A Climatological Analysis of the Extent of Rainfall Produced Over the U.S. by Atlantic Basin Tropical Cyclones

CAREER Award
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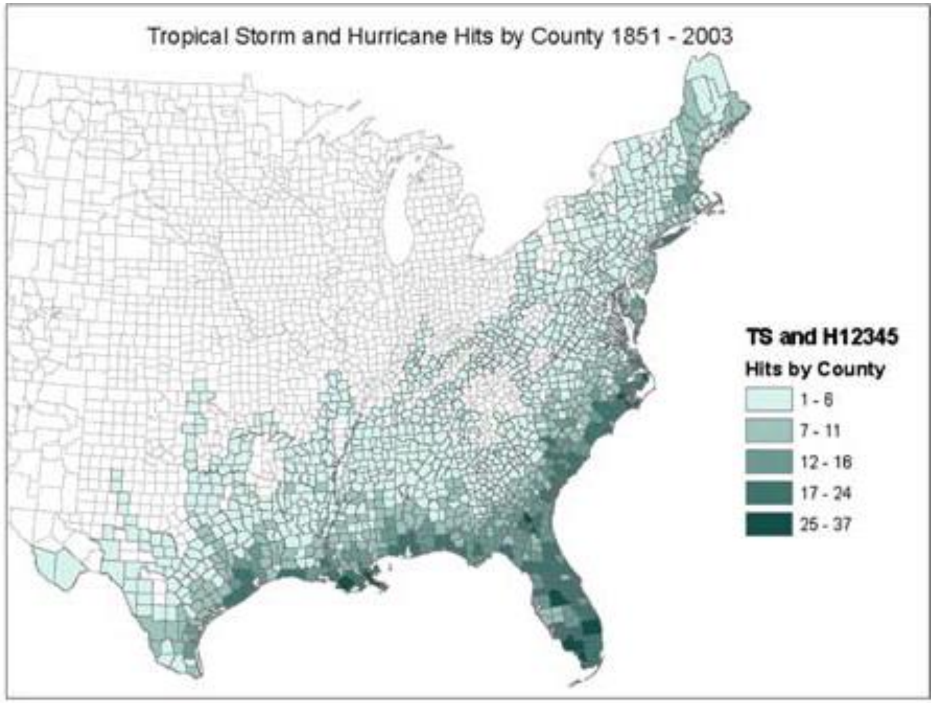
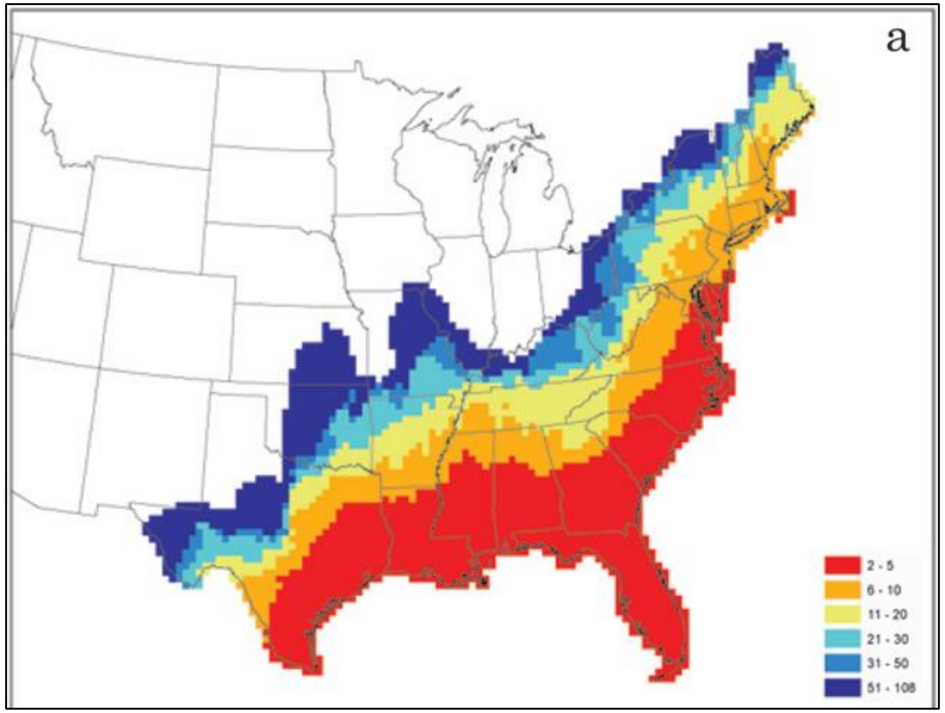
Motivation

- Previous studies estimated inland TC wind frequency (Zandbergen, 2009; Kruk et al., 2010)
- Lack of a similar study for TC precipitation



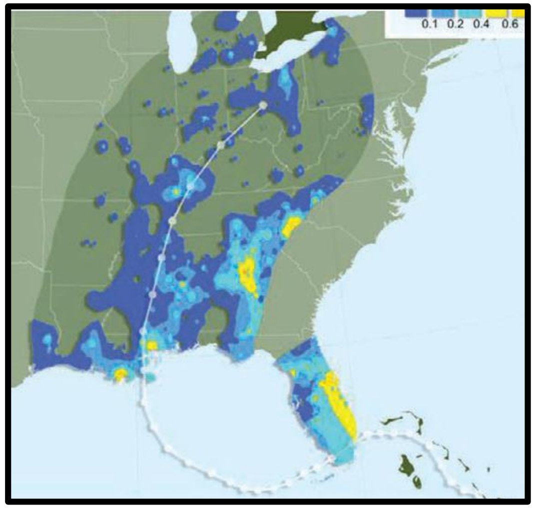
Tropical Storm and Hurricane Hits by County 1851-1999 (Zandbergen 2009)



