Relationship Between Hurricane Surface Winds, Surface Rain Measurements and Surface Roughness Observed With QuikSCAT

David E. Weissman
Hofstra University
Hempstead, New York 11549

Mark A. Bourassa
Center for Ocean Atmosphere Prediction Studies
Florida State University
Tallahassee, FL

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MOTIVATION: IS THERE A SUBSTANTIAL INFLUENCE OF RAIN ON THE AIR-SEA MOMENTUM EXCHANGE IN HURRICANES?

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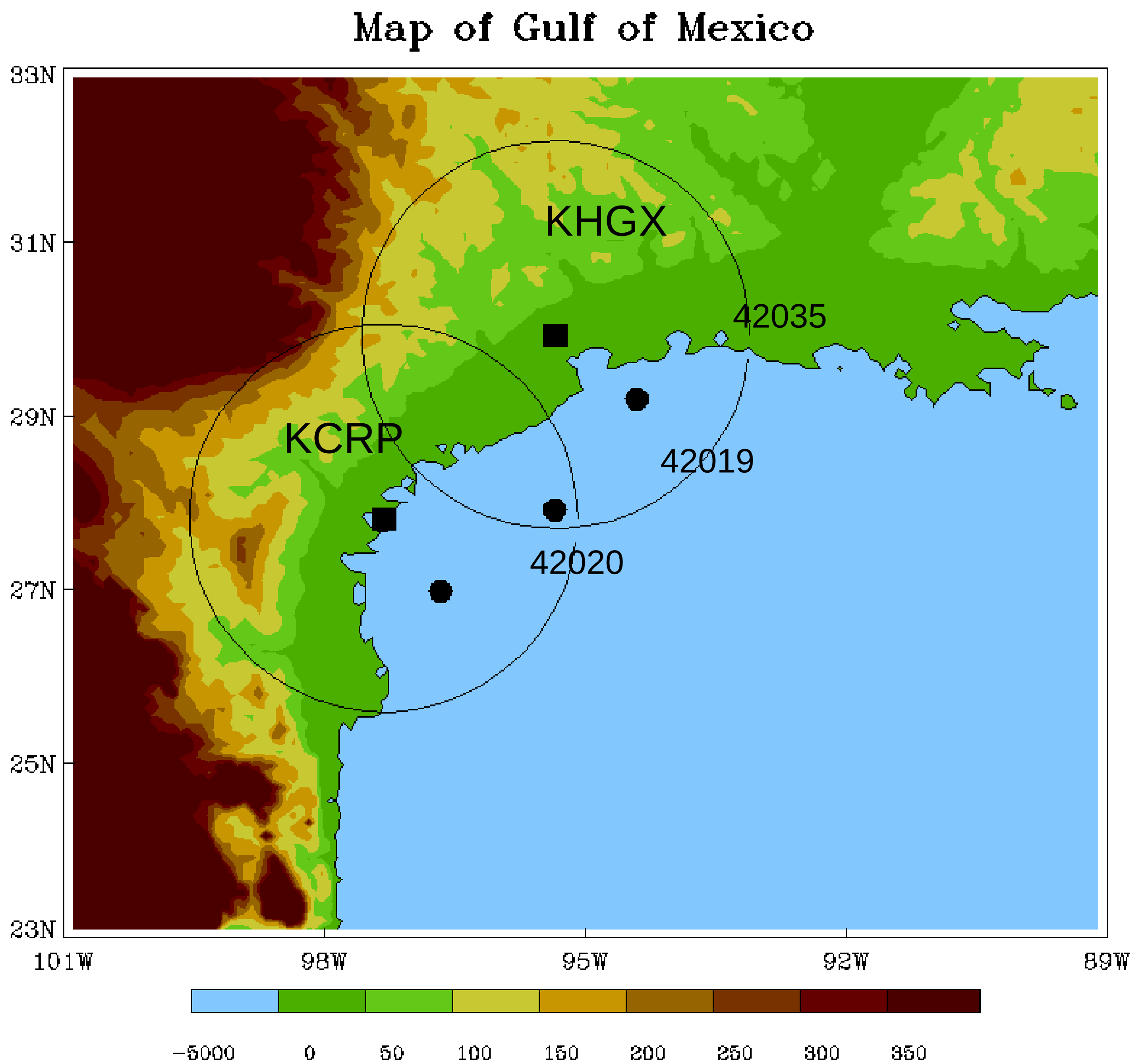
1. CAN WE OBSERVE A RELATIONSHIP BETWEEN THE WIND MAGNITUDES IN HURRICANES AND RAINRATE ?

2. WHAT IS THEIR COMBINED EFFECT ON THE SURFACE NRCS, AT Ku- BAND AND C-BAND?

Region of Observations

NEXRAD & BUOY Locations



I. Compare and analyze the observed rainrate (using NEXRAD) and the wind magnitude estimated by the NOAA Hurricane Research Division (AOML) near the coasts during Hurricanes Ike (2008) and Claudette (2003)

II. Present estimates of the rain-impact enhanced sea surface roughness (NRCS) observed by QuikSCAT for Ike and Claudette

III. Show a sample of the ASCAT NRCS during Hurr. Gustav (2008), as a function of rainrate and wind magnitude.

DATA SOURCES AND PROPERTIES:

a) ASCAT NRCS data, 25 km Product

b) QuikSCAT Level 2A NRCS data, H-pol and V-pol

c) Simultaneous NEXRAD 3-D Volume
Reflectivity (S-band) within scatterometer beam
(Inherent resolution is about 2 km)

d) Surface winds from NOAA Hurricane Research
Division Analysis and buoys (Max. 1-min winds)

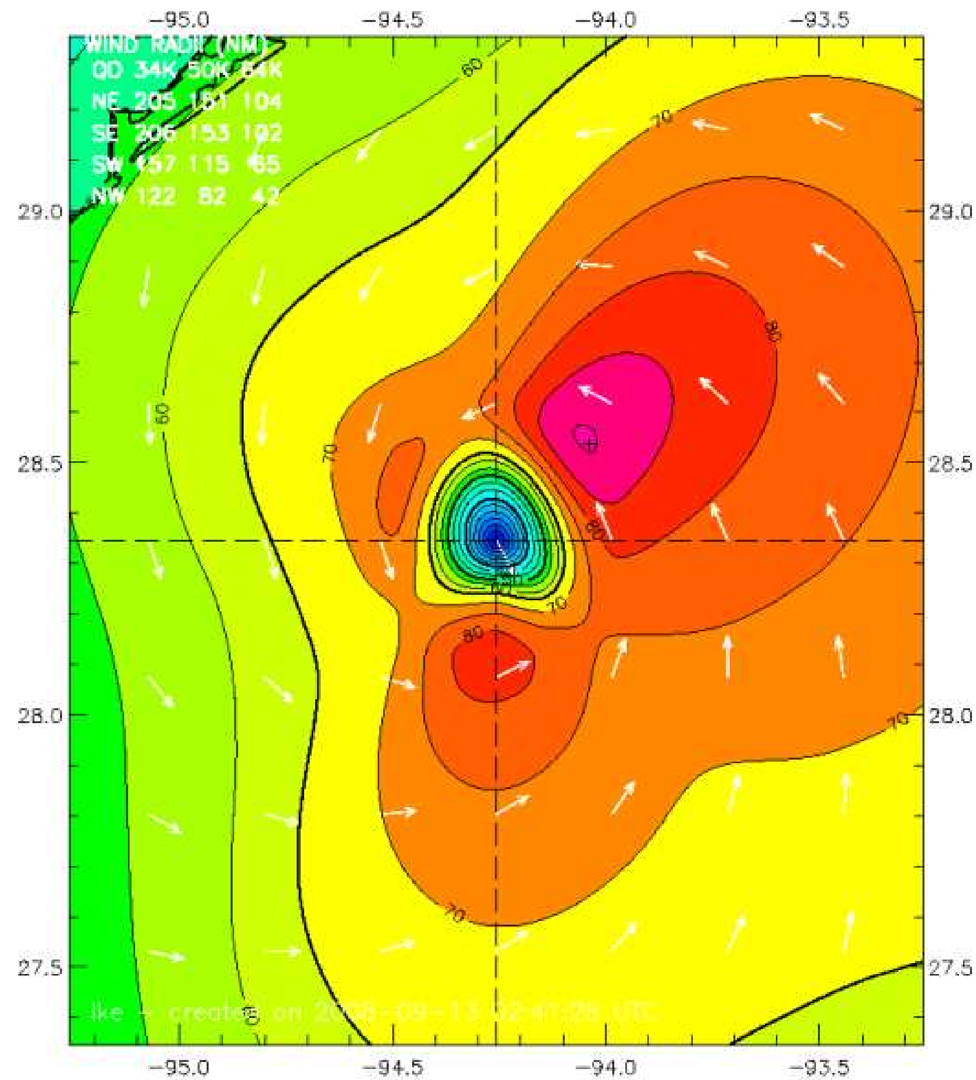
Hurricane Ike 0130 UTC 13 SEP 2008

Max 1-min sustained surface winds (kt)

Valid for marine exposure over water, open terrain exposure over land

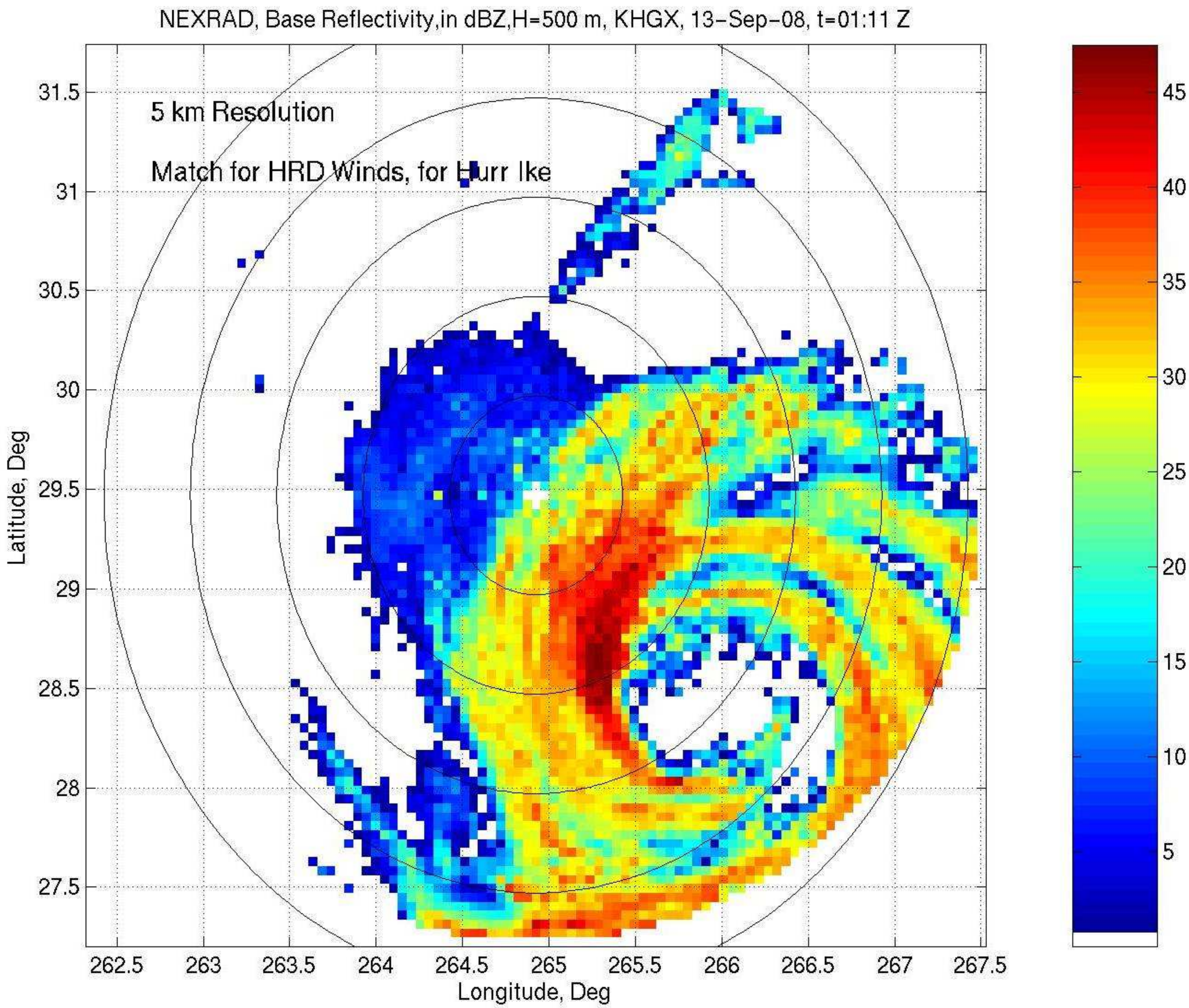
Analysis based on CMAN from 2009 - 0149 z; ASOS from 2004 - 0154 z; SFMR_AFRC from 0900 - 0156 z;
SHIP from 2000 - 0100 z; SFMR42 from 2220 - 0159 z;
FCMP_TOWER from 2005 - 0154 z; WEATHER_FLOW from 2000 - 0155 z;
GOES from 2202 - 2202 z; GPSSONDE_SFC from 2042 - 0155 z;
GPSSONDE_WL150 from 2042 - 0155 z; METAR from 2000 - 0155 z;
MOORED_BUOY from 2000 - 0149 z;

0130 z position interpolated from 0121 Estimator tool; mslp = 957.0 mb



Integrated Kinetic Energy: for Winds > TS force: 99 TJ, for Winds > Hurricane Force: 32 TJ

Destructive Potential Rating(0-6) Wind: 2.9 Surge/Waves: 4.8



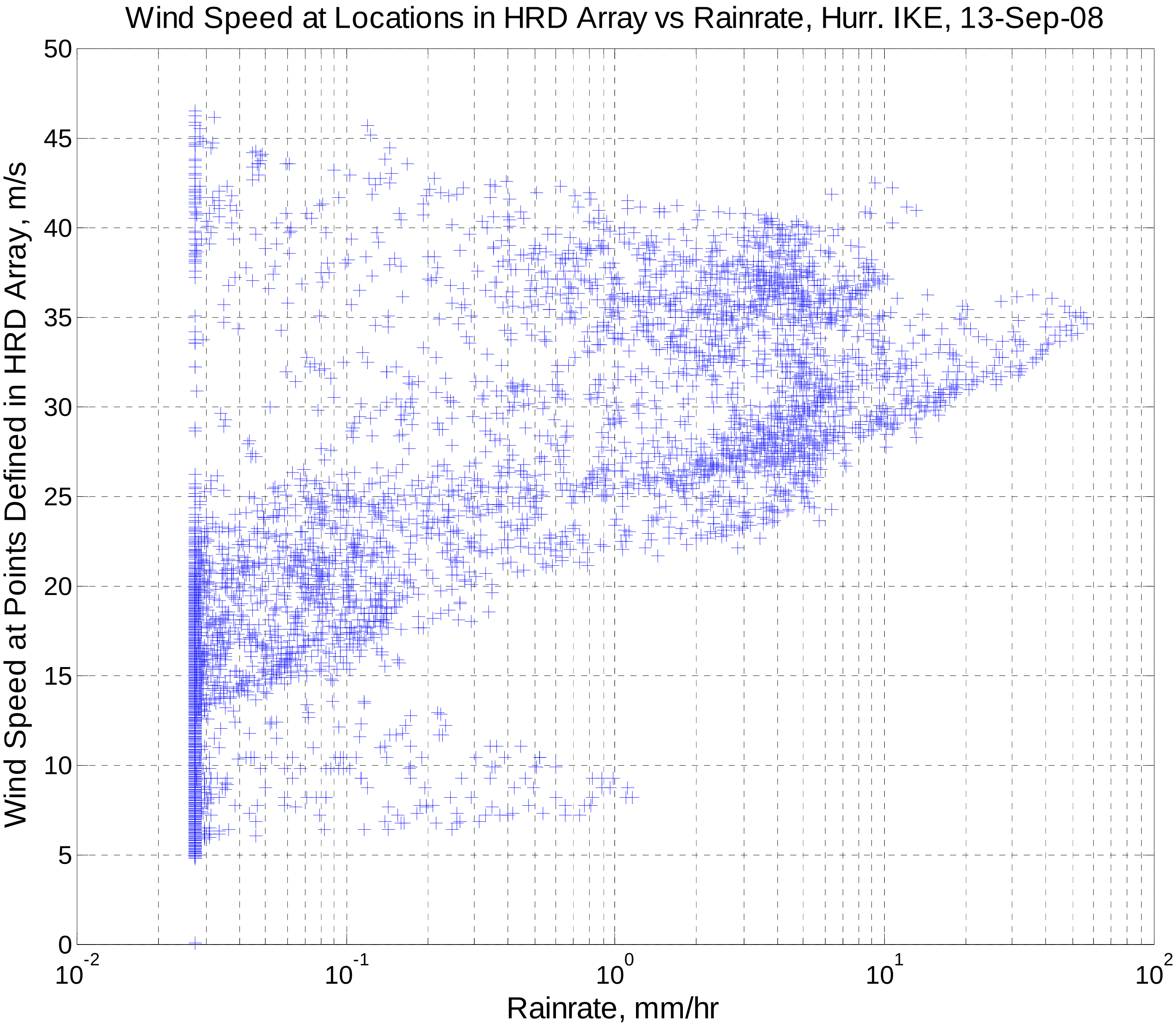
NEXRAD, Base Reflectivity,in dBZ,H=500 m, KHGX, 13-Sep-08, t=01:11 Z
5 km Resolution
Match for HRD Winds, for Hurr Ike
Latitude, Deg
Longitude, Deg
31.5
31
30.5
30
29.5
29
28.5
28
27.5
262.5
263
263.5
264
264.5
265
265.5
266
266.5
267
267.5
45
40
35
30
25
20
15
10
5

