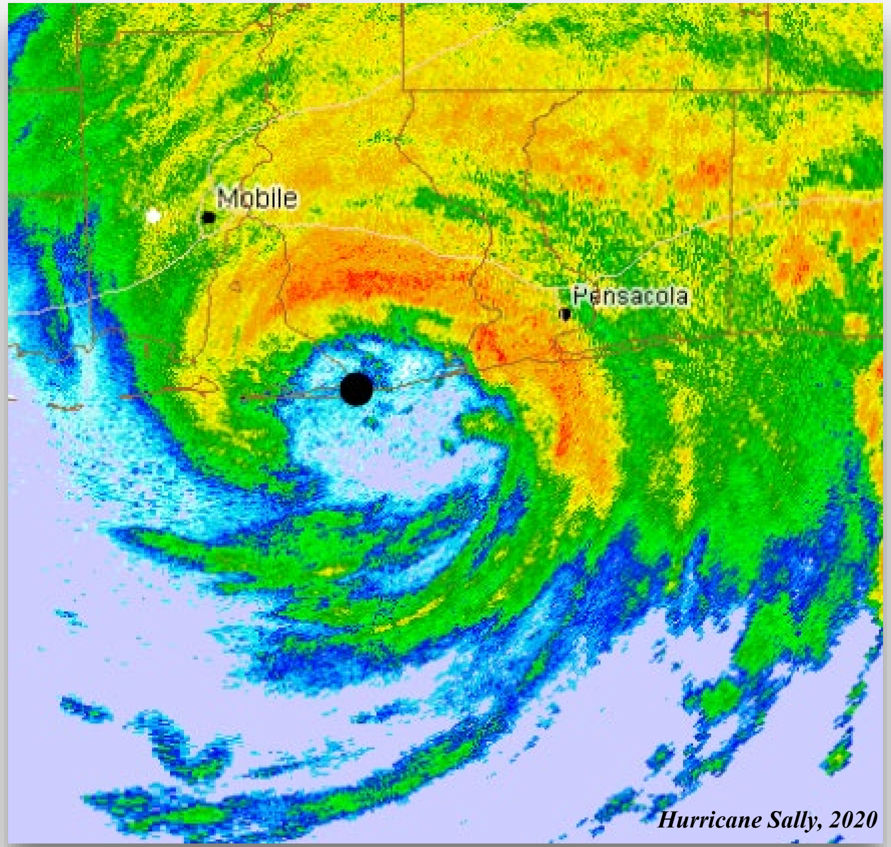
2024 RA-IV WMO Tropical Meteorology Course

WEATHER RADAR PRINCIPLES



Wallace Hogsett
Science & Operations Officer

NOAA/National Hurricane Center, Miami, Florida
April 2024

COURSE OBJECTIVES

- Overview of Basic Radar Principles
- Radar-Derived Parameters
  - Radar Reflectivity Data
  - Doppler Velocity Data
  - Reflectivity-Rainfall Relationships
- Practical Examples

Do you use radar data during your daily job function?

0

Yes, every day — 0%

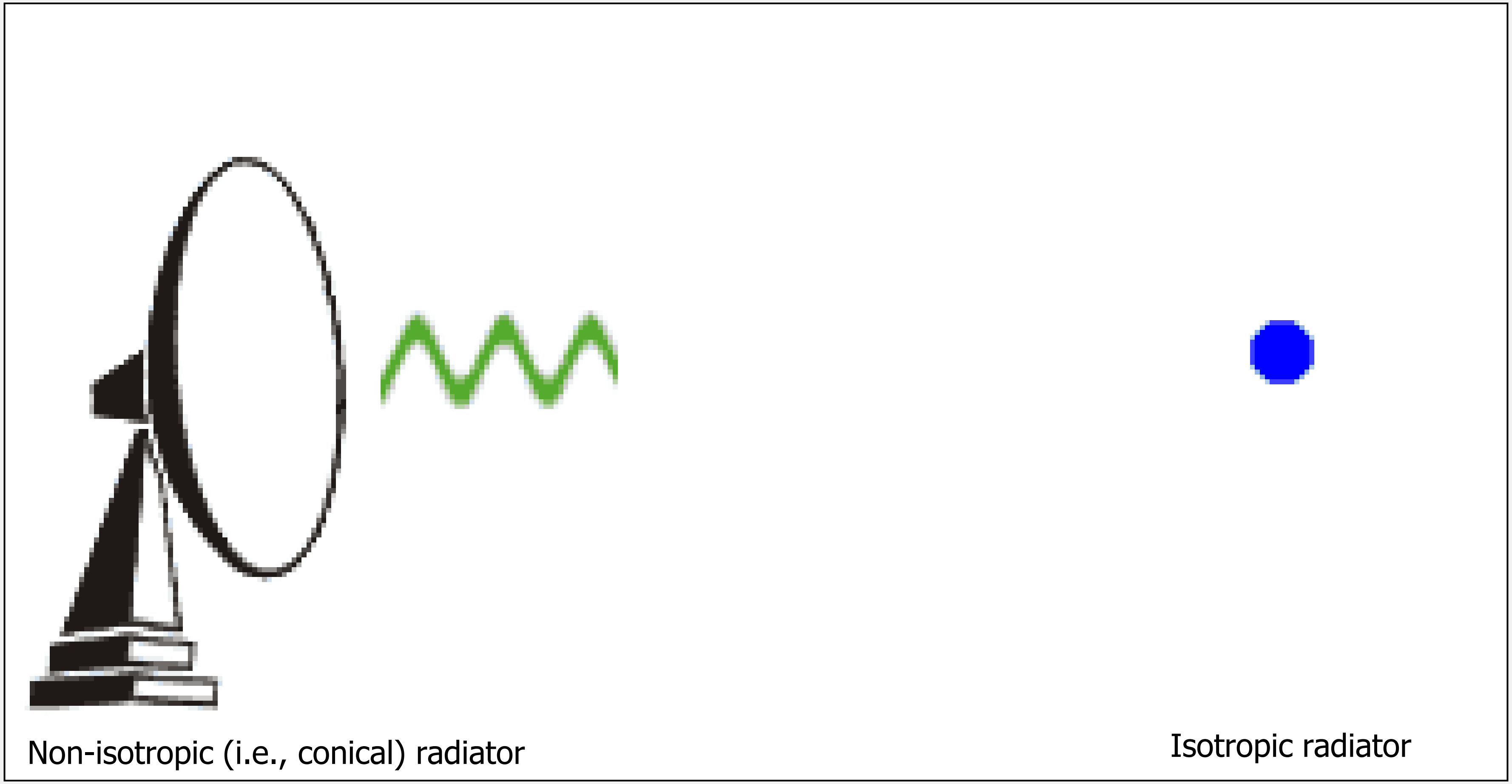
Yes, but not very often — 0%

No, my job doesn't require use of radar — 0%

No, we do not have a radar in our area of responsibility — 0%

Overview of Radar Principles

A large amount of horizontally polarized EM energy (~1,000,000 W) is transmitted…



…but only a <u>fraction</u> of that energy (~0.000001 W) is 'reflected' (i.e., returned) back to the radar receiver.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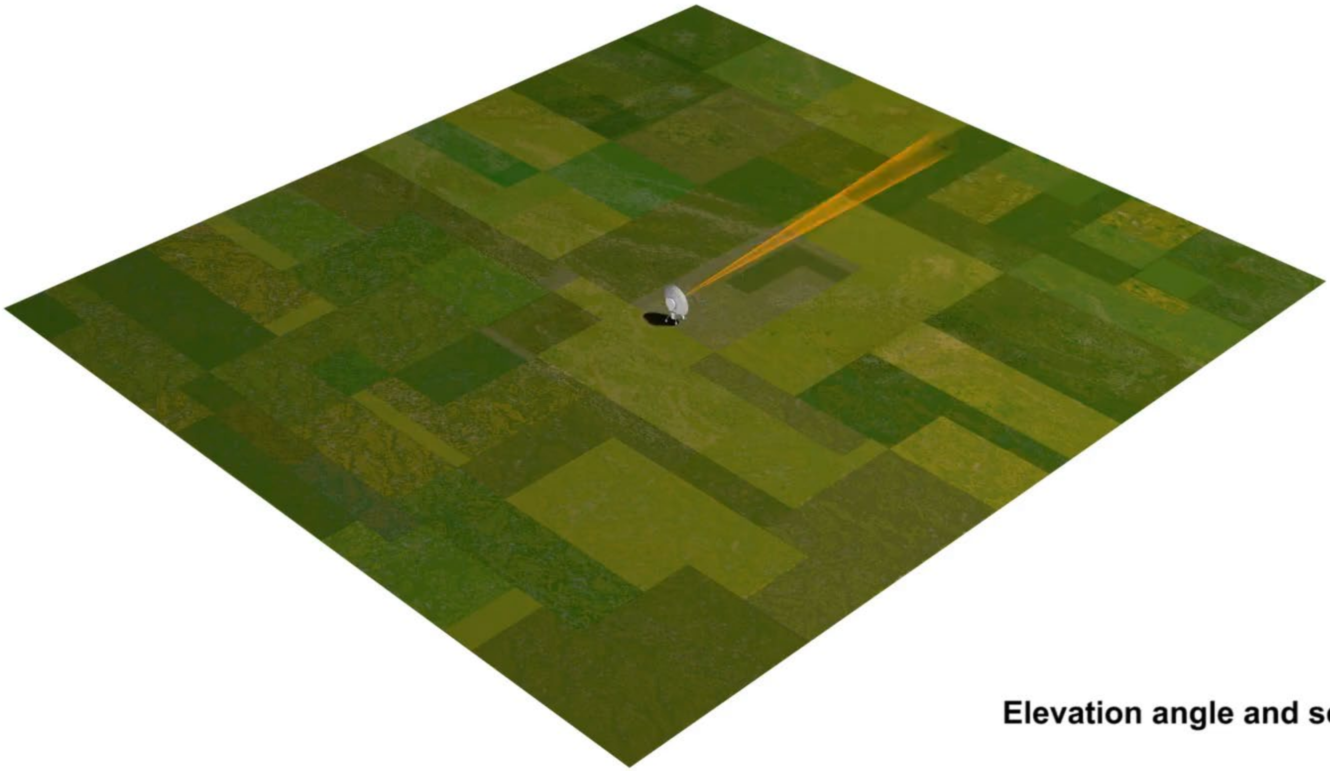
Radar Scanning Pattern

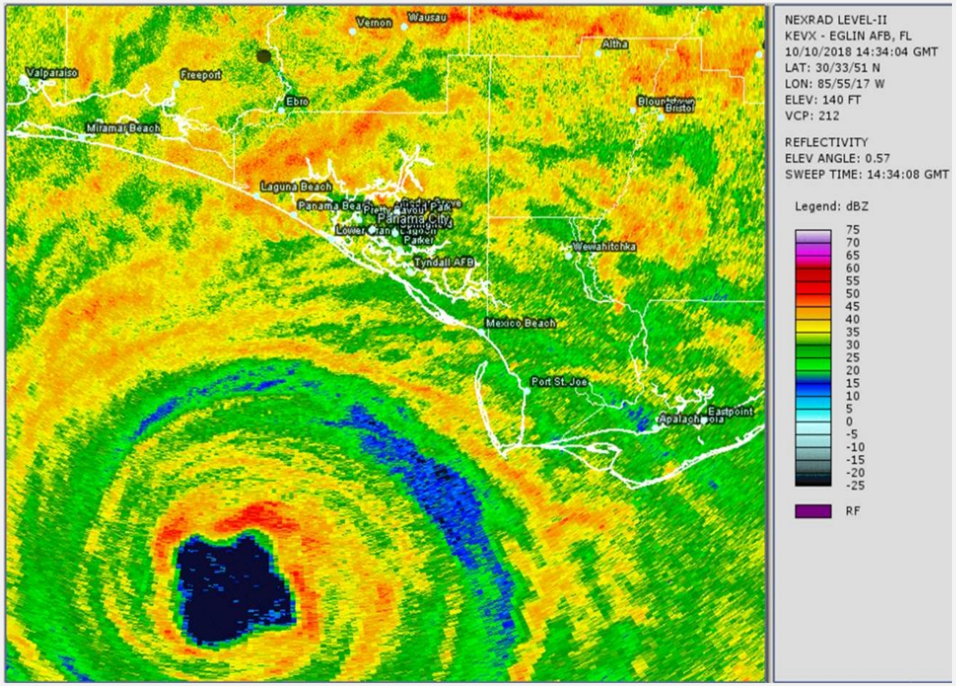


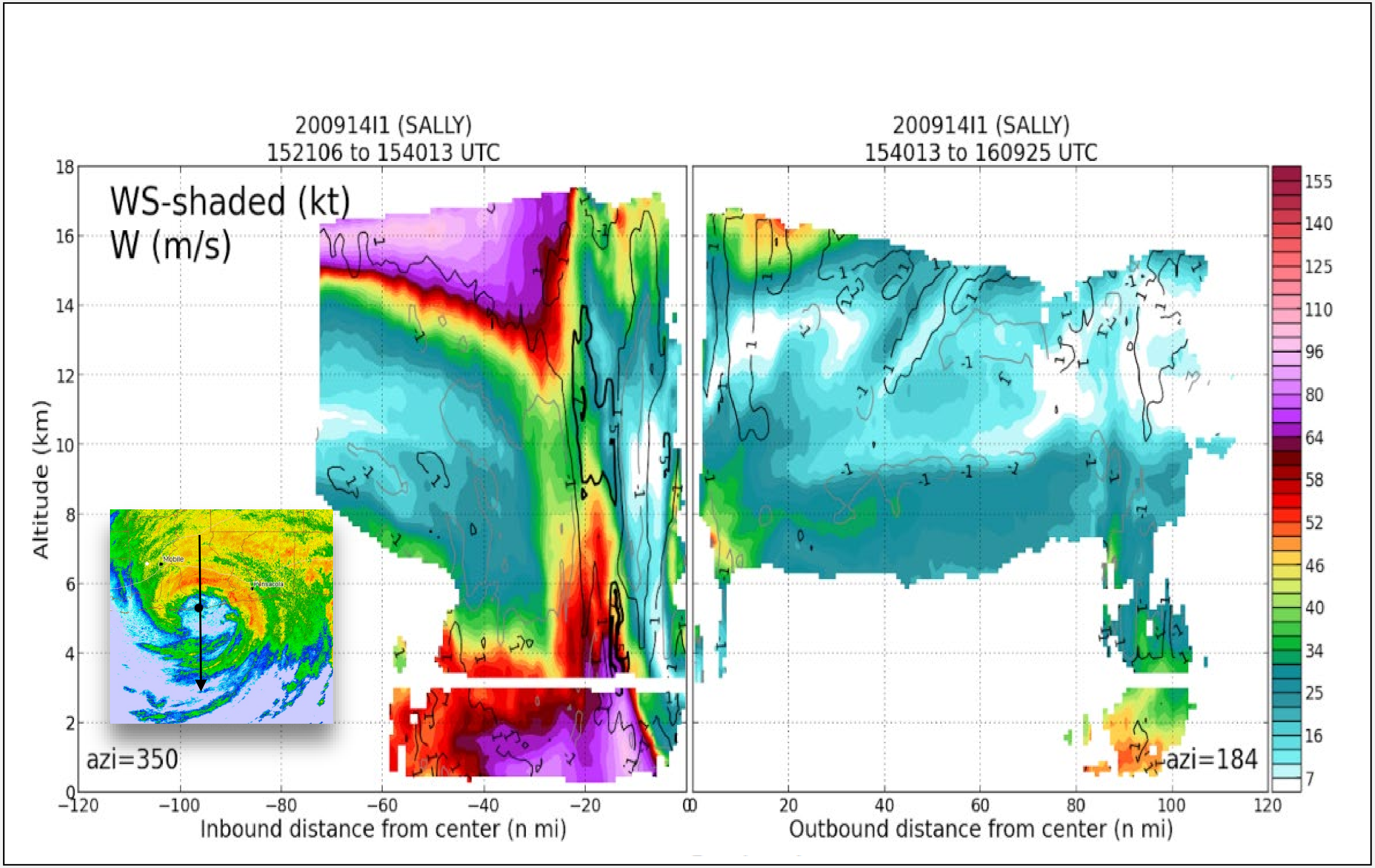
Footnote:
Elevation angle and scanning increased to show detail