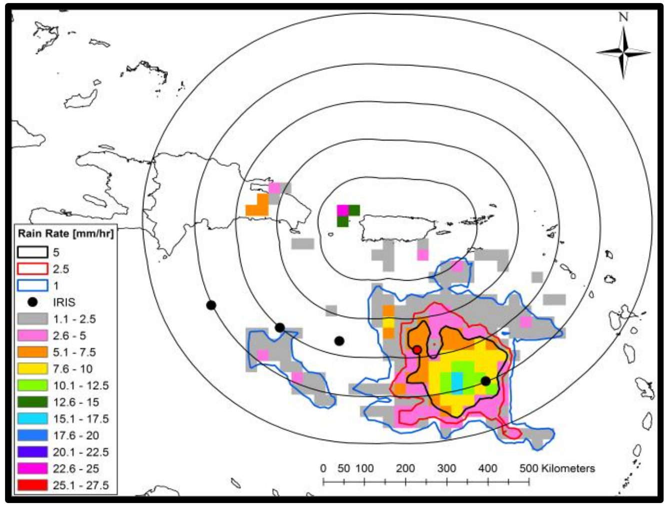
Return intervals in years for tropical storm–force winds (Kruk et al. 2010)

Identifying TC Rainfall

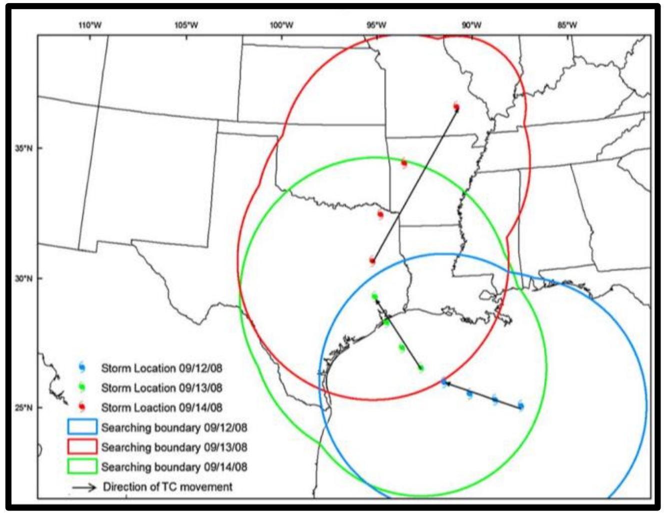
- Precipitation may arise from nearby weather systems such as fronts in addition to rainfall directly produced by the TC
- Methods from previous research:
  - Searching a uniform radius (e.g. 500-600 km, Lonfat et al., 2007; Nogueira and Keim, 2010; Villarini et al., 2011; Hernandez and Matyas 2016)
  - Searching multiple uniform circles (Konrad et al. 2002)
  - Utilizing the radius of outmost closed isobar (ROCI) (Zhu and Quiring, 2013)
- May underestimate or overestimate TCP area



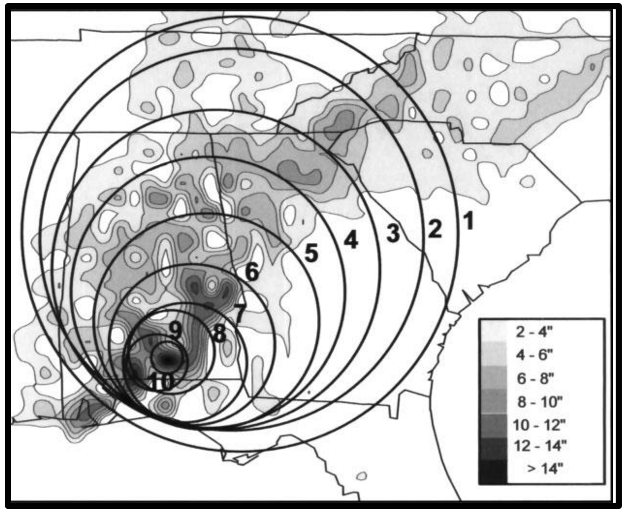
Katrina in 2005 (Villiarni et al. 2011)



Iris in 2001 (Heslar, Matyas, and Hernandez 2017)



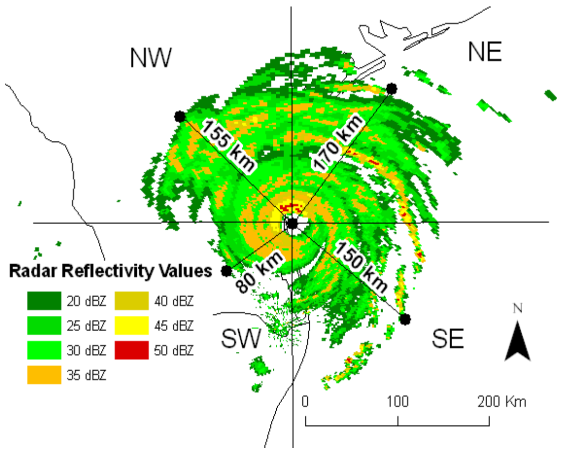
Ike in 2008 (Zhu and Quiring 2013)

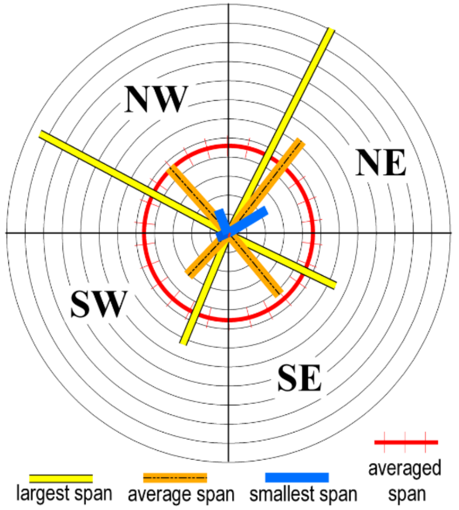


Opal in 1995 (Konrad et al. 2002)

