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Interpreting Ionogram Signatures of bottom-side Upwelling Structures: A Simulation Study

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In the equatorial ionosphere, bottom-side upwelling is a crucial phenomenon that occurs around the post-sunset hours and is considered an early precursor to the development of Equatorial Plasma Bubbles (EPBs). In the spatial domain, these upwellings can be observed as large-scale wave structures (LSWS) through steerable incoherent scatter radar; however, such observations are limited. These bottom-side upwellings can also manifest as satellite traces on ionograms under certain favorable conditions. Given the widespread deployment of ionosondes globally, understanding the signatures of upwellings/satellite traces on ionograms would significantly aid in predicting the occurrence of EPBs. In this study, a virtual ionosonde experiment is simulated to investigate the various satellite trace signatures on ionograms. Our simulation examines the different signatures of satellite traces during various stages of upwelling growth. Additionally, the study analyzes satellite trace signatures when the upwelling is located at different positions relative to the transmitter. It is shown that satellite traces occur at higher virtual heights than the main ionogram trace for off-centered upwellings and at lower virtual heights for overhead upwellings. Furthermore, the height separation between the main trace and the satellite trace increases with the deepening of overhead upwellings. Additionally, a proof-of-concept is demonstrated, showing that multiple satellite traces from ionograms can be used to reconstruct the spatial structure of bottom-side upwellings if the precise angle-of-arrival information can be resolved from wide-beam ionosonde systems. This method has the potential to reconstruct upwelling structures in the ionosphere using satellite traces and can contribute to improving predictive capabilities for EPBs