Rain Influences on High Wind Backscatter: SeaWinds Studies during Hurricanes Dennis, Isabel, and Claudette. Additional Studies with ASCAT

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Studies of Interest:

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.

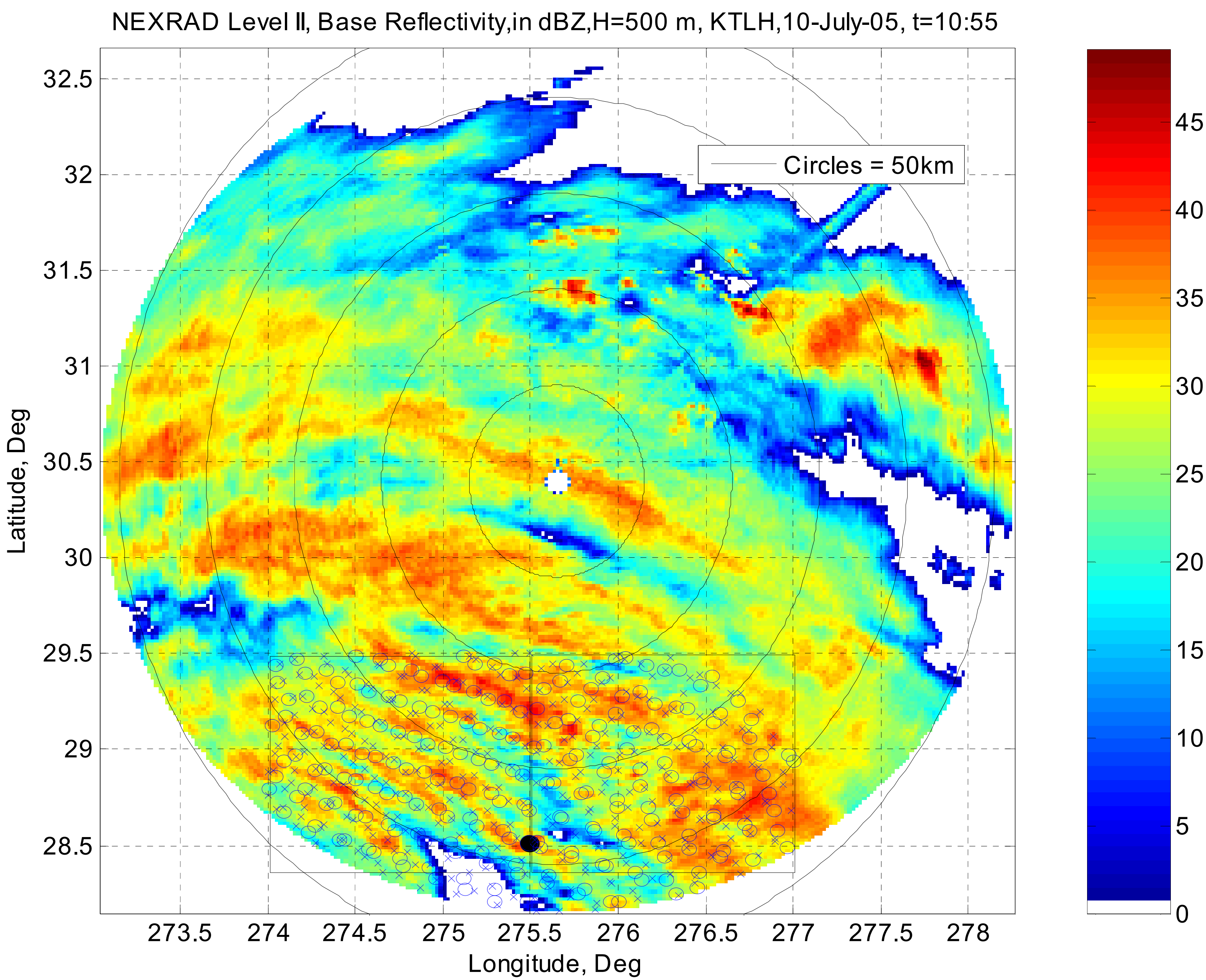
3. Interpret the results in terms of the interaction between wind waves and the splash products of rain impacts (ring waves, crowns and stalks)

DATA:

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

b) Simultaneous NEXRAD 3-D Volume Reflectivity (S-band) within scatterometer beam

c) Surface winds from NOAA Hurricane Research Division Analysis and buoys

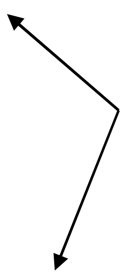

NEXRAD Level II, Base Reflectivity,in dBZ,H=500 m, KTLH,10-July-05, t=10:55
Circles = 50km
Latitude, Deg
Longitude, Deg
32.5
32
31.5
31
30.5
30
29.5
29
28.5
273.5
274
274.5
275
275.5
276
276.5
277
277.5
278
45
40
35
30
25
20
15
10
5
0

Hurr. Dennis 1055 UTC
10 July 2005

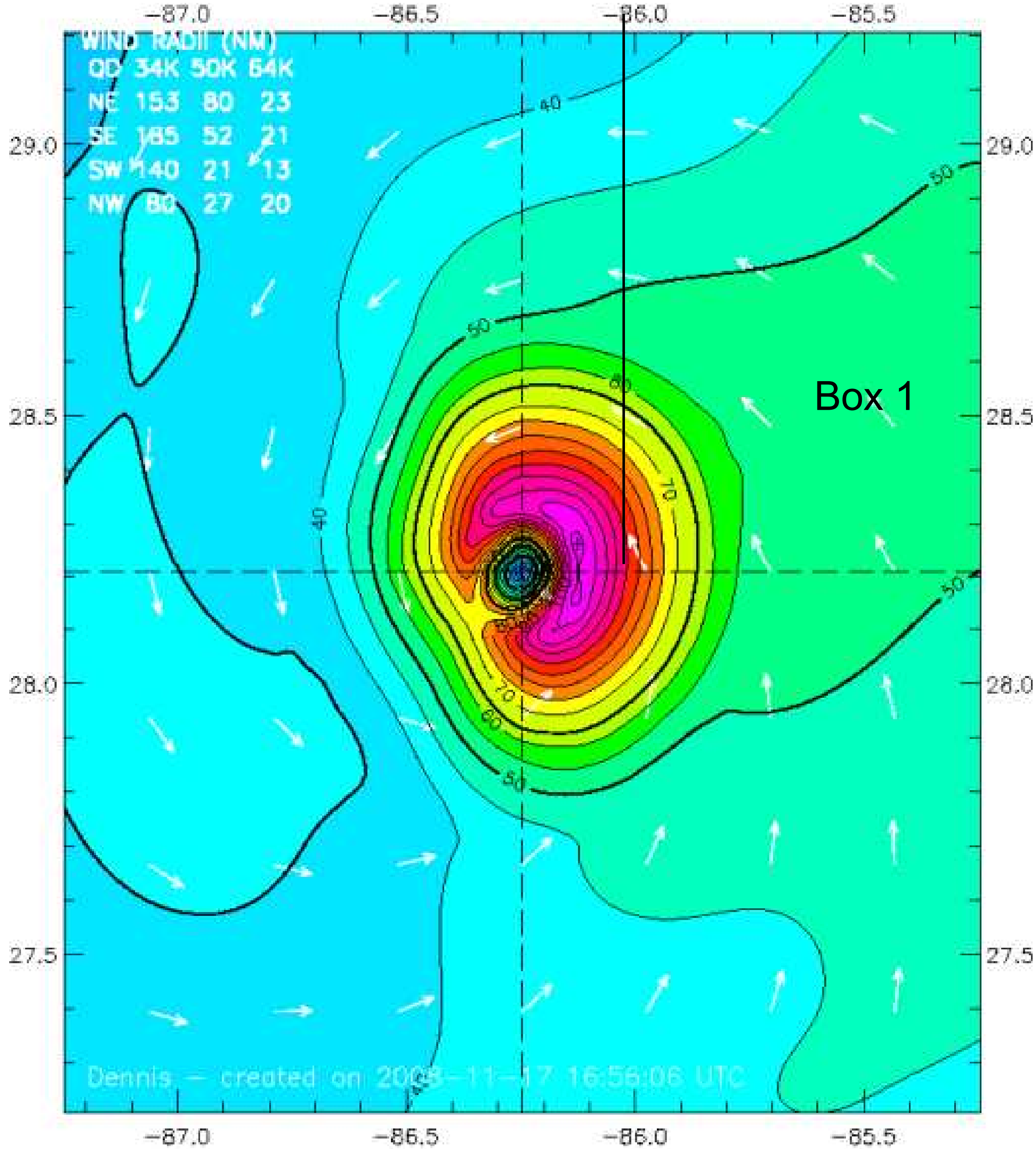
Product of
NOAA/AOML/HRD
Courtesy of Mark Powell

Max. 1-min sustained
surface winds (kt)

QS Azim. 2
310 deg



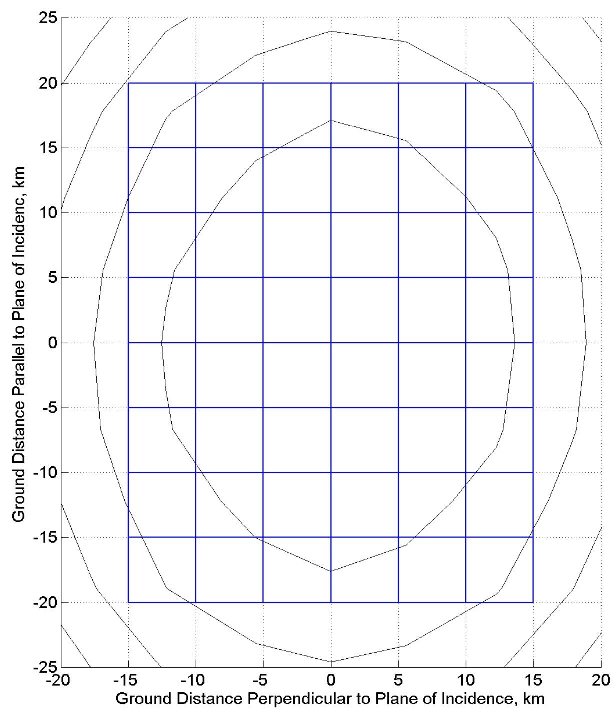
QS Azim. 1
210 deg

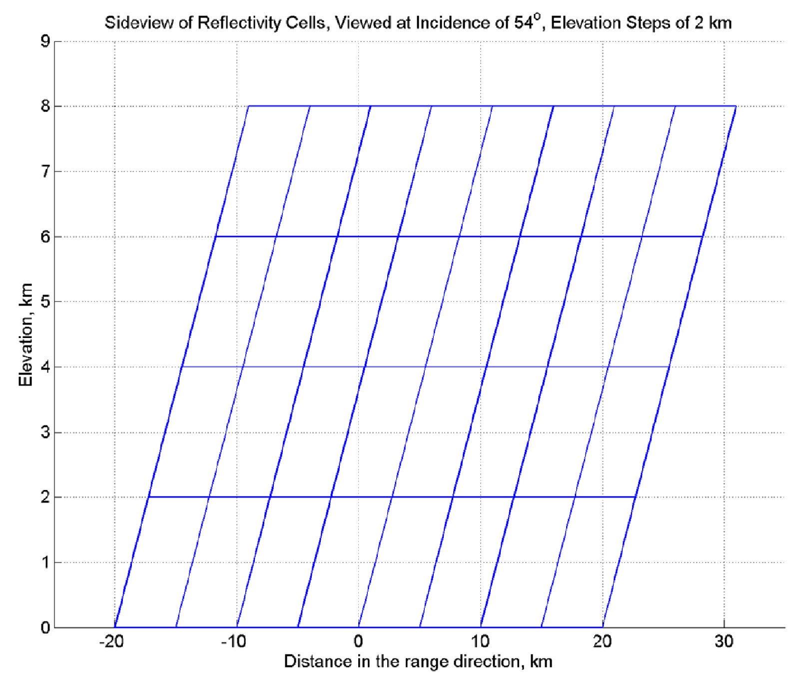


Method of Computing SeaWinds Volume Backscatter and Attenuation using NEXRAD data in discrete parallelograms

Subdivision of SCAT Footprint into 5 km Square, 2 km High Cells (0-to-8km)

NEXRAD Reflectivity is determined in each cell, weighted with EGG pattern gain Correction to SIGMA0 in <u>each</u> cell - 3 dB Contours Shown





Relative Positions of Reflectivity Cells Along Incident Beam, V-pol Case

Electromagnetic Model of the NRCS (σ_{ax}) Measured by the SeaWinds Scatterometer and Rain Impact NRCS, σ_{rn0}

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

σ_{ax} = Total measured NRCS at Receiver; Sum of Contributions from Sea Surface and Rain Volume=L2A data

σ_{wdx} = sea surface radar cross section due to wind driven roughness alone (wind-NRCS)

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

α_x(r)= attenuation, in nepers/m for each polarization, function of local volume rainrate or precipitation water content

σ_{ox} (r)= surface equivalent of volumetric rain RCS, = constant * Zx
(the radar reflectivity factor for Ku-band, Zx, varies with position, "r")

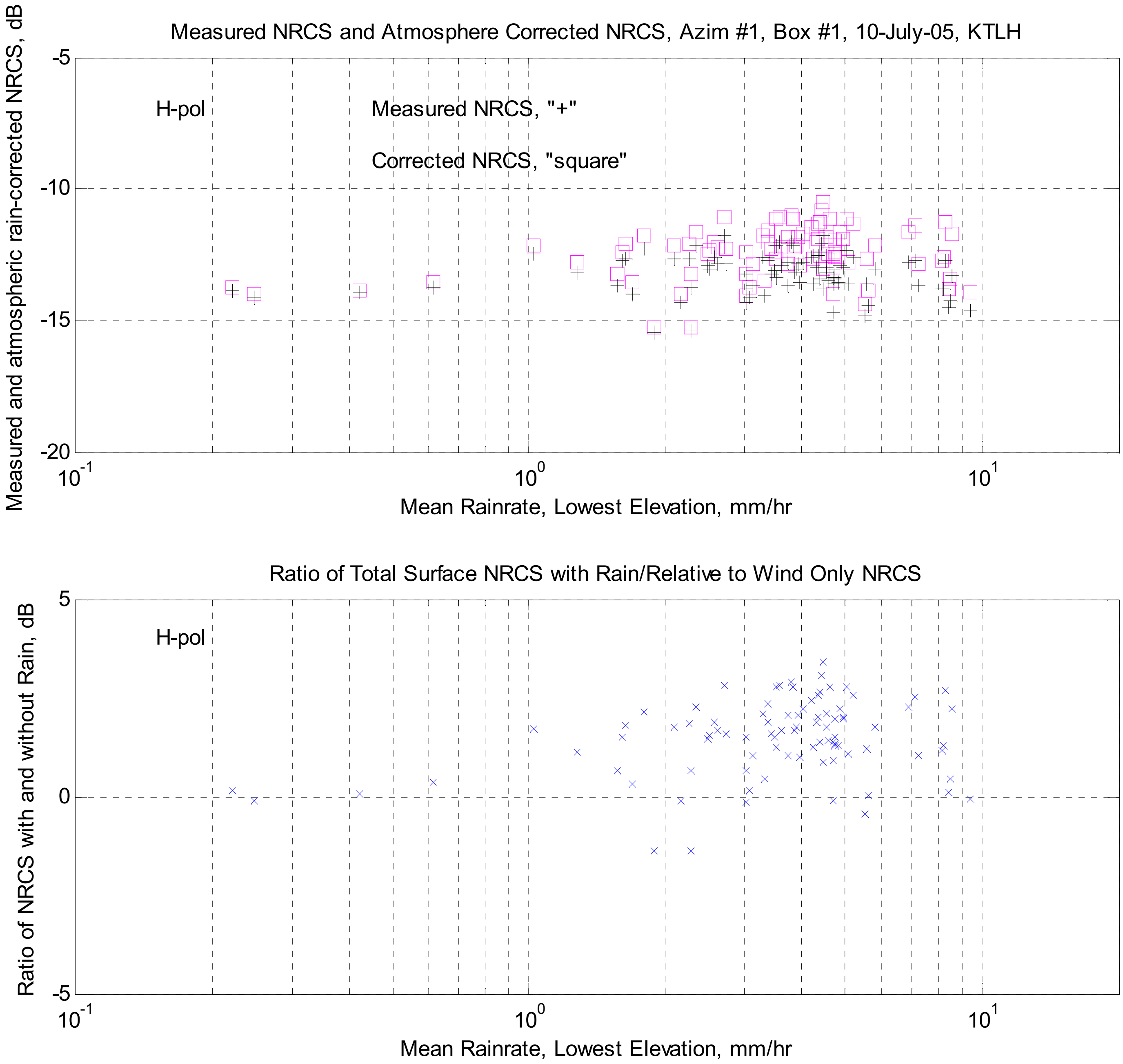
lenx=path length of radar beam for each polarization = len/Cos(θx)
(rain column height, over scatterometer footprint = len, θ_h=46° & θ_v=54°)

$$\sigma_{ax} = \int_0^{lenx} \sigma_{ox}\, e^{-4\int_r^{lenx} \alpha_x(s)\,ds}\, dr + (\sigma_{wdx} + \sigma_{rnx}) * e^{-4\int_0^{lenx} \alpha_x(s)\,ds}$$

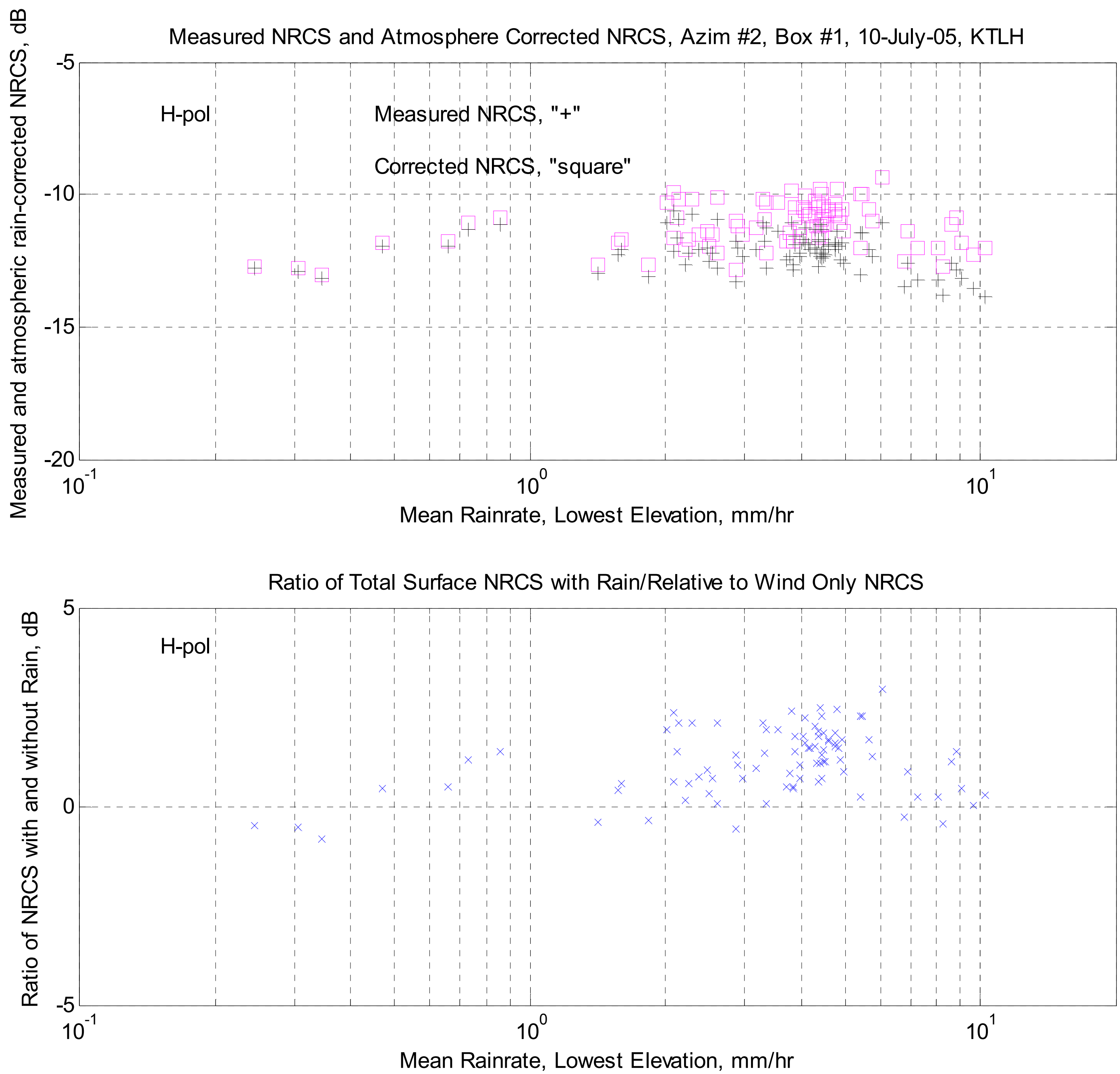
σ_{rn0} = model function for the normalized radar cross section due to rain impact; depends on wind magnitude and rainrate

