Using high resolution altimetry to observe mesoscale and sub-mesoscale signals

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Introduction

During the last 15 years, multi-satellite altimetry data was largely shown to be able to observe a significant fraction of sea surface height variability. Past altimeter constellations ranged from one to four satellites. It allowed to better assess the performances of the global altimetry observing system (multi-mission merged maps), and it underlined the limits of spatial and temporal sampling for observing smaller scales and high frequency signals.
In order to better observe sea surface variability, new technologies and new altimeter constellations are considered, and their sampling capability is assessed and compared to historical scenarios. In this study, an OSSE baseline was used to underline the observing capability of old and new altimeter systems to better sample mesoscale and sub-mesoscale signal in a mapping (objective analysis) context.

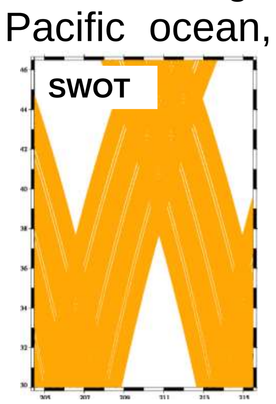
Data and Methods

Observing System Simulation Experiment (OSSE) used for estimation of the errors done on SLA and derivates using OA method.

Reference data sets:

Two different models are used over a **~1 year period:**

- **Earth Simulator (ES)** [1]: it simulates **mesoscale and sub-mesoscale** structures. A large fraction of the energy in output of this model is induced by scales < 100 km and with high frequency variability (< 10 days). The area was arbitrary positioned in the Pacific ocean, centered around two different latitudes: 38°N and 45°N
- **POP (POP)** [2]: it simulates **mesoscale variability** in the North and tropical Atlantic. Model output are exploited over the Gulf Stream area where typical scales in output of the model are > 100 km.



Constellations:

Five different altimeter constellations are considered (Fig. 1):

- 2 to 4 of the historical altimeters Jason2 (J2), Envisat (EN), Geosat Follow On (GFO) and Jason-1 tandem (J1N) are combined.
- SWOT (nadir + wide swath) with 22-day cycle, alone or combined with J2 and EN

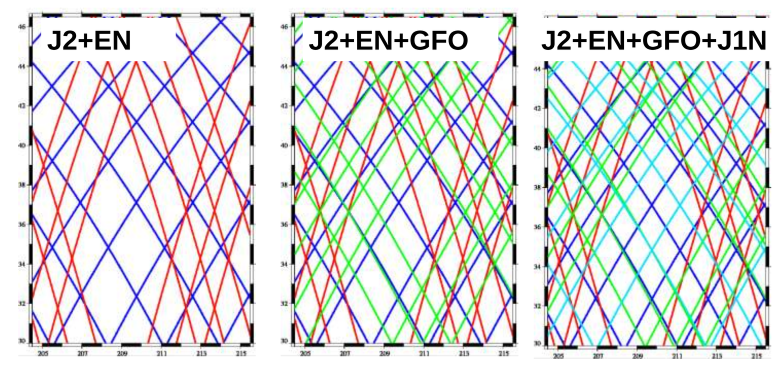


Figure 1: Coverage of different constellations for a 10-day period

Measurement errors:

Two different errors were considered (Fig. 2)

- **measurement noise**: it was fixed to 2 cm rms for the nadir measurement [3]. The measurement noise for the wide swath SWOT was fixed following Rodriguez (2010) recommendations (Fig 2).
- **residual roll error**: for the SWOT wide swath, the residual error after correction was estimated in a pessimistic and optimistic cases that are respectively 0.1 and 0.05 arcsec. This corresponds to a maximal variability of ~3.5 and ~2 cm in swath extremities.

