METEOROLOGICAL COMPUTER APPLICATIONS FINAL PROJECT

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City: Charleston, SC

Introduction

- Charleston is a coastal city located along the center point of the South Carolina coastline
- Downtown sits on a peninsula bounded by the Ashley, Cooper, and Wando rivers
- It is a humid subtropical (Cfa) climate, seeing sea breezes and frequent tropical cyclone impacts.

Data

- I chose to focus on tropical cyclone impacts, primarily flooding and tornadoes seen in outer rainbands.
- Downtown and much of the city is low-lying and coastal, making it susceptible to flooding in any event.
- Sounding data near landfall was chosen from the CHS upper air site.
- NWS Charleston monthly climatological summaries for the month from the North Charleston airport were also selected.

- **Events Chosen:**
  - Tropical Storm Debby (August 6, 2024)
    - Sounding: August 6, 2024 at 12Z
    - Climate Summary: August 2024
  - Tropical Storm Idalia (August 30, 2023)
    - Sounding: August 30, 2023 at 00Z
    - Climate Summary: August 2023
  - Hurricane Ian (September 30, 2022)
    - Sounding: September 30, 2022 at 12Z
    - Climate Summary: September 2022
  - Hurricane Florence (September 15, 2018)
    - Sounding: September 15, 2018 at 00Z
    - Climate Summary: September 2018
  - Hurricane Matthew
    - Sounding: October 8, 2016 at 00Z
    - Climate Summary: October 2016

- **Data Sources:**
  - Soundings: University of Wyoming upper-air sounding archive. https://weather.uwyo.edu/upperair/sounding_legacy.html
  - Monthly Climatological Reports: Iowa State University's Iowa Environmental Mesonet NWS text product archive. https://mesonet.agron.iastate.edu/wx/afos/list.phtml?source=KCHS&day=06&month=05&year=2025

Methods

- Precipitable Water
  - It represents the total amount of liquid water that can be condensed out of the atmosphere and fall to the ground as rain.
  - Not totally representative due to convergence bringing water vapor in from outside the area.

$$\frac{1}{g}\int_{p1}^{p2} w(p)\, dp$$

- Where $w(p)$ is the mixing ratio (kg/kg) at a given pressure.
- g is the gravitational constant (9.81 m/s^2)

- Bulk Shear
  - Represents the difference in horizontal wind between two layers in the atmosphere.
  - Quantifies how much the wind changes in speed and/or direction with height.
  - Bulk shear is a key parameter in forecasting supercell and tornado potential.

$$\sqrt{(u_2 - u_1)^2 + (v_2 - v_1)^2}$$

- Where u_2 and u_1 is the u-component of wind at the top and bottom of the layer.
- Where v_2 and v_1 is the v-component of wind at the top and bottom of the layer.

- Standard Deviation
  - A quantity that is calculated to show the extent of deviation from the mean there is for an entire sample or group
  - It is taken by taking the sum of the individual variances squared, divided by the number of sample points minus one, and all of that is taken to the square root.

$$\sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}}$$

- Where x_i is an individual sample point.
- Where $\bar{x}$ is the mean of all sample points.
- Where n is the number of sample points.

Methods

- K Index
  - It is a measure of thunderstorm potential based on vertical temperature lapse rate, and the amount and vertical extent of moisture in the atmosphere.
  - Higher K Index (over 35) values tend to be associated with heavy rain and thunderstorms.

$$K = (T_{850} - T_{500}) + Td_{850} - (T_{700} - Td_{700})$$

- Where T refers to temperature, and Td refers to dew point temperature.
- Where numbers in subscripts refers to a given pressure level.

- Total Totals Index
  - The sum of two metrics: Vertical and Cross Totals
  - Vertical Totals represents the lapse rate between 850 and 500 mb. Cross Totals is the difference between the 850 mb dew point and the 500 mb temperature.
  - Values over 55 are a strong signal for severe thunderstorms.

$$TT = (T_{850} + Td_{850}) - 2T_{500}$$

- Where T refers to temperature, and Td refers to dew point temperature.
- Where numbers in subscripts refers to a given pressure level.

- SWEAT Index
  - Combines several parameters into a single index to assess severe weather potential.
  - It incorporates low-level moisture, the Total Totals Index, low- and mid-level wind speeds, and warm air advection.
  - As it combines several thermodynamic and kinematic parameters into one number, it should be used for forecasting severe potential, not ordinary thunderstorms.