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:

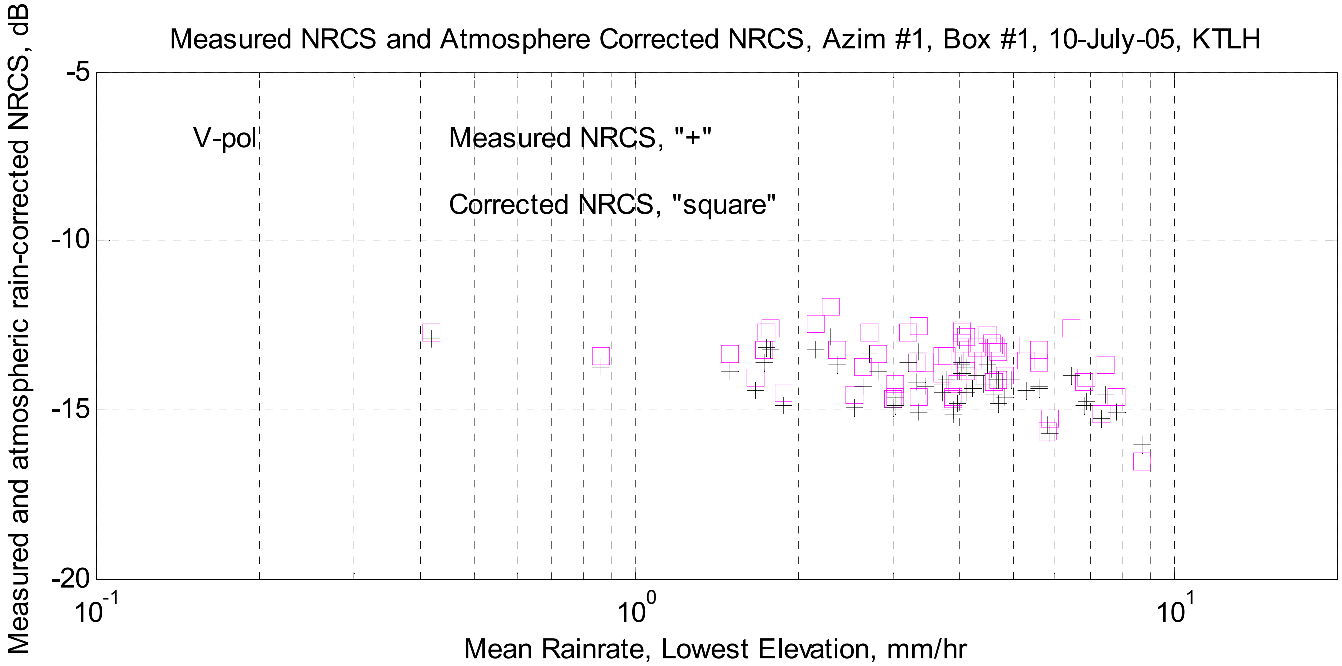
$$\sigma_{rn0} = \left(\frac{\sigma_{wdx} + \sigma_{rnx}}{\sigma_{wdx}}\right)$$

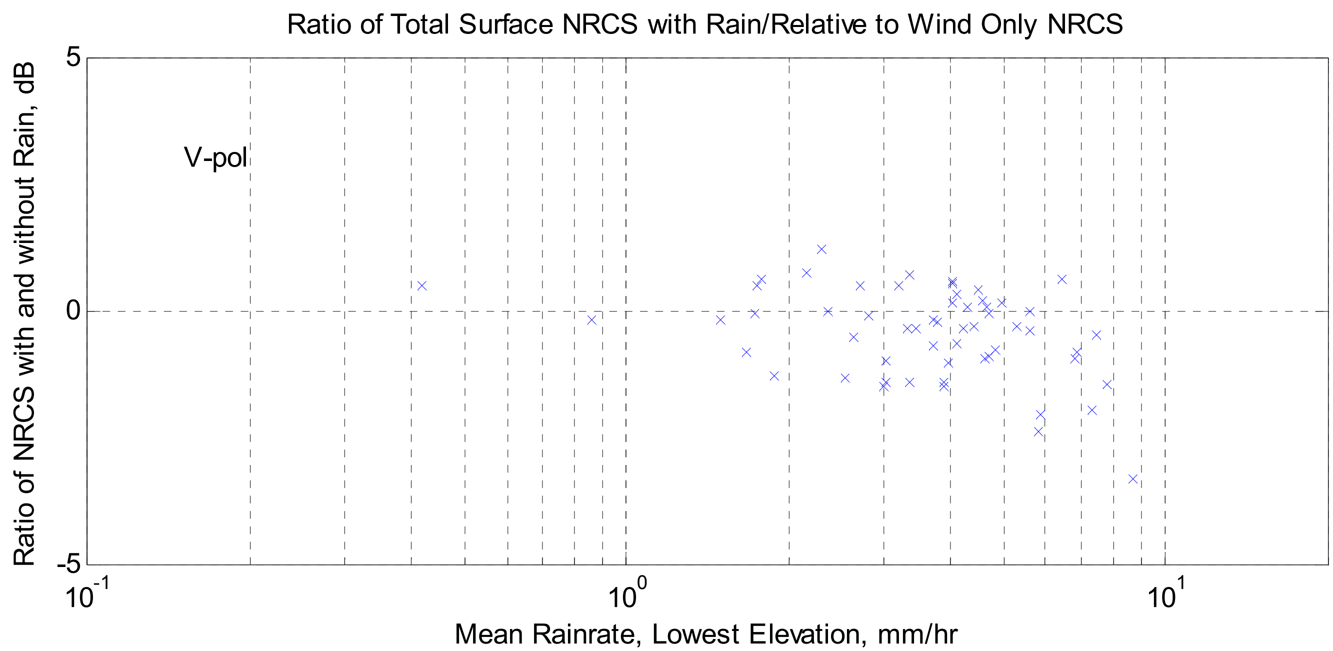


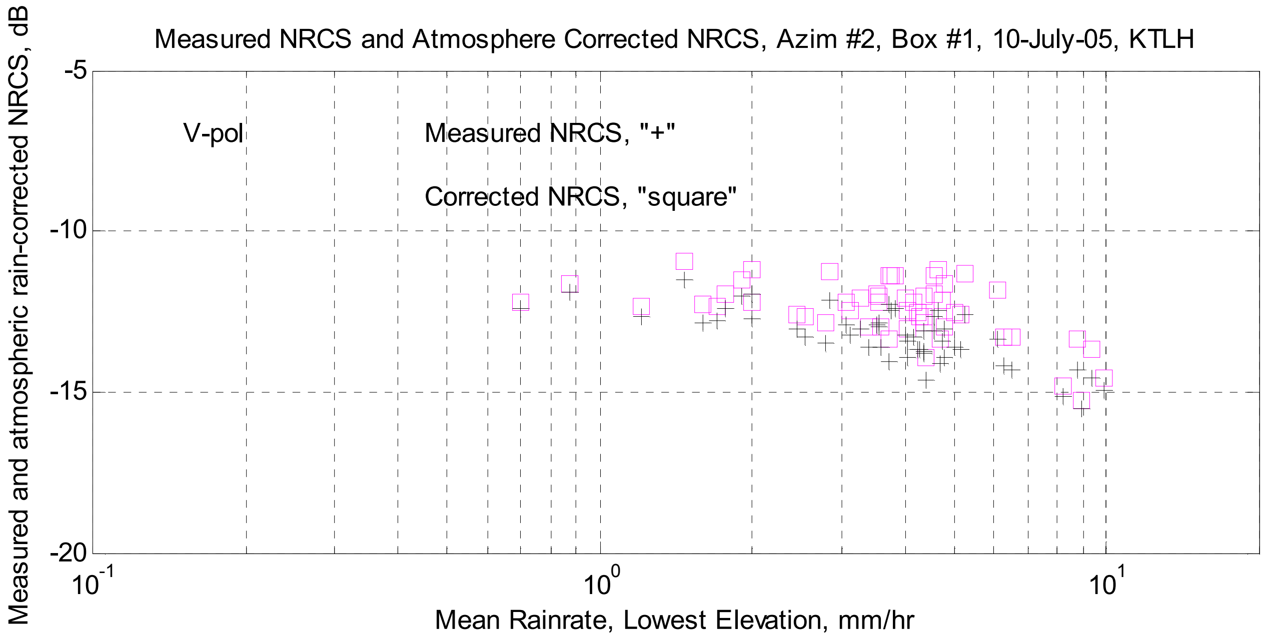
Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #1, 10-July-05, KTLH
Measured and atmospheric rain-corrected NRCS, dB
H-pol
Measured NRCS, "+"
Corrected NRCS, "square"
-5
-10
-15
-20
10^{-1}
10^{0}
10^{1}
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
Ratio of NRCS with and without Rain, dB
H-pol
5
0
-5
10^{-1}
10^{0}
10^{1}
Mean Rainrate, Lowest Elevation, mm/hr



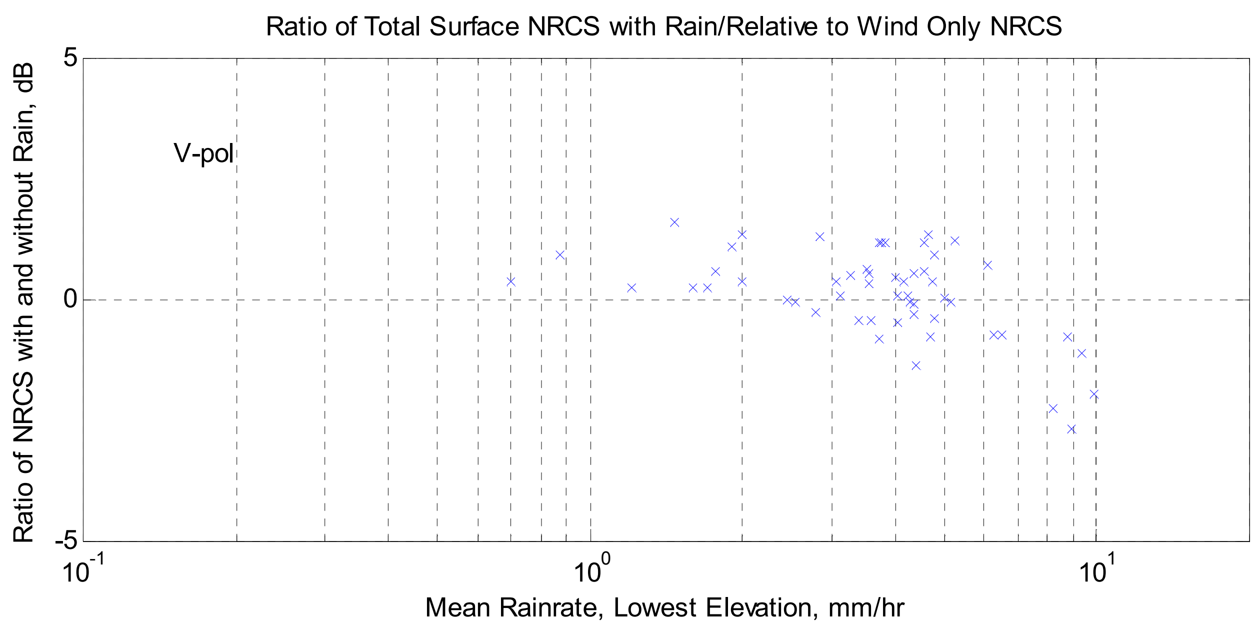
Measured NRCS and Atmosphere Corrected NRCS, Azim #2, Box #1, 10-July-05, KTLH
H-pol
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRCS, dB
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
H-pol
Ratio of NRCS with and without Rain, dB
Mean Rainrate, Lowest Elevation, mm/hr


Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #1, 10-July-05, KTLH
V-pol
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRCS, dB
-5
-10
-15
-20
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr

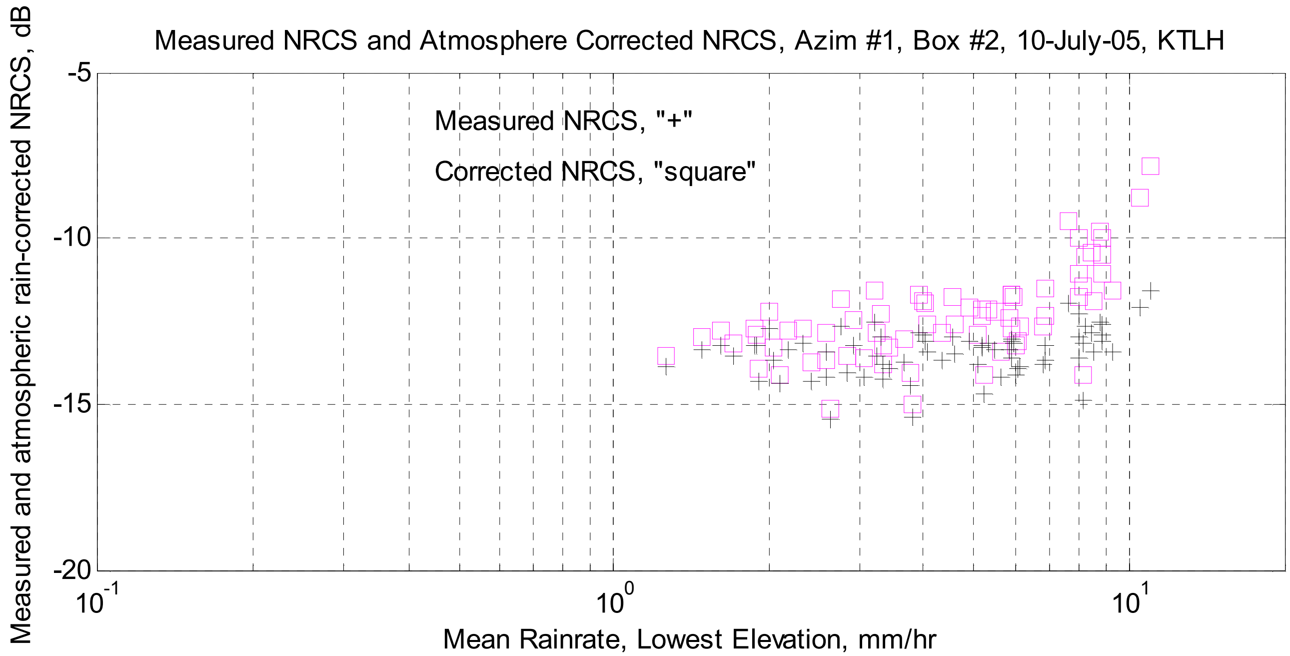

Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
V-pol
Ratio of NRCS with and without Rain, dB
5
0
-5
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr



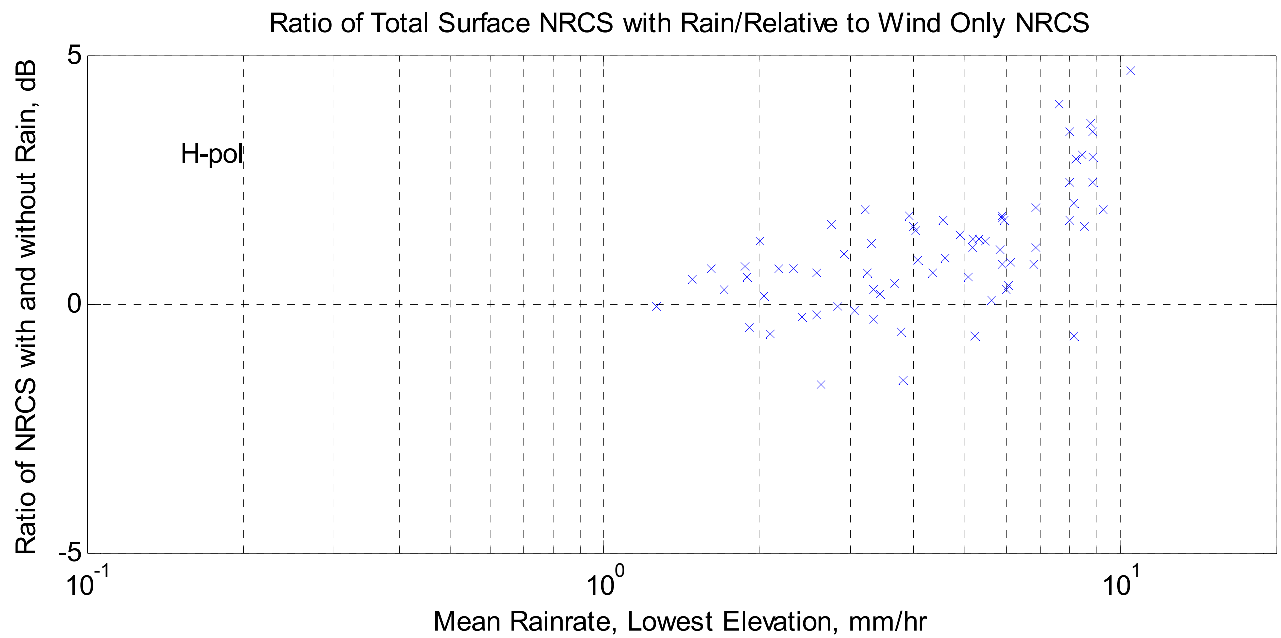
Measured NRCS and Atmosphere Corrected NRCS, Azim #2, Box #1, 10-July-05, KTLH
Measured and atmospheric rain-corrected NRCS, dB
V-pol
Measured NRCS, "+"
Corrected NRCS, "square"
-5
-10
-15
-20
10^{-1}
10^{0}
10^{1}
Mean Rainrate, Lowest Elevation, mm/hr



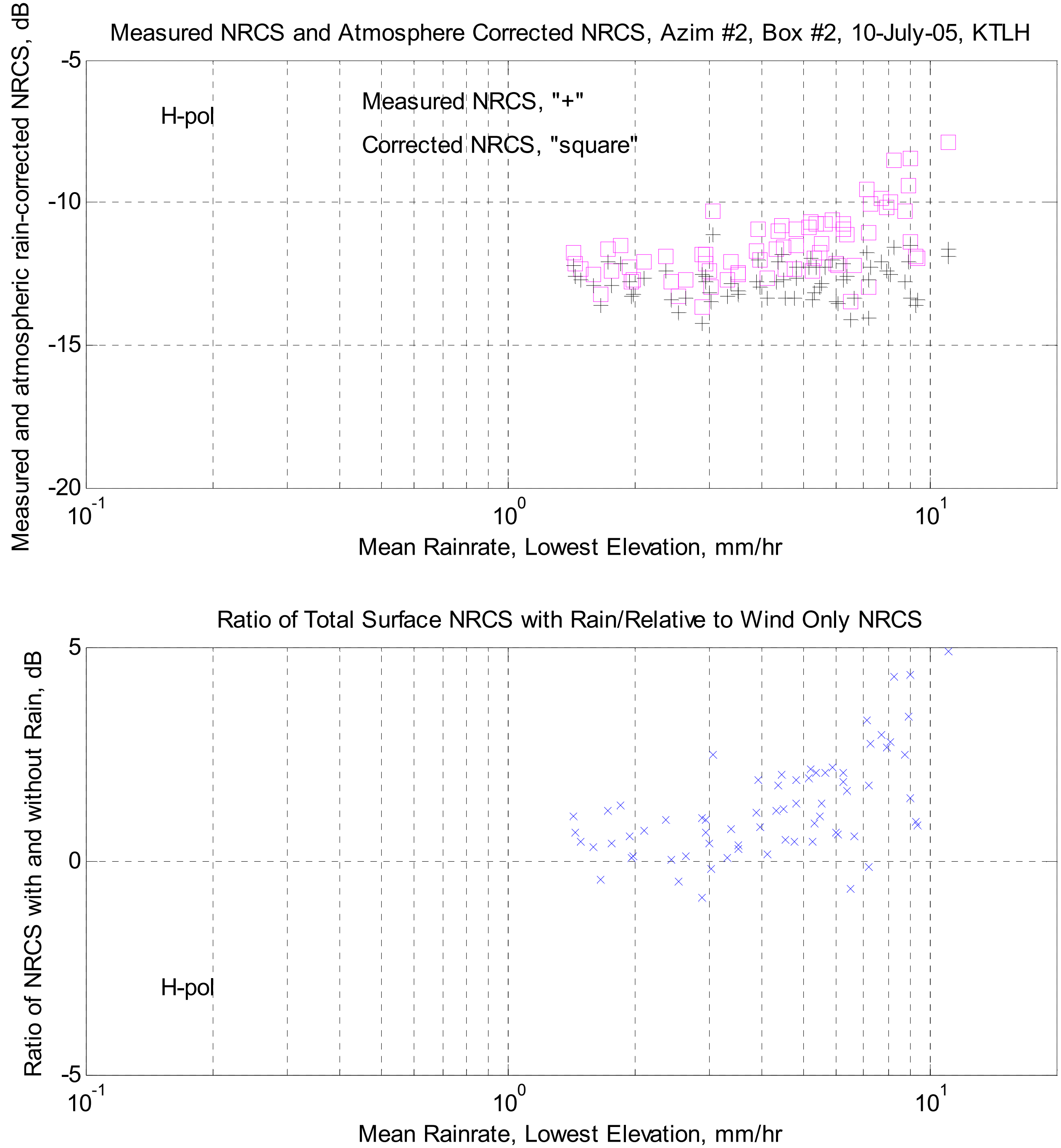
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
Ratio of NRCS with and without Rain, dB
V-pol
5
0
-5
10^{-1}
10^{0}
10^{1}
Mean Rainrate, Lowest Elevation, mm/hr



