ALBATROSS: Improving the bathymetry and ocean tide knowledge in the Southern Ocean with satellite observations

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Introduction

The knowledge about bathymetry and ocean tides is at the **crossroads of many scientific fields**, especially in the Polar regions, as it **has significant impact on the understanding of the coupled dynamical response of the ocean, sea ice and ice shelves system**, and on ocean and ice parameters derived from satellite measurements. Tides in the Southern Ocean strongly influence the whole global ocean (Fig. 1). Accurate and complete bathymetry information is crucial for tidal modelling, in particular under the Antarctic ice shelves.

In isolated regions such as the Southern Ocean, where very few in-situ campaigns are possible, **satellite observations bring invaluable information**.

The ALBATROSS project (ALtimetry for BAthymetry and Tide Retrievals for the Southern Ocean, Sea ice and Ice Shelves), led by NOVELTIS in collaboration with DTU Space, NPI and UCL, is funded by the European Space Agency in the frame of the Polar Science Cluster in the EO4Society Programme, with the objective to foster collaborative research and interdisciplinary networking within polar Earth Observation.

ALBATROSS is a 2-year project (2021-2023) with several objectives: first, to **improve the knowledge on bathymetry around Antarctica**, considering decade-long reprocessed CryoSat-2 datasets, innovative information on bathymetry gradient location through the analysis of sea ice surface roughness characteristics, and the compilation of the best available bathymetry and ice draft datasets in ice-shelf regions.

Second, to **improve the knowledge on ocean tides in the Southern Ocean** through the implementation of a high-resolution hydrodynamic model based on the most advanced developments in ocean tide modelling, and data assimilation of tidal observations, including satellite-altimetry tidal retrievals in the coastal zone.

Details on the project, results and outcomes can be found at https://albatross.noveltis.fr/

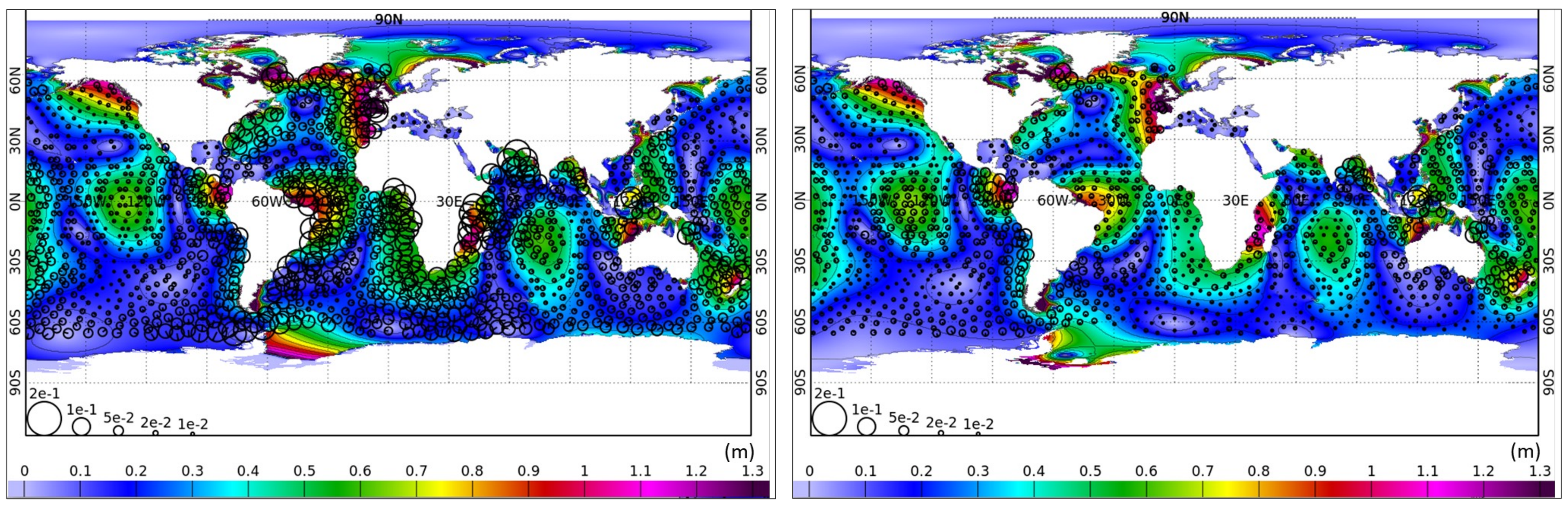

Fig. 1: Vector differences (m) on M2 between altimetry crossover points (deep ocean) and global tidal simulations based on GEBCO-2020 bathymetry (left) or Rtopo-2.0.4 bathymetry (right) in the Southern Ocean. Background: M2 amplitude (m) from the considered model simulation.

