Changes in the Spatial Patterns of Precipitation Bands in Hurricanes During Landfall along the Gulf of Mexico and Atlantic Coasts of the United States

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Background

Evolutionary periods of intensity change and precipitation distribution in tropical cyclones (TCs) are sometimes misrepresented in numerical weather prediction models due to the rapid nature of TC development and the importance of mesoscale and convective processes (Luitel, 2016). This study aims to a wholistic approach in contrast to previous case study research to improve our understanding of the evolution of TC precipitation in previous landfalling storms by quantitatively measuring patterns through landfall instead of qualitative assessment of shape. By better understanding changes in precipitation bands around landfall, operational meteorologists will be better equipped to aid in public preparedness and provide improved rainfall forecasts to emergency management personnel.

Objectives

1) Quantify changes in patterns of rainbands during the period around landfall along the Gulf of Mexico and Atlantic coasts of the United States from 1998 to 2014 using 3 spatial measurements (area, closure, dispersion) at 2 precipitation thresholds (0.254 mm hr^{-1} and 5 mm hr^{-1})
2) Determine if significant differences in the 3 metrics exist between Atlantic vs. Gulf of Mexico landfalling storms
3) Cluster storms using a k-means clustering analysis to further determine variability based on landfall location

Data & Methods

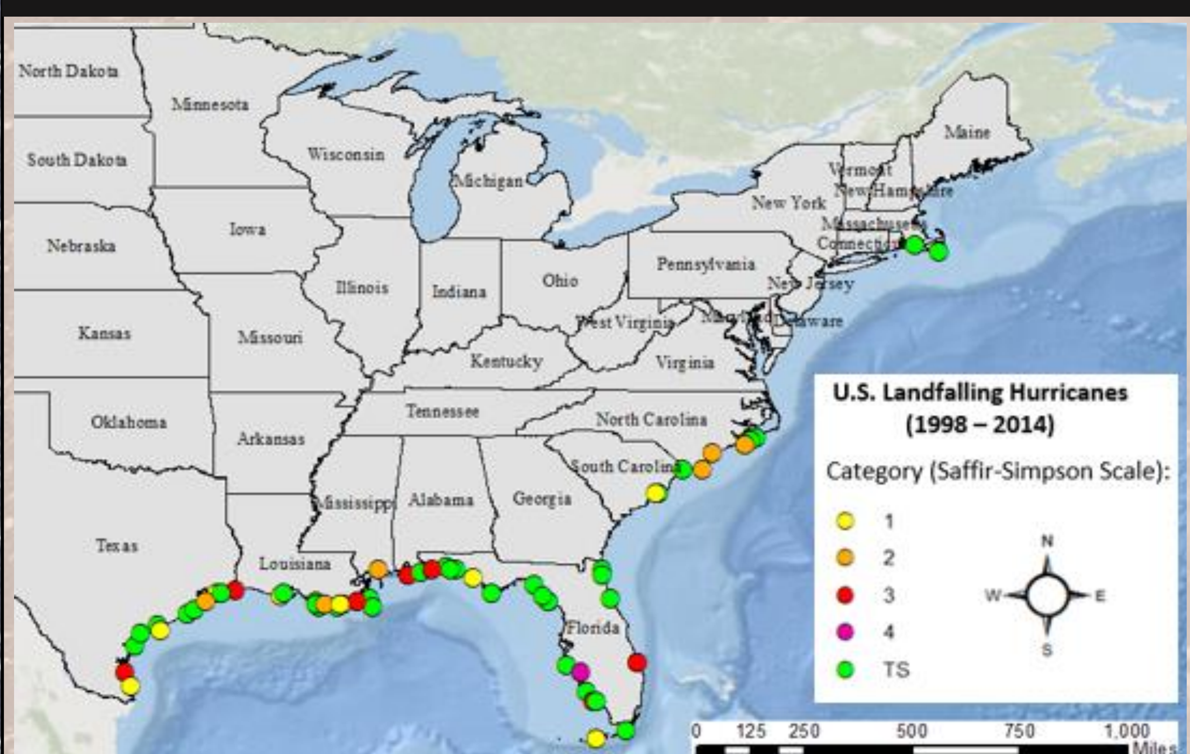

FIGURE 1. Map of all 62 landfalling storms (1998 – 2014) based on intensity and selection criteria.

