Merging CYGNSS with Other Datasets to Construct Hurricane Integrated Kinetic Energy

Patrick Duran

University of Alabama in Huntsville

Acknowledgement: Dan Cecil

CYGNSS Science Team Meeting

15 January 2019

Pasadena, CA

Integrated Kinetic Energy (IKE)

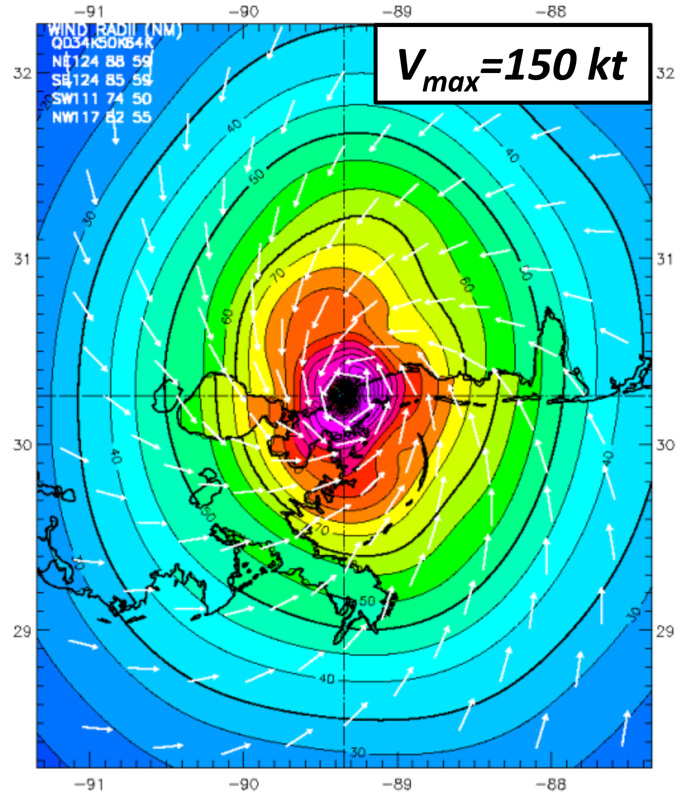
- A tropical cyclone (TC) intensity metric first proposed by Powell and Reinhold (2007):

$$IKE = \int_V \frac{1}{2} \rho U^2 dV$$

- Accounts for both maximum wind speed and the spatial extent of the surface wind field.
- Can be a better measure of destructive potential than maximum wind speed – particularly for large TCs.

The value of IKE

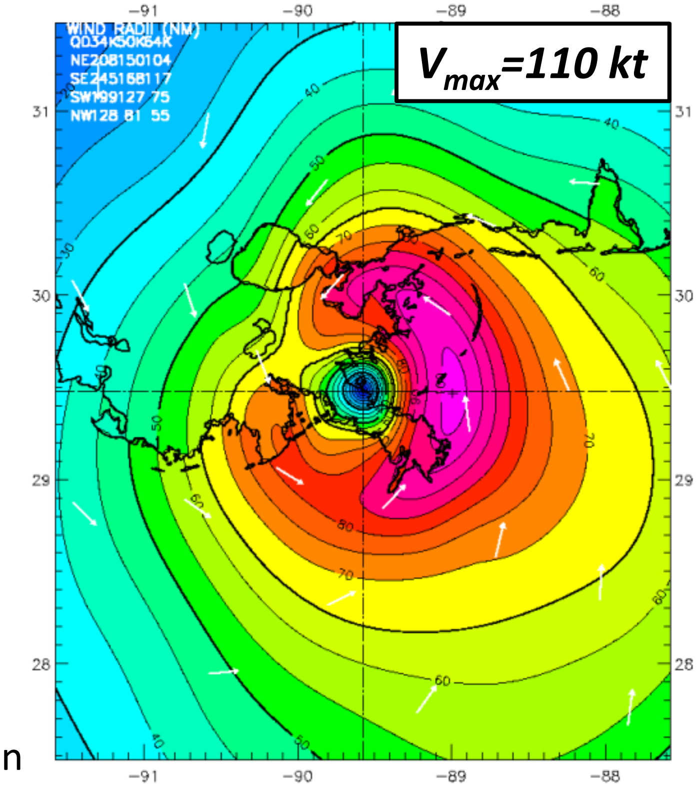
Hurricane Camille (1969)



Camille was stronger in terms of V_{max}.

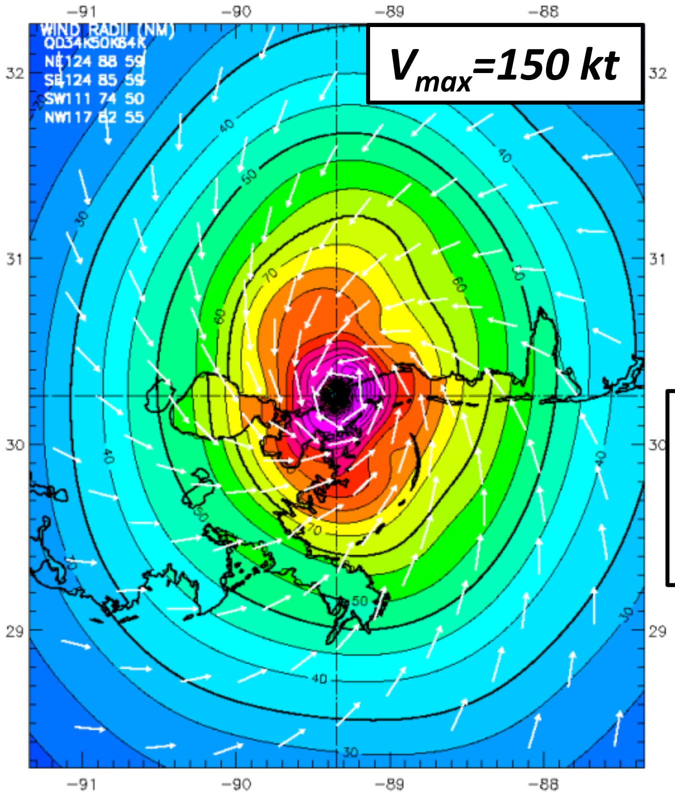
H*Wind analyses from NOAA/AOML Hurricane Research Division

Hurricane Katrina (2005)



The value of IKE

Hurricane Camille (1969)



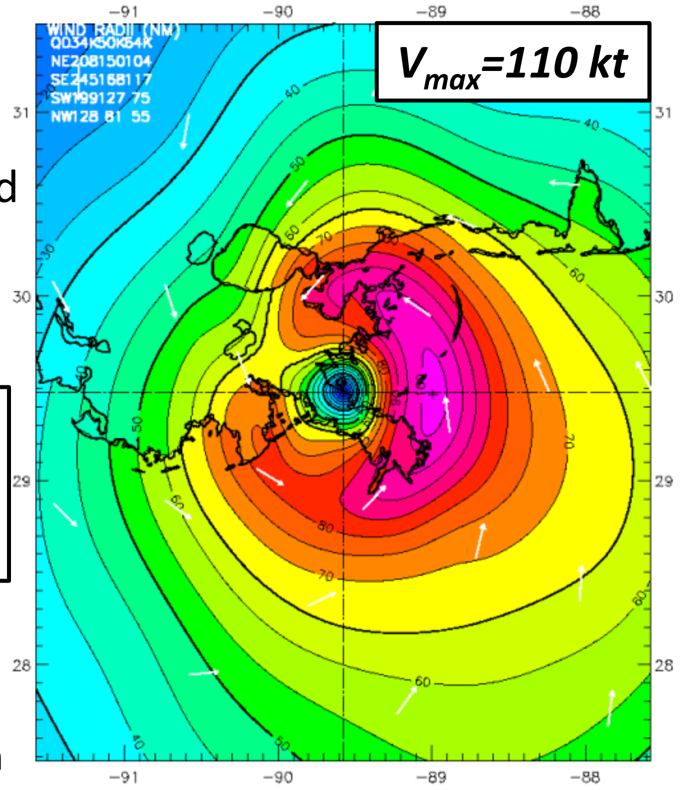
Camille was stronger in terms of V_{max}.

Katrina's larger wind field made it much more destructive.

Damage (2017 dollars)
Camille: $9.8 billion
Katrina: $160 billion

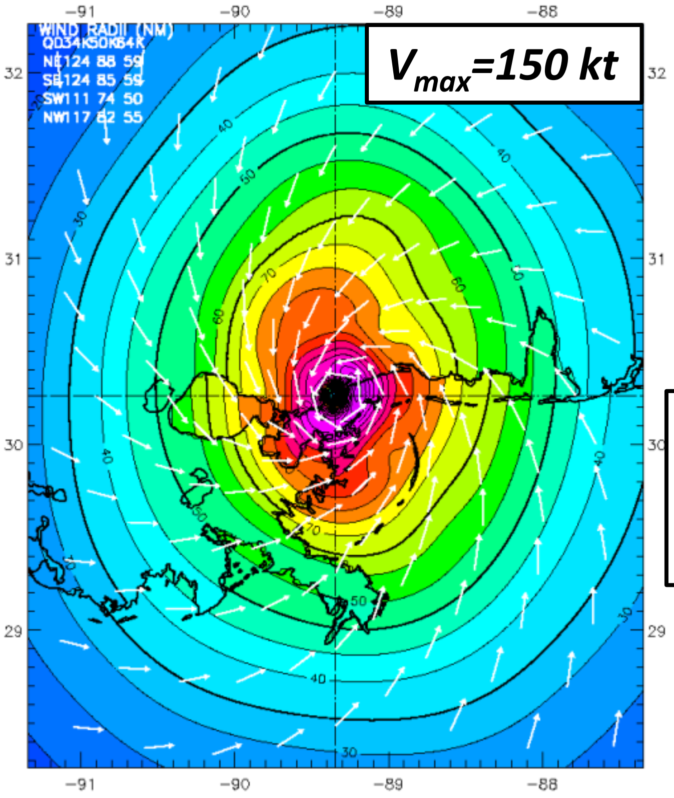
H*Wind analyses from NOAA/AOML Hurricane Research Division

Hurricane Katrina (2005)



The value of IKE

Hurricane Camille (1969)



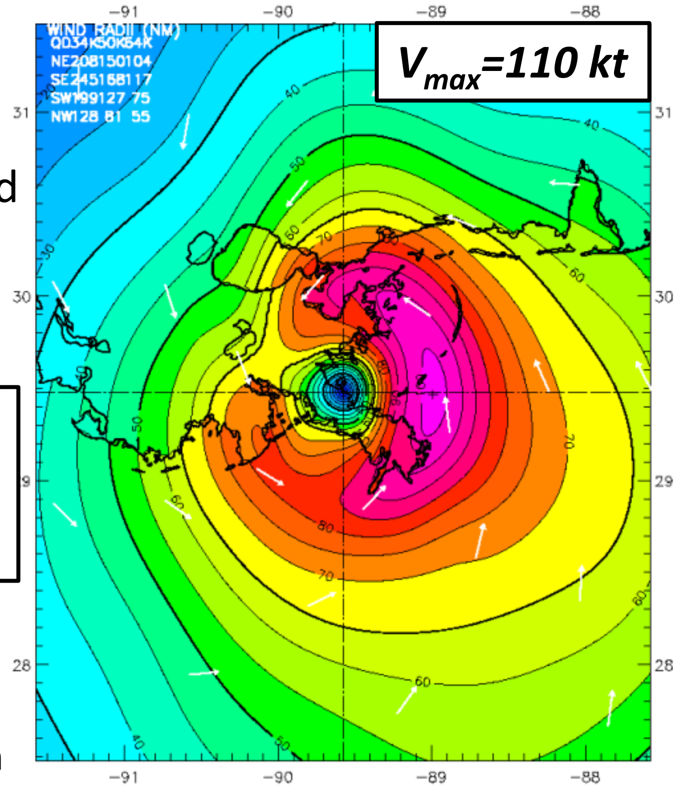
Camille was stronger in terms of V_{max}.

Katrina's larger wind field made it much more destructive.

