

Investigating Tropical Cyclone Size and Integrated Kinetic Energy using CYGNSS and Other Datasets

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Integrated Kinetic Energy (IKE)

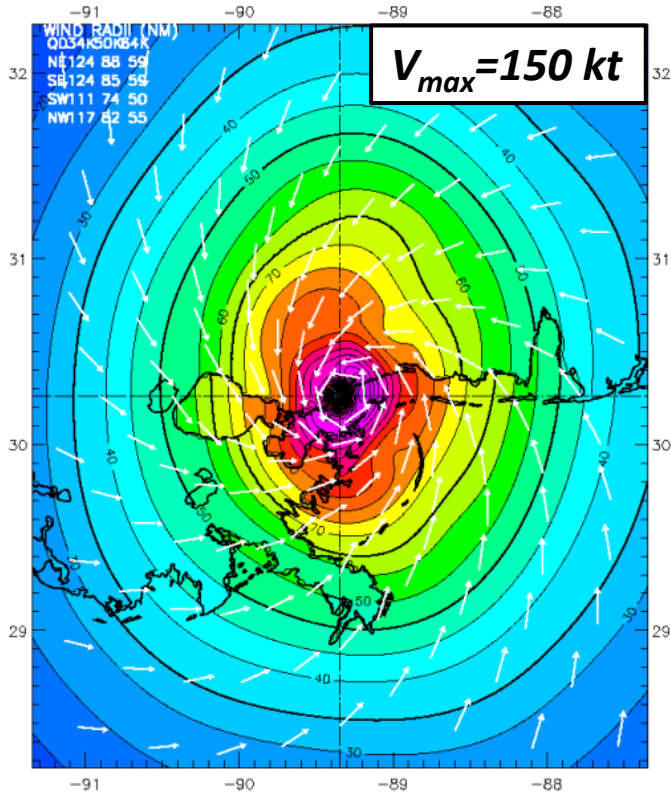
- A tropical cyclone (TC) intensity metric first proposed by Powell and Reinhold (2007):

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

- 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.

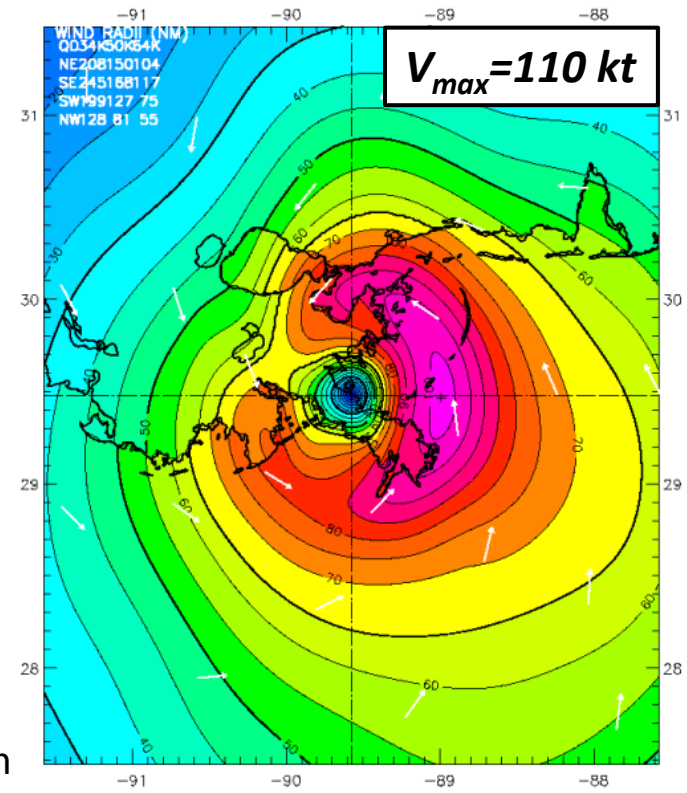
The value of IKE

Hurricane Camille (1969)



Camille was stronger
in terms of V_{max} .

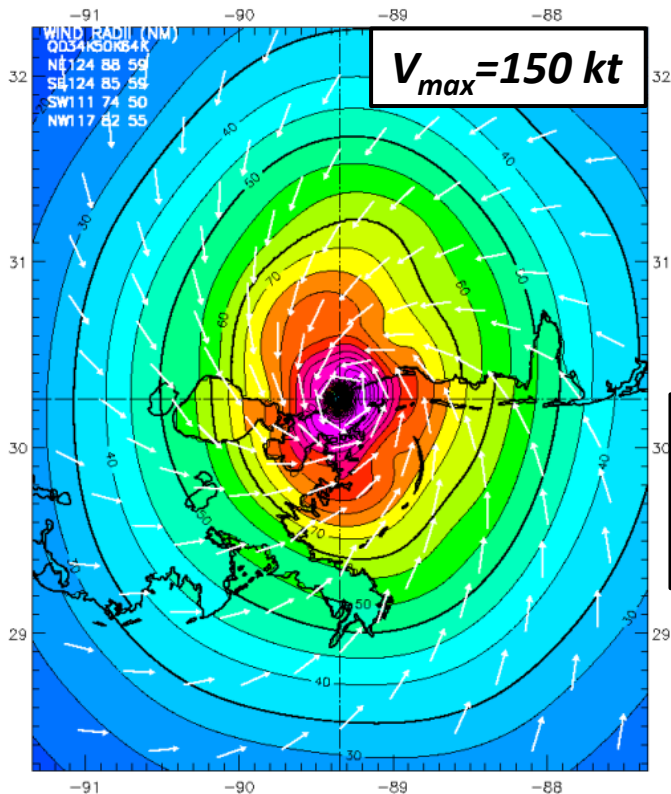
Hurricane Katrina (2005)



H*Wind analyses from
NOAA/AOML
Hurricane Research Division

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

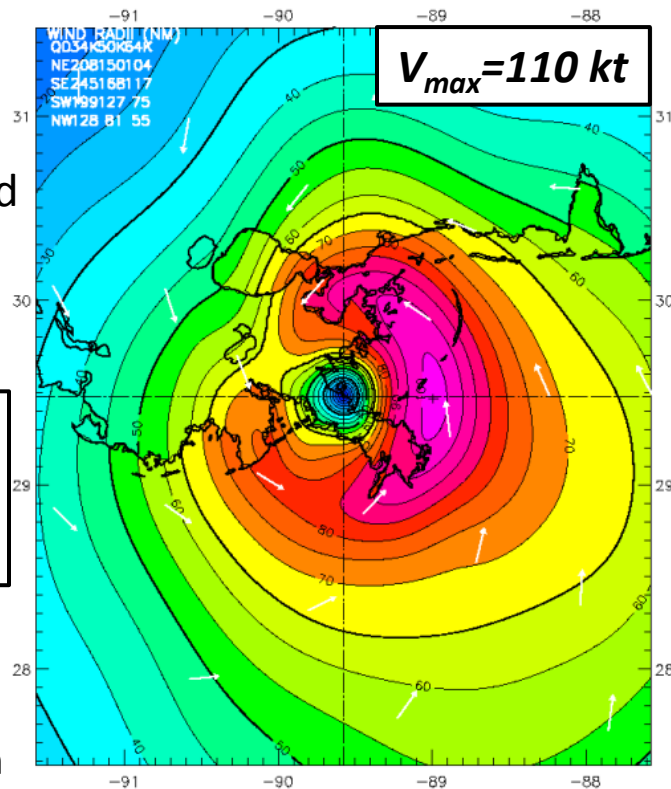
Damage (2017 dollars)

Camille: \$9.8 billion

Katrina: \$160 billion

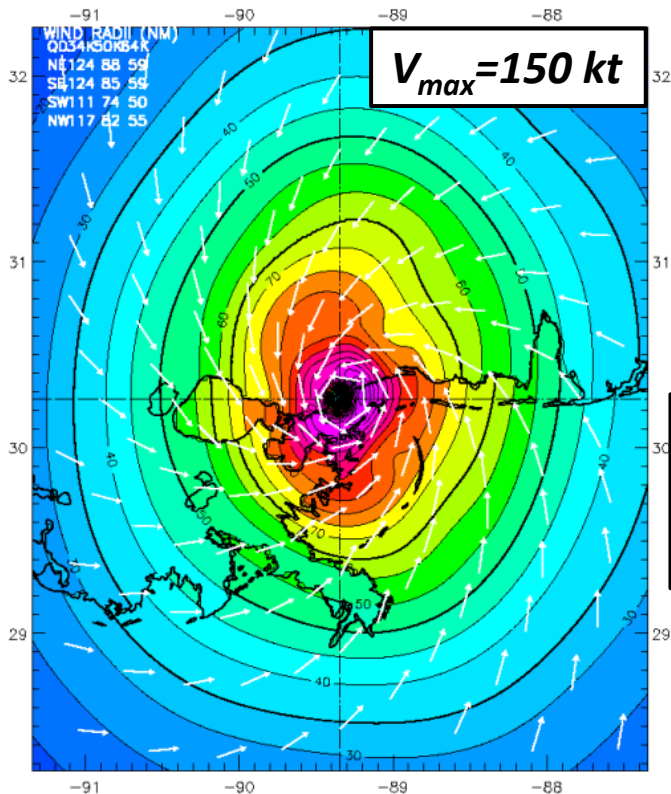
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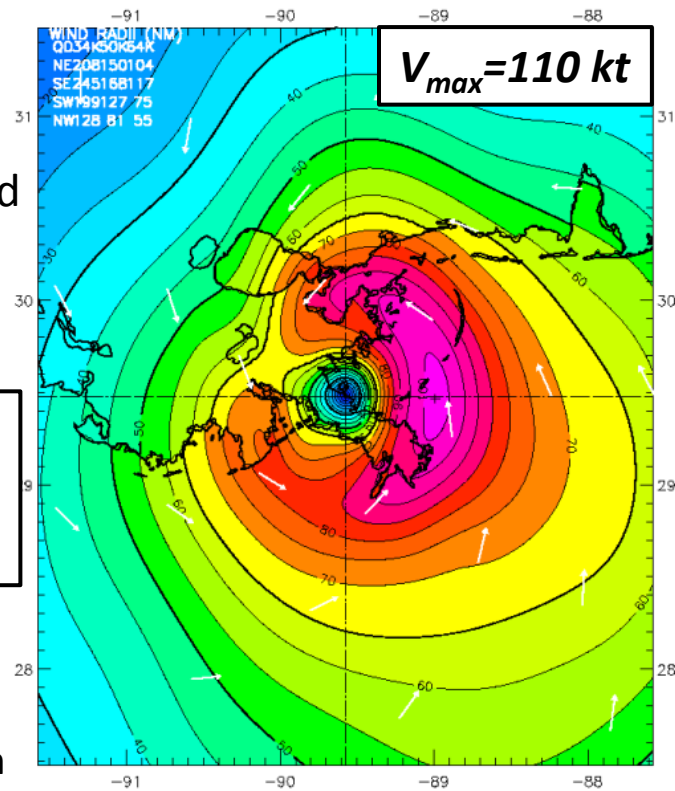
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IKE (Powell & Reinhold)
Camille: 63 Terajoules
Katrina: 122 Terajoules

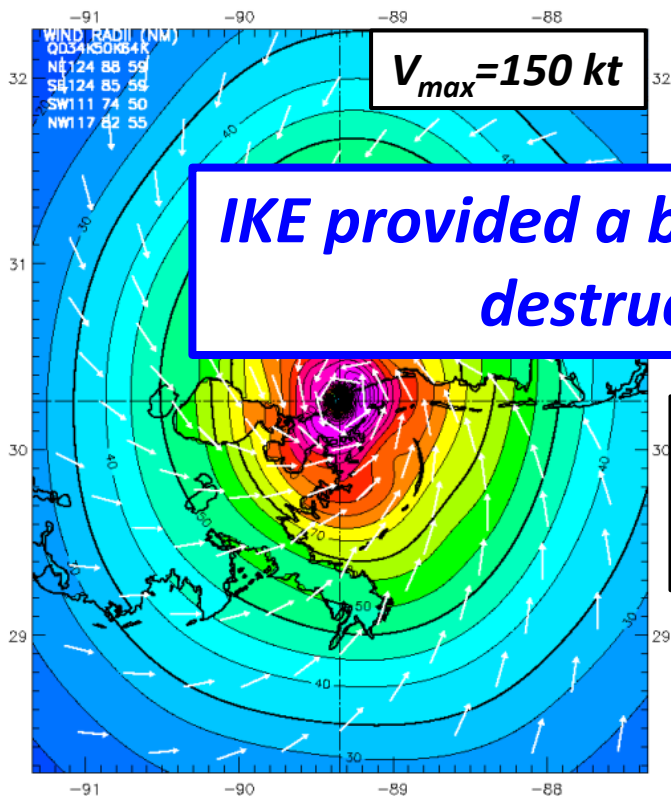
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Hurricane Katrina (2005)



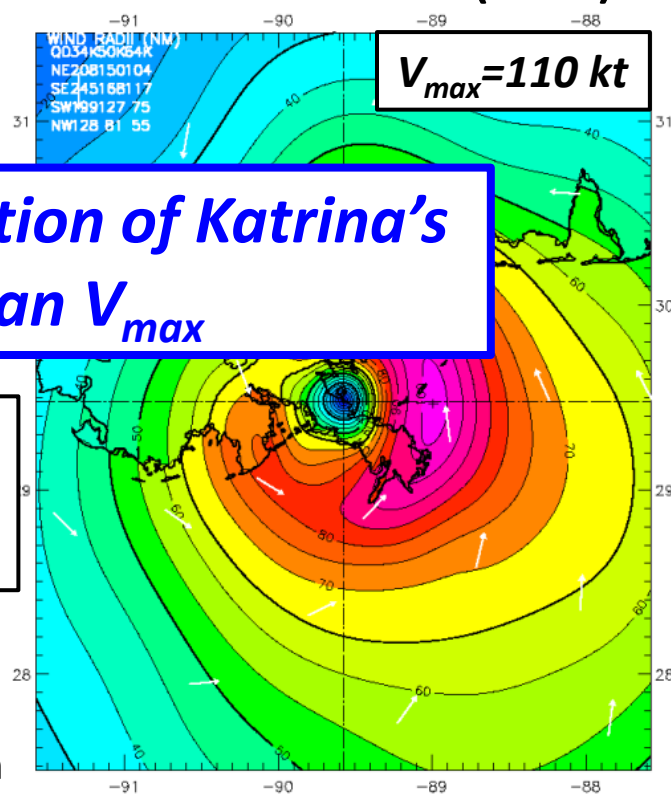
The value of IKE

Hurricane Camille (1969)



Camille was stronger
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Hurricane Katrina (2005)



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

IKE (Powell & Reinhold)

Camille: 63 Terajoules
Katrina: 122 Terajoules

H*Wind analyses from
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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

