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TROPICAL CYCLONE ACTIVITY AND THE GLOBAL CLIMATE SYSTEM

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1. INTRODUCTION

Some 90 tropical cyclones develop each year around the globe. This number is remarkably constant, having a standard deviation of only 10. At present there is little understanding of what controls this number, or why it is so stable. Nor is it known how, if at all, this number might change with the Earth's climate…were there more or fewer tropical cyclone during cold climates such as the ice ages? Were hurricanes especially frequent and intense during warm climates, such as the early Eocene? How might global warming affect the frequency of storms?

These questions are of far more than academic interest. Changes in the incidence, intensity, or location of tropical cyclones might prove to be among the more serious consequences of global warming, though at present there is little agreement on how such activity might change (Henderson-Sellers et al., 1998); (Houghton et al., 2001). Nor is the response of tropical cyclone activity to climate change necessarily passive. Recently, one of us argued that global tropical cyclone activity is an important driver of the ocean's thermohaline circulation (Emanuel, 2001), and through this mechanism alters the Earth's climate dynamic, stabilizing tropical climate while destabilizing the climate of higher latitudes (Emanuel, 2002). This suggests that understanding the climatic control of tropical cyclones may be necessary for understanding the climate system in general.

2. HYPOTHESIS

We hypothesize that tropical cyclones result from a type of subcritical bifurcation of the normal state of the tropical atmosphere, illustrated in Figure 1. On the abscissa is some measure of the climate forcing of tropical cyclones (e.g. sea surface temperature), while the ordinate shows a measure of the actual amplitude of events. The thick curve represents a neutral stability surface along which cyclone-like perturbations neither grow nor decay; this surface separates stable from unstable regimes. The backward slope of the curve away from its intercept on the abscissa is associated with the subcritical property of the phenomenon: if the climate state lies between points A and B, small perturbations are stable while sufficiently large ones can develop into full-fledged tropical cyclones.

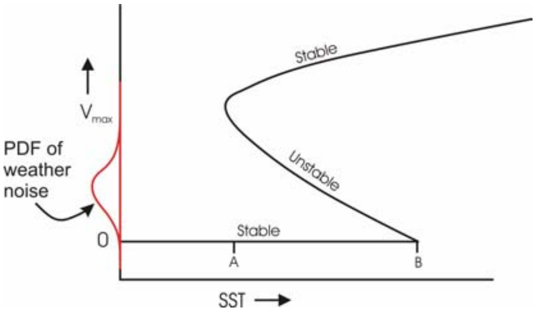

Figure 1: Proposed regime diagram for tropical cyclones

Now suppose that the system is subject to a statistically constant level of "weather noise", represented by the PDF on the ordinate of Figure 1. Then, every so often, a random fluctuation will drive the system across its stability boundary, and a storm will develop. It is clear from the geometry of Figure 1 that the frequency of events is controlled both by the PDF of the weather noise and the environmental forcing value (e.g. SST). For example, increasing the forcing while holding the weather noise constant should result in an increased number of events.

3. TESTING THE HYPOTHESIS

To test this hypothesis, we must first better define what we mean by “environmental forcing”. Clearly, TCs respond to much more than just the SST, as shown by Gray (1979). We are refining Gray’s TC genesis index using reanalysis data to empirically relate spatial and temporal variability of genesis to a limited number of environmental predictors, avoiding the use of factors, such as threshold SSTs, that we believe will themselves vary with global climate. We have developed a preliminary genesis index given by

$$I = \left|10^5 \eta\right|^{3/2} \left(\frac{\mathcal{H}}{50}\right)^3 \left(\frac{V_{pot}}{70}\right)^3 \left(1 + 0.1\, V_{shear}\right)^{-2},$$

Corresponding author address: KERRY EMANUEL, Rm. 54-1620 MIT, 77 Mass. Ave., Cambridge, MA 02139; e-mail: emanuel@texmex.mit.edu where η is the absolute vorticity in s^{-1}, $\mathcal{H}$ is the relative humidity at 700 hPa in percent, V_{pot} is the potential intensity in $m\ s^{-1}$, and V_{shear} is the magnitude of the vector shear from 850 to 200 hPa, in $m\ s^{-1}$. Figure 2 shows the hemispheric monthly mean index plotted against the total number of storms in each hemisphere in each month. The major features of the seasonal variability of genesis seem to be captured by the index. A more rigorous test is whether the index captures interannual variability within each of the major ocean basins, a test we plan to carry out once we have further developed our index.

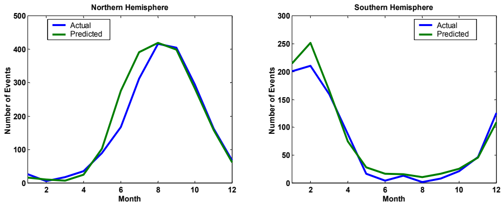

Figure 2: Total number of genesis events over a 30 year period in the northern (left) and southern (right) hemispheres. The blue curves show the observed number while the green curves show the index values.

As a test of the hypothesis illustrated in Figure 1, we first ask whether a reduced rendition of the tropical atmosphere contains a bifurcation point like B in Figure 1. To do this, we are running a cloud resolving model – the Weather Research and Forecast Model (WRF) version 1.3 – to a state of statistical radiative-convective equilibrium on an *f* plane in a three-dimensional domain with singly-periodic boundary conditions (doubly periodic boundary conditions are not yet available in WRF). At a fixed SST of 30 °C, the equilibrium state is characterized by random convection (Figure 3 left), but when the SST is increased to 35 °C, TCs spontaneously develop (Figure 3 right), suggesting that the bifurcation point B indeed exists in this model.

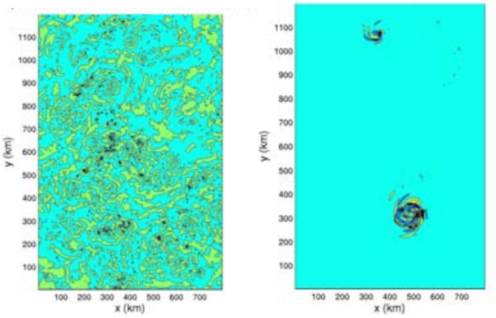

Figure 3: Snapshots of the vertical velocity in statistical radiative-convective equilibrium of the WRF model with an SST of 30 °C (left) and 35 °C (right). Domain is 800 km east-west and 1200 km north-south.

We plan to conduct further experiments introducing TC-like disturbances into the subcritical radiative-convective equilibrium states to flesh out the shape of the stability boundary, as in Figure 1.

3. SUMMARY

The climate control of tropical cyclone activity remains an important and largely unsolved problem. Solving it is not only key to predicting how TC activity will respond to global and regional climate change, but since TCs may play a fundamental role in driving the thermohaline circulation, their response to climate change may prove vital for understanding and predicting climate change in general. Our hypothesis that TCs are the result of a subcritical instability of the tropical atmosphere, illustrated in Figure 1, is supported by preliminary experiments with a cloud-resolving model that suggest that a bifurcation point like B exists in the model. This, together with our work on an empirical genesis index, suggests that TC activity may indeed be very sensitive to such factors as potential intensity. Such a sensitivity, when coupled with the sensitive dependence of ocean heat export from the Tropics on TC activity, forms the basis of an efficient tropical thermostat.

4. REFERENCES

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