Corrections to Scatterometer Wind Vectors For Precipitation Effects: Using High Resolution NEXRAD and AMSR With Intercomparisons

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CENTRAL QUESTIONS TO THE OCEAN VECTOR WINDS COMMUNITY:

I. OVER WHAT <u>RANGE</u> OF WIND SPEED AND RAIN INTENSITY CAN THE RETRIEVED WINDS BE IMPROVED ?

II. WHAT METHODS ARE MOST USEFUL TO CREATE CORRECTED WINDS, AND HOW CAN THEY BE EVALUATED?

GOALS OF THIS PROJECT:

To use the high resolution NEXRAD S-Band radar observations of 3-D precipitation:

Goal 1A: to provide rain correction for each scatterometer beam permitting corrected σ_o to be computed and used for wind vector retrieval.

Goal 1B: to understand how the geometry and spatial resolution of satellite observations impact rain corrections to the scatterometer wind

Goal 2A: To evaluate, understand and improve satellite passive microwave retrievals that use “Top of the Atmosphere” (TOA) brightness temperatures at low spatial resolution

Goal 2B: to evaluate understand and improve the AMSR retrieved:

- Liquid water product (and rainrate)
- volume backscatter
- Ku-band attenuation

-------------------- AMSR and NEXRAD Properties ---------------

AMSR was designed to measure atmospheric parameters on a spatial scale of ~25km, comparable to the SeaWinds scatterometer Optimal estimates of attenuation and volume backscatter require a knowledge of the beamfilling characteristics (the 3-D distribution of precipitation within the scatterometer footprint)

The AMSR algorithm deals with beamfilling issues by selecting retrieval databases at each point based on rain intensity and inhomogeneity as determined by a specially designed Rain Indicator.

The high spatial resolution of NexRad enables:
- examining the effect of non-uniform beamfilling
- evaluating and improving the AMSR retrievals
Studies of this type could also be useful to the current TRMM-TMI and the future GPM passive sensors.

AMSR Based Precipitation Estimates & Wind Retrievals:

1. The SeaWinds' AMSR algorithm uses a "Rain Indicator" to determine the intensity and degree of rain homogeneity within the sensors field of view. Three homogeneity classes are used: LIH (Low Intensity Homogeneous), HIH (High Intensity Homogeneous) and INH (Inhomogeneous)

2. This leads to estimates of the following geophysical parameters:

a) vertically integrated liquid water (Liquid water path)

