S128

THE STRUCTURE AND EVOLUTION OF TROPICAL CYCLONES IN THE NORTH ATLANTIC OCEAN BASIN

Ajay Raghavendra
Embry-Riddle Aeronautical University
600 S. Clyde Morris Blvd.
Daytona Beach, FL 32114

Faculty Advisors : Dr. Randell J. Barry and Dr. Christopher G. Herbster

Introduction: Tropical cyclones are a diverse phenomenon coming in many shapes, sizes and strengths. Our research is aimed at analyzing the structure and evolution of tropical cyclones in the North Atlantic Ocean.

Method: Using the Extended Best Track (EBT) dataset we have documented the size, structure, and seasonal evolution of the wind field associated with tropical cyclones in the North Atlantic Ocean. The latest version of this data set runs from 1988 to 2012 (version 2.01 - Feb 2012). Analyses, including a statistical analysis, have been conducted for the area of wind speeds greater than 17 ms^{-1}(tropical storm force), 25 ms^{-1}, and 33 ms^{-1}(hurricane force) and storm asymmetry.

Method (Cont.):

Quality control (QC) was conducted on the data set and inconsistent data along with data points which made landfall were eliminated. An asymmetry index was developed and, storm asymmetry was calculated for each observation and analyzed.

Discussion: The largest storm recorded was Tropical Storm Rafael (2012) with an estimated storm force wind area of 763486 km^2 and smallest storm recorded was Tropical Storm Karl (2010) with an estimated storm force wind area of 157 km^2. The largest area of hurricane force winds recorded was Hurricane Maria (2005) with an estimated area of 74500 km^2.

Discussion(Cont.):

The month that displays maximum storm activity (i.e., the greatest number of tropical cyclone events) was also the month containing the largest median value for the three aerial wind fields. Most tropical cyclones display a symmetric structure with the median values of the asymmetry index being 0.31, 0.28 and 0.13 for the 17, 25 and 33 ms^{-1} wind fields respectively. It is interesting to note that in the analysis of the entire data set the 17 ms^{-1} wind field indicates the most asymmetry. However, in the analysis of the subset containing tropical cyclones with wind speeds greater than 33 ms^{-1}, the 17 ms^{-1} wind field is more symmetrical that the 33 ms^{-1} wind field (see Graph 1 a. and b).

Formulae used to calculate the Asymmetry Index

1. Area of a windfield e.g. 17 m/s area

$$Area_{17\,m/s\,winds} = \frac{\pi}{4}(r_{NE}^2 + rSE^2 + r_{SW}^2 + r_{NW}^2)$$

2. Area based storm asymmetry i.e.

$$\frac{\frac{\pi}{4}(r_{NE}^2 + r_{SE}^2 + r_{SW}^2 + r_{NW}^2)}{\frac{\pi}{4}(Max\; r_{NE}, r_{SE}, r_{SW}, r_{NW})}$$

Results in a dimensionless value between 0.25 and 1.

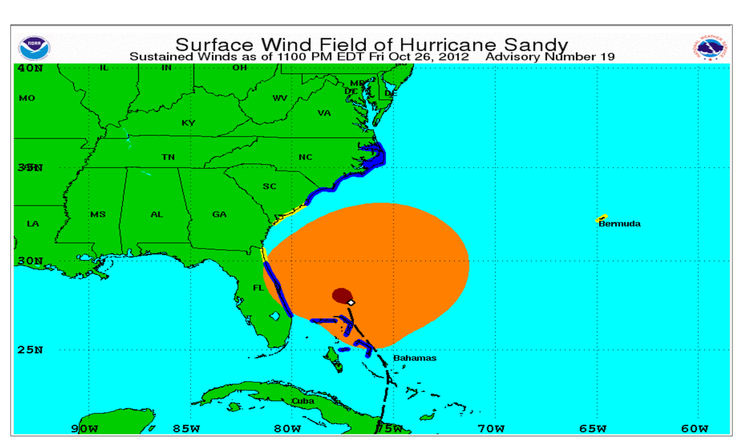
3. Radii based storm asymmetry i.e.

$$\frac{Std.Deviation\;(r_{NE}, r_{SE}, r_{SW}, r_{NW})}{Average\;(r_{NE}, r_{SE}, r_{SW}, r_{NW})}$$

Results in a dimensionless value between 0 and 2.

