Tidal downscaling in a 3D (structured) circulation model: a new approach based on tailored 2D (unstructured) simulations

F. Toublanc[1*], N. Ayoub[2], F. Lyard[2], P. Marsaleix[3], P. De Mey[2], T.Duhaut[3], D.Allain[4]

* florence.toublanc@legos.obs-mip.fr

[1]CNES/LEGOS, [2]CNRS/LEGOS, [3]CNRS/LA , [4]CELAD/LEGOS – Toulouse, France

Regional 3D circulation modelling is necessary to study small scale processes that global models cannot represent. Since theses processes are still partly determined by large scale dynamics, efficient downscaling is a great challenge, especially because open boundary conditions are, in essence, imperfect (Herzfeld, 2009 ; Oliger and Sundstrom, 1976). Here, we focus on tides in the Bay of Biscay, where they can be highly energetic (up to 6m in tidal range), and strongly non-linear (M4 amplitude up to 25 cm). We propose a new approach to tidal downscaling by using two numerical models, Symphonie (Marsaleix et al., 2008) and T-UGOm (Lyard et al., 2004), on the same rectangular mesh and bathymetry at the nodes. The horizontal resolution varies between 3 km at the oceanic open boundary and less than 300 m in the Gironde estuary. We compare three simulations of the 3D model Symphonie with three different tidal solutions prescribed at the open boundaries: the FES2012 atlas, a T-UGOm 2D spectral simulation and a Symphonie 2D clamped simulation. The impact on the tidal and circulation solutions of the 3D model is evaluated.

How to force a 3D circulation model with tides?

Tides

Open Boundaries

3D circulation model

Tidal elevations & tidal currents

Influence on sea surface height, current velocities, mixing

Tidal atlas FES2012

Global model
Based on T-UGOm
Satellite altimetry assimilation
Carrère et al., 2012 ; Lyard et al., 2004

2D circulation model S2D

Symphonie model
2D clamped simulation
Structured grid
No atmospheric & OGCM forcing
FES2012 tidal OBC

2D spectral model T-UGOm

T-UGOm model
2D spectral simulation
Unstructured adapted to quadrangle discretization
FES2012 tidal OBC
Lyard et al., 2004

3D circulation model S3D

Symphonie model
3D regional configuration
Structured grid
Marsaleix et al., 2008, 2009

Same grid
Same bathymetry

All time-stepping simulations ran over 7 months, with a 15 days spin-up for the online tidal analysis

