Using Flight Level Data to Improve Historical Tropical Cyclone Databases

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On the Need for Objective State Estimation

- Considerable epistemic uncertainty exists in current historical TC databases
  - Constantly evolving observation systems
  - Changing operational practices (and people!)
  - Advancements in scientific knowledge
  - Lack of clarity on the impact of a given observation on the analyzed result
  - Lack of best-tracking for some parameters
    - RMW
    - wind radius for 96-kt, 113-kt, 136-kt
    - structural characterizations such as presence of an eye, existence of multiple wind radii

Drawbacks of Subjective Reanalyses

- Labor intensive
- Requires a substantial amount of effort to add new parameters to the reanalysis
- Potential difficulties with reproducibility
- Potential requirement to repeat the whole process when significant scientific advances are made, or when (new) legacy observations are added

What is Objective State Estimation?

A technique whose goal is to optimally estimate one or more parameters of a system from estimates of the parameter or other aspects of the system

- Variational data assimilation techniques (dynamical models)
- “Hybrid” analysis techniques (H*WIND)
- Statistical model approaches (e.g., linear regression)
- Objective criteria-informed algorithmic approach
- Full-scale AI

Note: Input estimates do not have to be actual observations – they can be based on a model of the system evolution

Should we just let AI do it?

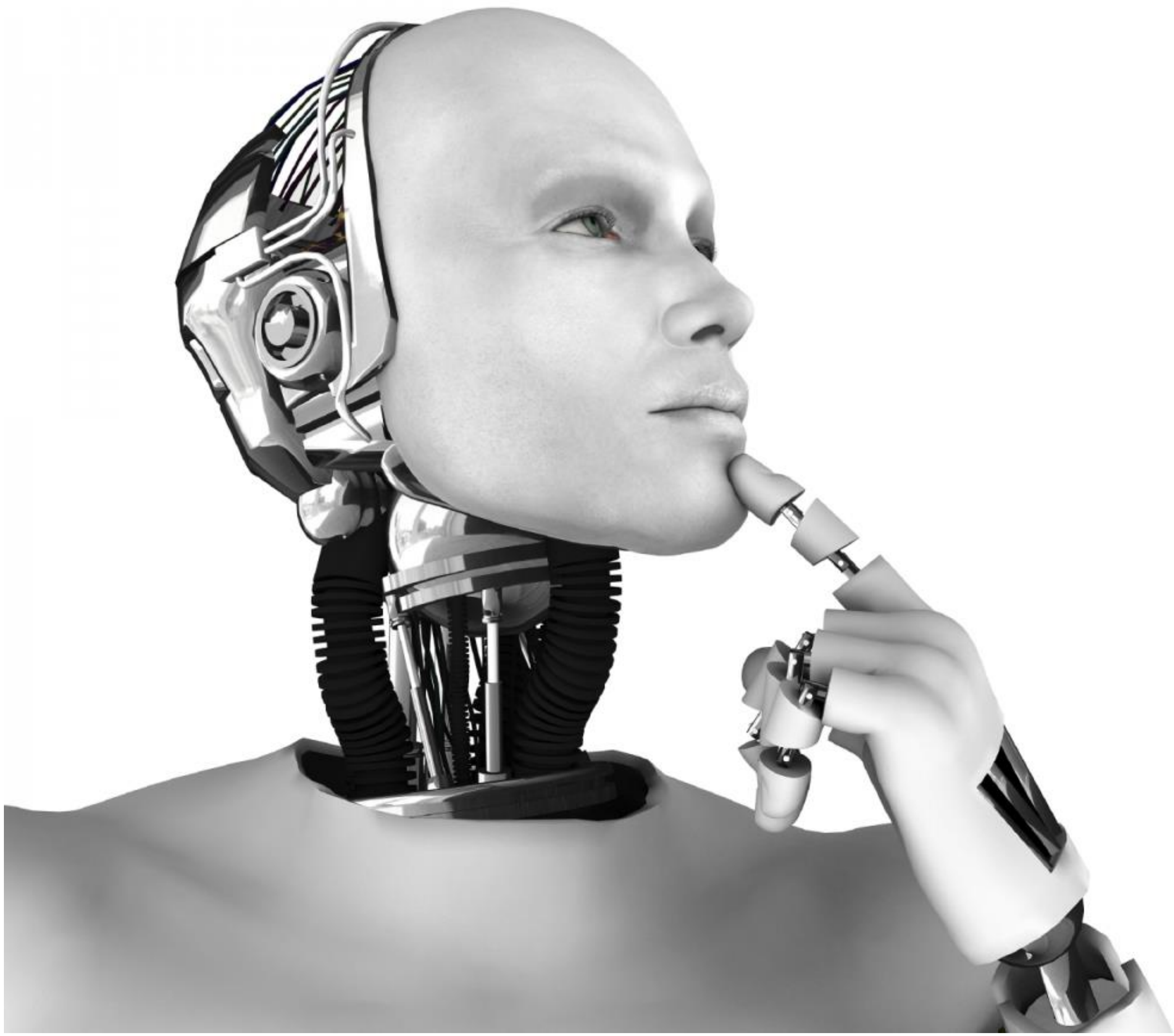

Image credit: Fist Ful of Talent: http://fistfuloftalent.com/2017/01/wild-west-ai-bots.html

Costs of Objective State Estimation

- Requires <u>considerable</u> effort to standardize the observational input data
- Requires development of methods, algorithms, and/or statistical relationships to determine the associated uncertainty characteristics of these data
- Requires effort to setup a program to undertake the analysis

Benefits of Objective State Estimation

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- Rapid computation without the need for additional human labor
- Relatively easy to:
  - add alternative state estimation methods for a given parameter
  - add analysis methods for entirely new parameters
  - add new data sources
  - add or modify the characteristics associated with different types of data
- The database can be easily revised when new advances are made in the science
- Full and complete reproducibility
- Full transparency on the impact of an observation on the analyzed parameter

Benefits, cont’d

- Automatic archiving of all metadata
  - Which can be made accessible in tabular and graphic formats, as well as machine-readable formats
- Community input
  - Codes for individual objective analysis methods (or even the entire analysis platform) can be made open source to allow input from the wider scientific community across a range of disciplines
- Time-dependent uncertainty bounds on each parameter
  - The analysis platform facilitates the estimation of time-dependent uncertainty bounds, subject to the characteristic uncertainty of the available observations and the number of observations

The Need

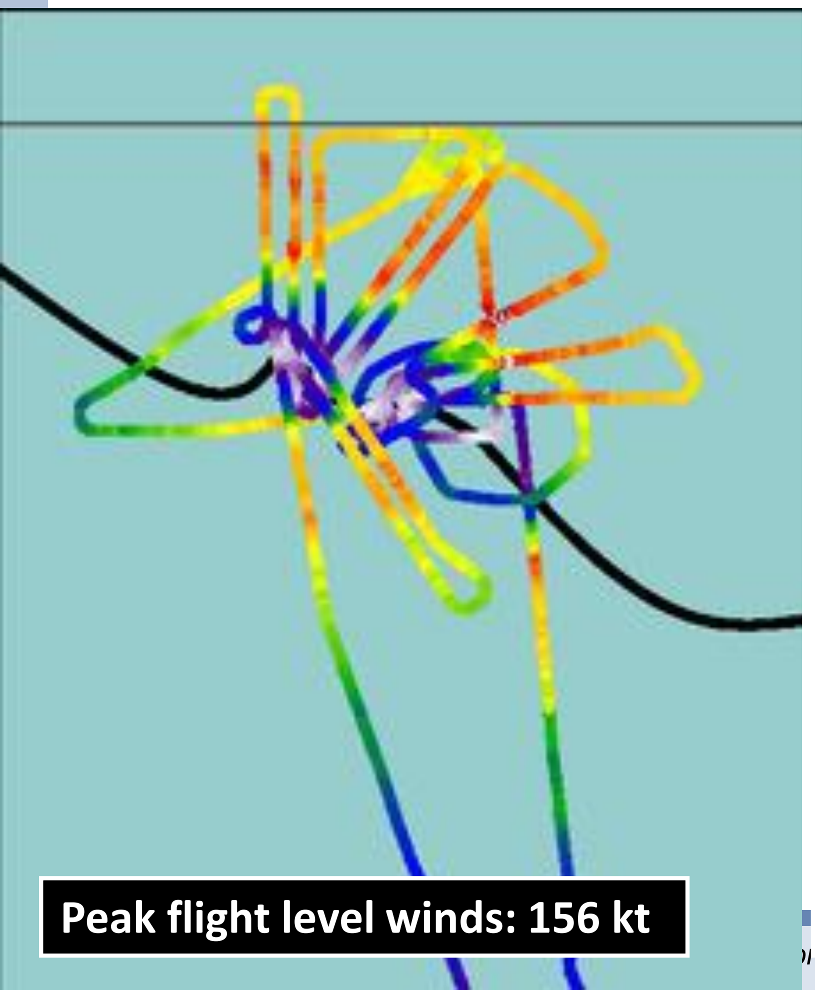
Better data needed to generate more realistic synthetic event sets for modeling risk

- Higher spatial resolution
  - HURDAT provides data at 0.1 deg (~6 miles)
- Higher temporal resolution
  - HURDAT is 6-hourly and only attempts to preserve fluctuations on the order of a day – m fluctuations get smoothed out
- Better description of wind structure
  - HURDAT rounds vmax to 5 kt and size to 5 nm
  - HURDAT does not include RMW as a best-tracked quantity
  - HURDAT only includes wind radii information back to 2004
  - HURDAT does not include any wind radii for winds higher than hurricane-force

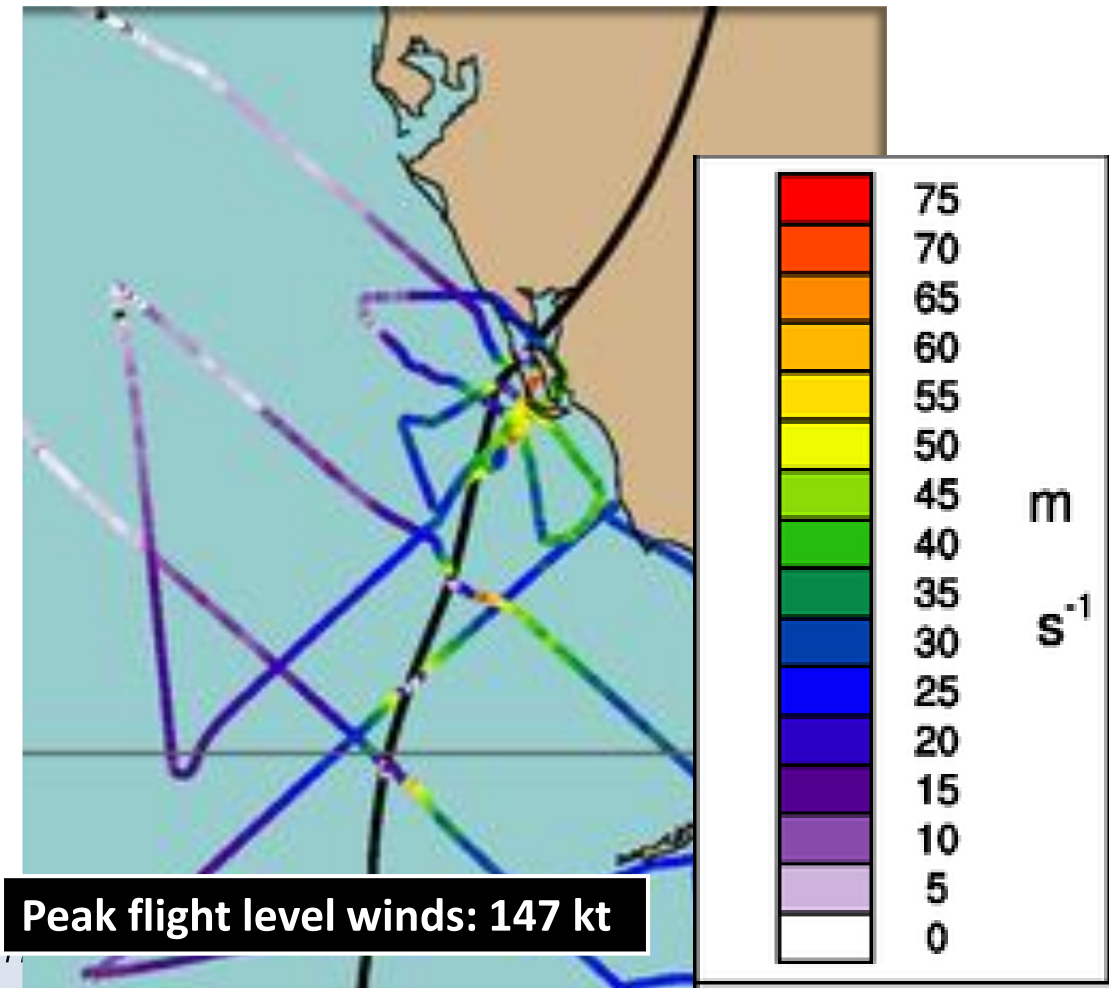
Hurricane Isabel
MSLP: 933 mb
VMAX: 140 kt
No wind radii in Best Track!

