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ENVIRONMENTAL INFLUENCES ON TROPICAL CYCLONE VARIABILITY AND TRENDS

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1. INTRODUCTION

Tropical cyclone activity has been increasing in concert with tropical ocean temperatures globally (Emanuel 2005; Webster et al. 2005). The correlation between tropical cyclone (TC) activity and sea surface temperature (SST) is especially evident in the North Atlantic, where the TC data is particularly good. Figure 1 compares the annual count of North Atlantic TCs with SST in the main development region (MDR) for Atlantic TCs, while figure 2 compares MDR SST to the annually accumulated storm lifetime maximum power dissipation index (PDI).

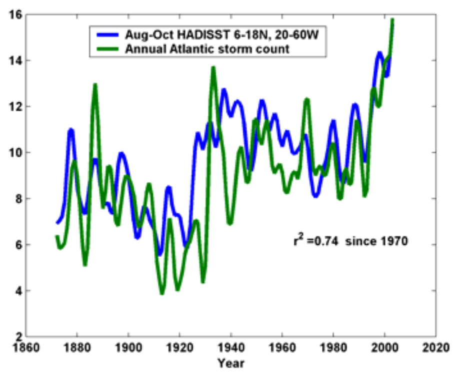

Figure 1: Scaled Aug-Oct MDR SST (blue) and annual North Atlantic TC count (green), both smoothed with a 1-3-4-3-1 filter.

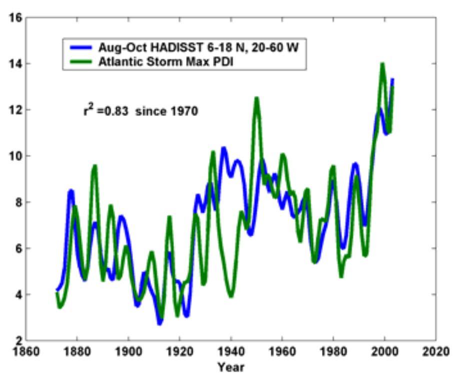

Figure 2: Scaled Aug-Oct MDR SST (blue) and storm lifetime maximum PDI (green) for the North Atlantic. Both curves smoothed as in Figure 1.

The MDR SST trend and variability that is driving the observed changes in TC activity is virtually identical to the trend and variability in northern hemisphere surface temperature (including land), as shown in Figure 3. This observation weighs heavily against the notion that late summer MDR SST variability is significantly influenced by any regional phenomenon, such as the Atlantic Multi-decadal Oscillation (AMO). It is generally understood that the observed variability in global and hemispheric surface temperature is driven by variability in solar output, volcanic activity, sulfate aerosols, and greenhouse gases (Stott et al. 2000).

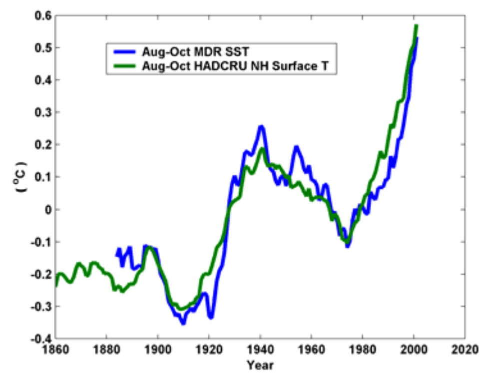

Figure 3: 10-year running average of Aug-Oct MDR SST (blue) and NH surface temperature (green).

2. PHYSICAL CAUSES

According to Figure 2, the storm lifetime maximum PDI has increased by 90% since the late 19th century. Of this increase, 67% is accounted for by an increase in the number of storms, with 19% accounted for by an increase in per-storm PDI. This implies an increase of 6% in the storm lifetime maximum wind speed. Given that the MDR SST has increased by 0.6 ^{o}C over this period, the theory developed by Emanuel (1987) and the modeling study by Knutson et al. (2004) would have predicted an increase in maximum wind speed of about 2.5%. Clearly, the average storm intensity has increased substantially more than this. Why?

