Rain Effects on Scatterometer Systems
A summary of what is known to date

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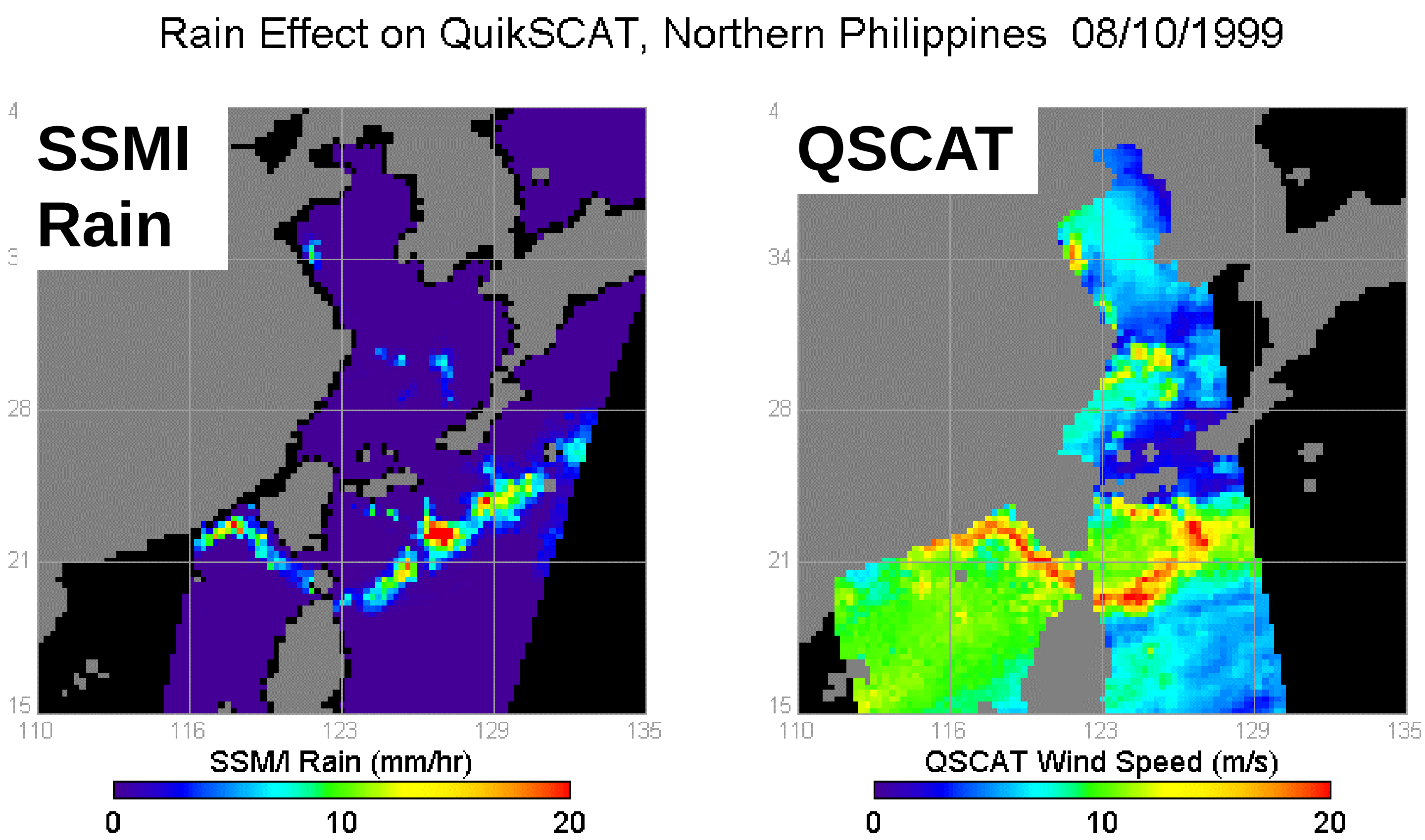
Part I

Examples of Rain Effects on Different Instruments

SeaSat
NSCAT
ERS1/2
QuikSCAT
ASCAT

Low Winds (~10 m/s) Result in Exaggerated Speeds



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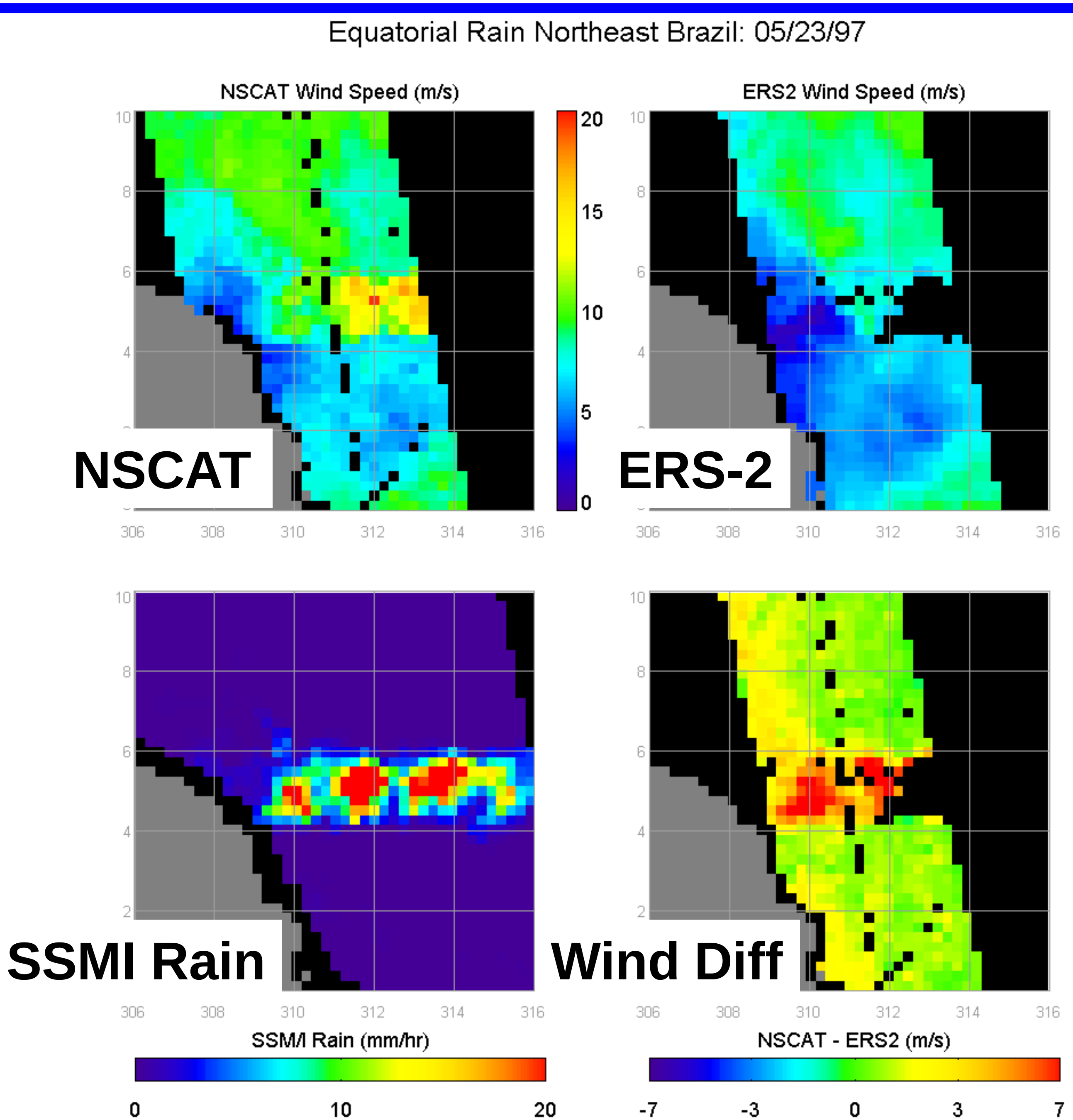

