FES 2012 : a new tidal model taking advantage of nearly 20 years of altimetry measurements

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Project website : http://www.legos.obs-mip.fr/recherches/equipes/ecola/projets/fes2012

Outline

1. Introduction
2. FES2012 : hydrodynamic configuration
3. Assimilation process
4. Results
5. Conclusions and perspectives

1. Introduction

Introduction

- Accuracy of tidal models has been much improved these last 20 years
- But errors remain in shallow waters + high latitudes
- Still need to improve tide correction for all altimeter missions and for SWOT mission (2020)

- FES2004 global atlas is getting out-dated …

- Develop a new high resolution tidal model on global ocean taking advantage of:
  - ~20 years altimeters time series: enough to properly analyse deep ocean and shelf seas tidal spectrum
  - Improvements in bathymetry+coastline knowledge
  - Improvements of modeling, assimilation techniques and computer power

- To reach GOT4.8/DTU10 performances or even better
  - Better correction of all altimeter measurements
  - Check 58.74 days signals on MSL

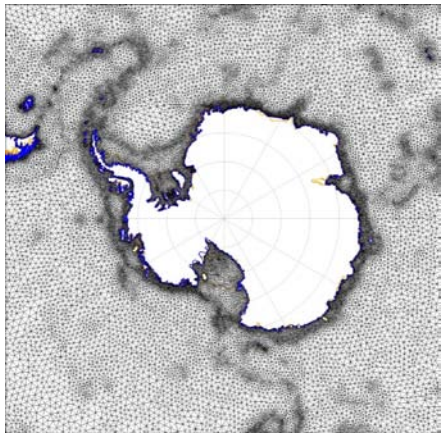
2. FES2012 : hydrodynamic configuration

Global bathymetry & mesh

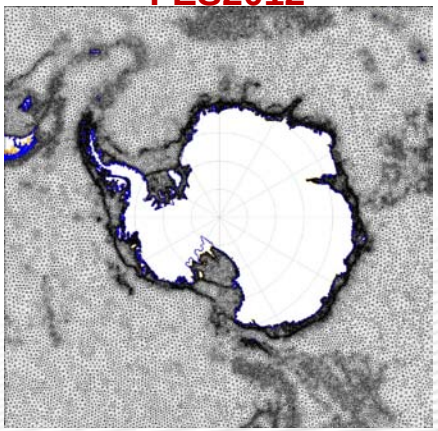
- **Building the most accurate bathymetry is the starting issue**
  - It constrains mesh resolution
  - It is the first accuracy
- **All quality datasets used to build a composite global bathymetry**
  - Global : GEBCO (30'' & 1') , Smith & Sandwell release14 , ETOPO1 (found to be inappropriate)
  - Regional: hydrographic services, PANGEA, IBCAO-IHO
- **Mesh generation**
  - starting from FES2004 mesh
  - Strategy :
    - Keep FES2004 coastal resolution (5-7 km P2) or a bit better
    - Locally resample FES2004 coastlines (Antarctic, Baltic sea …)
    - Diminish open ocean max size (now 75 km)
    - Increase mesh resolution above bathymetry slopes (ridges, continental shelves)
    - Iterative approach (based on test simulations to assess true model accuracy improvement)
  - 60 iterations to reach FES2012 mesh

