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A spatial analysis of Hurricane Katrina's outer rainbands prior to landfall in Louisiana

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Introduction

The rain fields of tropical cyclones (TCs) can affect people hours prior to landfall, particularly in the case of large hurricanes such as Katrina (2005). Preparedness actions such as securing outdoor property and evacuating are hindered when rainfall commences. This study focuses on the outer rainbands associated with Hurricane Katrina (2005)'s Louisiana and Mississippi landfalls. Estimating the time when rain begins along the coastline allows a distance and time to be calculated relative to the arrival of the storm's center. Measuring rainband shape, orientation motion, and position relative to the storm center facilitates the examination of TC-environmental interactions and reveals how the outer edge of the TC changes during interaction with continental air masses and land. Our objectives are to 1) determine the hour when rainfall begins at land-based locations relative to the time of the eye's landfall, and 2) track the position of the leading edge of the outermost rainband before and during landfall.

Defining Start of a Rainfall Event

- Dataset: Stage IV gridded precipitation (Fulton et al. 1998; Lin and Mitchell 2005) http://data.eol.ucar.edu/codiac/dss/id=21.093
- Hourly rainfall totals are tracked at NHC-designated breakpoints (http://www.nhc.noaa.gov/breakpoints.php) (Fig. 1).
- Rain event start time: 6 h period with hourly totals 1.21 mm or greater
- Corresponds to 25 dB*Z* radar reflectivity value using tropical *Z* to *R*
- Analysis for all U.S. landfalling TCs 2002-2012
- Ongoing work: developing statistical model to predict distance to center at rainfall start time (Comstock and Matyas 2014)

Measurements of WSR-88D Reflectivity

- Composite reflectivity (http://www.ncdc.noaa.gov/nexradinv/)
- Geographic Information System (GIS) mosaics data from four radars closest to Katrina's landfall location using method of Matyas (2009)
- Render lines along outermost rainbands containing 40 dB*Z* reflectivity values
- Compute the start, midpoint, and endpoint and length of lines
- Distance calculated to storm center and nearest point on coastline
- Calculate degree of closure as compared to a circle (Matyas 2007, Matyas and Tang 2014)
- Compute additional shape metrics of compactness, smoothness, convexity, solidity, orientation (Matyas 2008, Matyas et al. 2015)
- Results are reported each hour 28 Aug. 1800 UTC – 29 Aug. 1400 UTC

Examination of Environmental Moisture

- North American Regional Reanalysis (NARR) (Mesinger et al. 2006) http://www.esrl.noaa.gov/psd/data/gridded/data.narr.html
- Zick and Matyas (2015 a, b) found good representation of TCs and their environments for locations close to land
- Zick and Matyas (2016) found that Katrina's moisture convergence and precipitation fields as measured from NARR data changed shape 24 hours prior to landfall after reaching peak intensity, consistent with structural changes reported in Beven et al. (2008).
- Examine precipitable water in rainband regions

