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IMPACT OF CO_2-INDUCED WARMING ON SIMULATED HURRICANE INTENSITY AND PRECIPITATION: SENSITIVITY TO THE CHOICE OF CLIMATE MODEL AND CONVECTIVE PARAMETERIZATION

Thomas. R. Knutson[1] and Robert E. Tuleya[2]
[1] Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
[2] Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, Virginia

1. INTRODUCTION

Our previous studies have found that idealized hurricanes, simulated under warmer, high CO_2 conditions, are more intense and have higher precipitation rates than under present-day conditions. The present study explores the sensitivity of this result to the choice of climate model used to define the CO_2-warmed environment and to the choice of convective parameterization used in the nested regional model that simulates the hurricanes.

2. DESCRIPTION OF EXPERIMENTS

Approximately 1,300 five-day idealized hurricane simulations were performed using a higher-resolution version of the GFDL hurricane prediction system (grid spacing as fine as 9 km, with 42 levels). The initial condition contains a well-developed storm disturbance based on a real hurricane case with maximum surface wind speeds of approximately 35 m s^{-1} at a radius of 55 km. The storm disturbance was embedded in a uniform 5 m s^{-1} easterly background flow over an all-ocean domain, with no ocean coupling.

The large-scale thermodynamic boundary conditions for the experiments--atmospheric temperature and moisture profiles and SSTs for control and high CO_2 conditions--were derived from nine different climate models, available as part of the CMIP2+ coupled model intercomparison project. The CO_2-induced changes from the global models were based on 80-yr linear trends from +1%/yr CO_2 increase experiments. The SST changes ranged from +0.8 to +2.4°C in the three tropical storm basins studied (NW Pacific, NW Atlantic and NE Pacific).

Four different moist convection techniques were tested in the hurricane model experiments. These included the simplified Arakawa-Schubert scheme as implemented in the current global forecast system (GFS) at NCEP; Emanuel's convective adjustment scheme as implemented in the U.S. Navy's Operational Global Atmospheric Prediction System (NOGAPS); the "soft convective adjustment" scheme used in operational versions of the GFDL hurricane model prior to the 2003 hurricane season; and resolved convection (i.e., using no convective parameterization in the inner-most grid of the triply nested model). For simplification, no cloud microphysical packages were invoked.

* *Corresponding author address*: Thomas Knutson, Geophysical Fluid Dynamics Laboratory, P.O. Box 308, Princeton, NJ 08542; e-mail: Tom.Knutson@noaa.gov.

3. RESULTS

Nearly all combinations of climate model boundary condition and hurricane model convection scheme showed an increase in both storm intensity and near-storm precipitation rates under high CO_2 conditions. The aggregate results, averaged across all experiments (e.g., Fig. 1), indicate a 10 mb decrease in central pressure, a 14% increase in pressure fall, a 6% increase in maximum surface wind speed, and an 18% increase in average precipitation rate within 100 km of the storm center. The fractional change in precipitation was more sensitive to the choice of convective parameterization than was the fractional change of intensity. The more intense hurricanes and enhanced storm precipitation rates were correlated with warmer SSTs and higher CAPE in our simulations. The global models simulated greater CAPE under high CO_2 conditions (+21%) despite an enhanced upper tropospheric warming relative to the surface warming.

4. DISCUSSION

The idealized framework used here may be thought of as addressing the question of the potential intensity of tropical cyclones, since we presume the existence of a robust initial vortex and do not allow dynamical influences such as vertical wind shear to interfere with the modeled storm's development. In that sense our intensity results are analogous to potential intensity theories in terms of their applicability to the probability distribution of future intensities, the latter of which depends also on the future frequency of tropical cyclones. Application of hurricane potential intensity theories to the climate model environments yields an average increase of intensity (in terms of pressure fall) of 8% (Emanuel) to 16% (Holland) for the high CO_2 environments.

The enhanced near-storm precipitation rates in the high CO_2 hurricane simulations are consistent with a conceptual picture of enhanced moisture convergence in tropical cyclones in a warmer climate due to the greater atmospheric moisture content, augmented by a stronger convergent circulation toward the storm core region.

