Global 12-year Scatterometer Tropical Cyclone Wind Data Set from QuikSCAT and OceanSAT-2

Validation, Explanation, and Trends in Tropical Cyclone Intensity, Intensification, Size, and Shape

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Outline

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- Data Set Description and Examples
  - QuikSCAT and OceanSAT-2
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Overview:Problem Statement

- Goal: To optimize, produce, validate, and utilize ocean surface wind speed fields around all tropical cyclones (TCs) observed by QuikSCAT, OceanSAT-2, and ASCAT in order to:
  - Obtain a consistent 10-15 year data base of tropical cyclone surface wind fields over the global ocean.
  - Improve intensity forecasts for tropical cyclones [Brennan et al, 2009].
  - Enhance understanding of rapid intensification process in tropical cyclones.
  - Investigate tropical cyclone influence on ocean heat transport [Scoccimarro et al, 2011][Sriver and Huber, 2007]
  - Determine decadal trends in tropical cyclone size, shape, and intensity [Chan and Chan,2012], [Chavas and Emanuel, 2010]

Overview: How does it work?

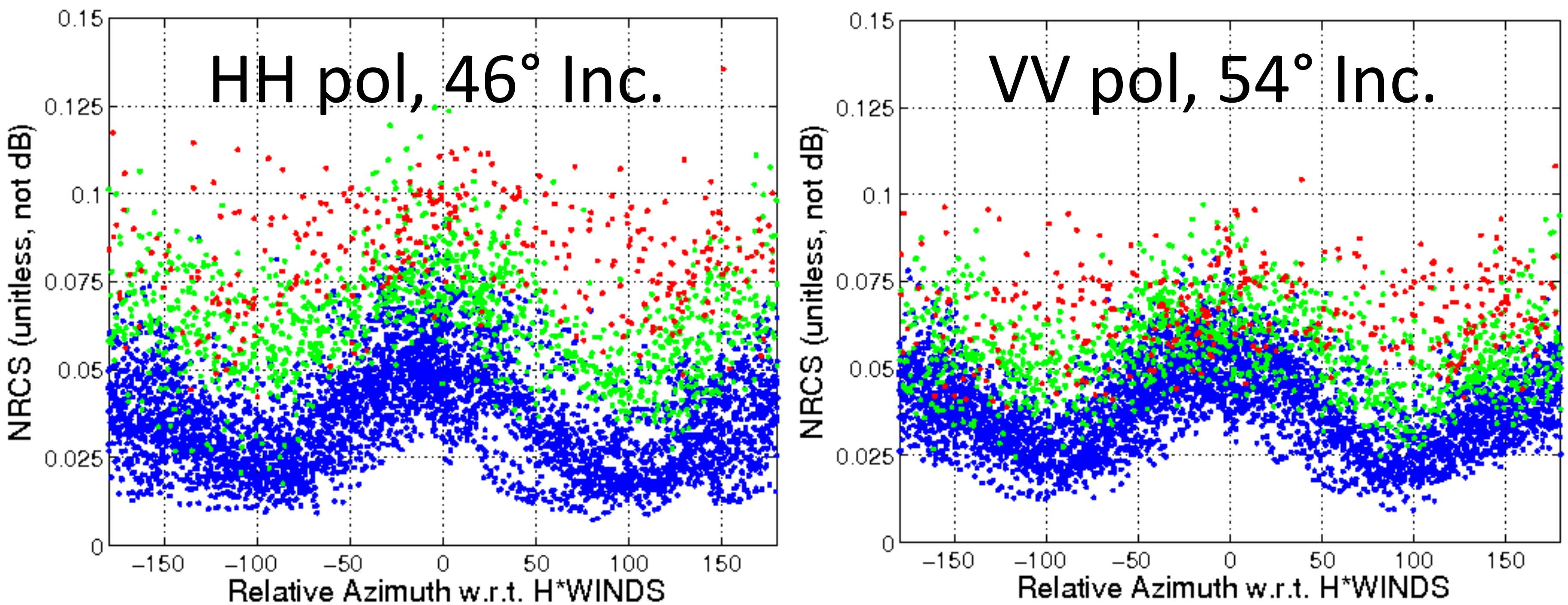
- The neural network determines corrections to the MLE speed as a function of
  - SRAD rain rate
  - Backscatter from two different polarizations, two different azimuths, and two different spatial resolutions (2 X 2 X 2 = 8 values)
  - Viewing geometry (cross track distance)
  - MLE speed
- The resultant multi-dimensional mapping is hard to visualize.
- The next 7 slides exemplify how this works by
  - Showing Ku-band sigma-0 is sensitive to winds from 20-40 m/s
  - Examining a specific case of MLE speed = 24-26 m/s and CTD = 400-450 km
    - We examine how the ANN utilizes three parameters of interest , Copol ratio, sum sigma-0, and SRAD rain rate (backup slides if time allows).

NRCS scatterplots for 20,30, and 40 m/s H*WIND

(QuikSCAT/H*WIND matched within 2 hours, *Clear conditions*)

- In *rainfree* conditions (rain impact quantity <= 2.5), QuikSCAT HH pol 46 degree incidence NRCS values are sensitive to wind speed and direction in the 20-40 m/s range.
- QuikSCAT VV 54 degree incidence values have less sensitivity.

(Blue, Green, Red) = (20,30,40) m/s + or -10% H*WIND

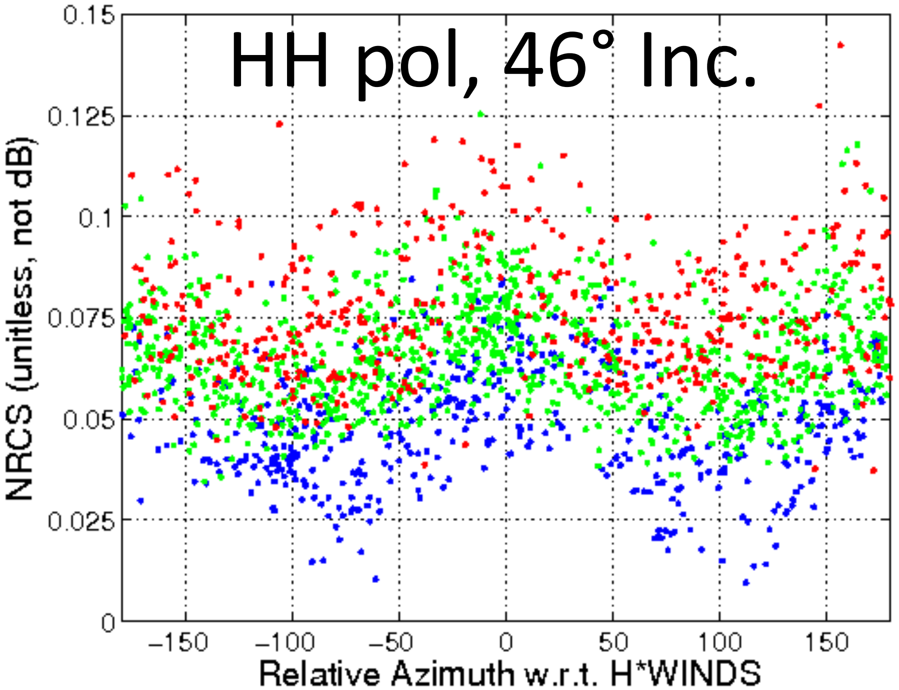


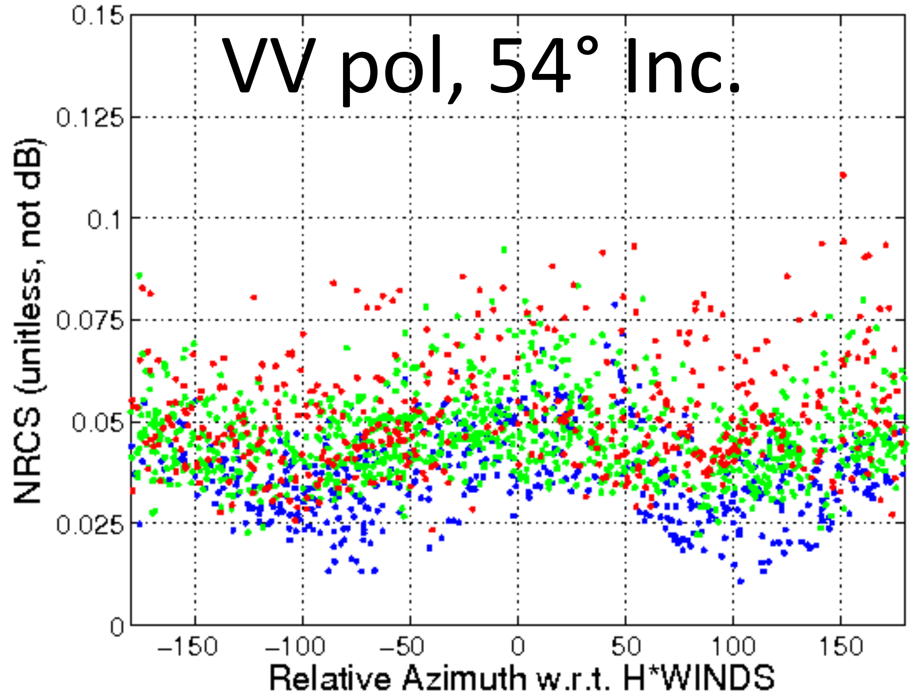
NRCS scatterplots for 20,30, and 40 m/s H*WIND

(QuikSCAT/H*WIND matched within 2 hours, *Rainy conditions*)

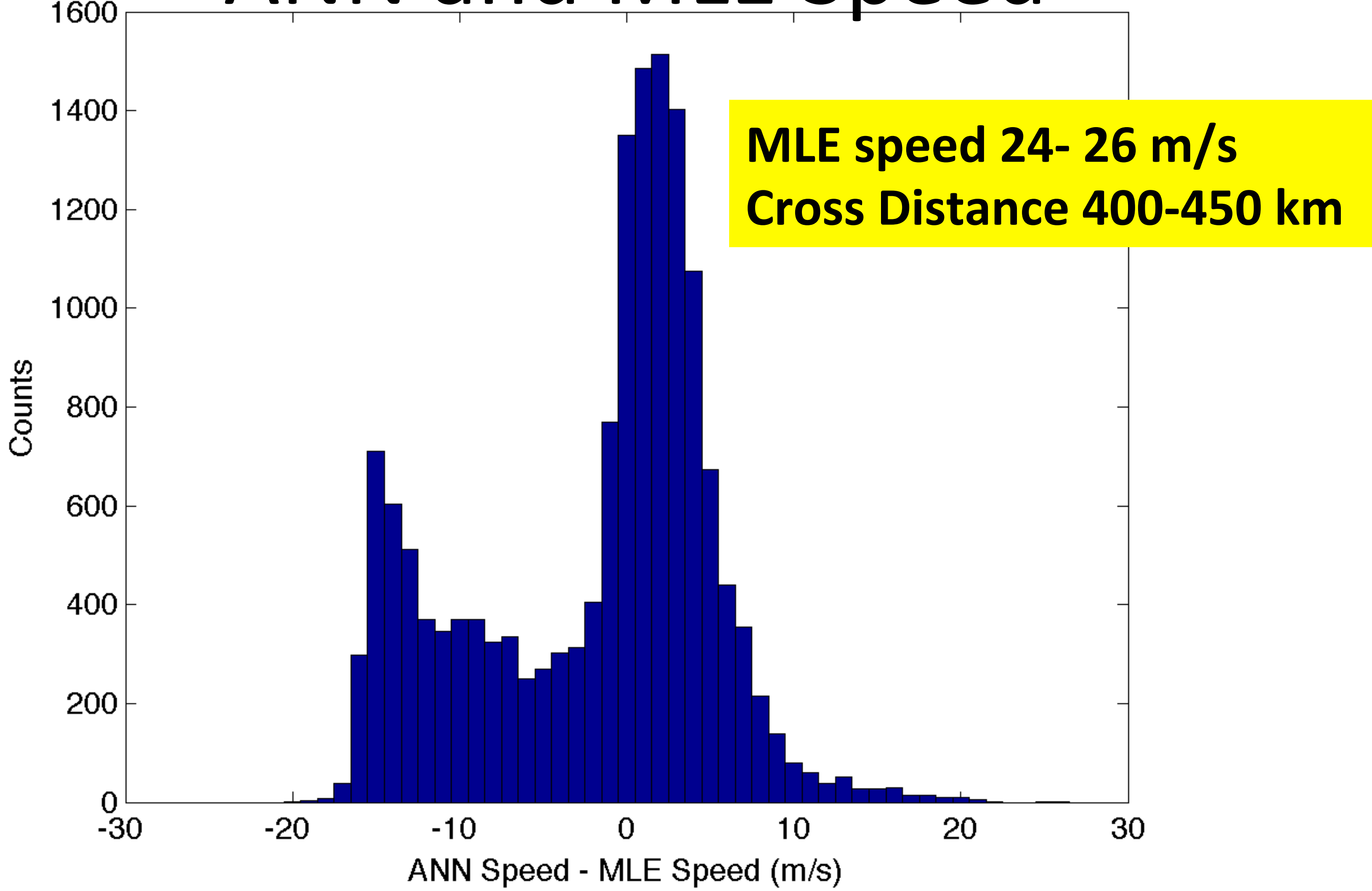
- In *rainy conditions* (rain impact quantity > 2.5), the wind sensitivity of both polarizations are reduced especially for VV pol, but still apparent at least for moderate rain.

