Wind Vector Retrievals under Rain with Passive Satellite Microwave Radiometers

Thomas Meissner and Frank Wentz
Remote Sensing Systems
Santa Rosa, CA

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Topics

- Radiometer H-Wind Algorithm
  - Wind Speed Retrievals in Hurricanes
- Global Radiometer Wind Speeds in Rain
- Wind Direction
- Comparison: Hurricane Wind Vectors Radiometer versus Scatterometer
- Sensor Capability
- (Surface Emissivity Signals)

Problems to Retrieve Passive MW Winds Under Rain
Possible Mitigations

- Attenuation
  - Signal/Noise decreases. Especially at higher frequencies.
  - ➢ Use C- Band + X- Band
  - ➢ Lower resolution

- Rain signal very similar to wind signal
  - Algorithm treats increase in rain the same way as increase in wind.
  - ➢ Train algorithm under rain.
  - ➢ Try to find channel combinations that are less or not sensitive to rain but sensitive to wind.

- Wind speed retrieval algorithm without rain is based on physical radiative transfer model (RTM).

  Rain is difficult to model in RTM
  - Cloud type
  - Beamfilling (rain filling part of retrieval cell)
  - Depression in atmospheric temperature (scattering, …)
  - ➢ Use statistical algorithm (measured TBs) rather than physical algorithm (modeled TBs).

H- Wind Algorithm

Wind Speed Retrieval in Tropical Cyclones

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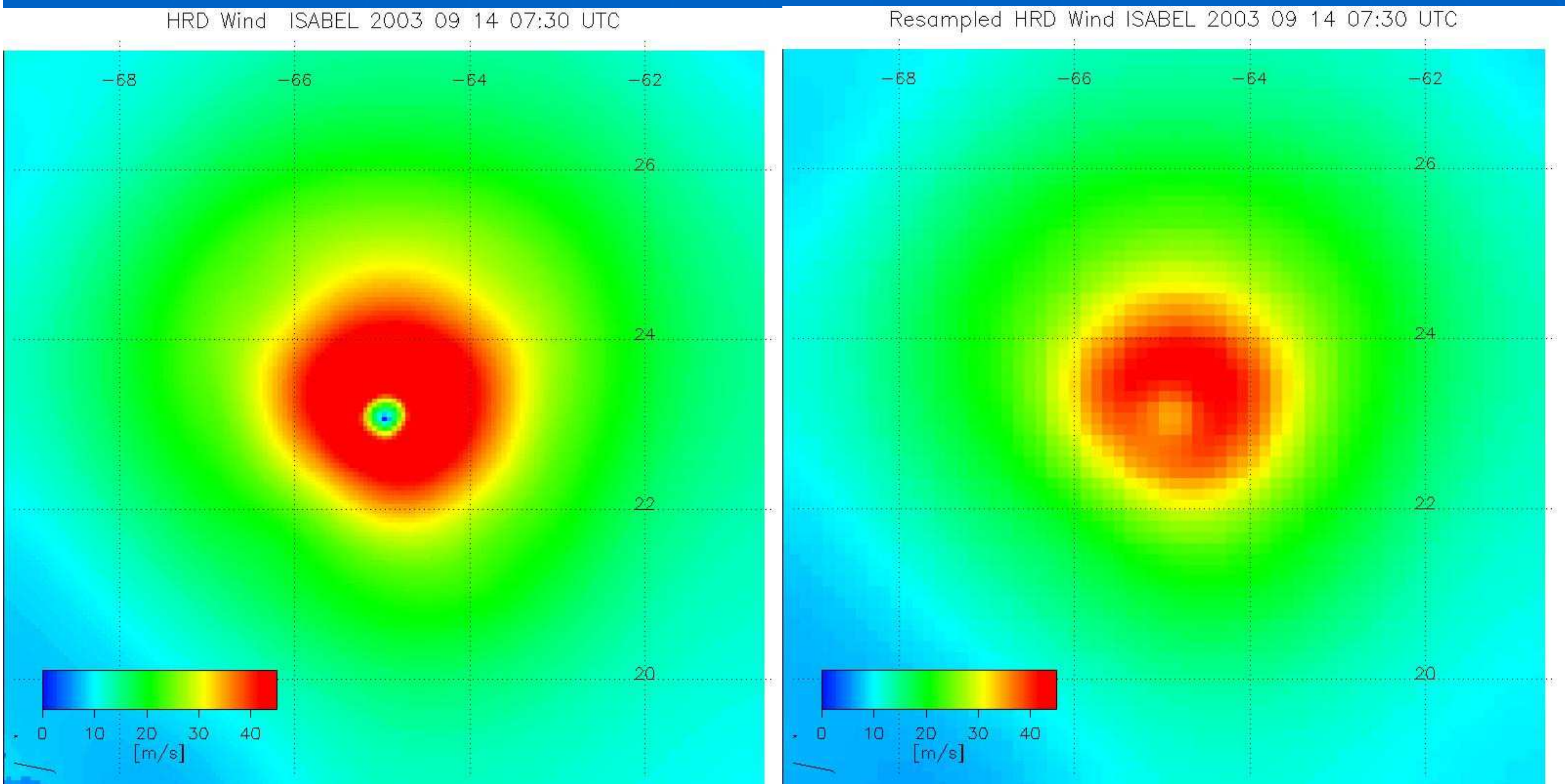
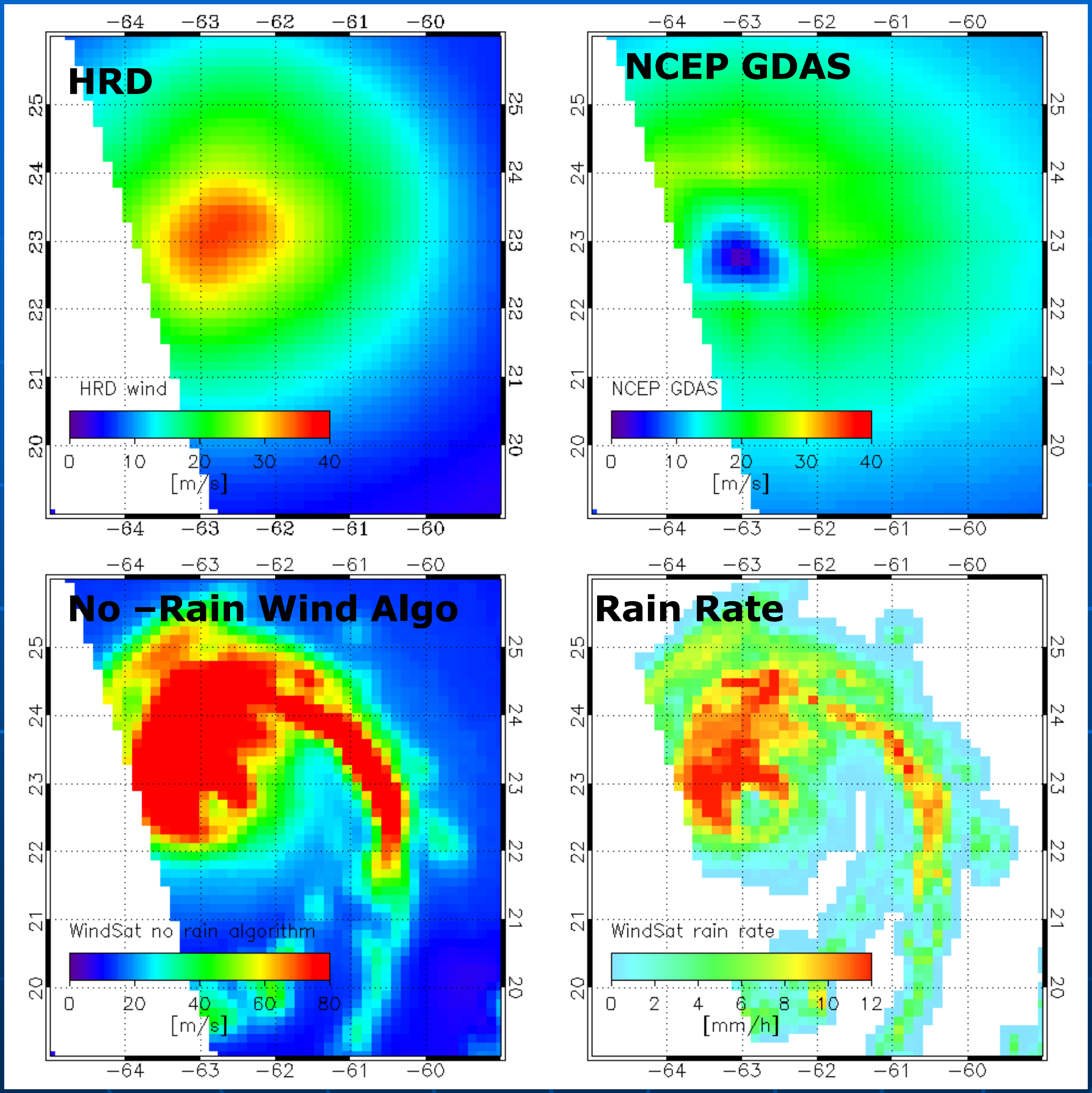
Study Data Sets

