HIGH RESOLUTION TIDAL MODELLING IN THE ARCTIC OCEAN: NEEDS AND UPCOMING DEVELOPMENTS

M. Cancet[1], O. Andersen[2], L. Stenseng[2], F. Lyard[3], D. Cotton[4], J. Benveniste[5], A. Schulz[6]

[1]NOVELTIS, 153 rue du Lac, 31670 Labège, France, Email: mathilde.cancet@noveltis.fr
[2]DTU Space, Elektrovej, Bldg 328, 2800 Lyngby, Denmark, Email: oa@space.dtu.dk
[3]LEGOS/OMP/UPS, 14 Avenue Edouard Belin, 31400 Toulouse, France, Email: florent.lyard@legos.obs-mip.fr
[4]Satellite Oceanographic Consultants Ltd, 49 Seal Road, Stockport SK7 2JS, UK, Email: d.cotton@satoc.eu
[5]ESA/ESRIN, Via Galileo Galilei, Frascati, I-00044, Italy, Email: jerome.benveniste@esa.int
[6]Delft University of Technology, Kluyverweg 1, NL-2629 HS Delft, Netherlands, Email: anntheres.schulz@gmail.com

ABSTRACT

The Arctic Ocean is a challenging region for tidal modelling, because of its complex and not well-documented bathymetry, together combined with the intermittent presence of sea ice and the fact that the in situ tidal observations are rather scarce at such high latitudes. As a consequence, the accuracy of the global tidal models decreases by several centimetres in the Polar Regions. In particular, it has a large impact on the quality of the satellite altimeter sea surface heights in these regions (ERS1/2, Envisat, CryoSat-2, SARAL/AltiKa and the future Sentinel-3 mission).

Better knowledge of the tides would improve the quality of the high latitudes altimeter sea surface heights and of all derived products, such as the altimetry-derived geostrophic currents, the mean sea surface and the mean dynamic topography. In addition, accurate tidal models are highly strategic information for ever-growing maritime and industrial activities in this region.

NOVELTIS and DTU Space are currently working on the development of a regional, high-resolution tidal atlas in the Arctic Ocean. In particular, this atlas will benefit from the assimilation of the most complete satellite altimetry dataset ever used in this region, including Envisat data up to 82°N and the CryoSat-2 reprocessed data between 82°N and 88°N. The combination of all these satellites will give the best possible coverage of altimetry-derived tidal constituents. The available tide gauge data will also be used either for assimilation or validation.

This paper presents the performances of the available global tidal models in the Arctic Ocean and the on-going development of an improved regional tidal atlas in this region.

1. PERFORMANCES OF THE GLOBAL TIDAL MODELS IN THE ARCTIC OCEAN

In order to evaluate the needs in terms of tidal modelling in the Arctic Ocean, a comparison was performed between the various recent global tidal models in this region. Fig. 1 shows the amplitude of the M2 tidal wave for six different models, including the most recent one (FES2014, not published yet), and the vector differences to the tide gauge observations available in the area. The bigger the red dot, the larger the difference between the model and the tide gauge. The overall mean vector difference for each model is given on each subplot.

It clearly appears that the largest errors are located in the areas of largest tidal amplitude, as expected. The performances of the various models are quite similar (7.5-8.5cm of mean vector difference vs TG), except for FES2014 which shows better performances (5.7cm). This is explained by the fact that the tide gauge database used for this comparison was assimilated in this model. As a consequence, the comparison is not totally independent for this model. However, the impact of the assimilation in FES2014 in this region is limited by the quality of the a priori solution, directly linked to the resolution of the mesh.

The implementation of a regional tidal model with a finer mesh resolution is clearly a means of improvement for the modelling of the tides in the Arctic Ocean.

2. REGIONAL TIDAL MODELLING

The tidal modelling strategy used by NOVELTIS is based on the TUGO hydrodynamic model provided by LEGOS and the Kalman ensemble assimilation method. It was previously used for the implementation of global models such as FES2004 [1], FES2012 [2] and FES2014, and for the development of regional models [3].

