13.6 RELATIONSHIP BETWEEN CLIMATOLOGY AND MODEL TRACK, BEARING, AND SPEED ERRORS

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1. INTRODUCTION

Climatology and persistence are known to be good predictors of tropical cyclone motion; they are routinely used as a benchmark to assess forecast skill. Numerical models developed in the last decade have led to significant reduction in track forecast errors. According to McAdie & Lawrence (2000), NHC official forecast track errors averaged 120, 260, and 400 nm at 24, 48, and 72 hrs in 1970. By 1998, these errors had fallen to 100, 160, and 250 nm, a decline that McAdie and Lawrence attribute to progress in numerical model forecast guidance.

However, this rapid advance in skill of numerical modeling has resulted in a decline in development and improvement of statistical prediction methods that use environmental and model data (Bessafi et al. 2002). Such statistical methods still have important forecast applications because they provide a simple, first-guess approach.

This work builds upon earlier climatology studies by examining the relationship between climatology and dynamical model track, forward speed, and bearing errors. By correlating climatology with model error, the goal of this work is to provide forecasters with a confidence level for each dynamic model prediction. For given climatology values, forecasters will have at their disposal the mean model track, bearing, and forward speed errors and standard deviations, as well as the correlation between climatology and errors.

Knowing a particular dynamical model's error-to-climatology correlation allows forecasters to place appropriate weight when considering that specific model prediction. This discounting of certain model solutions is especially useful today because, as was recognized more than two decades ago, "without guidelines on model attributes … multiple guidance can be counterproductive" due to conflicting results (Neumann 1981).

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2. METHODS

2.1 Motion climatology

For every point in the Atlantic basin, there exists a "motion climatology" derived from historical movement characteristics of all tropical cyclones that passed near that point. This motion climatology, pictured in Fig. 1, gives the historical probability that a storm located at a specific point will move with a certain direction and speed.

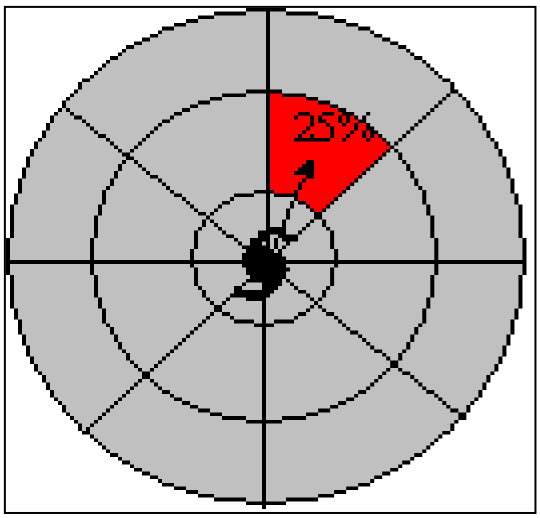

Figure 1: Hypothetical motion climatology. This hurricane has a 25% probability (based only on historical data) of moving into the highlighted *sector*. The other 75% probability is divided among the remaining sectors.

To compute the motion climatology used in this study, first collect the "Best Track" data of all Atlantic tropical cyclones from 1970 to 2002 (found at http://www.nhc.noaa.gov/tracks1851to2002_atl.txt). Then, filter this data to only include cyclones found within 250 km of a point. For each cyclone within this 250 km "radius of influence", examine its future 12-hr position and calculate the associated speed and direction of movement. Next, divide the 360-degree motion space into 60 sectors (in similar fashion to the 24-sector example shown in Figure 1), each with a 30-degree arc interval and a radial 5kt-speed interval. Then, count the number of future cyclone positions that fall into each sector. Finally, divide the number of cyclones in each 30-degree-by-5kt sector by the total number found in the radius of influence. The results, which range from 0.00 to 1.00, comprise the motion climatology for that point in the Atlantic basin; they can be duplicated for 24, 36, and 48hr future positions.

2.2 Model errors

This study takes 564 distinct operational NOGAPS and COAMPS model runs from the tropical Atlantic 2001 and 2002 seasons and calculates a motion climatology for each model forecast position. The grid system defined in section (*a*) is modified to shape a 30-degree-by-5kt sector around each forecast position. This ensures that the most representative climatology value is assigned to that forecast position. Furthermore, the climatology value associated with that forecast position now corresponds to model track, bearing, and forward speed forecast errors. These errors are calculated by comparing the actual cyclone position in the "Best Track" database to the model's forecast position using the "great circle distance" equation. The FORTRAN code that calculates errors and climatology values automatically filters some outliers and physically unrealistic points from the data set; however, manual inspection of the output required removal of 48 additional points.

