9C.3 IMPACTS OF ENVIRONMENTAL MOISTURE ON TROPICAL CYCLOGENESIS

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1. Introduction

The environment plays a crucial role in the development of a tropical cyclone. Warm sea surface temperatures (SSTs), weak vertical wind shear, moist boundary and mid-layer air, and convective instability are all necessary during cyclogenesis. Values for these parameters that are most favorable for genesis are presented in numerous studies (Riehl (1948), Gray (1968), and DeMaria et. al. (2001) are examples). Similar studies show if the value of a single parameter is significantly unfavorable, cyclogenesis is unlikely. Over the course of the tropical Atlantic hurricane season, there are periods when some parameters are favorable for development while others are neutral or even unfavorable. Since the dynamic effect of each parameter on cyclogenesis is not fully known, and the parameters are not independent of one another, it is difficult to forecast whether cyclogenesis will occur in this environment.

The impact of atmospheric moisture is probably the least understood factor affecting cyclogenesis. Monthly mean precipitable water (PW) from NASA Water Vapor Project (NVAP) (Randel et. al., (1996)) is used to compare variability in tropical cyclogenesis and PW. The annual cycle of SST primarily determines the annual cycle of PW over oceans. Figure 1 shows the average NVAP PW and Reynolds' SST (Reynolds and Stokes (1994)) for June-November from 1988 through 1997. Also included is the average monthly tropical cyclogenesis frequency. Each parameter is normalized. The maximum of each parameter occurs during September and the plot suggests a strong correlation among all three.

2. PW/Cyclogenesis Relationship

Where large-scale dynamics exist, significant modifications to the SST/PW relationship occur (Stephens (1990)). Figure 2 shows the spatial distribution of NVAP total-column PW. In addition, the genesis points of all named tropical cyclones (TCs) (based on TPC location of first 1200 UTC advisory of each storm) are plotted. The maximum in PW is evident along the ITCZ region between Africa and the Lesser Antilles. A significant number of TCs formed near this region, though displaced northward. Maximums in TC frequency, however, also occur in the Gulf of Mexico and off the coast of the SE US where PW is relatively low.

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These areas of high TC frequency are studied more directly to understand whether variability in PW affects genesis. Three regions within the Atlantic basin are examined. There is little correlation between the region-averaged SST or PW and TC genesis within either the first (between 24°-34°N, 60°-81°W) or second (10°-30°N, 81°-97°W) region. There is, however, an indication of a relationship between PW and cyclogenesis in the third region (7°-20°N, 20°-65°W). These results suggest that monthly variability in environmental PW is unimportant in the Gulf of Mexico and along the Gulf Stream region off the SE US coast, but may be instrumental in determining cyclogenesis frequency in the ITCZ region.

In order to understand why PW influences cyclogenesis in the ITCZ region, but not elsewhere, the dynamics of cyclogenesis are studied. Daily NVAP PW is used to describe the evolution of environmental PW surrounding a developing tropical wave, as well as the changes in moisture within the wave itself, during the 3-day period prior to tropical depression formation. Anomalous values of PW (with monthly means removed) are used. A composite of PW data for each of the three days before genesis is generated. These composites include data from those waves within the ITCZ region that eventually obtained at least tropical storm strength (35kts). They are created for each of NVAP's three layered PW products as well as the total column value. Locations of tropical waves prior to depression formation (when initial advisories are issued) are estimated from TPC storm summaries.

The changes in PW from day to day indicate significant increases in PW near the core of the composite and a decrease beyond 1000km. Figure 3a shows the PW distribution of the composite wave three days before formation. Note the NE-SW oriented peak

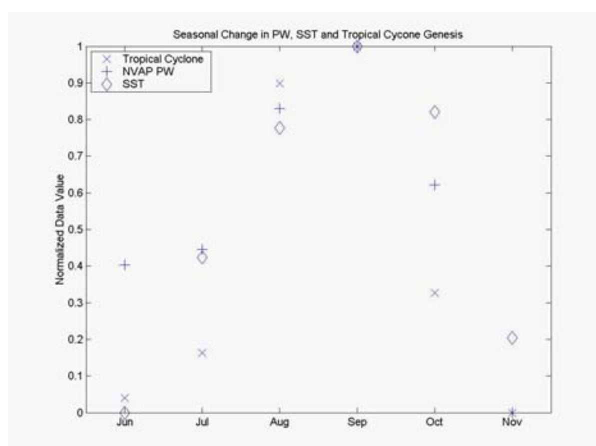

Figure 1) Seasonal change in monthly NVAP PW (+), SST (◊), and TC genesis (x). All values are normalized between dataset maximum and minimum.

