



A Climatology of Tropical Tornadoes Over Puerto Rico

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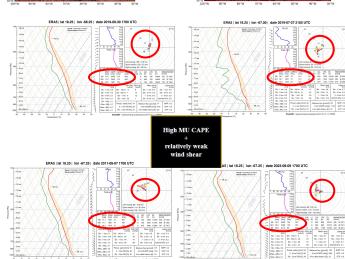
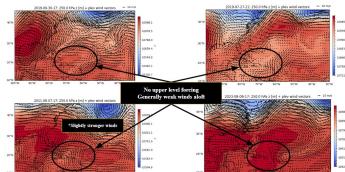
No prior peer-reviewed studies have focused on tornado formation in Puerto Rico or similar tropical island environments

- This study addresses an urgent need to identify recurring patterns contributing to tornado development in Puerto Rico.
- The Doppler radar's elevation at ~2,959 feet (0.9 km) limits its ability to capture critical data below 1 km, hindering the detection of tornado signatures and reducing lead time for warnings.
- Tornado risks in Puerto Rico remain underestimated, underscoring the need for improved forecasting and early warning systems.

Research Questions:

- How do tornado events in Puerto Rico impact critical infrastructure and public safety, and what challenges hinder in their real time detection and communication?
- How can a climatological analysis of past tornado events inform the development of improved tornado forecasting methodologies in tropical island settings?
- What atmospheric conditions, across synoptic, mesoscale, and microscale scales, are consistently associated with tornado formation in Puerto Rico?

I) Air Mass Thunderstorms

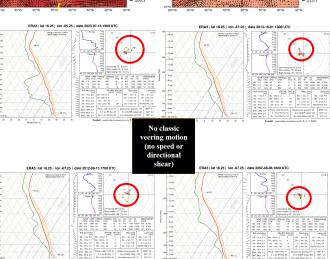
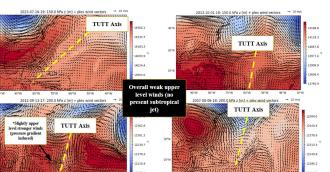


After analyzing reanalysis and observational data, tornado cases were categorized based on similarities in their respective setups

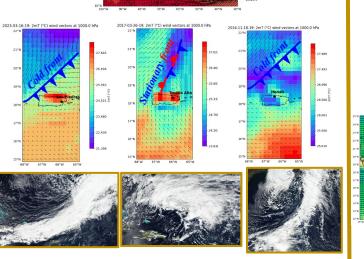
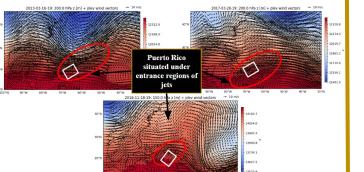
EVENT TYPE	EF-RATING	MEAN WINDS (MPH)	MEAN HUMIDITY (%)	MEAN RELATIVE HUMIDITY (%)	MEAN HGT (M)	MEAN DEP (M)	PROBABILITY (%)	MEAN
II) AIRMASS THUNDERSTORMS	EF-0 (0)	10.31	10.45	50.00	2150.50	-11.00	1.87	0.00
III) WEAK UL LEVEL DYNAMICS	EF-0 (0) EF-1 (0)	7.97 7.97	6.16 6.16	21.50 21.50	1770.67 1770.67	-7.80 -7.80	1.96 0.00	0.00
IV) STRONG UL LEVEL DYNAMICS	EF-0 (0)	5.69	20.1	35.00	622.67	-5.00	1.77	0.02
V) INFLUENCE FROM EASTERLY WAVE	EF-0 (0)	8.86	12.05	29.50	1630.00	-11.00	1.97	0.00
VI) TUTT + STRONG UPPER LEVEL DYNAMICS	EF-1 (0)	11.00	23.52	127.00	1477.00	-8.00	1.73	1.20

Table 1: Mean environmental parameters associated with different categories of tornado events in Puerto Rico (2005–2023). Parameters include EF-rating, mean winds (MPH), mean humidity (%), mean relative humidity (%), mean height (m), mean depth (m), probability of occurrence, and mean.