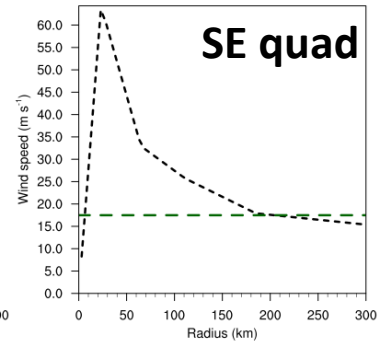
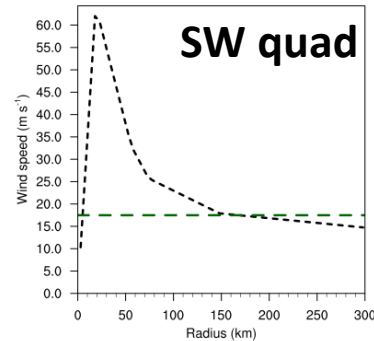
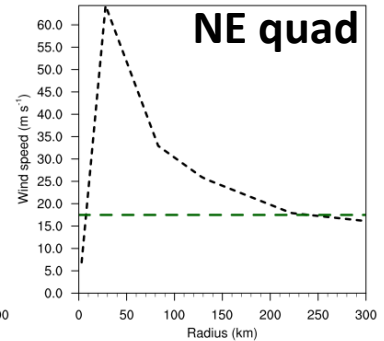
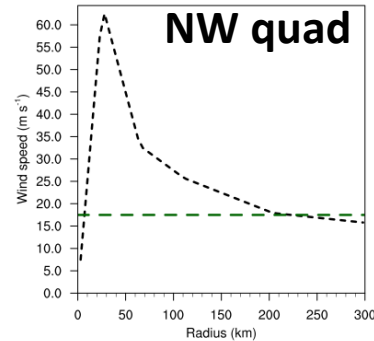
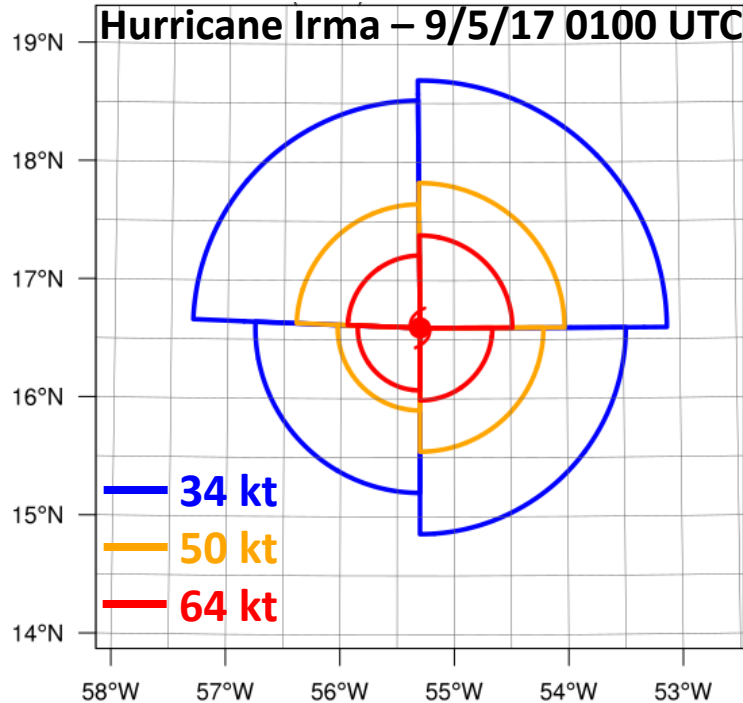
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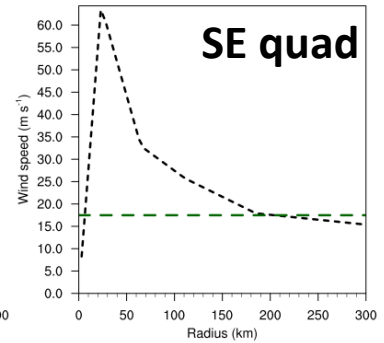
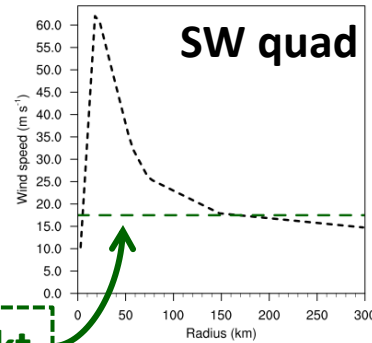
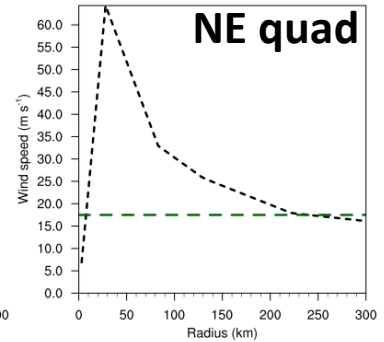
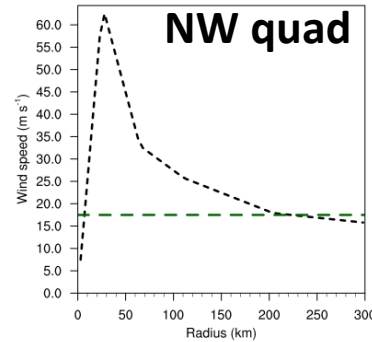
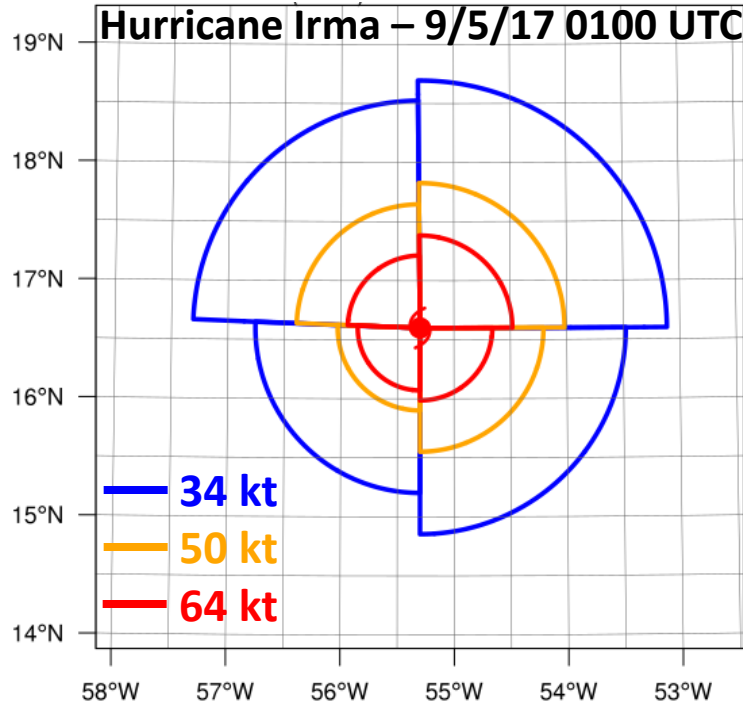
Constructing the radial wind profile

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

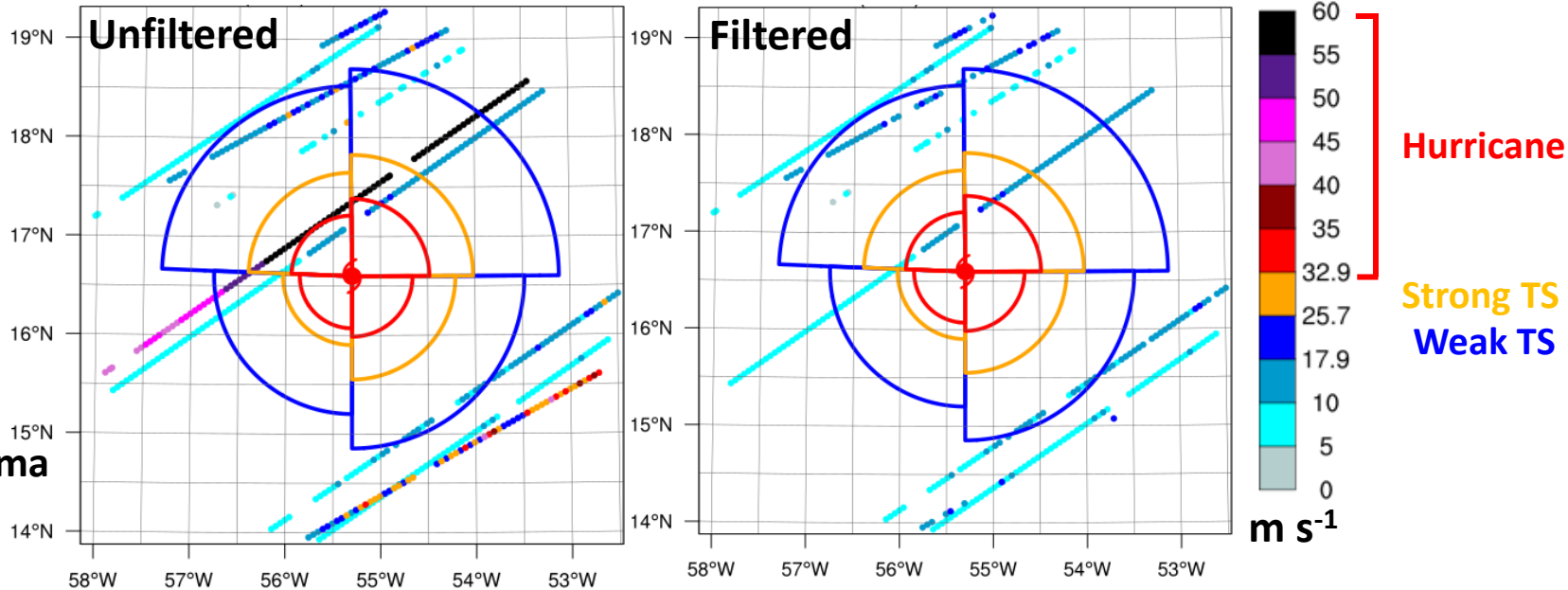
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34 kt

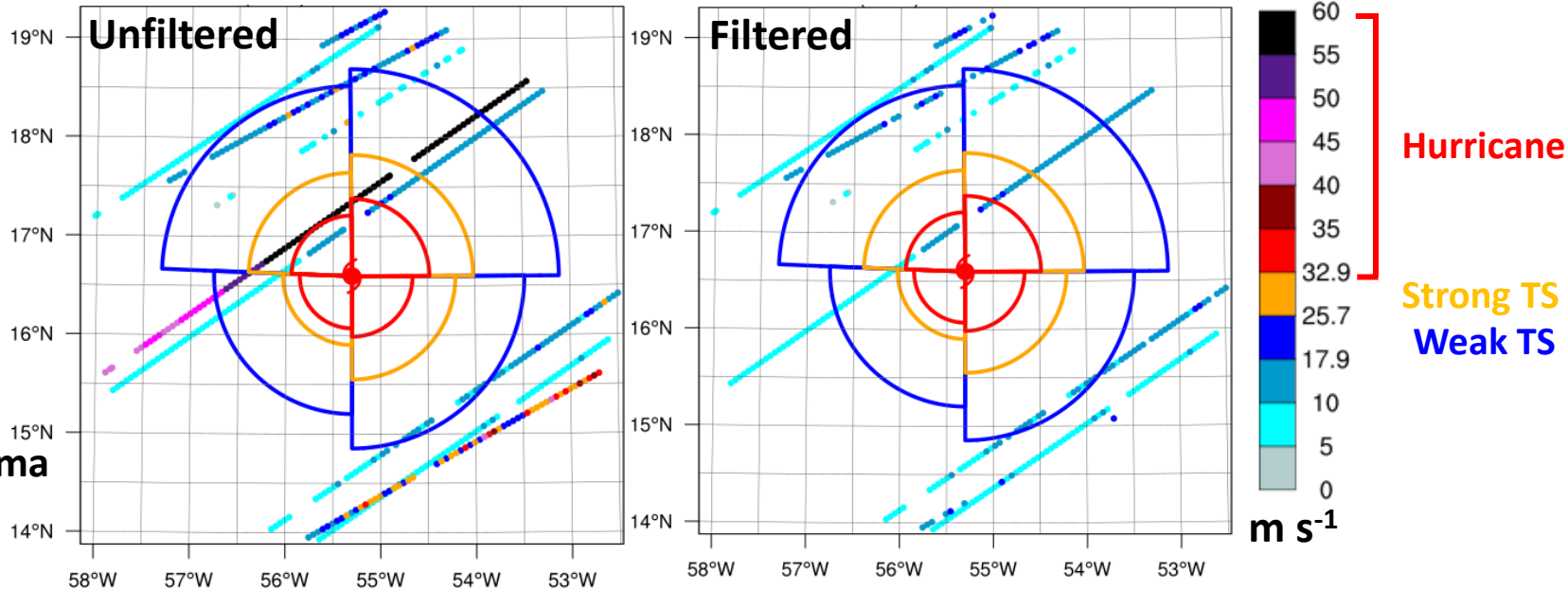
Constructing the radial wind profile

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



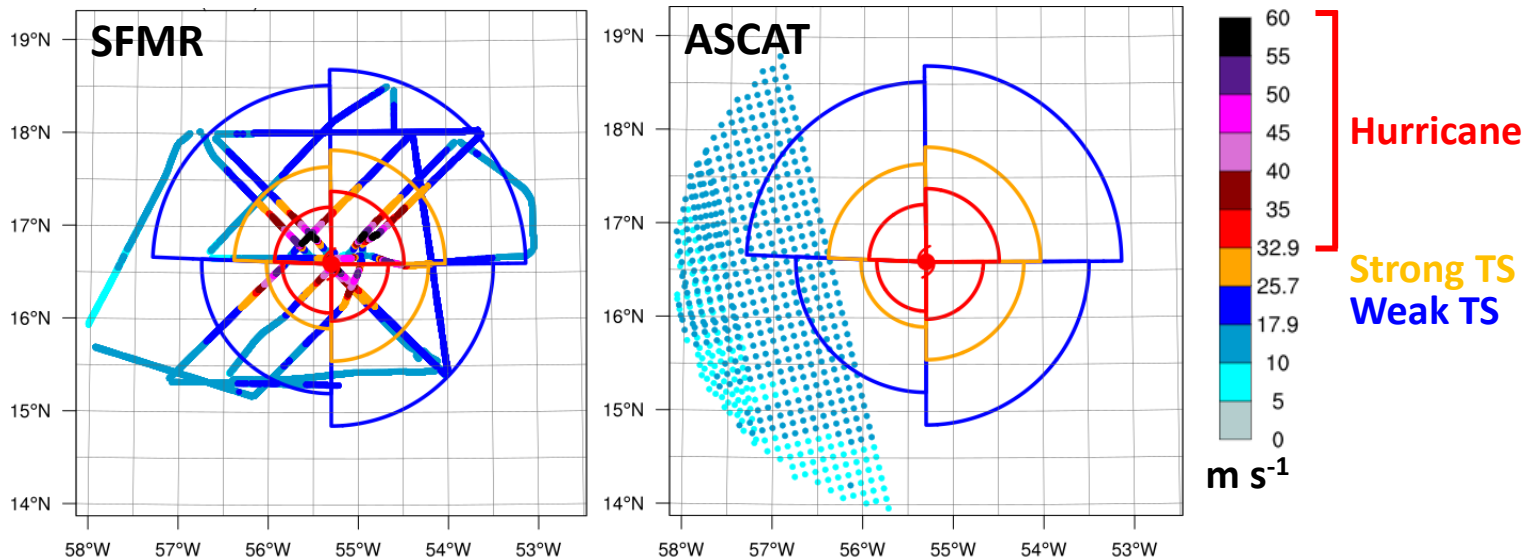
Constructing the radial wind profile

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



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**, **ASCAT**, and **SMAP**.
- **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.