Radar Reflectivity

- Reflectivity is simply defined as: "*the efficiency of a radar target in intercepting and returning energy*"

- Reflectivity depends not only on precipitation intensity, but also precipitation type, shape, and distance from the radar, among other factors



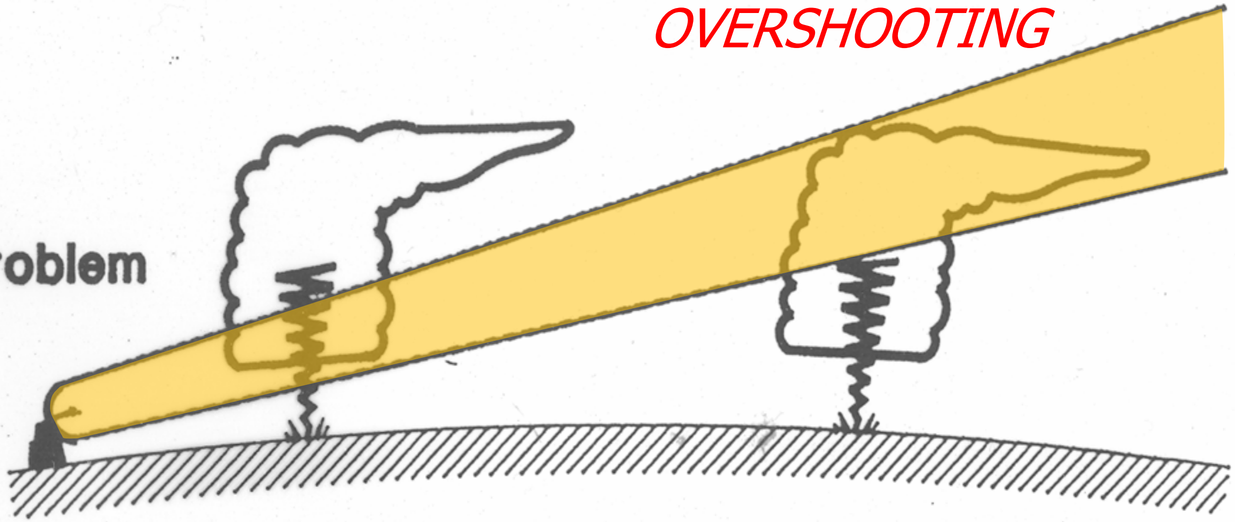


Scanning patterns yield information about the vertical structure

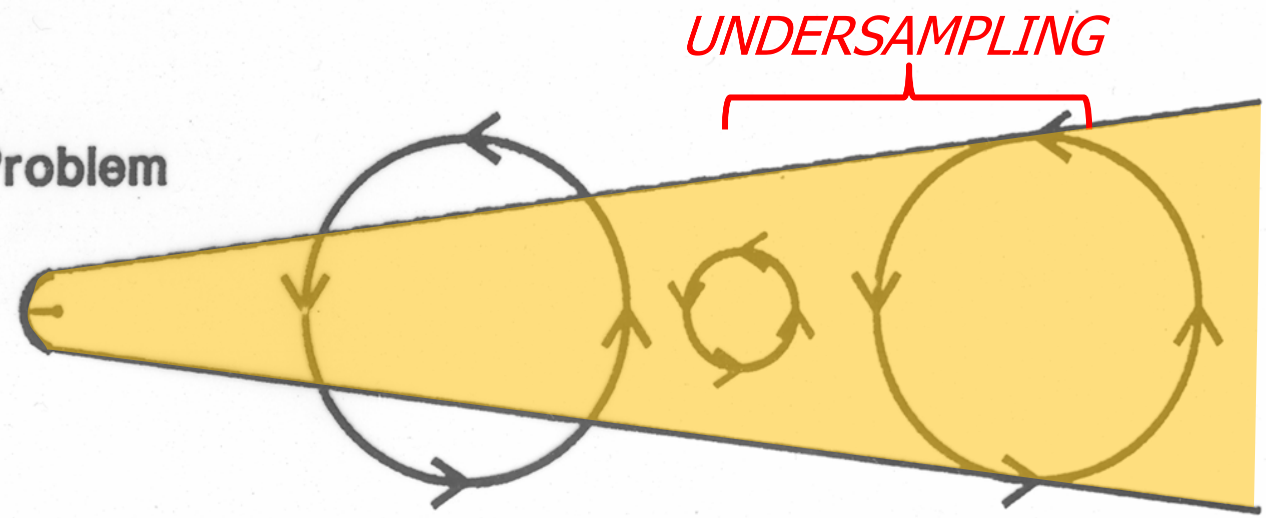
Note: RHI diagrams assume standard refractivity index

LIMITATIONS OF RADAR

1. Radar Horizon Problem

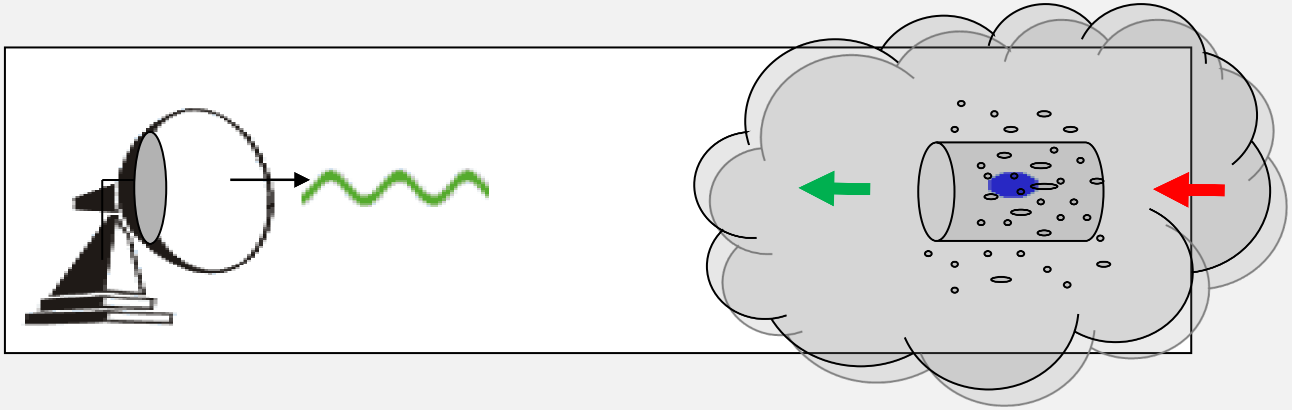


2. Aspect Ratio Problem



Radar Doppler Velocity Data

Radar Doppler Velocity



In addition to a measurement of power (reflectivity), we also have a measurement of particle motion.

A Doppler weather radar measures a single component of motion, but only *toward* or *away* from the radar.

Where is the Radar?

0

A

0%

B

0%

C

0%

D

0%

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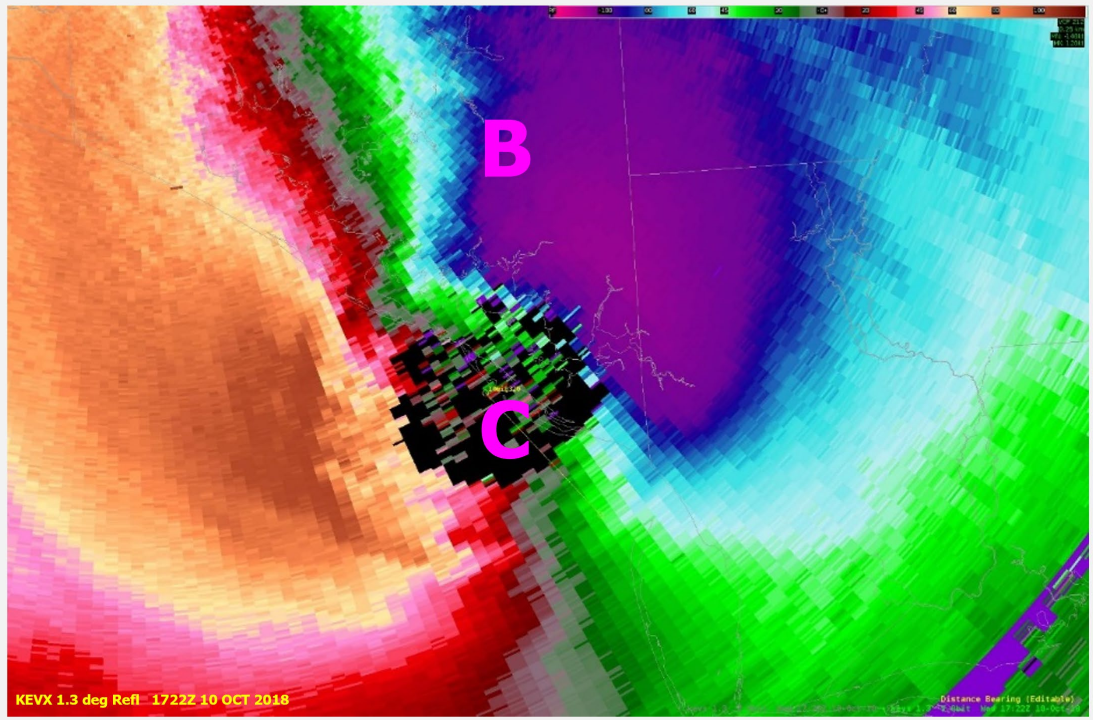
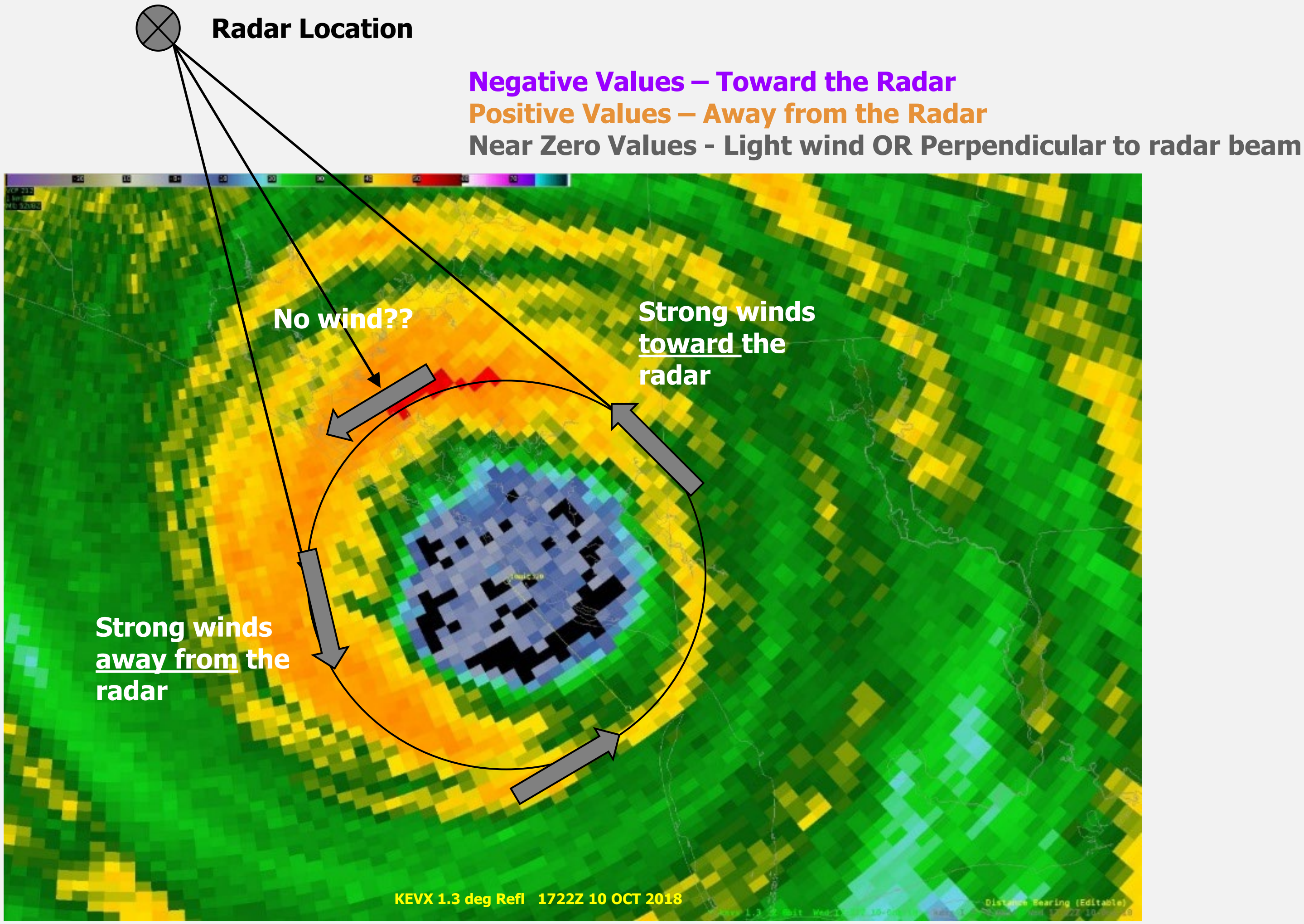
Example #1: Hurricane Michael (2018)

A



D

Example #1: Hurricane Michael (2018)



Why is there no velocity data in the eye?

