POLARIZATION AND WAVELENGTH DIVERSITIES OF GULF STREAM FRONTS IMAGED BY AIRSAR

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1. INTRODUCTION

During the 1990 Gulf Stream Experiment, NASA/JPL AIRSAR imaged the north edge of the Gulf Stream near the coast of Virginia (see Fig.1). Simultaneous in-situ measurements of currents, temperatures, salinities, etc. were made for several crossings of the north edge by the R/V Cape Henlopen (Marmorino et al., 1994).

Measurements identified two fronts with shearing and converging flows. The polarimetric SAR images from the fronts showed two bright linear features. One of them corresponds to the temperature front, which separated the warm Gulf Stream water to the south from a cool, fresh-water filament to the north. The other line, located about 8 km north of the temperature front, is believed to correspond to the velocity front between the filament and the slope water. At these fronts, wave-current interactions produced narrow bands of steep and breaking waves manifesting higher radar returns in polarimetric SAR images. A schematic diagram summarizing the observations is shown in Fig. 2.

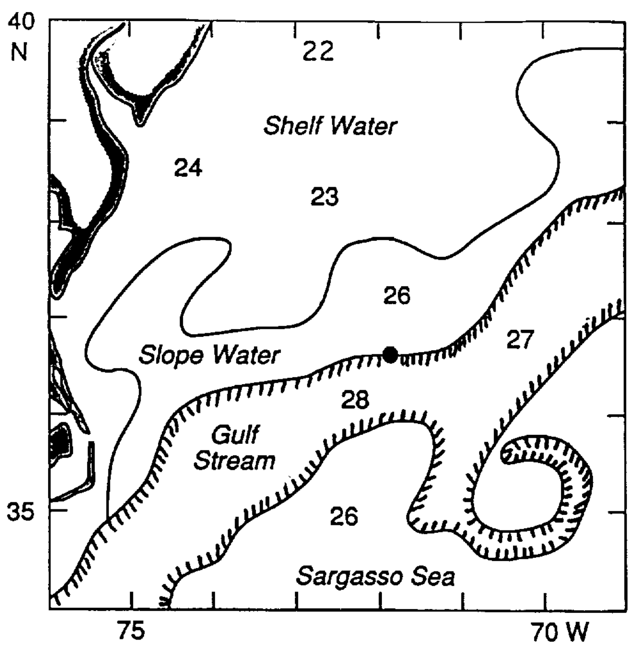


Fig. 1 The 1990 Gulf Stream Experiment site is shown as a black dot. Ocean surface temperature (in degree Celsius) reveals that Gulf Stream and slope water temperatures differ by two degrees.

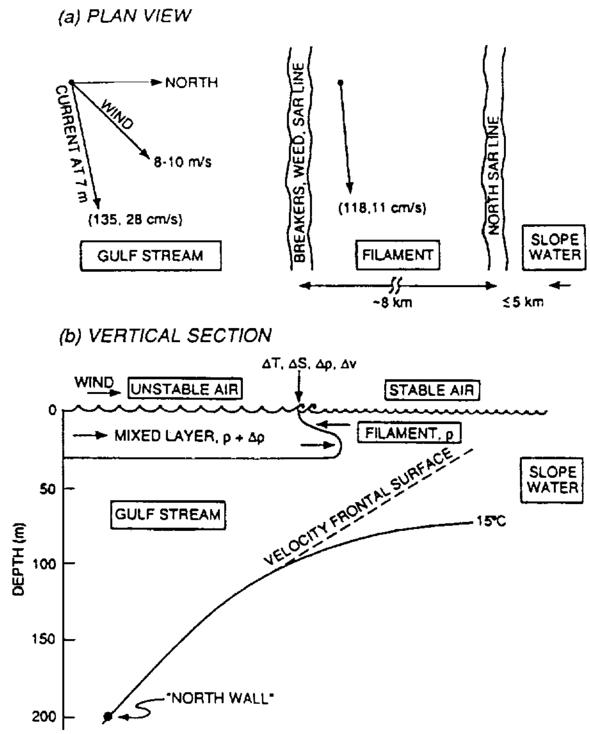


Fig. 2. Schematic diagram of the observations. (a) Plan view shows the temperature front on the left and the velocity front on the right. (b) Vertical section view indicates relative cross-front current motion and surface convergence.