Tidal retrievals from satellite altimetry

Tidal harmonic constituents (amplitude and phase lag) computed from sea surface height time series combining CryoSat-2, ENVISAT, SARAL/AltiKa and Jason-suite observations in 0.5 x 3 degree bins.

CryoSat-2 data reprocessed with SAMOSA+ retracker for the 2010-2019 period, LRM/SAR/SARin combined (LRM from RADS).

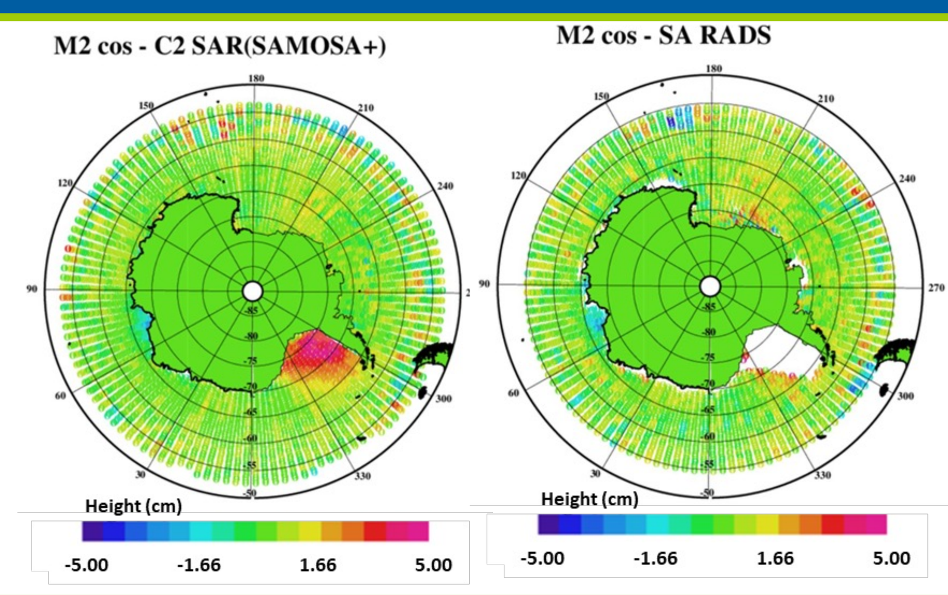

Fig. 2: M2 residual constituent from CryoSat-2 (left) and SARAL/AltiKa (right).

- **Very good agreement between the new altimetry-derived tidal retrievals and tide gauge data.**
- **Strong M2 tidal signal revealed** in the Weddell Sea, not observable with satellite before (latitudes not reached, or with altimeters too sensitive to sea ice).
- The ALBATROSS altimetry tidal retrievals can also help identify dubious in situ data (often old stations with very short records).
- Unprecedent validation dataset to assess the tidal models in the region.

Bathymetry & Tidal modelling

Open ocean

Use of the **most recently reprocessed CryoSat-2 data** (including SAR and SARin modes) in **DTU21 gravity field computation.**

- Bathymetry and gravity are correlated only on limited spectral bandwidth (20 to 100 km).
- Band-pass filtering and downward continuation of the ocean surface gravity to the sea floor, from DTU21 gravity field.
- Initial sea floor topography: BedMachine_Antarctica-2020-v2 (Morlighem et al., 2020) + RTopo-2.0.4 (Schaffer et al., 2019).