<u>IKE (Powell & Reinhold)</u>
Camille: 63 Terajoules
Katrina: 122 Terajoules

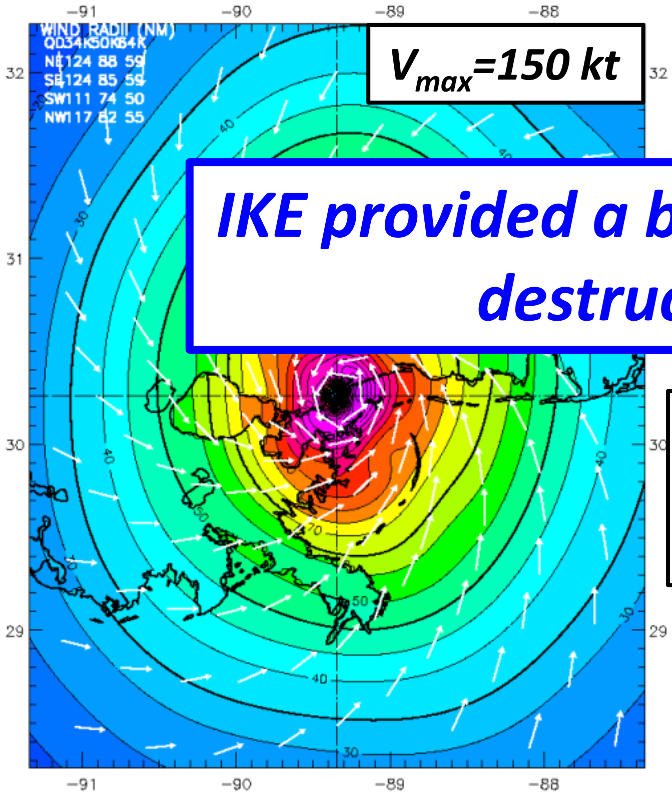
H*Wind analyses from NOAA/AOML Hurricane Research Division

Hurricane Katrina (2005)



The value of IKE

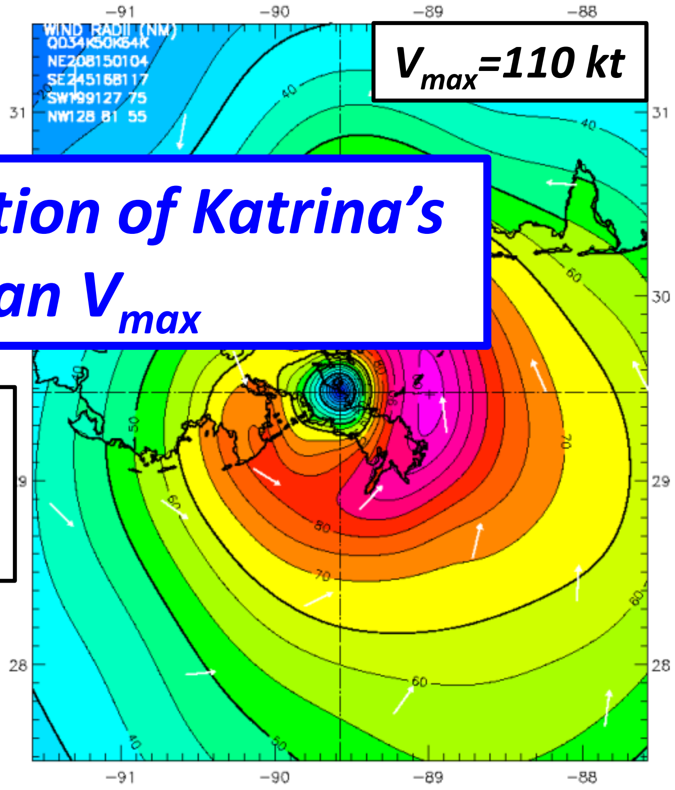
Hurricane Camille (1969)



V_{max}=150 kt

Camille was stronger in terms of V_{max}.

Hurricane Katrina (2005)



V_{max}=110 kt

IKE provided a better representation of Katrina's destructive potential than V_{max}

<u>IKE (Powell & Reinhold)</u>
Camille: 63 Terajoules
Katrina: 122 Terajoules

H*Wind analyses from NOAA/AOML Hurricane Research Division

IKE Computation

- Assume integration over a 1-m depth:

$$IKE = \frac{\rho_0}{2} \int_0^{2\pi} \int_0^R u(\theta, r)^2 r dr d\theta$$

- Requires knowledge of the velocity at every (θ,r).
  - Multiple methods possible:
    - Use a data assimilation scheme (e.g. H*WIND) or model analysis.
    - Fit observations to a parametric wind profile (e.g. Morris and Ruf).
    - Piecewise polynomial interpolation (e.g. tension splines).
    - Azimuthally average observations to get a radial profile of velocity.

IKE Computation

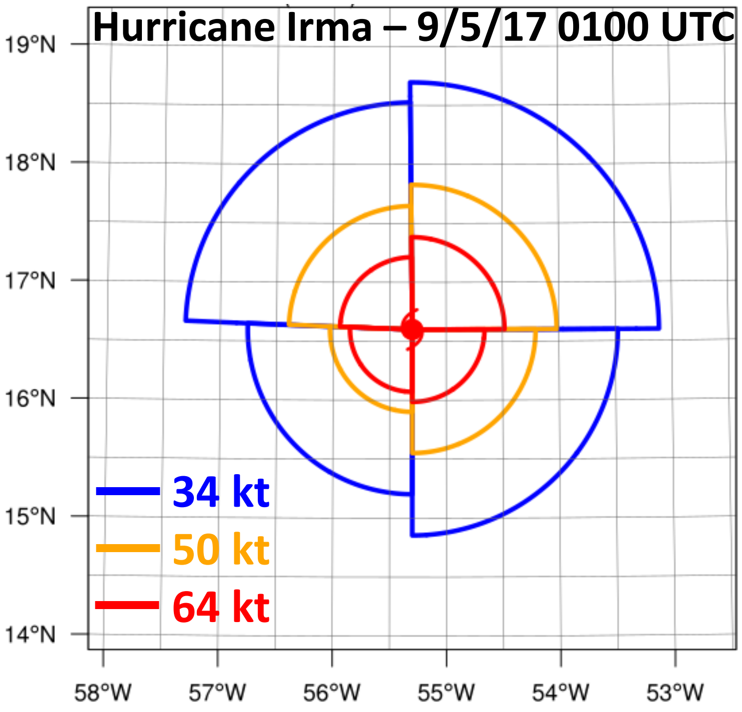
- Assume integration over a 1-m depth:

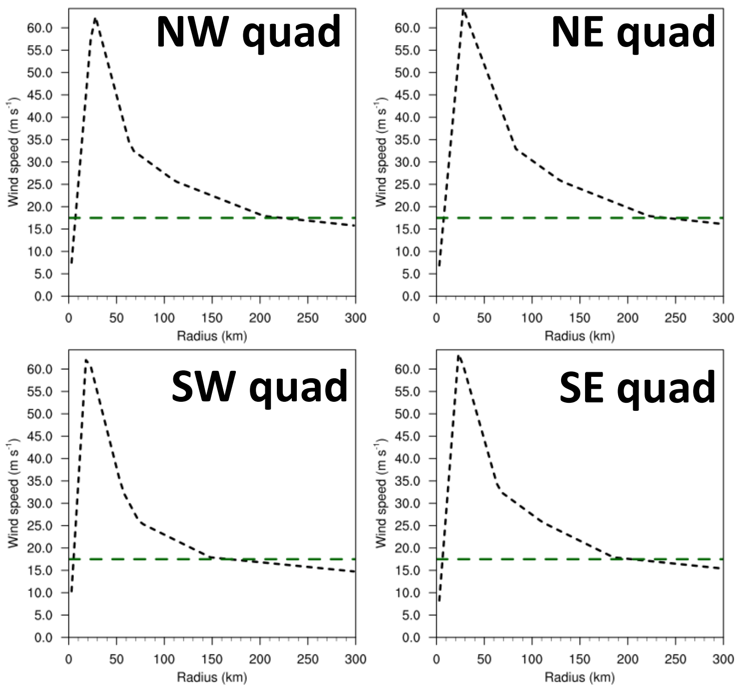
$$IKE = \frac{\rho_0}{2} \int_0^{2\pi} \int_0^R u(\theta, r)^2 r dr d\theta$$

- Requires knowledge of the velocity at every (θ,r).
  - Multiple methods possible:
    - Use a data assimilation scheme (e.g. H*WIND) or model analysis.
    - Fit observations to a parametric wind profile (e.g. Morris and Ruf).
    - Piecewise polynomial interpolation (e.g. tension splines).
    - Azimuthally average observations to get a radial profile of velocity.

Constructing the radial wind profile

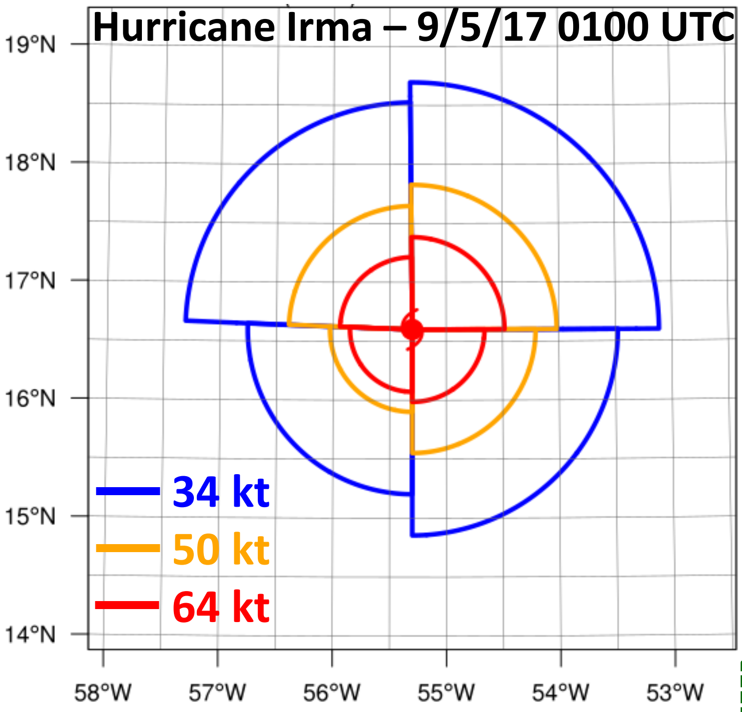
1. Start with an estimate of the radial wind structure using operational wind radii from the *Extended Best Track Dataset*.