- Wind vectors from Surface Wind Analysis from the NOAA's Hurricane Research Division (HRD)
- Collocated with WindSat brightness temperatures
  - NRL Level0 data processed by RSS into Level2
  - Calibrated
  - Optimum interpolated onto 1/8 deg fixed Earth grid (X-band resolution)
- 17 storms during 2003 and 2004
- Rain flagged (TB exceeds boundary for rain free ocean scenes)
- 3 hour time window
- Scale HRD winds (1 minute sustained) by 0.88 to compare with satellite winds (10 minute sustained)
- Resample HRD winds (5 km) onto WindSat footprint (30 km for X-band)
- Visual shift of HRD field so that storm center coincides with WindSat
- Half of the set is used for training, the other half for testing
- About 24,000 wind vector cells for test set
- Triple matchup: WindSat – QuikScat – HRD
  - within 3 hours
  - 8 storms during 2003 and 2004
  - exclude if HRD analysis uses QuikScat
  - about 16,000 wind vector cells for testing

Resampling + Scaling of HRD Winds



FABIAN 03 September 2003



Algorithm trained under rain free conditions

measures rain rather than wind

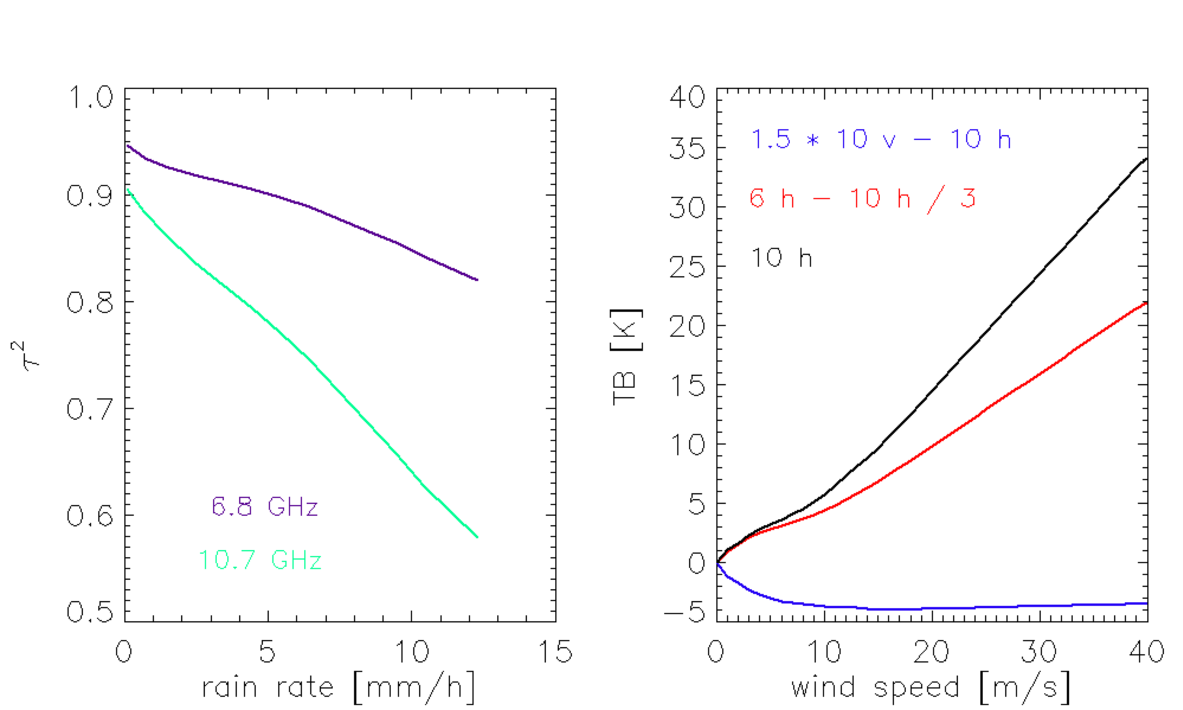
RTM

$$T_{BV} \approx \left(1 - R_V \tau^2\right) T_{eff}$$

$$T_{BH} \approx \left(1 - R_H \tau^2\right) T_{eff}$$

R: reflectivity

τ: transmittance



Polariztion Difference

$$\lambda \cdot T_{BV} - T_{BH}$$

$$\lambda = \frac{R_H}{R_V} \approx 1.5 \ldots 2.0$$

$\rightarrow$ τ drops out

insensitive to rain

but insensitive to wind above 8 m/s

Spectral Difference

$$R_{6H} \approx R_{10H} \equiv R_H$$

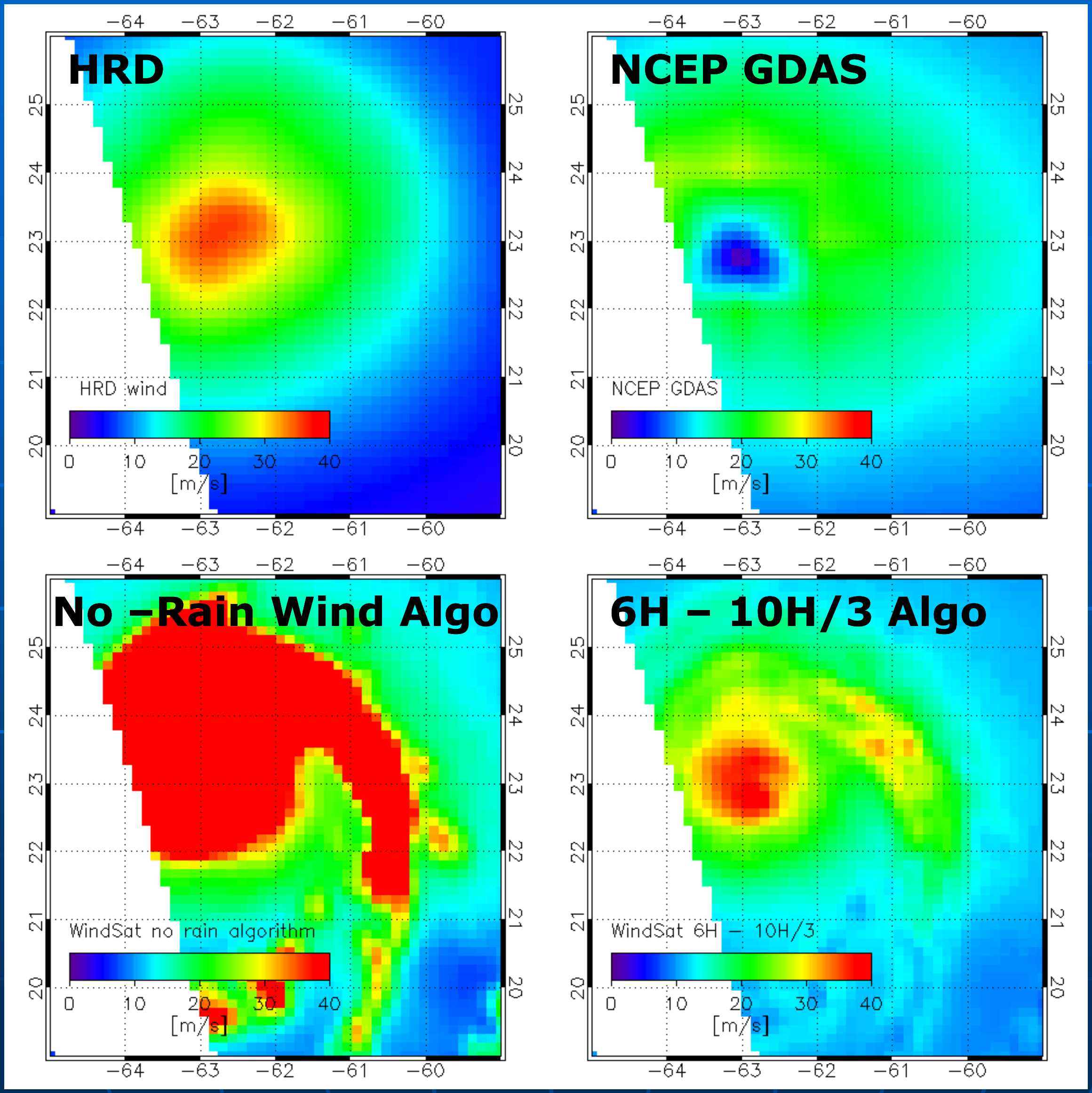
$$T_{BH}^{6.8\,GHz} - \lambda \cdot T_{BH}^{10.7\,GHz} \approx T_{eff}\, R_H \left(\tau_{6.8\,GHz}{}^2 - \lambda \cdot \tau_{10.7\,GHz}{}^2\right)$$

insensitive to rain :

$$\frac{\partial}{\partial R}\left(\tau_{6.8\,GHz}{}^2 - \lambda \cdot \tau_{10.7\,GHz}{}^2\right) = 0 \rightarrow \lambda = \frac{\partial \tau_{6.8\,GHz} / \partial R}{\partial \tau_{10.7\,GHz} / \partial R} \approx \frac{1}{3}$$

keeps sensitivity to wind

6H – 10H/3 Algo


HRD
HRD wind
NCEP GDAS
NCEP GDAS
No –Rain Wind Algo
WindSat no rain algorithm
6H – 10H/3 Algo
WindSat 6H – 10H/3
0 10 20 30 40
[m/s]
−64 −63 −62 −61 −60
20 21 22 23 24 25

Spectral difference between C-Band and X-Band allows to reduce the rain effect but retains sufficient sensitivity to wind speed.