Results: Rain Event Timing

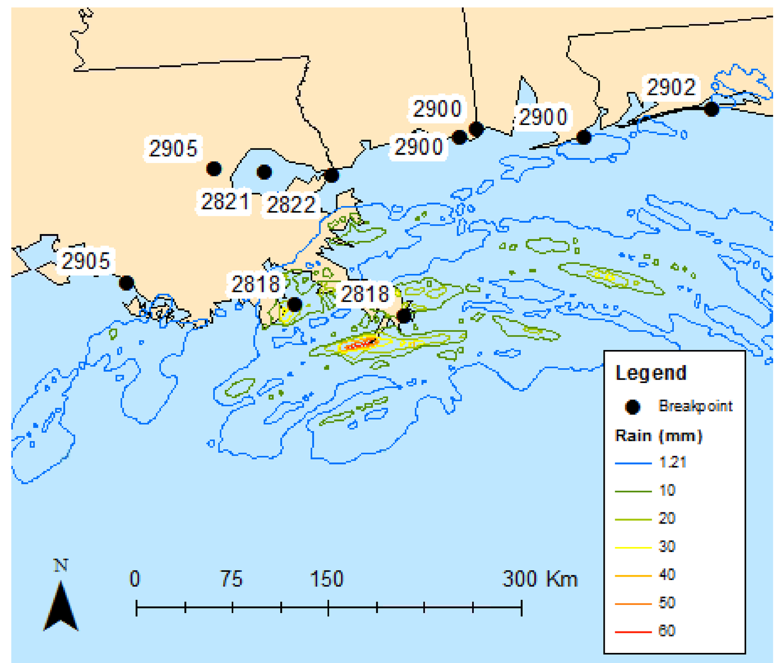


Fig. 1. Stage IV one-hour rainfall at 28 Aug. 1800 UTC. NHC breakpoint positions are labelled with day and time of rain event start.

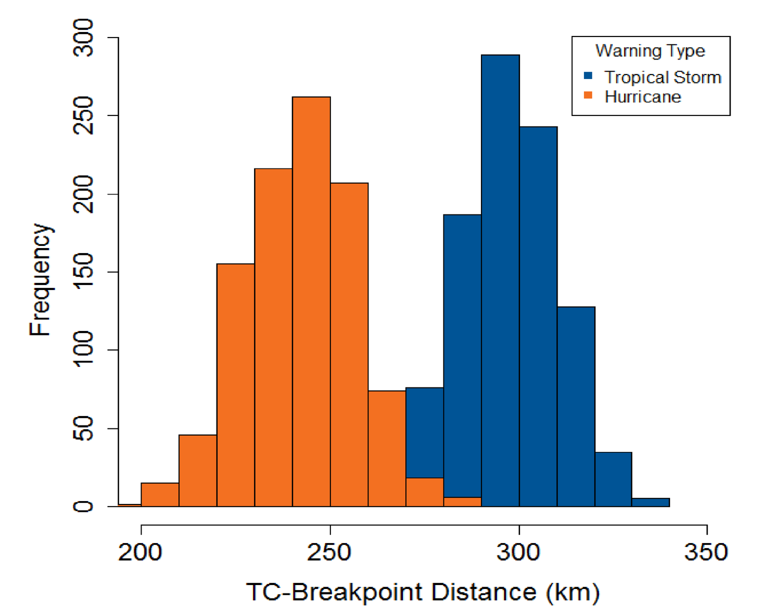


Fig. 2. Distance from TC center to breakpoint at rain event start for 43 TCs. Obs. grouped according to whether breakpoint is under a hurricane or TS warning at rain event start.

Breakpoint	Start Day Hour	Dist. to Center (km)	Avg. 6 hr Rain	Max. 6 hr Rain
Morgan City, LA	2905	255	3.30	5.02
Grand Isle, LA	2818	350	5.04	14.99
Mouth Miss. River	2818	320	3.14	8.85
Lake Maurepas, LA	2905	280	5.38	9.14
Lake Ponchartrain	2821	400	2.49	5.26
Mouth Pearl River	2822	375	1.98	3.14
Pascagoula, MS	2900	365	2.99	6.69
MS/AL border	2900	370	3.14	6.86
AL/FL border	2900	385	2.46	5.72
Destin, FL	2902	435	3.27	6.50

Table 1. Breakpoints, day and time of rain event start, distance from TC center at that time, average rainfall, and maximum rainfall over the 6-hr period used to calculate rain event start. Landfalls occur on 29 Aug. at 1100 and 1445 UTC.

The hour of issuance for a TC warning conveys the anticipated window of time remaining until gale-force winds arrive, yet TC rainfall lacks a formal definition. We identify rainfall onset at coastal locations for 43 landfalling TCs 2002-2012 and find that the average rainfall onset occurs 12 h prior to landfall when the TC is 250-300 km from the breakpoints (Fig. 2). Katrina is large (ROCI 555 – 650 km), which is in the 90th percentile for the Atlantic basin (Kimball and Mulekar 2004). Given Katrina's large size, it is not unexpected that rainfall begins earlier than for other TCs, averaging 15 h prior to landfall (Table 1). Additionally, McTaggart-Cowan et al. (2007) show that 17 ms^{-1} winds have not reached the coastline when rainfall commences at MS and AL breakpoints. Thus, rainfall can begin several hours before the arrival of gale-force winds, especially in locations not directly ahead of the TC. This shortens the time to complete storm preparations.