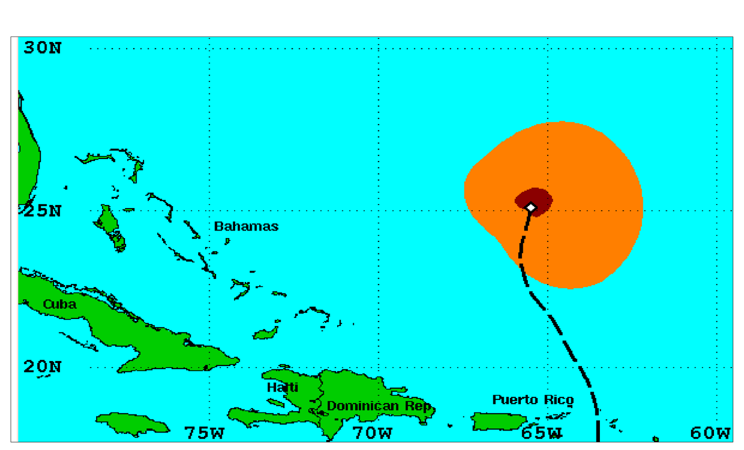
Visualizing the Asymmetry Index

Fig.1 Hurricane Sandy (2012)
Surface Wind Field of Hurricane Sandy
(Sustained winds as of 1100 PM AST Mon Oct 26, 2012)



Hurricane Sandy (2012) was a system with a asymmetry index value of 2.0 for the 33 ms^{-1} and 0.395 for the 17 ms^{-1} windfield.

Fig.2 Hurricane Rafael (2012)
Surface Wind Field of Hurricane Rafael
(Sustained winds as of 1100 PM AST Mon Oct 15, 2012)



Hurricane Rafael was a system with a asymmetry index value of 0.75 for the 33 ms^{-1} and 0.425 for the 17 ms^{-1} wind field.

Credit: Fig 1 and 2 to The National Hurricane Center (NHC) Graphics Archive . (http://www.nhc.noaa.gov/data/#advisories)

13th Annual AMS Student Conference: Opportunities in the New Job Climate and Beyond 1st and 2nd February 2014 as part of the 94th AMS Annual Meeting in Atlanta, Georgia

Table 1. Statistical analysis of the 17, 25 and 33 m/s wind area

Statistics on Storm Area	Values in Sq. Km			Values in 1° X 1° Lat/Long Boxes		
	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s
MAXIMUM	763486	345025	74534	61.8547	27.952649	6.0384848
90th Percentile	117342	42302	16081	9.5066367	3.4271105	1.3028238
75th Percentile	61850	19635	8345	5.0108607	1.5907494	0.6760685
MEDIAN	29452	8580	2827	2.3861241	0.6951575	0.2290679
25th Percentile	12900	3937	1433	1.0451224	0.3189453	0.1161247
10th Percentile	6042	1649	785	0.4894736	0.133623	0.06363
MINIMUM	157	39	79	0.012726	0.0031815	0.006363
MEAN	51331	16665	6351	4.1586219	1.3501173	0.5145406
STD. DEV	65976	21763	7848	5.3451036	1.7631712	0.6358429
NO. OF RECORDS	6628	4198	2631			

