Oceanic Fronts as a Source High Air-Sea Flux Due to Breaking of Standing Waves of Intermediate Scale

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ABSTRACT -- Marine radar sea scatter experiments were conducted as part of a remote sensing and fluid modeling program to study littoral ocean properties toward an improved understanding of ship and airborne radar ocean imaging. In particular, radar backscatter data were collected using an X-band marine radar at low grazing angles near oceanic fronts and internal gravity waves. These data were collected from a ship that passed perpendicularly through both type of linear oceanic features, so that their azimuthal aspect sensitivity could be studied and related to the fluid dynamics driving them. While the internal waves appeared different from either side of the crest, the polarization properties associated with fronts was the same as seen with either aspect. We hypothesize that standing waves occur at fronts and act as a scattering source rather than asymmetric bores that have previously been identified at strong radar scatterers at horizontal polarization in wind driven seas. A simple propagation model of waves into a current shear region is used to show that intermediate waves of a 10 to 30-cm scale are reflected from the current profile at a front and can produce such standing wave scattering sources.

INTRODUCTION

The polarization behavior of low grazing angle radar sea scatter imagery has been hypothesized as due to different scattering mechanisms dominating for horizontal (HH) and vertical (VV) polarizations (Trizna & Carlson [1]; Trizna, [2]), based upon azimuthal characteristics of the ambient echo. The VV echo was shown to have an azimuthal dependence similar to higher grazing angle scatterometry, and could be fit by an empirical Wentz model algorithm, which agrees generally with the predictions of a two-scale model. Alternatively, the lack of a strong echo downwind for HH forces the consideration of strongly asymmetric scattering sources, such as bores measured by Duncan [3] and calculated by Longuett-Higgins and Cleaver [4]. At intermediate angles, above 20^o, bound capillary waves have been hypothesized as a source of anomalously high HH scatter at higher Doppler frequency shift than can be explained by orbital wave current modulation of Bragg waves [5].

The HH and VV echo have also been shown to exhibit different behavior in the distribution function properties as a function of local grazing angle [1]. In this work we discuss grazing angle differences for the two polarizations for a series of calibrated marine radar images of an ocean salinity front.

In the following, we consider the polarization differences with look angle at a front from azimuthal looks 180^o apart. We will show that the HH echo does not exhibit the weaker downwind echo for scatter near the front, but has virtually the same RCS value from either perspective. This can only be due to a scatterer that is symmetric, for example, a wedge scatterer as might occur due to a standing wave. We have observed standing waves to occur when waves are reflected at a barrier. We hypothesize that such a reflection could occur due to waves being reflected at a strong current boundary, and model such a case, using the current shear associated with a rotor that Lyzenga [6] used to study current shear effects on wave current interactions. We find that short waves from 10 to 40 cm can reflect from realistic current shears to produce such standing waves.

DUAL POLARIZED SEA SCATTER IMAGERY

The radar data were collected using a dual polarized marine radar that could be switched from horizontal to vertical polarization on alternate antenna rotations. The characteristics of the radar were described in [1]. The received power signal was transformed for each radar pixel to normalized radar cross section (NRCS), σ^o. Data were collected every minute, switching polarization within 4 seconds for nearly simultaneous images, so that polarization differences should be due to scattering mechanisms differences exclusively.

Examples of HH and VV radar images after this transformation to σ^o for each pixel are shown in Fig. 1, where the range-time polar data format has also been transformed to a Cartesian coordinate system. The constant noise floor transformed by the radar equation introduces a range dependence that raises it to the 1st power, thus giving the noise the apparent pedestal rings shown. For the 25 MHz sampling rate used, the 256 samples correspond to 1536 m of total range coverage. The examples in Fig. 1 of HH and VV imagery of the front suggest that wave breaking near the front is responsible for the HH echo there. However, the asymmetry as seen from either side of