Results: Measuring Leading Edge and Moisture Distribution

- Fig. 3: Edge A forms near the mouth of the MS River extending east. It rotates counterclockwise and travels 250 km northwest before eroding. It has the fastest motion, averaging 22.5 ms^{-1}.
- Edge C takes a similar trajectory 9 h later, moving at 15 ms^{-1}. It has the shortest length .
- Edge B forms over Lake Borgne at 2200 UTC and moves north at an average speed of 14.4 ms^{-1}.
- Edge D develops 9 hours later in a location similar to B along the MS/AL coastline, moves the shortest distance of 110 km, but has the longest length. Its forward motion averages 12.5 ms^{-1} .
- Edge E forms 180 km west of the eye with a north/south orientation. It encircles more than 180° around the eye within 5 hours, growing in length each hour. Like D, it moves slowly at12.4 m s^{-1}.

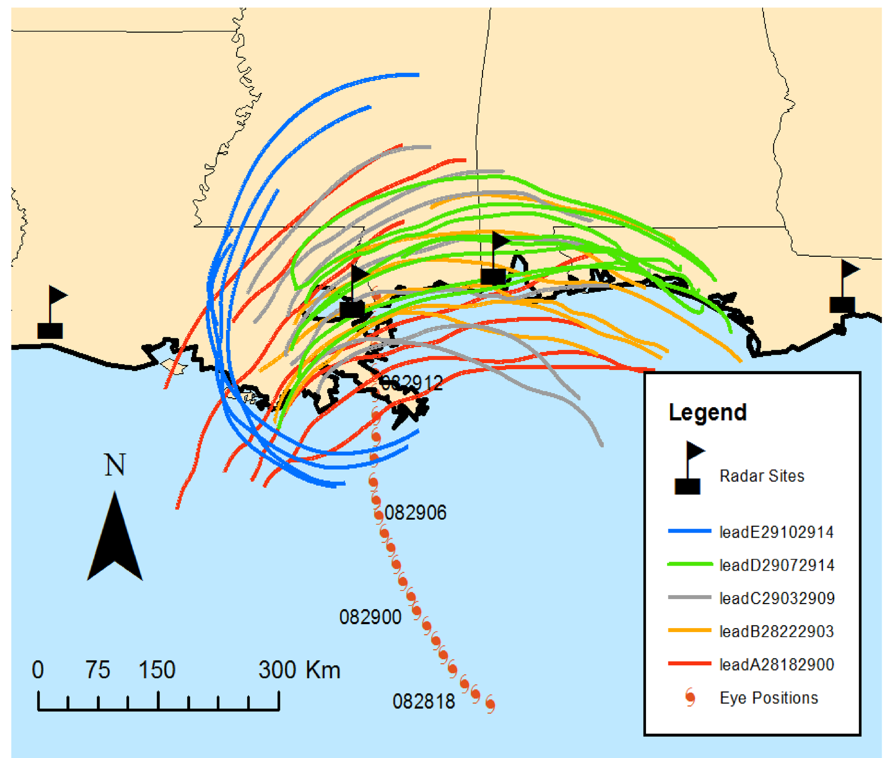


Fig. 3. Positions of 5 outer rainbands. Legend labels indicate day and hour of band formation and dissipation. TC centers are interpolated to each hour.