Data:

- Spline NHC positions every 3 hours
- Tropical Rainfall Measuring Mission (TRMM) 3B42 product, 0.25° × 0.25° resolution with 3-hour instantaneous rain-rate measurements

Storm Selection:

- Must have reached Tropical Storm status upon landfall
- If multiple landfalls, landfall with the most time over land will be selected
- Closest UTC observation time used for landfall (if in between, earlier time is used) and observation time series

Methods:

- Precipitation area, closure (Matyas et. al, submitted, 2017), and dispersion (Zick et al., 2016) (TABLE 1) measurements at 72, 48, and 24 hours prior to landfall; at landfall; and 24 and 48 hours post-landfall for 0.254 mm hr^{-1} and 5 mm hr^{-1} thresholds

Metric	Equation
Area (km^2)	$Area_i$, Combined area of largest precipitation polygons (≥ 100 pixels cluster)
Closure (0,1)	$C = \frac{no. 10° \ angles \ intersecting \ polygons}{360}$
Dispersion (0,1)	$D = \sum_{i=1}^{NC} \frac{Area_i}{\sum_j^{NC} Area_j} \left(\frac{r_{centroid,i}}{r_{search}} \right)$

TABLE 1. NC = # isolated clusters; r_{search} = 600 km; $r_{centroid,i}$ = ratio of the centroid radius

Results

All Storms

Precipitation Threshold	Area (km^2)	Closure (0,1)	Dispersion (0,1)
0.254mmhr^{-1}	-1.020 x 10^5	-0.204	0.166
5mmhr^{-1}	-1.316 x 10^4	-0.158	0.003

TABLE 2. Mean overall change in area, closure, and dispersion for all 62 storms based on 0.254 mm hr^{-1} and 5 mm hr^{-1} thresholds.

Time Interval	Area (km^2)	Closure (0,1)	Dispersion (0,1)	N
5mmhr^{-1}				
-72 to -48	3.718 x 10^3	-0.040	-0.021	38
-48 to -24	1.053 x 10^4	0.090	-0.042	52
-24 to Landfall	5.292 x 10^3	0.057	0.064	59
Landfall to +24	-2.532 x 10^4	-0.276	0.037	62
+24 to +48	-4.499 x 10^3	-0.023	-0.076	55
0.254mmhr^{-1}				
-72 to -48	-3.604 x 10^3	0.012	-0.027	38
-48 to -24	2.024 x 10^3	-0.022	-0.013	52
-24 to Landfall	-1.858 x 10^4	-0.016	0.040	59
Landfall to +24	-5.800 x 10^4	-0.153	0.132	62
+24 to +48	-2.908 x 10^4	-0.077	0.067	55

TABLE 3. Mean overall change in area, closure, and dispersion based on time interval for all 62 storms based on 0.254 mm hr^{-1} and 5 mm hr^{-1} thresholds.

	Area (km^2)	Closure (0,1)	Dispersion (0,1)	N
5mmhr^{-1}				
ET	-2.620 x 10^4	-0.206	-0.083	20
Dissipation	-1.826 x 10^4	-0.203	-0.102	23
0.254mmhr^{-1}				
ET	-1.538 x 10^4	-0.233	0.211	20
Dissipation	-2.250 x 10^3	-0.237	0.136	23

TABLE 4. Mean overall change in area, closure, and dispersion based on extratropical transition (ET) or dissipation later in lifecycle for all 62 storms.

Atlantic Vs. Gulf Landfalls

Landfall Location	Precipitation Threshold	Area (km^2)	Closure (0,1)	Dispersion (0,1)
Atlantic N= 19	0.254mmhr^{-1}	-5.924 x 10^4	-0.132	0.156
	5mmhr^{-1}	6.731 x 10^3	-0.053	0.220
Gulf of Mexico N= 43	0.254mmhr^{-1}	-1.209 x 10^5	-0.235	0.171
	5mmhr^{-1}	-2.195 x 10^4	-0.204	-0.093

TABLE 5. Mean overall change in area, closure, and dispersion metrics based landfall location along the Atlantic or Gulf of Mexico coast.