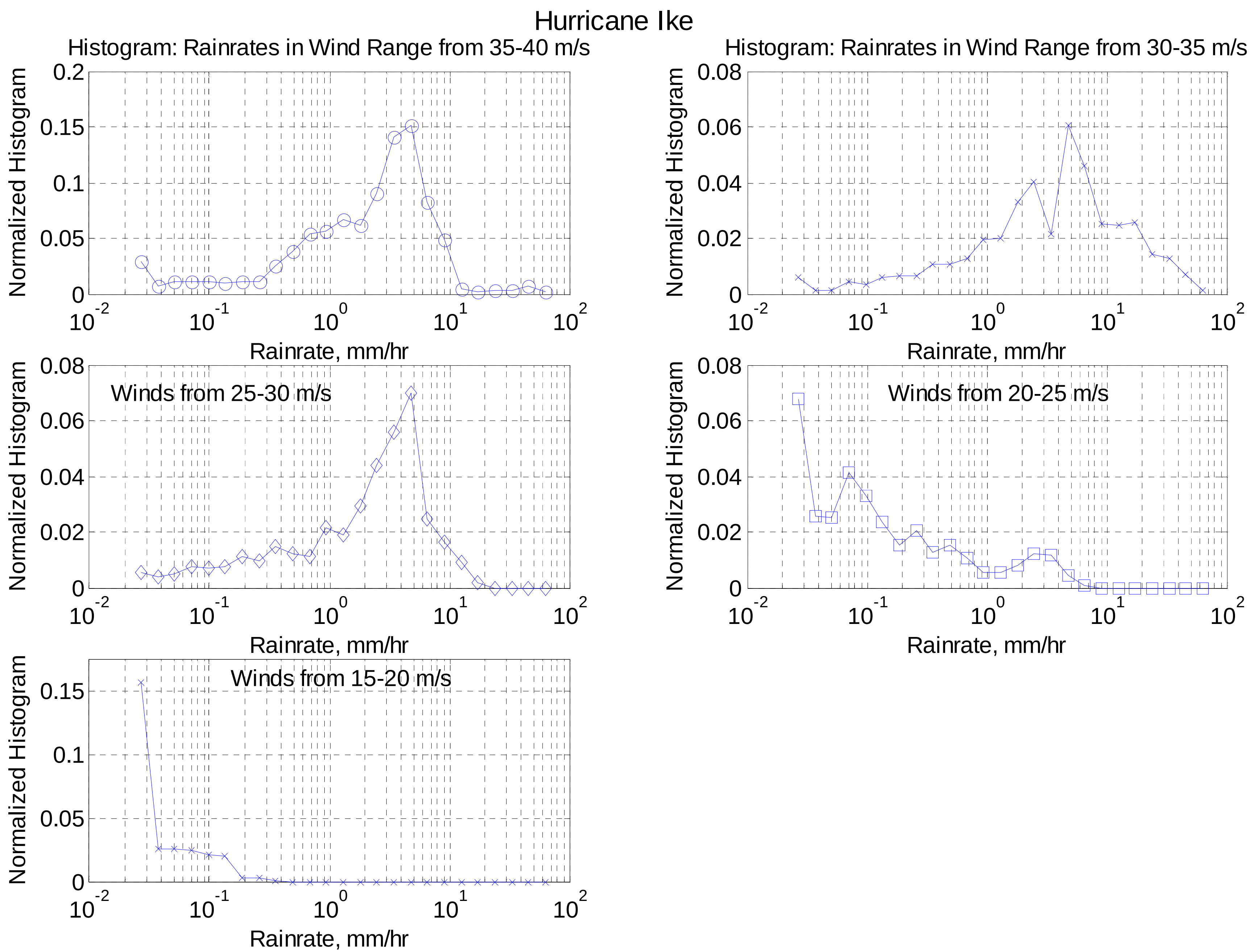
Data Characteristics and Methodology:

HRD Winds are provided in vector form, on a 6 km grid (lat-lon), in a 161 x 161 array.

The NEXRAD data is the lowest level of a 3-D volume; approximate H=500 meters. The horizontal cell size is a 5 km square. The rain array is 101 x 101.

The magnitude is the wind is extracted for each point in the rain-array. A 9x9 km mean rainrate is computed.


Wind Speed at Locations in HRD Array vs Rainrate, Hurr. IKE, 13-Sep-08
Wind Speed at Points Defined in HRD Array, m/s
Rainrate, mm/hr
0
5
10
15
20
25
30
35
40
45
50
10^-2
10^-1
10^0
10^1
10^2



Hurricane Ike
Histogram: Rainrates in Wind Range from 35-40 m/s
Histogram: Rainrates in Wind Range from 30-35 m/s
Winds from 25-30 m/s
Winds from 20-25 m/s
Winds from 15-20 m/s
Normalized Histogram
Rainrate, mm/hr

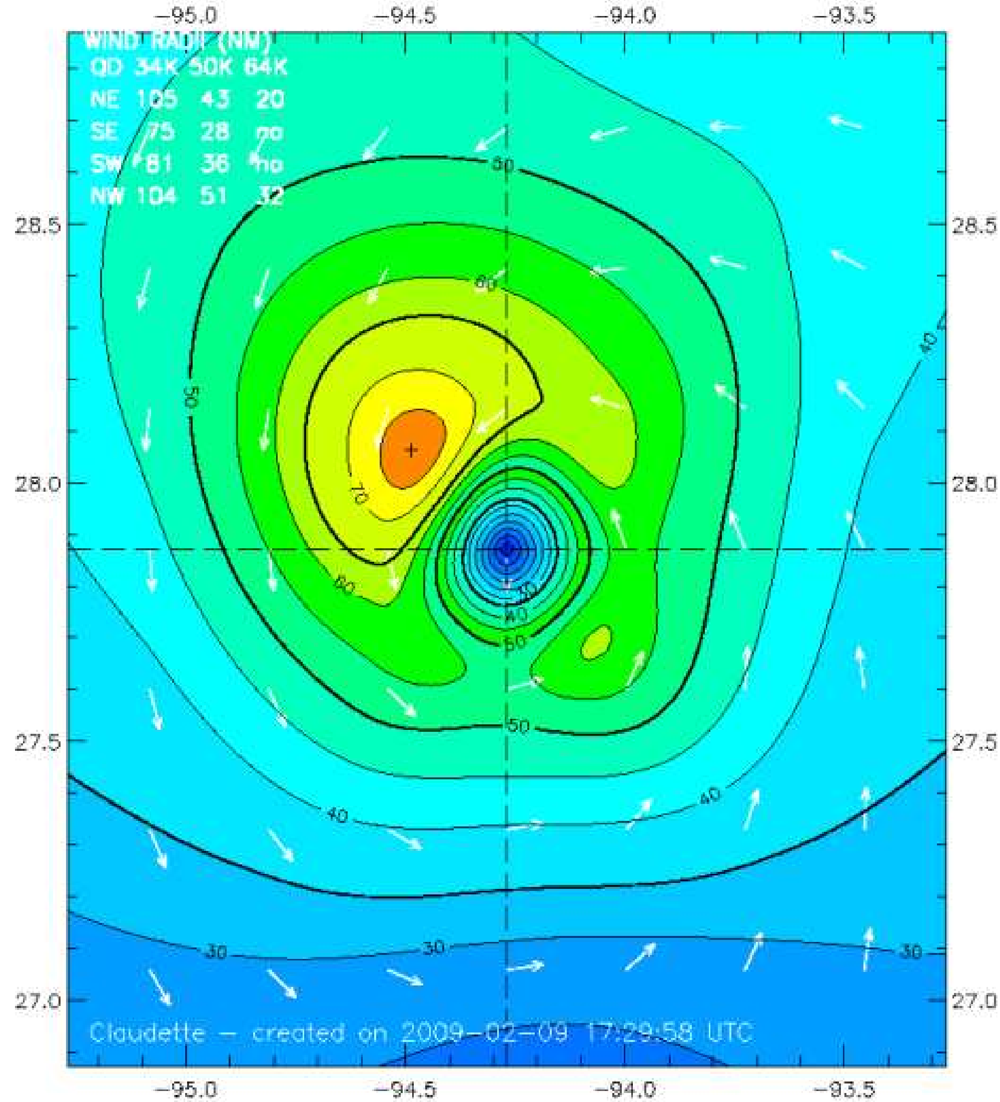
Hurricane Claudette 0400 UTC 15 JUL 2003

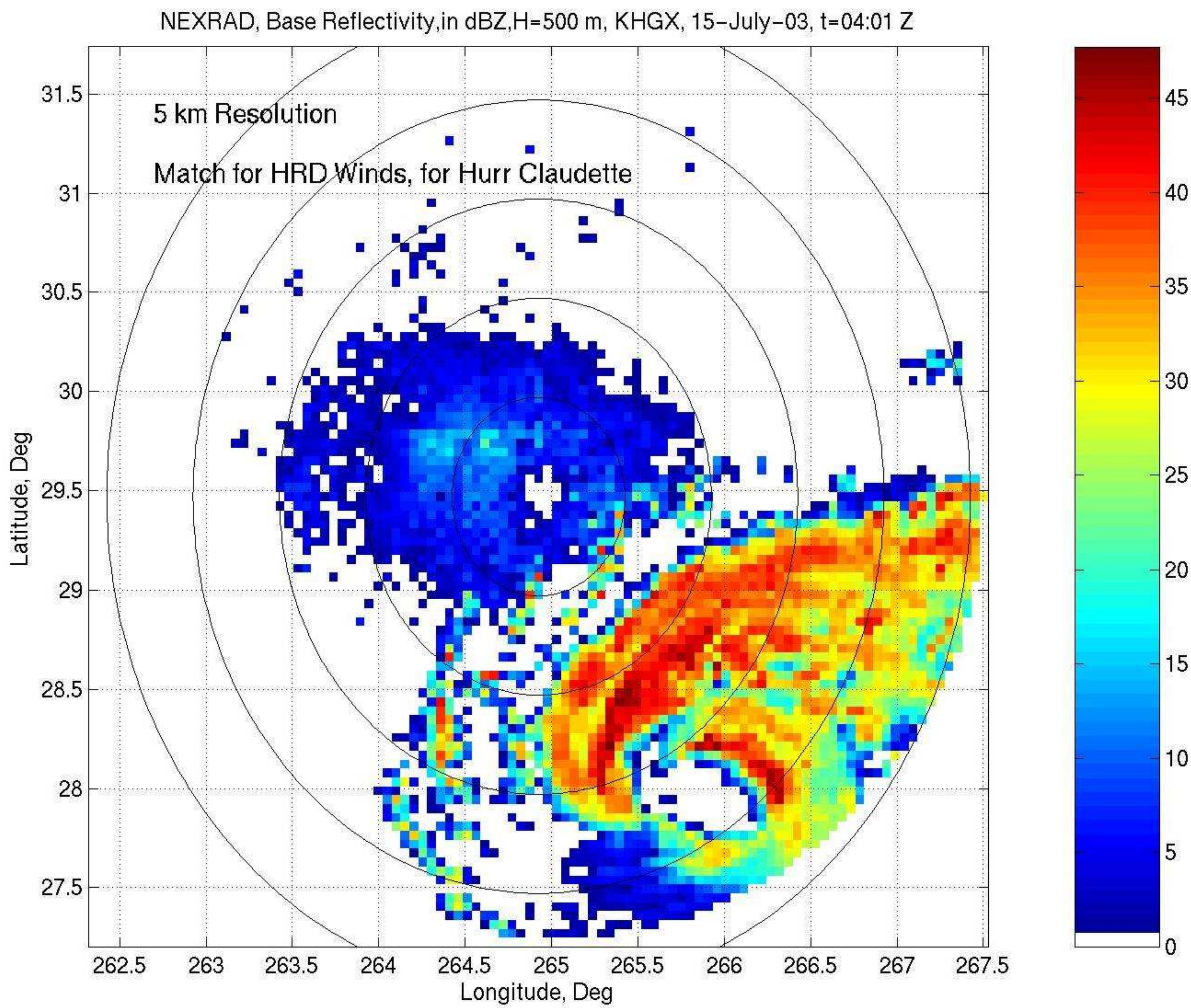
Max 1-min sustained surface winds (kt)

Valid for marine exposure over water, open terrain exposure over land

Analysis based on AFRC (SFMR-2007 adjusted) from 0019 - 0816 z; GOES_SWIR from 0402 - 0402 z;
GPSSONDE_SFC from 0239 - 0818 z; GPSSONDE_WL150 from 0134 - 0818 z;
QSCAT from 0058 - 0100 z; MOORED_BUOY from 0039 - 0750 z;
CMAN from 0100 - 0800 z; METAR from 0025 - 0805 z;

0400 z position interpolated from 0354 Vortex; mslp = 989.0 mb





NEXRAD, Base Reflectivity,in dBZ,H=500 m, KHGX, 15-July-03, t=04:01 Z
5 km Resolution
Match for HRD Winds, for Hurr Claudette
Latitude, Deg
Longitude, Deg
31.5
31
30.5
30
29.5
29
28.5
28
27.5
262.5
263
263.5
264
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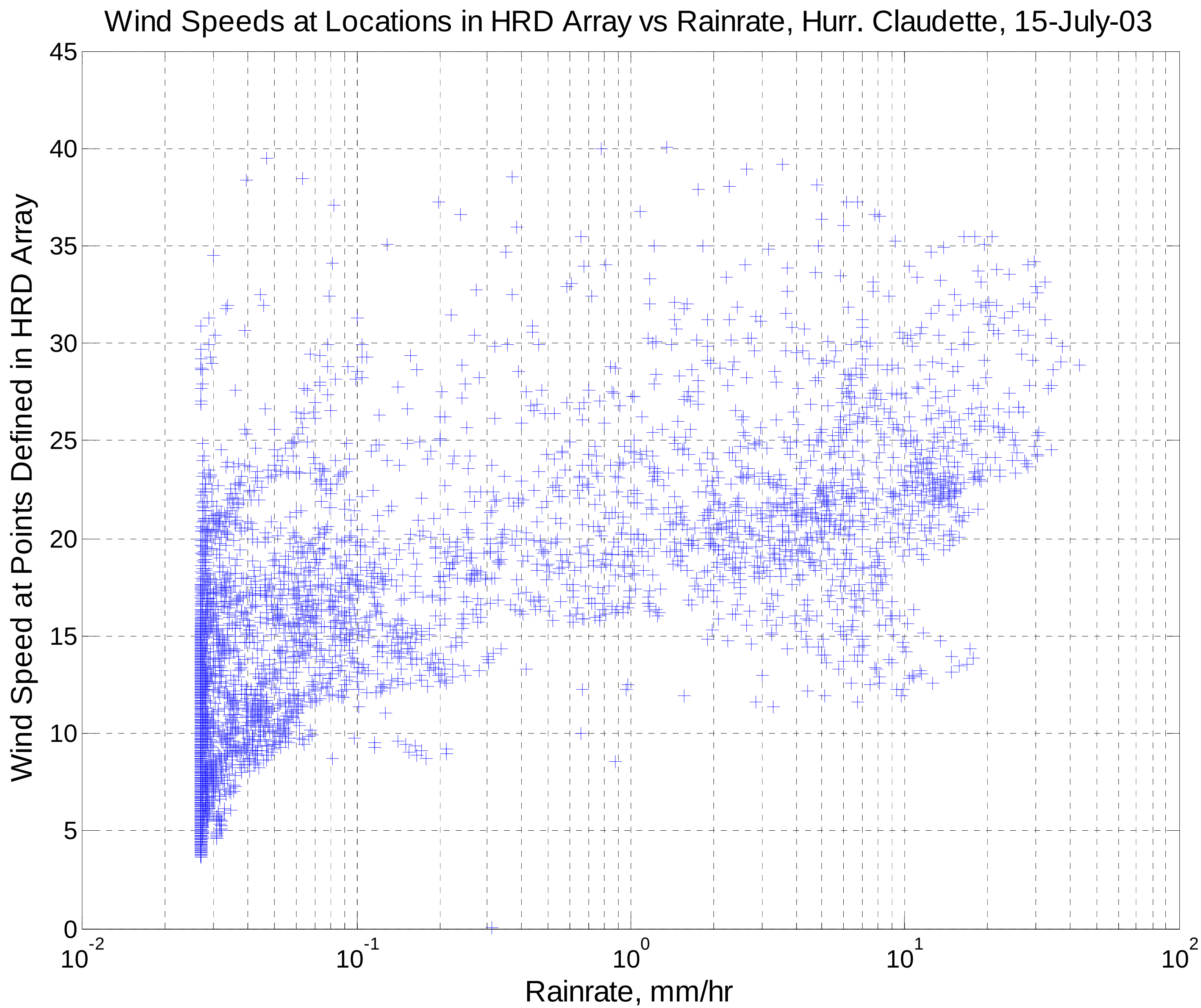
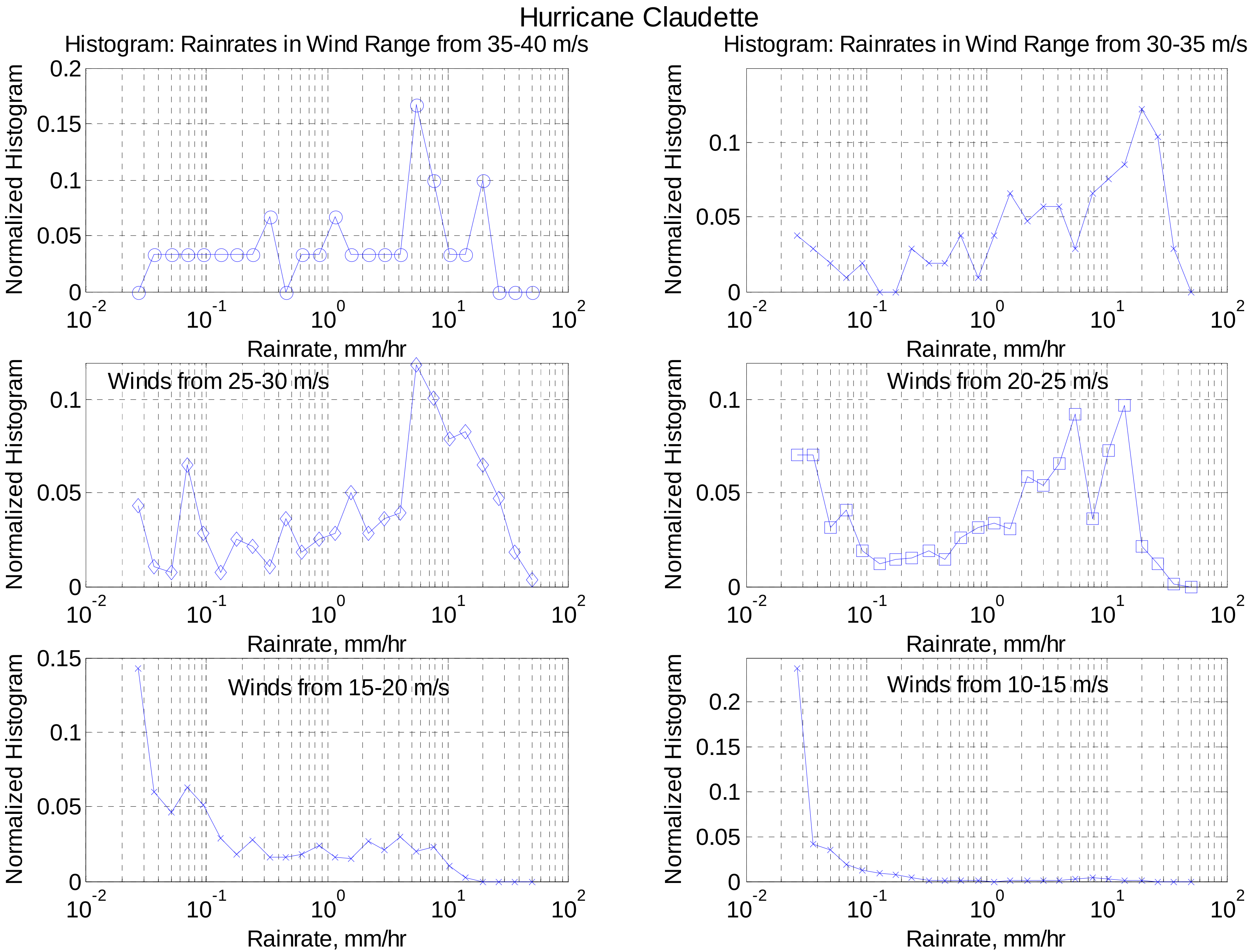
45