Fig.2 presents the methodology classically followed by NOVELTIS to implement a global or a regional tidal model. After having prepared the unstructured mesh (see section 2.1. for more details) and the bathymetry, the hydrodynamic model is set-up by tuning some parameters such as the bottom friction coefficient, to which the tide process is particularly sensitive.

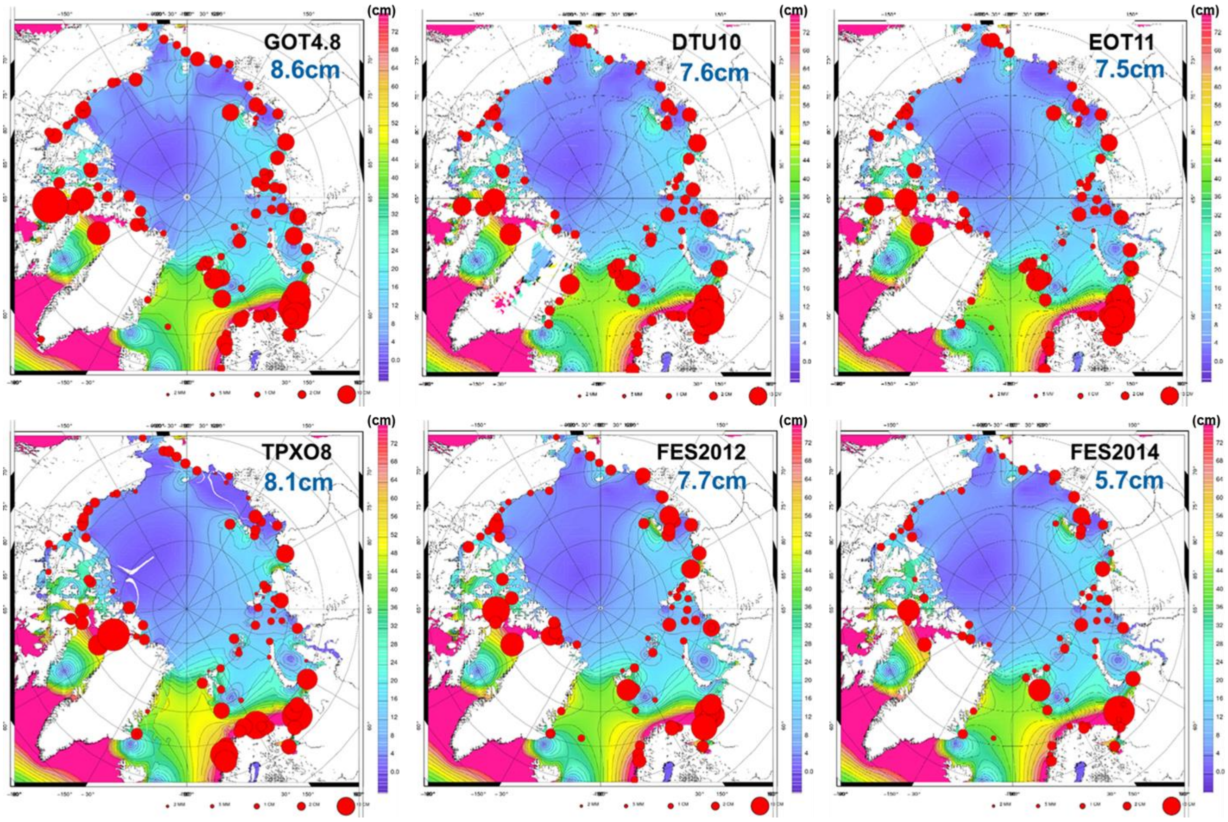

Figure 1: Amplitude (in cm, colour) of the M2 tidal wave for various global tidal models and vector differences to the tide gauges (red dots)

The performance of the a priori hydrodynamic solution is quantified by comparing with validation databases composed of satellite altimetry and tide gauge observations.

The next step consists in creating an ensemble of perturbed simulations in order to quantify the precision of the model through its sensibility to the variations of a number of parameters such as the bathymetry and the bottom friction coefficient. This information on the precision level of the a priori hydrodynamic solution is used in the assimilation process.