3. RESULTS

3.1 Climatology vs. error

The first step in examining relationships between two variables is to graph them. Therefore, each of

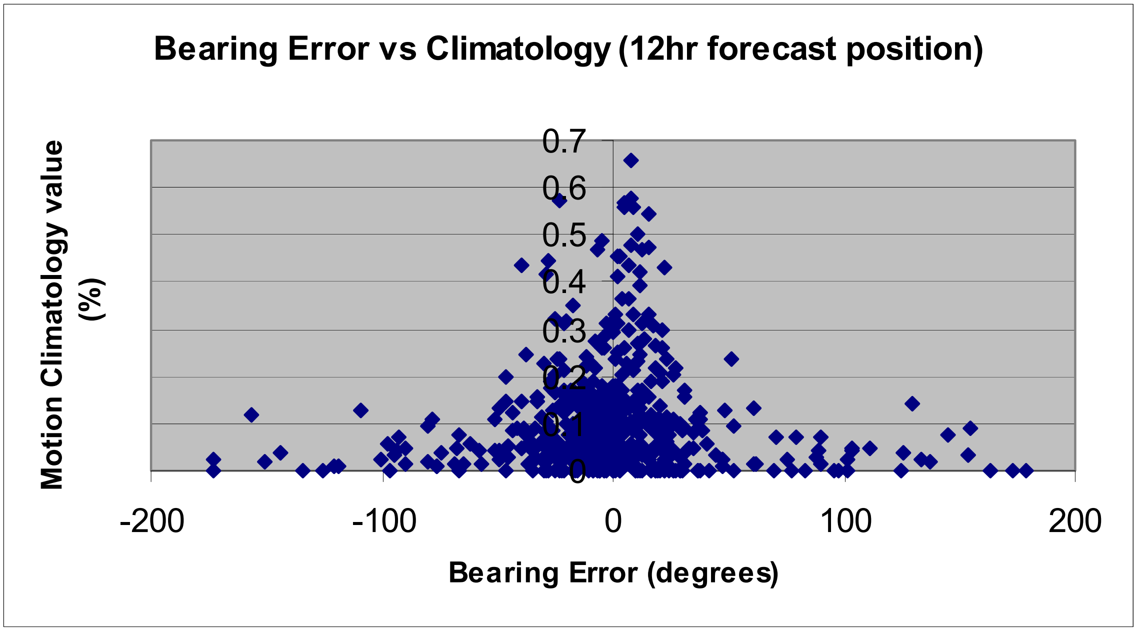

Figure 2: Bearing Error vs Climatology Bearing error decreases as climatology increases.

the three model errors – track, bearing, and forward speed – is shown plotted against climatology in figures 2, 3 and 4. The results are very interesting: the bearing errors (Fig 2) resemble a normal distribution and imply that as climatology value increases, error decreases. The model's accuracy increases in areas where forecasts more closely mimic climatology. In cases where the climatology value is above 0.30, the mean absolute bearing error is only 11.825°,