Objective Analysis (OA) method :

OA [4] was used for reconstruction of mesoscale (100 km, 10 days correlation) and sub-mesoscale (30 km, 5 days correlation) signals. In the last case, a specific 2-step reconstruction was applied (Fig 3)

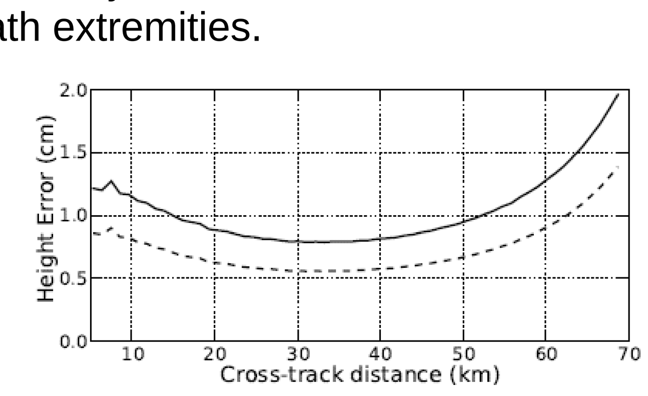


Figure 2 KaRIN height noise as a function of cross-track distance along the sphere. Full (dashed line) and half (solid line) theoretical azimuth resolution is achieved in the onboard SAR processing. (Rodriguez, 2010)

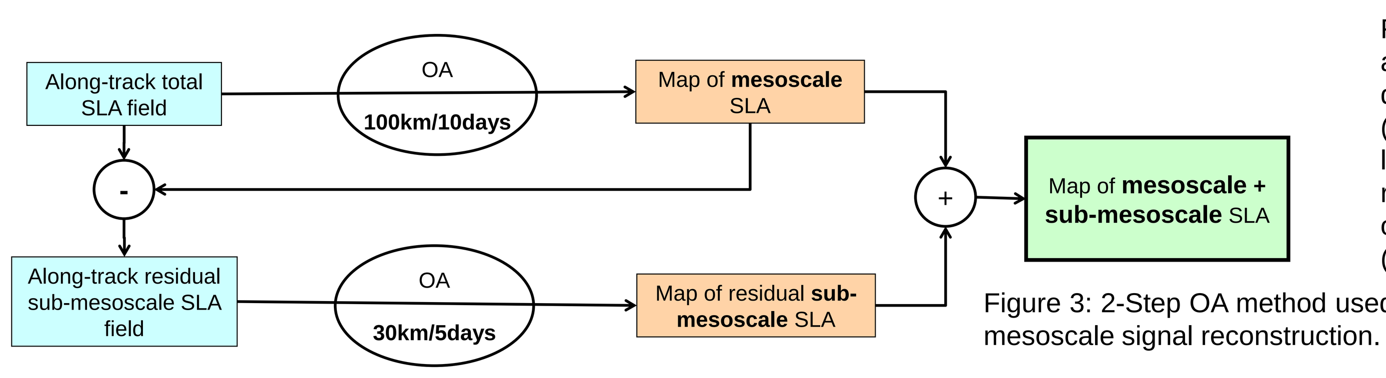


Figure 3: 2-Step OA method used for total mesoscale+sub-mesoscale signal reconstruction.

Error budgets computation:

Reconstructed gridded fields were compared to reference fields in order to estimates real errors on reconstructed SLA, geostrophic velocities, Vorticity and also vertical velocities.

Mesoscale signal reconstruction

Beneath swat position, SWOT allows more precise SLA reconstruction than historical 4-satellite constellation even in case of pessimistic roll error (Fig 4). Errors on SLA and derivates (U,V) geostrophic fields are near 1/3 lower beneath swat position than when historical 4-satellite constellation is used (Tab 1). Higher errors observed on V fields traduce the impact of spatial sampling that is degraded for V restitution due to the inter-track distance

