Improvement of the Arctic Ocean Bathymetry and Regional Tide Atlas – a CP4O initiative

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Introduction

The CryoSat Plus for Oceans (CP4O) project, under the ESA STSE program, aims to **develop and evaluate new ocean products from CryoSat-2 data** and so maximize the scientific return of CryoSat-2 over oceans. The main focus of CP4O has been on the additional measurement capabilities that are offered by the SAR mode of the SIRAL altimeter, with further work in developing improved geophysical corrections, such as a regional tidal model in the Arctic Ocean.

The Arctic Ocean is a challenging region, 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 scarce** at such high latitudes. In 2016-2017, the CP4O initiative successfully implemented the **Arctide2017 regional tidal model** in the Arctic Ocean. Some possibilities of improvements were identified, that are addressed in the current initiative. First, the **improvement of the Arctic bathymetry** ingested by the hydrodynamic model, by using the near 7 years of Cryosat-2 high quality and high resolution "geodetic" SAR altimetry all the way up to 88°N. Second, the **use of improved Cryosat-2 derived harmonic tidal constituents for assimilation** into the regional tide model.

The project runs during 2017 and in this poster we outline the initial steps to evaluate existing bathymetry in the Arctic (R-TOPO2, IBCAO etc). It also presents the methodology to develop the improved regional tidal model in the Arctic Ocean.

Evaluation of the existing bathymetry datasets

Bathymetry datasets:

- **LEGOS composite bathymetry** (used for FES2014 and Arctide2017)
  - Nucleus: etopo-1
  - 38 modifications worldwide (FES2014 bathymetry)
  - In the Arctic Ocean:
    - IBCAO v2
    - Smith and Sandwell (SW-16) patches
    - RTopo-1.0.5 patches
    - Laptev Sea improvement
- **Rtopo-1.0.5 bathymetry** (Timmermann et al, 2010)
  - S-2004 1-minute digital terrain model (Marks and Smith, 2006)
  - GEBCO at locations poleward of 72° latitude or shallower than 200 m depth (and on land)
  - Smith and Sandwell (1997) equatorward of 70°and deeper than 1000 m
  - Smooth blending for areas in between
  - Other data sources in the Antarctica region only
- **Rtopo-2 bathymetry** (Schaffer et al, 2016)

	Region	Data obtained from
1.	World Ocean bathymetry	GEBCO_2014 (Weatherall et al., 2015)
3.	Arctic Ocean bathymetry	IBCAOv3 (Jakobsson et al., 2012)
5.	Greenland ice sheet/glacier surface height and thickness and bedrock topography	Morlighem et al. (2014) (M-2014)
6.	Fjord and shelf bathymetry close to the Greenland coast	Bamber et al. (2013) (B-2013)
7.	Bathymetry on Northeast Greenland continental shelf	Arndt et al. (2015) (NEG_DBM)
8.	Bathymetry in several narrow Greenland fjords and on parts of the Greenland continental shelf	artificial, see Merging strategy and Data corrections in Sect. 2.2.3 for details
11.	Ice thickness for Nioghalvfjerdsfjorden Glacier and Zachariæ Isstrøm	DTU (Seroussi et al., 2011) Operation Icebridge (Allen et al., 2010, updated 2015) Alfred Wegener Institute (AWI) Mayer et al. (2000)

Assessment of the bathymetry datasets:

- **Visual check**
- **Comparison to other bathymetry datasets**
- **Tidal hydrodynamic modelling** with each bathymetry dataset as model input *(fig. 1)*

→Large reduction of the misfits to the tide gauge observations South of Greenland from RTopo-1.0.5 to Rtopo-2

→Larger misfits in the Barents Sea with RTopo-2

→Coastline generally better defined in RTopo-2 (not shown)