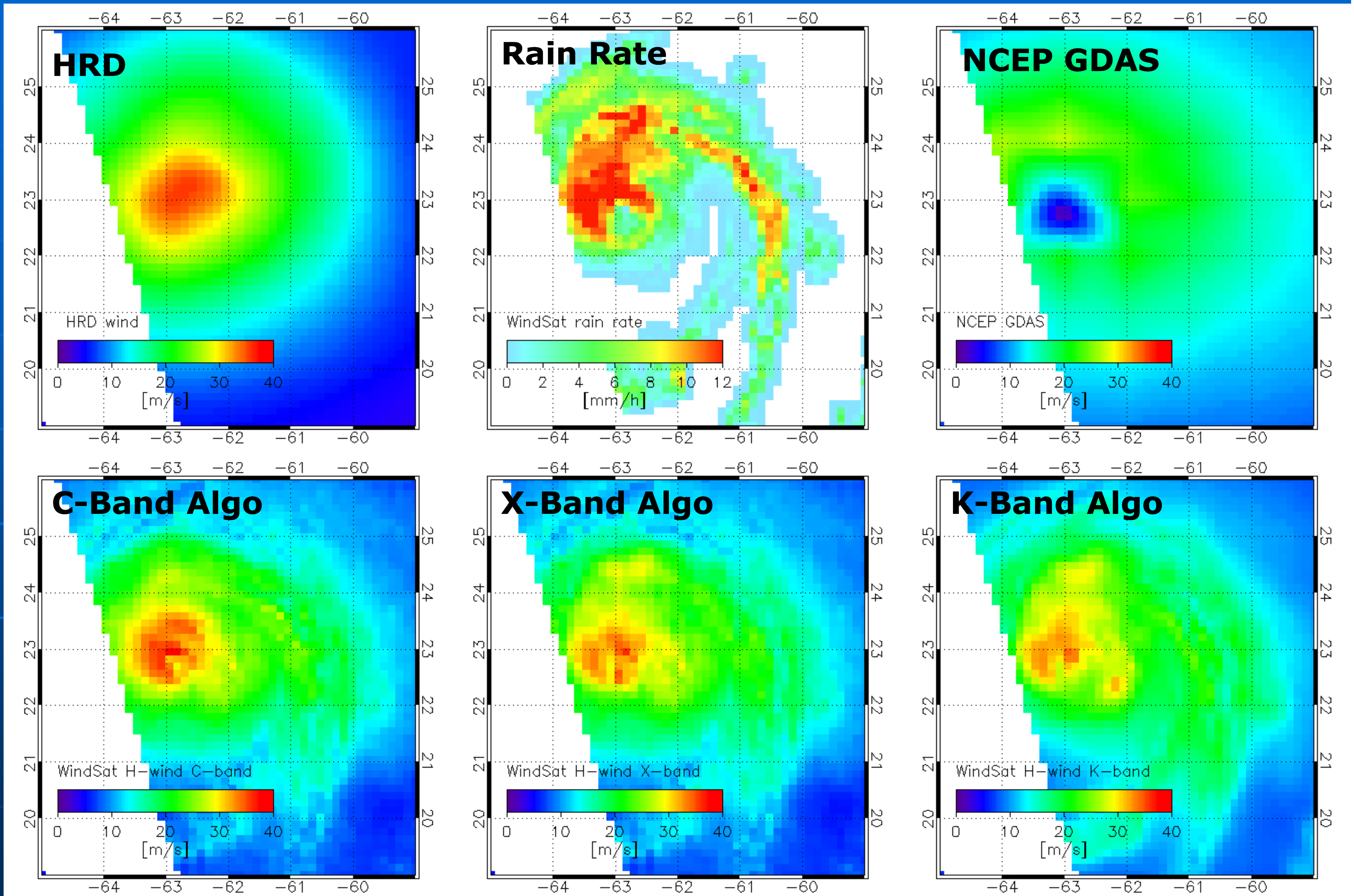
Multi-frequency microwave radiometer (C. Swift et al.)

- six frequencies at C-band
- aircraft

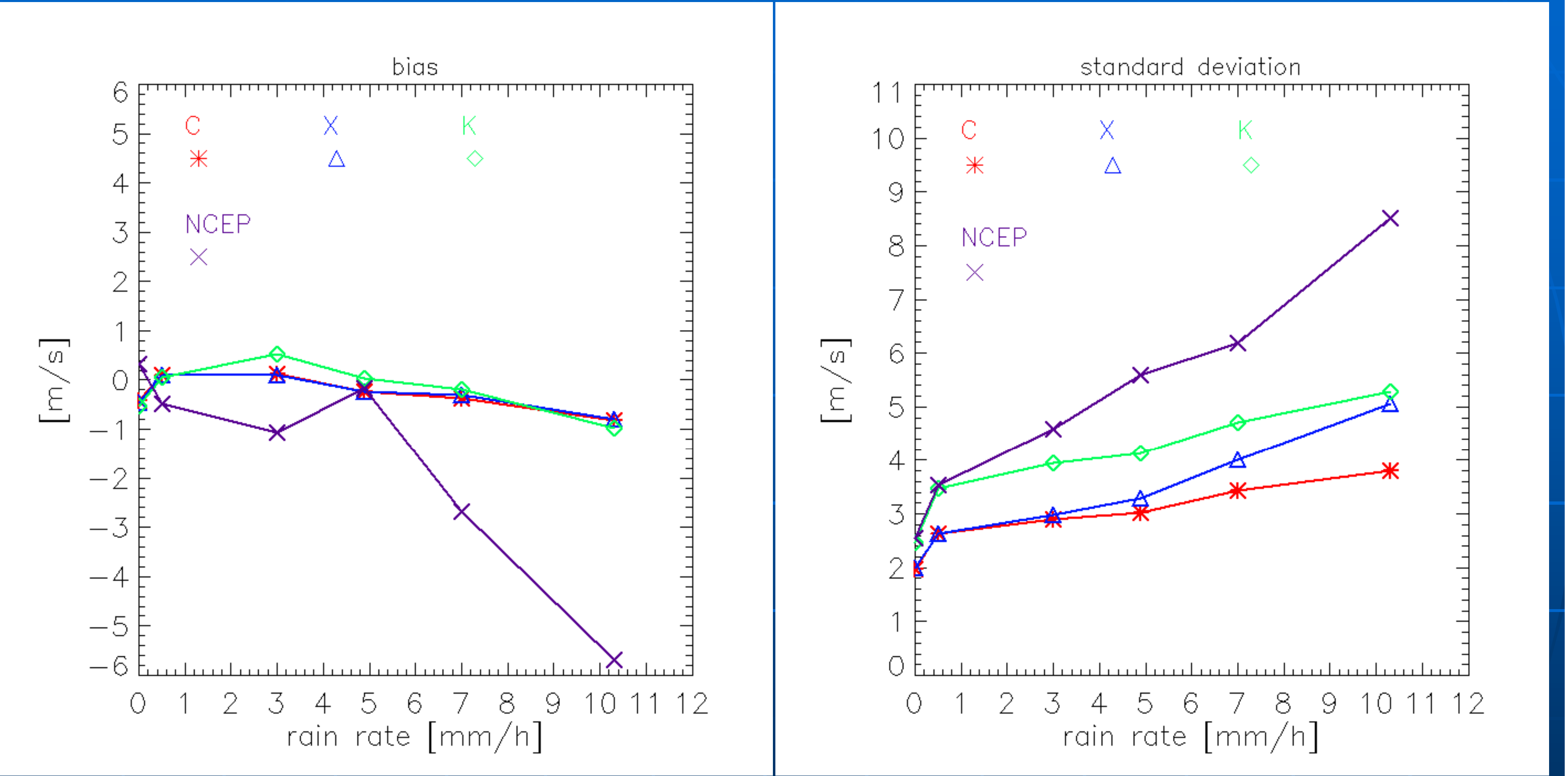
Training of H-Wind Algorithm

$$W = \alpha_0(\tau) + \alpha_1(\tau) \cdot SST + \sum_i \beta_i(\tau) \cdot T_{Bi} + \sum_i \gamma_i(\tau) \cdot T_{Bi}{}^2$$

- Sum over all WindSat channels
- Optimal channel configuration found by regression
- Regression coefficients dependent on atmospheric transmittance (rain rate)
- 3 Algorithms
  - C-band (6.8 GHz) + higher frequencies
  - X-band (10.7 GHz) + higher frequencies
  - K-band (18.7 GHz) + higher frequencies


HRD
HRD wind
[m/s]
Rain Rate
WindSat rain rate
[mm/h]
NCEP GDAS
NCEP GDAS
[m/s]
C-Band Algo
WindSat H-wind C-band
[m/s]
X-Band Algo
WindSat H-wind X-band
[m/s]
K-Band Algo
WindSat H-wind K-band
[m/s]