Hurricane Charley
MSLP: 947 mb
VMAX: 125 kt
64-kt wind radii: 20 20 10 10 (nm)
34-kt wind radii: 40 75 75 50 (nm)

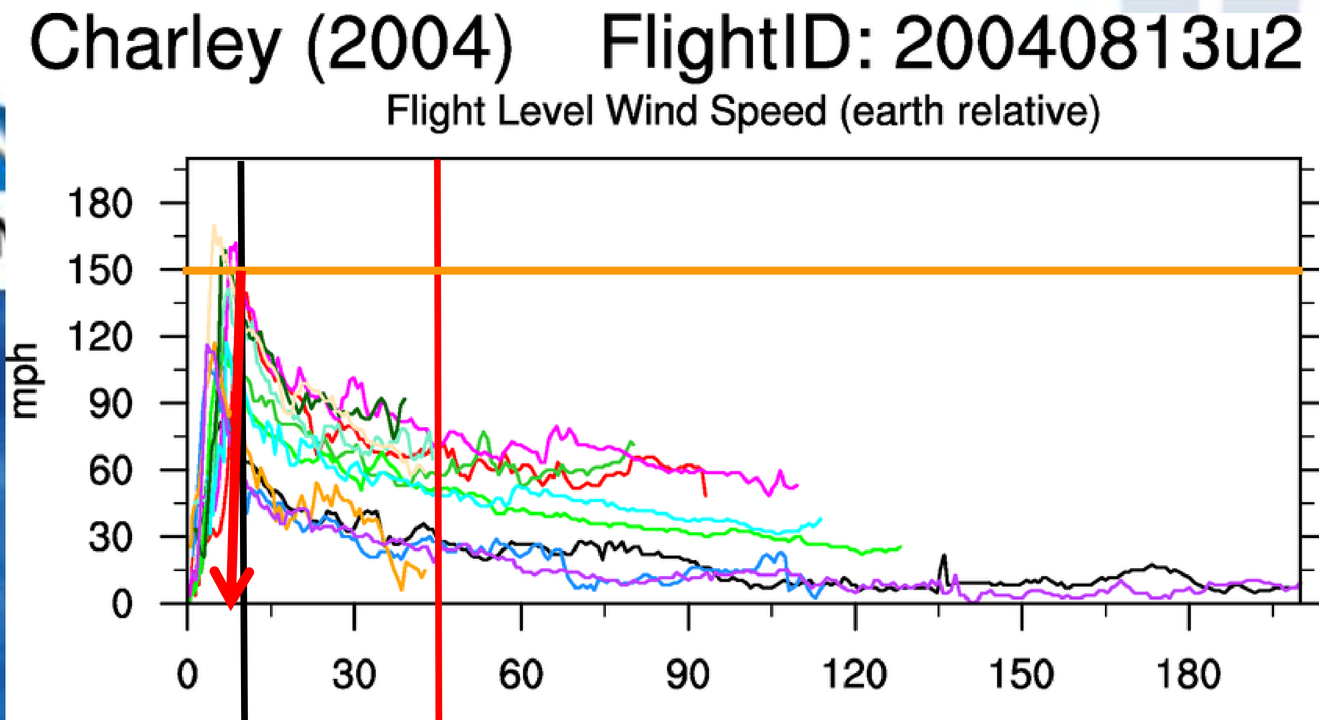
$15.1 billion damage



Peak flight level winds: 156 kt

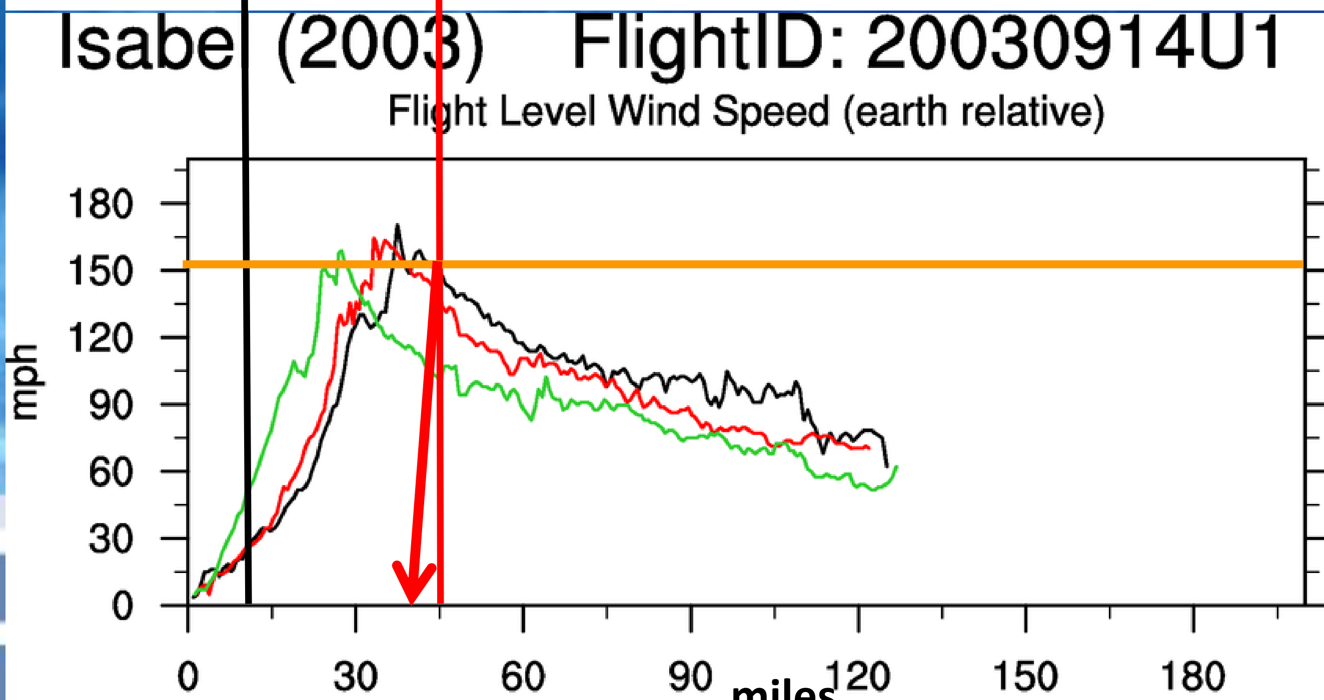


Peak flight level winds: 147 kt



Radius of Category 4 winds:

~10.5 miles



Radius of Category 4 winds:

~39 miles

Tropical Cyclone Observations-Based Structure (TC-OBS) Database

- Revised/refined **observations-based estimates** of track (position), intensity, RMW, and size (wind radii)
- Time-dependent observations-based **uncertainty bounds**
- Azimuthal mean wind speed
- Spatial/temporal **coherence** of location of maximum wind
- All parameters provided at 1-hour intervals
- All asynoptic time points included in HURDAT2 are also included (including all landfall times)
- No rounding for positional data precision
- Ancillary parameters that indicate distance to land, translation speed/direction, and whether the cyclone was over land
- Additional wind radii at the Saffir-Simpson category thresholds:
  - 83-kt (Cat1/2), 96-kt (Cat 2/3), 113-kt (Cat 3/4), 137-kt (Cat 4/5)
- All HUDAT parameters included for comparison

Extended Flight Level Dataset for Tropical Cyclones (FLIGHT+, v1.1)

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- Dataset coverage
  - 273 cyclones
  - Atlantic, Eastern Pacific, Central Pacific, Western Pacific
  - 1999 to 2015
  - 7500 “good” radial legs
    - All typical flight level parameters included
    - SFMR surface winds
- Dataset characteristics
  - Standardized data from U.S. Air Force Reserve and NOAA Hurricane Hunter research flights
  - Extensive quality control measures
  - Automatic parsing of radial legs, translation to storm-relative coordinates, azimuthal and radial winds, etc.
  - High resolution data binned to 100-m grid
  - Modern, user-friendly format (NetCDF)

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FLIGHT+ Dataset | About The Flight Level Dataset (FLIGHT+)

ABOUT THE FLIGHT LEVEL DATASET (FLIGHT+)

The second phase of this RPI-funded project has built a new dataset of standardized flight level data. This dataset covers all Atlantic, Eastern Pacific, and Central Pacific tropical cyclones with flight level data during the period from 1997 to 2015. The dataset also includes flights in certain Western Pacific TCs in 2008 and 2010. The flight level data is provided in both earth-relative and storm-relative coordinates at the highest temporal resolution available (e.g. 30-second, 10-second, or 1-second). Additionally, flight level data has been parsed by radial leg and interpolated to a standarized radial grid. Significant effort has been undertaken to quality control the data. The dataset was released to RPI member companies in August 2014. The dataset was released to the public on 20 April 2016.

Navigate this section

Use the links below to learn more about the data sources have gone into this dataset, to download the combined dataset and accompanying documentation, and to learn more about applications of this dataset.

- Source data< and information about versions/a>
- Download the dataset & documentation
- Applications & visualizations
- Dataset Users
- References

http://verif.ral.ucar.edu/tcdata/flight/

This page was last updated 20 April 2016 by Jonathan Vigh.

What's New in the FLIGHT+ Dataset?

20 April 2016

Version 1.1 of FLIGHT+ is now released to the public. This version extends the dataset to include data from 2014 and 2015 and addresses the issues with the storm relative winds discussed below. Several new parameters have been added to provide additional information about the flight level pressure and time of the wind maxima. For a full description of the differences between v1.1 and v1.0, click here

19 January 2016

A couple errors have recently been discovered in the formulas used for the calculation of the zonal and meridional components of the wind center of the cyclone. The result of these errors is that some significant errors with magnitudes up to twice the cyclone translation speed have been introduced into some of the storm relative wind speeds that are contained in the Level 3 (L3) dataset product. If you are not using the storm-relative wind speeds of the L3 data products, you should not be affected by this issue. The earth-relative wind speed parameters are unaffected. A new version of the FLIGHT+ Dataset will be generated in the near future to address this issue and add some enhancd metadata concerning the maximum wind location of each radial leg.

22 August 2014

The FLIGHT+ Dataset has been released to the RPI member companies. The public release of the FLIGHT+ Dataset is planned for April 2016.

Optimal Estimation of Track

1. **Filter/merge obs**: Eliminate duplicate fixes and use just the Willoughby-Chelmow (W/C) fixes when both are present.
2. **Supplement** with Best Track points when there are gaps of 3 h or more between observational fixes.
3. **Fit** an interpolatory cubic spline through all points

KATRINA (AL122005)