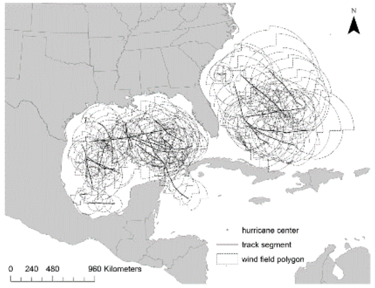
Measuring TC Rain Field Extent

- Matyas (2010) used 20 dBZ values of ground-based radar reflectivity to define edge of rain field
  - Average extent 223 km for 31 hurricanes at landfall
  - Moisture and vertical wind shear are key predictors
  - Rain fields can extend beyond radius of gale-force winds



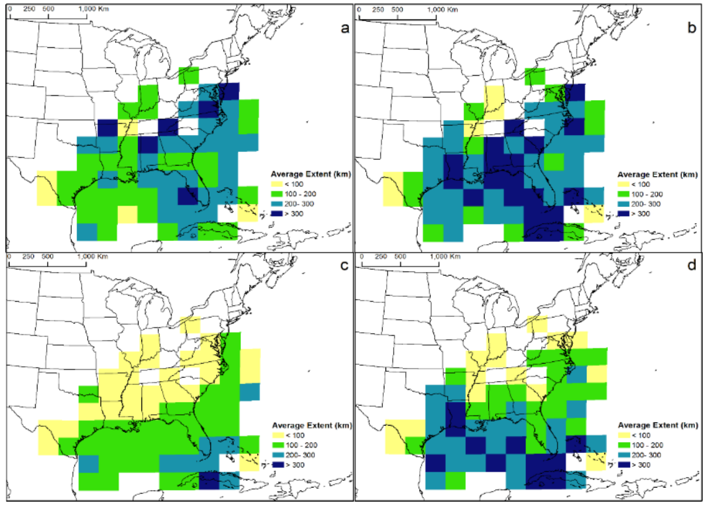


- Guo and Matyas (2016) used 5 mm h^{-1} rain rate from satellite-based dataset
  - Only considered observations over ocean
  - Wind and rain fields not always strongly correlated



Quadrant	Correlation coefficient
NE	0.364**
SE	0.194*
SW	0.227*
NW	0.473**

- Zhou and Matyas (in preparation) used 2.5 mm h^{-1} rain rate from satellite-based dataset
  - Left front quadrant can increase in size after landfall
  - Left side smaller western Gulf and after landfall TX
  - Moisture and 200 hPa divergence are key predictors



Research Objectives

- Construct a spatial climatology of rainfall from Atlantic Basin TCs
  - Develop a Geographic Information System (GIS)-based method to delineate the outermost extent of TC rainfall
  - Measure the extent of rainfall swaths for all TCs
  - Examine the trend of rainfall extent to the left of track and explore TC attributes related to these trends
  - Estimate return interval and cumulative frequency for receipt of TC rainfall events at the county level; compare to TC wind events

Data

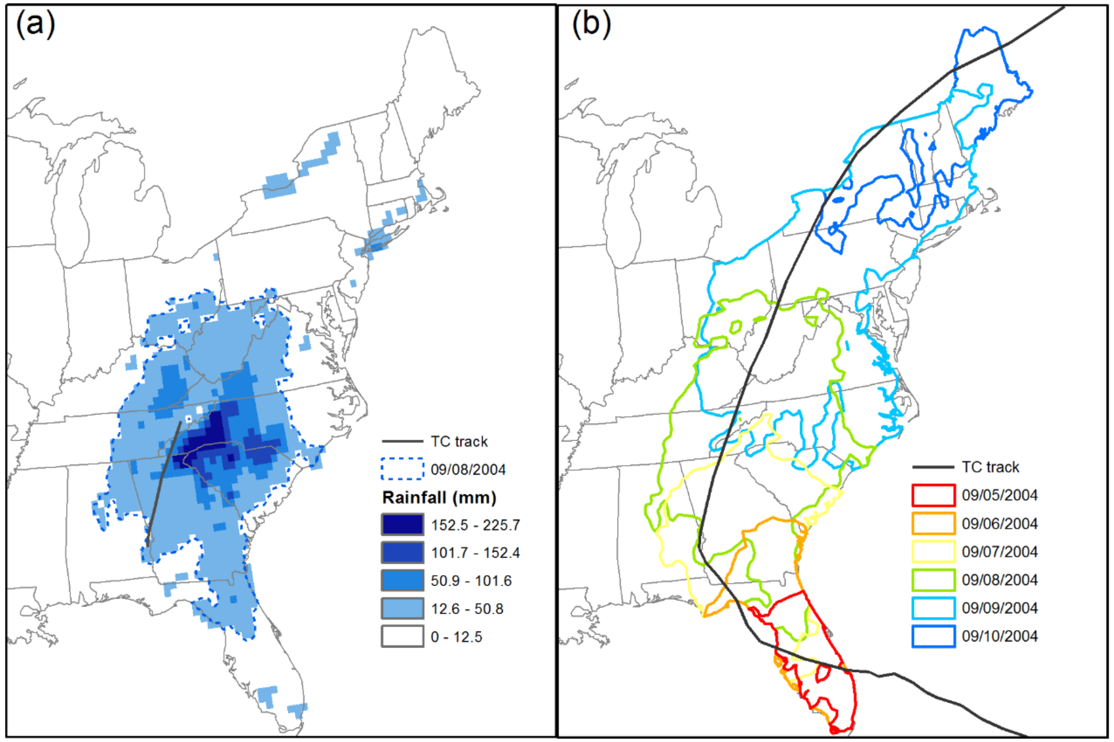
- Daily precipitation data:
    - Unified precipitation dataset (UPD) from Climate Prediction Center (CPC-NCEP)
    - Rain gauge-based (1200-1200 UTC); interpolated using a Optimal Interpolation scheme (Higgins et al., 2007, Higgins and Kousky, 2013)
    - 0.25°× 0.25° latitude-longitude grid; Contiguous U.S. (1948 – present)
    - Used in East Pacific TC rainfall study (Corbosiero et al. 2009)