→ **New open ocean bathymetry produced.**

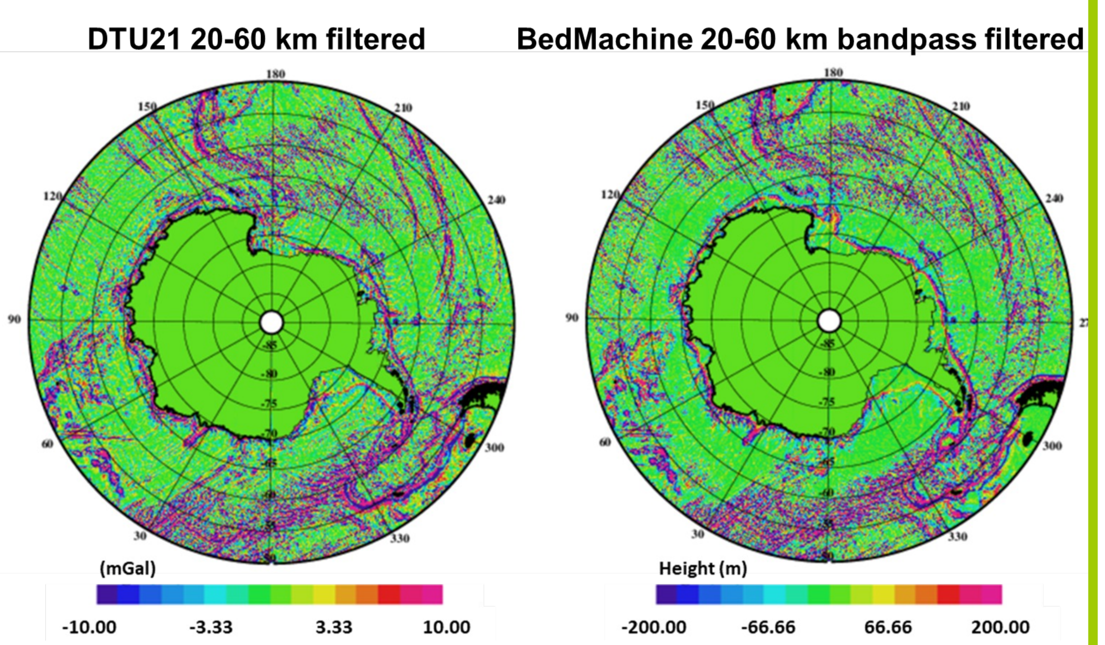

Fig. 3: DTU21 gravity field (left) and BedMachine+RTopo-2.0.4 bathymetry (right) band-pass filtered between 20 and 60 km.

Sea ice roughness and bathymetry gradients

Bathymetry controls ocean currents, temperature and sea ice presence. Locations of steep bathymetry act as hot spots of enhanced vertical heat fluxes mediated by tides and increased turbulence, and higher lead density correlates very well with steep bathymetry.

→ Exploration of the linkage between **sea ice surface properties and bathymetry gradients**, based on a novel technique developed at ES_UCL using NASA MISR (Multi-angle Imaging Spectro-Radiometer) data to produce sea ice surface roughness maps (Johnson et al., 2022).