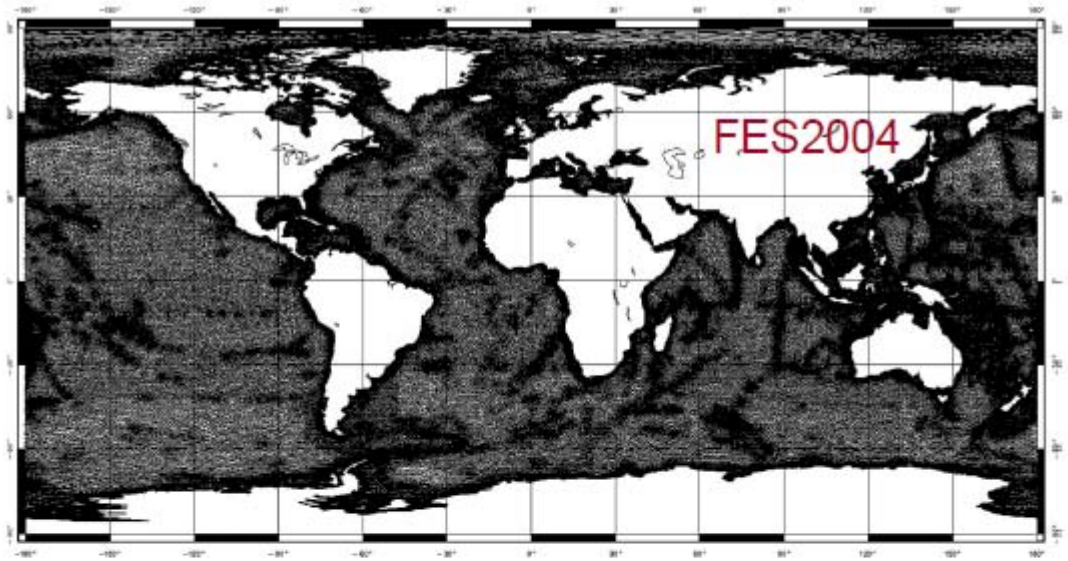
FES2012 Mesh

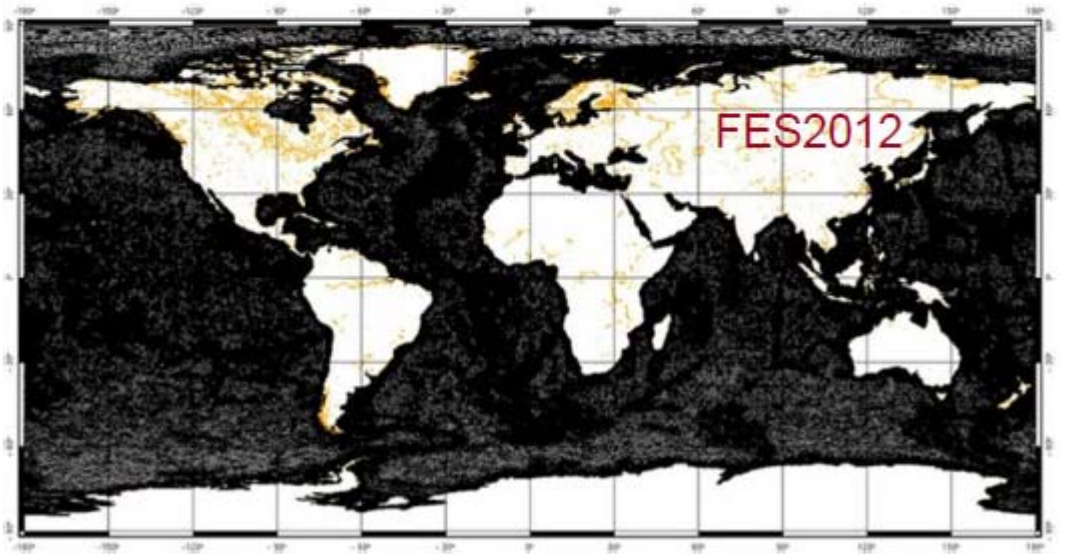
FES2004



FES2012







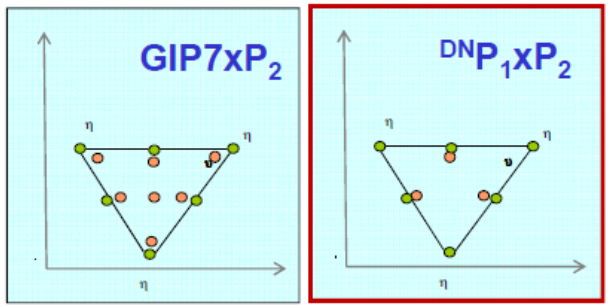
Equations - Resolution

- Quasi-linearised, spectral SW equations, with gravitational forcing
  - Momentum equation $j\omega\mathbf{u} + f \times \mathbf{u} = -g\nabla(\eta + \delta) + g\nabla\Pi - \mathbf{F} \quad -\mathbf{D}$
  - continuity equation $j\omega\eta + \nabla \cdot h\mathbf{u} = j\omega\eta + \nabla \cdot U = 0$

$$\mathbf{F} = \begin{bmatrix} r & r' \\ r'' & r''' \end{bmatrix} \qquad \mathbf{D} = c\rho_0 \frac{\kappa^{-1}}{\omega}\left[(N^2 - \omega^2)(\omega^2 - f^2)\right]^{\frac{1}{2}}\left[\nabla h \cdot^t \nabla h\right]$$

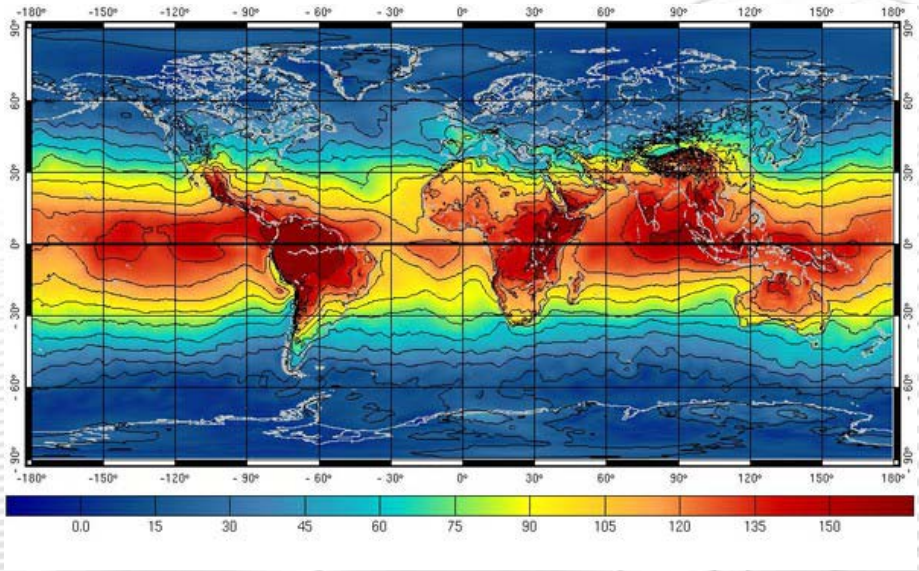
see Lyard et al., 2006, Modelling the global ocean tides: modern insights from FES2004, Ocean Dynamics
http://dx.doi.org/10.1007/s10236-006-0086-x