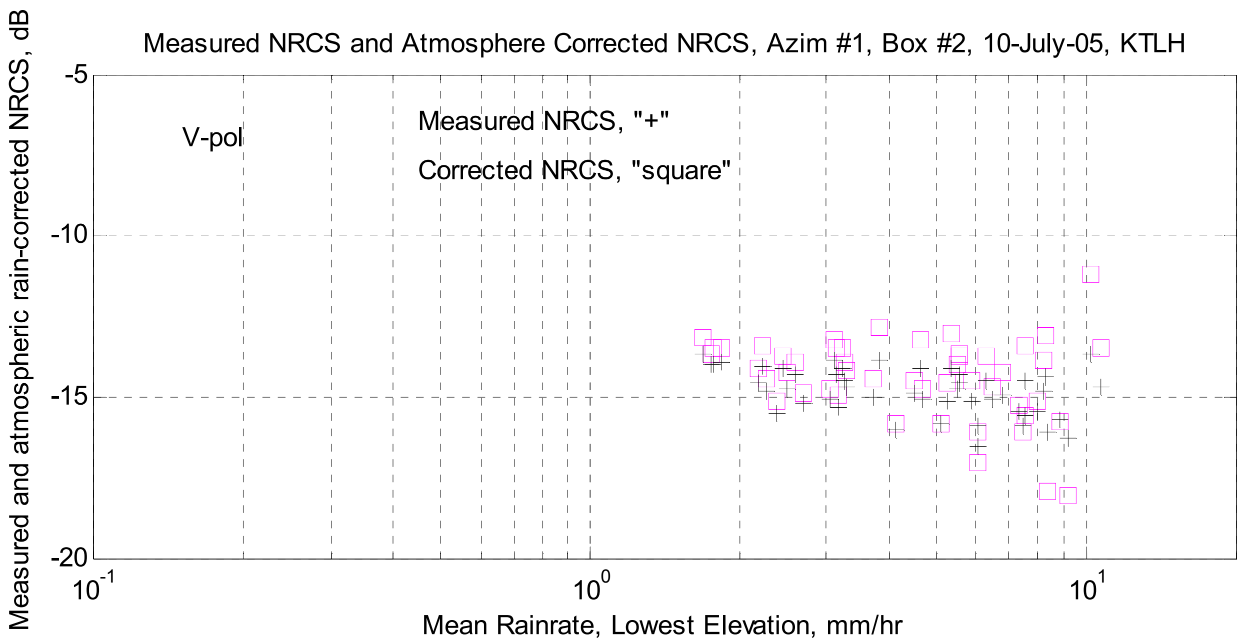
Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #2, 10-July-05, KTLH
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRCS, dB
-5
-10
-15
-20
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr



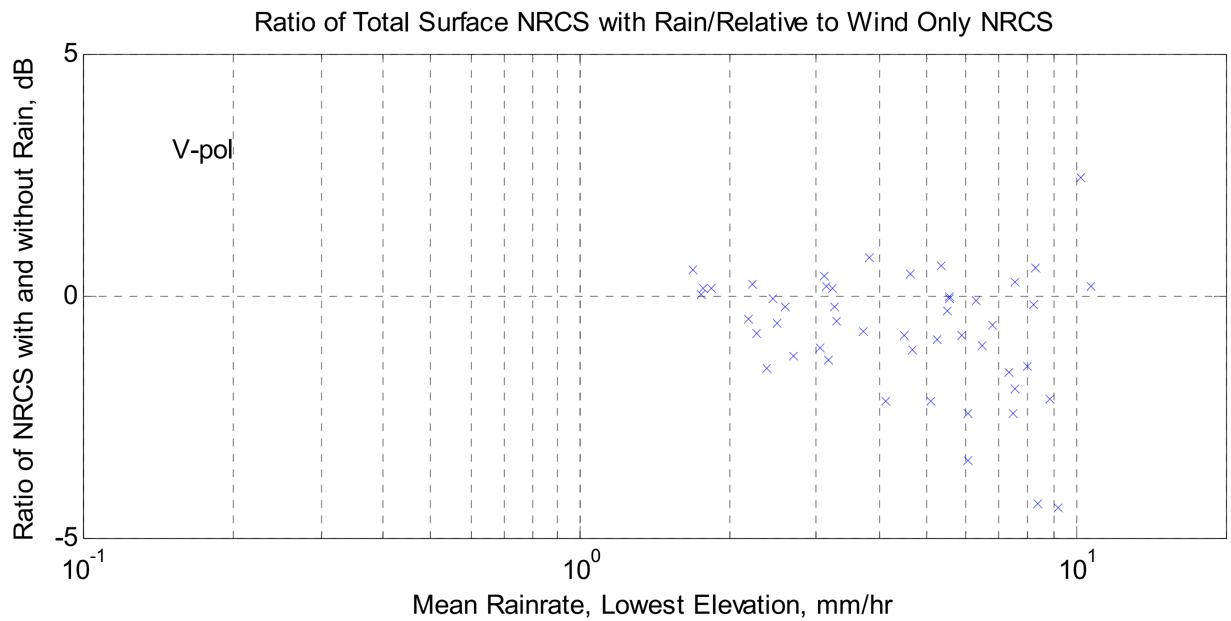
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
H-pol
Ratio of NRCS with and without Rain, dB
5
0
-5
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr



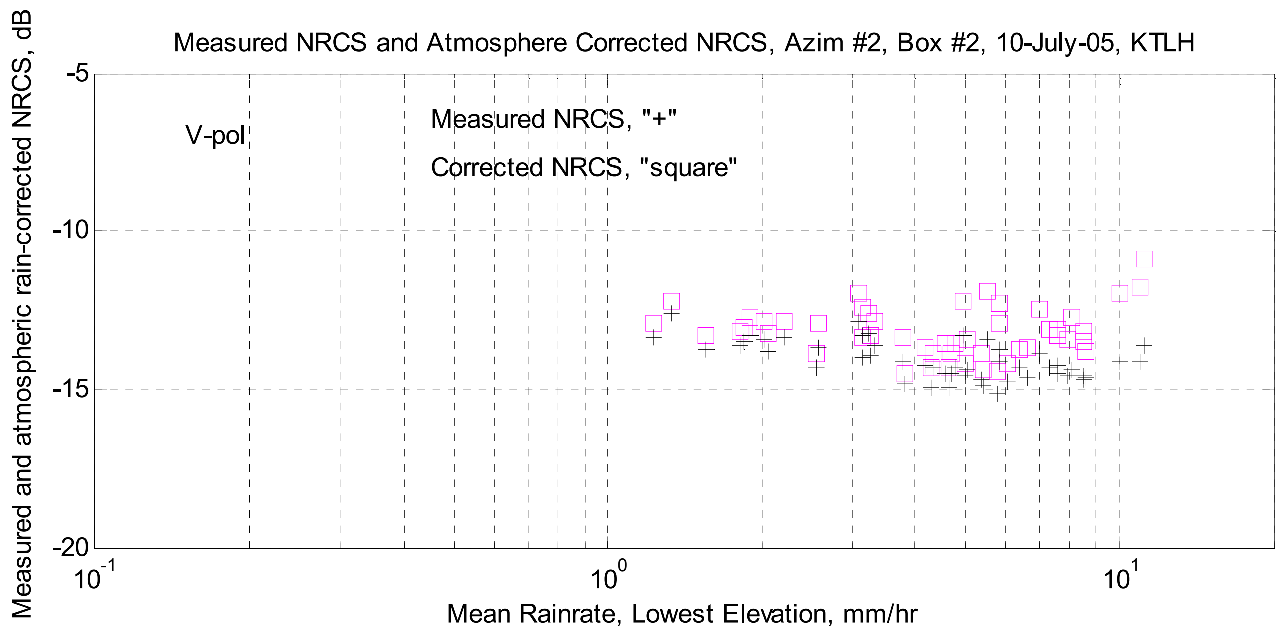
Measured NRCS and Atmosphere Corrected NRCS, Azim #2, Box #2, 10-July-05, KTLH
Measured and atmospheric rain-corrected NRCS, dB
H-pol
Measured NRCS, "+"
Corrected NRCS, "square"
-5
-10
-15
-20
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
Ratio of NRCS with and without Rain, dB
H-pol
5
0
-5
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr



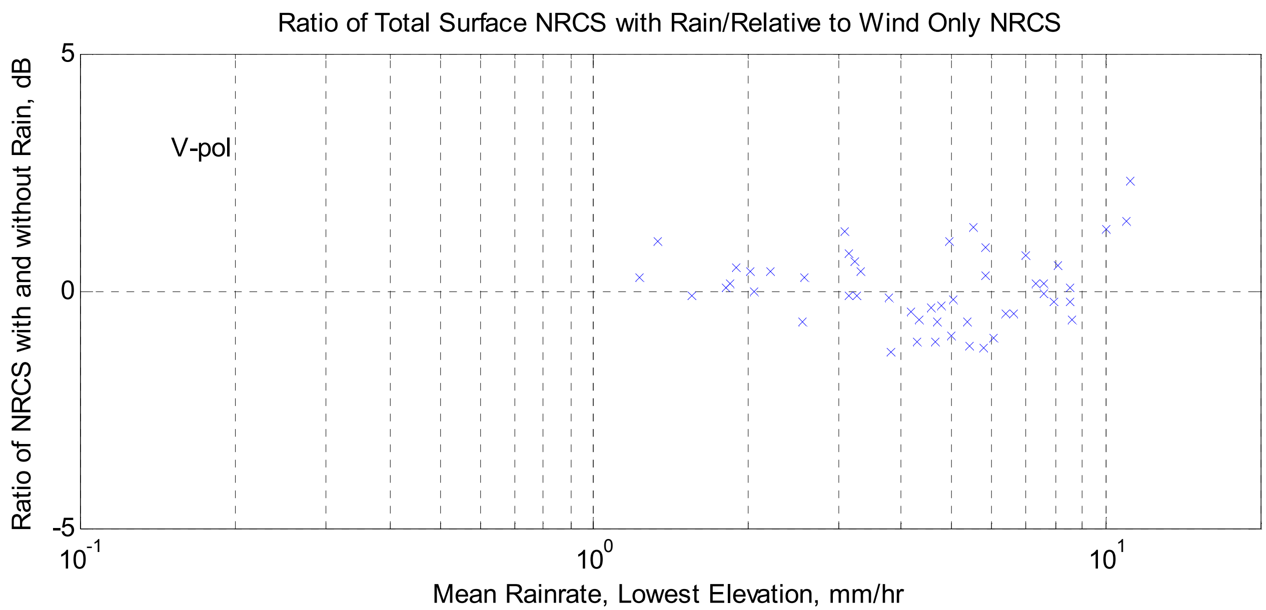
Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #2, 10-July-05, KTLH
Measured and atmospheric rain-corrected NRCS, dB
V-pol
Measured NRCS, "+"
Corrected NRCS, "square"
-5
-10
-15
-20
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr



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



Measured NRCS and Atmosphere Corrected NRCS, Azim #2, Box #2, 10-July-05, KTLH
V-pol
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRCS, dB
-5
-10
-15
-20
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr



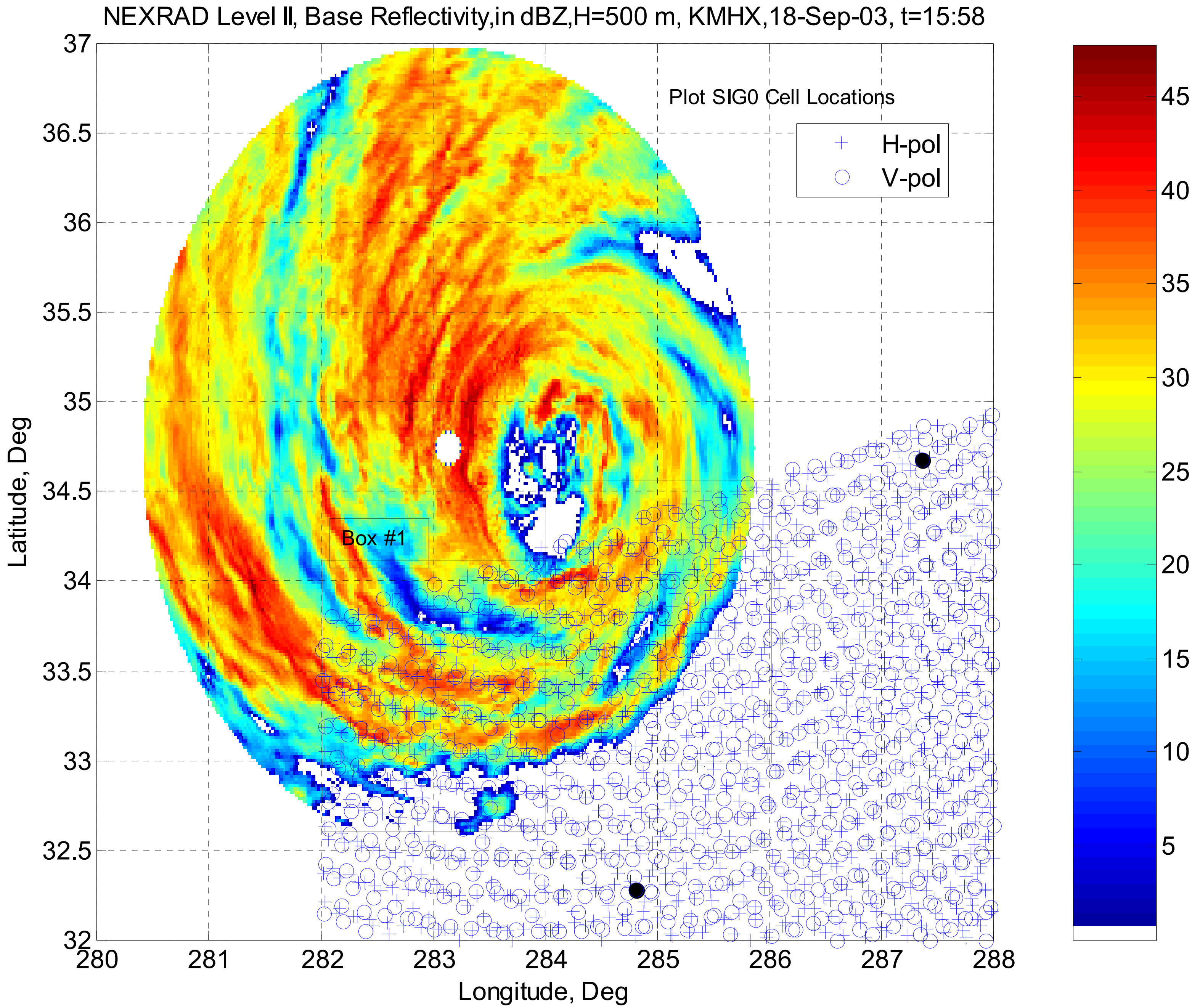
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
V-pol
Ratio of NRCS with and without Rain, dB
5
0
-5
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr

<u>Quick Summary</u>:

The rain-induced backscatter for H-pol and V-pol both increase with rainrate, but by smaller amounts than at lower winds (≤ 8 m/s). Effects start at 4 mm/hr.

BUT $\Delta\sigma_{ov} \leq \Delta\sigma_{oH}$ and $\Delta\sigma_{ov}$ can be negative at high rainrate

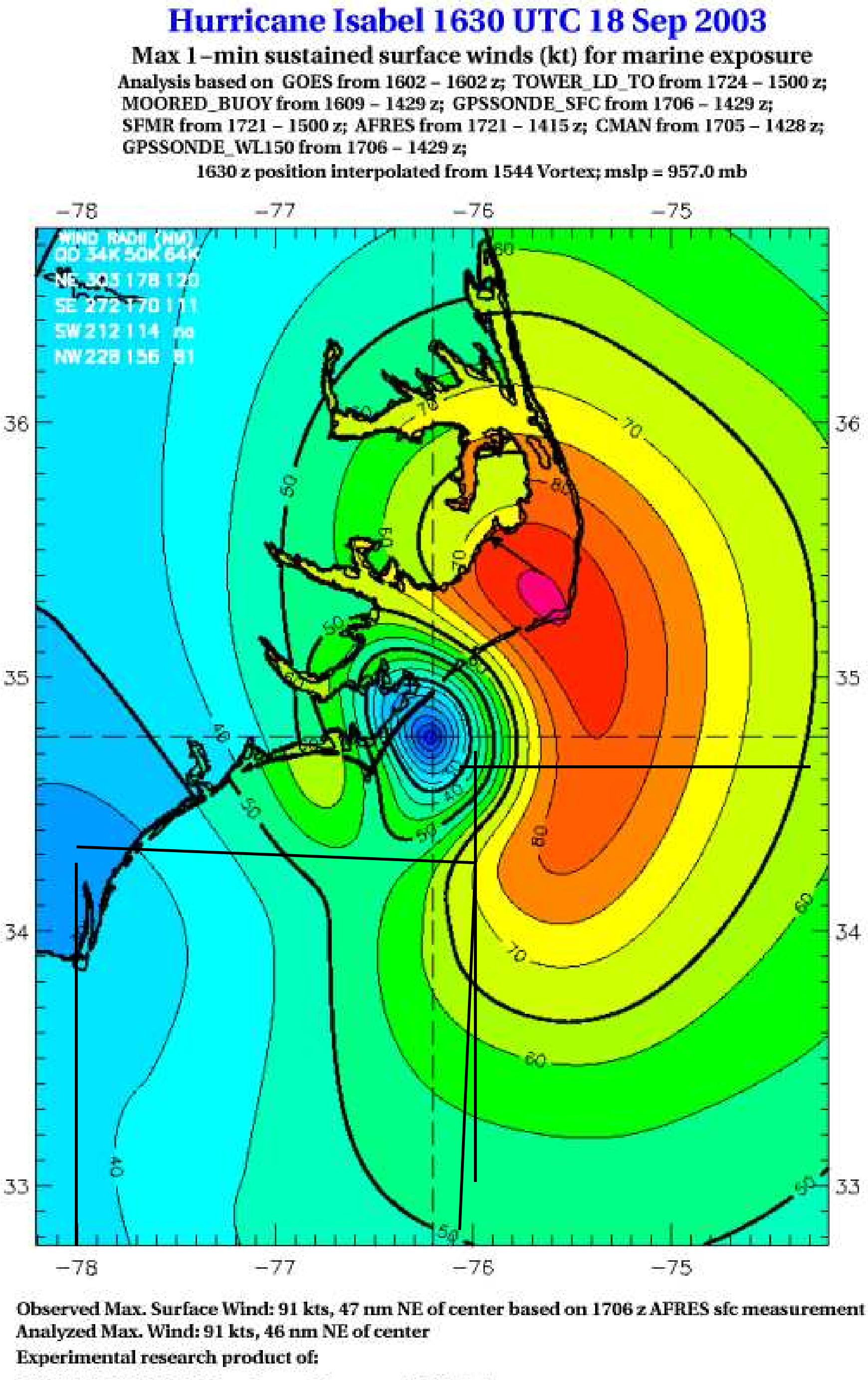
Interpretation: the velocity of raindrops striking the surface at winds above 10 m/s are now affected by both gravity and the wind vector.The roughness effects need to be interpreted in terms of the rain splash products (stalks & ring waves), the modified surface turbulence and wind generated waves (including breakers). <u>Could the wind stress be decreasing with rainrate??</u>


