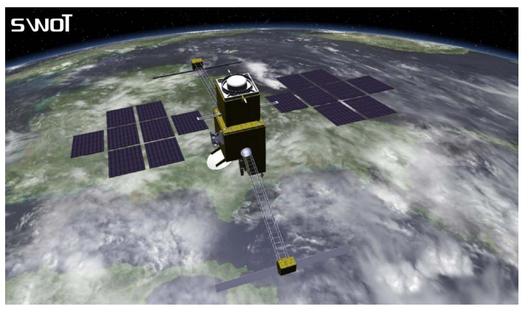


Estimation of Roll Angle Error Over Land Surfaces for SWOT Mission

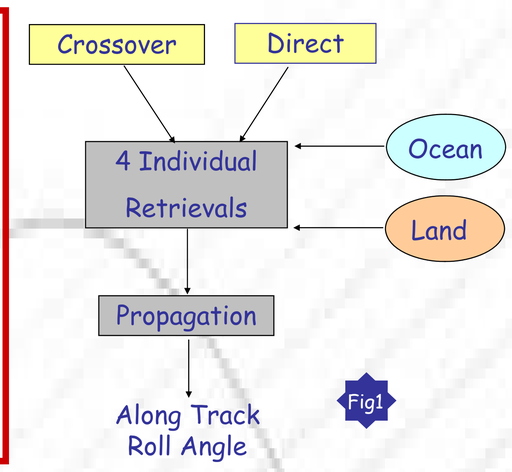
S. Labroue[1], G. Dibarboure[1], Y. Lejeune[1], F. Briol[1], M. Ablain[1], R. Fjortoft[2] , J. Lambin[2] and V. Enjolras[3]

[1]CLS, Space Oceanography Division, Toulouse, France
[2]CNES, Centre National d'Etudes Spatiales, Toulouse, France
[3]TAS, Thales Alenia Space, Toulouse, France

Context

SWOT mission is designed to acquire elevations of ocean and terrestrial water surfaces. The instrument concept is based on an interferometric altimeter in Ka band, with two SAR antennae at opposite ends of a 10 m boom. This geometric configuration requires stringent accuracy on the roll angle of the interferometric baseline (an error of 0.1 arcseconds translates into an error of 3.5 cm on the height at the far end of the swath). Technology available on star trackers and gyros should allow the AOCS system to meet the requirements on the roll angle for most of the wavelengths. Nevertheless, a ground calibration process will be needed to remove residual roll angle errors. Past studies in the framework of the WSOA project (Rodriguez et al. 2000 , Dibarboure et al. 2006) have shown that the roll angle can be accurately estimated using crossover calibration techniques over ocean. For continental water surfaces, Enjolras et al (2007) proposed another technique, using an external reference (Digital Elevation Model). The authors showed that the roll angle can be well retrieved and that residual errors on water bodies are at the centimeter level. We propose an optimal strategy using the roll angle retrieval over both ocean and land surfaces. A two-step scheme is proposed for the roll angle retrieval (Fig 1):

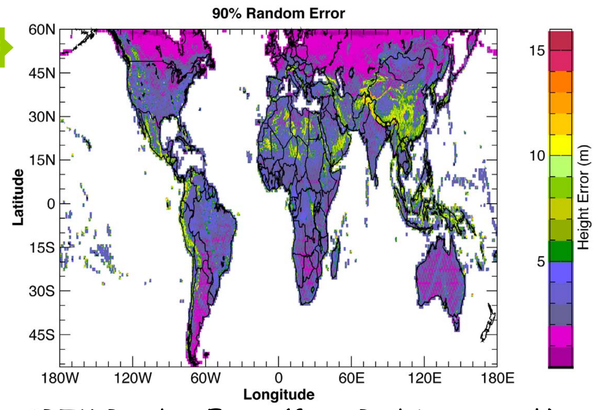
1. Individual retrieval over each surface with 2 methods (crossovers or along track using a DEM over land and a MSS over ocean).
2. Along track propagation of the angles retrieved point by point.