Wind Speeds at Locations in HRD Array vs Rainrate, Hurr. Claudette, 15-July-03
Wind Speed at Points Defined in HRD Array
Rainrate, mm/hr
0
5
10
15
20
25
30
35
40
45
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}



Hurricane Claudette
Histogram: Rainrates in Wind Range from 35-40 m/s
Histogram: Rainrates in Wind Range from 30-35 m/s
Winds from 25-30 m/s
Winds from 20-25 m/s
Winds from 15-20 m/s
Winds from 10-15 m/s
Normalized Histogram
Rainrate, mm/hr

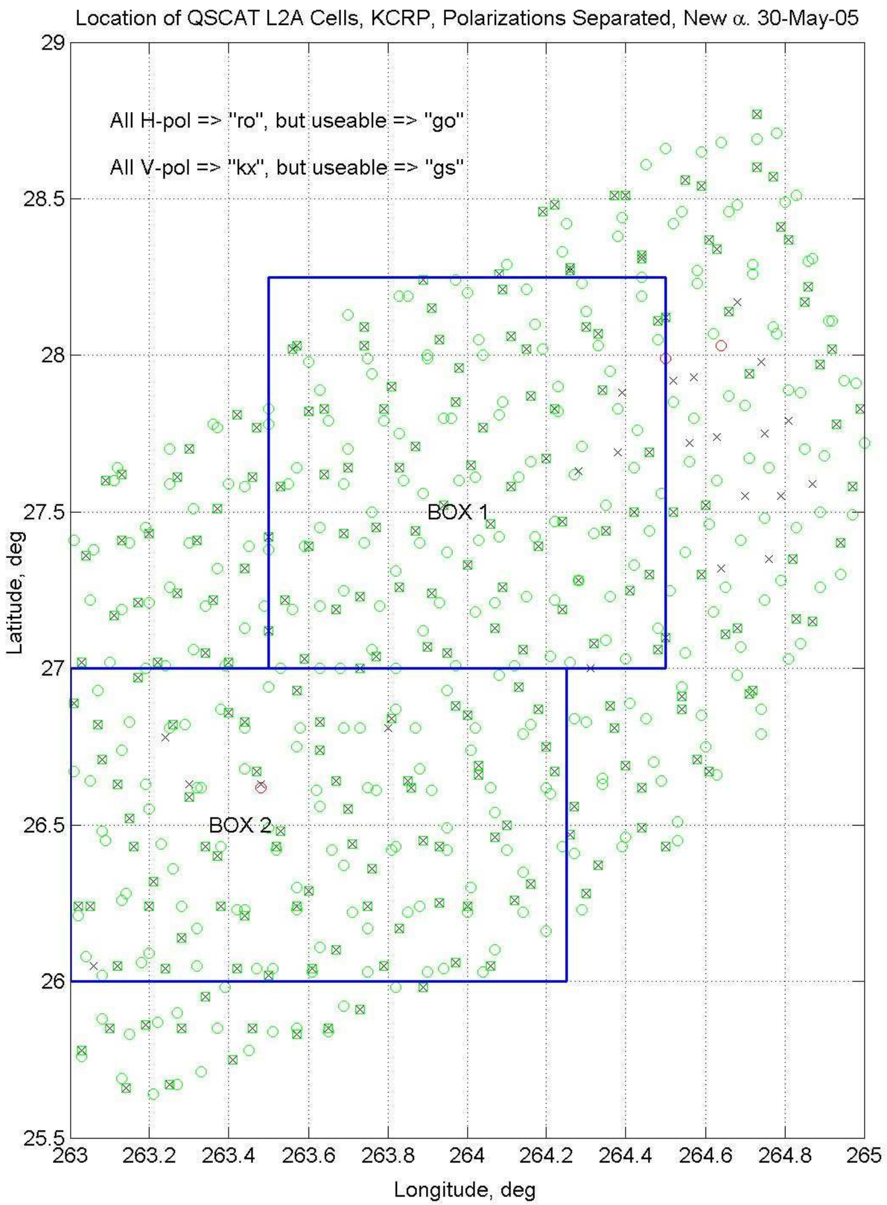
Studies of NRCS Changes Due to Rain Impacts

USING the *QuikSCAT Scatterometer and NEXRAD Measurements* of the 3-D Rain Volume:

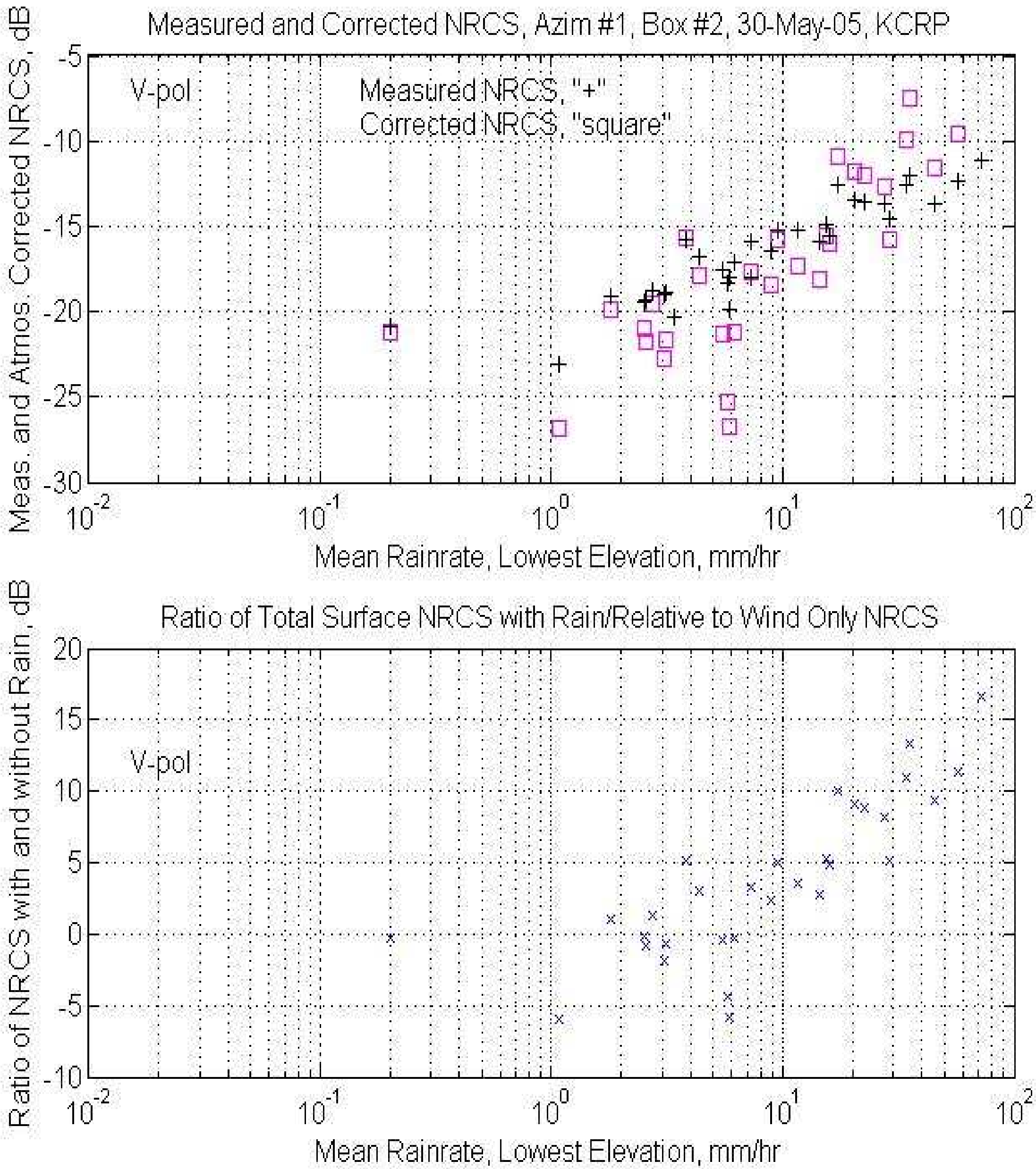
1. To measure the effect of rain impacts on total sea surface roughness (Ku-band NRCS), *as a function rain rate, wind speed, polarization and azimuth look direction*

2. Develop a model for the change (increase or decrease) of the surface normalized radar cross section (NRCS for Ku-band) as a function of rainrate, wind speed, etc.

3. Interpret the results in terms of the interaction between wind waves and the splash products of rain impacts (ring waves, crowns and stalks)



The locations of the QScat L2A cells within a rain event near the KCRP NEXRAD. The usable H-pol and V-pol points are designated with green circles or green squares respectively. QuikSCAT cell size typically 30-by-40 km.



Box # 2, Azimuth Angle #1

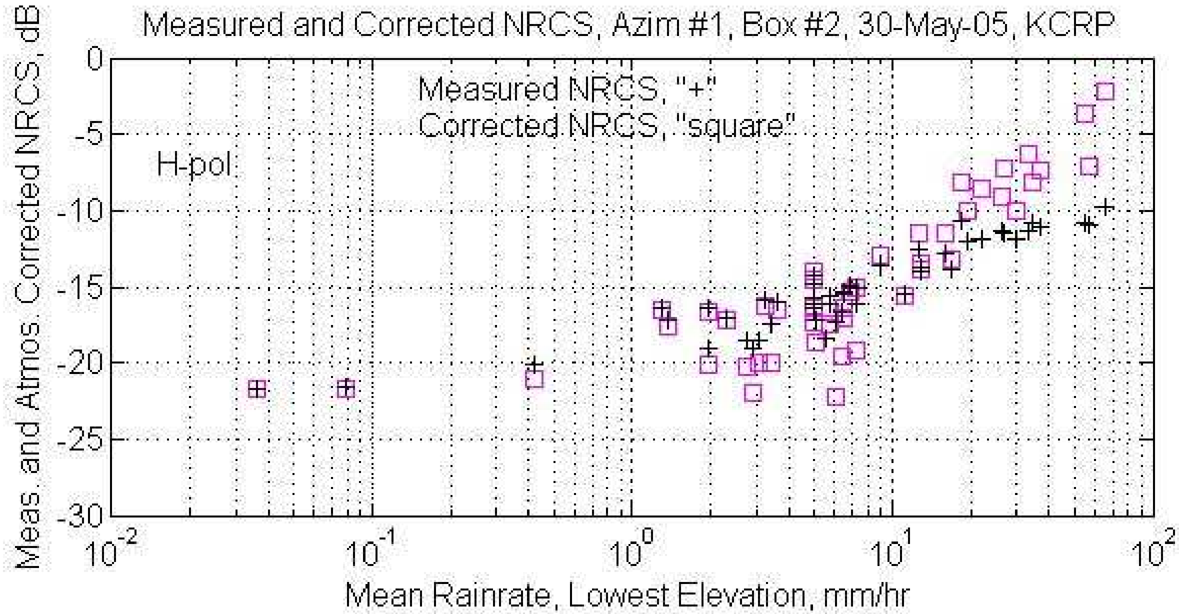
Winds = 5 m/s

+ measured NRCS

□ adjusted NRCS

Upper plot: Uncorrected and corrected (for atmospheric rain) V-pol NRCS versus mean rainrate at each QSCAT cell.

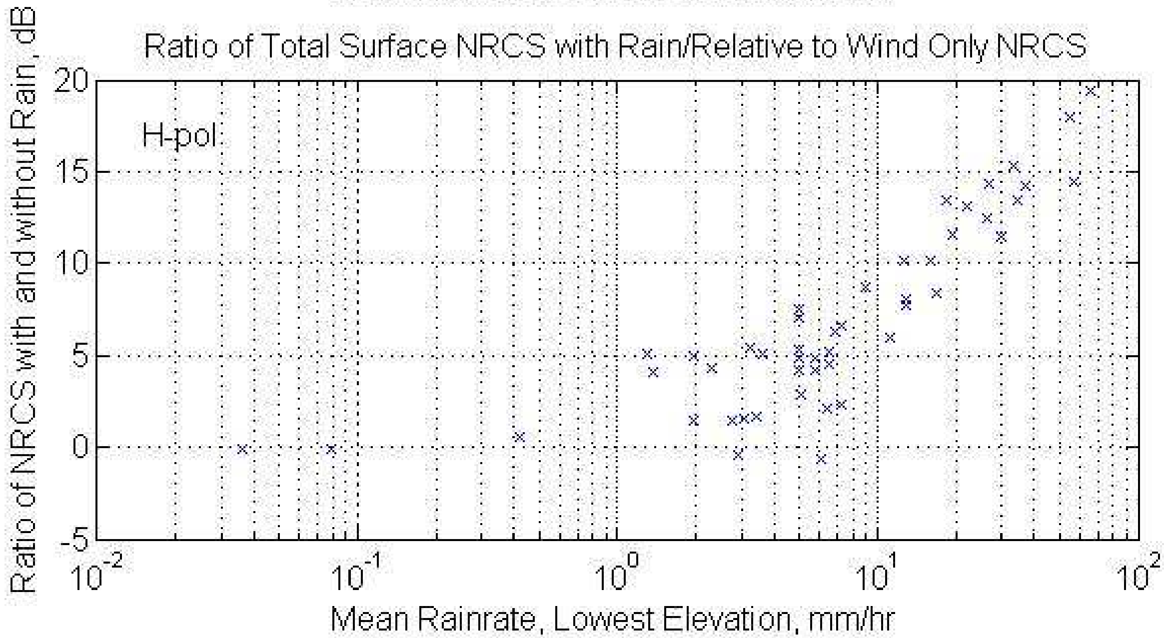
Lower Plot: Ratio of total surface NRCS to wind-driven NRCS vs. rainrate.



Box # 2, Azimuth Angle #1

Winds = 5 m/s

Upper plot: Uncorrected and corrected (for atmospheric rain) H-pol NRCS versus mean rainrate at each QSCAT cell.



Lower Plot: Ratio of total surface NRCS to wind-driven NRCS vs. rainrate.

Electromagnetic Model of the NRCS (σax) Measured by the SeaWinds Scatterometer and Rain Impact NRCS, $\sigma rn0$

Use of "*x*" subscript below will represent either "h" or "v" polarization

σ_{ax} = Total measured NRCS at Satellite Receiver

σ_{wdx} = sea surface NRCS due to wind driven roughness alone (wind-NRCS) – NO RAIN AREA

σ_{rnx} = sea surface radar cross section due to rain impact roughness alone (rain-NRCS) -> ADDS to wind NRCS

σ_{rn0} = model function for the normalized radar cross section due to rain impact; depends on wind magnitude and rainrate

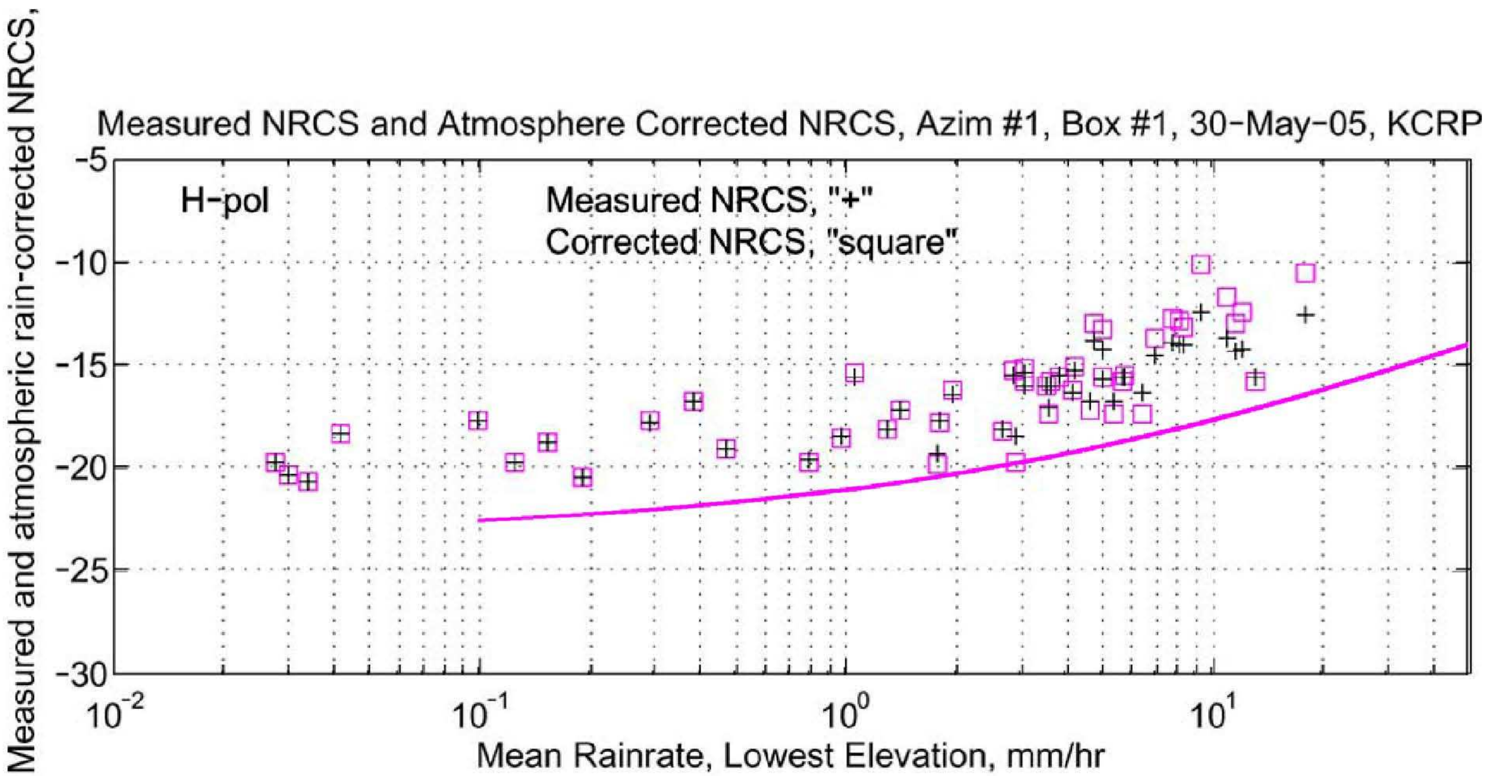
After solving for the total surface NRCS = $(\sigma_{wdx} + \sigma_{rnx})$ from a rain affected area, the wind-driven term alone is estimated from a nearby rain-free area: σ_{wdx}. Then their ratio σ_{rn0} is computed, producing:

$$\sigma_{rn0} = \left(\frac{\sigma_{wdx}+\sigma_{rnx}}{\sigma_{wdx}}\right)$$

Results published in IEEE Transactions on Geoscience and Remote Sensing, October, 2008, D.E. Weissman and M.A. Bouassa