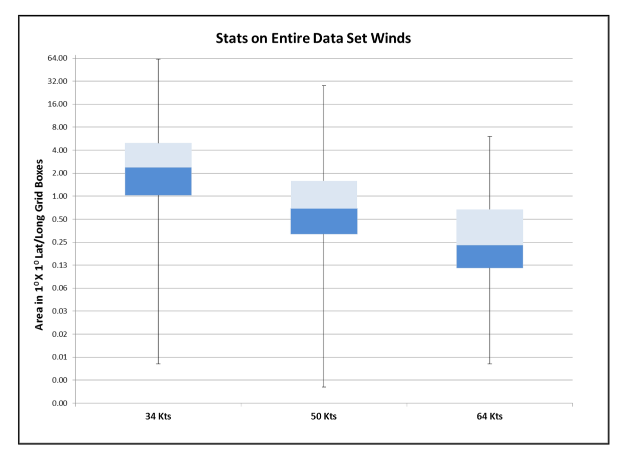


Table 2. Statistical analysis of the 17 m/s, 25 m/s and 33 m/s wind radii by quadrant.

Statistics of the 17,25, 33 m/s Wind Radii by Quadrant (Value in Km)	17 m/s				25 m/s				33 m/s			
	NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW
MAXIMUM	600	600	640	600	550	300	330	360	180	250	150	180
90th Percentile	220	200	175	180	125	125	100	110	90	75	60	75
75th Percentile	160	150	125	150	100	90	75	75	60	50	40	50
MEDIAN	120	100	80	100	60	60	50	50	30	30	30	30
25th Percentile	75	75	50	60	40	40	30	40	25	25	20	25
10th Percentile	50	50	30	40	30	25	25	25	20	20	15	20
MINIMUM	10	10	10	10	5	5	10	10	10	10	5	10
MEAN	128	120	97	109	73	69	57	63	46	41	34	39
STD. DEV	72	72	67	68	45	43	35	39	29	27	18	23
NO. OF RECORDS	6424	6238	5420	5878	4040	3804	3331	3597	2537	2440	2166	2277

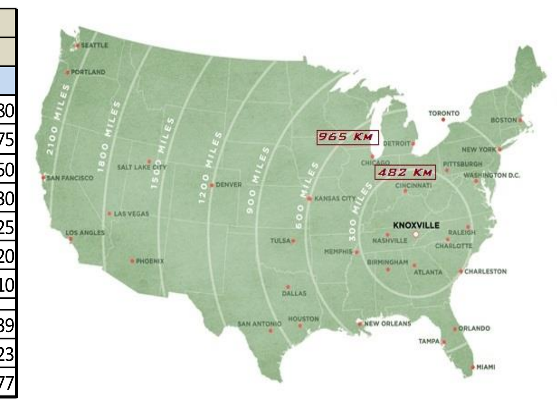


Table 3. Statistical Analysis of Storm Force Wind Area by Geographical Region

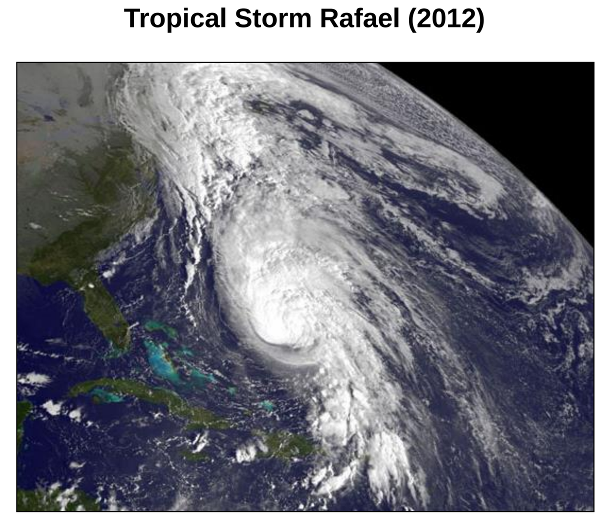
Statistics of Storm Area and Asymmetry by Geographical Area

