How can Surface Water Ocean Topography (SWOT) satellite better reconstruct horizontal and vertical velocities?

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1. Introduction

➢ **Measurements of Sea Surface Heigh (SSH) is essential for:**
- **Understanding of global ocean circulation**
- **Modeling of global ocean circulation**
- **Prediction of global ocean circulation**

Nadir Altimeters

❖ **Provided SSH measurements, since more than two decades**

❖ **Limited by the spatial resolution!!!**

➢ **Impirically infer the 3D ocean structure in model that lead to major breakthroughs such as :**
- **eddy kinetic energy quantification**
- **mesoscale eddy identification, and tracking**
- **vertical velocities**

SWOT future mission

❖ **Extending the capability of existing nadir altimeters to two dimensional mapping.**

❖ **Spatial resolution up to 15km wavelength over a 120km wide swath**

❖ **Temporal resolution of 22 days of SWOT is an issue !!!**

Objective:
Use **the Observing System Simulation Experiments (OSSEs)** to investigate how can the future mission SWOT better reconstruct horizontal and vertical velocities into a high resolution Ocean General Circulation Model (OGCM) in the Iberian-Biscay-Ireland (IBI) region with respect to conventional nadir altimeters.

What is an OSSE ????

➢ **Rigorous methods used to:**
- ✓ **Evaluate the potential impact of new observing systems**
- ✓ **Alternate the deployments of existing systems**

➢ **Data-denial experiments (twins experiments) using:**
- ✓ **NR (Nature Run) to simulate the synthetic experiments**
- ✓ **RF (Reference Run) to assimilate the synthetic experiments**

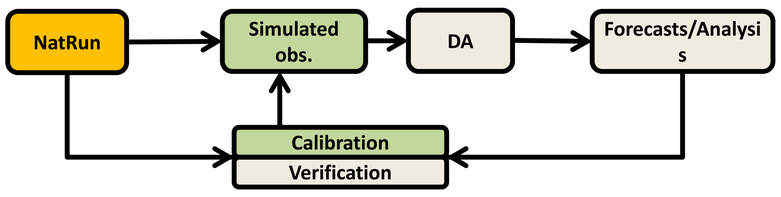


Fig. 1 A top-level view of an OSSE system (Ross N. Hoffman and Robert Atlas 2016)

2. Experimental set-up

Fig.2 shows the configuration used for both OSSEs and data assimilation (DA)

Truth: Nature Run (IBI36)	Freesim: Reference Run (IBI12)
NEMO3.6: 3km of horizontal resolution; 50 verticals levels	NEMO3.6: 7km of horizontal resolution; 75 verticals levels
Boundary conditions: PSY4V3	Boundary conditions: GLORYS
Initial conditions: PSY4V3	Initial conditions: GLORYS
Tide: FES2004	Tide: IBI12
Forcing: 3-h ECMWF (operational analyses)	Forcing: 3-h ECMWF

Fig. 2 OSSEs design. Left panel: "Truth" data configuration (NatRun). Right panel: DA configuration.

Simulated observations

25h mean outputs of NatRun is used to simulate observations over the year of 2009

➢ **In-situ and Sea Surface Temperature (SST): extracted from NatRun at the same position and date as real in-situ in CORA3.2 database from CORIOLIS data center (Cabanes et al. 2013)**

➢ **Nadir altimeters used are: Jason1 (J1), JAson2 (J2) and Envisat (EN)**

➢ **SWOT satellite: simulated using SWOT simulator version 1 (Fig. 3) (Gaultier, L. et Ubelmann, C.; Fu, L.L. 2015)**

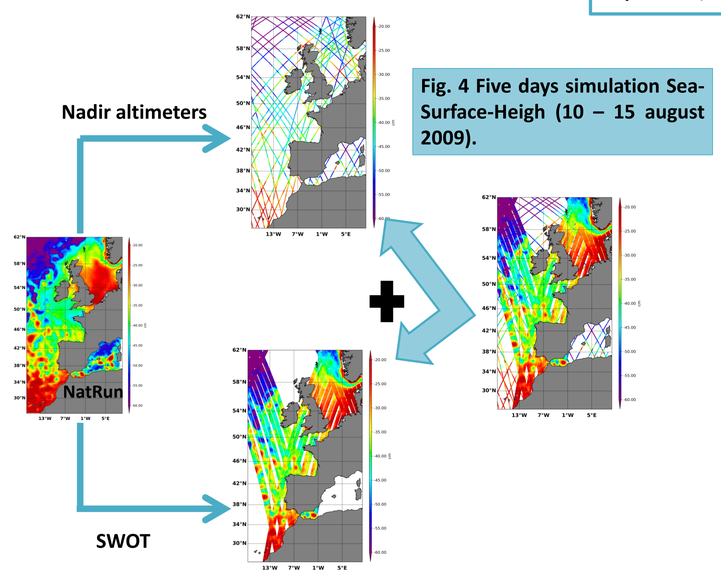


Fig. 4 Five days simulation Sea-Surface-Heigh (10 – 15 august 2009).

