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A Data-Driven Approach to Isolate the Role of Radiative Heating in Tropical Cyclone Intensification

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Quantifiable assessment of how different physical processes promote tropical cyclone (TC) development is paramount in improving basic understanding of TC genesis and TC intensification forecasts. This assessment can be made via Eulerian budgets or by linearizing the equations of motion. For instance, the Sawyer-Eliassen equation gives the secondary circulation driven by a steady thermodynamic forcing. However, existing diagnostic frameworks often make implicit assumptions such as axisymmetry and temporally-averaged forcing, precluding discussions on how spatially heterogeneous or transient forcing may affect TC intensity.

In this work, we combine principal component analysis with multiple linear regression to build a linear framework that predicts the evolution of three-dimensional wind fields at different forecast windows, based on current heating and wind conditions. We apply this model to ensembles of WRF simulations on Hurricane Maria (2017) and Typhoon Haiyan (2013). Uniquely, the simulations include cloud radiative feedback denial experiments, which enables us to quantify the extent to which radiative processes drive TC intensification. Given their simplicity, our models are reasonably accurate, with coefficients of determination exceeding 0.8 for forecast windows longer than six hours. The linear nature of our model allows us to cleanly decompose the contributions of different physical processes to three-dimensional TC kinematic changes. Using radiative heating as an example, preliminary results suggest that this heating creates outward-propagating diurnal variability in wind perturbations during critical intensification periods of Hurricane Maria. These wind perturbations resemble a shallow lower-tropospheric secondary circulation; implications of this circulation to TC intensification are explored.

More generally, our framework can map thermodynamic forcing to kinematic changes without relying on axisymmetric assumptions, which opens the door to data-driven discovery of the leading physical pathways to TC intensification.