Low wind speed example

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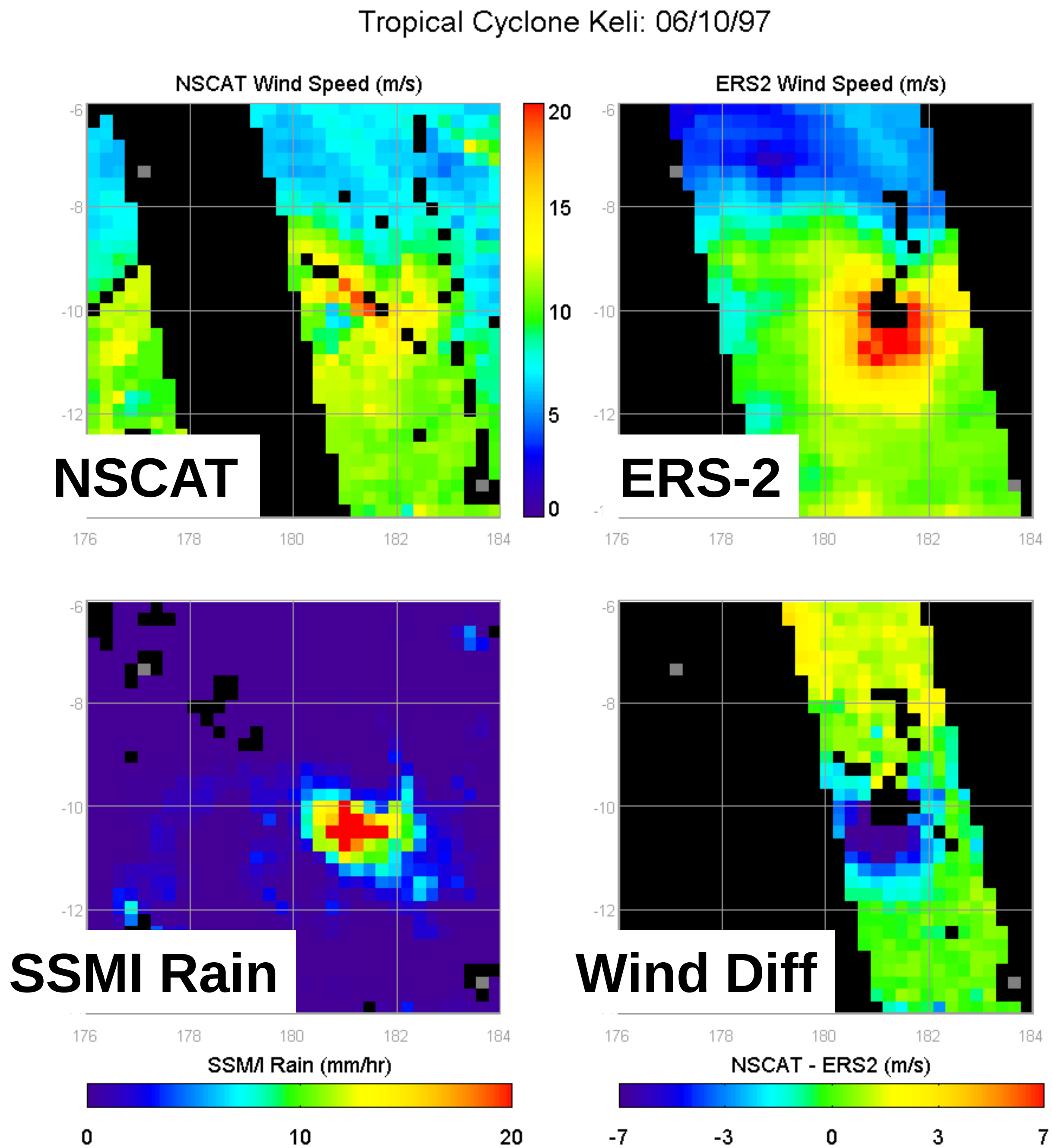