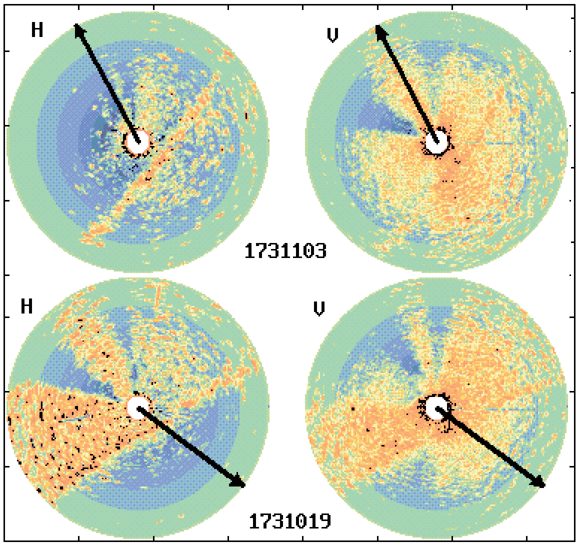

Figure 1. Up (u) and down (l) wind images of an oceanic front for HH (l) *and VV* (r) *polarization (arrow = wind direction).*

the front requires a closer examination as to the type of braking waves responsible for the scatter.

The data were further quantified by calculating a mean value over three range samples and 20^o in azimuth, centered about the normal direction to the front. These are plotted for looks from the upwind side of the front in Fig. 2, and from the downwind side in Fig. 3, noting the V-pol difference reflecting this perspective at the lower grazing angles.

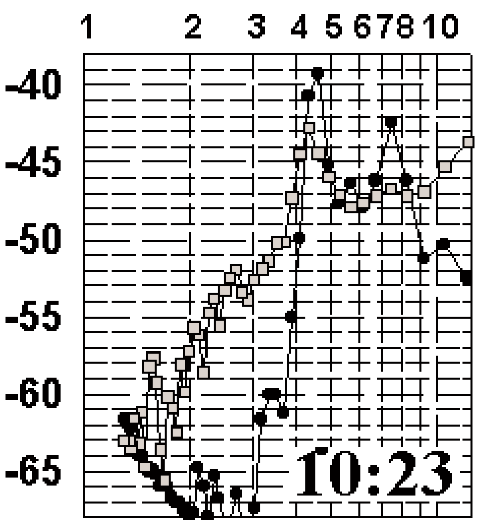

Figure 2. Mean RCS vs grazing angle for HH (gray) and VV (black)symbols shows larger HH echoes at the front.

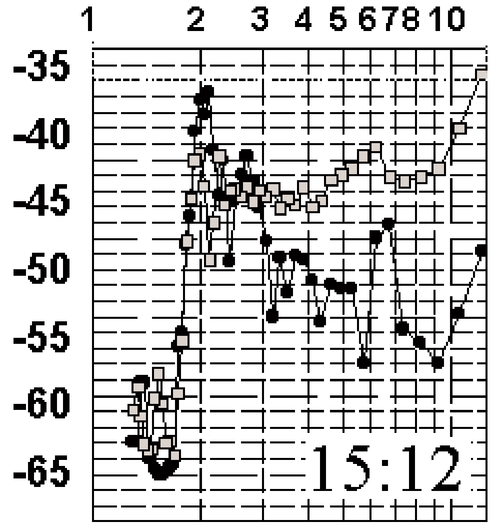

Figure 3. As Fig. 2, but a downwind look, still showing HH>>VV at the front, suggesting symmetric scattering features.

It is clear that the HH echo is larger than VV at the lowest grazing angles, as was observed for internal waves [2], so that wave breaking processes may be dominating the HH echo here as well.

H/V RATIO vs LOOK ANGLE

Results of mean value analyses for 47 images were further analyzed by picking the HH and VV RCS values at front, cataloguing the grazing angle for each, and is shown as a summary plot in Fig. 4.

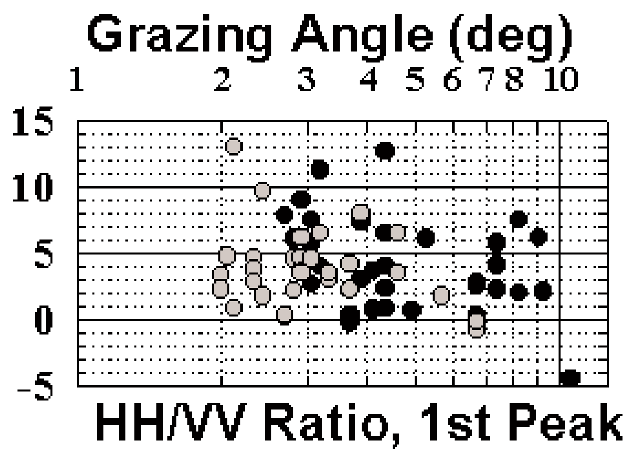

Figure 4. H/V rations at the front, with up/down wind results in grey/black, showing little difference with aspect or grazing angle between 2 and 10 deg.