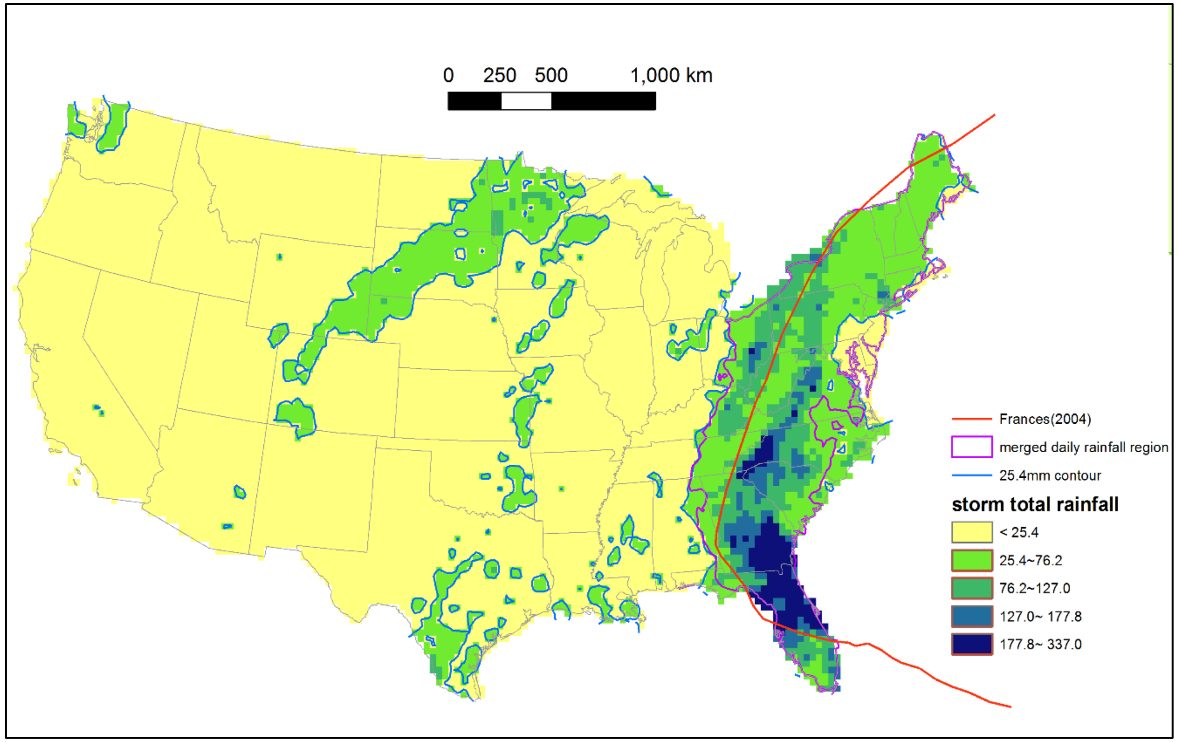
- TC position and intensity:
    - International Best Track Archive for Climate Stewardship (IBTrACS) (Knapp et al. 2010)
    - 6-hour location and intensity of TC center (1851-present)
    - **257 TCs producing rainfall over eastern U.S. (1948-2014)**

- Demise-type information extracted from National Hurricane Center's storm reports (http://www.nhc.noaa.gov/data/tcr/)

Methods

- Define daily TC precipitation features (PFs)
  - 12.5 mm/day contour polygons (Konrad et al., 2002; Ensor and Robeson, 2008)
  - Centroids within 550km of daily track
- Merge daily TC PFs to get storm total TCP swaths
  - From time entering 550 km range of the U.S.
  - To time dissipated over land or left 550 km range of U.S.
  - Remove polygons < 3360 km^2