High wind speed example

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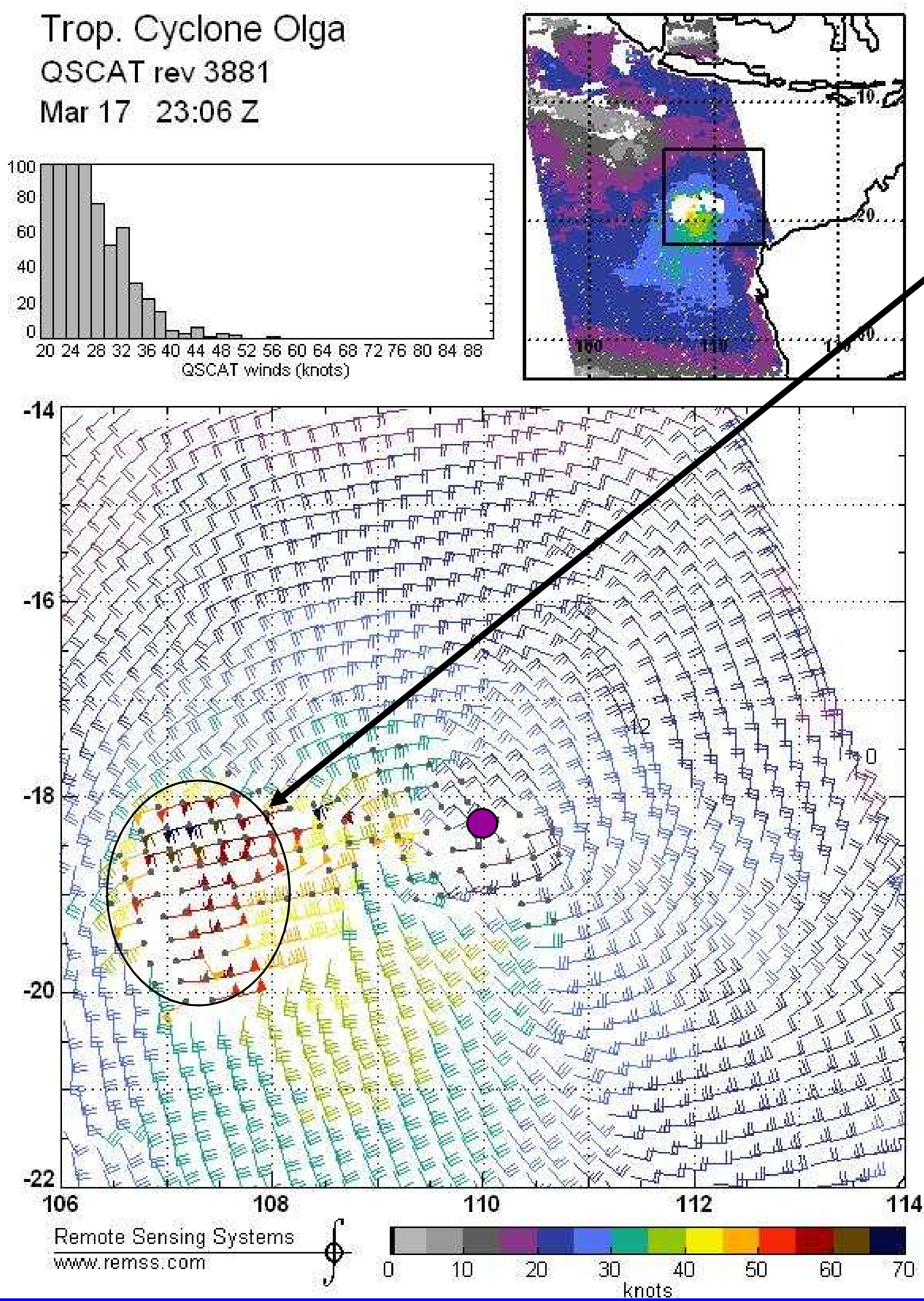
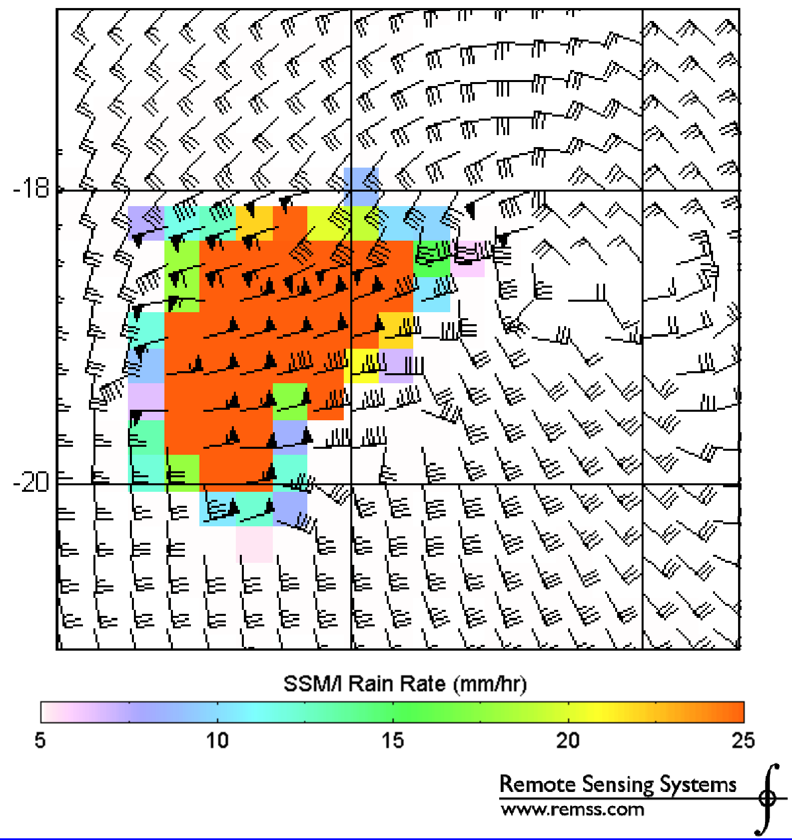
Reported storm location at 0 Z Mar 18 2000

QSCAT

Rain effects:
Cross swath vectors
Higher wind speeds





Effects of Rain on Scatterometer Data are Documented in the Literature

Moore, R. K., A. H. Chaudhry and I. J. Birrer (**1983**), Errors in scatterometer-radiometer wind measurement due to rain, IEEE Journal of Oceanic Engineering, 8.

Bliven, L. F., and others (**1993**), An analysis of scatterometer returns from a water surface agitated by artificial rain: Evidence that ring-waves are the main feature, International Journal of Remote Sensing, 14.

Stiles, B. W. and S. H. Yueh (**2002**), Impact of rain on spaceborne Ku-band wind scatterometer data, IEEE Transactions on Geoscience and Remote Sensing, 40.

Contreras, R. F., and others (**2003**), Effects of rain on Ku-band backscatter from the ocean, Journal of Geophysical Research, 108.

Tournadre, J. and Y. Quilfen (**2003**), Impact of rain cell on scatterometer data: 1. Theory and modeling, Journal of Geophysical Research, 108.

Draper, D. W. and D. G. Long **(2004**), Evaluating the effect of rain on SeaWinds scatterometer measurements, Journal of Geophysical Research, 109.

Hoffman, R. N., C. Grassotti and S. M. Leidner (**2004**), SeaWinds validation: effect of rain as observed by East Coast radars, Journal of Atmospheric and Oceanic Technology, 21.

Ahmad, K. A., and others (**2005**), Oceanic rain rate estimates from the QuikSCAT radiometer: A global precipitation mission pathfinder, Journal of Geophysical Research, 110.

Weissman, D. E. and M. A. Bourassa (**2008**), Measurements of the effect of rain-induced sea surface roughness on the QuikSCAT scatterometer radar cross section, IEEE Transactions on Geoscience and Remote Sensing, 46.

Part II

RAIN EFFECTS

Physical Processes At Work:
Surface Splash
Rain Signal Attenuation
Rain Drop Backscatter

Variables Involved:
Incidence Angle
Frequency
Polarization
Actual Wind Speed
Rain Rate
Rain Type

Basic Model

$$\sigma_{0,meas} = \tau^2 \left(\sigma_{0,wind} + \Delta\sigma_{0,rain} \right) + \sigma_{0,vbs}$$

surface splash

surface signal

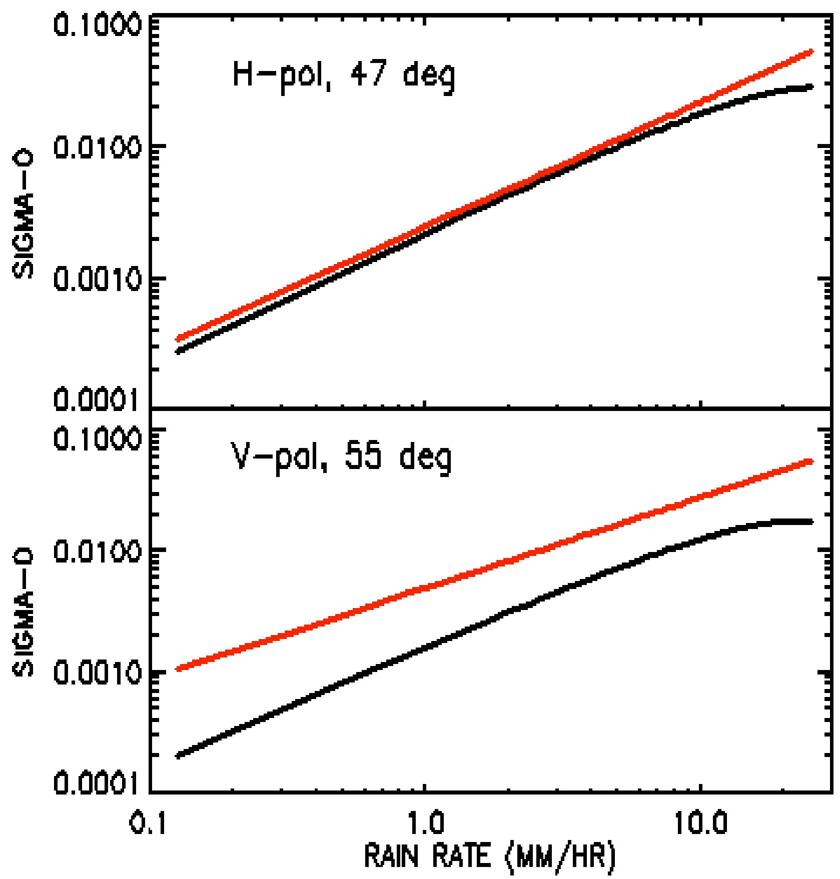
volumetric rain backscatter

transmittance

atmospheric signal

Surface Roughening (Splash)