b) vertically integrated water vapor

c) near surface wind speed

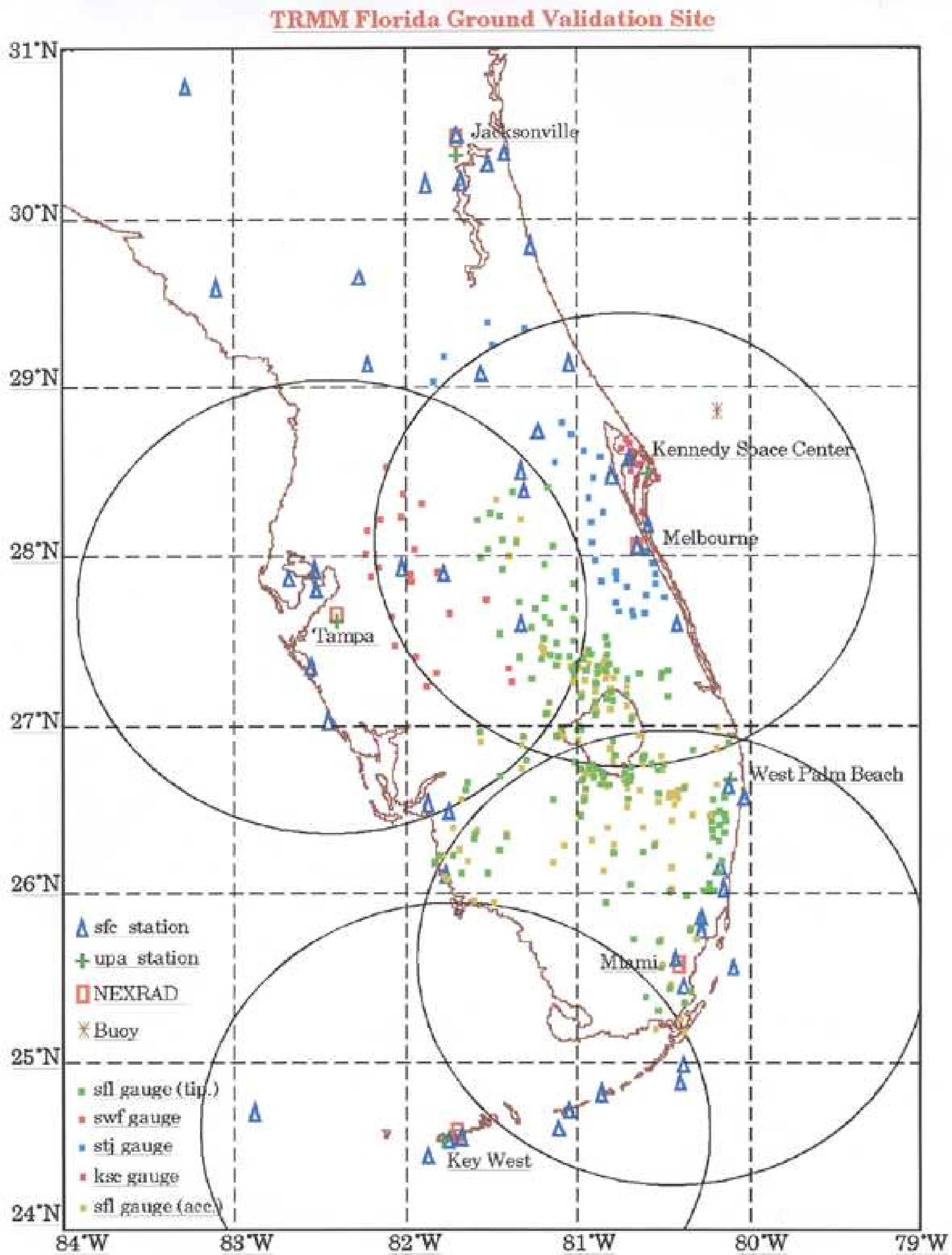
d) sea surface temperature

3. Using AMSR-retrieved geophysical parameters, atmospheric correction to scatterometer observations may be estimated using either "Physical" or "Empirical" approach

References:

1. S.M. Hristova-Veleva, et al, "Revealing the SeaWinds OVW under the rain using AMSR. Part I: The physical approach", 14th Conf. on Satellite Meteorology & and Oceanography, Atlanta, GA, Jan. 29-Feb. 2, 2006

2. B.W. Stiles, et al, "Revealing the SeaWinds OVW under the rain using AMSR. Part II: The empirical approach", 14th Conf. on Satellite Meteorology & and Oceanography, Atlanta, GA, Jan. 29-Feb. 2, 2006



The NWS NEXRAD measures reflectivity, "Z", at S-band in 3-D spherical coordinates out to range=450 km, but only 250 km is used in this study.

The spatial resolution varies with distance:
1 km (range) and 1 degree (azim)

