Radar Altimetry Waveform Inversion

Topography and Water Bodies

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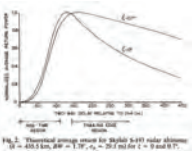
Waveform Analysis

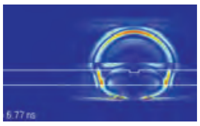
Brown's Model, waveform classification

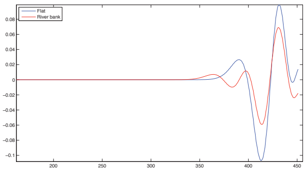


Brown's Model (1977) is an analytical approximation of the response of a rough medium to radar waves. A certain number of key assumptions are made: (1) Scattering of a large number of *random independent elements*, and (2) constant surface height statistics. Clearly, these assumptions are *not* valid for the case of water bodies on continental surfaces.

Water on continental surfaces

Geometric Effects





Not only the radar signal has a different signature than that of the Brown model because of non-gaussian reflectors. In the numerical modeling shown above (finite-differences, 2D scheme), the effect of a subsidence on the reflector (a very simplistic river bed) creates a very different signal.

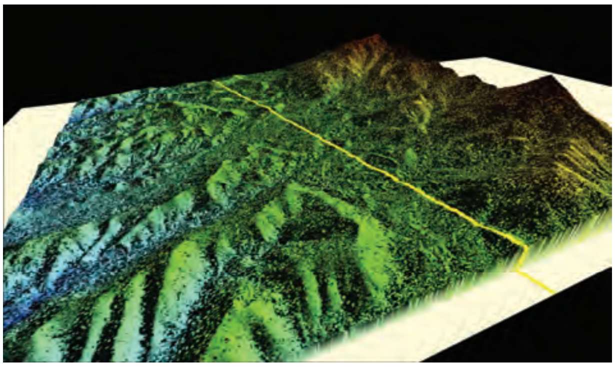
Forward Modeling

$$\nabla \cdot \boldsymbol{E} = \frac{\rho}{\epsilon_0} \qquad \nabla \cdot \boldsymbol{B} = 0$$

$$\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t} \qquad \nabla \times \boldsymbol{B} = \mu_0 \boldsymbol{J} + \mu_0 \epsilon_0 \frac{\partial \boldsymbol{E}}{\partial t}$$

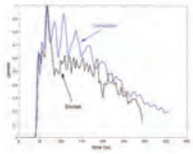
For complex geometries and/or reflective properties, full modeling of the radar scattering phenomenon (solving Maxwell's equations) is the only way of reproducing accurately the behaviour of the system - the field of Computational Electrodynamics (CED) tackles this very problem. Many approaches exist - from the simplest finite-difference (i.e. above), to complex finite-element and asymptotic methods. Here, we use the ray-tracing method as an asymptotic approximation to explore waveform inversion as controlled by topography and water-level.

Topography and boundary conditions



To validate forward modeling, accurate topography is used: Lidar data, 3.5 x 3.5Km, 15-38 cm horizontal resolution, 62 mm vertical resolution.

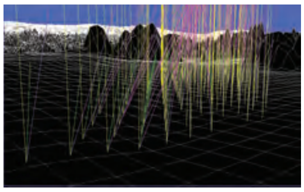
Example: topography on ice



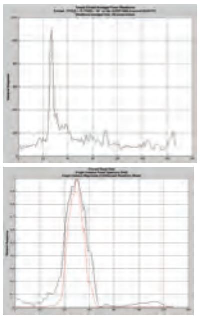
In December 2005 a GPS survey was performed on the Amery ice shelf in order to validate the ENVISAT RA2 measurements. We used the GPS topography to simulate waveforms as per ENVISAT point of view, using an analytical expression similar to that of Brown; by improving the modeling method, even better agreement can be expected.

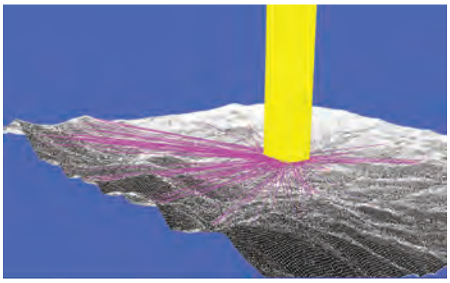
Geometrical Inversion

Forward modeling by ray tracing



Ray tracing is a well known asymptotic approximation for high-frequencies; it is well suited for the interaction of radar waves with the landscape. Furthermore, optimisation by parallel processing is natural and straightforward. Multipath effects can also be taken into account. In the figure below, a square array of (yellow) rays from the altimeter, 500x500, fall on a topography with 50 cm resolution; violet rays bounce to the mountain and back to the altimeter.





Inversion as optimisation

"Topography" = substrate + vegetation + water

variabilty : (long term) + (mid-term) + (short-term)

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Loop:
   Forward modeling with "topography"
   Calculate convergence criterion wrt data
   if criteron > threshold:
      Modify "topography"
   else:
      goto loop
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Convergence criterion: cross-correlation of signal

Key Ideas:

- Geometry-controlled inversion
- The approach is valid for coastal and continental zones
- All waveform data contribute as boundary conditions, so *all* information is taken into account.
- Ray-tracing method can be implemented with GPU technology

Special thanks to D. Hancock for providing us the images from his ray-tracing code

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