Simulator of Interferometric Radar Altimeters concept and first results

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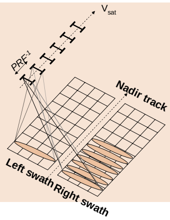
Abstract : To improve further its understanding of mesoscale ocean variability, the oceanographic community needs to observe the ocean at higher spatial and temporal resolution than is presently allowed by classical nadir radar altimeters. The **interferometric radar altimeter is an attempt to meet this requirement** using a single platform. From this point of view, we developed a **simulator of interferometric radar altimeters (SIRA)** that includes a realistic modelling of the ocean surface, an original two scales waveforms generation modelling and a complete inversion modelling from waveforms to height maps.

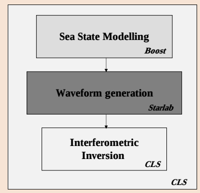
Wide Swath Ocean Altimetry : concept

At the pulse repetition frequency (PRF) rate, the instrument transmits a modulated pulse from one antenna and receives the ocean backscattered signal via two passive antennas. For a given "shot", the waveforms are defined as the pair of time-resolved, *complex* signals obtained after on-board processing - which includes down-conversion and focusing (i.e. range compression) - of the electric fields received by both antennas. **A major difference between conventional altimetry and interferometry is that the interferometer measurement of range relies on the complex phase information which is available for each imaged pixel in the scene**

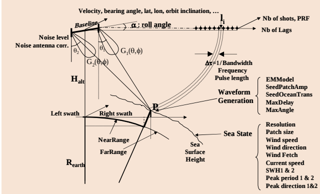
- Resolution along track is determined by the size of the antenna (along track)
- Resolution cross track is determined bythe bandwidth of the emitted pulse



Architecture



Parametrisation



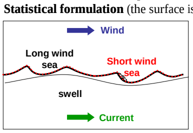
Sea State Module

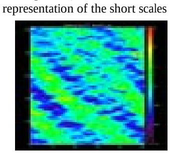
The sea surface state model developed within this simulator is able to produce a virtual but realistic ocean surface in a broad range of wind/wave and current conditions. A two-scales approach has been chosen.
The resolution cell is divided in patches which size is the size of the largest coherent waves

➔ **Deterministic formulation** (swell and long sea wind) (Jonswap, 2003)

Each patch is then divided in sub-patches on which a statistical representation of the short scales is used

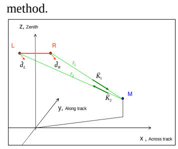
➔ **Statistical formulation** (the surface is not generated)





Waveform Generation Module

A core module of the simulator handles the generation of the instrument waveforms, driven by the altimeter configuration and a realization of the ocean's surface. The selected scattering model is required to faithfully render some phenomena well-known in ocean altimetry -such as the EM bias or the Doppler anomalies caused by surface currents- while remaining numerically tractable in typical scenarios.
Our approach has been to adopt a **two-scales integration scheme**. Since the ocean's surface is provided in a multi-scale fashion, we have adopted an **exact EM model** to explicitly integrate the longer scales and have addressed the shorter scales in a statistical manner, relying on various statistical methods. Hence, short-scale ocean surface realizations may be used to estimate the required statistics (e.g. elevation and slope distributions or spectrum) while long-scale ocean surface realizations are readily integrated with an exact method.



"Large waves" "Small waves"

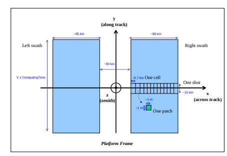
$$W(\tau)=K|\Omega|\sum_{patches}\frac{G_1G_2}{r_1r_2}\chi\left(\tau-\frac{r_1+r_2}{c},f_D\right)e^{iK(r_1+r_2)}\cdot Ae^{i\phi}$$

Doppler frequency : $f_D=\frac{1}{\lambda}\frac{\partial(r_1+r_2)}{\partial t}$

Analytical models are selected for the ambiguity function χ and the antenna pattern G

$Ae^{i\phi}$ is the small scale contribution of the ocean

- Fundamental assumption: EM *local* method (no shadowing/double-bounce). See [Beckmann1963], [Picardi1998], [Zavorotny2000]
- Radar equation computed for the left/right antennas
- The right antenna is active, the left is passive (bistatic)
- No ping-pong mode
- Multi-scale approach: Swath>Shot>Cell>Patch
(Figure given for a WSOA configuration)

