26.5 THE IMPACT OF SEA SURFACE TEMPERATURE ON SPONTANEOUS CYCLOGENESIS IN ROTATING RADIATIVE-CONVECTIVE EQUILIBRIUM

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1. INTRODUCTION

We simulate tropical cyclone (TC) formation and its sensitivity to climate change using the idealized framework of rotating radiative-convective equilibrium (RCE) which is a statistical equilibrium between convective heating and radiative cooling. When this framework is run for an extended period of time and on a large enough domain, the convection clumps together through a process called "self-aggregation" as there is no external forcing that promotes the grouping of convection. If this framework is set to a constant rotation, the aggregated convection manifests itself as a TC. This study aims to determine how a changing climate impacts the intrinsic properties of a TC in this framework.

2. METHODS

We test the sensitivity of properties of a spontaneously generated TC to a changing climate by performing simulations of rotating RCE using different sea surface temperatures (SSTs). The SSTs examined are 285K, 290K, 295K, 300K, 303K, and 305K, which encompasses the global average SST of past, present, and future climates. The model used to run these RCE simulations is the System for Atmospheric Modeling (SAM) version 6.8.2 with a one-moment microphysics parameterization and Rapid Radiative Transfer Model (Khairoutdinov and Randall, 2003). The simulations are run on a constant f-plane with a Coriolis parameter of 5x10^{-5} s^{-1} which corresponds to a latitude of 20^o N. We follow the set-up of Wing et al. (2016) and use a 512x512x64 grid with 3-km horizontal grid spacing, giving a domain length of 1536 km; large enough to allow a TC to occur. The simulation is initialized from random noise and run for 100 days for each of the six different SSTs, where the ocean temperature is fixed in space and time. A second ensemble member at each SST is generated by different random noise and was run until genesis occurred and the storm reached its lifetime max intensity. We define genesis as the first time that the maximum surface winds are greater than or equal to tropical storm force (18 m/s). Using the model output we examine different properties of each TC in order to diagnose its variability. We use the budget for spatial variance of frozen moist static energy (FMSE), introduced by Wing and Emanuel 2014, in order to quantify feedbacks that contribute to the formation and intensification of the TC (Wing et al. 2016, Wing et al. 2019).

3. RESULTS

We examine how different properties of the simulated TC scale with SST. Figure (1) shows that the TC's lifetime maximum intensity (LMI) increases with increasing SST and scales with the potential intensity (PI). PI is the theoretical maximum intensity a TC can reach given its thermodynamic environment (Emanuel 1986). Using the initial soundings and the SST for each simulation, the resulting max wind speed, we calculate the PI for each simulation (Bister and Emanuel, 2002). In Figure (1) it is clear that PI is increasing with increasing SST (as expected from theory, Emanuel 1987), with an average rate of 2.712 m s^{-1} K^{-1} which is skewed due to the change in PI between 303K and 305K. The increase in LMI of the simulated TC is consistent with expectations from PI theory. There is a dropoff in the rate at which LMI increases with SST between the 303K and 305K simulation, with the change in LMI being less than 5 m/s between the two SSTs for both ensemble members. Another note is that of the six sets of simulations, the only one in which LMI exceeds PI is the pair of simulations at 303K.. Despite this, the relationship between LMI and PI is highly linear, with variations in PI explaining over 95% of the variance in LMI.

Figure (2) examines the maximum intensification rate and how it scales with PI, based on the maximum winds smoothed with a twenty-four hour running mean. Overall, the two appear are correlated despite some outliers. At the cooler SSTs, 285K and 290K, there is less variability in maximum intensification rate compared to the warmer simulations. The seed 3 ensemble member at 300K stands out as an anomaly, having a lower max intensification rate than both of the 295K simulations. Considering the lifetime maximum wind speed of the 300K simulation, the storm's maximum intensity intensifies at a slow rate and also has a small period of weakening followed by more intensification. The other simulations intensify more exponentially as the storm reaches its maximum intensity. The correlation between PI and maximum intensification rate indicates that the intensification rates of TCs increase with warming following the thermodynamic potential for TC intensity (consistent with Emanuel 2017 and Bhatia et al. 2019).