Time Interval	Area (km^2)	Closure (0,1)	Dispersion (0,1)	N
5mmhr^{-1}				
-72 to -48	1.113 x 10^4	-0.079	0.001	14
-48 to -24	5.231 x 10^3	0.074	0.072	17
-24 to Landfall	1.706 x 10^4	0.127	0.061	18
Landfall to +24	-2.169 x 10^4	-0.229	0.008	19
+24 to +48	-5.004 x 10^3	0.020	0.160	17
0.254mmhr^{-1}				
-72 to -48	-2.463 x 10^3	0.010	-0.073	14
-48 to -24	-1.166 x 10^4	-0.044	0.024	17
-24 to Landfall	-2.875 x 10^3	0.034	0.009	18
Landfall to +24	-4.624 x 10^4	-0.106	0.125	19
+24 to +48	-4.989 x 10^3	-0.058	0.116	17

TABLE 6. Mean overall change in area, closure, and dispersion based landfall location along the Atlantic coast for all 19 landfalling TCs.

Time Interval	Area (km^2)	Closure (0,1)	Dispersion (0,1)	N
5mmhr^{-1}				
-72 to -48	-6.028 x 10^2	-0.017	-0.033	24
-48 to -24	1.311 x 10^4	0.098	-0.098	35
-24 to Landfall	1.289 x 10^2	0.026	0.066	41
Landfall to +24	-3.161 x 10^4	-0.303	0.049	43
+24 to +48	-7.697 x 10^3	-0.076	0.044	38
0.254mmhr^{-1}				
-72 to -48	-4.271 x 10^3	0.014	0	24
-48 to -24	8.673 x 10^3	-0.012	-0.031	35
-24 to Landfall	-2.543 x 10^4	-0.038	0.054	41
Landfall to +24	-7.395 x 10^4	-0.173	0.135	43
+24 to +48	-6.179 x 10^4	-0.053	-0.174	38

TABLE 7. Mean overall change in area, closure, and dispersion based landfall location in the Gulf of Mexico for all 43 storms.