	GULF OF MEXICO			CARABIAN SECTOR			EAST COAST			NORTH ATLANTIC			SOUTH ATLANTIC		
STORM AREA															
	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s
MAXIMUM	208621	98175	40252	178678	98175	40252	541296	149717	43118	763486	172473	74534	591012	345025	37365
90th Percentile	97342	37591	20273	68644	27650	11891	122954	51510	22070	374918	118202	74534	110961	33379	12763
75th Percentile	53034	20062	12468	43266	16081	6440	76576	35323	14137	229022	73140	21461	54664	16621	5478
MEDIAN	28471	11104	5360	21108	6372	2611	35343	13862	8306	135717	40998	13254	28274	7854	2827
25th Percentile	12763	3848	1900	9817	2042	982	15188	5341	2729	67402	23091	9763	12763	4251	1414
10th Percentile	5400	1455	982	5027	982	511	6597	2121	1257	36600	9052	4178	6362	1963	844
MINIMUM	707	314	177	157	39	79	491	177	157	3004	314	982	353	177	79
MEAN	40548	16212	8699	30438	10921	4825	56835	22335	9864	169380	52320	22844	47747	14084	5002
STD. DEV	38379	17496	8993	28264	12422	6015	64589	22141	8989	133916	39213	24758	59643	20041	6124
STORM ASYMMETRY															
	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s
MAXIMUM	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
90th Percentile	1.178	1.225	1.155	1.155	1.245	1.155	1.155	1.164	1.164	1.155	2.000	1.185	1.155	1.155	1.155
75th Percentile	0.766	0.719	0.667	0.731	0.883	0.667	0.688	0.727	0.777	0.756	1.165	1.155	0.495	0.467	0.354
MEDIAN	0.410	0.373	0.360	0.385	0.339	0.250	0.339	0.348	0.385	0.427	0.445	0.667	0.266	0.231	0.163
25th Percentile	0.225	0.230	0.222	0.222	0.182	0.128	0.196	0.185	0.210	0.240	0.269	0.264	0.133	0.000	0.000
10th Percentile	0.164	0.133	0.131	0.105	0.000	0.000	0.115	0.080	0.088	0.164	0.168	0.206	0.000	0.000	0.000
MINIMUM	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.192	0.000	0.000	0.000
MEAN	0.551	0.589	0.501	0.534	0.568	0.451	0.502	0.537	0.567	0.559	0.759	0.697	0.393	0.377	0.311
STD. DEV	0.429	0.540	0.411	0.458	0.569	0.504	0.460	0.509	0.508	0.458	0.603	0.474	0.406	0.477	0.457
NO. OF RECORDS	393	238	136	987	628	405	1258	825	535	265	144	29	3725	2363	1526

Hurricane Maria (2005)

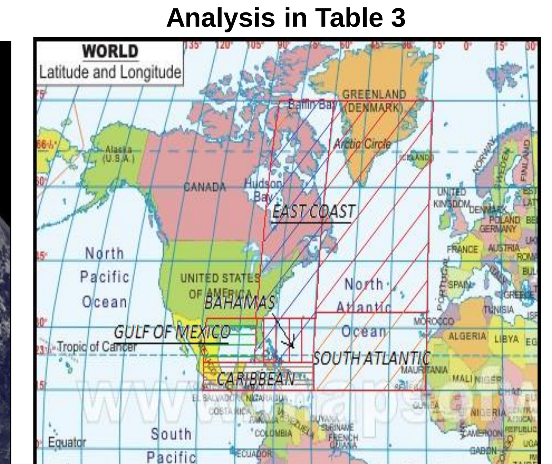
Credit: MODIS Aqua RGB using the MOD02HKM product. This image is of the swath data from Sept 08 at 1640 hrs

