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THE RELATIONSHIP BETWEEN PRECIPITATION IN THE TROPICS AND TROPICAL CYCLONE FREQUENCY

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1. INTRODUCTION

A previous modeling study found that the June-November Atlantic precipitation from the GFDL CM2.1 coupled atmosphere-ocean general circulation model seemed to be a good proxy for tropical cyclone frequency derived from a 20th century run of the model. Normalized five-year running anomalies from a 20th century run of the model of June-November area-averaged precipitation and tropical cyclone counts were highly correlated with a correlation coefficient of 0.8 (G. Vecchi 2009, personal communication). If the entire spectrum of convection is enhanced over regions of tropical cyclone genesis during periods in which the frequency of tropical cyclone genesis is enhanced, a correlation could be seen between the two fields. However, it was unknown if such a correlation could be seen in observed data. The objective of this study is to determine what, if any, relationship exists between tropical cyclone frequency and tropical rainfall observations.

2. BACKGROUND

Why should we expect a relationship between precipitation and tropical cyclone frequency? The factors that govern tropical cyclone frequency are relatively unknown. The empirically defined genesis potential index of Emanuel and Nolan (2004) (later revised by Emanuel (2010)), has had some success in reproducing temporal and spatial variations of tropical cyclone genesis with monthly mean absolute vorticity, humidity, potential intensity, and wind shear (Camargo et al., 2007b,a; Emanuel, 2010). It is reasonable to think of these factors as predictors for genesis. Tropical precipitation, though, wouldn't seem to be controlled by these factors. The overall radiative balance of the tropics constrains the overall precipitation, because the tropics are in a near state of radiative-convective equilibrium. Boundary layer quasi-equilibrium theory, which allows for deviations from radiative-convective equilibrium, predicts that convective updraft mass flux is determined by surface entropy flux, radiative cooling of the troposphere, and the humidity of the free troposphere (via the middle troposphere entropy). There are, however, some indications that convective activity may have a connection with tropical cyclone frequency (Royer et al., 1998; Chauvin et al., 2006).

Most of the previous work on the relationship between precipitation and tropical cyclones focuses on rainfall on the percentage of rainfall in a given month or season caused by tropical cyclone activity at a specific location, which can be a large amount (Groisman et al., 2004; Larson et al., 2005; Shephard et al., 2007). However, the relative contribution of tropical cyclones to the precipitation over a large region of an ocean basin is not as well known. Rodgers et al. (2000) used satellite SSM/I-based rainfall estimates to determine that tropical cyclones contribute 7% of the rainfall to the entire North Pacific tropical cyclone basin during the tropical cyclone season, and 12%, 3%, and 4% of the rainfall to the western, central, and eastern third of the North Pacific, respectively. Rodgers et al. (2001) performed a similar analysis for the North Atlantic, and found that tropical cyclones contribute 4% of the rainfall to the entire North Atlantic tropical cyclone basin during the tropical cyclone season, and 4% and 3%of the rainfall to the western and eastern North Atlantic, respectively. In contrast to these earlier studies looking at how much rainfall tropical cyclones provide, this work seeks to determine the relationship between total tropical precipitation and tropical cyclone frequency.

3. DATA

The estimates of rainfall used in this project are from NASA's Tropical Rainfall Measuring Mission, the TRMM 3B43 monthly 0.25° x 0.25° merged TRMM and other sources estimate from the TRMM Multi-Satellite Precipitation Analysis (TMPA). This product combines estimates from the TRMM microwave imager and precipitation radar, other

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Table 1: Tropical cyclone seasons and regions used for each basin

