SEASONAL ENVIRONMENTAL CONDITIONS RELATED TO HURRICANE ACTIVITY IN THE NORTHEAST PACIFIC BASIN

Jennifer M. Collins
Department of Geography and Geosciences
Bloomsburg University
Bloomsburg, PA 17815
jcollins@bloomu.edu
Tel: (570) 389-4140

Ian M. Mason
Dept. of Space and Climate
Physics
University College
London, U.K.

Abstract: A study on interannual hurricane activity in the Northeast Pacific basin is presented, using statistical methods to investigate tropical cyclone frequency and its relationship to seasonal environmental conditions in the years 1972-1997. This follows the work of Collins and Mason (2000) who noted that the NE Pacific has more than one population of tropical cyclones with regard to causal factors, and that tropical cyclone frequencies in the two identified development regions show large differences over time and in their relationships with seasonally averaged environmental variables. Here, we focus on the main factors responsible for variations in hurricane frequency. In the western development region (west of 116°W), mid-tropospheric relative humidity, and sea surface temperature are found to be the dominant factors. These are two of Gray's (1979) necessary controls on tropical cyclone formation. Analyses of the National Center for Environmental Prediction/ National Center for Atmospheric Research reanalysis data show that both variables are probably acting locally on tropical cyclone genesis, as threshold effects provide conducive/non-conducive conditions in different parts of the region. Interannual variations in hurricane frequency therefore occur when considering a spatial averaging over the whole development region. The interannual variability of mid-tropospheric relative humidity in this area, as the dominant control on hurricane frequency, is then studied in detail. It is found that interannual variations in seasonal relative humidity are significantly influenced, via the wind field, by El Niño Southern Oscillation (ENSO) and by the intensity of the thermal low in North America. It is shown that ENSO has different effects on hurricane frequency in the eastern development region (east of 116°W) compared with the western development region.

Keywords: NE Pacific, hurricanes, tropical cyclones, El Niño Southern Oscillation (ENSO)

INTRODUCTION

In a recent paper, we showed that an improved understanding of interannual variations of tropical cyclone (TC) frequency can be achieved in the NE Pacific basin by subdividing the basin east and west of 116°W (Collins and Mason, 2000). For the western development region of the NE Pacific (WDR); defined as 10°N to 20°N, 116°W to 180°W, it was shown that several environmental factors have a significant relationship with TC frequency while other factors, such as the east-west orientated winds in the lower stratosphere, called the Quasi-biannual Oscillation (QBO), do not. No significant

relationships were found for the eastern development region (EDR); defined as 10°N to 20°N, 93°W to 116°W. With the use of both atmospheric and oceanic data, we extend that work by identifying the best models to explain interannual hurricane variations in the WDR, and examining the underlying causes of these relationships.

METHODOLOGY

The data used for this study are described in detail by Collins and Mason (2000). The source for the hurricane index in this study is the official historical tropical cyclone track database obtained from the Tropical Prediction Center/National Hurricane Center (TPC/NHC) best track file for the NE Pacific (Brown and Leftwich, 1982; TPC, 2000). The location used to identify a hurricane in the analysis is the point where the storm reached the wind speed of 64 knots (33 meters per second). We examine the period 1972-1997, averaging data for the months July-September. The year 1972 was used as a start date for this study since the hurricane data set for the NE Pacific basin is considered reliable from that date forward. National Center for Environmental Prediction/ National Center for Atmospheric Research (NCEP/NCAR) 40-year reanalysis data was used (Kalnay et al., 1996). This includes both atmospheric and oceanographic variables. The global data are available on a 2.5° x 2.5° latitude/longitude grid and have a six-hourly and monthly time resolution. We use deviance tests (McCullagh and Nelder 1989; Elsner et al. 2001) to find the dominant environmental variables explaining interannual variations in hurricane frequency in the WDR. To explore the underlying causes of these relationships, we then look for correlations between these dominant variables and other environmental factors (both local and non-local).

RESULTS

The deviance test shows that the best model for explaining the interannual variation of hurricane numbers is a single variable model containing mid-tropospheric (500 mb) relative humidity (RH). Another good model is a single-variable model containing sea surface temperature (SST). Both models are statistically significant at the 99% level.

