Final version of the FES2014 global ocean tidal model, which includes a new loading tide solution

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Abstract
An improved FES 2014b tide model has been developed. As several issues had been detected in FES2012 bathymetry, these have been corrected for FES2014 version. Moreover the grid resolution has been increased in areas of interest like shallow waters and on the slope of the continental shelves.
Additional upgrades have been carried out, such as the use of longer altimeter time series (TP-J1-J2), new altimeter standards (instrumental and geophysical corrections, and orbits), and the assimilation of tidal gauges.
Last improvement concerns the computation of a new loading tide solution based on the FES2014 oceanic tide model, and computed in collaboration with J.P. Boy (Univ. Strasbourg). The FES2014 oceanic tide has then been updated to take into account the new loading tide through an iterative process.
New FES2014b oceanic and loading tide model performances have been estimated thanks to comparisons to tidal gauges and altimeter measurements, and validation results are presented here.
FES2014a = FES2014 tide model based on GOT4v8ac loading tide; **FES2014b** = FES2014 tide model based on new FES2014 loading tide
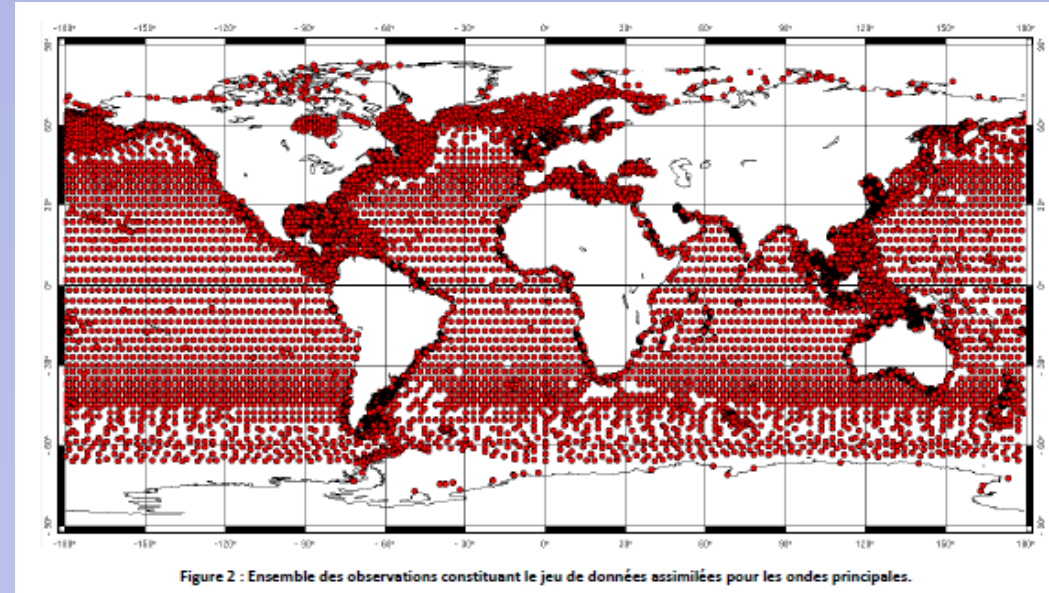
1. FES2014 model configuration

- Improvement of FES2012 bathymetry: merging of several databases and in situ data, specific smoothing
- Refinement of FES2012 mesh on shelves and slopes and some complex coastal regions
- T-UGO model equations (Lyard et al. 2006)
- Modeling improvements including better energy fluxes in Hudson bay, implementation of variable gravity