WindSat H-Wind minus HRD Wind



Degradation of X-band algorithm in higher rain

Degradation of K-band algorithm already in light rain

- better than NCEP GDAS
- 5 m/s standard deviation error in hurricane still useful

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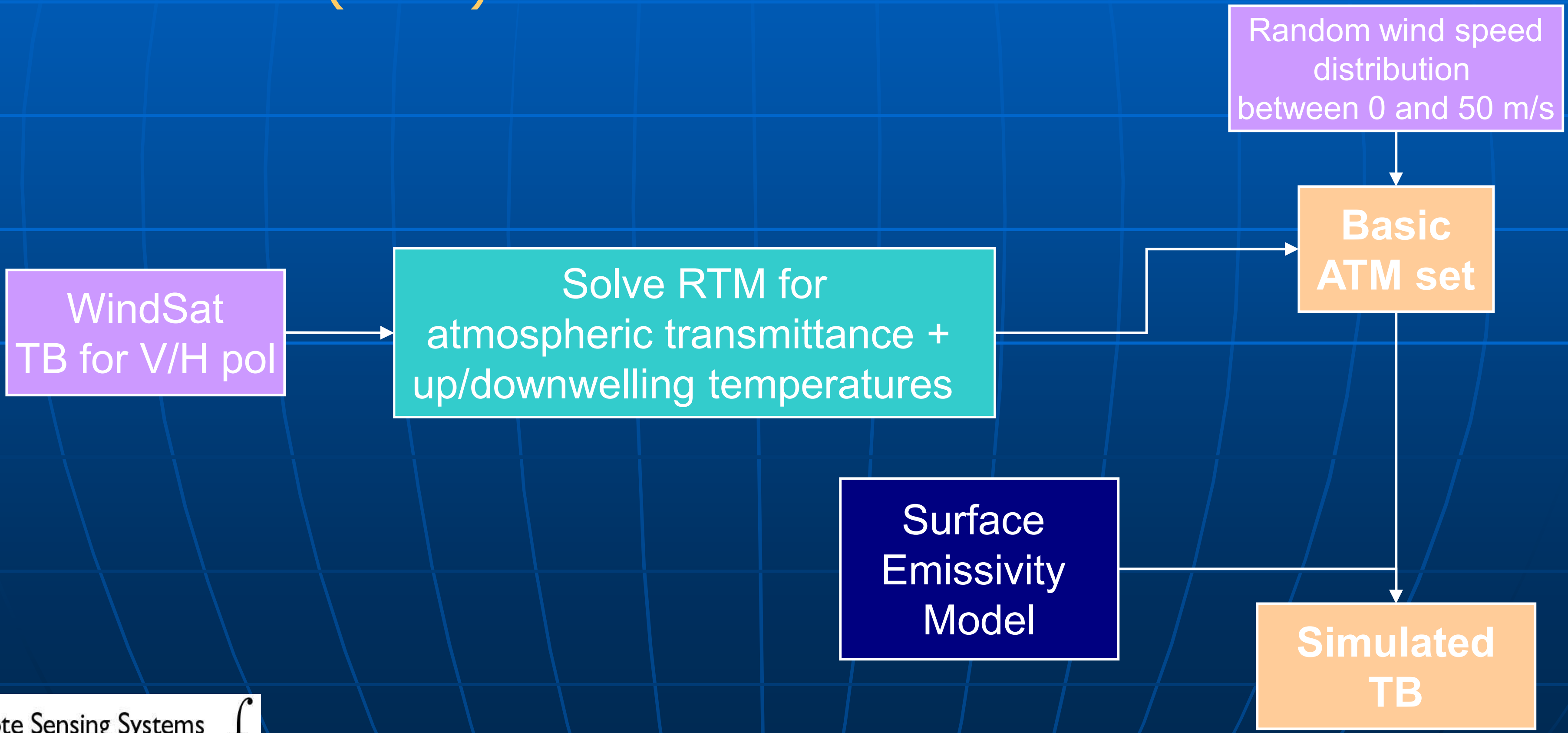
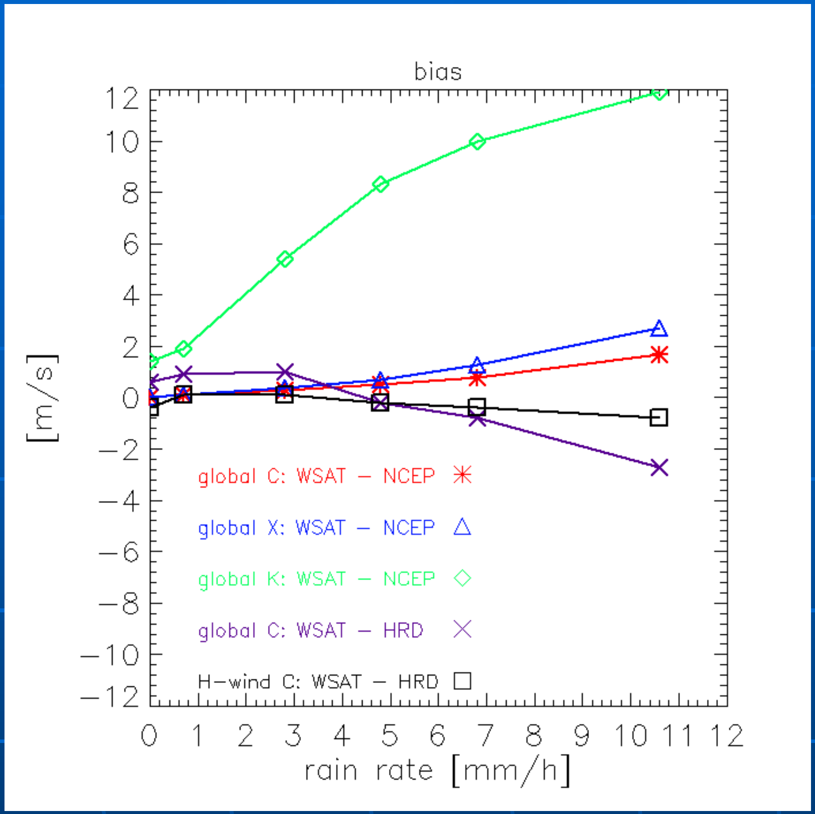
Global Wind Speed Algorithm in Rain

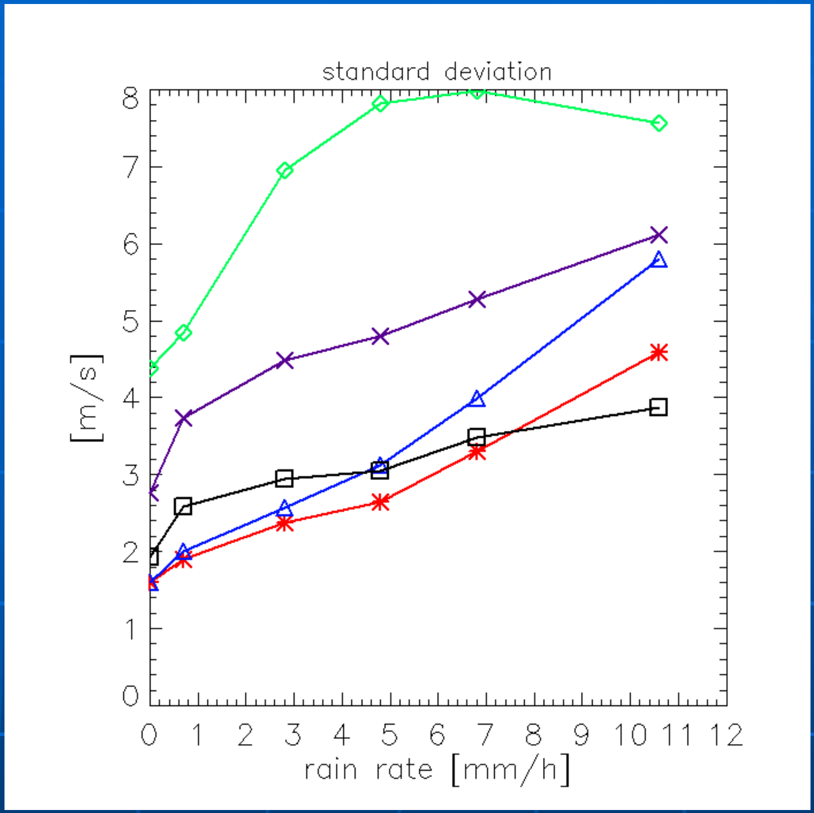
can be applied globally under all rain conditions

- NCEP wind speeds as ground truth.
- Good at low winds, but NCEP is bad and insufficiently populated at high winds (> 25 m/s).
- Hybrid (Statistical-Physical) Algorithm
- Decouples rainy atmosphere (statistical) from surface (RTM)