NEXRAD Level II, Base Reflectivity,in dBZ,H=500 m, KMHX,18-Sep-03, t=15:58
Plot SIG0 Cell Locations
H-pol
V-pol
Box #1
Latitude, Deg
Longitude, Deg
37
36.5
36
35.5
35
34.5
34
33.5
33
32.5
32
280
281
282
283
284
285
286
287
288
45
40
35
30
25
20
15
10
5

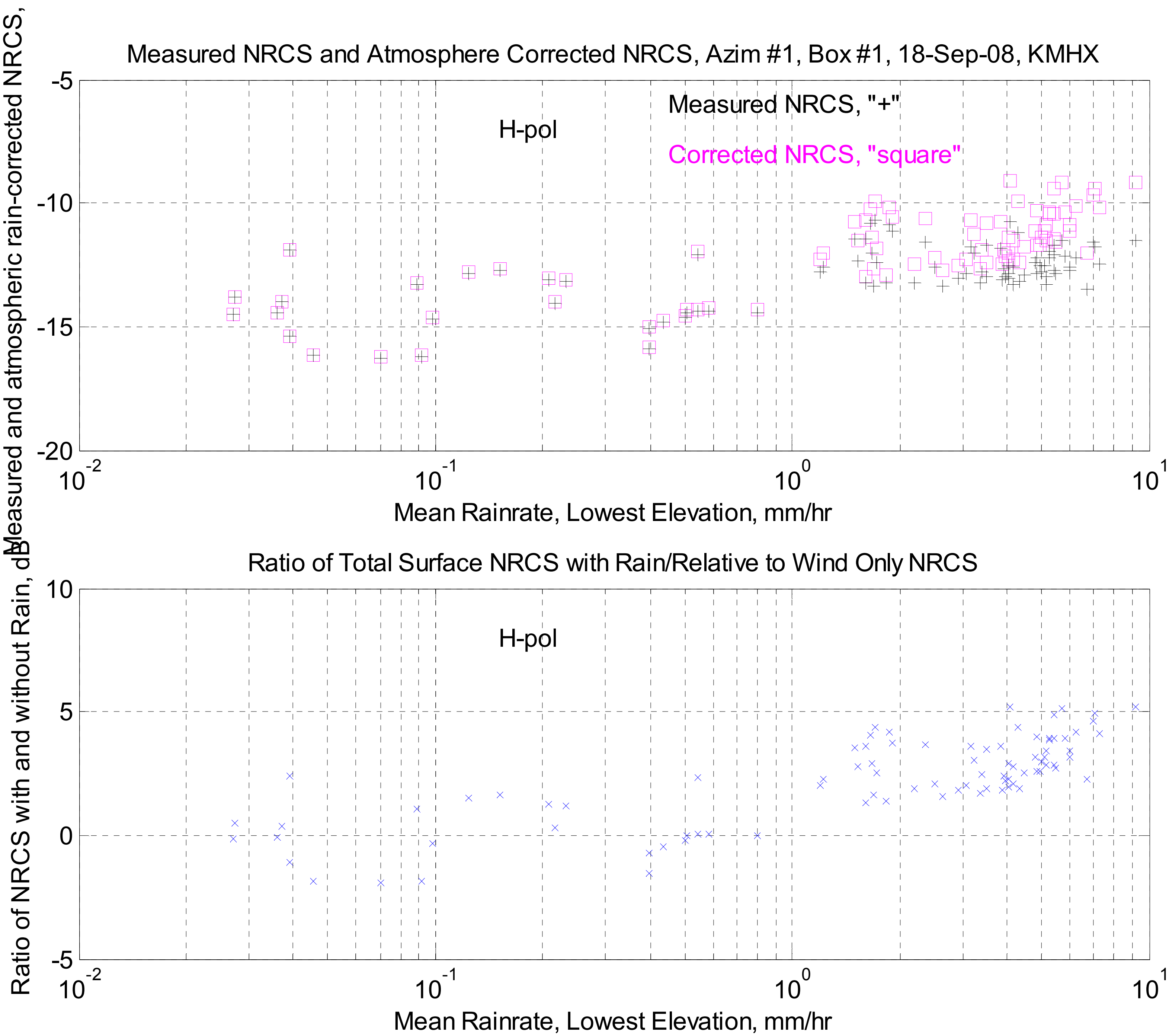
Azim. #1 = 30 deg

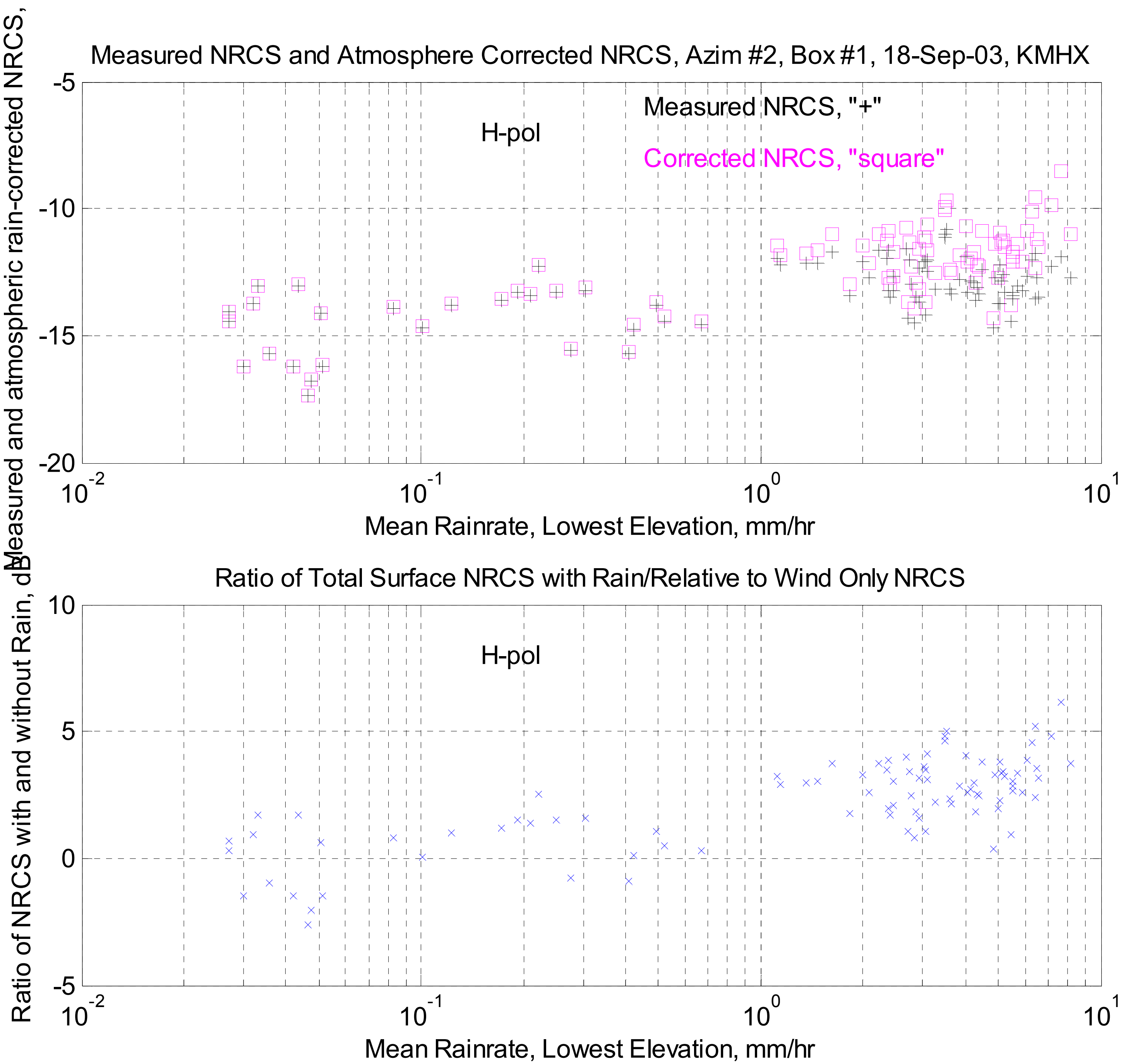
Azim #2 = 185 deg

Box #1 >>

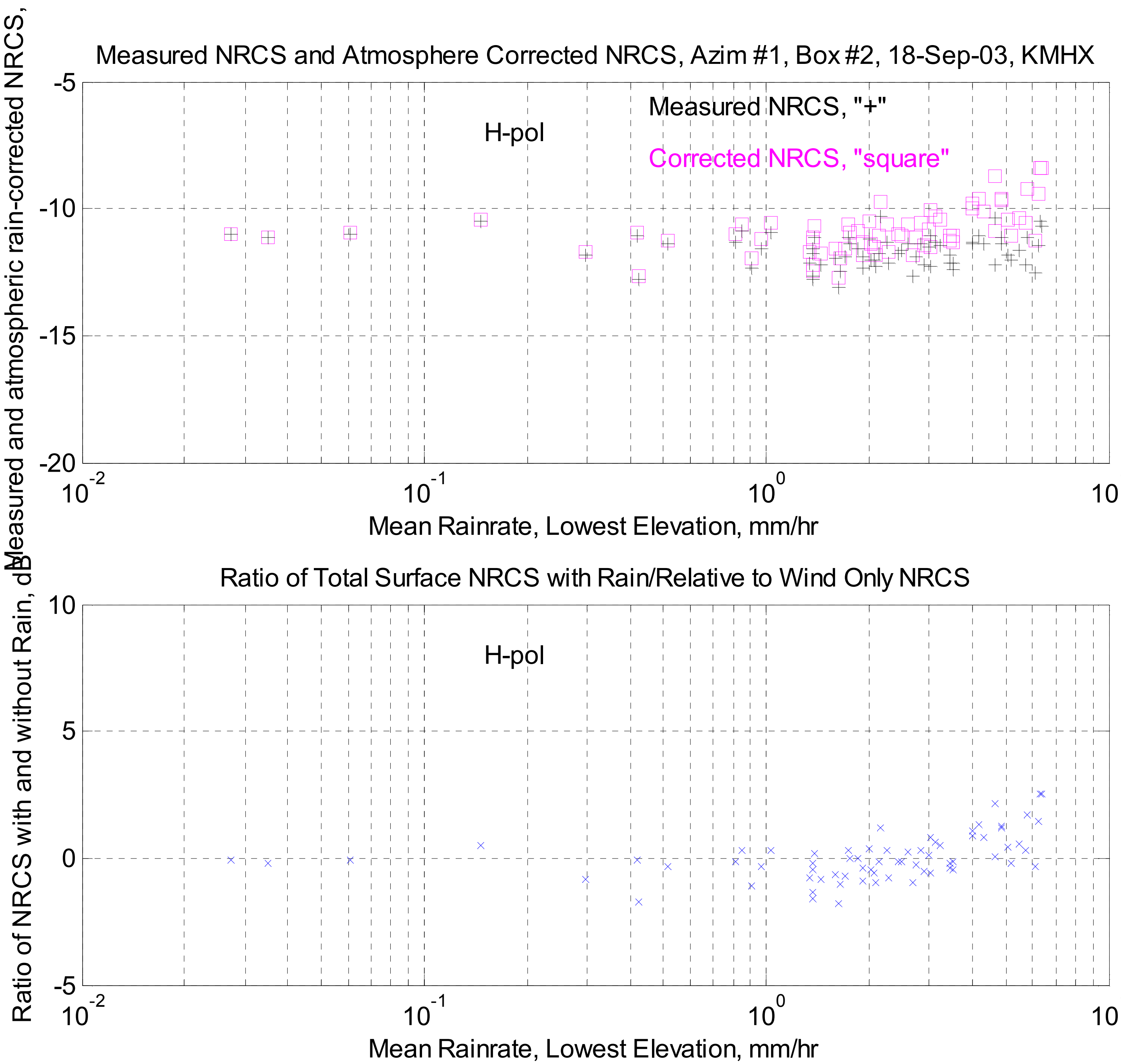


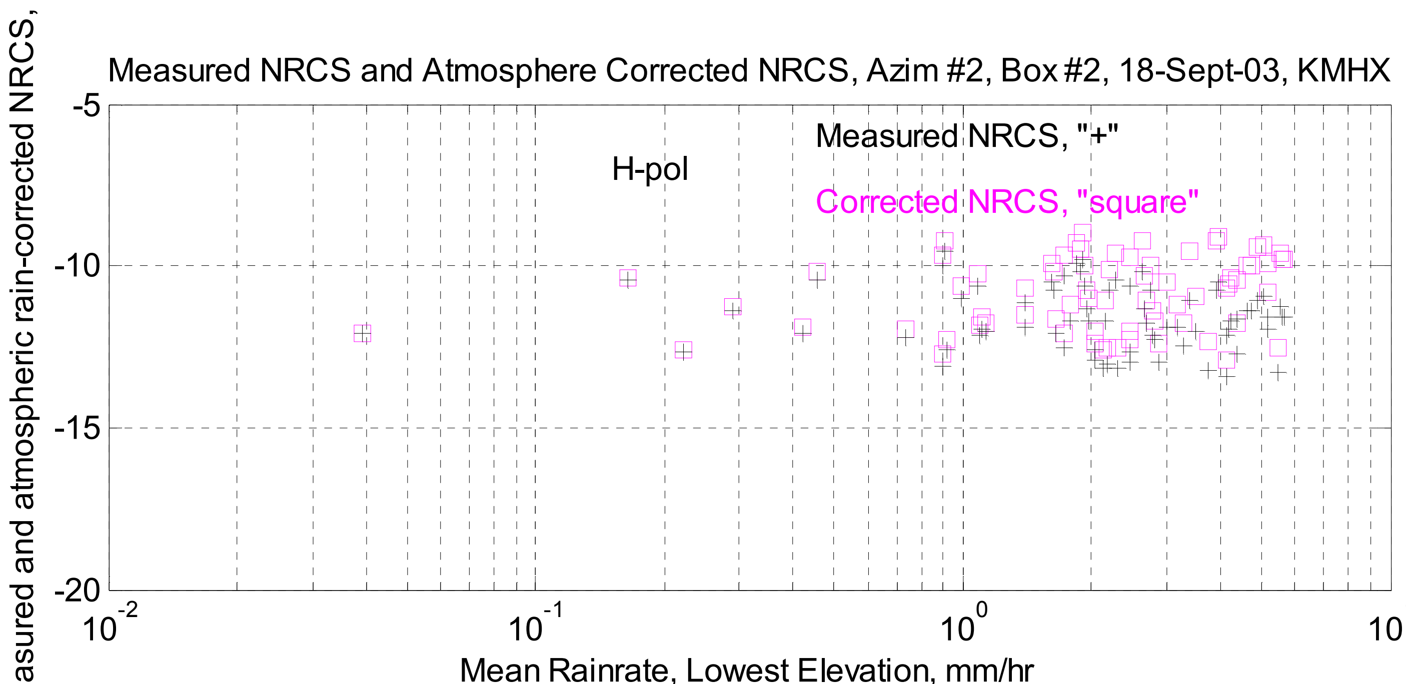
<< Box #2


Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #1, 18-Sep-08, KMHX
Measured and atmospheric rain-corrected NRCS, dB
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

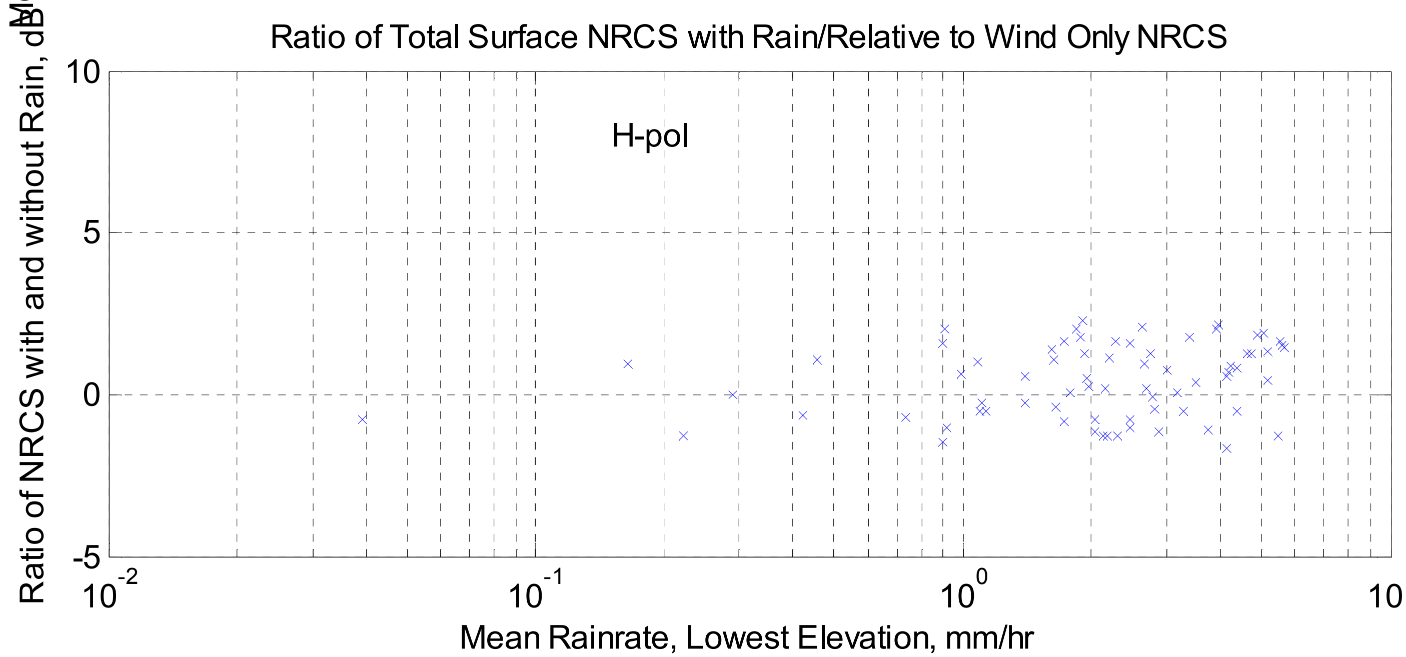


Measured NRCS and Atmosphere Corrected NRCS, Azim #2, Box #1, 18-Sep-03, KMHX
Measured and atmospheric rain-corrected NRCS, dB
H-pol
Measured NRCS, "+"
Corrected NRCS, "square"
-5
-10
-15
-20
10^-2
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to 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

