SEASONAL AND MONTHLY MEAN SHEAR AND STEERING FLOW IN RELATION TO TROPICAL CYCLONE TRACKS

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I. INTRODUCTION

2004 was a year in which the state of Florida received five landfalls and one significant impact from a major hurricane which made landfall in eastern Alabama. In contrast is 1995 where except for Erin and Jerry, which formed in the Bahamas, all of the tropical cyclones that formed in the Atlantic remained well to the east of the United States (U.S.) eastern sea board. 1996 and 1999 featured a different pattern in which TC’s consistently tracked near or into North Carolina. Atlantic Basin TC’s typically form in the tropical Atlantic, Caribbean Sea, Gulf of Mexico, or subtropical western Atlantic near the U.S. eastern sea board and are steered mainly by the environmental wind flow. There have been many works documenting this fact about the steering, such as Elsberry (2004), as well as Hodanish and Gray (1993) that have described the mechanisms that cause a tropical cyclone to be steered. However, these works have focused on the motion of individual cyclones and not on the seasonal or even monthly track patterns. The purpose of this study is to determine if the frequency, location of formation, as well as the tracks of tropical cyclones can be predicted using the seasonal or monthly means of both the shear and the deep-layered (200-850mb) steering flow. If these quantities prove to be able to predict the TC tracks, this study aims to document the extent of the predictability using long-term means.

II. DATA

Data for this study consists of two major sources. The first of which is monthly mean NCEP
reanalysis data from 1948-2004, available from the Climate Prediction Center (CDC). For this topic, only the wind data from 200 to 850mb was used. The data has a resolution of 2.5 degrees in both the north/south and east/west directions. Mean steering flow and wind shear data must be calculated (calculations to be explained in the next section) and are not provided by the CDC. Best Track data is from the National Hurricane Center, as well as Unisys Weather. Best track data consists of six-hourly tropical cyclone positions at 0000, 0600, 1200, and 1800 UTC, for each day of a tropical cyclone's existence. Best track data for this study has only been used since 1976 as this was the first season in which a GOES satellite was in existence (University of Illinois).

III. METHODOLOGY

As previously stated, there are two objectives of this study. The first focuses on determining whether or not the seasonal or monthly wind shear values over the Atlantic Basin affect the frequency and or locations of TC's. The reason why this is the first step of the project is because any relation between the mean steering flow and the tracks of the TC's is irrelevant if there are no cyclones.

Before determining the correlation between mean seasonal and monthly shear and TC frequency, climatological mean shear for the Atlantic Basin needs to be calculated. This is not used in determining a correlation, but instead is used as a reference to shear for the years being examined. Once this is done, a domain averaged seasonal shear is calculated. The bounds of the domain are the main development region (MDR), as defined as south of 20N, from 20W to 87.5W, covering the entire tropical Atlantic and the southern portions of the Caribbean Sea. To calculate the shear from the CDC data set, one must sum all months of the season together, and
divide by that number. Since there are few instances of TC genesis in the MDR during June or November, these two months can be disregarded for the purposes of calculating the mean seasonal shear magnitude. The seasonal mean shear is then correlated to the number of TC’s of tropical storm or hurricane intensity that formed within the MDR within the given year and the number of hurricanes in the MDR during the same year. If there not a strong correlation between the seasonal mean shear and TC frequency, then the above is repeated using the monthly mean shear and monthly TC frequency.

Once the relation between seasonal or monthly shear and TC frequency is established, the question regarding the steering of the TC’s can be addressed. First, a climatological steering pattern for July-October needs to be calculated. Once this is done, a similar process as used for the shear/frequency correlation is used to address this question, though quantification of the steering flow/track relation is far more difficult. Therefore, one can analyze the individual seasonal mean steering flow and the TC tracks for each of the seasons from 1976-2004 to determine whether or not there is a strong relation between seasonal steering flow and tracks. If there is not a strong relation, as in the case of the wind shear, an analysis of the monthly mean steering patterns and TC tracks must be conducted. In the event that a cyclone forms in one month and lasts into another, it is to be included in the analysis of both months.

After determining whether or not there is a relation between mean seasonal or monthly steering an TC tracks, an analysis of the causes of the steering flow is conducted. This enables one to determine what the atmospheric feature is that is causing the steering flow, such as the subtropical high, or mid-latitude waves.

IV. RESULTS
Results from comparing the seasonal mean shear and TC frequency in the MDR indicate that there is a strong correlation between the overall number of TC's within the region, as well as the number of hurricanes. However, the difference in the shear for active and inactive MDR seasons is less than 3 m/s.