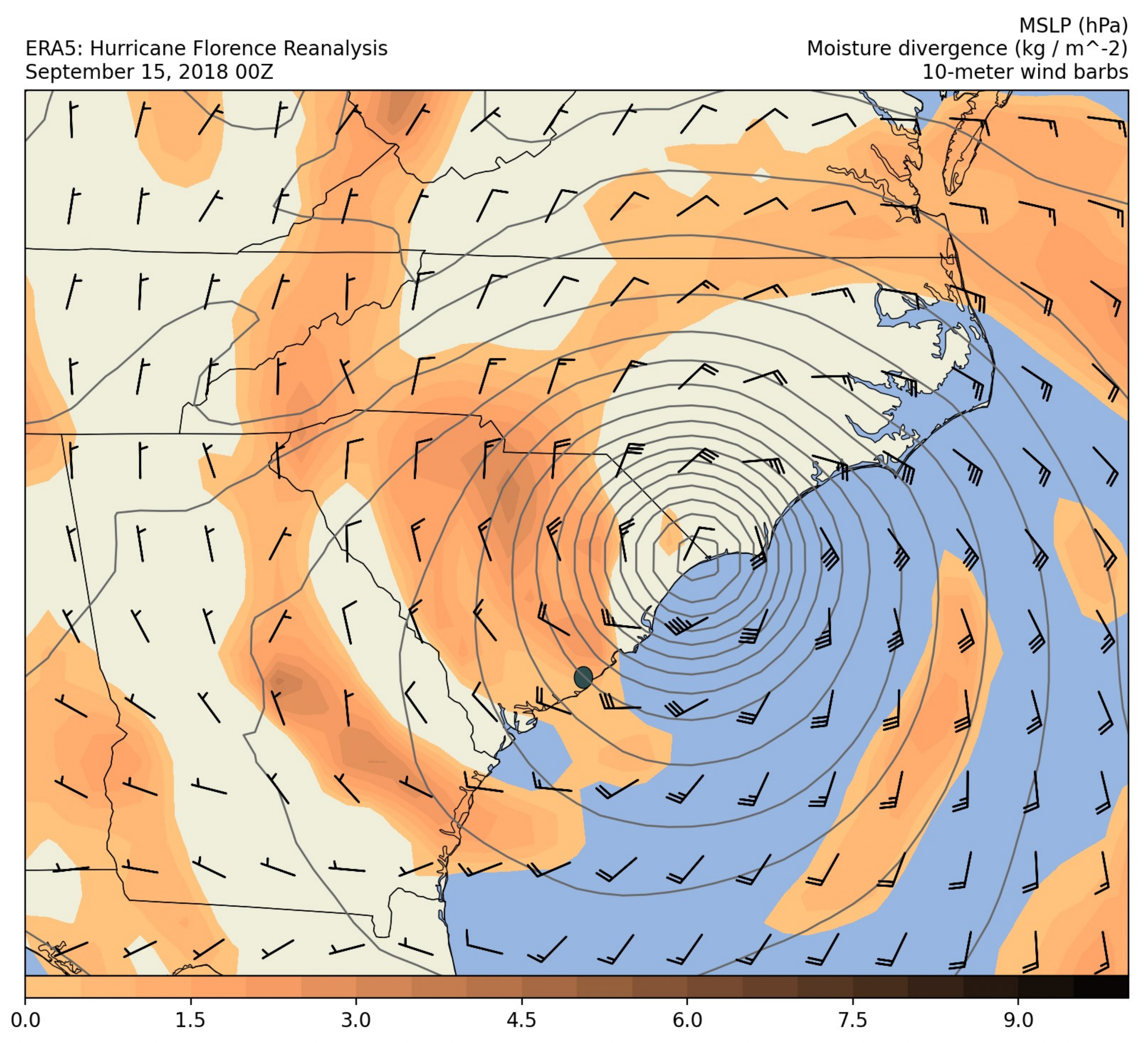
$$2Td_{850} + 20(TT - 49) + 2vv_{850} + vv_{500}$$
$$+125[\sin(dd_{500} - dd_{850}) + 0.2]$$

- Where T refers to temperature, Td refers to dew point temperature, vv refers to wind speed, and dd refers to wind direction.
- Where numbers in subscripts refers to a given pressure level.
- Where TT refers to the Total Totals Index

