3B.5 IMPACTS OF CLIMATE VARIABILITY ON TROPICAL CYCLONE TRACKS

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1. INTRODUCTION

The impact of rising CO_2 on tropical cyclones (TCs) is an area of great interest. While consensus on changes in frequency and intensity has begun to emerge (Knutson et al. 2010), possible changes in TC tracks from anthropogenic climate change has received less attention.

The genesis location is an important factor in determining TC tracks. Vecchi and Soden (2007) found an eastward shift in climate model simulations of the Genesis Potential Index (GPI, Emanuel and Nolan 2004) over the North Atlantic main development region (MDR) in response to increased CO2. Murakami and Wang (2010) hypothesize that this eastward shift in genesis was the primary cause for a decrease in southeastern landfalling tracks and an increase in northeastern landfalling tracks in the North Atlantic in their high resolution model simulations.

This study uses a Beta and Advection Model (BAM) to examine the impact of changes in the large-scale steering flow and genesis location on TC tracks. Our approach allows us to isolate the impact of changes in the large-scale steering flow from changes in genesis location. This separation allows for a more detailed understanding of the cause for potential shifts in track, while still examining their combined influence.

We use the Atlantic hurricane database (HURDAT) for 1950 to 2010, with particular focus on TCs which form in the MDR (Jarvinen et al. 1984; McAdie et al. 2009). Wind fields from National Centers for Environmental Prediction – National Center for Atmospheric Research (NCEP-NCAR) reanalysis (Kalnay et al. 1996) are used following the methodology and model developed by Colbert and Soden (2012; CS12). The monthly wind fields and corresponding monthly GPI for 17 Coupled Model Intercomparison Project version 3 (CMIP3) models under the A1B scenario are also used (Vecchi and Soden 2007).

2. LARGE-SCALE STEERING FLOW

To identify large-scale circulation changes due to rising CO_2, monthly zonal (*u*) and meridional (*v*) vertical wind anomalies are computed for each of the CMIP3 models. The anomalies are calculated as the difference between the 20-year averages at the beginning and end of the 21st century ([2081-2100] - [2001-2020]). In order to obtain comparable wind fields across models, the difference for each model is normalized by the change in global annual temperature for that model. Then, the normalized difference is multiplied by a 3 degree temperature change to acquire a probable anomalous wind field for an equilibrium response to doubled CO2. The monthly anomalies for each model are then added to the corresponding NCEP-NCAR reanalysis winds.

The BAM from CS12 is used to generate the TC tracks. The BAM uses a deep layer steering flow that is computed from the resulting 2-dimensional wind fields (**V)** at 850, 500 and 200 mb defined as: $V^* = 0.25^*\mathbf{V}_{850\ mb} + 0.5^*\mathbf{V}_{500\ mb} + 0.25^*\mathbf{V}_{200\ mb}$. The average wind trajectory is computed over a 7.5° box for each component with an empirically-fit β-drift added for each time step, creating a simulated track. For each experiment, tracks for all 256 TCs which formed in the MDR during the period 1950-2010 are simulated for both the control and double CO2 experiments. The distribution of TCs is then recorded on a 5° by 5° grid for both experiments.

In order to determine the significance of changes in track density, the tracks are classified into three categories: straight-moving (SM), recurving landfall (RCL), and recurving ocean (RCO) as defined in CS12 (Fig. 1). Following the methodologies from CS12, significance testing of the differences in TC frequency between the three track categories is determined for each experiment.

Figure 2 displays the resulting mean track density difference plot when changes in the large-scale steering flow are isolated for MDR forming TCs. Although a majority of the differences do not display a clear pattern of shifts in tracks, two spatially coherent patterns emerge. Over the Mid-Atlantic there is an increase in track density of approximately 2 TCs per decade. In addition, a noticeable decrease in track density of approximately 1.5 to 2 TCs per decade occurs over the Caribbean and Southern Gulf of Mexico. These shifts result in a decrease of 5.8% of SM

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TCs and an increase of 6.3% of RCO TCs (Fig. 5). However, only the increase in RCO TCs is deemed statistically significant at the 95% level.