Results

Trends by Cluster

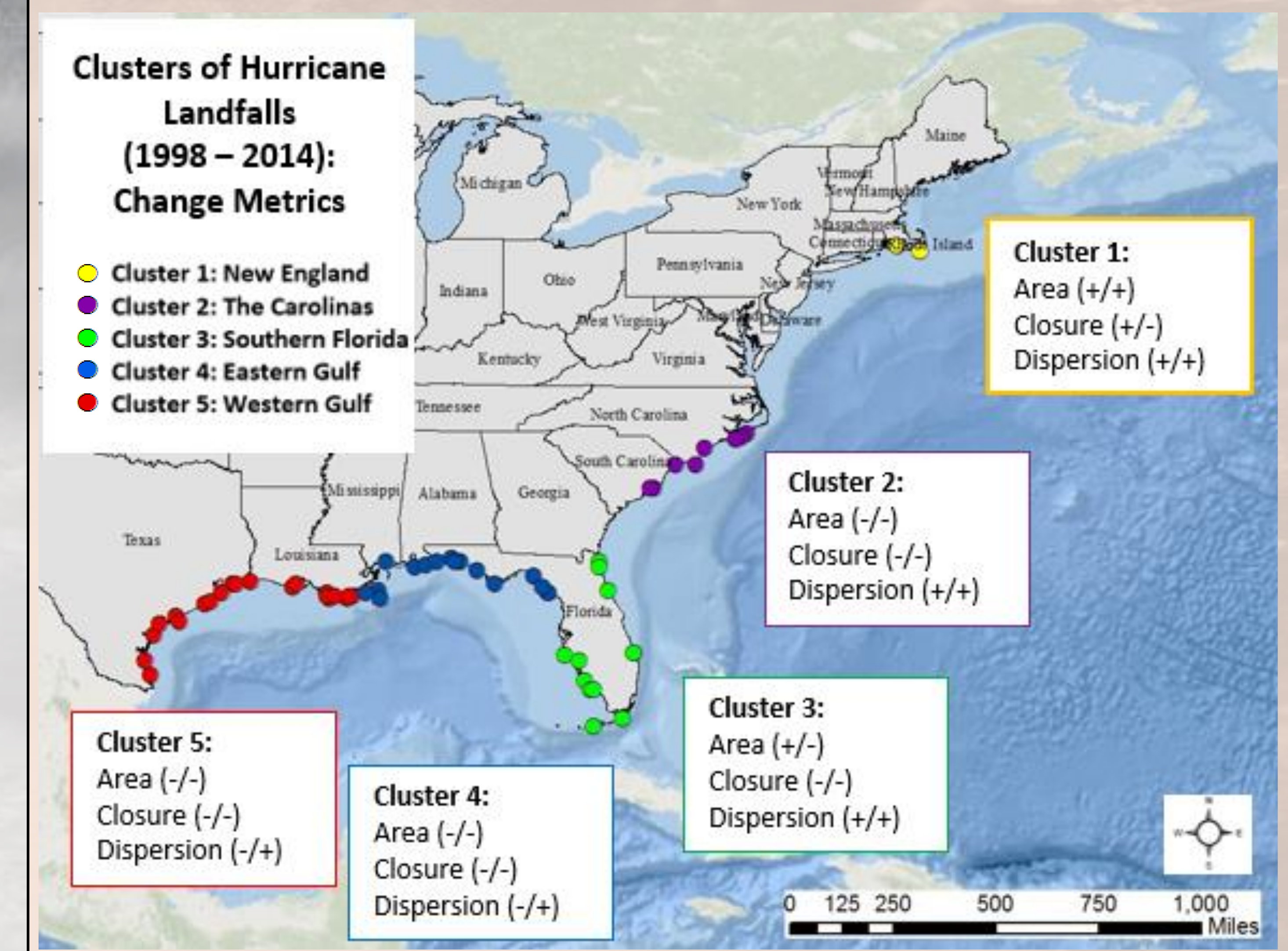

FIGURE 2. Mean overall change, +/- (5mmhr^{-1}, 0.254mmhr^{-1}) in area, closure, and dispersion for clusters based on landfall location. N=5

Cluster	Area (km^2)	Closure (0,1)	Dispersion (0,1)	N
5mmhr^{-1}				
1	1.625 x 10^4	0.389	0.620	2
2	-1.668 x 10^3	-0.161	0.147	10
3	8.670 x 10^3	-0.064	0.031	13
4	-2.680 x 10^4	-0.205	-0.021	16
5	-2.456 x 10^4	-0.230	-0.125	21
0.254mmhr^{-1}				
1	6.914 x 10^4	-0.097	0.291	2
2	-1.290 x 10^5	-0.136	0.176	10
3	-4.455 x 10^4	-0.134	0.102	13
4	-1.292 x 10^5	-0.262	0.193	16
5	-1.203 x 10^5	-0.245	0.169	21

TABLE 8. Mean overall change in area, closure, and dispersion based cluster for all 62 storms at 0.254 mmhr^{-1} and 5 mmhr^{-1} precipitation thresholds.

Discussion & Future Work

Using Tukey-Kramer's HSD and Kruskal-Wallis' nonparametric test for significance between means ($\alpha = 0.05$), the rate of change of precipitation area and closure were found to be statistically different before and after landfall at the 0.254 mmhr^{-1} and 5 mmhr^{-1} threshold levels. Only the dispersion metric for Atlantic vs. Gulf landfalling storms is statistically significant at both rain rates and neither ET or dissipation was shown to influence mean metrics around landfall (-72 to +48). Due to little differences in the average area, closure, and dispersion metrics and small sample size, it is not surprising that there are little significant differences between clusters. Figure 2, however, expresses interesting trends for the metrics at each cluster location. Future work should aim to include Global Precipitation Measurement (GPM) data to increase the sample size, including most recent storms, and compare results to TCs in other ocean basins.

References

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