Comparison of Cyclone Position Information

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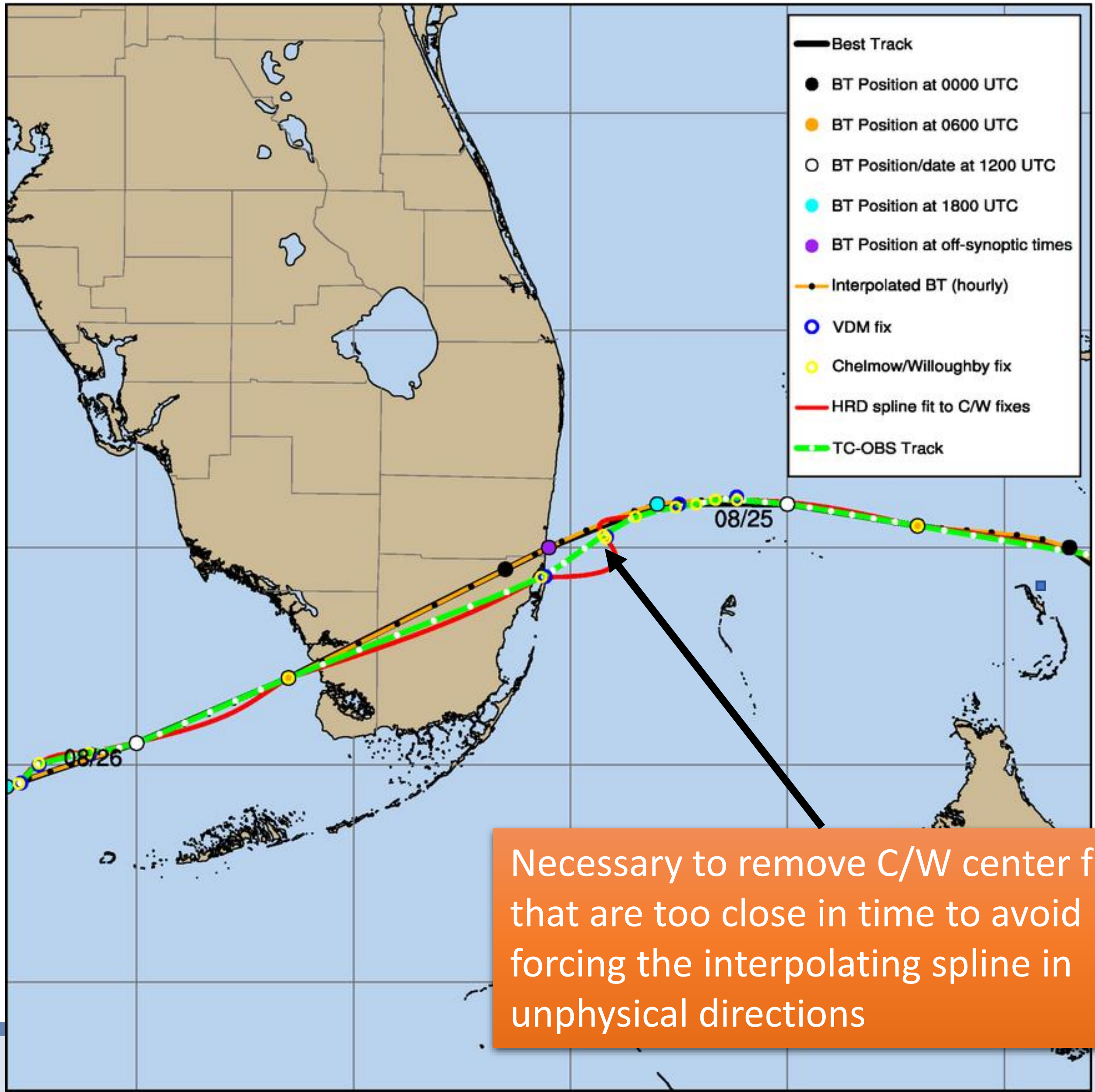
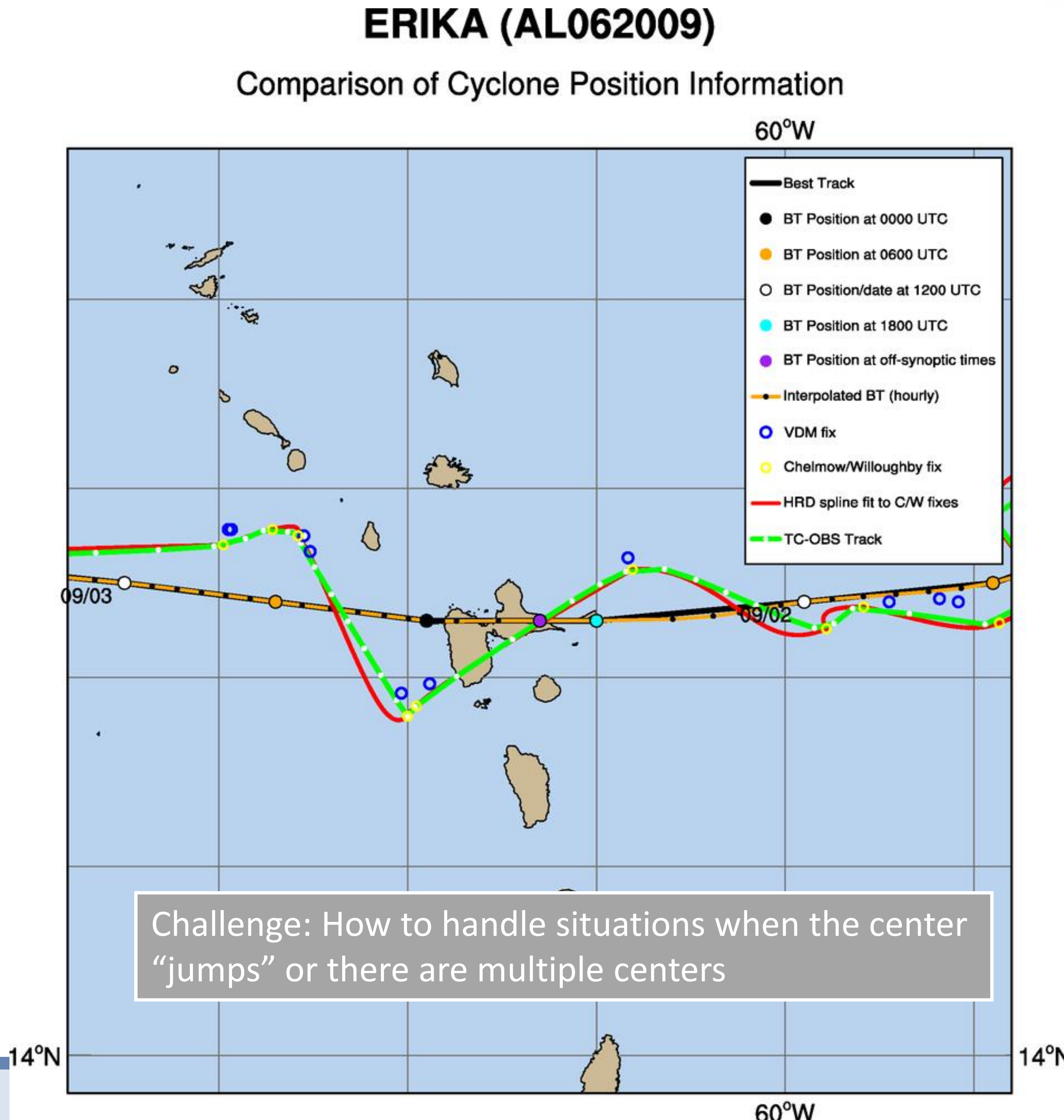


Necessary to remove C/W center fixes that are too close in time to avoid forcing the interpolating spline in unphysical directions



Challenge: How to handle situations when the center "jumps" or there are multiple centers

ISAAC (AL092012)

Comparison of Cyclone Position Information

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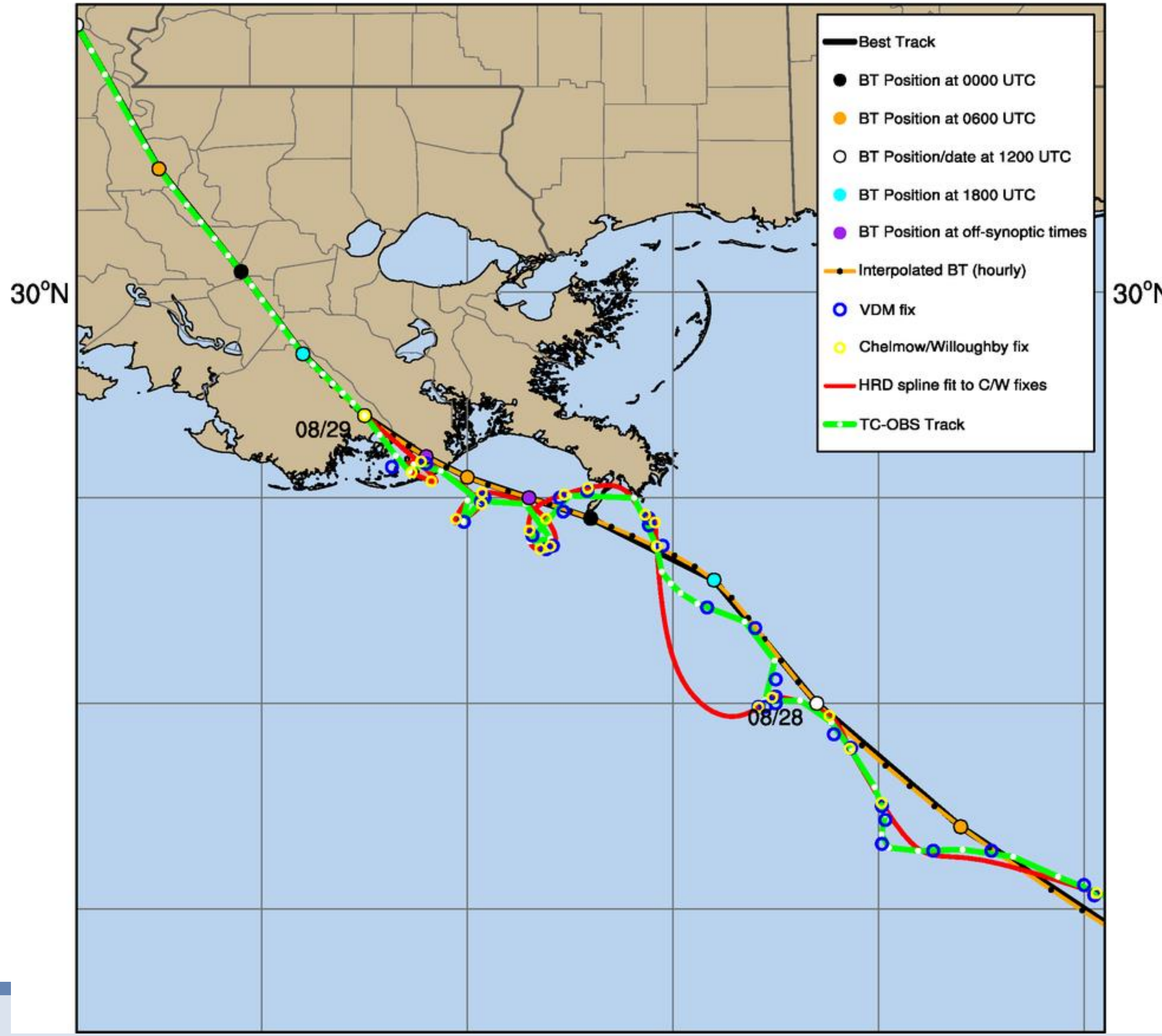

General Methodology for Optimal Estimation from Observations

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1. Filter/merge step: eliminate duplicatory or conflicting data, keep best observations

2. Traverse data using moving window centered on the target time for estimation

3. Determine # of effective data points using some sort of "goodness" criteria as well as nearness to time of interest

4. From # of effective data points, compute total observational weight, then compute background weight as residual weight

5. Optimally estimate parameter value as a weighted average of observations and background value

Objective Estimation of Intensity

1. Filter/merge obs
   - Reduce flight level maxima to surface equivalent values using Franklin et al 2003 relationships

2. Traverse time domain with a moving analysis window
   - Half width of 6 h (compromise between maintaining “sharpness” and robustness)

Objective estimation of Intensity, cont'd

3. Determine effective # of data points using nearness-in-time and "goodness" criterion

- Nearness-in-time criterion:

$$w_{provisional\ data\ weight} = \frac{\delta\ t}{\lambda_{observational\ influence}}$$

where $\lambda_{observational\ influence}$ is the e-folding time scale for observational data influence. In most situations,

$\lambda_{observational\ influence}$ = 4 is used.

δt (hours)	Effective data weight
0	1.000
± 1	0.794
± 2	0.607
± 3	0.368
± 6	0.223

- Goodness criterion:

"how close is the VMAX ob to the time-trended upper bound"?

Objective Estimation of Intensity, cont'd

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4. Compute total observational and background weights
   - Give higher collective weight to obs when # of effective data points is large
   - Give higher weight to the background value when the # of effective data points is low

$$w_{combined\ observations} = \exp(-\frac{n_{effective\ data\ points}}{\lambda_{background\ influence}}$$

where $n_{effective\ data\ points} = \sum w_{provisional\ data\ weight}$

and $\lambda_{background\ influence}$ = 0.666667 is the e-folding length-scale for background data influence.