- Rain increases surface roughness for SeaWinds frequency and incidence angles
- Effect is typically parameterized in terms of rain rate
- Surface roughening by rain is crucial to explain rain effects at low rain rates (backscatter is not enough by itself)
- We found values similar to **Contreras et al., 2003** for h-pol, and smaller values for v-pol

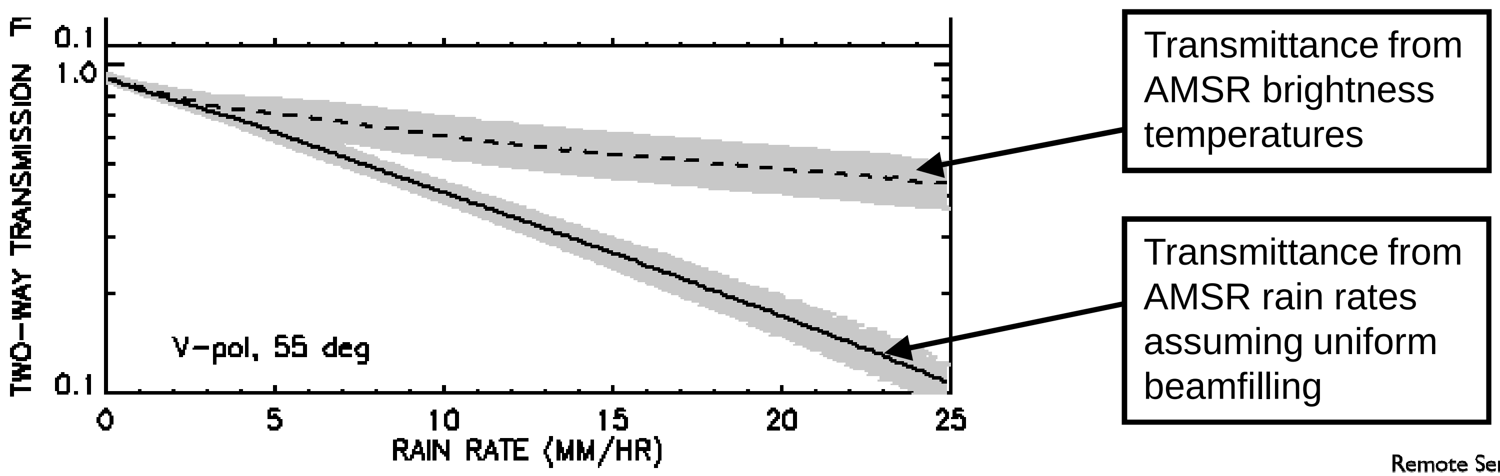


Estimation of Atmospheric Transmittance

- Radiometer provides direct estimate of τ^2 from h-pol and v-pol brightness temperatures:

$$T_B = T_E\left(1-\tau^2\rho\right)$$

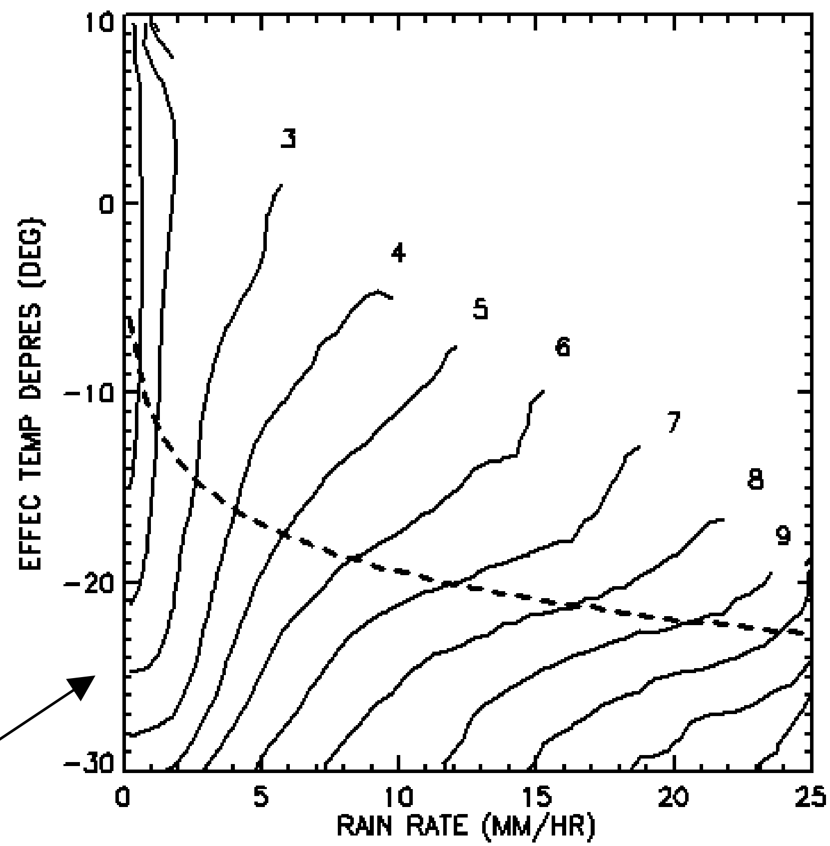
- Estimating transmittance using the "footprint average rain rate" gives too small a value due to the beamfilling effect, and consequently, results in too high a value of "corrected wind"



Rain Backscatter

- Well known: relationship between radar reflectivity and rain rate has variability due to drop size distribution variability
- Ku-band is "attenuating frequency", so need to account for the vertical profile as well
- DSD and profile both related to type of precipitation; we diagnose using radiometric scattering information (effective temperature depression)

Contours: SeaWinds – NCEP Wind Speed (m/s)



SeaWinds minus NCEP wind speed: artifacts are a function of rain rate and effective temperature depression, as evidenced by the diagonal contours (dashed line: mean relationship between rain rate and effect. temp. dep.)

