Energy And Water Cycles In Hurricanes

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This study focuses on the production and analysis of high-resolution simulations of CAMEX-3 and CAMEX-4 hurricanes with an emphasis on the validation of the simulations using the CAMEX and TRMM datasets. Once the simulations have been produced and validated, the research objectives focus on the conduct of budget studies of momentum, heat, and water for the purposes of examining intensification mechanisms, warm core formation mechanisms, and water cycling within hurricanes. In addition, the full-physics simulations will be compared to idealized models of hurricane-like vortices in order to examine the underlying dynamical mechanisms that lead to storm intensification including the effects of vortex Rossby waves and vorticity mixing.

Among our recent accomplishments, we include research related to a simulation of a non-CAMEX hurricane because the tools and ideas developed for that case will be applied to simulations of CAMEX cases. In this work, we have computed a momentum budget that compares the contributions of the azimuthal mean secondary circulation and the asymmetries to changes in the mean vortex strength. The effects of asymmetries, assumed to represent the effects of vortex Rossby waves, were found to be comparable to those associated with the mean secondary circulation. In addition, information on the azimuthal mean tangential wind and vorticity, along with forcing terms associated with diabatic heating and friction, have been used as input to a two-dimensional Sawyer-Eliassen balance model in order to derive the balanced radial and vertical motions. These results suggest that a major portion of the secondary circulation can be explained by balanced dynamics, including low-level outflow frequently seen in the eyewall. In addition to this research on a non-CAMEX hurricane, we have produced a simulation of Hurricane Bonnie (1998) from CAMEX-3 using multiple grid nests extending to a maximum grid resolution of 2 km. The simulation is initialized at 00 UTC 22 August and covers a 30-hour period ending at 18 UTC 23 August, with the 2 km grid started at 6 h. The simulation reproduces well the observed track and intensity of the storm. The simulated precipitation structure is compared to TRMM PR reflectivity data. While the general precipitation structure is in good agreement with observations, including the highly asymmetric organization of the precipitation and the production of multiple rainbands on the eastern side of the storm, the model produces simulated reflectivities above the freezing level that are higher than observed, apparently as a result of an over-production of graupel. Data from EDOP and other sources are being examined to determine whether the over-production of graupel is caused by the cloud microphysics scheme, excessive vertical velocities, or other factors.

Ongoing research related to the Hurricane Bonnie simulation focuses on the sensitivity of the precipitation structure to variations in cloud microphysics, an examination of the basic structure and dynamics of the storm, and the water budget of the storm. The sensitivity studies involve variations of parameters or conversion terms within the cloud microphysics scheme in an attempt to understand the processes that lead to excessive graupel production. Results from each simulation will be compared to TRMM PR reflectivity and TMI brightness temperatures to determine those changes that best improve the cloud microphysics scheme. Ongoing work related to the storm structure focuses on the effects of vertical wind shear and relative flow on the asymmetric circulation and precipitation patterns. The average vertical wind shear over the storm is about 1m s-1/km directed out of the northwest with the precipitation and vertical motion maxima concentrated in the down shear left quadrant. Previous studies have related the asymmetries produced by vertical shear to the effects of either vortex tilt or flow relative to the vortex. Vortex tilt in this case is relatively small and so does not appear to be the cause of the asymmetry. The relative flow within the boundary layer is in the right direction to account for the asymmetry, but is not of the right magnitude. In future work, in order to understand the effects of relative flow, we may use a simple boundary layer model to examine the effects of storm motion and relative flow on the pattern of radial velocity and convergence in the boundary layer. Convective feedbacks may also be important. Convection may produce vorticity asymmetries that may then result in balanced flow asymmetries. The relationships between diabatic heating, friction, and vortex asymmetries will be deduced from a three-dimensional asymmetric balance model and should provide a means for understanding the interrelationships between relative flow, convection, and flow asymmetries.

For CAMEX-4 related work, we have begun simulations of Hurricane Erin. The simulation is initialized at 00 UTC September 7, 2001 and is run for a 96 hour period ending at 00 UTC September 11. At this time, the simulation has been conducted with a maximum grid resolution of 12 km; however, simulations at higher resolution are in progress. The simulation captures the evolution of the system from a weak tropical storm to a category 3 hurricane and therefore provides a unique opportunity to examine the cyclogenesis process. The simulation is currently being validated against TRMM data and will also be validated against CAMEX-4 data as it becomes available. Comparisons to TRMM suggest that the simulation is capturing a transition in the storm structure that occurs between the 9th and 10th of September in which an outer rainband shifts from the north-northeastern side of the storm to the western side of the storm. The model suggests that this outer rainband is associated with the development of a secondary wind maximum, although this needs to be confirmed with observational data. Thus, the model also provides an opportunity to examine the formation of a secondary wind maximum and an outer rainband.