Precipitable Water

Event	PW (mm)	Rainfall (in.)
Tropical Storm Debby:	68.23 mm	9.53 in
Tropical Storm Idalia:	55.56 mm	2.71 in
Hurricane Ian:	57.28 mm	5.57 in
Hurricane Florence:	63.07 mm	0.98 in
Hurricane Matthew:	67.34 mm	10.47 in
Average:	62.30 mm	5.58 in
Standard Deviation:	5.74 mm	4.13 in

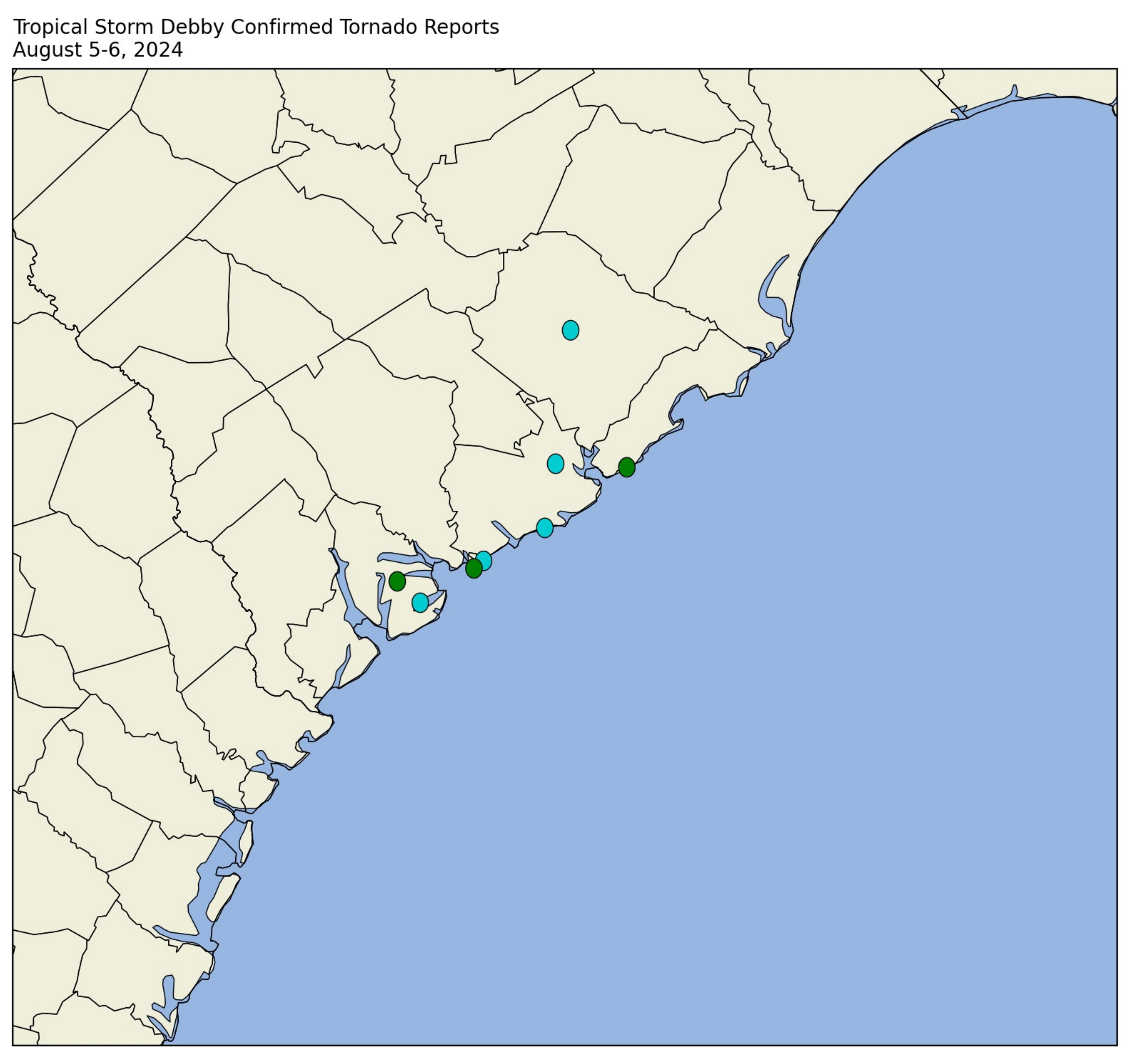
On the back side of Florence, there was moisture divergence, meaning moisture was diverging outward, away from Charleston. Despite high PW values, this helped to limit total rainfall in Charleston during the event.