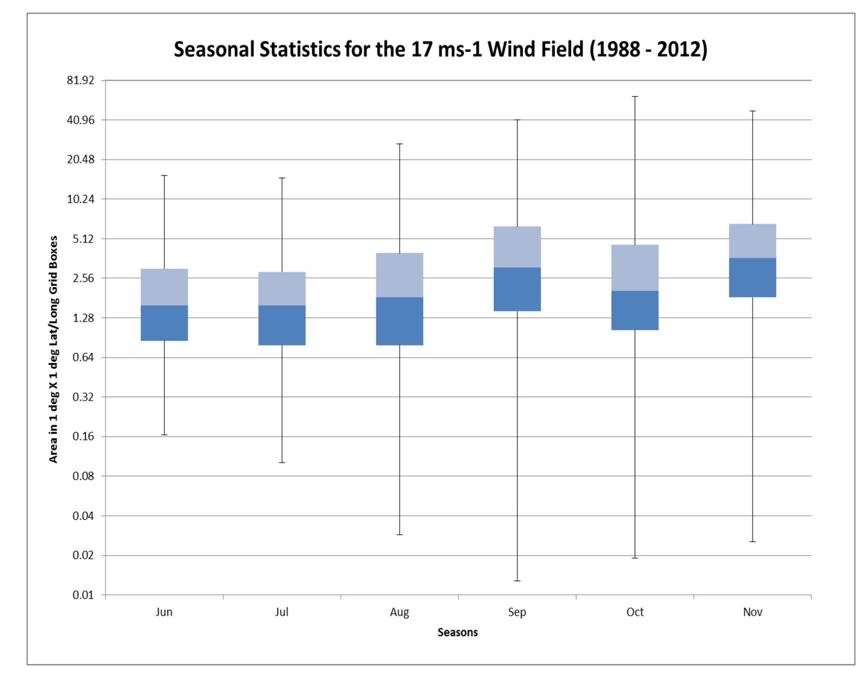
Tropical Storm Rafael (2012)

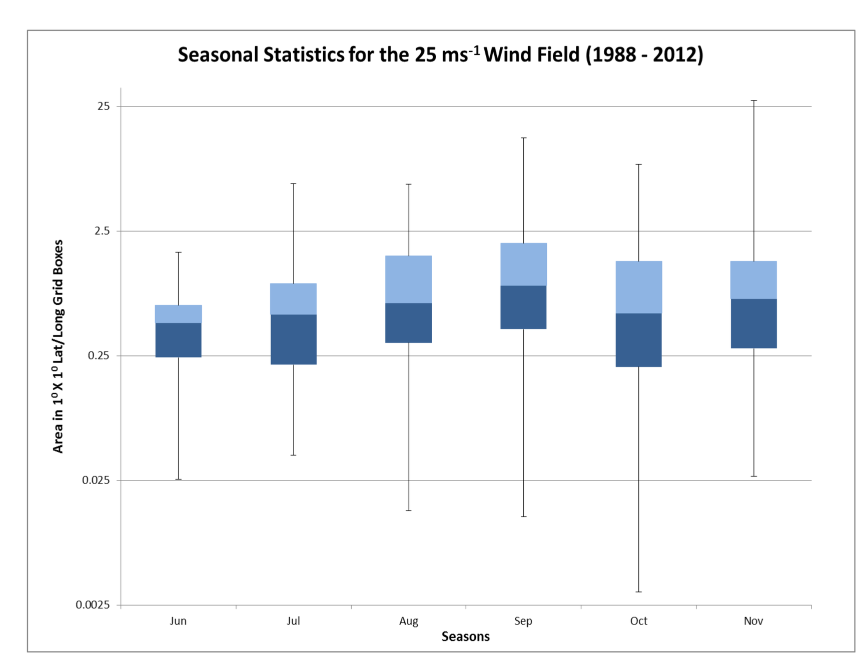


Credit: NASA/NOAA GOES Project NOAA's GOES-14 satellite captured this visible image of Tropical Storm Rafael in the Atlantic on Oct. 16 at 7:45 a.m. EDT.

