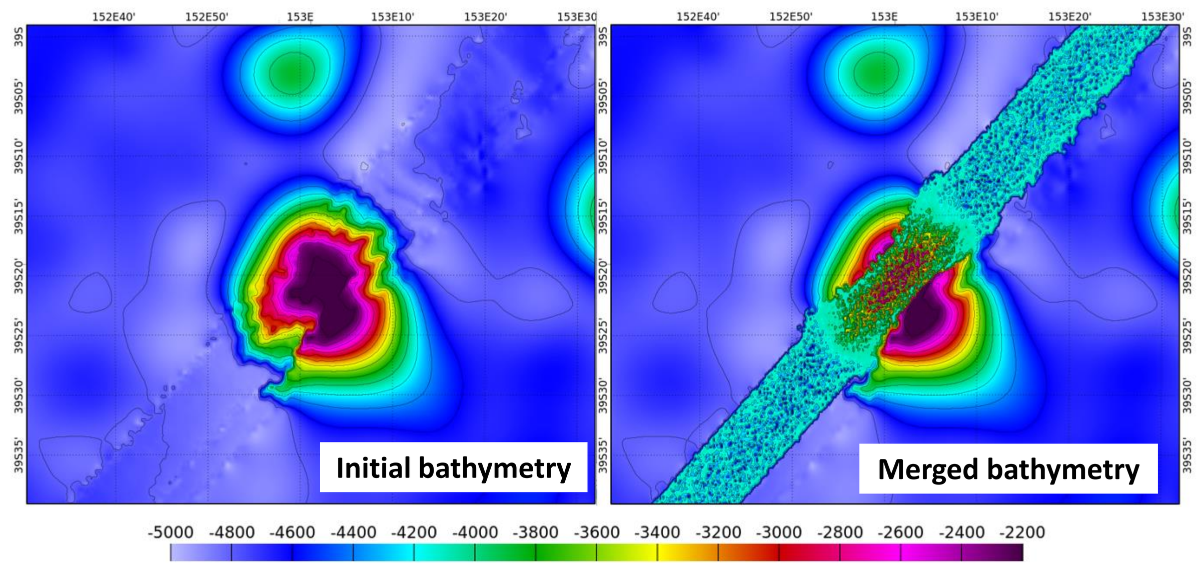


Fig. 1: Tentative merge of Geoscience Australia DEM50m dubious bathymetric survey into the reference bathymetry. Colors show depth in meters.

Regional tidal models setup and validation data

Tidal modelling strategy based on the TUGO-m hydrodynamic model, previously used for the development of global models such as FES2014 (Lyard et al., 2021) and regional tidal models (Cancet et al., 2018).

For each area, a RegAT regional tidal model is implemented (Fig.2) based on:

- The new composite bathymetry;
- High-resolution unstructured mesh-grid with refinement on the continental shelves.

Validation considering **tidal elevation harmonic constituents** from in situ (tide gauges) and satellite altimetry data.

Regional tuning of the model key parameters (roughness length, wave drag). Local values can be used in case of local specificities.

TUGO model used in **spectral mode to obtain the linear tidal components:** less computation-resource demanding than time-stepping mode, allows **large number of tests**.