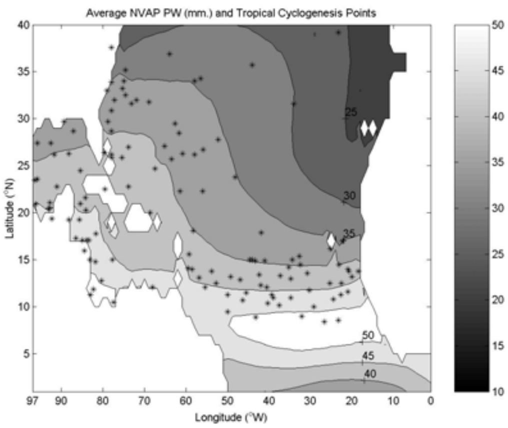

Figure 2) Average NVAP PW (mm.) and locations of tropical cyclogenesis (*). Contours are at 5mm.

in PW (composite storm motion is upward). This is anticipated for a westward progressing tropical wave. Figure 3b shows the PW distribution on the day of depression formation. At this point of cyclone evolution, many of the characteristics of a mature cyclone are present. The PW indicates the cyclone is nearly axis-symmetric with the maximum shifted slightly toward the right front quadrant of the cyclone. This bias is likely caused by an increase in sea surface evaporation due to higher wind speeds in this quadrant.

Several assumptions are made at this point. First, little advection occurs across the composite boundary located 1500 km. from the core. Second, precipitation is concentrated near and along the wave. These assumptions imply sea-surface flux is the primary source of moisture within the composite boundaries and decreases in environmental moisture (beyond 1000km.) result from inward transport of moisture. Therefore, changes in moisture quantities can act as tracers and indicate the strength of the developing circulations of the cyclone.

The secondary circulation of a tropical cyclone continually fuels the cyclone and is essential for intensification and maintaining maturity. The layered data shows PW transport into the core occurring at all levels three days before depression formation. Two days later, the transport in the upper layer has reversed with decreasing values near the core and increasing moisture values around 1000km. Since lower layer transport remains inward, it is clear the transverse circulation is present at the earliest stages of the cyclone's existence.

3. Conclusion

The primary dynamic changes in a developing tropical cyclone occur during the pre-depression stage. The cyclonic circulation is apparent from the radially symmetric distribution of PW about the core. The secondary circulation is described by the moisture transports between the core and its outer environment. This radial transport of environmental moisture may be an important source of energy for cyclones in the ITCZ

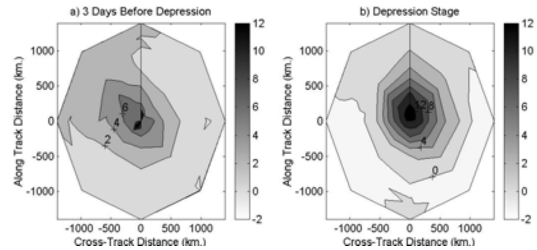

Figure 3) Distribution composites of anomalous NVAP PW at (a) 3 days before the depression forms, and (b) the day of depression formation. Positive values are shaded and contours are at 2 mm. Forward storm motion is along the upward vertical line.

region and indicate the nature of the PW/TC genesis relationship there.

The lack of a strong relationship between TC genesis and either PW or SST in the first and second regions suggests a separate genesis mechanism is present. These systems general form as cut-off lows imbedded in fronts passing from continental to coastal regions. It is likely that the front creates the necessary environment for cyclogenesis on its own and at times scales smaller than a month. The background environment would then be less influential.

Future work will focus on how moisture is used by the cyclone as it transitions from wave to depression and where that moisture comes from. Current thought maintains that sea surface flux supplies the majority of the cyclone's energy. Yet, by definition, surface winds are light (~10 ms^{-1}) during depression formation implying a smaller flux occurs. This suggests that supply of environmental moisture may be significantly more important at this stage. Modeling studies will be conducted to determine the relative importance of each moisture source during this critical stage of cyclogenesis.

4. References

DeMaria, M., J. A. Knaff, B. H. Connell, 2001: A tropical cyclone genesis parameter for the topical Atlantic. *Wea. and For.*, **16**, 219-233.

Gray, W. M., 1968: Global view of the origin of tropical disturbances and storms. *Mon. Wea. Rev.*, **96**, 669-700.

Randel, D. L., T. H. Vonder Haar, M. A. Ringerud, G. L. Stephens, T. J. Greenwald, C. L. Combs, 1996: A new global water vapor dataset. *Bull.Amer. Meteor. Soc.*, **77**, 1233-1246.

Reynolds, R. W. and D. C. Stokes, 1994: NCEP Reynolds historical reconstructed sea surface temperature data set. ftp://podaac.jpl.nasa.gov/pub/seasurface_temperature/reynolds/rsst/doc/rsst.html.

Riehl, H., 1948: On the formation of typhoons. *J. Meteor.*, **5**, 247-264.

Stephens, G. L., 1990: On the relationship between water vapor over the oceans and sea surface temperature. *J. Clim.,* **3**, 634-645.