P3.43 THE SENSITIVITY OF MULTIPLE EQUILIBRIA TO SEA SURFACE TEMPERATURE CHANGES IN WEAK TEMPERATURE GRADIENT SIMULATIONS

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1. INTRODUCTION

The response of the tropical atmosphere to global temperature changes is important for understanding the development of phenomena originating in the tropics, e.g. hurricanes and the Maden-Julian oscillation. Observations show that areas of developing synoptic systems exhibit self-aggregation of convection, the process of drying out of the atmosphere in favor of a sharply defined moist region. The study of self-aggregation can lead to increased knowledge of tropical cyclogenesis and other phenomena originating in the tropics.

Recently, Sessions et al. (2010) investigated a cloud resolving model (CRM) of Raymond and Zeng (2005) utilizing the weak temperature gradient (WTG) approximation. They found that the model exhibits multiple equilibrium states, defined as precipitating and non-precipitating steady state, which depend on the initial moisture profile in a fixed size and resolution domain. Also, they occur for horizontal wind speed smaller than a critical value.

Khairoutdinov and Emanuel (2010) found that their model exhibited self-aggregation in radiative convective equilibrium (RCE) simulations and that it had strong nonlinear dependence on sea surface temperatures (SST).

In this paper we show that the critical imposed wind velocity which is the limit between the precipitating and non-precipitating multiple equilibria is a strongly nonlinear function of SST. Linked with findings of Khairoutdinov and Emanuel, this implies a possible connection of multiple equilibria in a limited domain CRM to self-aggregation of convection in radiative convective equilibrium (RCE) simulations.

In section 2 we explore the WTG approximation, while in section 3 we explain the normalized gross moist stability, a diagnostic measure useful for studying of moist processes. In section 4 we discuss our current results. Section 5 gives the conclusions and ongoing work.

2. WEAK TEMPERATURE GRADIENT APPROXIMATION

Effectively, the WTG approximation parameterizes the large scale in a limited domain CRM. It assumes weak large scale horizontal gradients of equivalent potential temperature. Any perturbations arising in the vertical profiles of temperature due to convection are radiated out by gravity waves. In a CRM this can be achieved by imposing a hypothetical vertical velocity that counteracts radiative heating. In our CRM the perturbed profiles are relaxed to a reference profile at the rate t_θ, physically interpreted as the time that it takes for a gravity wave to cross the domain.

In our simulations the CRM of Raymond and Zeng (2005) was used with a 2D domain with fixed size of 100km and WTG relaxation constant of 0.51h. Reference profiles were calculated by averaging over the last 60 days of RCE simulations with different imposed SSTs. These profiles were then used for WTG simulations with two control variables: dry or moist initialized moisture profile, and horizontal wind speed.

3. NORMALIZED GROSS MOIST STABILITY

Normalized gross moist stability (NGMS) used here is defined as: normalized ratio of lateral moist entropy export to lateral moisture import. It can be viewed as a measure of precipitation efficiency. Raymond et al. (2009) give a thorough discussion on NGMS.

(Need to expand on this section after talking to Dr. Sessions)

4. RESULTS AND DISCUSSION

Figure 1 shows the dependence of precipitation on horizontal wind speed ranging from 3 to 20 m/s and SSTs from 300 to 305K (line color), for moist (solid line) and dry (dashed line) initialized simulations. Clearly, it can be seen that there is a range of wind speeds that sustain two equilibrium states, a precipitating and a non-precipitating state. Also, it can be seen that the critical horizontal wind speed that separates multiple equilibria from the single equilibrium is a nonlinear function of SSTs. Further, a monotonic increase in precipitation with horizontal wind speed is noticeable.

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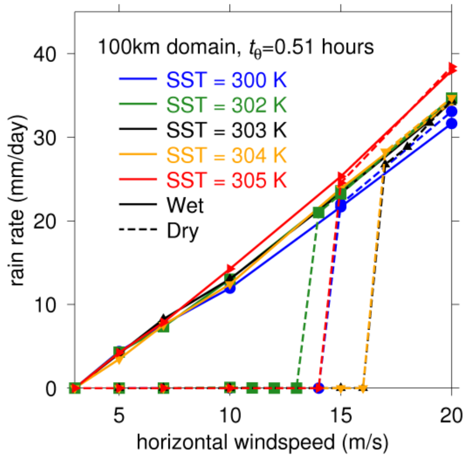

Figure 1**:** Precipitation as a function of horizontal wind speed and SST exhibits multiple equilibrium states. The critical velocity separating the precipitating and non-precipitating states of the dry initialized (dashed line) tests is a strongly nonlinear function of SST. Precipitating equilibrium (solid line) is a monotonically increasing function of horizontal wind speed.

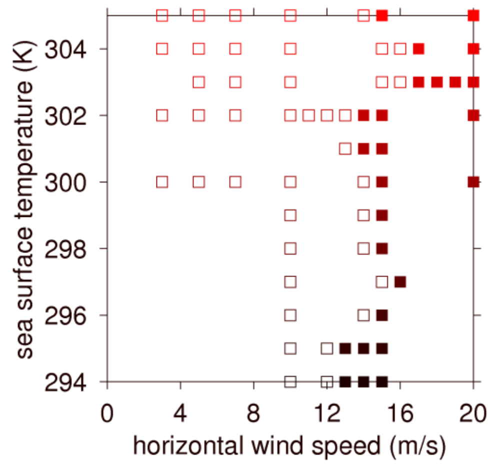

Figure 2: Dependence of multiple equilibria on SST and horizontal wind speed. Shown points represent dry initialized tests. Filled (empty) squares represent precipitating (non-precipitating) equilibrium. Note the highly nonlinear dependence of the critical velocity on SST. Shade increases with increasing SST.

