Prediction of Tropical Cyclogenesis with GNSS RO Data Assimilation through the WRF Hybrid 3DEnVar

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Recent decades have seen a confirmed increase in the intensity of typhoons and hurricanes. This severe weather event, characterized by strong winds and heavy rainfall, poses significant hazards. Early prediction of cyclogenesis can provide a critical time for disaster prevention efforts. Since tropical cyclones primarily develop over oceans where observational data is sparse, Global Navigation Satellite System (GNSS) radio occultation (RO) data, particularly from the FORMOSAT-7/COSMIC-2 mission, offers valuable coverage of tropical regions and improved further penetration to close to the surface.

This study examines the impact of GNSS RO data assimilation on the cyclogenesis of ten tropical cyclones in the northwestern Pacific from 2020 to 2022. Using a hybrid 3DEnVar in the WRFDA system, four data assimilation (DA) experiments were conducted: assimilating conventional data only (GTS), adding GNSS RO data (EPH), adding radiance data (RAD), and using all observations (ALL). Results show that incorporating GNSS RO and radiance data significantly improves predictions of tropical cyclogenesis. The ALL experiment demonstrated the best overall predictive capabilities, while EPH excelled in simulating vortex formation within a 24-hour prediction range, underscoring the critical role of GNSS RO data. Verification with ERA5 reanalysis confirmed that satellite data experiments (EPH, RAD, ALL) performed better than conventional data (GTS), especially in reducing errors in water vapor mixing ratio and temperature. GNSS RO data notably enhanced mid- to upper-troposphere refractivity simulations. Case studies of typhoons Chanthu (2021) and Hagupit (2020) further highlighted the effectiveness of GNSS RO and radiance DA in improving moisture and temperature accuracy, which is essential for vortex formation forecasts. The analysis also emphasized the role of latent heat release in vortex development and maintenance.