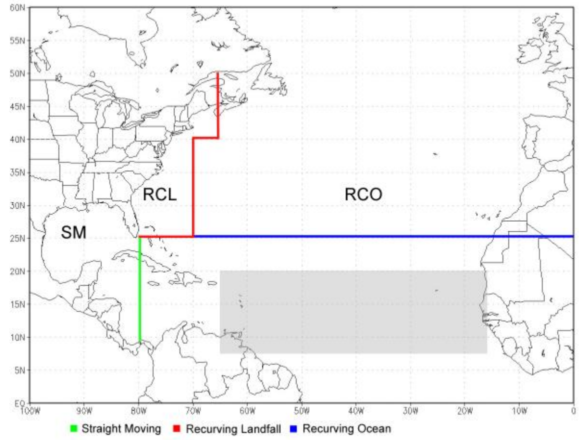

Fig. 1: *The track boundaries for classifying TC tracks. The straight-moving (SM, Green) TCs threatened the Gulf Coast and Western Caribbean. The recurving landfall (RCL, Red) TCs threatened the East Coast of the US. The recurving ocean (RCO, Blue) TCs never threatened the US. All TCs had to form in the Main Development Region (MDR, Gray). (From CS12)*

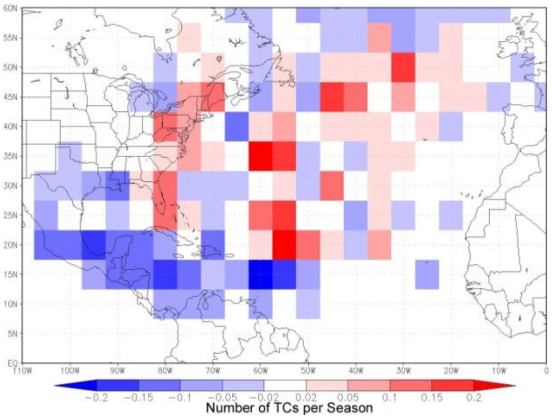

Fig. 2: *The mean track density difference (CC-CUR) in MDR forming TCs over 61 seasons for BAM simulated tracks with the historical wind fields (CUR) and BAM simulated tracks with the 17 model ensemble anomalous winds from each respective model added to the historical wind fields (CC). The contour levels are 0.2, 0.15, 0.1, 0.05, and 0.02 where blue is negative and red is positive.*

3. GENESIS

To examine the influence of changes in genesis location on TC tracks, the GPI is calculated based on the A1B scenario for 17 CMIP3 models (Vecchi and Soden 2007). The seasonal (June-November) 20-year average GPI is calculated for the current (2001-2020) and future (2081-2100) climates. As discussed in Vecchi and Soden (2007), the 17 model ensemble mean difference ([2081-2100]-[2001-2020]) normalized per degree warming shows a slight eastward shift in genesis in the MDR.

To determine the importance of this change in GPI on TC tracks, the BAM simulated tracks are weighted by the average GPI for the current and future climates. Each TC track is weighted by the GPI for that grid box. Thus if a given location’s GPI were to double, the tracks from that grid box would be weighted twice as much. It is important to mention that this method uses the historical genesis locations and corresponding GPI. Thus we are unable to account for TCs forming in areas that they did not historically occur.

Figure 3 illustrates the difference between the current and future weighted GPI mean track densities for MDR forming TCs. These differences are very small and statistically insignificant. However, there is a very slight increase in RCO TCs and decrease in SM and RCL TCs (Fig. 5). This is expected with an eastward shift of genesis in the MDR and is consistent with the observed genesis distribution and track preference found in the MDR in CS12.

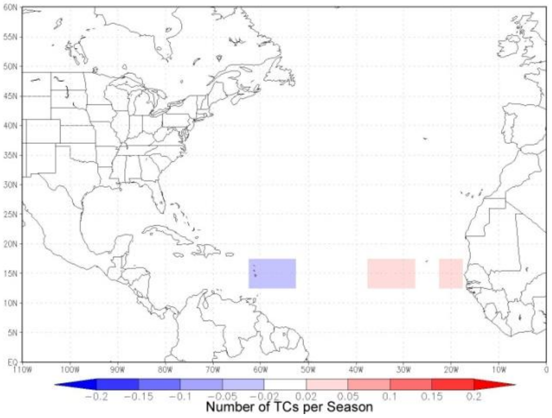

Fig. 3: *The mean track density difference (CC-CUR) in MDR forming TCs over 61 seasons for BAM simulated tracks weighted by the 20-year, 17 model ensemble GPI at the beginning of the 21st century (2001-2020, CUR) and BAM simulated tracks weighted by the 20-year, 17 model ensemble GPI at the end of the 21st century (2081-2100, CC). The contour levels are 0.2, 0.15, 0.1, 0.05, and 0.02 where blue is negative and red is positive.*

4. COMBINED EFFECT

When genesis and the large-scale steering flow are isolated, both have a limited effect on track density; however, when they are combined, they may act to reinforce a change in certain regions. Similar to the methodology in section 3, the simulated current and future large-scale steering flow isolated mean track densities are weighted by their respective 17 model ensemble mean GPI.