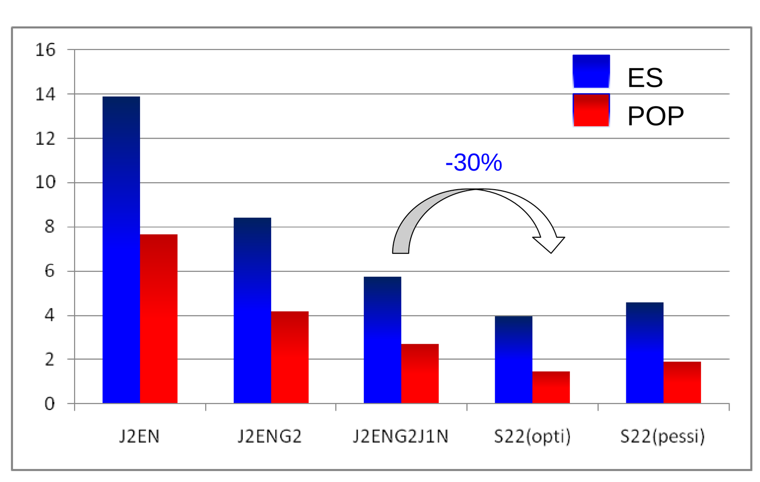
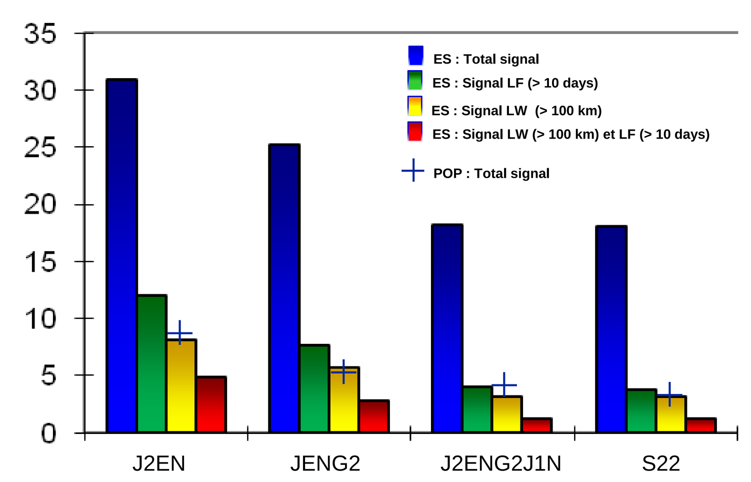


Figure 4: SLA error budget (in % of signal variance) on mesoscale gridded fields using ES (lat 38°N) and POP as reference. Errors are presented for long wave part of the signal (> 100km). For S22, result are presented beneath swath.

Tab 1: U and V error budget (in % of signal variance) on mesoscale gridded fields using ES (lat 38°N) as reference. Errors are presented for long wave part of the signal (> 100km). For S22, result are presented beneath swath

	J2EN	J2ENG2	J2ENG2J1N	S22(opti)
U	13	8	5	4
V	23	13	9	6



Errors reported using POP model are lower than errors observed with ES (38°N). This traduces the impact of sub-mesoscale signal present in ES fields while it is not in POP. 100km/10days correlation scales used for mesoscale fields reconstruction don't allow to resolve this sub-mesoscale signal. Using only LW (> 100km) part of ES signal in imput of OSSE give near same result as with POP model (Fig 5)

Figure 5: SLA error budget (in % of signal variance) on mesoscale gridded fields using different components of ES (lat 38°N) signal in input of OSSE. For S22, result are presented without swath selection