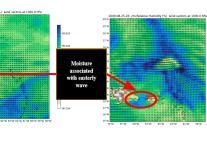
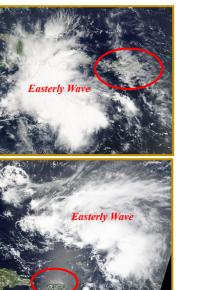
II) TUTT + Weak Upper Level Dynamics



III) Strong Upper Level Dynamics



IV) Influence From Easterly Waves



Between 2005 and 2023, tornado activity in Puerto Rico peaked around August, with 37.5% of events associated with a combination of Tropical Upper-Tropospheric Troughs (TUTTs) and weak upper-level dynamics

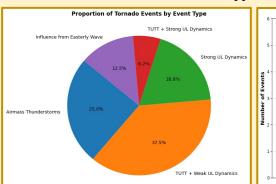


Chart 1: Proportion of tornado events categorized by event type and color coded. These included TUTT + Strong UL Dynamics (orange), Arms Thunderstorms (blue), TUTT + Weak UL Dynamics (green), and Strong UL Dynamics (purple).

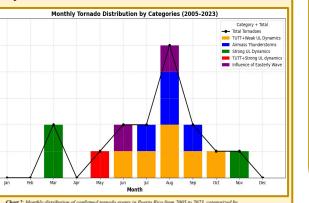


Chart 2: Monthly distribution of confirmed tornado events in Puerto Rico from 2005 to 2023, categorized by event type. The total number of events per month is shown on the y-axis, and the percentage of events per month is shown on the x-axis. The legend indicates the categories: Category 1 (Total), Category 2 (TUTT + Weak UL Dynamics), Category 3 (TUTT + Strong UL Dynamics), Category 4 (Arms Thunderstorms), Category 5 (Strong UL Dynamics), and Category 6 (TUTT + Strong UL Dynamics). The blue line represents the percentage of tornadoes per month.

Recognizing atmospheric, spatial, and temporal patterns highlight opportunities to improve tornado forecasting in Puerto Rico

- Most tornadoes in Puerto Rico are linked to TUTTs.
→ Future simulations using Weather and Research Forecasting Model (WRF) will help understand how these systems interact with local weather patterns.

- All events showed high atmospheric instability (CAPE), but wind shear and helicity varied, depending on the type of setup.
- Comparing these values to normal seasonal conditions can help identify what makes tornado days stand out.

- Tornadoes mainly occur from June to September, during the wet season.
- The seasonal pattern suggests a chance to improve early warnings by focusing on high-risk months.

- Findings indicate that most tornadoes are concentrated in the northeastern part of the island.
- This spatial pattern highlights regions with higher potential for tornado development.



Fig. 1. Map of Puerto Rico showing the location of 100+ tornado cases analyzed in this study and relative location of under a notable location of cases is observed in the northern region.

References:

- Charney, J., 2024. Python Notebook for Mesoscale Atmospheric Analysis. GitHub repository. <https://github.com/mesoscale-analysis/python-notebook>
- National Oceanic and Atmospheric Administration. 2024. National Centers for Environmental Prediction (NCEP) Reanalysis Version 2 (R2). NCEP-DOE Atmospheric Reanalysis Project. <http://www.ndbc.noaa.gov/reanalysis.html>
- National Oceanic and Atmospheric Administration. 2024. Forecast Initialization. NOAA. <http://www.ndbc.noaa.gov/initializations.html>
- National Weather Service. 2024. Forecast Model. NOAA. <http://www.ndbc.noaa.gov/forecast.html>
- National Weather Service. 2024. Radar. NOAA. <http://www.ndbc.noaa.gov/radar.html>
- National Weather Service. 2024. Satellite. NOAA. <http://www.ndbc.noaa.gov/satellite.html>
- Papageorgiou, G., & Lof, P., 1998. A Review of Static Stability and Convective Available Potential Energy. *Journal of the Atmospheric Sciences*, 55(10), 1401–1418. [https://doi.org/10.1175/1520-0469\(199810\)55:1401:AROSAS&2.0.CO;2](https://doi.org/10.1175/1520-0469(199810)55:1401:AROSAS&2.0.CO;2)
- Rawlins, Q., 2024. Severe Composite Hurricane. NOAA. <http://www.ndbc.noaa.gov/severecomposite.html>
- University Corporation for Atmospheric Research. 2024. Radar Data Archive at the NCAR-NESDIS Radar Data Archive. NOAA. <http://www.ndbc.noaa.gov/radararchive.html>
- Verguts, Q., 2016. Severe Composite Hurricane. NOAA. <http://www.ndbc.noaa.gov/2016/05/06/severecomposite-pasture>