0

Winds are weak in the eye

0%

The radar signal is attenuated

0%

There are not enough precipitation particles to return a signal

0%

Radar signal cannot penetrate the eyewall

0%

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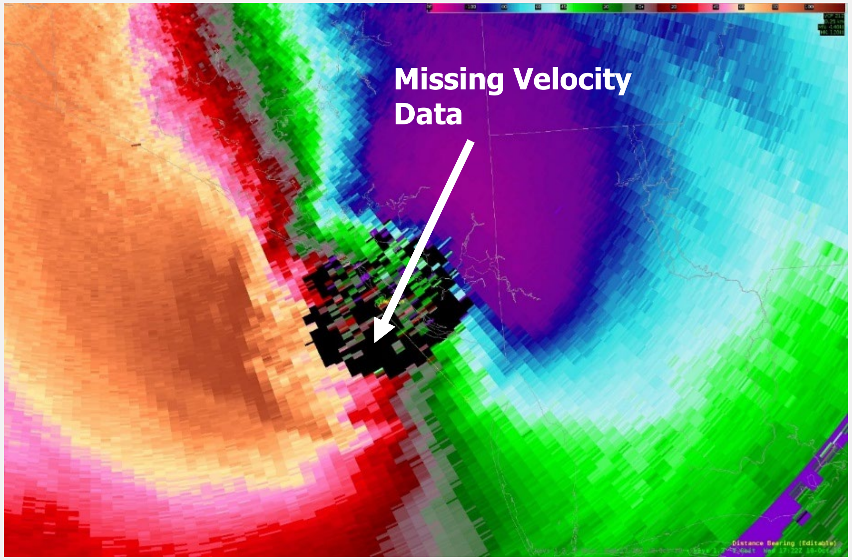
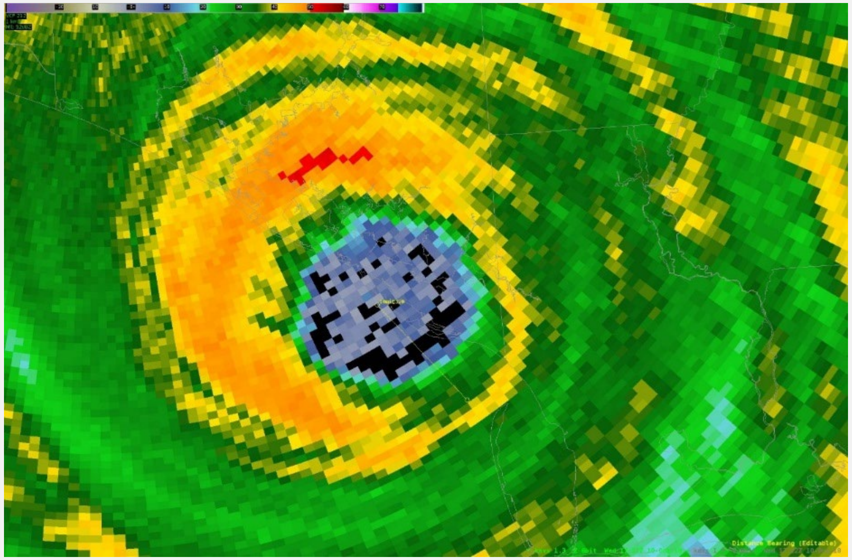




What is the intensity of the storm based on radar? Select one response.

80 kt

0%

90 kt

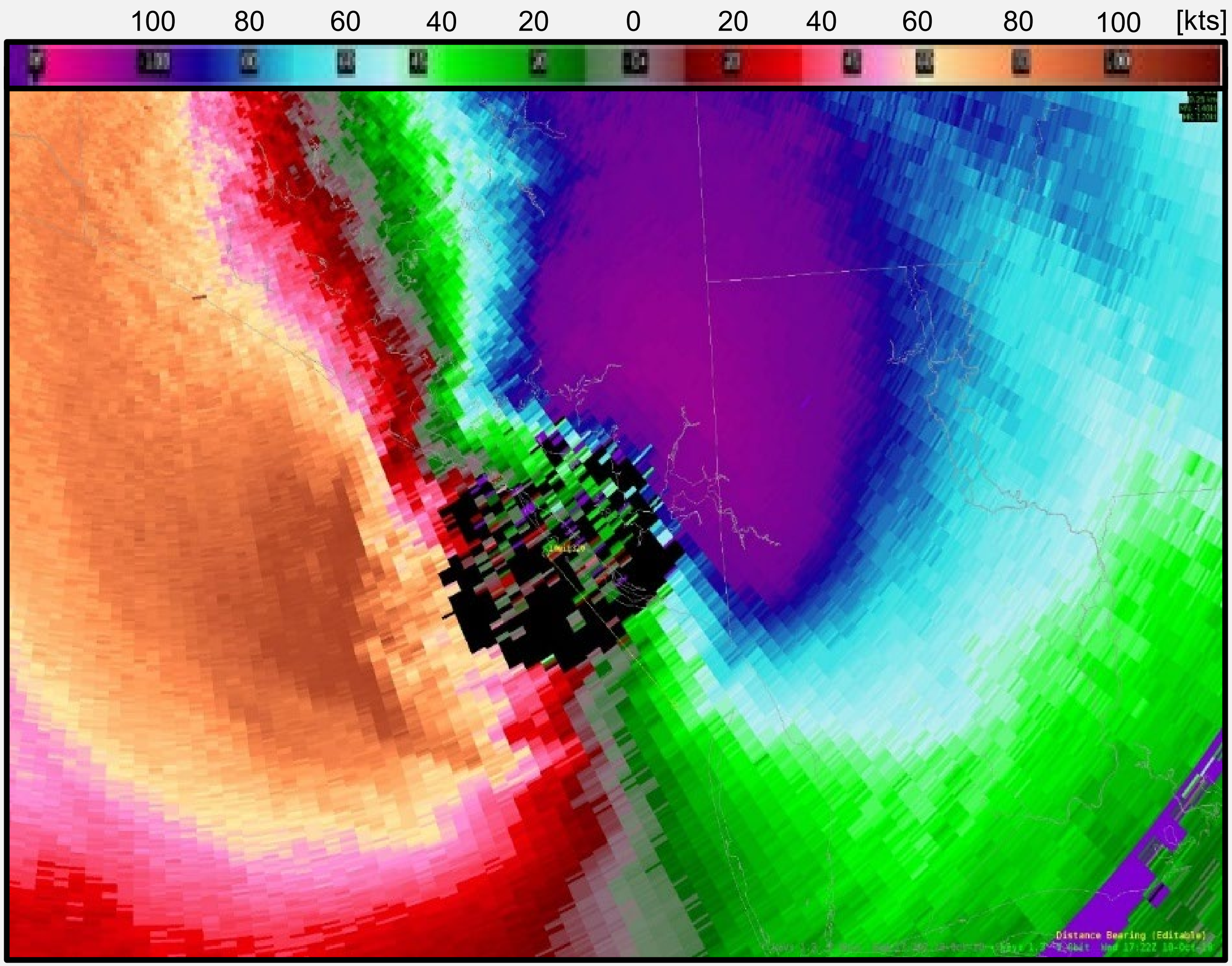
0%

100 kt

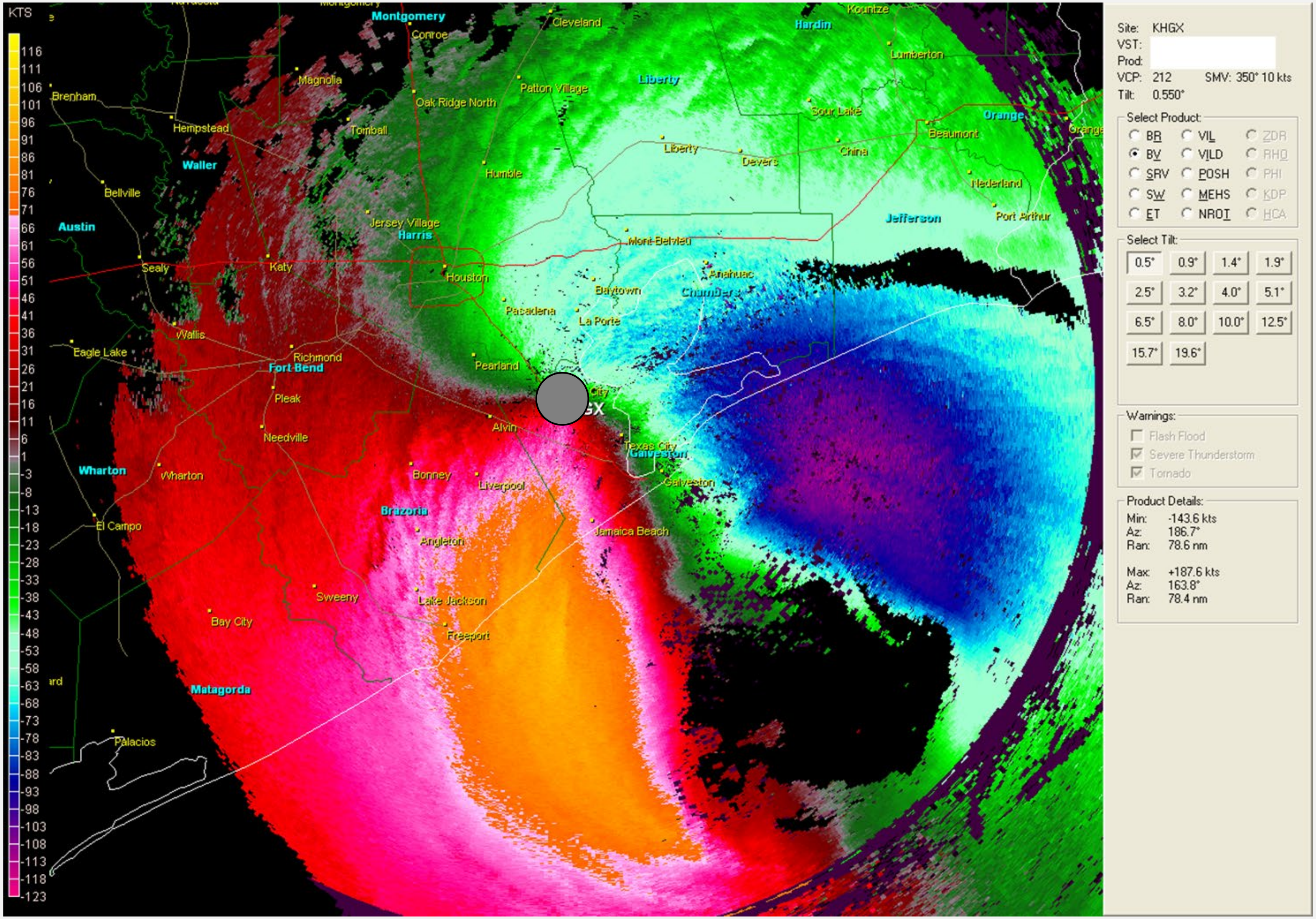
0%

Don't know

0%

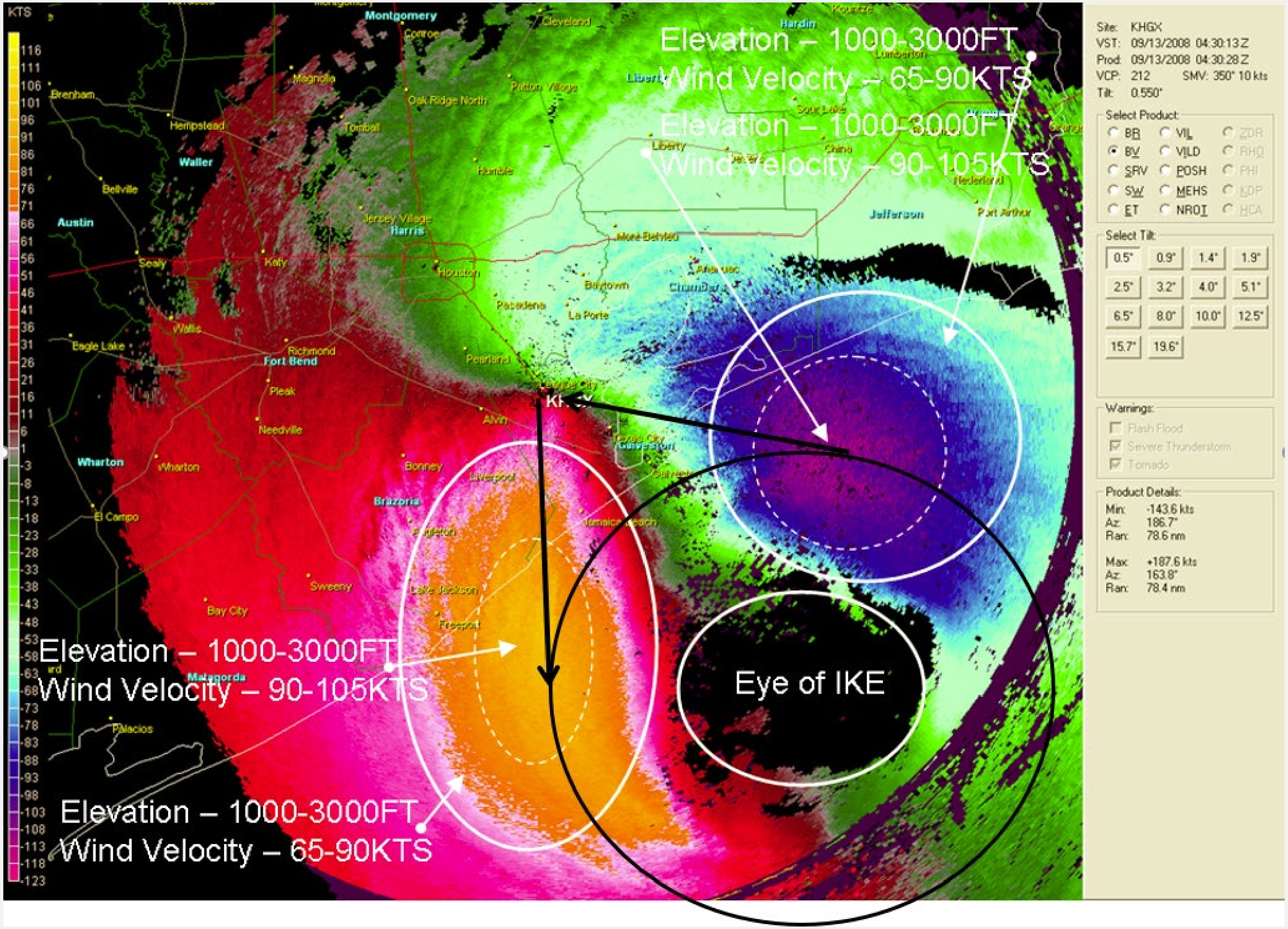


Example #2: Ike (2008)



https://www.weather.gov/hgx/projects_ike08_wind_analysis - – Houston/Galveston, TX Weather Forecast Office

Example #2: Ike (2008)



https://www.weather.gov/hgx/projects_ike08_wind_analysis - – Houston/Galveston, TX Weather Forecast Office

Example #3: Ike (2008) (later)

In which part of the storm is the radar located at this time?