Conversion to Ku-band "Z" requires assumptions about drop size distribution

NEXRAD SCAN PROPERTIES

ELEVATION RANGE OF COVERAGE OF EACH OF THE AZIMUTHAL NEXRAD SCANS

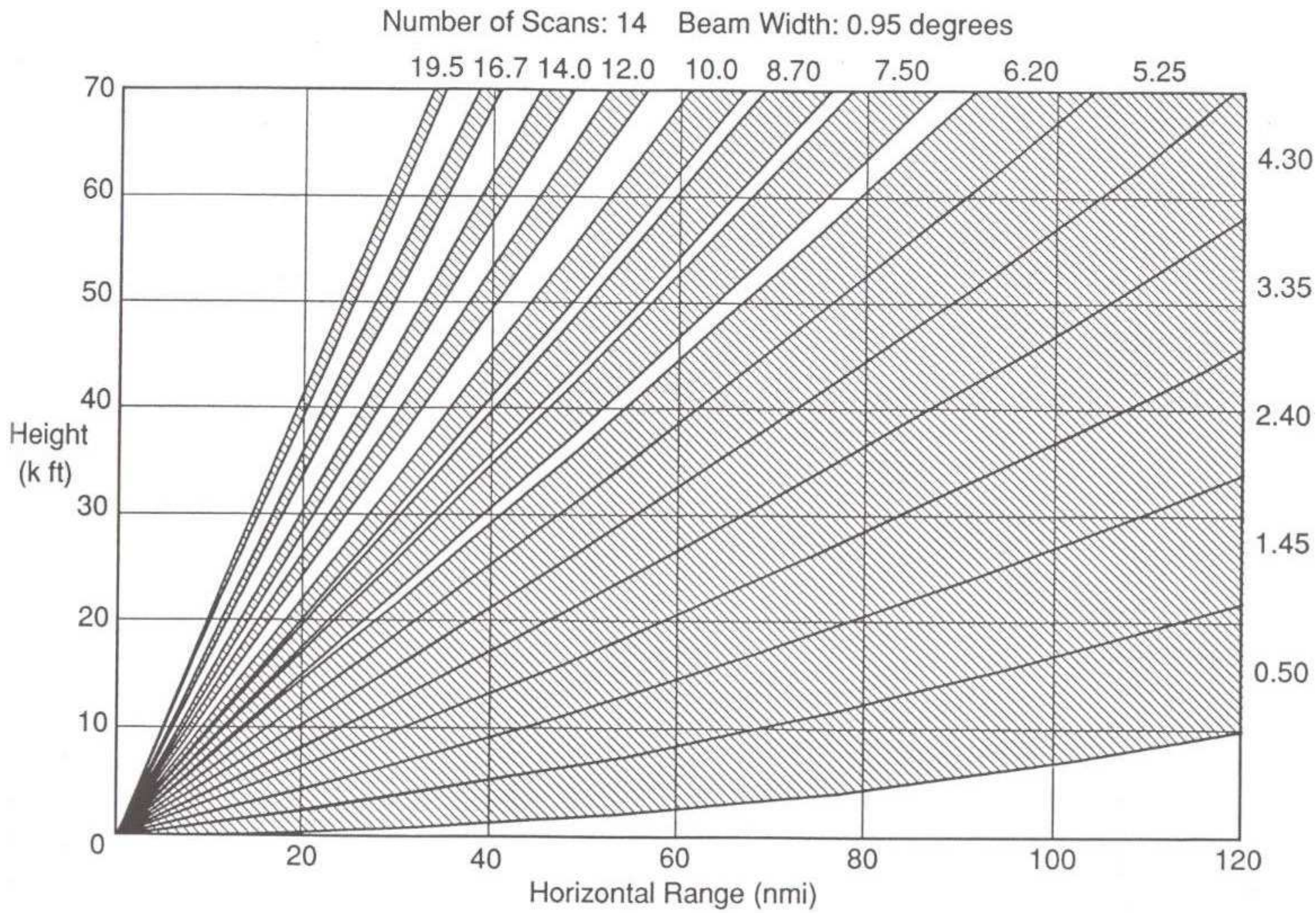
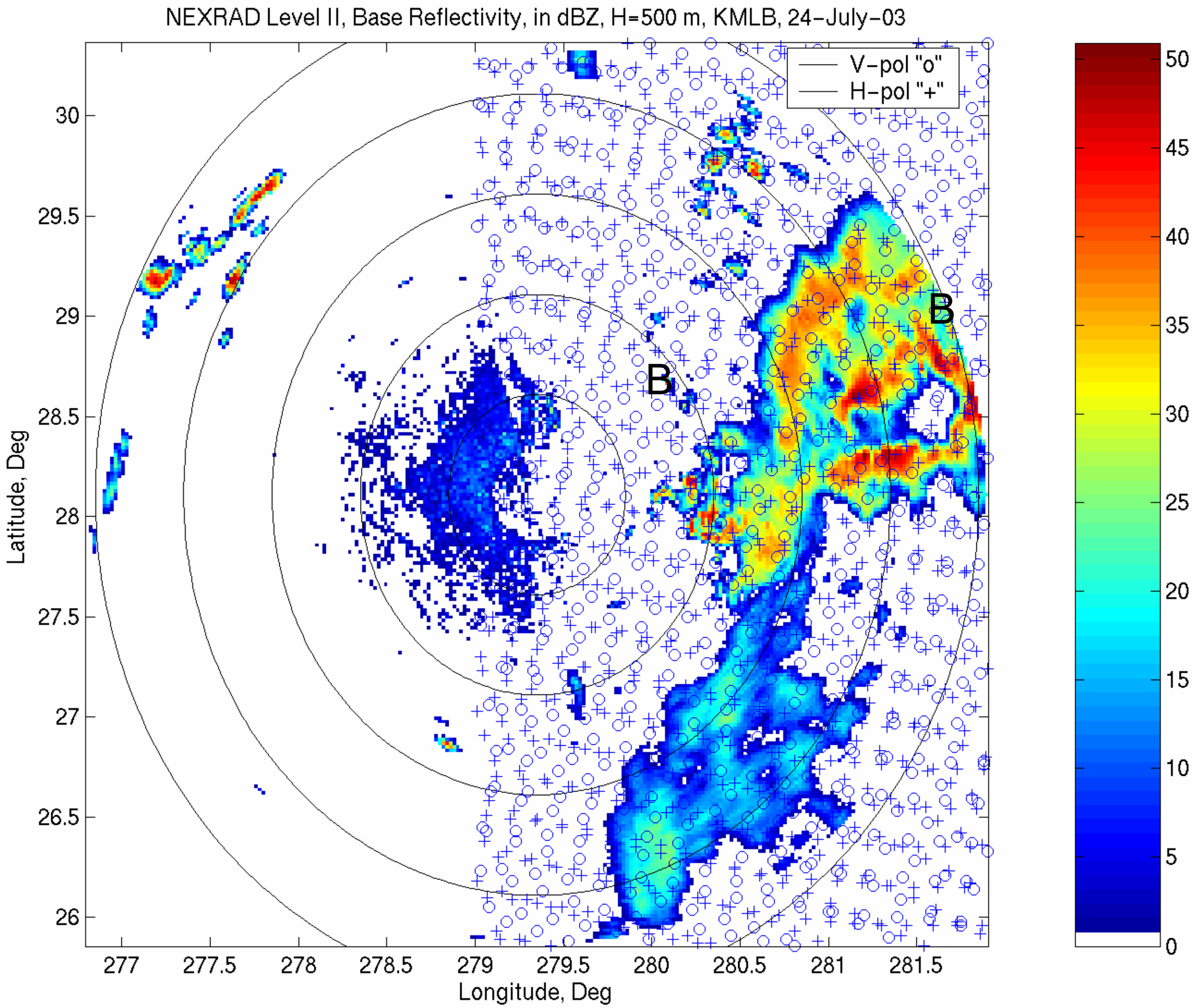