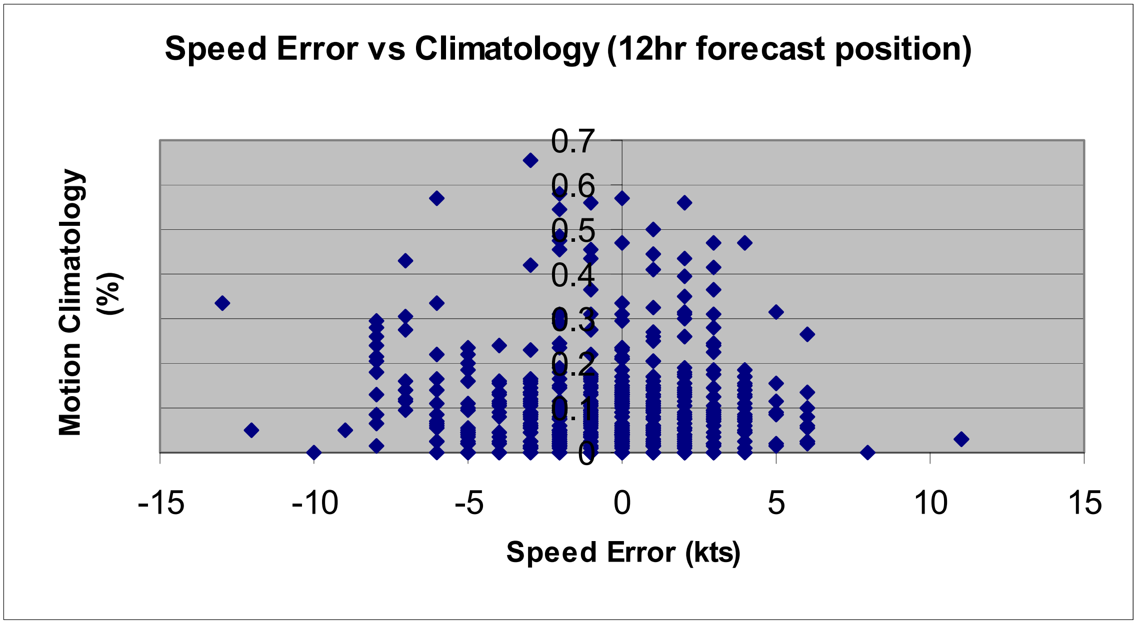

Figure 3: Speed Error vs Climatology Speed error has little connection to climatology.

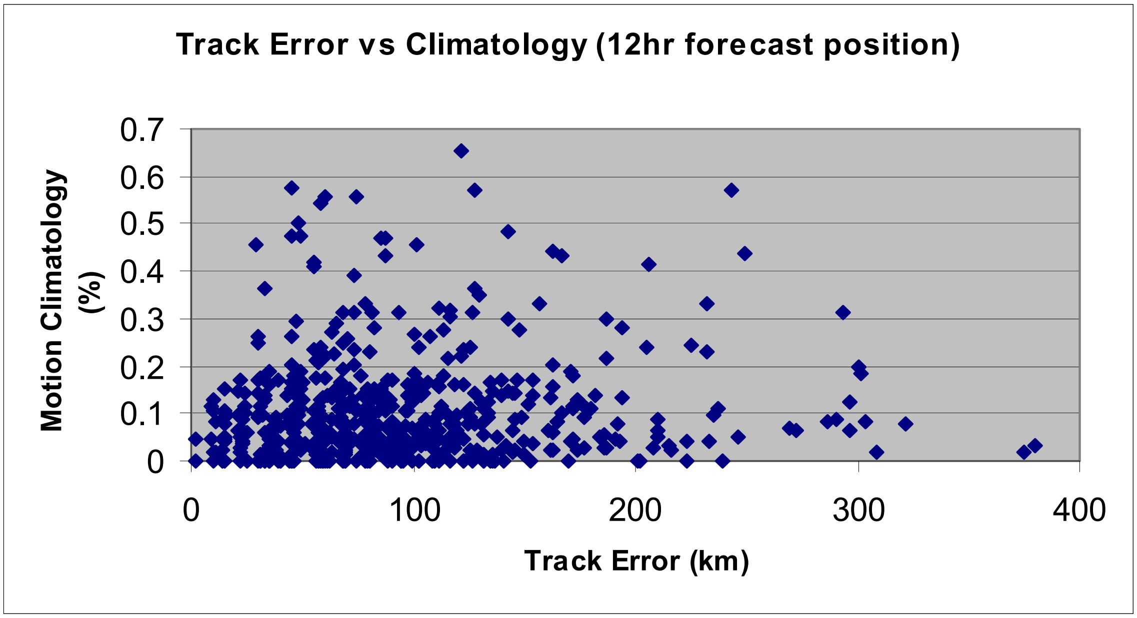

Figure 4: Track Error vs Climatology Track error has little relationship to climatology.

and 95% of all bearing errors are less than 30°. The forward speed errors (Fig 3) also cluster around zero but less resemble a normalized distribution and have greater spread than the bearing errors. The mean absolute speed error is 2.4kts with a standard deviation of 2.1kts; the mean relative speed error is –0.55kts, indicating a slow bias in the model. Track errors (Fig 4), perhaps the most important model error to forecasters, do not show any discernable relationship to climatology. The mean track error for all cases is 96.4km, but the mean track error for cases where the climatology value is above 0.30 is 113.5km, almost 20km *greater* than the error for cases with lower climatology. Forecast errors are summarized in Table 1 below. "Absolute" errors are used instead of "relative" errors to remove the cancellation that occurs when averaging positive and negative values.