(Blue, Green, Red) = (20,30,40) m/s +or -10% H*WIND

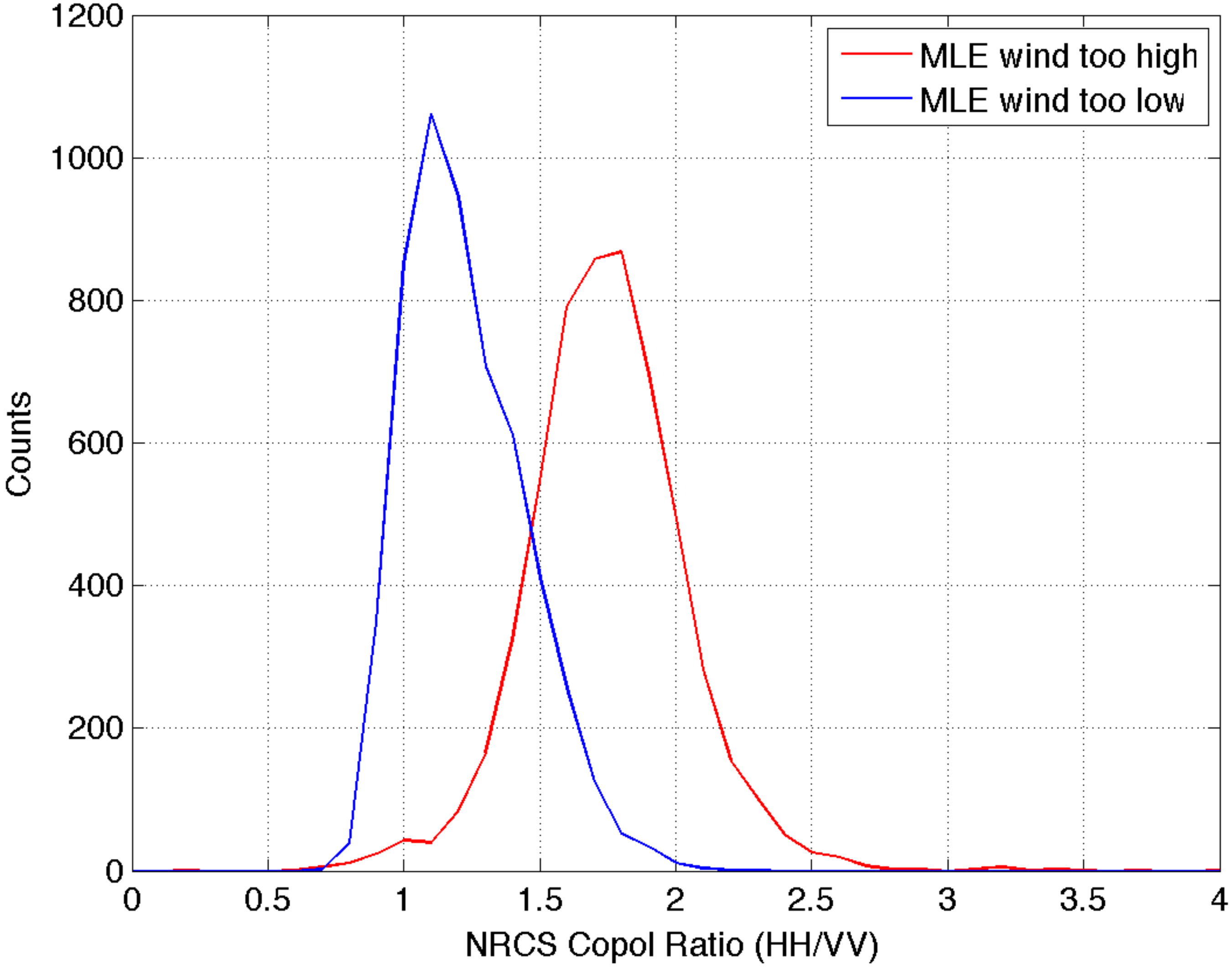




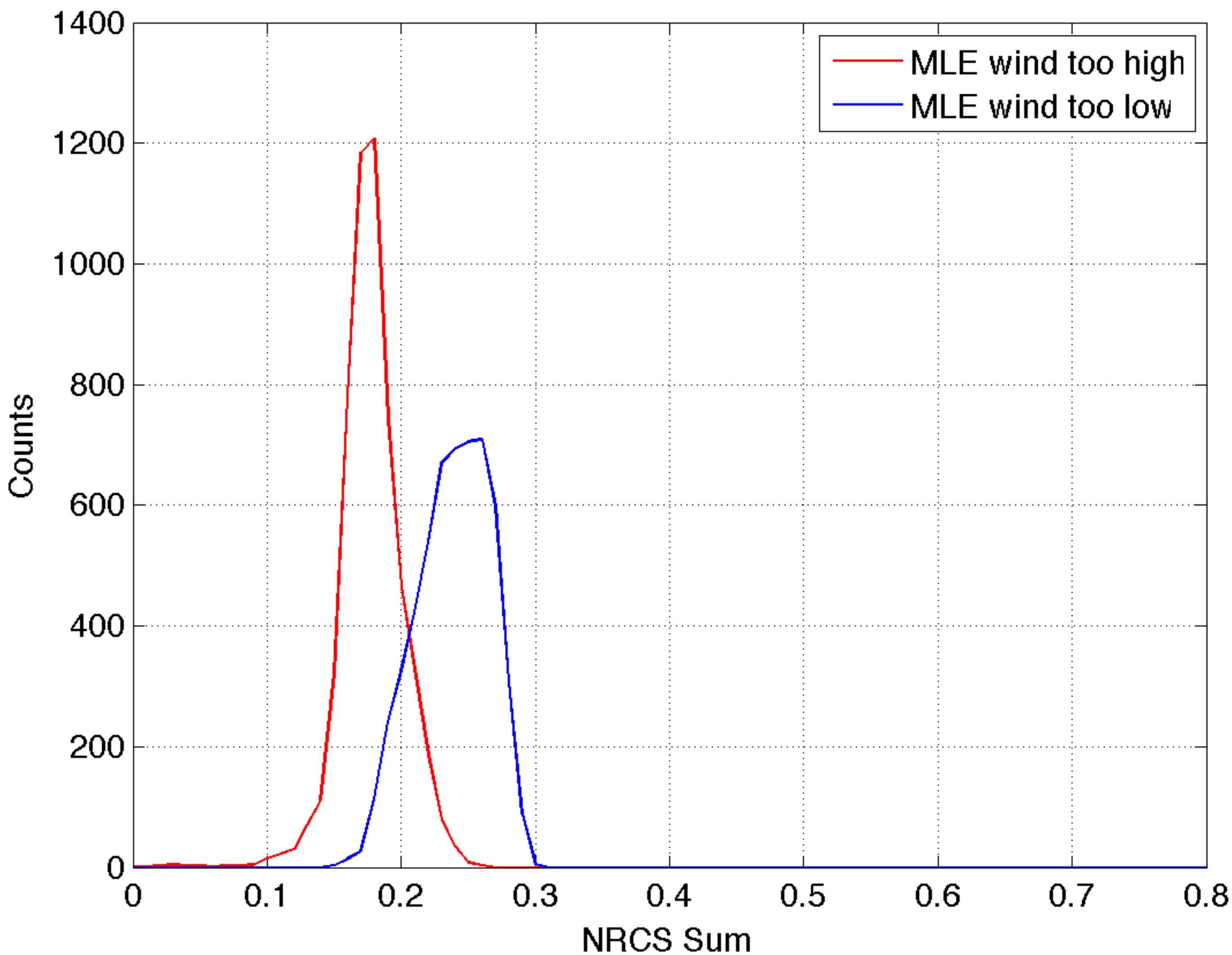
Histogram of Difference Between ANN and MLE Speed