Figure 1 indicates the relation MDR mean shear vs TC and hurricane frequency. $r$ for the TC comparison is -.73, while it is .67 for the hurricane comparison. This results in about 54 percent of the variance of seasonal TC frequency in the MDR being explained by the mean seasonal shear alone, while about 45 percent of the variance in hurricane frequency is explained. Of note is the year 2000. This is an outlier in the plot as there was a large amount of shear in the MDR; however, there was a high frequency of tropical storms and hurricanes within the region. Excluding 2000, $r$ increases to -.76 for the TC group, explaining about 57 percent of the variance, while $r$ increased to -.71 for the hurricane group, explaining about 50 percent of the variance. Despite 2000 being a statistical outlier, this season was heavily affected by the mean seasonal
While there were many storms forming within the MDR in 2000, as the TC's moved into the region of high shear, they all either weakened if they were of hurricane intensity (Alberto, Debby, and Isaac), or dissipated of they were of tropical storm intensity. Joyce, a hurricane, also quickly dissipated as it was moving through the Windward Islands. Despite being a statistical outlier regarding the direct correlation between frequency and mean shear, the seasonal mean shear was able to detect the region that the systems would weaken or dissipate.
Figure 3: 1997 shear and TC frequency/location vs 2004. Green represents July storms

Figure 3 shows the difference between the high shear 1997 and the low shear 2004. Only 1 MDR storm forms in 1997, forcing all of the remaining storms to form in the higher latitudes, while the low shear 2004 features many more MDR storms. Other years, such as 1983 on the high-shear end and 1999 on the low shear end indicated the same results. Therefore, not only are there more storms in the low shear years, in high shear years, TC's tend to form in higher latitudes, confirming the results of many studies in the past.

Since there is a strong correlation between seasonal mean shear and TC frequency and location, no formal monthly shear values have been calculated. Preliminary results from a monthly mean shear vs TC frequency correlation indicate that the relation is less well-defined and that significantly less of the variance can be explained.

Unlike the seasonal mean shear, there is little, if any relation between the seasonal mean steering flow and TC tracks.
Figure 4 demonstrates that the seasonal mean steering for 1995 and 1996 were similar, with each year's seasonal mean indicating a ridge over Florida. However, the preferred storm track in 1995 is out to sea, while in 1996, the preferred track is closer to the eastern sea board of the United States, and into North Carolina. This suggests little relation between the mean seasonal steering pattern and the preferred TC tracks. An analysis of other yields leads to the same conclusion. Therefore, an analysis of the monthly mean steering vs TC tracks must be conducted. Results from analyzing the monthly mean steering flow indicate that there is a strong relation between monthly mean steering and TC tracks. Months where the preferred track takes TC's into
Florida have different mean steering flows than do months where the preferred tracks are into the Carolinas, which also have different mean flows than months where the preferred tracks are out to sea.

Figure 5: August 1992 on top, September 2004 on bottom

There are two different patterns that enable the preferred TC track to be into Florida. The first, as demonstrated by August 1992, is for the subtropical ridge to be strong, and to extend to the coast of Florida. The other is for the long wave pattern to feature a large ridge over the eastern portions of the United States. September of 2004 features some ridging off of the eastern seaboard of the United States; however, this ridge does not extend across the entire Atlantic, as it did in August
of 1992. This enabled systems that formed north of 12N in the far eastern Atlantic to recurve into the open Ocean, while those forming farther south and west were able to move into Florida. This suggests that the location in which the TC forms is very important to its future motion.

Months in which the preferred TC track is into the Carolinas feature the subtropical ridge being displaced somewhat to the east of where it is for months where the preferred track is into Florida. In addition, there is amplification of the long wave pattern, with a trough located near the east coast. TC’s move around the subtropical ridge and as they are recurving, they impact the Carolinas.
Month where the preferred TC track is out to sea feature the subtropical ridge being located well into the open Atlantic. TC's then move around the ridge, remaining well offshore.

While the monthly mean steering flow does indicate what the general preferred track will be, it does not indicate the precise track. As figure 7 shows, there is variability in the exact recurvature points. This is likely due to daily oscillations in the subtropical high or long wave position.

**V. CONCLUSION**

Seasonal mean wind shear does correlate very well with frequency and location of tropical cyclone genesis. Seasons with below normal shear features seasons with many systems forming
at low latitudes, within the MDR. While it is not impossible to have an active MDR season in terms of the number of named storms, such as 2000, these seasons typically feature storms weakening significantly or dissipating as they move into the high-shear region. In addition, seasons with high shear in the MDR feature systems forming at higher latitudes, closer to the westerlies, which results in a greater likelihood of them moving out to sea.

While the seasonal steering flow is not well correlated with TC preferred track, the monthly mean steering flow is. The monthly mean steering pattern indicates what the general TC track for the month will be. However, due to daily oscillations of the atmospheric phenomena, the precise tracks of TC’s cannot be predicted using the monthly mean.