The BOBSHELF configuration: a tool for downscaling

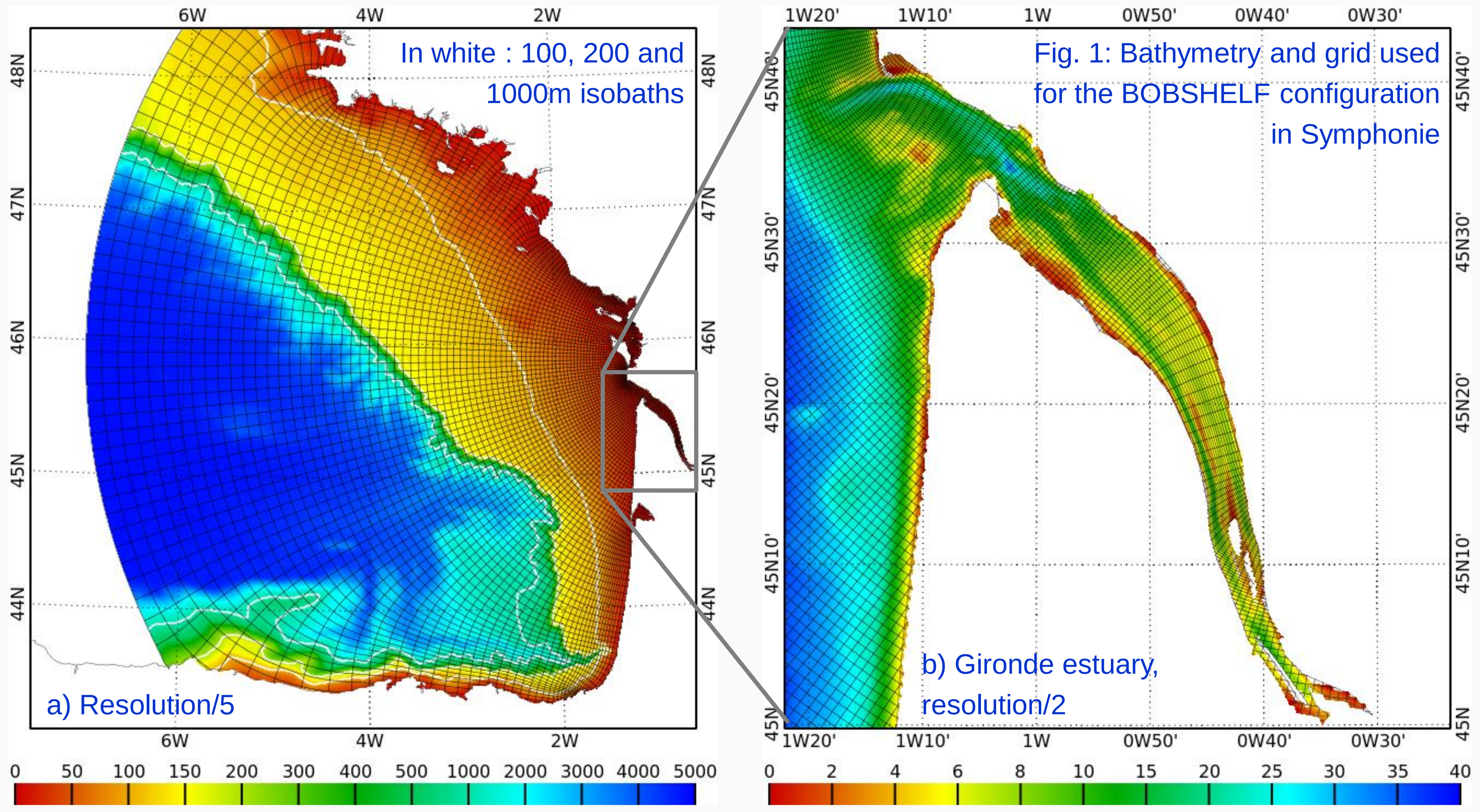


Fig. 1: Bathymetry and grid used for the BOBSHELF configuration in Symphonie

Variable horizontal resolution
- 3km in the open ocean
- **< 800m on the shelf**
- **< 300m in the Gironde estuary and Pertuis Charentais**

55 sigma levels

Intertidal areas: wetting/drying

OGCM forcing
- IBI operational model (MERCATOR-Océan)

Atmospheric forcing
- ECMWF operational analyses…
- AROME (Météo-France) by the end of 2016

Forcing tides	Model	Simulation name	Characteristics	
FES2012	Symphonie	S2D	2D Clamped ~~Atmospheric & OGCM forcing~~	2D => forcing solutions
FES2012	T-UGOm	Tugo	2D Spectral	
FES2012	Symphonie	S3D_FES	3D Atmospheric and OGCM forcing	3D => circulation solutions
S2D	Symphonie	S3D_S2D		
Tugo	Symphonie	S3D_Tugo		