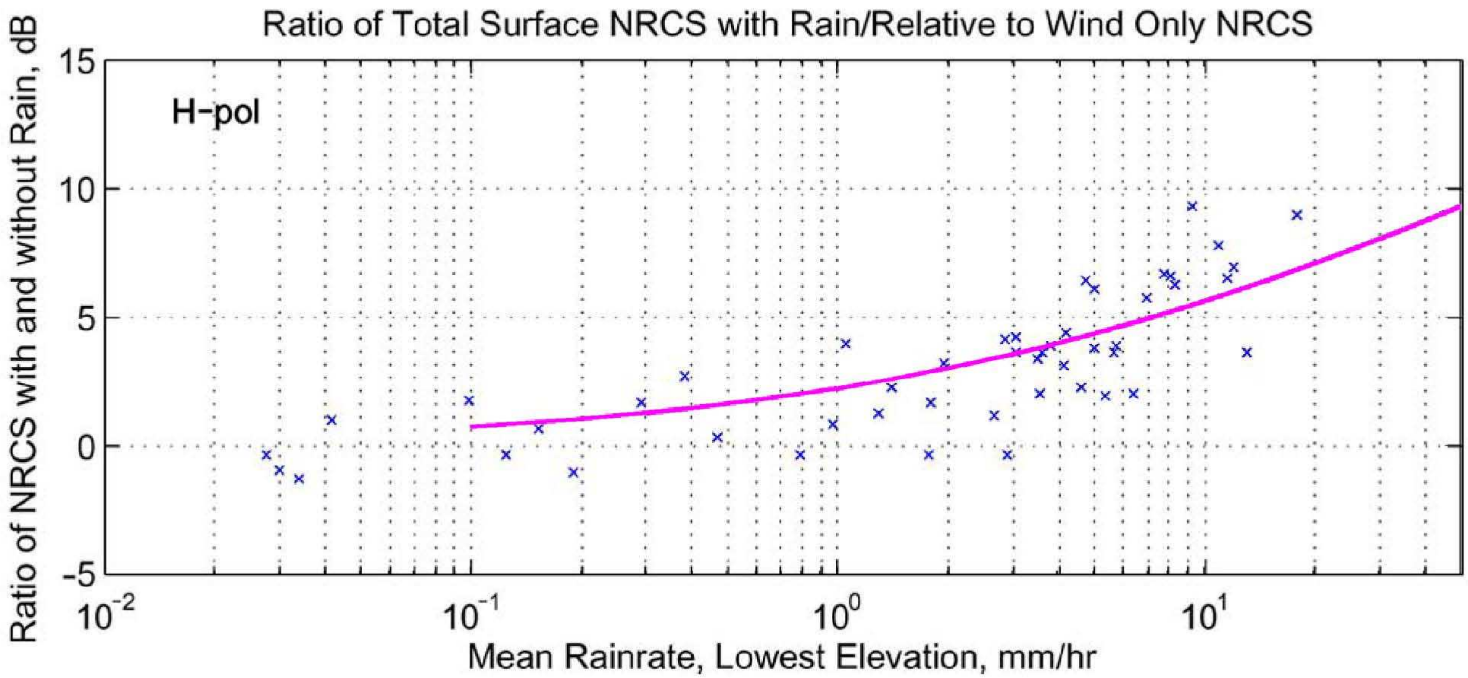
Personal communication from Drs. Piotr Sobieski and Christophe Craeye, of Catholic University de Louvain, Belgium *to show normalized radar cross section of rain impacting a wind driven sea*

Theoretical model by Sobieski and Craeye



H pol, U10=7m/s Weissman,Bourassa 2008, fig 9a

Theoretical model by Sobieski and Craeye



H pol, U10=7m/s Weissman,Bourassa 2008, fig 9b

The theoretical results from Sobieski & Craeye is a validation of the 3-D rain reflectivity model and the attenuation and volume backscatter calculations

A fundamental study to: “.. establish a theory on the interaction between rain and water waves, based on momentum exchanges, and to assess its relative importance regarding the wave prediction models” was published by LeMehaute and Khangaonkar, J.Phys.Oceanogr, Dec. 1990

Rain horizontal momentum transfer (τ_R),

τ_R = raindrop mass density x rainrate x horizontal wind speed

For example: for rainrate = 25 mm/hr and U_{10} = 25 m/s, the ratio

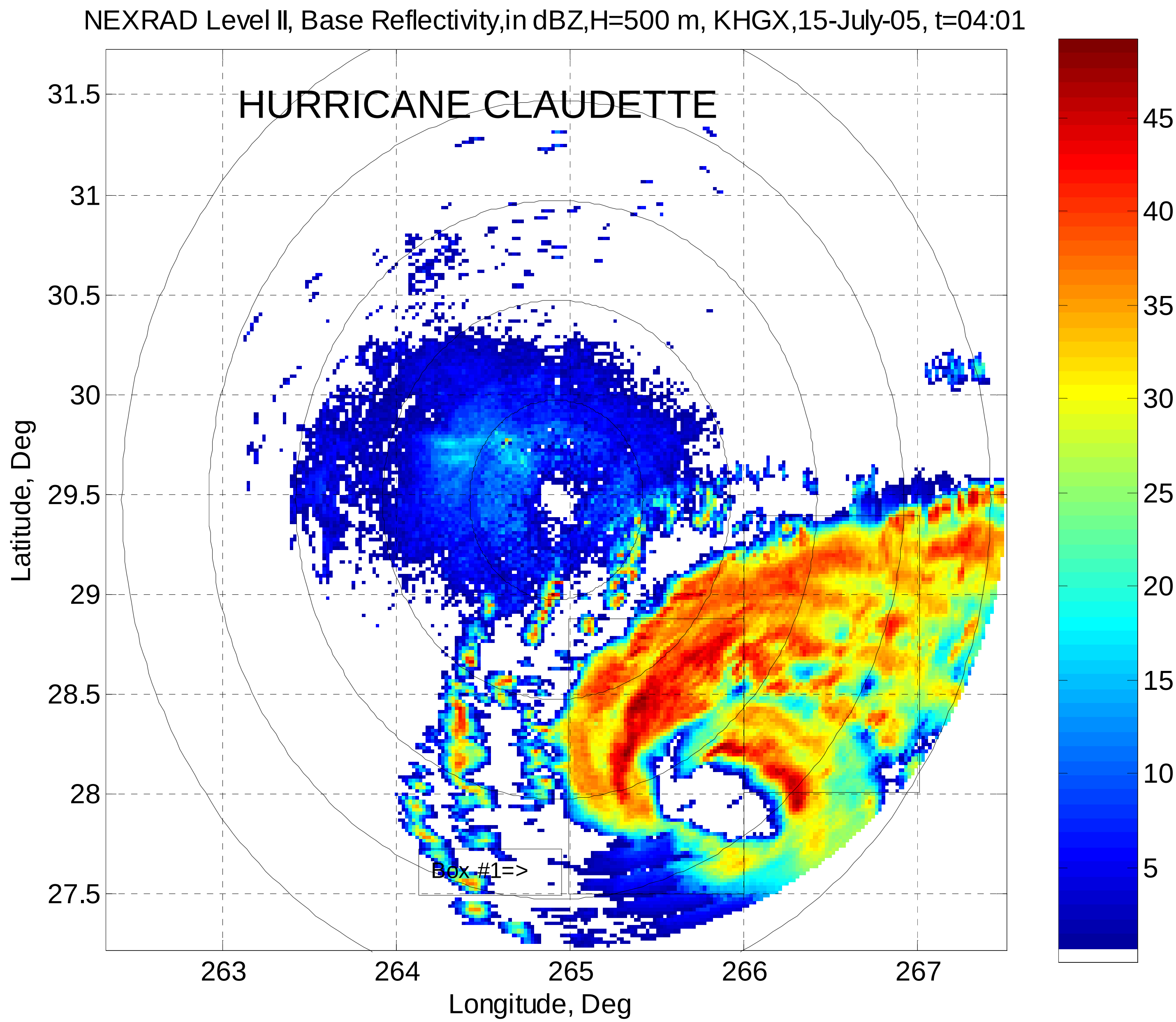
τ_R / wind stress = 8.4 %

However this number gives no direct indication about the roughness properties to which Ku-band and C-band radar responds.

Wind: 17 m/s
@ 58 deg
at #42035
Buoy

Azim #2 =
305 deg

Azim # 1=205
deg



Hurricane Claudette 0400 UTC 15 JUL 2003

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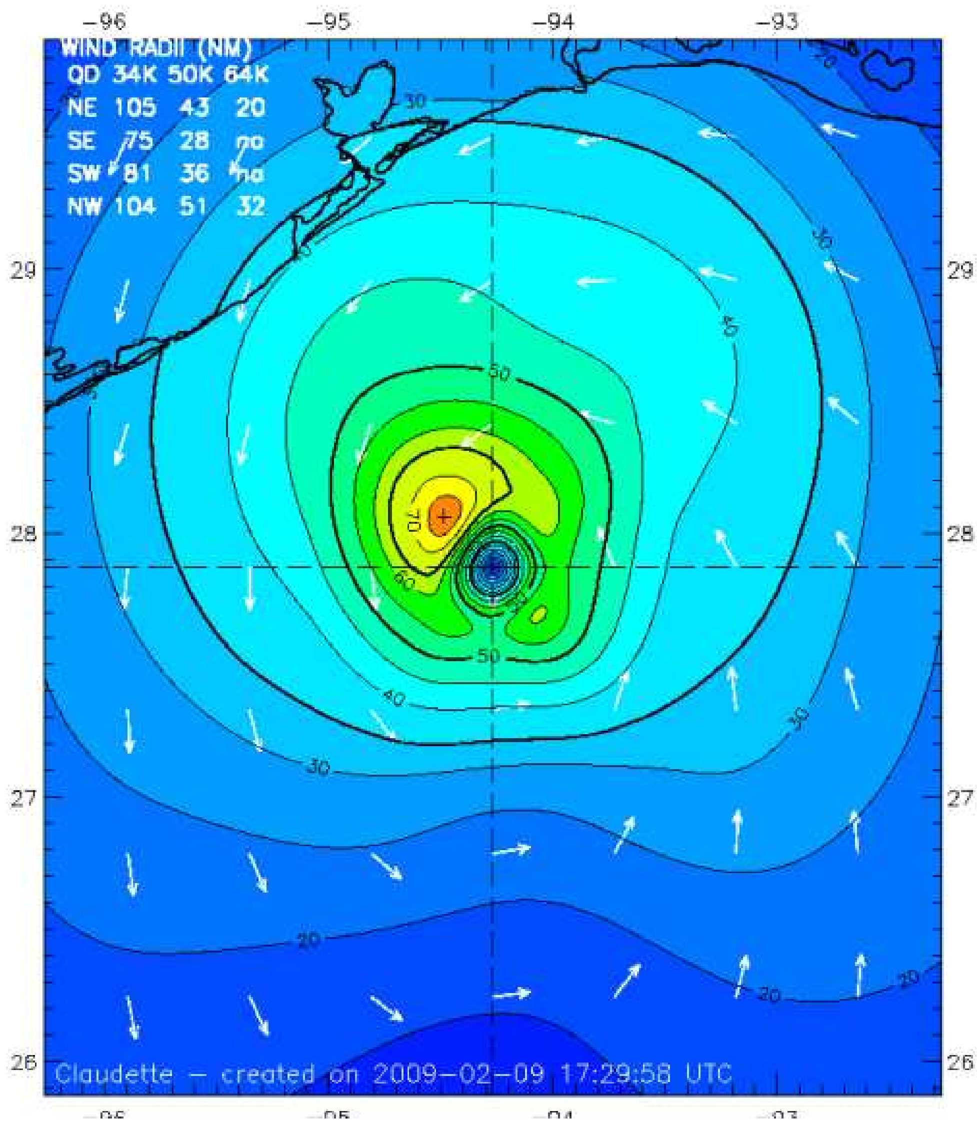
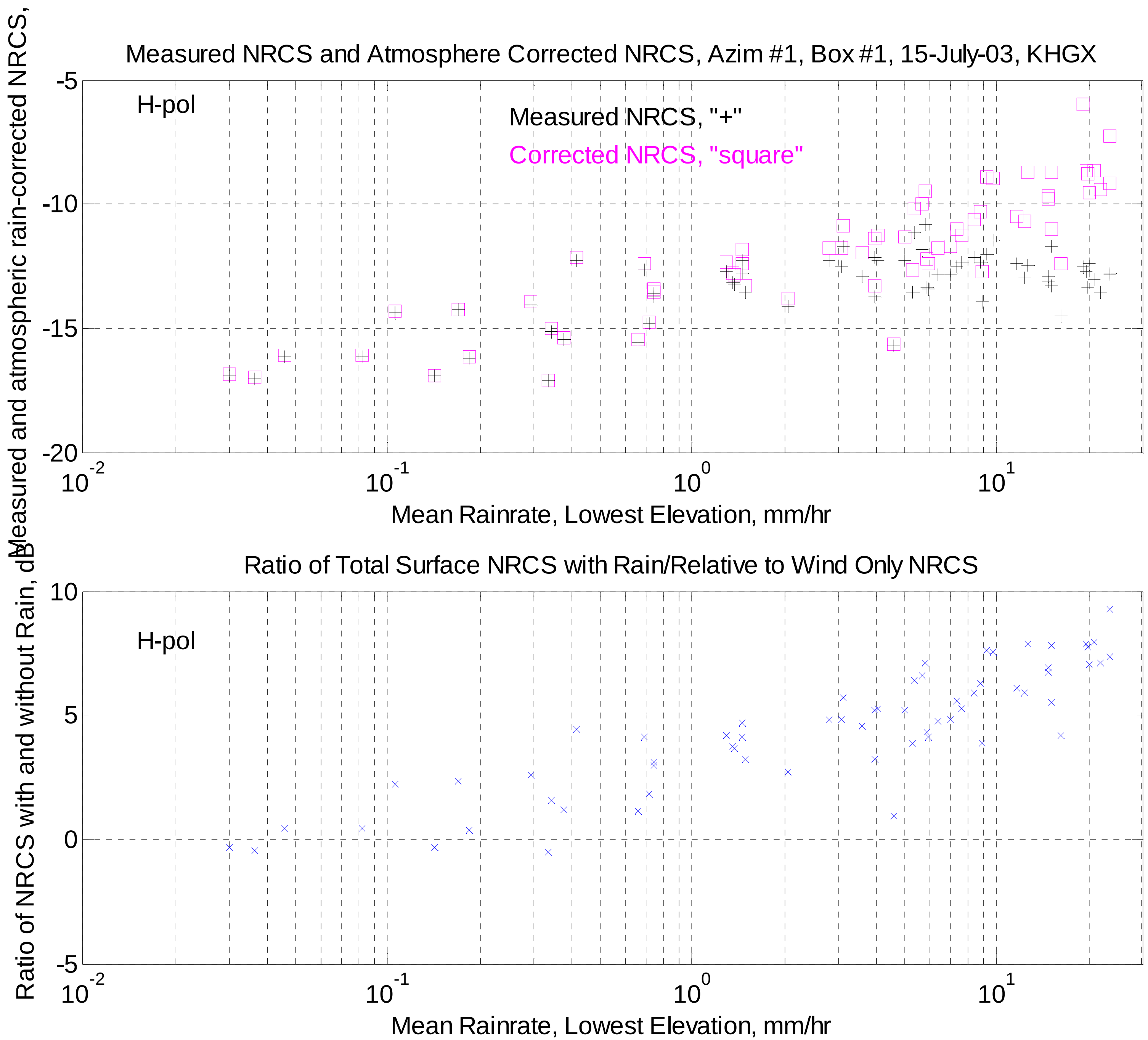
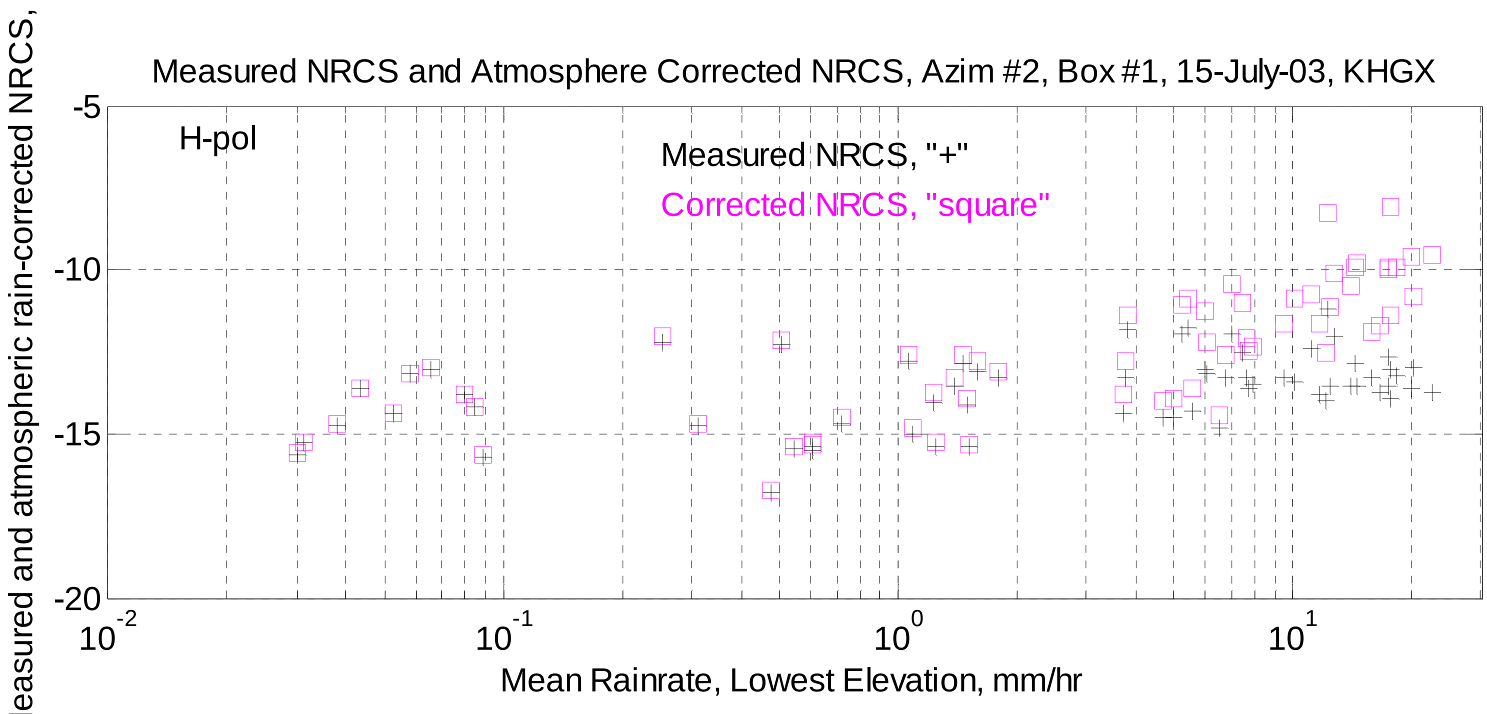
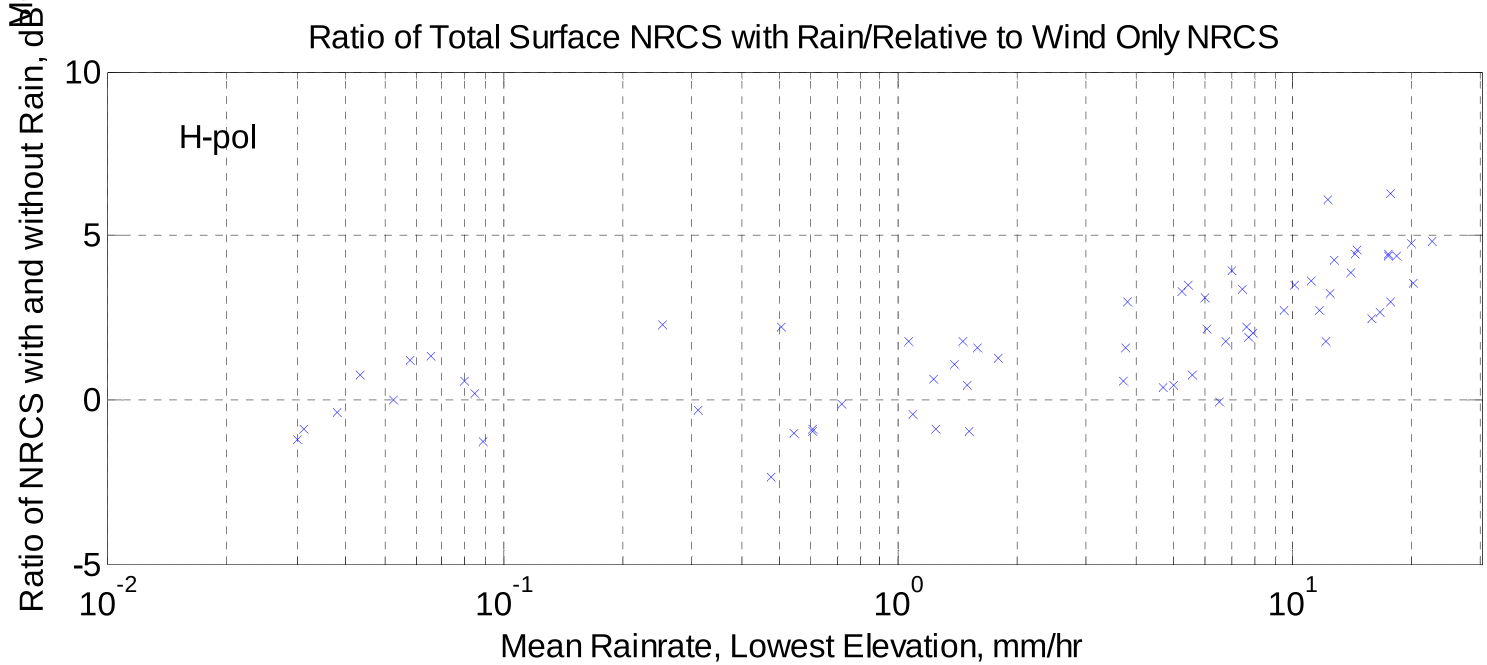