- FES 2012 resolution
  - 730 000 triangles
  - 1 500 000 elevation nodes / 2 200 000 velocity nodes
- FES2004
  - 500 000 triangles
  - 1 000 000 elevation nodes / 3 500 000 velocity nodes



S2 atmospheric surface pressure forcing

- The radiational contribution represents about 15% of the total S2 ocean tide (astronomical plus radiational).
- Separation of the astronomical and radiational component in a S2 ocean tide observation is quite tricky
- It was decided to add the S2 (surface) pressure tide to the forcing of the prior S2 ocean tide simulation, so it gets more consistent with the assimilated data.



S2 atmospheric tide (Pa), 10years of ECMWF DCDA analysis

3. Assimilation

Preparation of assimilation database

- Main issue in altimeter data harmonic analysis = aliased frequencies and subsequent separation periods (depends on the considered mission)

- After nearly 20 years of duration,
  - most of the alias issue have vanished in T/P and Jason nominal mission
  - This is not the case for the T/P interleaved mission nor for GFO or ERS/EN missions => need to use Xovers !

- Time series for along-track 1Hz measurements + Crossovers:
  - TPJ1J2, TPNJ1N, E1E2EN, GFO

- CLS/CALVAL/PVA databases have been used
  - DAC_ERA_interim correction is used for TP mission
  - the COG correction is not used
  - A multimissions orbit-error is used for GFO and ERS-EN missions (PVA standards)

Preparation of assimilation database

•Several specific filtering have been performed to improve the assimilation database:

- ❑ along-track-filtering to **remove internal-tide surface signatures**
- ❑ **use of GLORYS-V2** 20 years re-analysis to remove non-tidal annual and semi-annual contaminations (K1 aliased frequency is 6 months in TPJ1J2, 1 year in ERS/Envisat)

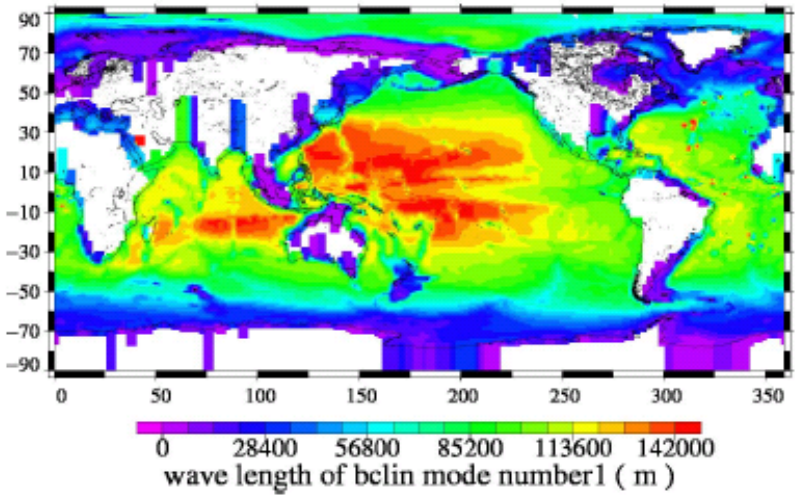
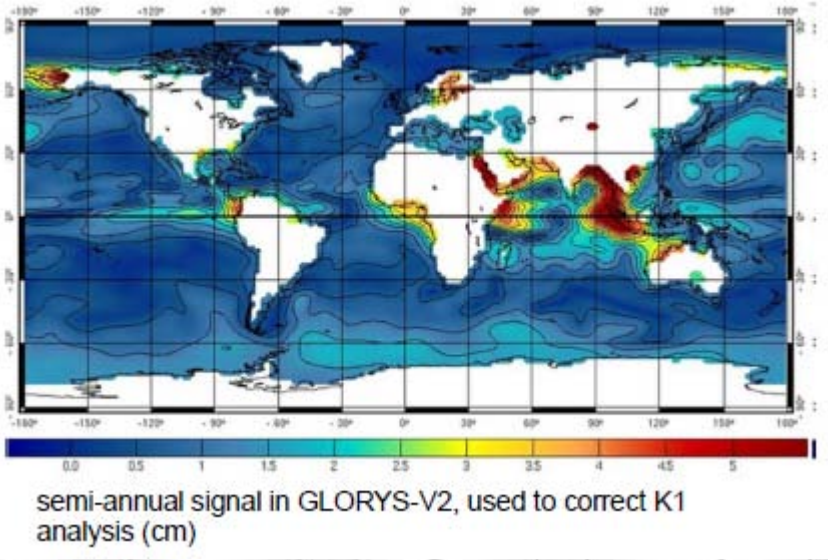


Figure 11 : wavelength of first baroclinic mode (m) (from L. Bessières, 2007).