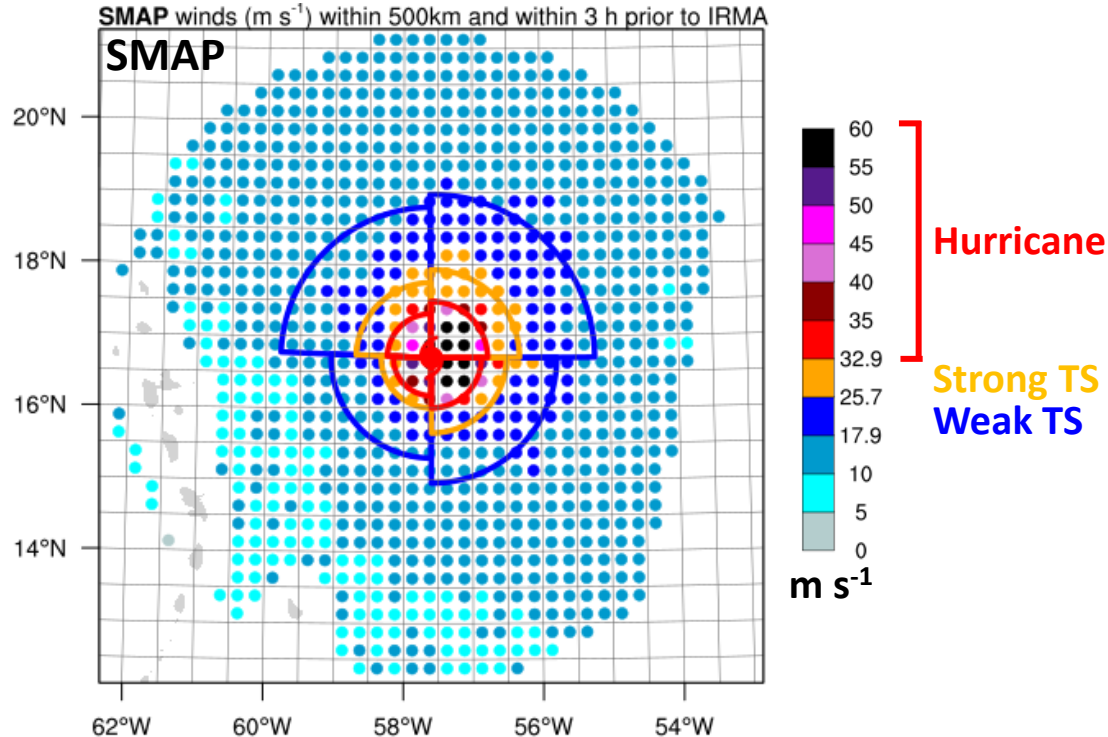


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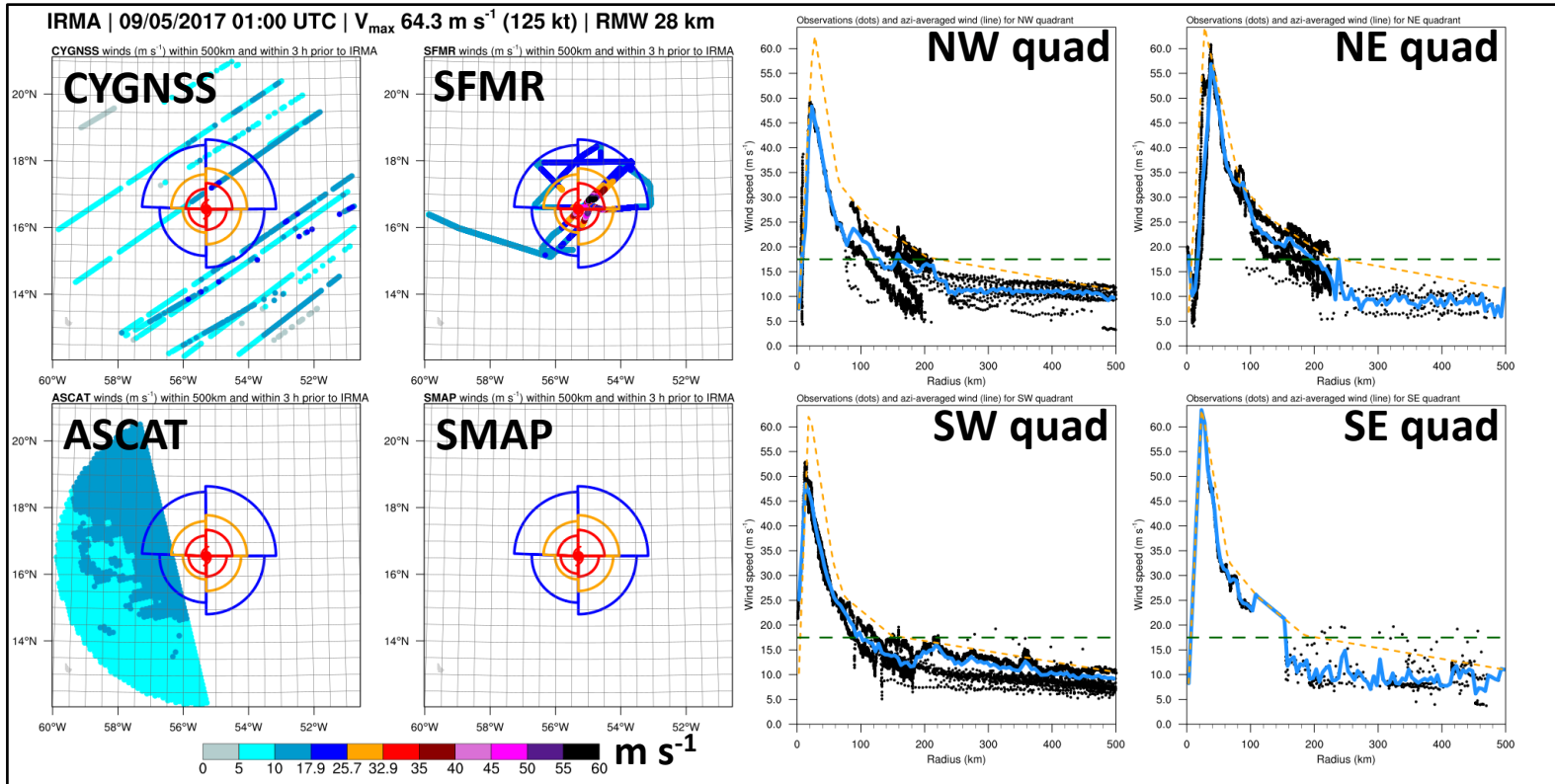
SMAP winds from
Remote Sensing
Systems
(Meissner et al. 2017)

Hurricane Irma
9/5/2017
11 UTC



Constructing the radial wind profile

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



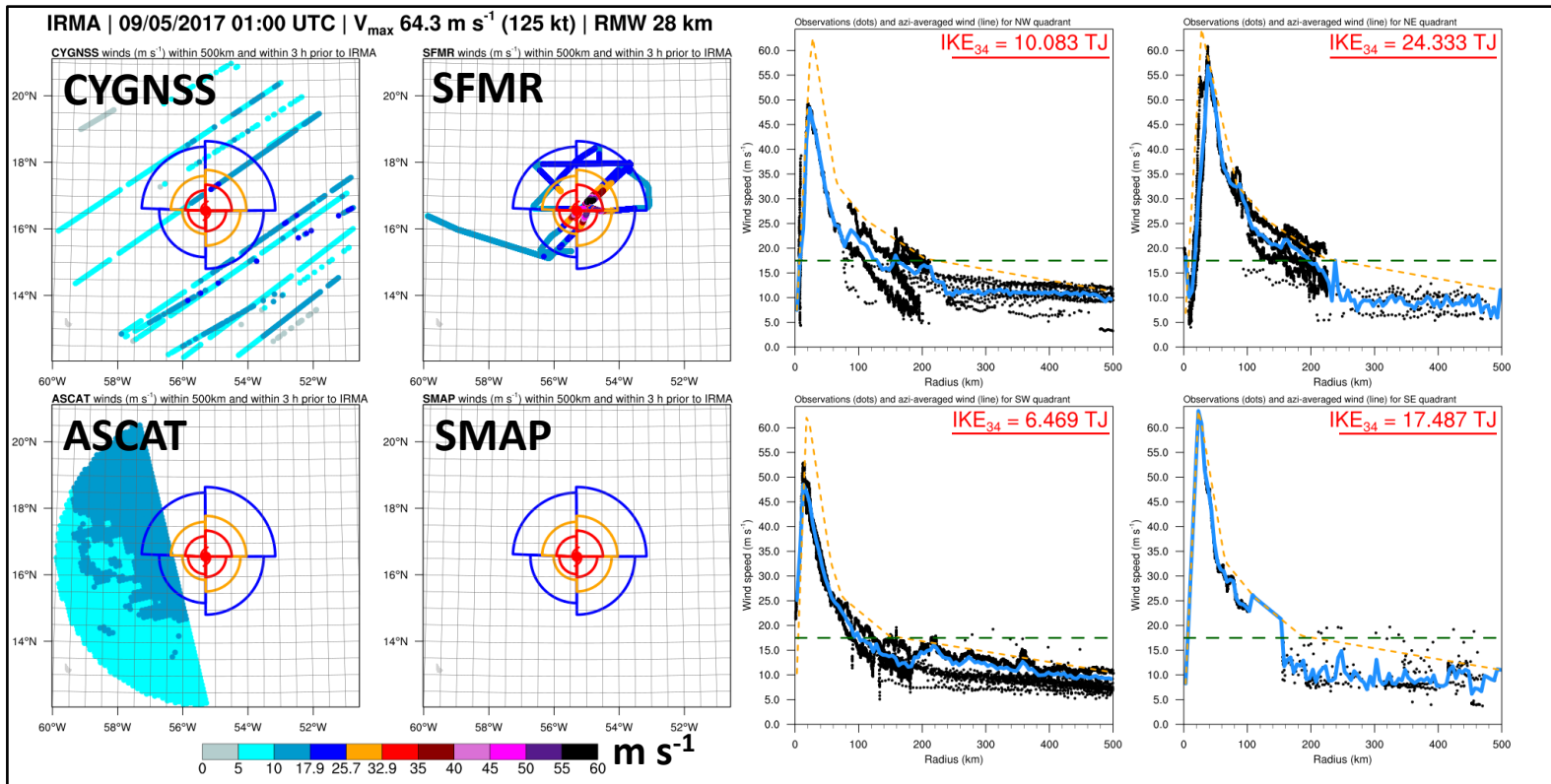
Black Dots:
Individual
Wind
Observations

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

Blue Lines:
Azimuthally
averaged
wind profiles.

Computing IKE

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



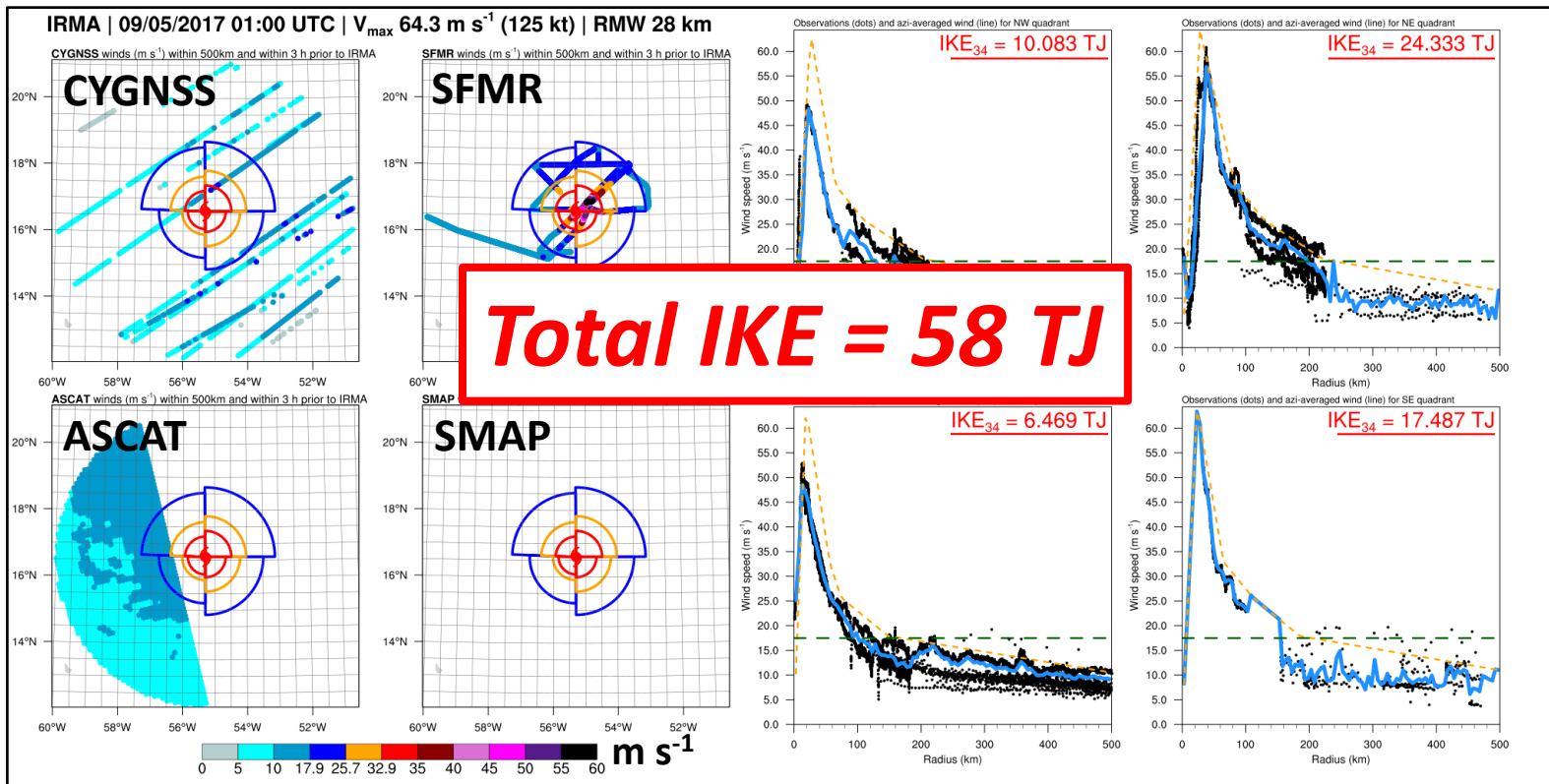
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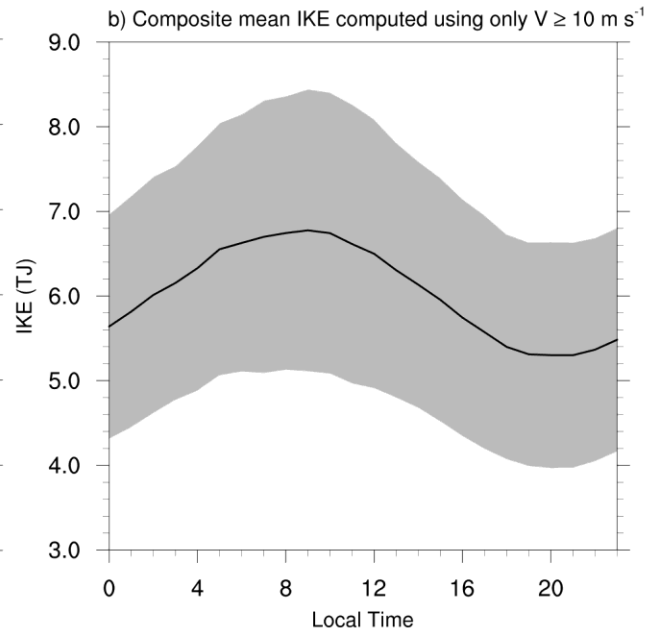
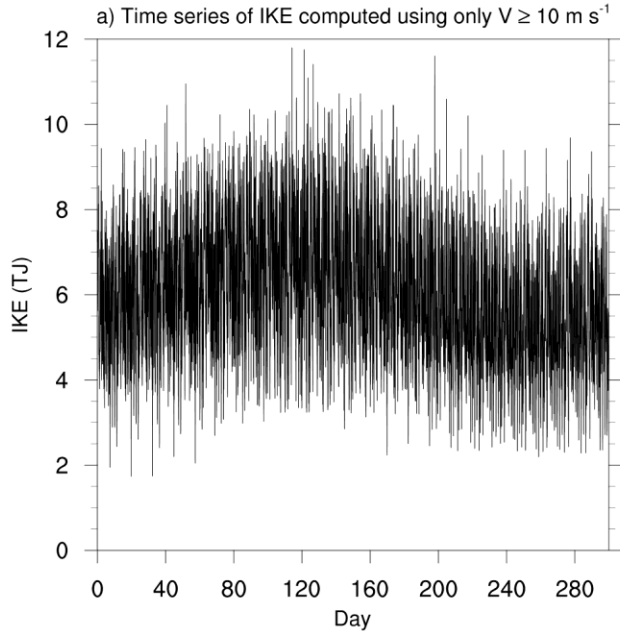
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Potential Applications