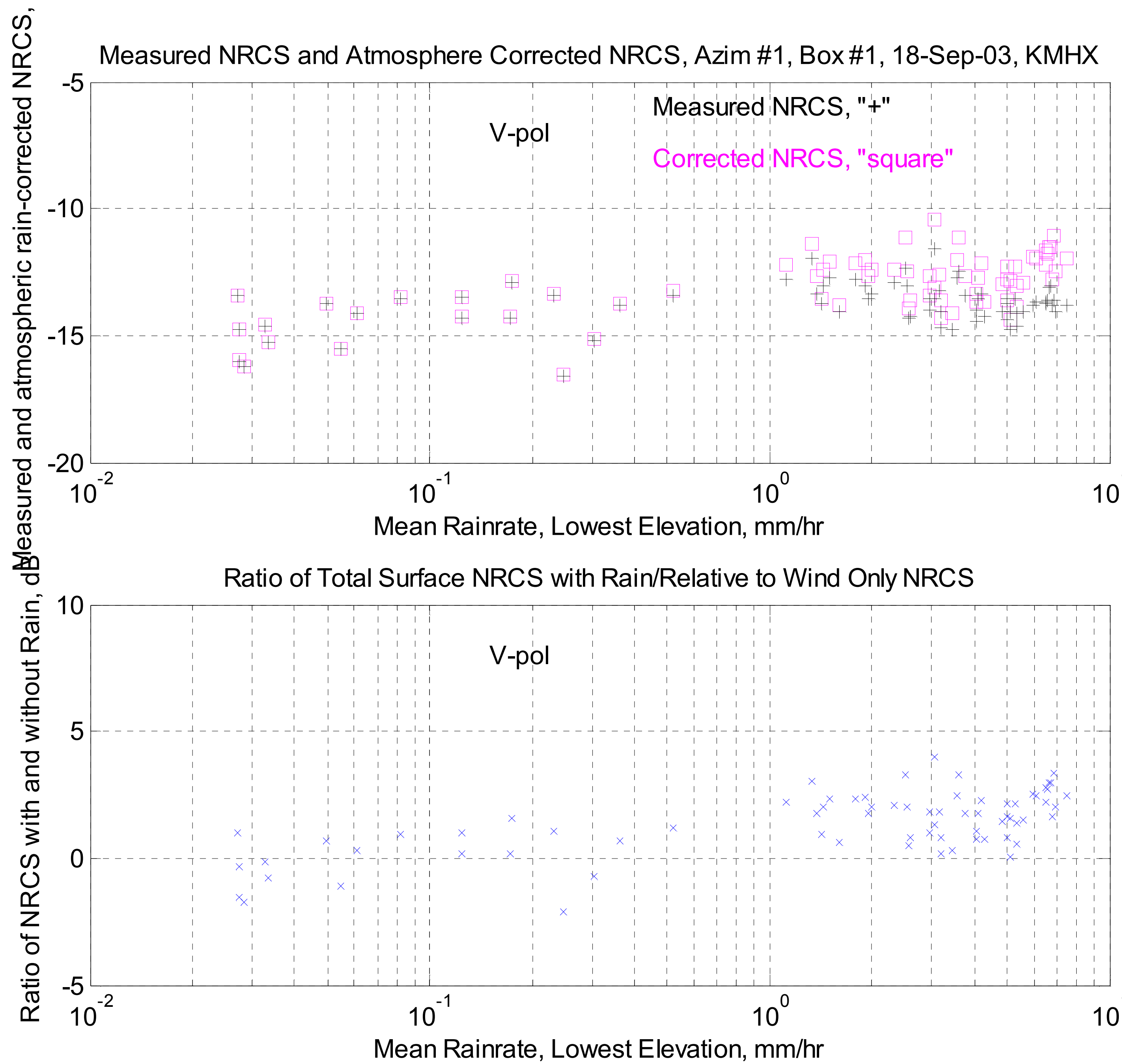

Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #2, 18-Sep-03, KMHX
Measured and atmospheric rain-corrected NRCS, dB
H-pol
Measured NRCS, "+"
Corrected NRCS, "square"
-5
-10
-15
-20
10^{-2}
10^{-1}
10^{0}
10^{1}
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative 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

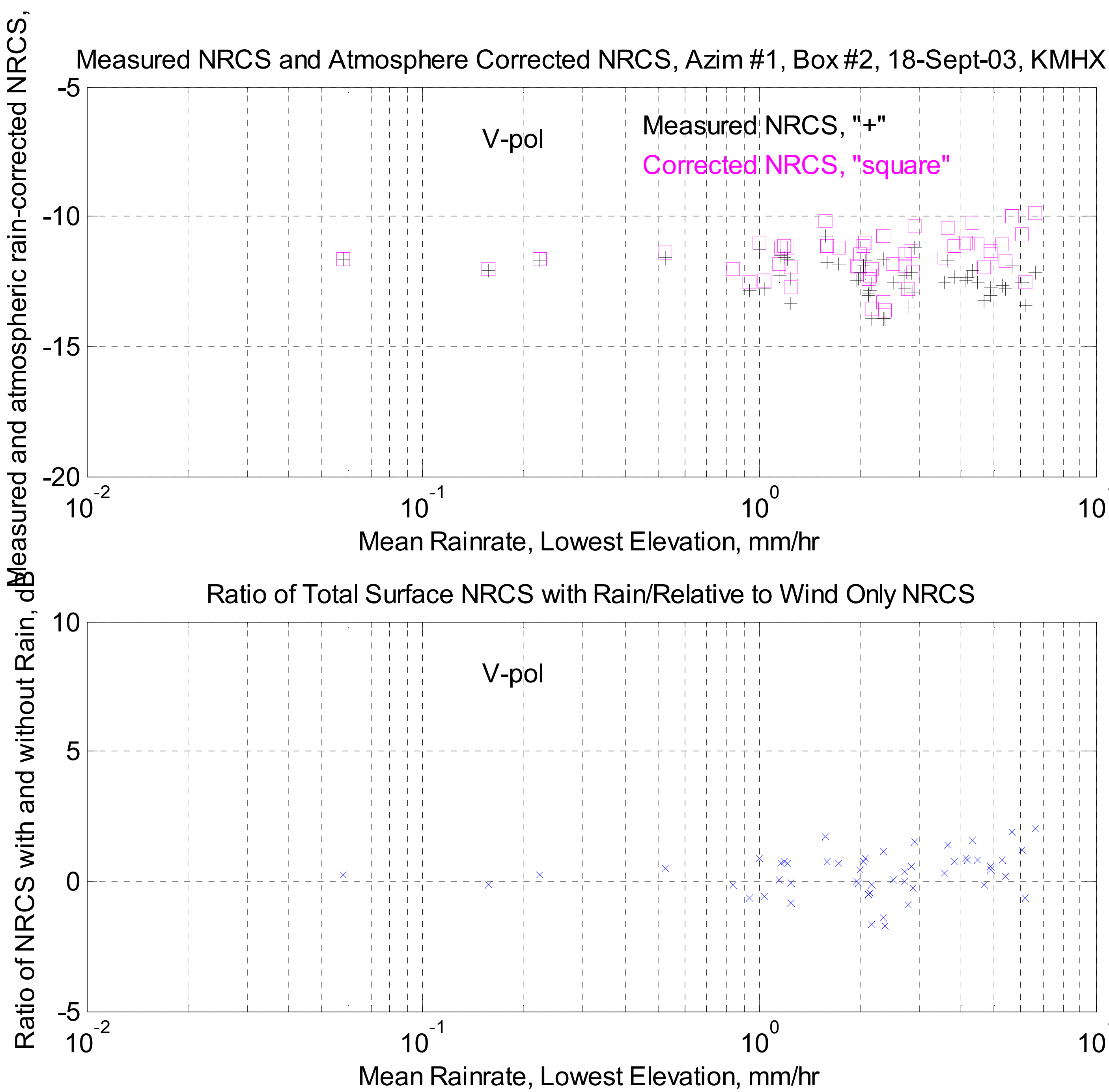


Measured NRCS and Atmosphere Corrected NRCS, Azim #2, Box #2, 18-Sept-03, KMHX
Measured and atmospheric rain-corrected NRCS,
H-pol
Measured NRCS, "+"
Corrected NRCS, "square"
-5
-10
-15
-20
10^-2
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr



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, 18-Sep-03, KMHX
Measured and atmospheric rain-corrected NRCS, dB
V-pol
Measured NRCS, "+"
Corrected NRCS, "square"
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
Mean Rainrate, Lowest Elevation, mm/hr



Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #2, 18-Sept-03, KMHX
V-pol
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRCS, dB
-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
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

Quick Observation for Hurr Isabel:

Winds in Box # 1 ≈ 40-50 kts and Box #2 ≈ 50-80 kts

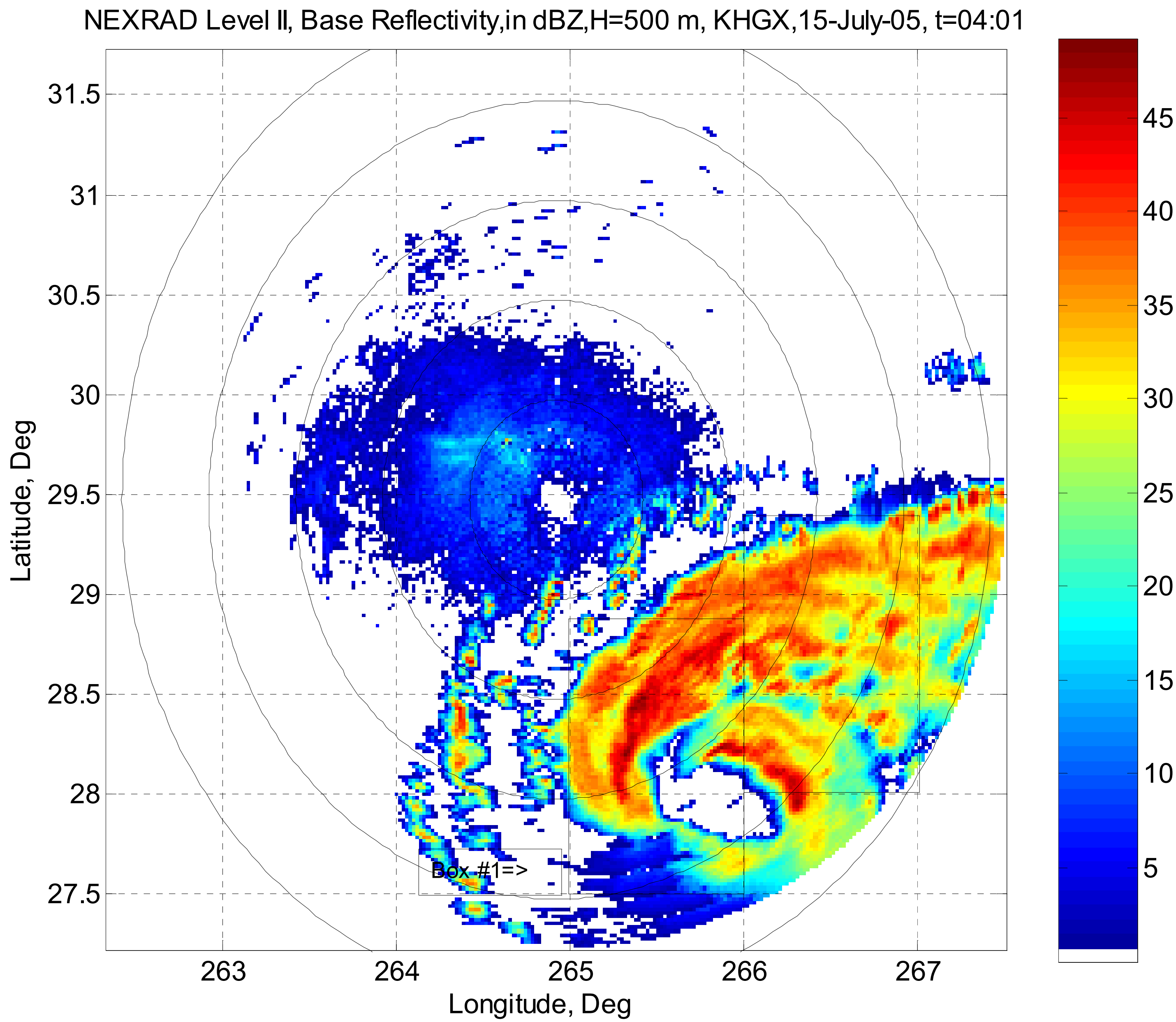
In Box #1 changes in NRCS start at about 10 mm/hr and can be a few dB for H-pol and V-pol

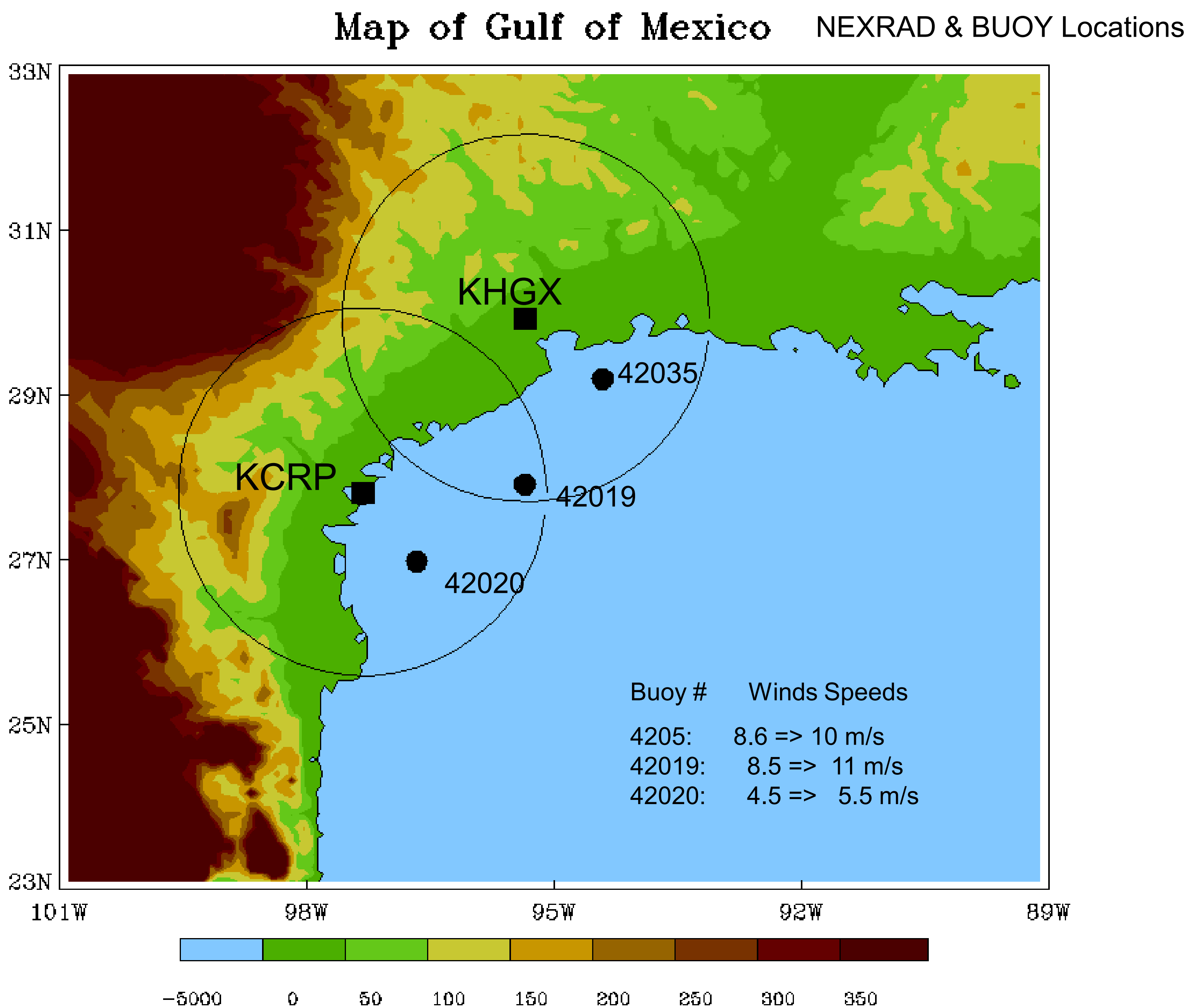
In Box #2 negligible changes in NRCS for all rainrates.

