8A.7 DIFFERENTIATING BETWEEN TORNADIC AND NONTORNADIC MESOCYCLONE USING FRACTAL GEOMETRY

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1. INTRODUCTION

It has not been easy to distinguish between tornadic and nontornadic mesocyclones based on single parameters such as maximum rotational speed, maximum vertical vorticity, or radius of maximum tangential speed. Past studies trying to use these single parameters to estimate a mesocyclone's tornadic potential turn out to be inclusive. Wakimoto and Cai (2000) did a detailed side-by-side comparison between the Garden City tornadic and Hays nontornadic mesocyclone using ELDORA airborne Doppler radar data collected during VORTEX 95 and found these two mesocyclones are almost identical. Trapp (1999) analyzed 3 tornadic and 3 nontornadic mesocyclones from VORTEX and concluded that the tornadic mesocyclones have slightly larger vertical vorticity, smaller core radii and are associated with stronger convergence. Inspired by rapid spreading of fractal geometry into numerous areas of physical sciences (Gouyet, 1995), this paper will investigate the Garden City tornadic and Hays nontornadic mesocyclone from the fractal geometry perspective.

2. VERTICAL VORTICITY AS A FRACTAL STRUCTURE

The term "fractal" was first introduced by B. Mandelbrot (fractal, i.e., that which has been infinitely divided). The past several decades have witnessed fractal geometry found its applications in numerous natural phenomena in various scientific domains. Its wide-spreading applications derived from the fact that fractal geometry is closely linked to properties invariant under change of scale: a fractal structure is the same "from near or far". In other words, the fractal geometry demonstrated the concept of self-similarity and scale invariance appeared independently in various areas of physics. An example of fractal structure occurred in nature is a coastline. It was found that the length of a coastline is a function of the unit used to measure the length of the coastline. In other word, the length of the coastline is dependent on the unit of the measurement. When the unit goes to infinitely small, the length approaches infinitely large. The linear relationship between ln (length) and ln (unit) is a manifestation of fractal characteristic and it is common to all different kind of fractal structures.

Now let's apply fractal geometry to a simple parameter such as maximum vertical vorticity of a mesocyclone. It is well known that the maximum vorticity could be different depending on the grid space of dual-Doppler analysis, but it is not clear whether the vorticity demonstrating itself as a fractal structure, that is, if there is a linear relationship between ln (VORT) and ln (L), where L is the horizontal grid spacing and VORT is the maximum vertical vorticity of the mesocyclone. In order to find out if vorticity is a

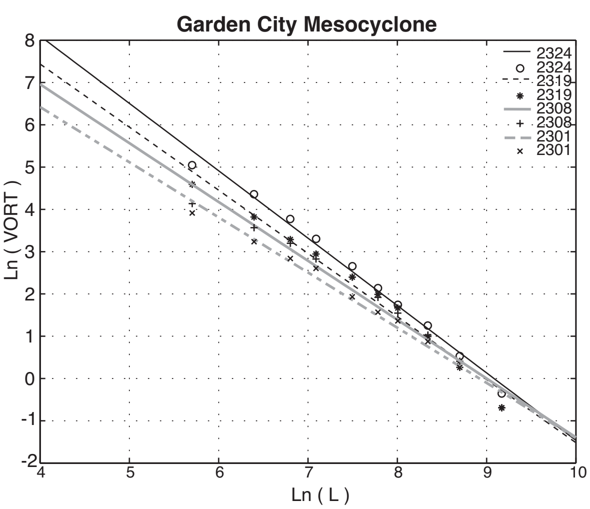

Fig. 1. Vorticity curves for the Garden City mesocyclone at 2301,2308,2319 and 2324 UTC at 0.6 Km AGL.The unit for L and VORT are m and 10^{-3} s^{-1}, respectively. The linear correlation coefficients for 2301,2308,2319 and 2324 UTC are 0.98,0.97,0.98 and 0.99, respectively.

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fractal structure, airborne Doppler radar data collected by NCAR ELDORA during VORETX for two mesocyclones were analyzed. Dual-Doppler synthesis using different horizontal grid space from 0.3 to 9.6 km was performed. Maximum vertical vorticity at 0.6 km AGL for the Garden City supercell at four different times using various grid space is shown in Fig. 1 as an example of some typical ln (VORT)/ln (L) curves. All the curves show a linear relationship with correlation coefficients between 0.97 and 0.99. Apparently Fig. 1 proves that the maximum vorticity of a mesocyclone is a fractal structure. This finding will have important implications discussed later.