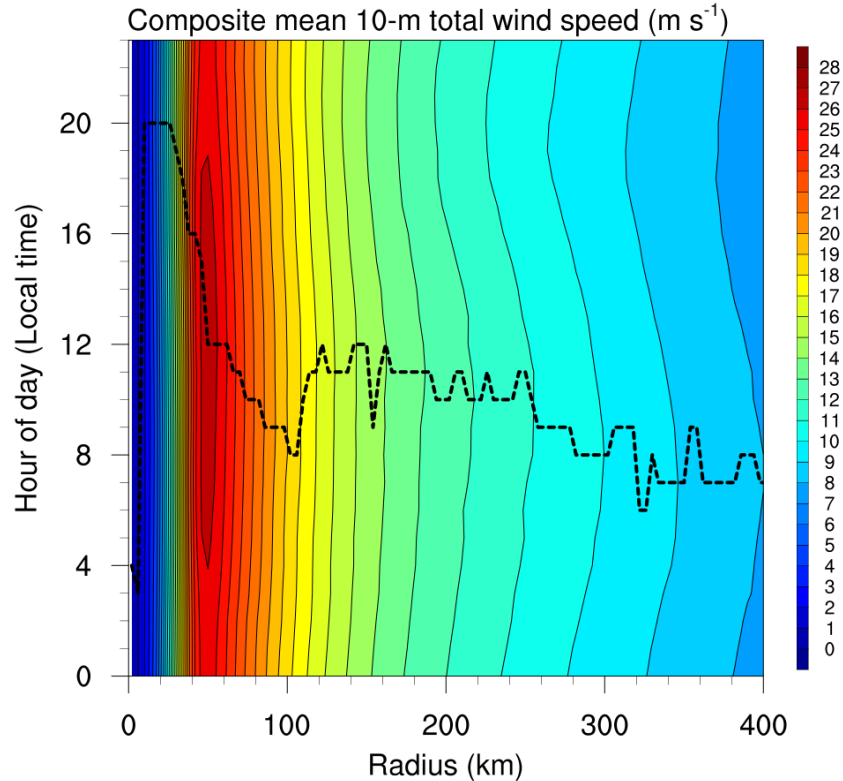
- Is there a time of day when TCs exhibit higher IKE?



In an idealized simulation,
IKE maximizes at 9 AM and
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Potential Applications

- Is there a time of day when TCs exhibit higher IKE?

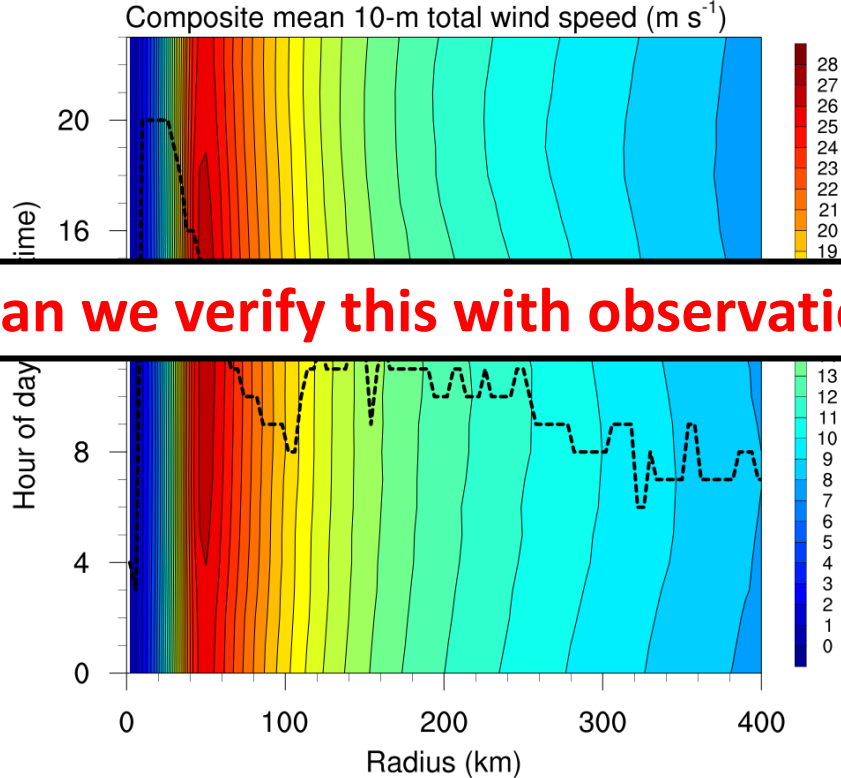


In an idealized simulation, **IKE maximizes at 9 AM** and **minimizes at 9 PM**.

Related to a **radial expansion** of the TC wind field overnight and through the morning, and a contraction during the afternoon, into the evening.

Potential Applications

- Is there a time of day when TCs exhibit higher IKE?

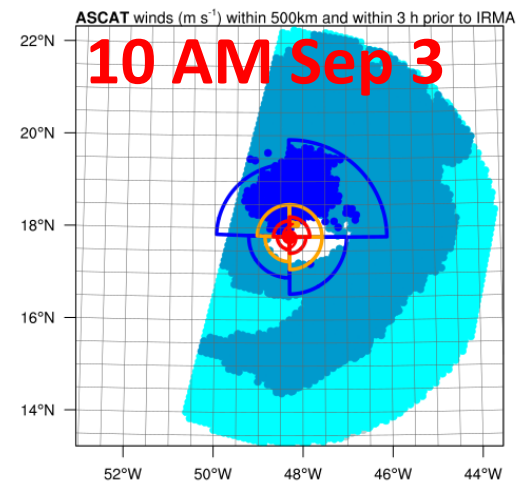
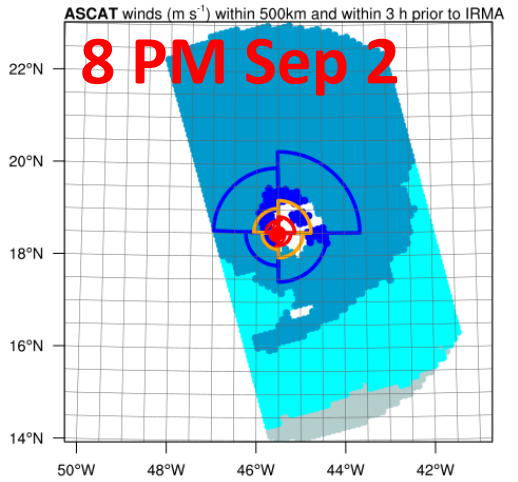
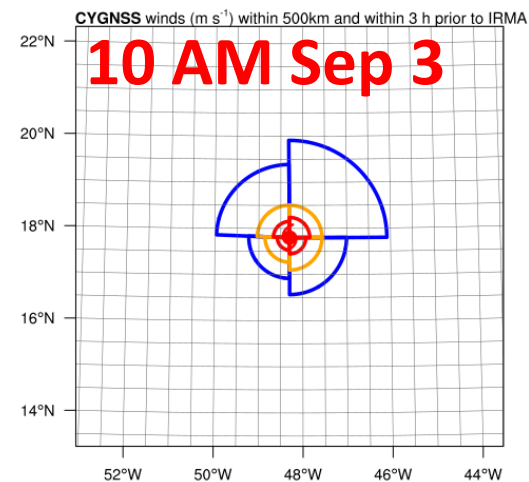
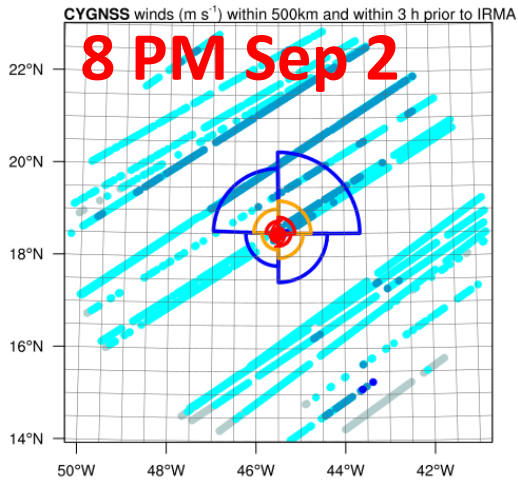


Can we verify this with observations?

In an idealized simulation, **IKE maximizes at 9 AM** and **minimizes at 9 PM**.

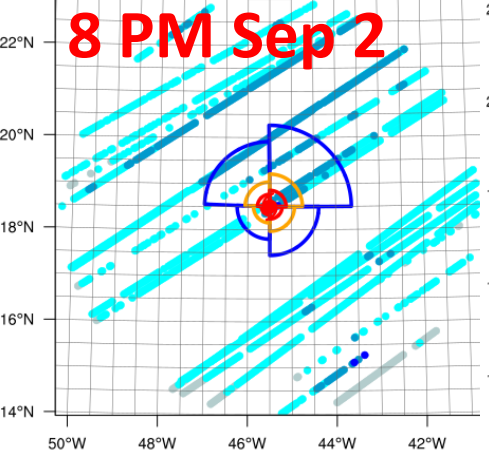
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Hurricane Irma – September 2-3, 2017

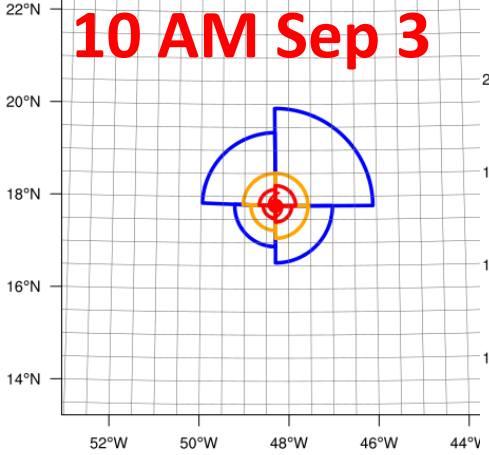


Hurricane Irma – September 2-4, 2017

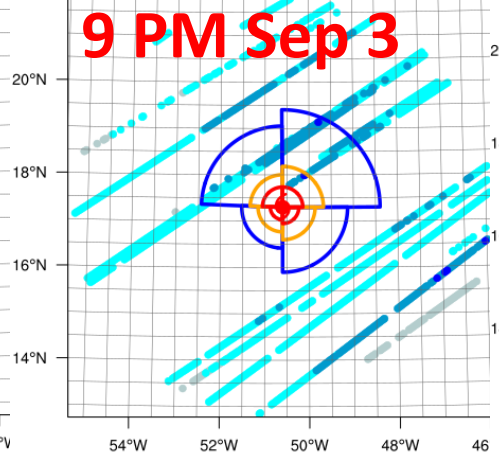
CYGNSS winds ($m s^{-1}$) within 500km and within 3 h prior to IF



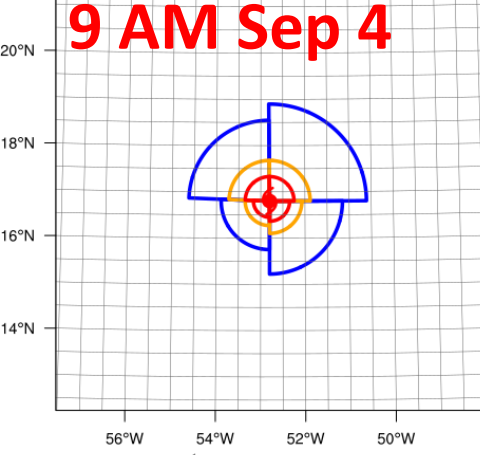
CYGNSS winds ($m s^{-1}$) within 500km and within 3 h prior to I