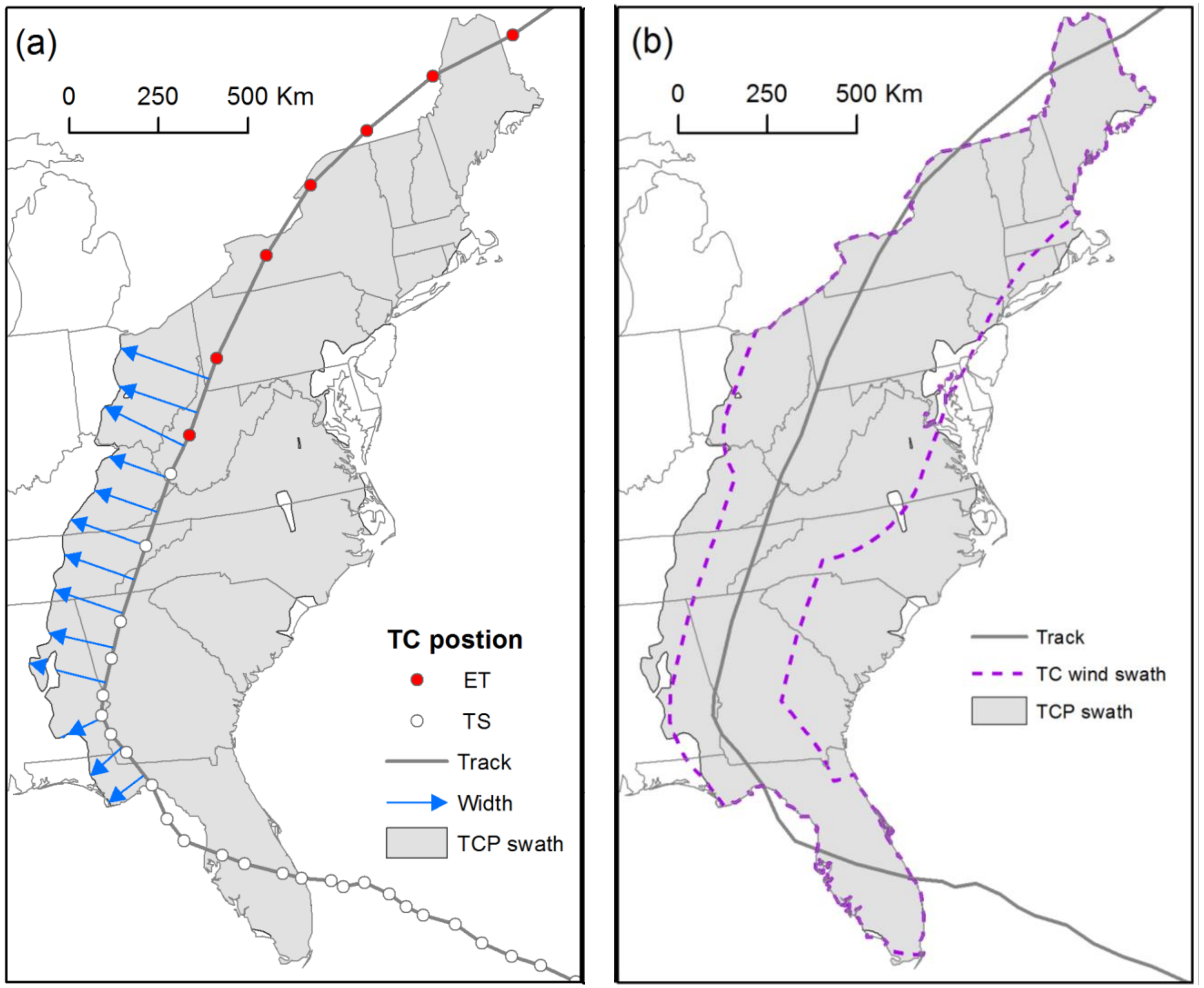


Analysis for Frances in 2004

Methods

- Measuring swath width
  - Equal-distance projection
  - Draw straight lines perpendicular to track every 10 km
  - Calculate line length
  - Exclude points where edge of swath located on the U.S. border or coastline

- Methods of constructing wind swaths from Kruk et al. (2010)
- Replicating all wind swaths of storm-force wind (+ 17ms^{-1}) for all 257 TCs



Averages of radii for 17-ms^{-1} wind (unit: km) (Kruk et al., 2010)

Category	PT	TS	Category 1	Category 2	Category 3	Category 4-5
Left radius	217	121	148	211	221	208
Right radius	357	186	240	300	328	268

Results

	Gulf Coast	Florida	East Coast
TC cases	104	108	53
Mean TC days	2.1	1.5	1.1

Spatial characteristics of TCP swaths in landfalling groups (width unit: km)

Gulf Coast

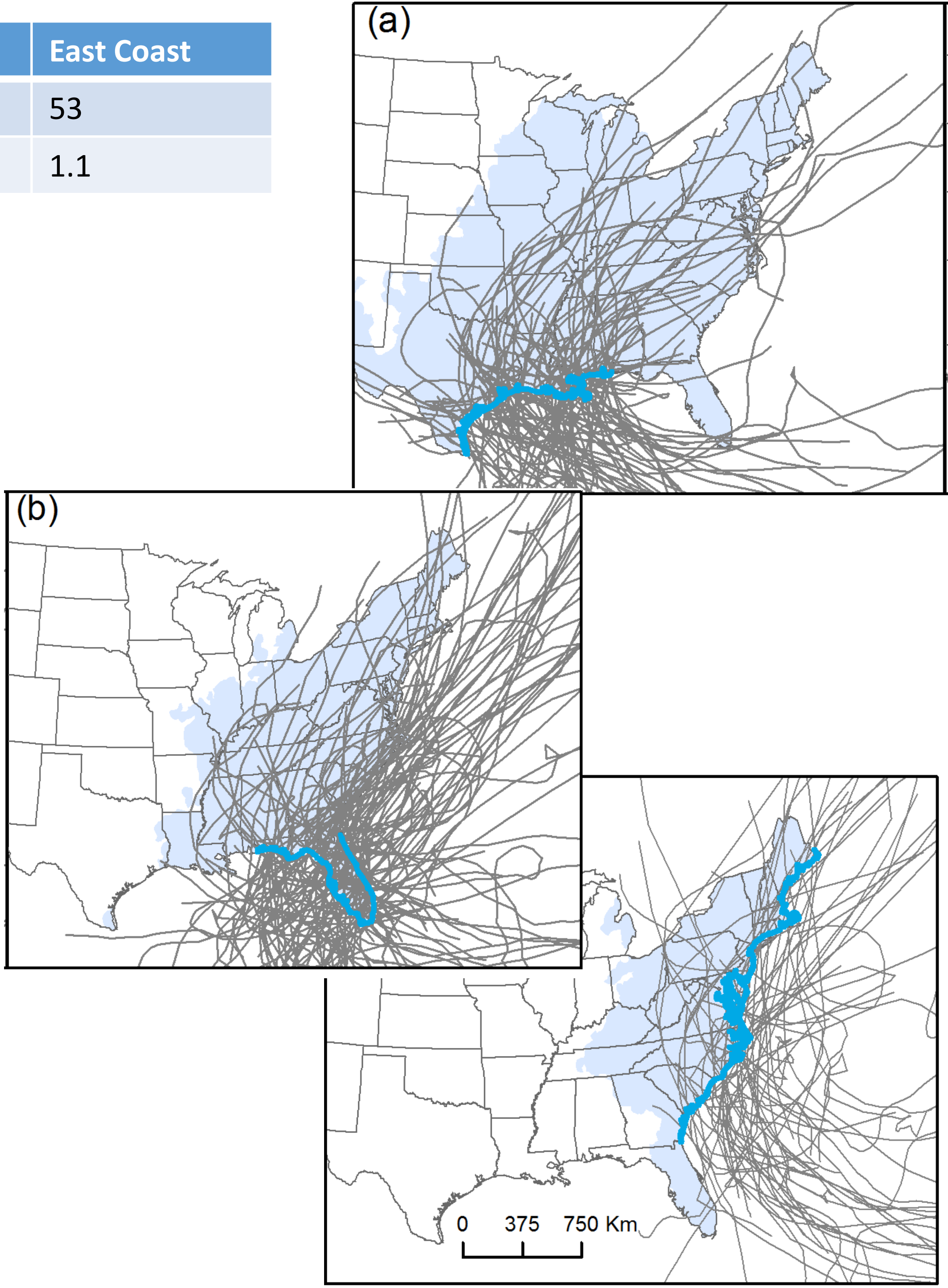
Storm-total period	Variables	Number of cases	Average	Std. Deviation	Percentile		
					25	50	75
< 1 day	Left Width	12	144	130	33	95	274
	Right Width	9	269	165	70	329	377
1-3 days	Left Width	41	189	120	98	165	263
	Right Width	42	316	186	197	306	398
> 3 days	Left Width	23	236	173	120	204	298
	Right Width	21	264	115	154	272	376