3.2 Statistical correlation

Another way to examine relationships between variables is to study their statistical correlation. Correlations range between –1.0 and 1.0; -1.0 indicates the variables move in exactly opposite directions; 1.0 indicates the variables

Table 1. Mean errors and standard deviations for the 12hr forecast positions. Absolute errors are presented here, along with a subset with motion climatology greater than 0.30

Mean Errors and Standard Deviations (12hr forecast position)

	Absolute mean error (*all cases*)	Absolute mean error (*climo > 0.30*)	Absolute std dev (*all cases*)	Absolute std dev (*climo >0.30*)
Bearing error (°)	25.9	11.82	32.9	9.09
Speed error (kts)	2.43	2.73	2.14	2.59
Track error (km)	96.4	113.6	62.1	64.4

move in tandem, and 0.0 indicates no connection between the variables. Using the data analysis tools found in Microsoft Excel, the correlation between climatology and model track, bearing, and forward speed error is shown in Table 2. As was expected based on the results in Figs. 2, 3, and 4, the track and speed correlation values are very low, while the bearing correlation is larger: track error correlation is 0.03, speed error correlation is –0.03, and bearing error correlation is –0.265. These correlations imply that bearing error decreases as climatology increases, while track and speed errors have no relation to climatology. When examining the condition where climatology is greater than 0.30, the track and speed correlations are greater, and the bearing correlation is smaller: track error correlation is –0.19, speed error correlation is –0.20, and bearing error correlation is –0.03. The smaller bearing correlation indicates that the principal connection between bearing error and climatology occurs when climatology values range from 0.00 – 0.30. For climatology values above 0.30, the bearing error is to small to have any additional variability explained by climatology. The increase in track and speed correlations indicate that, for this case, these errors are more closely related to climatology than those with smaller climatology values.

Table 2. Bearing, speed, and track errors correlated with climatology. Values approaching -1.0 and 1.0 indicate strong correlation

Error Correlations with Climatology

	All Cases	Cases with climo > 0.30 only
Bearing error (degrees)	**-0.265**	-0.03
Speed error (kts)	-0.03	**-0.20**
Track error (km)	0.03	**-0.19**

3.3 Asymmetry test

While these correlation values indicate some connection between climatology and error, because they are generally below 0.3, the amount of noise in the calculation remains high. To attempt to raise the correlation values and reduce the noise, the model runs were searched for asymmetric cases. The asymmetric group meets two criteria: (1) at least 90% climatology in one quadrant of the motion space, and (2) the quadrant with >90% climatology contains a sample size of at least 20 tropical cyclones (see figure 5 for a pictorial explanation).

Applying the asymmetry condition, however, did not change the correlations as expected. The bearing error correlation did decrease to –0.301, indicating a slightly stronger relationship between climatology and bearing error in cases where the whole climatology is symmetric. However, the track and speed error correlations continue to hover around zero (correlations summarized in Table 3). The mean absolute bearing error in the asymmetric case is only 12.8°, roughly ½ the 24.4° error for the non-asymmetric case. The mean track and speed errors, though, are approximately equal for both the asymmetric and non-asymmetric cases. These results indicate that asymmetric cases provide forecasters with added confidence in model forecast bearing but not in track or speed errors.

Table 3. Bearing, speed, and track errors correlated with climatology. Asymmetry condition met when one motion quadrant has >90% clim

Asymmetric Error Correlations with Climatology

	Non-Asymmetric Cases	Asymmetric cases only
Bearing error (degrees)	**-0.233**	**-0.301**
Speed error (kts)	0.116	-0.005
Track error (km)	0.076	0.087

3.4 Climatology bins

To further analyze relationships between climatology and model errors, we separate the model runs into bins and contrast means and standard deviations between the bins. Figures 6 to 8 display the mean model error and standard deviation for eight climatological bins with roughly equal numbers of model runs. Once again, absolute mean bearing errors (Fig. 6) increase when climatology decreases. In addition, the standard deviation more than doubles as the climatology values decrease. The track and speed error means and standard deviations (Figs. 7 and 8) are erratic, however, and do not show any connection to climatology.