Bulk Shear

Event	0-500m (kts)	0-1km (kts)
Tropical Storm Debby:	25.5 kts	27.6 kts
Tropical Storm Idalia:	10.0 kts	10.1 kts
Hurricane Ian:	58.6 kts	56.0 kts
Hurricane Florence:	46.1 kts	45.6 kts
Hurricane Matthew:	48.4 kts	50.4 kts
Average:	37.7 kts	37.9 kts
Standard Deviation:	19.6 kts	18.8 kts

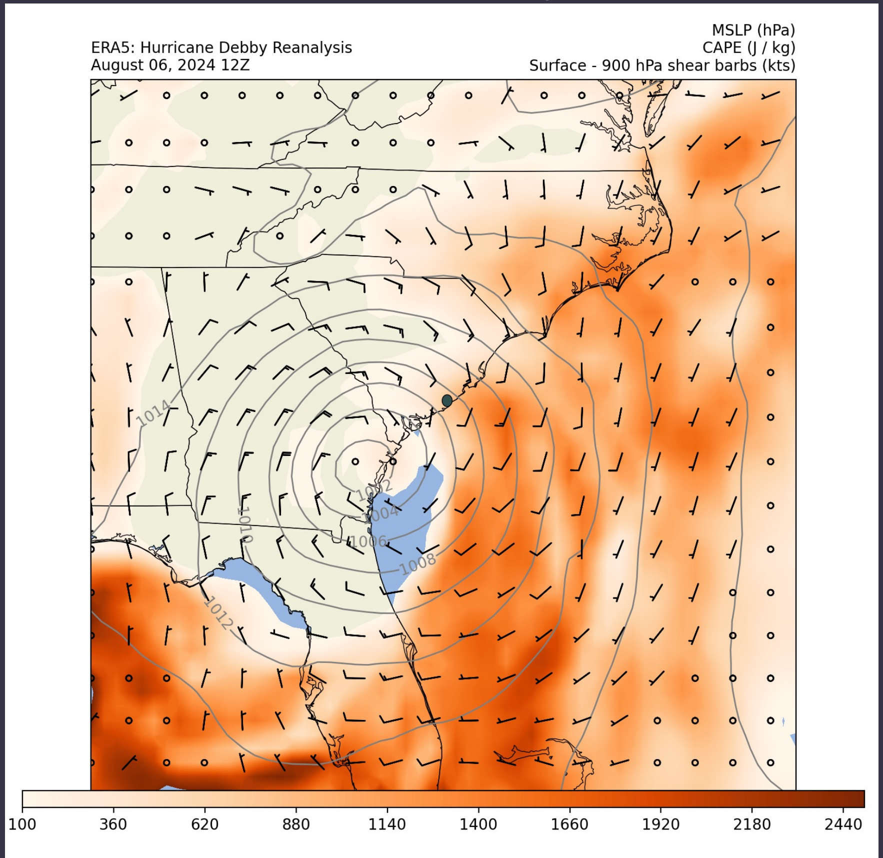
Despite the strong shear, Ian produced no tornado reports in South Carolina. Debby, with less than half the low-level shear of Ian, produced **eight** tornado reports, three rated at EF1, five rated at EF0. Why?