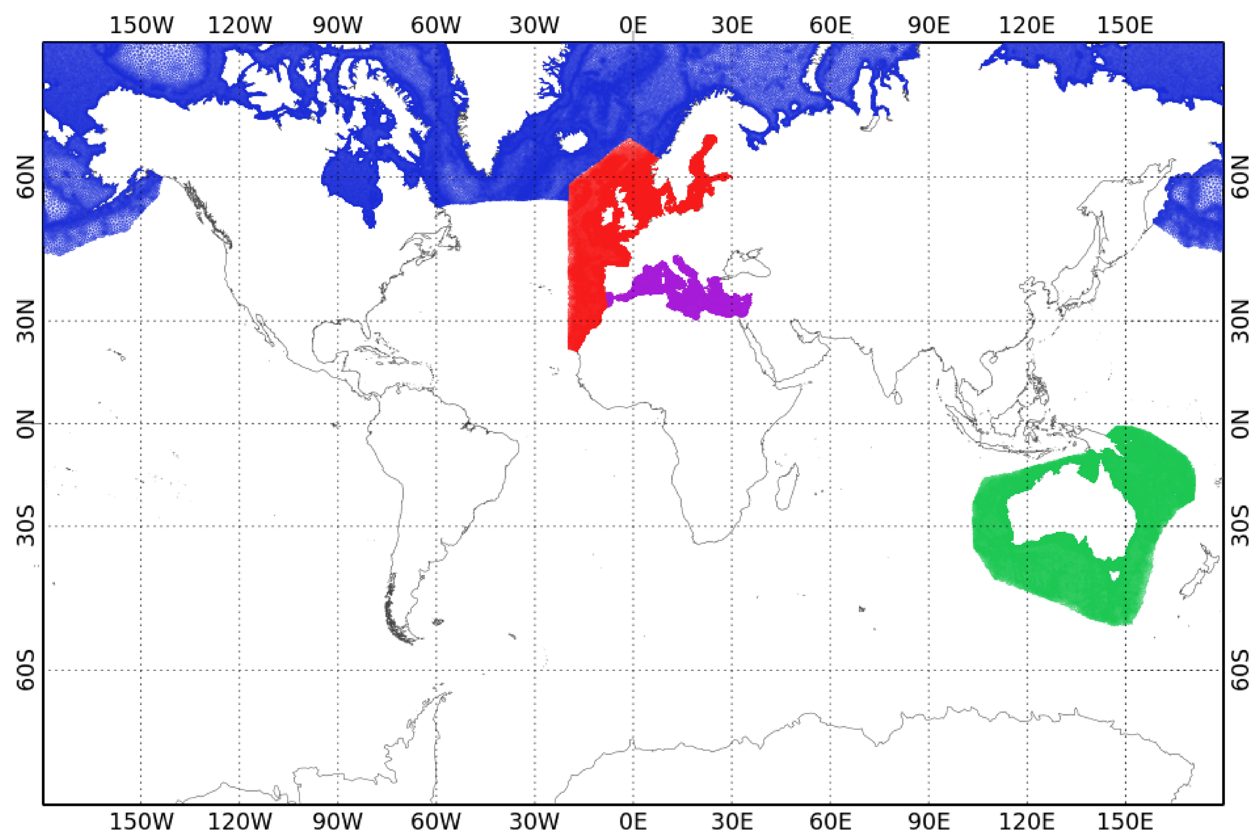


Fig. 2: Mesh-grid extents of the new regional models: Arctic (blue), North-East Atlantic (red), Med. Sea (purple) and Australia (green).

Time-stepping mode run over one year to complete the spectrum with **non-linear and long-period complex waves**.

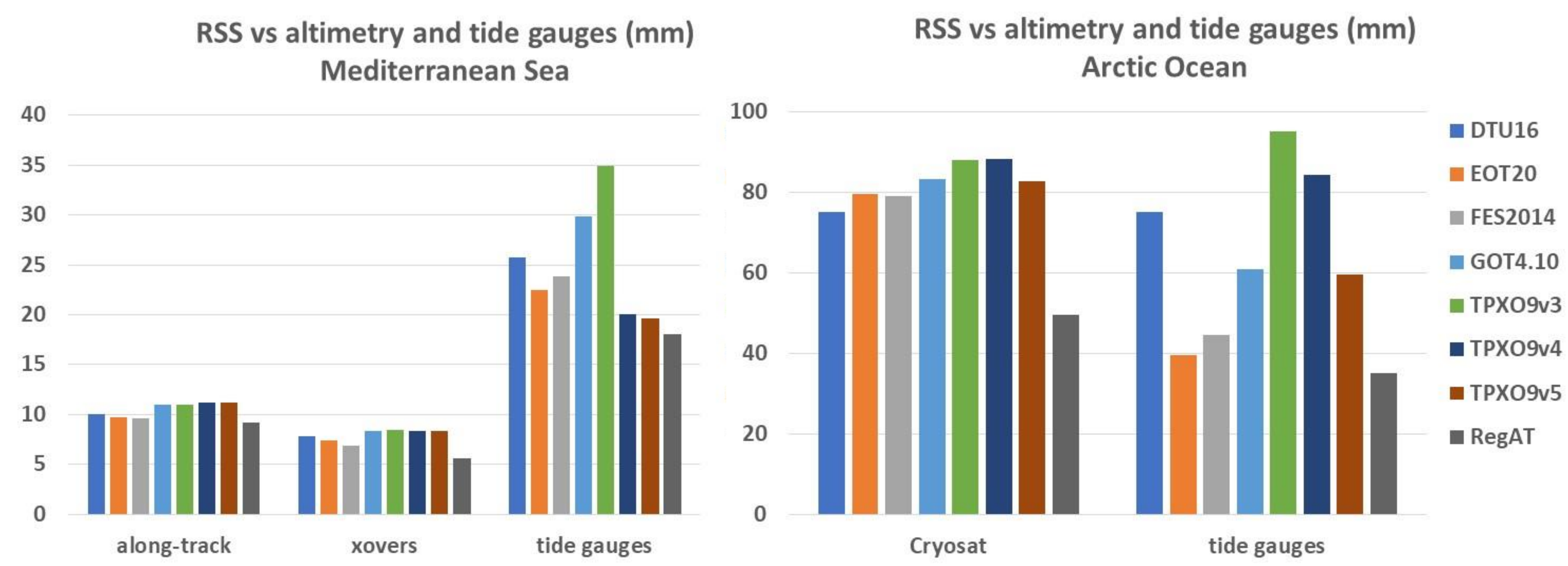
Data assimilation of tide gauge and satellite altimetry observations performed on the main tidal components.