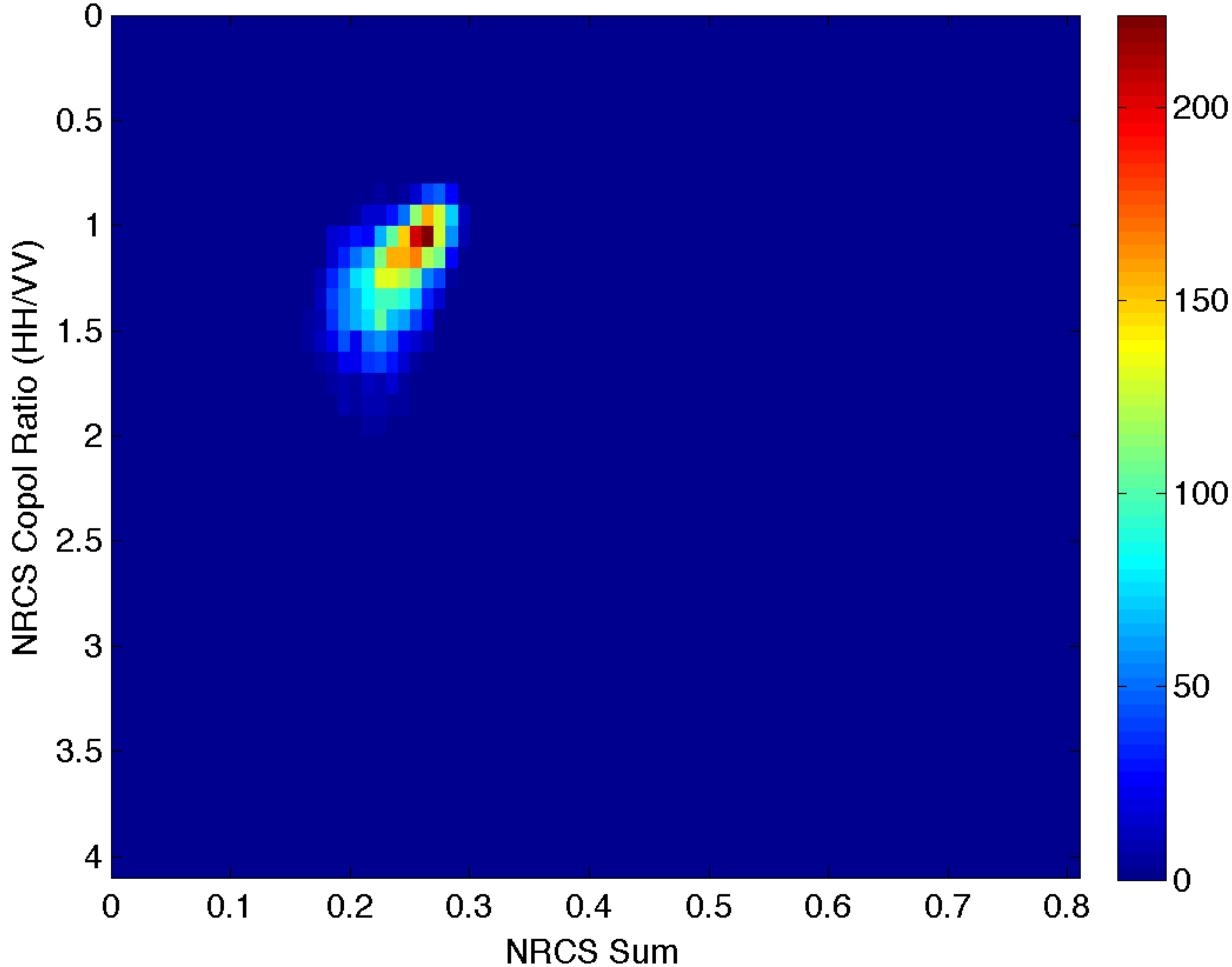
Co-pol Ratio Histograms



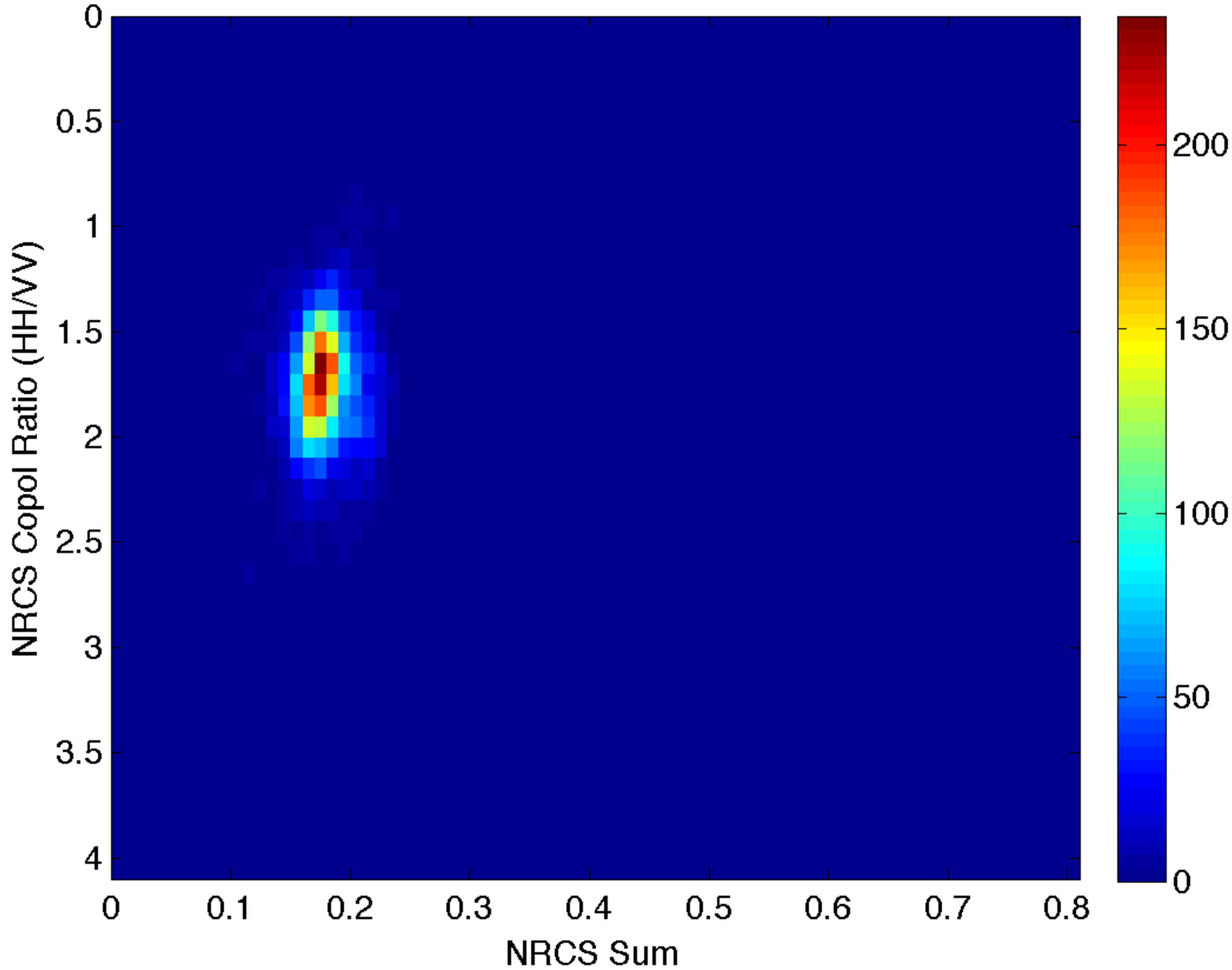
Histogram of Sum of 4 Sigma0s



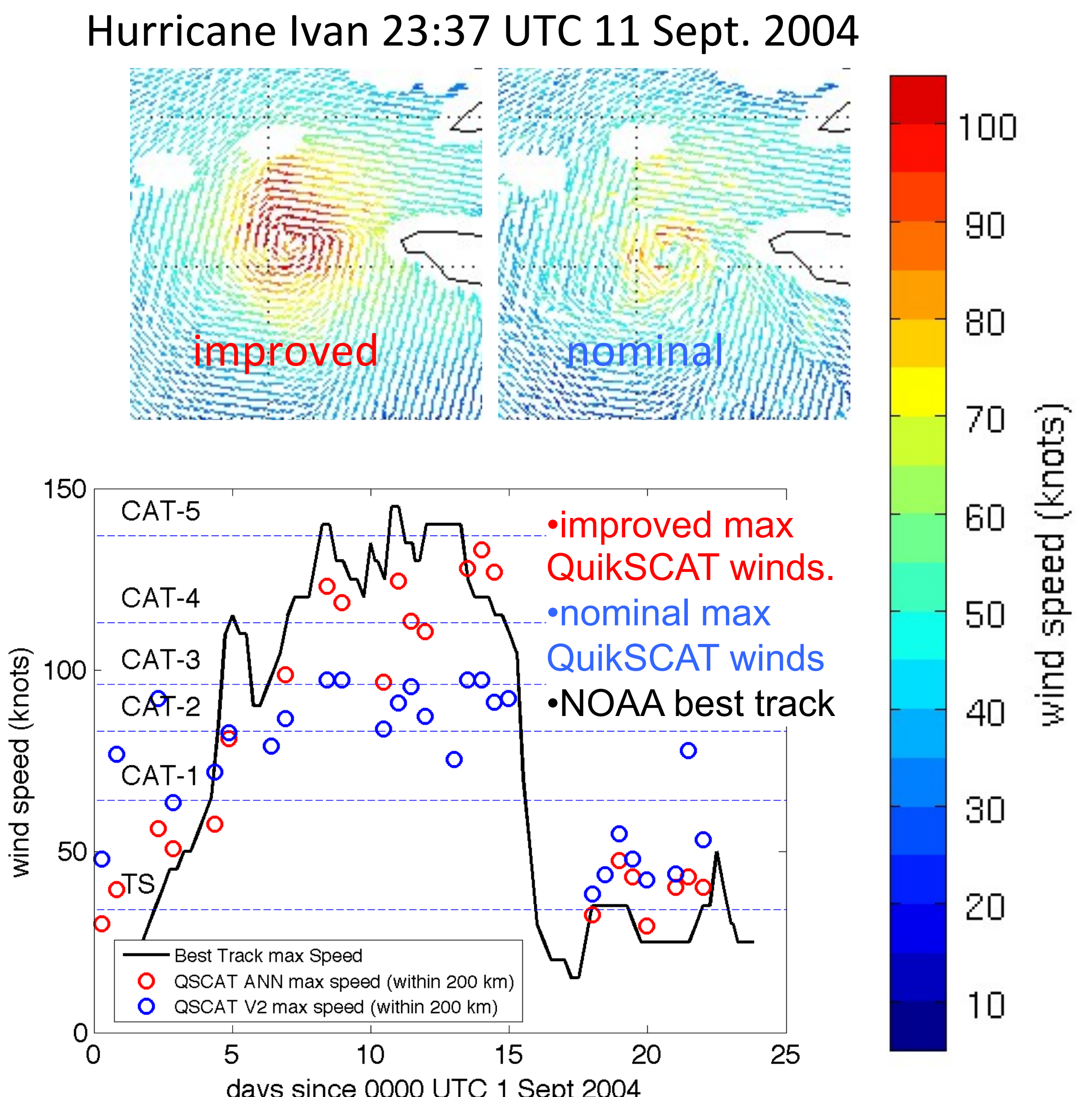
Joint Histogram Low MLE winds



Joint Histogram High MLE winds



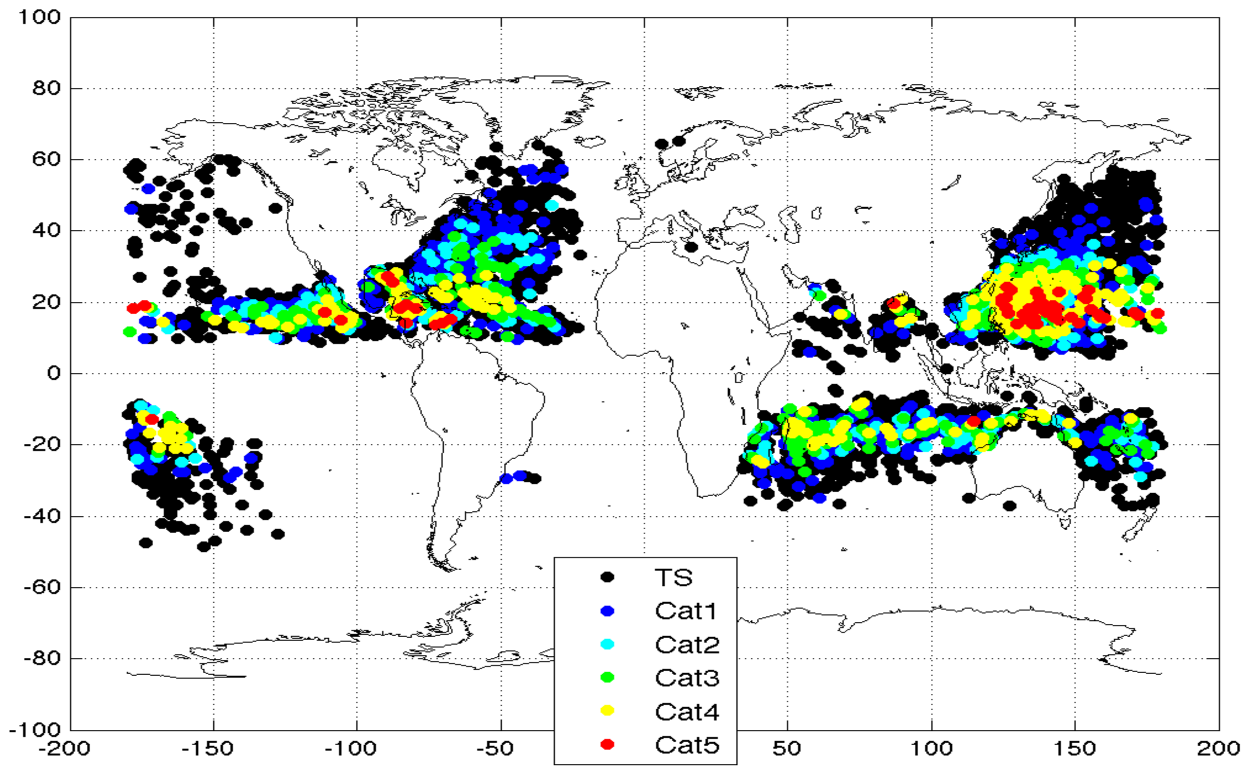
Data Set Description



See http://tropicalcyclone.jpl.nasa.gov

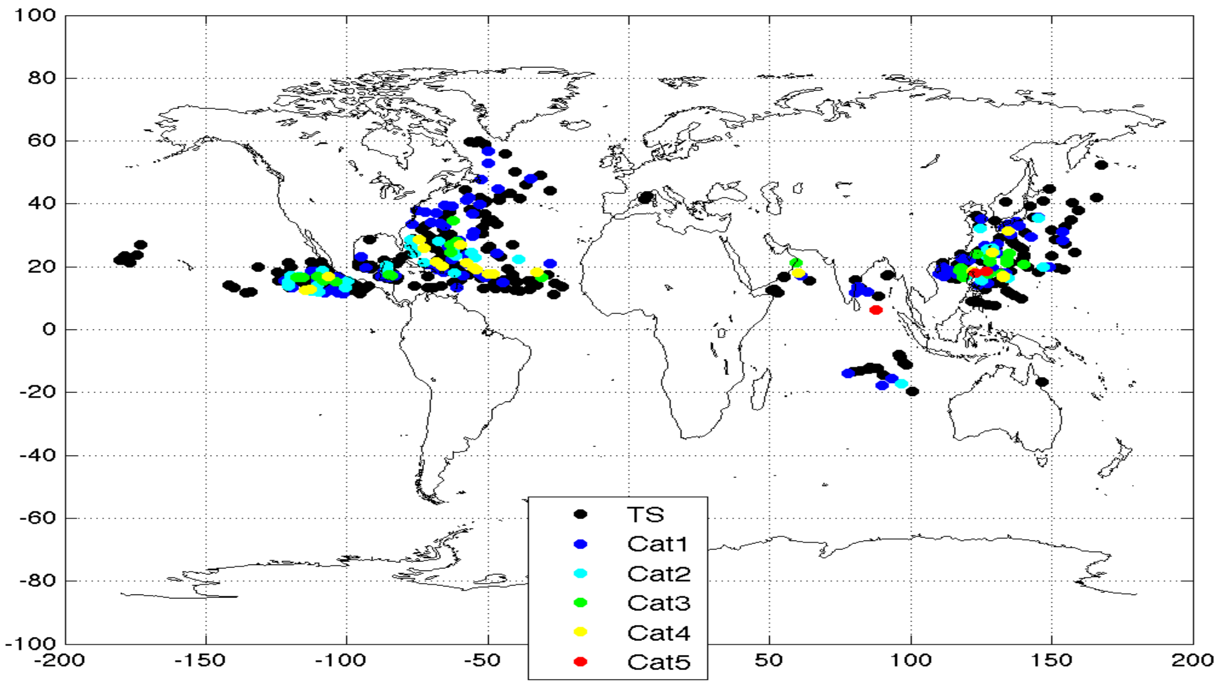
- Improved QukSCAT tropical cyclone (TC) wind speed fields
  - –12,476 storm scenes over 12 years
  - –Validated vs. hurricane analysis fields and aircraft overflight measurements.
- Problem: Scatterometer winds are corrupted by rain and use empirical retrievals not optimized for high winds.
- Solution: Neural network retrieval method trained specifically for TC winds.
- Developing similar datasets for the ASCAT (ESA) scatterometers.