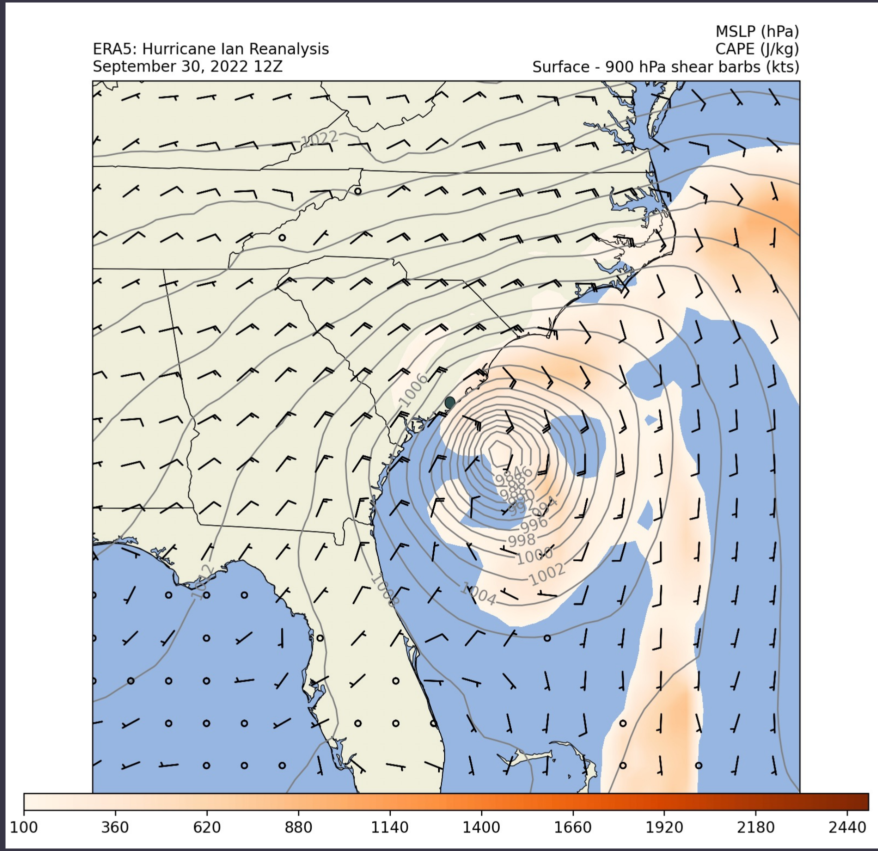
EF0 Tornado

EF1 Tornado

Debby



Ian



Debby provided a more conducive thermodynamic environment for supercells along the outer bands overnight on August 5th and 6th, 2024. About 400-800 J/kg of CAPE was available, and combined with over 20 knots of low-level shear, it allowed eight tornadoes to form overnight ahead of landfall. With limited thermodynamics on the west side of Ian, few tornadoes could spin up ahead of the storm.

Severe Indices

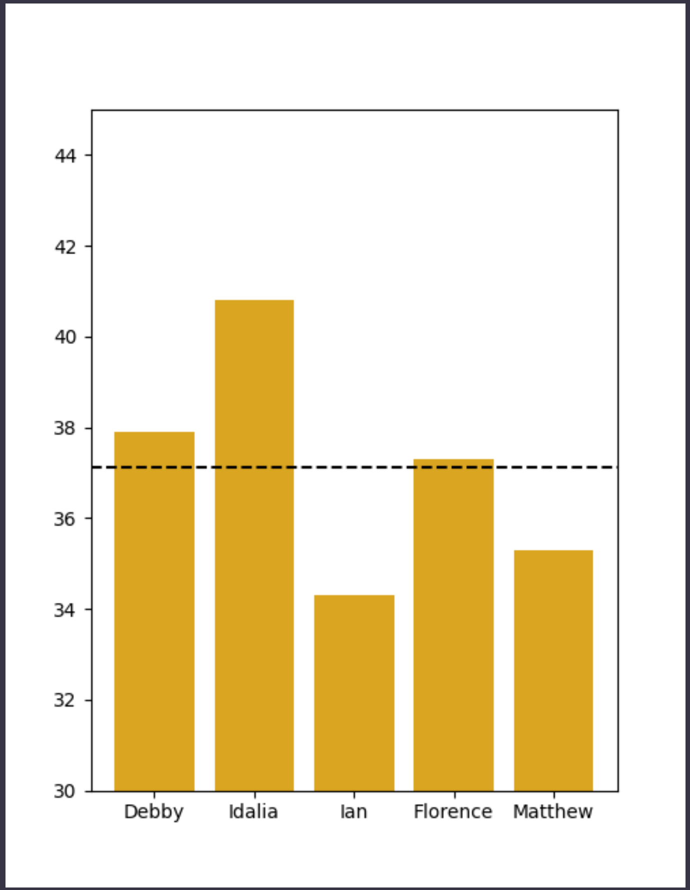
Event	K Index	Total Totals	SWEAT
Tropical Storm Debby:	37.9	41.4	288.0
Tropical Storm Idalia:	40.8	46.5	225.6
Hurricane Ian:	34.3	39.4	320.2
Hurricane Florence:	37.3	41.0	351.6
Hurricane Matthew:	35.3	39.0	375.8
Average:	37.1	41.5	312.2
Standard Deviation:	2.5	3.0	58.6

On paper, hurricanes can provide some favorable indices for severe storms. The K Index, a measure of the chance of storms and heavy rain, was all above 30, indicating the risk of heavy rain.

