Evaluating Storm Energy Metrics as Indicators of Hurricane Structure and Duration

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INTRODUCTION

Tropical cyclones vary not only in intensity, but also in size and duration, which influence their impact and output of energy.

- Identifying comparative and analytical metrics that best encompass hurricane trends has been a field of interest for decades.
- While maximum wind speed is commonly used to classify hurricanes, hurricane analysts have begun to explore additional variables that may better characterize hurricanes and their behavior.
  - Accumulated cyclone energy (ACE): Uses the maximum sustained winds only without accounting for the structure of the storm.

$$\mathrm{ACE} = 10^{-4} \sum v_{\max}^2$$

    - Where v_{max} is maximum sustained wind speed in knots (kts).
  - Track Integrated Kinetic Energy (TIKE): Accounts for the intensity and size of the tropical cyclones.

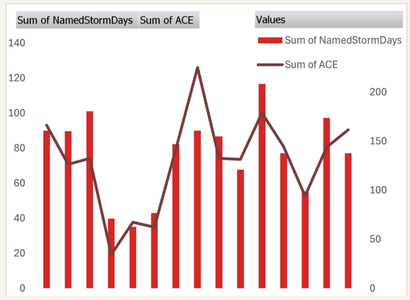
$$\mathrm{IKE} = \int_v 1/2 \rho A V^2$$

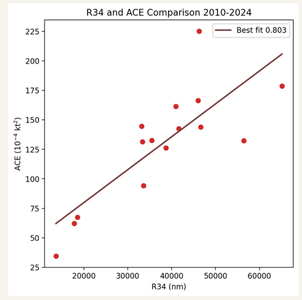
    - Where ρ is air density, A is the area of the 34-kt wind speeds, and V is the mean of the 34-kt wind speeds.
- With these variables, I aimed to analyze the trends of storm intensity, size, and length from 2010-2024, to see how these variables compare with the general overview, but also on a year-by-year basis.

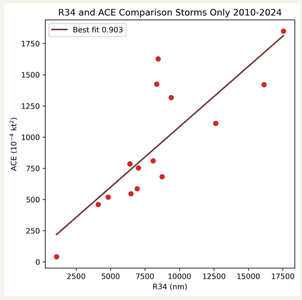
METHODS

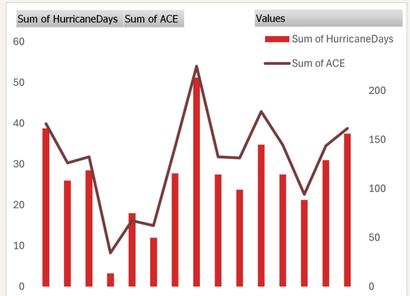
- Historical datasets from Moody's HWind dataset and NOAA's HURDAT dataset were organized in Excel and Python to examine how ACE and TIKE relate to structural and temporal variables.
  - This includes radius of maximum winds (R34), hurricane days, and named storm days.
    - Storm length was defined as total duration (in days) from first 34-kt reading to dissipation.
    - Hurricane length was defined as total duration (in days) from first 64-kt reading to dissipation.
- The HURDAT dataset and HWind storm catalog were condensed to only include Atlantic Basin systems from 2010-2024 that reached a Tropical Storm status or higher (also known as a named system) utilizing Python (Pandas) for data analysis.
- Then, 3 comparison scatterplots were created for each yearly total ACE and TIKE vs. yearly total R34 for:
  - All systems
  - Hurricanes only
  - Tropical storms only
- A comparison was made with said variable and hurricane length from 2010-2024 through Excel.
  - A visual analysis was conducted to observe the relationship between each yearly total ACE and TIKE vs. yearly total hurricane days and named storm days.

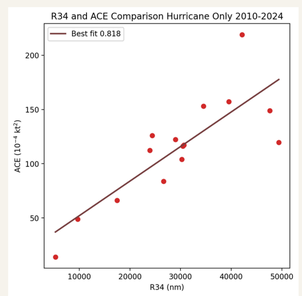
RESULTS: ANALYSIS OF ACE









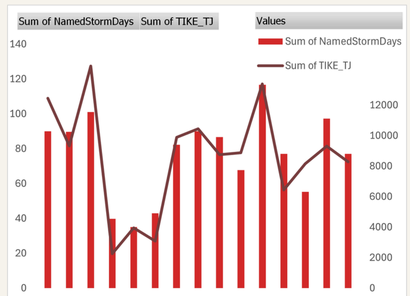


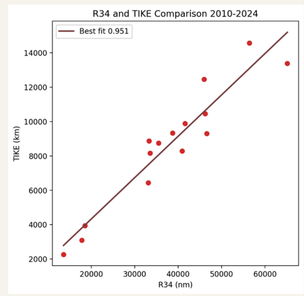
R Coefficients	
Category	ACE/ R34
Hurricanes Only	0.818
Storms Only	0.903
Combined	0.803

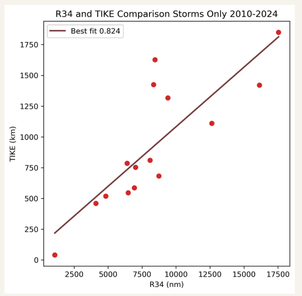
This comparison of the year-by-year storm duration vs. ACE presents a stronger alignment when observing **total hurricane days**.