Figure 4 shows that since 1982, potential intensity in the MDR has increased by more than 10%. (Calculation of potential intensity from re-analysis data is strongly influenced by changes in techniques for observing upper air temperatures

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and trends derived there from are generally not considered reliable before about 1980.) This is consistent with the observed change in average storm lifetime maximum wind speed over this period, but it is somewhat more than the aforementioned studies would have predicted.

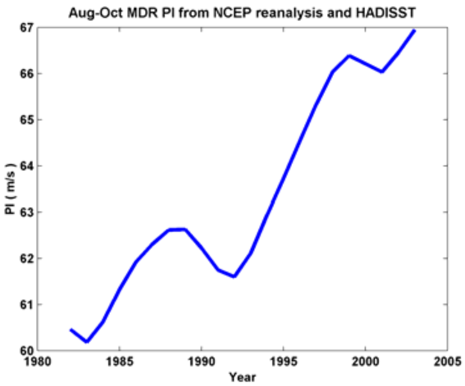

Figure 4: Aug-Oct MDR potential intensity from HADISST and NCEP re-analysis data. Smoothed as in Figure 1.

In addressing why the observed changes in storm intensity and potential intensity are more than theory and models predict, it is important first to recognize that potential intensity is not simply a function of sea surface temperature. Specifically, it is a function of air-sea thermodynamic disequilibrium (hereafter ASTD) and the difference between surface and upper troposphere temperature. ASTD cannot be regarded as a function of SST. This can be seen by comparing two formulae: The equation for potential intensity, and the heat balance of the upper ocean, in the absence of enthalpy advection in the ocean:

$$V_{max}^2 = \frac{C_k}{C_D}\frac{T_s - T_o}{T_o}\left(k_0^* - k\right) \qquad (1)$$

and

$$C_k \rho \,|\, \mathbf{V_s} \,|\left(k_0^* - k\right) = F_\downarrow - F_\uparrow - F_{entrain} \qquad (2)$$

where C_k and C_D are the surface exchange coefficients for enthalpy and momentum, T_s and T_o are the surface and outflow temperatures, $k_0^* - k$ is the ASTD, $|\mathbf{V_s}|$ is the surface wind speed, and the right side of (2) consists of the solar radiative flux into and net infrared flux out of the ocean surface, and the turbulent flux of heat across the base of the ocean mixed layer. Combining (1) and (2) gives

$$V_{max}^2 = \frac{T_s - T_o}{T_o}\frac{F_\downarrow - F_\uparrow - F_{entrain}}{C_D \rho \,|\, \mathbf{V}_s \,|} \qquad (3)$$

This shows that, among other things, the potential intensity varies with the net radiative flux into the ocean (which is increased, e.g., by greenhouse gases and diminished by sulfate aerosols) *and with the mean surface wind speed*. SST also varies with these same processes, but not necessarily in the same proportion.

To test the sensitivity of potential temperature to the various quantities in (3), we ran a single column model (Bony and Emanuel 2001) into radiative convective equilibrium, calculating potential intensity and ocean mixed layer temperature. Varying greenhouse gases gives a rate of change of potential intensity with SST of 3 ms^{-1} K^{-1}, consistent with the earlier theoretical predictions, while varying the surface winds speed gives a much larger sensitivity of 8 ms^{-1} K^{-1}. Reanalysis data shows that mean Aug-Oct 10 m wind speeds have declined by 18% over the MDR since 1980, suggesting that much of the potential intensity increase is owing to this effect.

3. SUMMARY

Atlantic tropical cyclone activity co-varies with late summer and early fall SST in the MDR. Trends and variability of Aug-Oct MDR SST mirror that of the whole northern hemispheric surface temperature, whose changes have been caused by variations in solar, volcanic, aerosol and greenhouse gas forcing. Observed changes in MDR potential intensity are consistent with observed changes in radiative forcing and mean surface winds.

4. REFERENCES

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