These results show little difference with aspect, suggesting that symmetric scatterers are responsible for scattering processes at the front. We draw this conclusion by referring to previous results with the same radar that showed a 18 dB or greater upwind/downwind ratio for the HH echo. These scatterers were suggested as bores, which scattered radar energy only when illuminated from the forward direction [1].

FRONTAL SHEAR, & WAVE REFLECTIONS

Figure 5 shows a model for current shear associated with a frontal rotor, but allowing the current to the left of the front to successively larger values relative to the first at 34 cm/s, which corresponds to the model of Lyzega [6].

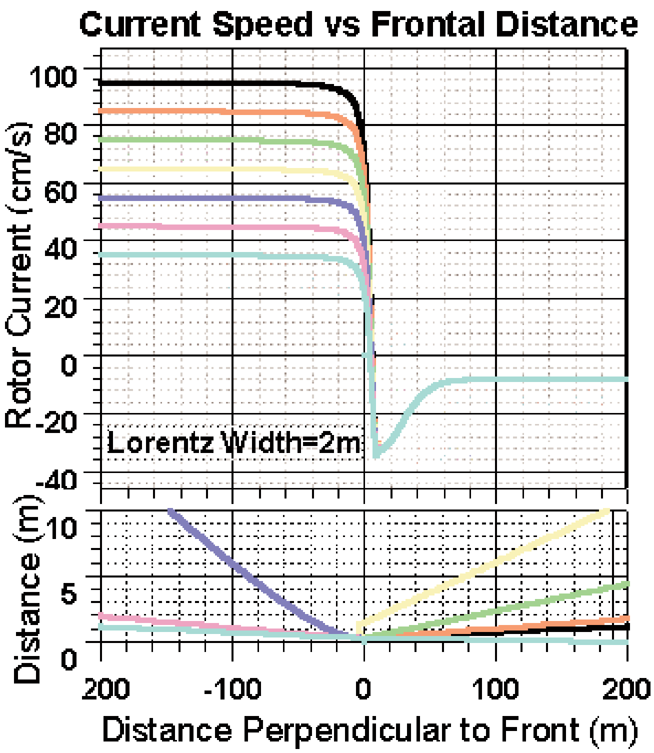

Figure 5. Modeled rotor current shear (top), and refracted rays for20-cm waves incident along X-axis from the right.

These bottom part of the figure shows the propagation rays for 20-cm waves incident one degree below the X-axis from the right. The weakest three currents of the set refract the wave train but do not reflect them. All currents beginning at 65 cm/s and higher from the left cause reflection of the 20-cm waves back toward the right. Such a condition could cause standing waves to occur due to interaction with the incoming waves, and form symmetric wedge-like patterns that could cause the type of radar polarization responses that we observed.

SUMMARY

We have shown that low grazing angle radar echoes between 2 and 10^o from waters in the region of an oceanic front have HH/VV polarization ratios consistenly larger than one, whether seen one side of the front or the other. Previous results showed that HH/VV ratios in the open ocean were greater than one only for upwind directions, and were hypothesized as due to scatter from asymmetric bore structures to explain this behavior. These new results suggest the scattering sources stand above the mean surface and are symmetric, similar to a wedge-like feature. Such structures could result from standing waves due to wave reflections from strong current shear. We modeled a rotor frontal structure that previously had been used to calculate radar scattering properties at a front, but used a ray tracing model to estimate the currents necessary to reflect 20-cm long waves. We found that an incoming current of at least 65 cm/s was necessary to cause such reflection. This minimum current value will change for different water wavelengths, and for 50-cm waves, no reflection occurs. Thus such a current shear acts as a band pass filter for wave reflections for waves between 10 cm and 50 cm, and these are the only waves that can interfere to produce standing waves. Such a size range is consistent with photographs of breaking wave structures near oceanic fronts, and provides a hypothesis to test in future experiments.

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