In general, our AIRSAR imagery shows that the signal-to-clutter ratio of radar cross sections for the temperature front is higher than that of the velocity front. In this paper, we study the polarization and wavelength diversities of radar response of these two fronts using the P-, L- and C-Band Polarimetric SAR data. The north-south flight path of the AIRSAR crossed the temperature front several times and provided valuable data for analysis. Three individual passes are investigated. We found that for the temperature front, the cross-pol (HV) responses are much higher than co-pol responses (VV and HH), and that P-Band HV has the highest signal to clutter ratio. For the velocity front, the ratio is the strongest in P-Band VV, and it is indistinguishable for all polarizations in C-Band.

The radar cross sections for all three polarization (HH, HV and VV) and for all three bands are modelled using an ocean wave model (Jansen et al., 1993) and a composite Bragg scattering model. In our initial investigations, the theoretical model agrees qualitatively with the AIRSAR observations.

2. AIRSAR OBSERVATIONS

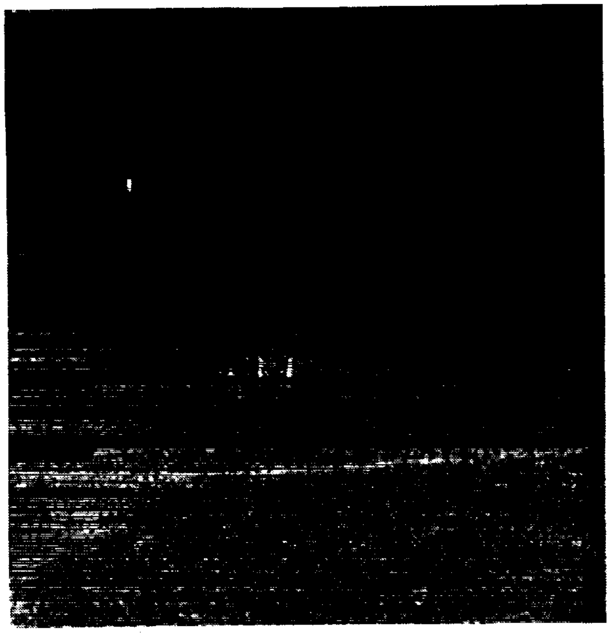
SAR images from several AIRSAR passes across the north boundary of the Gulf Stream have been analyzed. Due to the page limitation, images from one pass only are shown in Fig. 3. The altitude of the JPL/DC-8 was 5.5 km, and it was traveling from north to south. The resolution is 12.1 m in azimuth and 6.7 m in slant range. Each image is 12.4 km in north-south extent and near 9 km in slant range. The near range is on the left, and the range of incidence angles across the images is 25 to 60 degrees. Images are oriented with north toward the top. The R/V Cape Henlopen was traveling north, and is shown with its wake in the upper left part of each image.

The P-Band HV image (Fig. 3A) clearly shows the temperature front as a bright line located at the lower part of the image, and the velocity front is shown at 8 km toward north with a wide dark strip before it. The response of the temperature front is much weaker for P-Band VV as shown in Fig. 3B, but the velocity front is more distinct. The C-Band images (Fig. 3C and 3D) exhibit distinctive wavelength diversity in radar response. The velocity front is almost invisible, and the signal to clutter ratios of the temperature front are detectable but weaker than that of P-Band. The V shaped dark region in Fig. 3D was due to the wave damping attenuation by rain. Wave damping is most pronounced for waves shorter than 25 cm (L-Band) (Tsimplis, 1992). However, this effect is almost absent in the cross-polarization image (C-Band HV, Fig. 3C).

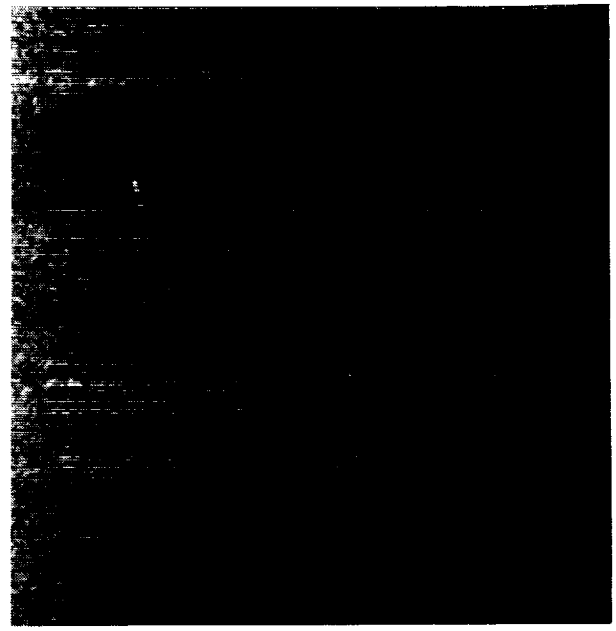
Several other north-east SAR passes have also been analyzed. Similar SAR responses in polarization and wavelength were observed. In general, the temperature front is more visible than the velocity front. For the temperature front, the HV polarization has much higher signatures than co-polarizations, and P-band HV has the highest signal to clutter ratio, followed by L-Band and C-Band. From in situ measurements and observations by video camera, surface current convergence was evident by the narrow width of the temperature front, an adjacent band of breaking waves, and the accumulation of Sargassum. The presence of strong signature in HV polarization indicates significant wave-current interaction from large surface tilts and possibly breaking waves, which causes higher order scattering. It is interesting to note that P-Band VV polarization has a very weak signature for the temperature front. For the velocity front, the P-Band is much weaker, and has the strongest signature among the three bands. The velocity front is invisible in the C-band images. In all three bands, the VV polarization has the strongest signature followed by HV and HH.