Cancet, M., Andersen, O.B., Lyard, F., Cotton, D., Benveniste, J. (2018), Arctide2017, a high-resolution regional tidal model in the Arctic Ocean, ASR, V. 62, 6, 1324-1343

Lyard, F. H., Allain, D. J., Cancet, M., Carrère, L., and Picot, N. (2021), FES2014 global ocean tide atlas: design and performance, Ocean Sci., 2021, 17, 615–649

Main results

For each regional tidal model, the vector differences relative to tide gauges and altimetry observations are computed for the main tidal components (M2 K1 S2 O1 K2 N2 P1 Q1) and compared with the scores obtained with the global models in the area. The Root Sum Square (RSS) of the vector differences (Fig. 3) gives an overall estimate of the performance of each model, relative to observations. It should be noted that part of the observations have been assimilated into or used to constrain the regional and global models, so the assessment is not fully independent, whatever the model.



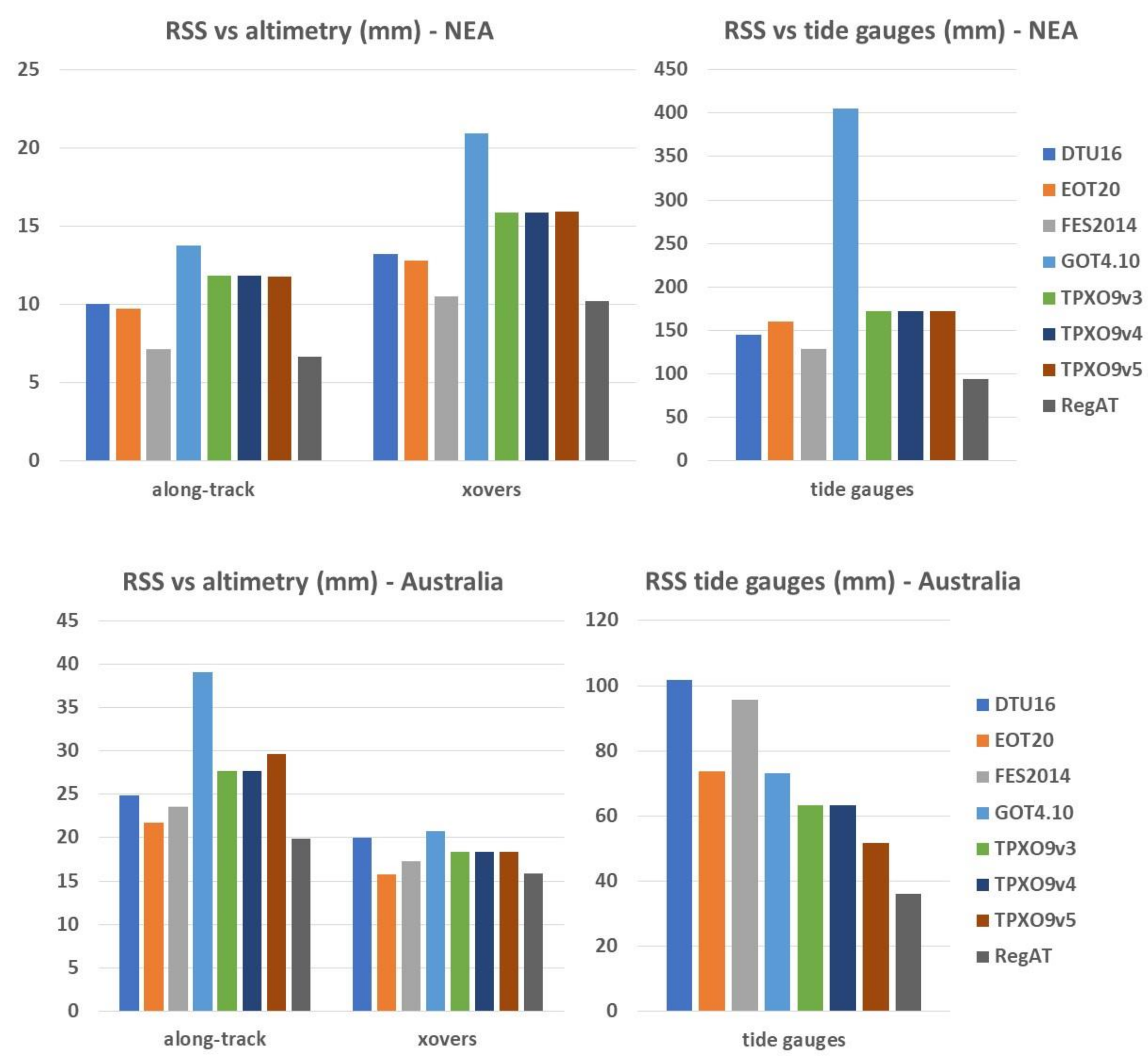


Fig. 3: RSS scores (mm) of the tide models in the four regions of interest, computed from the vector differences of 8 main tidal components, relative to altimetry and tide gauge observations, for the regional and global models.