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

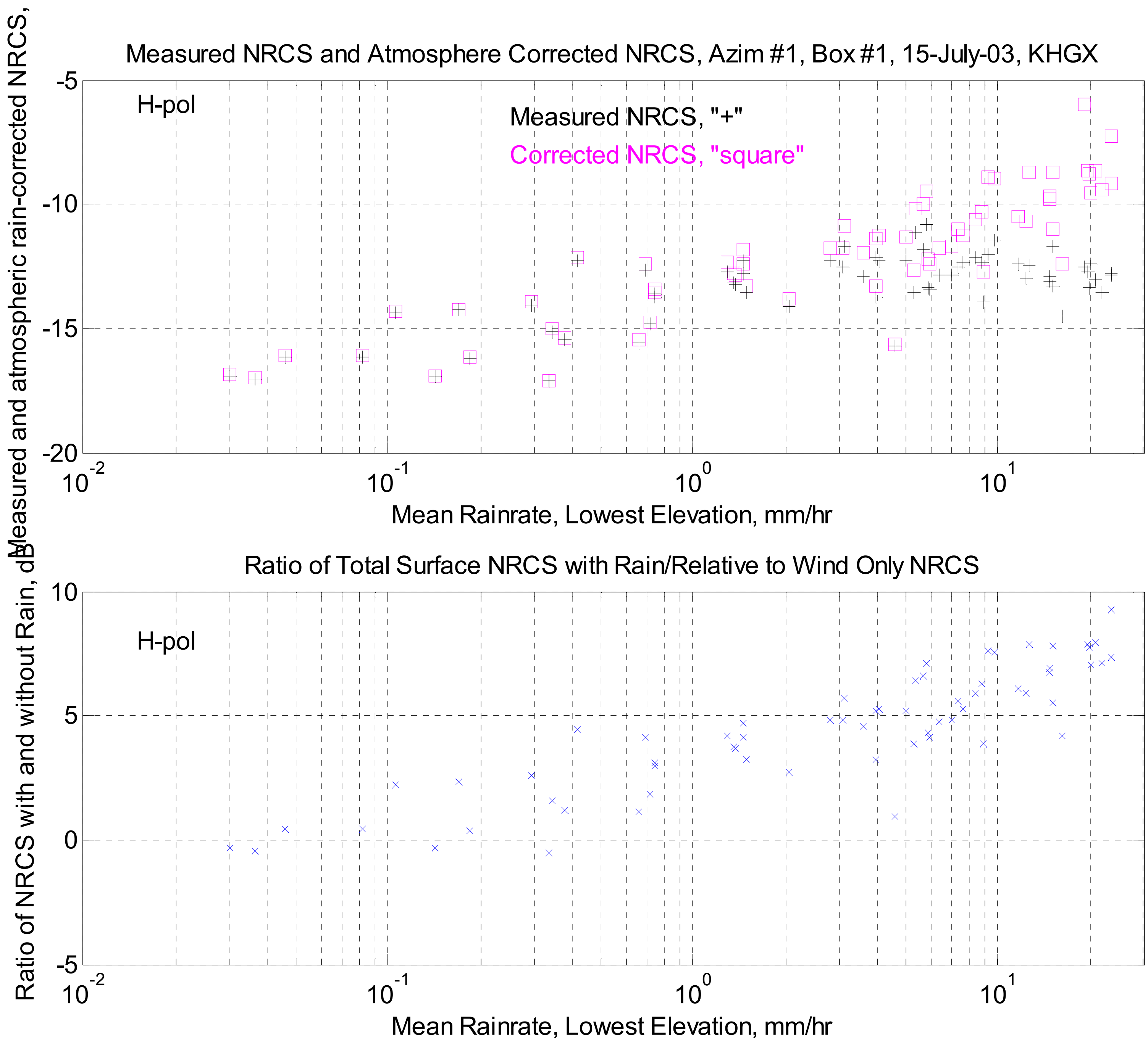
Azim #2 =
305 deg

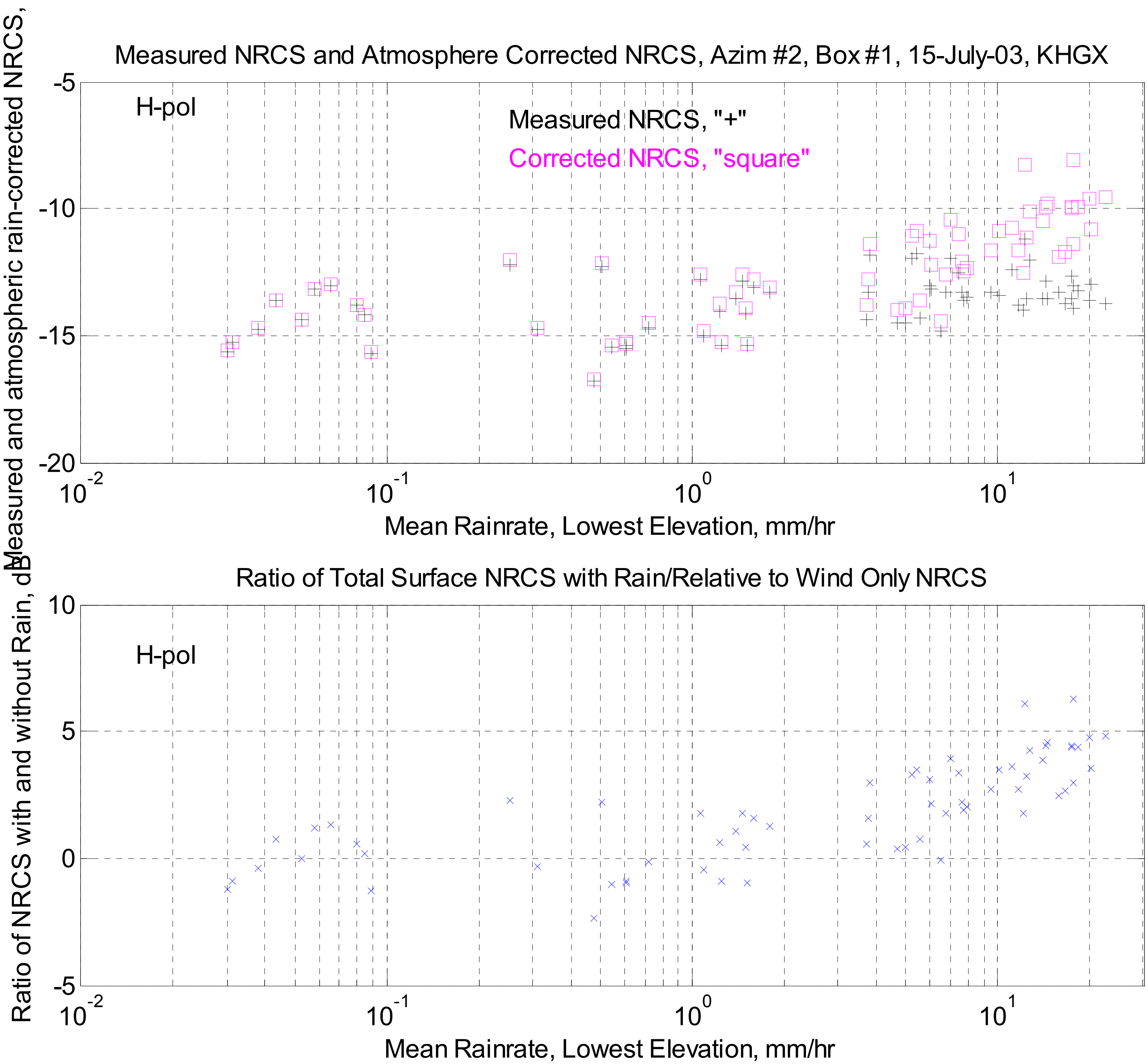
Azim # 1=205
deg

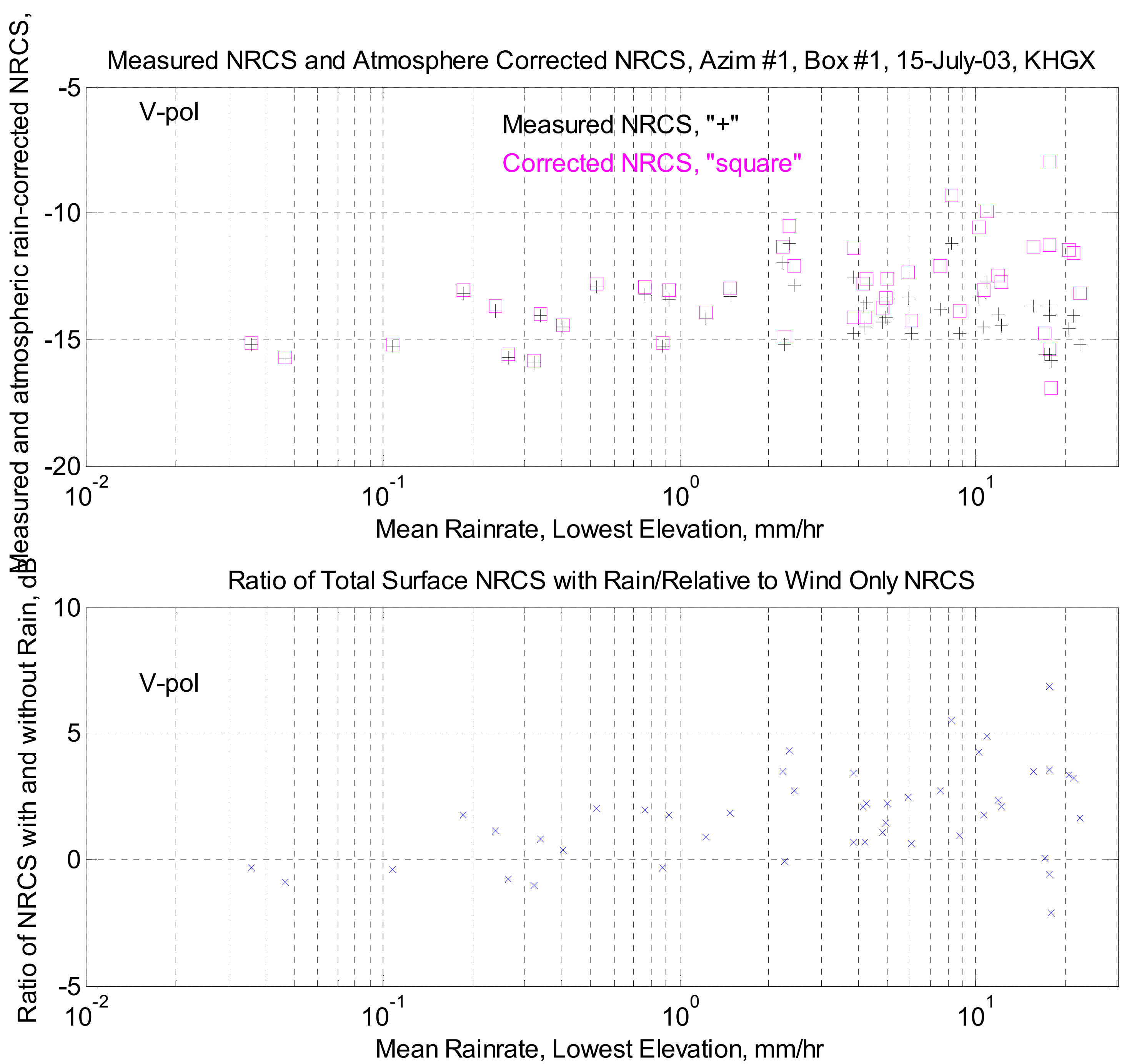


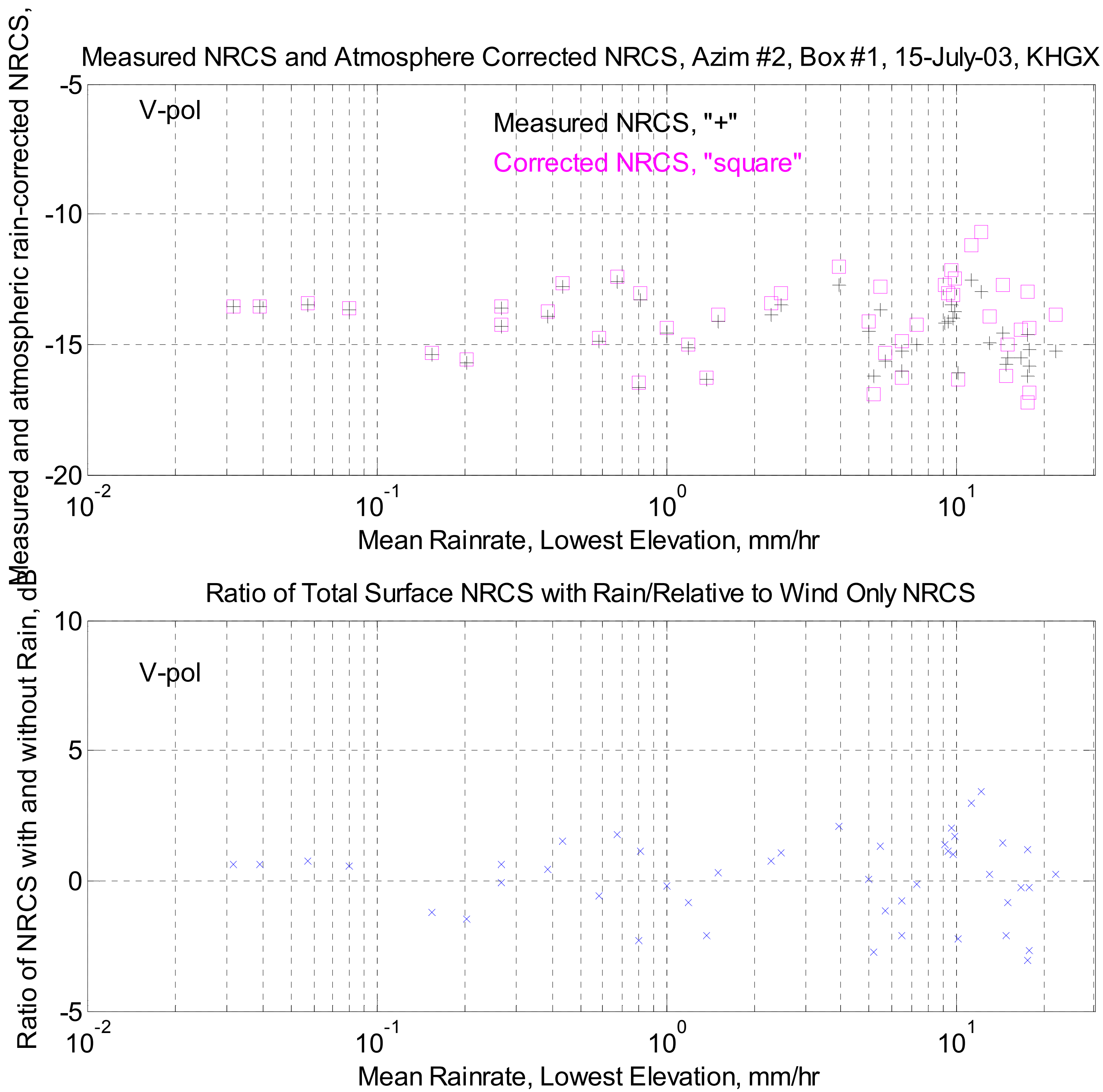


Map of Gulf of Mexico
NEXRAD & BUOY Locations
33N
31N
29N
27N
25N
23N
101W
98W
95W
92W
89W
KHGX
KCRP
42035
42019
42020
Buoy # Winds Speeds
4205: 8.6 => 10 m/s
42019: 8.5 => 11 m/s
42020: 4.5 => 5.5 m/s
-5000
0
50
100
150
200
250
300
350

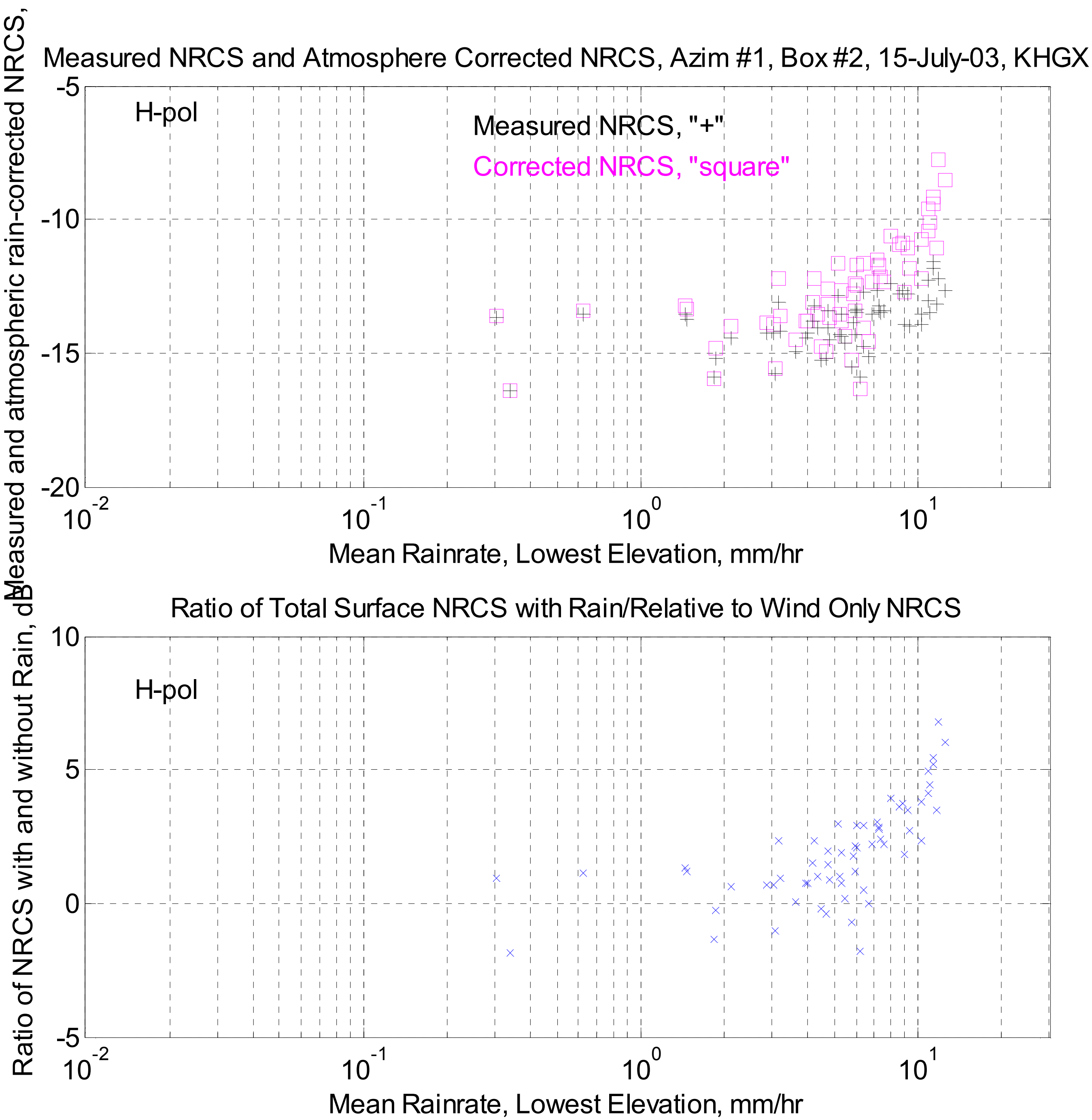

Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #1, 15-July-03, KHGX
H-pol
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRCS, dB
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
H-pol
Ratio of NRCS 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
H-pol
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRCS, dB
-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
H-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

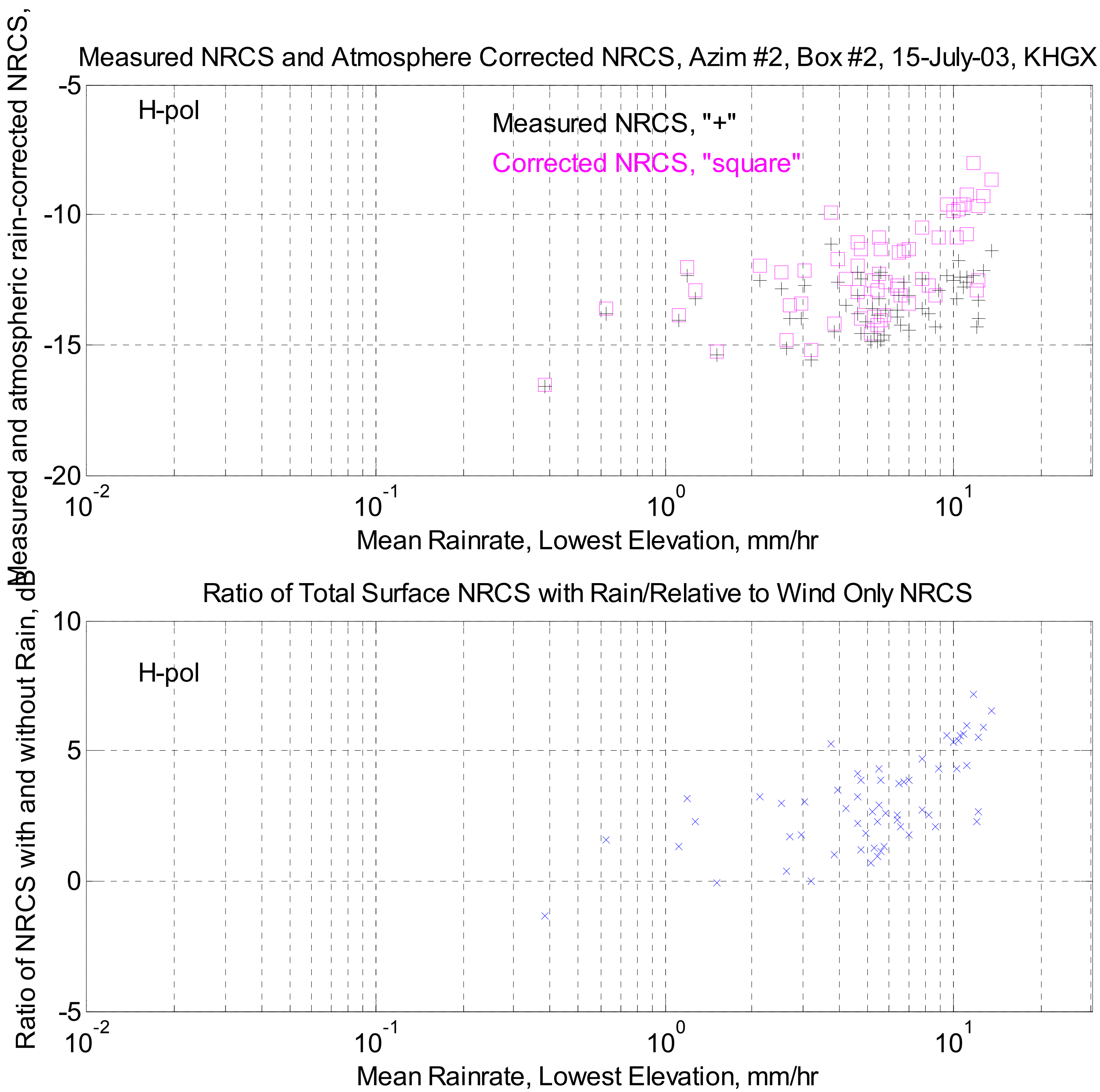

Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #1, 15-July-03, KHGX
V-pol
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRCS, dB
-5
-10
-15
-20
10^-2
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
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

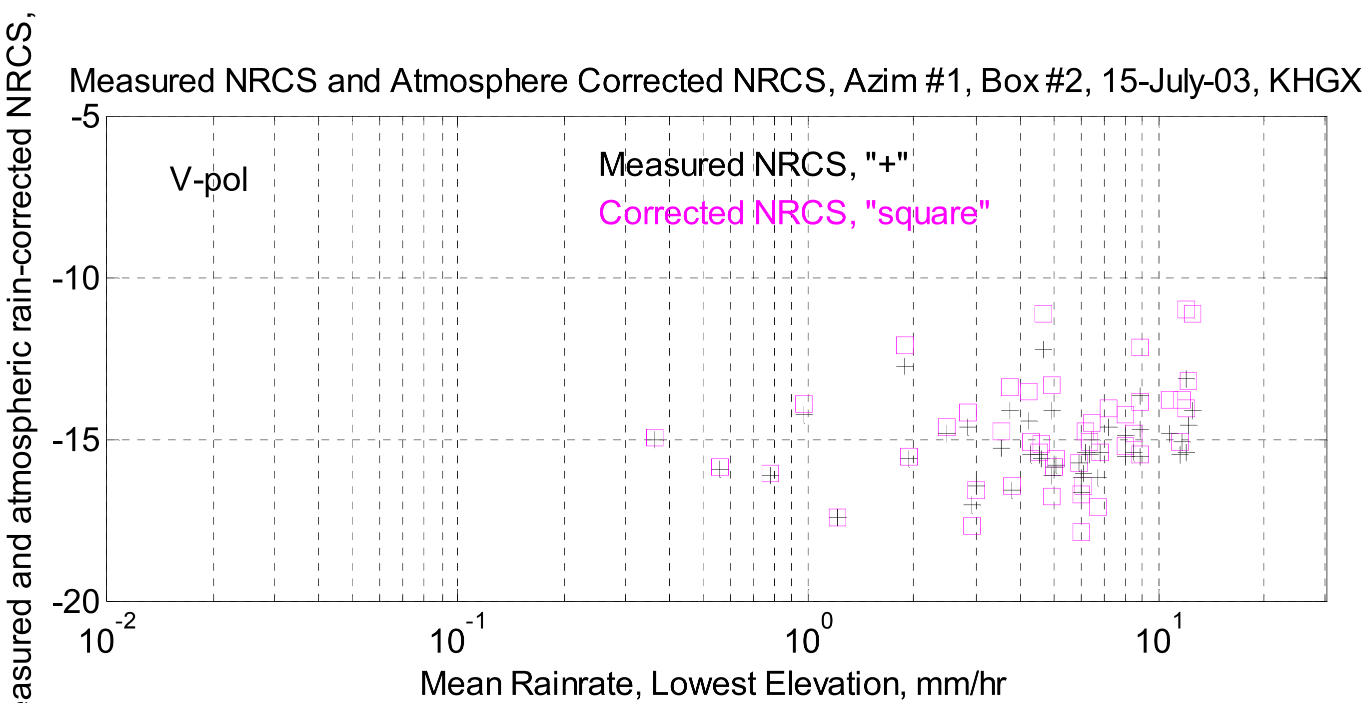


Measured NRCS and Atmosphere Corrected NRCS, Azim #2, Box #1, 15-July-03, KHGX
V-pol
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRCS, dB
-5
-10
-15
-20
10^{-2}
10^{-1}
10^{0}
10^{1}
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
V-pol
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