Then comes the assimilation part, which aims to constrain the a priori hydrodynamic solution in the regions where it shows the largest errors. The altimetry and tide gauge observations that are assimilated are specifically processed in order to retrieve the tidal harmonic constituents from the sea surface height time series. In the case of the tidal model developed in the Arctic Ocean, the altimetry data from CryoSat-2 were specifically processed by DTU Space, as presented in section 2.2.

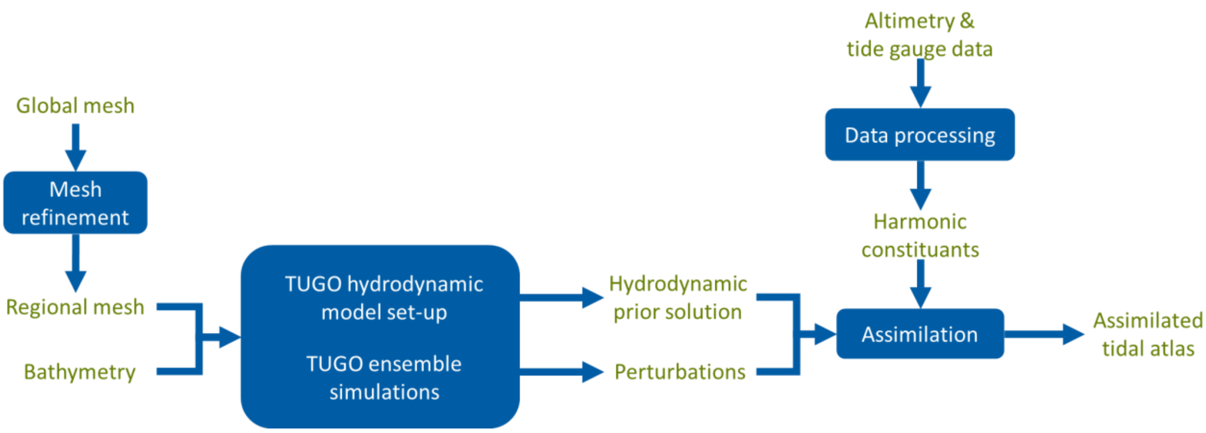

Figure 2: Regional tidal modelling methodology

2.1. Hydrodynamic model set-up: mesh refinement

As mentioned in section 1, refining the mesh resolution is one of the means to improve the tidal modelling in the Arctic Ocean. The strategy followed by NOVELTIS consisted in starting from the global mesh implemented for the FES2014 model and increasing the resolution in the most demanding zones over the Arctic Ocean. The resolution of the global unstructured mesh ranges between 15 km at the coast and 80 km in the open ocean, in the Arctic. The local mesh refinements include the resampling of the coastline (~5 km at the coast), the increase of the resolution in the open ocean (<40 km in the open ocean) and the increase of the resolution on the bathymetry gradients.

Fig. 3 shows the refinement of the mesh in the North-West Passage, in the Canadian Archipelago, with the initial global mesh on the left and the final refined mesh on the right. Fig. 4 gives the resolution of both meshes in terms of kilometres. The refinement is clearly visible, in particular around the North Pole, in the Southern part of Greenland, in the North-West Passage, and along the Russian coasts.