Figures (3) and (4) show the contribution of longwave radiation and surface enthalpy flux feedbacks, respectively, to the FMSE variance budget near the time of TC genesis. Both feedbacks are positive and thus contribute to TC formation and intensification. The longwave feedback plays a smaller role at 285K than at the warmer SSTs, except for one ensemble member at 305K (Figure 3). There is no well-defined correlation between longwave feedbacks and SST, in contradiction to Wing and Cronin (2016)'s results for non-rotating self-aggregation. The opposite is true with the surface enthalpy flux feedbacks in Figure (4), which shows that this feedback is stronger at the colder SSTs, with a strong negative correlation between the surface flux feedback and SST. These results are non-intuitive, as the spatial variance of FMSE increases with TC intensity (Wing et al. 2019, and confirmed here (not shown)) and longwave radiation and surface flux feedbacks contribute to increasing FMSE variance (Wing et al. 2016, Muller and Romps 2018, Wing et al. 2019).

4. CONCLUSION

LMI and maximum intensification rate of spontaneously generated TCs increase with warming and scale with PI. Longwave radiative and surface flux feedbacks contribute to TC formation and intensification, but the surface flux feedback decreases with increasing SST. There is no correlation between the longwave feedback and SST. Further analysis is needed to understand the sensitivity of these feedbacks to SST and their contribution to TC intensification.

5. REFERENCES

Bister, M., and K. A. Emanuel, 2002: Low frequency variability of tropical cyclone potential intensity, 1, Interannual to interdecadel variability. J. Geophys. Res., 107, 4801.

Bhatia, K. T., et al. 2019: Recent increases in tropical cyclone intensification rates, Nat. Commun., 10, 2041–1723. Emanuel, K. A., 1986: An Air-Sea Interaction Theory for Tropical Cyclones. Part I: Steady-State Maintenance. J. Atmos. Sci., 43, 585–605. Emanuel, K. A., 1987: The dependence of hurricane intensity on climate. Nature, 326, 483-485.

Emanuel, K., 2017: Will global warming make hurricane forecasting more difficult? Bull. Amer. Meteor. Soc., 98, 495-501.

Khairoutdinov, M. F., 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.

Muller, C. J. and D.M. Romps, 2018: Acceleration of tropical cyclogenesis by self-aggregation feedbacks. Proc. Natl. Acad. Sci. USA, 115, 2930–2935.

Wing, A. A., and K. A. Emanuel, 2014: Physical mechanisms controlling self-aggregation of convection in idealized numerical modeling simulations, J. Adv. Model. Earth. Syst., 6, 59–74.

Wing A. A., and T. W. Cronin, 2016: Self-aggregation of convection in long channel geometry. Q. J. R. Meteorol. Soc., 142, 1–15.

Wing, A.A., et al., 2016: Role of Radiative–Convective Feedbacks in Spontaneous Tropical Cyclogenesis in Idealized Numerical Simulations. J. Atmos. Sci., 73, 2633–2642.

Wing, A. A., et al., 2019: Self-aggregation of deep convection and its implications for climate. Curr. Clim. Change Rep., 5, 1–11.

FIGURE 1: Scatter plot of simulated lifetime maximum intensity (LMI) and potential intensity (PI). Each dot represents a different simulation and its color reflects the SST with the warmer simulations being warmer colors. Runs for the same ensemble are connected with a solid line (seed 3) or dashed line (seed 4) in order to compare the runs to one another. Correlation coefficients between LMI and PI for all the runs (r^2 all) and each individual seed (r^2 Seed 3 and Seed 4) are shown in the text box inset.