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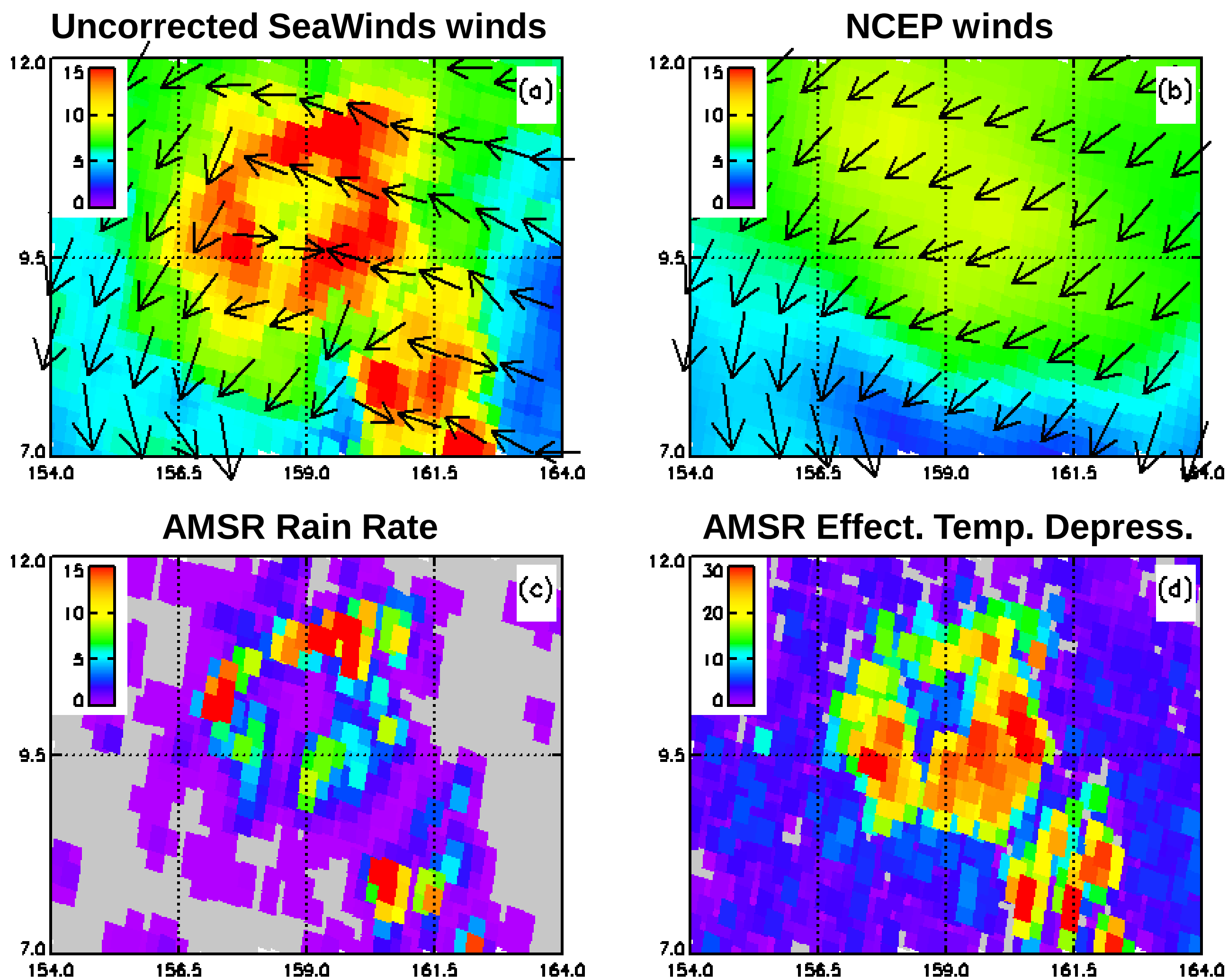
Wind Artifacts Depend on Rain Rate and the Effective Temperature Depression



28 June 03, West of the Marshall Islands, Rev 2806

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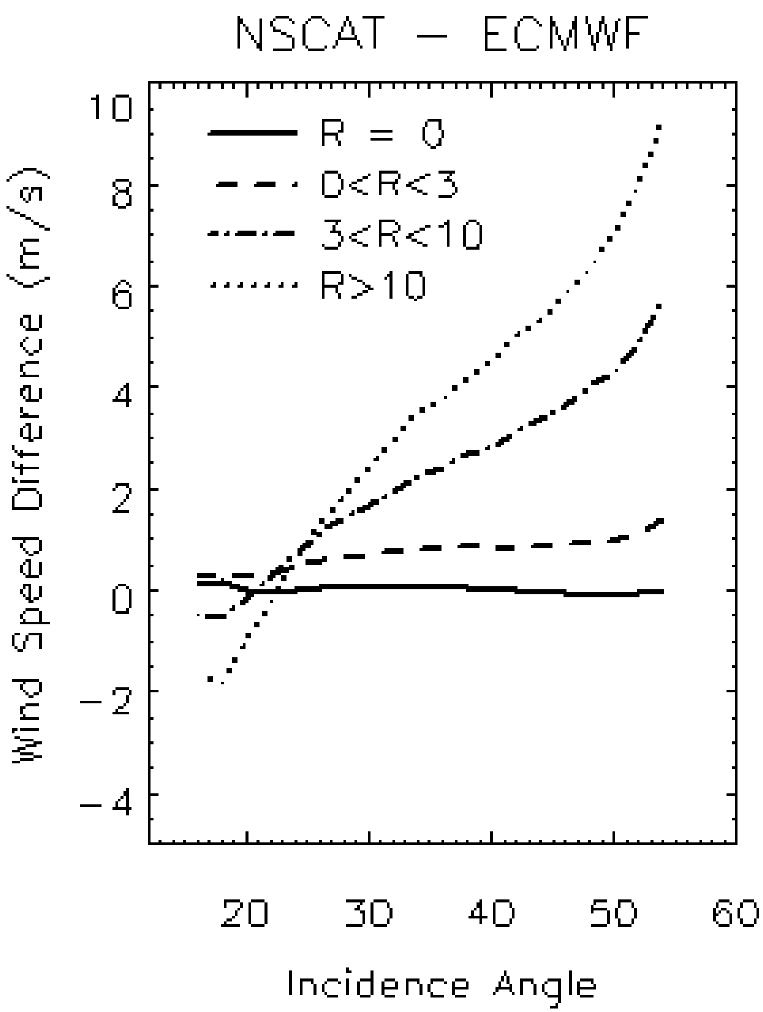
Incidence Angle



NSCAT's broad range of incidence angles shows that rain effects are greater at higher incidence angles (like those of QSCAT).