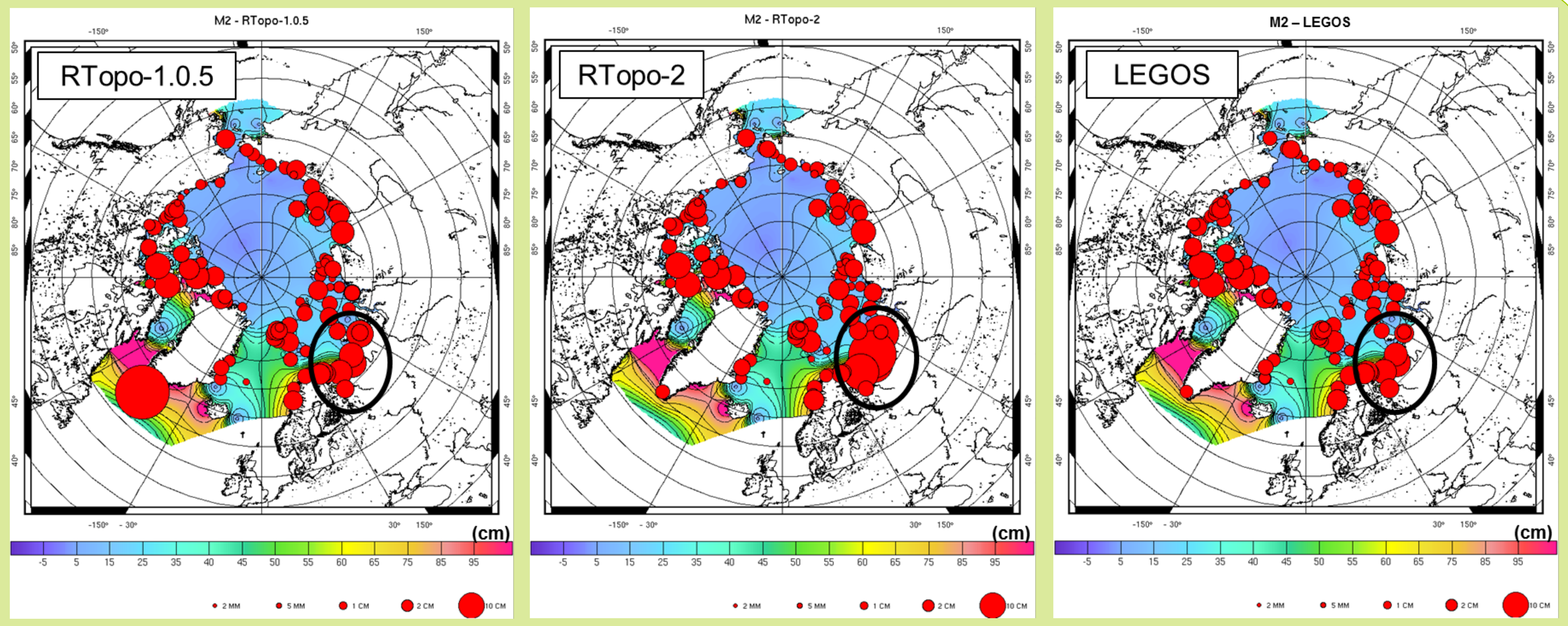
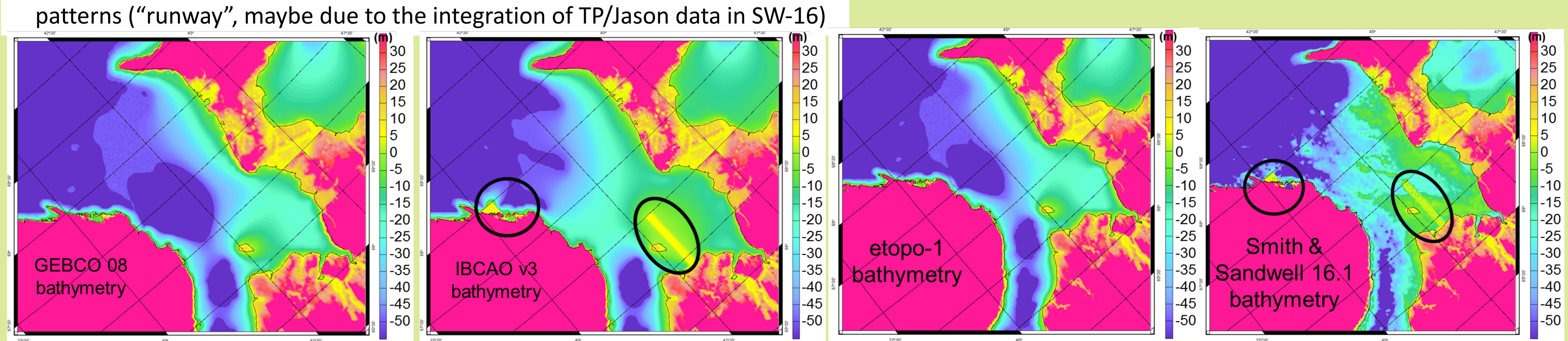