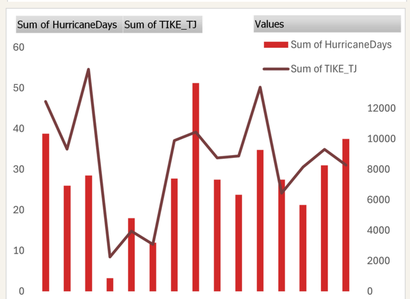
These plots visualize the relationship between R34 and ACE, observing the relationship with **all storms** included (top left), **only tropical storms** included (top right), and **only hurricanes** included (bottom left).

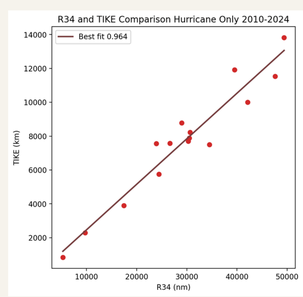
RESULTS: ANALYSIS OF TIKE









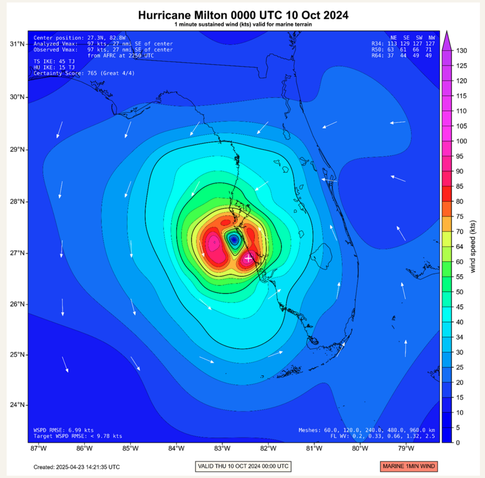


R Coefficients	
Category	TIKE/ R34
Hurricanes Only	0.964
Storms Only	0.824
Combined	0.951

This comparison of the year-by-year storm duration vs. TIKE presents a stronger alignment when observing **total named storm days**.

These plots visualize the relationship between R34 and TIKE, observing the relationship with **all storms** included (top left), **only tropical storms** included (top right), and **only hurricanes** included (bottom left).

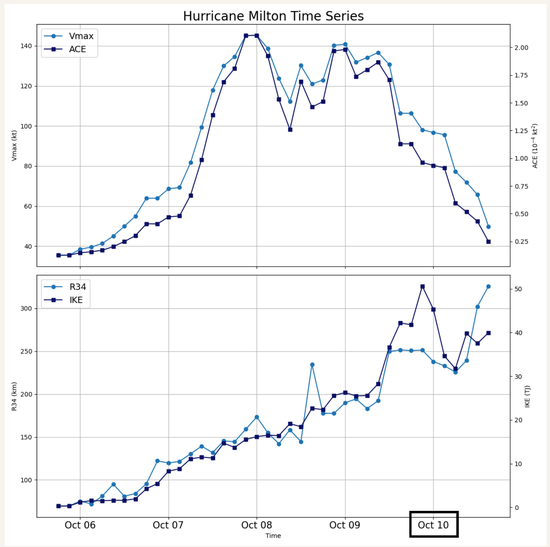
CONCLUSIONS AND FUTURE DIRECTIONS



Snapshot of **Hurricane Milton** at landfall, visualizing the wind speeds (in kts) of the storm.

- TIKE better captures integrated storm size and duration, while ACE more directly reflects peak intensity and wind speed outcomes.
- Together, TIKE and ACE provide complementary insight into storm energy and variability.
- Example shown: Hurricane Milton (2024)
  - Initial conditions: Small radius (low R34), but fast wind speeds (large v_{max}).
  - Landfall conditions: Large radius (high IKE) and declining wind speeds (lower v_{max}).
  - This specific hurricane shows us both the instances where ACE and IKE are best representative for each of its respective strengths.
  - Strong correlations accurately characterize storm structure and its trends.

- Future directions include diversifying analyses across different regions.
  - Compare across different ocean basins; datasets only focused on Atlantic Basin.
- Explore the correlation within storm energy metrics and more variables, including societal variables (rainfall, storm surge).
  - With this, utilizing these storm metrics and previous historical trends to predict potential economic damages caused by hurricanes.
- Creating a variable that takes the strengths of both ACE and TIKE into account in regards to both hurricane and tropical storm analysis.
  - Accounts for size, duration, and wind speed outcomes.



Landfall occurs at approximately 00 UTC on **October 10th**.

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