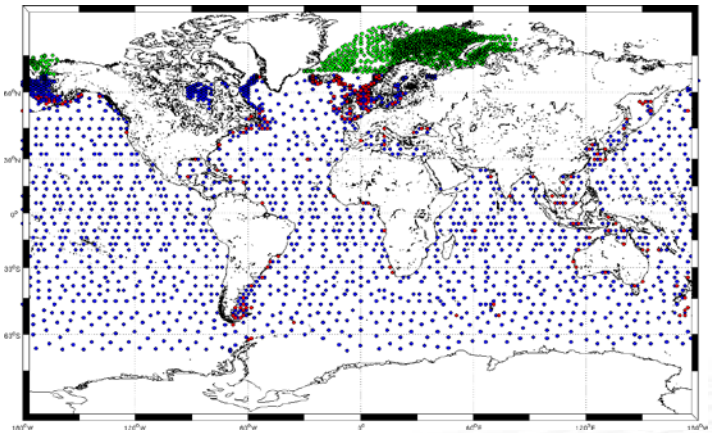
semi-annual signal in GLORYS-V2, used to correct K1 analysis (cm)

FES2012 – Assimilation

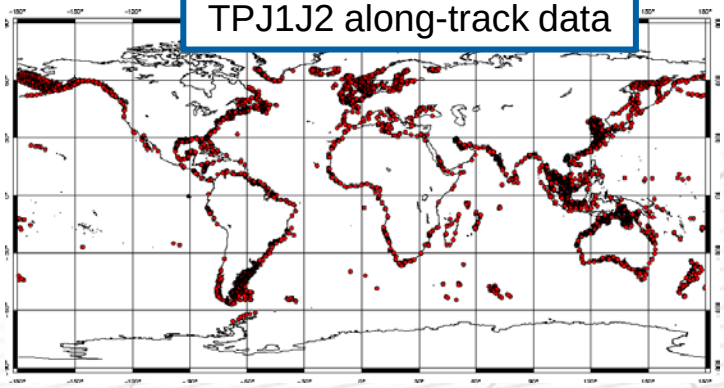
- **Spectral data assimilation code (SpEnOI)**
  - Ensemble method within representers approach: perturbations on bathymetry, friction coefficient, wave drag coefficient -~150 members)

- **6000-12000 assimilated points + 3 TG in Arctic**

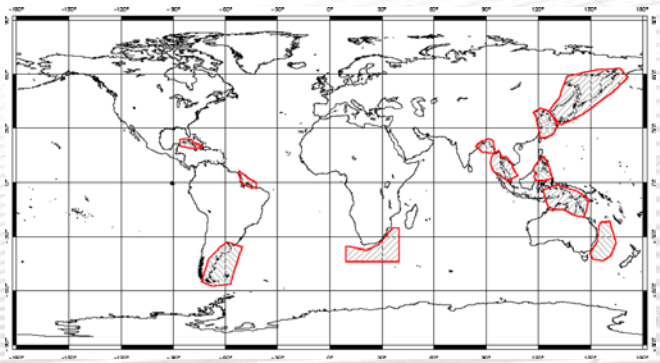
Xovers used



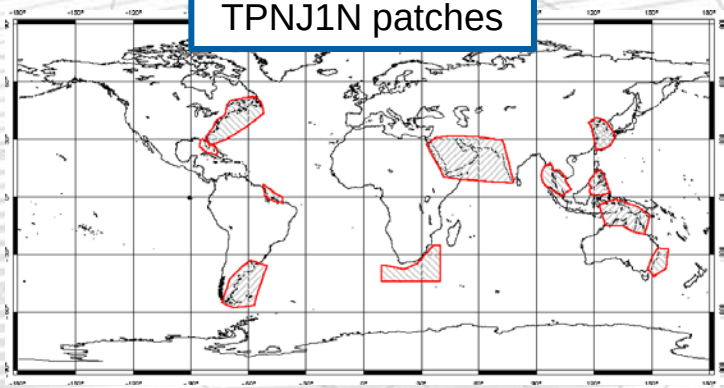
TPJ1J2 along-track data



TPJ1J2 patches



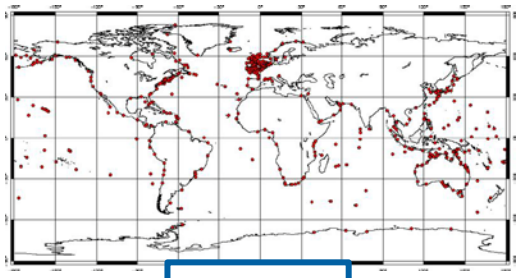
TPNJ1N patches



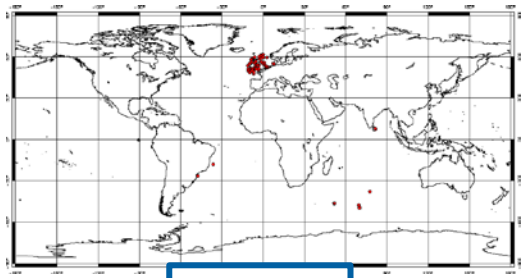
4. Results

Validation in spectral domain

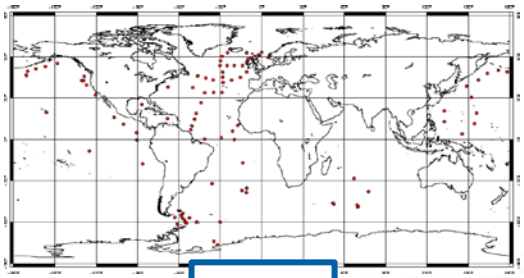
- **Performances vs tide gauge databases**
  - **Coastal =** BODC + WOCE + R. Ray database (shallow_fes09) + SONEL
  - **Shelf =** GLOUP (shelf) + ROSAME
  - **Deep =** ACCLAIM + DART + GLOUP (open ocean)



