A Radar Modulation Transfer Function for Oceanic Internal Waves

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Introduction

Signatures of oceanic Internal Waves (IW) is the most striking and abundant feature when studying SAR imagery from the South China Sea. These oceanic internal waves are disturbances of the thermocline, often resulting from interaction of the tidal currents with abrupt gradients in the bathymetry. Most of the IW's in the region are formed in the strait between Taiwan and Luzon (Phillippines), and are travelling westwards with a speed on the order of 1 m/s (Liu et al. 2006).

Although these internal waves are disturbances of the thermocline, at typically 100 meter depth, they induce surface currents, which is the reason they can be observed by SAR sensors. For most of the IWs, the surface current is convergent in front of the IW, and the surface roughness is increased since the wave energy is condensed. Behind the IW crest, the surface roughness is decreased since divergent current spreads the wave energy over a larger area. Hence, IW's can often be observed on SAR images as a bright band followed by a dark band. Sometimes a single pair of dark/bright bands is observed (soliton), and sometimes a train of such bands is following, usually weaker than the leading one.

From SAR imagery one can not only spot the location of the IW's, but also quantify the degree of roughness modulation, which in turn can be used to retrieve properties of the IW's, such as the strength of the surface convergence/divergence. A radar imaging model is here used to develop a modulation transfer function which relates the strength of the induced surface current to the measured amplitude of radar backscatter across Internal Waves.

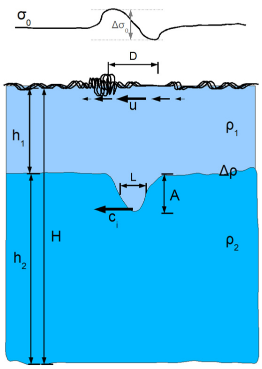
Objectives

The overall objective is to retrieve the amplitude of the internal waves, and the depth and strength of the pycnocline from SAR imagery.

The specific objective of this study is to find a quantitative relationship between the IW induced surface current gradient and the modulation of the radar backscatter signal.

The figure below illustrates an oceanic solitary internal wave (depression) with amplitude ***A*** propagating from right to left with a phase speed c_i on the pycnocline between the upper (mixed) layer with thickness h_1 and density ρ_1, and the lower layer with higher density ρ_2 and thickness h_2. The gradients of the induced surface current ***u*** leads to a modulation of the radar backscatter σ_0 which can be observed with SAR sensors.

The phase speed of the IW can be estimated when two wave packets are seen on the same SAR image, as their separation time is known to be 12.5 hours; under the assumption of tidal generation.



Acknowledgement

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Envisat ASAR data is provided by ESA.

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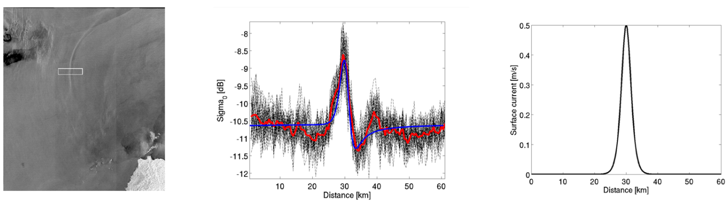
Radar Imaging Model

To quantify and study the relation between the observed radar (SAR) signature of internal waves (IW) and the geophysical parameters, we use a radar imaging model (RIM) described in e.g. Kudryavtsev et al. (2003, 2005) and Johannessen et al. (2005). The model takes as input geophysical parameters such as wind, boundary layer stability and surface current, and calculates the radar backscatter for any viewing geometry or radar wavelength. The capability of RIM to reproduce the IW signature as observed with SAR is illustrated below.

The left figure shows part of an Envisat ASAR scene with a clear IW signature. The black lines in the middle figure are the transects of backscatter within the white rectangle on the left figure, and the solid red line is their mean. The blue line is simulated with RIM, for the given imaging geometry and with wind speed and direction from the NCEP GFS forecast model. The input surface current profile is given by a classical analytical result for IW solitons by Korteweg and de Vries (1895): $U = U_{max} \cosh(x/L)^2$ where x is horizontal distance, L is the characteristic width of the IW (see figure under "*Objectives*") and U_{max} is the maximum of the induces current. The best fit with the observed σ_0 profile was obtained by adjusting U_{max} to 0.5 m/s, as seen in the right figure.

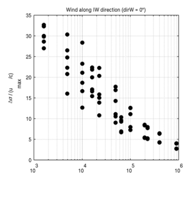


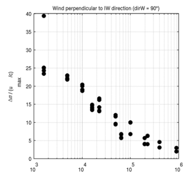
Model experiment setup and results

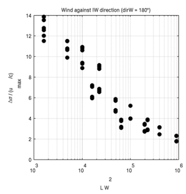
To quantify the relationship between IW induced surface current and the radar backscatter modulation, simulation of the IW radar signature with RIM as described above is performed where the following input parameters are varied systematically over the given values:

- Wind speed (***W***) = 4, 7, 10 and 15 m/s
- Wind direction: 0, 30, 90 and 180 degrees inclined from the IW propagation direction
- Radar azimuth look direction: 0, 30 and 90 degrees inclined from the IW propagation direction
- Radar incidence angle: 20, 30 and 40 degrees
- Characteristic width of the IW (***L***): = 100, 1000 and 4000 m
- Maximum IW surface induced current (U_{max}): 0.2, 0.5 and 1 m/s
- IW phase (propagation) velocity (c_i): 1, 1.5 and 2 m/s

The results are plotted on the figure to the right.







With a proper scaling of the axes, a clear realationship is found between the roughness modulation ($\Delta\sigma_0$, see figure to the left) and other known parameters listed above:

$$\Delta\sigma_0 = \alpha \frac{U_{\max}}{W^2 \; L \; C_i}$$

The parameter α is dependent on the wind direction, as seen from the upper, middle and lower figures, and can be tabulated from the numerical simulations.

The roughness modulation is seen to be proportional to the ratio of maximum induced surface current and the characteristic width of the IW (U_{max}/L), which is a natural measure of the induced surface current gradients. However, the relationship depends also on the wind speed and the phase speed of the IW. This modelled relationship needs to be validated against in situ measurements in the future.

Conclusion

- A new relationship is found between the surface current gradient induced by an oceanic internal wave and the corresponding modulations of backscatter observed with SAR.
- Provided accurate local wind field estimates are available, the relationship will give estimates of maximum current and current gradient associated with the propagating IW.
- The relationship need validation against in situ measurements.