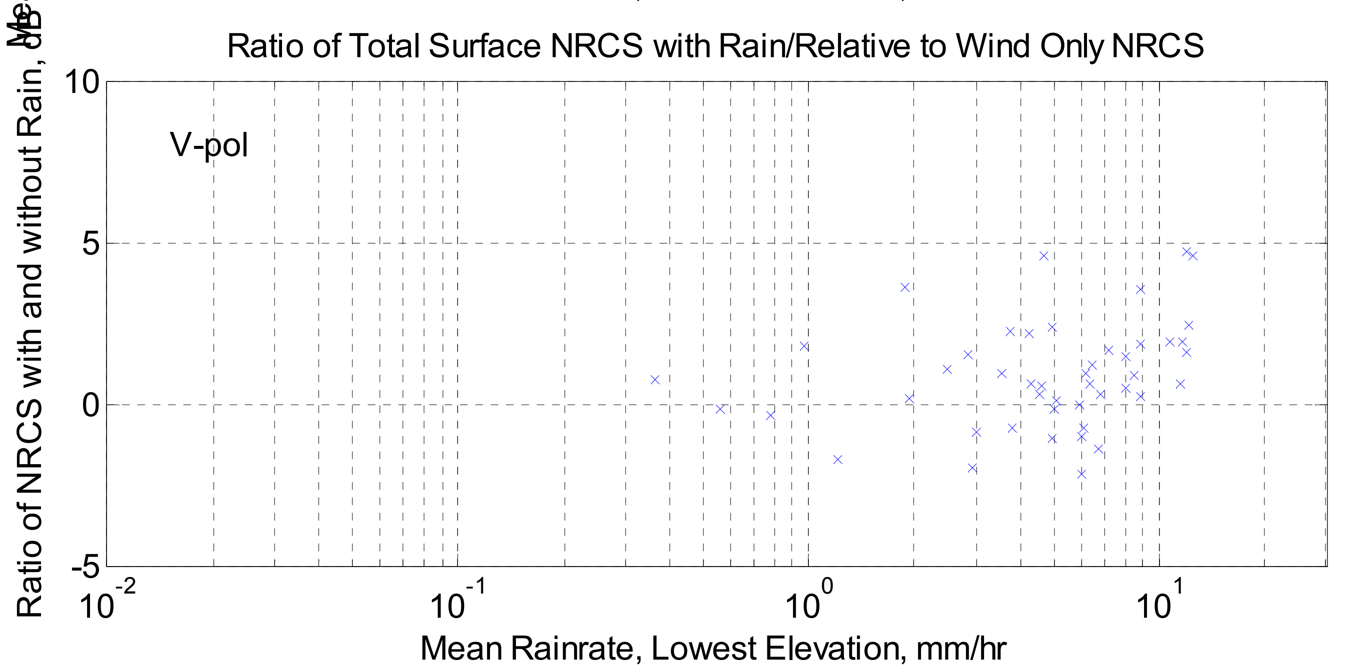


Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #2, 15-July-03, KHGX
H-pol
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRCS, dB
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
H-pol
Ratio of NRCS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

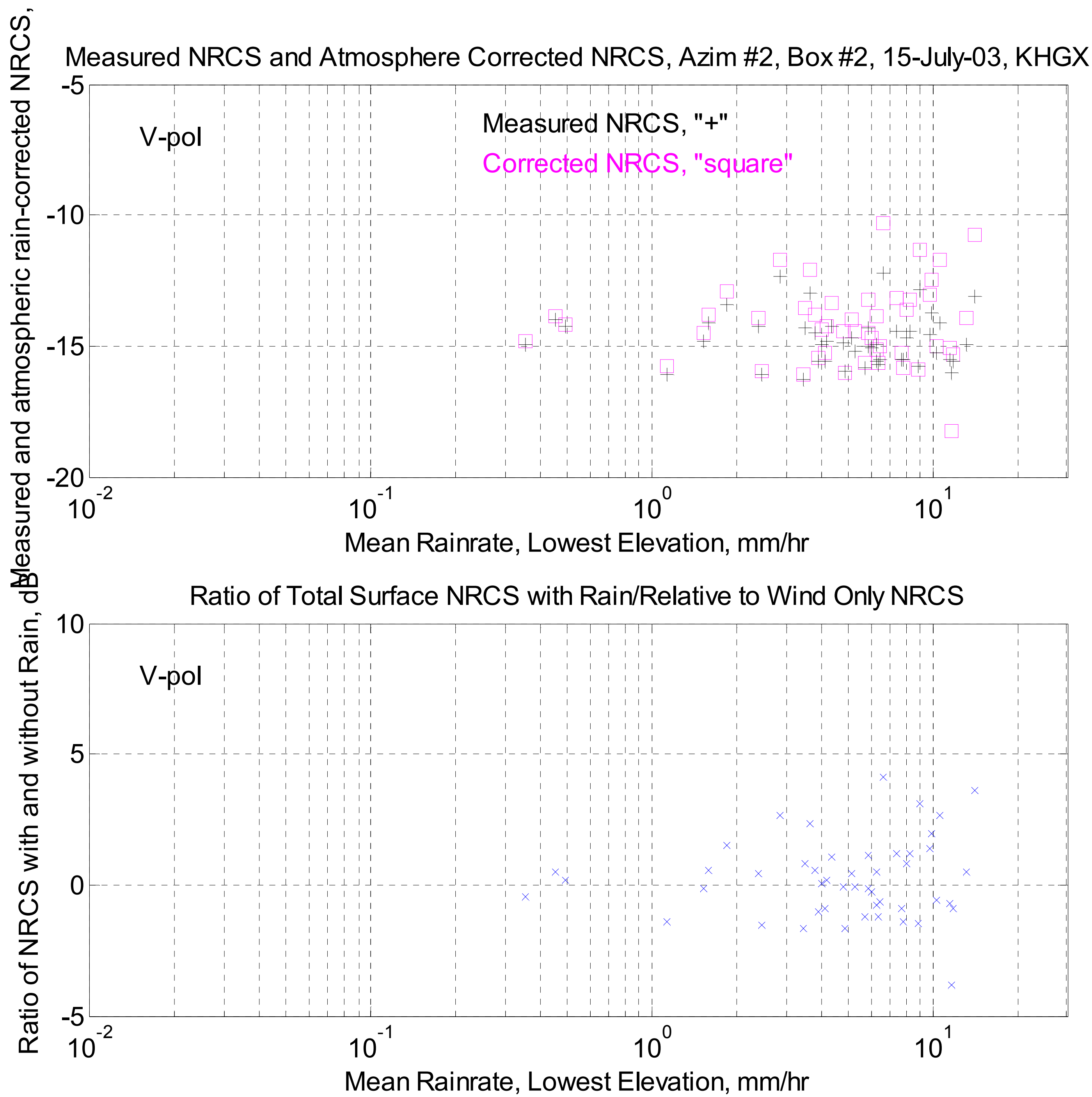

Measured NRCS and Atmosphere Corrected NRCS, Azim #2, Box #2, 15-July-03, KHGX
H-pol
Measured NRCS, "+"
Corrected NRCS, "square"
Measured and atmospheric rain-corrected NRCS, dB
-5
-10
-15
-20
10^-2
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr
Ratio of Total Surface NRCS with Rain/Relative to Wind Only NRCS
H-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



Measured NRCS and Atmosphere Corrected NRCS, Azim #1, Box #2, 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
5
0
-5
10^-2
10^-1
10^0
10^1
Mean Rainrate, Lowest Elevation, mm/hr



Measured NRCS and Atmosphere Corrected NRCS, Azim #2, Box #2, 15-July-03, KHGX
V-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
V-pol
Ratio of NRCS with and without Rain, dB
Mean Rainrate, Lowest Elevation, mm/hr

Summary for Hurricane Claudette:

The properties of the NRCS vs Rainrate are similar in many respects to those seen in Hurricanes Dennis and Claudette; V-pol has notable differences with respect to H-pol.

Which polarization is more representative of the surface stress properties ??

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 become progressively pronounced.

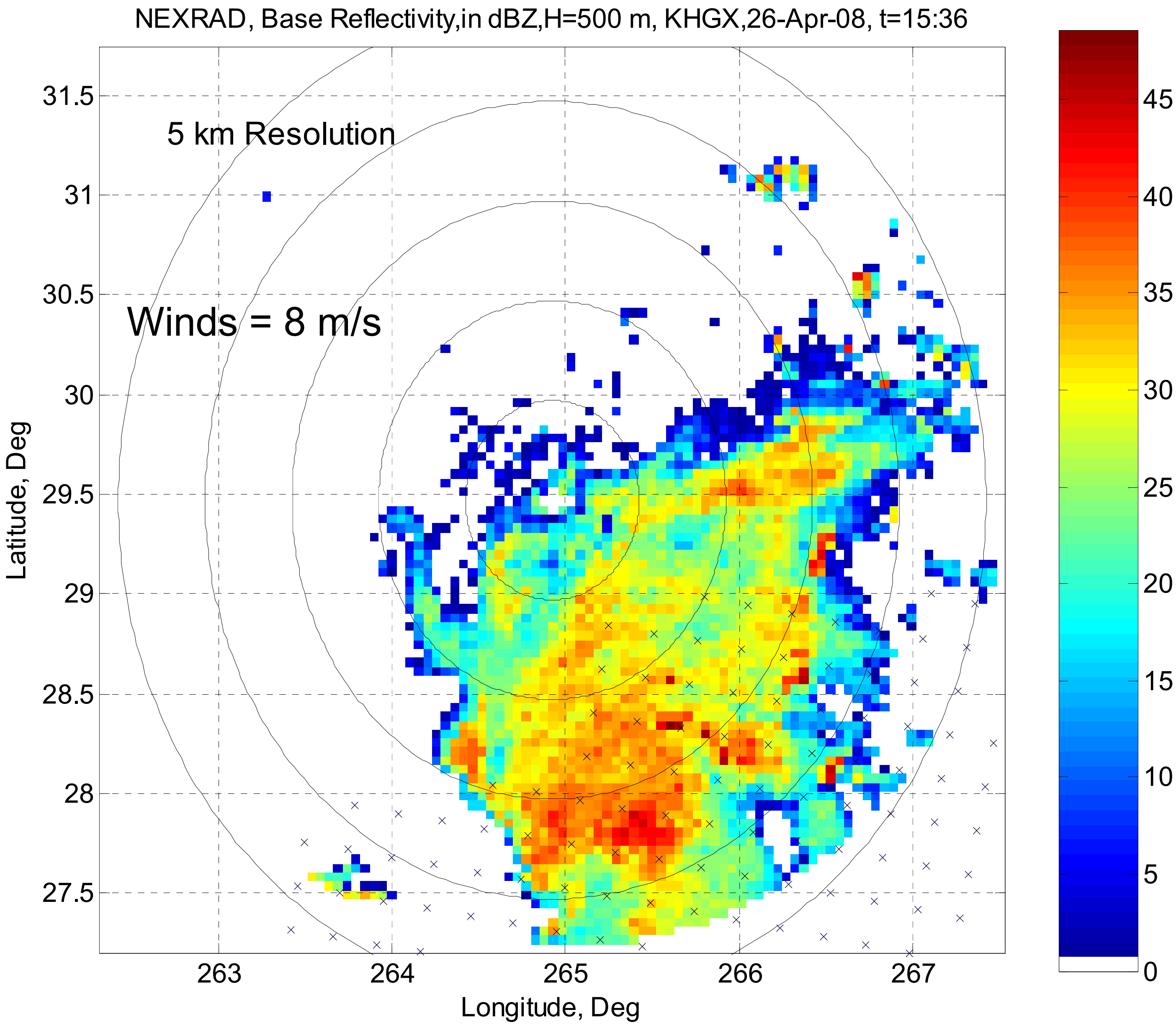
This indicates there is an interaction between the rain impact products and the wind driven wave spectrum that produces new roughness characteristics that have a distinct and differential polarization response.

ASCAT Studies of the NRCS vs Rainrate were made. These were located in the Gulf of Mexico near the Texas and Louisiana Coast

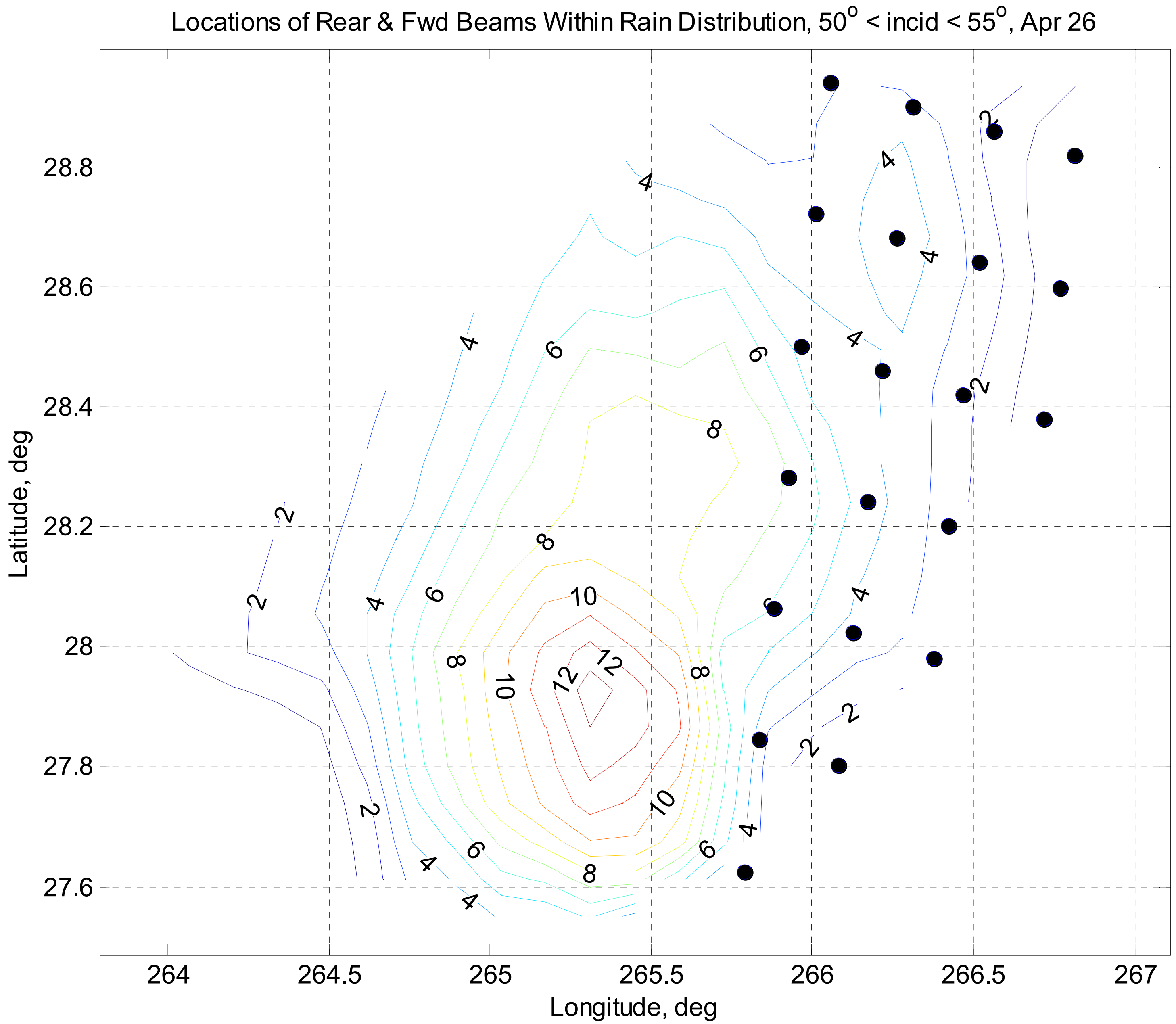
Two events have been studied:

1. April 26 near the Houston Nexrad (KHGX)
2. March 7, near the Lake Charles, La. Nexrad (KLCH)

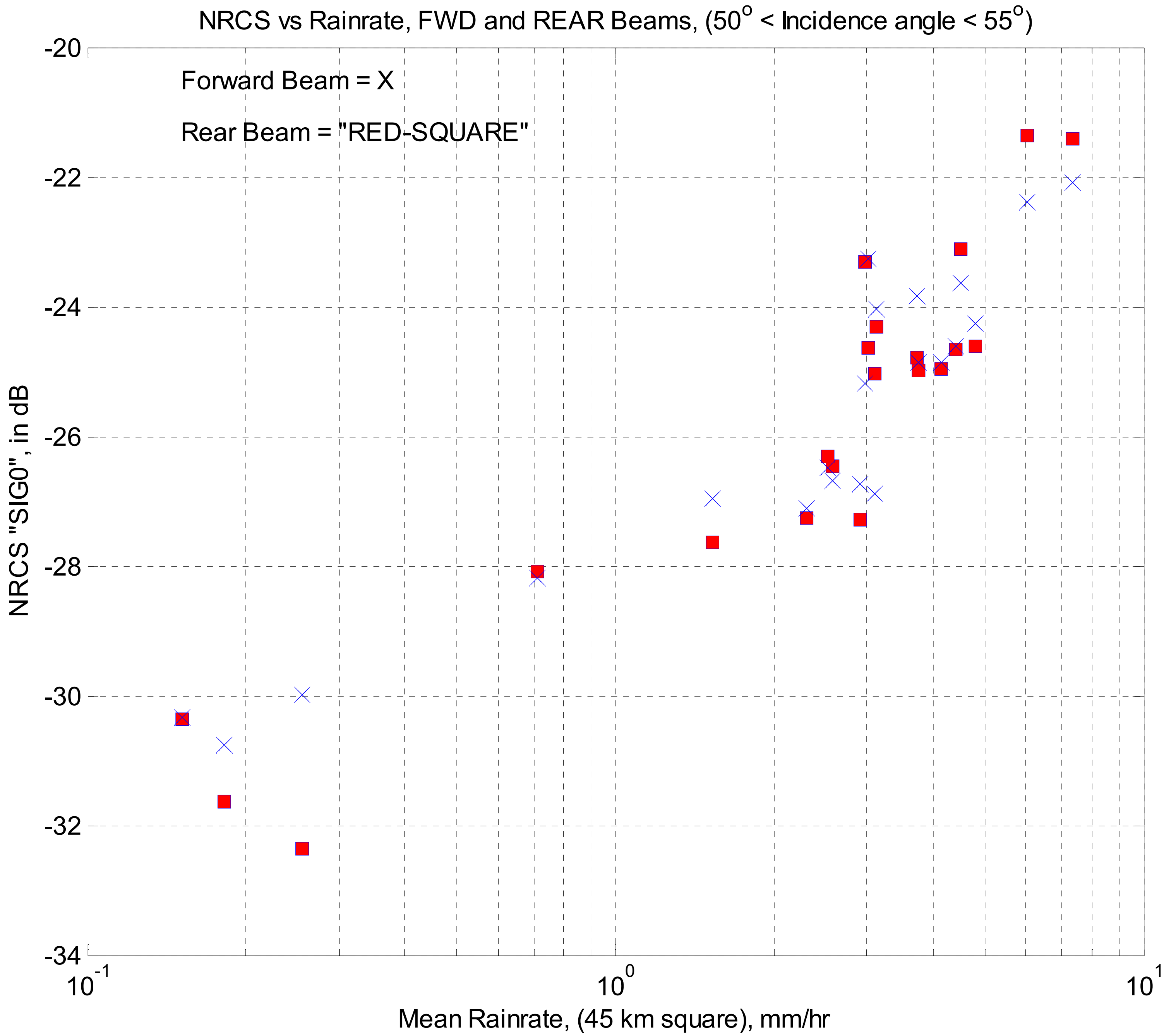
Acknowledge with appreciation the contribution of Scott Dunbar who provided us with the data and software that we needed.