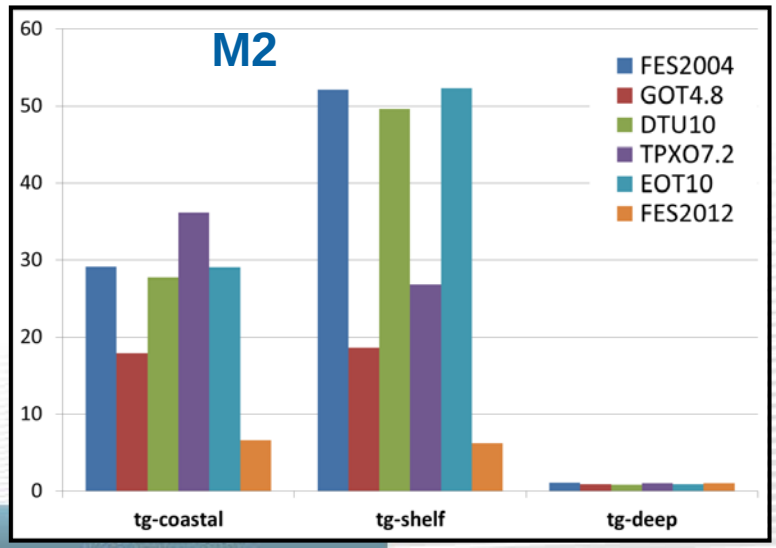
Coastal



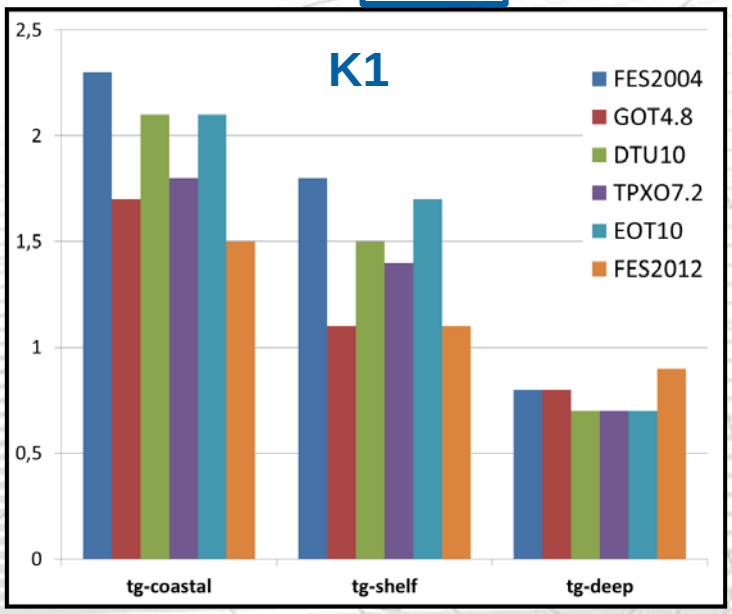
Shelf



Deep

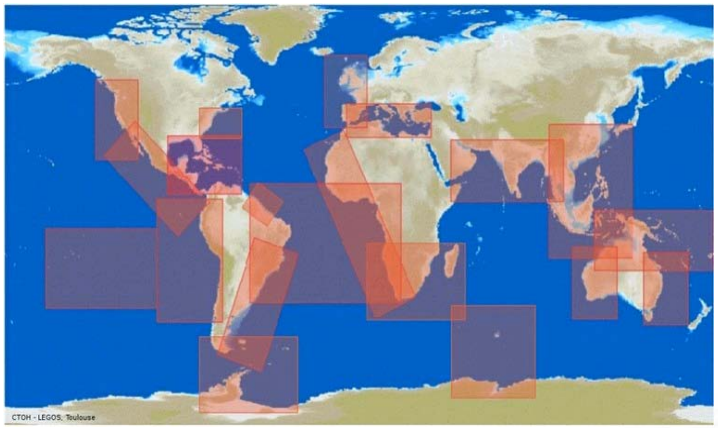


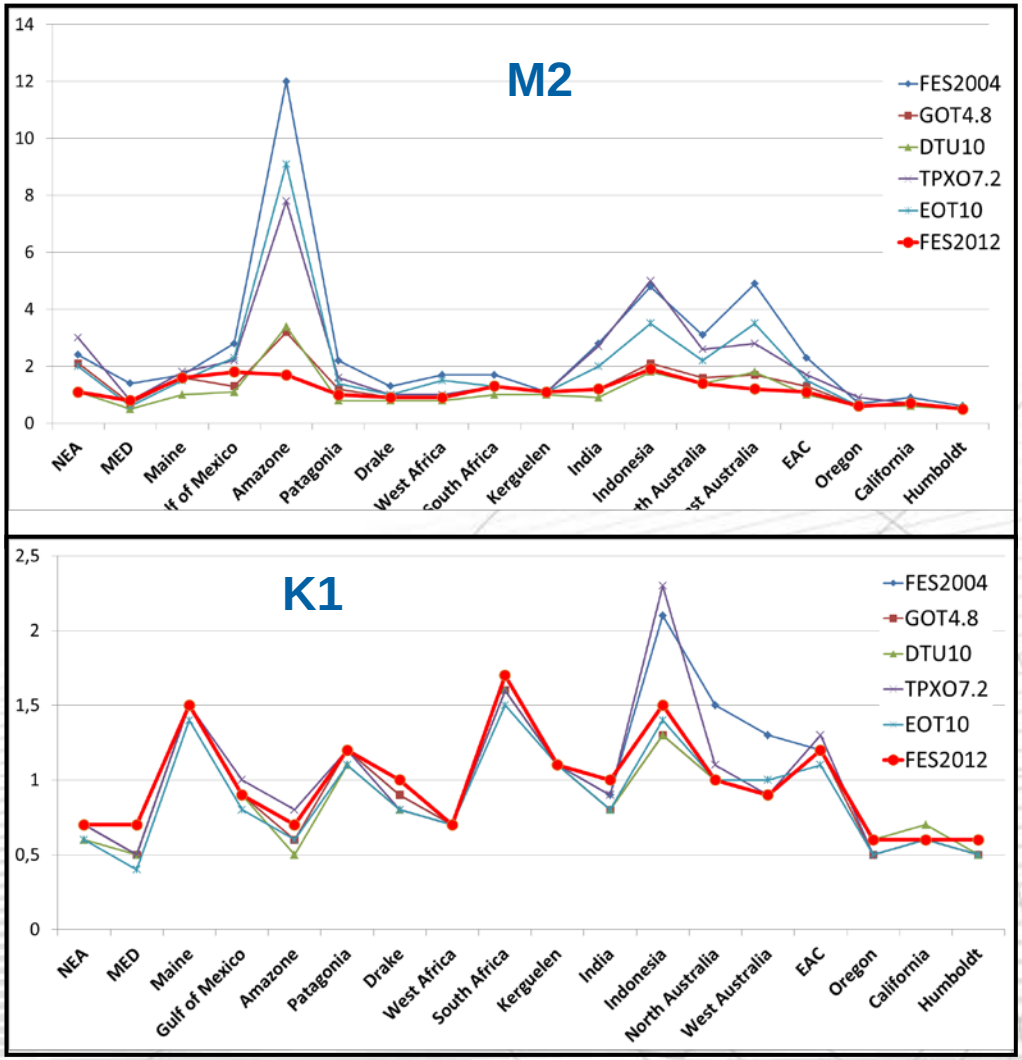
Vector differences (cm)



Validation in spectral domain

- **Performances vs altimeter tidal constituants (CTOH; cf. L. Roblou