RegAT regional models performance

➔ In the four regions of interest, the new regional tidal models demonstrate some clear improvement relative to observations, compared to the global models. Reduction of the error to tide gauges is particularly strong in the North-East Atlantic (more than 4 cm RSS compared to FES2014), thanks to the higher-resolution grid (1 to 2 km along the coast) and the more accurate bathymetry.

CONCLUSIONS, LESSONS LEARNED AND PERSPECTIVES

- The **four RegAT regional tide models** can be used as **alternative tidal corrections for coastal altimetry data**. They are **compatible with the FES2014** global tidal model at their open boundaries.
- The RegAT tidal corrections are considered for ERS1/2, ENVISAT and CryoSat-2 coastal products within the frame of the FDR4ALT and CRYOTEMPO ESA projects.
- This work paved the way for the new **FES2022 global tidal model**, which **includes part of these regional developments.**
- Regarding bathymetry processing, multi-beam bathymetry data and DEMs generally provide better continuous spatial coverage than single-beam data, and lead to more chance of improvements when merged into the reference dataset.
- Strong mesh refinement is not always relevant, especially in areas of poor-quality bathymetry, as the model becomes more sensitive to bathymetry flaws.
- The coastline can locally be shifted by several kilometers (Fig. 4), which leads to misrepresentation of some bays.
- Bathymetry and coastline detection can be improved using satellite data (optic and/or SAR).

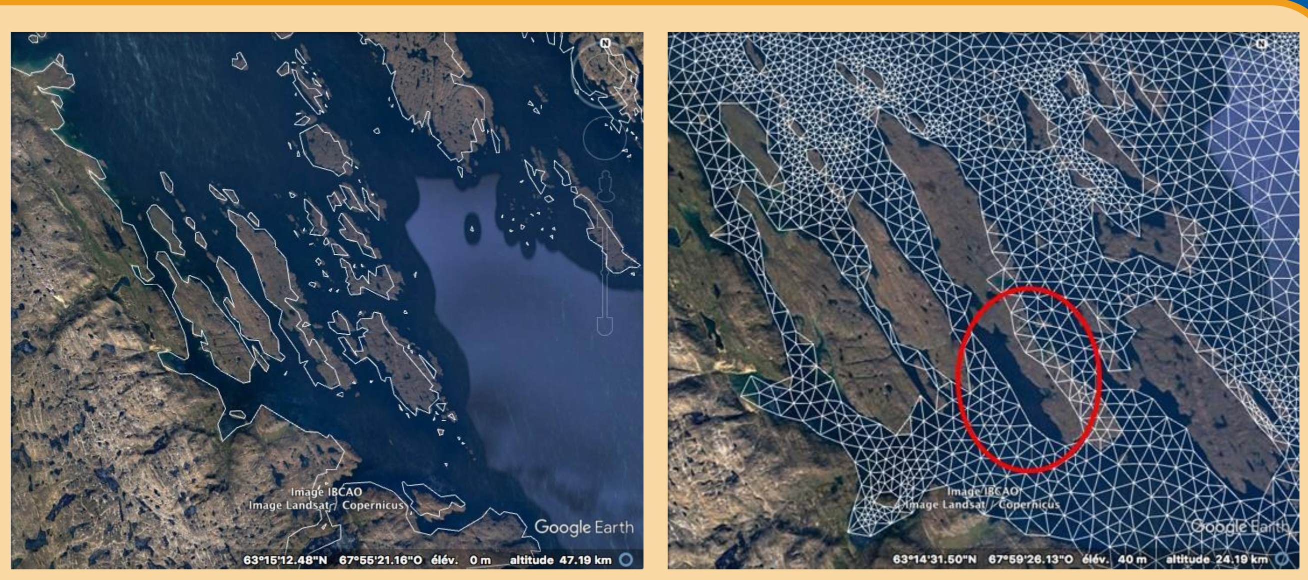


Fig. 4: Left: GSHHS-2.3.7 coastline superimposed in the Frobisher Bay (Labrador Sea). Right: Resulting model mesh-grid. The main shift is encircled in red.