Basin	Region	Season
North Atlantic	90°W-20°W,10°N-25°N	June-November
Western North Pacific	125°E-160°E,5°N-25°N	April-December
Eastern Pacific	120°W-90°W,10°N-20°N	May-November
West North Indian	60°E-72°E,5°N-20°N	April-December
East North Indian	85°E-95°E,5°N-18°N	April-December
South Indian	60°E-120°E,10°S-18°S	November-April
South Pacific	150°E-179°E,5°S-18°S	November-April

satellite microwave imagers, infrared data from geosynchronous-orbit satellites (calibrated to microwave estimates), and available rain gauge data in a global band extending from 50° S to 50° N (Huffman et al., 2007). This data product is available from 1998 to the present as version-6 TRMM 3B43 at http://disc.sci.gsfc.nasa.gov/data/datapool/TRMM. The tropical cyclone data for the North Atlantic and Eastern Pacific are from the best track database of NOAA's National Hurricane Center/Tropical Prediction Center. The tropical cyclone data for the Western North Pacific, North Indian Ocean, and Southern Hemisphere are from the US Navy's Joint Typhoon Warning Center.

4. METHODS

In order to determine the relationship between tropical precipitation and tropical cyclone frequency, the data were analyzed in a variety of ways. All methods involve averaging monthly rainfall over a specified region in each ocean basin and counting the number of tropical cyclones that passed through that region. The regions used are defined in Table 1, and were chosen as those that encompass most of the genesis points for a given basin.

The results discussed here were obtained by averaging the rainfall over the region for each month and counting the number of tropical cyclones forming in that month. A mean annual cycle was then defined for both monthly regionally averaged rainfall and tropical cyclone count. It is defined as the mean of all Januarys, mean of all Februarys, etc ... An "annual cycle" time series is constructed by taking this sequence of means and repeating for the 11 years of the data record. The mean annual cycle time series is then normalized by its mean over the analysis period, as is the monthly time series for both rainfall and tropical cyclone count. The normalized annual cycle for rainfall (and tropical cyclone count) is then subtracted from the normalized monthly rainfall (and tropical cyclone count) to obtain monthly rainfall and tropical cyclone count anomalies. Anomalies from the mean annual cycle are examined because the common annual cycle in precipitation and tropical cyclone frequency in most basins dominates the correlation when looking at the monthly values. Figure 1 shows an example of the common annual cycles.

5. RESULTS

The method of analysis of monthly anomalies from the annual cycle gives the most consistent results between the basins, and thus is the only method discussed here. The anomalies from the annual cy-

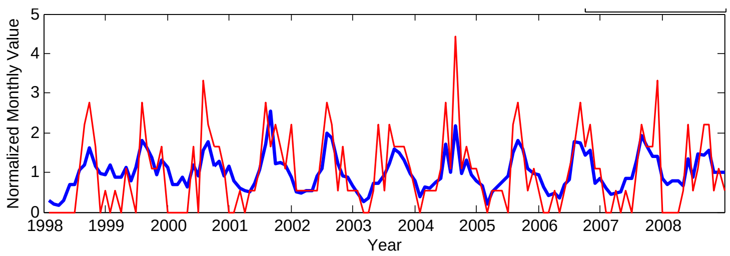

Figure 1: Monthly rainfall (blue line) and tropical cyclone count (red line) for the Western North Pacific, each normalized by their mean over the analysis period. The correlation coefficient is r = 0.80, p = 0.00.