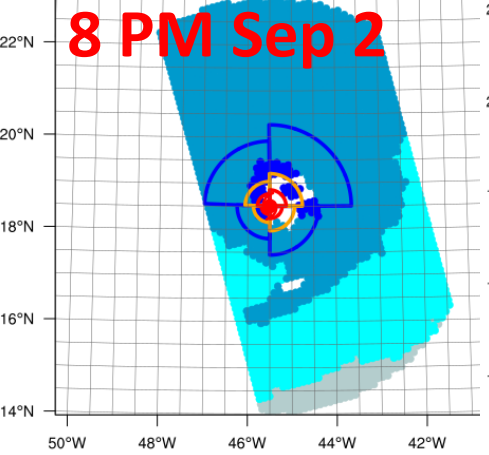
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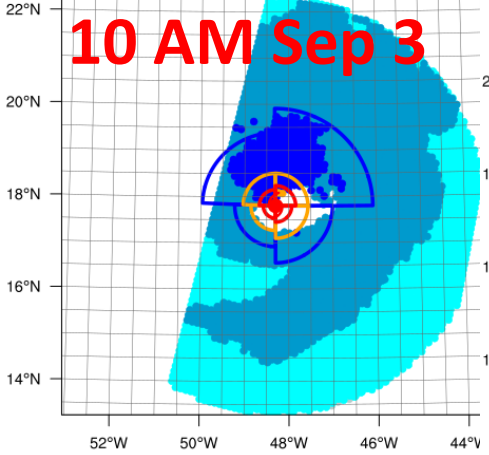
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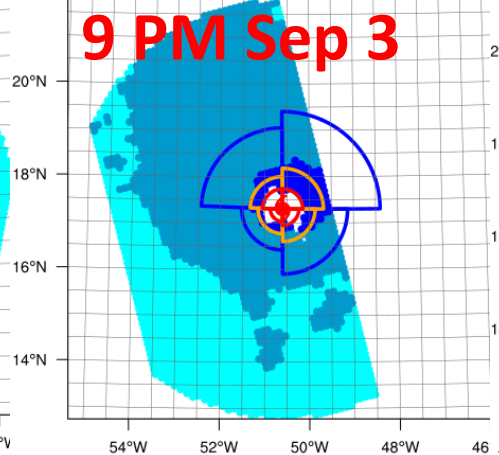
ASCAT winds ($m s^{-1}$) within 500km and within 3 h prior to IRI



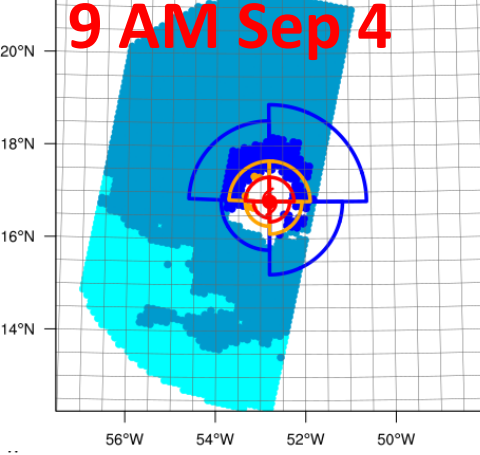
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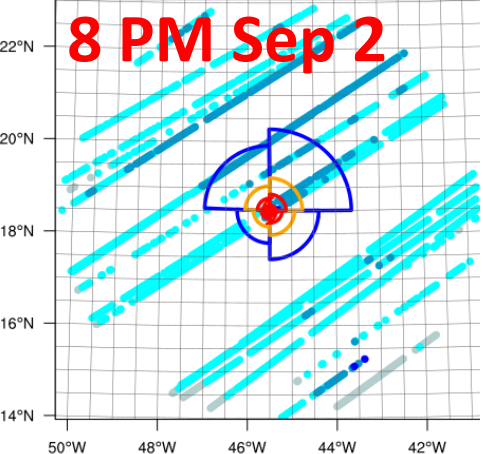


ASCAT winds ($m s^{-1}$) within 500km and within 3 h prior to IRI

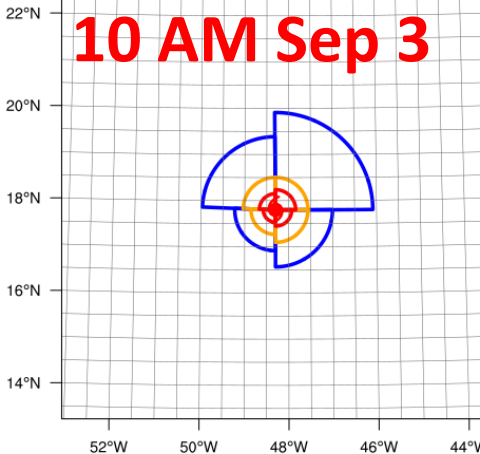


Hurricane Irma – September 2-4, 2017

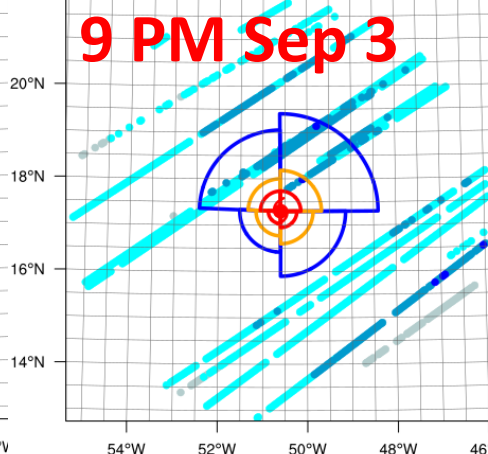
CYGNSS winds (m s^{-1}) within 500km and within 3 h prior to IF



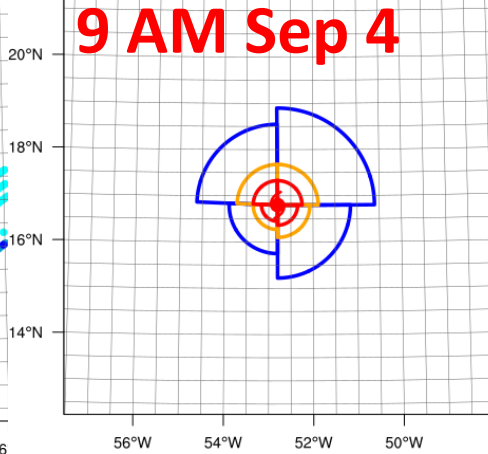
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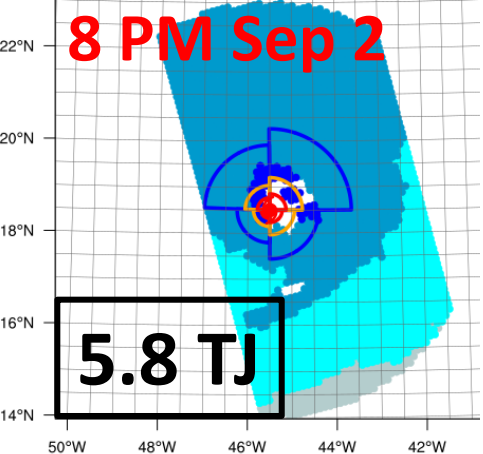
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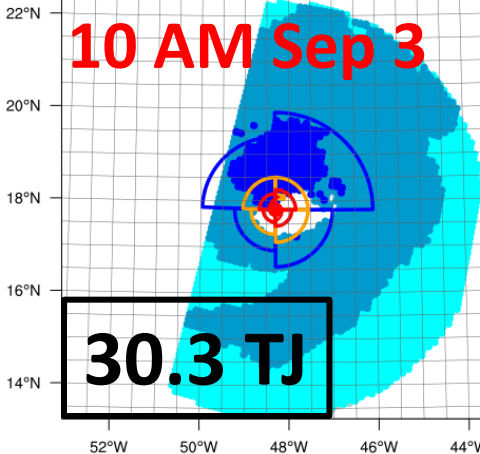
CYGNSS winds (m s^{-1}) within 500km and within 3 h prior to IF



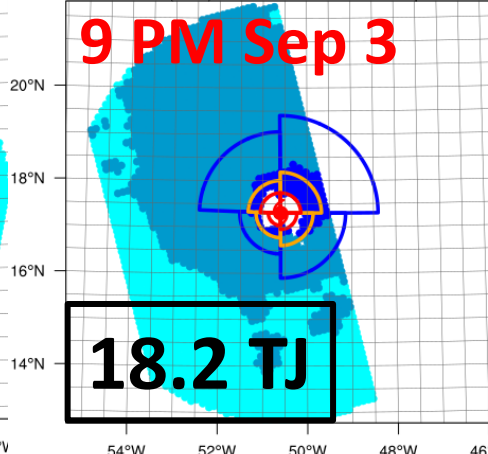
ASCAT winds (m s^{-1}) within 500km and within 3 h prior to IRL



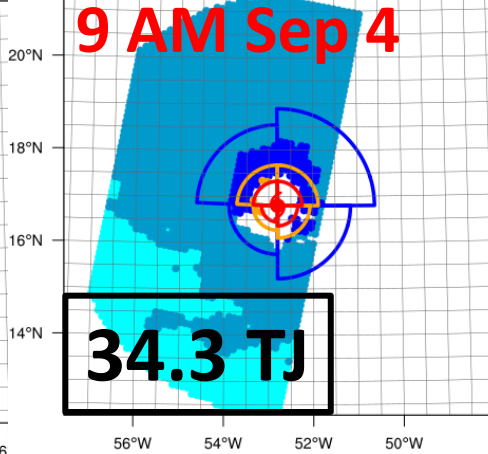
ASCAT winds (m s^{-1}) within 500km and within 3 h prior to IRI



ASCAT winds (m s^{-1}) within 500km and within 3 h prior to IRI



ASCAT winds (m s^{-1}) within 500km and within 3 h prior to IRL

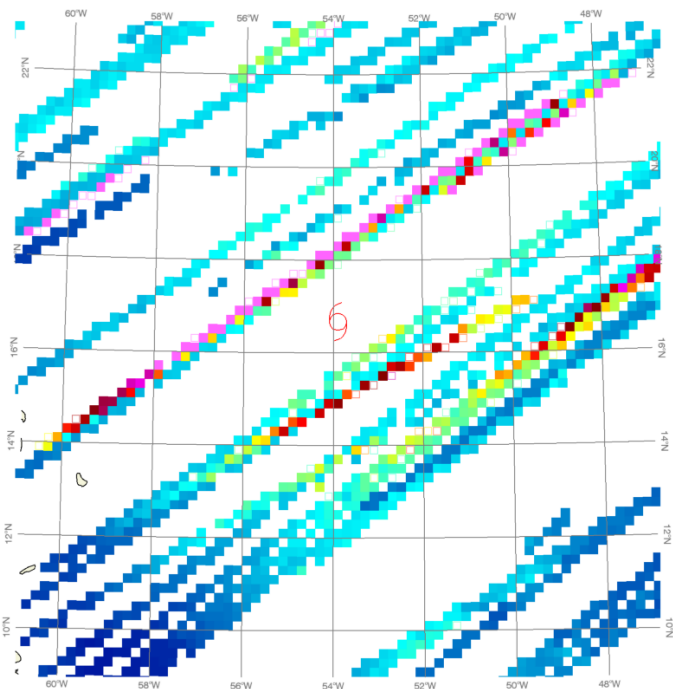


Future Directions

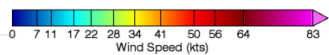
- Use CYGNSS, ASCAT, and SMAP to construct climatologies of wind radii and IKE in TCs across the globe.
 - Stratify by TC intensity, vertical wind shear, ocean basin, etc.
- Investigate the diurnal cycle of TC wind radii and IKE using the climatologies as a reference point.
- Refine algorithm to combine observations from different platforms and construct radial wind profiles.
 - Weight observations by observation platform and/or average the wind speeds from each platform first, then take total average.
 - Account for differences in horizontal resolution.
 - Take maximum value in each radial bin instead of average.

Extra Slides

CYGNSS L3 WIND SPEED : 20170904 (1800Z-0000Z)
AL11 [IRMA] : VMAX 115 KTS

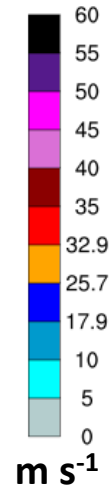
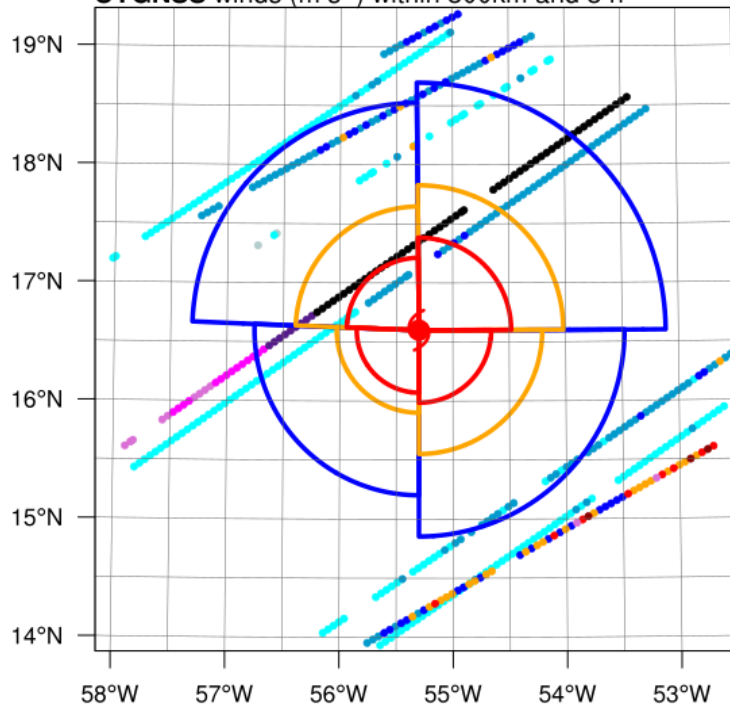


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SCHOOL of MARINE &
ATMOSPHERIC SCIENCE



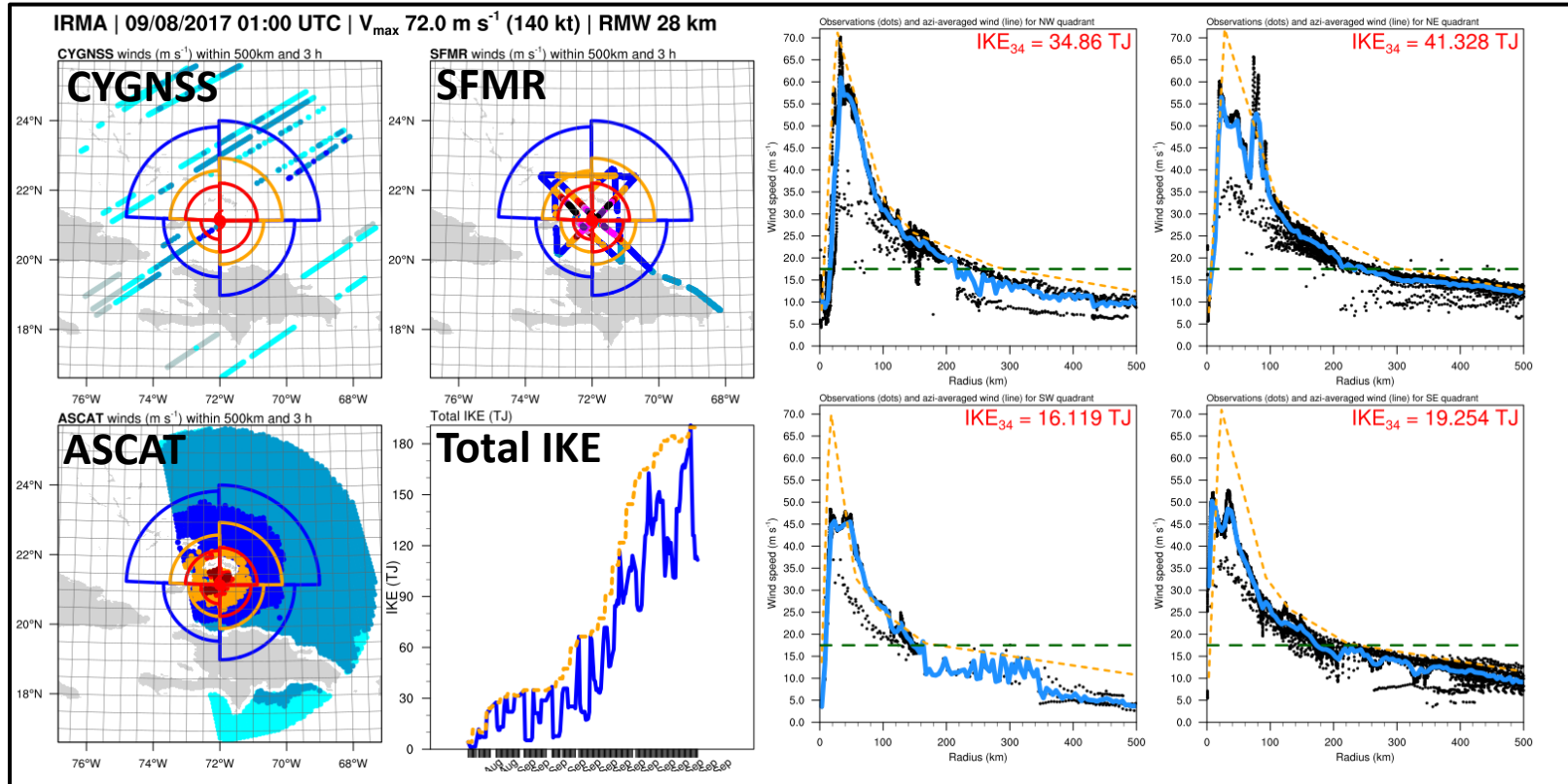
- Retrievals where std dev of wind speed error ≥ 3.0 m/s denoted by hollow squares.
- v2.1. Young Seas with Limited Fetch (YSLF) algorithm
- Storm marker placed at beginning of 6-hour window.