Florida

Storm-total period	Variables	Number of cases	Average	Std. Deviation	Percentile		
					25	50	75
< 1 day	Left Width	34	241	126	149	231	322
1-3days	Left Width	24	217	99	147	188	257
> 3 days	Left Width	17	241	72	190	222	282

East Coast

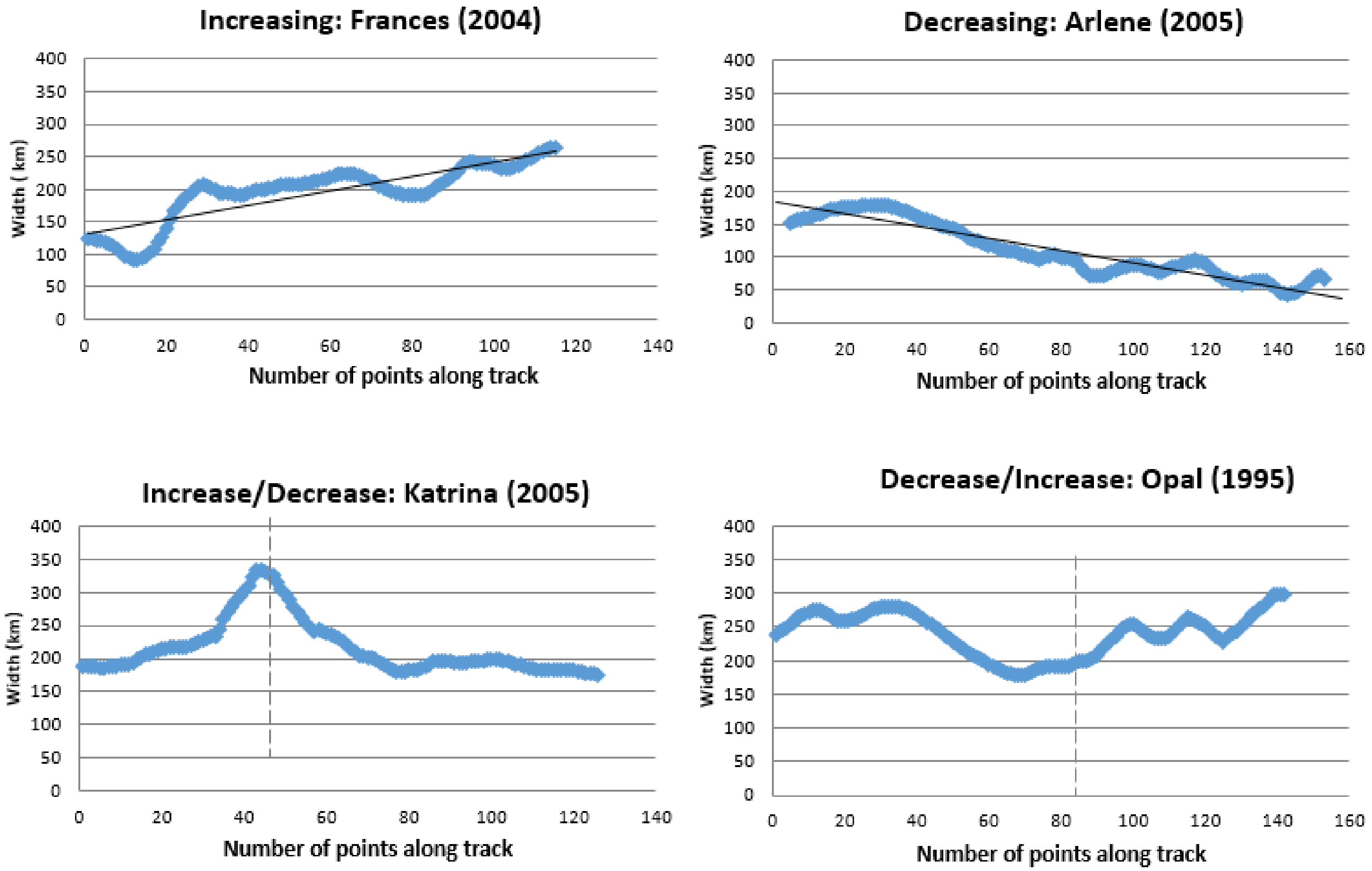
Storm-total period	Variables	Number of cases	Average	Std. Deviation	Percentile		
					25	50	75
< 1 day	Left Width	46	228	90	174	223	277
>1 day	Left Width	21	238	75	182	222	297