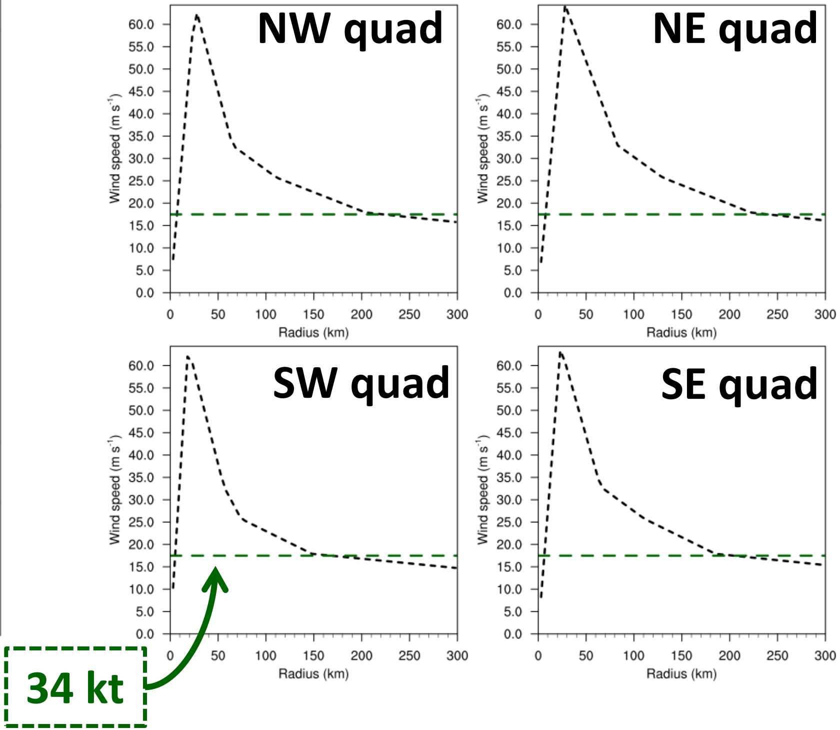




Constructing the radial wind profile

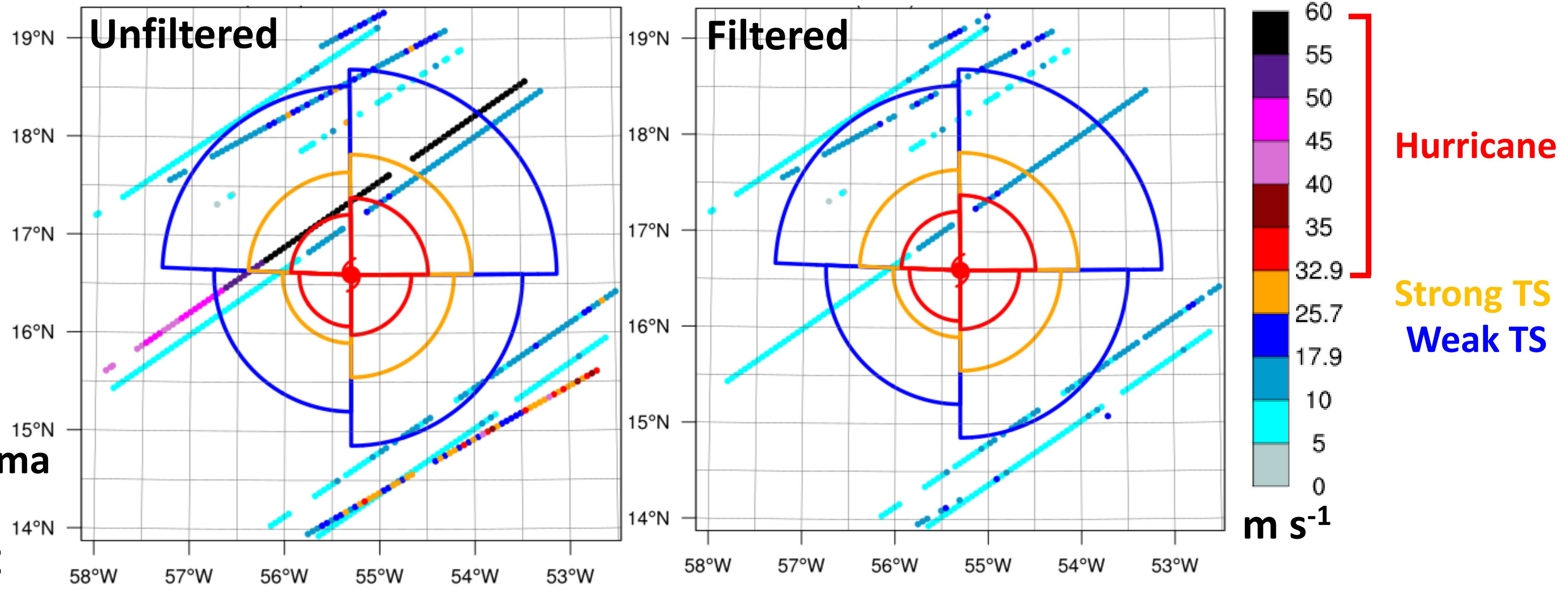
1. Start with an estimate of the radial wind structure using operational wind radii from the *Extended Best Track Dataset*.





Constructing the radial wind profile

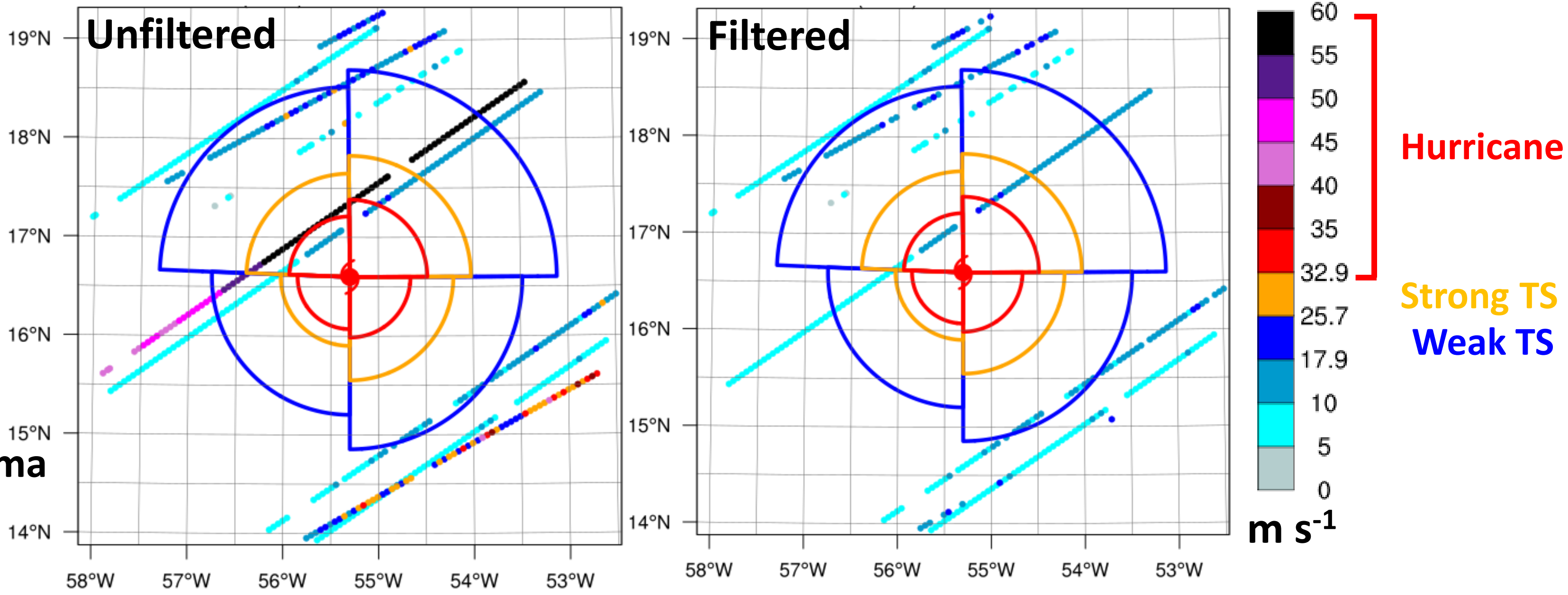
2. Gather all observations collected within 3 hours and 500 km of the best-track storm center from ***CYGNSS***, ***SFMR***, and ***ASCAT***.
   - **CYGNSS v2.1:** NBRCS wind retrievals using only the YSLF GMF. All winds with “uncertainty” > 3.5 m s^{-1} filtered out.



Hurricane Irma
9/5/2017
0100 UTC

Constructing the radial wind profile

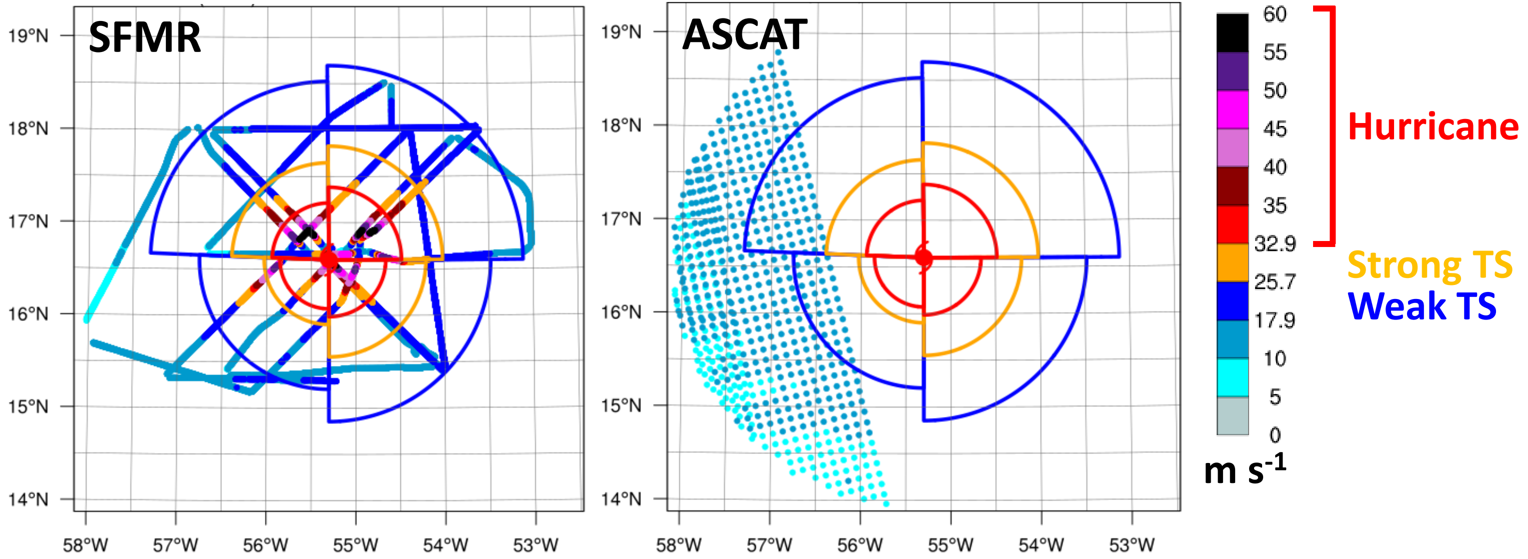
Removing all observations with "uncertainty" (standard deviation of error) > 3.5 m s^{-1} eliminates unrealistically large wind speeds without removing too many good observations.



Hurricane Irma
9/5/2017
0100 UTC

Constructing the radial wind profile

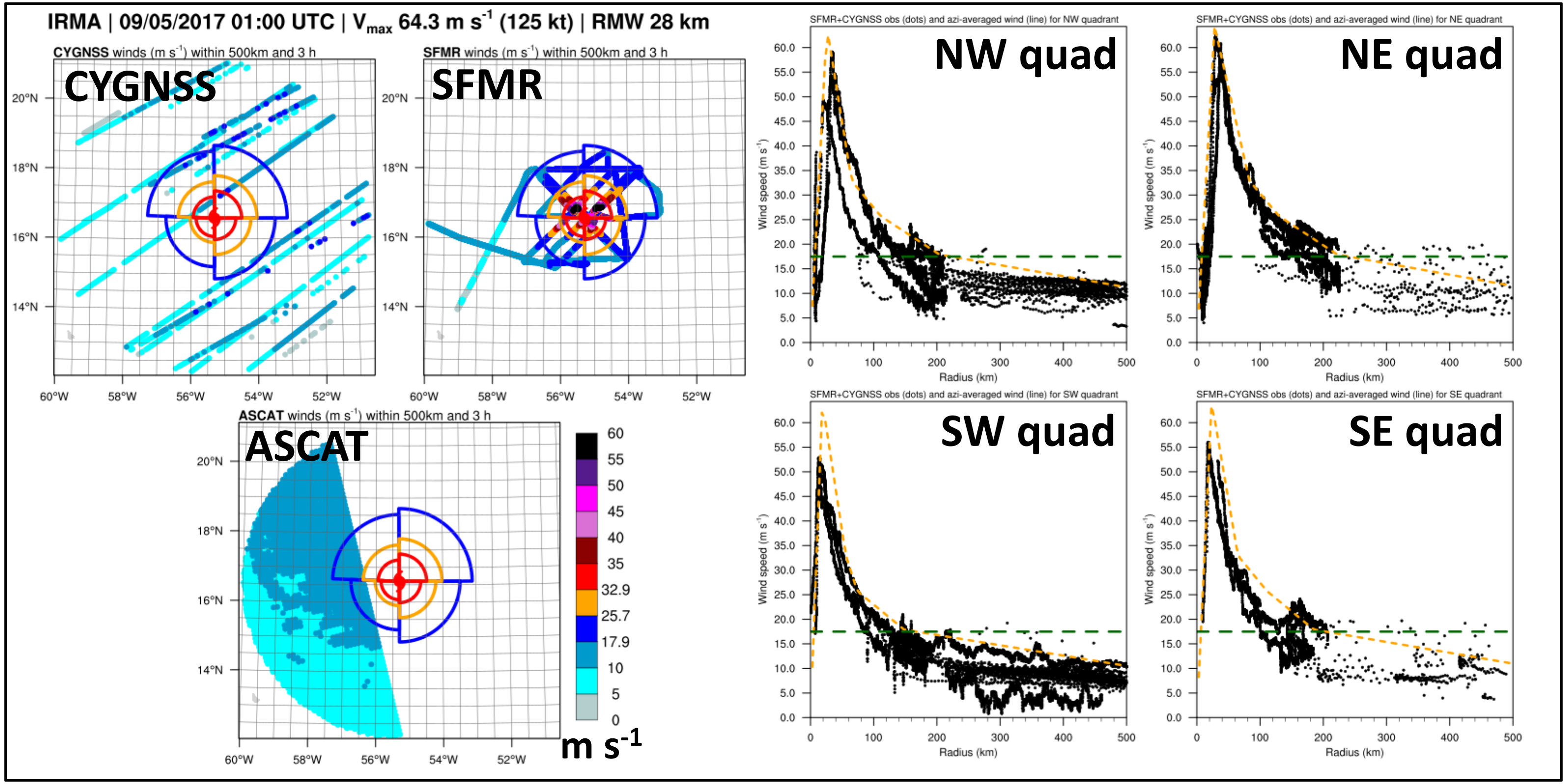
2. Gather all observations collected within 3 hours and 500 km of the best-track storm center from ***CYGNSS***, ***SFMR***, and ***ASCAT***.
   - **SFMR:** All wind retrievals that did not have any QC flag flipped.
   - **ASCAT:** All wind retrievals that did not have the product monitoring, KNMI, or variational QC flags flipped.



