P2E.6 SCALE ANALYSIS OF SPATIAL VARIABILITY IN OBSERVATIONS OF TROPICAL CYCLONES

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1. INTRODUCTION

Many studies over the past few years suggest that small-scale processes in the inner core region of tropical cyclones can have a significant effect on intensity (e.g., Braun, et al 2006). Observations also show that much of the eyewall convection seems to be concentrated in kilometer-scale updrafts (Eastin, et al. 2005; Braun, et al. 2006), with undiluted ascent likely facilitated by strong PV gradients. Other processes include small-scale mixing of entropy or angular momentum between the eye and eyewall (Schubert, et al. 2001). Continuing increases in computational power have allowed full physical simulations of hurricanes at resolutions on the scale of a kilometer (e.g., Braun, et al 2006). To the extent that small scale inner core processes play a role in intensity change, it is necessary to develop methods that can be used to determine whether the small-scale structure in simulated cyclones is realistic. The work presented here is motivated by the question as to whether there are any statistical properties of the scale-dependent variability in observed tropical cyclones that may be of use in evaluating the model-generated variability over a range of scales. To this end, we have performed a study of five Atlantic hurricanes, focusing on scales below ten kilometers using in-situ NOAA WP-3D Orion (P3) wind data. We also provide preliminary results using ER-2 EDOP Doppler wind data.

Analysis of the aircraft data for the purpose of this study is challenging because the flight paths are a 1D, sparse sampling of fields that are nonstationary, nonhomogeneous and nonisotropic. It is not always clear when a data sample is a representative subsample of a larger statistical population, or how to restrict the statistics to "dynamically similar" subensembles without loss of statistical robustness. Other problems arise from biases in the sampling, for example, many radial transects are along or across the large scale environmental wind shear, which will not capture information about features 45 degrees left of shear, such as the hot towers spawned in simulations and observations of Hurricane Bonnie (Braun, et al 2006; Heymsfield, et al. 2001).

Despite these sampling issues, our analysis has shown consistent features in the statistics of the P3 winds in the five hurricanes analyzed. Preliminary results from the ER-2 EDOP Doppler wind corroborate some of the P3 wind results.

2. DATA AND METHODS

This study is based on one-second in-situ P3 wind data from Atlantic hurricanes Helene (2006), Humberto (2001), Isabel (2003), Katrina (2005) and Rita (2005). The data was collected by NOAA WP-3D Orion aircraft at altitudes from 1.8 to 3 kilometers. We used data ranging from the storm center to just outside the eyewall.

The aircraft data was divided up into radial transects. For each transect, we took all possible pairs of points and computed the radial separation $r=r_2-r_1$ (where $r_2 \geq r_1$), and corresponding radial and vertical wind increments $\Delta_r u=u(r_2)-u(r_1)$ and $\Delta_r w=w(r_2)-w(r_1)$. We then computed the probability distribution functions (PDFs) of $\Delta_r u$ and $\Delta_r w$ across radial scales r=200m, 400 m, 1 km, 2.5 km and 6.5 km. We also calculated the second order structure function, $S_2(r) = \langle(\Delta_r V)^2\rangle$ (V=u,w), defined as the variance of the wind increments across scales in the range 200 m to 2 km.

In addition to the P3 data, we also present preliminary results using Doppler winds from the downward-pointing ER-2 EDOP radar. The EDOP data was collected as part of the Tropical Cyclone Systems and Processes (TCSP) experiment in hurricane Dennis (2005). The EDOP radar determines the Doppler wind at altitudes ranging from 20 km down nearly to the ground. We split up the ER-2 data into radial transects in the same way as the P3 data. However the EDOP radar collects data in a column from the location of the aircraft all the way to the ground. We took the points closest to

1000 m, 1500 m, 2000 m, 2500 m and 3000 m from each vertical column and performed the same analysis described above.