Trends in Left Side Extent

- 85 TCs spending >1.5 days over land with rainfall swath length > 500km
- Linear regression to test overall trend (R^2 => 0.3)
- Join point regression for cases with change in trend ($R^2 < 0.3$)
- Classify into 4 groups :
  - Increasing trends (Group I)
  - Decreasing trends (Group II)
  - Increasing-decreasing trends (Group III)
  - Decreasing-increasing trends (Group IV)

Examples for each group

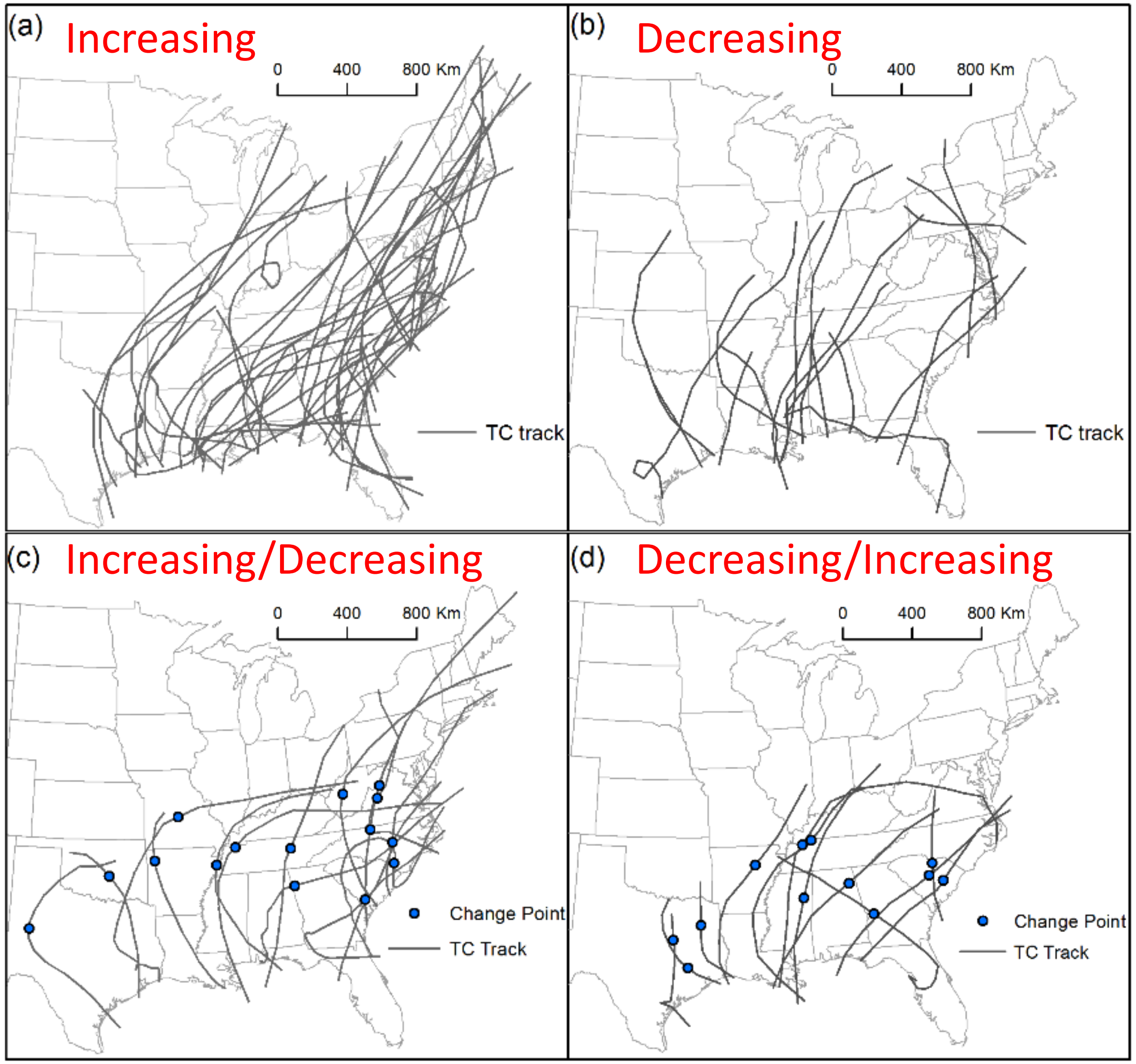


Results

- Change magnitude calculated by subtracting the first width measurement from the last of a segment with a significant trend

Chi-square test results

Attributes	$\chi 2$	*p*-value	Sub-category	Count	
Landfall intensity	5.914	0.015		I and III	II and IV
			TD and TS	18	18
			HU	**37**	12
Re-intensify over land	8.910	0.003	True	**25**	4
			False	30	26
Moved back over ocean	5.559	0.018	True	**23**	5
			False	32	25
Dissipated over U.S.	11.814	0.001	True	11	17
			False	**44**	13
Completed extratropical transition	5.686	0.017	True	**35**	11
			False	20	19