The difference between the current and future mean track densities for MDR forming TCs (Fig. 4) is somewhat noisy, similar to Figure 1. There is a larger reduction in track density over the Southern Gulf of Mexico and Caribbean resulting in a decrease of approximately 2 TCs per decade. The increase in mean track density throughout the Mid-Atlantic is also enhanced. Statistically significant changes in TC track frequency occur with a decrease of 7.8% in SM TCs and an increase of 6.3% in RCO TCs (Fig. 5).

The changes in the large-scale steering flow are the primary contributor to the shifts in TC track frequency. However, the significant decrease in SM TCs is not observed when the large-scale steering flow is isolated suggesting that the eastward shift in genesis in the MDR is an important factor to changes in TC tracks.

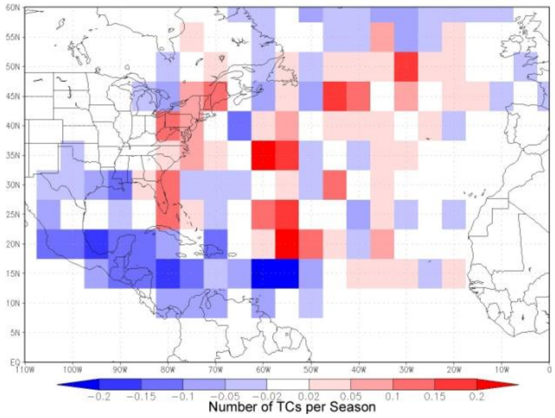

Fig. 4: *The mean track density difference (CC-CUR) in MDR forming TCs over 61 seasons for BAM simulated tracks weighted by the 20-year, 17 model ensemble GPI at the beginning of the 21st century (2001-2020, CUR) and 17 model ensemble BAM simulated tracks with anomalous winds from each respective model added to the historical wind fields weighted by the 20-year, 17 model ensemble GPI at the end of the 21st century (2081-2100, CC). The contour levels are 0.2, 0.15, 0.1, 0.05, and 0.02 where blue is negative and red is positive.*

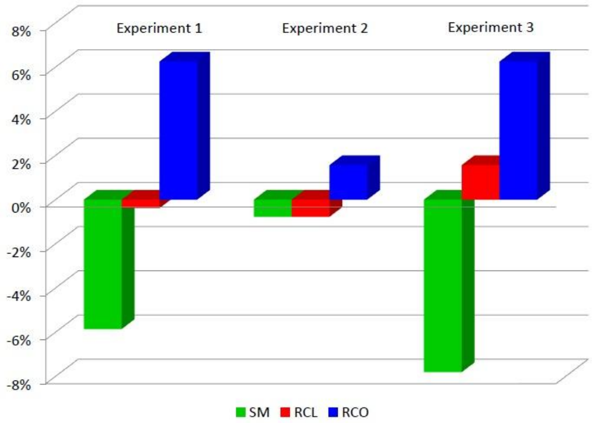

Fig. 5: *The change in percent of SM (green), RCL (red), and RCO (blue) TC track frequency for the three experiments. Experiment 1: large-scale steering flow changes isolated. Experiment 2: genesis (GPI) changes isolated. Experiment 3: Combined effect. All experiments are for future (CC) minus current (CUR).*

5. SUMMARY AND FUTURE WORK

We examined the impacts of increased CO_2 on North Atlantic TC tracks by investigating how changes in the large-scale steering flow and GPI, both individually and as a combined effect, influence track density and frequency. Focusing on MDR forming TCs, the larger changes in magnitude for mean track density occur with shifts in the large-scale steering flow compared to shifts in the GPI. Although weaker in magnitude, the changes in GPI, mainly an eastward shift in the MDR, result in slightly more RCO TCs. This compliments a reduction of TCs over the Southern Gulf of Mexico and Western Caribbean that is found from changes in the large-scale steering flow.

When these individual changes are combined, the reduction in track density over the Southern Gulf of Mexico and Caribbean is enhanced to a decrease of 2 TCs per decade throughout the region. In addition, an increase in the mean track density through the Mid-Atlantic of approximately 2 TCs per decade is found. Corresponding to the track density, we found a statistically significant decrease in SM TCs and increase in RCO TCs. This suggests that changes in both the large-scale steering flow and genesis location are important factors for TC tracks in the North Atlantic.

The overall impact in the North Atlantic from changes in TC tracks due to rising CO_2 levels in the atmosphere will have a limited, but possibly consequential, scope. Analysis of the changes in tropical cyclone tracks in other ocean basins is underway and will be presented at the conference.

6. REFERENCES

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