Cloud Microphysics Impact on Hurricane Track as Revealed in Idealized Experiments

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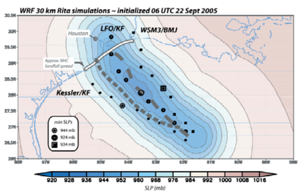
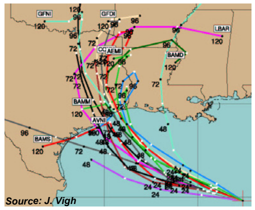
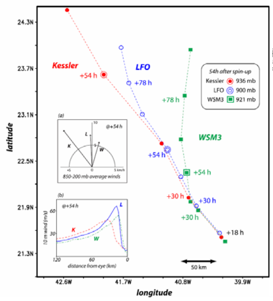
Introduction

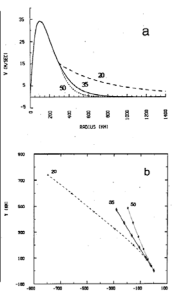
Cloud microphysical parameterizations (MPs) have been shown to have a tremendous impact on forecasts of both tropical cyclone (TC) intensity and track (Wang 2002; Zhu and Zhang 2006; Fovell and Su 2007). Indeed, a physics based forecast ensemble varying the available MPs in one model produces a spread in forecast tracks equal to that of a multi-model ensemble.



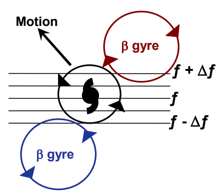


Fovell and Su (2007) showed that different MPs modulated storm width and speculated this could be one reason for the substantial difference in tracks, similar to the findings of Fiorino and Elsberry (1989).





In the absence of environmental steering flow, the motion of a TC results from "ventilation flow" across the vortex from beta gyres, which owe their existence to differential advection of planetary vorticity by the TC. The strength of the wind field at large radii controls the strength and orientation of the gyres and thus the direction of storm motion.

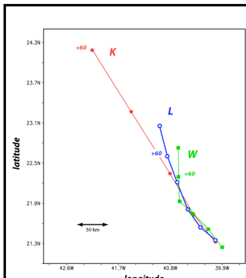


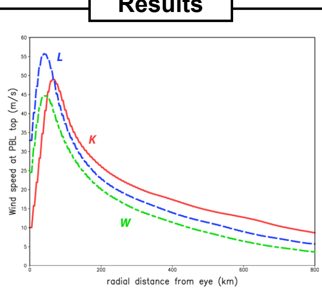
The goal of the present research is to uncover and understand the physical processes in MPs that control TC size, and to first order, storm motion.

Model Design

- "Real-Ideal" WRF V2.2.1: ARW core, retains Earth's curvature, but no land (Hill and Lackmann 2008)
- Three telescoping domains 27/9/3 km, 30 vertical levels, 50 hPa model top, RRTM radiation scheme
- Initialized with the Jordan (1958) sounding but with no initial environmental flow and a constant 29°C sea surface temperature
- A coherent vortex is spun up from the additional of a warm, moist anomaly to the initial conditions {No MP scheme is used during the spin up, but the Kain-Fritsch cumulus parameterization (CP) is on}
- After 24 hrs, the CP is turned off and one of three MPs (Kessler, LFO, or WSM3) is turned on
- In addition to the standard run, sensitivity experiments with the CAM radiative scheme, no radiation, no graupel in the LFO run, and all condensate in the Kessler MP immediately turns to rain were conducted

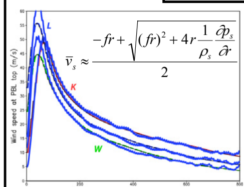
Results





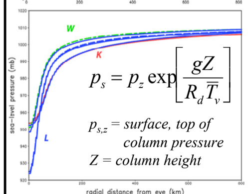
The tracks and tangential wind profiles of Fovell and Su (2007) are reproduced: The Kessler storm moves much more quickly and further to the west than either of the storms with ice microphysics (left), and exhibits a much broader tangential wind profile out to large radii at 850 hPa (right).