Performance of Global Algorithm



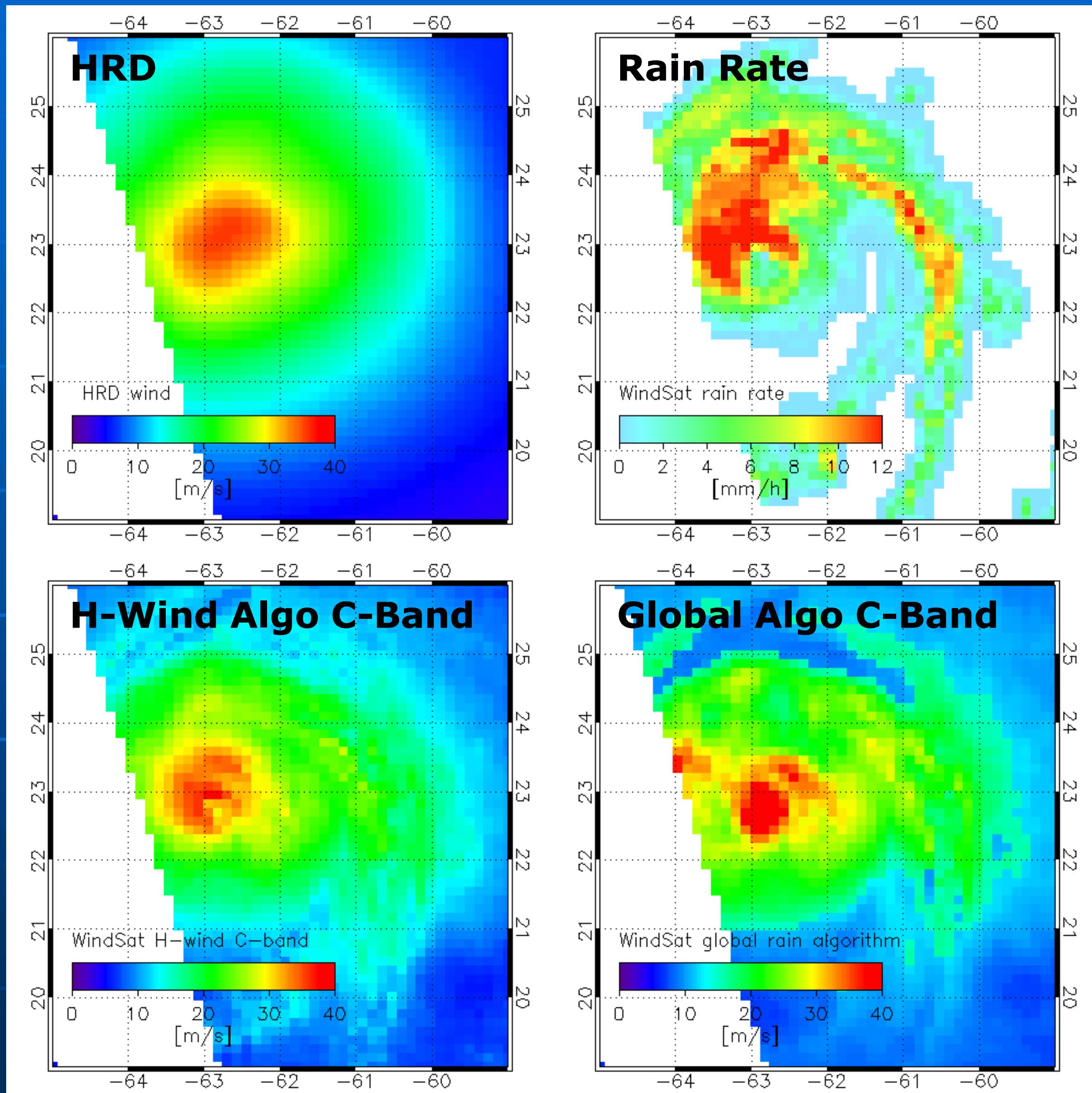


Ground Truth used for evaluation

- NCEP, 1 year, globally
  Wind speeds below 25 m/s
- WindSat – HRD matchups
  High winds

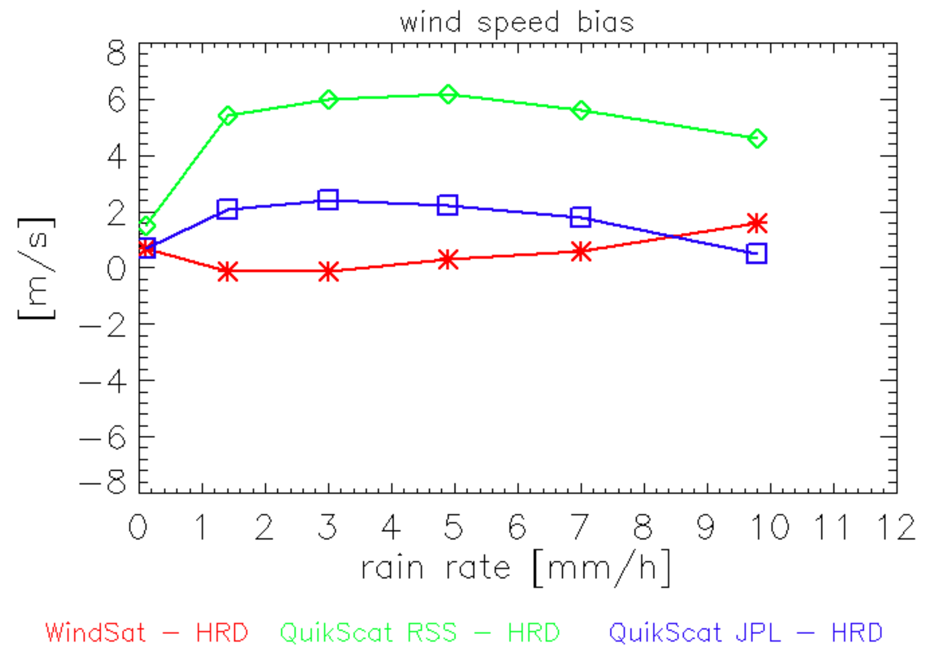
- global C-band algorithm on HRD winds is less accurate than H-wind algorithm
- global C/X-band algorithms work well
- global K-band algorithm does NOT work well

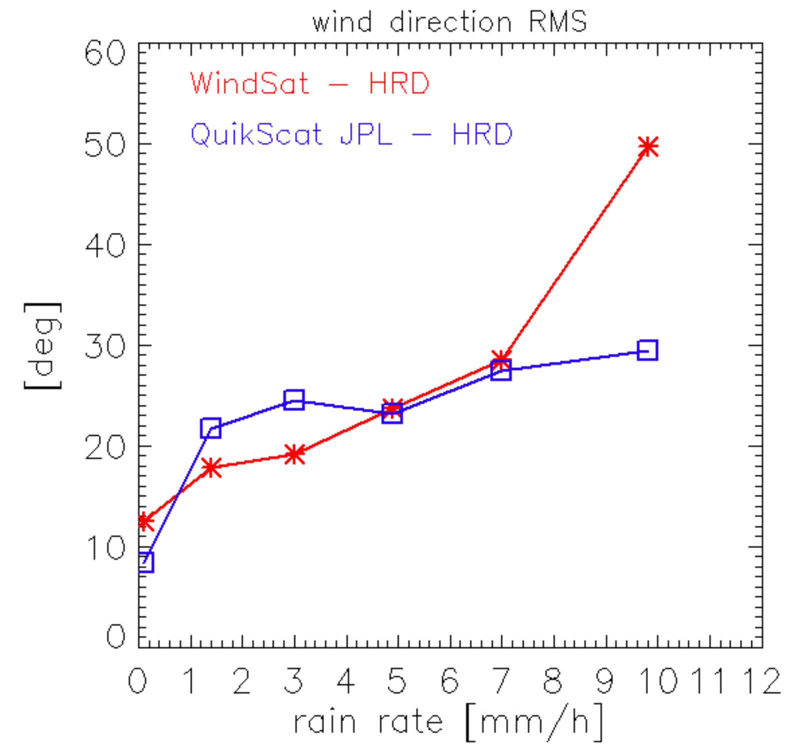
WindSat H-Wind versus Global Algorithm

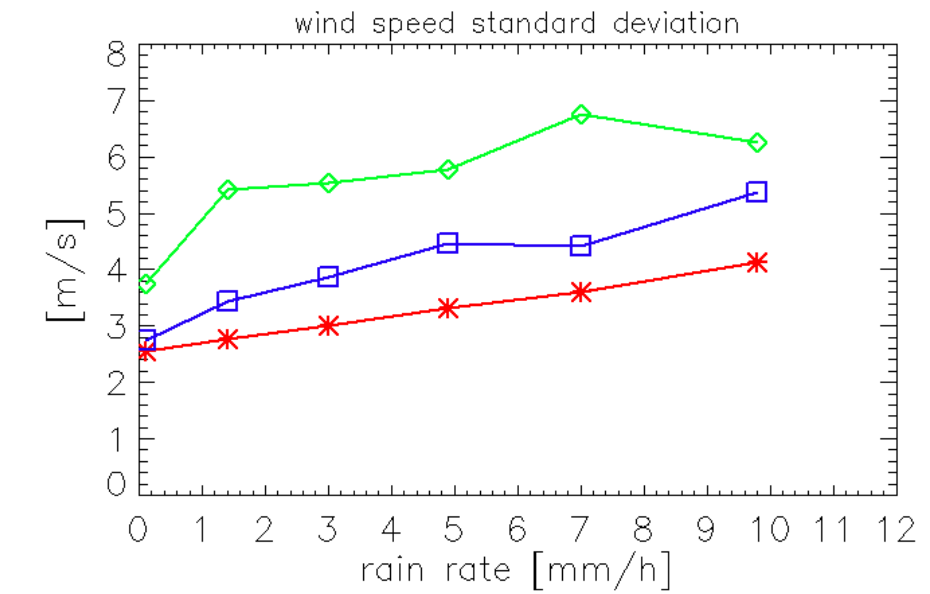


Radiometer versus Scatterometer

Triple Matchup Set
WindSat – QuikSCAT – HRD
Wind Speed > 8 m/s
WindSat H-Wind X-band Algo