Hurricane Irma
9/5/2017
0100 UTC

Constructing the radial wind profile

3. Transform observation locations into a storm-centered polar coordinate system, and split up by quadrant.

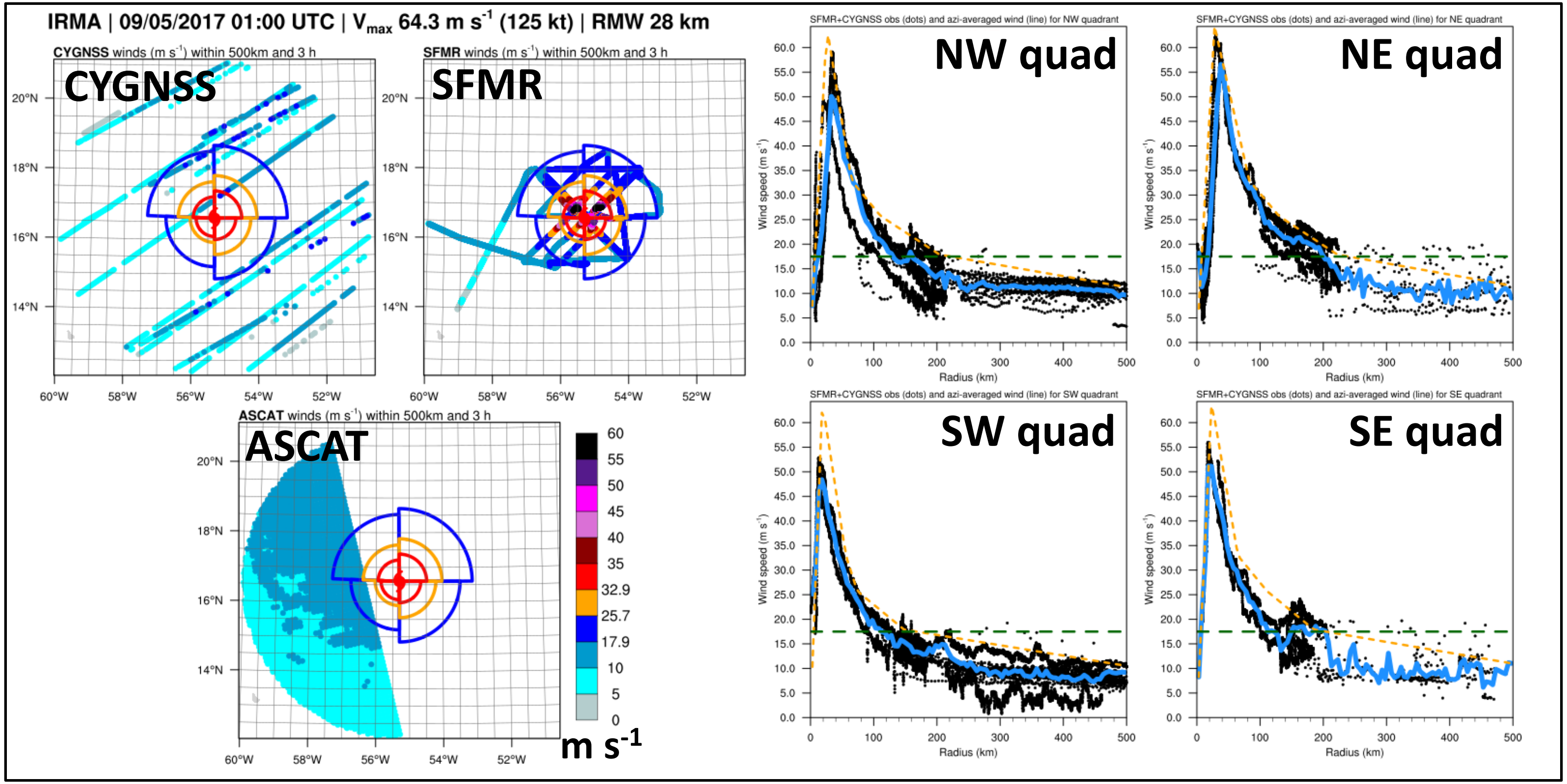


Black Dots: Individual Wind Observations

Orange dotted lines: Initial guess wind profiles from best track.

Constructing the radial wind profile

4. Azimuthally average the wind observations in each quadrant independently, using 5-km-wide radial bins.



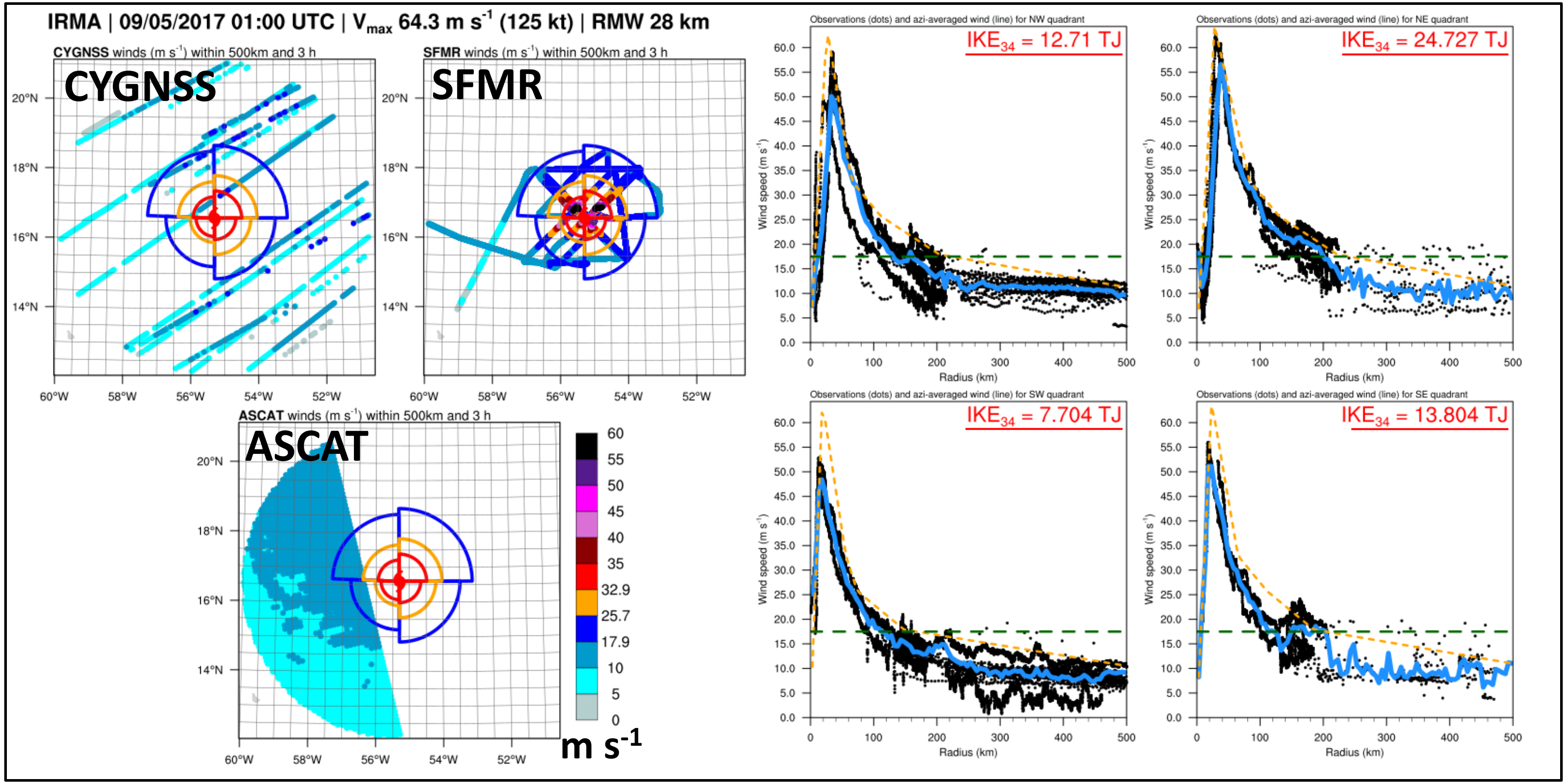
Black Dots:
Individual Wind Observations

Orange dotted lines:
Initial guess wind profiles from best track.

Blue Lines:
Azimuthally averaged wind profiles.

Computing IKE

5. Integrate kinetic energy in each quadrant, using only azimuthally averaged winds greater than 34 kt, and sum them to get total IKE.



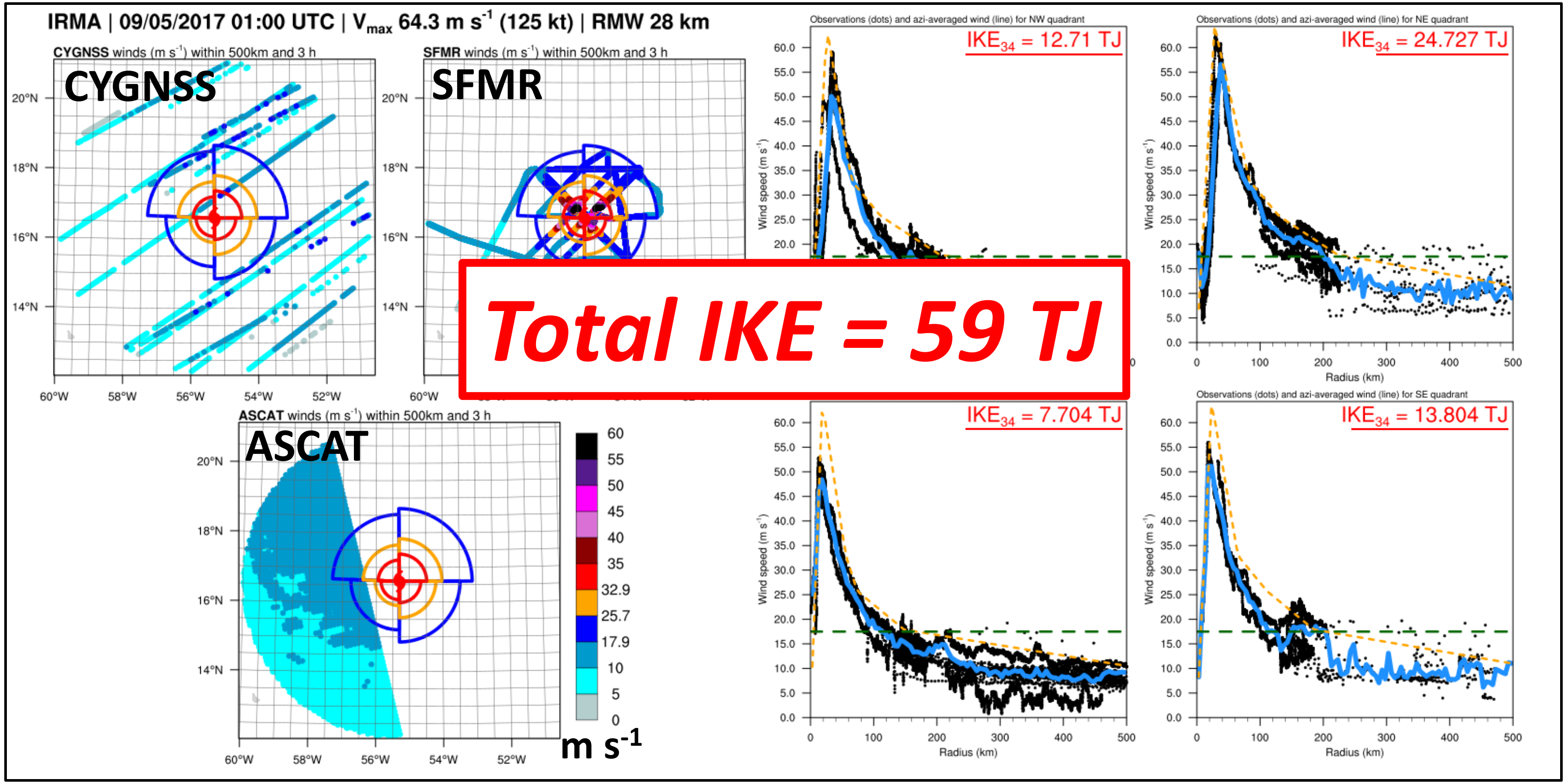
Black Dots:
Individual Wind Observations

Orange dotted lines:
Initial guess wind profiles from best track.