We would not anticipate that a CO_2 induced increase in tropical cyclone intensity such as that simu-

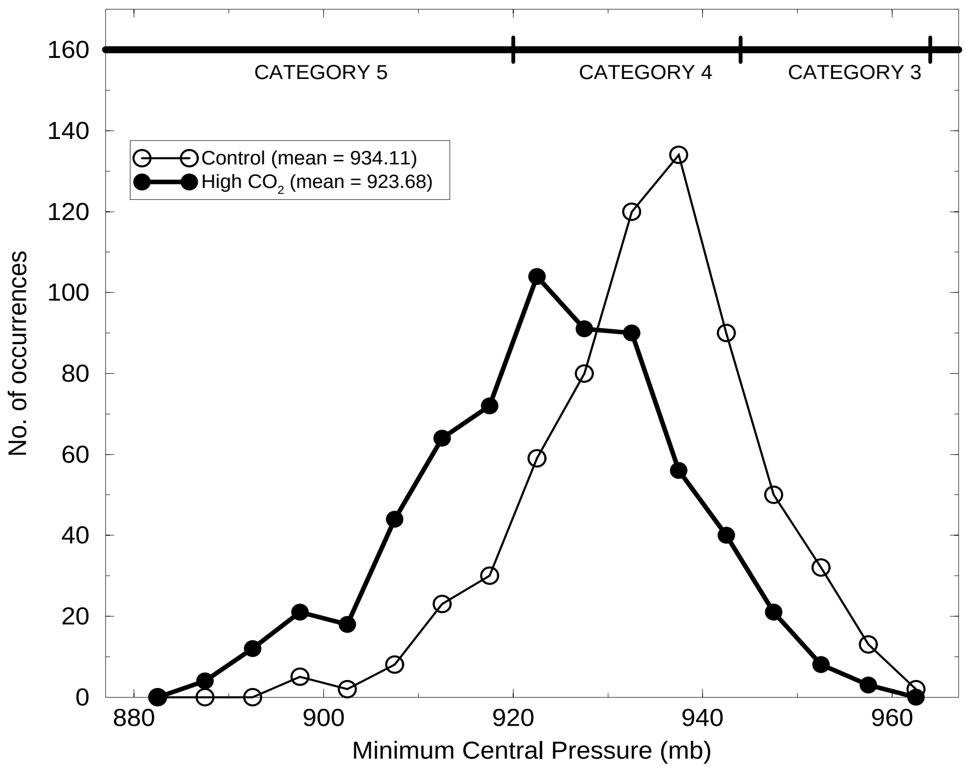

FIG. 1. Frequency histograms of hurricane intensity results (mb) aggregated across all 1,296 experiments performed for the study. The light (dark) line with open (solid) circles shows results for the control (High CO_2) cases. The central pressures for experiments using data from each of nine different CMIP2+ climate models, three tropical storm basins, and using four different convective parameterization treatments, and six ensemble members differing only slightly in their initial conditions all are combined to form a single histogram for either the control or High CO_2.

lated in our study would be detectable in historical observations and perhaps not for many decades to come. This expectation is due to the modest anticipated rate of change of potential intensity over time; limitations of tropical cyclone intensity observations--both ongoing and those in the available climate observations, and the presence of pronounced multidecadal variability of tropical cyclone activity in some basins, such as the North Atlantic. There are a number of caveats to our results. For example, there is considerable uncertainty in projections of future climate change--due to uncertainties in future radiative forcing, global climate sensitivity, and regional-scale details of climate change such as ENSO variability. There are also uncertainties introduced by our idealized simulation approach and the current level of understanding of the tropical cyclone intensity problem.

5. SUMMARY

The main purpose of the study was to test how sensitive earlier simulation results were to the particular host climate model or to the details of the convection technique in the hurricane model used to simulate the storms. The results indicate that the earlier findings (increased hurricane intensities and near-storm precipitation rates in warmer high-CO_2 environments) are generally reproduced across a range of host climate models and convective parameterizations in the GFDL hurricane model. Our earlier research had indicated that our results are robust to the inclusion of ocean coupling beneath the simulated hurricanes.

These results lend support to the notion that future greenhouse warming will gradually raise the upper limits on tropical cyclone intensity imposed by the thermodynamic environment so as to allow for tropical cyclones with greater precipitation rates and higher intensity--by roughly half a category a century from now according to our highly idealized calculations--than occur in the present climate.