Radar waveform inversion

An application to coastal altimetry

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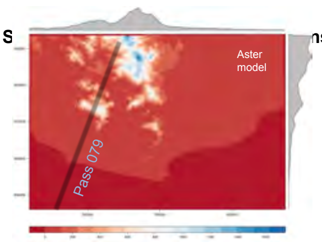
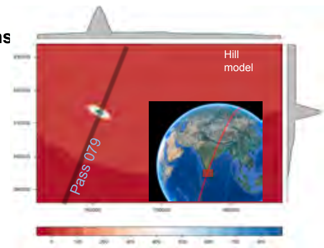
Can topography explain coastal waveforms ?

We study the approach to the indian coast (Jason-2 pass 79, blue line on topography representation). Is an approximation of the topography enough to explain coastal waveforms ? Longitude at coast is ~77.329°E (orange vertical line).

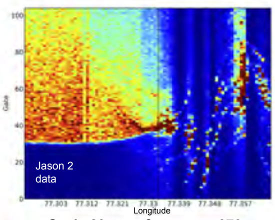
Our approach is based on forward modeling using a simple physical model which computes the contribution of each surface tile to the backscattering radiation power, taking into account the sphericity of the Earth, the antenna gain, the height and backscatter coefficient of the surfaces. We applied this forward model to the case of India (cf. inset below) using Jason-2 waveform data Two initial models are considered: an ASTER model of India (the *Aster* model, derived from the ASTER GDEM v2 dataset with horizontal resolution of ca. 80m similar to SRTM). The *Hill* model which is an ellipsoid lying on an otherwise flat surface. Water backscatter σ_{0W} was taken to be 13dB and for land σ_{0L} =1 dB. Pixel size is 30m.



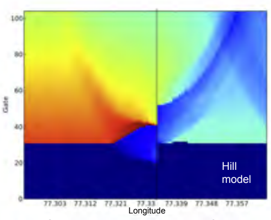
Aster Data for India pass 079



Synthetic Topography for pass 079

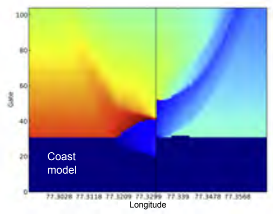


Cycle 29 waveform pass 079

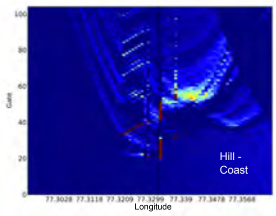


Cycle 29 synthetic waveform with one hill

The effect of the synthetic topography is more clear when compared with a configuration that reproduces the coastline and backscatter values, but topography is mostly flat (and set to constant 10m elevation). This is the so-called "Coast" model. The vertical orange line indicates the position of the coastline.



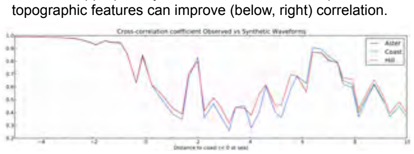
Synthetic waveform w/coast but no topography

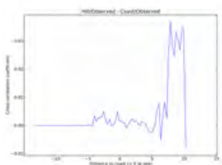


Difference synthetic waveforms with and without topography

Quality criterion: when are waveforms similar ?

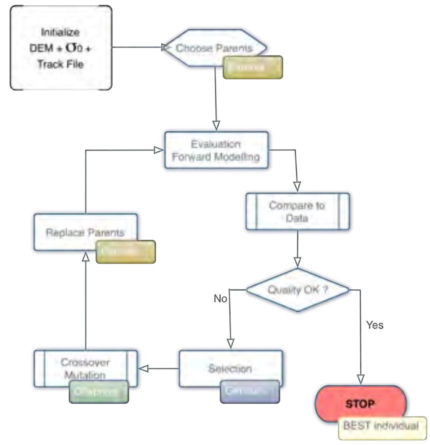
The simplest "obvious" answer is a simple cross-correlation coefficient. For the above example, we look at the effect of having an accurate coastline on of the correlation coefficient for a waveform for three models: the ASTER DEM model, the Hill model, and the Coast model (below, left) as function of distance to coast. The correlation is surprisingly good even up to the coastline (coeff > 0.8 mostly); adding more topography features degrades the correlation while approaching the coast from the sea, whereas it improves waveform correlation on land, mostly next to the coatline. Interestingly, the more complete Topography (derived from Aster) is *not* the one that behaves the best (except between 6 and 7 km of the coast – at the foothill position). Thus, an appropriately chosen coastline can explain much of the received signal; appropriate topographic features can improve (below, right) correlation.





Waveform inversion by genetic algorithms

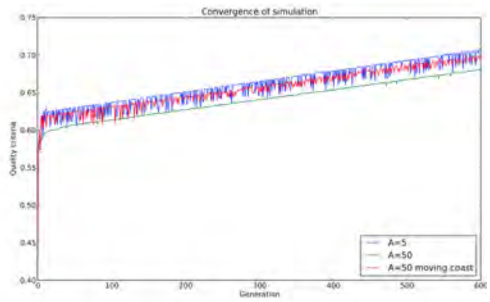
The waveform inversion goal is to obtain the heights and backscatter values of the surface reflectors. The flowchart is given below: it is an iterative procedure based on a genetic algorithm approach. An individual is a geometric configuration and its properties (i.e. the DEM and σ_0); a population explores phase space with genetic operators: cross-over (tile exchange), mutation (random elevations) and *tournament* selection (we run several "tournaments" among a few individuals chosen at random from the population; the winner of each tournament -the one with the best fitness- is selected for crossover). The crucial part is the evaluation of best-fitting individuals. For this, we use the the forward modelling of waveforms of the previous section, with a quality criterion based on the cross-correlation coefficient shown before.



Key aspects: the behavior of the genetic algorithm is controlled by the EASEA platform, an Artificial Evolution platform facilitaing the use of many-core architectures and GPGPU computing. The most costly step in this iterative algorithm is the modelling/evaluation step. The forward modelling algorithm is ideally suited for parallel applications (each contribution of a surface facet can be computed individually) and GPU computations in particular.

Inversion for the Indian coast

First results for the full waveform inversion of pass 079 are shown below. The parameters for the evolution are elevation (evolving from 10 to 400m) and σ_0 for each land surface element, the latter being able to change in values of 0, 1, 2, and 4 dB whilst the water backscatter σ_{0W} remains fixed at 13 dB. The quality criterion is the *integral* of the cross-correlation coefficients shown before. Strong elitism is used to preserve the best solution from one generation to the next.



Conclusions

The prototype for full waveform inversion is now complete; convergence is found relatively easily but the search for an optimum can be improved (topography smoothing, tile interchange optimisation ...). The code is now able to work both sequentially and with a GPGPU architecture.

Acknowledgements

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