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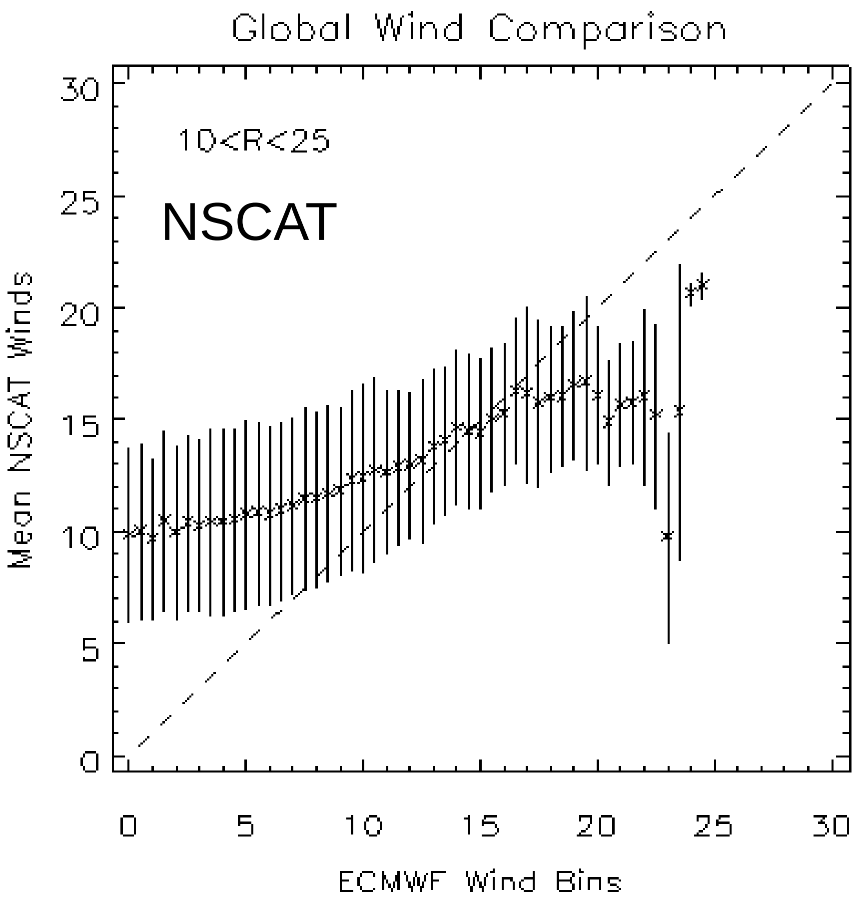
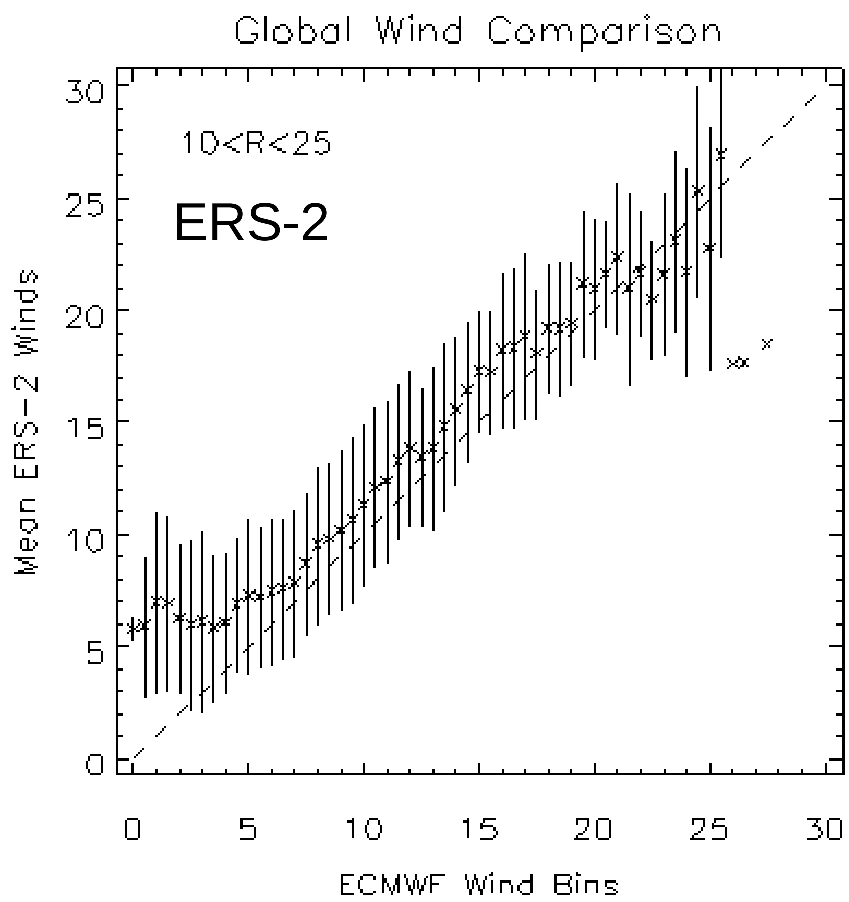
Frequency

Ku-Band



C-Band



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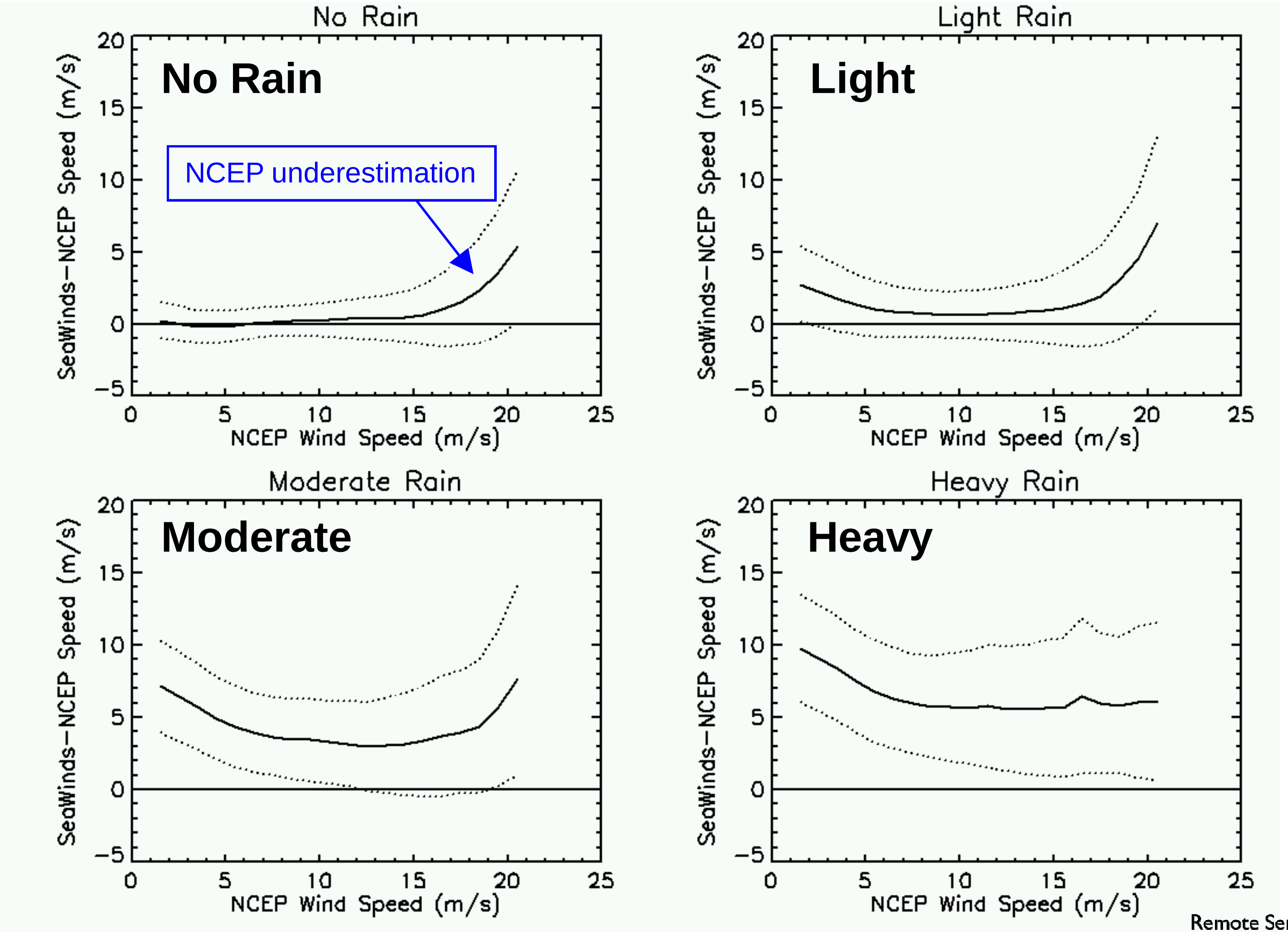
Wind Speeds