3. EVOLUTION OF THE VORTICITY CURVE

The evolution of ln (VORT)/ln (L) curves for the Garden City tornadic mesocyclone at 4 different times before tornadogenesis is shown in Fig. 1. The linear correlation coefficient for 2301, 2308, 2319 and 2324 UTC are 0.98,0.97,0.98 and 0.99, respectively. The vorticity reaches its peak value at all scales at 2324 UTC just before tornadogenesis, while the increase of vorticity apparently is much larger in small scale. This larger increase of vorticity at smaller scales leads to the increase of the slope of the vorticity curve as the Garden City mesocyclone intensified. It is speculated that the position of the vorticity curve is an indication of a mesocyclone's tornadic potential. Further illustration of this claim will be investigated in Section 4.

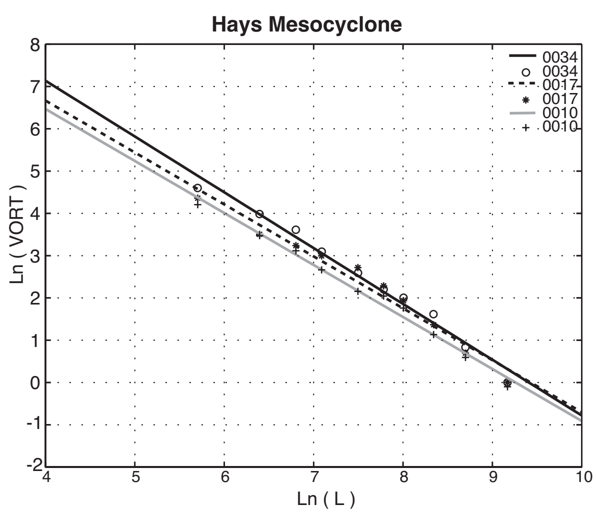

Fig. 2. Vorticity curves for the Hays mesocyclone at 0010,0017 and 0034 UTC at 0.8 Km AGL.The unit for L and VORT are m and 10^{-3} s^{-1}, respectively. The linear correlation coefficients for 0010,0017 and 0034 UTC are 0.99,0.97 and 0.98, respectively.

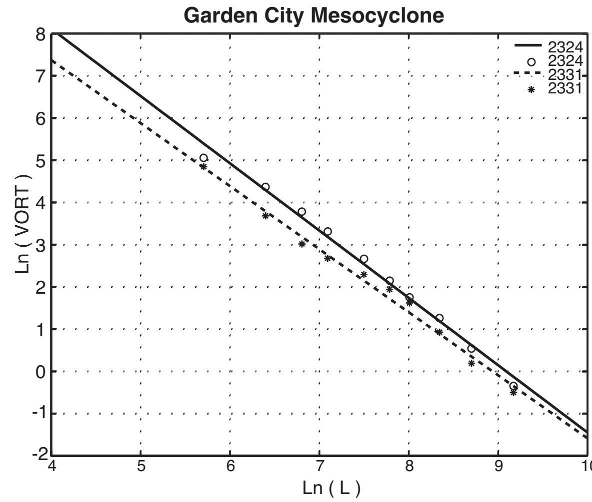

Fig. 3. Vorticity curves for the Garden City mesocyclone just before (2324 UTC) and after (2331UTC) tornadogenesis at 0.6 Km AGL. The unit for L and VORT are m and 10^{-3} s^{-1}, respectively. The linear correlation coefficients for 2324 and 2331 UTC are 0.99 and 0.98, respectively.

The similar ln (VORT)/ln (L) curves for the Hays nontornadic mesocyclone at 0010, 0017 and 0034 UTC at 0.8 km AGL is shown in Fig. 2. Basically the same trend as in Fig. 1 is noted. The linear correlation coefficient for 0010,0017 and 0034 UTC is 0.99, 0.97 and 0.98, respectively. Again the increase of vorticity is much more prominent at smaller scales and the vorticity curve moves upward as the Hays mesocyclone became stronger.