Size of mesh cells in km

FES2014
- 1 464 500 triangles
- 2 981 213 elevation nodes
- 4 393 500 velocity nodes
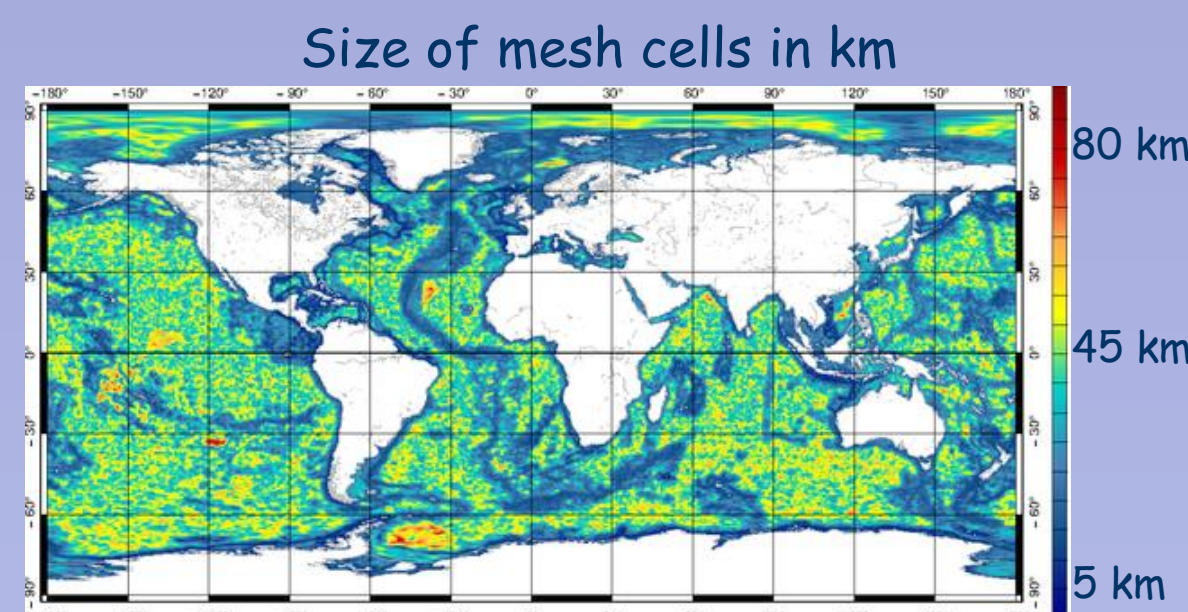
- Assimilation of 12622 data for M2 wave :
  - 600 tidal gauges
  - crossovers for TPJ1J2, TPNJ1N , E1E2EN
  - a selection of along-track 1Hz TPJ1J2

Color map : amplitude of M2 wave (cm)
Red circles: RMS between model and TPJ1J2 crossovers estimations for M2

FES2012

FES2014b

Sim ref FES2014 + loading FES2014

1   2 10 cm

Mean RMS versus TP/J1/J2 crossovers for FES2014b hydrodynamic configuration:

