A51A-2026: Viscous and Turbulent Stress Measurements over Wind-driven Surface Waves

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In recent years, the exchange of momentum and scalars between the atmosphere and the ocean has been the subject of several investigations. Although the role of surface waves on the air-sea momentum flux is now well established, detailed quantitative measurements of the turbulence in the airflow over surface waves remain scarce. The current incomplete physical understanding of the airflow dynamics impedes further progress in developing physically based parameterizations for improved weather and sea state predictions, particularly in high winds and extreme conditions.

Using combined Particle Image Velocimetry (PIV) and Laser Induced Fluorescence (LIF) in the laboratory, we have acquired detailed quantitative measurements of the airflow over wind-driven waves and down to within the viscous sub-layer. Various wind-wave conditions are examined with mean wind speeds ranging from 0.86 to 16.63 m s-1. The mean, turbulent, and wave-induced velocity fields are then extracted from instantaneous two-dimensional velocity measurements. Individual airflow separation events precipitate abrupt and dramatic along-wave variations in the surface viscous stress. In the bulk flow above the waves, these separation events are a source of intense vorticity. Phase averages of the viscous stress present a pattern of along-wave asymmetry near the surface; it is highest on the upwind of wave crest with its peak value about the crest and its minimum occurs at the middle of the leeward side of waves. The contribution of the viscous stress to the total momentum flux is not negligible particularly for low to moderate wind speeds and this contribution decreases with increasing wind speed. Away from the surface, the distribution of turbulent Reynolds stress forms a negative-positive pattern along the wave crest with a separation-induced maximum above the downwind side of the wave. Our measurements will be discussed in the context of available previous results.

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