Tidal elevations

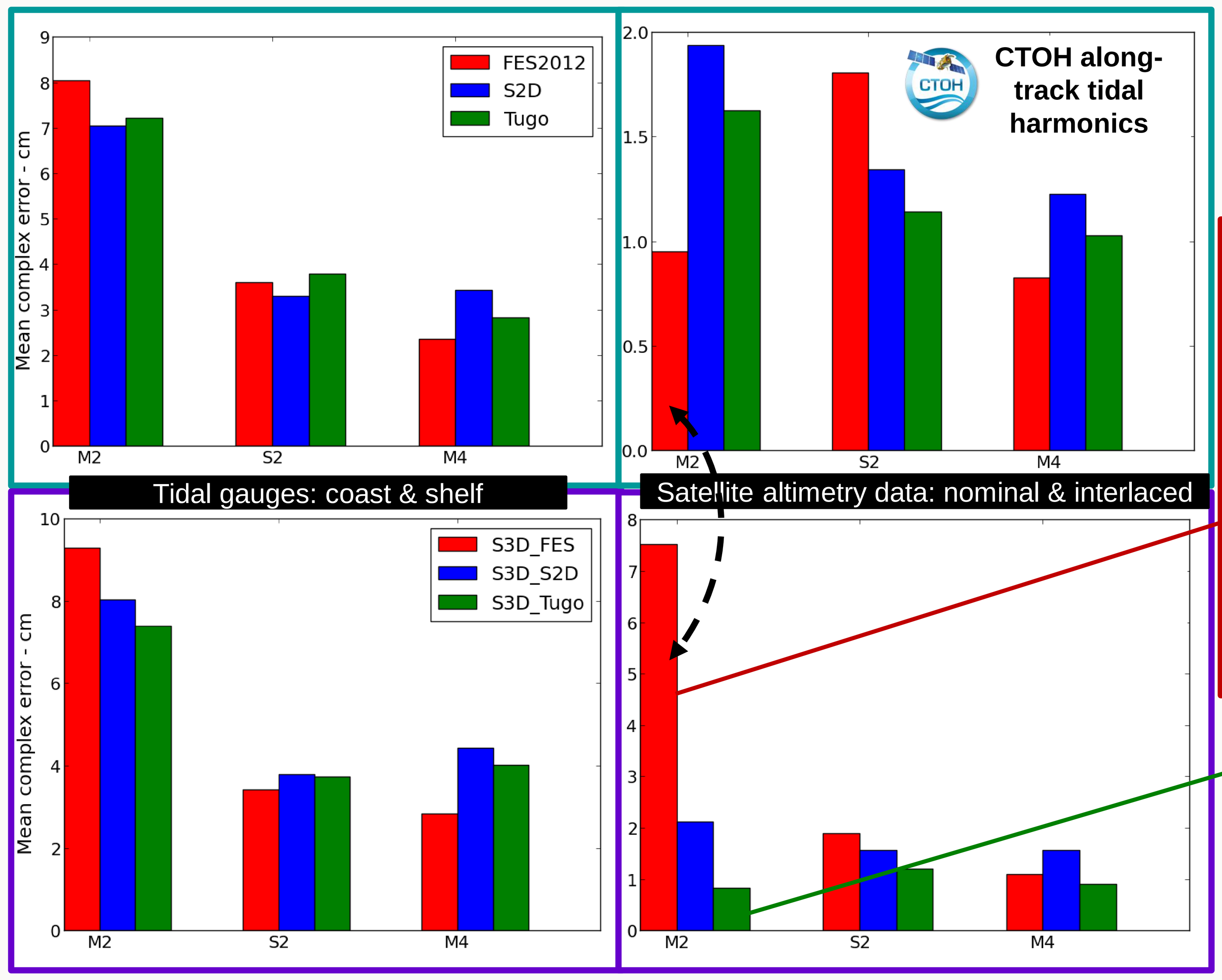


Fig. 2: Mean complex errors for M2, S2 and M4 harmonics, between the forcing (top) and circulation (bottom) tidal solutions and available observations

M2 & M4: FES2012 better than S2D & Tugo (Fig. 2, top)