Figure 5-1
Precipitation/Severe Weather Scan
Volume Coverage Pattern 11

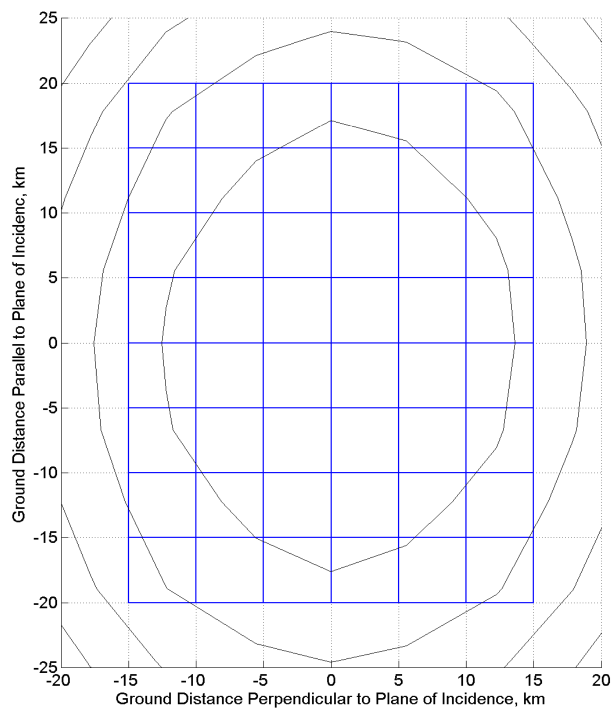
Locations of the SeaWinds L2A SIGMA0 Cells – “O” = V-pol, “+” = H-pol

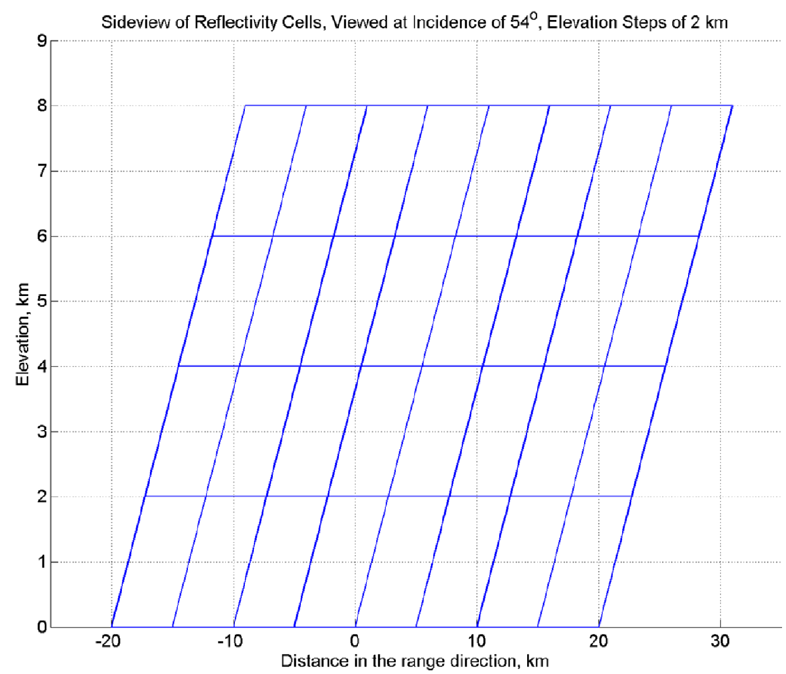


Method of Computing SeaWinds Volume Backscatter and Attenuation using NEXRAD data in discrete parallelograms

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 each cell - 3 dB Contours Shown