	M2	K1
Deep ocean	1,53 cm	0,88 cm
Shelf seas	6,44 cm	2,26 cm

=> Error divided by nearly 2 compared to FES2012 !
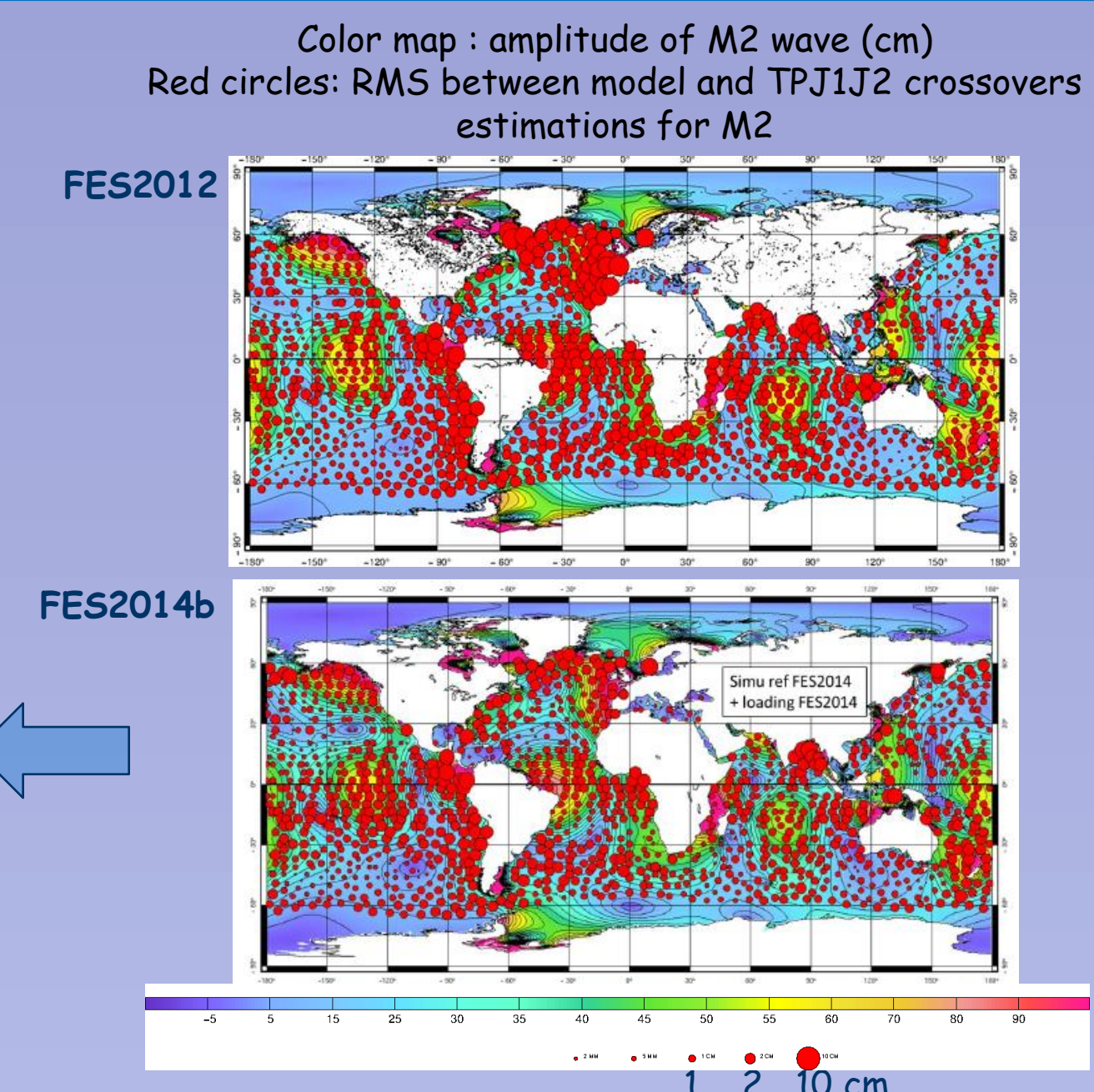
34 waves available in FES2014b final atlas
9 non-linear + 6 long-period + 4 minor + 15 assimilated: M2, M4, S2, 2N2, K2, N2, K1, O1, P1, Q1, Mu2, Nu2, E2, La2, L2
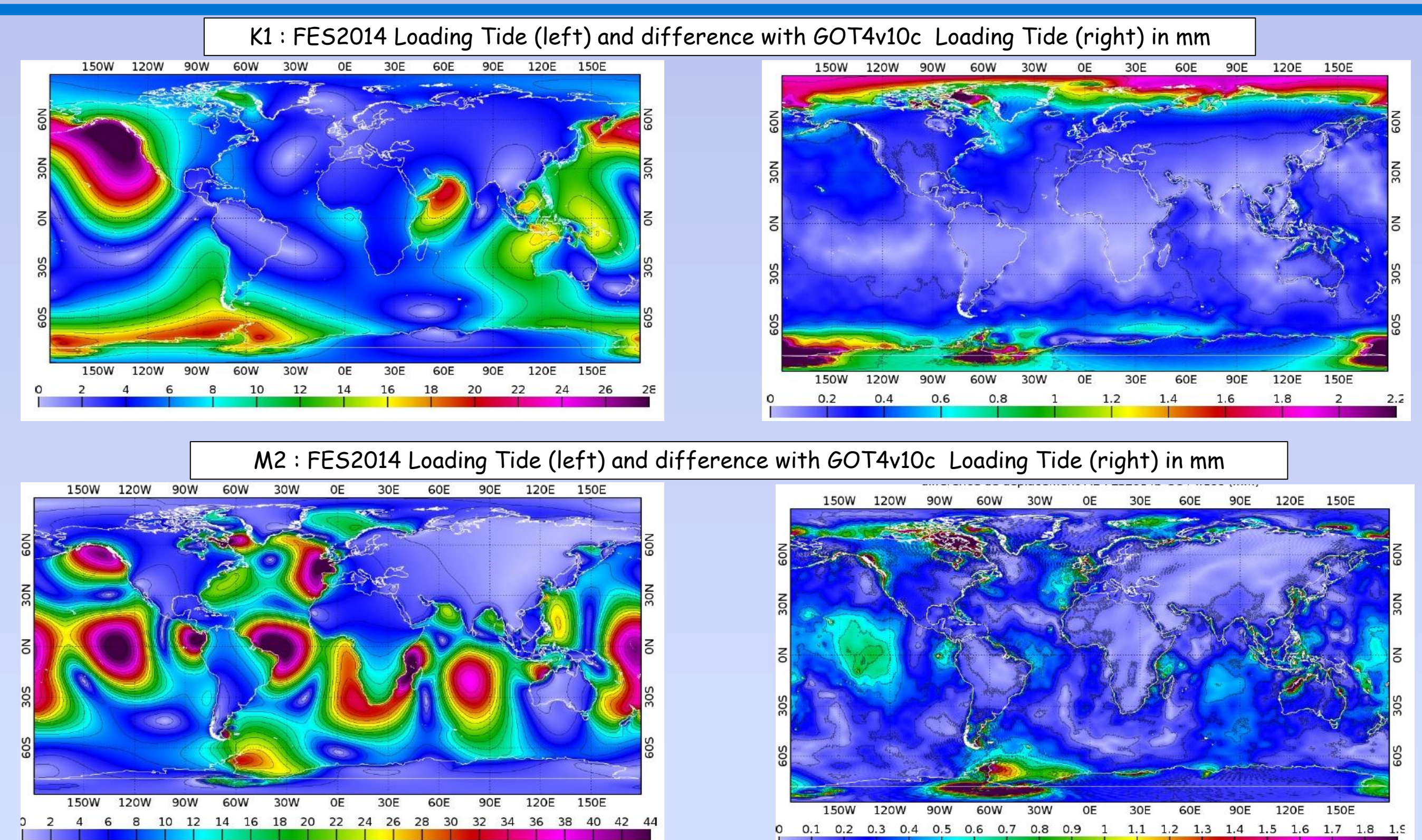
3. New Loading Tide for FES2014

