Monte Carlo Simulation of Altimeter Pulse Returns and the Electromagnetic Bias

Praphun Naenna[1], Joel T. Johnson[1], and C. K. Shum[2]

[1]Department of Electrical and Computer Engineering, and ElectroScience Laboratory

[2]School of Earth Sciences, The Ohio State University

Motivation

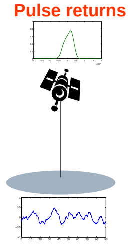
The electromagnetic (EM) bias is an important error term in sea surface height estimation from satellite radar altimetry. Present EM bias models are empirically based and globally-averaged functions of the altimeter-measured significant wave height and wind speed alone. Recent studies have shown that a reduction in the EM bias error variance can be achieved by incorporating ancillary wave model data into the EM bias model. This motivates an improved understanding of the physical mechanisms of the EM bias, so that an optimal means for incorporating ancillary data can be developed. New altimeter systems at Ka band also requires new consideration of the EM bias.

Monte Carlo Approach

While the EM bias has been studied extensively, most studies are based on low-order hydrodynamic and electromagnetic models. Herein, an alternate approach for EM bias studies is presented. This study employs a Monte Carlo procedure using numerical nonlinear hydrodynamic simulations coupled with numerical physical optics methods for electromagnetic scattering from the sea surface to produce a deterministic set of sea surface profiles and the corresponding altimeter pulse returns. The coupled simulation allows the impact of various physical effects to be investigated without resorting to decomposition of the sea surface into long and short sea waves.

1. Generate a set of non-linear sea surfaces.
2. Compute near-normal incidence backscattering over a range of frequencies.
3. Transform backscattered fields versus frequency into the time domain.
4. Average over realizations.
5. Estimate sea surface height and electromagnetic bias from pulse returns.

Pulse returns

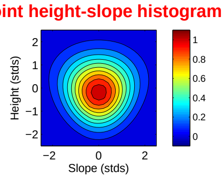


Surface profiles

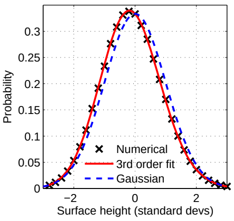
Pulse Return Simulation: A set of sea surface profiles and the corresponding altimeter pulse returns are produced, allowing studies of various physical effects.

Surfaces to be used in the Monte Carlo simulation are generated by two hydrodynamic models: a linear Gaussian random rough surface with an ocean-like Pierson-Moskowitz spectrum, and a nonlinear surface generated by the "improved linear representation" of the ocean waves (ILR) by Creamer et al. (1989). The ILR method can capture hydrodynamic effects beyond the low-order model of Longuet-Higgins (1963), which previous theoretical studies are based on. In this study, the generated sea surfaces are assumed to be long-crested and perfectly conducting to reduce computational requirements.

Joint height-slope histogram

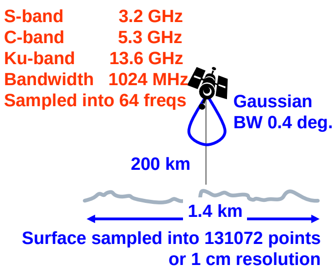


Specular height pdf



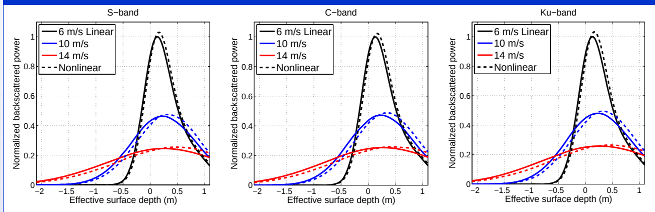
The ILR method: Joint height-slope histogram and specular surface height pdf obtained using the ILR method. Results used 10000 surface realizations with a 15 m/s Pierson-Moskowitz spectrum used to produce the underlying linear surfaces. Non-Gaussian statistics obtained demonstrate the applicability of the ILR method for studying the EM bias.