Blue Lines:
Azimuthally averaged wind profiles.

Computing IKE

5. Integrate kinetic energy in each quadrant, using only azimuthally averaged winds greater than 34 kt, and sum them to get total IKE.



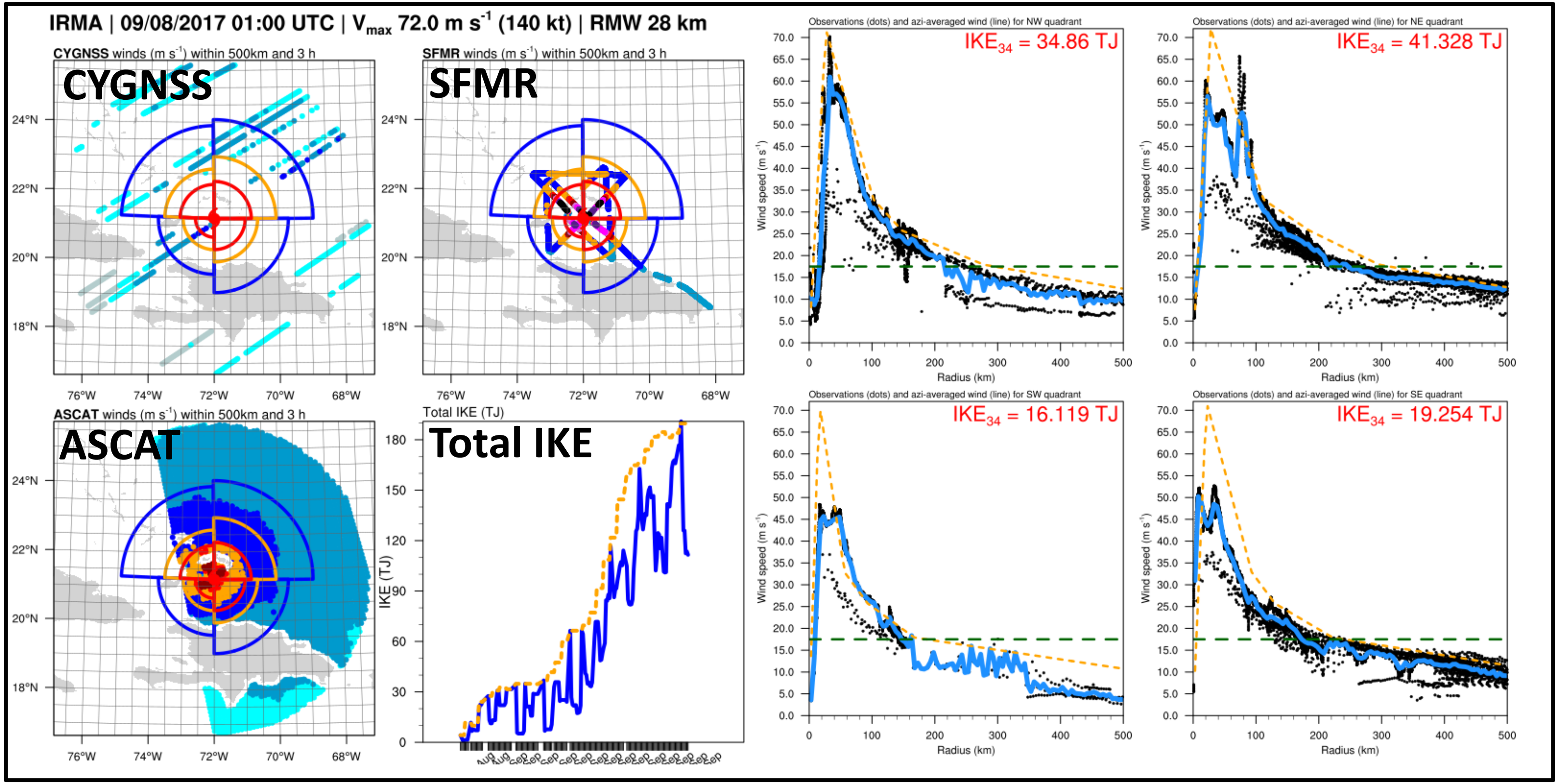
Black Dots: Individual Wind Observations

Orange dotted lines: Initial guess wind profiles from best track.

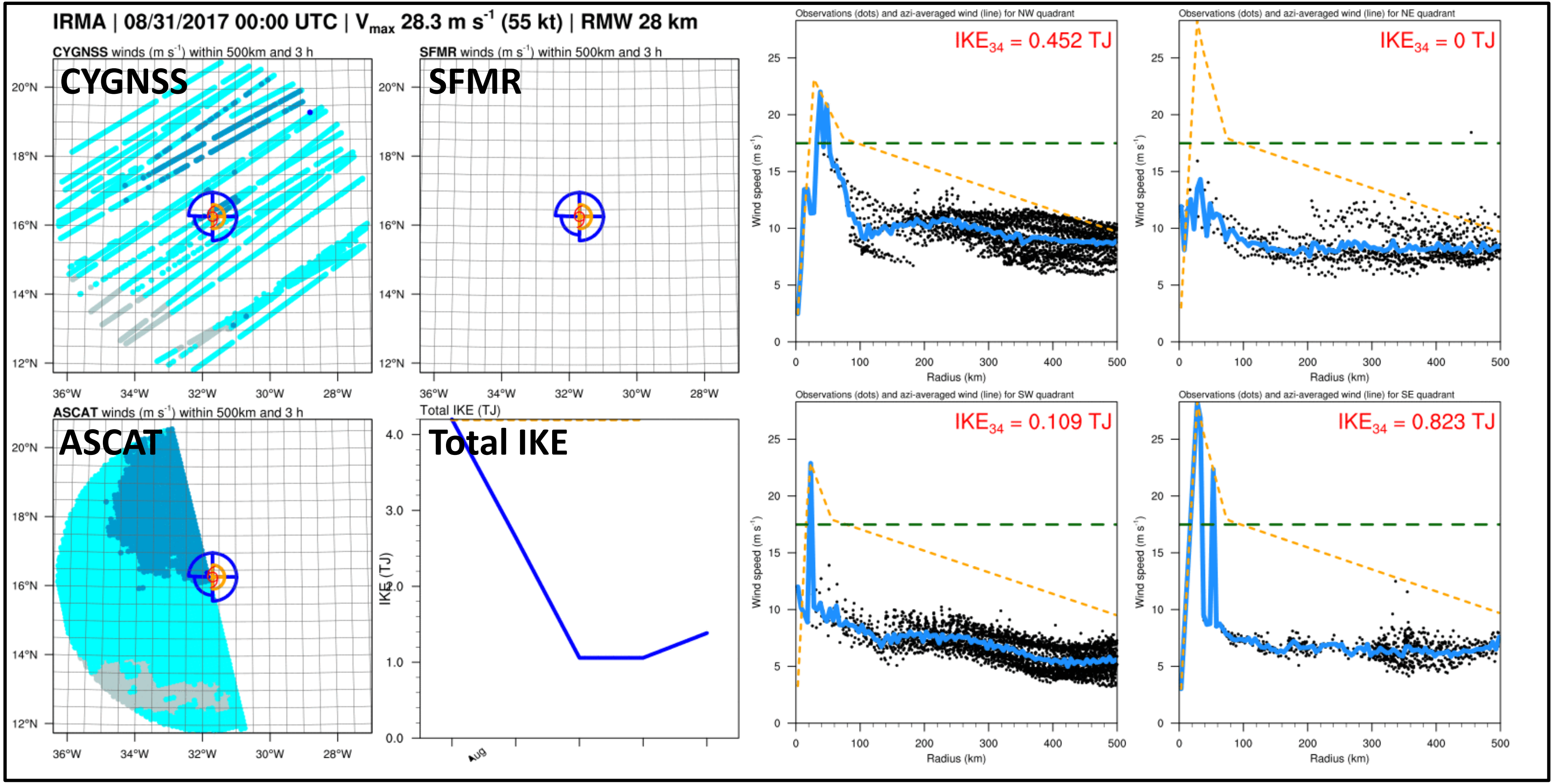
Blue Lines: Azimuthally averaged wind profiles.

IKE History – Hurricane Irma (2017)

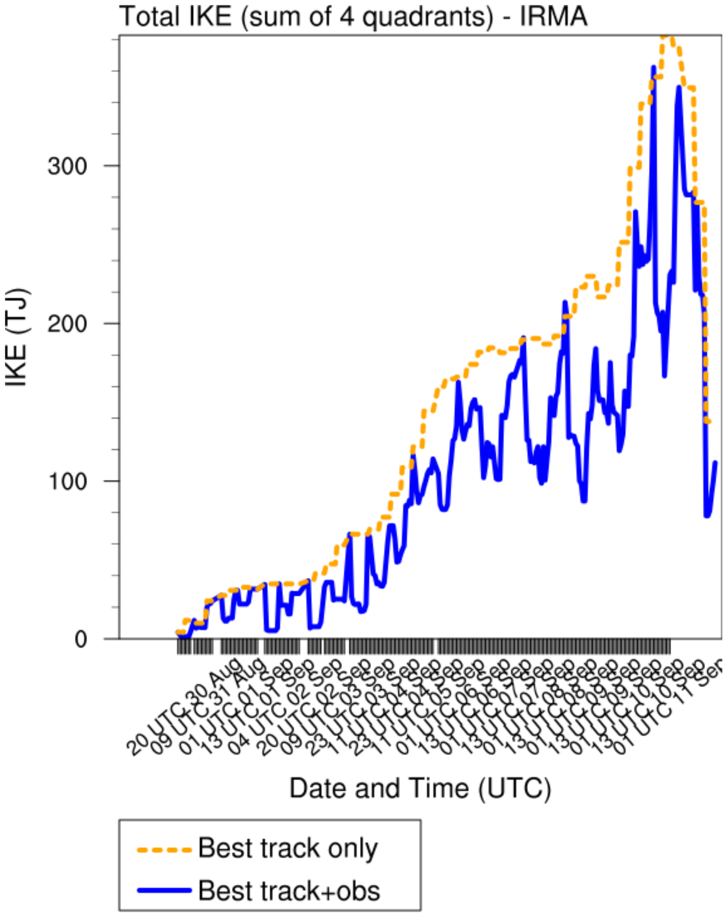
- Compute IKE every hour, using 6 hours of observations (all observations within 3 hours before or after best track time).