Geographical Division for Analysis in Table 3







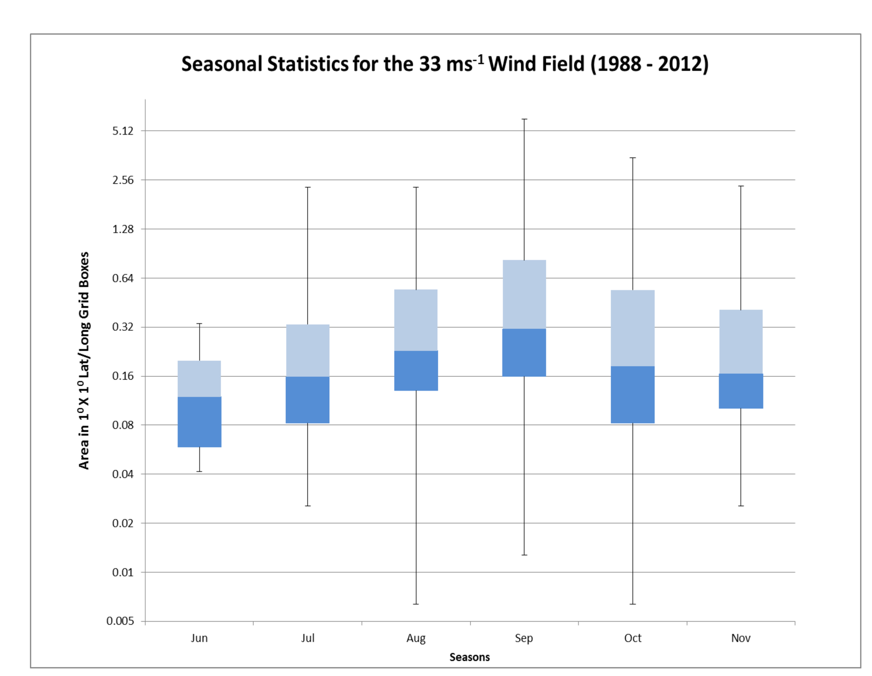


Table 4. Statistical Analysis of Storm Force Wind Area by Month

Statistics of Variation of Storm Area and Asymmetry for the 17, 25 and, 33 m/s windfields from June to November (1988-2012)