Highest overall error budget for S2D

Strong impact of altimetry assimilation for FES2012

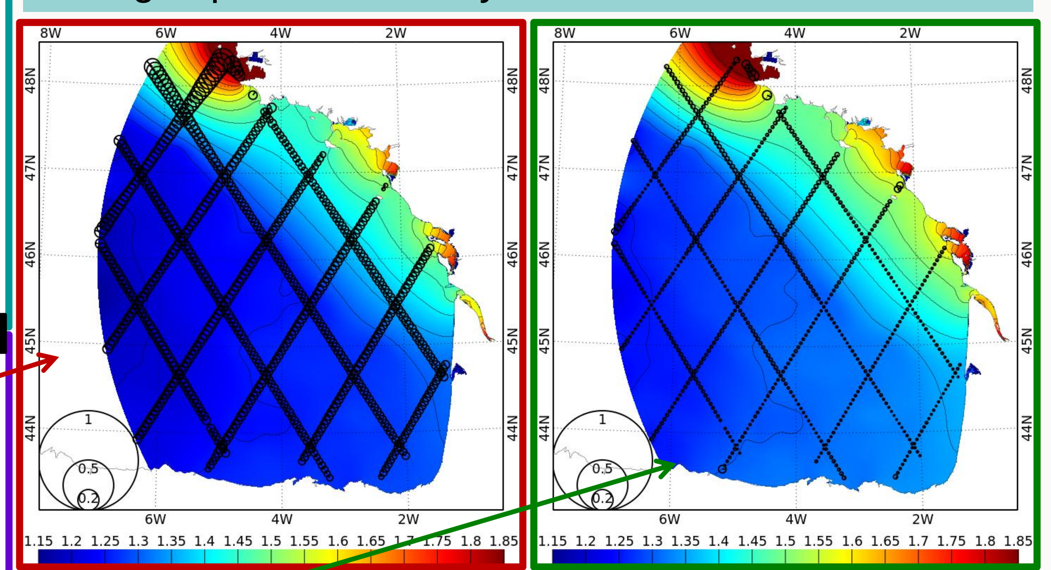


Fig. 3: Comparison between satellite altimetry tidal harmonics and S3D for M2. The circle size is proportional to the complex error.

M2: errors reduced by more than 75% between S3D_FES and S3D_Tugo (S3D_S2D: 70%) (Fig. 3)

Overall lowest error budget: S3D_Tugo (Fig. 2, bot.)

Bathymetry and resolution inconsistencies => gap in performance between FES2012 and S3D_FES

Impact on the circulation?

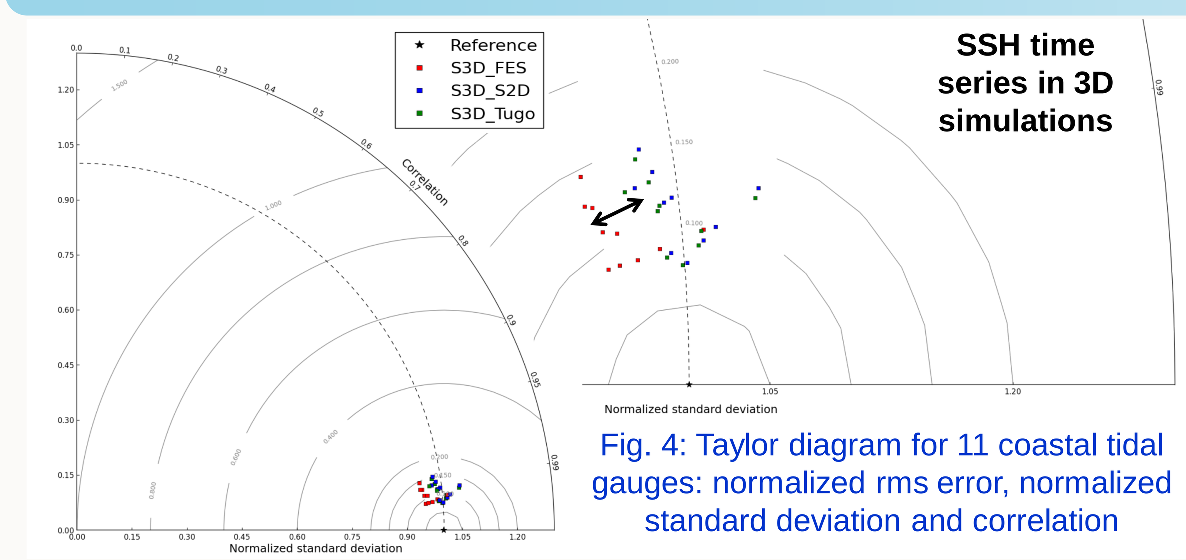


Fig. 4: Taylor diagram for 11 coastal tidal gauges: normalized rms error, normalized standard deviation and correlation