3. VERIFICATION WITH OCEAN WAVE MODEL

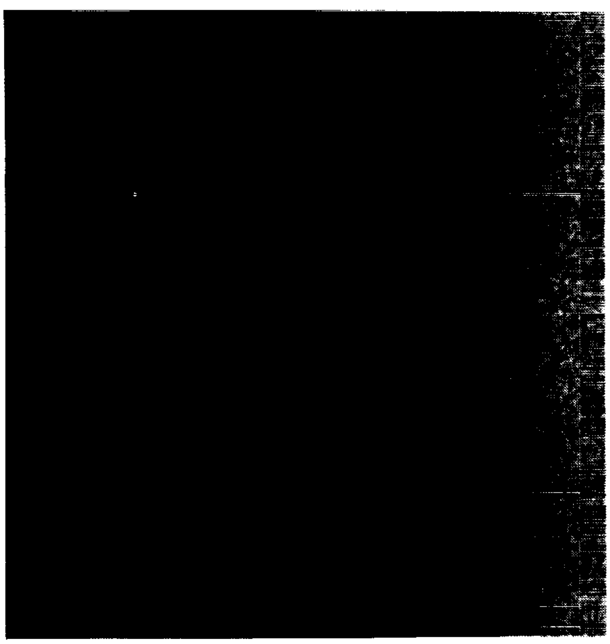
Theoretical predictions were made for the temperature front where in-situ data was available. The modelling for the velocity front will not be addressed here for lack of measurements. The temperature front is predominantly a current convergence which was modelled



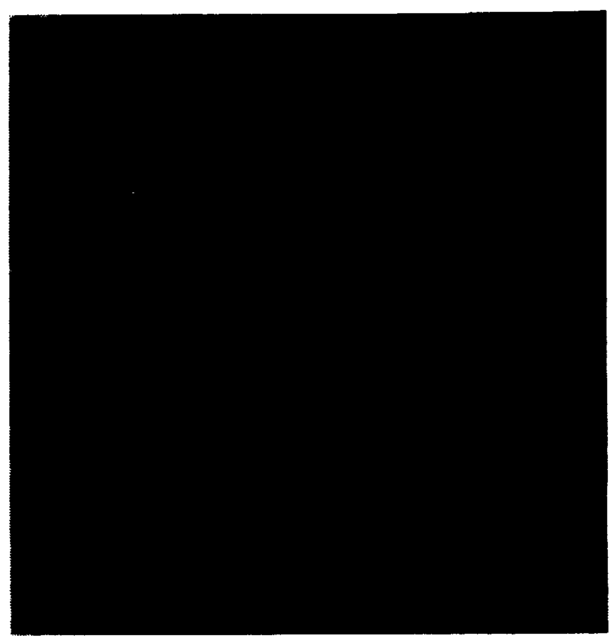
(A) P-Band HV



(B) P-Band VV



(C) C-Band HV



(D) C-Band VV

Fig. 3 P-Band and C-Band Polarimetric SAR imagery of Gulf Stream fronts. North is toward the top. The AIRSAR was flying from north to south. The R/V Cape Henlopen was traveling northbound, and is shown with its wake in the upper left part of each image. (A) The P-Band HV image clearly shows the temperature front in the lower part of the image, and it also shows a dark wide strip before the velocity front, which is located 8 km to the north of the temperature front. (B) The P-Band VV image, however, has much a smaller radar response at the temperature front, but the velocity is more distinct. (C) The C-Band HV image shows the temperature front less well-defined than the P-Band. (D) The C-Band VV shows the damping attenuation by rain and other effects on the response of the temperature front. The cross sections of the velocity front in both C-Band images are very weak, making the fronts nearly indistinguishable.