A comparison of vorticity curve just before and after tornadogenesis for the Garden City tornadic mesocyclone is shown in Fig. 3. Interestingly, the vorticity became smaller at all scales after tornadogenesis. This is a demonstration that the mesocyclone became weaker after tornadogenesis, which is a well documented phenomena associated with mesocyclone tornadogenesis.

4. COMPARISON BETWEEN TORNADIC AND NONTORNADIC MESOCYCLONES

Although Wakimoto and Cai (2000) found no significant differences between the tornadic Garden City and nontornadic Hays mesocyclones in terms of various parameters such as maximum vertical vorticity, maximum tangential speed, mesocyclone core radii and swirl ratios, they do pointed out that the tangential velocity profile of these two mesocyclones shown substantial differences in the far field and speculated

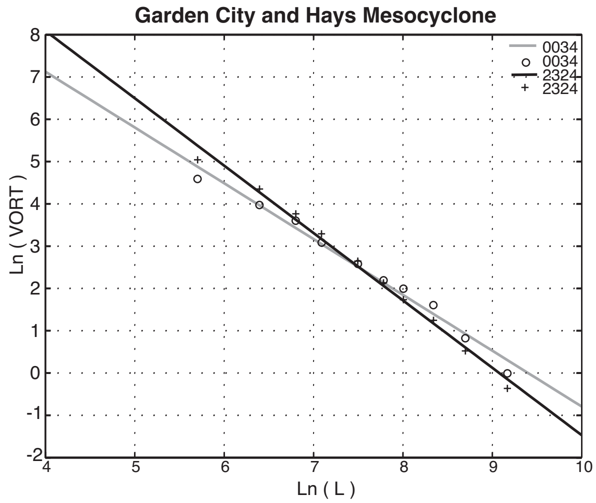

Fig. 4. Vorticity curves for the Garden City mesocyclone at 2324 UTC at 0.6 Km AGL and the Hays mesocyclone at 0034 UTC at 0.8 Km AGL. The unit for L and VORT are m and 10^{-3} s^{-1}, respectively.

that the difference in the tangential velocity profile might be the reason that one mesocyclone was tornadic while the other was not. Since fractal geometry provided a method to look at the same characteristic at different scales, it is expected that the Garden City and Hays mesocyclones will show some difference on the vorticity curve.

The vorticity curve at 2324 UTC for the Garden City tornadic mesocyclone and at 0034 UTC for the Hays nontornadic mesocyclone is shown in Fig. 4. 2324 UTC is the time just before tornadogenesis for the Garden City supercell while 0034 UTC is the time when the Hays supercell reaches its peak intensity. The difference between these two vorticity curves is apparent. The Garden City mesocyclone has larger vorticity at smaller scales compared with the Hays mesocyclone, while the Hays mesocyclone has larger vorticity at larger scales. For scales in between, these two mesocyclones have similar vorticities. The two vorticity curves in Fig. 4 may explain why Wakimoto and Cai (2000) found no significant differences between these two mesocyclones. In their analysis, the resolvable scale is about 2 km, which is right in the scale range where the two vorticity lines intercept. Fig. 4 illustrated that on certain scales, the tornadic and nontornadic mesocyclones do look very similar and almost indistinguishable, just as Wakimoto and Cai (2000) pointed out in their paper. More importantly, Fig. 4 demonstrated that if you look at the same mesocyclone from different scales at the same time, these two mesocyclones do look different. Apparently the tornadic mesocyclone has higher vorticity at smaller scales. Suppose the self-similarity assumption is true between tornado and mesocyclone scale and assume tornadoes have a tangential velocity profile of a combined-Ranking vortex, then the maximum tangential velocity Vmax can be estimated by

$$Vmax=R*VORT/2 \qquad (1)$$

Where R is the radius of the maximum tangential velocity of the combined-Ranking vortex, VORT is the vertical vorticity. By extrapolating the vorticity curves of the Garden City and Hays mesocyclone into L = 100 m, we can calculate the corresponding vorticity values to be 1.25 s^{-1} for the Garden City mesocyclone and 0.57 s^{-1} for the Hays mesocyclone at 100 m scale. Using Eq. 1 and assuming R=50 m, the corresponding Vmax for the Garden City and Hays mesocyclone is 32 m/s and 14 m/s, respectively. Apparently these two numbers will suggest that the Garden City mesocyclone is tornadic while the Hays is not. Remember that the Garden City tornado was rated F1, which should have a maximum wind speed between 32 and 50 m/s. Considering the inaccuracy of various assumptions involved in the velocity estimation from the vorticity curves, the estimated velocity should be regarded as in line with the tornado's F scale rating. Therefore, it is hypothesized that the vorticity curve of a particular mesocyclone has some indications of its tornadic potential. If a mesocyclone's vorticity curve gives a higher vorticity prediction when extrapolating the line into