Eyewall

0%

Eye

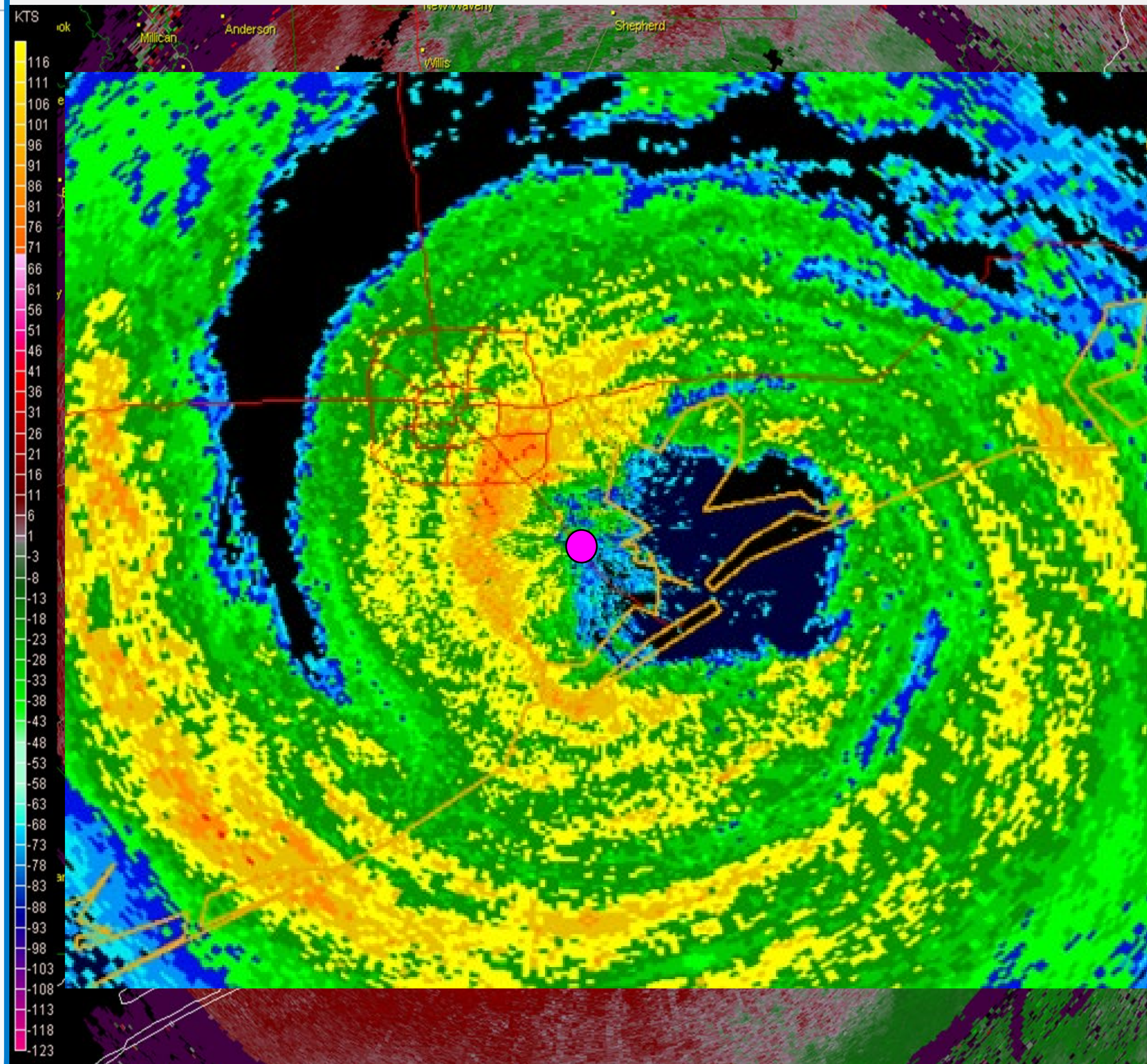
0%

Rainband

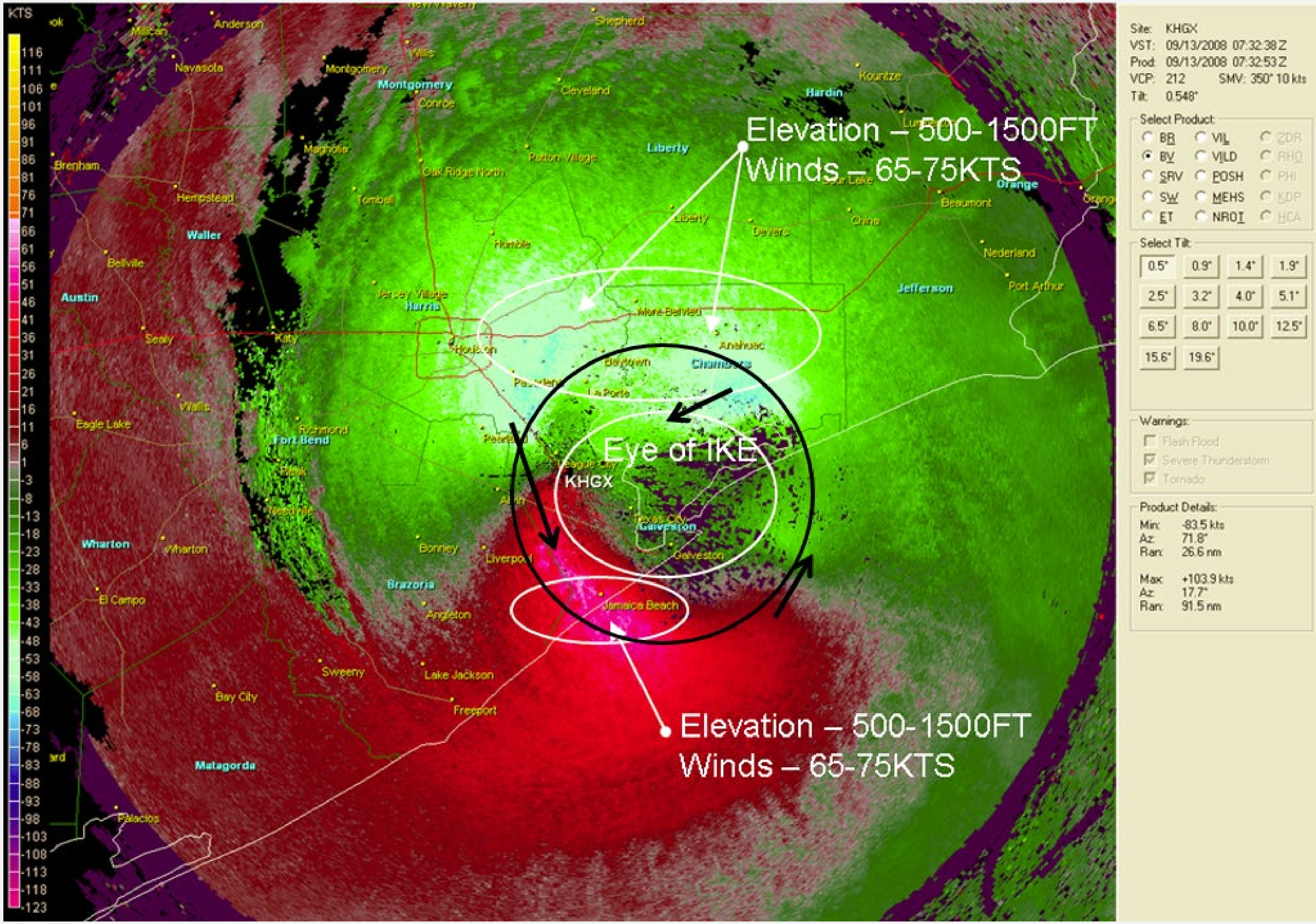
0%

Secondary Eyewall

0%



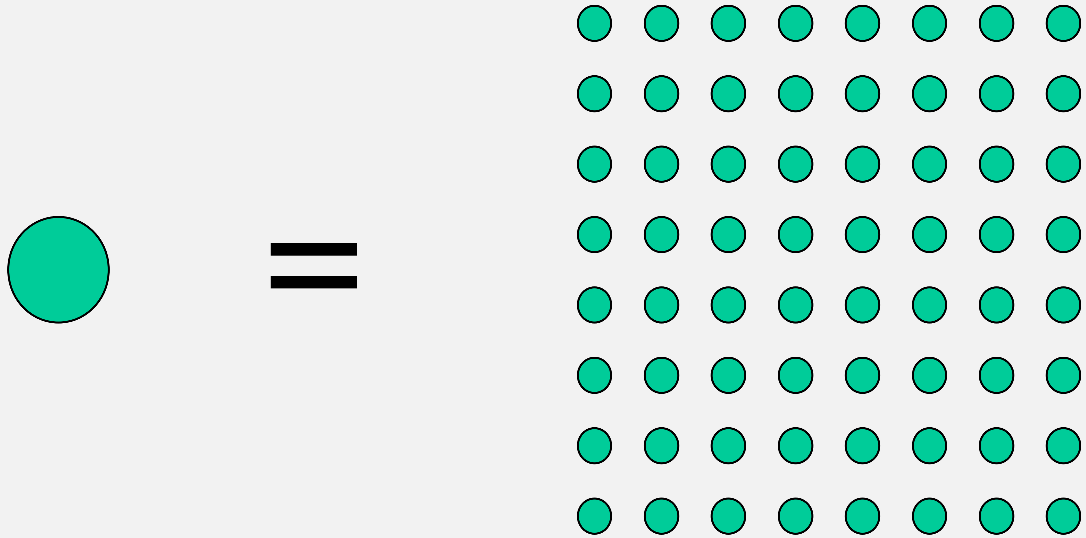
Example #2: Ike (2008)



https://www.weather.gov/hgx/projects_ike08_wind_analysis – Houston/Galveston, TX Weather Forecast Office

Rainfall Rates & Equivalent Reflectivity (dBZ)

Effect of Drop Size on Reflectivity



One 1/4-inch diameter drop returns as much energy as 64 drops of 1/8-inch diameter.

However, one 1/4-inch diameter drop has a volume of only 0.065 in^3, whereas sixty-four 1/8-inch diameter drops yield a volume of 0.52 in^3 …or **8 times as much total water mass**!

REFLECTIVITY DILEMMA

The one 3-mm diameter rain drop returns more power and produces a larger reflectivity than the sixty-four 1-mm drops do… yet the one 3-mm diameter rain drop ***contains much less total water mass*** than the sixty-four 1-mm rain drops!

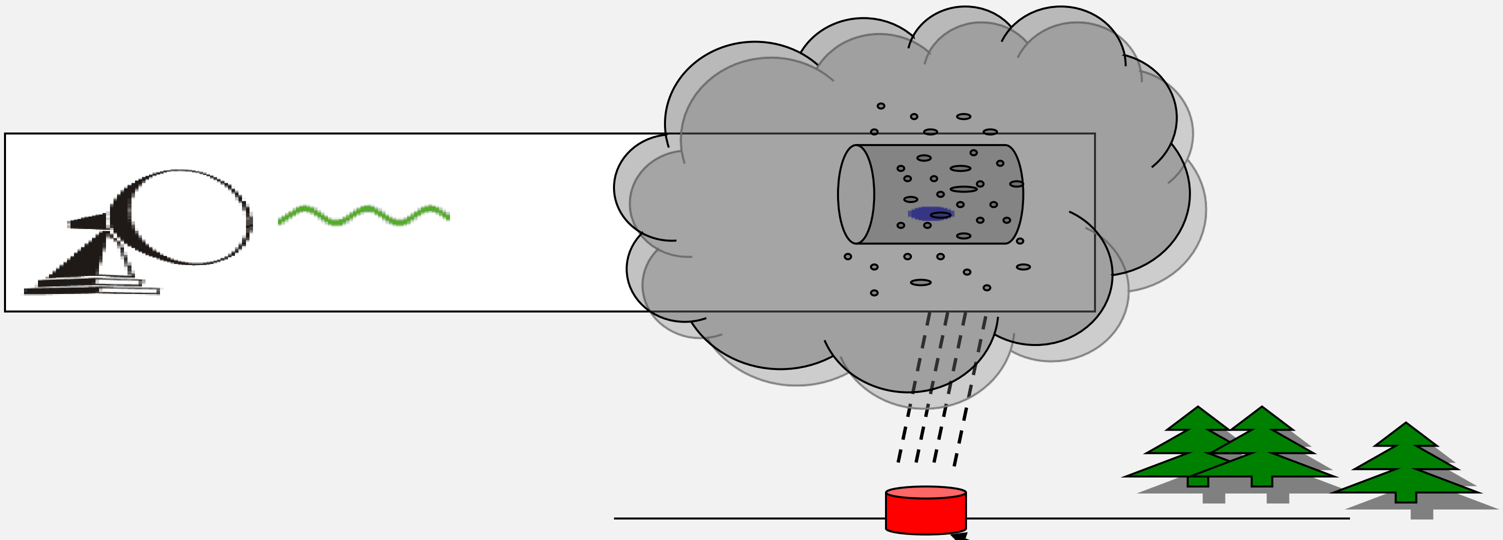
Estimating Rainfall Rates – Z-R (Reflectivity-Rainfall) relationships

Since we don't know the distribution of precipitation particles, we can

1. Use **equivalent reflectivity** (instead of reflectivity), which is a function of the power returned and the range / distance from radar
2. Apply empirically derived relationships to estimate the precipitation rates for different regimes, for example:
   a. Default
   b. Conventional
   c. Convective
   d. Snowfall
   e. **Tropical**
3. Solve a simple equation to estimate rainfall rate

Z-R or Reflectivity-Rainfall Relationships

we now have the input we need (i.e. Z_e), to find…



…an <u>empirical</u> relationship to estimate rainfall rate using the logarithmic function equation –

$$Z_e = a\,R^b$$

$$Z_e = 250\,R^{1.2}$$ where R is rain rate (mm/h)

Example: Storm-Total Rainfall for Harvey (2017)