IKE History – Hurricane Irma (2017)

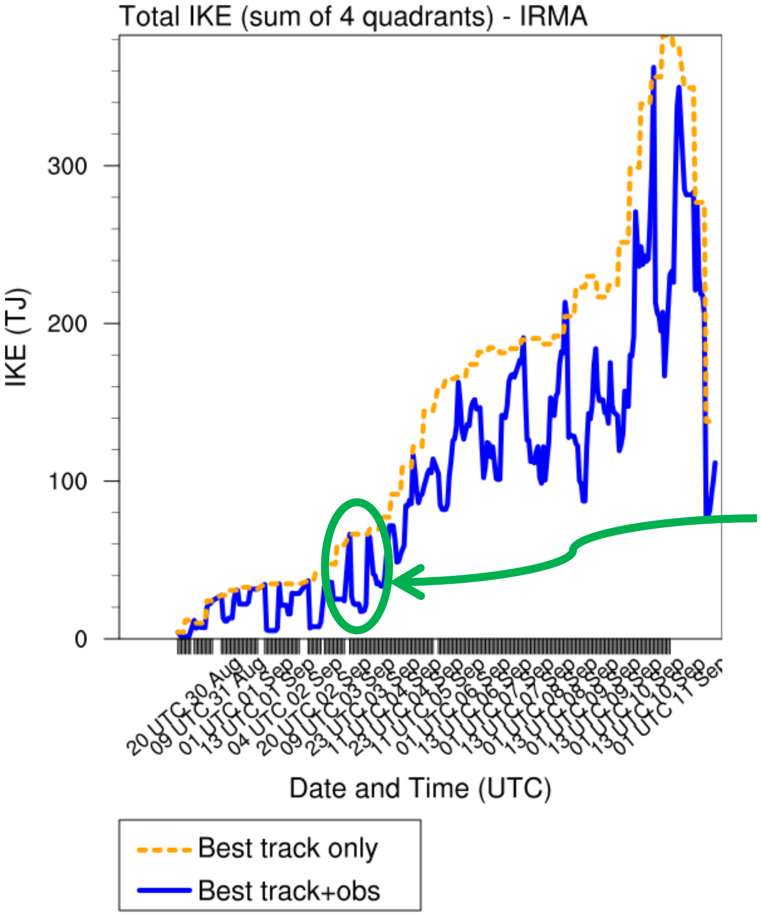


IKE History – Hurricane Irma (2017)



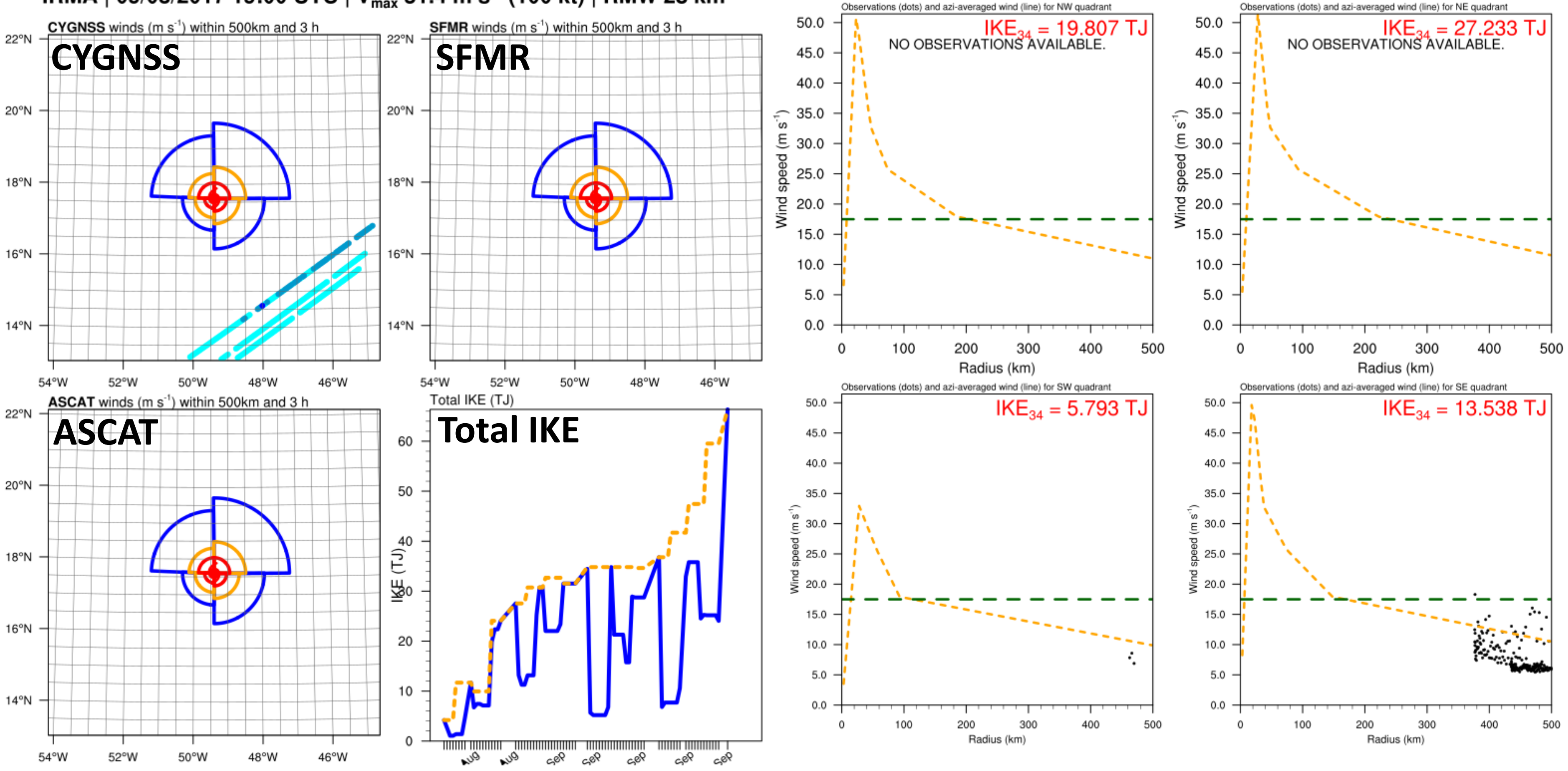
- Observations typically produce smaller IKE estimate than best track wind radii.
  - A good thing.
  - Best track wind radii are the *maximum extent* of the winds in a given quadrant.

IKE History – Hurricane Irma (2017)

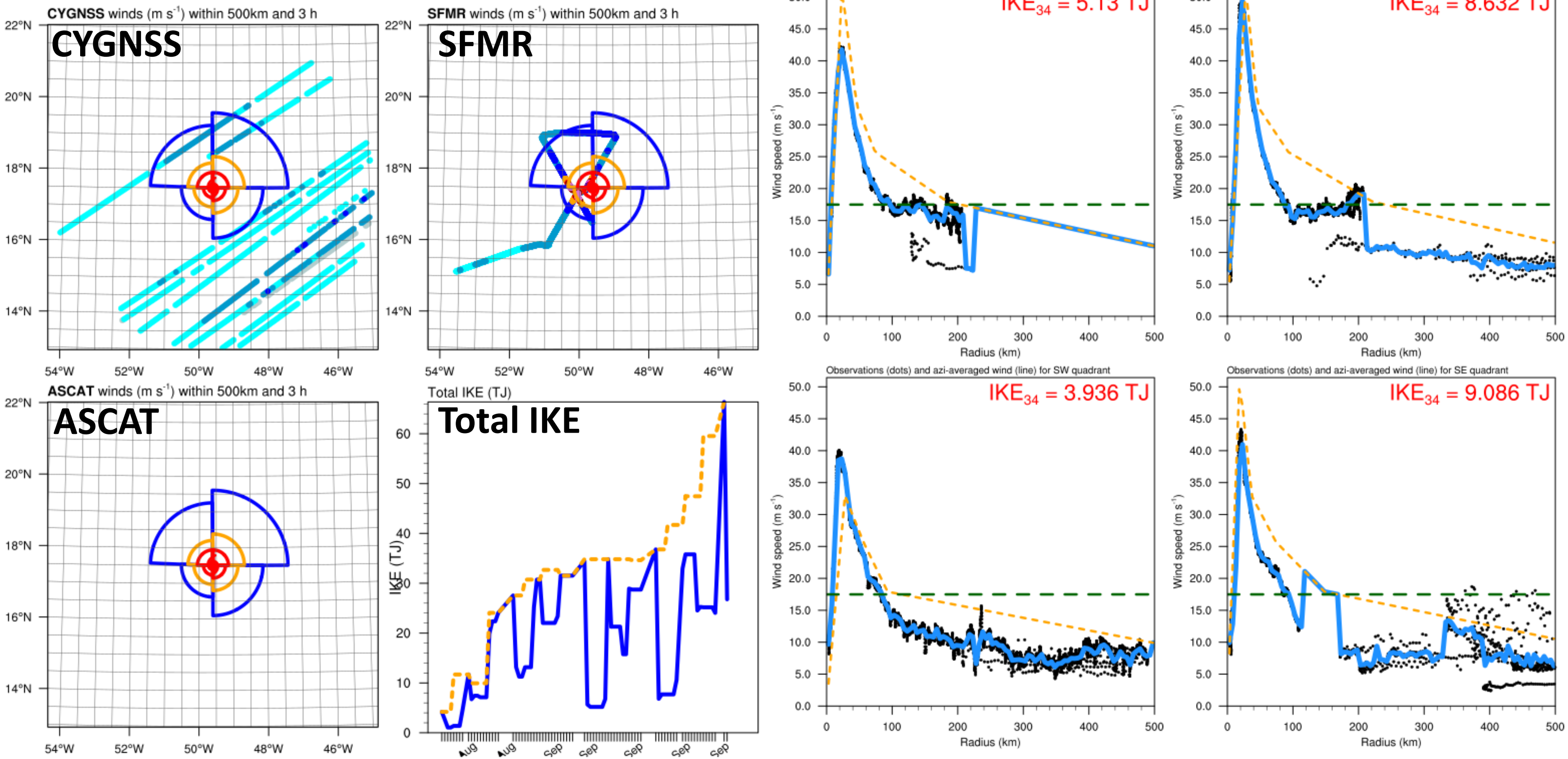


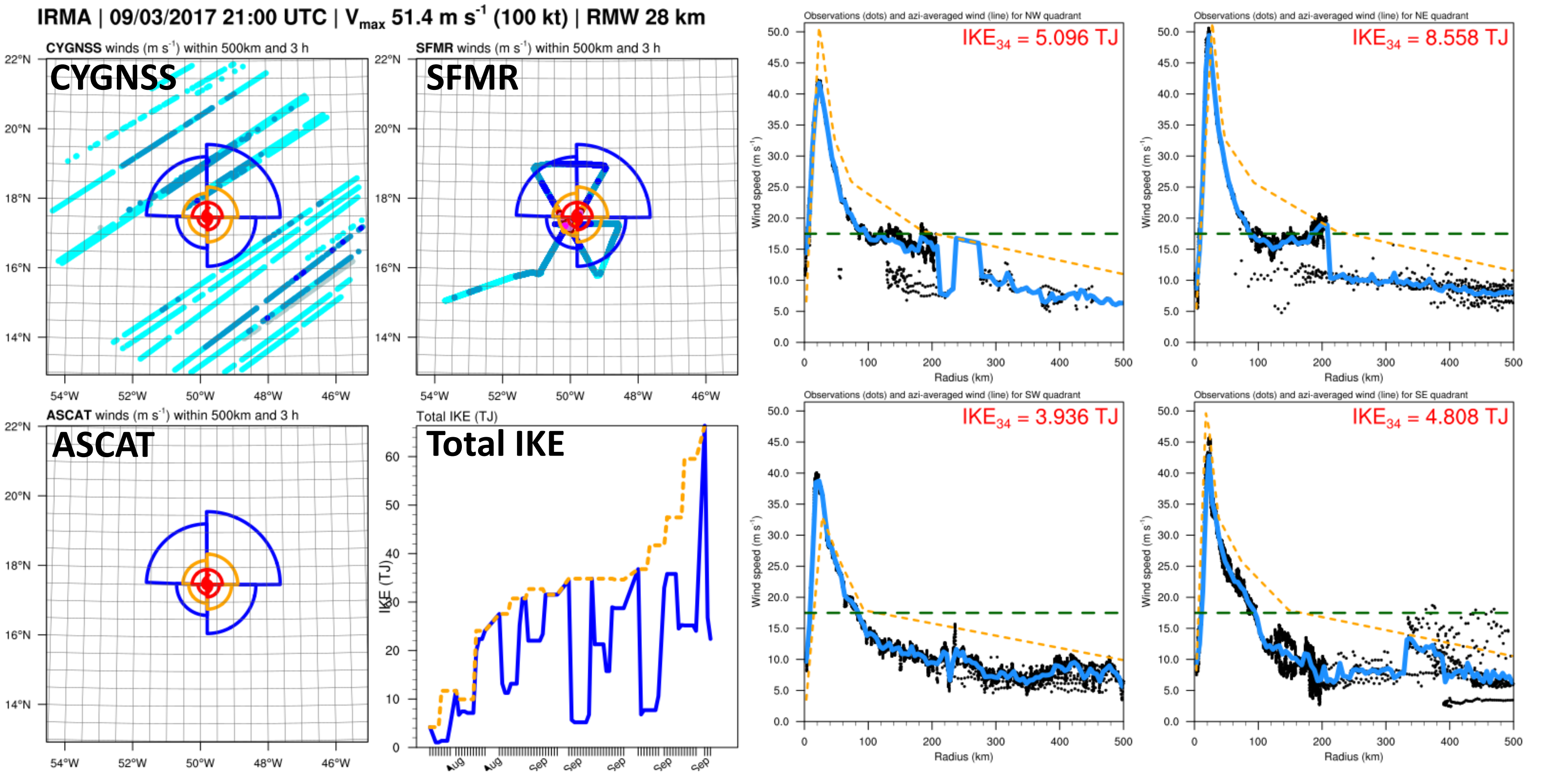
- Observations typically produce smaller IKE estimate than best track wind radii.
  - A good thing.
  - Best track wind radii are the *maximum extent* of the winds in a given quadrant.
- Sharp drops in IKE can occur when observations become available.
  - Sometimes good; sometimes not.
- Large temporal fluctuations are related to availability of observations, and are typically unphysical.