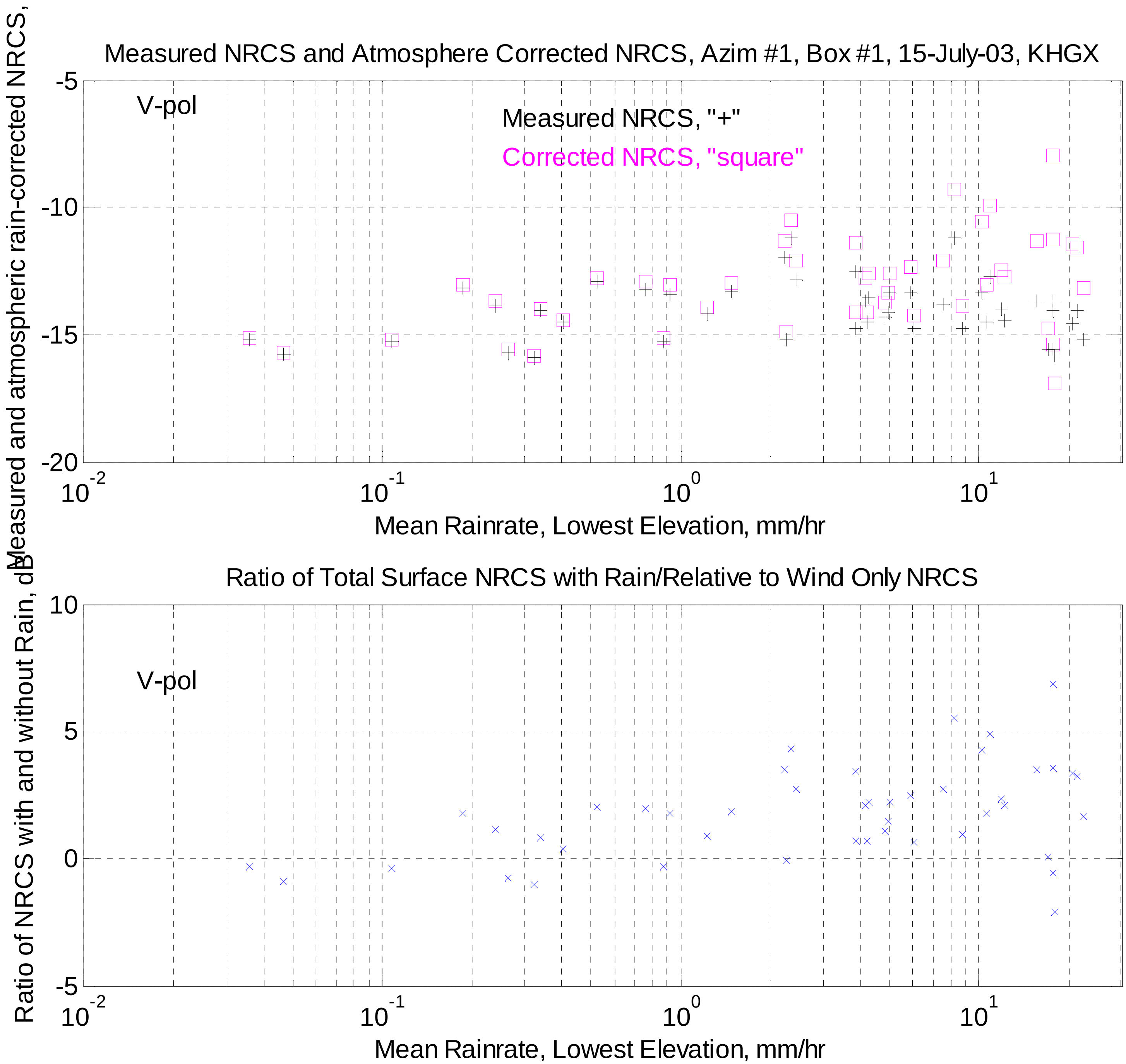
Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #1, 15-July-03, KHGX
H-pol
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRCS, dB
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
H-pol
Ratio of NRCS with and without Rain, dB
Mean Rainrate, Lowest Elevation, mm/hr



Measured NRCS and Atmosphere Corrected NRCS, Azim #2, Box #1, 15-July-03, KHGX
Measured and atmospheric rain-corrected NRCS,
H-pol
Measured NRCS, "+"
Corrected NRCS, "square"
-5
-10
-15
-20
10^{-2}
10^{-1}
10^{0}
10^{1}
Mean Rainrate, Lowest Elevation, mm/hr



Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
Ratio of NRCS with and without Rain, dB
H-pol
10
5
0
-5
10^{-2}
10^{-1}
10^{0}
10^{1}
Mean Rainrate, Lowest Elevation, mm/hr



Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #1, 15-July-03, KHGX
Measured and atmospheric rain-corrected NRCS, dB
V-pol
Measured NRCS, "+"
Corrected NRCS, "square"
-5
-10
-15
-20
10^-2
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
Ratio of NRCS with and without Rain, dB
V-pol
10
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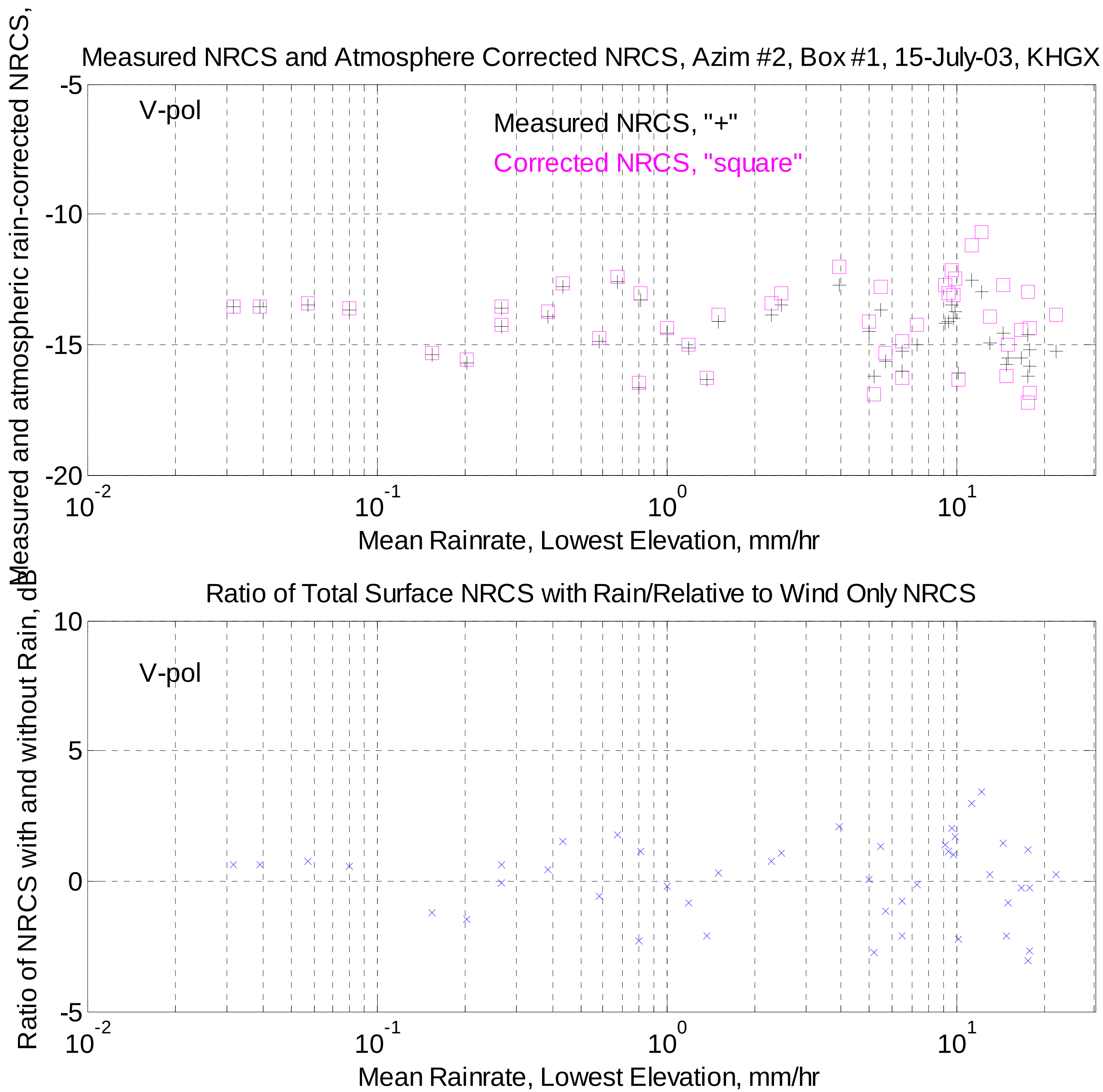
-5
10^-2
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr


Measured NRCS and Atmosphere Corrected NRCS, Azim #2, Box #1, 15-July-03, KHGX
V-pol
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRCS, dB
-5
-10
-15
-20
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10^{-1}
10^{0}
10^{1}
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
V-pol
Ratio of NRCS with and without Rain, dB
10
5
0
-5
10^{-2}
10^{-1}
10^{0}
10^{1}
Mean Rainrate, Lowest Elevation, mm/hr

Summary for Hurricane Claudette:

The properties of the NRCS vs Rainrate:

For H-pol, there is a clear increase in NRCS with rainrate.

For V-pol, there is no clear increase on average, in NRCS with increasing rainrate.

Hurricane Ike 0130 UTC 13 SEP 2008

Max 1-min sustained surface winds (kt)

Valid for marine exposure over water, open terrain exposure over land

Analysis based on CMAN from 2009 - 0149 z; ASOS from 2004 - 0154 z; SFMR_AFRC from 0900 - 0156 z;
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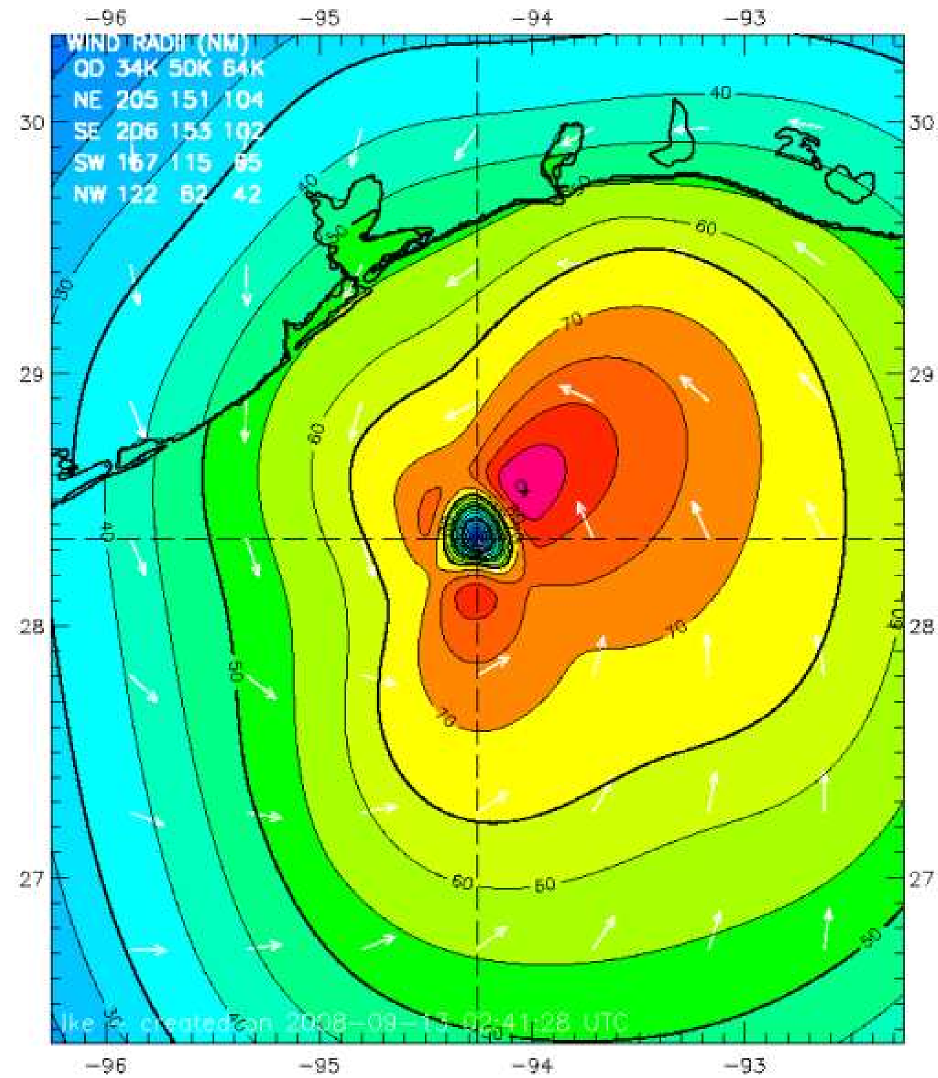