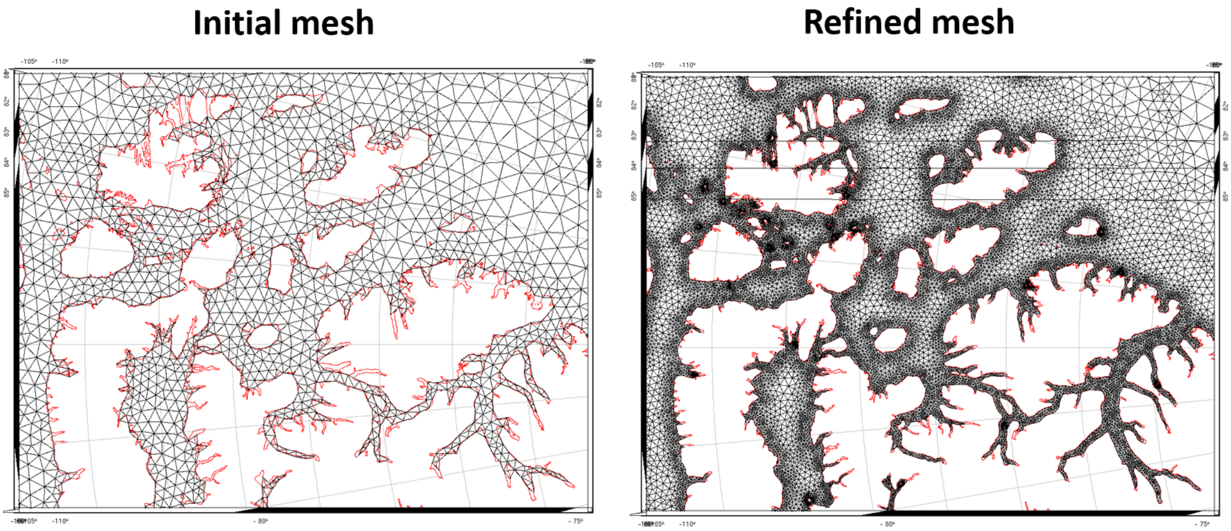

Figure 3: Extracts of the unstructured initial and refined meshes in the North-West Passage (Canadian Archipelago)

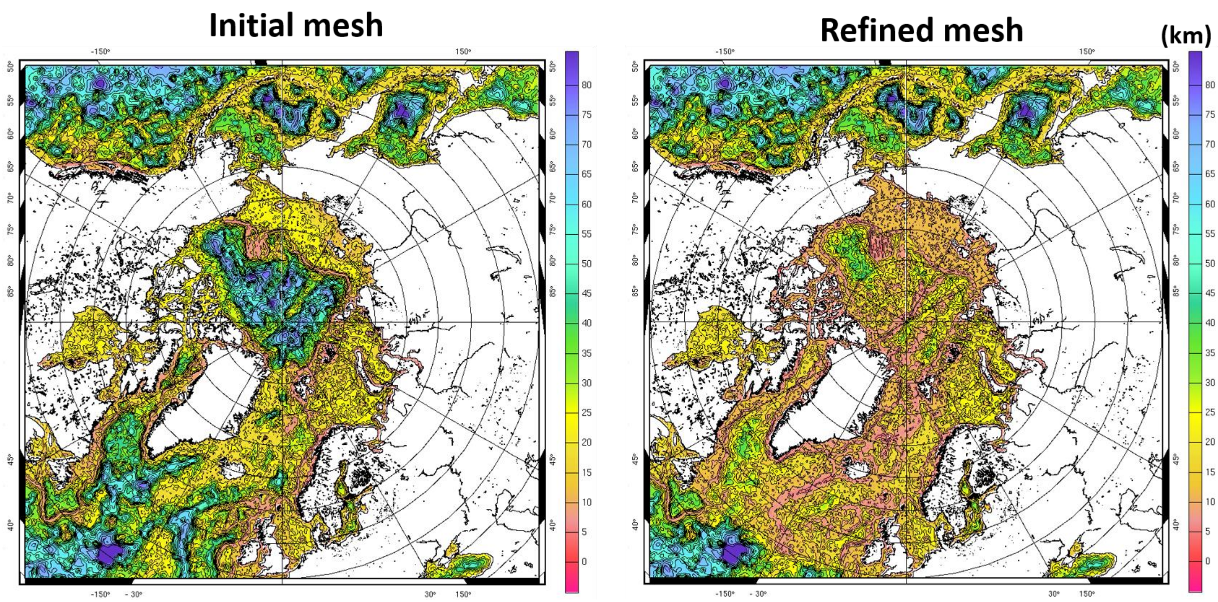

Figure 4: Resolution (in km) of the unstructured initial and refined meshes in the Arctic Ocean

However, increasing the resolution of the mesh does not systematically guarantee the better quality of the hydrodynamic simulations. Indeed, with a refined mesh, the model will be more sensitive to the defaults in the bathymetry. As a consequence, the next step in the implementation and set-up of the model is to identify and smooth the potential bathymetry defaults that will be revealed by the model set-up simulations.

