Tropical Cyclogenesis from Self-Aggregated Convection in Idealized Numerical Simulations: Sensitivity to Planetary Vorticity

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INTRODUCTION

- Self-aggregation: a mode of convective organization found in cloud-resolving model (CRM) simulations of radiative-convective equilibrium (RCE).
- Feedbacks involving clouds, water vapor, and radiation help organize random convection despite homogeneous boundary conditions.
- In rotating RCE, aggregation often takes the form of spontaneous TC genesis. Prior studies have primarily examined this issue on a 20° f-plane, with little attention to lower latitudes.

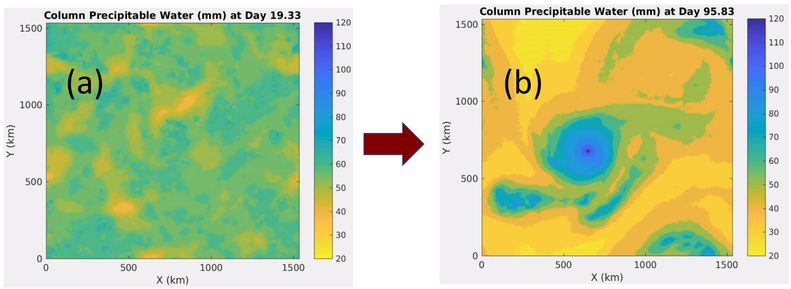


FIGURE 1: Evolution of rotating RCE simulation from (a) random convection into (b) a major hurricane.

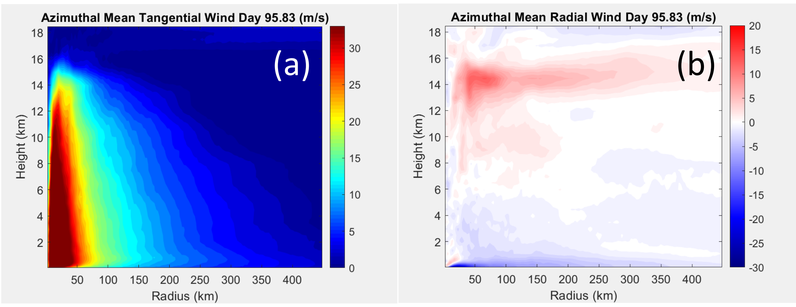


FIGURE 2: Radius-height profiles of (a) primary and (b) secondary circulations from same TC featured in Figure 1b.

MODEL DETAILS

- System for Atmospheric Modeling (SAM) version 6.8.2, a CRM at 3 km grid spacing. [1]
- f-planes corresponding to 10 latitudes: 0°, 0.1°, 1°, 2°, 3°, 5°, 7.5°, 10°, 15°, 20°.
- Simulations run for 100 days with constant solar insolation.

SST	305 K
Vertical Levels	64
Radiation	RRTM
# of simulations	24
Domain Size	$(1536\ km)^2$
Boundary Conditions	Doubly Periodic

TABLE 1: Additional model specifications for SAM

[1] Khairoutdinov, M. F., and D.A. Randall, 2003: Cloud-resolving modeling of the ARM summer 1997 IOP: Model formulation, results, uncertainties and sensitivities. J. Atmos. Sci., 60, 607-625

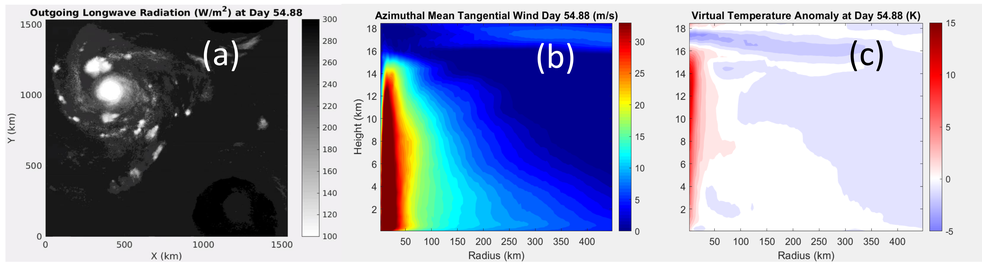
RESULTS – WHAT SIMULATIONS FORM A TC?

- Simulations at 10°, 15°, and 20° formed intense hurricanes.
- Time to genesis generally faster with higher Coriolis parameter.
- 3 low-f (1-2°) simulations produce a TC *after* aggregation, in contrast to 10-20° cases in which a broad circulation emerges during aggregation.

f-Plane	Fraction with TCs	Peak TC Intensity (m/s)	Range of Genesis Days
0°	0/1	-----	-----
0.1°	0/1	-----	-----
1°	2/3	28.56	77.33-80.42
2°	1/3	31.72	64.5
3°	0/3	-----	-----
5°	0/3	-----	-----
7.5°	0/2	-----	-----
10°	1/1	85.34	79.92
15°	1/1	97.44	53.38
20°	5/5	96.56	25.04-61.21
Total	10/23	97.44	25.04-80.42

TABLE 2 (left): Summary of simple results. Time of genesis is defined subjectively using an 18 ms^{-1} wind speed threshold.