- RSS QuikScat (Ku 2001 GMF) wind speeds biased high
- Radiometer wind directions comparable with scatterometer beside in very high rain
- Degradation of radiometer performance gradual with increasing rain rate
- Scatterometer performance varies by storm

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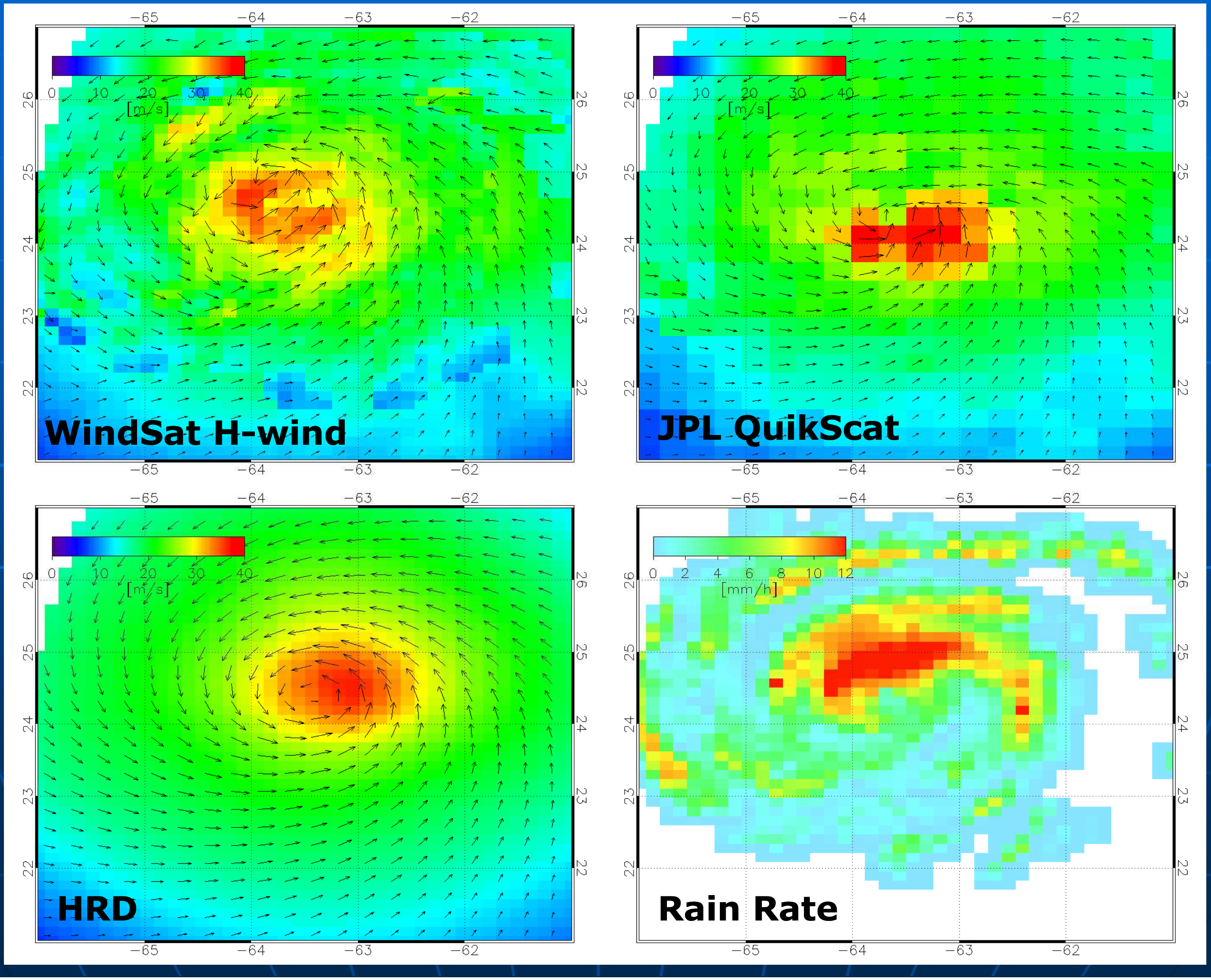