Figure 1 shows that for active and inactive hurricane years, the variation in RH in the WDR, which is for the most part mirrored by an equivalent variation in SST, is largely characterised for active (inactive) years by a northward (southward) shift in the boundary between the main trade wind region to the north (with cooler SST and dry mid-tropospheric air above the trade inversion) and the region of warmer SST further south (with deep convection and moist mid-tropospheric air). SST and RH are two of Gray's thermodynamic parameters (Gray, 1979), requiring values above a threshold for TC genesis to occur. It is likely that they act to increase (reduce) hurricane numbers in the WDR by providing conducive (non-conducive) conditions over a larger fraction of the WDR's area. Spatial averaging of SST and RH over the WDR then produces the relationships seen. There will also be an 'intensity-frequency' effect, whereby an increase of the SSTs will increase the number of TCs reaching a particular category (e.g. hurricane strength) by raising the average TC intensities. Whether the intensity-frequency

effect provides a significant contribution to the observed relationships, however, is unclear.
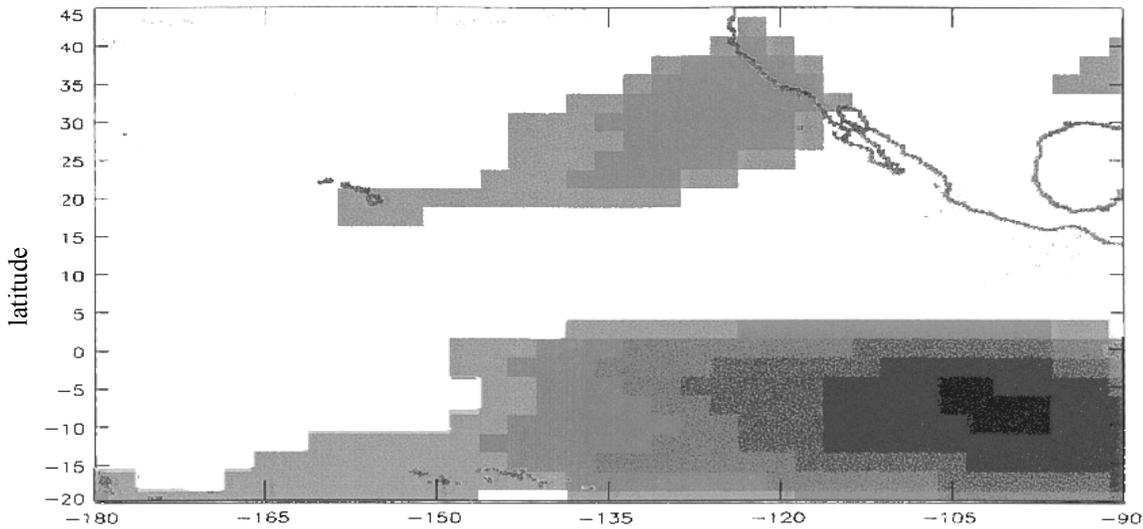

Figure 1a Plot of RH averaged for July-September for the five most active years (1972-1997)
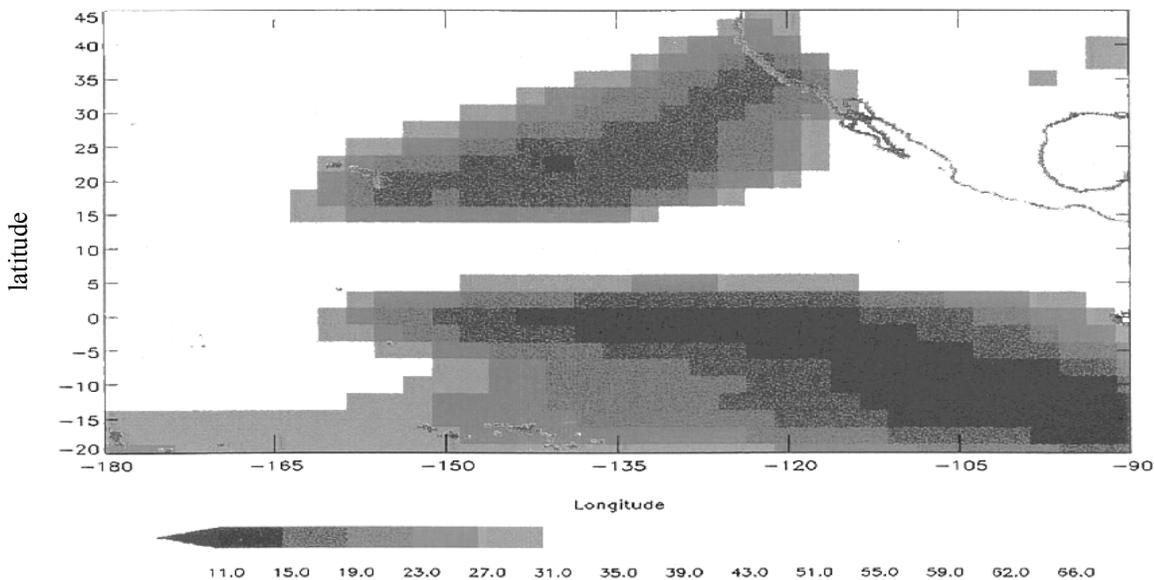