FIGURE 3 (below): TC structure in 15° simulation, 1.5 days after genesis and 3 days before peak intensity. (a) OLR (b) Primary circulation (c) Warm-core structure.



- Low-f simulations: TC generally produced if aggregated cluster is quasi-circular; no TC forms if aggregation occurs as an elongated band.
- Low-f TCs are weaker and characterized by pulses of convection.

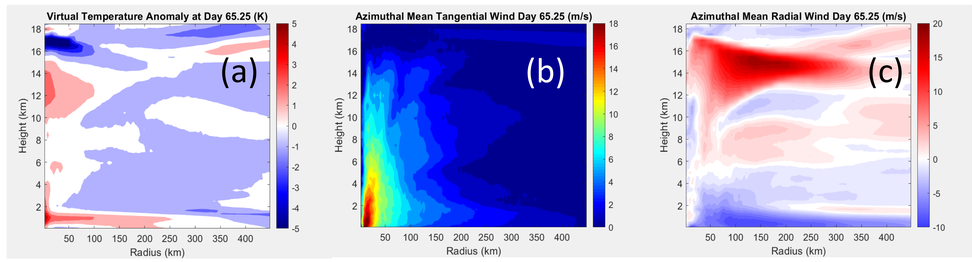


FIGURE 4: Radius-height profiles of (a) warm-core structure, and (b)/(c) primary/secondary circulations for TC-producing 2° simulation, 0.75 days after genesis.

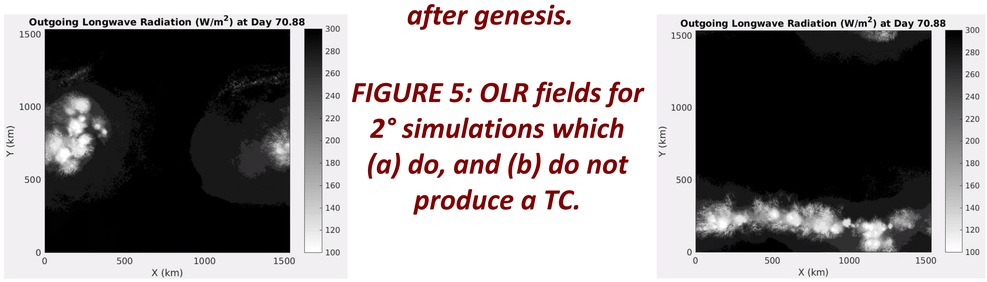
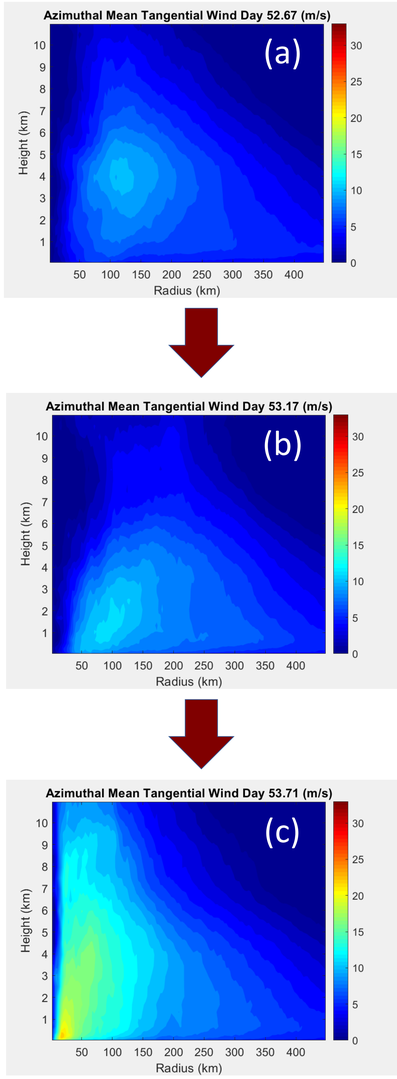


FIGURE 5: OLR fields for 2° simulations which (a) do, and (b) do not produce a TC.

RESULTS – WHY?

- High-f simulations: Aggregation occurs concurrent with development of a broad circulation.



- Mid-level vortex emerges, creating shallow cold-core below, favoring bottom-heavy convective profile and strengthening low-level vorticity.
- Low-f simulations: Aggregation occurs first, then circulation develops.
- Distribution of early random convection may be an important factor in determining if a TC forms in these cases.

FIGURE 6: Vertical evolution of vortex for 15° simulation. (a) 17 hours before genesis. (b) 5 hours before genesis. (c) 8 hours after genesis.

CONCLUSIONS

- Self-aggregation feedbacks can play a role in TC genesis in low-f rotating RCE environments.
- Multiple pathways: aggregation before rotation to 5°, rotation while aggregating from 10° to higher f.
- Initial emergence of mid-level vortex in high-f cases.
- Wide range of genesis time suggests distribution of initial random convection may be significant, particularly in low-f scenarios.