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MEASUREMENT OF OCEAN WAVE SPECTRA USING POLARIMETRIC AIRSAR DATA

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1.0 BACKGROUND

Azimuthally traveling waves are seldom well imaged in either synthetic-aperture radar (SAR) or real-aperture (RAR) images of the ocean (Alpers et al., 1981). A polarimetric technique has been investigated (Schuler et al., 1993) which increases a radar's sensitivity to ocean wave tilting when the waves have a component of their propagation vector in the azimuthal direction. The technique offers improvement for polarimetric measurements of azimuthal wave slope spectra. A modification of this technique involving wave-induced changes of the polarization signature location offers a means of measuring azimuthal wave spectra for both polarimetric SAR and RAR. This method senses wave-tilts directly and does not require knowledge of the microwave modulation transfer function.

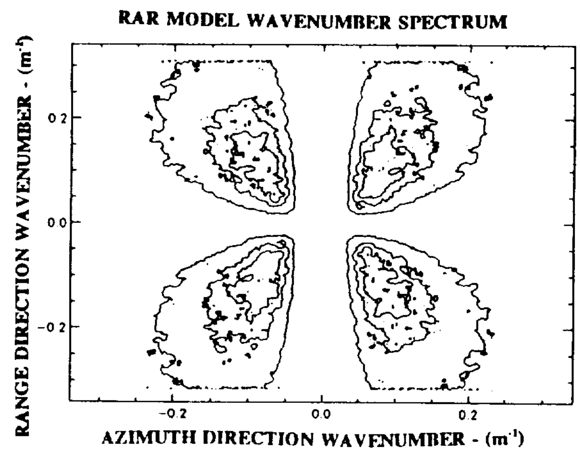
In the case of RAR images, cross section modulation by ocean waves is normally attributed to two principal sources, tilt modulation and, hydrodynamic modulation. The effect of these modulations is described mathematically by a complex modulation transfer function (MTF). For radar images of ocean waves both of these modulation sources roll-off to zero in the azimuthal direction. Therefore, complete two-dimensional k-space wave spectra derived from microwave data are often quite different than the physical ocean spectra. Evidence will be presented to show that a new source for backscatter modulations will result when the polarization properties of the scattering matrix are utilized specifically to sense wave tilts occurring in the azimuthal direction. The improvement in the fidelity of 2-D wave spectra created using optimal polarizations was investigated using a RAR ocean imaging model. The new method was derived from observations made on the properties of ocean polarization signatures. The new imaging technique reported here utilizes linear co-polar signature information to maximize a microwave instrument's sensitivity for azimuthally traveling waves.

Resolved wave tilts create a modulation of the cell polarization orientation which, in turn, modulates the backscatter intensity in an image. Critical to the success of the new techniques is the property that ocean linear co-polar signatures have regions which are highly sensitive to wave tilts. When an image is processed using a polarization orientation which maximizes this sensitivity, tilt perturbations due to azimuthally-traveling ocean waves have a large effect on the backscatter intensity.

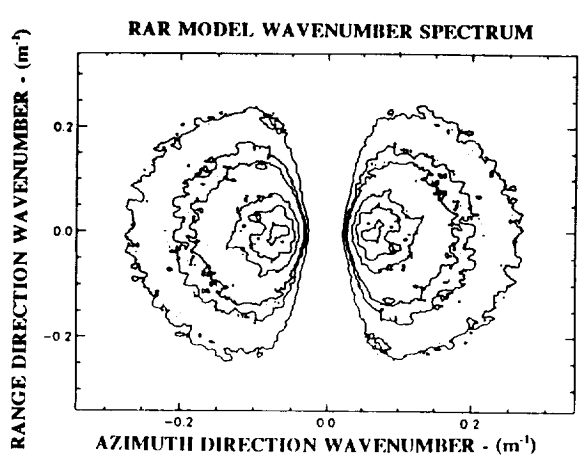
This polarization orientation modulation acts as a new source-term for the overall microwave modulation transfer function. The magnitude and phase of this modulation have been quantitatively evaluated. The determination of the magnitude was demonstrated by making polarization gratings in P-band SAR images of the ocean. The polarization modulation transfer function contribution has also been evaluated using signatures developed from a theoretical tilted-Bragg model. The magnitude of the polarization modulation contribution to the MTF is equal to 2-5 for mid-range incidence angles. The effect is in phase with the tilt-modulation and has a phase of 90° relative to the hydrodynamic term.

2.0 APPLICATION TO WAVE SPECTRAL MEASUREMENTS

A model (Lyzenga, 1988) for the radar imaging of ocean waves has been modified to include both the amplitude and the phase effects of the new polarization modulation source term. Results using this model indicate that undesirable effects such as distortion and spectrai-splitting of the actual spectrum may be greatly reduced for the case of azimuthally traveling waves.



(A)



(B)

Fig1(A-B): Conventional Model RAR spectrum (A), and the Model RAR spectrum modified to include the new polarization term (B). The spectrum of (B) is similar in shape to the input waveslope spectrum, whereas the spectrum of (A) exhibits spitting and distortion about the $\Phi=0$ direction

Figure 1 shows comparisons made between conventional RAR spectra, and spectra developed with the new polarization modulation term included. Fig.1(A) shows the conventional RAR waveslope spectra, with the dominant wave ($\lambda=100$m, significant waveheight $h_s=3$m) traveling in the azimuthal direction ($\Phi=0°$). Severe spectral splitting (abnormal four-lobed pattern) and distortion occurs because of the roll-off of the transfer function as the direction approaches $\Phi=0$. Fig.1(B) includes a polarization modulation term of magnitude 3.0 in phase with the tilt modulation, but having a $\cos\Phi$ dependence. Fig.1(B) indicates that polarization modulation MTF contributions are capable of compensating for distortions in the RAR spectra which are due to azimuthal roll-off of the modulation transfer function.