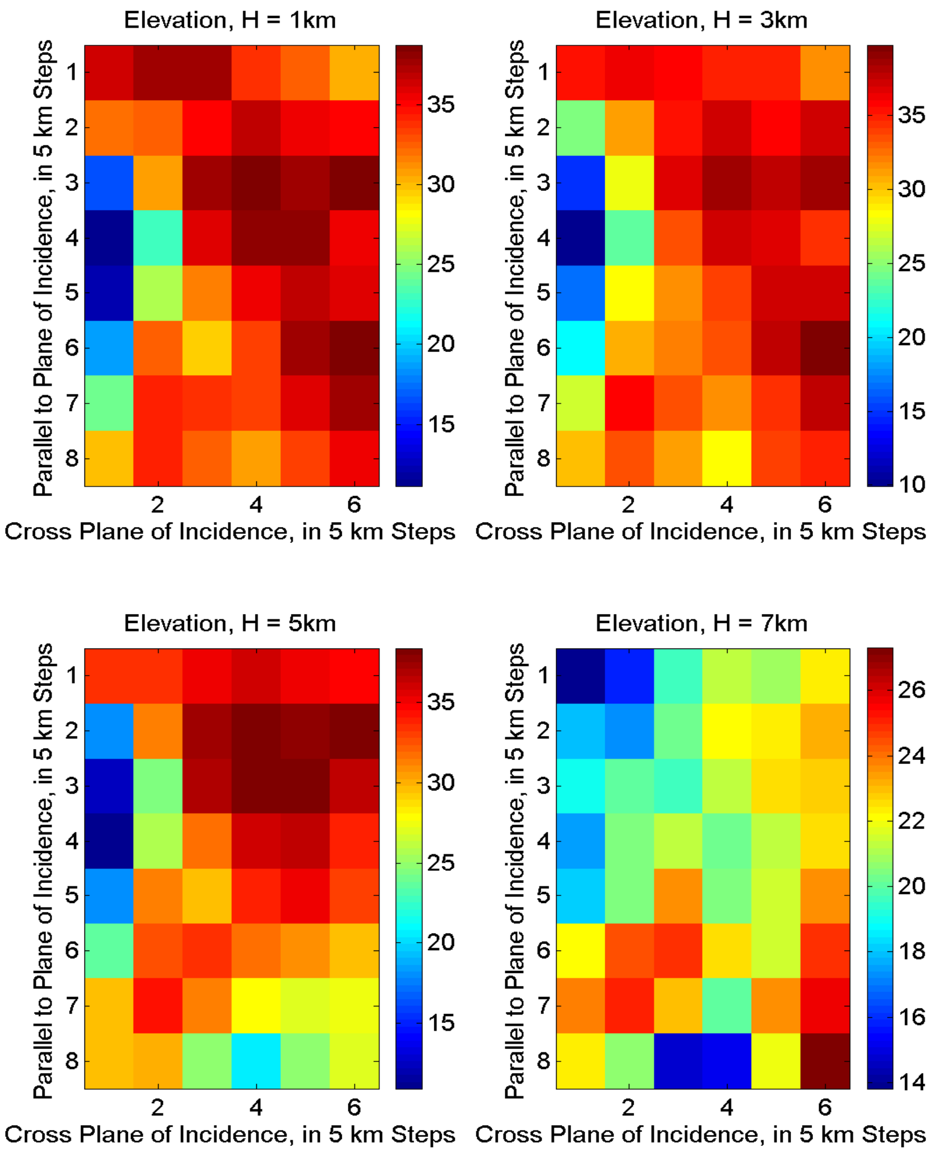




Relative Positions of Reflectivity Cells Along Incident Beam, V-pol Case

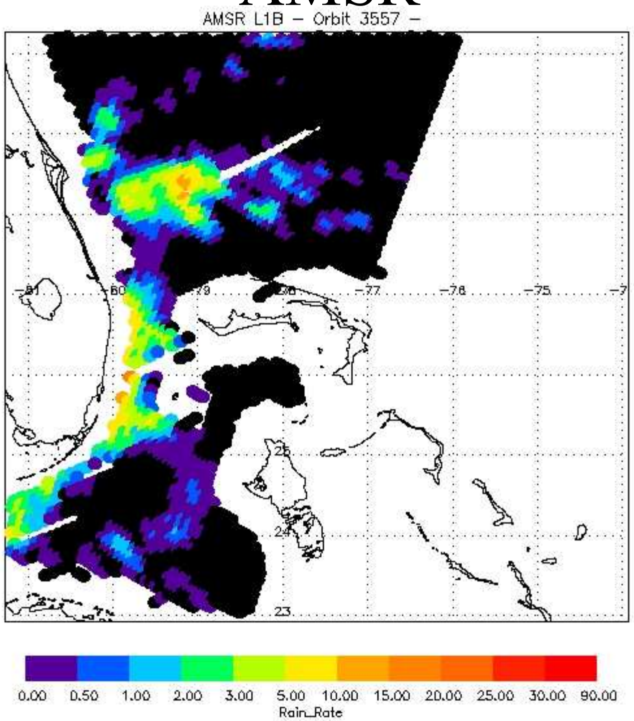
ILLUSTRATION OF THE HIGH PRECIPITATION VARIABILITY WITHIN ONE SCATTEROMETER CELL

Horizontal slices of the NEXRAD Reflectivity, in dBZ, of a H-pol Cell (Lat=29°, Long=281°)