CYGNSS winds (m s^{-1}) within 300km and 3 h



IKE History – Hurricane Irma (2017)

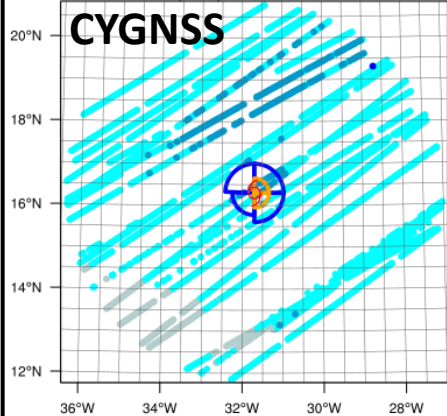
- Compute IKE every hour, using 6 hours of observations (all observations within 3 hours before or after best track time).



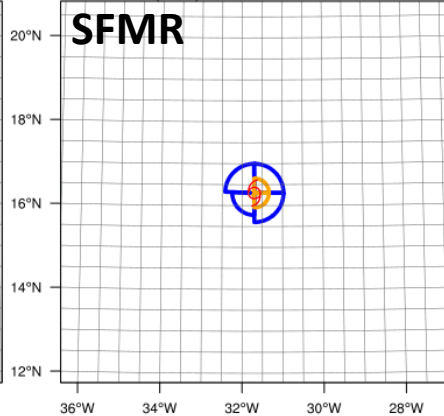
IKE History – Hurricane Irma (2017)

IRMA | 08/31/2017 00:00 UTC | V_{max} 28.3 m s⁻¹ (55 kt) | RMW 28 km

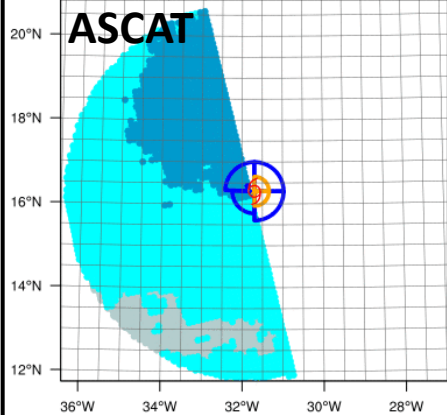
CYGNSS winds (m s⁻¹) within 500km and 3 h



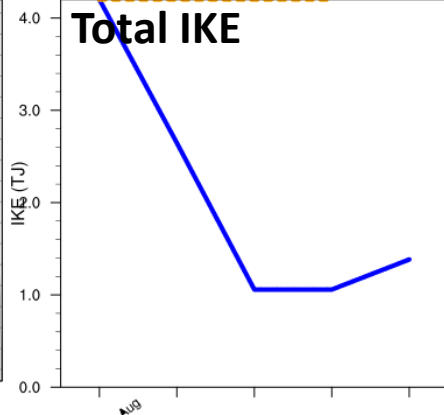
SFMR winds (m s⁻¹) within 500km and 3 h



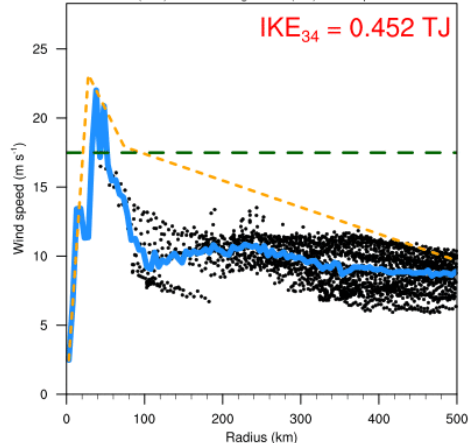
ASCAT winds (m s⁻¹) within 500km and 3 h



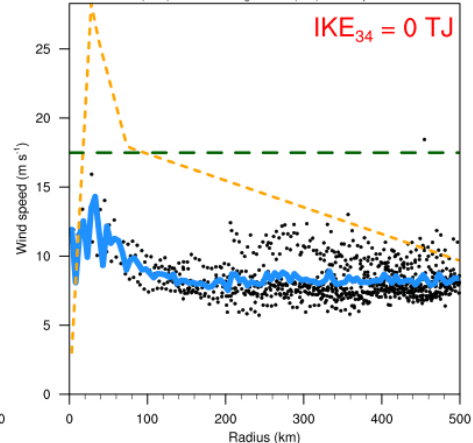
Total IKE (TJ)



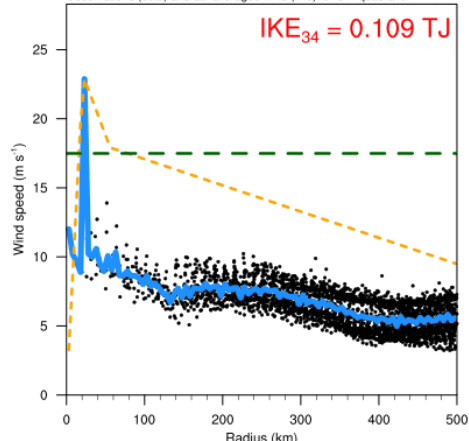
Observations (dots) and azi-averaged wind (line) for NW quadrant



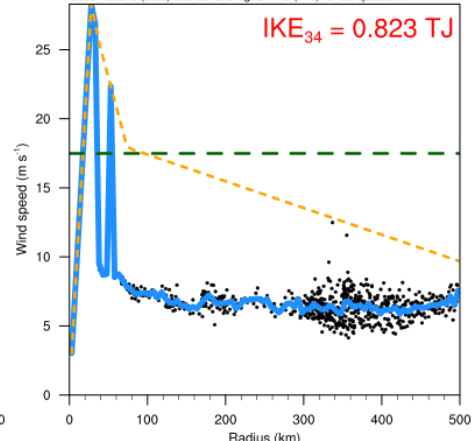
Observations (dots) and azi-averaged wind (line) for NE quadrant



Observations (dots) and azi-averaged wind (line) for SW quadrant

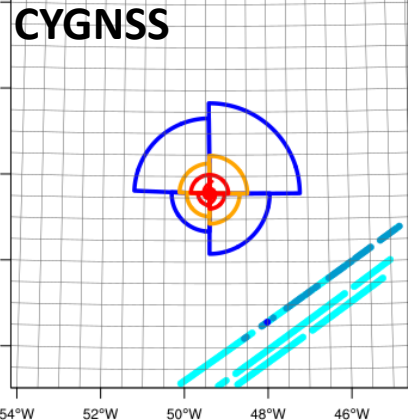


Observations (dots) and azi-averaged wind (line) for SE quadrant

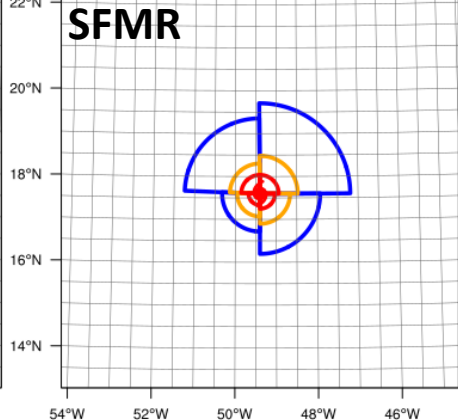


IRMA | 09/03/2017 19:00 UTC | V_{max} 51.4 m s⁻¹ (100 kt) | RMW 28 km

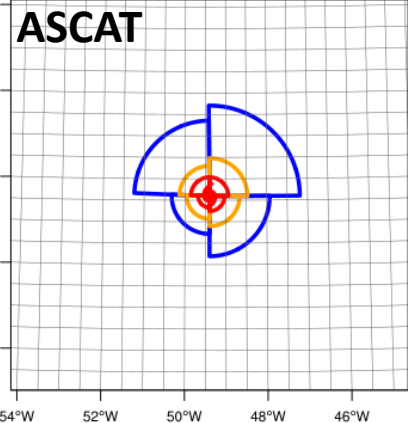
CYGNSS winds (m s⁻¹) within 500km and 3 h



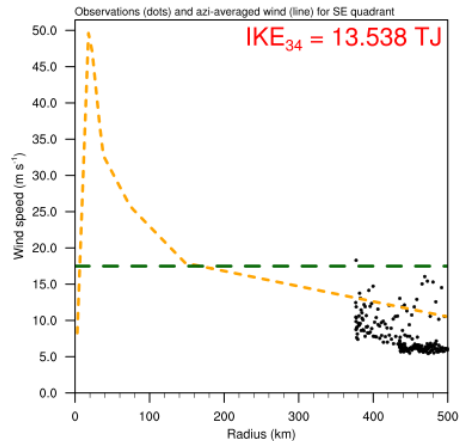
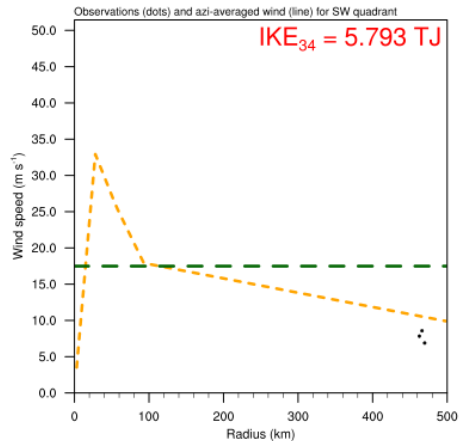
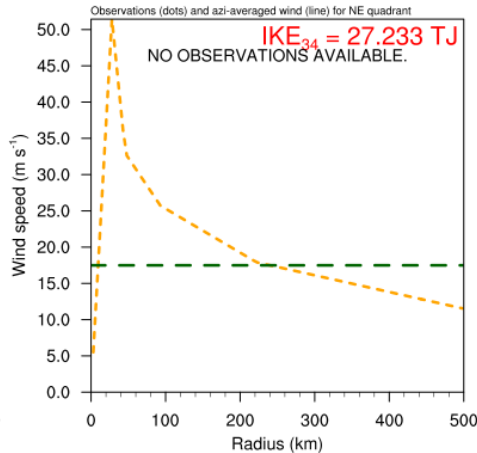
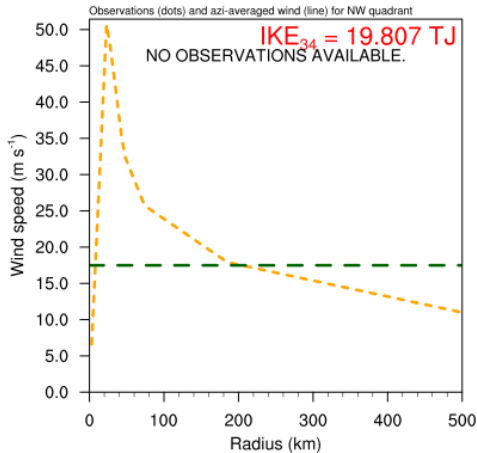
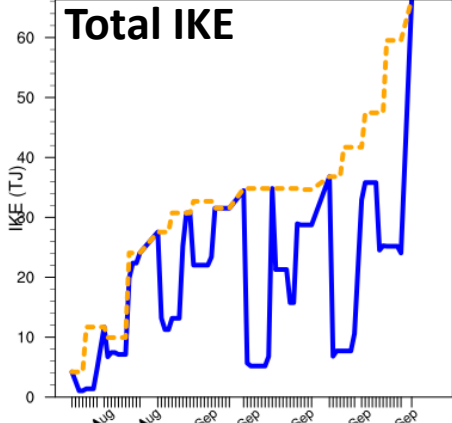
SFMR winds (m s⁻¹) within 500km and 3 h



ASCAT winds (m s⁻¹) within 500km and 3 h

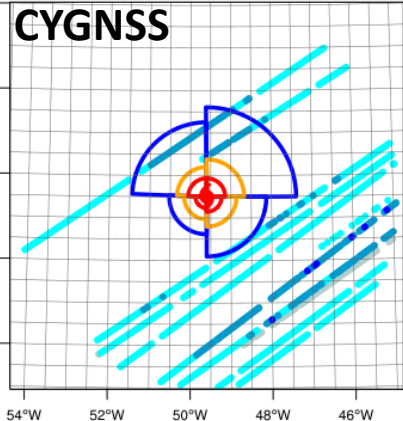


Total IKE (TJ)

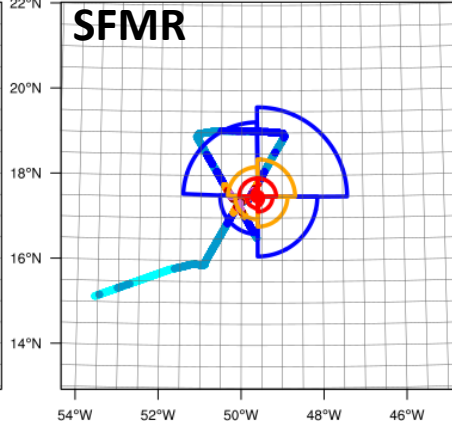


IRMA | 09/03/2017 20:00 UTC | V_{max} 51.4 m s⁻¹ (100 kt) | RMW 28 km

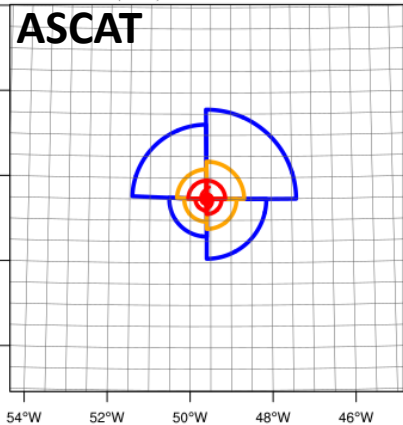
CYGNSS winds (m s⁻¹) within 500km and 3 h