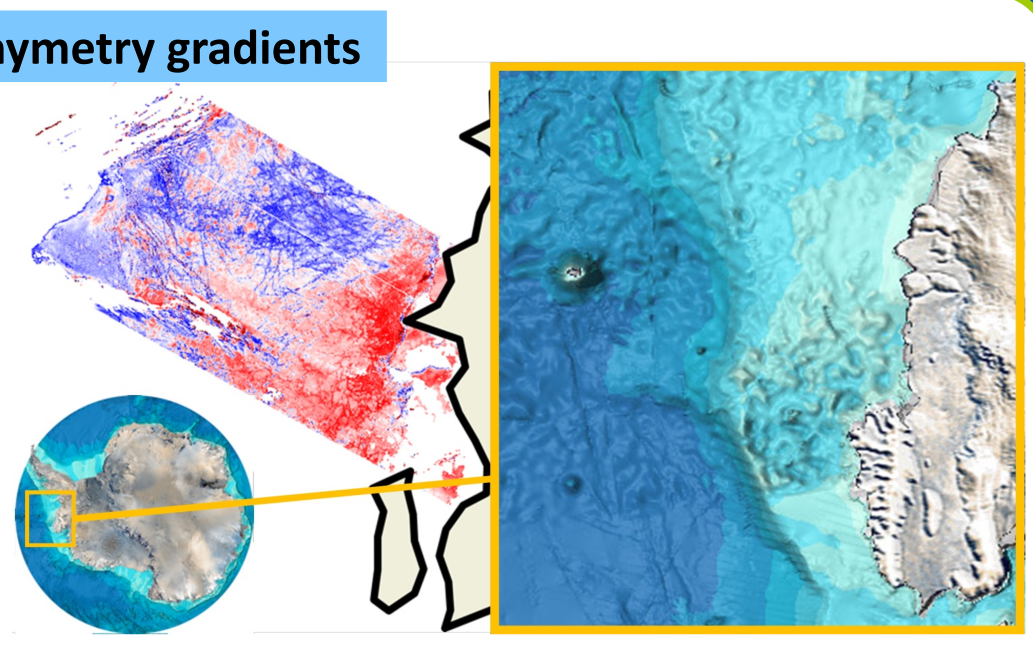

Fig. 4: MISR sea ice surface roughness (red to blue colors, left) and bathymetry features (right) close to the Antarctic Peninsula

High-resolution tidal modelling

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).

- High-resolution unstructured mesh grid
- Careful definition of the model extent
- Regional/local tuning of the model parameters
- Altimetry and tide gauge data assimilation

→ **Clear reduction of the errors on the M2 tide in the Weddell Sea** thanks to the new ALBATROSS ice-shelf bathymetry (vector diff. on altimetry decrease by 23%, from 31.4 mm to 24.2 mm)

→ **Strong improvement in the shelf areas.**

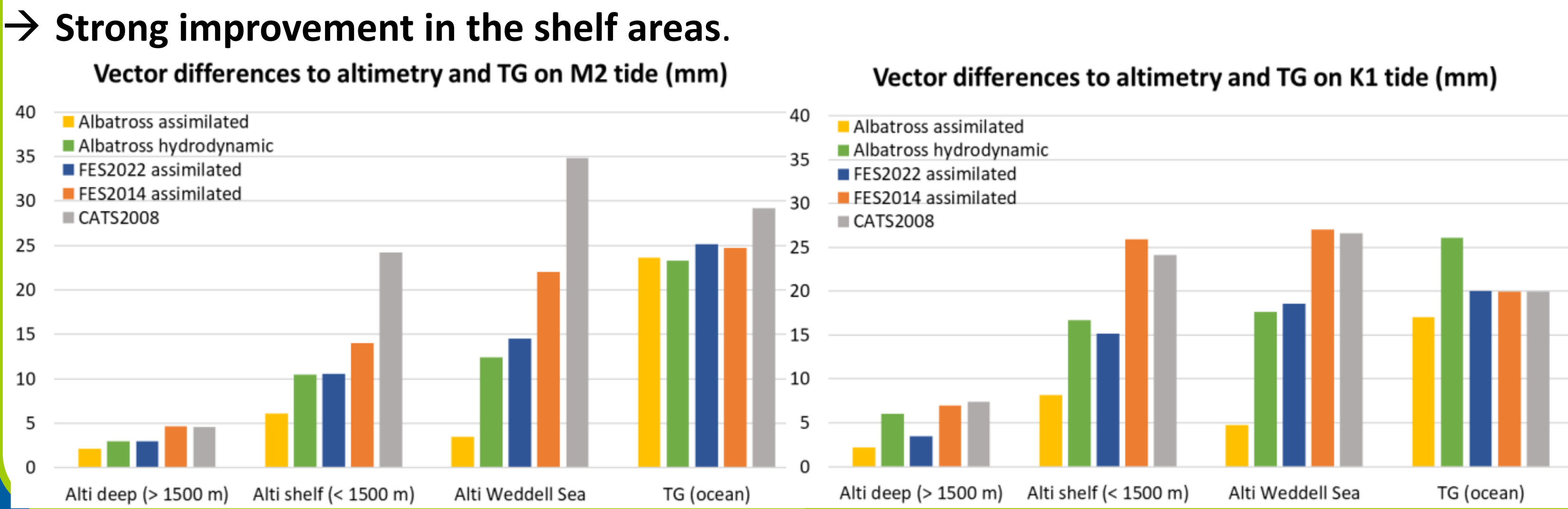

Fig. 5: M2 and K1 vector diff. (m) for ALBATROSS solution in comparison with FES2022, FES2014 and CATS2008 assimilated solutions.

Ice shelves, coastline and grounding line

Accurate information about grounding line location, bedrock topography and ice draft under the ice shelves is crucial to perform accurate tidal simulations.

→ **Updated masks for grounding line and coastline**, based on SAR interferometry, altimetry, and new Landsat-8 imagery: large changes in some under-ice-shelf bays, new islands, new straits…

→ **Updated ice-shelf bathymetry and draft**, based on recent bathymetry datasets.