Figure 1: *Vector differences between the hydrodynamic simulations based on various bathymetry datasets and the tide gauges, for M2*

Example of analysis in the Mezen Bay (White Sea)

- Shallow region, Mezen river estuary
- Large differences between the three bathymetry datasets, some unrealistic patterns ("runway", maybe due to the integration of TP/Jason data in SW-16)



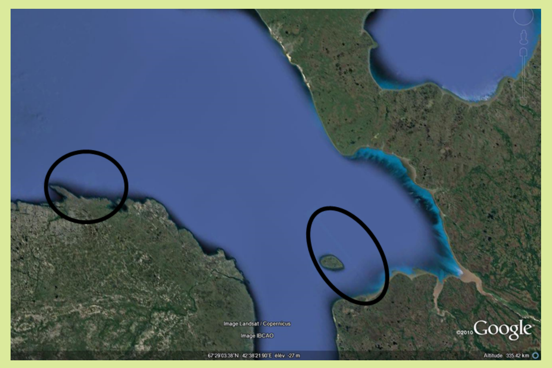


Figure 3: *Zoom on Google-Earth image in the Mezen Bay (White Sea)*

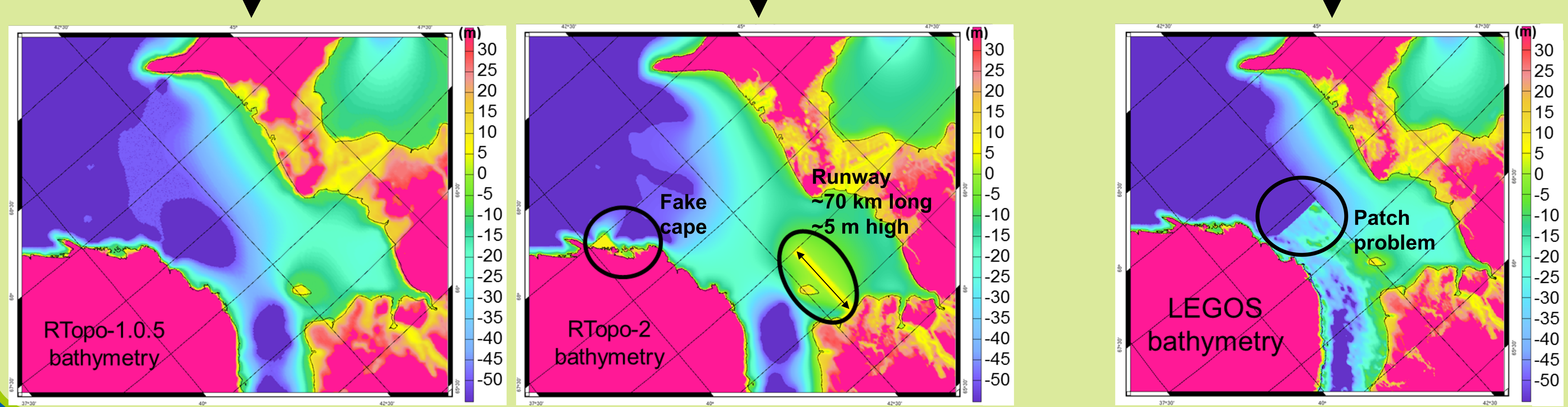


Figure 2: *Zoom on the various bathymetry datasets and their dataset sources in the Mezen Bay (White Sea)*

Take home messages

→There are strong links between the bathymetry datasets and defaults are transmitted from one dataset to the others.

→The "composite approach" of LEGOS is very relevant but some patch problems must be corrected in the database.

→The integration of the CryoSat-2-derived bathymetry should improve the current bathymetry dataset, offshore.

Regional tidal modelling

TUGO hydrodynamic model and Kalman ensemble data assimilation method, as 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*).