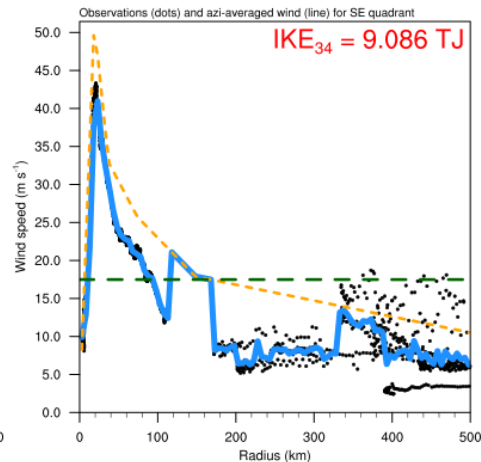
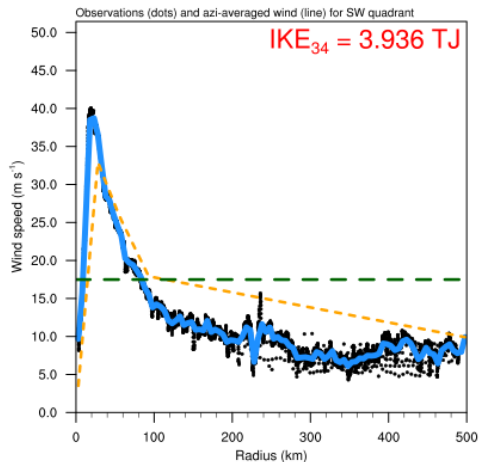
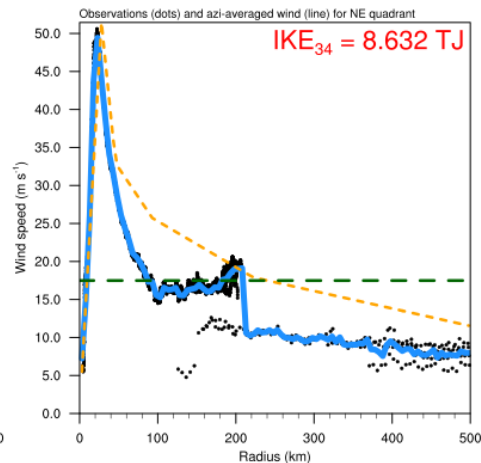
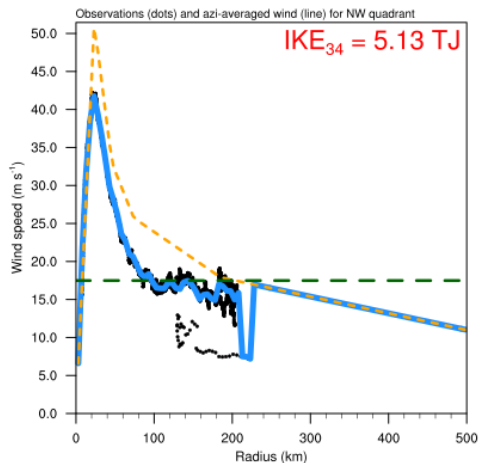
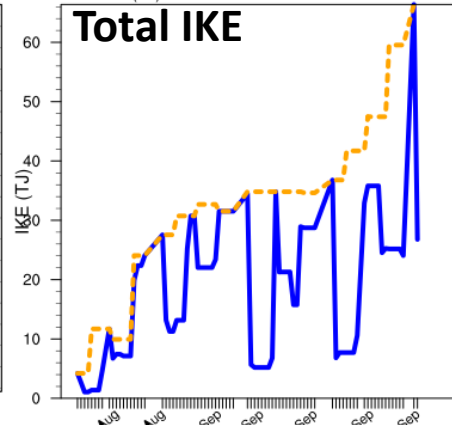
SFMR winds (m s⁻¹) within 500km and 3 h



ASCAT winds (m s⁻¹) within 500km and 3 h

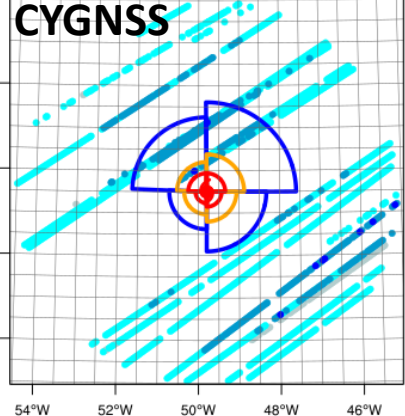


Total IKE (TJ)

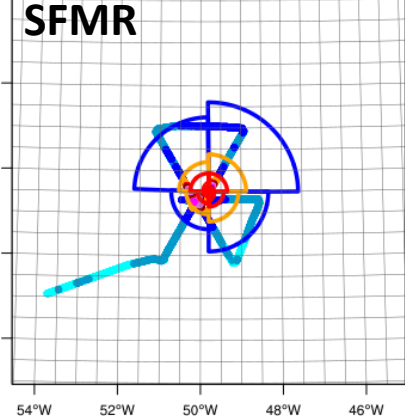


IRMA | 09/03/2017 21:00 UTC | V_{max} 51.4 m s⁻¹ (100 kt) | RMW 28 km

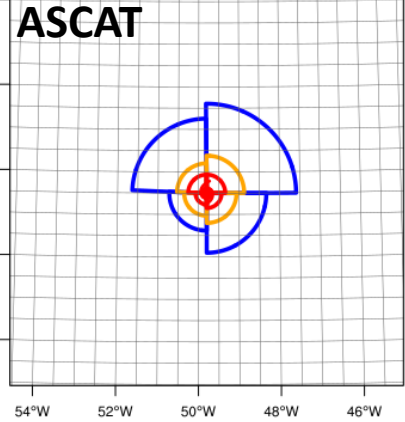
CYGNSS winds (m s⁻¹) within 500km and 3 h



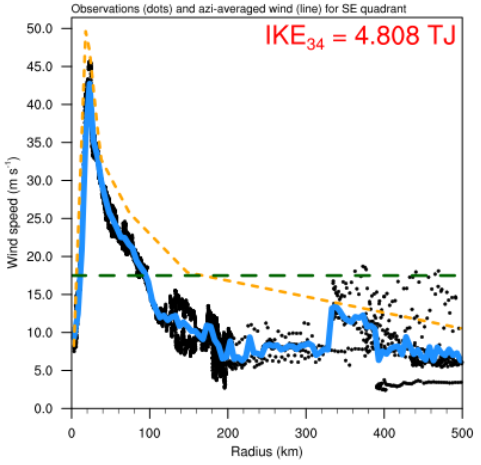
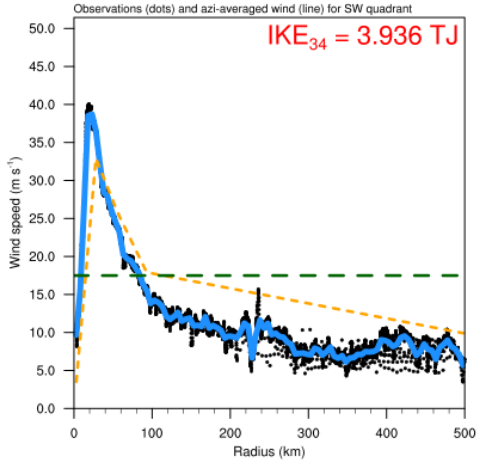
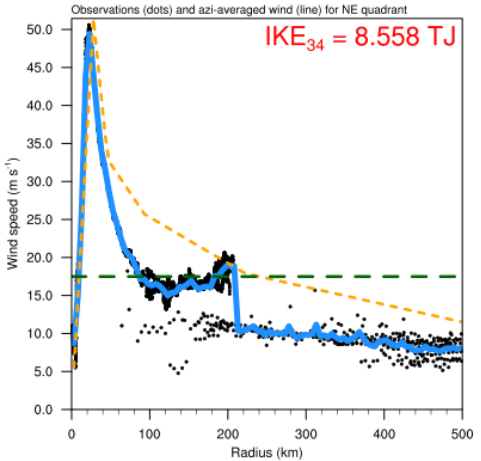
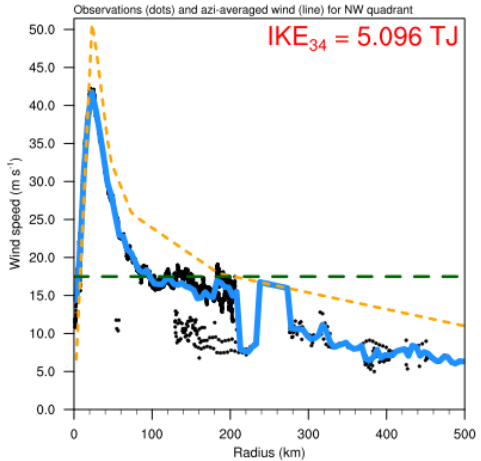
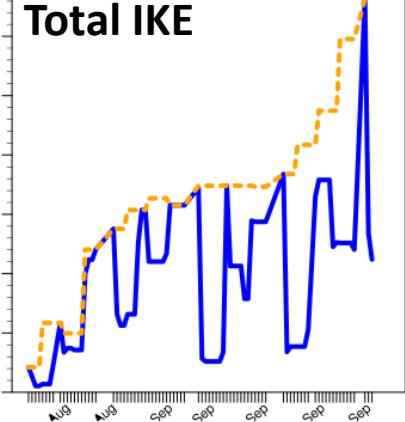
SFMR winds (m s⁻¹) within 500km and 3 h



ASCAT winds (m s⁻¹) within 500km and 3 h

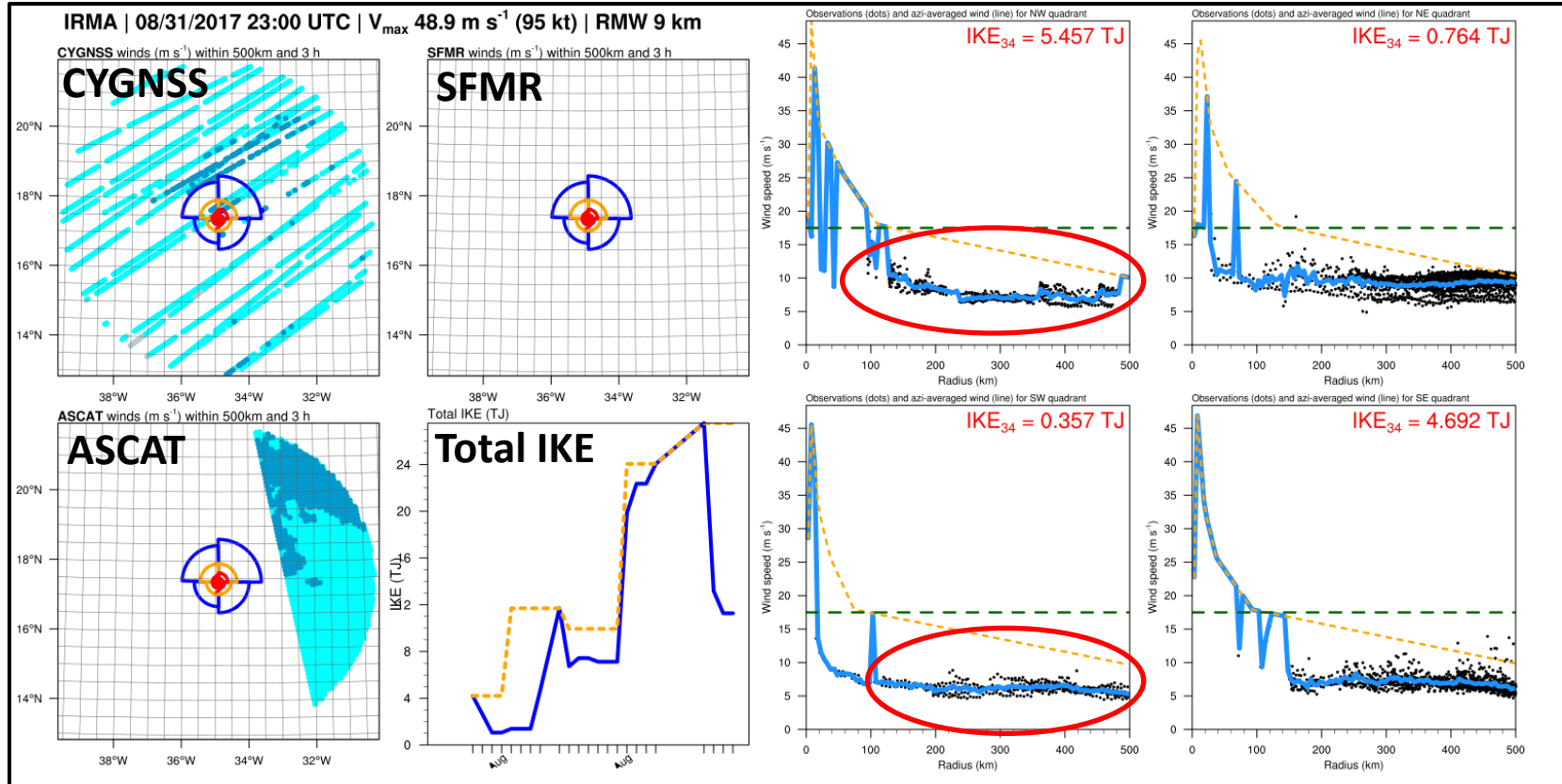


Total IKE (TJ)

