High resolution tidal modeling in the Arctic Ocean

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Introduction

The Arctic Ocean is a challenging region for tidal modeling, 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 centimeters 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 and SARAL/AltiKa 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 poster presents the current performances of global tidal models in the Arctic Ocean and the on-going work to develop an improved regional tidal atlas in this region. This work is supported by the ESA STSE program, in the framework of the CP4O "CRYOSAT Plus for Ocean" project.

Performances of global tidal models in the Arctic Ocean

Evaluation of the global tidal models vs tide gauges: vector differences for the M2 wave

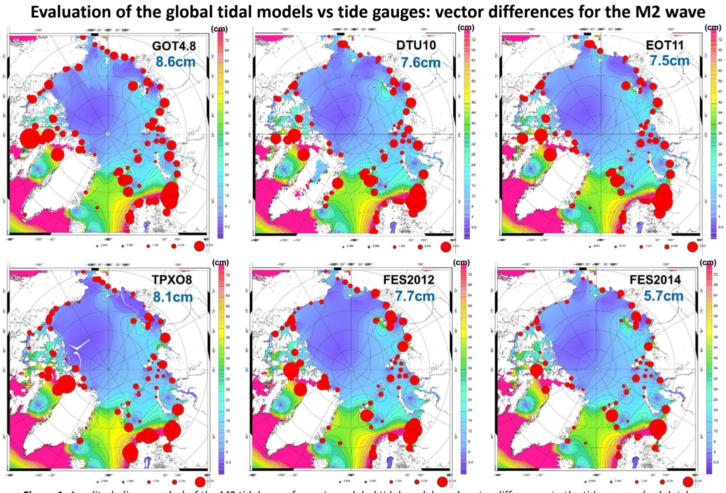


Figure 1: Amplitude (in cm, color) of the M2 tidal wave for various global tidal models and vector differences to the tide gauges (red dots)

- Largest errors in the areas of largest tidal amplitude, as expected
- The performances are quite similar: 7.5-8.5cm of mean vector difference vs TG
- Except for FES2014 (5.7cm) explained by the assimilation of the tide gauge database.

➔ **Means of improvement: regional tidal modeling with finer mesh resolution.**

3 Altimetry data processing, in preparation of the assimilation

Data Processing

- CryoSat-2 data in LRM and SAR mode (2010-2014) and Envisat data (2002-2010) are included in the analysis. C2 LRM+ENVISAT from RADS, SAR retracked using primary peak retracker.
- An Arctic grid of 1°x3° (optimal based on experiments) was used with the response method to determine sine and cosine values for each grid cell and for each major constituent including 4 shallow water constituents.
- The determination of the tidal constituents was performed in a remove/restore methodology where FES2004 is removed prior to tidal prediction and subsequently restored to obtain the final tidal signal.
- Satellites observe the residual geocentric tide, the tidal components are corrected by 8%.
- A first evaluation against tide gauges was performed to validate the altimetric derived harmonic constituents.

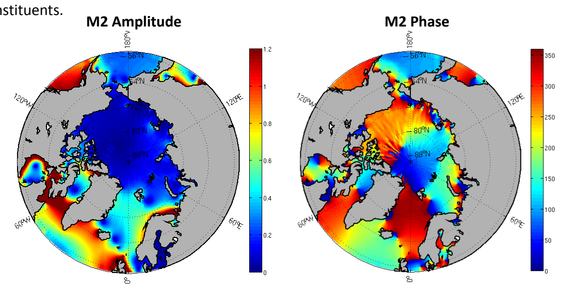


Figure 7: Amplitude (in m) and Phase (in deg) for M2 from altimetry (1 x 3 degree boxes)

Results:

- Model validation using tide gauges in the Arctic is ongoing.
- We need to include SAR-in data as most coastal regions is within the SAR-in mask for Cryosat.
- Some phase fluctuations are seen close to 88N due to a very small amplitude of M2.

NEXT STEPS

The results obtained with the hydrodynamic regional solution are quite encouraging and should be confirmed by the assimilation of altimetry and tide gauge data.

The next steps in the implementation of the tidal atlas will consist in:

- Taking into account the seasonality of the sea ice extent in the hydrodynamic solution ;
- Running the assimilation process, using the altimetry data processed by DTU Space and some tide gauge data.