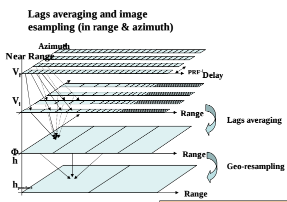


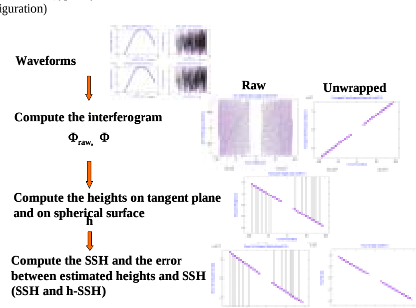
Inversion Module

The inversion module is devoted to the generation of height maps from couples of complex waveforms. Interferograms are computed for each lag of the waveforms or after lags averaging according to Rodriguez's formula.

$$\hat{\Phi}=\arctan\left[\frac{Im\left(\sum_{i=1}^{N_L}v_i^{(1)}.v_i^{(2)*}\right)}{Re\left(\sum_{i=1}^{N_L}v_i^{(1)}.v_i^{(2)*}\right)}\right]$$

A geo-resampling in azimuth and range can then be applied to obtain height images at the required resolution size (typivally 1 km x 1km for a WSOA configuration)

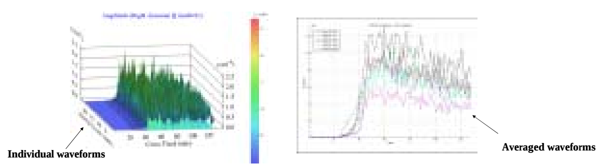




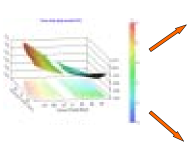
Validation of the simulator for Jason-1 configuration

One way to validate the sea state and waveform generation modules was to configure the simulator with Jason-1 characteristics (nadir pointing, ..). The results are really good as shown in the next figures. On the upper figure, are plotted individual echoes (at the PRF rhythm) obtained for a given sea state (SWH=1m, Wind 7m/s). The bottom figure shows six waveforms obtained for six sea-surfaces defined by their input wind speeds and significant wave heights. The six amplitude waveforms qualitatively match the Brown model: from early to late gates, they are made of three regimes: (1) flat plateau (thermal noise), (2) leading edge up to a peak and (3) trailing edge (antenna mispointing angle). These features' dependence with sea-surface is as expected:

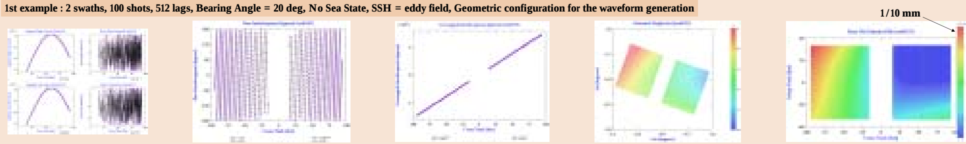
- the peak height decreases with increasing wind speed
- the leading edge starts earlier with larger wave heights
- the trailing edge's slope is independent from the surface



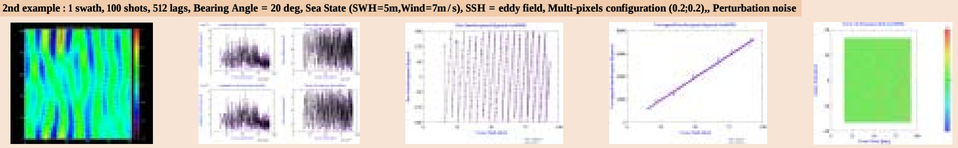
Examples of results



1st example : 2 swaths, 100 shots, 512 lags, Bearing Angle = 20 deg, No Sea State, SSH = eddy field, Geometric configuration for the waveform generation



2nd example : 1 swath, 100 shots, 512 lags, Bearing Angle = 20 deg, Sea State (SWH=5m,Wind=7m/s), SSH = eddy field, Multi-pixels configuration (0.2;0.2),, Perturbation noise



Conclusions

SIRA simulator :

- **provides a very good representativity** of the sea surface, of the electromagnetic backscattering model, of the waveform generation and of the inversion process
- **is an open tool easy to configure** (geometric parameters, sea state, algorithms of the simulator). It is a easy for the expert **to generate scenarios** (from 1 sample of one waveform of one swath of one pass **to** M samples of N waveforms (X seconds of simulation) of two swaths and two passes)**, to run simulations and to visualize the results. It has been designed to allow future evolutions of the models, of the characteristics (instrumental and geometric) and of the processing.**
- gives the possibility to run Monte Carlo simulations on pseudo static geometry and the possibility to adapt the processing complexity to study some particular points
- **allows many potential scientific studies**