- New FES2014 loading tide has been computed using the **FES2014a** ocean tide (Credits = J.P. Boy, Univ. Strasbourg)

- FES2014 loading tide atlas is composed of **34 waves** => significant differences are noted with GOT loading tide, particularly at high latitudes and in some coastal areas for M2.

- New FES2014 loading tide was used to correct altimeter data and then the assimilation procedure has been completed to produce the new **FES2014b** solution (iterative process)

  => **FES2014b** tide model has been improved compared to previous version **FES2014a**

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K1 : FES2014 Loading Tide (left) and difference with GOT4v10c Loading Tide (right) in mm

M2 : FES2014 Loading Tide (left) and difference with GOT4v10c Loading Tide (right) in mm
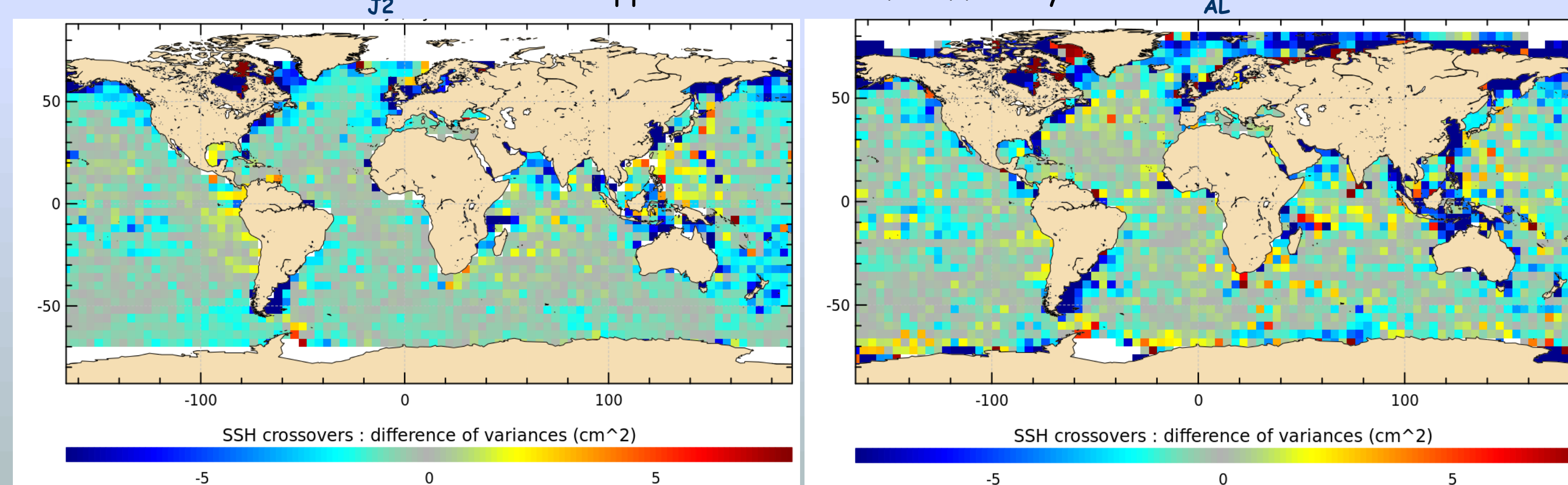
4. Validation results in temporal domain
- Validation versus altimetry in multi-missions context (Jason-1, ENVISAT, ALTIKA, Cryosat-2) and vs tidal gauges (TG). AL data are independent from the tide models tested.