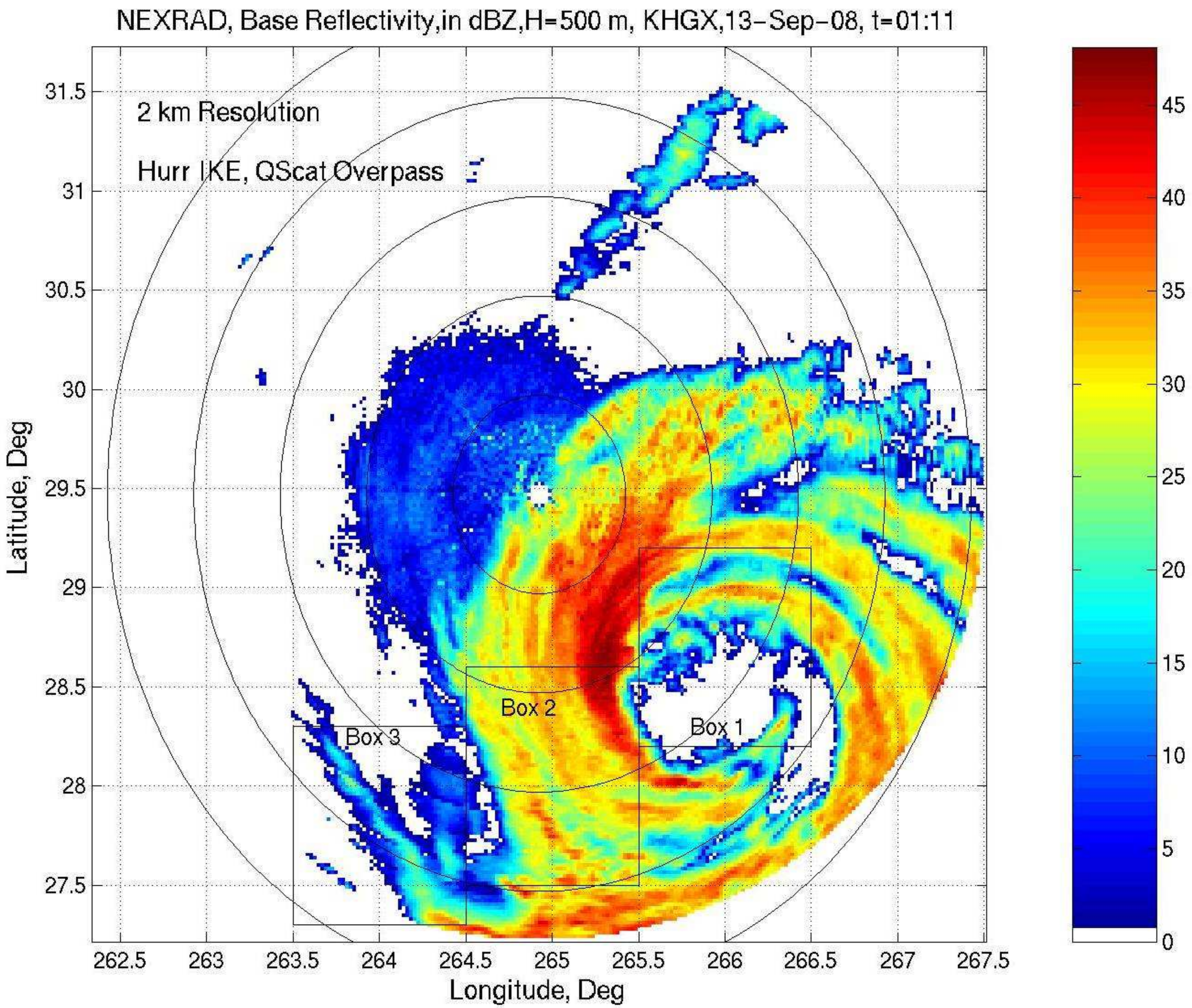
NEXRAD, Base Reflectivity,in dBZ,H=500 m, KHGX,13-Sep-08, t=01:11
2 km Resolution
Hurr IKE, QScat Overpass
Box 1
Box 2
Box 3
Latitude, Deg
Longitude, Deg
31.5
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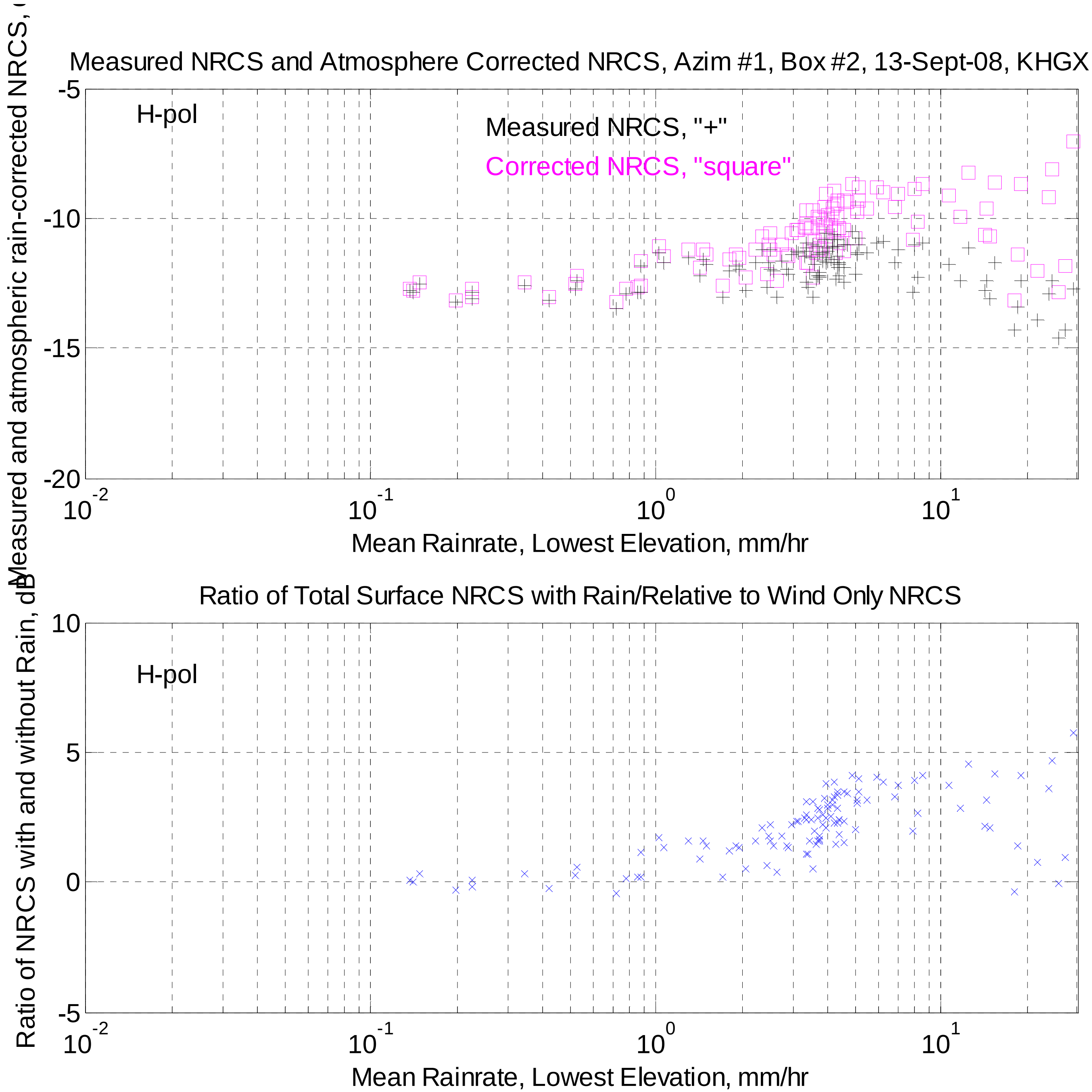
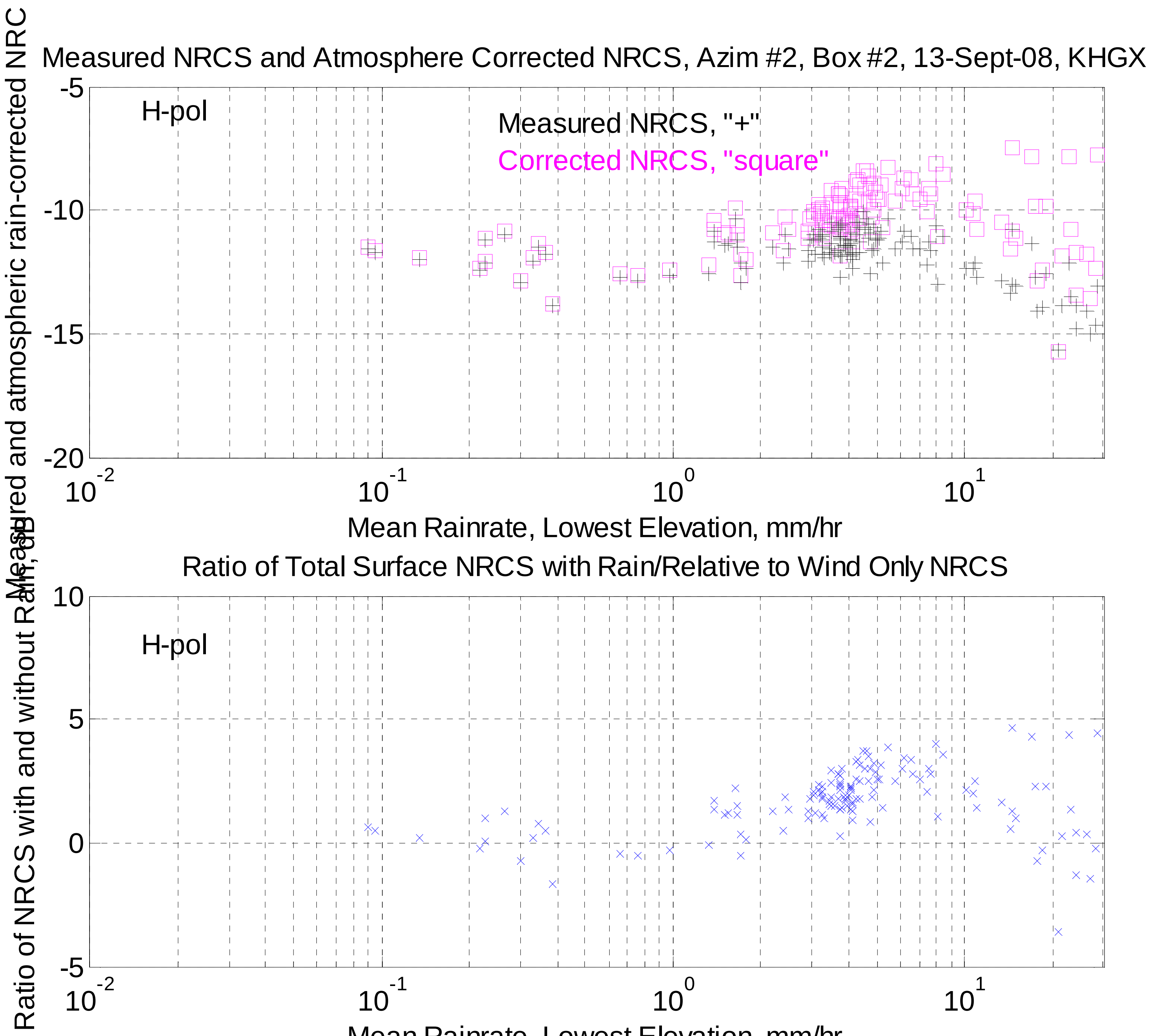
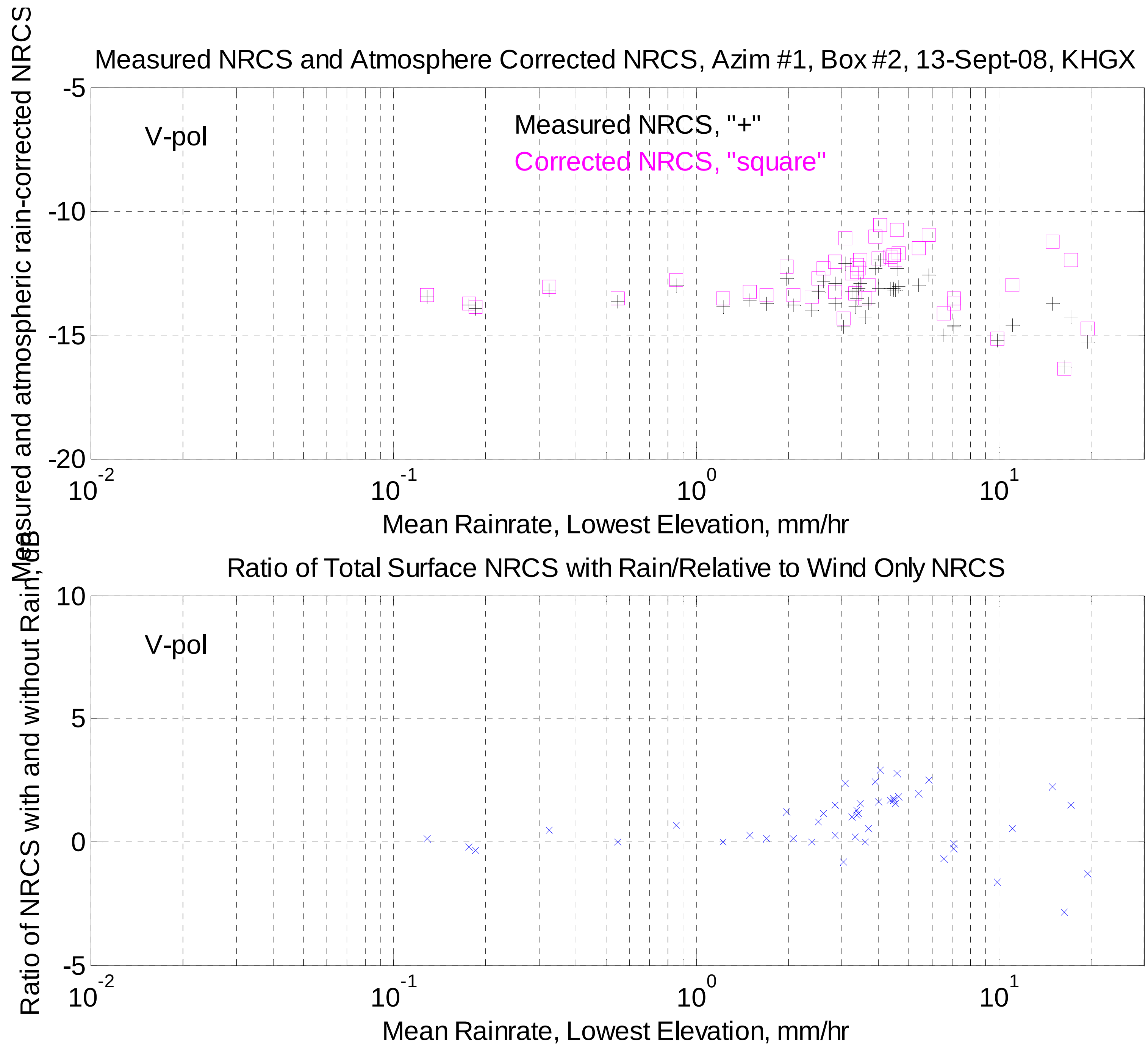


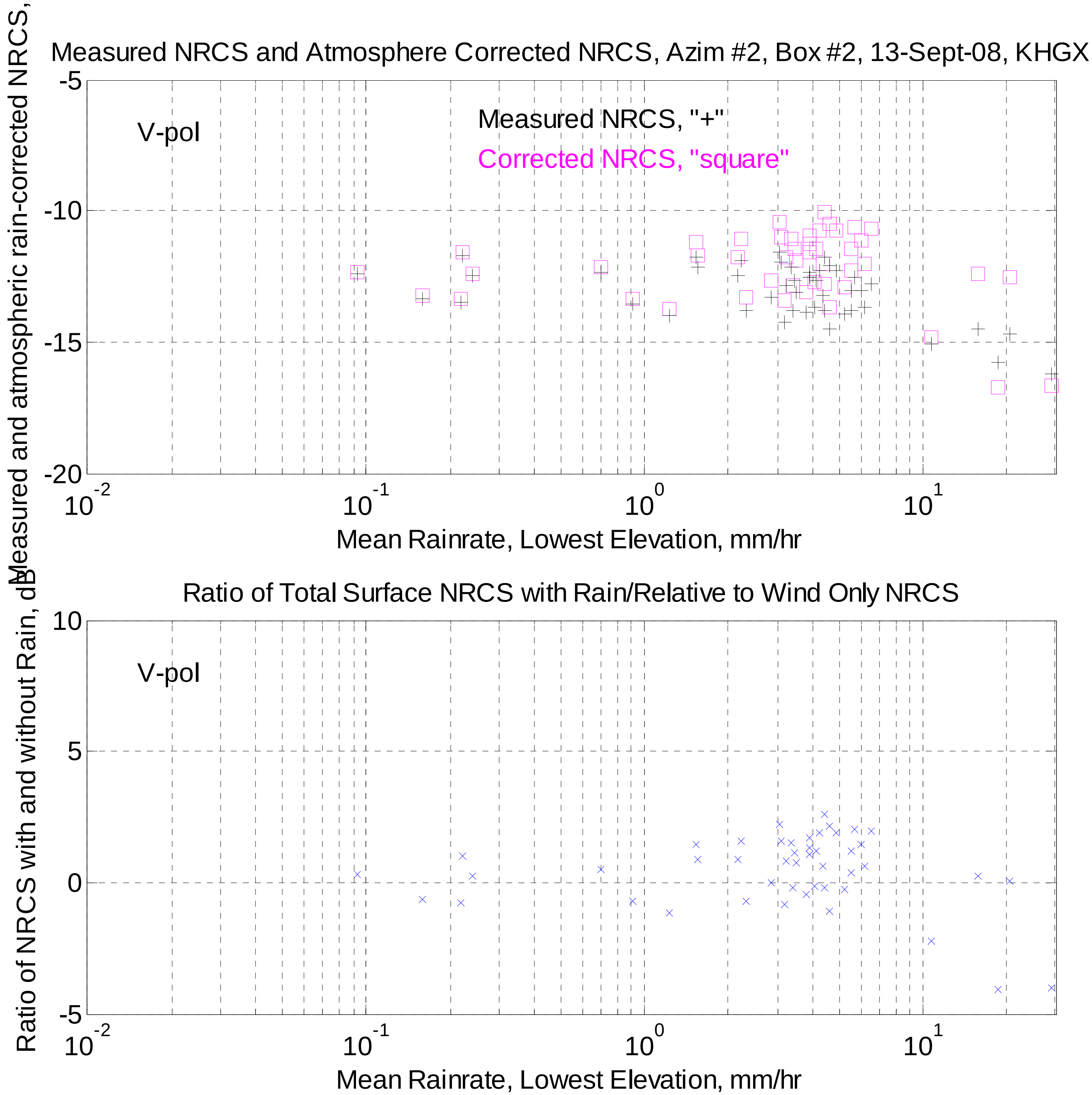
Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #2, 13-Sept-08, KHGX
H-pol
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRCS, dB
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
H-pol
Ratio of NRCS with and without Rain, dB
Mean Rainrate, Lowest Elevation, mm/hr



Measured NRCS and Atmosphere Corrected NRCS, Azim #2, Box #2, 13-Sept-08, KHGX
H-pol
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRC
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
H-pol
Ratio of NRCS with and without Rain, dB
Mean Rainrate, Lowest Elevation, mm/hr



Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #2, 13-Sept-08, KHGX
Measured and atmospheric rain-corrected NRCS
V-pol
Measured NRCS, "+"
Corrected NRCS, "square"
-5
-10
-15
-20
10^{-2}
10^{-1}
10^{0}
10^{1}
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
Ratio of NRCS with and without Rain, dB
V-pol
10
5
0
-5
10^{-2}
10^{-1}
10^{0}
10^{1}
Mean Rainrate, Lowest Elevation, mm/hr



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Measured and atmospheric rain-corrected NRCS, Ratio of NRCS with and without Rain, dB
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Measured NRCS, "+"
Corrected NRCS, "square"
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-10
-15
-20
10^-2
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
V-pol
10
5
0
-5
10^-2
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr

GENERAL SUMMARY

At low wind speeds (< 7 m/s), the changes in NRCS caused by rain roughness was very similar for both H-pol and V-pol

As the wind speed increases, and approaches the terminal velocity of gravity driven falling rain, the differences in NRCS for the two polarizations become progressively larger.