IRMA | 09/03/2017 19:00 UTC | V_{max} 51.4 m s^{-1} (100 kt) | RMW 28 km



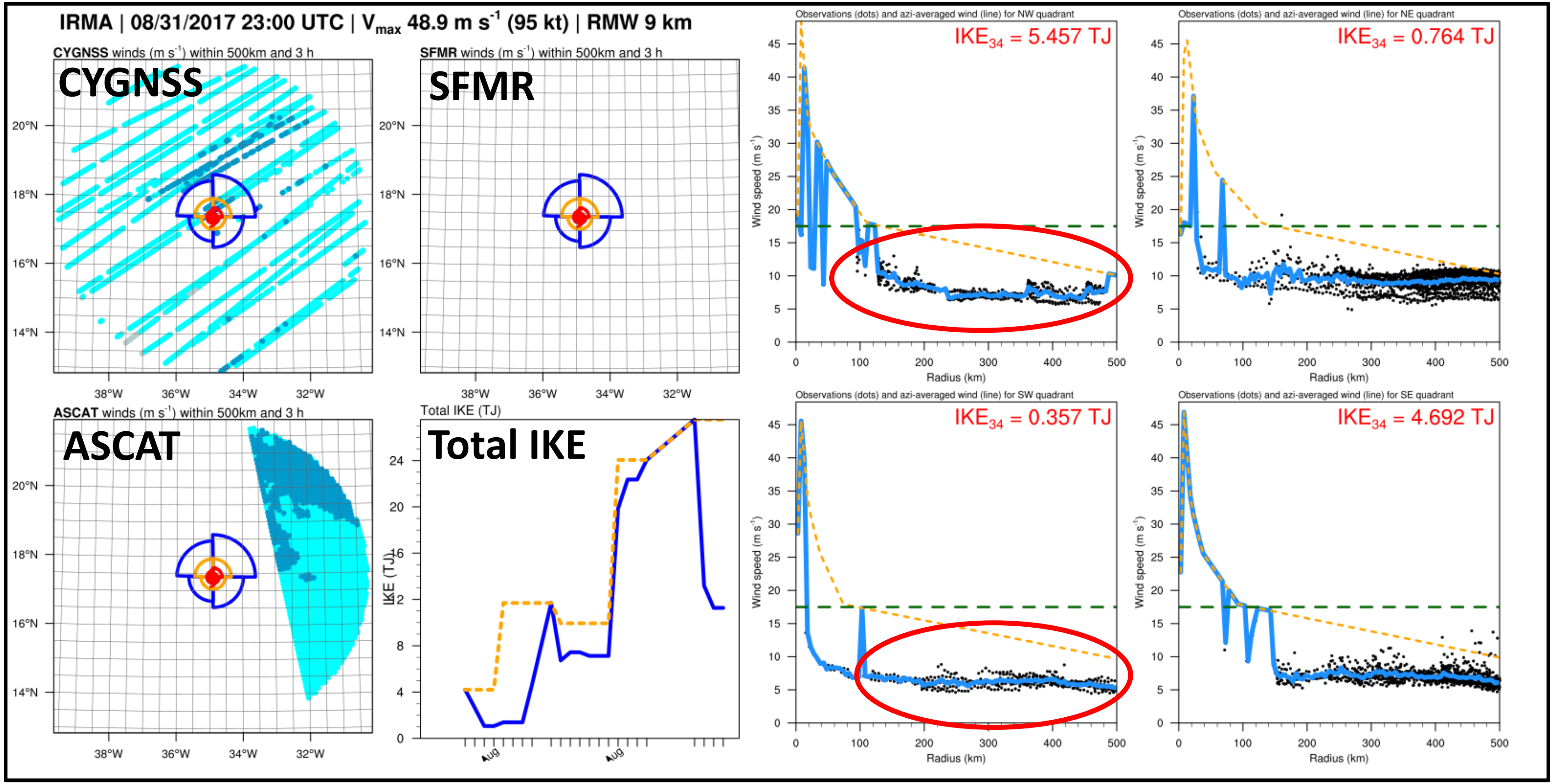
IRMA | 09/03/2017 20:00 UTC | V_{max} 51.4 m s^{-1} (100 kt) | RMW 28 km



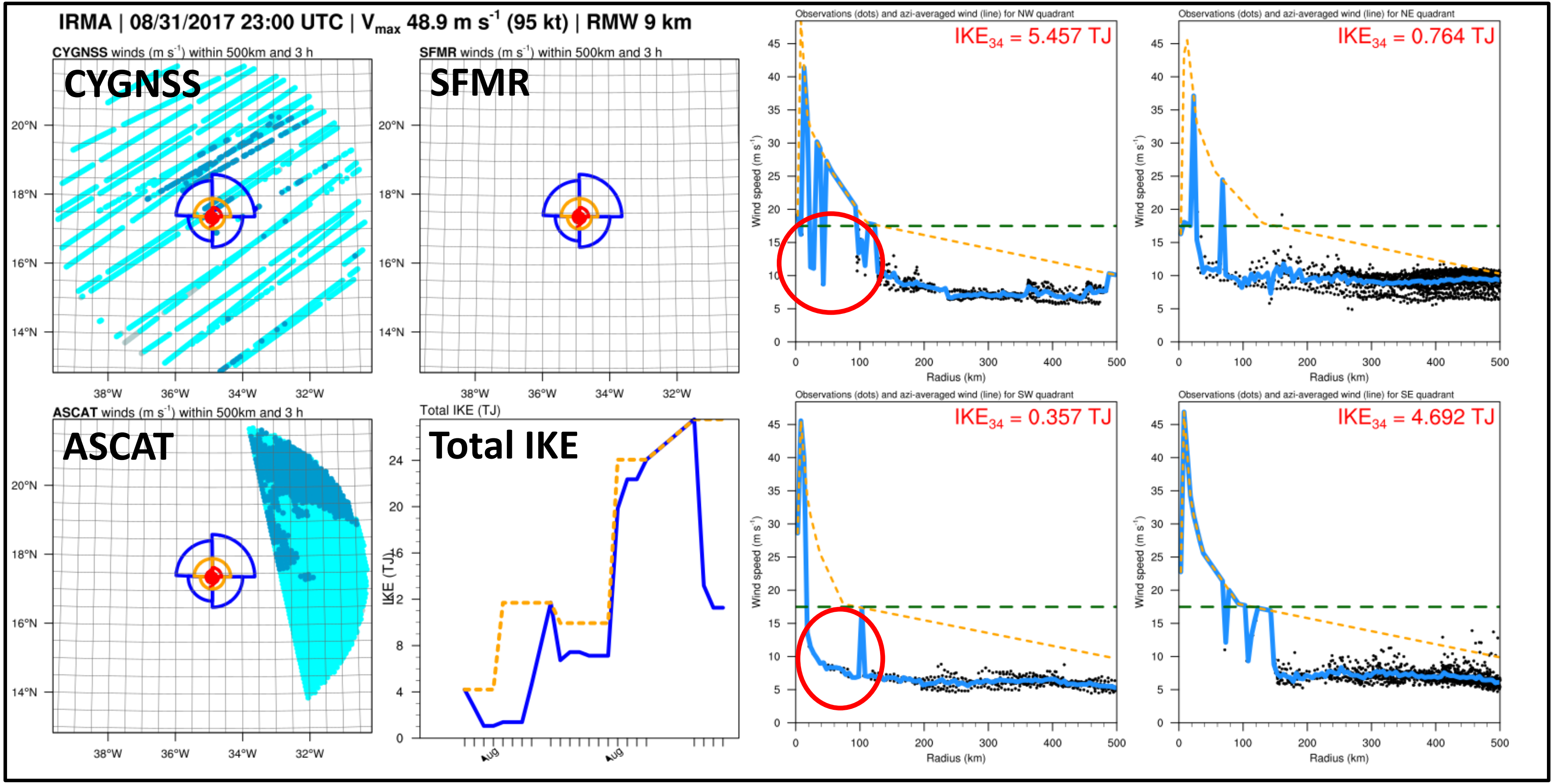

IRMA | 09/03/2017 21:00 UTC | V_{max} 51.4 m s^{-1} (100 kt) | RMW 28 km
CYGNSS winds (m s^{-1}) within 500km and 3 h
CYGNSS
SFMR winds (m s^{-1}) within 500km and 3 h
SFMR
ASCAT winds (m s^{-1}) within 500km and 3 h
ASCAT
Total IKE (TJ)
Total IKE
IKE (TJ)
Observations (dots) and azi-averaged wind (line) for NW quadrant
IKE_{34} = 5.096 TJ
Observations (dots) and azi-averaged wind (line) for NE quadrant
IKE_{34} = 8.558 TJ
Observations (dots) and azi-averaged wind (line) for SW quadrant
IKE_{34} = 3.936 TJ
Observations (dots) and azi-averaged wind (line) for SE quadrant
IKE_{34} = 4.808 TJ
Wind speed (m s^{-1})
Radius (km)

Where CYGNSS Adds Value

- When aircraft reconnaissance is unavailable (e.g. far from land).