Bibilography:
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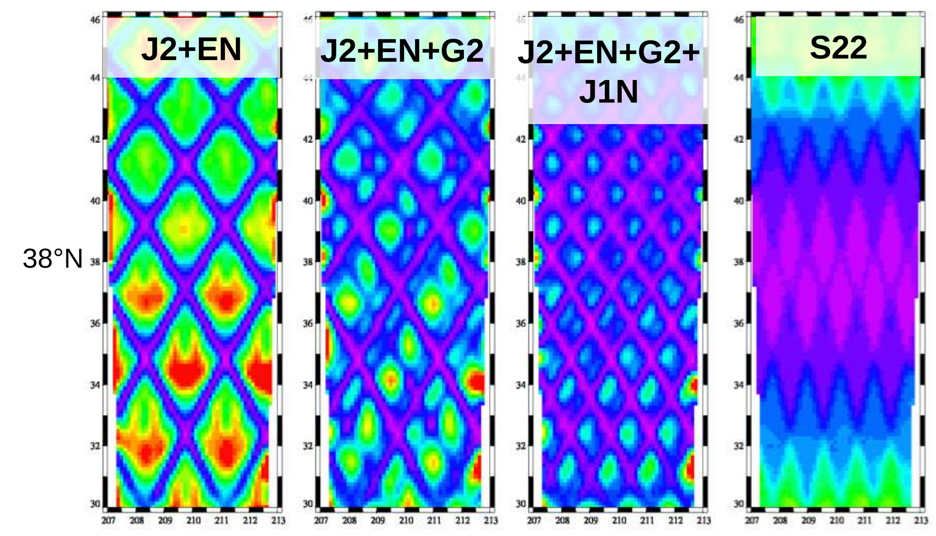
Out of swath position, SWOT capabilities to sample mesoscale signal strongly depend on the latitude considered:

- At 38°N, intertrack distance is minimized and SWOT allows a good mesoscale sampling. Formal mapping error (Fig. 6) underlines this phenomenon with important patch where few measurement are available. Real errors done on SLA using SWOT alone are comparable to results obtained with historical 4-satellite constellation (Fig 8).



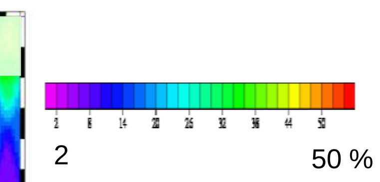


Figure 6: Formal mapping error (in % of signal variance) done on mesoscale SLA signal reconstruction, using ES (lat 38°N) as reference field

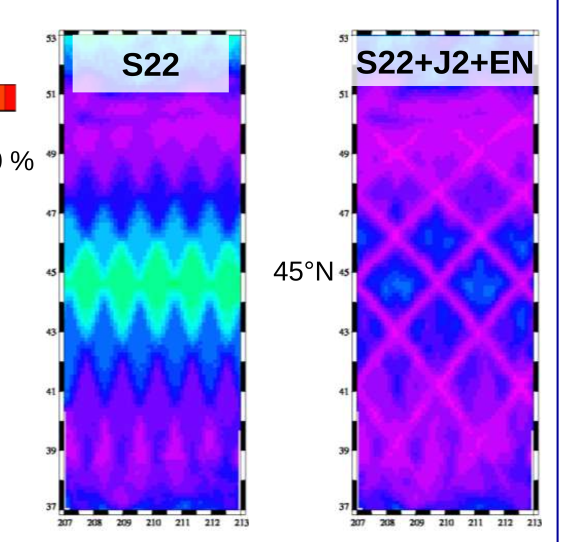


Figure 7: idem as Fig.6, but using ES (lat 45°N) as reference field

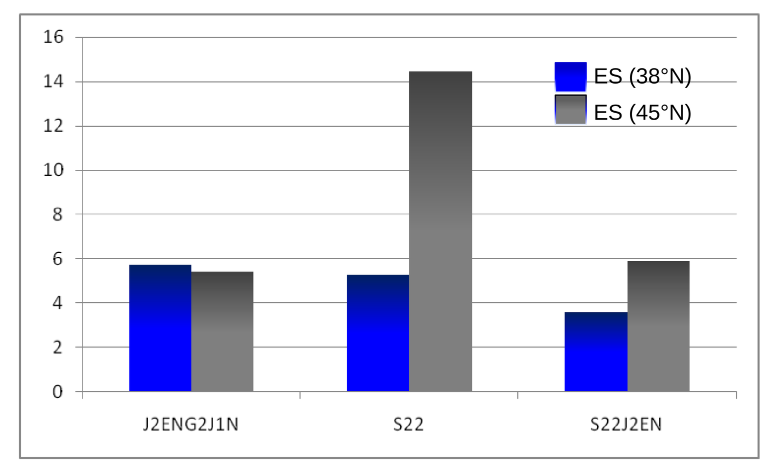


Figure 8: SLA error budget (in % of signal variance) on mesoscale gridded fields using ES (lat 38°N and 45°N) as reference. Errors are presented for long wave part of the signal (> 100km). For S22, result are presented without swath selection