presentation) :** http://ctoh.legos.obs-mip.fr/products/coastal-products/

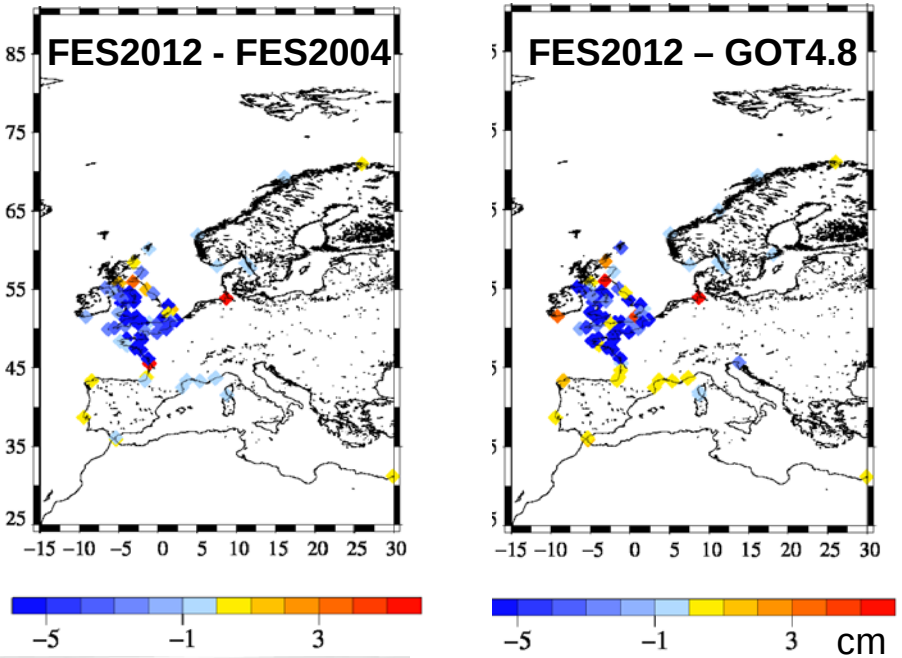




Validation in temporal domain

- **Modeling + omission error**
- **Performances vs TG data**
  - WOCE, BODC, SONEL, Puerto del Estado, OPPE (MyOcean)
  - Comparing with FES2004 and GOT4.8