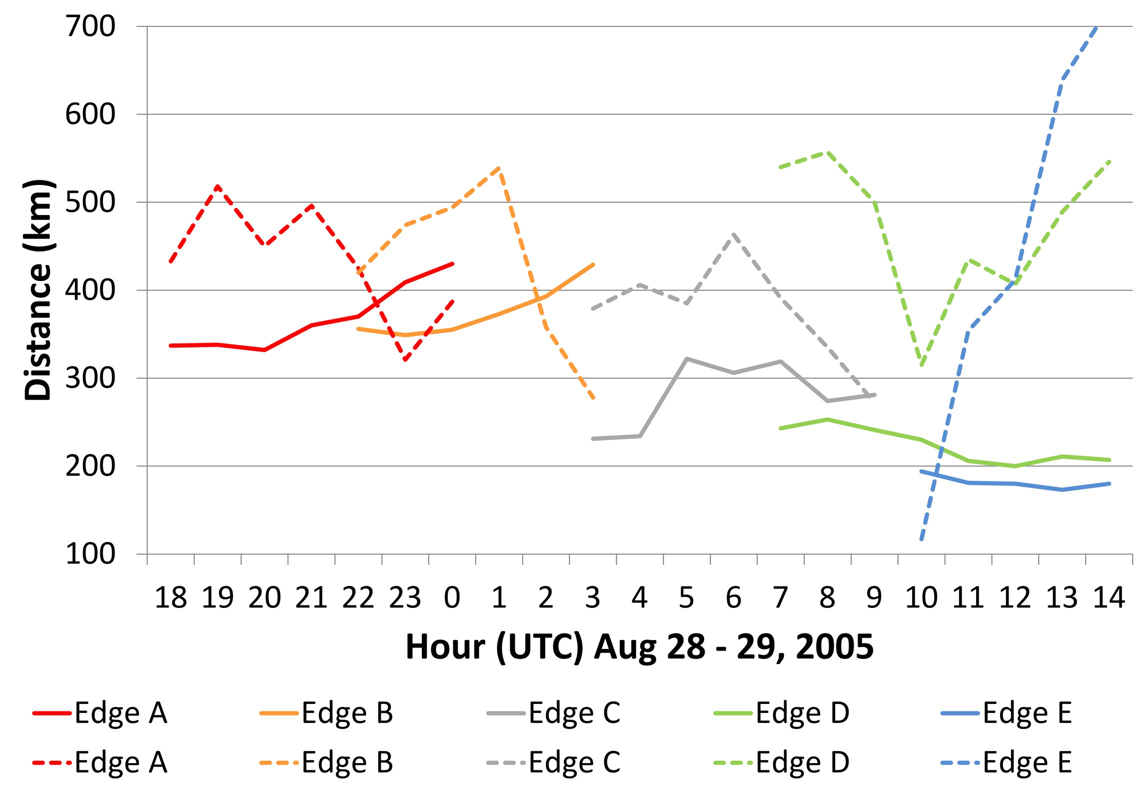
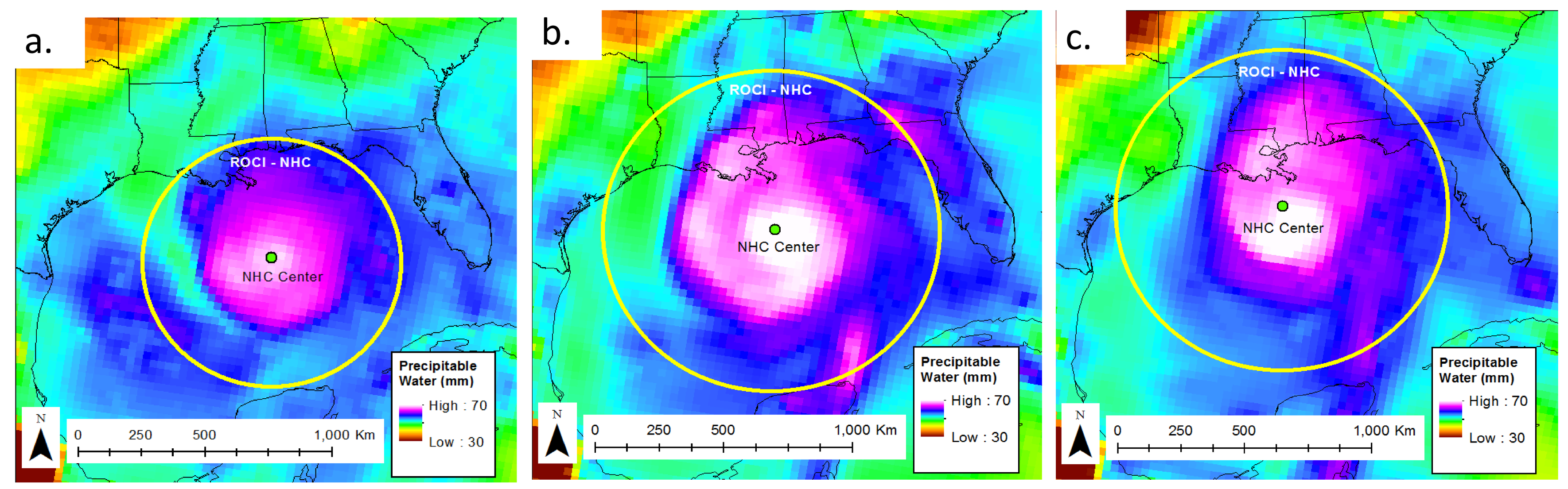