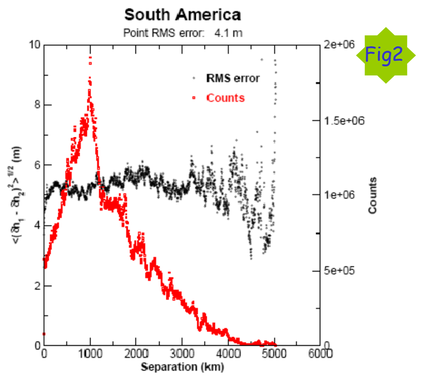
DEM Error Analysis

The roll retrieval over land using a DEM is revisited in order to take into account realistic DEM errors. A review of available DEMs has lead to analyze 2 different models: SRTM and ACE2 models.
The SRTM DEM has a spatial resolution of 90 m and covers latitudes between 56S and 60N. The errors present in SRTM DEM have been carefully assessed by Rodriguez et al. (2005). Rodriguez showed that the SRTM error can be separated in two components:

- **Large scale errors at continental scales** (Fig. 2)
This error of 2 m rms comes from residual attitude error and baseline oscillations on the shuttle.
- **Smaller scale errors with scales below 400 m.** (Fig. 3)
This error comes from the interferometric technology. This error is spatially correlated with the topography, the type of the flown surface and the number of measurements. The error is completely random at the pixel scale (90 m).



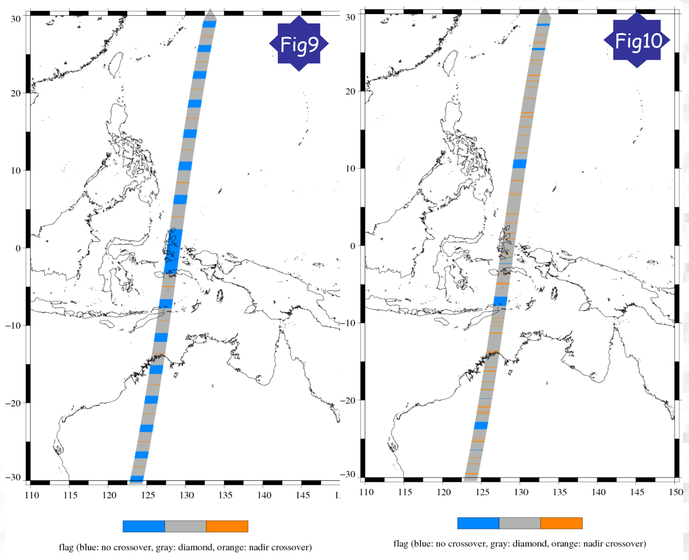
SRTM Random Error (from Rodriguez et al.)



SRTM Error for South America (from Rodriguez et al.)

The ACE2 model is based on SRTM DEM and altimetry data (ERS and EnviSat) is added to improve the DEM under altimetry ground track, especially over water bodies. Unfortunately, at the time of the study, there was no document available describing the spectrum of the different errors. Even if ACE2 model has strong advantages (latitude coverage up to 90° and heights over inland waters) compared to SRTM model, the lack of description of the associated error spectrum, which is a critical issue for an accurate roll angle estimation, leads to use SRTM model for roll angle retrieval. At the time of the SWOT launch, a new generation of high-resolution DEMs (TandemX) will be available.