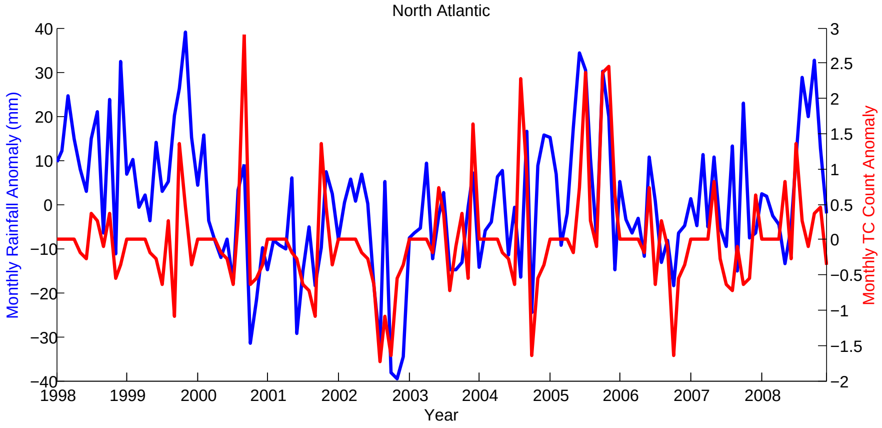

Figure 2: Monthly rainfall (blue) and tropical cyclone count (red) anomalies from the mean annual cycle, normalized by their means over the analysis period, January 1998 to December 2008. The North Atlantic (r = 0.42, p = 0.00) is shown as an example.

cle can be quite large; in the Western North Pacific, for example, there are monthly rainfall anomalies of up to 100mm while the annual cycle goes between 100mm and 250 mm. When comparing the anomalies of monthly regionally averaged rainfall with the anomalies of monthly tropical cyclone count (only counted if passed through the specified region), all the basins have statistically significant correlations at the 99% confidence level. The correlations (r) are $0.42, 0.44, 0.32, 0.41, 0.35, 0.36$, and 0.43, for the Atlantic, Western North Pacific, Eastern Pacific, West North Indian, East North Indian, and South Pacific, respectively. These results are shown in Figure 2. The magnitude of the correlations is not particularly impressive. The correlations of $r \sim 0.3$ in the Eastern Pacific and Indian Ocean are arguably too weak to consider having much importance, but there is a statistically significant relationship between the two fields in each basin of approximately the same order of magnitude. This is the main result: there is a statistically significant correlation between the monthly regionally averaged rainfall anomaly and the monthly tropical cyclone frequency anomaly in each ocean basin.

6. DISCUSSION

The main limiting factor on these results is that there was no effort to remove precipitation caused directly by tropical cyclones. Tropical cyclones contribute substantially to rainfall and it is reasonable to think that some part of the variability of precipitation might be caused by the variability of tropical cyclones. Some part of the correlation observed could be because tropical cyclones are being correlated with something they themselves provide. On the other hand, the near state of radiative-convective equilibrium in the tropics (on large enough space and time scales) constrains the overall precipitation independently from tropical cyclones. The amount of tropical precipitation in a given season should therefore not necessarily depend on the number of tropical cyclones. However, the high precipitation efficiency of tropical cyclones makes it possible that they dry the atmosphere, depleting water vapor, a powerful greenhouse gas. More tropical cyclones would then mean less water vapor, which would allow for more radiative cooling, thus enhancing overall precipitation in order to stay in equilibrium. Given these uncertainties, there is at least the possibility that the precipitation caused by tropical cyclones is dominating the relationship found here. Since previous work indicated that tropical cyclone precipitation is only a few percent of the seasonal basin-wide totals, this shouldn't affect the seasonal analysis results too much (which were not discussed here, but indicate relatively strong correlations in some basins, and no correlations in others). On the monthly time scale, however, tropical cyclone precipitation can be a significant proportion of the total, so this may affect the already weak correlations in that analysis.

Another interpretation of these results is that there is a cofactor causing tropical precipitation and tropical cyclone frequency to vary together. As alluded to in the background section, one of the factors that determines the convective updraft mass flux is the middle troposphere entropy, as captured by the nondimensional parameter χ_m. According to boundary layer quasi-equilibrium, convective updraft mass flux is

$$M_u = w + \frac{C_k|V|}{\chi_m} \tag{1}$$

where w is the large-scale vertical velocity at the top of the boundary layer, C_k is the enthalpy surface exchange coefficient, $|V|$ is the surface wind speed, and χ_m is a nondimensional parameter (Emanuel et al., 2008). χ_m , defined as