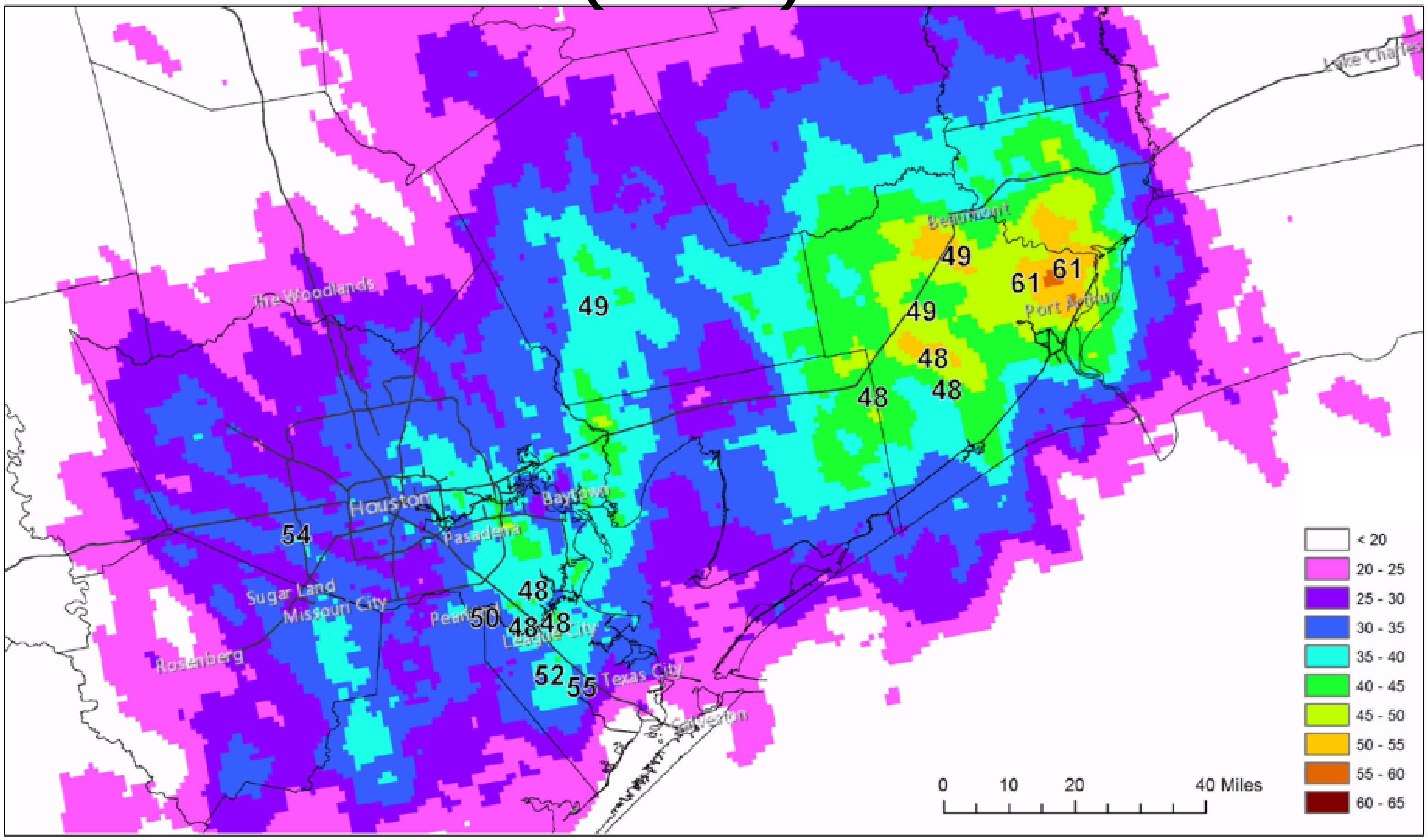
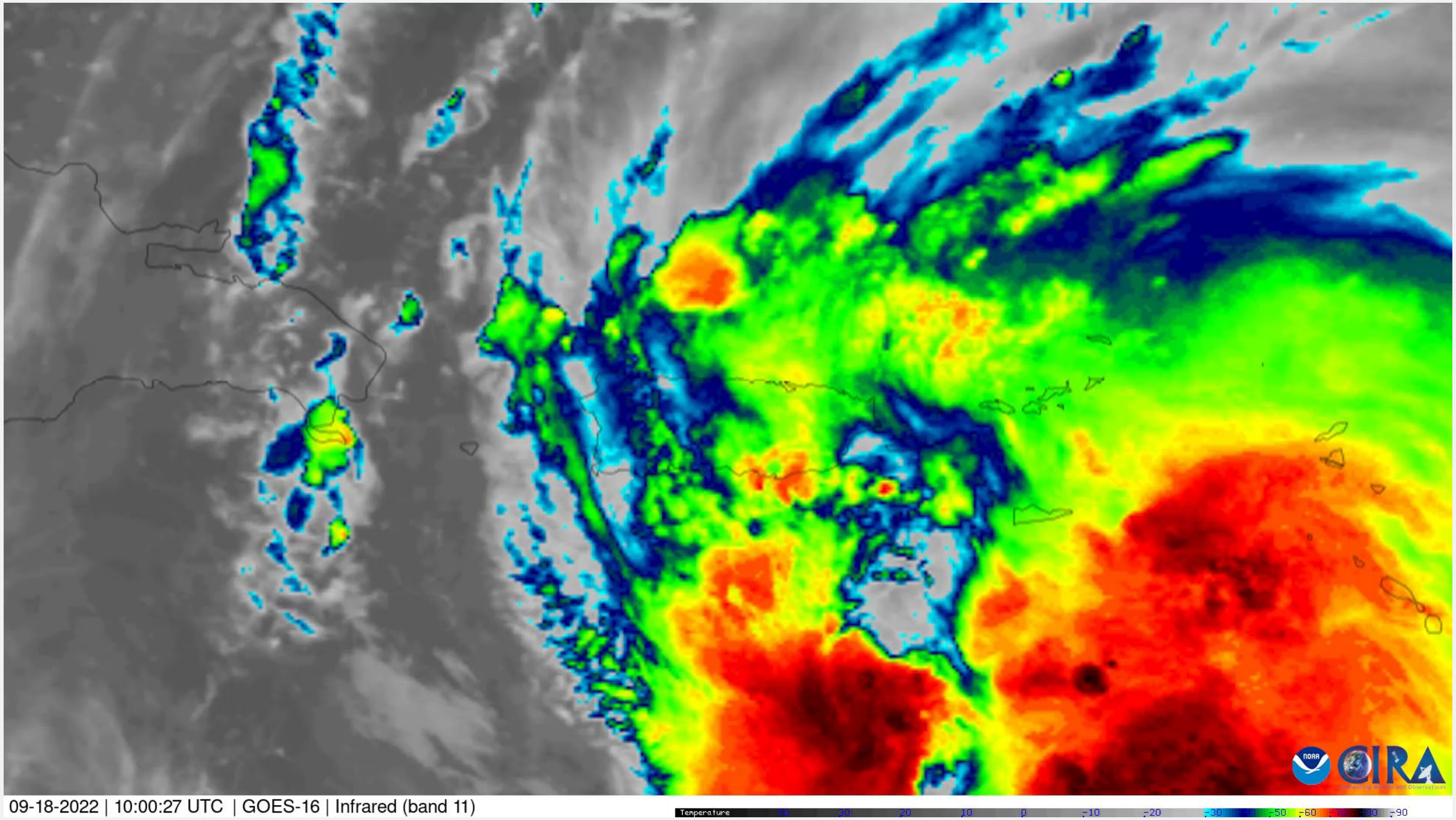


Figure 9. NOAA gauge-corrected, multi-radar multi-sensor quantitative precipitation estimates for Harvey (inches), 25 August-1 September 2017. The black numbers are actual rain gauge values, all of which exceed the previous U.S. continental rainfall record for a tropical cyclone.

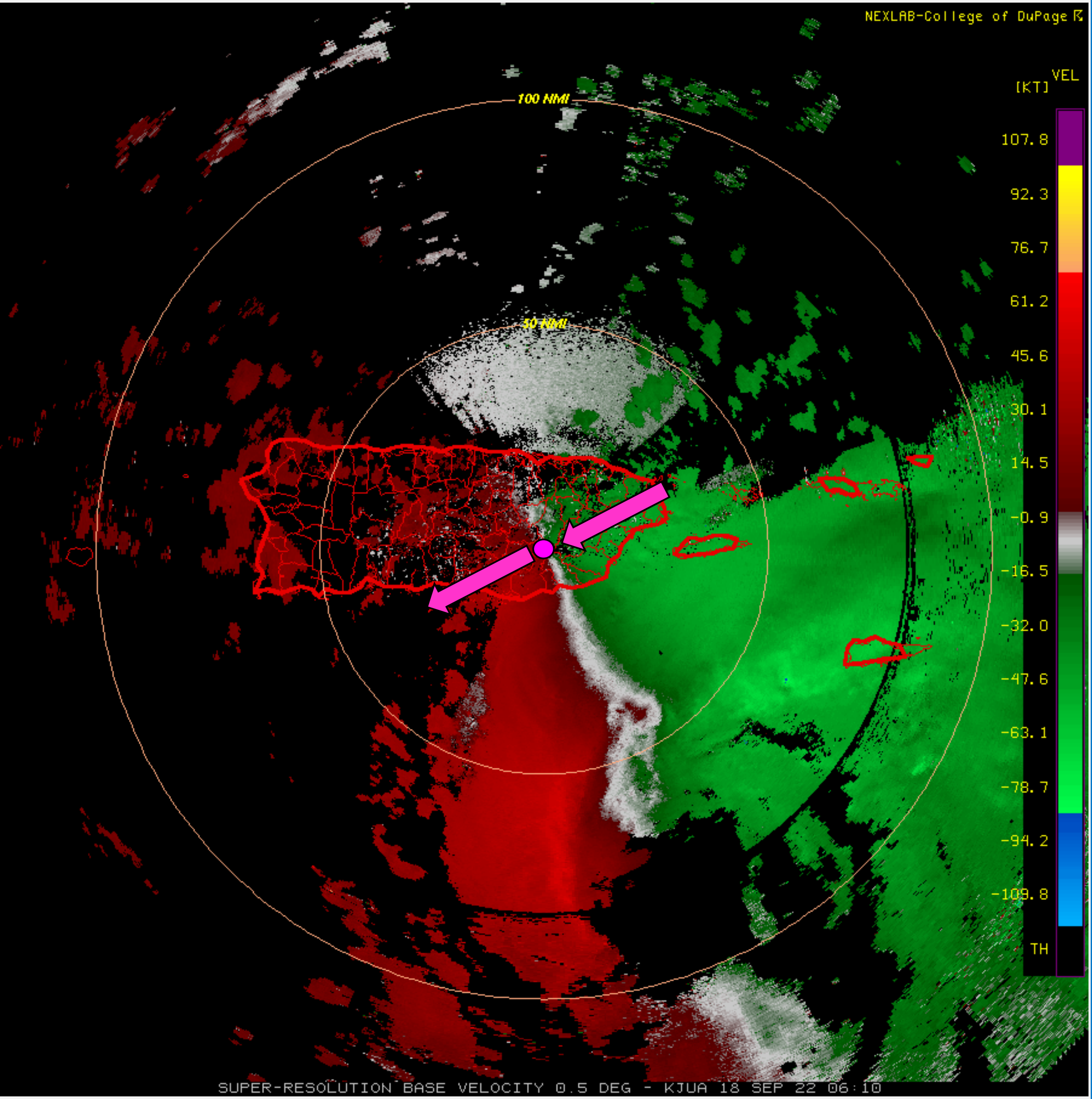
Exercise: Fiona (2022)

Fiona (2022) Overview

- Fiona became a hurricane during morning of Sept 18, and intensified in close proximity to the Puerto Rico NEXRAD radar



IR satellite loop - 1000Z - 2000Z on Sept 18



What is the wind direction at the radar?

NE

0%

SW

0%

NW

0%

SE

0%

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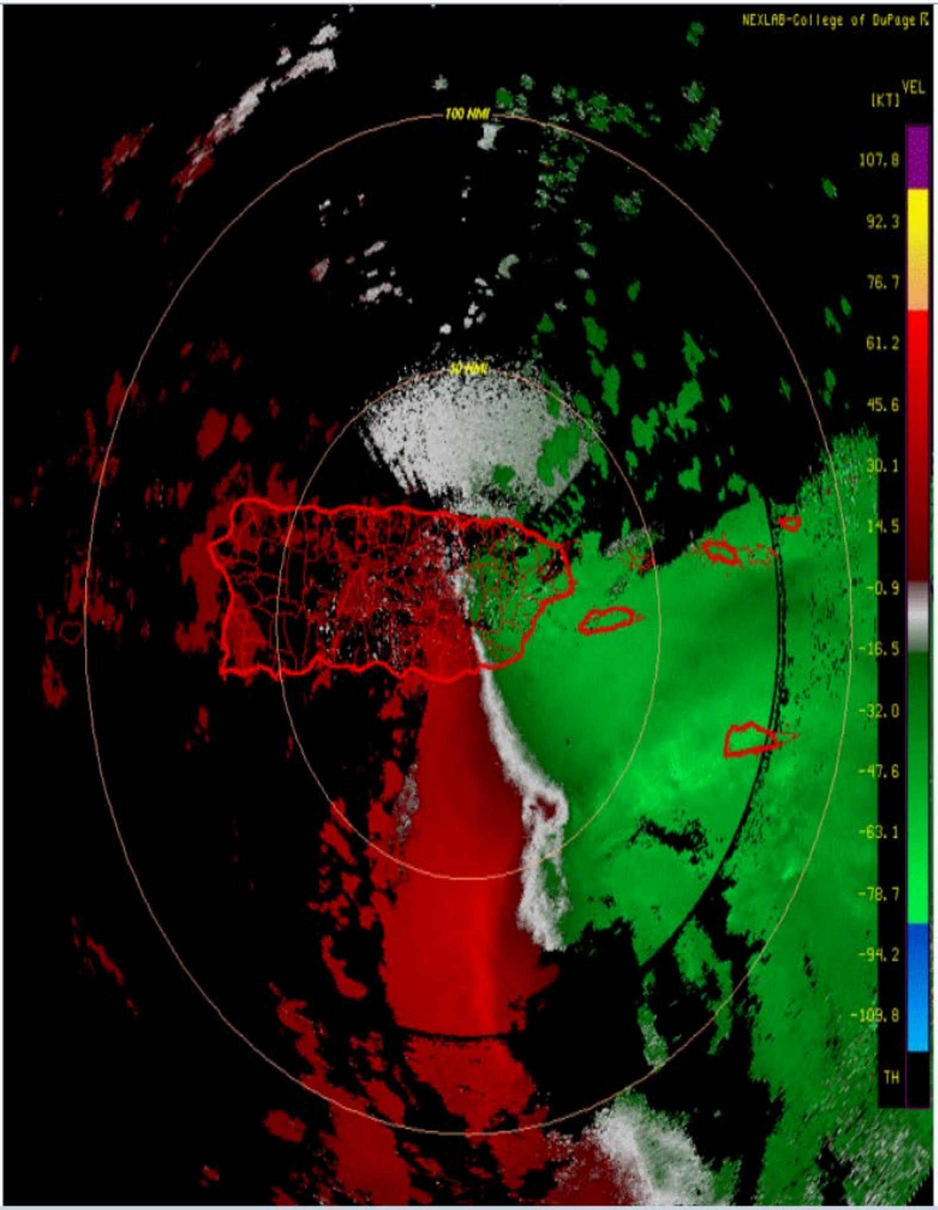
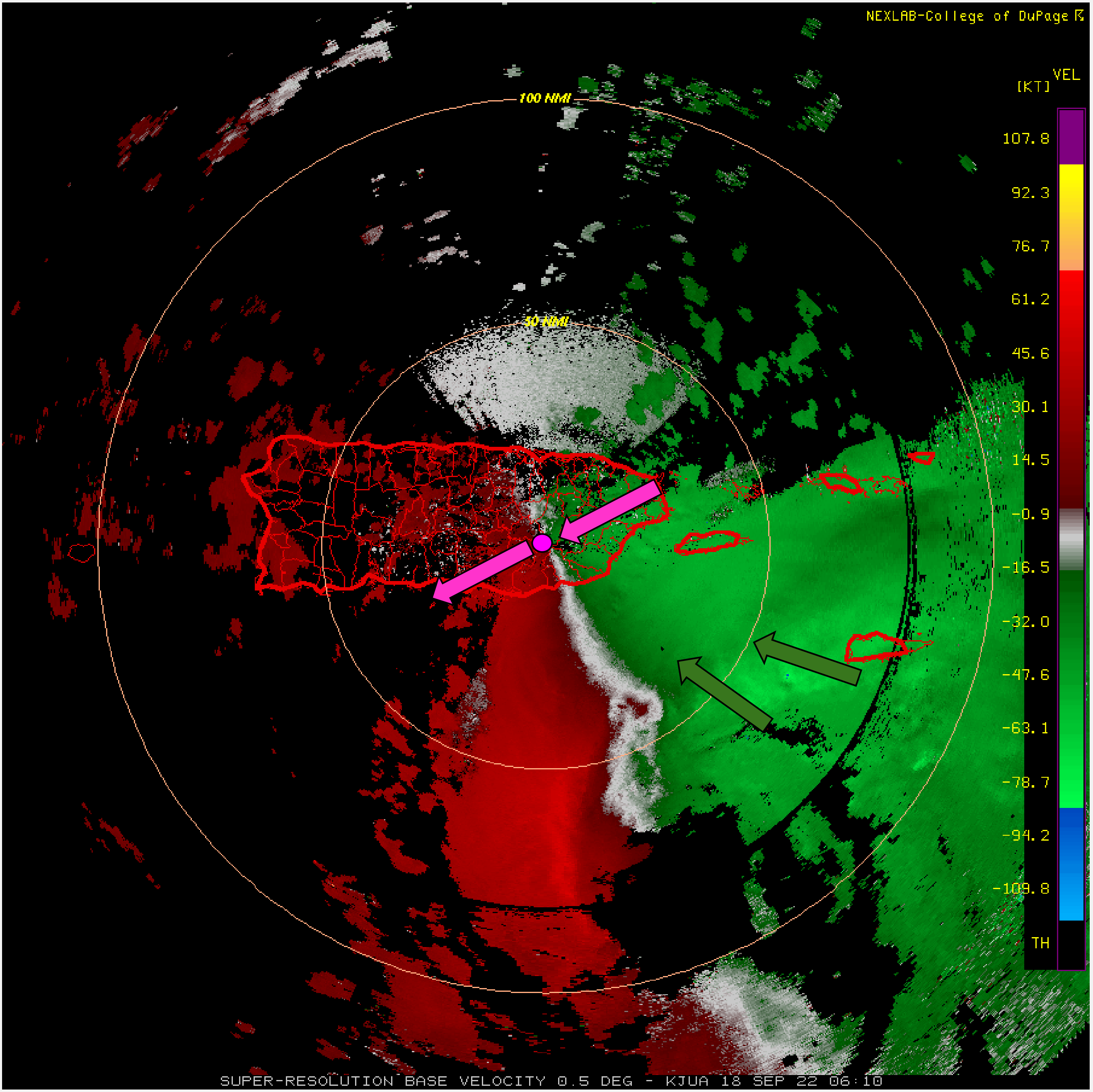
Where are the strongest winds toward the radar?