as the one-dimensional function,

$$V(y) = -\frac{\delta V}{2}\tanh\left(\frac{y}{\delta y/2}\right)$$

The depth and current widths were taken to be δy=100m and δV=25cm/s, consistent with shipboard estimates. This current was used as an input into the action density equation with a Plant-Hughes type source to derive the ocean wave spectrum near the temperature front (see Jansen et al, 1993). The radar image modulation is then predicted using the wave field slope statistics in a composite scattering radar model. We do not consider the effects of velocity bunching or speckle, which would be present in a more complete SAR model.

Fig. 4A shows the P-Band HH, HV and VV radar modulation around the temperature front at 45 degree incidence angle, using the ocean wave model but excluding any contribution from breaking waves. The HV polarization has a much higher radar modulation than both the HH and the VV. This agrees with our observations on polarization diversity for the temperature front. Fig. 4B shows the cross-section dependence on wavelength. For the cross-polarization (HV), P-Band has the highest value with peak near 2.0 dB, and L-Band and C-Band are 1.6 and 1.1, respectively. This theoretical result also verifies our observed trend in wavelength diversity.

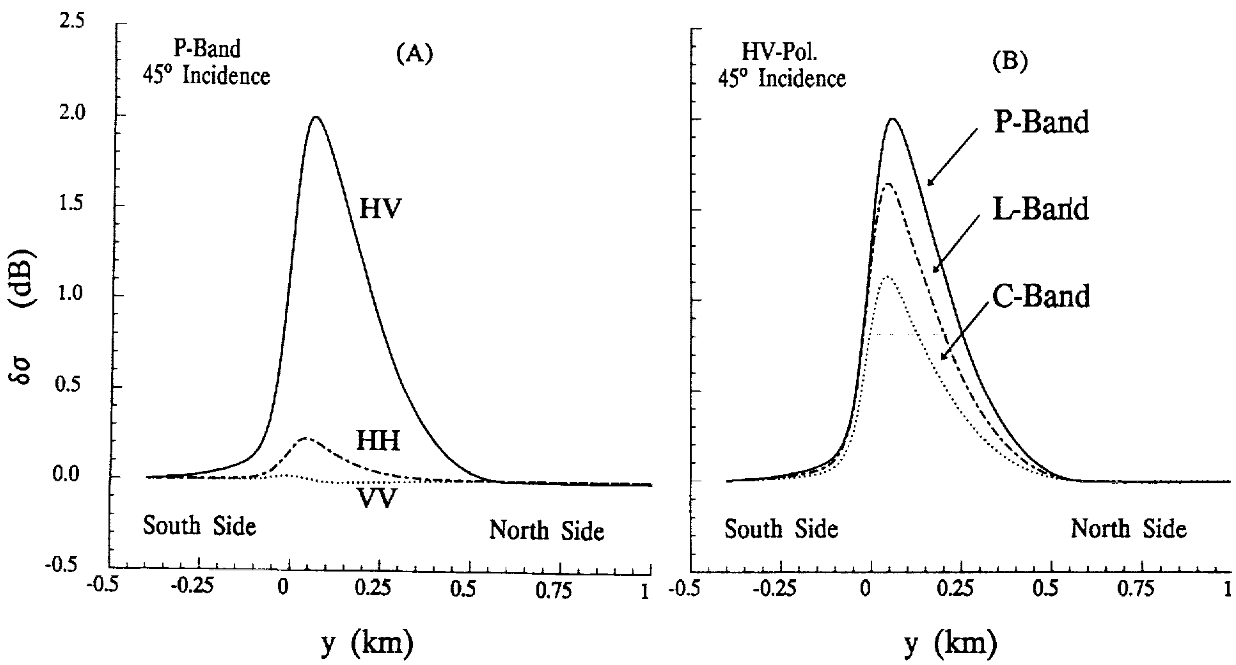


Fig. 4 Theoretical modeling of radar modulations of the temperature front at 45 degree incidence. This model does not include the breaking waves. The horizontal axis indicates the distance in km from the temperature front. (A) The P-Band HV cross-section values are much higher than the comparable of HH and VV. (B) Peak-values for HV polarization for P-, L- and C-Band, respectively are 2.0, 1.6 and 1.1. These results qualitatively confirms the AIRSAR measurements.

REFERENCES

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