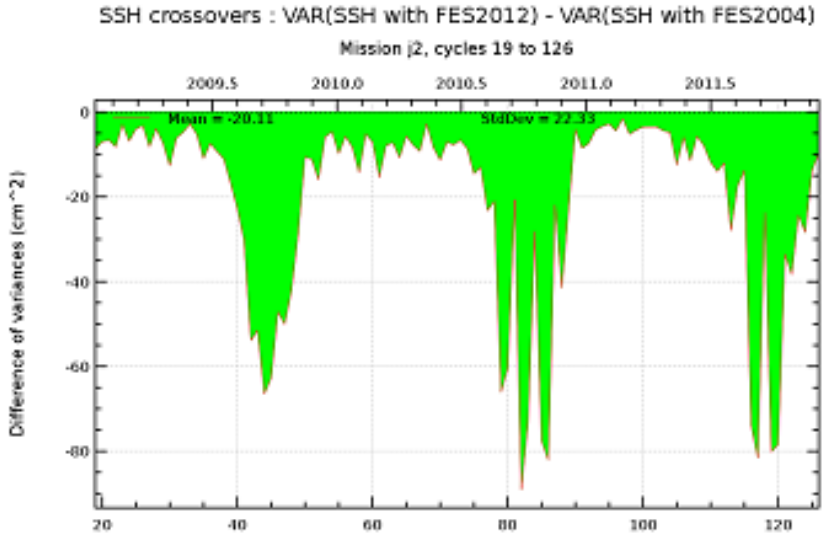
  - FES2012 globally better than FES04 and GOT
  - Some points show a degradation : FES04/GOT4.8 assimilate/include TG and FES2012 not yet

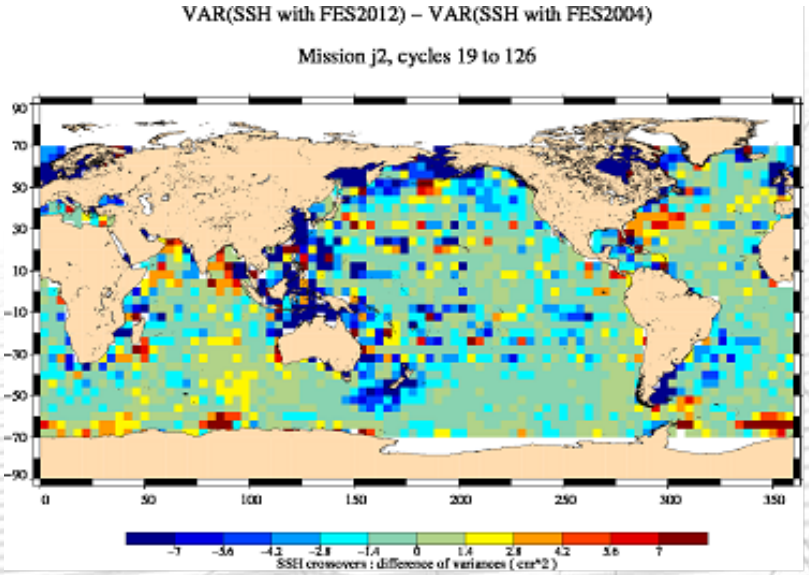


Validation in temporal domain

- **Performances vs global altimetry databases (CLS/CALVAL)**
  - Global ocean, multi-missions diagnostics : J2, EN
  - Along-track and crossovers series
  - First results on variance reduction analysis

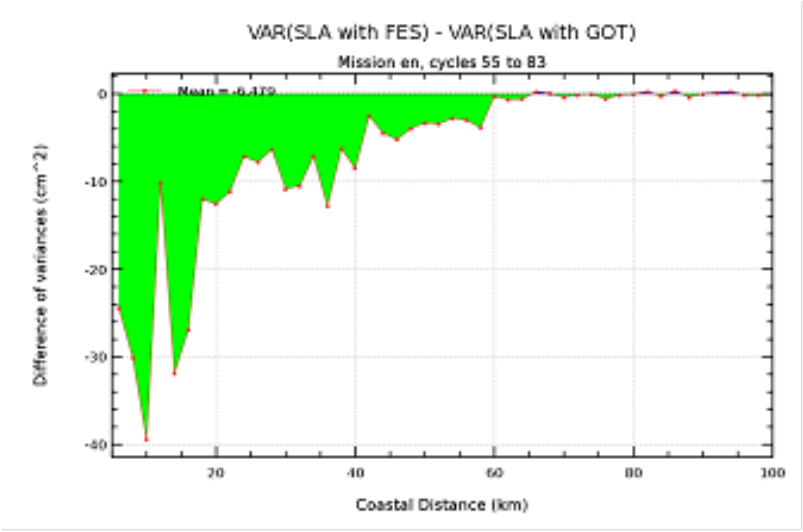
SSH crossovers variance reduction using FES2012 instead of FES2004 for J2 (cm²)