0





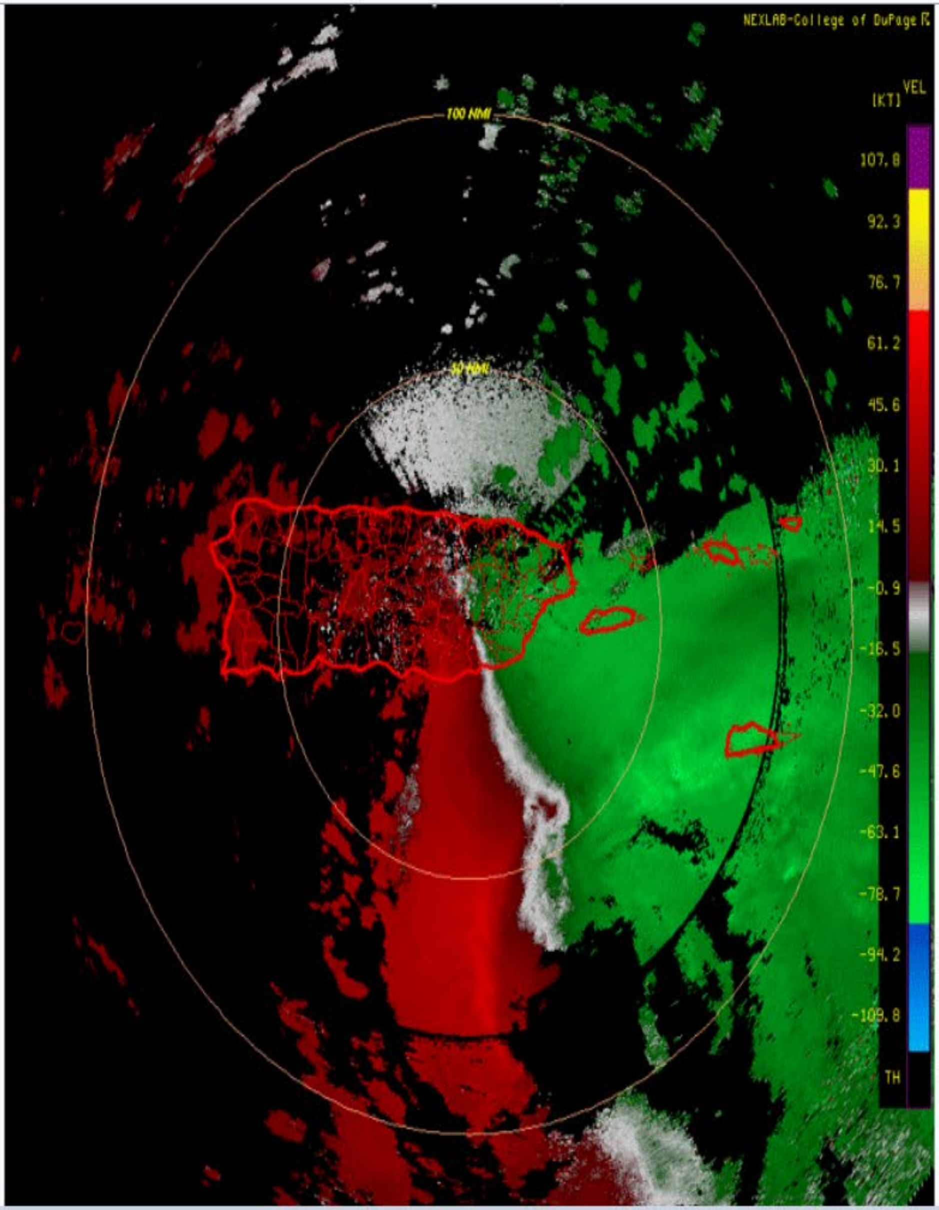
0610 UTC

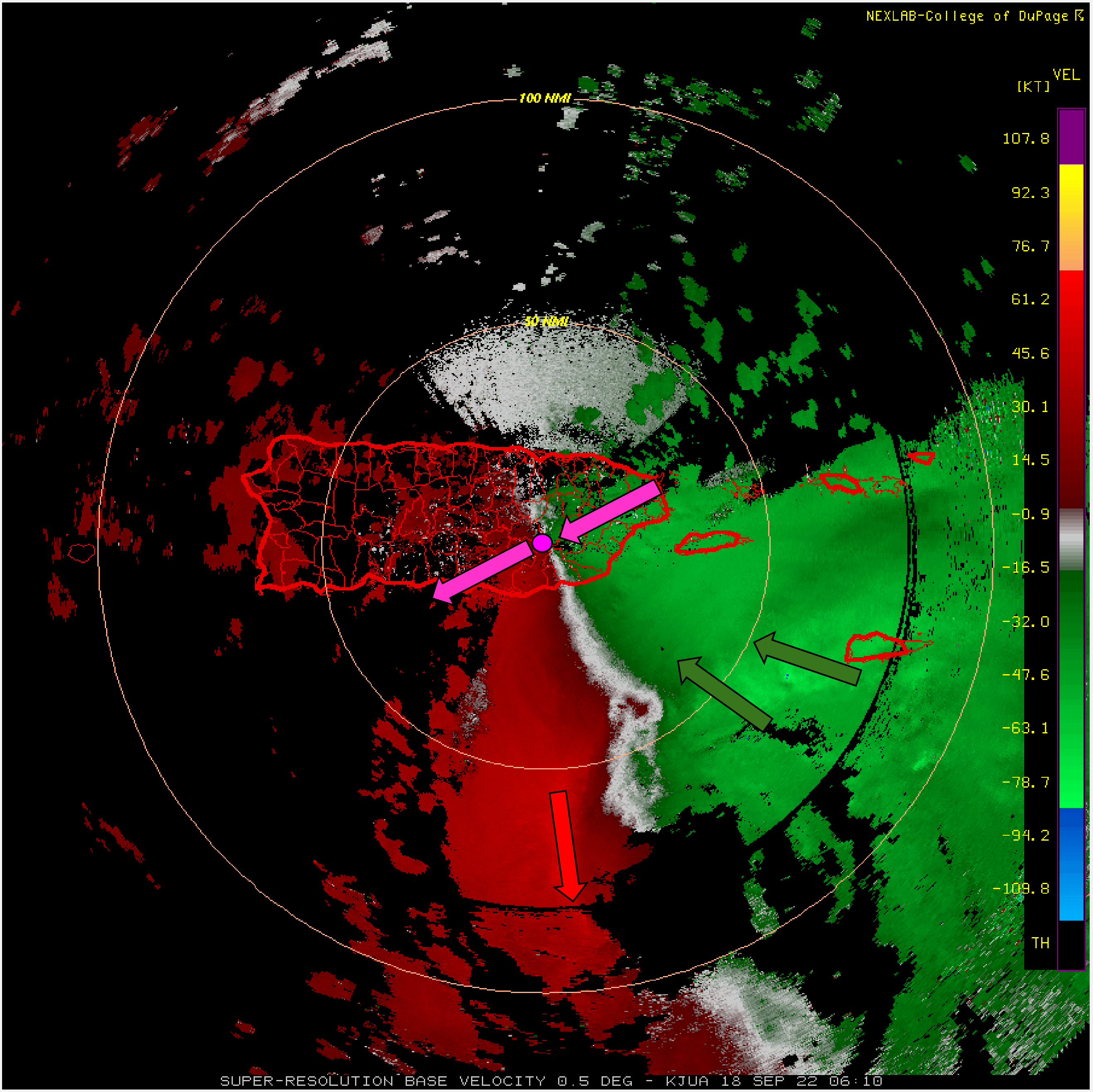
Find your radar location!

What is the wind direction at the radar?

Where are the strongest winds toward the radar?

Where are the strongest winds away from the radar?





0610 UTC

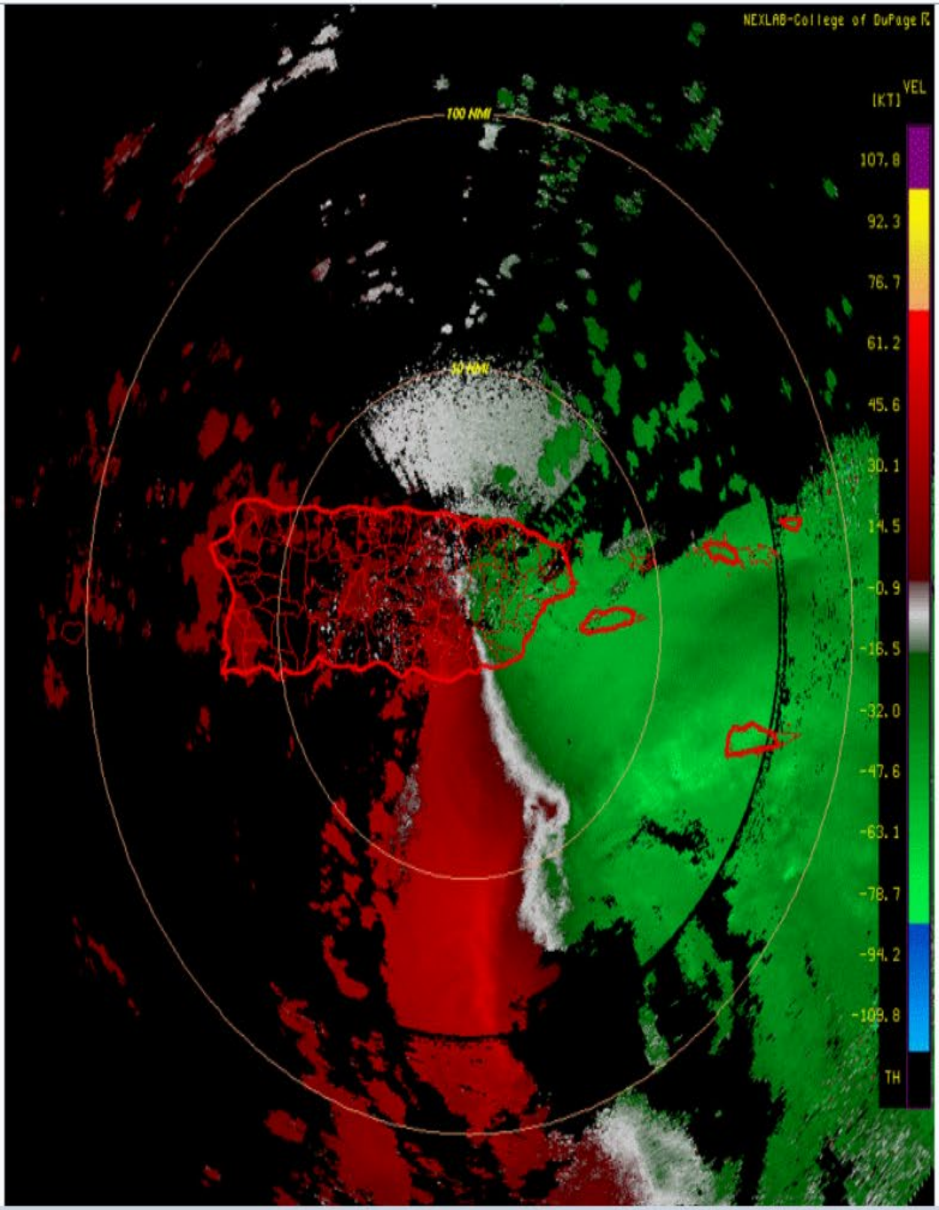
Find your radar location!