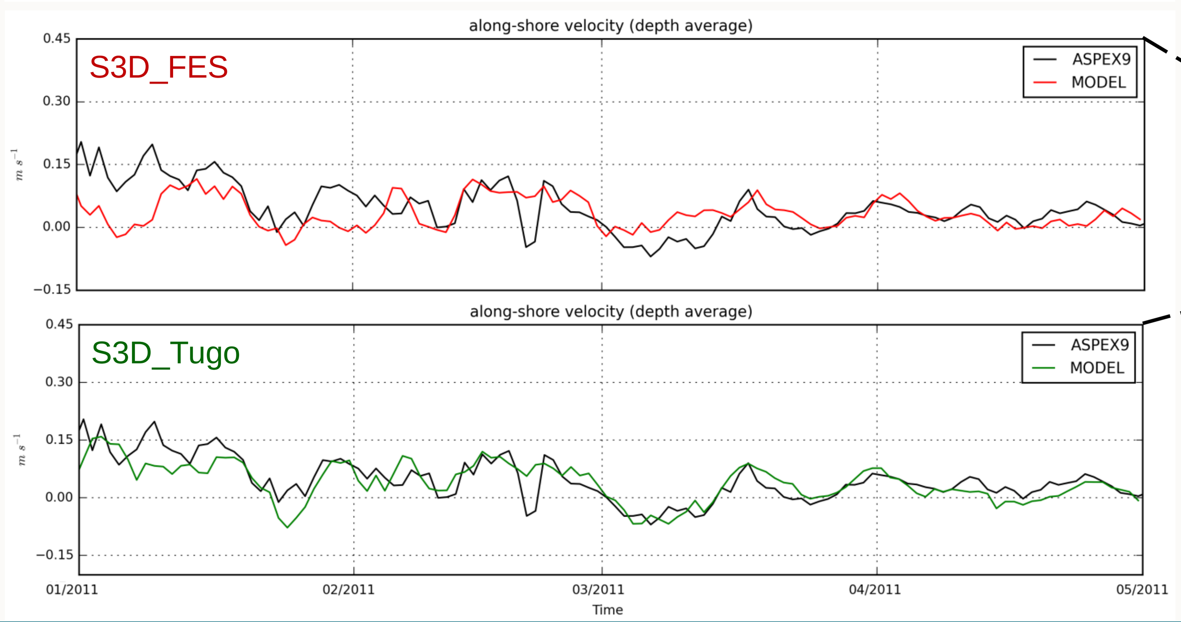
Comparison of SSH time series from 11 tide gauges and from the 3D simulations:

Good results for all the solutions (Fig. 4)

High frequency elevations signals more constrained by local features (bathymetry, coastline) than by remote large scale forcing

RMS errors slightly lower for S3D_FES

Signal variability (STD) better represented in S3D_S2D and S3D_Tugo (zoom Fig. 4)



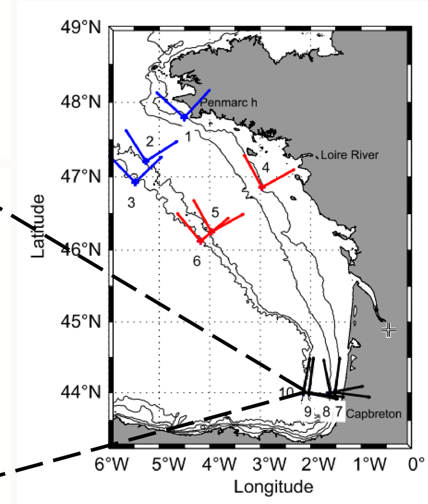


Fig. 5: Daily means of 2D current velocities, projected on the along-shore and the cross-shore axes (left) and ADCP locations from Le Boyer et al.(2013) (right)

Along-shore	Cross-shore
Lowest $\overline{RMSE}$ and highest $\overline{corr}$ for S3D_Tugo Highest differences in the SW corner of the Bay (Fig.5)	Close $\overline{RMSE}$ for all solutions Highest $\overline{corr}$ for S3D_Tugo

	S3D_FES		S3D_S2D		S3D_Tugo	
	$\overline{RMSE}$ (cm/s)	$\overline{corr}$	$\overline{RMSE}$ (cm/s)	$\overline{corr}$	$\overline{RMSE}$ (cm/s)	$\overline{corr}$
Along-shore	4.96	0.448	4.77	0.510	**4.55**	**0.585**
Cross-shore	2.94	0.125	**2.89**	0.188	2.95	**0.202**

Comparison of 2D current velocities from ADCP moorings (ASPEX campaign) and from the 3D simulations

Conclusions and perspectives

The 3D simulations forced by the "tailored" 2D forcings (S2D and Tugo) perform better when compared to available observations. A better forcing solution does not necessarily imply a better 3D solution: the M2 error is strongly amplified between FES2012 and S3D_FES. The M4 coastal tide is more determined by local features than by the remote forcing. SSH variability in 3D simulations is better represented with the S2D and Tugo forcing, and there is a global better agreement between S3D_Tugo and ASPEX ADCP data.

Single-point model/data comparisons are difficult to perform and interpret, and underline the importance of satellite altimetry data. Future work will now focus on the sea level signal observable by SWOT on the shelf, and the influence of wind and waves. In the perspective of SWOT, the question of using regional instead of global models for detiding in coastal regions can also be asked.

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