SSH crossovers differences: **Var(SSH with _FES2014b_) – Var(SSH with _FES2014a_)** in cm². Blue patches show improvement of _FES2014b_ vs _FES2014a_: some improvement in coastal regions + some deep ocean regions (Atlantic, Indian, Pacific oceans and Arctic).
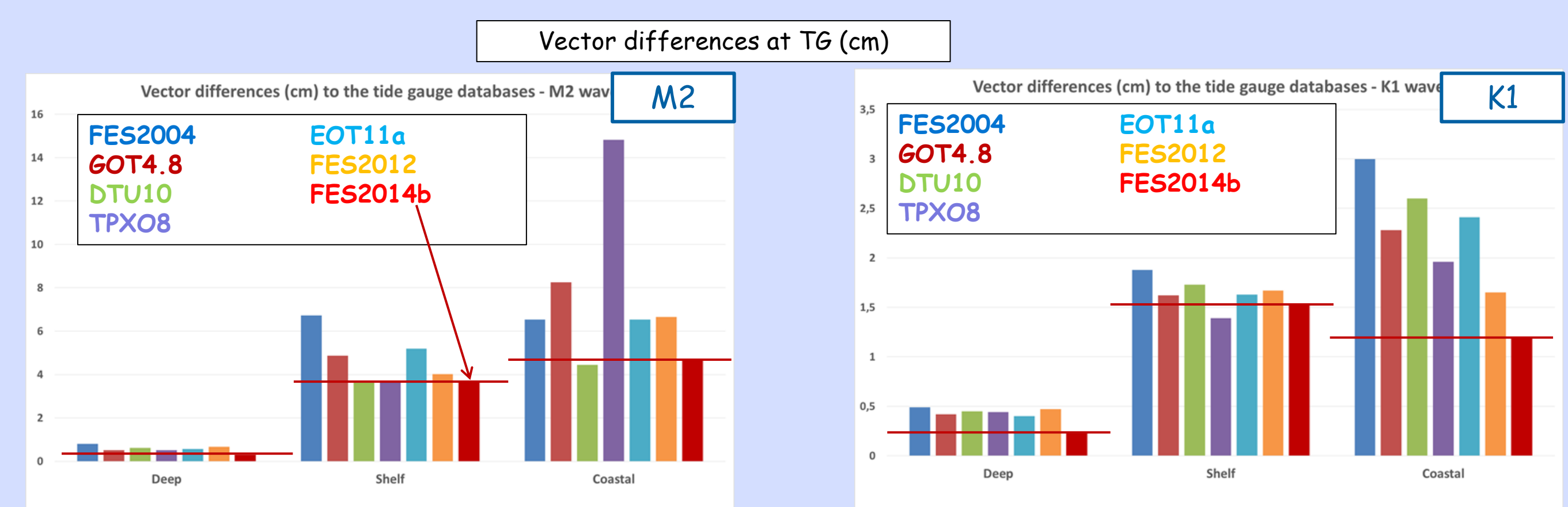