$$\chi_m = \frac{s_b - s_m}{s_o^* - s_b} \tag{2}$$

measures the thermodynamic disequilibrium between the ocean and atmosphere and the dryness of the middle troposphere compared to the boundary layer (Emanuel et al., 2008). In addition to determining the convective updraft mass flux, χ_m is also important to tropical cyclone activity. The thermodynamic disequilibrium between the ocean and atmosphere is what drives the surface fluxes that fuel tropical cyclones and the dryness of the middle troposphere affects how long it takes an initial disturbance to saturate the middle troposphere so that intensification to tropical cyclone status and beyond can occur. Furthermore, a revised genesis index explicitly depends on χ_m instead of relative humidity and better captures the variability of tropical cyclone activity than the previous genesis potential index (Emanuel, 2010). Therefore, the dependence of both convection and tropical cyclone activity on χ_m could be driving the correlation between tropical rainfall and tropical cyclone frequency found here.

In summary, there appears to be a consistent relationship on the monthly time scale characterized by weak correlations $(r \sim 0.3, 0.4)$ of statistical significance between monthly anomalies from the mean annual cycle of tropical rainfall and tropical cyclone frequency in each region. Although the results indicate that there is some sort of relationship between regionally averaged tropical precipitation and tropical cyclone frequency, the caveats discussed above prevent a definitive conclusion regarding the nature of this relationship.

7. ACKNOWLEDGMENTS

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8. REFERENCES

Camargo, S., K. Emanuel, and A. Sobel, 2007a: Use of a genesis potential index to diagnose enso effects on tropical cyclone genesis. *J. Climate*, **20**, 4819–4834.

Camargo, S., A. Sobel, A. Barnston, and K. Emanuel, 2007b: Tropical cyclone genesis potential index in climate models. *Tellus*, **59**, 428–443.

Chauvin, F., J.-F. Royer, and M. Deque, 2006: Response of hurricane-type vortices to global warming as simulated by ARPEGE-Climat at high resolution. *Clim. Dyn.*, **27**, 377–399.

Emanuel, K., 2010: Tropical cyclone activity downscaled from NOAA-CIRES Reanalysis, 1908-1958. *J. Adv. Model. Earth Syst.*, **2**, 1–12.

Emanuel, K. and D. Nolan, 2004: Tropical cyclone activity and global climate. Preprints. *26th Conf. on Hurricanes and Tropical Meteorology*, Miami, FL, Amer. Meteor. Soc., 240–241.

Emanuel, K., R. Sundararajan, and J. Williams, 2008: Hurricanes and global warming: Results from downscaling IPCC AR4 simulations. *Bull. Am. Meteorol. Soc.*, **89**, 347–367.

Groisman, P., R. Knight, T. Karl, D. Easterling, B. Sun, and J. Lawrimore, 2004: Contemporary changes of the hydrological cycle over the contiguous United States: Trends derived from in situ observations. *J. Hydrometeor.*, **5**, 64–85.

Larson, J., Y. Zho, and R. Higgins, 2005: Characteristics of land-falling tropical cyclones in the United States and Mexico: climatology and interannual variability. *J. Appl. Meteorol.*, **40**, 1785–1800.

Rodgers, E., R. Adler, and H. Pierce, 2000: Contribution of tropical cyclones to the North Pacific climatological rainfall as observed from satellites. *J. Appl. Meteorol.*, **39**, 1658–1678.

Rodgers, E., R. Adler, and H. Pierce, 2001: Contribution of tropical cycones to the North Atlantic climatological rainfall as observed from satellites. *J. Appl. Meteorol.*, **40**, 1785–1800.

Royer, J.-F., F. Chauvin, B. Timbal, P. Araspin, and D. Grimal, 1998: A GCM study of the impact of greenhouse gas increase on the frequency of occurrence of tropical cyclones. *Climatic Change*, **38**, 307–343.

Shephard, J., A. Grundstein, and T. Mote, 2007: Quantifying the contribution of tropical cyclones to extreme rainfall along the coast southeastern United States. *Geophys. Res. Lett.*, **34**, L23 810, doi:10.1029/2007GL031 694.