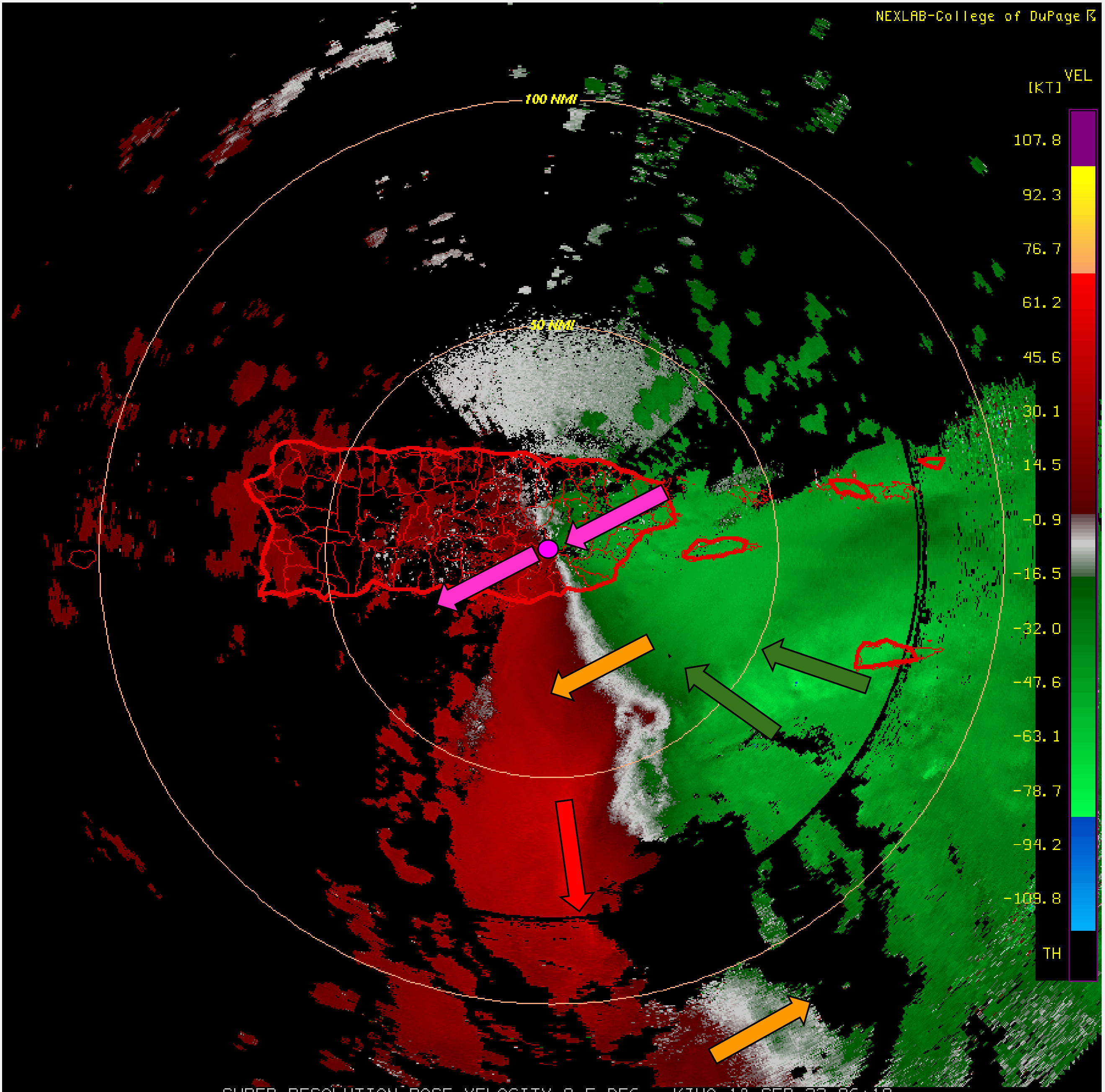
What is the wind direction at the radar?

Where are the strongest winds toward & away from the radar?

Where are winds perpendicular to the radar? You may select multiple locations.

0





0610 UTC

Find your radar location!

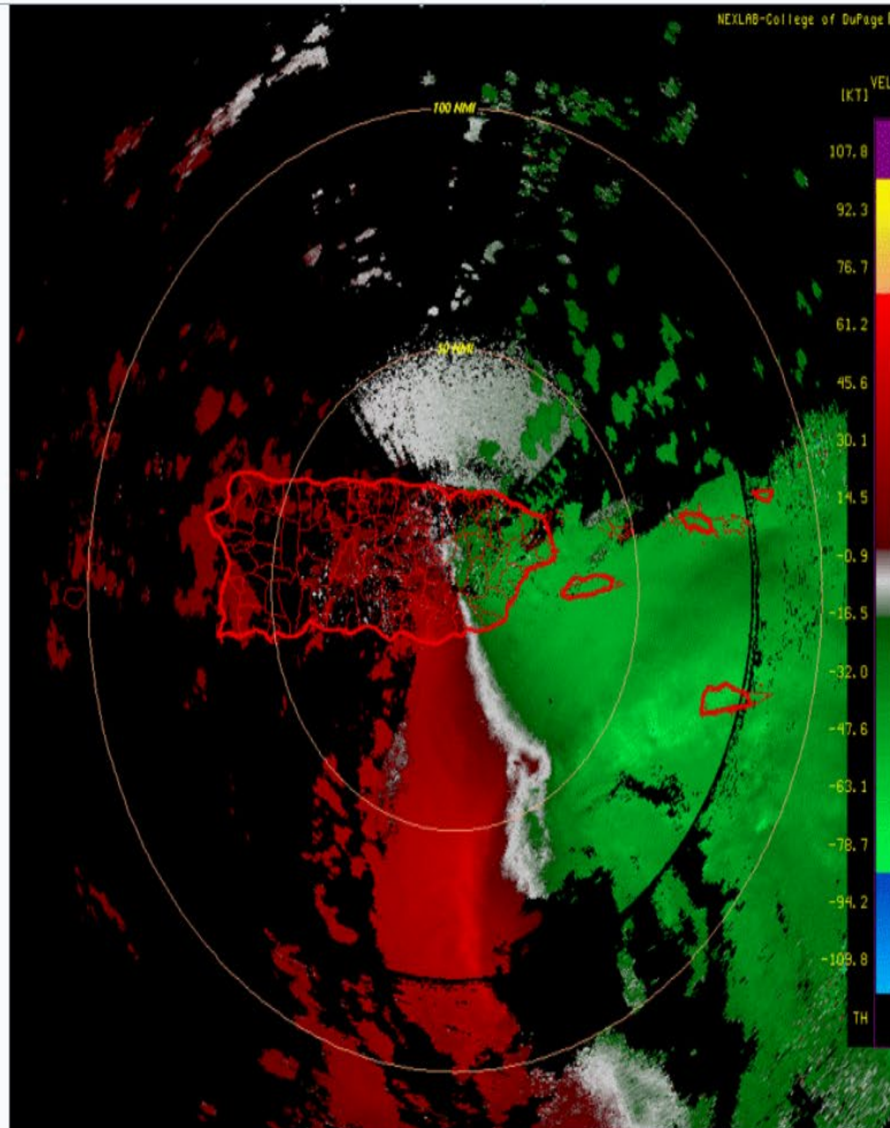
What is the wind direction at the radar?

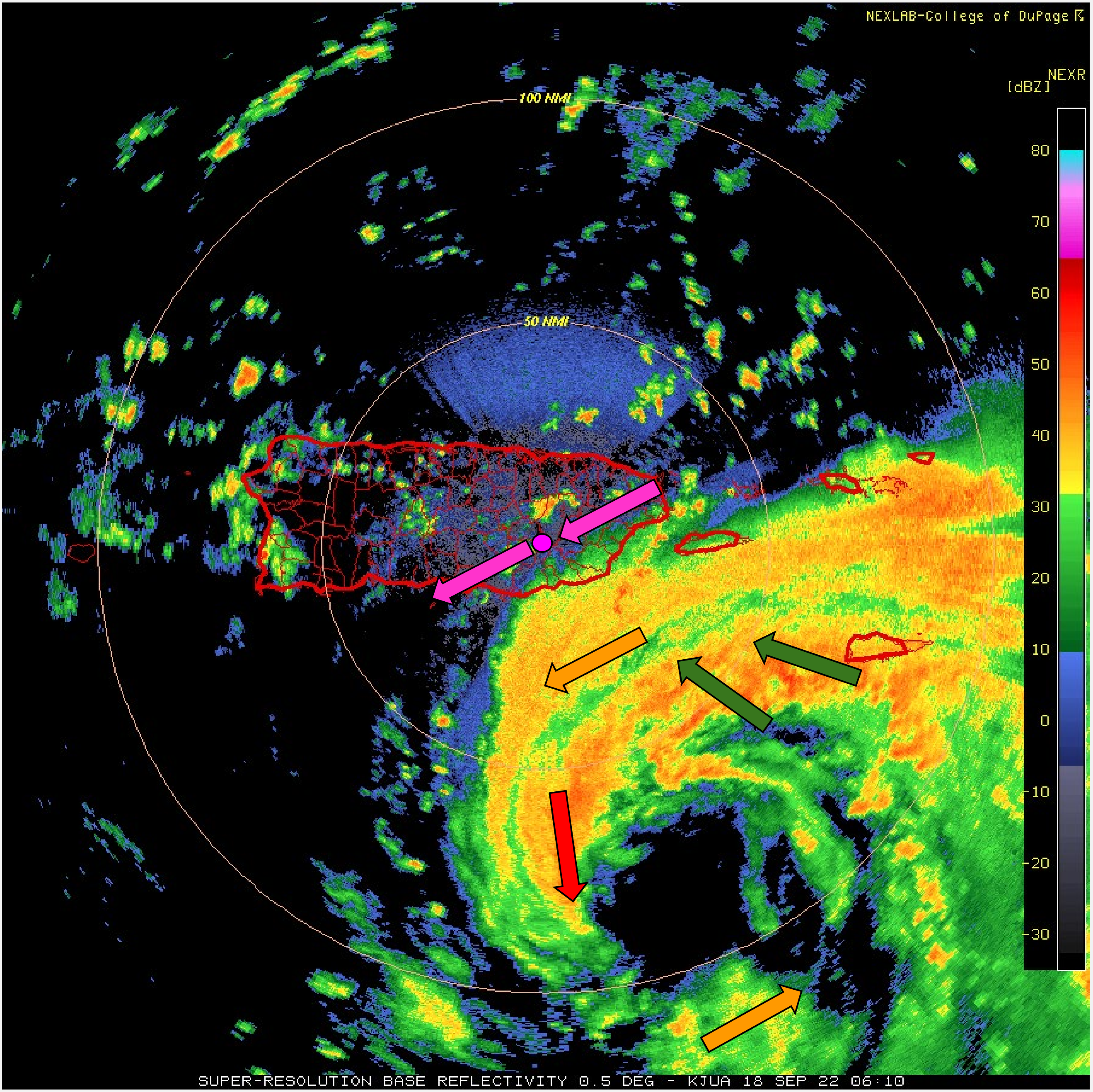
Where are the strongest winds toward & away from the radar?

Where are winds perpendicular to the radar beam?

What is your best estimate for the center of the TC?

0





0610 UTC

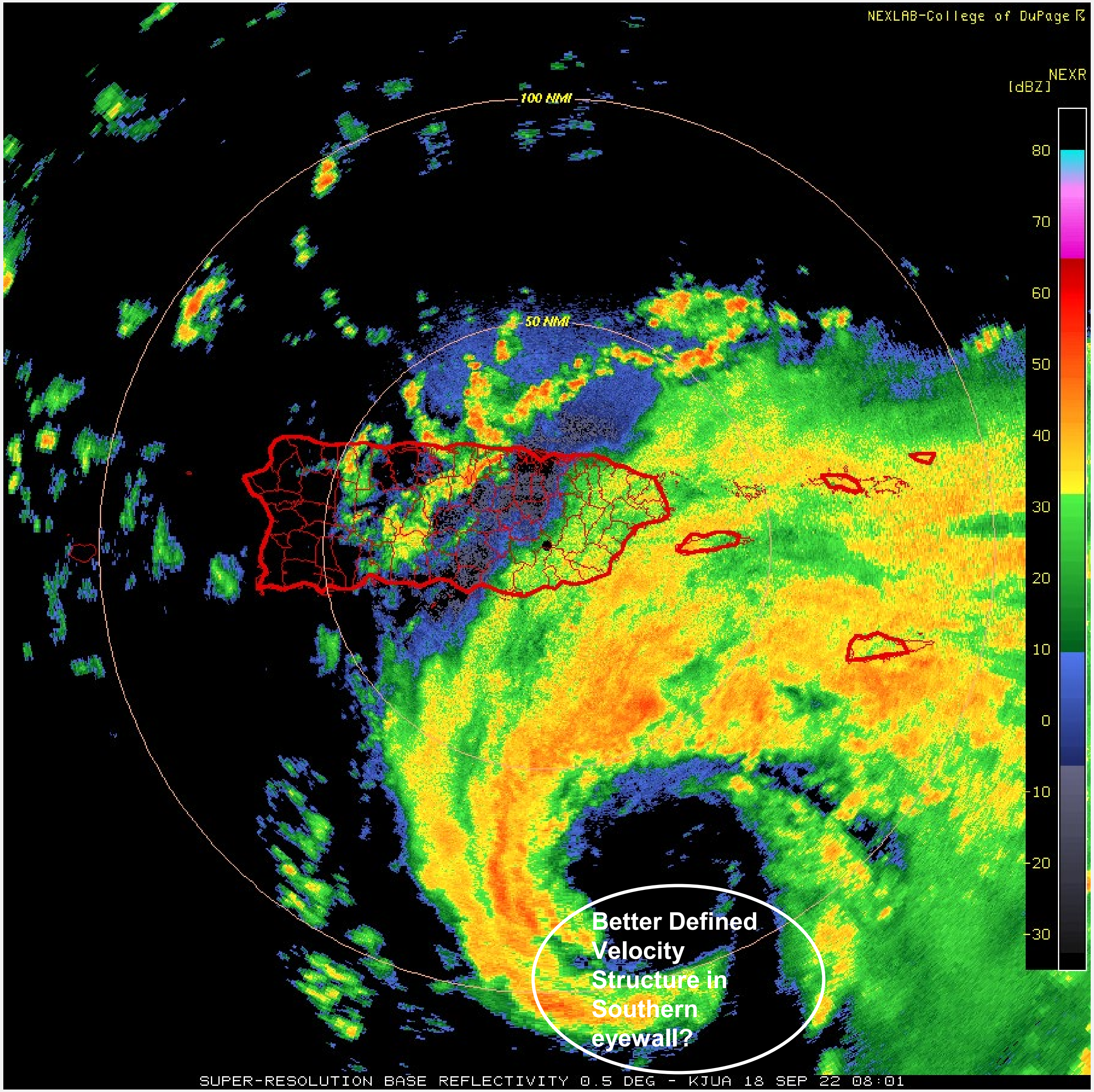
Find your radar location!

What is the wind direction at the radar?

Where are the strongest winds toward & away from the radar?

Where are winds perpendicular to the radar?