J2

AL
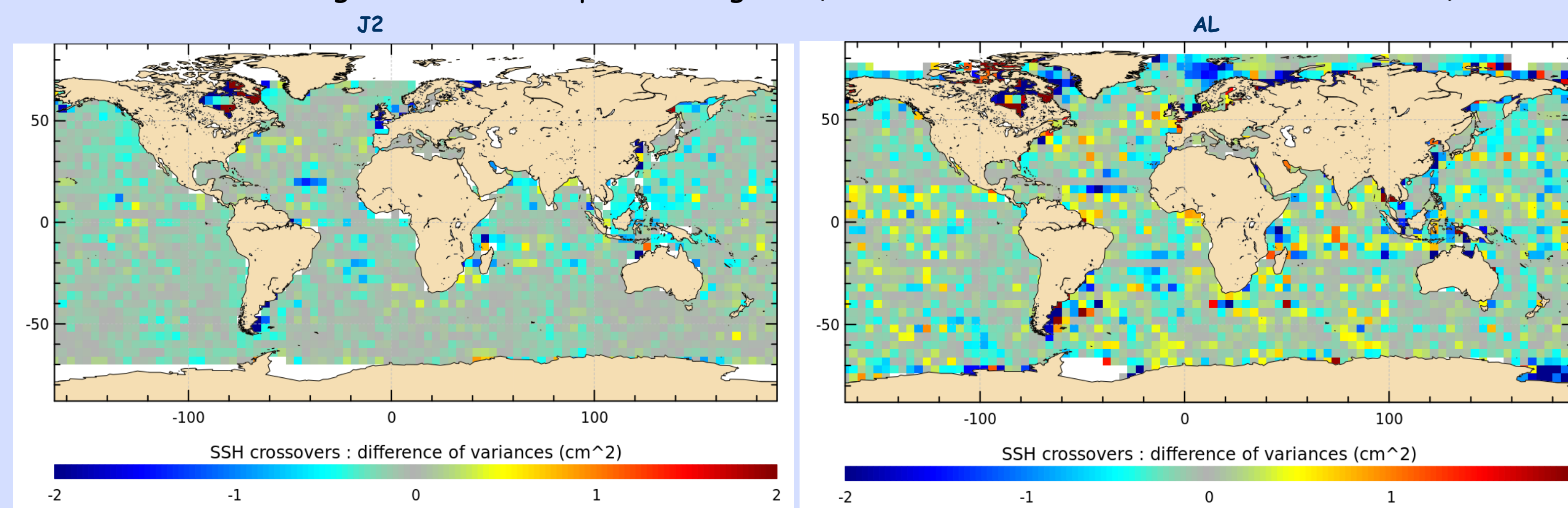
SSH crossovers differences: **Var(SSH with _FES2014b_) – Var(SSH with _GOT4V10_)** in cm². Blue patches show improvement of _FES2014b_ vs _GOT4V10_: large patterns in shallow waters + Arctic + some weaker light blue patterns in deep ocean. Slight variance raise west of Peru, east of Philippines and north of Baffin bay.

J2

AL

5. Validation results in spectral domain
- FES2014b model's performances are estimated for deep, shelf and coastal tidal gauges databases (Stammer et al. 2014, R. Ray) and compared to other global tidal models.

Vector differences at TG (cm)

Vector differences (cm) to the tide gauge databases - M2 wave   M2

Vector differences (cm) to the tide gauge databases - K1 wave   K1

6. Conclusions and perspectives
- FES2014b shows very good performances compared to other global tide models (FES2012, GOT4.10, DTU10, TPXO8) particularly in continental shelves regions, near the coasts and in some deep ocean regions (north Indian and Pacific oceans, around Australia). The model is also very interesting for the Arctic region.
- Assessment of FES2014 tidal currents is presented in the poster « Assessment of the FES2014 tidal currents around Australia », by M. Cancet, F. Lyard, D. Griffin, L. Carrere, N. Picot.
- Specific FES2014 tidal loading solution have been computed.
- FES2014 tidal atlas (elevations, tidal loading and currents) are now available on a regular grid of 1/16° on the AVISO website:
http://www.aviso.altimetry.fr/en/data/products/auxiliary-products/global-tide-fes.html
Perspectives of improvements envisioned for a FES20XX new version are:
- Still improve the bathymetry and mesh resolution
- Test massive assimilation of altimeter data
- Try to improve altimeter tides estimations at high latitudes (ice cover effects) using C2, AL, S3, ERS-EN data
- Integrate some regional modelling using FES2014 at open boundaries
- 3D simulations to get barotropic and baroclinic tides

OSTST 2016   La Rochelle, Nov. 2016