3.0 POLARIMETRIC SIGNATURE MODULATION

A JPL AIRSAR image (20 July 1988) of azimuthally traveling Pacific swell occurring off the coast of San Francisco was used to apply the new techniques to SAR images rather than RAR images, or models. The wave-induced intensity modulations in this image were strong and essentially uni-directional. The modulations were likely produced by velocity-bunching effects. A first attempt to enhance the wave modulations by changing the linear polarization through a range of values did not produce any significant changes. This was probably due to the strength of the velocity-bunching effects and a mismatch in phases between this effect and the polarization modulation. The original technique was then modified to detect changes in location of the polarization signature rather than intensity modulations. A strip image parallel to the azimuthal direction was formed which had pixel averaging (20) in the range direction and (2) in the azimuthal direction. Polarization signatures were formed for 350 cells formed parallel to the direction of wave propagation. Gates were set at the peak at other points in the signature to sense wave-induced movement parallel to the Orientation axis of the signature. Fig 2 shows a power waveslope spectrum of the strip. this SAR wave spectrum shows a strong peak at a wavenumber $k=.032\ m^{-1}$ indicating the presence of a dominant wave of 192 m wavelength.

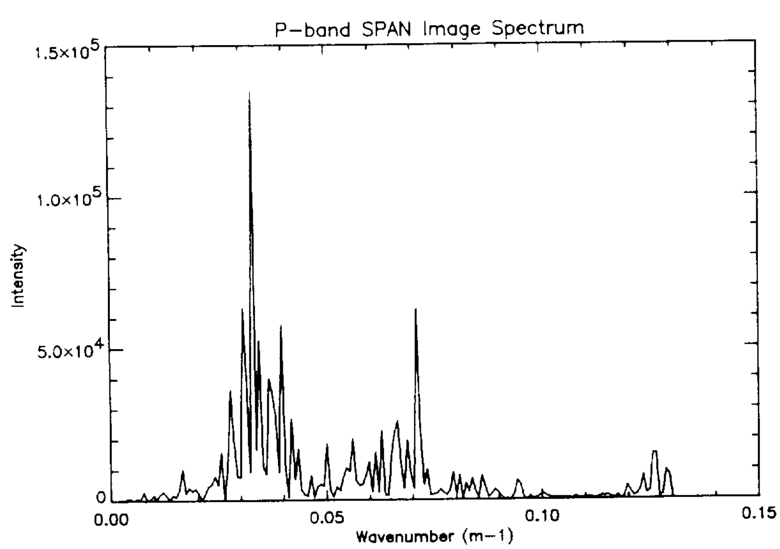


Fig. 2: SAR intensity waveslope spectrum for the image strip.

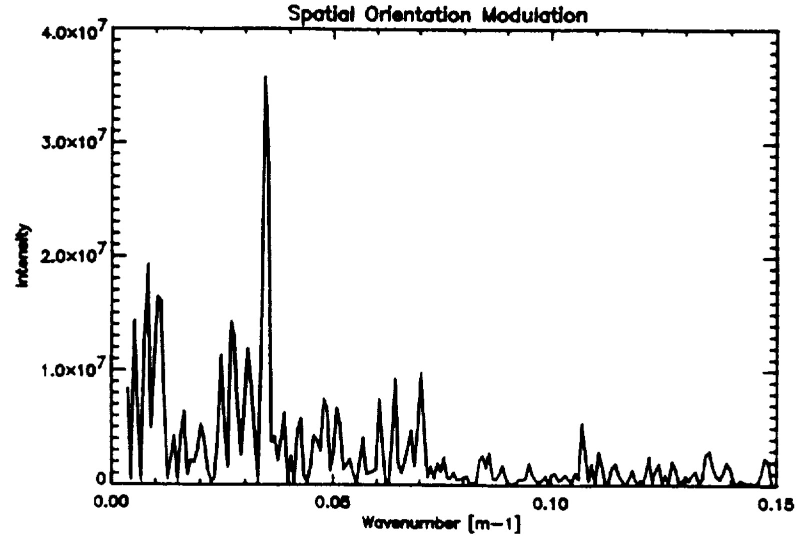


Fig. 3: Polarization orientation modulation spectrum for the same azimuthally-traveling waves.

Fig. 3 gives a polarization orientation modulation spectrum for the strip which, again, has a strong peak at the same wavenumber position. The signatures used to produce Fig.3 were all normalized to unity to minimize any intensity modulation. The peak is produced by signature location changes due to wave slopes. This preliminary study indicates that in cases where changes in the polarization signature morphology are slight, slope induced orientation changes can be detected - and possibly measured. The technique works for the ocean (or selected land areas) where the signature is sharply peaked and relatively constant.

4.0 CONCLUSIONS

A polarimetric technique for improving the visibility of waves, whose propagation direction has an azimuthal component, in RAR or SAR images has been investigated. The technique shows promise as a means of producing more accurate 2-D polarimetric RAR ocean wave spectra. For SAR applications domination by velocity-bunching effects may limit its usefulness to long ocean swell. A modification of this technique involving measurement of polarization signature modulations in the image is useful for detecting waves in SAR images and, potentially, estimating RMS wave slopes.

REFERENCES

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