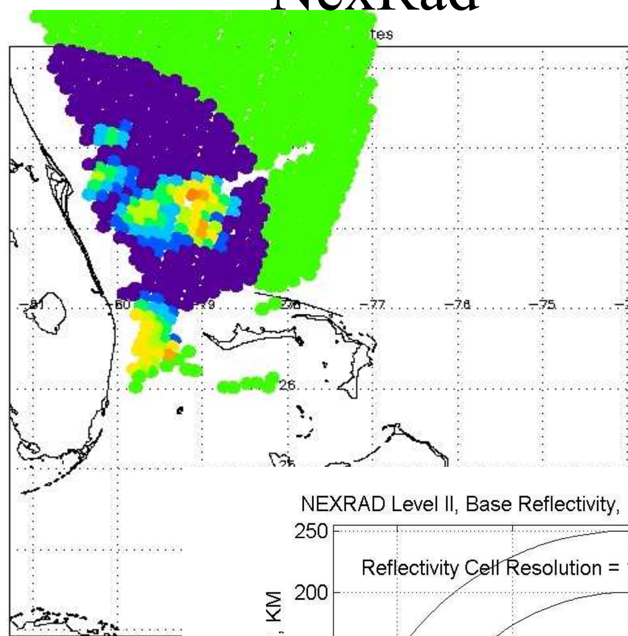


Case 1: ADEOS-II Observes Isolated Convection, Melborne, FL on 20-Aug-03

AMSR

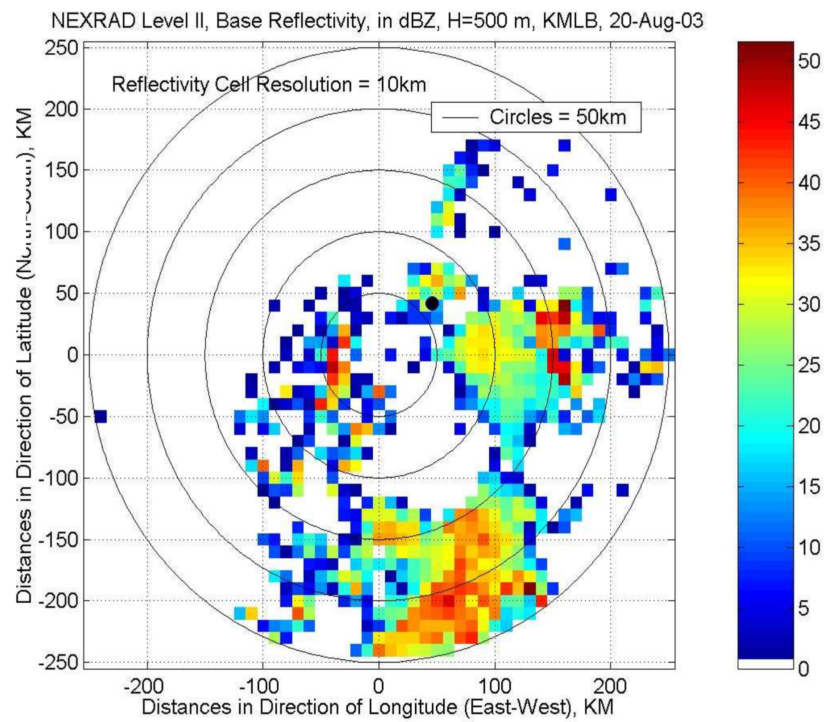


NexRad

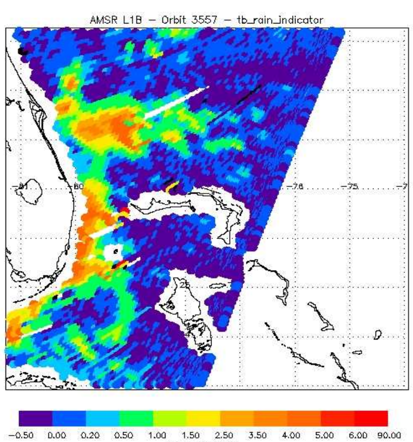


NOTE:
AMSR retrievals are done mostly with INH and LIH classes

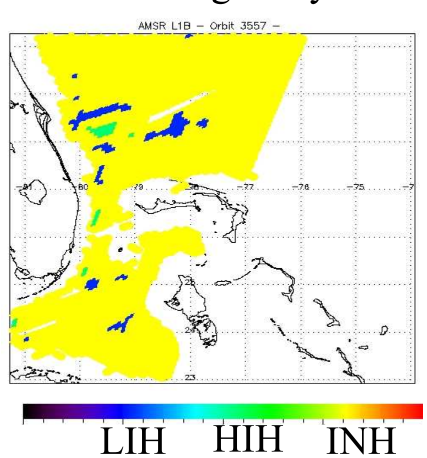
NEXRAD S-Band Reflectivity Interpolated into 10 km cells