# of effective data points	background weight
0.0	1.000
0.4	0.513
1.1	0.189
4.0	0.002

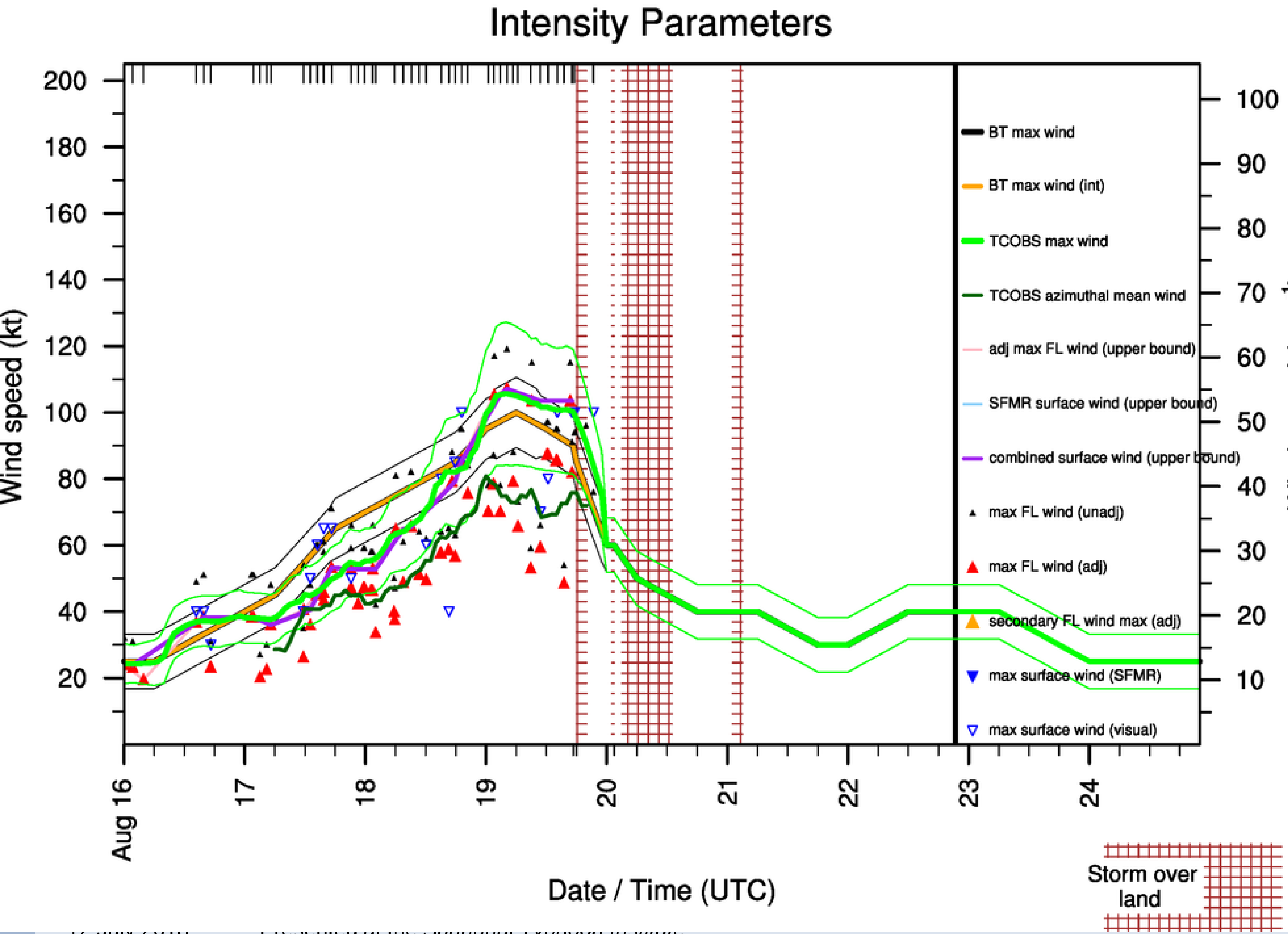
Objective Estimation of Intensity, cont'd

5. Optimally estimate the intensity value as a weighted average of the observations and the background value

This procedure is essentially a *criteria-informed weighted average*

This algorithmic approach ensures that the TC-OBS intensity relaxes smoothly back to the HURDAT2 track when intensity fixes are sparse

BOB (AL031991)



WILMA (AL252005)

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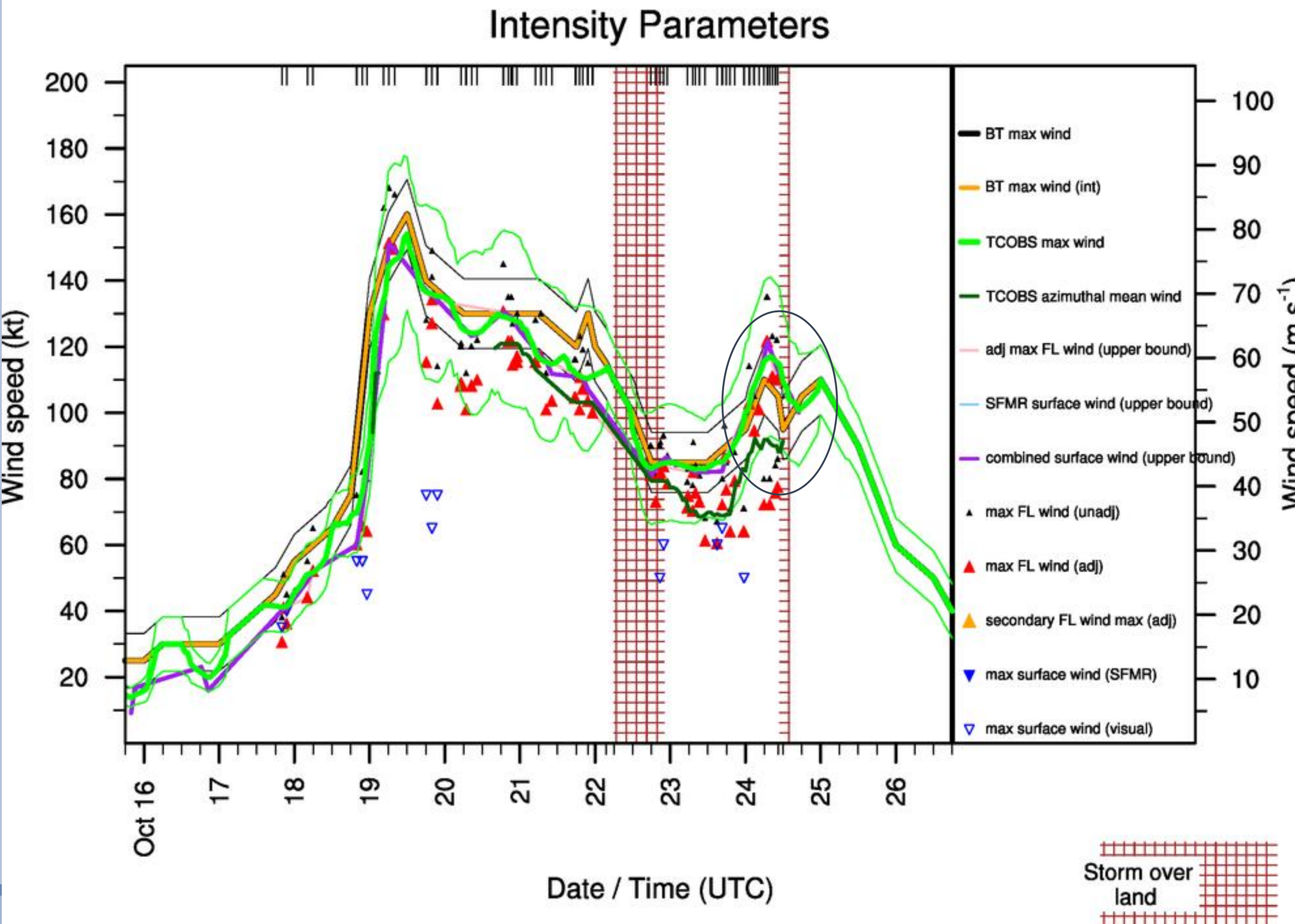
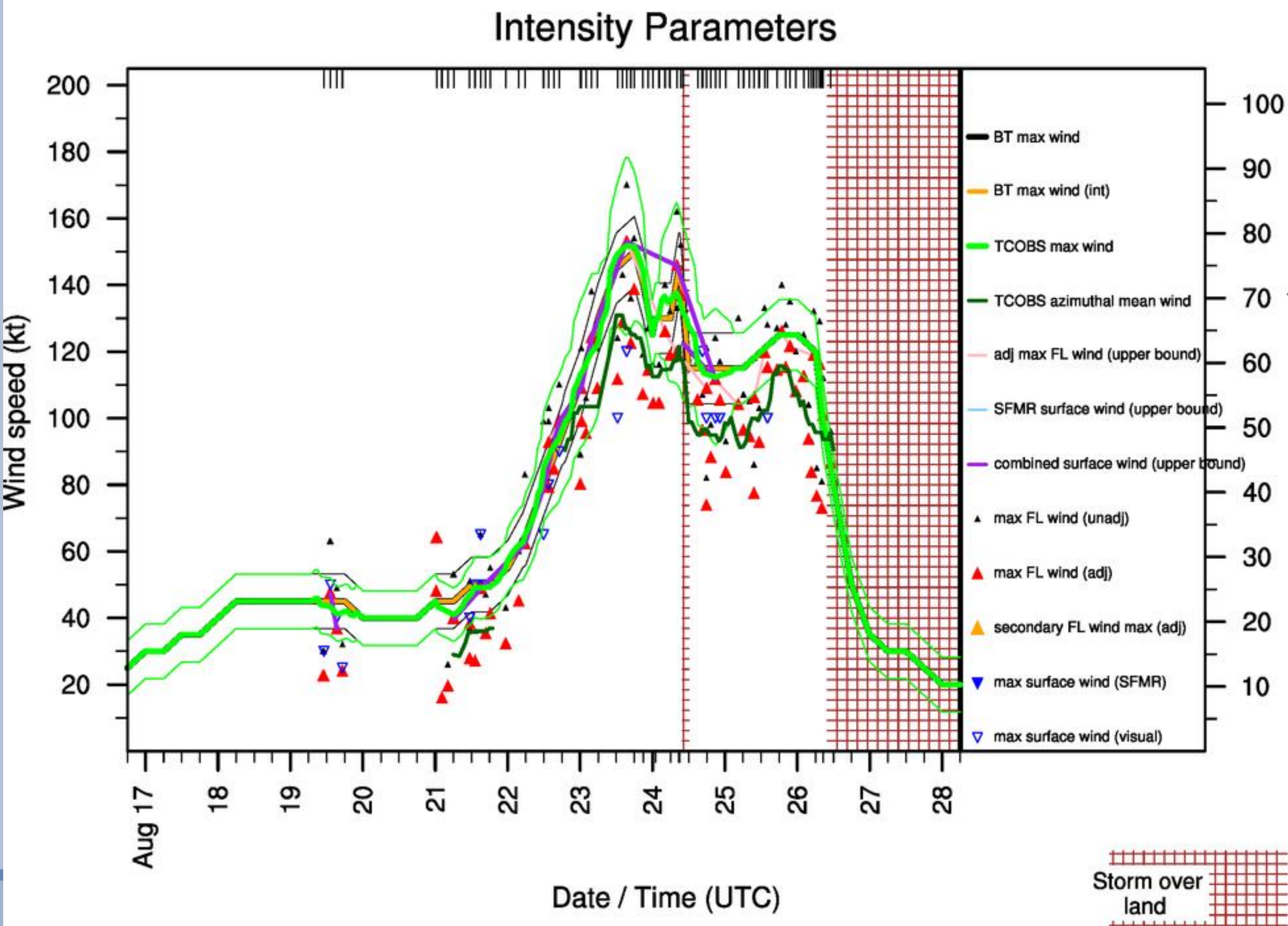
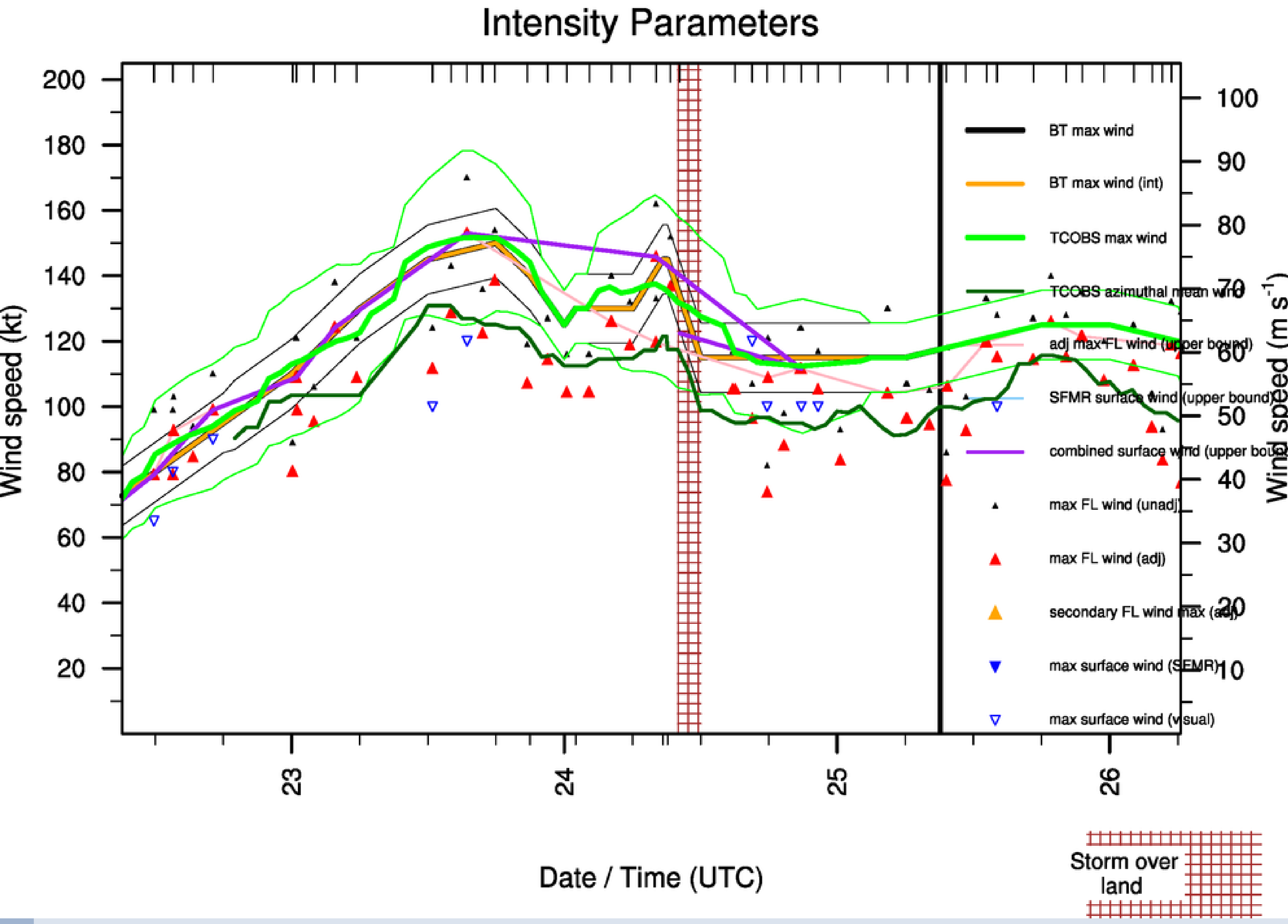