QuikSCAT Tropical Cyclone Data Set (1999-2009)



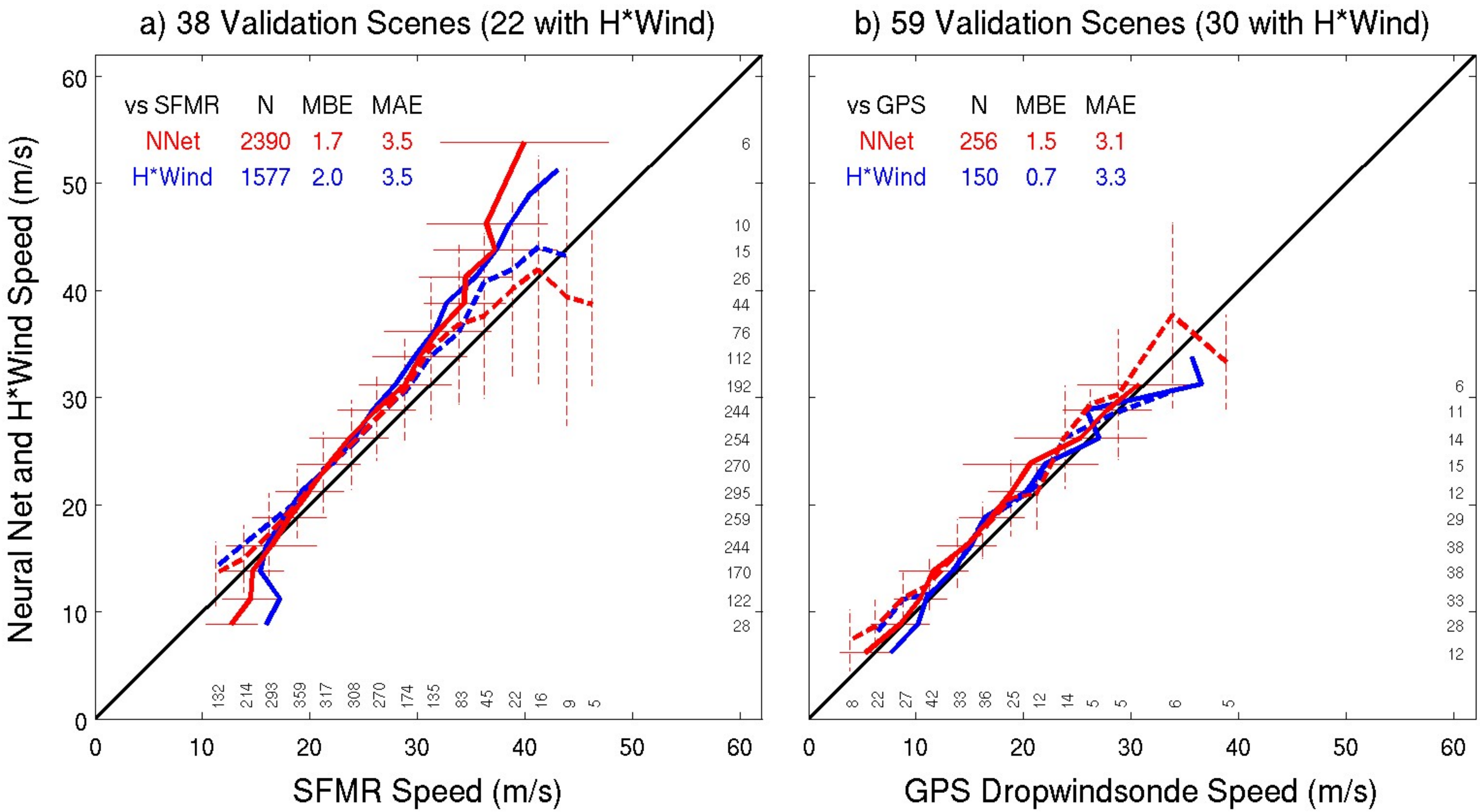
- http://tropicalcyclone.jpl.nasa.gov
- 21600 total storm scenes from October 1999 to November 2009
- 11435 scenes with best track center within the image, including:
  - 3295 TS, 788 CAT-1, 367 CAT-2, 330 CAT-3, 289 CAT-4, 55 CAT-5
- Data on the site includes:
  - JPEG Images of tropical cyclone optimized winds and two versions of the JPL global wind product.
  - Netcdf files containing, all three wind sets, SRAD rain rates, and all 8 backscatter sets
  - A comprehensive set of best track data from a variety of sources.

OceanSAT-2 Tropical Cyclone Data Set (2010-2011)

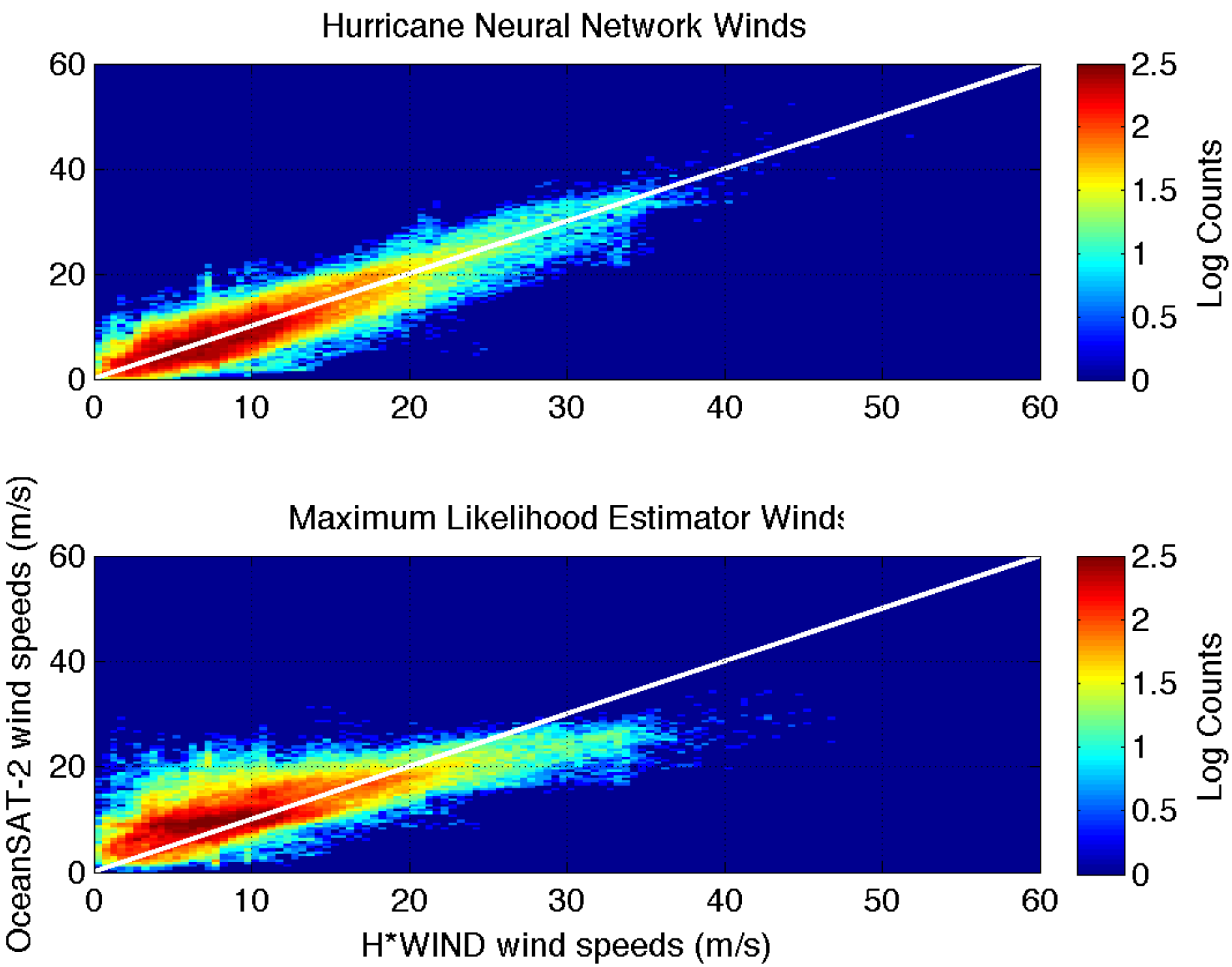


- http://tropicalcyclone.jpl.nasa.gov
- 2575 total storm scenes from Jan 2010 to December 2011
- 1041 scenes with best track center within the image, including:
  - 298 TS, 90 CAT-1, 35 CAT-2, 27 CAT-3, 20 CAT-4, 3 CAT-5
- Data on the site includes:
  - JPEG Images of tropical cyclone optimized winds and MLE winds.
  - Netcdf files containing, all both wind sets, detrended brightness temperatures, and all 8 backscatter sets
  - A comprehensive set of best track data from a variety of sources.