Fig. 4. Distance of each outer rainband from the circulation center (solid) and length of rainband (dashed) each hour.

Rainbands are located farther from the eye (A, B) and expand outwards as they decrease in length (Fig. 4). NARR shows that precipitable water expands (Fig. 5 a, b), and ROCI increases from 555 – 650 km. This is likely due to expansion of the gale-force wind field as Katrina weakens and moves poleward. Increased convergence in the boundary layer as the forward edge of Katrina crosses land could also contribute to the expanding and increasing precipitable water field. Bands C, D, E form 300-180 km from the eye and maintain this distance. However, D and E grow in length towards the end. Rainbands arched along the MS/AL coastline move slowest, then move faster once crossing the coastline. The increased friction at the coastline might play a role in slowing forward progress. Additional studies should explore jointly the roles of frictional convergence and moisture gradients.



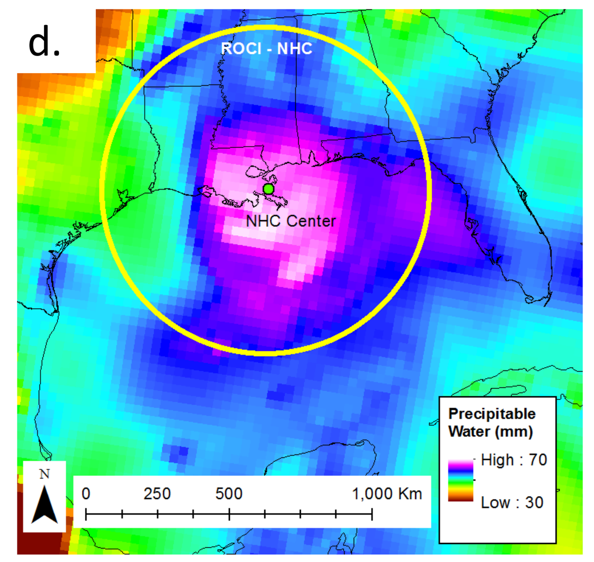


Fig. 5. Precipitable water from NARR at a) 28 Aug. 1800, b) 29 Aug. 0000, c) 29 Aug. 0600, and d) 29 Aug. 1200 UTC. Position of center and radius of outermost-closed isobar (ROCI) reported by NHC are indicated. Katrina's maximum intensity occurs at time a, but NARR analysis (Zick and Matyas 2015a) shows it occurring at time b, explaining the increasing amount and extent of precipitable water. Edge A forms along values of 62 mm at time a, while it dissipates along the gradient from 65 to 55 mm spanning 100 km at time b. Edges B, C, D remain in the region of 62.5 mm. Edge E does not expand away from the storm, but remains near 65 mm values that form a gradient 65 – 45 mm spanning 200 km. Thus, leading edge rainbands may tend to exist on the inside of a moisture gradient of 1 mm per 10 km.

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