Figure 1b Plot of RH averaged for July-September for the five least active years (1972-1997)

An examination was made of the influences on the interannual variations of RH in the WDR (given that RH was the dominant model variable). It was found that interannual variations of El Niño Southern Oscillation - ENSO (best described by the Niño4 index – SSTs within the region 5°S to 5°N, 160°E to 150°W – see Figure 2) and of the thermal low that develops in the summer months over southern North America (quantified by its minimum value at 30°N, 112.5°W) together best describe these RH variations. Table1 shows the percentage of variance explained by each model. Based on the deviance, the multiple model is significantly better than either single model. It should also be noted that ENSO and the thermal low are found statistically to operate largely independently of

each other. As expected, each of these controls on RH acts by shifting the relative locations of the trade inversion and deep convection regions within the WDR (Figures 3 and 4). In each case the mechanism appears to involve an associated change in the surface wind field. Figure 3 is a composite of the six warmest ENSO years in the record subtracted from the six coldest years.
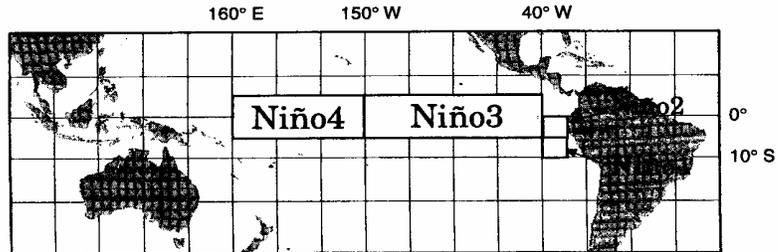

Figure 2: El Niño regions in the equatorial Pacific Ocean Glantz, 1996 p. 54. [Image used by permission of author]

For the western part of the Niño4 region (see Figure 2) and extending into the southwestern part of the WDR, northeasterly wind vector differences result. Thus, in an El Niño, the winds here have a weaker northerly component, and the warm water and associated deep convection (allowing for a higher RH) in the Niño4 region have spread further north.
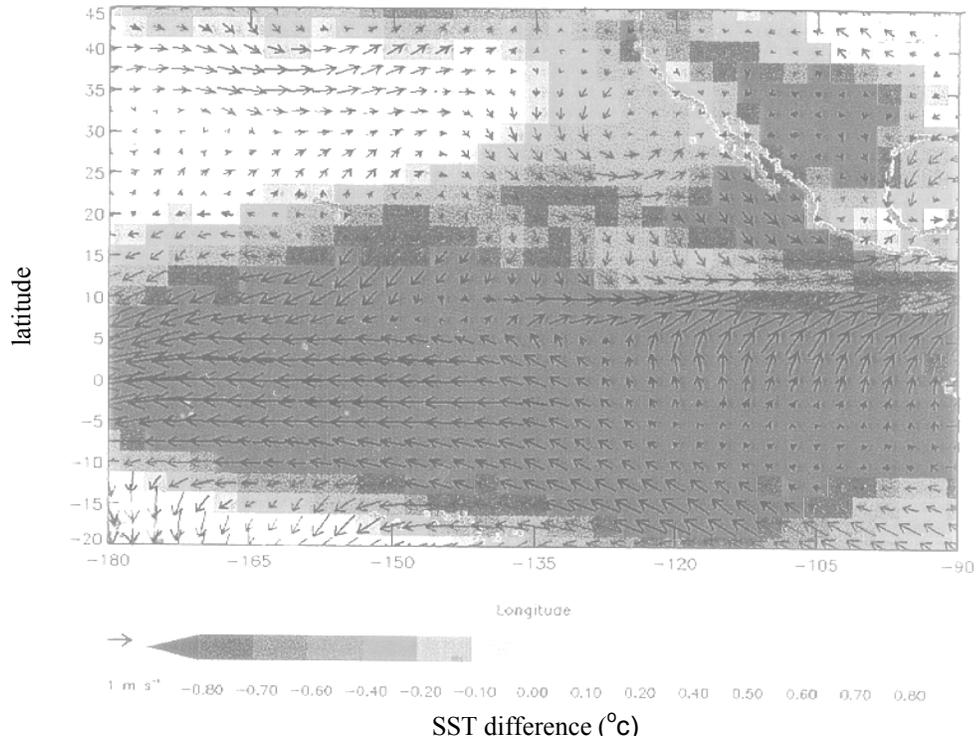

Figure 3: SST (and land temperature) anomalies and surface wind (10 m) anomalies in the six coldest ENSO (Niño4) years minus the six warmest ENSO years.