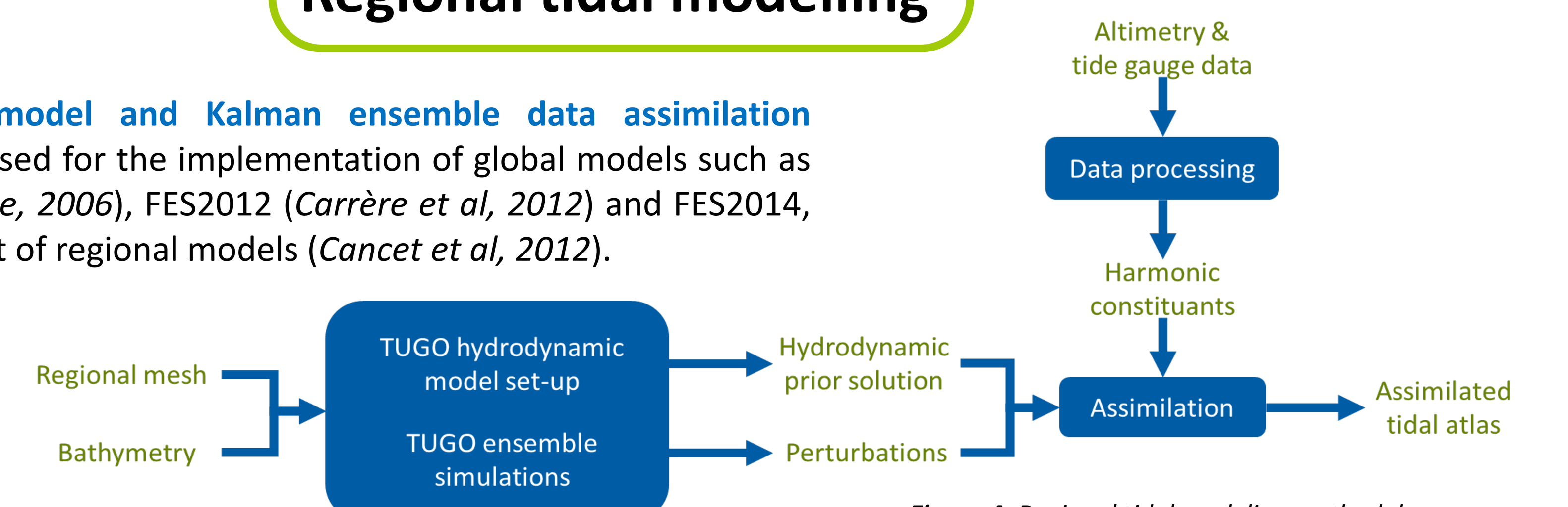


Figure 4: *Regional tidal modeling methodology*

Regional mesh in the Arctic Ocean

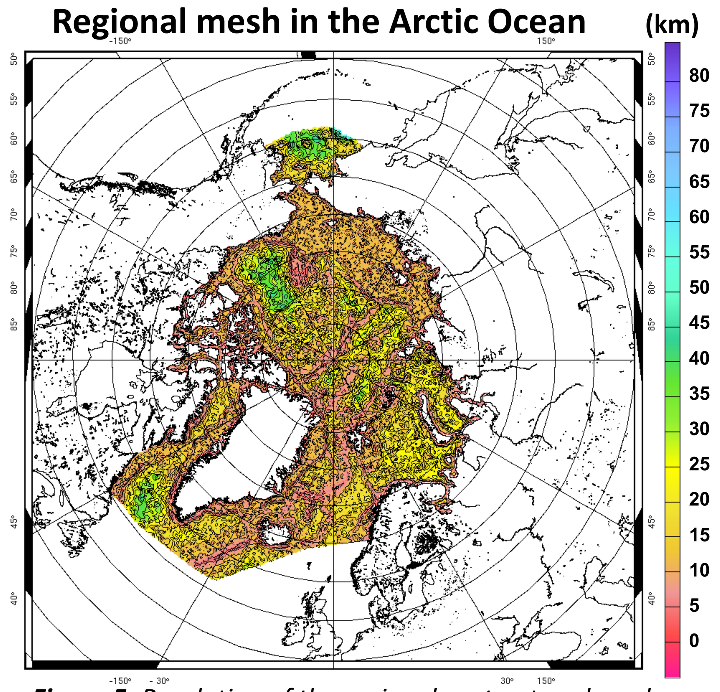


Figure 5: *Resolution of the regional unstructured mesh*

Hydrodynamic modelling

- Tuning of the TUGO model parameters:
  - Bottom friction
  - Wave drag coefficient (energy transfer from the baroclinic mode to the barotropic mode)
- Boundary conditions: FES2014 tidal atlas
- Evaluation of the performance wrt tide gauge database
- Comparison to the global tidal models

➔ **Even without data assimilation, the regional hydrodynamic model performs equally or better than the global solutions** with data assimilation *(results on Arctide2017, Cancet et al, submitted).*