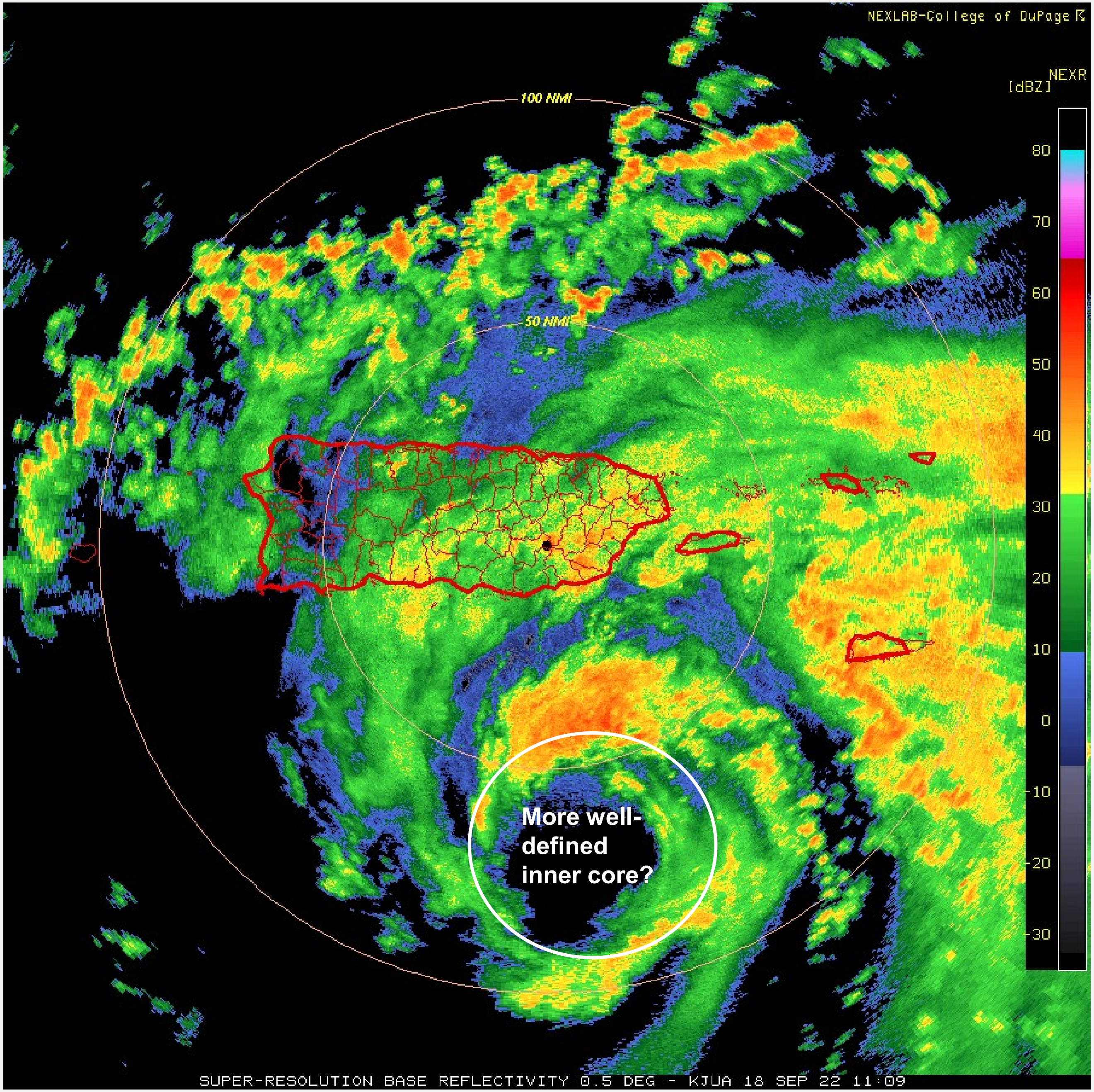
Where is the TC center?



0801 UTC

What's changed?

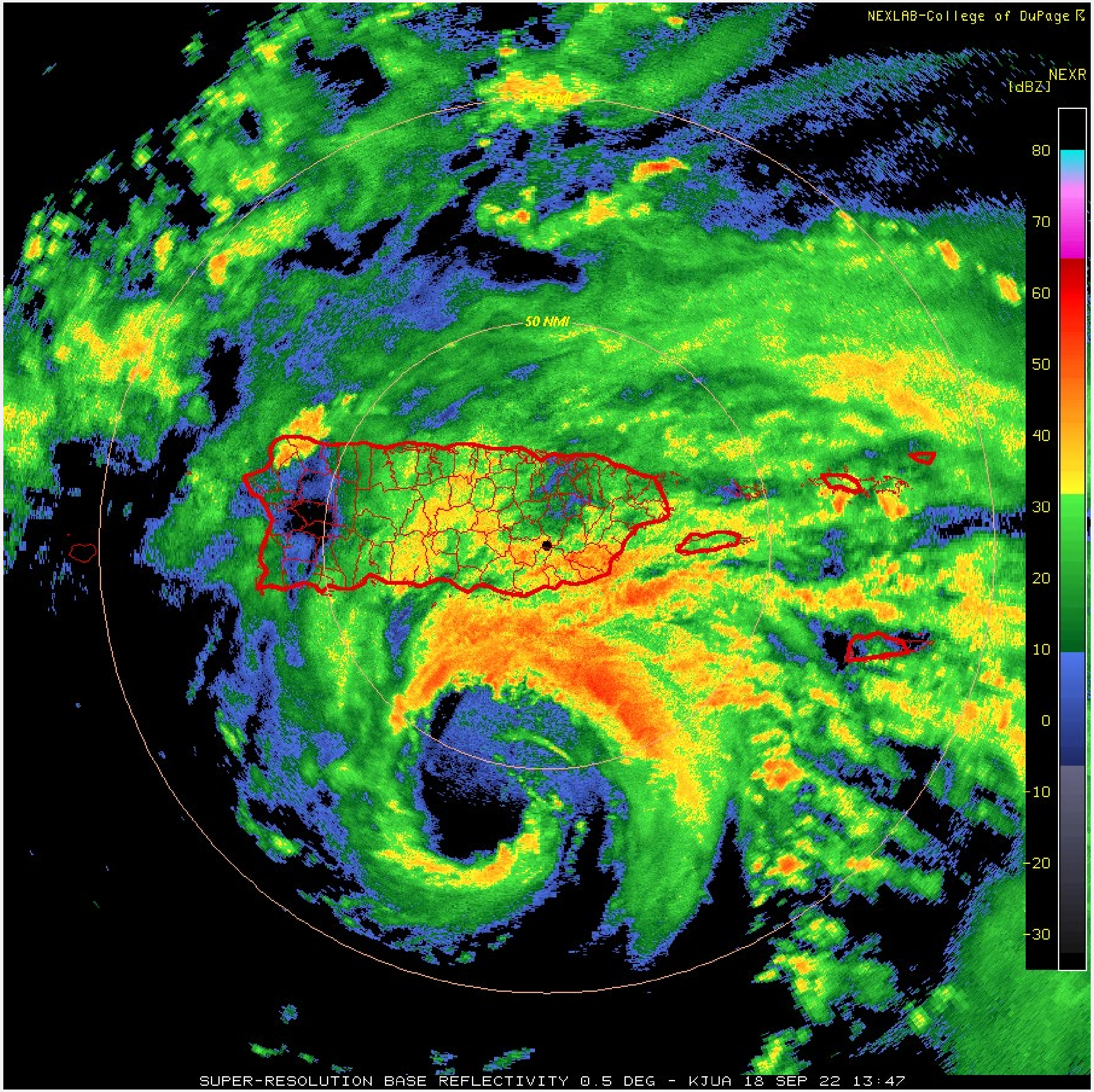
Can you estimate the center?



1109 UTC

What's changed?

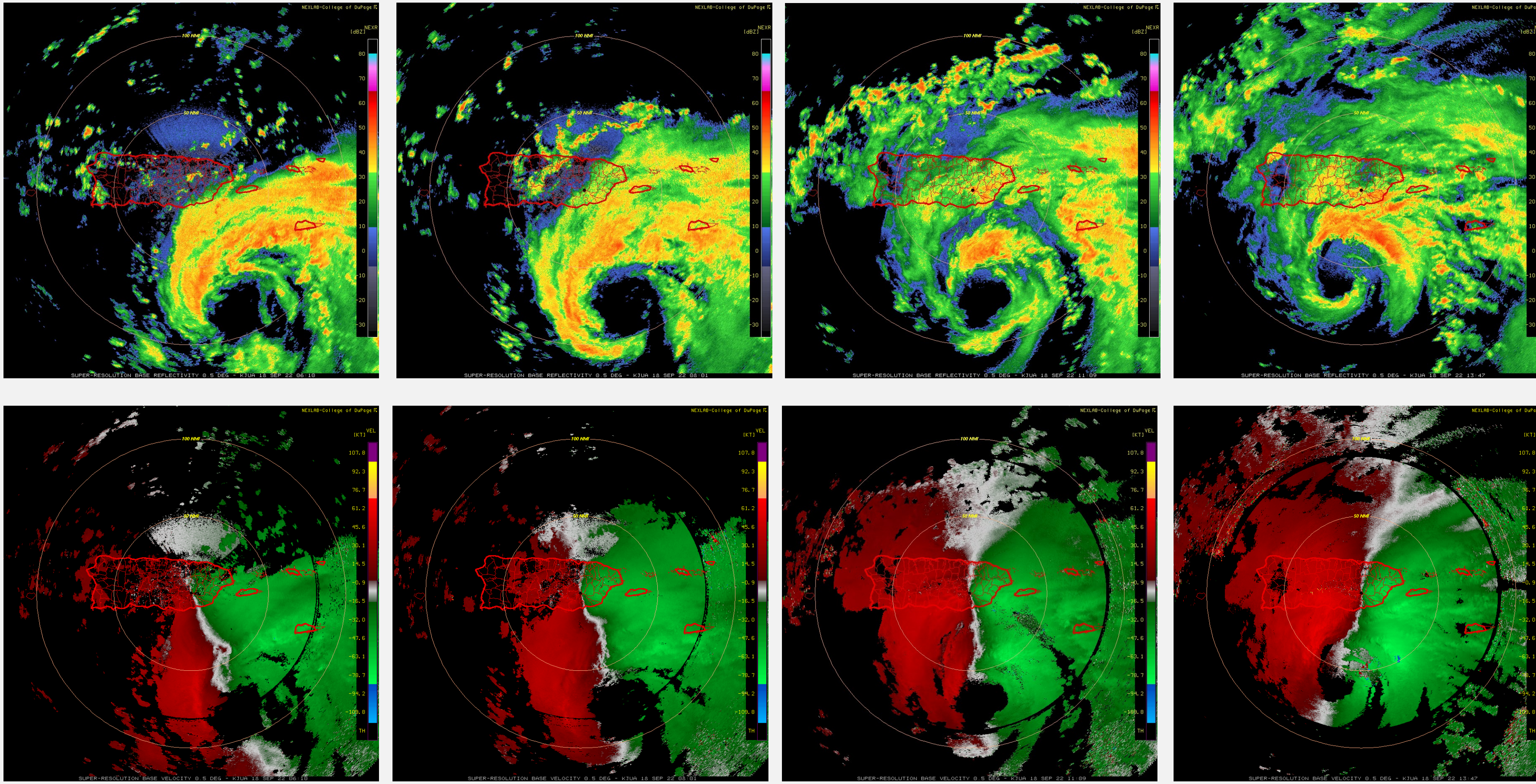
Can you estimate the center?



1347 UTC

What's changed?

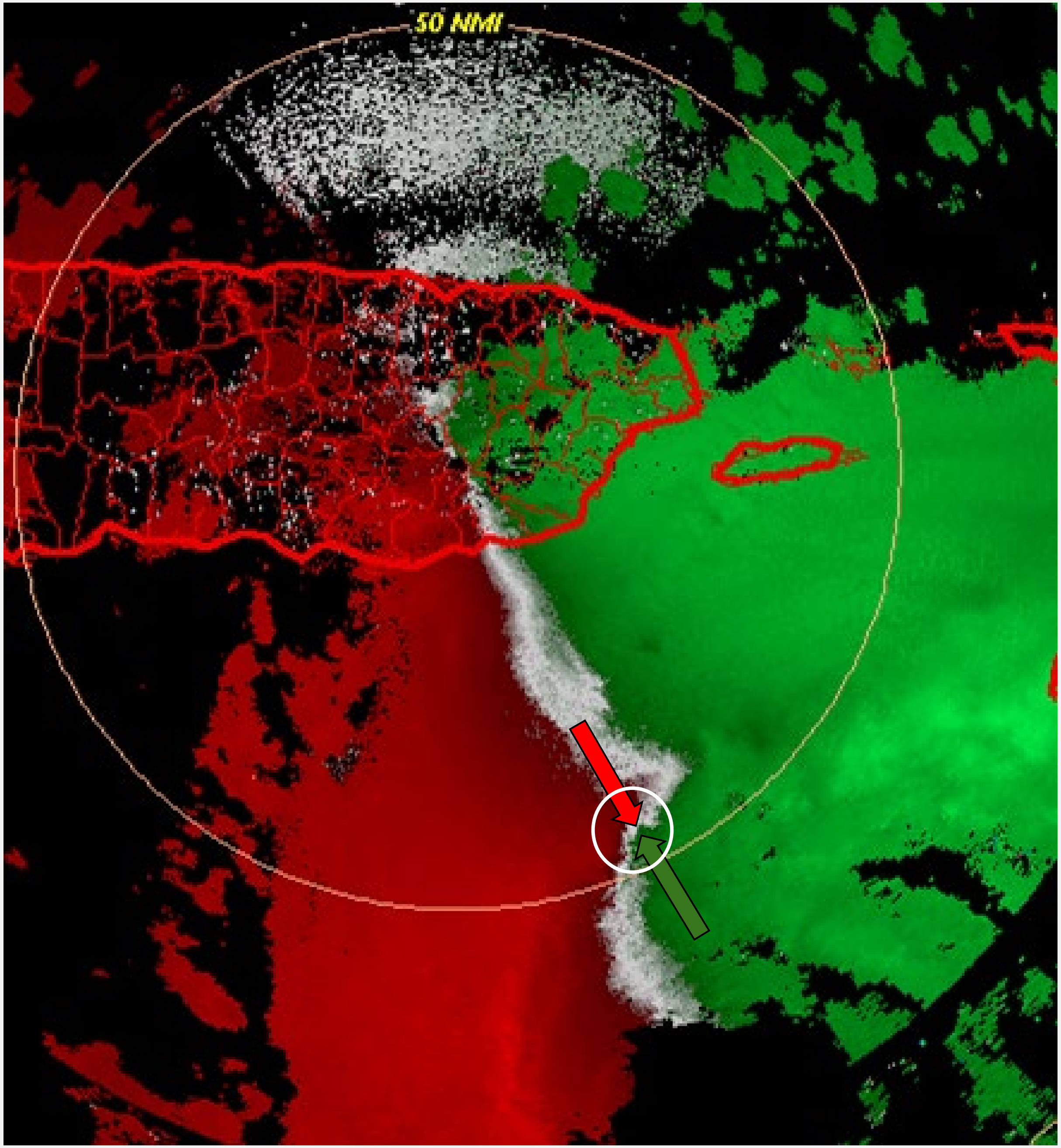
Can you estimate the center?



In the case of Fiona, radar enabled:

- High-resolution analysis of structural evolution
- Approximation of the wind maxima & center location, which was difficult to identify via satellite
- Hints of intensification (eyewall contraction)

*note - Fiona was approaching the radar, resulting in lower-altitude sampling at later times



0552 UTC

Use velocity to identify smaller scale features

What is happening here?

Summary

• Radar reflectivities and Doppler velocity are effective tools in determining tropical cyclone location and structure, and monitoring intensity changes

• When analyzing radar data, remember that **1)** the altitude of the radar beam is very important, **2)** radar only measures one component of the velocity vector, and **3)** TC intensity can rarely, if ever, be determined from radar alone