4. CONCLUSIONS AND FUTURE WORK

Comparing climatology to NOGAPS and COAMPS track, bearing, and speed errors reveals that climatology by itself is generally not a good predictor of the model errors. However, several significant conclusions can be drawn from the statistical results. First, bearing errors resemble a

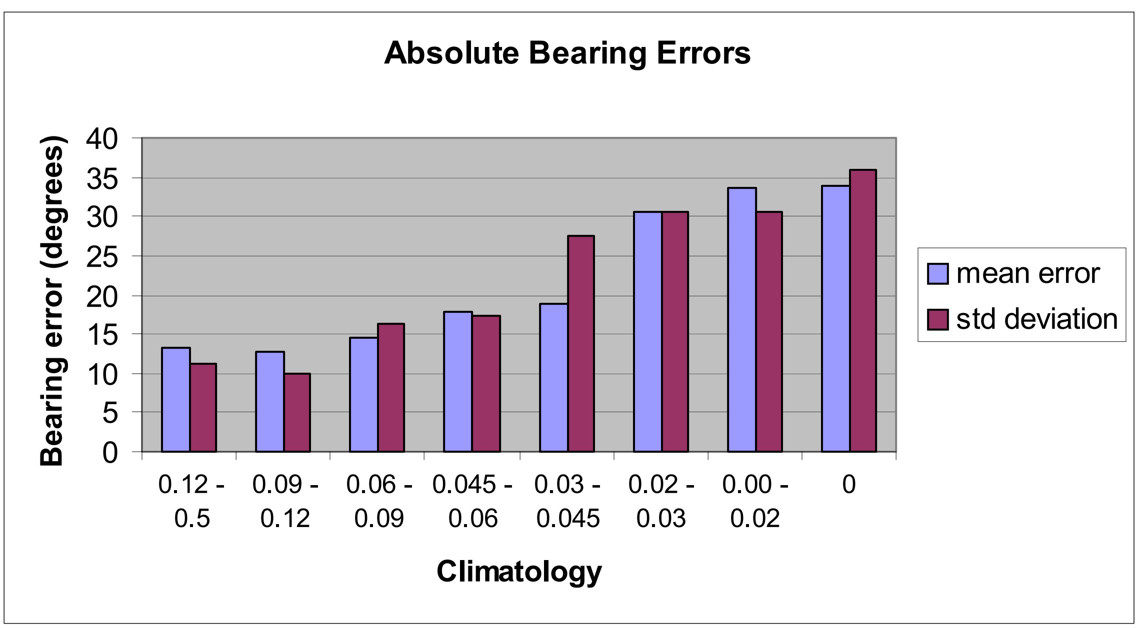

Figure 6: Absolute bearing errors. Bearing errors decrease as climatology increases

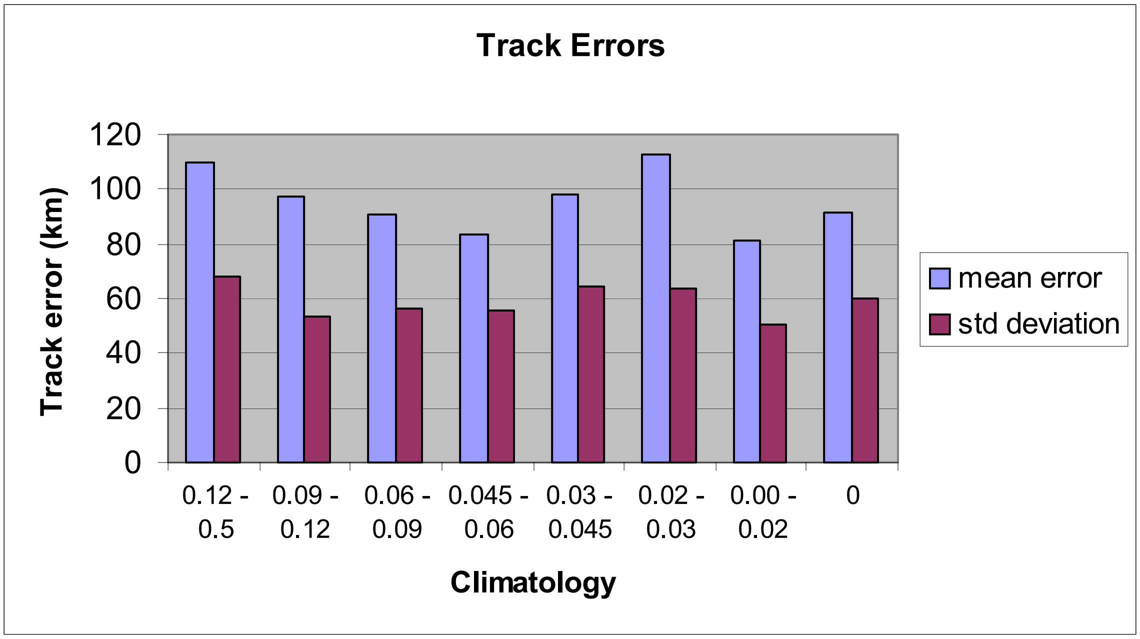

Figure 7: Track errors. Track errors show little to no relationship to climatology.