This indicates there is an interaction between the rain impact roughness products and the wind driven wave spectrum. It appears that rain impacts produce new roughness characteristics that have a distinct and differential polarization response.

ASCAT Studies During Hurricane Gustav

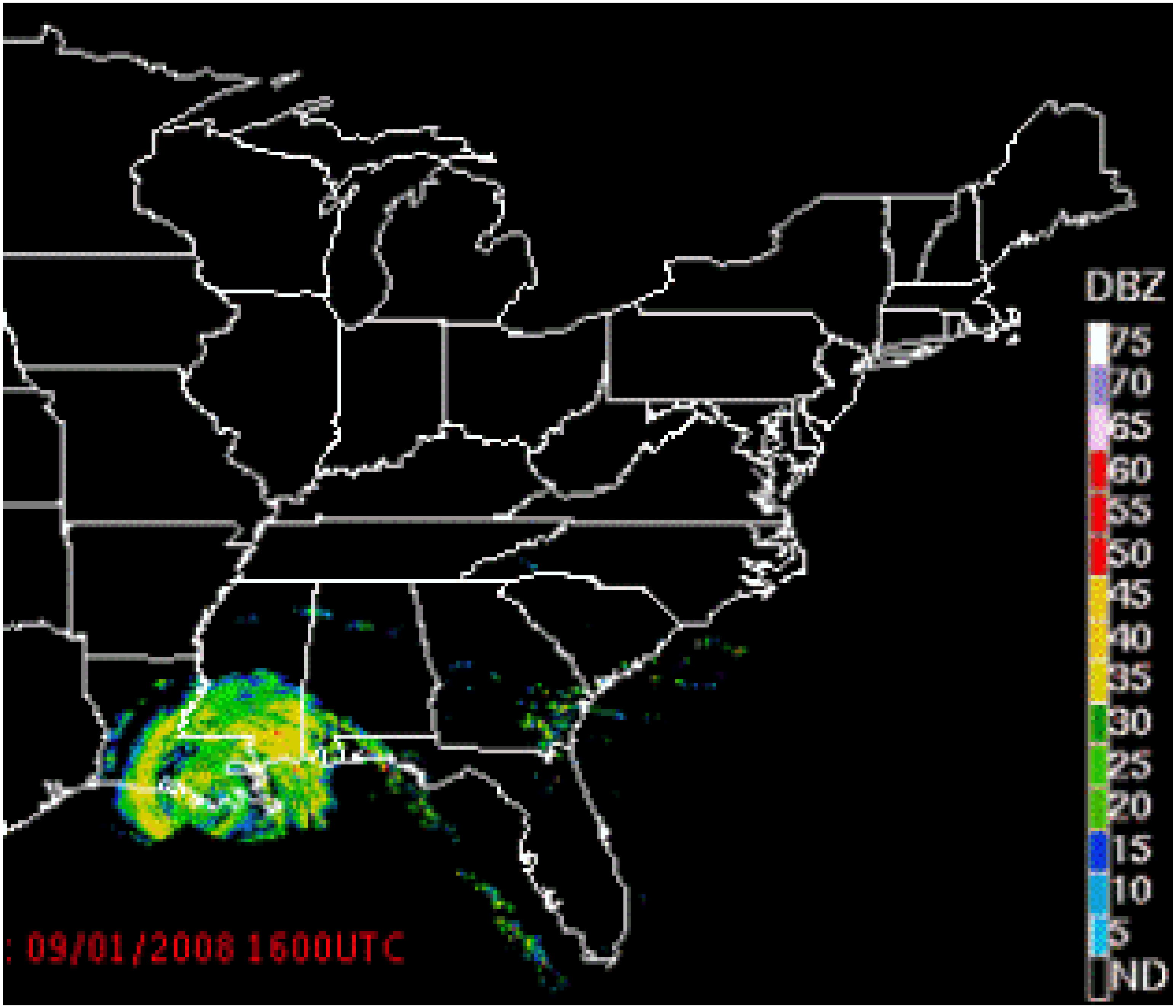
Date: Sept. 1, 2008
Time: 16:30 Z

Location: Near New Orleans, LA

NEXRAD Station: KLCH

Thanks to KNMI Scatterometer Group for NRCS 25 km data.

Will examine NRCS, Rain and Wind magnitudes


DBZ
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70
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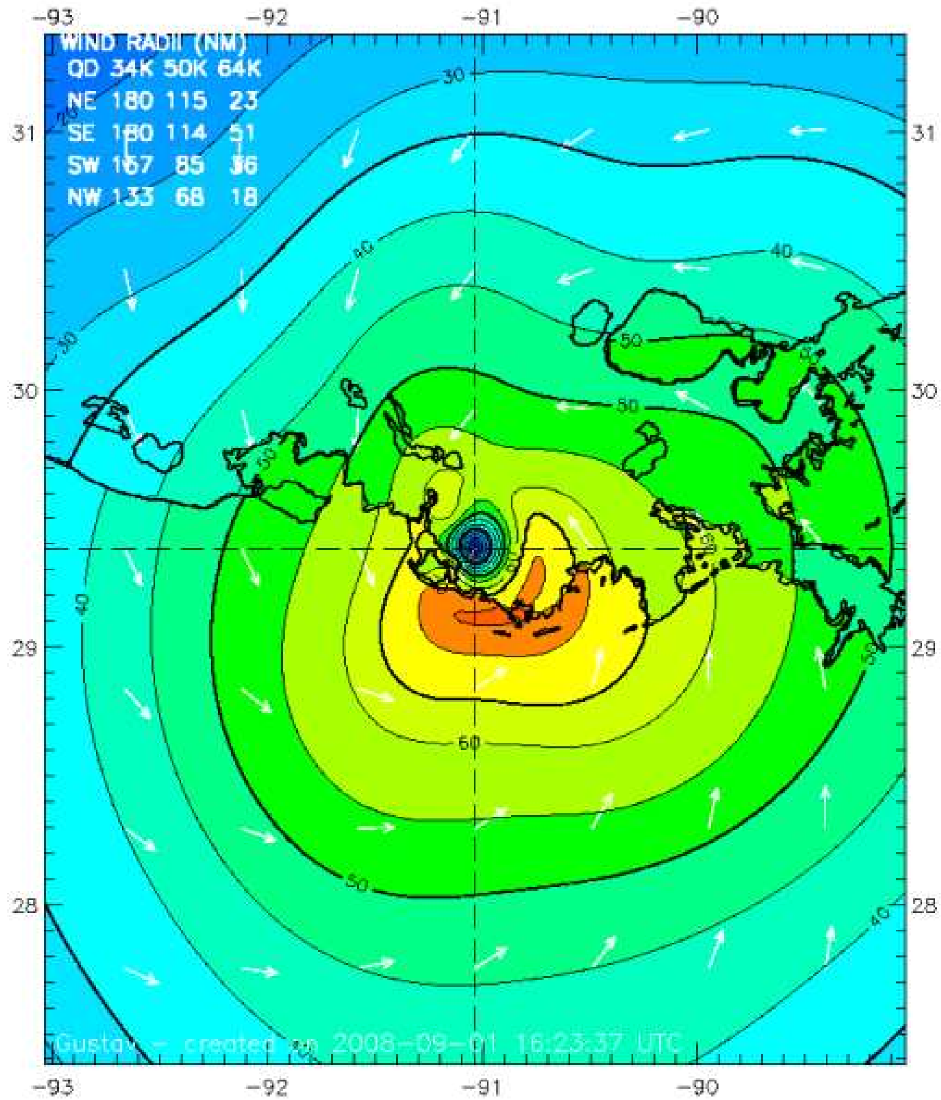
15
10
5
ND
: 09/01/2008 1600UTC

Hurricane Gustav 1630 UTC 01 SEP 2008

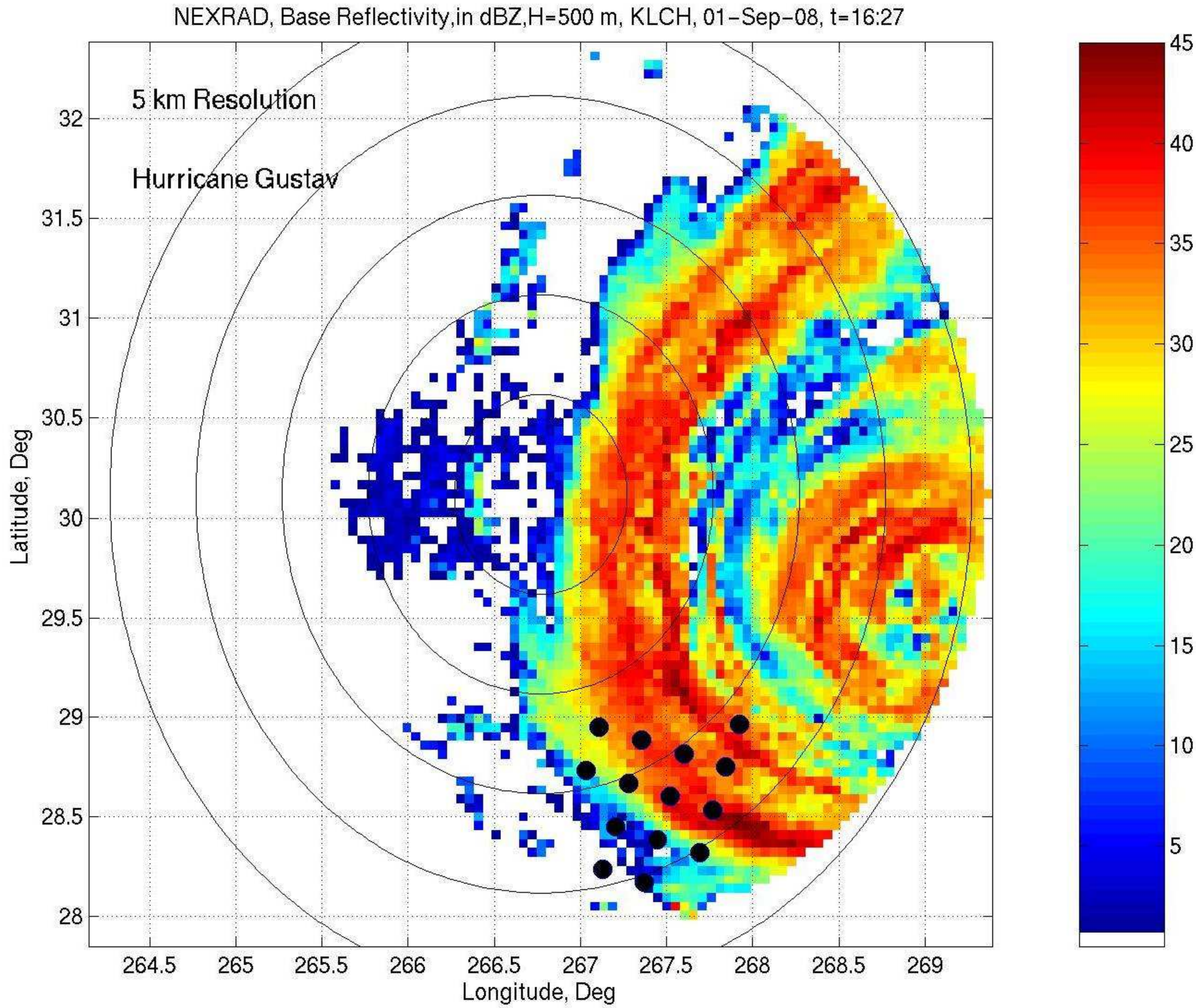
Max 1-min sustained surface winds (kt)

Valid for marine exposure over water, open terrain exposure over land

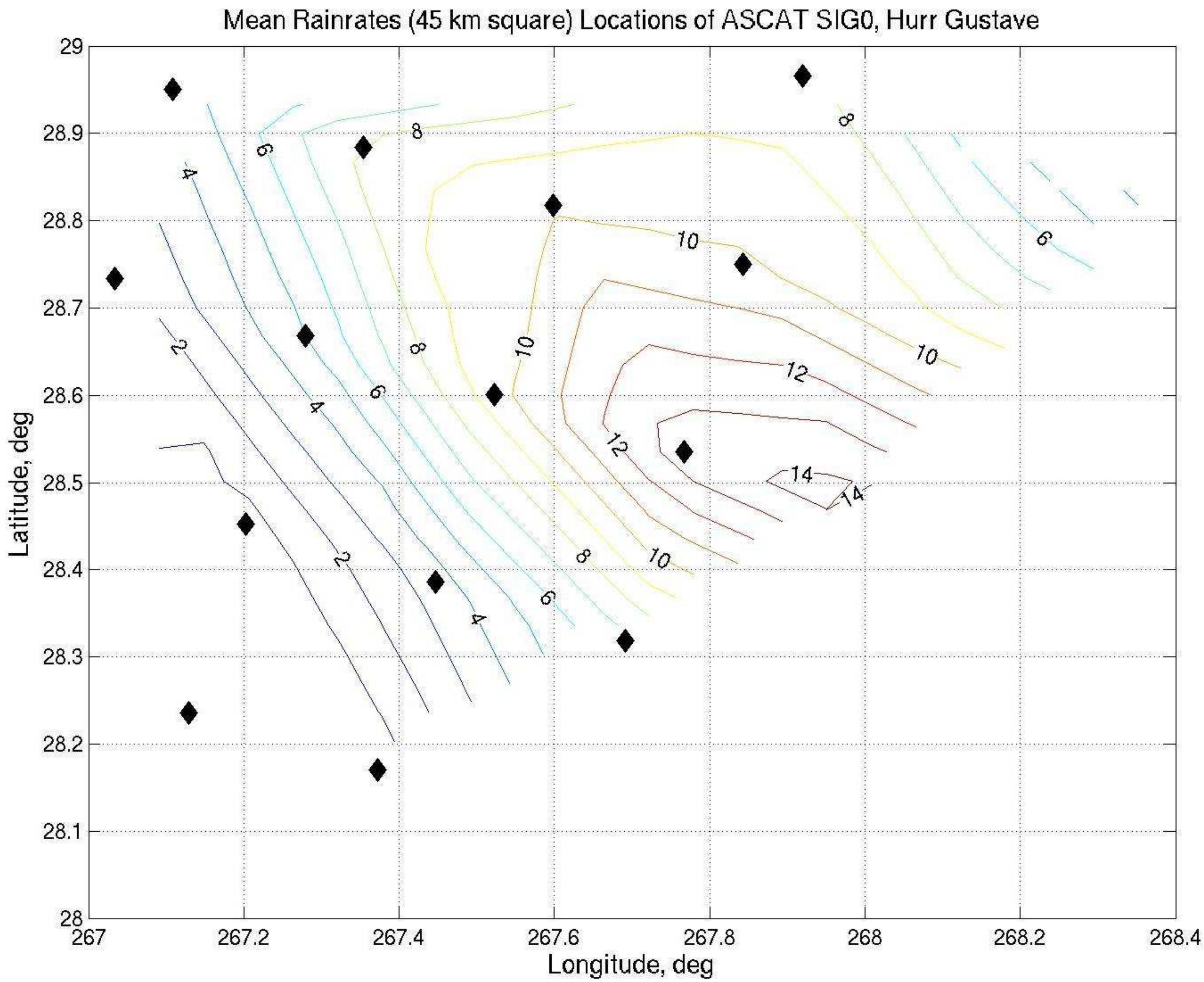
Analysis based on CMAN from 1239 - 1559 z; MOORED_BUOY from 1239 - 1549 z; ASOS from 1232 - 1605 z;
GPSSONDE_SFC from 1233 - 1429 z; SHIP from 1300 - 1600 z;
METAR from 1232 - 1611 z; FCMP_TOWER from 1232 - 1609 z;
GPSSONDE_WL150 from 1233 - 1429 z; SFMR43 from 1230 - 1452 z;
SFMR_AFRC from 1230 - 1550 z; QSCAT_HIRES from 1235 - 1237 z;
GOES from 1302 - 1302 z; AFRC (SFMR-2007 adjusted) from 1230 - 1550 z;
1630 z position extrapolated from 1533 z Vortex wind center using 315 deg @ 12 kts; mslp = 956.0 mb