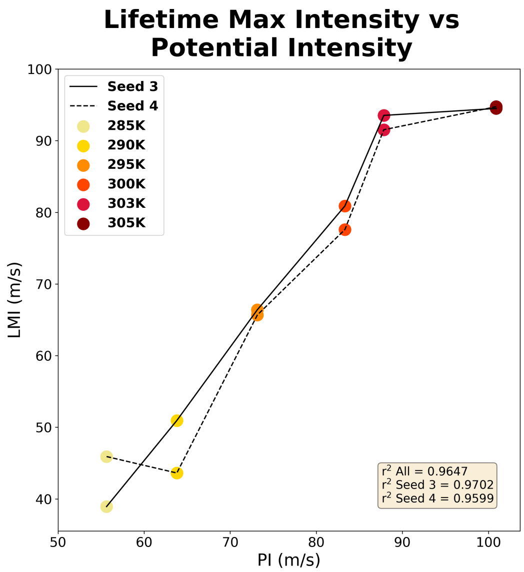

FIGURE 2: As in Figure 1 but for the simulated maximum intensification rate. The maximum intensification rate is calculated by finding the maximum rate of change of the maximum wind speed smoothed with a 24 hour running mean.

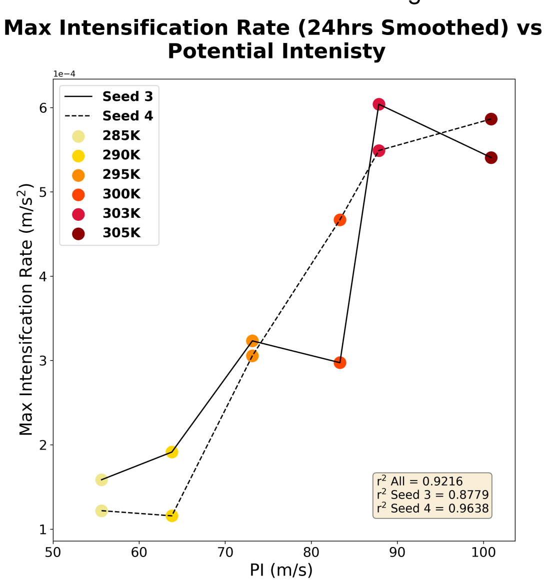

FIGURE 3: The contribution of the domain-mean longwave feedback < $\widehat{h}'N_L'$ > to the FMSE variance budget, normalized by the domain-mean variance *var*($\widehat{h}$), as a function of SST. The feedback is averaged over a period from three days days prior to genesis to three days after genesis.Each dot represents a different simulation and its color reflects the SST with the warmer simulations being warmer colors. Runs for the same ensemble are connected with a solid line (seed 3) or dashed line (seed 4) in order to compare the runs to one another. Correlation coefficients between the longwave feedback and SST for all the runs (r^2 all) and each individual seed (r^2 Seed 3 and Seed 4) are shown in the text box inset.

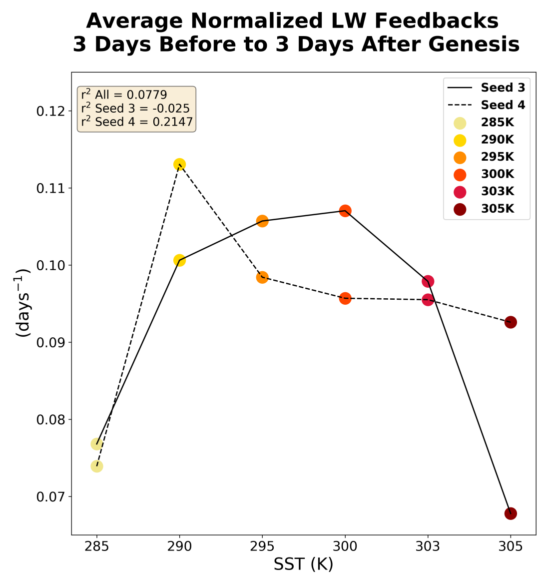

FIGURE 4: As in Figure 3 but for the normalized domain-mean surface flux feedback $\widehat{h}'F_S'$ > normalized by the domain-mean variance *var*($\widehat{h}$).