Improved coverage over ocean crossovers

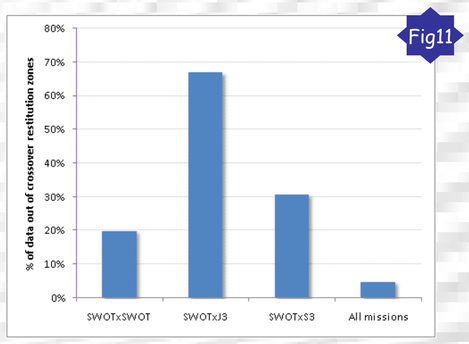


Roll angle retrieved at crossovers (blue: no data, grey: SWOTxSWOT data, orange: NadirxSWOT) for SWOT mission (left), SWOT+Jason-3+Sentinel-3 (right)

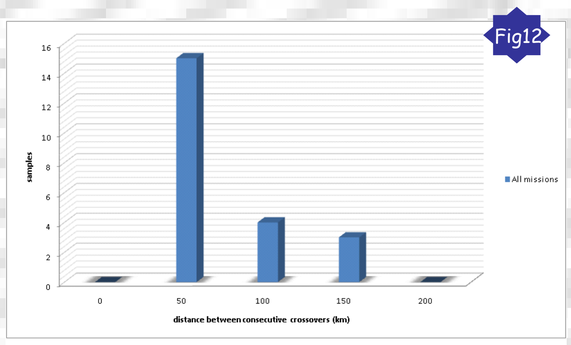
The propagation step is meaningful if individual roll angle retrievals are equally distributed along track. SWOT ocean crossover coverage can be improved by using data from Sentinel 3 and Jason-3 that will fly in the same period.

Based on crossover geometry, a flag of valid along track roll angles issued from the crossover retrieval has been derived. Considering the SWOT mission only, larger data gaps are observed, especially in equatorial regions (Fig.9). The coverage can be greatly improved by considering Sentinel 3 and Jason-3 (Fig. 10).

The configuration with 3 missions provides an excellent coverage with maximum blind spots of 150 km and most of the gaps being 50 km long (Fig.11 and 12). This insures the capacity of retrieving along track roll angle signal, even at high frequency.



Roll angle coverage over ocean with different mission configurations



Roll angle coverage over ocean with 3 missions

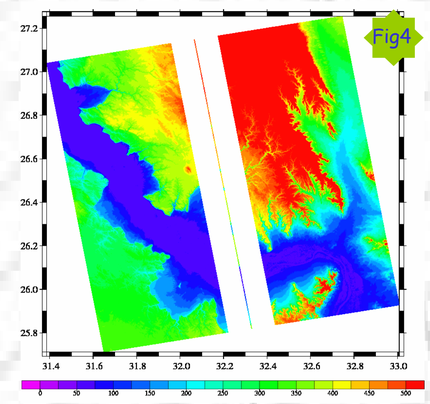
Roll Angle Estimation over land with a DEM

Simulation Assumptions

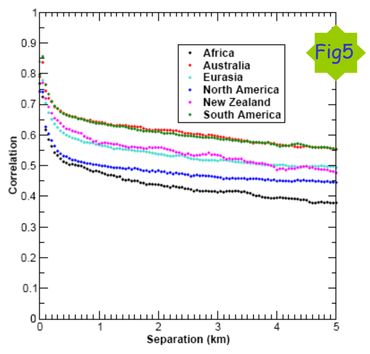
The roll angle error is estimated from the difference between SWOT and SRTM elevations. The basic assumptions are the following:

- SWOT height measurements will be available everywhere on the land (Fig. 4). Layover effects that will corrupt SWOT measurements have been neglected in this study case.

- SWOT pixels are simulated at a very high resolution (90 m x 20 m) and heights are averaged over larger zones for roll angle retrieval.



SRTM Heights (m) over the Nile



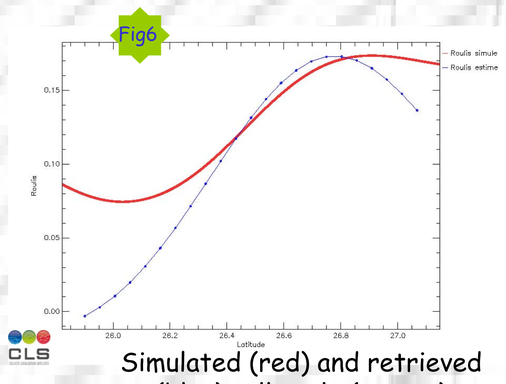
Correlation scale for short wavelengths of SRTM error (from Rodriguez et al.)