Rain Indicator

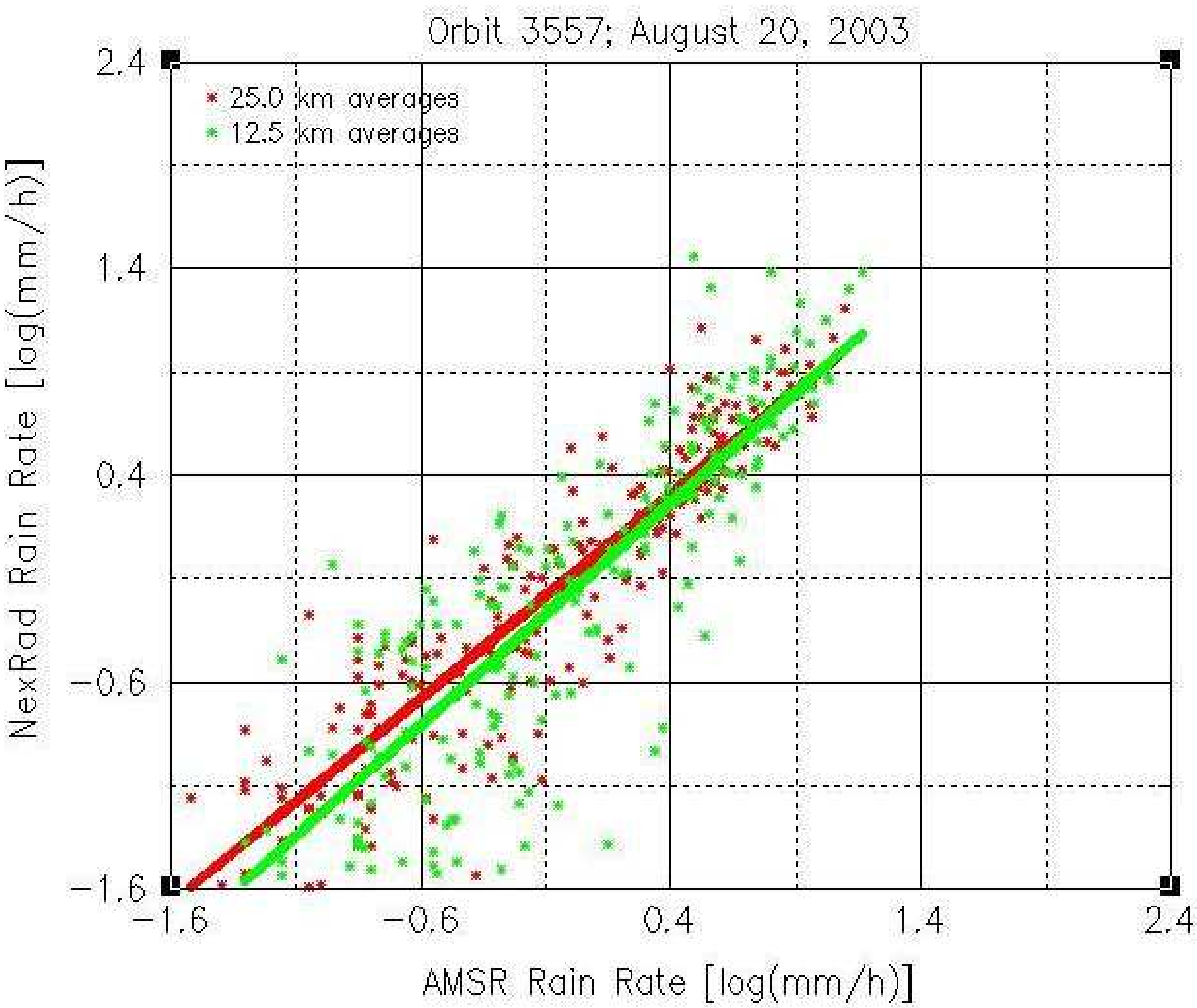


Homogeneity



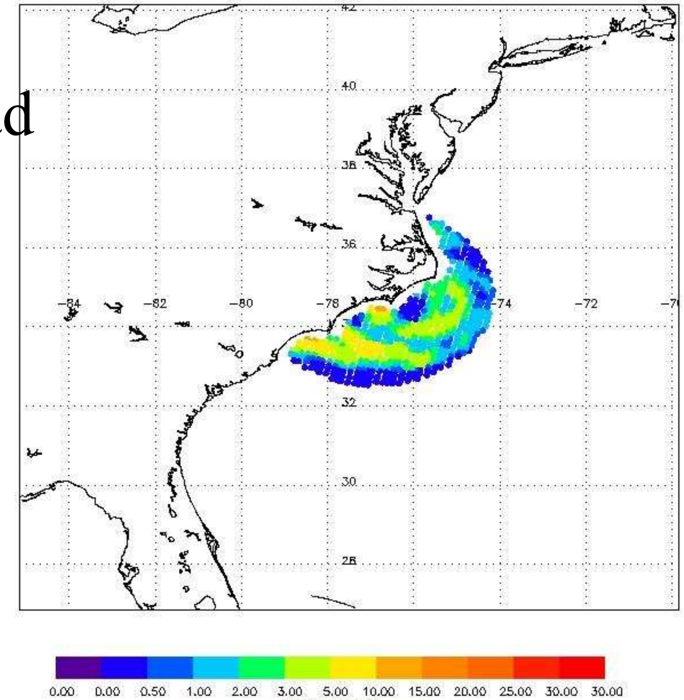
Case 1: Isolated convective precipitation retrievals with INH and LIH classes

The Good Comparison

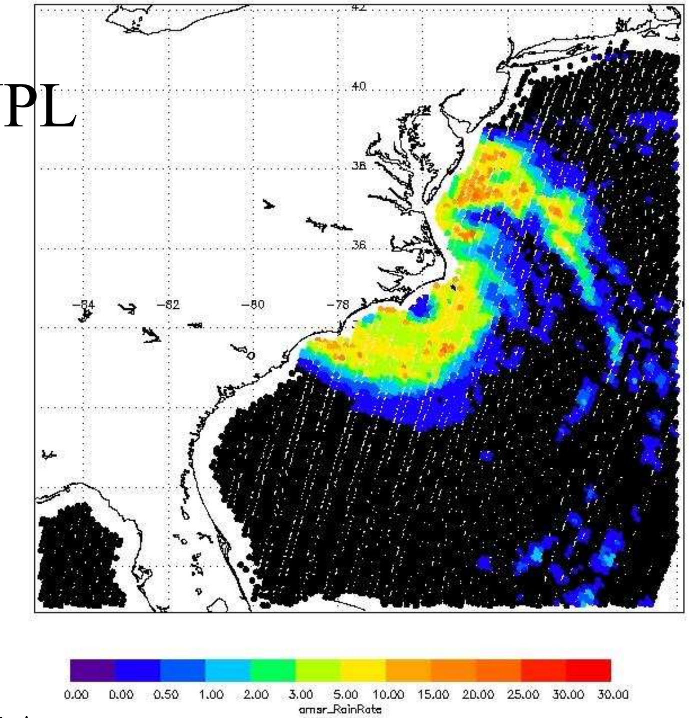


The results of two spatial averaging sizes for the NEXRAD data are shown (red is the averaging to a 25 km spatial resolution while the green is the averaging to a 12.5km spatial resolution). The lines of best fit are also shown. As expected, the 25 km NEXRAD average compares better to AMSR retrieval than the 12.5 km.