	Jun			Jul			Aug			Sep			Oct			Nov		
Storm Area (Sq. Km)																		
	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s
MAXIMUM	191912	20833	4163	182605	74122	28471	331831	73140	28451	506582	172473	74534	763486	105950	43118	591012	345025	28981
90th Percentile	63617	15237	3138	67741	19615	13106	87376	35323	12763	135968	51051	20126	133219	38312	14854	165326	49904	14176
75th Percentile	37306	7854	2464	35343	11712	4099	49087	19478	6715	78049	24544	10161	56725	17671	6676	81485	17671	5027
MEDIAN	19635	5655	1473	19635	6646	1954	22619	8168	2827	38327	11300	3848	25447	6794	2278	45082	8836	2042
25th Percentile	10603	2985	726	9817	2611	1021	9817	3907	1610	17671	5027	1963	12763	2513	1021	22619	3534	1257
10th Percentile	6912	785	511	5486	1414	628	5027	1414	962	7854	1963	982	5832	1319	628	8490	2278	628
MINIMUM	2042	314	511	1257	491	314	353	177	79	157	157	157	236	39	79	314	334	314
MEAN	30127	6368	1724	29347	10781	4547	37424	14236	5200	59817	19532	7604	56770	13627	5170	75232	22032	4895
STD. DEV	32343	5046	1247	30022	13746	6421	42862	15200	5180	65147	22319	9064	86926	17394	7144	98553	44975	6347
Storm Asymmetry																		
	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s	17 m/s	25 m/s	33 m/s
MAXIMUM	2.000	2.000	0.673	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
90th Percentile	1.200	2.000	0.610	1.155	1.171	1.165	1.155	1.200	1.155	1.155	1.155	1.155	1.155	1.169	1.155	1.157	1.155	1.155
75th Percentile	1.155	1.225	0.371	0.747	0.750	1.155	0.667	0.622	0.542	0.462	0.410	0.389	0.667	0.743	0.845	0.667	0.622	0.667
MEDIAN	0.634	1.155	0.231	0.408	0.457	0.506	0.299	0.287	0.231	0.235	0.231	0.215	0.360	0.353	0.231	0.360	0.289	0.053
25th Percentile	0.385	0.444	0.041	0.245	0.223	0.286	0.171	0.133	0.000	0.136	0.080	0.000	0.202	0.154	0.000	0.219	0.105	0.000
10th Percentile	0.231	0.190	0.000	0.136	0.095	0.105	0.000	0.000	0.000	0.000	0.000	0.000	0.087	0.000	0.000	0.065	0.000	0.000
MINIMUM	0.000	0.128	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MEAN	0.740	0.978	0.262	0.546	0.614	0.669	0.467	0.498	0.386	0.380	0.379	0.350	0.486	0.542	0.487	0.513	0.409	0.374
STD. DEV	0.492	0.639	0.241	0.428	0.524	0.510	0.453	0.557	0.455	0.397	0.463	0.455	0.426	0.544	0.558	0.468	0.424	0.521
Count	151	53	10	485	266	124	1607	980	638	2743	1942	1343	1089	677	386	383	215	106

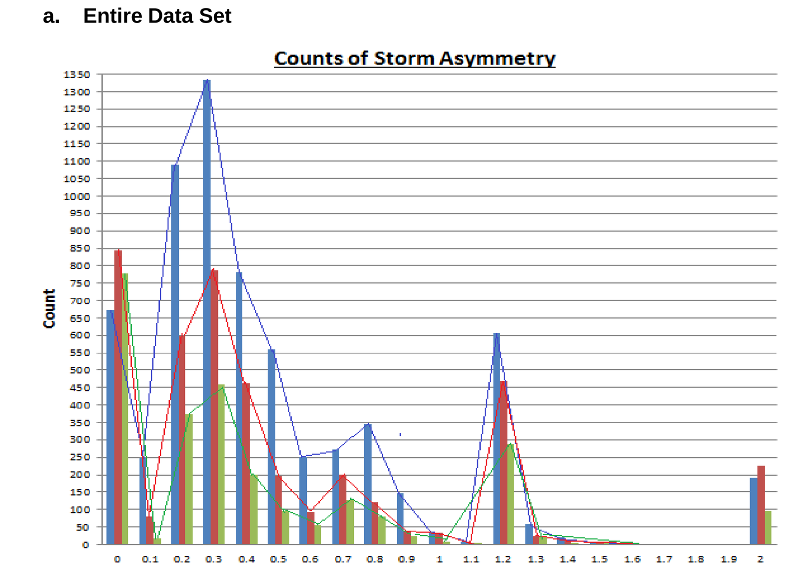
Table 5. Degree of Asymmetry within the 17, 25, 33 ms^{-1} Windfields

Statistics on Storm Asymmetry	34 Kts	50 Kts	64 Kts
MAXIMUM	2	2	2
90th Percentile	1.155	1.155	1.155
75th Percentile	0.667	0.667	0.603
MEDIAN	0.315	0.286	0.231
25th Percentile	0.167	0.128	0.000
10th Percentile	0.056	0.000	0.000
MINIMUM	0.000	0.000	0.000
MEAN	0.465	0.471	0.407
STD. DEV	0.445	0.522	0.493
NO. OF RECORDS	6968	4358	2709