ANDREW (AL041992)



ANDREW (AL041992)



Objective Estimation of Intensity Uncertainty

- Follows same general approach as for intensity itself, but instead of a weighted average, a *weighted variance* is computed
- Characteristic uncertainty for a given flight level observation comes from flight-to-surface standard deviations reported in Franklin et al 2003
- For SMFR, the uncertainty is the +/- 4 m/s reported in Uhlhorn et al 2007

KATRINA (AL122005)

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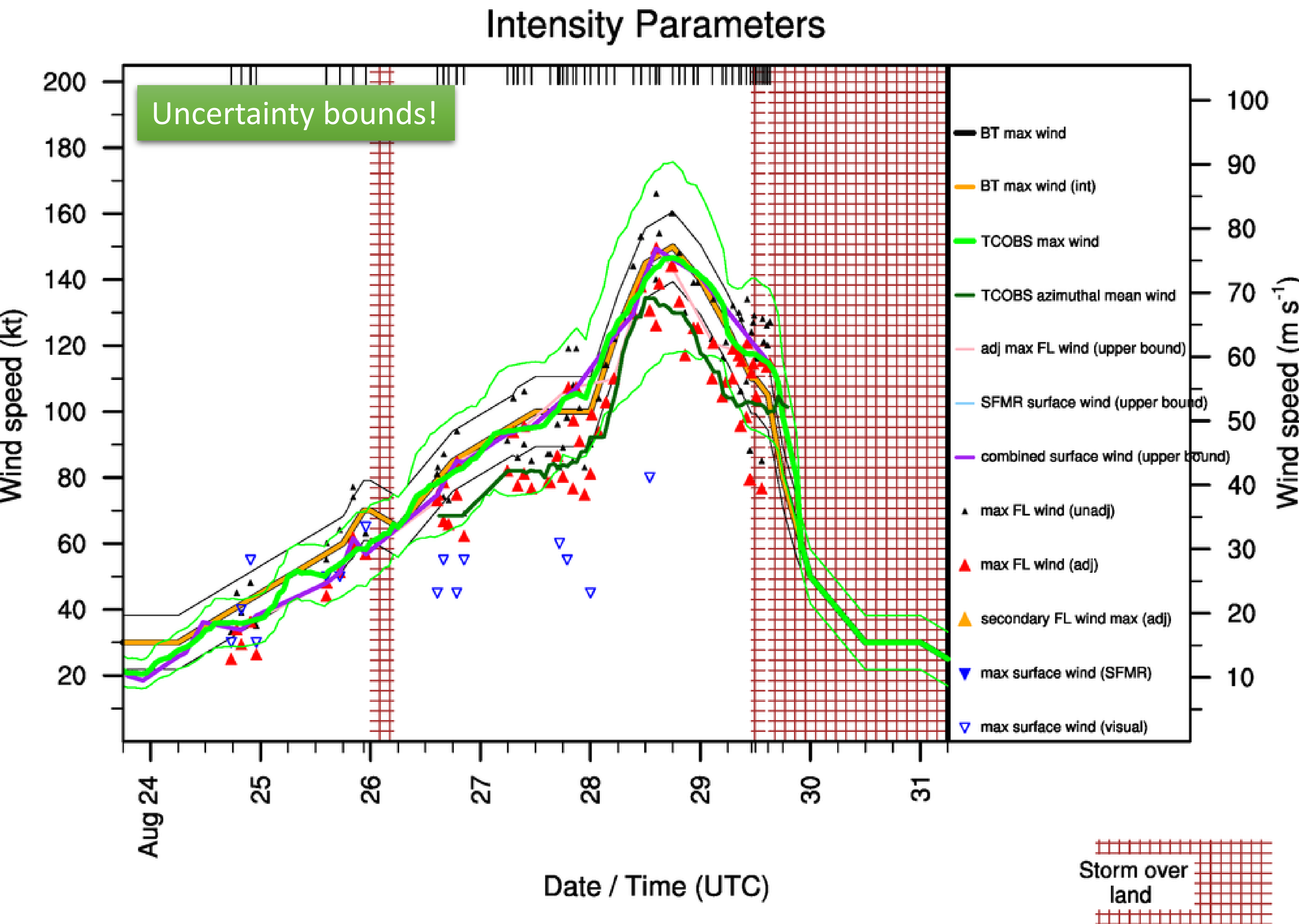
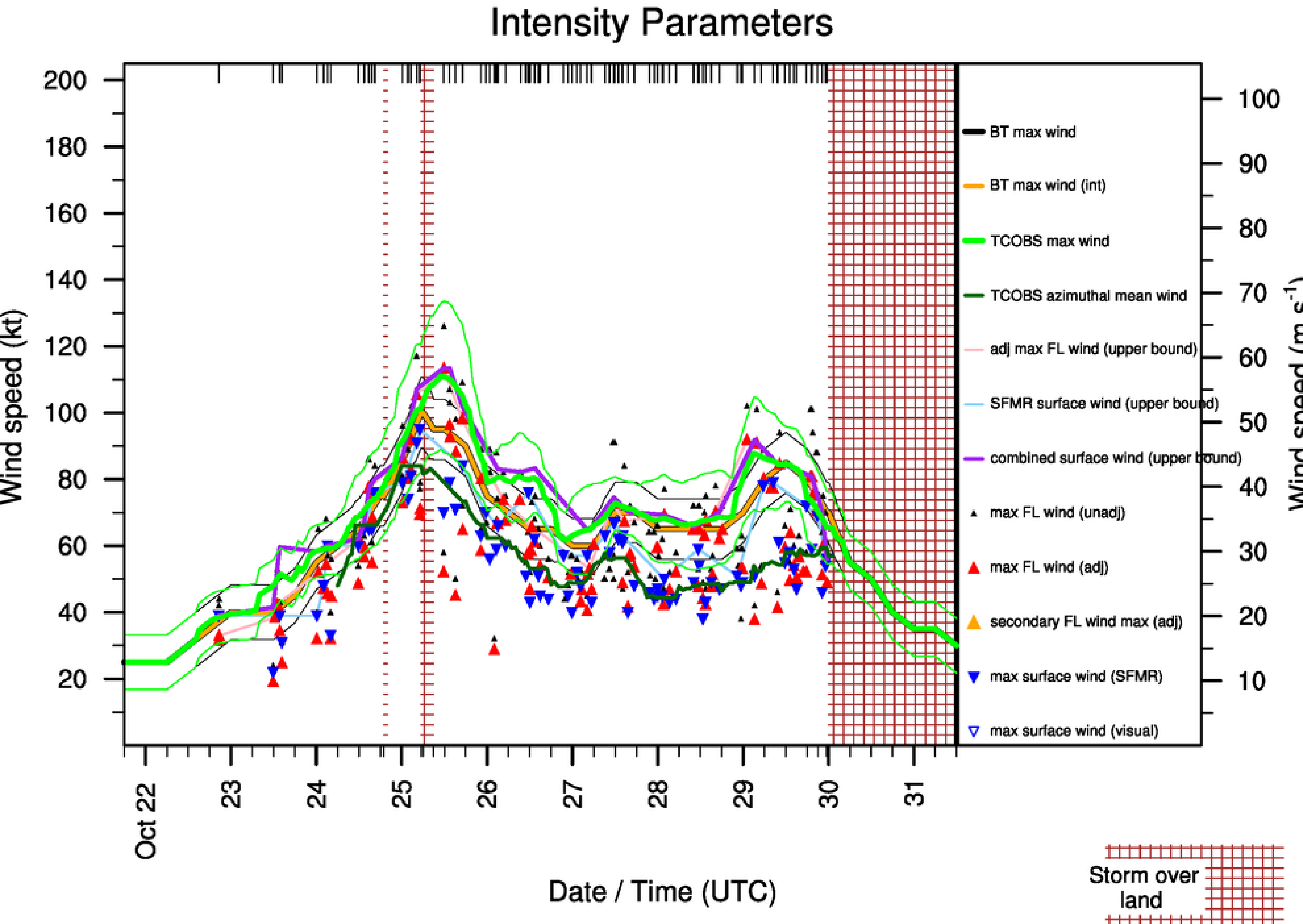


SANDY (AL182012)