3. RESULTS

This study is based on differences between measurements across small scales which can be sensitive to the precision of measurements. (Overall biases in measurements are not important since they will cancel out when taking differences.) To determine the distribution of errors, we examined the PDF of vertical and horizontal wind increments between adjacent measurements (separated by about 100m). An example of the vertical wind using the Isabel data is shown in Figure 1. The PDFs at these small separations have a Gaussian core which is present during all time periods and for all storms hence it is likely due to random errors in the wind measurements. The Gaussian core has a standard deviation of 0.2 m/s and the deviation from the Gaussian occurs at 0.4 m/s. This is consistent with the reported wind error of 0.1-0.3 m/s (Aberson, et al. 2006). The stretched exponential tails show that large changes in the vertical wind occur even on these very small scales.

A similar form for the PDF is also seen at other scales. Figure 2a shows the radial wind increment PDF $P(\Delta_r u)$ for all storms overplotted. There is considerable variation across scales and a smaller variation among different storms at the same scale. The variation is considerably reduced when the wind increment is normalized by the standard deviation, as shown in Figure 2b. Here, an exponential form that is similar for all scales emerges. This is made even more apparent when we average across all storms. Figure 3 shows the PDFs of the normalized increments for both radial and vertical wind increments. In all cases the PDFs are well-described by a stretched exponential of the form $\exp(-a|x|^q)$ with an exponent q of about 0.6, except for the Gaussian core. The stretched exponential form is similar to what is found in experimental studies of turbulence (Frisch, 1996) and passive scalar variability in the atmosphere (Sparling and Bacmeister, 2001).

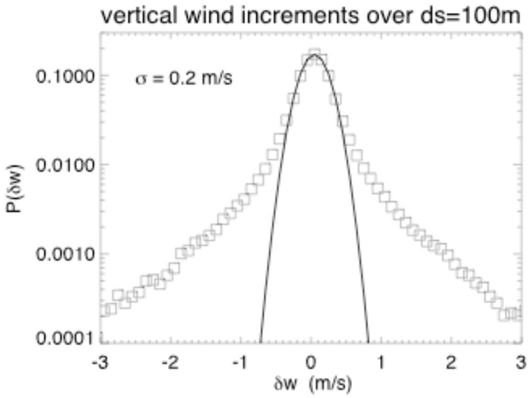

Figure 1: PDF of radial increments in the vertical wind across very small scales.

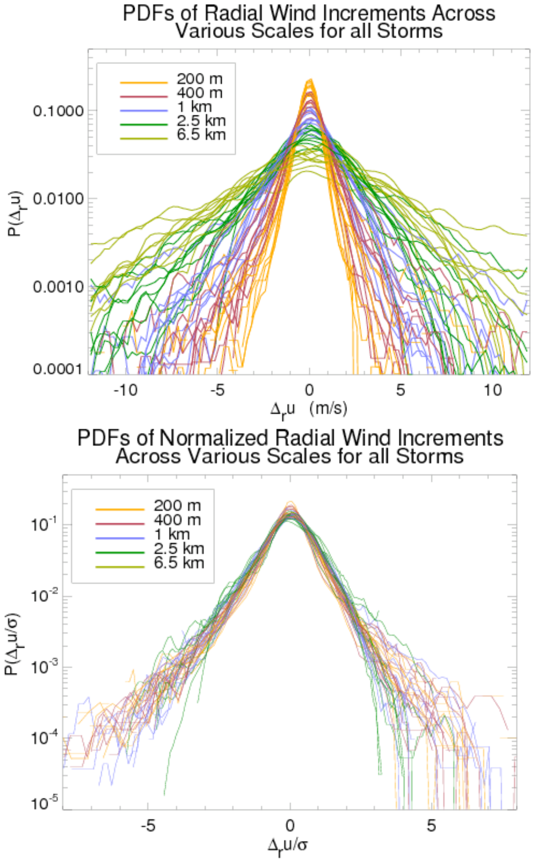

Figure 2: PDF of $\Delta_r u$ across various scales and for several storms. (a)(top) Non-normalized wind increments. (b) (bottom) Increments normalized with the standard deviation of the distribution.