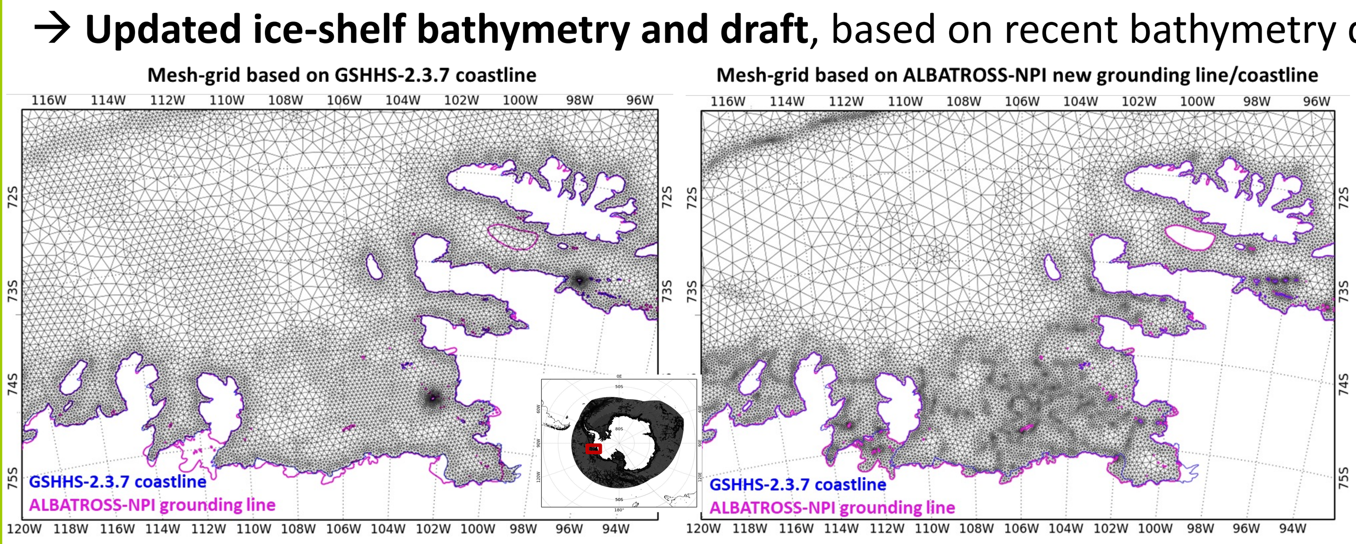

Fig. 6: Zoom on the ALBATROSS unstructured mesh grids based either on the GSHHS-2.3.7 (left) coastline or on the new grounding line (right).

CONCLUSIONS AND PERSPECTIVES

- **CryoSat-2 provides invaluable tidal estimates** in areas of the Southern Ocean not observed before, complementary to the scarce, coastal in situ observations.
- A **new open ocean bathymetry dataset** has been produced, based on CryoSat-2 data.
- A new coastline and grounding line dataset has been produced, as well as new merged bathymetry and ice draft products in the ice-shelf regions.
- Exploration of the links between sea ice specificities, tides and bathymetry features.
- The implementation of a **high-resolution regional tidal model with data assimilation**.

References:

Cancet, M., Andersen, O.B., Lyard, F., Cotton, D., Benveniste, J. (2018), Arctide2017, A High Resolution Regional Tidal Model in the Arctic Ocean, Advances in Space Research, 62(6), 1324-1343, doi: https://doi.org/10.1016/j.asr.2018.01.007

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, https://doi.org/10.5194/os-17-615-2021

Morlighem, M. (2020), MEaSUREs BedMachine Antarctica, Version 2. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/E1QL9HFQ7A8M.

Schaffer, J., Timmermann, R., et al. (2019), An update to Greenland and Antarctic ice sheet topography, cavity geometry, and global bathymetry (RTopo-2.0.4). PANGAEA, https://doi.org/10.1594/PANGAEA.905295

Johnson, T., Tsamados, M., et al. (2022), Mapping Arctic Sea-Ice Surface Roughness with Multi-Angle Imaging SpectroRadiometer, Remote Sens., 14(24), 6249, https://doi.org/10.3390/rs14246249