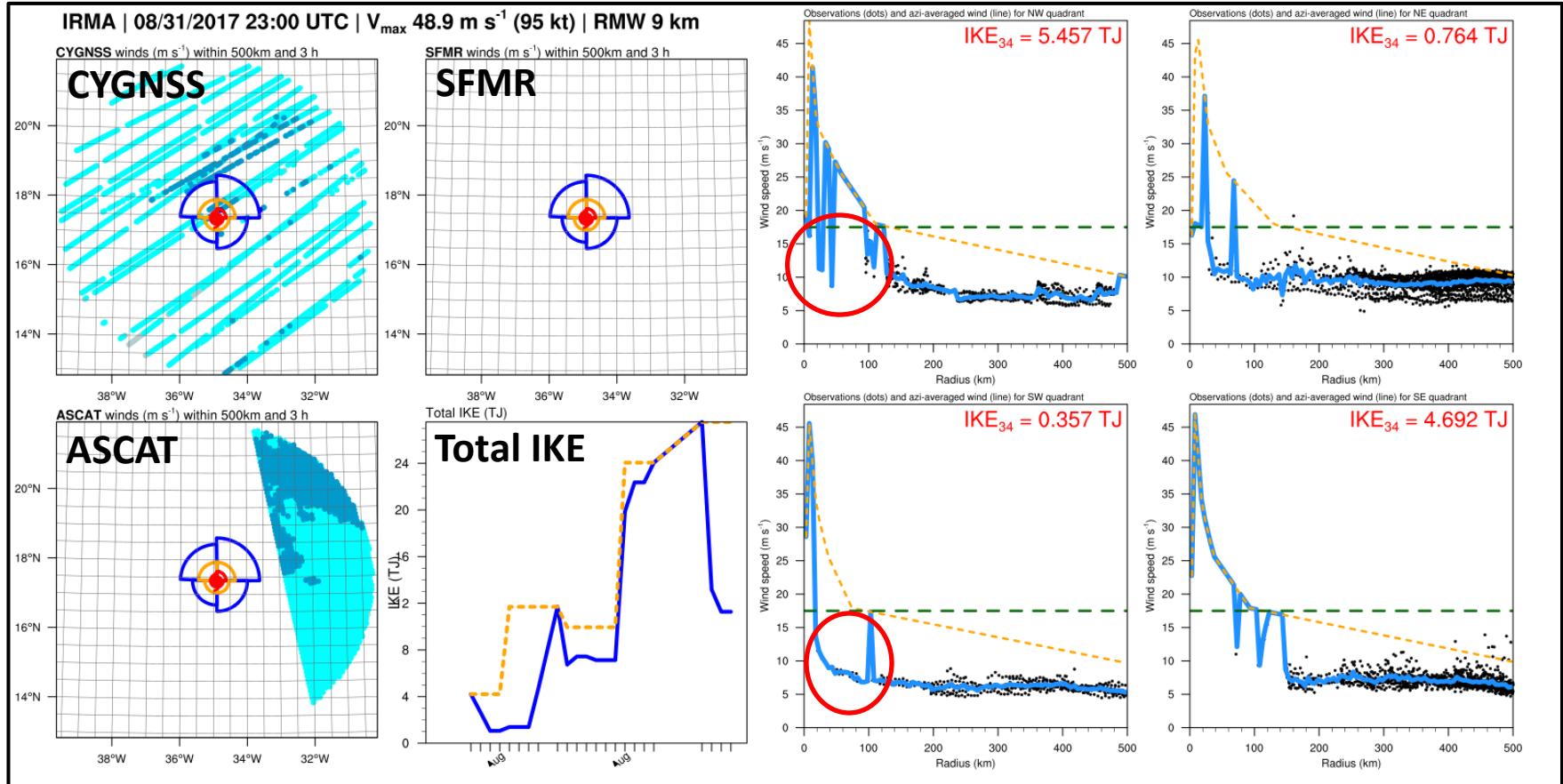


Where CYGNSS Adds Value

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



Where CYGNSS Could be Improved



Where CYGNSS Could be Improved

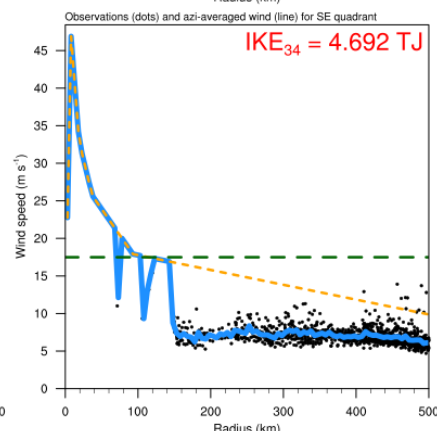
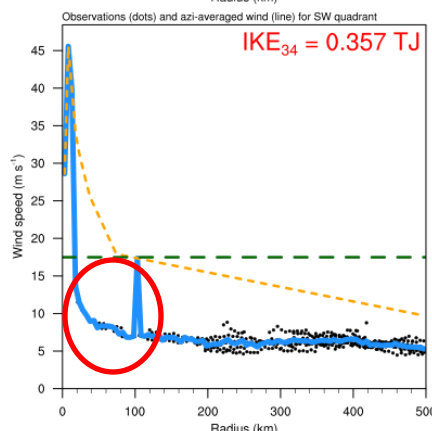
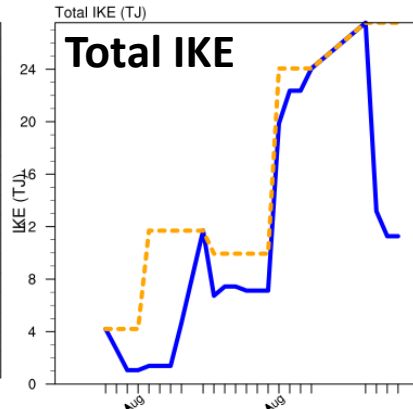
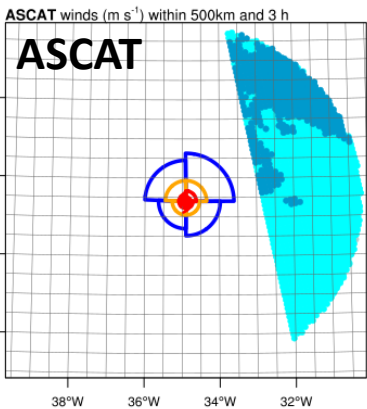
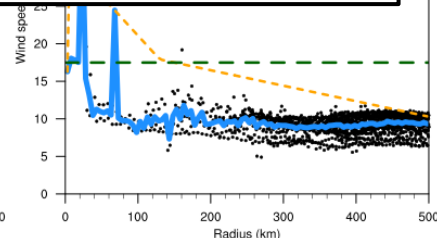
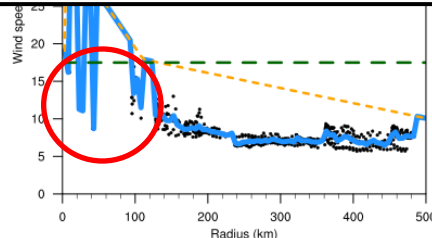
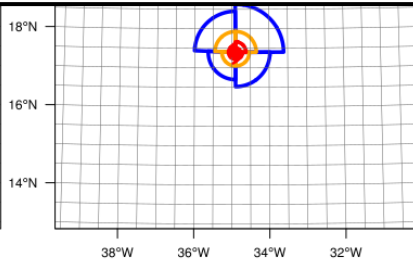
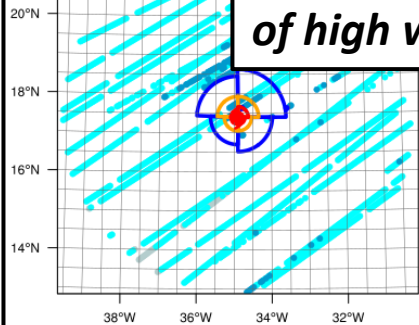
IRMA | 08/31/20

CYGNSS winds (m s⁻¹) with

CYGNSS

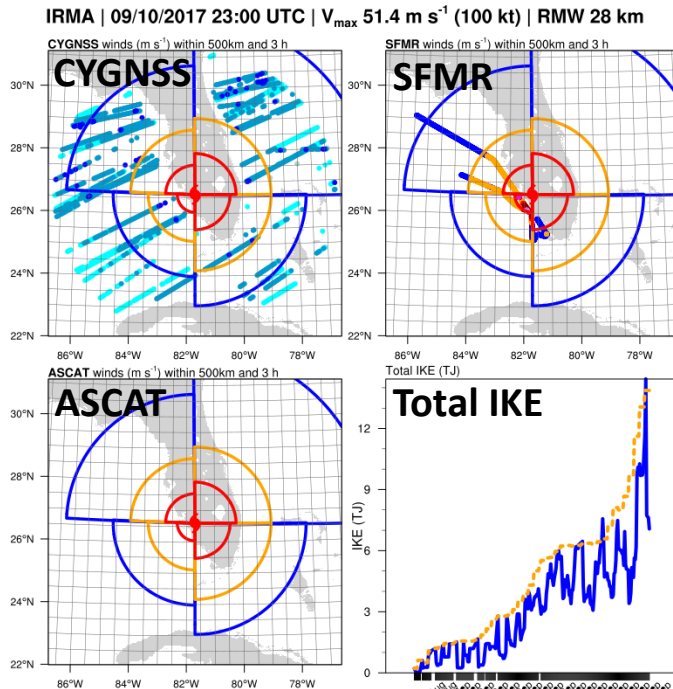
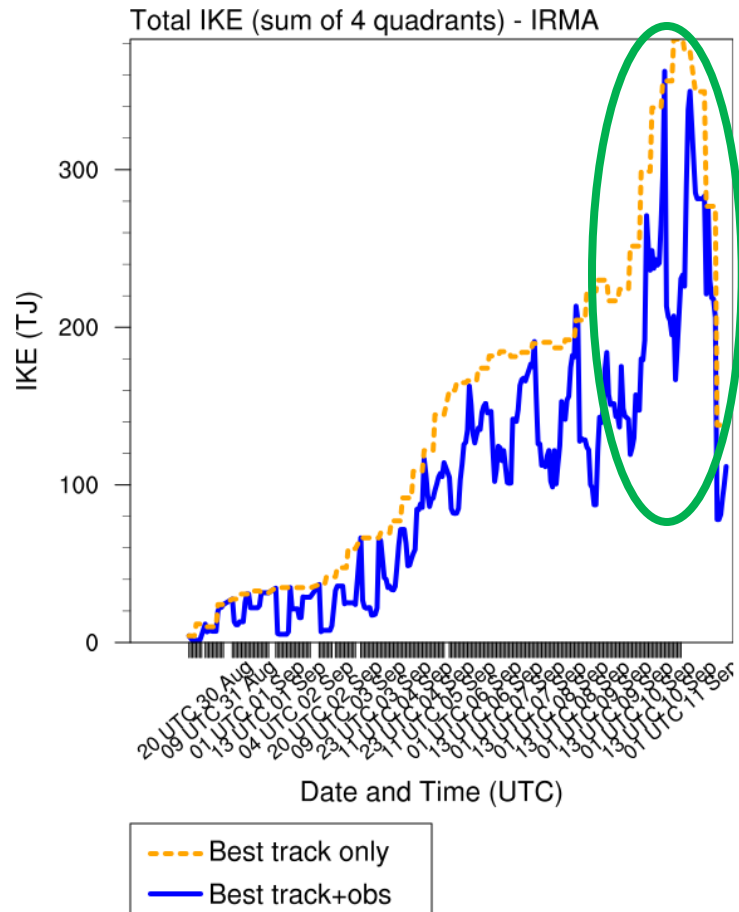
CYGNSS rarely depicts (with confidence) the very high wind speeds that should be present in the inner core, *other than producing streaks of high wind speed that appear dubious*, and are filtered out.

TJ

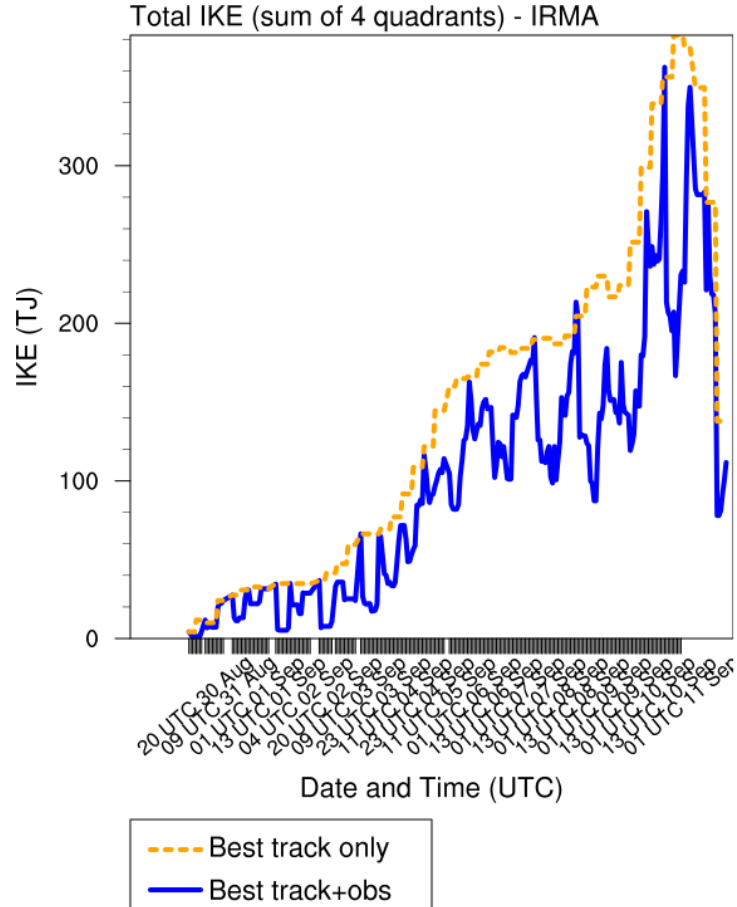


Other Causes of Large IKE Fluctuations

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

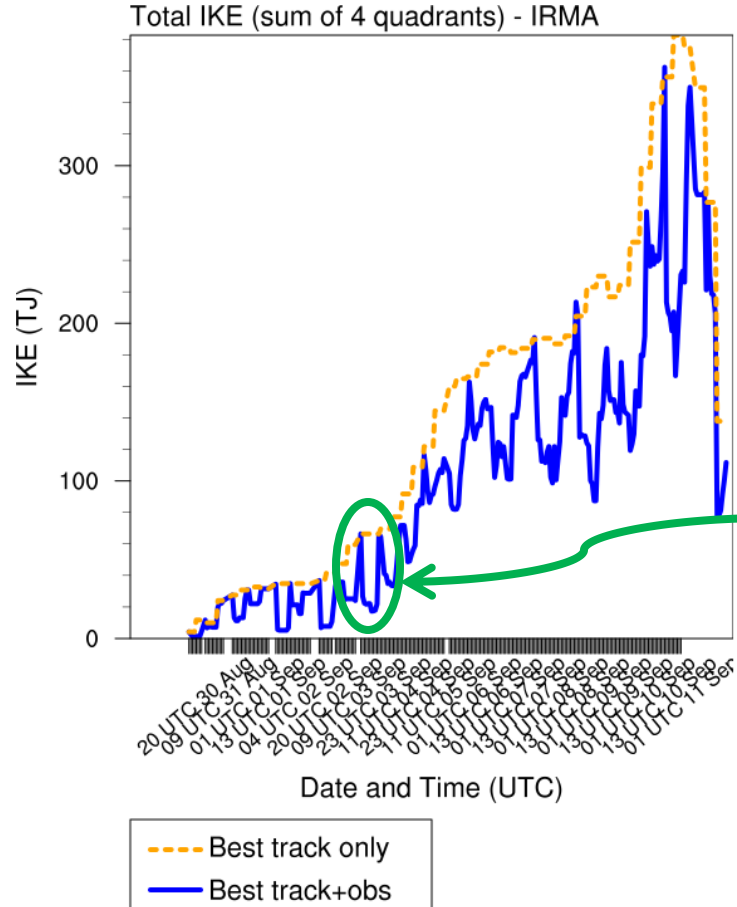


IKE History – Hurricane Irma (2017)



- 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.

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.