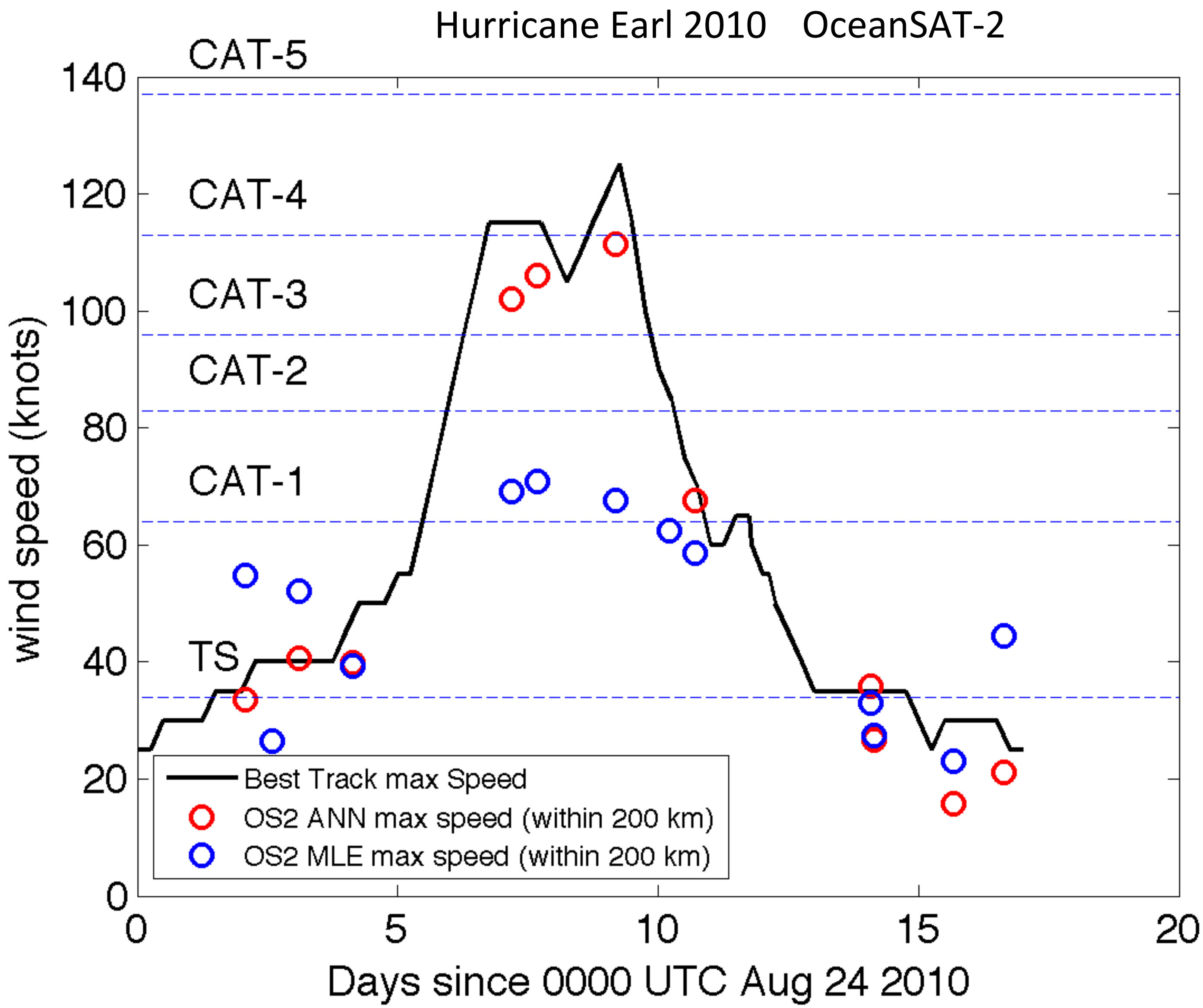
Validation: QuikSCAT



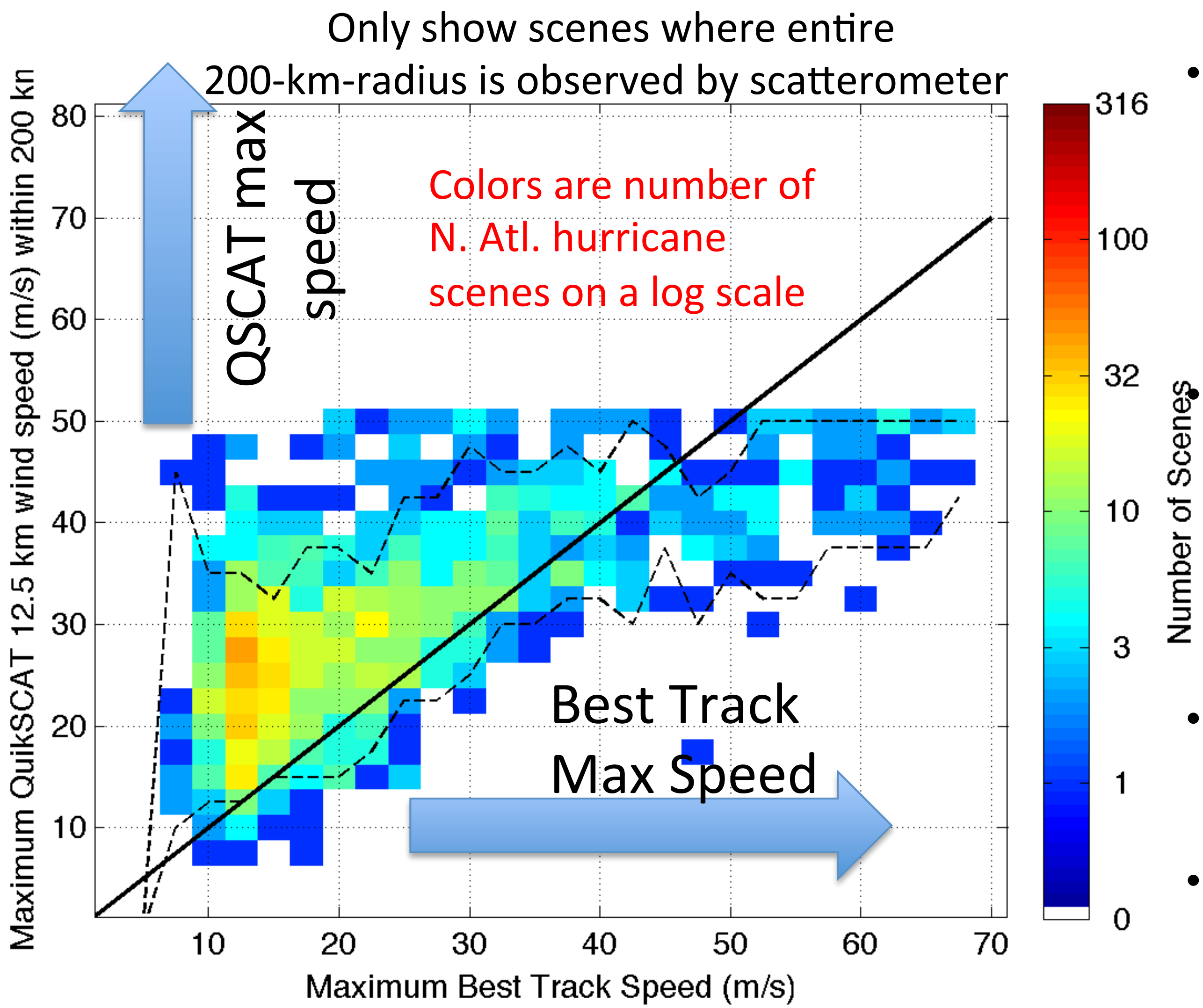
Validation: OceanSAT-2



Naive Intensity Estimation Example:

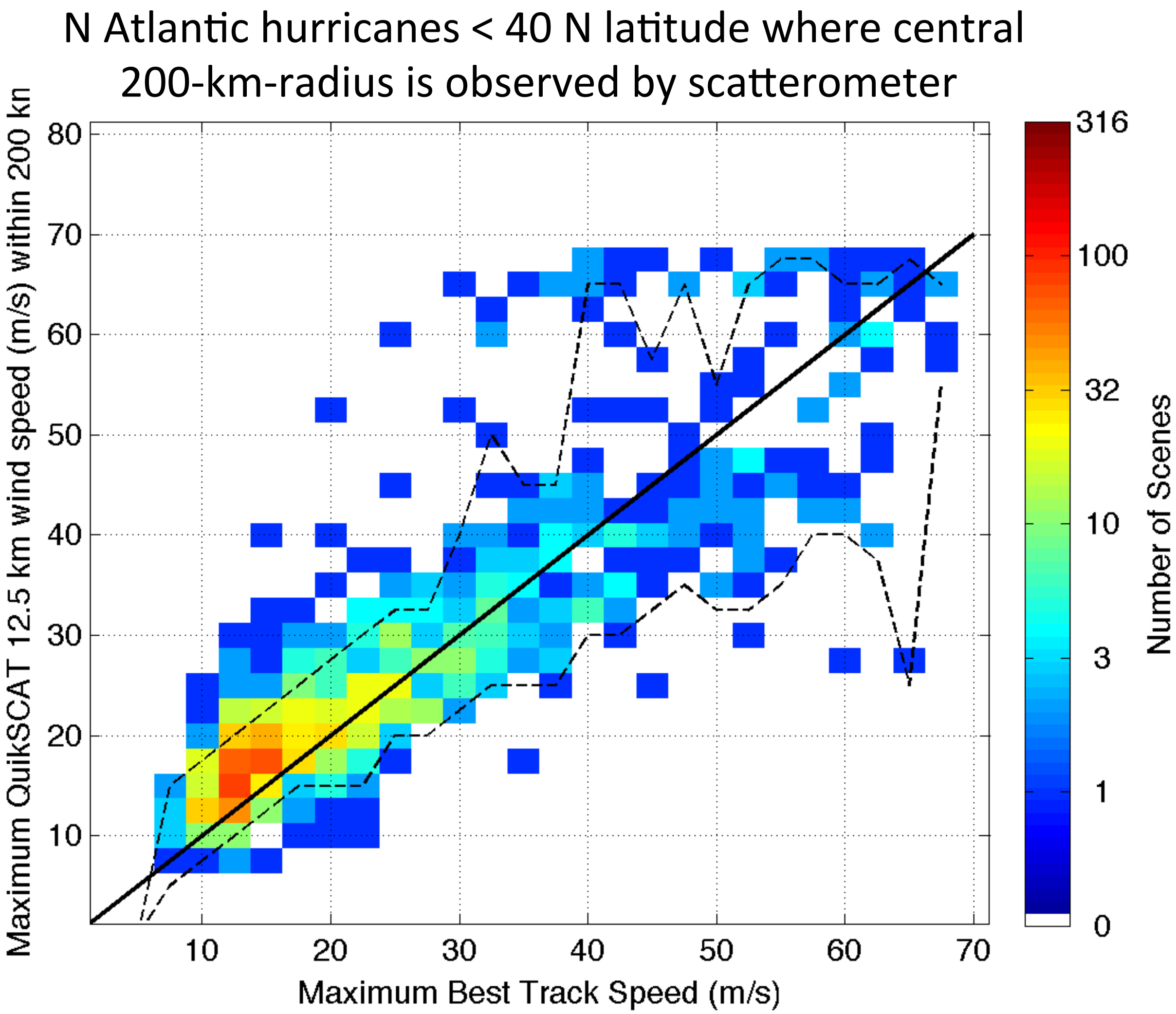


Naive Intensity Estimator: QuikSCAT MLE Stats



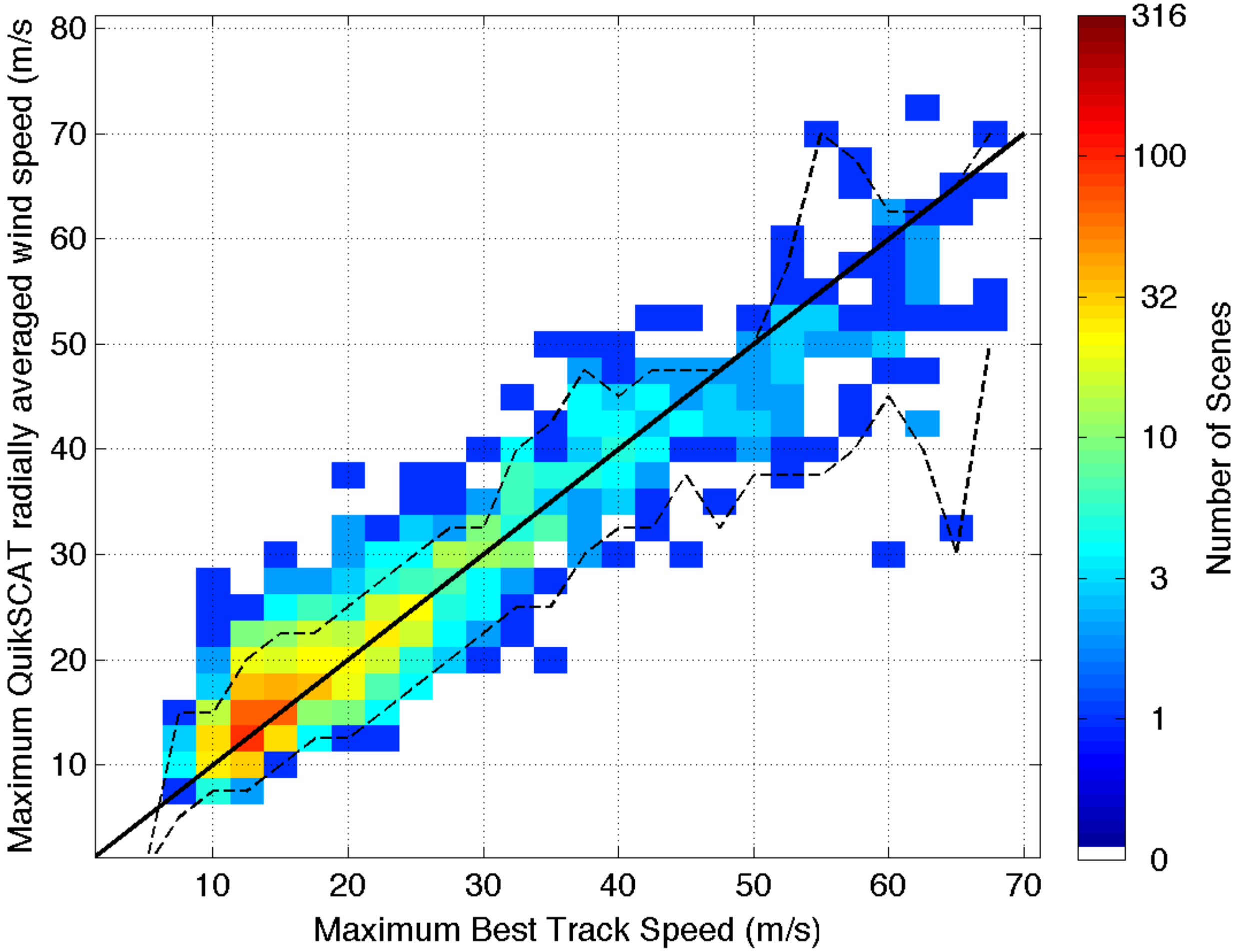
- Technique: take maximum single vector within 200 km of best track center
- Rain contamination leads to extreme overestimation in 10-30 m/s range
- No trend above 30 m/s
- Clipping at 50 m/s due to hard limit in MLE implementation