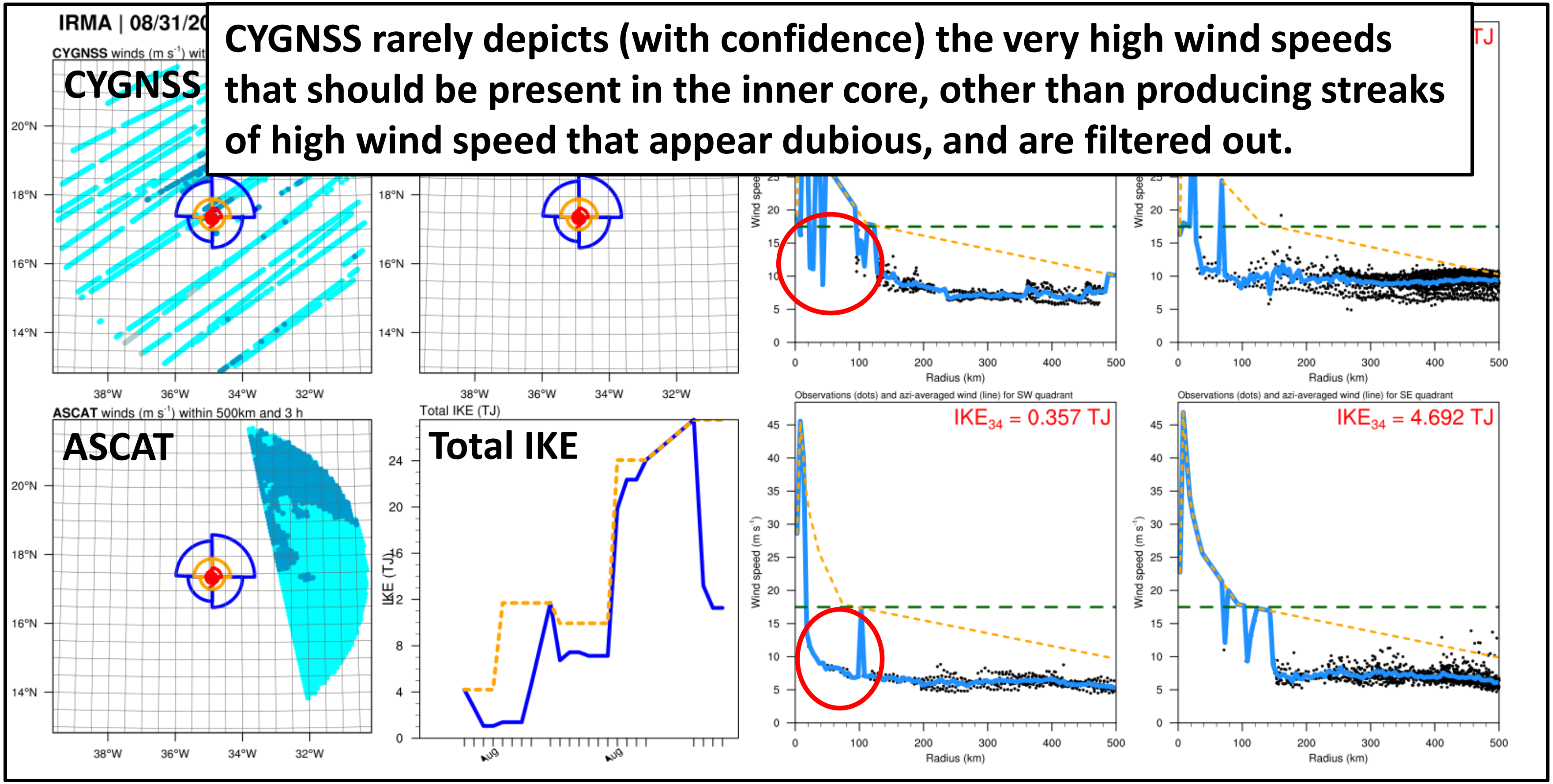


Where CYGNSS Could be Improved

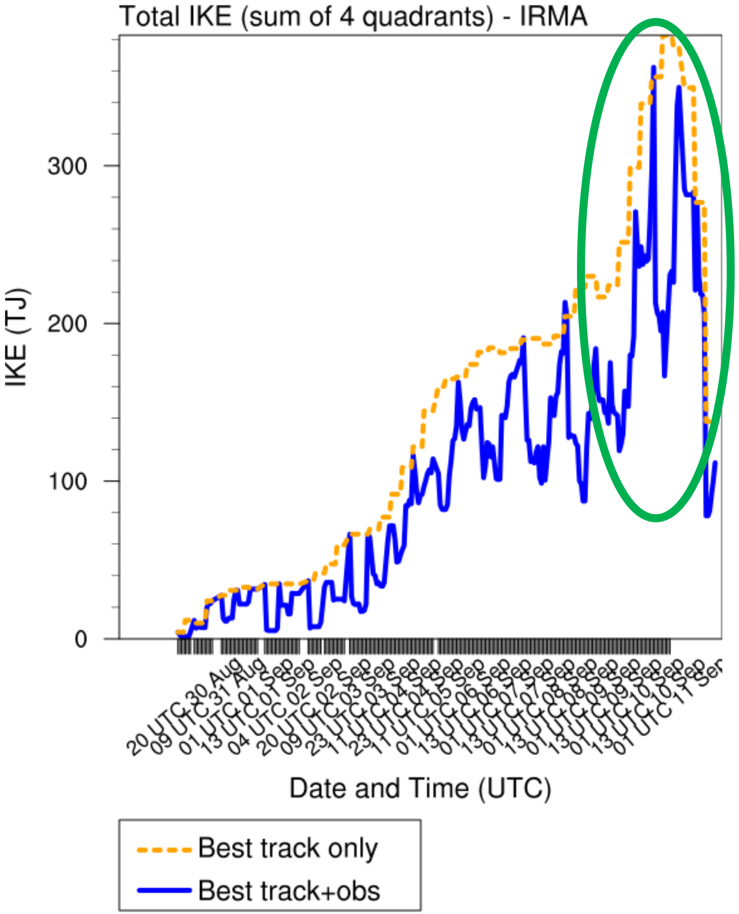


Where CYGNSS Could be Improved

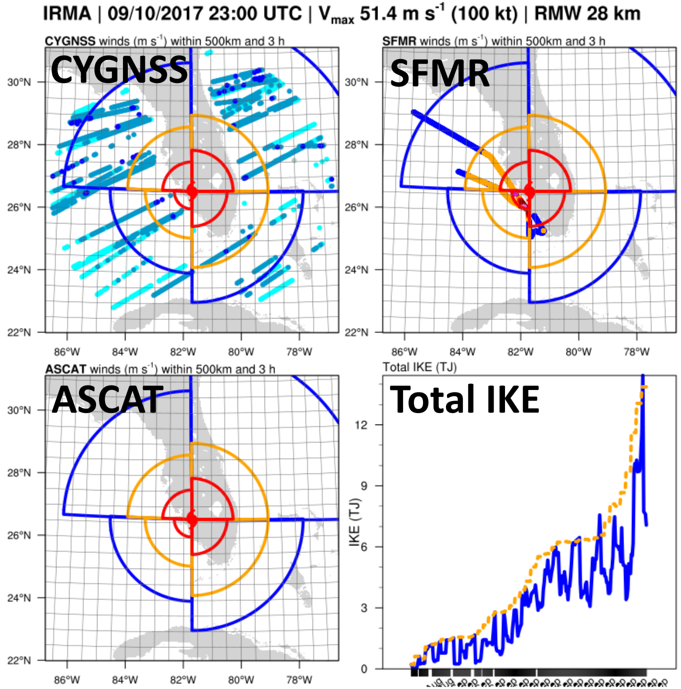
CYGNSS rarely depicts (with confidence) the very high wind speeds that should be present in the inner core, other than producing streaks of high wind speed that appear dubious, and are filtered out.



Other Causes of Large IKE Fluctuations



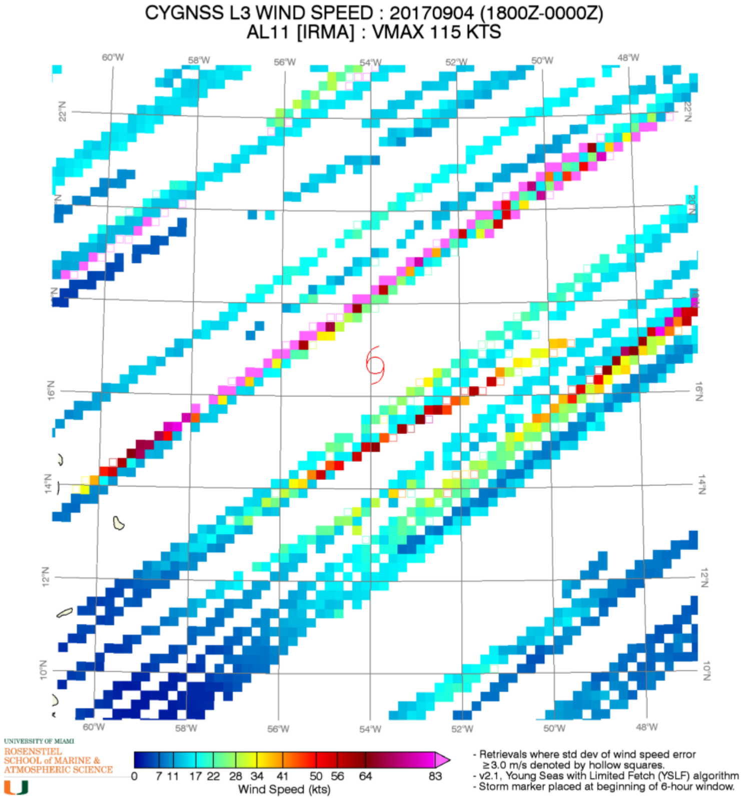
- Presence of land in the averaging radii precludes observations from all platforms currently in the dataset.

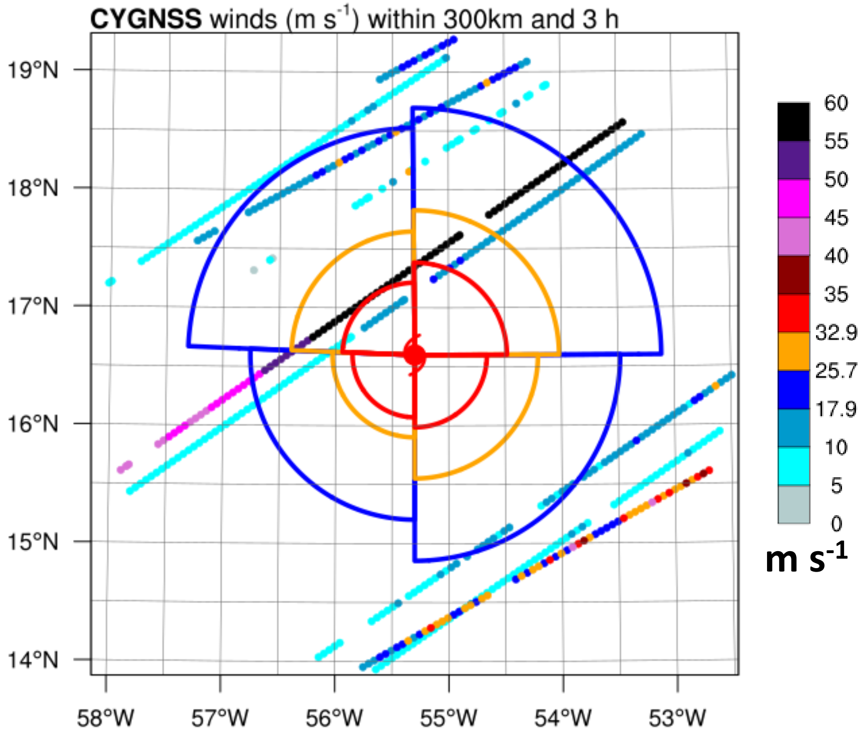


Future Directions

- Include land-based surface observations.
- Add SMAP to the observation set.
- Consider weighting the CYGNSS observations based on the ratio of the uncertainty of the wind speed retrieval to the retrieved wind speed.
- Consider other ways to interpolate between observations.
  - Piecewise polynomial interpolation?
- Assign a IKE estimate quality rating based on number and quality of available observations.

Extra Slides


CYGNSS L3 WIND SPEED : 20170904 (1800Z-0000Z)
AL11 [IRMA] : VMAX 115 KTS
60°W 58°W 56°W 54°W 52°W 50°W 48°W
22°N 16°N 14°N 12°N 10°N
UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE
0 7 11 17 22 28 34 41 50 56 64 83
Wind Speed (kts)
- Retrievals where std dev of wind speed error ≥3.0 m/s denoted by hollow squares.
- v2.1, Young Seas with Limited Fetch (YSLF) algorithm
- Storm marker placed at beginning of 6-hour window.


CYGNSS winds (m s-1) within 300km and 3 h
19°N
18°N
17°N
16°N
15°N
14°N
58°W 57°W 56°W 55°W 54°W 53°W
60 55 50 45 40 35 32.9 25.7 17.9 10 5 0
m s-1

Extra Details on Best Track Radial Wind Profile

- Use RMW and V_{max} from best track.
  - Assume that RMW is valid in quadrant with largest r_{34}, and scale the RMW by r_{34} in all of the other quadrants (i.e., a quadrant with a smaller r_{34} has a smaller RMW.
  - V_{max} is the same in each quadrant, *unless* there is no corresponding wind radius (e.g., if V_{max} = 60 kt, but there is no 50-kt wind radius defined in a quadrant, it does not make sense for v_{max} to be 60 kt in that quadrant).
    - In this case, define V_{max} in that quadrant to be 5 kt less than the lowest missing wind radius in that quadrant.
      - In the above example, V_{max} would be 45 kt.