Nonlinear dependence of multiple equilibria to SST was further studied by extending the SST range down to 294 K. Figure 2 shows the dependence of multiple equilibira on SST and horizontal wind speed. All plotted points represent dry initialized simulations. Red shading increases with temperature. The filled boxes represent runs that exhibited precipitating steady state while empty boxes present non-precipitating steady state runs. We find that the nonlinear dependence of the critical wind speed on SST extends down to 294K. Opposing intuition is the critical velocity dip for 294K and 295K SST. With lower SST surface fluxes decrease so one would expect the need of higher wind speeds to produce the same surface flux of moisture to produce a precipitating state. Same counterintuitive process happens at 303K and 304K, but with an opposite sign: the critical velocity is higher. This paradox points to a negative feedback mechanism that entails horizontal wind speed.

Normalized gross moist stability (NGMS) can be used to elucidate the nonlinear dependence of multiple equilibira to SST. Figure 3 shows NGMS against horizontal wind speed. High positive NGMS is seen for the precipitating equilibrium states, because we have export of moist entropy and import of moisture, while the non-precipitating equilibrium states observe small positive and negative values. There is a distinct jump that occurs in the NGMS at 10 m/s horizontal wind speed that extends to higher wind speeds. NGMS at 3, 5, and 7 m/s decreases with increasing SST, while for higher wind speeds NGMS increases for increasing SST. We hypothesize that understanding the behavior of this jump can lead to better understanding of mechanisms leading to multiple equilibria.

Figure 4 shows the dependence of NGMS on saturation fraction, defined as column integrated mixing ratio divided by column integrated saturated mixing ratio. We see a strong monotonic dependence of NGMS to saturation fraction for the precipitating equilibrium states that increases with SST. The figure exposes a striking pattern in the non-precipitating equilibrium states, an even more clear separation that in figure 3. This points out to the fact that there is a mechanism closely related to moisture and moisture transport responsible for the onset of this transition. Even though surface fluxes (i.e. dynamics) are necessary for supplying the atmosphere with the potential for developing precipitation, thermodynamic mechanisms seem to control the onset of multiple equilibria because the moisture content of the troposphere will be dependent on the amount of convection.

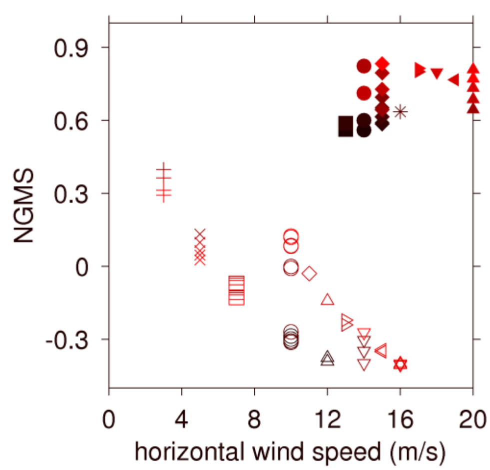

Figure 3: NGMS as a function of horizontal wind speed. Symbols present the legend for figure 4. Shading turns to red for higher SST. There is a distinct boundary between precipitating (filled symbols) and non-precipitating (empty symbols) equilibrium states. The non-precipitating states also exhibit a jump obvious at 10 m/s.

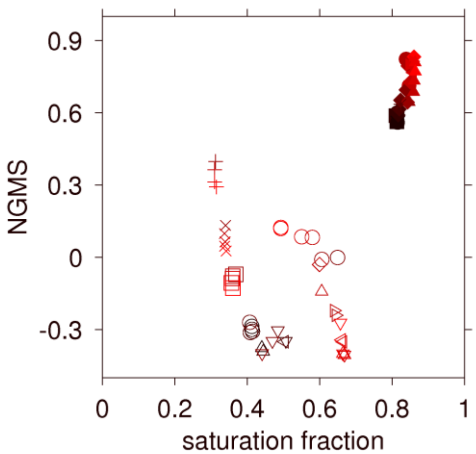

Figure 4: NGMS as a function of saturation fraction. Symbols represent wind speed (see figure 3), precipitating (non-precipitating) steady states are represented with filled (empty) symbols. The non-precipitating steady states exhibit a distinct pattern. The separation visible in figure 3 is even more evident. The precipitating steady states show how NGMS is a strong monotonically increasing function of saturation fraction.

5. CONCLUSION AND FUTURE WORK

In this paper we present results and ongoing work from investigating multiple equilibria simulations in a limited domain cloud resolving model utilizing the weak temperature gradient approximation in relation to self-aggregation on large domain radiative convective equilibrium simulations.

We find that multiple equilibria simulations exhibit strong nonlinear dependence to sea surface temperature which is visible in the critical imposed horizontal wind speed bounding the multiple equilibria from the single equilibrium state (figures 1 and 2). Khairoutdinov and Emanuel found that self-aggregation of convection has strong nonlinear dependence to sea surface temperatures. This shows that limited domain multiple equilibria simulations can be used to study self-aggregation in a computationally more economical manner. Further work entails obtaining self-aggregation in radiative convective equilibrium simulations utilizing our cloud resolving model and comparing the dry and moist regions of self-aggregation to the dry and moist equilibrium from the limited domain weak temperature gradient simulations

Further, we explore the nonlinearity in sea surface temperature in our multiple equilibria simulations using the normalized gross moist stability. We find indirect evidence that there are nonlinear moisture and horizontal wind speed feedback mechanisms that modulate moist entropy and moisture fluxes in the dry equilibrium. Further work is necessary to understand these feedback mechanisms.

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