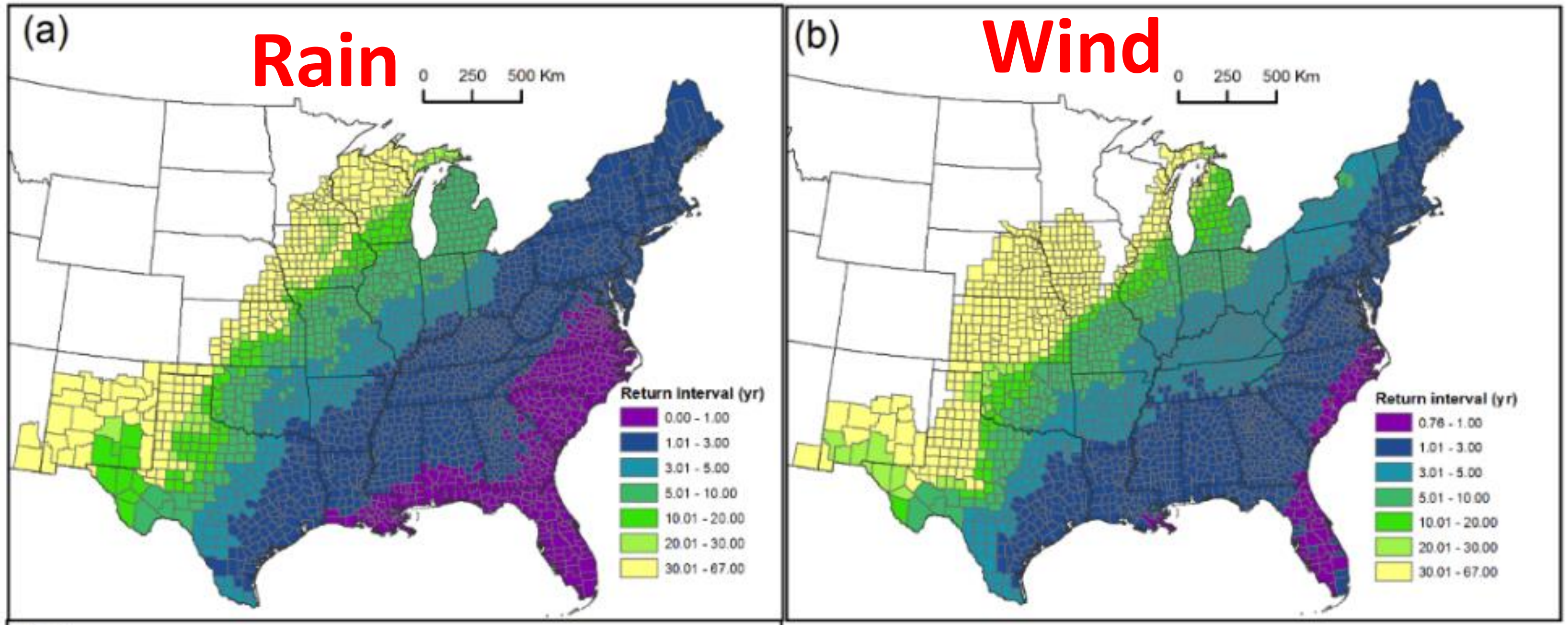


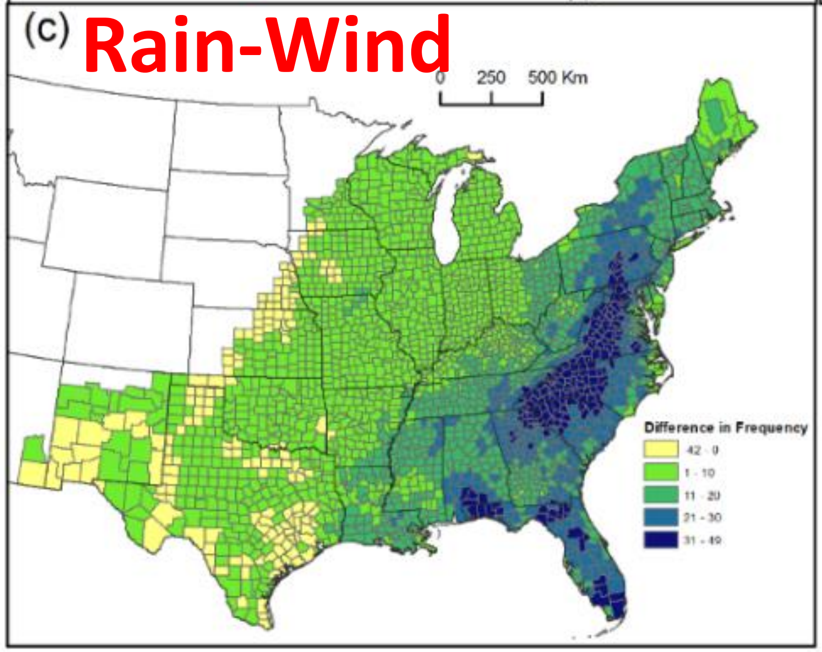
	Group I		Group II		Group III		Group IV	
Number of TCs	40		18		15		12	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Total change	212	190	-98	-81	63	55	-37	-19
Increasing segment	/	/	/	/	134	106	96	97
Decreasing segment	/	/	/	/	-73	-66	-133	-127

TC tracks and change points in : (a) Group I with increasing trend, (b) Group II with decreasing trend, (c) Group III with increasing-decreasing trend, (d) Group IV with decreasing-increasing trend (Units : Km)

Results

- Return intervals of TC rainfall and wind events
- 2435 counties in 25 states affected at least once
- 278 fewer counties receive one wind event per year as compared to those receiving one rainfall event per year
- Only 6% of counties received more wind than rain events (TX, NM)





(a) Return interval of TCP events per county
(b) Return interval of TC wind events per county
(c) Difference in cumulative frequency of rainfall and wind events of TCs

Conclusions and Future Research

- Average left width: 196 km Gulf Coast; 233 km Florida; 222 km East Coast
- Average right width: 295 km Gulf Coast
- Support Matyas (2010), useful for hydroclimatic studies (e.g., Knight and Davis 2007), baseline for future studies under climate change scenarios (e.g., Wright et al. 2015)
- More TCs have rainfall expansion on the left side than contraction
- Expanding width attributes: higher intensity at landfall, re-intensifying over land, undergoing ET, and/or a position near the coastline
- Most counties are exposed more to rainfall than wind from TCs, especially near the Appalachian Mountains
- Key limitation: Spatial and temporal resolution of gridded rainfall
- Zhou and Matyas (in preparation) measure rainfall extent in each quadrant every 3 hours; correlate with environmental conditions

Shapefiles of rainfall swaths are available: contact **Matyas@ufl.edu**