For the electromagnetic model, the physical optics approximate theory of rough surface scattering is used to compute backscattered fields in the frequency domain. The antenna pattern is also accounted for in the computations. A sweep over frequencies is required to model pulse returns in the time domain. The EM bias (shift in pulse returns) is so small that a large number of realizations is required for good convergence. Parallel computing is utilized. The CPU time required for the ILR computation for one surface realization is approximately 9 minutes.



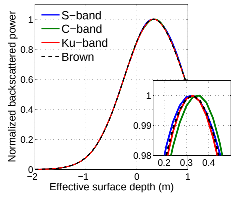
Geometry of problem: The altimeter altitude and corresponding antenna footprint are scaled down to reduce the computational complexity.

Simulated Pulse Returns



Average pulse power returns: 6 m/s, 10 m/s, and 14 m/s wind speeds

The above figure compares average pulse returns from the linear surfaces and the ILR- transformed surfaces. The horizontal axis represents the time axis multiplied by one half the speed of light. Results are averaged over 42000 surface realizations. Clear evidence of a shift in pulse return time is observed, with the nonlinear pulses apparently originating from a surface shifted lower with respect to the true surface.

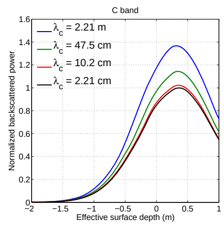


Simulated pulse returns are in good agreement with the analytical model by Brown (1977). Note the significant wave height and skewness parameters used in the model are taken directly from the set of generated ILR-transformed surfaces. This indicates that the Brown model is reasonable and that nonlinear effects can be adequately captured by third-order skewness parameters. However small differences are observed near the peak of the pulse returns which change with the radar frequency.

Comparison with the Brown model: 10 m/s nonlinear

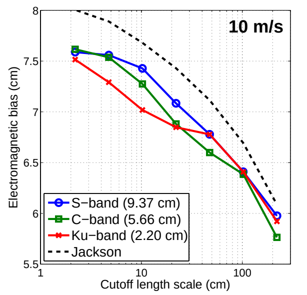
EM Bias and Conclusion

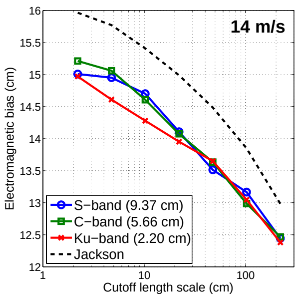
Short wave effects are examined by varying the range of length scales included in the surface profiles; the ILR transformed surfaces are passed through low pass filter before the electromagnetic scattering is computed. The cutoff wavelength of the low pass filter is varied in order to reduce the short wave spectral content of the sea surfaces considered. The right figure illustrates the change in pulse returns as the short wave surface content is varied. As more short waves are included, the surface gets rougher which in turn reduces the backscattering radar cross section resulting in smaller amplitudes of the pulse returns. Pulses with the two smallest cutoffs are closer together showing signs of a saturation in short wave effects as the short waves become much shorter than the electromagnetic wavelength



C-band pulse return as the cutoff is varied

A further examination of short wave effects is provided in the figures below, where the EM bias in the three frequency bands is plotted as a function of the short wave cutoff wavelength. Under the Brown model, the EM bias as defined by Jackson (1979) can be obtained from the pulse returns as the difference between the normalized first moments of the nonlinear and linear pulses.





EM bias as a function of the short wave cutoff wavelength

The results show the dependence of the EM bias on the short wave surface content and the radar frequency. The EM bias increases when more short waves are included in the surface. For S and C bands, a saturation appears to occur for sea waves shorter than the EM wavelength. Comparisons with the Jackson (1979) model show that the basic effect of changes in the surface skewness parameters is captured by the theory, but the variations with frequency are not. Present efforts are comparing these results with the theory by Elfouhaily et al. (2000) in order to obtain more clear conclusions regarding surface cutoff wavelength effects which will lead to an improved understanding of short sea wave influence on the EM bias and its variations with frequency. Studies of the impact of swell and other long waves are also planned.