Roll error reduction on a wide-swath altimeter

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Abstract

An important limitation of wide swath altimetry (hereafter WSA) is the error induced by the uncertainty on satellite attitude and notably by the roll angle.

Uncorrected, the platform roll angle can induce decimetric to metric errors on altimeter measurements (Fig. 1). This error would be one to two orders of magnitude higher than the accuracy needed for most altimetry applications. It can be minimized with various algorithms, but the question becomes: can we **realistically** reach the performance needed for the most demanding ocean applications?

This work uses an OSSE (Observing System Simulation Experiment) approach to analyze the performance one could obtain with various error scenarios, using swath crossover diamonds (Fig. 3) and optimal inverse methods.

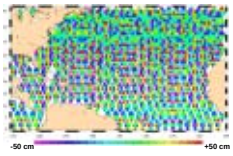


Fig 1 : Roll signal on SSH for one cycle

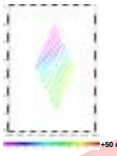


Fig 2 : Observation of the roll angle signal on SSH differences on a crossover diamond

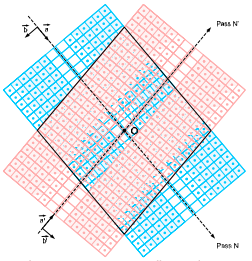


Fig 3 : WSA crossover diamond. Two measurements on the same location can be used to estimate the roll-induced SSH signal

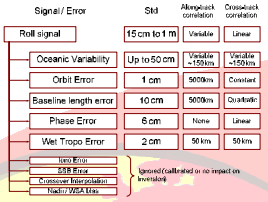


Fig 4 : Altimeter measurement simulation : roll angle signal and errors. Order of magnitude (std) on swath border and correlations

Approach and simulations

Perfect SSH measurements are simulated using the Los Alamos North Atlantic high-resolution model as a reference for oceanic variability (Fig. 5).

Various scenarios are considered: roll angle (optimistic to pessimistic), error budget and correlation (Fig. 4)… Large swath and nadir altimeter data sets are then simulated. A roll angle is then estimated using crossovers and inverse methods (Fig. 2).

Various roll error removal reduction processes are assessed and compared. Local (crossover diamonds, perfect or coastal) and global analyses are used to produce nominal and "worst case" statistics and to estimate each method performance through the accuracy of the output correction.

Sensibility studies are also carried out to assess the performance loss when the error simulated is not consistent with the a priori knowledge used (correlation, variance), or when additional errors are neglected.

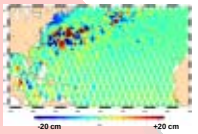
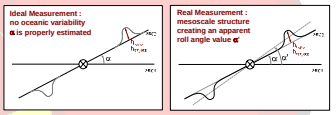


Fig 5 : 10-day crossover differences on the WSA : up to 50cm of mesoscale variability (top). The ocean variability is a serious source of error in the roll signal determination as it creates artificial cross-track gradients perceived as roll angle (bottom)



Impact of crossover observability

The roll-induced SSH signal is observed through differences on WSA crossovers. Yet the signal observability on a diamond is heterogeneous (Fig. 6) : in the middle of the diamond, one can use symmetric observations (left and right-hand side of each Nadir) to better estimate each roll angle. However on each extremity, the observation is not symmetric.

Biases (e.g : orbit error) and small structures (e.g : oceanic variability) on the SSH are inverted as apparent roll angle. As a result, any error on the SSH translates into residual error on the estimated roll angle (Fig. 7). This phenomenon can be significantly reduced with an optimal inversion method and a priori knowledge on the errors.

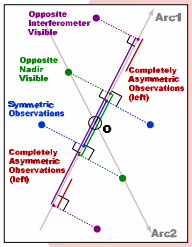


Fig 6 : Crossover observability color code. What kind of crossover differences can be used in the inversion ?

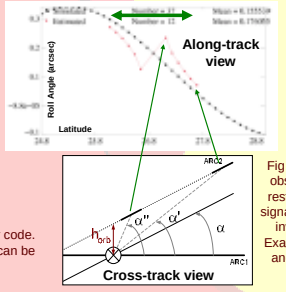


Fig 7 : Impact of crossover observability on roll angle restitution. False roll angle signals are created when the inversion is not optimal. Example for orbit error (left) and baseline length error (right).