Ensemble simulations

- Data assimilation method based on the ensemble Kalman Filter: requires an estimate of the covariance matrix of the errors of the prior hydrodynamic solution → ensemble of simulations.
- Local perturbations of the bottom friction
  - In 8 coastal zones
  - Local coefficient: 13 different values
  - Two sea ice extent configurations (median Summer and median Winter)

➔ **312 hydrodynamic simulations**

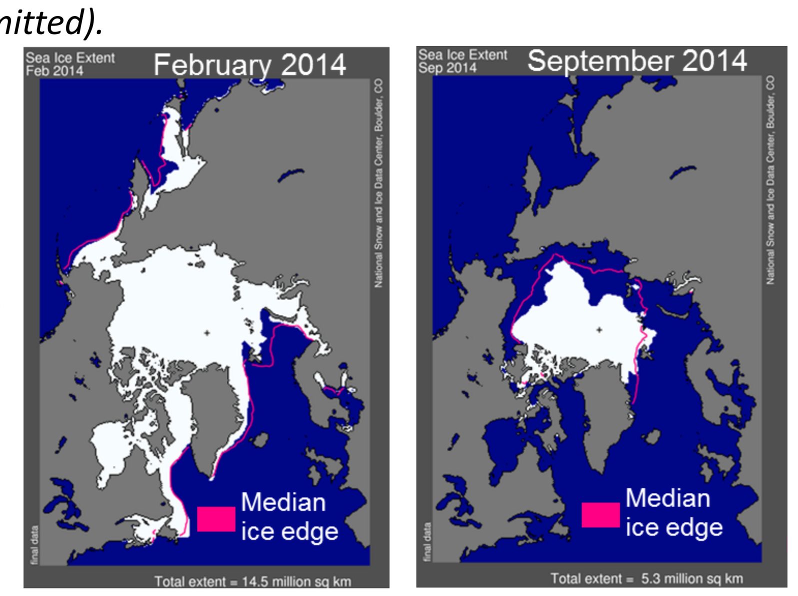


Figure 6: *Monthly Arctic sea ice extent (NSIDC maps)*

Altimetry data processing for assimilation

- Envisat (2002-2010, RADS) and CryoSat-2 in LRM (RADS) and SAR mode (2010-2014, retracked with primary peak retracker).
- Response method used on Arctic grid of 1°x3° to determine the harmonic constituents (amplitude and phase) at each grid cell, for the major tidal component (M2, K1, S2, O1, N2, K2, P1, Q1).
- Tidal constituents computed with the remove/restore methodology: FES2004 removed from the altimeter sea surface heights prior to the tidal analysis and then restored to obtain the total tidal estimates.
- Finally, the tidal components were corrected by 8% to account for the loading tide.

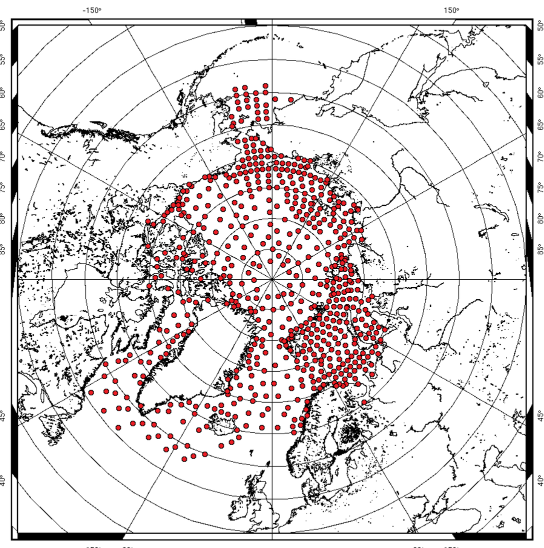


Figure 7: *Assimilation dataset (altimetry and tide gauges)*

Data assimilation

Data selection

- Decimation of the altimetry dataset: more data on the shelves
- Strict editing of the tide gauge database (lots of dubious data)

Validation of the optimal regional tidal model

- Comparison to the global tidal models
- Performance for sea ice freeboad computation

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., et al. Latest improvements in tidal modeling: a regional approach, Proceeding of the 20 YPRA Symposium, Venice, Italy, 2012.
Cancet, M., Andersen, O., Lyard, F., et al, Arctide2017, A High-Resolution Regional Tidal Model in the Arctic Ocean using CryoSat-2 Data (submitted, 2017)