ADVANCED REMOTE SENSING OF OCEANIC INTERNAL WAVES BY SPACEBORNE ALONG-TRACK INTERFEROMETRIC SAR

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Since the SEASAT mission in 1978, scientists have used satellite-based synthetic aperture radar (SAR) images to study oceanic internal waves [1]. Internal waves become visible in SAR images because their orbital currents modulate the surface roughness [2]. While this leads to an accurate spatial representation of wave patterns, the complexity of the imaging mechanism makes it difficult to estimate currents and internal wave amplitudes quantitatively from conventional SAR images [3]. A more direct interpretation is possible with along-track interferometry (ATI), which permits direct scatterer velocity retrievals from a pair of SAR images. ATI data are currently available from the satellite TerraSAR-X as an experimental product. We present an example dataset with strong signatures of internal waves at Dongsha (South China Sea) and demonstrate how internal wave properties can be estimated using a simple parameterization of internal solitons and a numerical SAR imaging model. Further model results show how ATI signatures are more sensitive to currents and less sensitive to secondary model parameters than conventional SAR signatures.

A High-Resolution Image of the Surface Velocity Field

The dataset considered here was acquired by TerraSAR-X on April 22, 2010, 22:13 UTC, at Dongsha (South China Sea). This region is well known for its internal waves, but we had good luck to find a particularly well-organized internal wave train, propagating almost exactly in radar look direction, in the center of the image. The intensity image on the left, covering an area of 29 km × 88 km, shows the typical surface roughness variations due to hydrodynamic wave-current interaction that have been observed in many satellite images. The phase image in the center is a unique product that is obtained from ATI data only. While the phase signatures are clearly noisier than the intensity signatures, some correlated patterns are visible. Applying a special filter and converting the phases into scatterer velocities, we can derive a horizontal Doppler velocity field of the first two solitons, as superimposed in color in the third figure. Profiles of image intensity and Doppler velocity variations at Transects 1–3 are analyzed and interpreted further in the box on the right.

Data Analysis and Interpretation

To estimate properties of the internal waves from the SAR image intensity and Doppler velocity profiles, we generate theoretical radar signatures for a variety of parameter combinations. We start with the “two-amplitude” solution of the Korteweg-de Vries equation with cubic nonlinearity [7,1], which describes solitons with amplitudes and widths determined by the upper and lower layer depths and densities and by a nonlinearity parameter ν with values between 0 and 1. To convert the pycnocline displacement η into a surface current U, we use

\[ U(x,t) = -\frac{1}{\eta} \frac{\partial}{\partial x} \left( \frac{\eta(x,t)}{\eta(x,t)} \right) \]

where \( \nu \) is the propagation speed of the soliton and \( \eta \) the height of the upper layer. For Transects 1 and 2 we generate two solitons, for Transect 3 a single one. The current field and a wind vector are fed into a numerical SAR imaging model [8], which computes spatially varying surface wave spectra and corresponding image intensity and Doppler velocity signatures that can be compared with the observed ones. The soliton parameters that lead to best agreement represent our best estimate of the conditions at the time of the TerraSAR-X overpass. Based on weather station data, we assume a wind speed of 4.4 m/s from 45°. Furthermore, like in [3], we use a reduced relaxation rate in the wave-current interaction model to be able to reproduce the observed image intensity modulations. For \( \nu \), which should be on the order of 80–110 m, we find that large values make the simulated signatures too wide, indicating that the best choice is near 80 m. With this, the only remaining tuning parameter is \( \nu \).

The diagrams below show our best model results (red curves) together with the observed intensity and Doppler velocity profiles (black). Good agreement of all profiles is obtained with a parameter combination that is consistent with known typical conditions at the test site. This is all we can say for now, since we have not been able to obtain reference data from April 2010 for a complete validation.

An important question is how sensitive the image intensity and Doppler signatures are to parameter changes – this sensitivity determines how accurate internal wave parameters can be retrieved from radar data. The pink, blue, and orange curves in the diagrams show how the model results change if we reduce the internal wave amplitude or wind speed or if we use the full relaxation rate instead of the reduced one. We find that a change of 1 m/s in the wind speed has a stronger effect on some image intensity signatures than an internal wave amplitude change by 20%, while the Doppler signatures are clearly more sensitive to current than to wind variations. Similarly, a modification of the relaxation rate has a much stronger effect on the intensity than on the Doppler signatures. The low sensitivity of Doppler signatures to these secondary parameters is the main reason why the ATI technique permits more accurate and robust internal wave parameter retrievals than the conventional SAR image analysis.

References and Acknowledgments


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