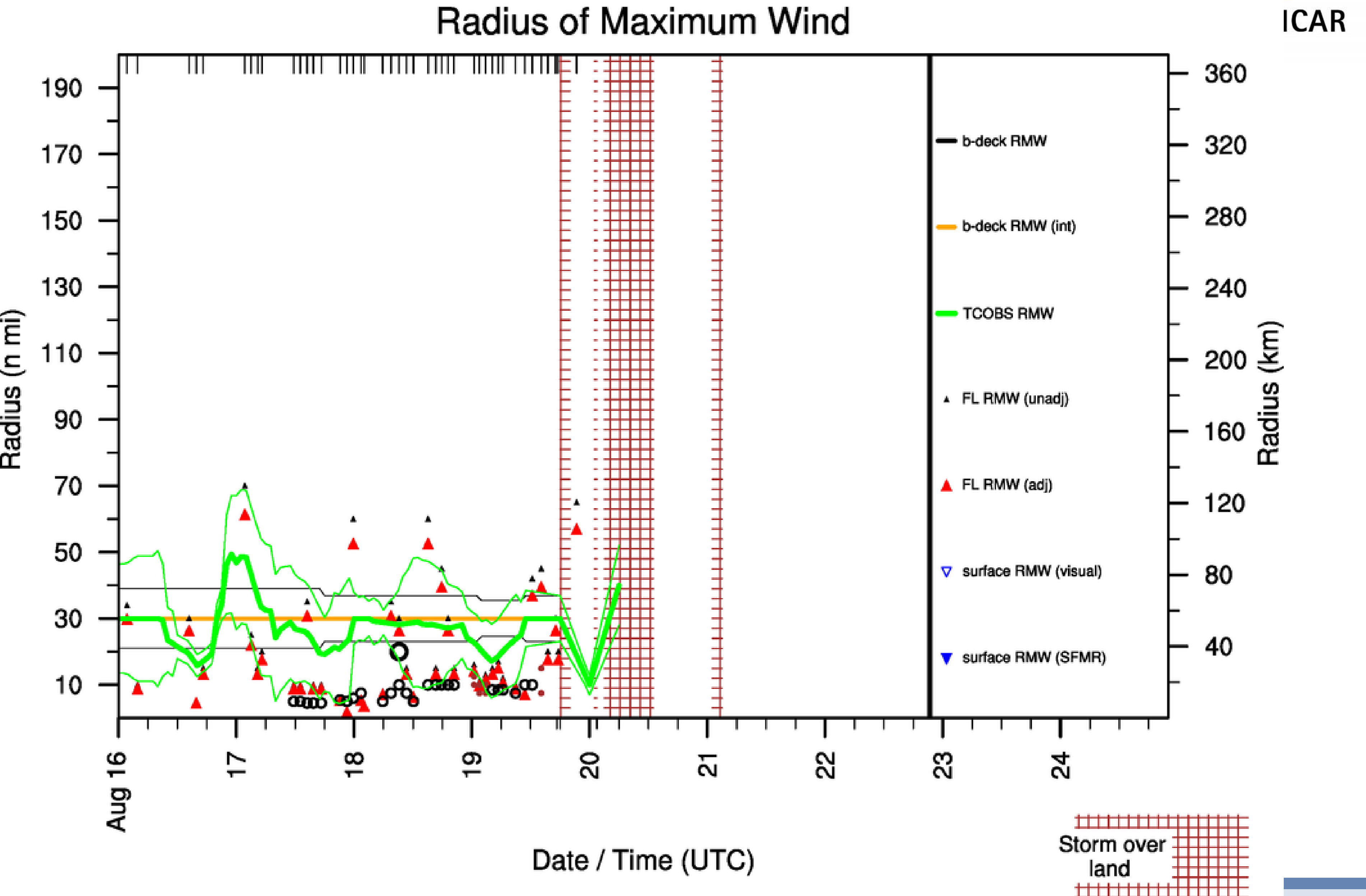


Objective Estimation of RMW

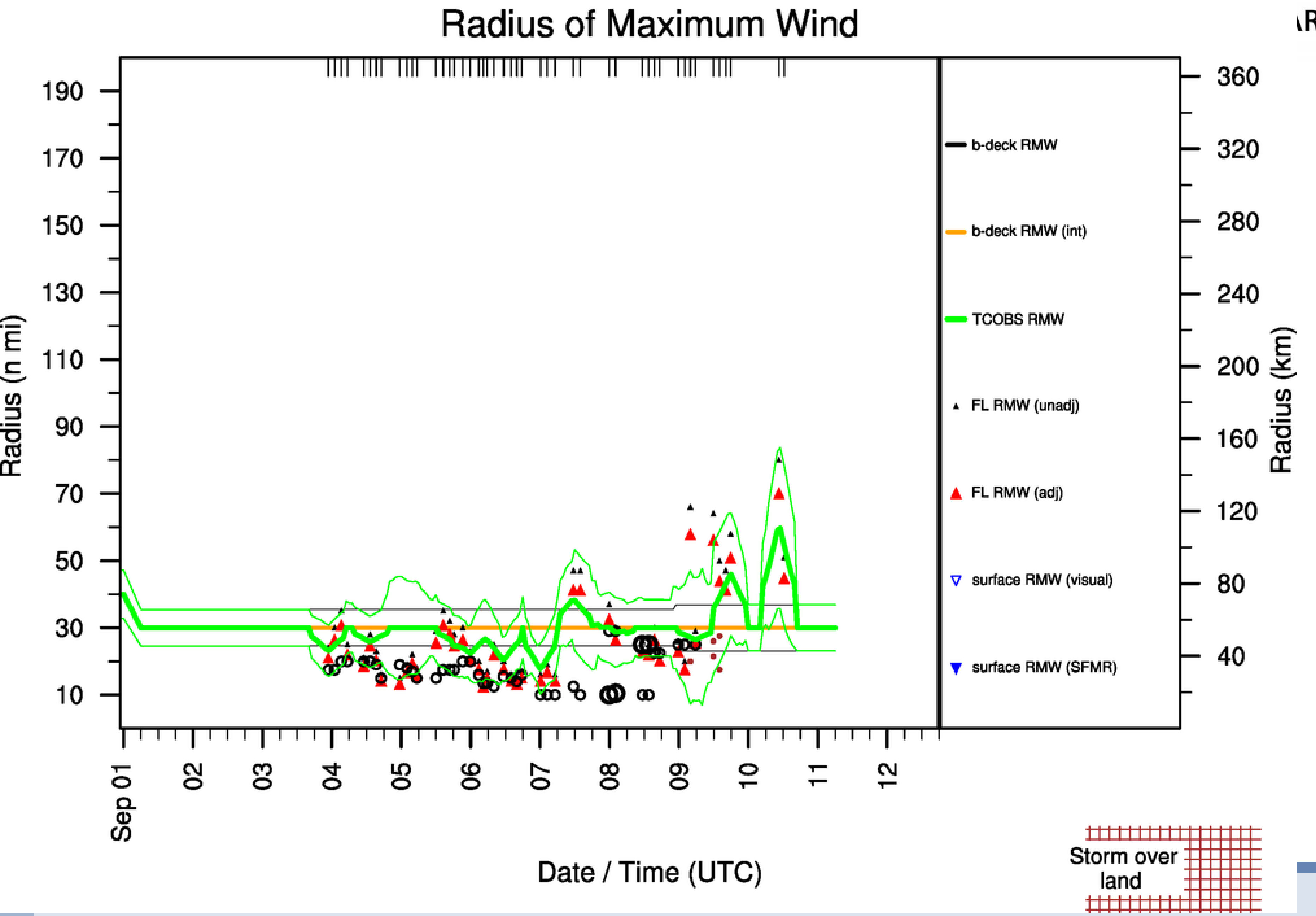
Follows same general approach as for intensity, but applies the Powell et al 2009 statistical relationship:

$$RMW_{surface} = 0.875\ RMW_{flight\ level}$$

BOB (AL031991)

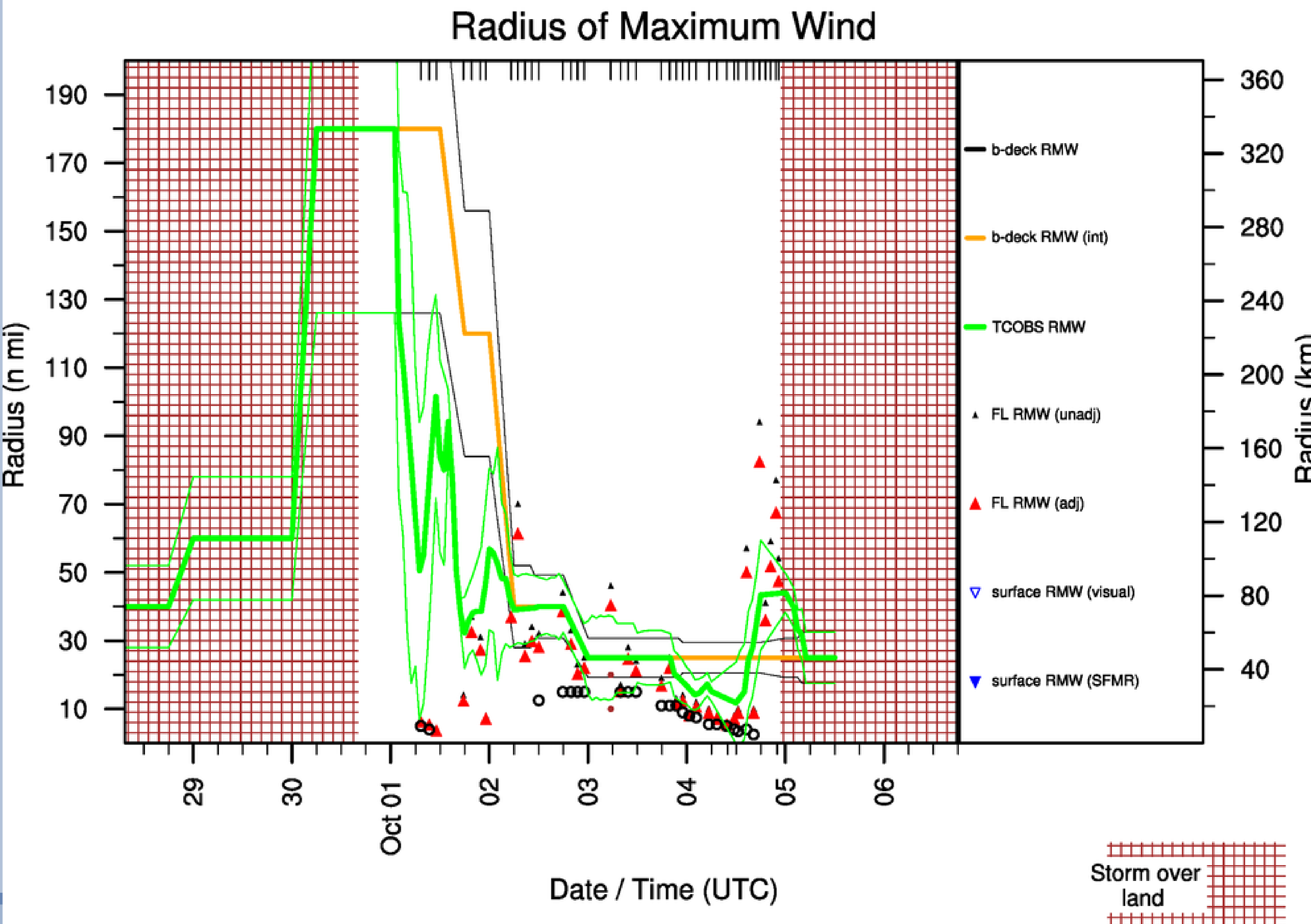


LUIS (AL131995)

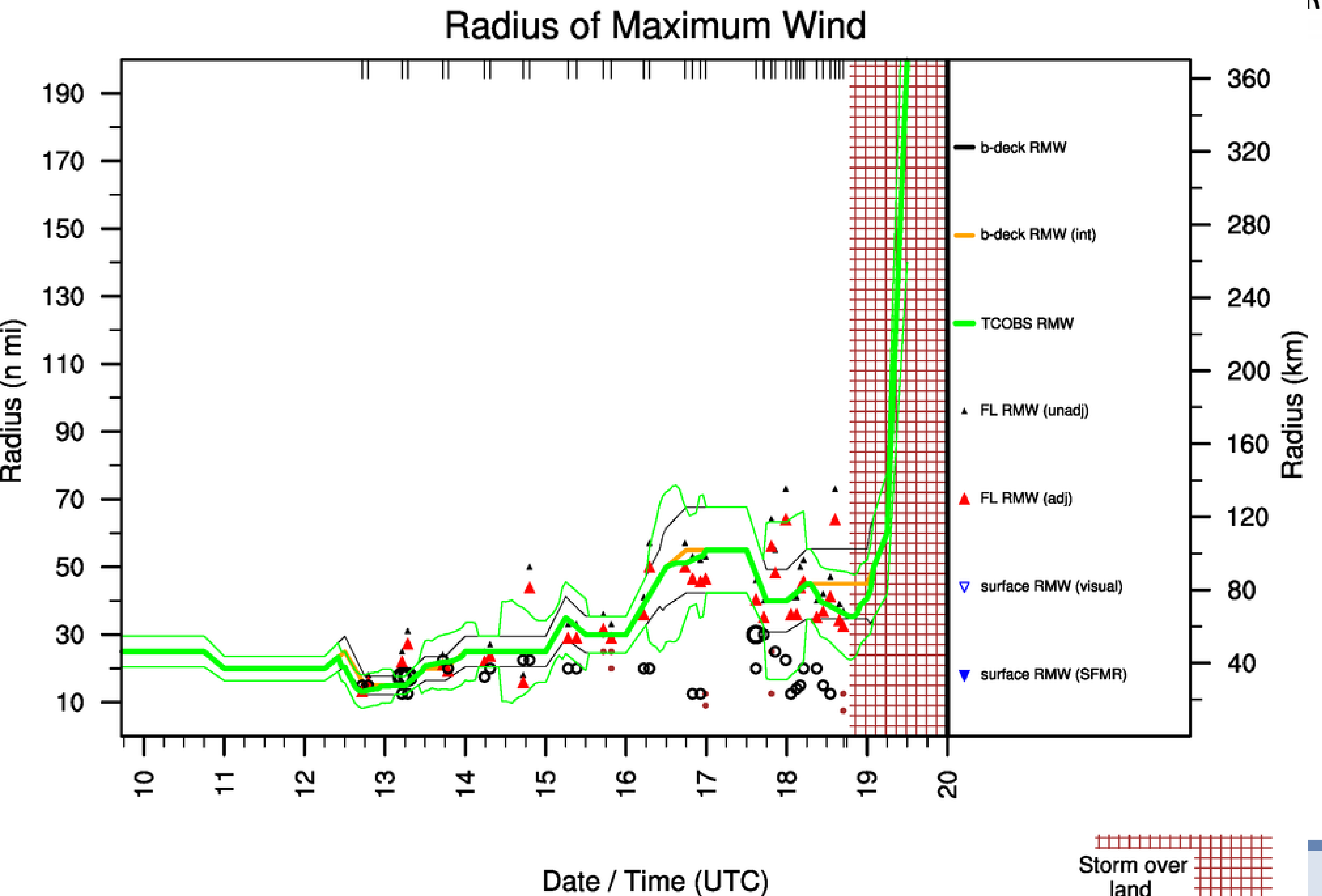


OPAL (AL171995)