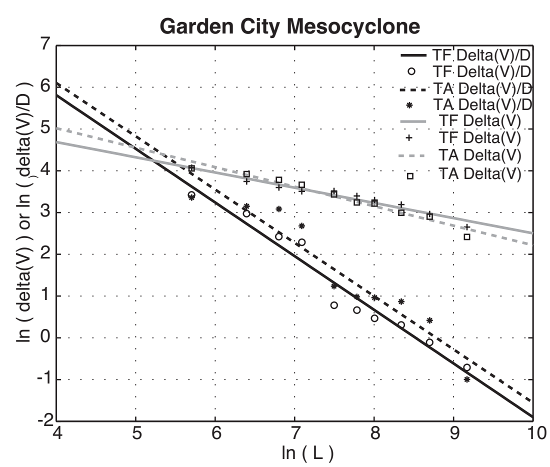

Fig. 5. Delta(V) and Delta(V)/D curves for the Garden City mesocyclone at 2319 UTC at 0.6 Km AGL.The unit for L, Delta(V) and Delta(V)/D are m, m/s and 10^{-3} s^{-1}, respectively. TF represents values from fore antenna, TA represents values from aft antenna.

smaller scales, the mesocyclone might be tornadic.

5. OTHER PARAMETERS AS FRACTAL STRUCTURES

Previous sections have suggested that the maximum vorticity of a mesocyclone is a fractal structure. Since dual-Doppler winds are rare in operational environment, the application of using vorticity curve to predict a mesocyclone's tornadic potential is greatly hampered. In order to apply the major findings of this paper to the real world, other parameters that can be directly estimated from single Doppler velocity need to be investigated to see if they are also fractal structures. Two alternatives for vertical vorticity are proposed. The first parameter is called delta (V), which is the difference between maximum and minimum single Doppler velocity associated with a mesocyclone. The second parameter is defined as delta (V) / D, where D is the distance between the maximum and minimum velocity and delta (V) is the same as defined above. An example of ln (delta (V)) and ln (delta (V)/D) as a function of ln (L) for various L is shown in Fig. 5. Again the linear relationship is noted although the linear correlation coefficient is not as good as that of the vorticity curve. The reason for this is not clear. The linear correlation coefficients of Delta (V) for fore and aft antenna at 0.6 km AGL at 2319 UTC are 0.95 and 0.96, respectively. For Delta (V) / D, the linear correlation coefficients are 0.95 and 0.96 for fore and aft antenna. Also noted in Fig. 5 is the fact that there is not much difference between the curves calculated from the fore and aft antenna for both Delta (V) and Delta (V) / D. This suggest that the view angle of antenna might not cause severe probelms when the single Doppler velocities are used to calculate the parameters proposed in this paper.

The findings that both delta (V) and delta (V)/D can be regarded as fractal structure pave way to apply the fractal geometry of these parameters to operational applications. By comparing the delta (V) curve and delta (V)/D curve from 2324 UTC of the Garden City mesocyclone and 0034 UTC of the Hays mesocyclone, similar conclusions are obtained as using vorticity curve in section 4. Simple calculations indicate that the Garden City mesocyclone would have tornadic winds if the resolvable scale L goes to tornado scale. Therefore, it is possible that the same technique can be used in WSR-88D single Doppler data to estimate a mesocyclone's tornadic potential if the major findings of this paper can be verified by large samples of data.

6. DISCUSSIONS

More case studies of various tornadic and nontornadic mesocyclones will be needed to verify the hypothesis that the positions of vorticity, delta (V) or delta (V)/D curve can be used to estimate a mesocyclone's tornadic potential. Further investigations using high-resolution radar data to test if the fractal structure is still valid at tornado scale is also imperative.

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