Gnerate the domain and orbit specified grid files

OGCM input data linearly interpolated in space into the SWOT grid

Simulates SSH for each possible path in time + space domains ➔ SSH_model

Adds instrumental noise + geophysical error ➔ SSH_obs

Fig. 3. Flowchart of the SWOT simulator procedure

❑ **For this study, four OSSEs were conducted by Mercator Ocean to show the impact of SWOT for ocean analyses, with respect to conventional nadir altimeters.**

experimens	SSH (J2, J1n, En)	SSH SWOT	SSH SWOT + (J2, J1n, En)	SST	T&S
NatRun	NO	NO	NO	NO	NO
Fresim (OSSE0)	NO	NO	NO	NO	NO
OSSE1	YES	NO	NO	YES	YES
OSSE2	NO	YES	NO	YES	YES
OSSE3	NO	NO	YES	YES	YES

Tab. 1. List of experiments used for the study

OSSE0: Free Run model. No assimilation; OSSE1: three nadir altimeter (J1, J2 and En); OSSE2: SWOT satellite; OSSE3: 3 nadir & SWOT

In **Tab. 1**:
T&S: simulated Temperature and Salinity profiles .
SST: simulated Sea-Surface Temperature
SSH: simulated Sea-Surface-Heigh

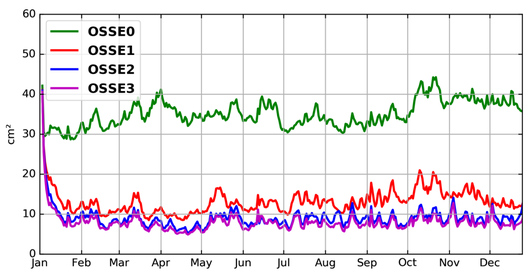


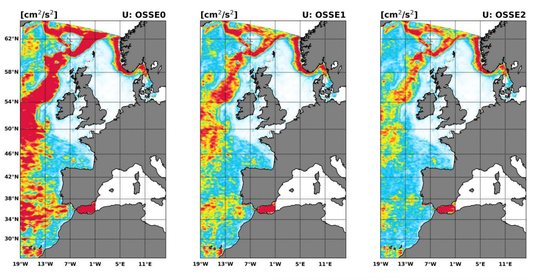
Fig. 5. Time evolution of the Mean Square Error (NR - experiments) of SSH for free run (OSSE0) and the three assimilated run (OSSE1, OSSE2 and OSSE3) in the IBI region in 2009. The values are expressed in [cm²].

Experiments	OSSE0	OSSE1	OSSE2	OSSE3
MSE [cm²]	38.94	16.89	12.82	11.84
MSE*[cm²]	--	43.37	32.92	30.41

Tab. 2. SSH (IBI) Mean Square Error (MSE) analysis during Jan-Dec 2009. First row: Explained MSE in each experiment. The values are expressed in [cm²] Second row: Explained MSE in each experiment, with respect to the MSE of OSSE0. Values expressed as[%]

3. Impact on the horizontal velocities

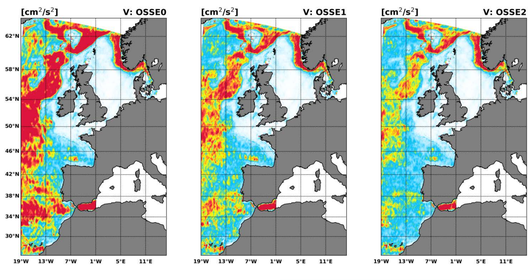
The **free run (OSSE0)** shows almost everywhere higher values of MSE both for U (Fig. 6) and V (Fig. 7). A significant reduction of the MSE is observed from OSSE1 to OSSE3 (**Tab. 3 and Tab. 4**) and are much lower than OSSE0. The MSE of **OSSE1** in the IBI region represent 63% of the OSSE0 MSE's (**Tab. 3 and Tab. 4: second row**). Additional error reductions of 12 and 3% occur for **OSSE2 and OSSE3**.



Tab. 3. U (IBI) Mean Square Error (MSE) analysis during Jan-Dec 2009. First row: Explained MSE in each experiment. The values are expressed in [cm²/s²]. Second row: Explained MSE in each experiment, with respect to the MSE of OSSE0. Values expressed as[%]

Exp.	OSSE0	OSSE1	OSSE2	OSSE3
MSE [cm²]	170.18	105.87	87.37	80.42
MSE*[%]	--	62.21	50.17	47.25

Fig. 6. MSE of zonal velocity (U) from Jan-Dec 2009. the values are in [cm²/s²]



Tab. 4. V (IBI) Mean Square Error (MSE) analysis during Jan-Dec 2009. First row: Explained MSE in each experiment. The values are expressed in [cm²/s²]. Second row: Explained MSE in each experiment, with respect to the MSE of OSSE0. Values expressed as[%]

Exp.	OSSE0	OSSE1	OSSE2	OSSE3
MSE [cm²]	161.55	107.44	85.18	80.78
MSE*[%]	--	66.51	52.73	50.01

Fig. 7. MSE of meridional velocity (V) from Jan-Dec 2009. the values are in [cm²/s²]

Assimilation of SWOT data does not only improve the surface velocity; it also improves velocity field at the depth.