Rain biases are positive and largest at low wind speeds



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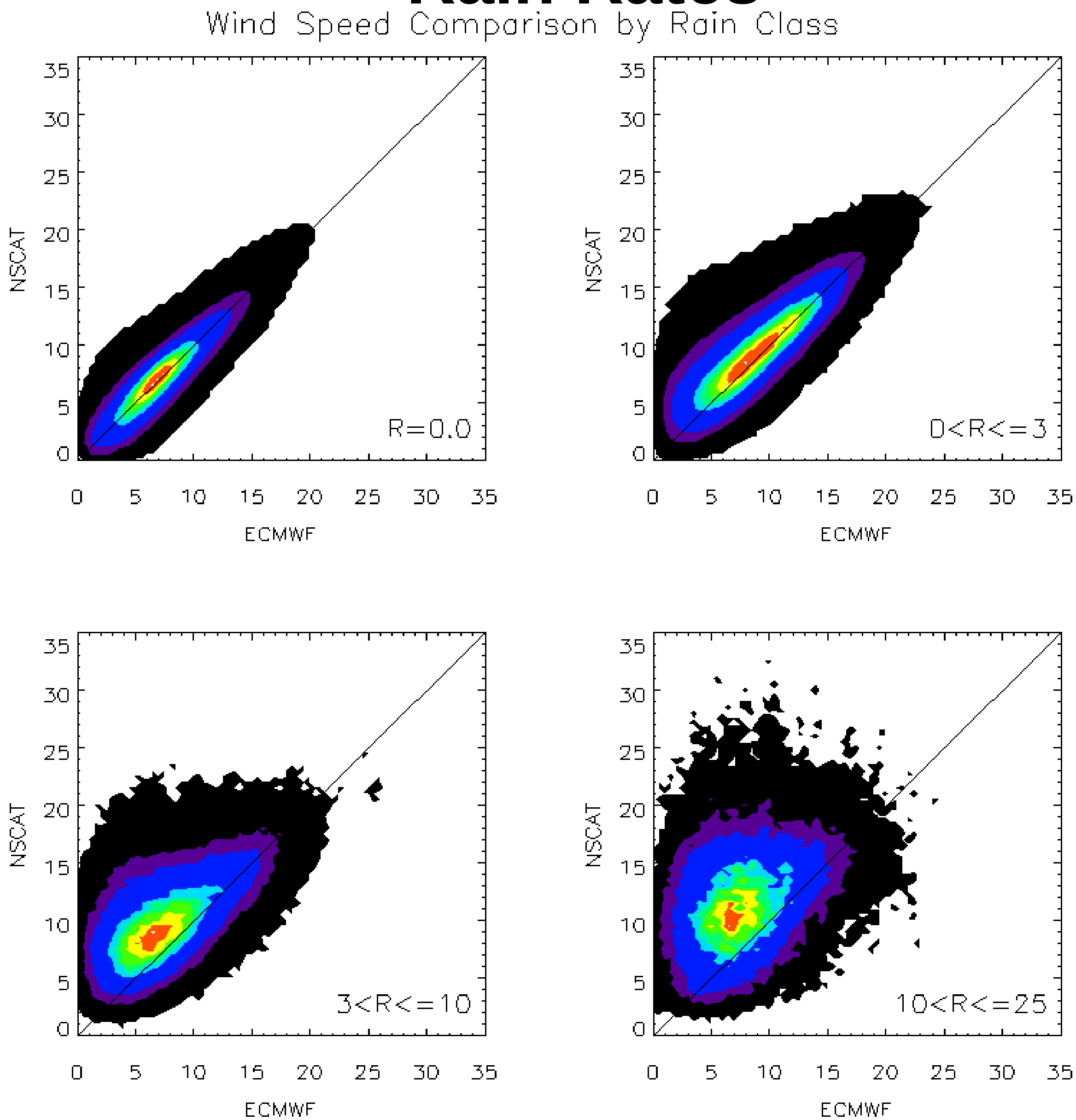
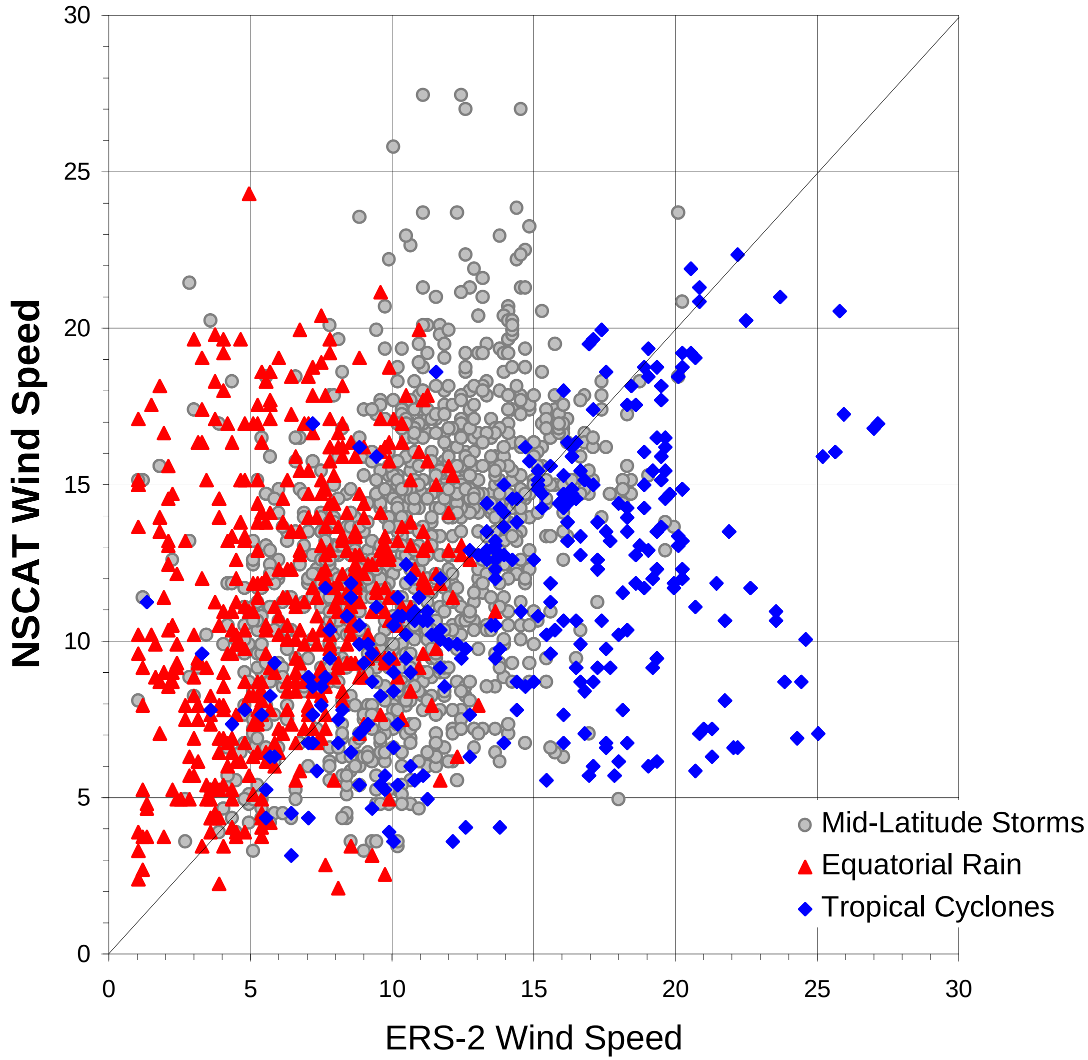
Rain Rates


