Measuring Spatio-temporal Patterns of Three-dimensional Structures of Convective Rainbands in Land-falling Tropical Cyclones

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INTRODUCTION

A tropical cyclone (TC) typically contains rainbands that spiral in toward the eyewall of the storm (Willoughby et al. 1984). In TCs, types of rainbands could be classified into convective and stratiform. The convective rainbands consist of more convective precipitation upwind and the stratiform rainbands consists more stratiform precipitation downwind (Barnes et al. 1983, Jorgensen 1984). During landfall, convective rainbands produce high rain rates than can lead to flash flooding. By identifying the structure and position of convective rainbands inside TCs, it helps us better understand the intensity and spatial distribution of TC rainfall. We aim to identify convective cells embedded inside principle and outer rainbands of TCs using its geometric characters rather than its kinetic and microphysics properties.

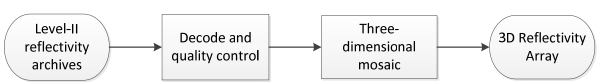
In this research, we are going to test two hypotheses:

1. Convective rainbands usually bring high precipitation, thus they are expected to be located in high reflectivity areas in principal and outer spiral rainbands.
2. Convective rainbands represent significant updrafts and downdrafts in rainbands, thus their geometric character are expected to hold large vertical expansion and/or large vertical change along time.

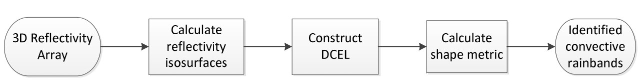
DATA AND METHODOLOGY

Following steps are carried out to test the hypothesis:

1. Construct three-dimensional reflectivity mosaic of hurricanes using observations from multiple Doppler radars. Reflectivity data are obtained from NEXRAD Level II products. Quality control is applied by using w2qcnn program from Warning Decision Support System -- Integrated Information.



2. Identifying convective cells from spiral rainbands. In this step, we first calculate an isosurface based on three-dimensional reflectivity array obtained from Step 1 in MATLAB. Then we compile faces and vertices information from calculated isosurface into a data structure named doubly-connected edge list (DCEL) to describe topological relationships of all faces and vertices. Then we trace its vertical evolvement during TCs' landfall periods to determine whether the calculated isosurface is representing convective rainbands.



3. Verify convective rainbands using rain-gauge observations by comparing rain-gauge data from stations underneath the rainbands.

THREE-DIMENSIONAL MOSAIC

The process of creating 3D radar image mosaic is mainly about calculating radar beam propagation which could be described by 4/3 effective earth radius model. For a radar at given latitude-longitude-altitude position, a grid point at latitude α_g, longitude β_g, and at a height of h_g above mean-sea-level, the range gate at a distance r from the radar (α_r,β_r,h_r) on a radial at an angle a from due-north and on a scan tilted e to the earth's surface could be calculated as:

$$h_g = \sqrt{r^2 + R^2 + rR\sin(a)} - R + h_r$$

$$s = R \cdot \sin^{-1}\left(\frac{r\cos(e)}{R + h_g}\right)$$

$$\beta_g = s * \sin(e) + \beta_r$$

$$\alpha_g = s * \cos(e) + \alpha_r$$

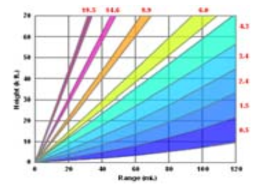


Fig. 1 Demonstration beam propagation in volume coverage pattern of WSR-88D.

where R is the effective radius of the earth, taken to be 4/3 of mean earth radius of 6731 km.

BUILDING DOUBLY-CONNECTED EDGE LIST

Doubly-connected edge list (DCEL) is a data structure to represent an embedding of a planar graph in the plan and polytopes in 3D (Muller and Preparata 1977). This data structure provides efficient manipulation of topological information for geometrical computation questions (e.g. vertices traversal, intersection). The *isosurface* function in MATLAB returns two tables, face table and vertex table. By using a deep-first traversal, we create edge table and DCEL table.

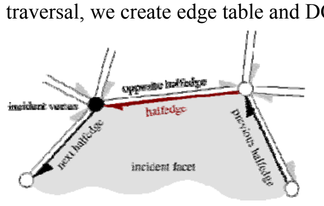


Fig 2. A sample segment of DCEL. In DCEL, each segment contains six elements, half-edge, opposite half-edge (twin-edge), previous half-edge, next half-edge, incident vertex and (left) incident face. each segment is stored as a row in DCEL table.

Edge Index	Start Vertex	End Vertex
1	1	2
2	2	1
3	2	3
4	3	2
5	3	1
...	...	...

Face Index	Vertex on faces
1	(1,2,3)
...	...

Vertex Index	Coordination (Lon,Lat,Alt)
1	(-84.56,29.98.6,1)
2	(-84.56.7,29.98,1)
3	(-84.56,29.98.5,1)
...	...

Half Edge	Twin Edge	Previous Edge	Next Edge	Incident Face	Incident Vertex
1	2	5	3	1	2
...	...	...	...	...	...

Table 1, Constructing DCEL table using face table, vertex table and edge table.

CASE STUDY AND RESULTS

Hurricane Charley (2004) Aug. 13-14 is our study case (Matyas 2009). We use 15-min precipitation rain-gauge observations from Florida Automated Weather Network (FAWN) stations and Stage IV radar-estimated and gauge-corrected precipitation data during same period.

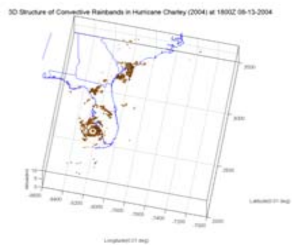


Fig. 3 Demonstration of constructing convective rainbands isosurface in Hurricane Charley(2004) using DCEL and visualizing as patches

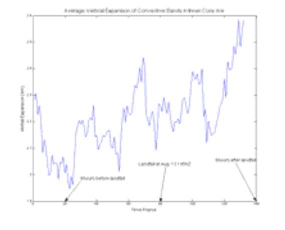


Fig. 4 Temporal change of mean vertical expansion of convective rainbands from 12hr before landfall to 12hr after landfall


Fig. 5 Spatial overlay of convective rainbands over high rainfall observations (red mark)

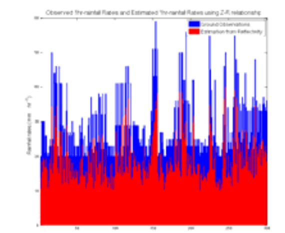


Fig. 6 Comparing observed high rainfall data with corresponding radar estimation.

We have following conclusions from results in this case study:

1. Using 38d*BZ* to identify convective bands generally matches spatial distribution of ground high-rainfall observations. However, gauges report higher rainfall than radar estimates which concurs with Matyas (2009).
2. Vertical expansions of convective rainbands changed rapidly in both spatial and temporal aspects. After landfall, convective rainbands tend to increase in thickness. This may indicate stronger updrafts after landfall.

References

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