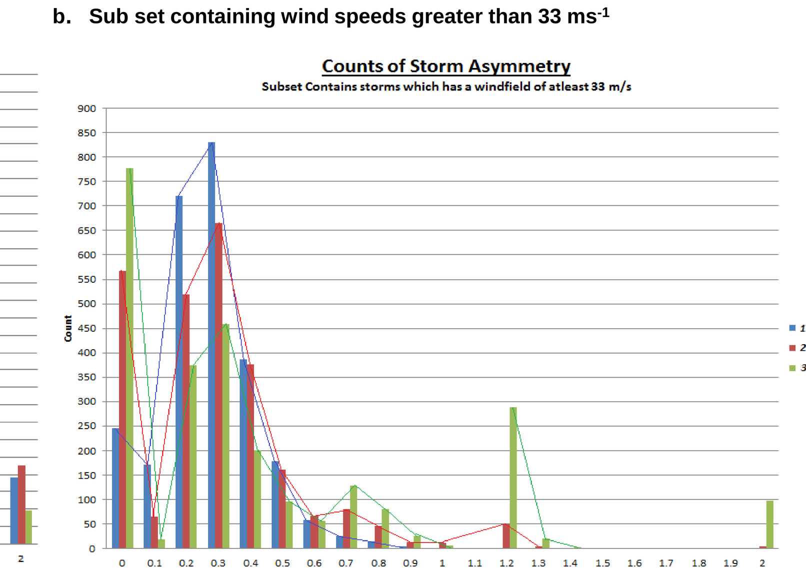
Statistics on Storm Asymmetry (Winds greater than 33 m/s)	34 Kts	50 Kts	64 Kts
MAXIMUM	0.86163859	2	2
90th Percentile	0.409357991	0.524863881	1.154700538
75th Percentile	0.303661392	0.348155312	0.577350269
MEDIAN	0.220364533	0.225276967	0.230940108
25th Percentile	0.133333333	0.104972776	0
10th Percentile	0.057142857	0	0
MINIMUM	0	0	0
MEAN	0.229068746	0.254826651	0.398886406
STD. DEV	0.143045549	0.241734384	0.485824216
NO. OF RECORDS	2631	2631	2631

Graph 1. Degree of asymmetry within the 17, 25, 33 ms^{-1} windfields:

a. Entire Data Set



b. Sub set containing wind speeds greater than 33 ms^{-1}



COMMENTS AND FUTURE WORK

Though the EBT is a relatively coarse data set, we were able to understand many aspects regarding the structure and evolution of tropical cyclones. We were also able to compare various storm parameters against each other (e.g. change in central pressure and radius of max winds). In addition, we examined a potential vorticity (PV) merger event (Hurricane Irene (2011)) and the associated change in storm structure.

The data available in the EBT contains a wealth of information from a research standpoint. We can derive many parameters (e.g. storm motion vector) and conduct statistical as well as case analyses. Since this project stemmed from the necessity to understand the wind field structure and behavior of tropical cyclones for forecasting and aiding the evacuation of people and aircraft prior to landfall (Barry, 2008), we plan to conduct multiple individual storm analyses to further our understanding of tropical cyclone rain bands, wind field structure and storm track.

REFERENCES

DeMaria, M. (1998, February). *Extended best track dataset*. Retrived from http://rammb.cira.colostate.edu/research/tropical_cyclones/tc_extended_best_track_dataset/

Barry, R.J., and Guinn, T.A., 2012: An Observational and Modeling Study of Tropical Cyclone Outer Rainbands. Preprints, 30th Conf. on Hurricanes and Tropical Meteorology, Ponte Vedra Beach, FL

Barry, R.J., 2008: Tropical Cyclone Weather Support and Education at Embry-Riddle Aeronautical University, Preprints, 17th Symposium on Education, New Orleans, LA

Kimball, S. K., and M. S. Mulekar, 2004: A 15-year climatology of North Atlantic tropical cyclones. Part I: Size parameters. J. Climate, 17, 3555–3575.