normal distribution; lower errors correspond to a higher climatology. Error–to–climatology correlation values around 0.30 reveal that there is some connection between the two, and forecasters can expect lower directional errors when a model forecast falls in a climatologically favored sector. Second, track and speed errors are not statistically correlated with climatology, and forecasters should not place extra confidence in forecasts with higher climatology values (nor

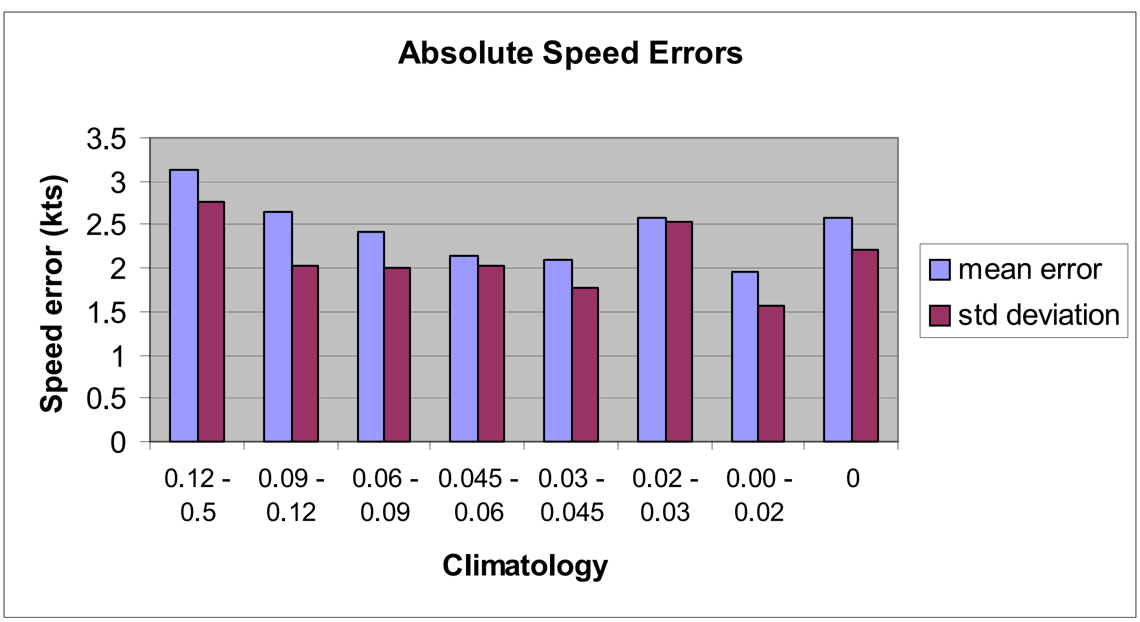

Figure 8: Speed errors. Speed errors also show little to no relationship to climatology.

should they automatically discount forecasts that do not follow climatology). Third, by sorting the data and examining different cases – climatology >0.30 and asymmetry to name two – subtle relationships can be found between model errors and climatology.

To continue exploring possible relationships between model errors and climatology, Hurricane Isabel (2003) was examined. Isabel's model errors have stronger links to climatology because the hurricane followed a traditional track. As a result, point climatology values are higher than those used in the broader annual study discussed above, and the correlations are much more promising. The specific results linking Isabel's track to climatology data will be presented at the 2004 AMS annual meeting.

Additionally, very recent work to recalculate the correlations between model error and climatology by filtering the climatology by time of year will also be presented at the meeting. The filtering method yields promising results because the distribution of storms substantially changes as a function of the time of year. By restricting the time period, the spread of storm tracks decreases, the climatology of tracks clusters together, and the individual point climatology values increase.

Finally, by using more model data in future work (this study used only 2001 and 2002 data), trends can be established into the more distant past, and year-to-year comparisons can be made. Also, this study examined the case of asymmetry but lumped all non-asymmetric cases together. Additional correlations could be found in a symmetric case. Sorting both model runs and climatology values by intensity and previous motion bearing hopefully will boost correlation values.

5. REFERENCES

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