Fig. 8. shows the MSE in the IBI region for both **U (Fig. 8a)** and **V (Fig. 8b).** These plots are similar for the two velocities components and show decrease error profile with depth. There is clear positive impact of the assimilation of SWOT up to **1000m** of depth. The improvement brought by each experiment is almost uniform on the vertical.

The assimilation of sea level **(Fig. 5)** SWOT like data also improves the **resolution of the mesoscale eddies and their fronts** in the considering region represent by black square as presented in the right panel of the figure. **Fig.9**.

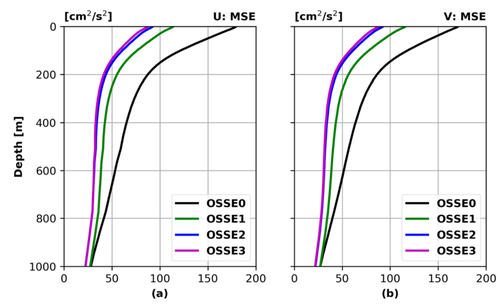
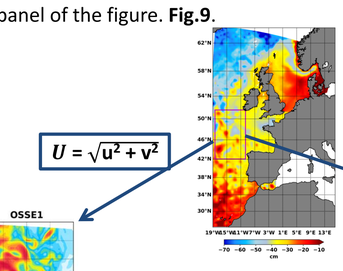


Fig. 8. IBI MSE of U (a) and V (b) profile in [cm²/s²] for OSSE0 (black), OSSE1 (red), OSSE2 (blue) and OSSE3 (magenta).

❑ **Intensity of total horizontal current**

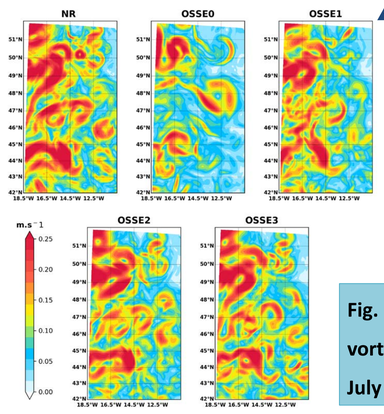
$U = \sqrt{u^2 + v^2}$



Depth = 120m

ε = curl (U)

❑ **Relative vorticity**



❖ **From OSSE0 to OSSE3, there is a clear amelioration of the structures and fronts when comparing to the NatRun**

Fig. 9 Total current (m/s) (left) and Relative vorticity (1/s) (right) in the magenta square for July month at 120m of depth

4. Impact on the vertical velocities.

Vertical velocity is highly variable and reflects many small scale and high frequency signals. We just started investigating how vertical velocities can be reproduced in our OSSEs in the IBI region. In specific areas such as the section (14°W, 38 – 39.5°N) shown in Fig. 10, SWOT tends to represent rather well the vertical velocities but in other places there is little skill in reproducing them. This requires more in depth analysis and a better understanding of the vertical velocity signals and their space and time scale characteristics (e.g. mesoscale/submesocale balanced motions versus internal gravity waves).

Fig. 10. Ocean vertical velocity section at 14°W and 38 -39°N on 14/09/2009.

5. On going work.

The actual work is being done on the global ocean. Where the OSSEs are conducted at the moment.

- ✓ Preliminary work was done to define a suitable configuration for these OSSEs (choice of nature run (NatRun) and assimilated run with both 1/12° of horizontal resolution)
- ✓ Choice of nadir altimeters (J3, S3A and S3B) that will be use for the comparaison with SWOT.
- ✓ Simulation of SWOT like data and nadir altimeters (J3, S3A and S3B) (Fig. 11) for the **year 2015**

❖ **Currently these experiments are underway on the global and the analysis of the first results starts**.

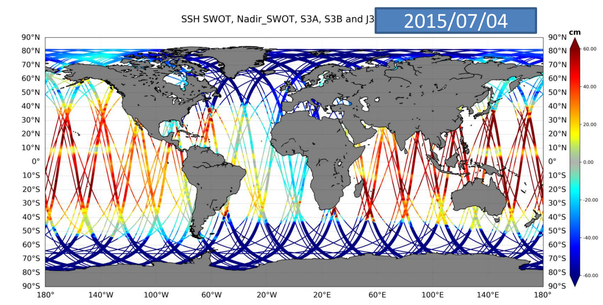


Fig. 11 one day simulation Sea-Surface-Heigh (07 July 2015).

6. Key Messages

- ✓ SWOT satellite has a **major impact for the ocean analyses**, with respect to conventional nadir altimeters (Jason 1, Jason 2 and Envisat). A combination of SWOT and conventional nadir altimeters thus allow reducing MSE in ocean analysis by more than **50 %**.
- ✓ The **information** provided by SWOT data **at the surface is propagated also in the vertical** and has a **considerable impact on the ocean circulation**, both at the surface and in the water column.

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