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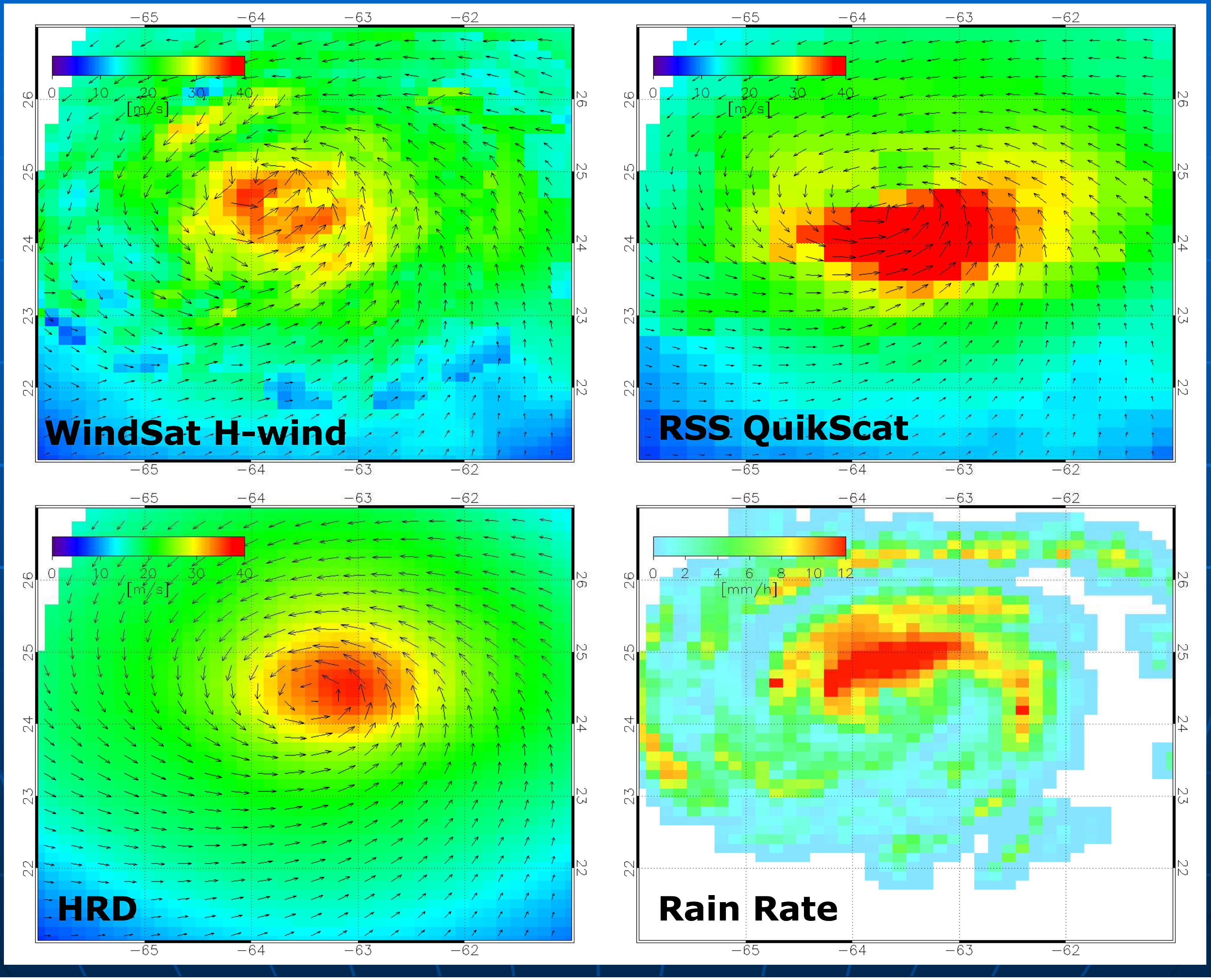
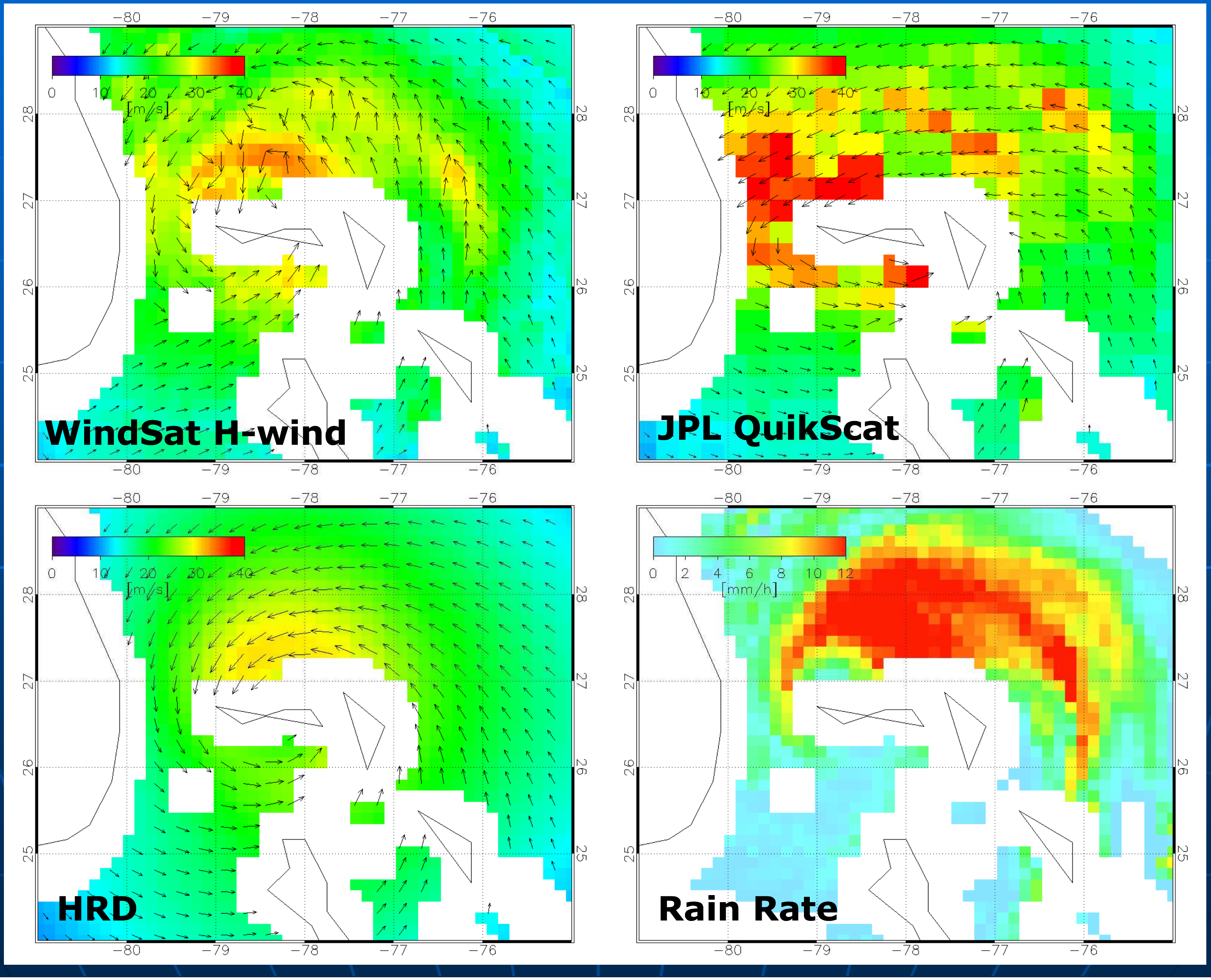
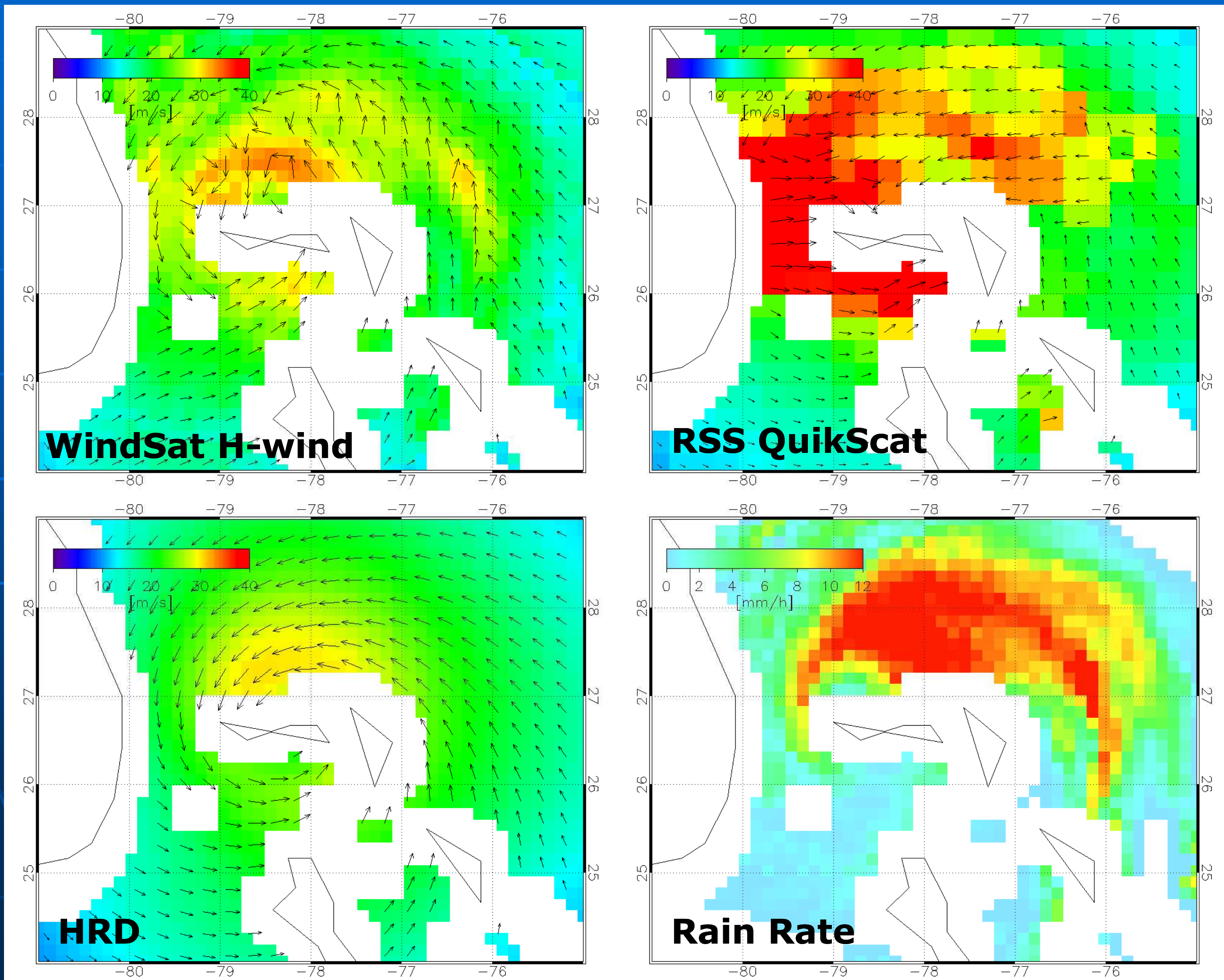


FRANCES 04 September 2004



FRANCES 04 September 2004



Radiometer Wind Vectors in Rain

Capability Chart

<table>
<tr><th></th><th colspan="6">Wind Speed
Hurricanes</th><th colspan="2">Wind Speed
Global Rain</th><th colspan="2">Wind Direction
Hurricanes</th></tr>
<tr><td>SSM/I</td><td colspan="6">K</td><td colspan="2">no</td><td colspan="2">no</td></tr>
<tr><td>SSMIS</td><td colspan="6">K</td><td colspan="2">no</td><td colspan="2">no</td></tr>
<tr><td>TMI</td><td colspan="3">X</td><td colspan="3">K</td><td colspan="2">X</td><td colspan="2">no</td></tr>
<tr><td>GMI</td><td colspan="3">X</td><td colspan="3">K</td><td colspan="2">X</td><td colspan="2">no</td></tr>
<tr><td>AMSR-E</td><td colspan="2">C</td><td colspan="2">X</td><td colspan="2">K</td><td>C</td><td>X</td><td colspan="2">no</td></tr>
<tr><td>GCOM</td><td colspan="2">C</td><td colspan="2">X</td><td colspan="2">K</td><td>C</td><td>X</td><td colspan="2">no</td></tr>
<tr><td>WindSat</td><td colspan="2">C</td><td colspan="2">X</td><td colspan="2">K</td><td>C</td><td>X</td><td>X</td><td>wspd > 8 m/s
rain rate < 8 mm/h</td></tr>
<tr><td>MIS</td><td colspan="2">C</td><td colspan="2">X</td><td colspan="2">K</td><td>C</td><td>X</td><td>X</td><td>wspd > 8 m/s
rain rate < 8 mm/h
3rd Stokes at X-band</td></tr>
</table>