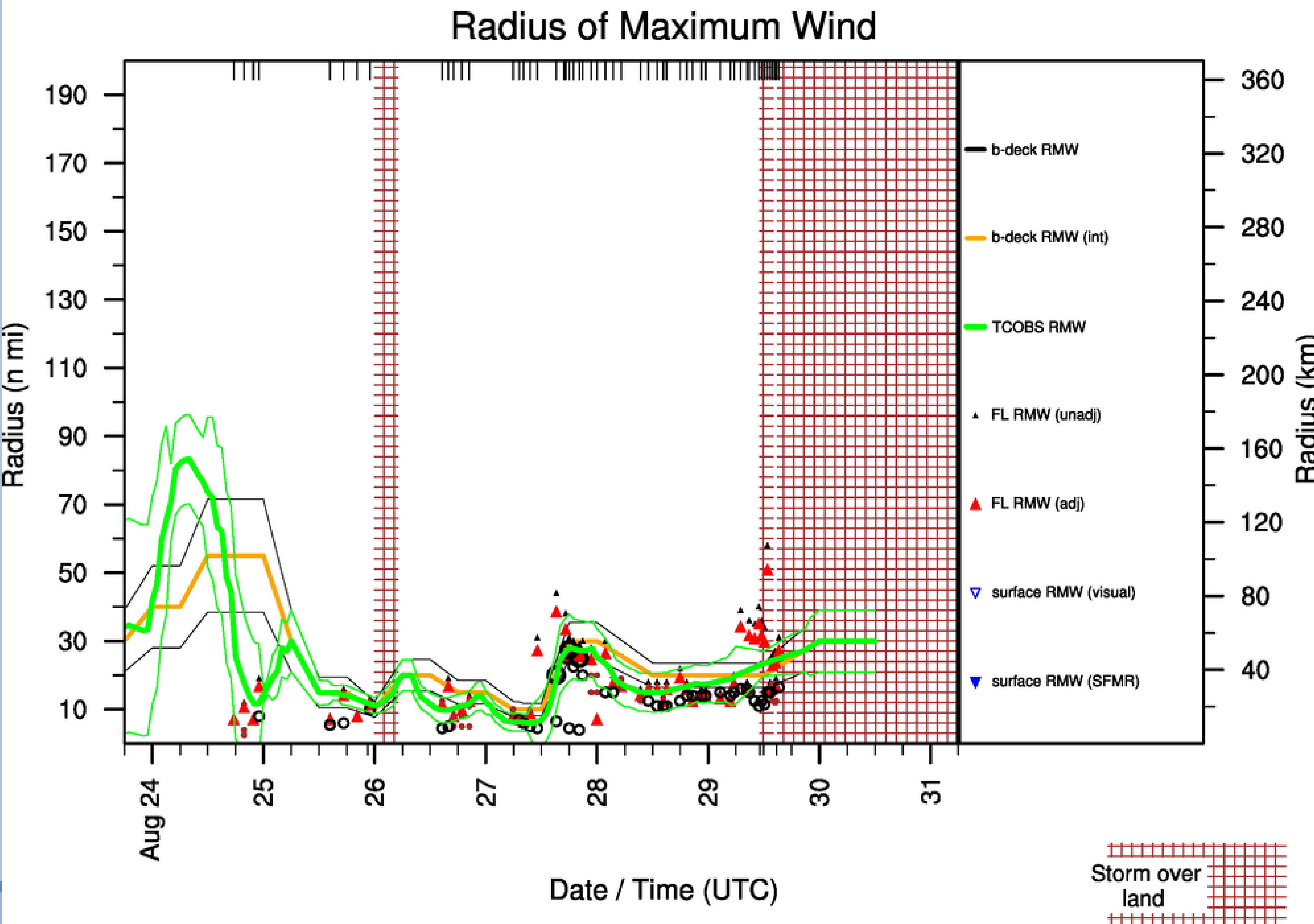
CAR



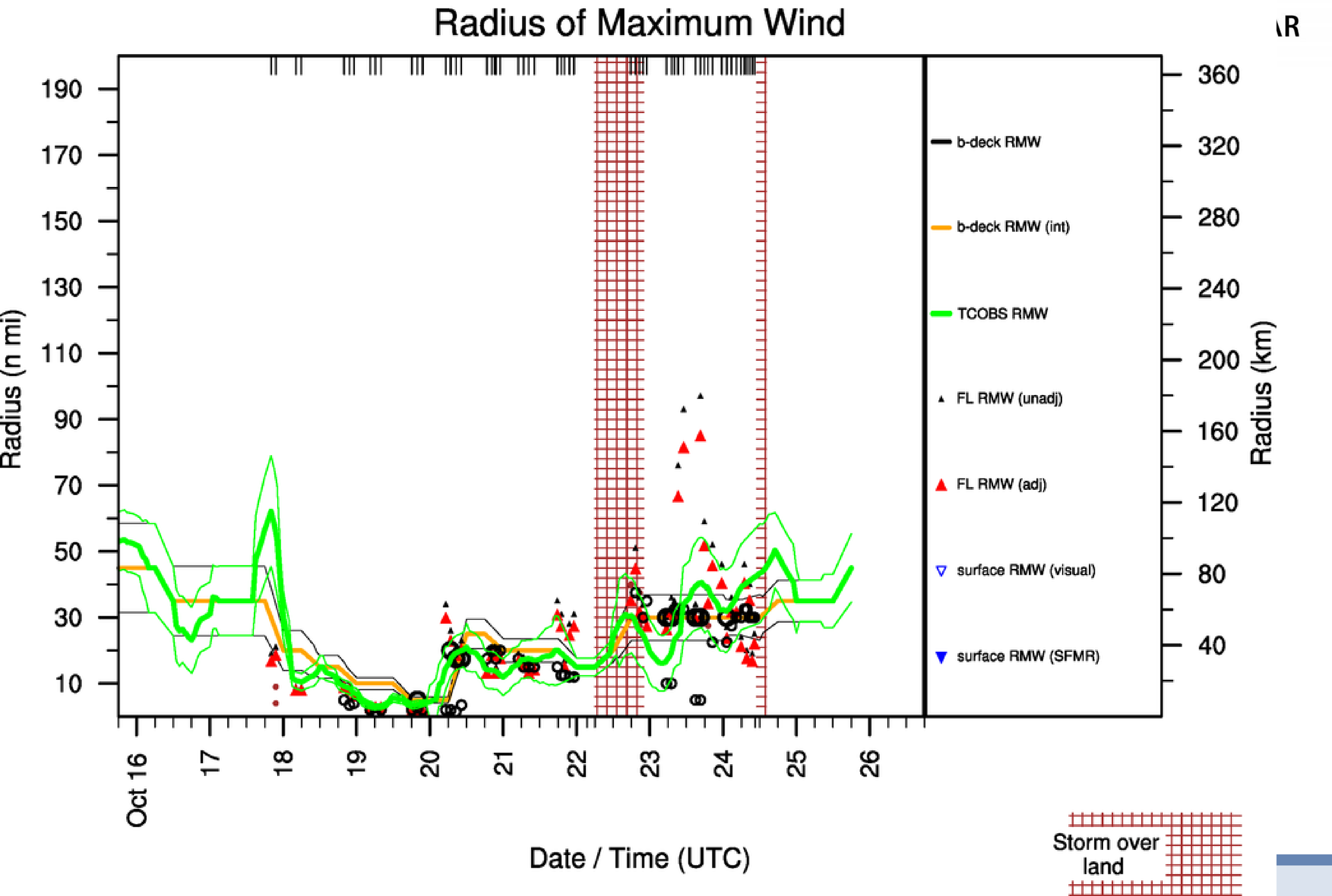
ISABEL (AL132003)



KATRINA (AL122005)

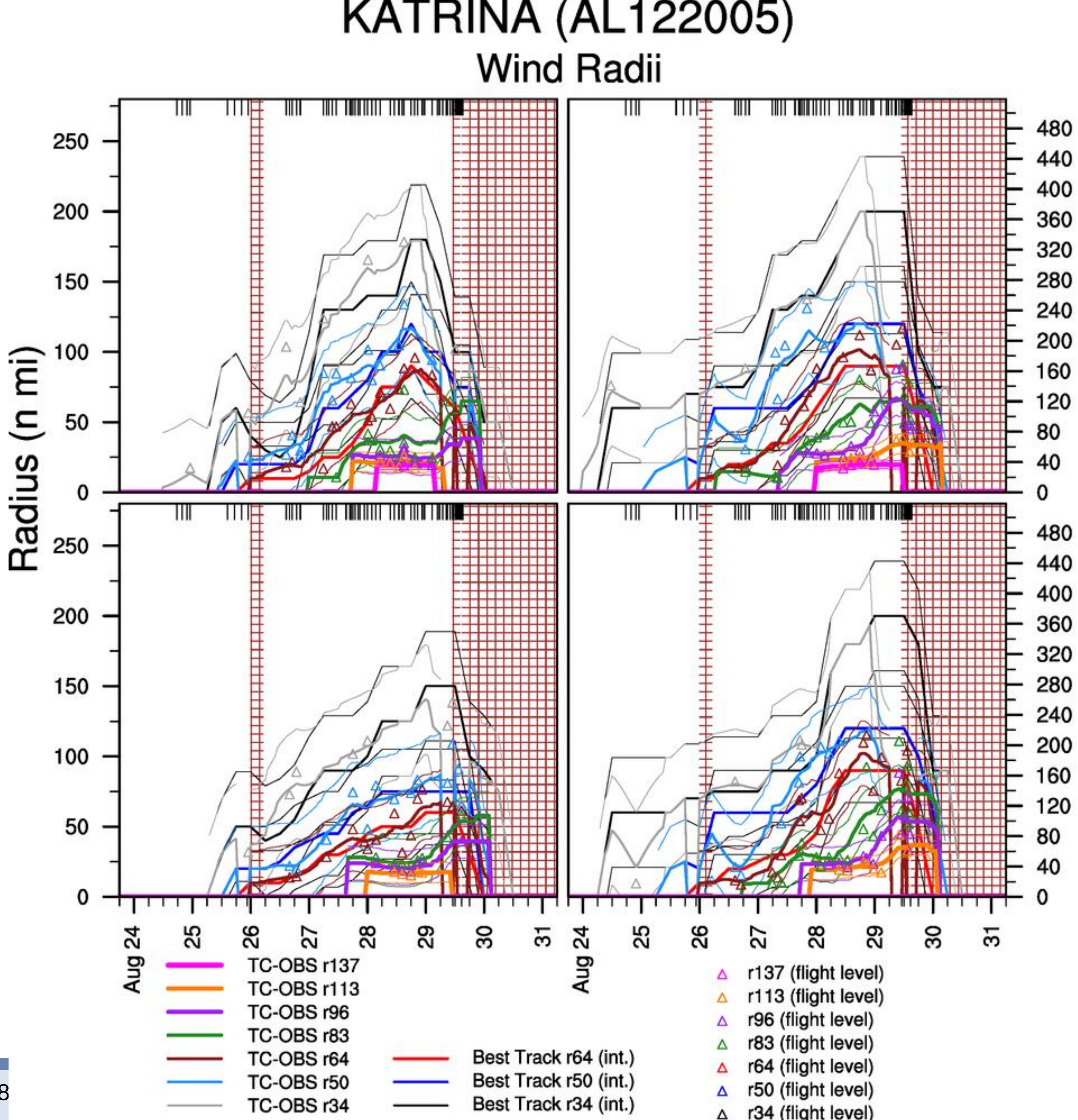


WILMA (AL252005)



Objective Estimation of Wind Radii

- Follows same general approach as for intensity and RMW (but now with no “goodness criterion”)
- Uncertainty in flight level-to-surface reduction factors translates into radial uncertainty for flight level wind radii fixes
- Uncertainty in SFMR is a steady +/- 4 m/s based on Uhlhorn et al 2007
  - TCs with SFMR data have considerably smaller uncertainty than TCs without


KATRINA (AL122005)
Wind Radii
Radius (n mi)
Radius (km)
Aug 24
25
26
27
28
29
30
31
TC-OBS r137
TC-OBS r113
TC-OBS r96
TC-OBS r83
TC-OBS r64
TC-OBS r50
TC-OBS r34
Best Track r64 (int.)
Best Track r50 (int.)
Best Track r34 (int.)
r137 (flight level)
r113 (flight level)
r96 (flight level)
r83 (flight level)
r64 (flight level)
r50 (flight level)
r34 (flight level)