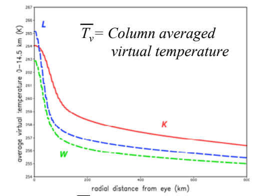
Physical Mechanisms and Sensitivity Tests

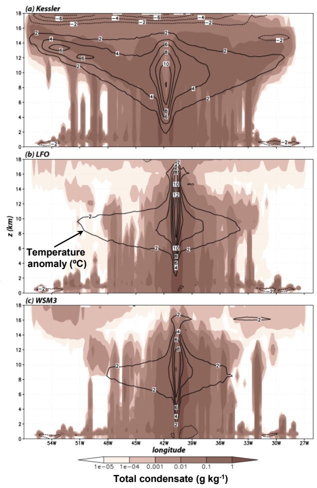


To explain the differences in the tangential wind profiles, we turn to the steady state, horizontal momentum equation in cylindrical coordinates (top left). Away from the storm core, this approximation does an excellent job of reproducing the wind field.

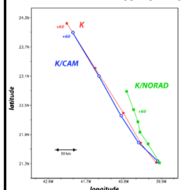
Hydrostatic balance also does an excellent job of replicating the radial distribution of p_s in the vortex (bottom left). Here Z=14.5 km, a height where p_z does not vary much among the cases, and thus $\overline{T}_v$ (below, middle) controls the surface pressure differences between the runs.

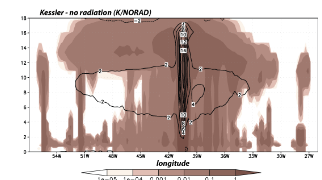




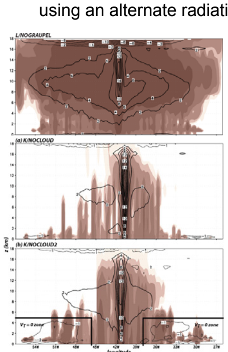


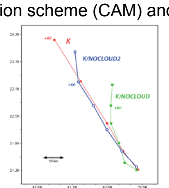
The warmer, and larger radial gradient of $\overline{T}_v$ in the Kessler storm results from a much more prominent anvil than in either of the two ice MP storms (right). This is the opposite of squall line simulations because of the much weaker mean updraft speed in TCs, less condensation, and slower conversion of cloud droplets to rain drops in the Kessler scheme.

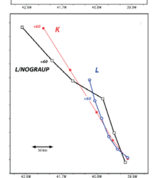


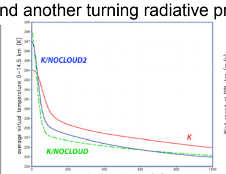


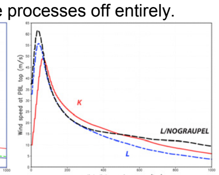
The large vertical and horizontal extent of the Kessler anvil produces prominent warming beneath and cooling above the anvil due to cloud-radiation interactions as shown above in sensitivity experiments using an alternate radiation scheme (CAM) and another turning radiative processes off entirely.











Particle fall speed is the most important factor in determining whether a given MP can develop a substantial anvil. Thus, three sensitivity experiments were conducted: 1) The formation of quickly falling graupel was excluded from the LFO run, 2) all condensate in the Kessler run immediately became rain (K/NOCLOUD), and 3) the same as (2), but with the fall speed (V_T) set equal to zero in the lowest 5 km where p_s>1005 hPa (K/NOCLOUD2).

The L/NOGRAUPEL storm produces a huge anvil and travels the furthest west. K/NOCLOUD has almost no anvil and resembles the ice MP tracks, while K/NOCLOUD2 moves like the original K. This was due to similar $d\overline{T}_v/dr$ in the runs because of cooling in the V_T = 0 zone where rain is more likely to evaporate.

Discussion and Summary

- Clearly, there are other effects on storm motion not examined here, including tilt of the vortex (Wu and Emanuel 1993; Wang and Holland 1996) and convective asymmetries (Nolan et al. 2001), but the assumptions used in cloud MPs drastically affect the motion of TCs
- This effect is realized here by the size of the upper tropospheric anvil and its cloud-radiation feedback effects on the horizontal temperature gradients, pressure gradients and ultimately, the wind fields