Wind Speed Comparison by Rain Class
NSCAT
ECMWF
0 5 10 15 20 25 30 35
R=0.0
0<R<=3
3<R<=10
10<R<=25

Rain Types

High Rain (>10 mm/hr) Events



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Part III

Approaches to Dealing with Rain Effects

SIMULTANEOUS WIND/RAIN RETRIEVAL

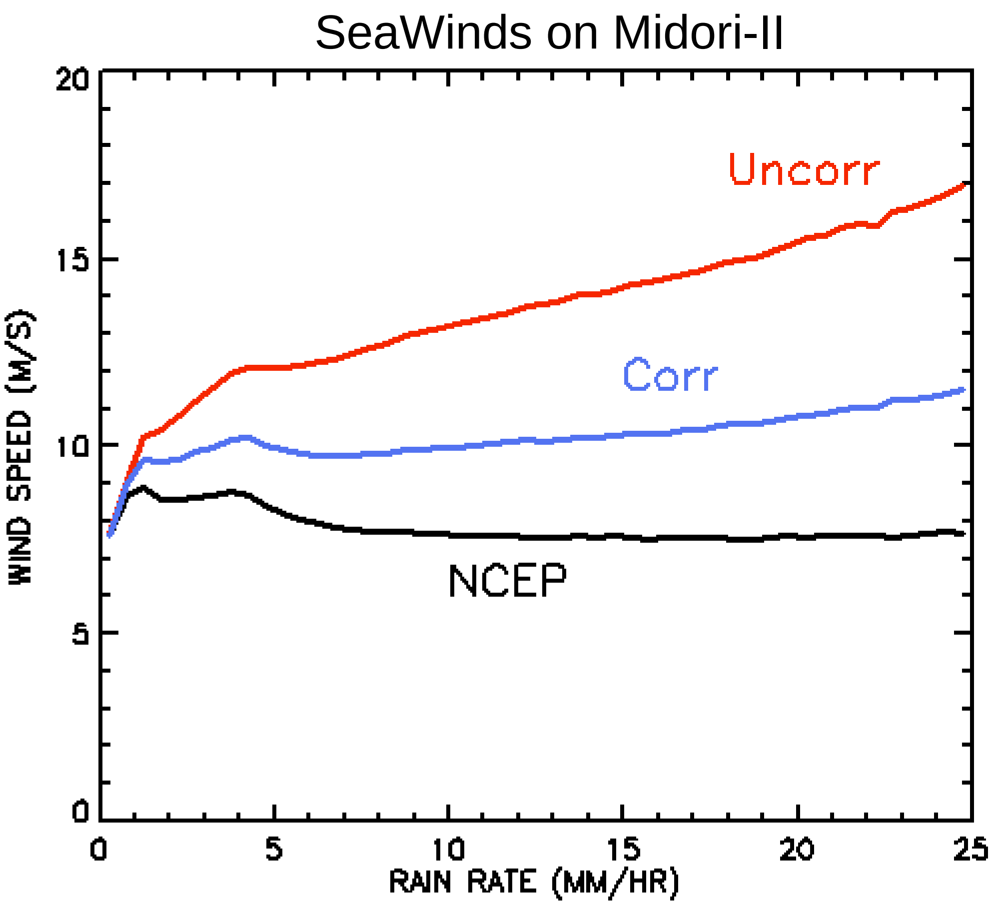
PHSYICALLY-BASED

NEURAL NET

Approaches to Dealing with Rain Effects

Authors, Year	Short Title	Method	Data Set Available?
Draper & **Long** 2004	Simultaneous Wind and Rain Retrieval	Add rain rate as a parameter to GMF	Yes
Tournadre & **Quilfen** 2005	Correction of SeaWinds	Use TRMM PR to correct sigma-0	No
Hilburn and others 2006	RSS Rain Correction	Use radiometer Tb to correct scat sigma-0	Yes
Weissman & **Bourassa** 2005	Correction to Scat using NEXRAD	Uses collocated NEXRAD data	No
Hristova-Veleva and others 2007	JPL Rain Correction	Uses radiometer data to correct scat	Yes

Average Wind Speed is Improved by the Rain Correction



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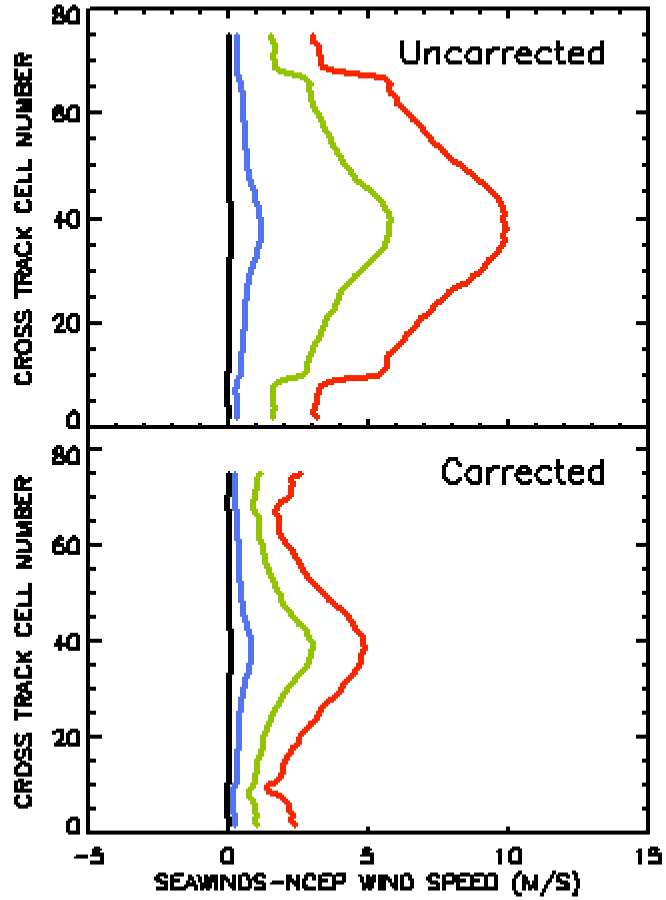
Cross-Track Biases are Reduced by the Rain Correction



NO-RAIN, LOW, MODERATE, HEAVY

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Only 12 years ago, few identified rain as much of a problem… Now effects are documented and correction schemes have been introduced.
Careful design of the next scatterometer system can mitigate rain problems