Furthermore, in the eastern part of the WDR, the wind vector differences, though smaller, are mainly northerly and westerly, showing that the trade winds, which are approximately northeasterly in La Niña years, become slightly less northerly and more easterly during El Niño years, when the cooler trade inversion region is located further north.
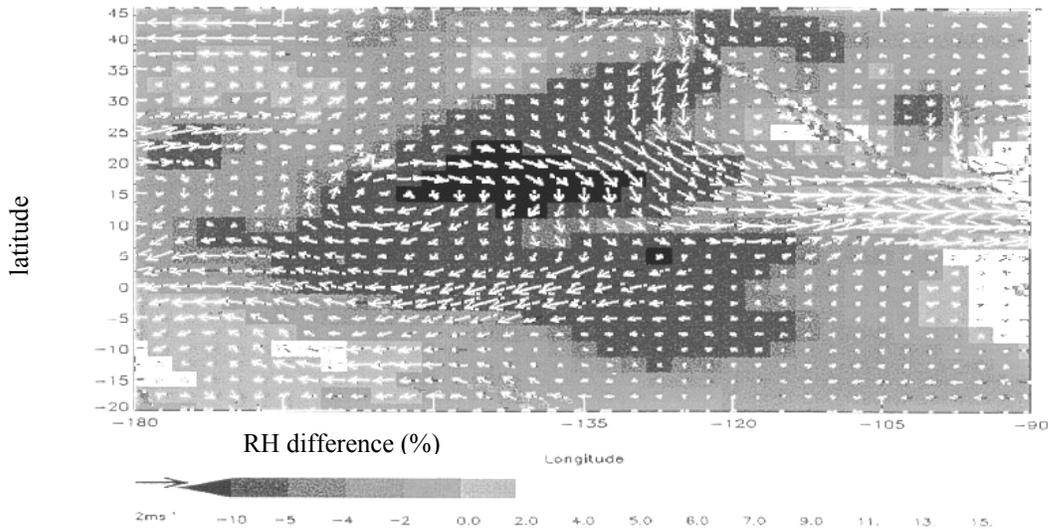

Figure 4: Plot of RH anomalies and surface wind anomalies (10 m) in the six deepest minus six shallowest thermal low years. Values averaged over July-September.

Atlantic, ENSO affects hurricane numbers through one of Gray's (Gray, 1979) dynamic parameters, namely wind shear (Gray and Sheaffer, 1991), whereas in the WDR of the NE Pacific ENSO operates through one of Gray's thermodynamic parameters (RH). Second, the fact that there is a relationship with ENSO in both the WDR and Atlantic basins, where warm ENSO years are associated with more (less) conducive conditions in the WDR (Atlantic), and vice versa, accounts for the anti-correlation of tropical cyclone frequency observed between the two basins. It is interesting to note that although there is no significant relationship between ENSO and tropical cyclones in the EDR, the sign of the relationships is such that more TCs tend to occur in a La Niña rather than an El Niño phase.

CONCLUSIONS

Through an examination of many environmental variables, both atmospheric and oceanographic, it was found through a statistical study that variations in relative humidity (RH) best explain interannual variations of hurricane numbers in the western development region of the NE Pacific basin (WDR: 10°N to 20°N, 116°W to 180°W). It is interesting to note that RH, one of Gray's (Gray, 1979) thermodynamic variables is most important to explain variations in hurricane numbers. The dynamic factors did not significantly explain interannual variations of hurricane numbers. This is in contrary to the North Atlantic where a dynamic factor (wind shear) does significantly explain variations in hurricane numbers there.

Interannual variations in RH itself can be understood largely by examining interannual changes in both El Niño Southern Oscillation (best characterized here by the Niño4 region SSTs) and a surface Summer thermal low pressure centered around 30°N, 112.5°W over N. America. The relationship between El Niño and RH is positive, i.e. higher SSTs in the Niño4 region relate to a higher RH in the western development region. The relationship between the thermal low and RH is also positive, i.e. higher pressures in the region (30°N, 112.5°W) relate to a higher RH in the western development region. Both of these variables operate via the wind field to affect RH.

Finally, an anti-correlation of tropical cyclone frequency exists between the WDR and North Atlantic basin. This relationship exists since both basins are affected by ENSO, where warm ENSO years are associated with more (less) conducive conditions in the WDR (Atlantic), and vice versa.

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