Naive Intensity Estimator: QuikSCAT ANN Stats



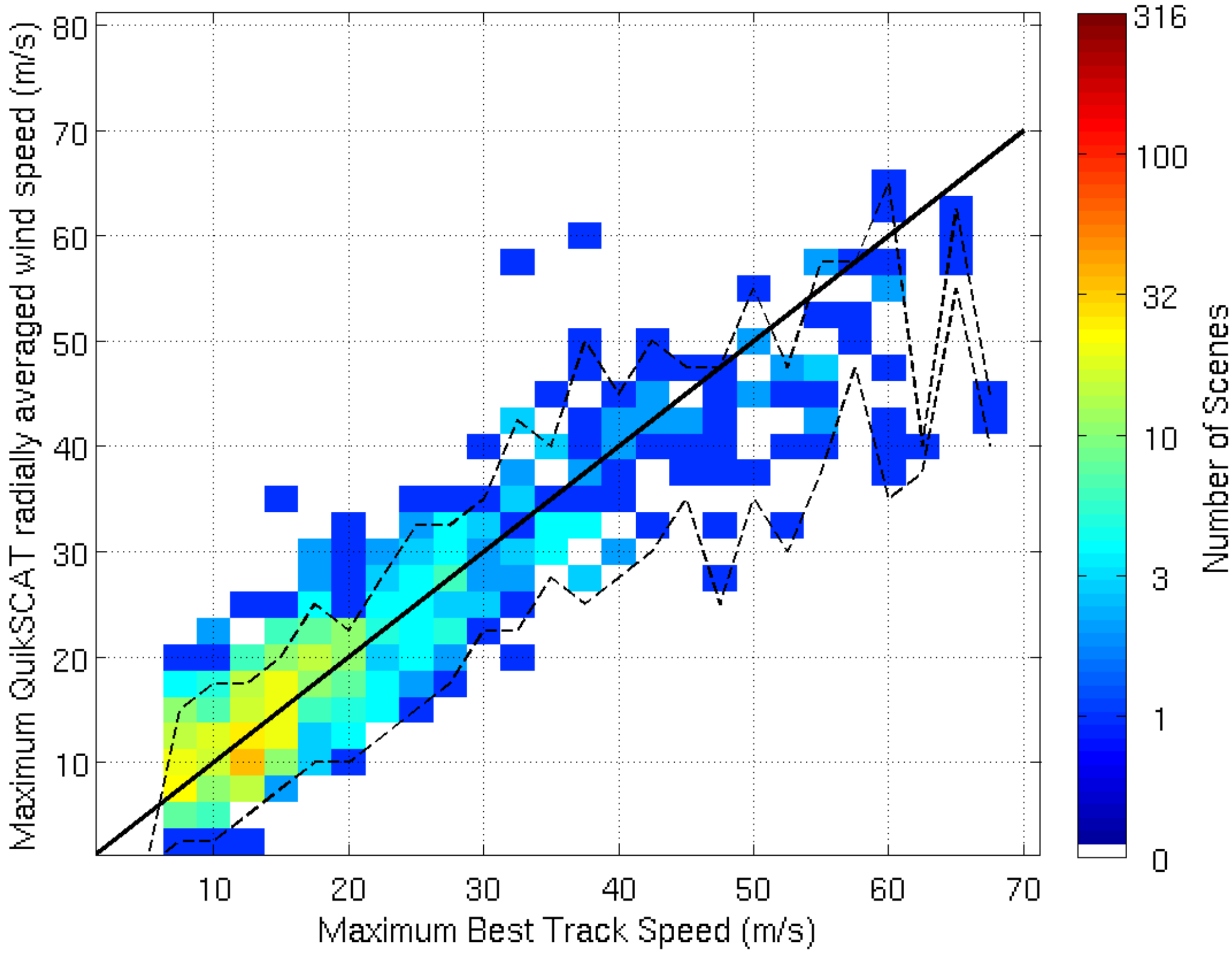
- Rain much reduced in 10-30 m/s range
- Linear trend with max best track speed
- Dark blue cases are single outlier scenes occuring due to noise in retrieval

Improved Intensity Estimator: QuikSCAT ANN Stats



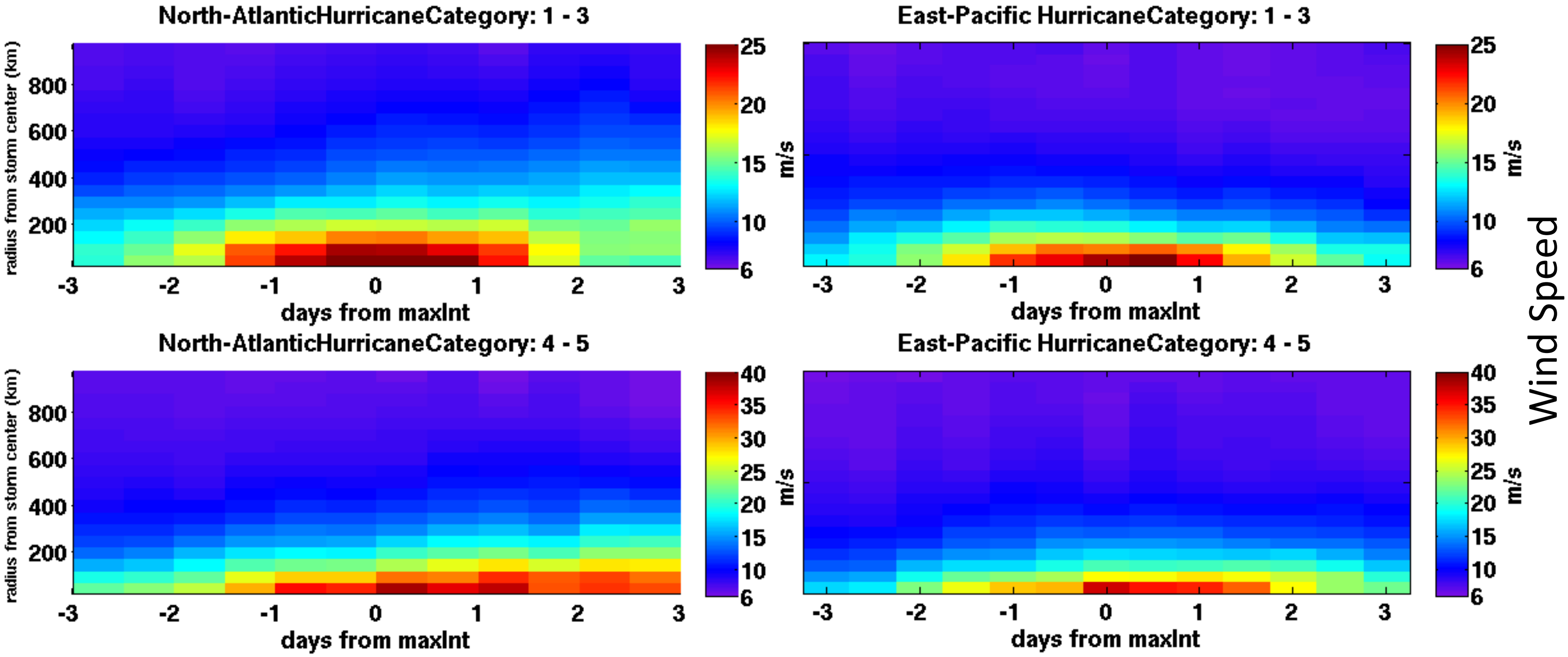
- Technique:
  - Compute average of wind vectors in concentric circles about center.
  - Take maximal average value.
  - Multiply by 1.4 to account for reduced resolution
- Reduces occurrence of outliers substantially

Improved Intensity Estimator: OSAT-2 ANN Stats



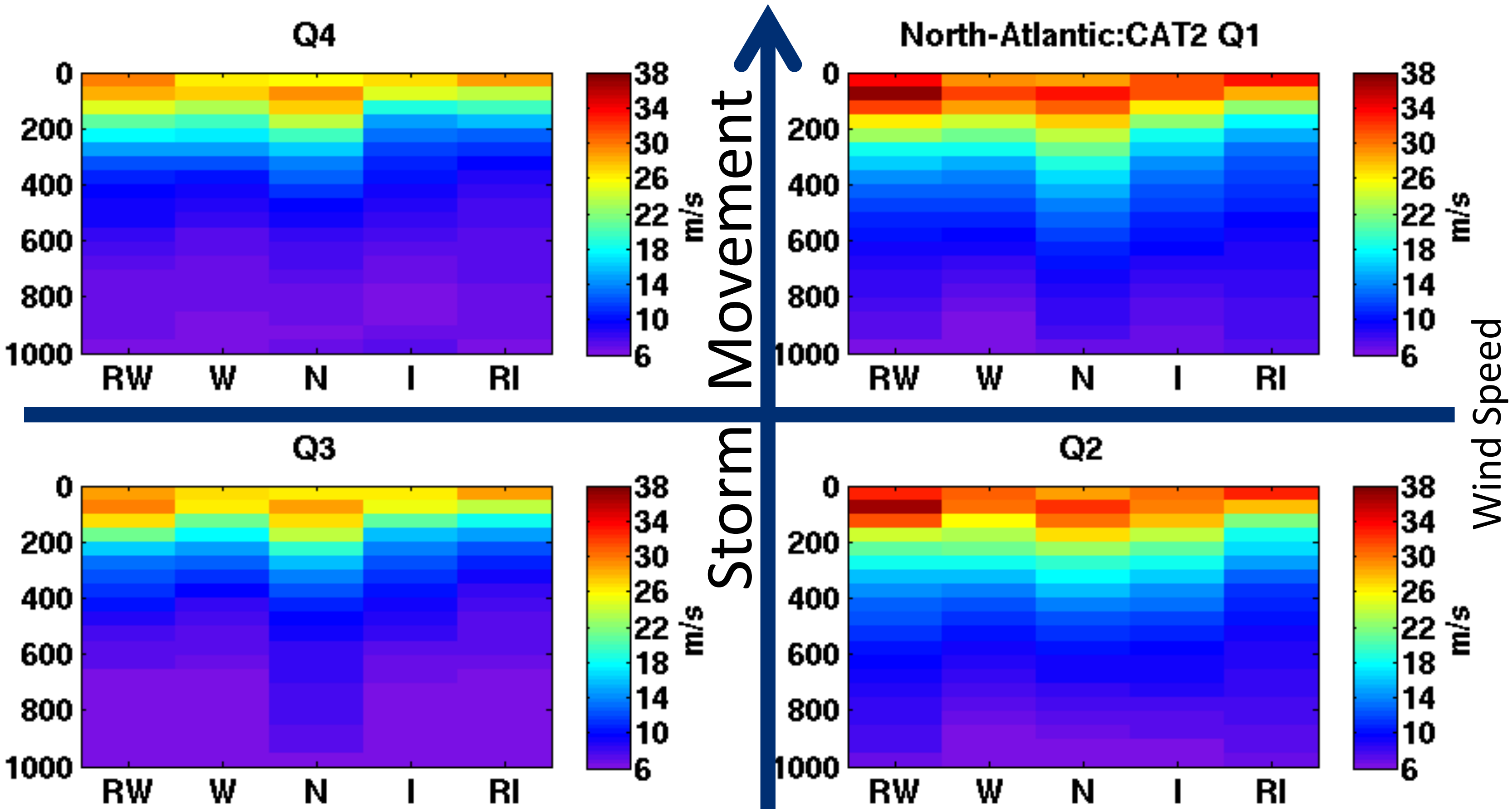
- Performance similar to QuiKSCAT but biased low at at highest speeds.
- Low bias is likely due to lack of highest wind speeds in OSCAT training set.
- 2010 (OSCAT train set) was a slower Atlantic hurricane season than 2005 (QuiKSCAT train set).

Climatology 1999-2009: Storm Size and Trends



1. In North Atlantic area of tropical storm force winds continues to increase 3 days after maximum intensity.
2. Major storms intensify rapidly and decay more slowly.
3. Regions of intense winds are smaller in East Pacific than in North Atlantic.

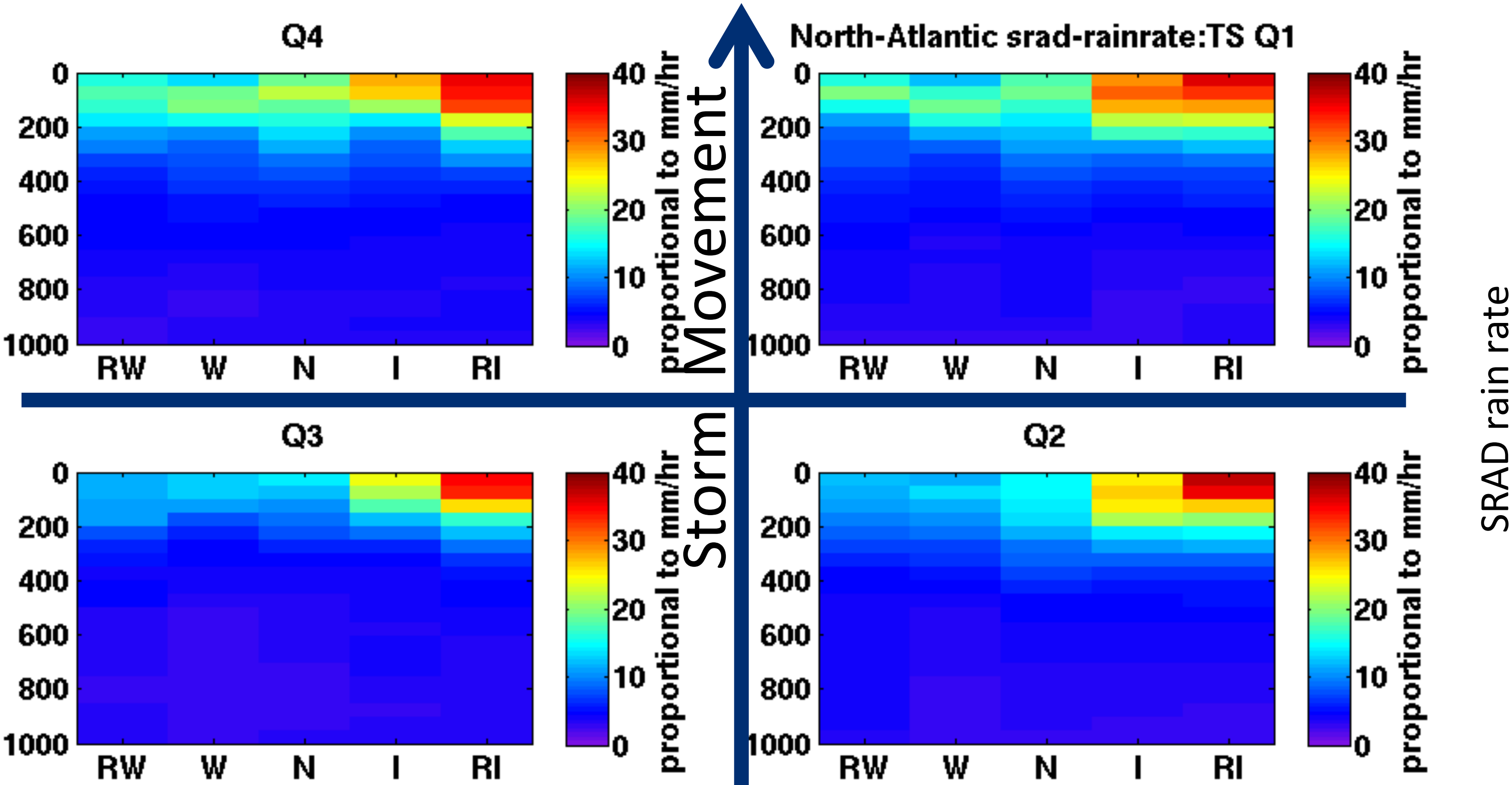
Climatology (1999-2009): Rapid Intensification



RW= Rapidly Weakening, a < - 0.8 m/s/hr
W= Weakening, -0.8 m/s/hr < a < -0.125 m/s/hr
N= No change, -0.125 m/s/hr < a < 0.375 m/s/hr
I= Intensifying, 0.375 m/s/hr < a < 0.8 m/s/hr
RI= Rapidly Intensifying, > 0.8 m/s/hr

1. For Category 2 storms the region of intense winds is smaller in RI storms
2. True for other categories as well (data not shown).