C	X	K	resolution

Backup Slides

Wind Induced Surface Emissivity Signal

WindSat TB over HRD Winds

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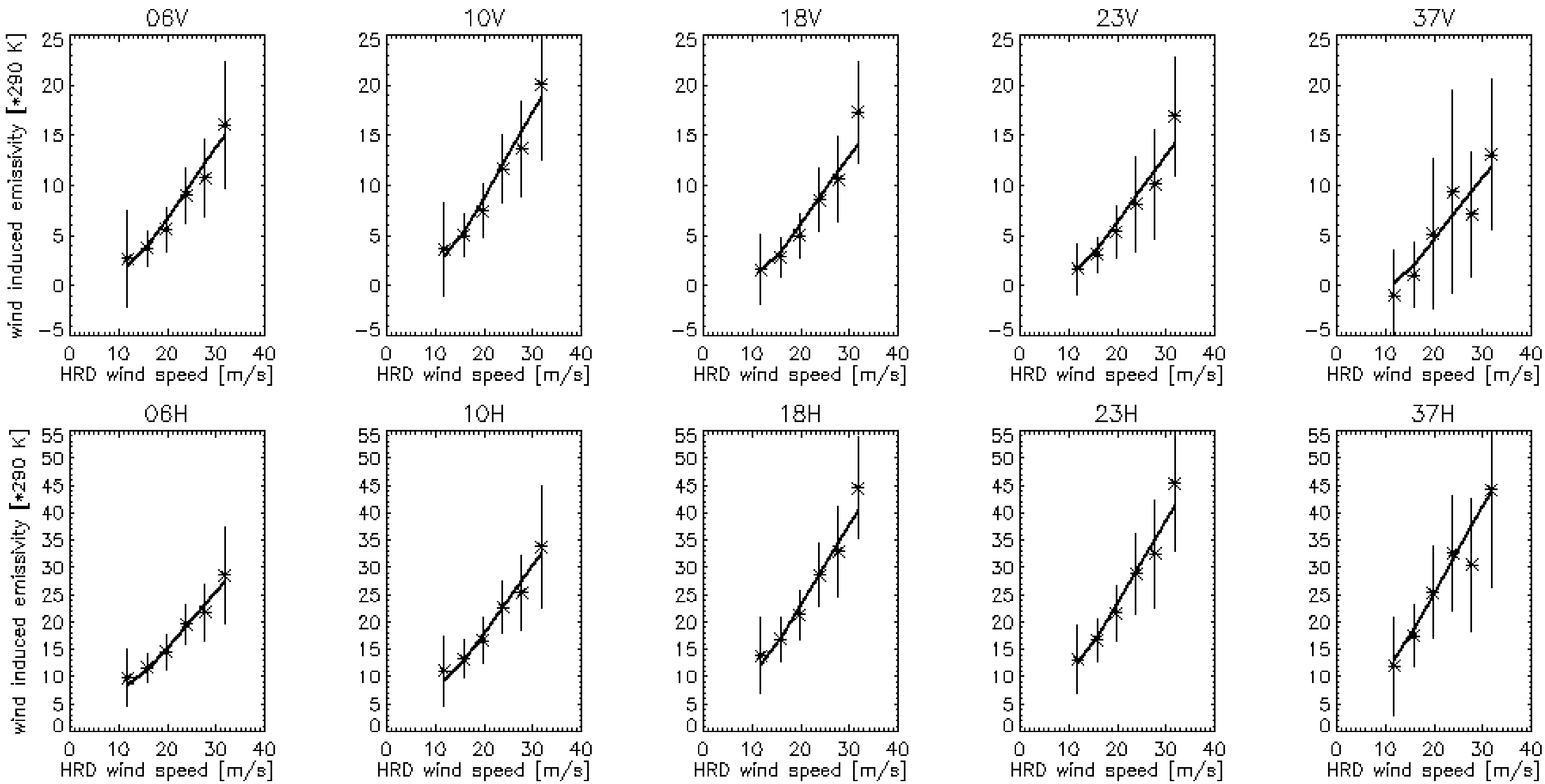
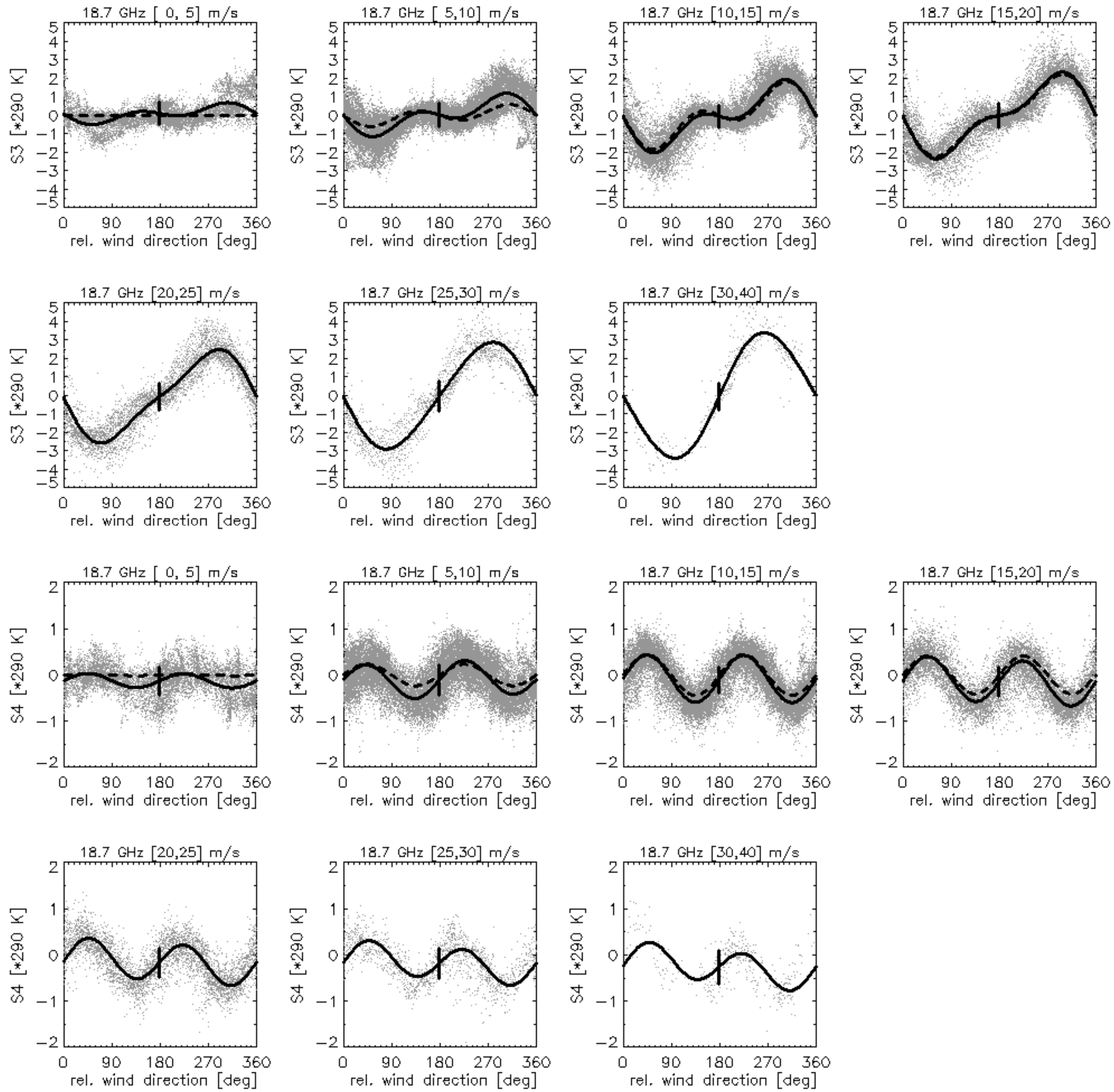


- Above 12 m/s wind induced emissivity is mainly due to sea foam.
- Solid lines: RSS Ocean Emissivity Model that was developed for wind speeds below 18 m/s linearly extrapolated to high wind speeds.
- Asterisks: Result of WindSat TB versus HRD wind speed analysis.
- No signs of saturation at high winds



18.7 GHz
3rd and 4th Stokes

7 wind speed bins
between 0 - 40 m/s

solid line:
2nd order harmonic fit

dashed line:
RSS Ocean Emissivity Model that was developed for wind speeds below 18 m/s

3rd Stokes:
6K amplitude at high winds

Radiometer Wind Direction Retrieval in Rain

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H-Wind Direction Algorithm

- Crucial: Increase of directional signal (3rd Stokes) of surface emissivity at high wind versus attenuation by rain
  - Strong correlation of high winds and high rain in tropical cyclones
- Maximum Likelihood Estimate (MLE) matches measured TB to RTM
- In rain use only 3rd and 4th Stokes but no V/H
  - Small V/H signal swamped by atmosphere
- Wind speed from H-wind X-band algorithm
  - MLE only done over wind direction space
  - Important to have good wind speed for MLE
  - Cannot use no-rain algorithm for retrieving wind speed
- Atmospheric transmittance from auxiliary regression algorithm
- SST from Reynolds
- Ambiguity selection
  - Median Filter
  - Nudged with NCEP field if wind speed lower than 12 m/s or if rain rate above 2 mm/h