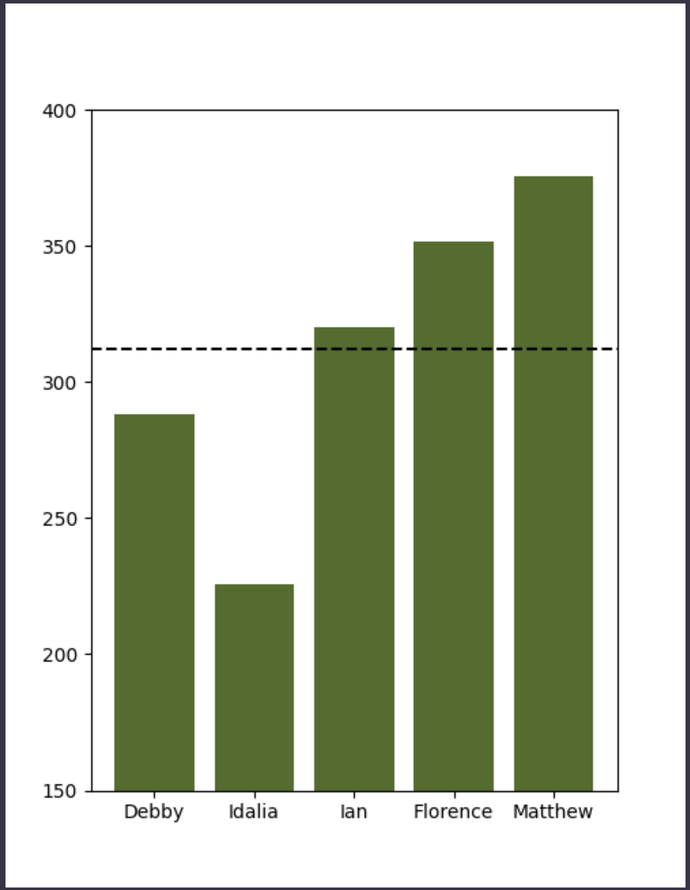
Total Totals is a metric that combines instability in lapse rates and moisture to assess the chance of convection. Generally figures above 45 are a good indicator of convection, of which only Idalia met this.

SWEAT explicitly forecasts for severe thunderstorms and tornadoes, not general storms and rain. Figures over 300 support severe storms, and over 400 supports the possibility of tornadoes.

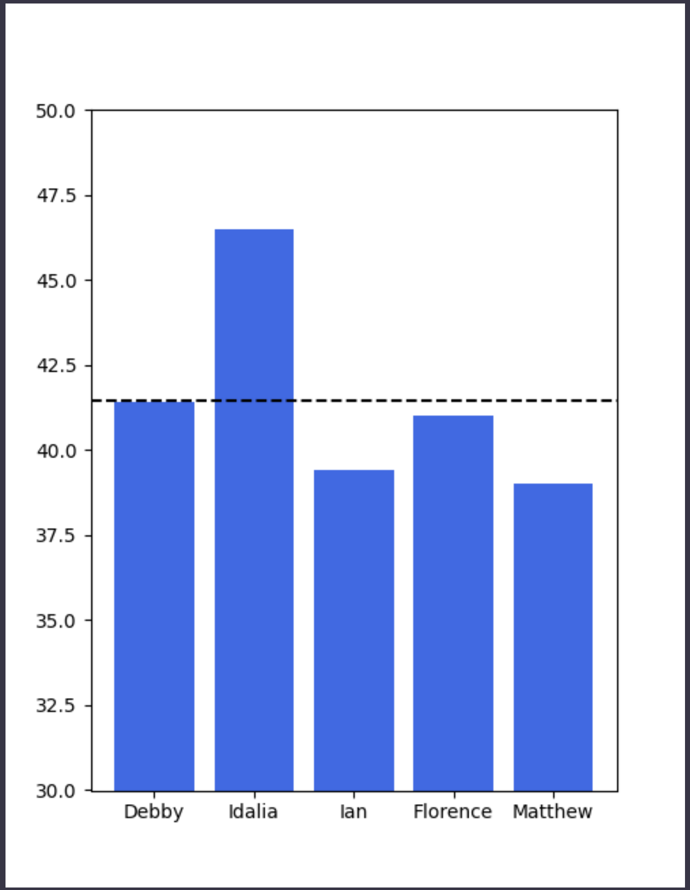
Severe Indices



K Index



Total Totals



SWEAT Index

Conclusions

- Hurricanes are incredibly complex meteorological phenomena, and can provide environments conducive to heavy flooding, tornadoes, and severe weather.

- Favorable environments or single parameters alone aren't predictive, however.

- Some storms provide setups that are just dead convectively, and nothing can spin up.

- The storm's dynamics can prevent the ingredients from being realized, as can location and track.

- Always evaluate parameters in context when analyzing events!