Are Nadir data useful ?

Even with the best inversion method, it is important to take into account as many data as possible. When all crossover observations are used, the amount of roll angle values estimated is increased by 50% and the estimation accuracy is improved by 20%.

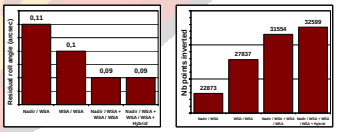


Fig 8 : Roll angle estimation performance (residual error on left hand side, nb of points inverted on right hand side) when Nadir and/or WSA measurements are used.

Global results

According to WSOA specifications, the roll determination accuracy must be 0.1 arcsec or less to allow the 5 cm precision needed on the SSH.

Whatever the input roll angle scenario, some sources of errors can disrupt the roll angle estimation when not properly taken into account in the inversion (Fig. 10). A simple least square inversion with a α,α' formulation cannot achieve the accuracy needed (Fig. 11).

With a more robust algorithm ($\alpha(t)$ scheme and optimal inversion taking into account a priori knowledge on the roll angle signal, and SSH errors), the estimation is improved by 30 to 60% and it reaches the 0.1 arcsec RMS accuracy needed (Fig. 11), even in worst case scenarios (input: 2arcsec with 120s modes) and with realistic sources of error on the SSH.

These results are not sensitive to errors on the a priori knowledge on the error budget (6% degradation for a SLA variance wrong by a factor 2) yet sensitive to the a priori knowledge on the error correlation (20% degradation for correlation scales wrong by a factor 1.5).

The optimal approach also provides an accurate formal error of its inversion : comparison with the actual estimation error (Fig. 9) gives 0.05 arcsec RMS. It is thus possible know where the estimated roll angle can be trusted.

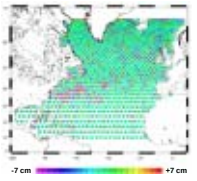


Fig 9 : Roll signal on SSH after inversion. The signal on SSH has been reduced by a factor >20.

Fig 10 : Impact of crossover observation perturbations on roll angle restitution and on SSH error (uncorrected roll signal). Improvement observed with optimal inversion and a priori knowledge.

Residual Roll Indetermination (arcsec)	Orbit Error	Baseline	Phase (random)	Oceanic Variability (low)	Oceanic Variability (high)	Geophys. Corrections
Least Squares	0.01	0.11	0.14	0.14	0.26	0.07
Optimal Inversion	0.001	0.1	0.05	0.07	0.16	0.05

SSH error from residual roll angle (cm)	Orbit Error	Baseline	Phase (random)	Oceanic Variability (low)	Oceanic Variability (high)	Geophys. Corrections
Least Squares	0.5	5.5	7	7	13	3.5
Optimal Inversion	0.05	5	2.5	3.5	8	2.5
Gain (%)	90	9	64	50	38	29

WSOA specifications : 0.1 arcsec roll angle determination 5 cm SSH accuracy

Fig 11 : Roll angle estimation performance (RMS of residual angle in arcsec) in the North Atlantic and in high ocean variability areas. Impact of the formulation (α,α' vs. $\alpha(t)$) and of the inversion method used.

Formulation	α, α'	$\alpha(t)$	$\alpha(t)$	$\alpha(t)$
Inversion	Least Squares	Least Squares	Rxx	Rxx & Rvv
Global	0,13	0,18	0,12	0,09
Gulf Stream	0,21	0,27	0,2	0,14

Perspectives

This technique is still in infancy and many improvements are being considered:

- Hybrid formulation with a well-controlled formulation of α with higher order polynom and Taylor development variance limitation
- Integration of all parameters (orbit error, baseline length…) as variables to estimate instead of as errors on the SSH data. Preliminary results show a 20% improvement with the baseline length error
- Preprocessing some errors to reduce their impact: reduction of ocean variability with Nadir-only maps (DUACS-like processing), calibration with Nadir data…
- Multi-satellite approach to benefit from other Nadir altimeters flying along with the wide swath altimeter.

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