- At 45°N, , intertrack distance is degraded and SWOT mesoscale sampling is not sufficient (Fig 7). In it optimistic roll error case, SWOT alone allows to reconstruct mesoscale fields with near the some error budget than with historical 2-satellite constellation. However, merging SWOT with historical 2-satellite constellation strongly reduces the errors. With S22+J2+EN constellation, errors done on SLA, U, V are comparable to results obtained with historical 2-satellite constellation (Fig 8).

Sub-mesoscale signal reconstruction

Historical 4-satellite constellation is not adapted for sub-mesoscale sampling, while SWOT wide-swath is better adapted, at least beneath swath position. Errors done on SLA reconstruction are near 2.5% beneath swath (i.e. near 80% lower than errors reported for historical 4-satellite constellation). Errors on U and V geostrophic fields are higher traducing limits of OA parameterization for SLA gradients reconstruction. (Tab 2)

Tab 2: Error budgets (in % of signal varaince) on gridded mesoscale+sub-mesoscale fields, when different part of the signal are considered. Result are presented for S22 (optimistic case), beneath swath position.

	Total signal	LW (> 30km)	SW (< 30km)
SLA	2.5	1	53
U	11	4	69
V	18	8	96
Vorticity	47	18	-

Degradation of geostrophic velocities is faster than observed for mesoscale signal, traducing the difficulty to accurately reconstruct finest gradients. Actually, main part of the errors are observed on smallest scales. Errors on LW (> 30 km) of the signal are quite low (Tab 2). For these wavelengths, SWOT allows to estimate geostrogic velocities with errors < 5% for U component and < 10% for V. This allows to estimate vorticity field with an error near 20% of signal variance.

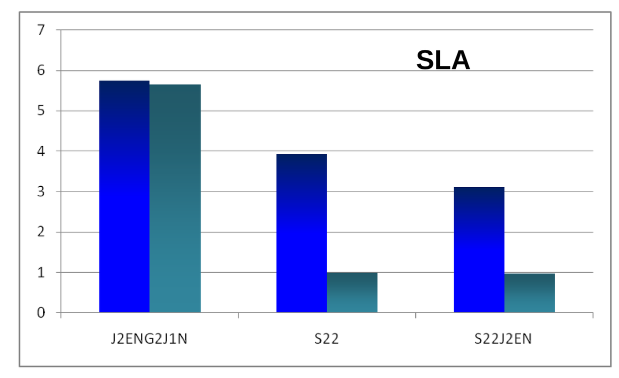
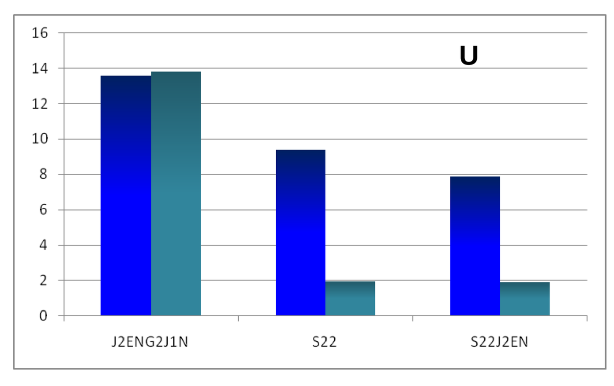
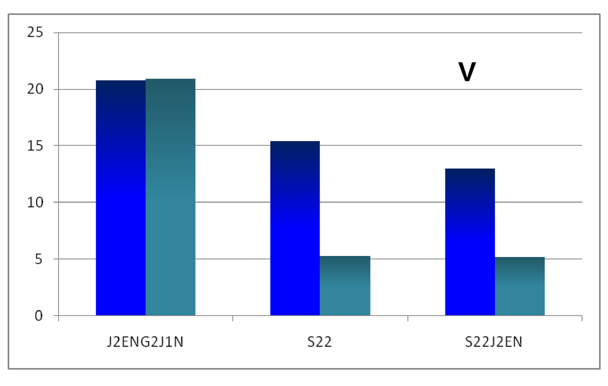