The analysis of the different error terms in the SWOT measurements showed that the DEM errors were predominant because of their short correlation scales.

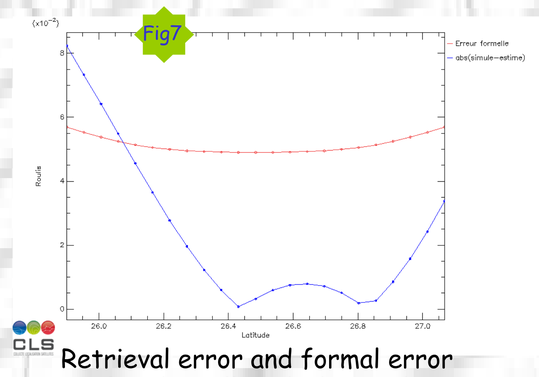
- The DEM measurements are simulated by adding to the reference height, only the short wavelength error (3 m rms and 400 m correlation scale) (Fig.5).

- SWOT measurements are simulated by adding only the roll error to the reference height (signal of 0.1 arcsec and 70 km scale).

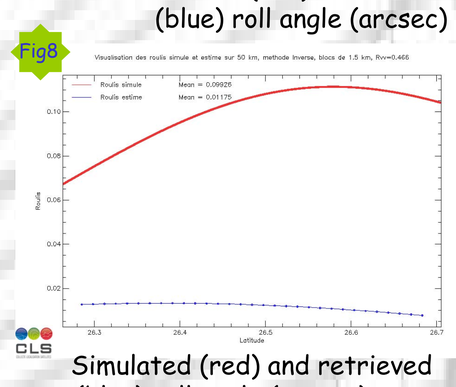
Results



Simulated (red) and retrieved (blue) roll angle (arcsec)



Retrieval error and formal error for the roll angle (arcsec)



Simulated (red) and retrieved (blue) roll angle (arcsec) over a 50 km data block

The roll angle is well retrieved with an error of 0.02 arcsec over 60% of the along track portion of data (Fig.6).The formal error provided by the inverse method is relevant with a mean value of 0.05 arcsec (Fig.7).
A test is performed over a shorter along track data block (50 km instead of 150 km). The roll angle is biased over the whole track portion by 0.1 arcsec (Fig. 8) because the block of data is too short to stabilize the retrieval.

The long wavelength error of 2 m rms present in the SRTM DEM translates directly into a roll angle error of 5 cm at the far end of the swath. Such DEM errors cannot be separated from the roll signal. Merging the long wavelength errors and the 400 km correlated errors, the resulting errors due to the DEM errors is of 0.15 arcsec (5 cm in height), which still meet the SWOT requirements of 10 cm error on water bodies.

Conclusion

In this study, we show that the roll angle can be retrieved over land, provided that the correlation scales of the MNT errors are known. The roll angle is retrieved with an error of 5 cm which fulfills SWOT requirements over water bodies. The error of 5 cm is mainly due to MNT long wavelength errors that cannot be separated from the true roll angle errors. After a few years of SWOT measurements, a more accurate DEM can be calculated using SWOT measurements. Until this SWOT DEM becomes available, the roll angle can be retrieved using the crossover technique only over land.

Perspectives

The final scheme for roll angle retrieval should merge ocean and land results in order to get continuous along track roll angle correction. A preliminary analysis has shown that a multi-mission configuration over ocean surface provides an excellent coverage. For both surfaces, the coverage of roll angles retrieved using crossovers can be completed by roll angles retrieved using a DEM or a MSS. When the performance levels on the roll retrieval has been assessed for each method and surface, the propagation step will be analyzed in order to obtain the final performance for the roll angle error of the SWOT mission.