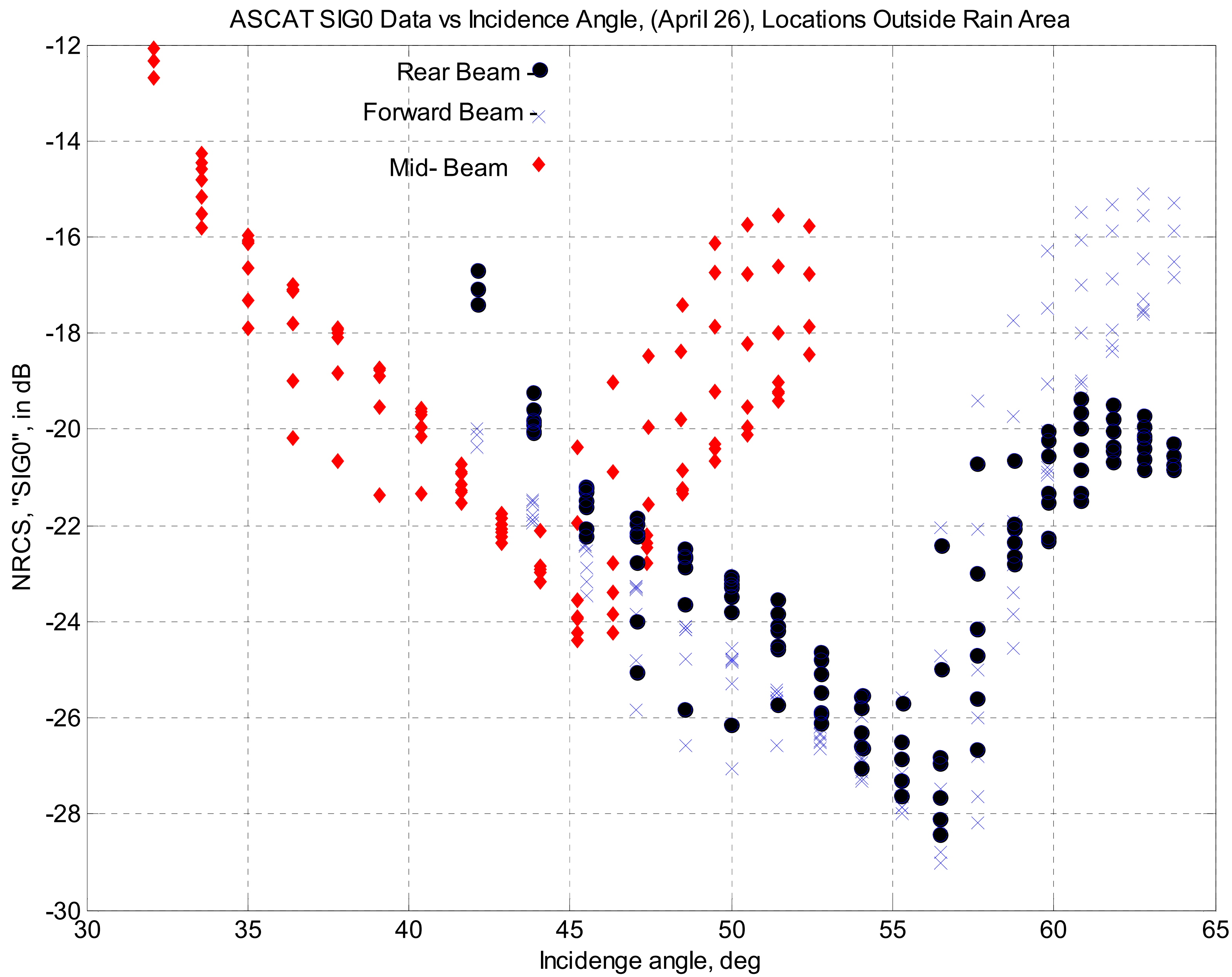
NEXRAD, Base Reflectivity,in dBZ,H=500 m, KHGX,26-Apr-08, t=15:36
5 km Resolution
Winds = 8 m/s
Latitude, Deg
31.5
31
30.5
30
29.5
29
28.5
28
27.5
Longitude, Deg
263
264
265
266
267
45
40
35
30
25
20
15
10
5
0

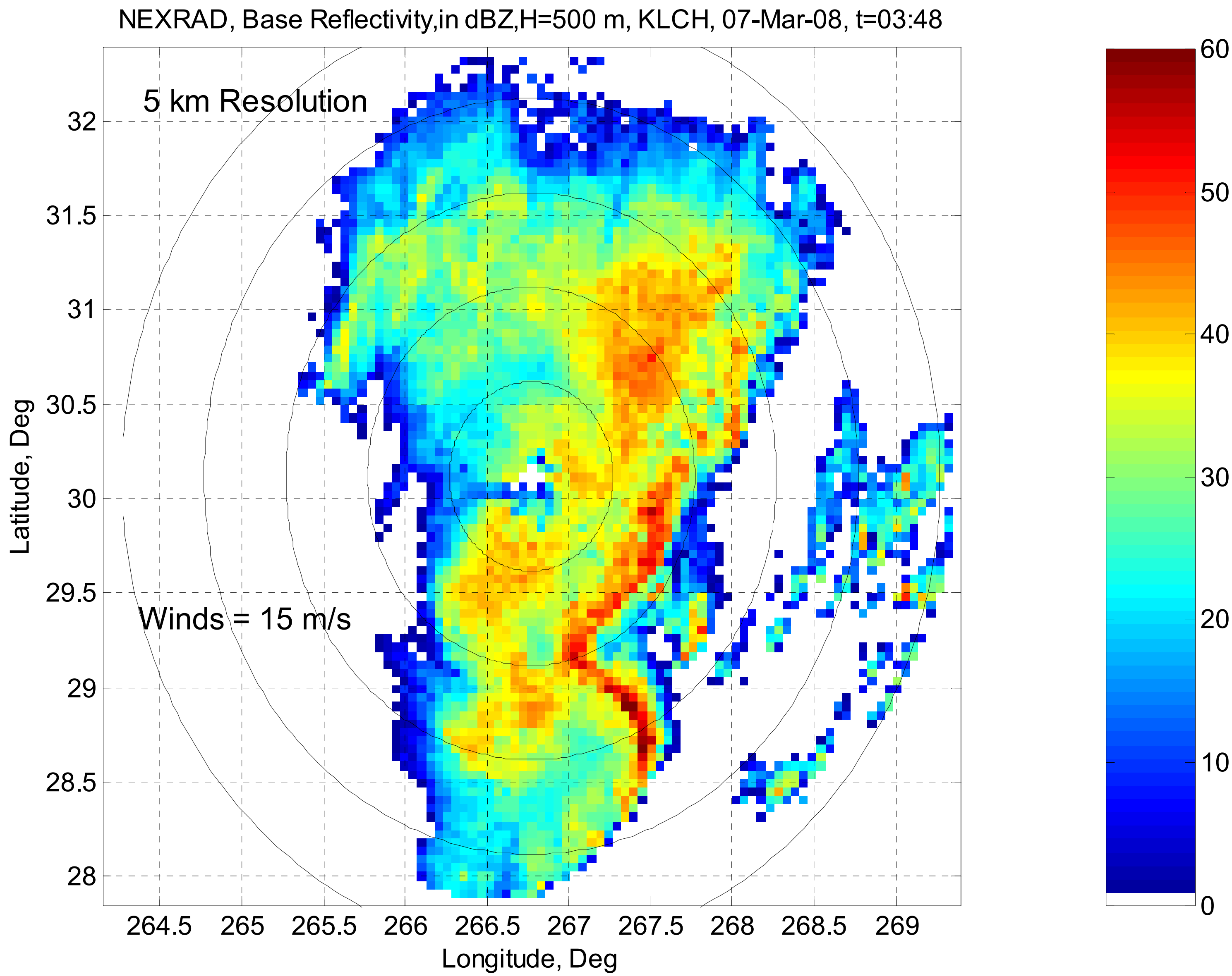


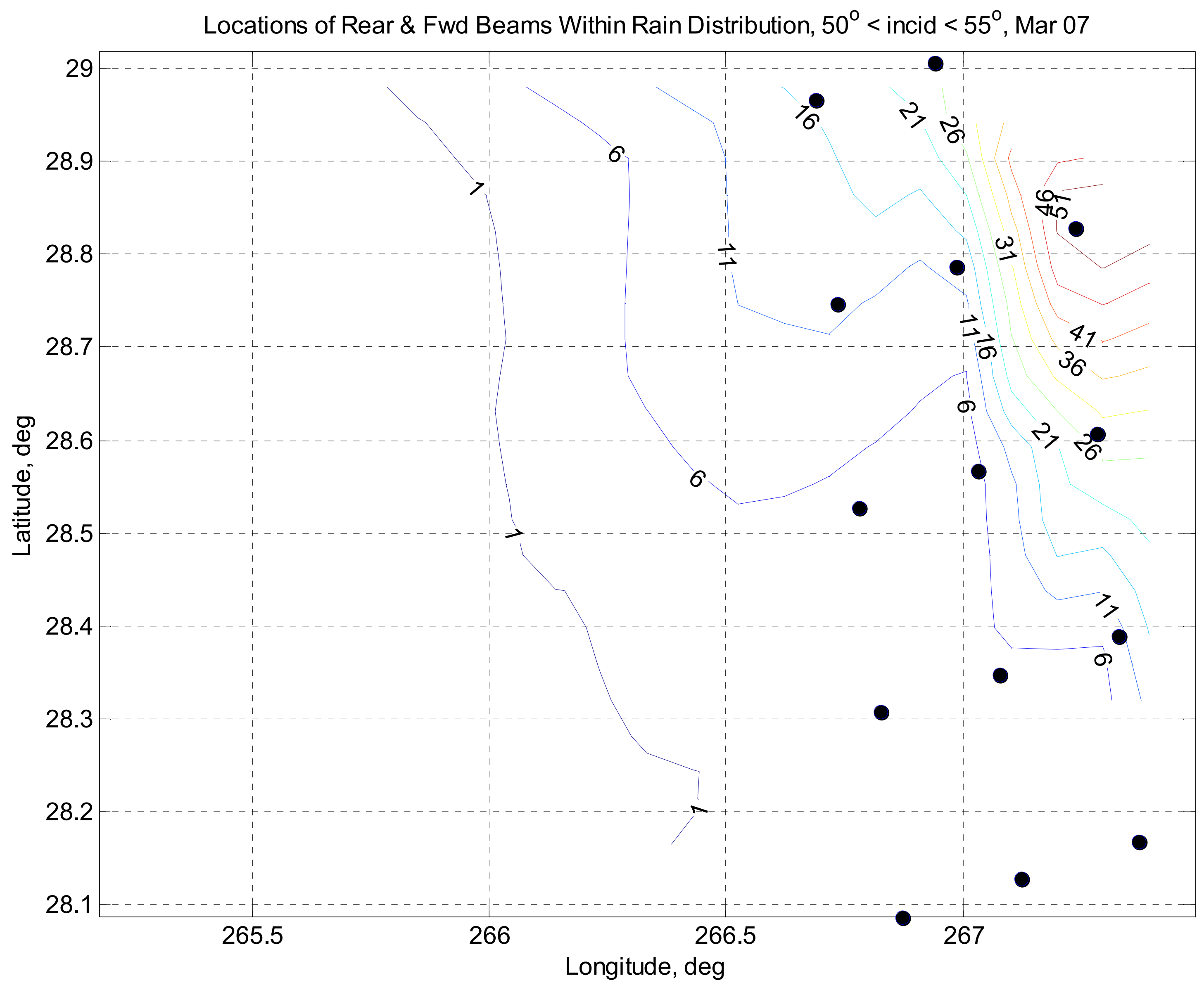
Locations of Rear & Fwd Beams Within Rain Distribution, 50° < incid < 55°, Apr 26
Latitude, deg
Longitude, deg
28.8
28.6
28.4
28.2
28
27.8
27.6
264
264.5
265
265.5
266
266.5
267
2
4
6
8
10
12

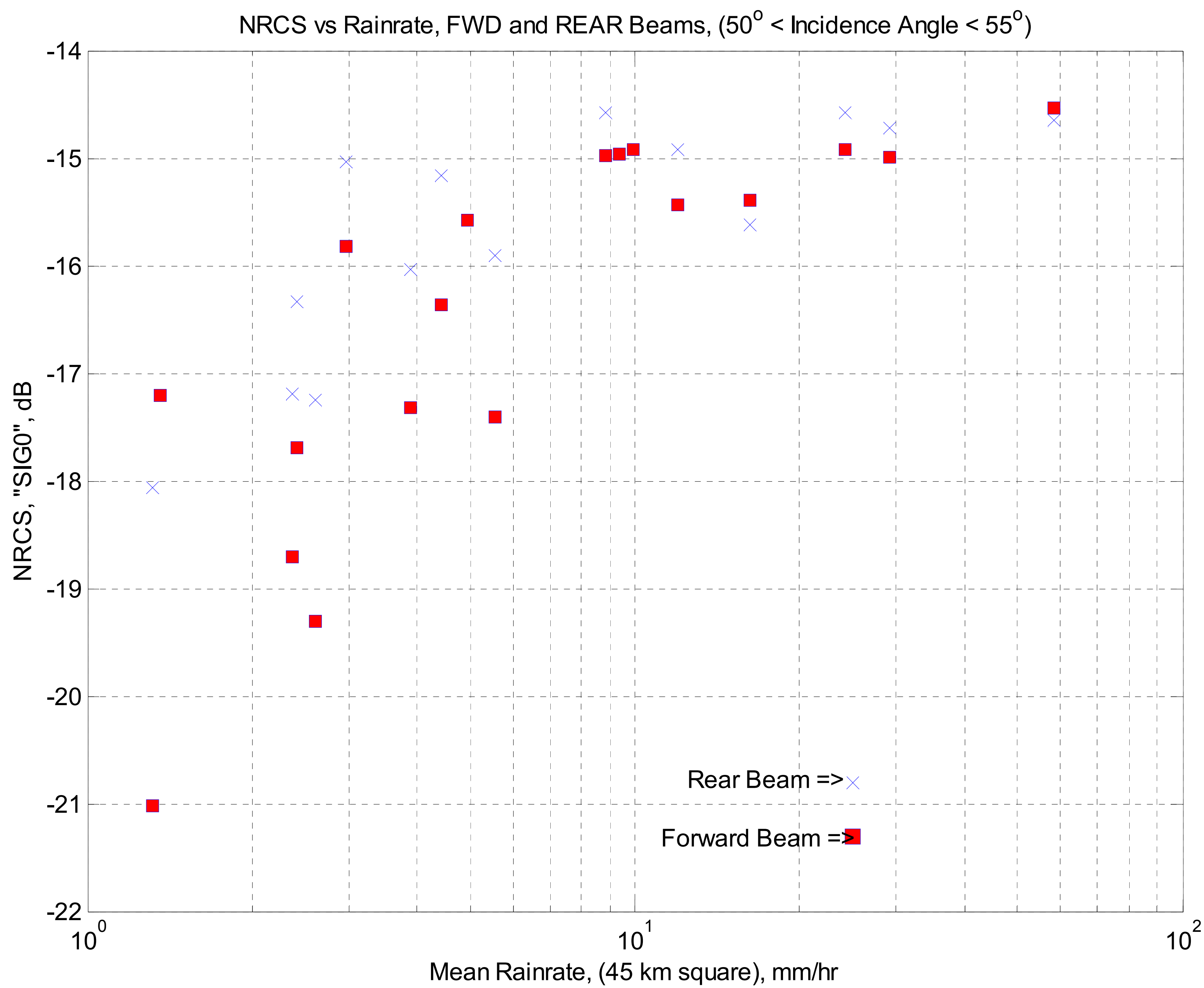


NRCS vs Rainrate, FWD and REAR Beams, (50° < Incidence angle < 55°)
Forward Beam = X
Rear Beam = "RED-SQUARE"
NRCS "SIG0", in dB
Mean Rainrate, (45 km square), mm/hr
-20
-22
-24
-26
-28
-30
-32
-34
10^-1
10^0
10^1

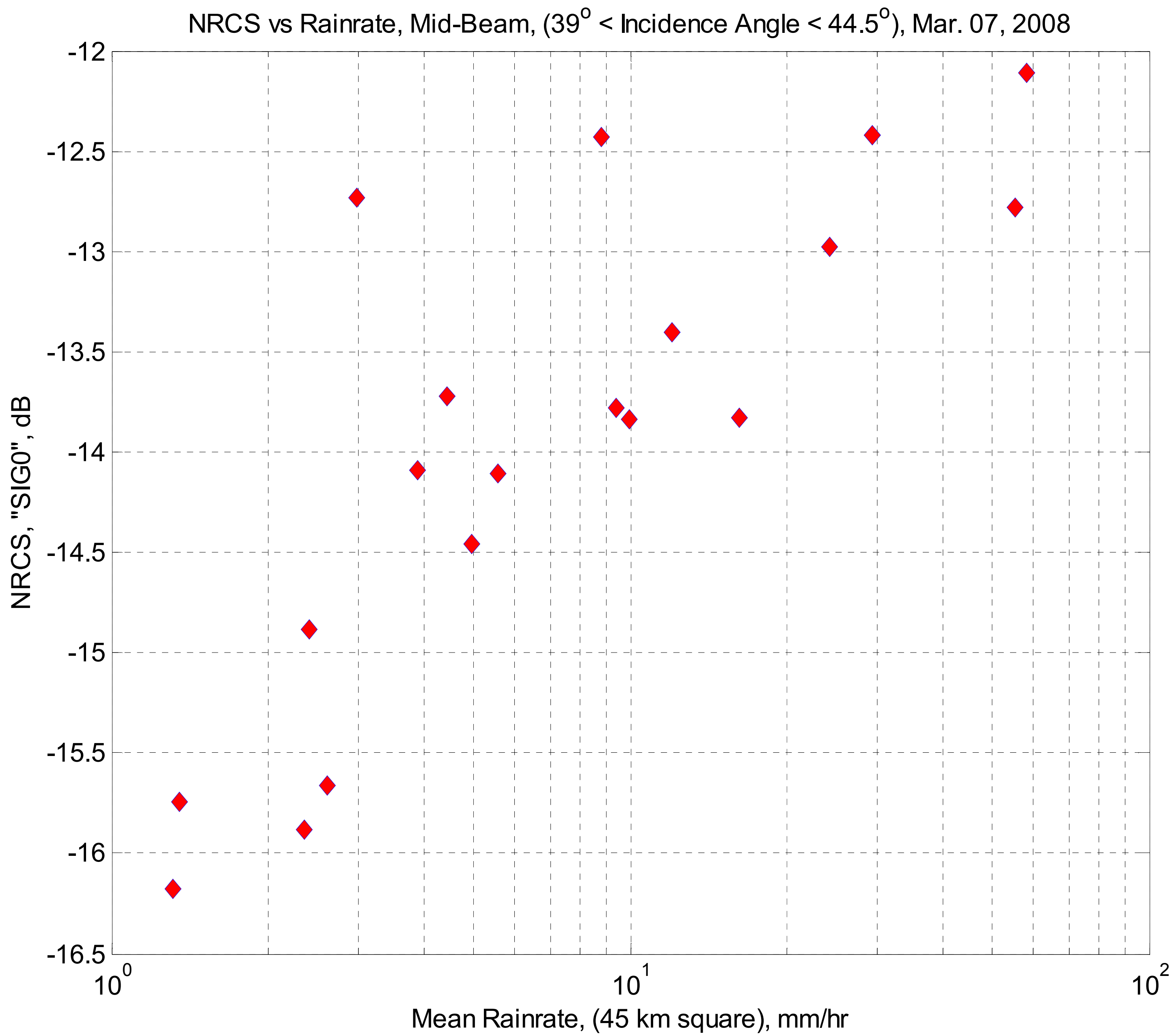

ASCAT SIG0 Data vs Incidence Angle, (April 26), Locations Outside Rain Area
Rear Beam -
Forward Beam -
Mid- Beam
NRCS, "SIG0", in dB
Incidenge angle, deg
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
30
35
40
45
50
55
60
65


NEXRAD, Base Reflectivity,in dBZ,H=500 m, KLCH, 07-Mar-08, t=03:48
5 km Resolution
Winds = 15 m/s
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
60
50
40
30
20
10
0


Locations of Rear & Fwd Beams Within Rain Distribution, 50° < incid < 55°, Mar 07
Latitude, deg
Longitude, deg
29
28.9
28.8
28.7
28.6
28.5
28.4
28.3
28.2
28.1
265.5
266
266.5
267
1
6
11
16
21
26
31
36
41
46
51



NRCS vs Rainrate, FWD and REAR Beams, (50° < Incidence Angle < 55°)
NRCS, "SIG0", dB
Mean Rainrate, (45 km square), mm/hr
-14
-15
-16
-17
-18
-19
-20
-21
-22
10^0
10^1
10^2
Rear Beam =>
Forward Beam =>



NRCS vs Rainrate, Mid-Beam, (39° < Incidence Angle < 44.5°), Mar. 07, 2008
NRCS, "SIG0", dB
Mean Rainrate, (45 km square), mm/hr
-12
-12.5
-13
-13.5
-14
-14.5
-15
-15.5
-16
-16.5
10^0
10^1
10^2