2.2. Altimetry data processing in the Arctic Ocean, in preparation of the assimilation

CryoSat-2 data in LRM and SAR mode (2010-2014) and Envisat data (2002-2010) are included in the analysis to derive harmonic constituents for subsequent assimilation. The ENVISAT and CryoSat-2 LRM data are extracted from the Radar Altimeter Database System (RADS) [4]. The CryoSat-2 SAR and SAR-in data have been processed at DTU using standard range corrections [5], using the retracking method by Jain et al. [6].

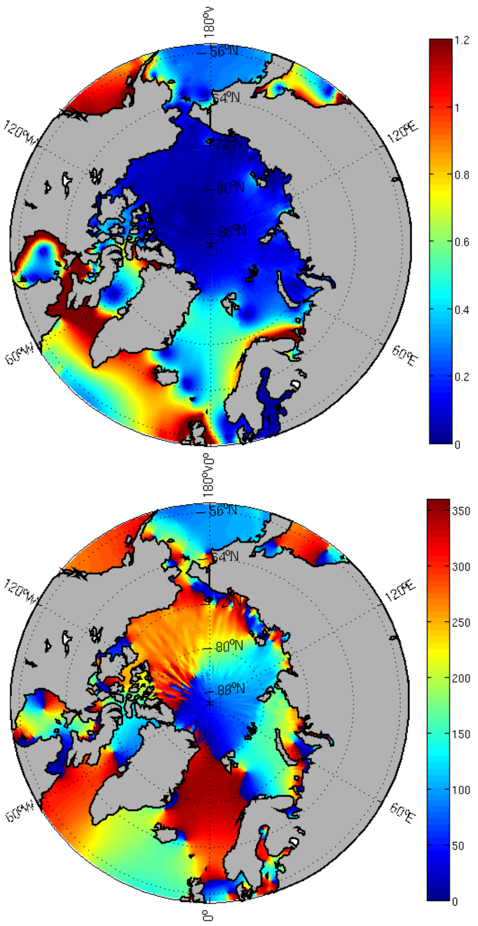

Figure 5: Amplitude (upper plot, in m) and phase (lower plot) of the estimated M2 constituent in the Arctic from CryoSat-2 SAR and LRM data in grid of 1°x3°. The data have been interpolated to a finer grid for plotting.

An Arctic grid of 1°x3° (optimal based on experiments) between 55°N and 88°N was subsequently used with the response method to determine the tidal constituents [7]. All data from each mission within each box were extracted in the way that the averaged along track height for each box crossing was kept for the subsequent tidal prediction. Also potential bias within each box for each missions (like the potential offset for CryoSat-2) was corrected for by removing the mean value for each mission.

All major constituents as well as the M4 shallow water constituent were included in the estimation. The determination of the tidal constituents were performed in a remove/restore methodology where FES2004 is removed prior to tidal prediction and subsequently restored to obtain the final tidal signal.

As we are operating relative to the FES2004 ocean tide model, satellites observe the residual geocentric tide. In order to correct for loading and estimate the residual ocean tide, the tidal amplitude is increased by 6%.

The amplitude and the phase of the M2 constituent derived from CryoSat-2 in boxes of 1°x3° boxes, is shown in Fig. 5. Interpolation has been used to prepare the plot. This explains the tidal constituents across the North Pole where no altimetry is available.

3. CONCLUSIONS AND PERSPECTIVES

The work presented in this paper is under progress and there is still much to be done, but these analyses already show the importance and the need for such a high resolution tidal model in the Arctic Ocean. It is particularly critical with the upcoming Sentinel-3 mission, which will fly over high latitudes regions.

This tidal atlas in the Arctic Ocean is expected to be released by the end of the year 2015. The next steps in the implementation are the tuning of the hydrodynamic model parameters (bottom friction coefficient…) and to run the assimilation process, using the altimetry data processed by DTU Space.

4. ACKNOWLEDGEMENT

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