Climatology (1999-2009): Rapid Intensification



In addition to speed climatology, the co-located rain information from the QuikSCAT noise channel [Ahmad et al, 2005] can also be analyzed to find signatures in RI storms.

Rapidly intensifying tropical storms have a distinct high SRAD rain rate signature near the center of the storm.

Summary

- QuikSCAT tropical cyclones speed fields have been
  - Optimized for accuracy
  - Produced for all ten years of the QuikSCAT mission including over 5,000 observations of tropical storms and above.
  - Validated vs. H*WINDS, Dropsondes, SFMR, and best track wind speeds.
  - Made available online to the community at large in a browsable data base.
    - Ancilary data such as backscatter imagery and co-located rain information are also included.
- QuikSCAT data is being investigated to determine
  - How storm size and shape evolves as a function of time.
  - Correlation of storm features with rapid intensification and de-intensification events
  - Importance of storm asymmetry in modeling ocean heat transport (collaboration with Isaac Ginis, University of Rhode Island)
  - Synergy with C-band SAR hurricane data
- OceanSAT-2 algorithm has been trained using 2010 OceanSAT/H*WIND co-locations
  - Preliminary validations results are similar to QuikSCAT
  - Two years of global OceanSAT-2 tropical cyclones are currently available online.
- A paper describing the production and validation of the QuikSCAT data set has been submitted.

Acknowledgements

- The work reported here was performed at the Jet Propulsion Laboratory, California Institute of Technology, and at the National Hurricane Center under contract with the National Aeronautics and Space Administration.
  - This work described in this presentation is funded by NASA's Ocean Vector Winds program.
  - The website portal used to distribute the data set is part of a program funded by NASA's Hurricane Science Research program.

References

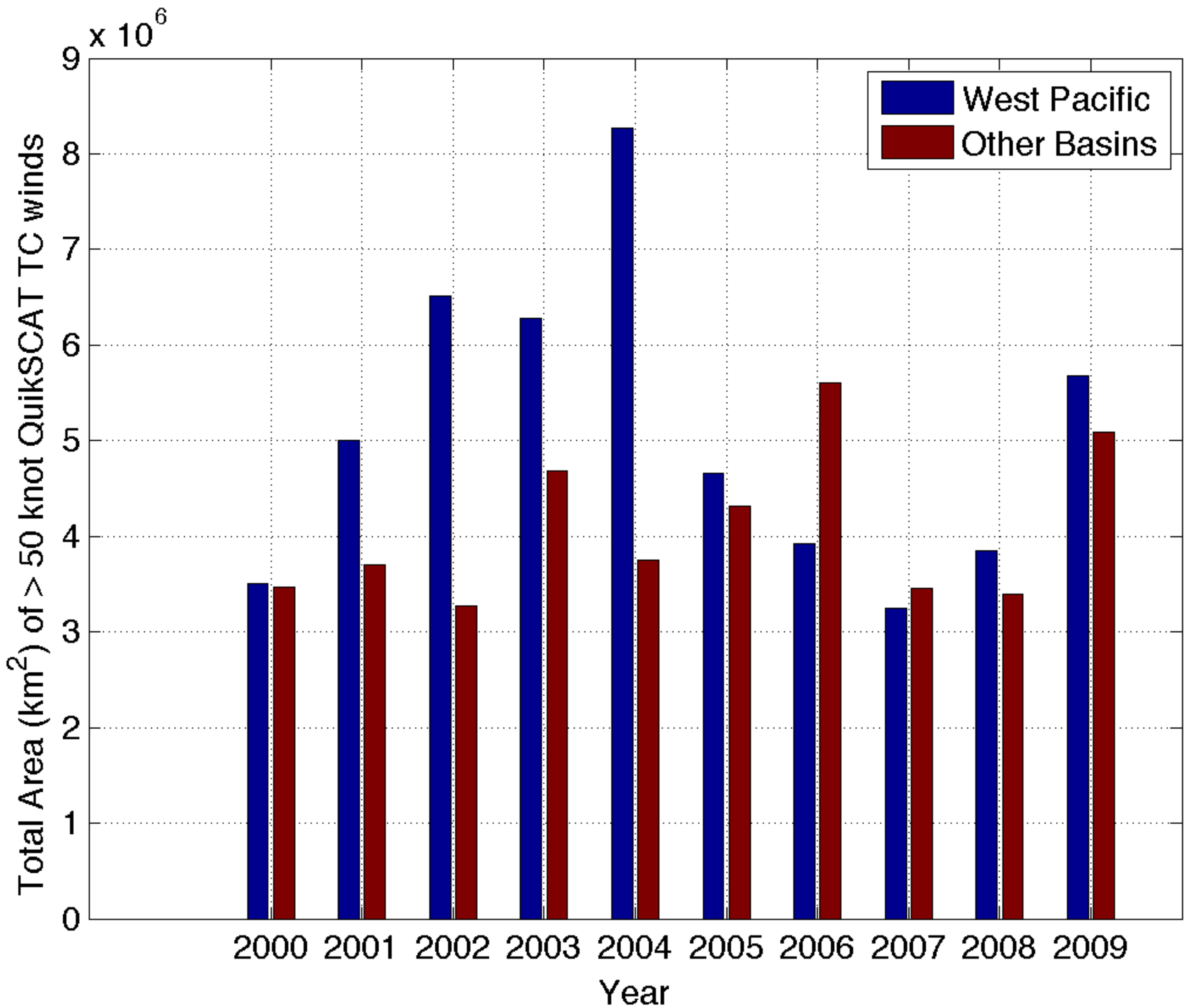
- Ahmad, K. A., W. L. Jones, T. Kasparis, S. W. Vergara, I. S. Adams, and J. D. Park, "Oceanic rain rate estimates from the QuikSCAT Radiometer: A Global Precipitation Mission pathfinder", *J. Geophys. Res.*, *110*, D11101, 26 pages, 2005.
- Brennan, M.J., C.A. Hennon, and R.D. Knabb, "The operational use of QuikSCAT ocean surface vector winds at the National Hurricane Center." *Weather and Forecasting*, 24, pp 621–645, 2009.
- Chan, Kelvin T. F., Johnny C. L. Chan, "Size and Strength of Tropical Cyclones as Inferred from QuikSCAT Data". *Monthly. Weather. Review.*, **140**, 811–824. 2012.
- Chavas, D. R. and K. A. Emanuel, "A QuikSCAT climatology of tropical cyclone size,"*Geophysical Research Letters*, VOL. 37, L18816, doi:10.1029/2010GL044558, 2010.
- Powell, M. D., Sam H. Houston, Luis R. Amat, Nirva Morisseau-Leroy, *"*The HRD real-time hurricane wind analysis system," *Journal of Wind Engineering and Industrial Aerodynamics 77&78* pp 53-64, 1998.
- Scoccimarro, E., Gualdi, S., & Bellucci, A. (2011). Effects of Tropical Cyclones on Ocean Heat Transport in a High-Resolution Coupled General Circulation Model. Journal Of Climate, 24(16), pp 4368-4384, 2011.
- Sriver, R. L., and M. Huber, "Observational evidence for an ocean heat pump induced by tropical cyclones", Nature, Vol 447, pp 577-580, 2007.
- Stiles, B.W.; Dunbar, R.S.; , "A Neural Network Technique for Improving the Accuracy of Scatterometer Winds in Rainy Conditions," *Geoscience and Remote Sensing, IEEE Transactions on* , vol.48, no.8, pp.3114-3122, Aug. 2010
- Uhlhorn, E. W., and P. G. Black, J. L. Franklin, M. Goodberlet, J. Carswell, and A. S. Goldstein, "Hurricane surface wind measurements from an operational Stepped Frequency Microwave Radiometer". Mon. Wea. Rev., 135, 1370–1385, 2007

Recent Publications by Team Members

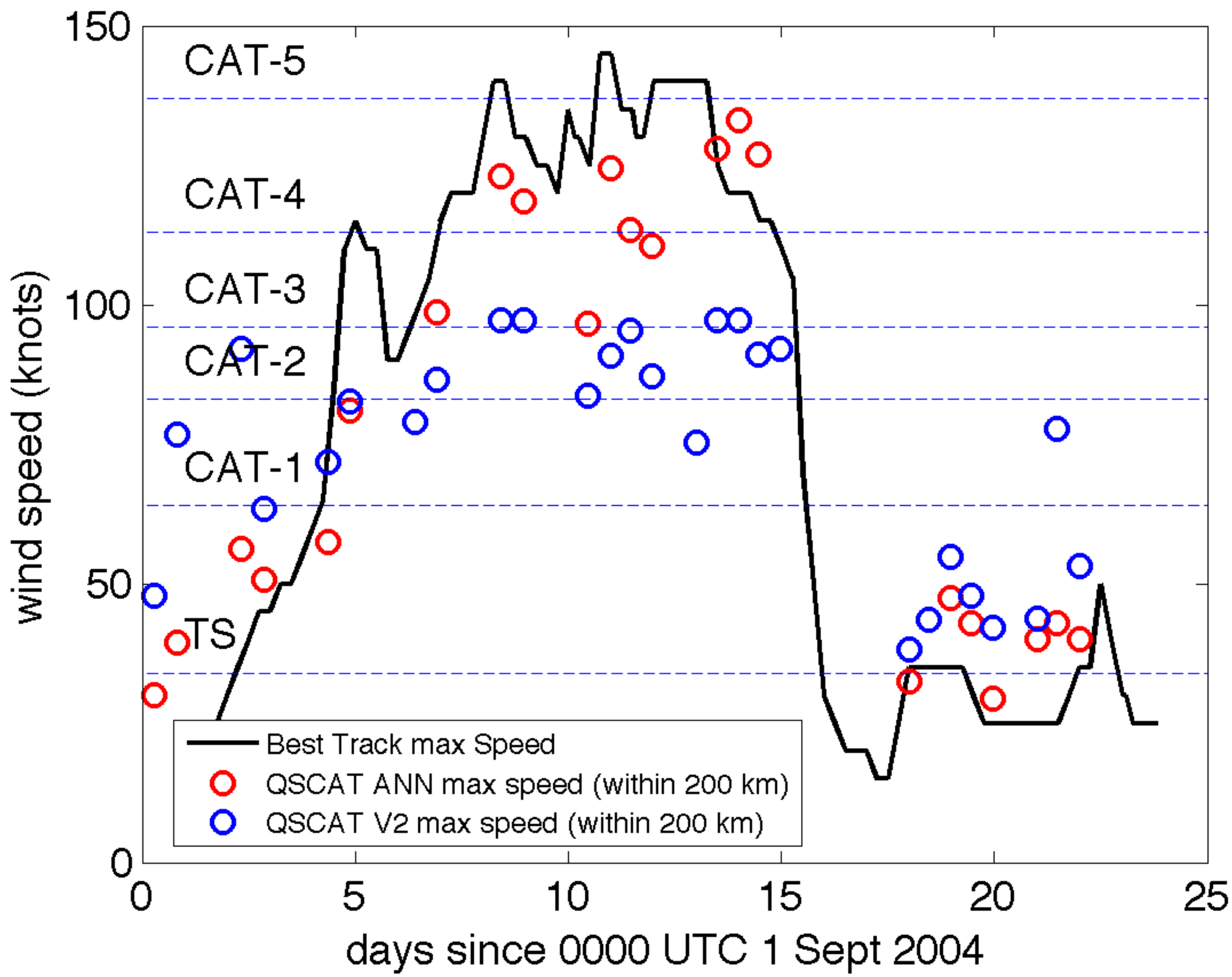
- B. W. Stiles, R. E. Danielson, W. L. Poulsen, M. J. Brennan, S. Hristova-Veleva, T. J. Shen, and A. G. Fore , "Optimized Tropical Cyclone Winds from QuikSCAT:A Neural Network Approach," submitted.
- A.G. Fore, Stiles, B.W., Chau, A.H., Williams, B.A., Dunbar, R. S., and Rodríguez E., "Point-wise Wind Retrieval and Ambiguity Removal Improvements for the QuikSCAT Climatological Data Set," Accepted for publication in IEEE Trans. Geoscience and Remote Sensing, doi:10.1109/TGRS.2012.2235843, 2013.
- T. M. Hamill, Brennan, M. J., Brown, B., DeMaria, M., Rappaport, E. N., Toth, Z., & Hamill, T. M. "NOAA's Future Ensemble-Based Hurricane Forecast Products". *Bulletin of the American Meteorological Society*, *93*(2), 209, 2012.
- Fore, A., Haddad, Z. S., Krishnamurti, T. N., & Rodriguez, E. Improving Scatterometry Retrievals of Wind in Hurricanes Using Non-Simultaneous Passive Microwave Estimates of Precipitation and a Split-Step Advection/Convection Model. *Pure and Applied Geophysics*, *169*(3), 415-424, 2012.