Figure 9: SLA,U and V error budgets (in % of signal variance) on mesoscale+sub-mesoscale gridded fields using ES (lat 38°N and 45°N) as reference. Errors are presented for long wave part of the signal (> 50km). For S22, result are presented beneath swath position

Simple OA 100km/10days
2-step OA 100km/10days+30km/5days





These results are obtained thank to the 2-step OA method that allows to consider different correlation scales for SLA reconstruction (Fig 3). This method strongly impacted reconstructed fields quality in the 50-100km wavelength (Fig 9). Errors observed for wavelengths > 50 km reconstructed with 2-step method are comparable to errors obtained on wavelengths > 100km reconstructed with direct OA method.

These results suggest that smallest scales could be better reconstructed thanks to a multiple-step OA method.

SWOT capabilities allow to access vertical velocities (W) estimation. W where reconstructed at different depths using a Surface Quasi-Geostrophic (SQG) method [5]. Errors observed on these fields are quite high, especially in upper layers (around 50% at 100m depth) (Tab 3), traducing sensibility of W estimation to quality SLA gradients reconstruction. However, error budgets reported on W estimation are quite comparable to errors reported on mesoscale geostrophic velocities fields when historical 2-satellite constellation is considered (Fig 10). In case of pessimistic roll error correction, errors reported on W are increased. In this case, merging SWOT with J2+EN seems to reduce the impact of residual roll error on SLA gradients reconstruction (Tab 3).

	Z=-100m	Z=-500m	Z=-1000m
S22(opti)	50	39	29
S22 (pessi)	61	47	36
S22J2EN(pessi)	55	43	33

Tab 3: Error budgets (in % of signal variance) on reconstructed vertical velocities fields at -100, -500 and -1000m. Result are presented beneath swath position, for LW (> 50km) part of the signal.

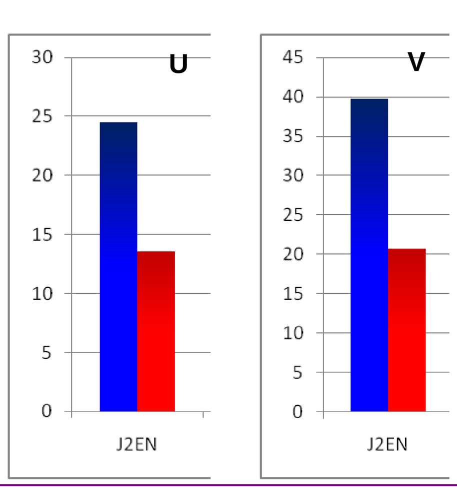


Figure 10: U and V geostrophic fields error budgets (in % of signal variance) on mesoscale gridded fields using ES (lat 38°N) and POP as reference. Errors are presented for long wave part of the signal (> 50km).

Conclusions

The results obtained clearly underline SWOT wide-swath capabilities for improved reconstruction of ocean surface topography. Beneath swath position, SWOT allows a quite good reconstruction of mesoscale and sub-mesoscales structures. Precision obtained on SLA gradients allows the estimation of vorticity field with errors < 20% for scales > 30km. A first estimation of vertical velocities can also be obtained. The results obtained on scales <30 km could be improved with an adjustment of the multiple-step OA method here applied.
SWOT also contributes to mesoscale reconstruction. Out of swath position, errors reported with SWOT alone, on latitudes where inter-track distance is minimized, are comparable to errors observed with historical 4-satellite constellation. Otherwise, SWOT should be combined with at least 2 nadir satellites to reach the same error budgets.