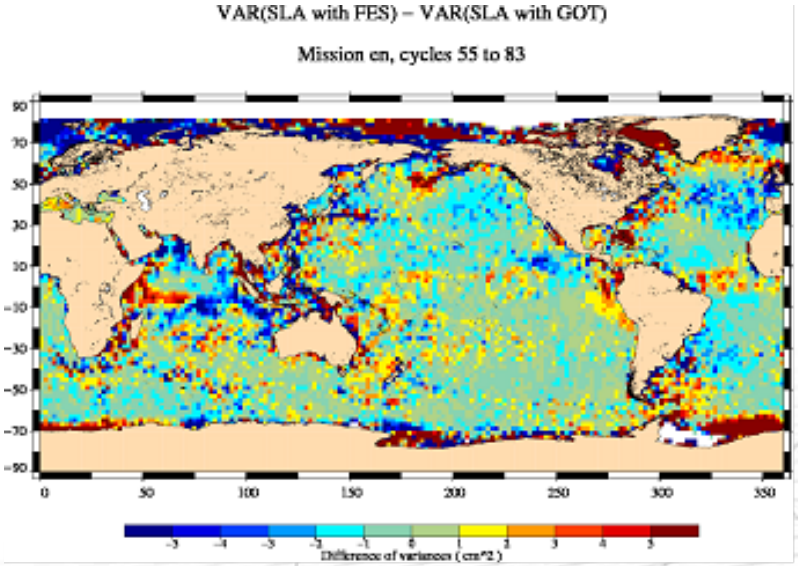




Validation in temporal domain

SLA variance reduction using FES2012 instead of GOT4.8 for EN (cm²)





– More validation diagnostics are still computed …

Conclusions

- A new HR hydrodynamic tidal model had been developed for global ocean
- M2 wave is clearly better than DTU10 and GOT4.8, particularly in coastal and shelf regions;
- K1 is better in coastal/shelf regions but not in deep ocean
- First global validation vs FES2004 shows :
  - strong global improvement vs FES2004, particularly in shelf regions
  - slight degradation in some few deep ocean regions + some TG sites
    - Likely due to the non assimilation of TG in this version of FES2012
    - No data assimilated at southern HL
- Global validation vs GOT4.8 :
  - seasonal improvement due to HL impact
  - Improvement in coastal/shelf regions
  - validation is on going …
- Good results obtained in shelf regions are explained by its finer resolution (1/16°), and the specific selection of assimilated data in these regions. FES2012 also benefits from an accurate bathymetry.

Perspectives

Global validation vs GRACE data is on going

FES2012 results can be improved soon, thanks to all development not yet used:

- assimilate TG and more data at HL
- improved bathymetry (ETOPO-1 found to be inappropriate)
- improved modeling (the reference simulation)
- improved assimilation ensembles
- compute new tidal load/self-attraction

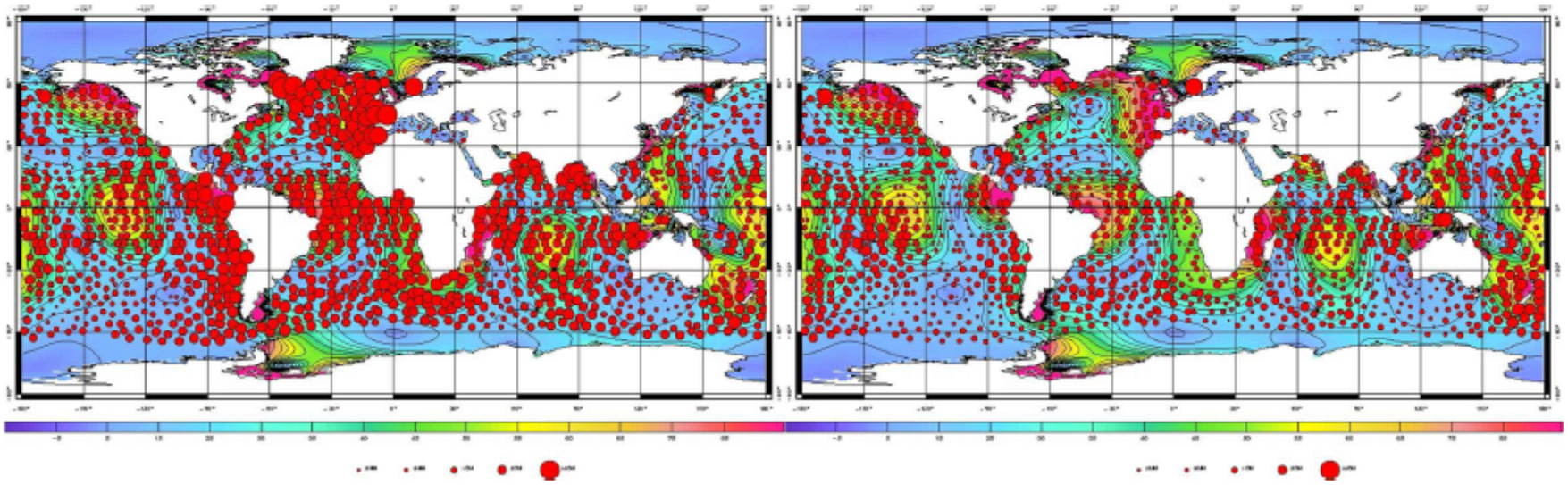
•=> FES 2013 …

Latest hydrodynamic experiments

State of the art

comparisons against TP/J1/J2 (deep / shelf)

	FES2012	FES2013
M2	24 / 93	13 / 53
S2	10 / 28	9 / 22
K1	11 / 30	10 / 23
O1	12 / 30	7 / 19



FES2012 reference

June 2012