Backup Slides

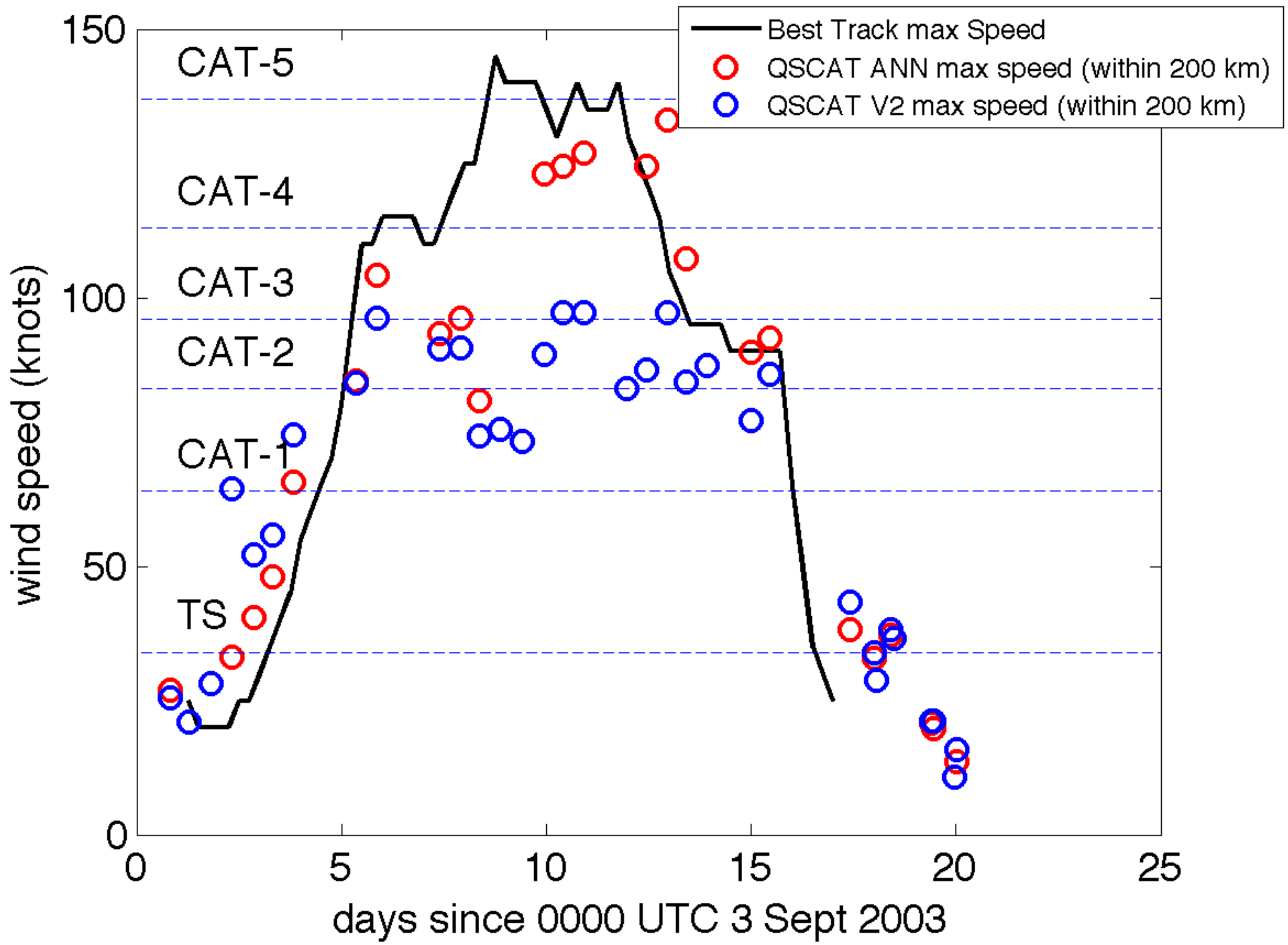
Trend in Overall Storm Area



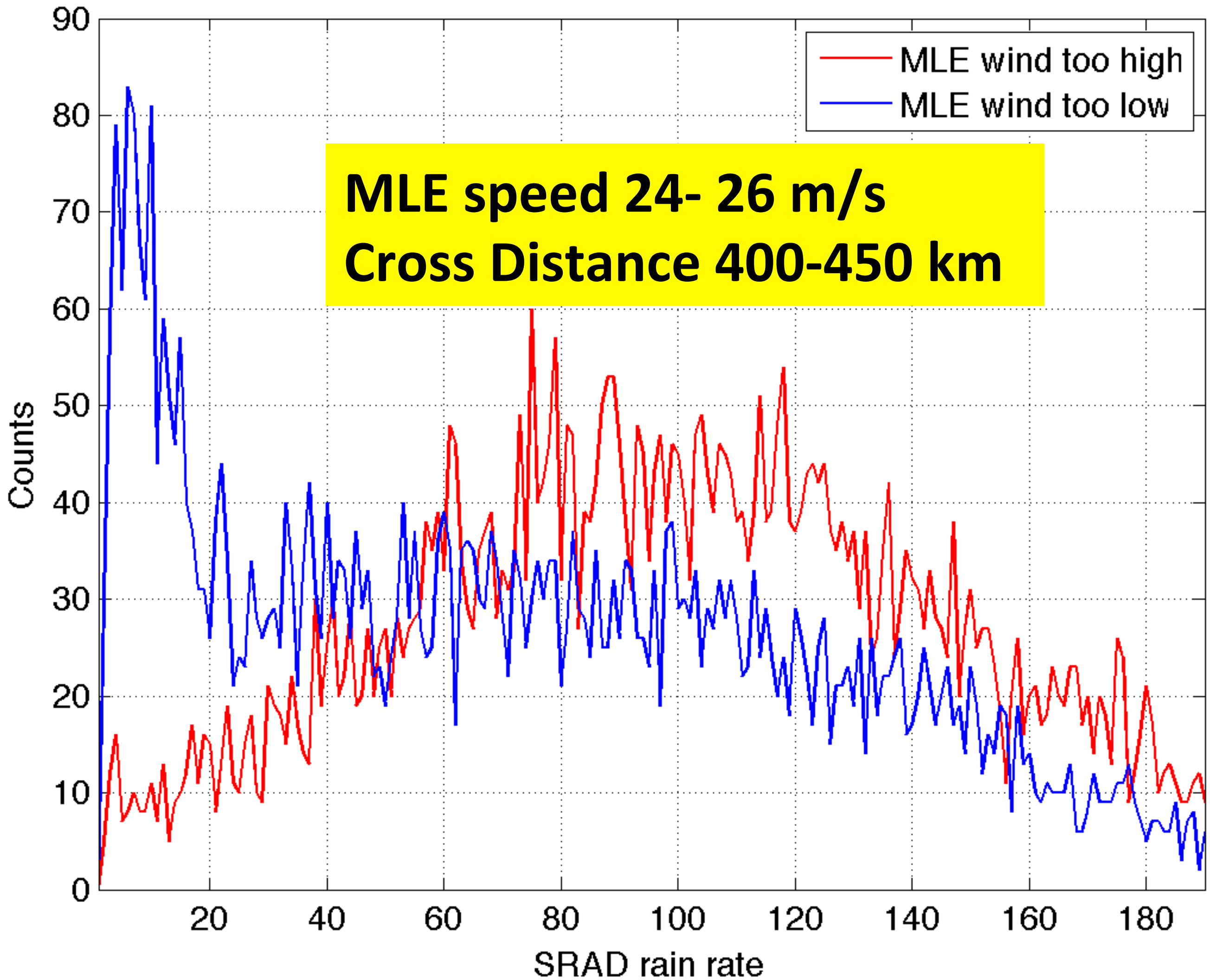
Examples Maximum Speed Tracks – Ivan 2004



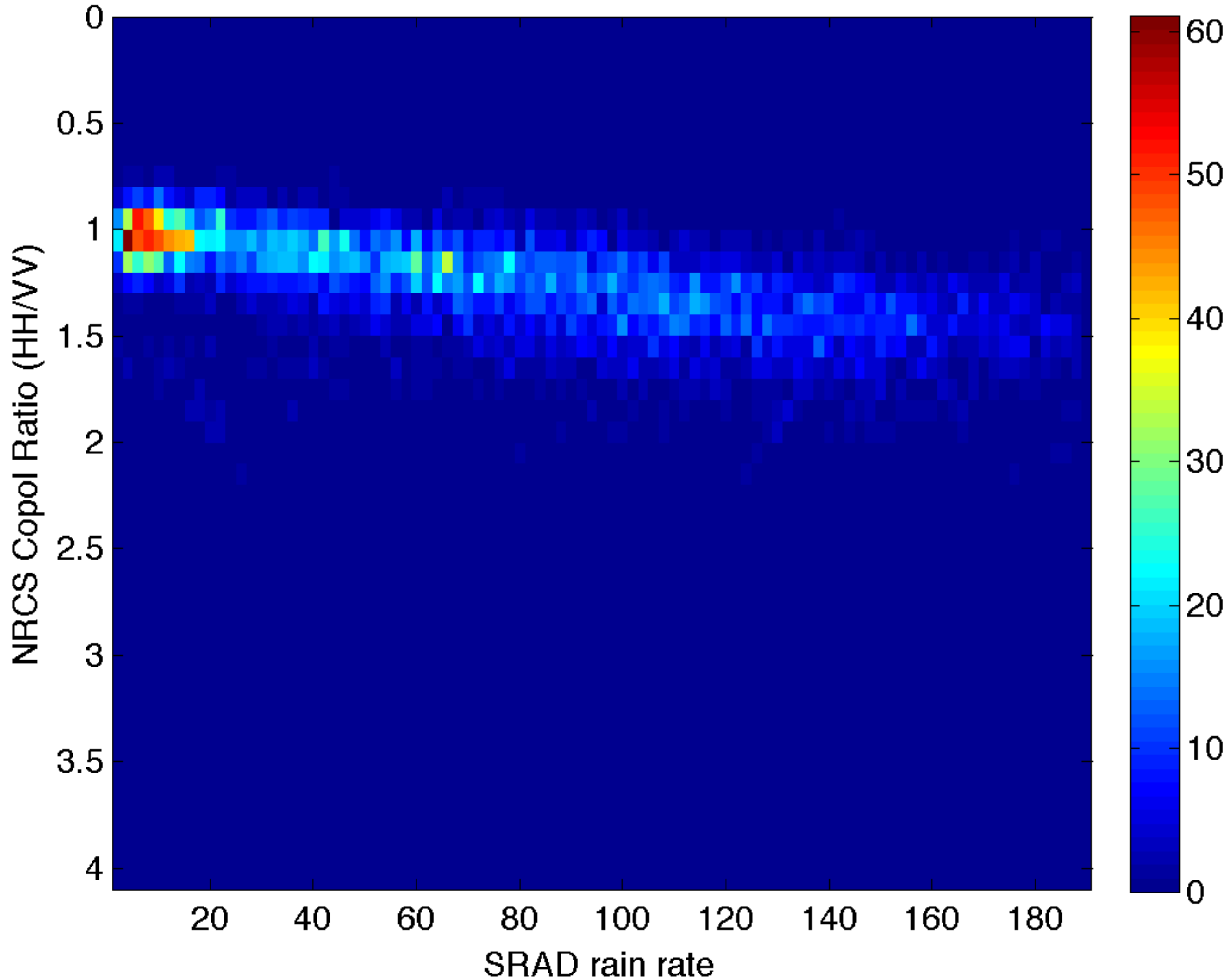
Examples Maximum Speed Tracks – Isabel 2003



SRAD Rain Rate Histogram



Joint Histogram Low MLE Wind



Joint Histogram High MLE Wind