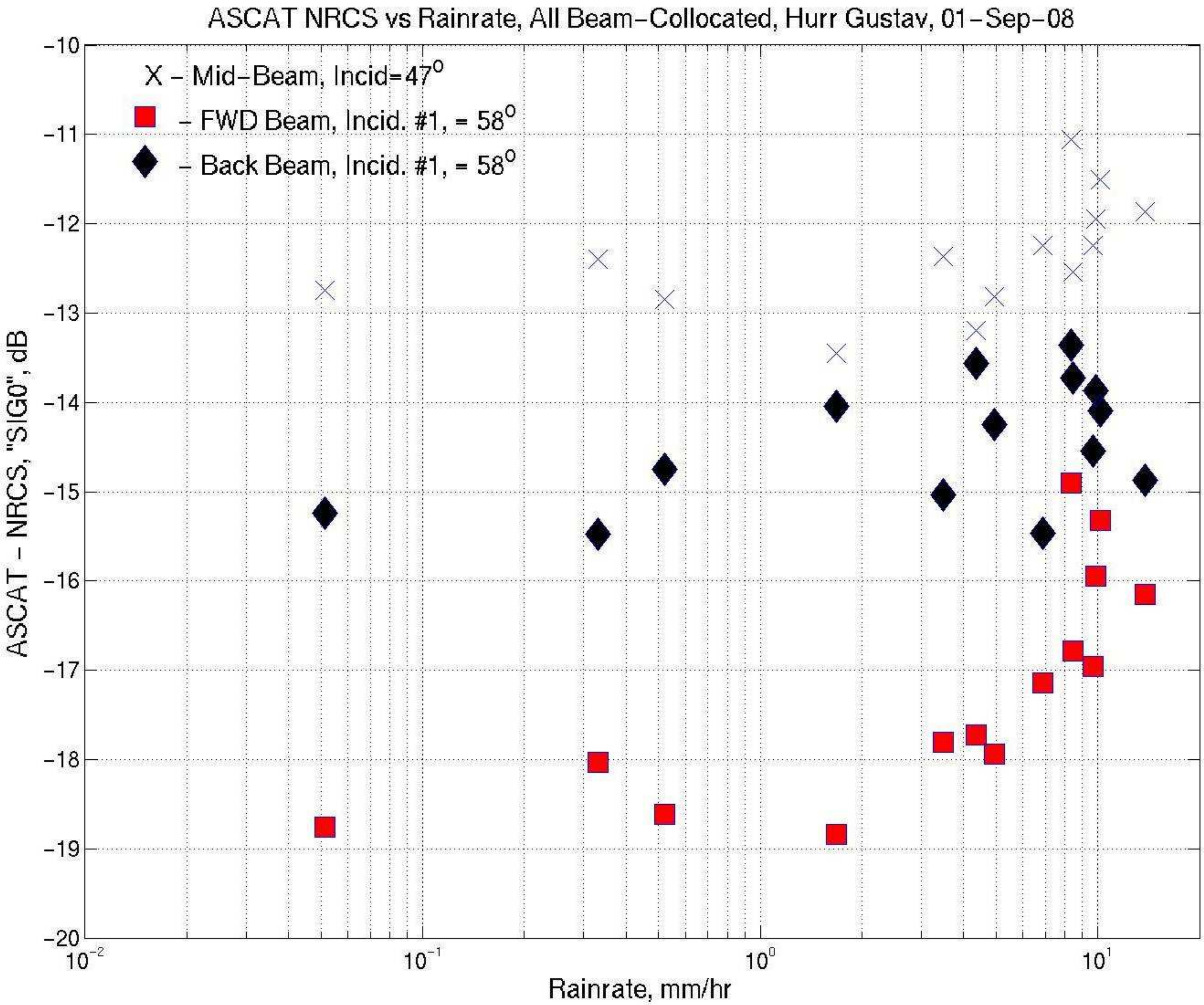


Integrated Kinetic Energy: for Winds > TS force: 64.1 TJ for Winds > Hurricane Force: 6.7 TJ

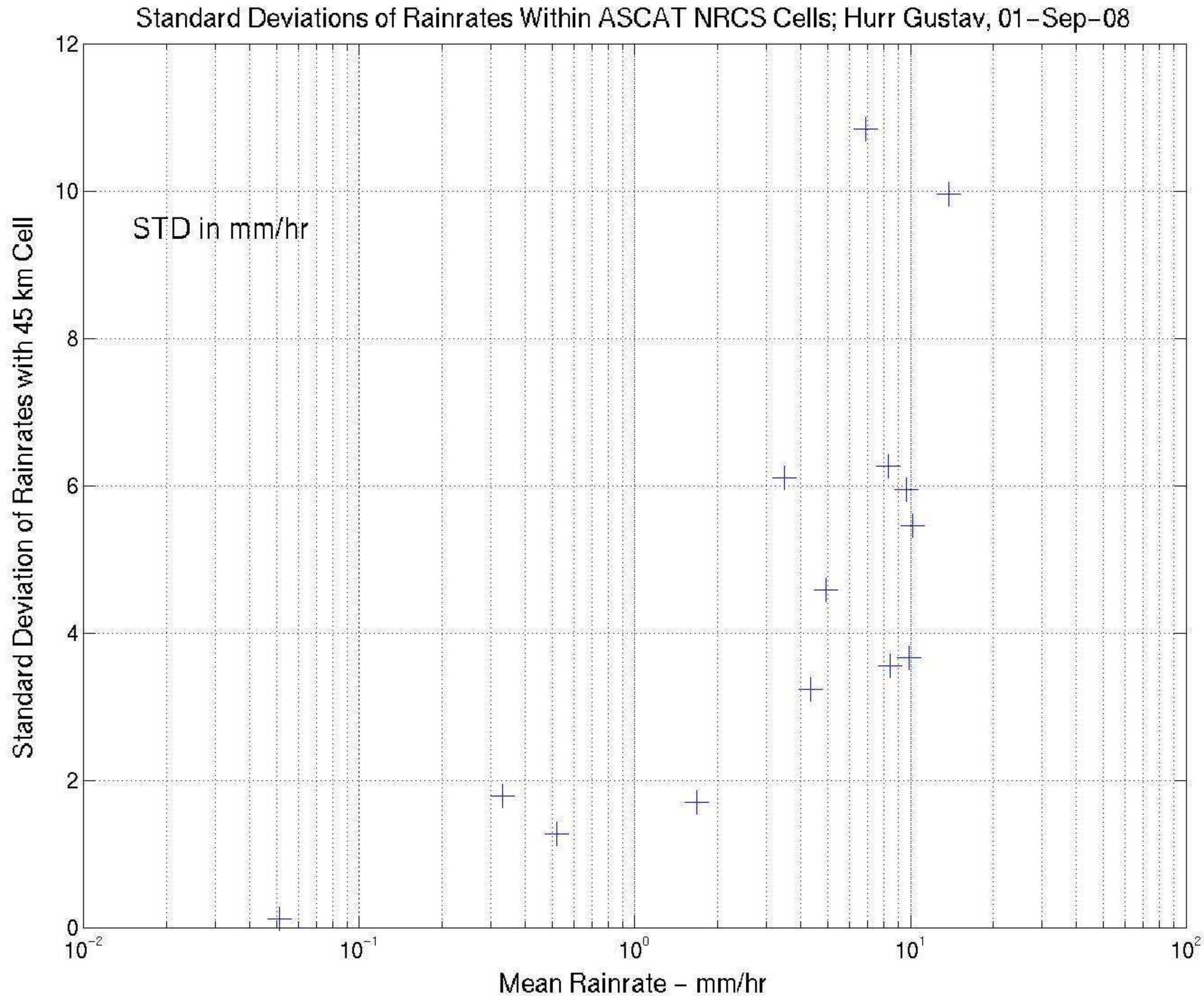


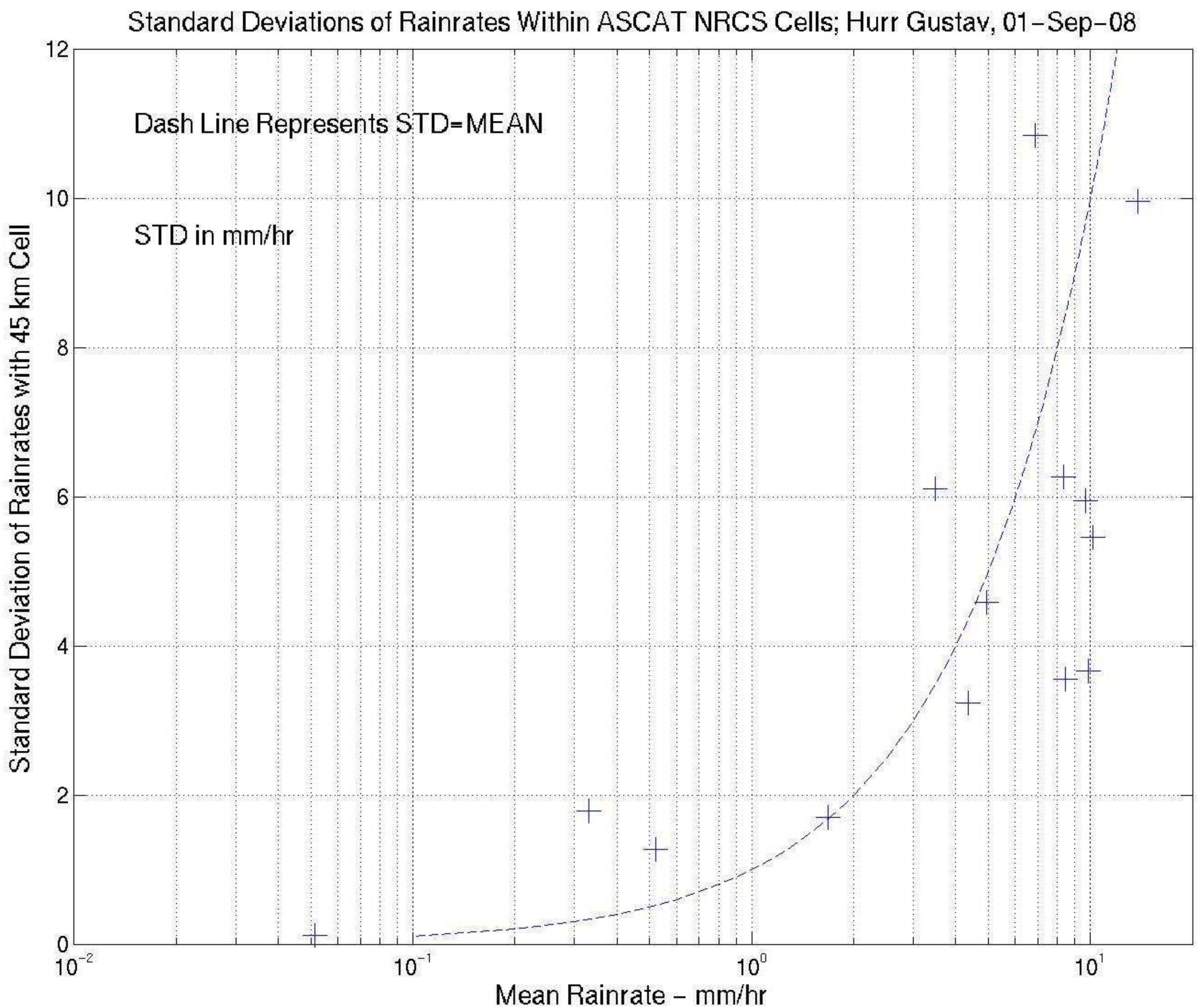
NEXRAD, Base Reflectivity,in dBZ,H=500 m, KLCH, 01-Sep-08, t=16:27
5 km Resolution
Hurricane Gustav
Latitude, Deg
Longitude, Deg
32
31.5
31
30.5
30
29.5
29
28.5
28
264.5
265
265.5
266
266.5
267
267.5
268
268.5
269
45
40
35
30
25
20
15
10
5


Mean Rainrates (45 km square) Locations of ASCAT SIG0, Hurr Gustave
Latitude, deg
Longitude, deg
29
28.9
28.8
28.7
28.6
28.5
28.4
28.3
28.2
28.1
28
267
267.2
267.4
267.6
267.8
268
268.2
268.4
2
4
6
8
10
12
14

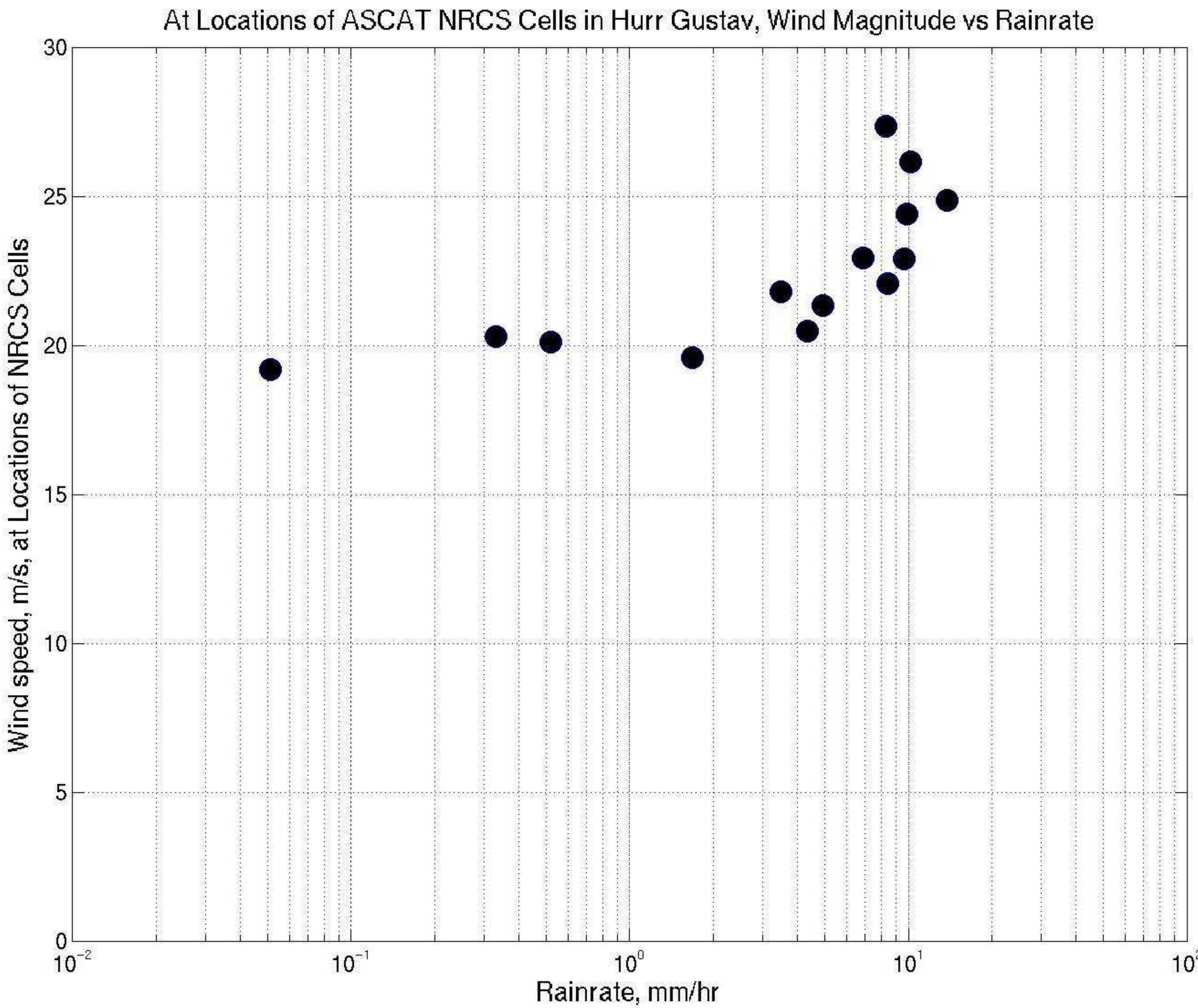


ASCAT NRCS vs Rainrate, All Beam−Collocated, Hurr Gustav, 01−Sep−08
X − Mid−Beam, Incid=47°
− FWD Beam, Incid. #1, = 58°
− Back Beam, Incid. #1, = 58°
ASCAT − NRCS, "SIG0", dB
Rainrate, mm/hr
−10
−11
−12
−13
−14
−15
−16
−17
−18
−19
−20
10^-2
10^-1
10^0
10^1


Standard Deviations of Rainrates Within ASCAT NRCS Cells; Hurr Gustav, 01-Sep-08
STD in mm/hr
Standard Deviation of Rainrates with 45 km Cell
Mean Rainrate - mm/hr
0
2
4
6
8
10
12
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}



Standard Deviations of Rainrates Within ASCAT NRCS Cells; Hurr Gustav, 01-Sep-08
Dash Line Represents STD=MEAN
STD in mm/hr
Standard Deviation of Rainrates with 45 km Cell
Mean Rainrate - mm/hr
0
2
4
6
8
10
12
10^{-2}
10^{-1}
10^{0}
10^{1}


At Locations of ASCAT NRCS Cells in Hurr Gustav, Wind Magnitude vs Rainrate
Wind speed, m/s, at Locations of NRCS Cells
Rainrate, mm/hr
30
25
20
15
10
5
0
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

PROPERTIES OF ASCAT NRCS OBSERVED IN HURRICANE GUSTAV:

1. In the measurement area the winds were between 20-27 m/s
2. The average rainrates extended to 12 mm/hr. It is believed that rain volume effects: two-way attenuation and backscatter are negligible at this rain intensity level.
3. We see that the changes in observed NRCS vs rainrate shows and expected increase; but the wind variation is closely correlated.
4. There appears to be a dependence on both incidence angle and azimuth angle (FWD and BACK beams are 90 deg. apart)
5. The azimuth differences may be related to the wave field, but no measured data is available.

Why Is This Interesting To A Meteorologist or Oceanographer

The air-sea momentum exchange in hurricanes is not well understood

- Surface drag
  - Which is related to surface roughness for $U_{10} < 25 ms^{-1}$,
  - If it continues to increase of $U_{10} > 25\ ms^{-1}$,
    - The drag is too great to produce strong hurricanes
    - Unless there is a proportional increase in evaporation
- However, the highest winds are found in or near rain bands
  - Therefore, it seems likely that surface drag is somehow reduced by rain
  - Rain and sea spray likely act to reduce the surface drag
  - Does rain act to increase sea spray via wave-wave interaction or is the process more direct?
- Current hurricane intensity forecasts do not consider these processes
  - Intensity forecasts are bad – but there could be other reasons
- Ocean mixing due to tropical cyclones could be important for climate
  - If the drag is reduced there will be less mixing than otherwise modeled!
  - Reduced stress results in reduced turbulent heat fluxes