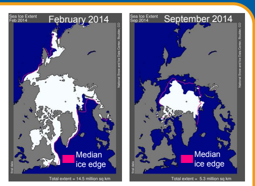
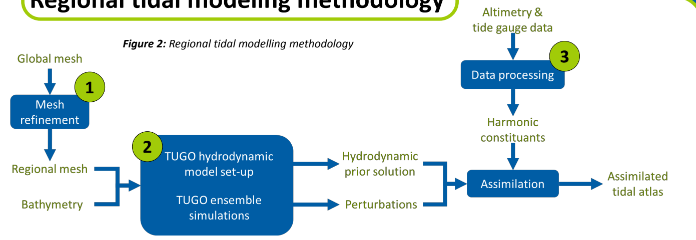


Figure 8: Monthly Arctic sea ice extent (NSIDC maps)

➔ **The Arctic tidal atlas should be released by the end of the year 2015.**

Regional tidal modeling methodology

Figure 2: Regional tidal modelling methodology



The tidal modeling strategy is based on the **TUGO hydrodynamic model** and the **Kalman ensemble assimilation method**. It was previously used for the implementation of global models such as FES2004 (*Lyard & Lefèvre, 2006*), FES2012 (*Carrère et al, 2012*) and FES2014, and for the development of regional models (*Cancet et al, 2012*).

Lyard, F., F. Lefèvre, et al. (2006). "Modelling the global ocean tides: a modern insight from FES2004." Ocean Dynamics 56: 394-415.

Carrère, L., Lyard, F., Cancet, M., Guillot, A., & Roblou, L., FES2012: A new global tidal model taking advantage of nearly twenty years of altimetry, Proceeding of the 20 Years of Progress in Radar Altimetry Symposium, Venice, Italy, 2012.

Cancet, M., Lyard, F., Birol, F., Roblou, L., Lamouroux, J., Lux, M., Jeansou, E., Boulze, D., Bronner, E., Latest improvements in tidal modeling: a regional approach, Proceeding of the 20 Years of Progress in Radar Altimetry Symposium, Venice, Italy, 2012.

1 Mesh refinement

Strategy:

- Starting from a global unstructured mesh with a resolution ranging between 15 km at the coast and 80 km in the open ocean, in the Arctic Ocean.
- Local mesh refinement with resampling of the coastline : ~5 km at the coast, ~20 km in the open ocean, increase of the resolution on bathymetry gradients.

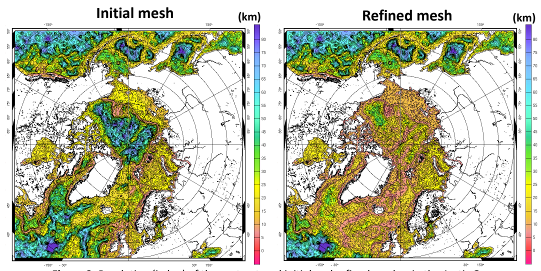


Figure 3: Resolution (in km) of the unstructured initial and refined meshes in the Arctic Ocean

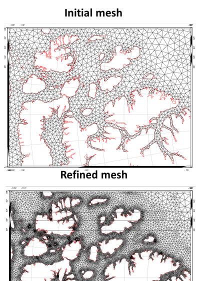


Figure 4: Zoom on the Canadian Archipelago

2 Hydrodynamic model set-up

Strategy:

- Tuning of the model parameters:
  - Bottom friction coefficient
  - Wave drag coefficient (energy transfer from the baroclinic mode to the barotropic mode)
- Boundary conditions: FES2014* tidal atlas
- Evaluation of the performance of each simulation wrt tide gauge database
- Comparison to the global models (both hydrodynamic and assimilated solutions)

➔ **Even without assimilation (yet), the new regional model performs equally or better than the assimilated global solutions.**

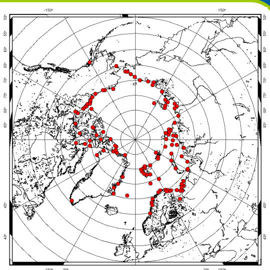


Figure 5: Tide gauge database for validation

*FES2014: Only available for the moment on request for validation team. The official release is foreseen late 2015.

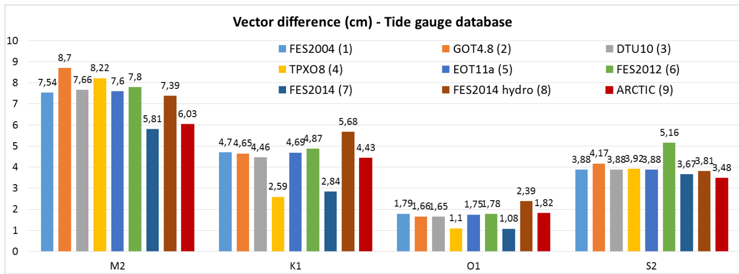


Figure 6: Performances of some hydrodynamic and assimilated global solutions in the Arctic Ocean compared to tide gauges, and for the regional hydrodynamic model developed by NOVELTIS (Arctic (9) on the plot), for four main tidal waves.