The structure function of the radial wind is shown in Figure 4 on a log-log plot. It is consistently linear over the radial scale range 200m - 20km, indicating that $S_2(r) \sim r^\alpha$ The slope varies somewhat from storm to storm and between different time periods of different storms, but typically is in the range 0.6 – 1.1. Slopes close to 2/3 are sometimes found; this slope corresponds to both the 2D upscale cascade and 3D downscale energy cascades (Frisch 1995). However, it is not at all clear whether either of these concepts are relevant here. More data will be required to determine whether there is a correlation between the structure function slope and the storm dynamics.

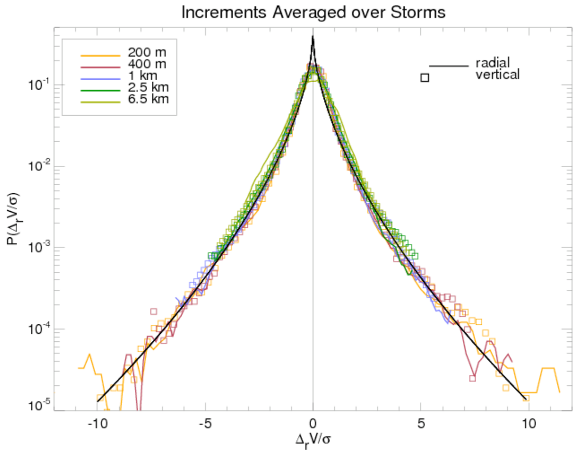

Figure 3. PDFs of normalized radial and vertical wind increments overplotted, together with the stretched exponential $p(x) = 0.4\exp(-2.6|x|^{0.6})$.

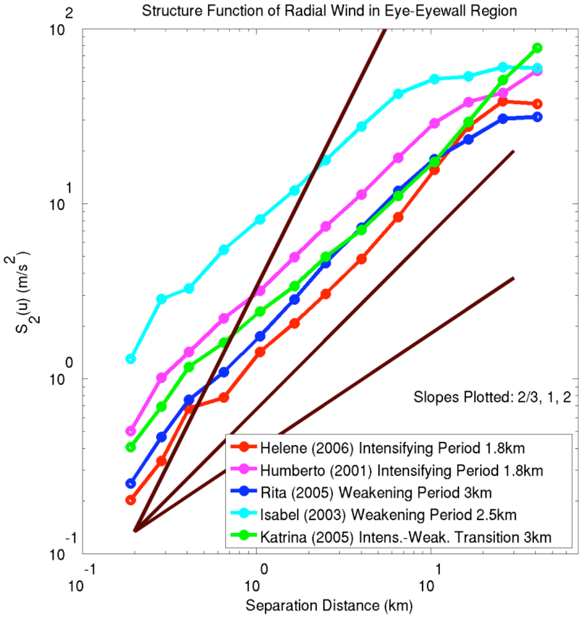

Figure 4. Radial structure function $S_2(r)$ vs. radial scale r for all storms.

The vertical wind structure function (not shown) rapidly rises with increasing separation distance and levels off at a radial correlation length in the range 2-6 km. The vertical motion across radial scales larger than this is uncorrelated. This agrees with the scales of convection found in the study of Eastin, et al., 2005. Another study is in progress to determine the azimuthal correlation length, which could be larger.

4. CONCLUSIONS AND FUTURE WORK

This study suggests that there may be some statistical aspects of variability on scales <10 km that are observed in all tropical cyclones. This may be useful in evaluating the statistical accuracy of small-scale features in numerically modeled cyclones. In an examination of in-situ P3 wind data and preliminary examination of ER-2 downward-pointing EDOP radar Doppler wind data, this study has shown the following consistent statistical features to be present in radial transects of hurricanes at altitudes 1.8-3 km:

- The structure function of vertical wind along radial transects has a horizontal correlation length in the range 2-6 km.
- The structure function of radial wind appears to be a power law. $S_2(\Delta_r u) \sim r^{\alpha}$ in the scale range from 200m-12km with an exponent α in the range 0.6-1.1 that varies from storm to storm and time period to time period.
- The PDFs of normalized wind increments has a stretched exponential form that is similar for all time periods studied.

These results are encouraging, and this study will be extended by including additional storms and data from other platforms. We are exploring different ways of forming statistical ensembles that may provide clearer signatures of the underlying dynamics.

5. REFERENCES

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