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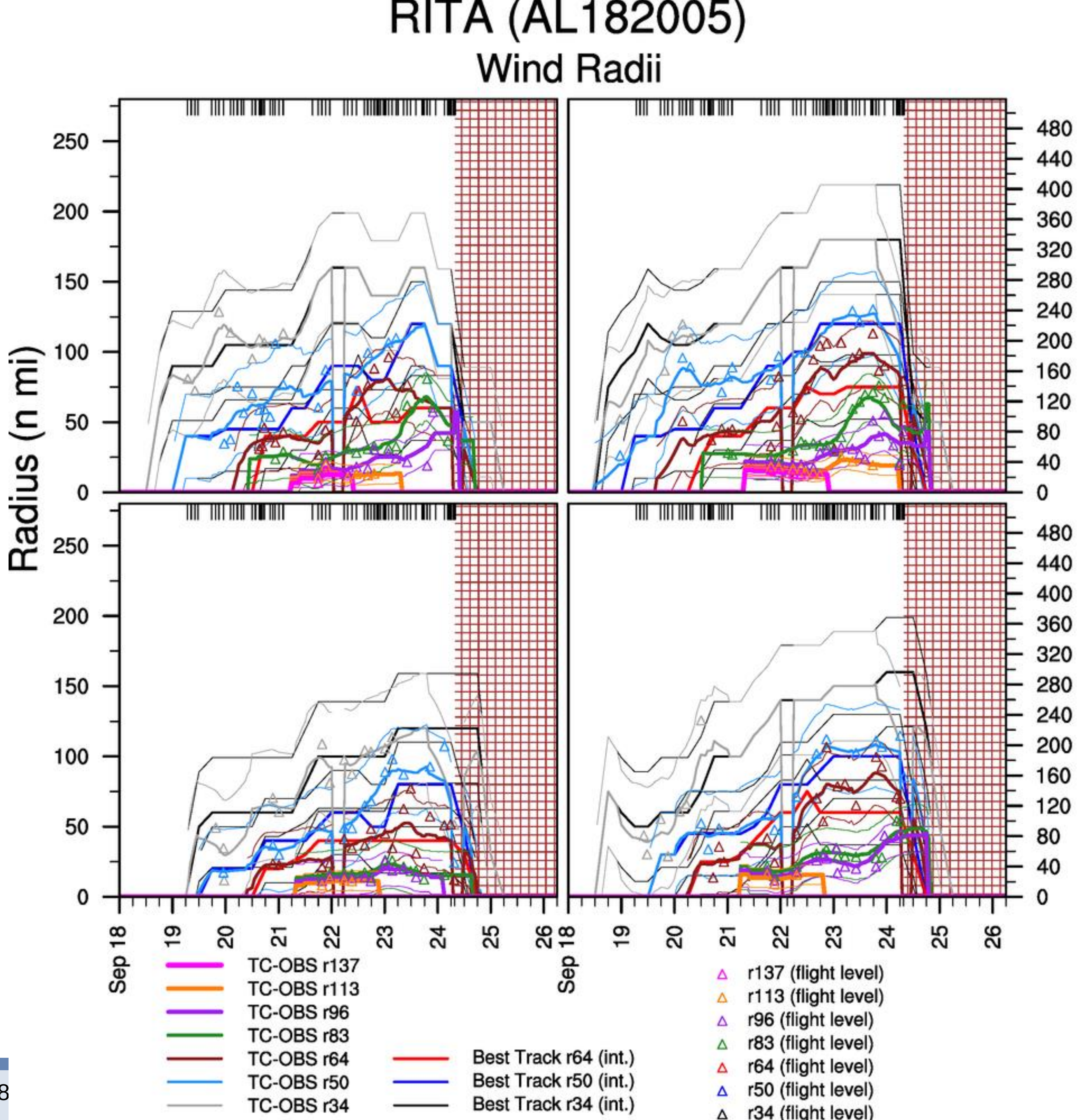
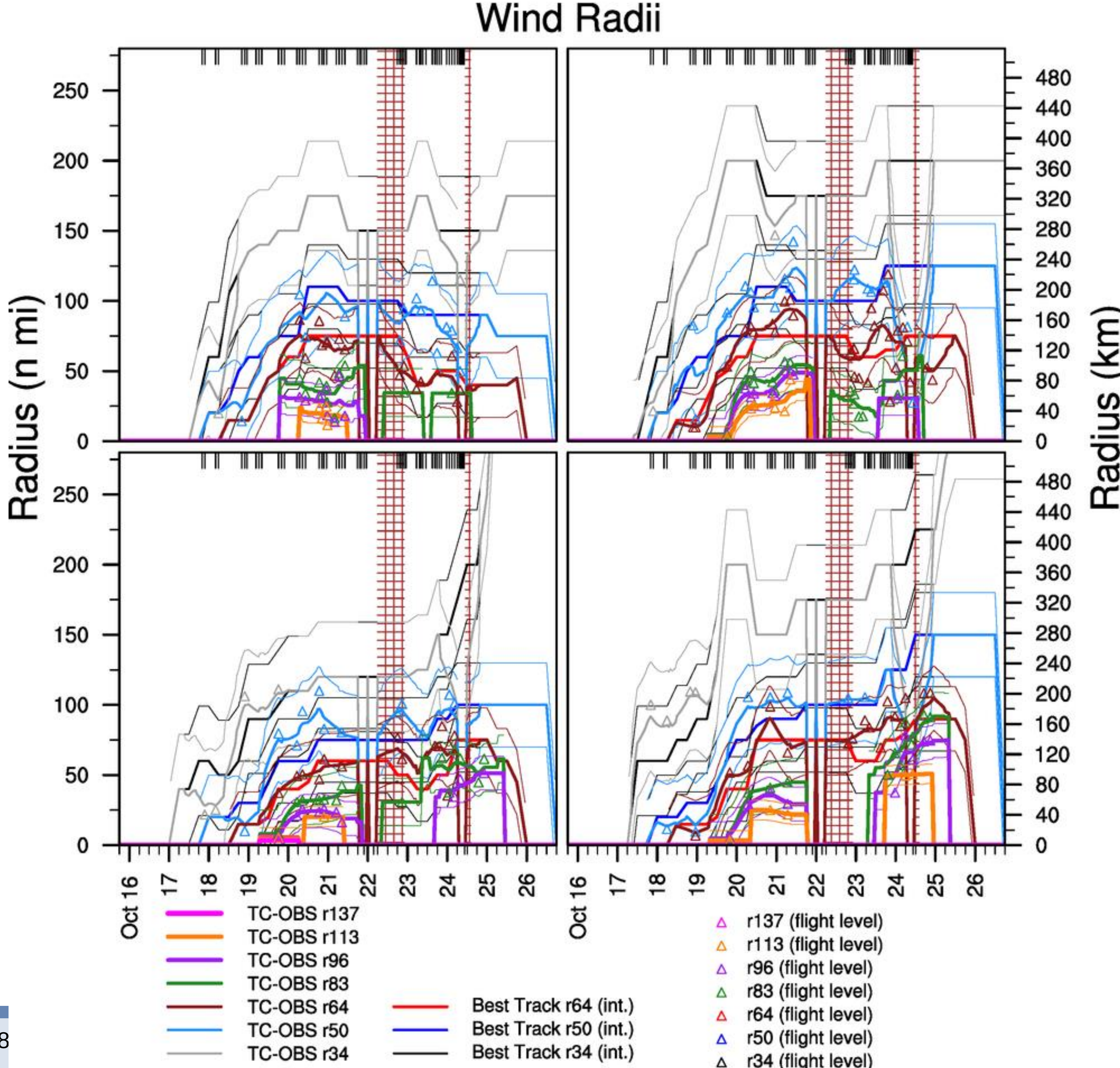

RITA (AL182005)
Wind Radii
Radius (n mi)
Radius (km)
Sep 18
19
20
21
22
23
24
25
26
TC-OBS r137
TC-OBS r113
TC-OBS r96
TC-OBS r83
TC-OBS r64
TC-OBS r50
TC-OBS r34
Best Track r64 (int.)
Best Track r50 (int.)
Best Track r34 (int.)
r137 (flight level)
r113 (flight level)
r96 (flight level)
r83 (flight level)
r64 (flight level)
r50 (flight level)
r34 (flight level)

WILMA (AL252005)



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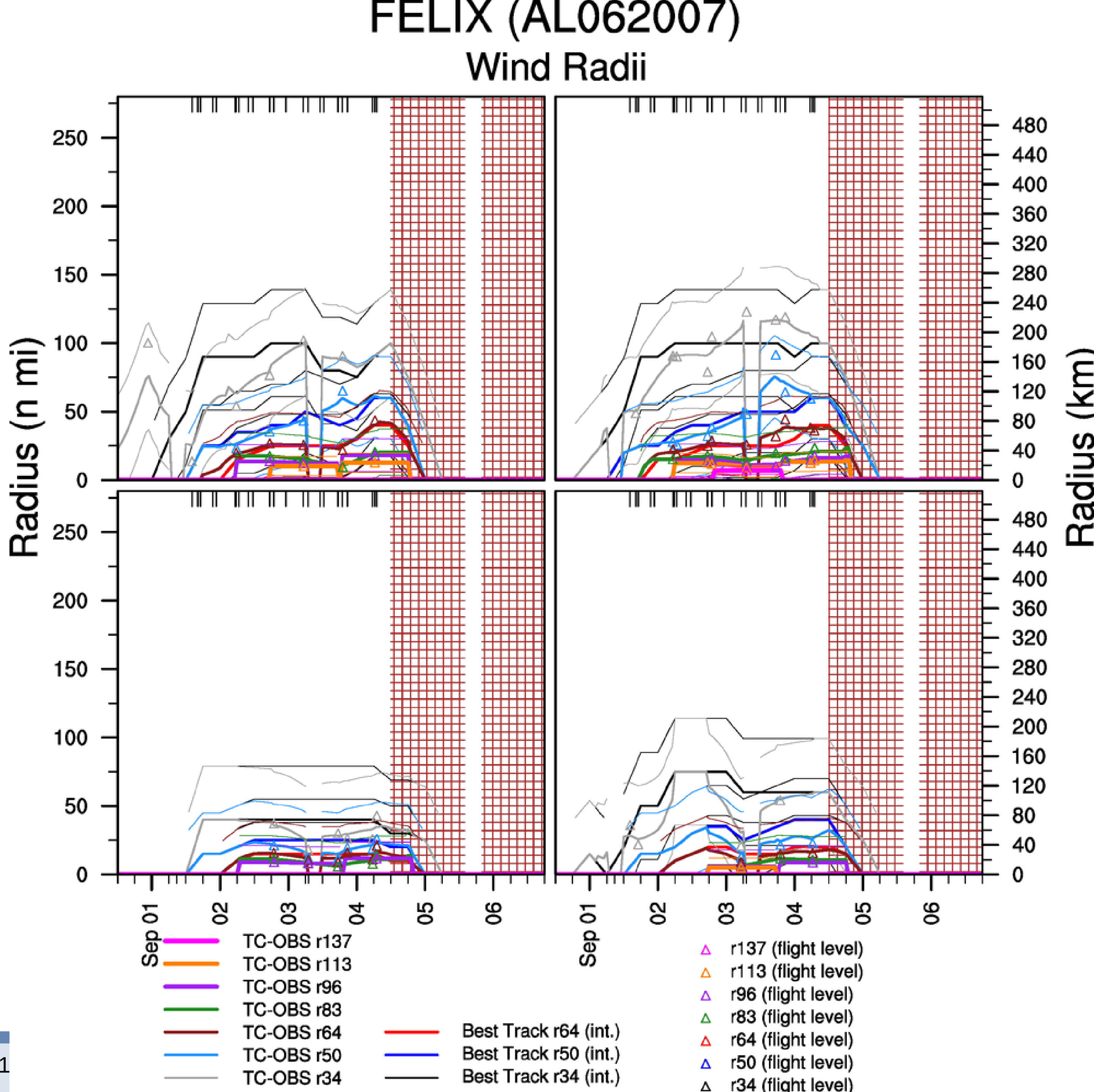
FELIX (AL062007)
Wind Radii
Radius (n mi)
Radius (km)
0
50
100
150
200
250
0
40
80
120
160
200
240
280
320
360
400
440
480
Sep 01
02
03
04
05
06
TC-OBS r137
TC-OBS r113
TC-OBS r96
TC-OBS r83
TC-OBS r64
TC-OBS r50
TC-OBS r34
Best Track r64 (int.)
Best Track r50 (int.)
Best Track r34 (int.)
r137 (flight level)
r113 (flight level)
r96 (flight level)
r83 (flight level)
r64 (flight level)
r50 (flight level)
r34 (flight level)

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Summary

- The TC-OBS project demonstrated that objective state estimation shows significant potential for use in reanalysis efforts
- Methods will need to be refined to be appropriate for the much wider set of data sources
- Challenge of using "meta" inputs
  - How independent are the wind radii estimates of Knaff et al 2016 from those of Dolling et al 2016, etc.? Dvorak from ADT, etc.
- Developing the underlying relationships will result in a lot of good science as a by-product

Future Work (TC-OBS)

- **Expand FLIGHT+ Dataset further back in time**
  - Calculate flight level pressure for all AFRES flights prior to 2004
  - Use HRD's reprocessed SFMR data
- **Use the vmax/rmax/wind radii data contained in the f-decks**
  - TAFB/SAB Dvorak fixes, AMSU, CIMSS, CIRA, ADT/ODT, SAR/ASCAT/QSCAT)
- **Update the QSCAT-R Dataset with quadrant-specific wind radii**
  - Use to refine r34, r50, r64, and r83 estimates
- **Include surface observations from land/buoys**
- **Apply/develop a new set of flight->surface reduction factors based on the FLIGHT+ Dataset**
  - Explore whether time-dependent SST information and dropsonde profiles can be used to improve flight->surface reduction factors
- **Examine the sensitivity of wind hazard risk using TC-OBS vs. HURDAT, case studies of damage for major landfalling storms**
- **Implement Bayesian and/or boot-strapping-based models to estimate uncertainty**
- **Estimate the actual uncertainty of the Best Track**