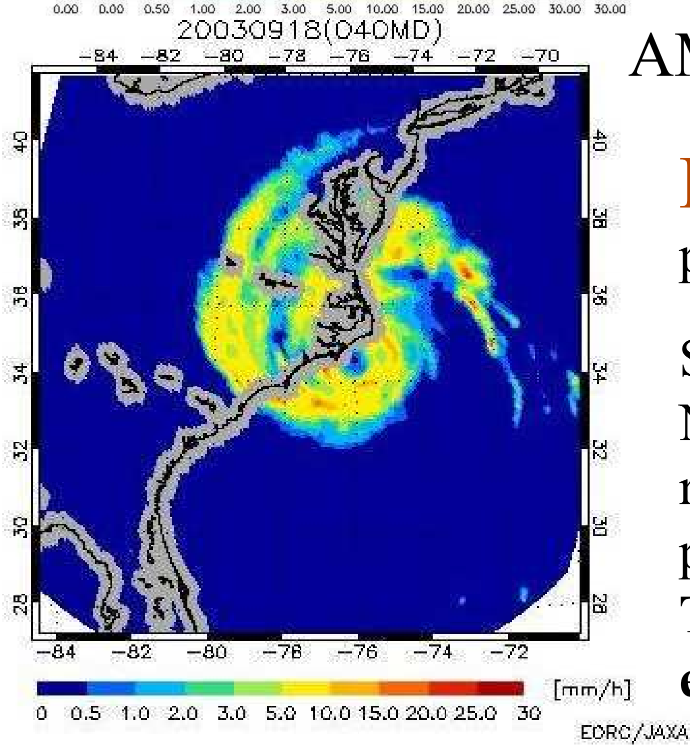
NexRad



AMSR-JPL



AMSR-JAXA

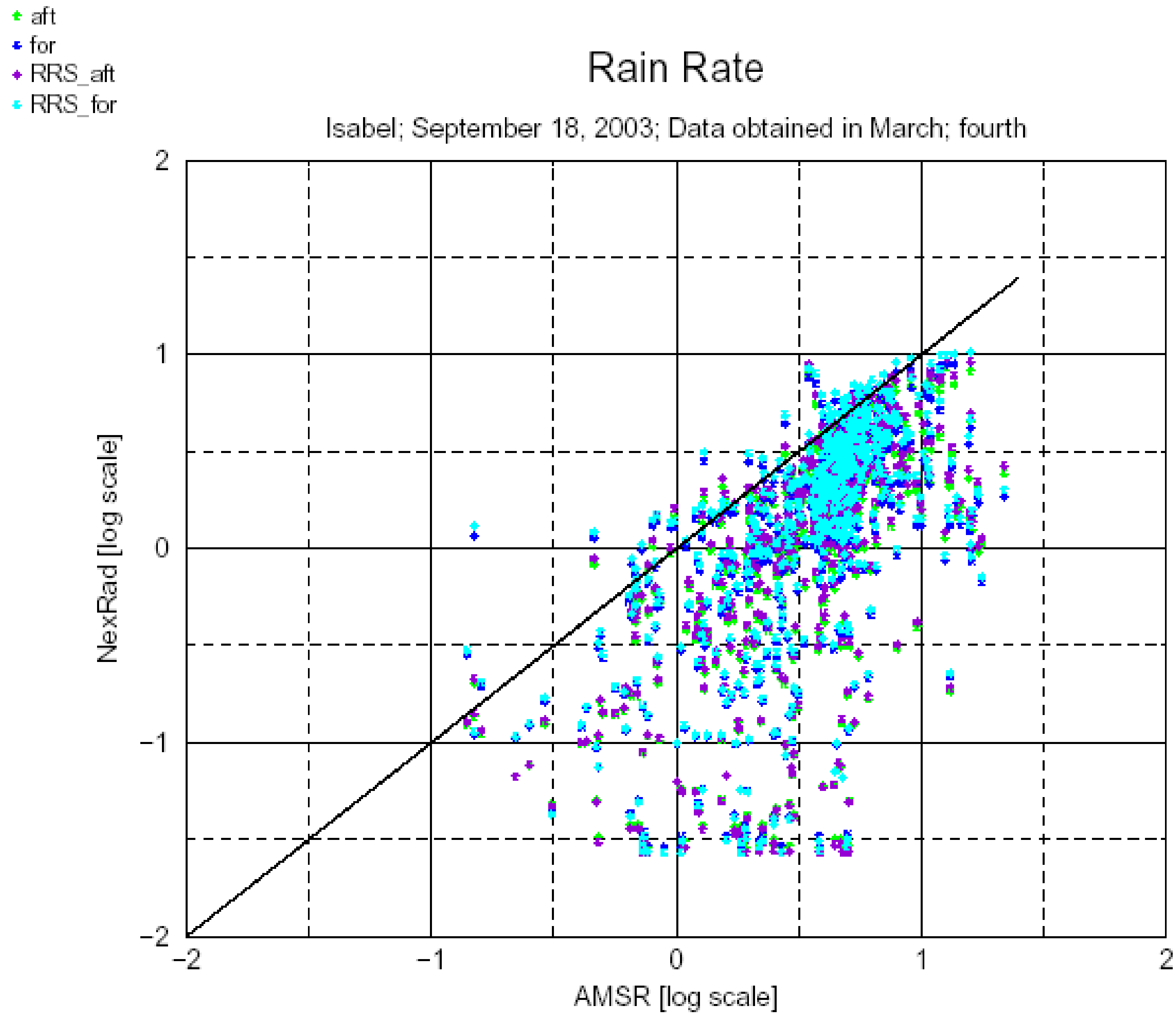


Hurricane Isabel Case 2 – Widespread precipitation near Outerbanks, NC

Shown are the rain rate estimates from NEXRAD (top-left panel), AMSR-JPL (top-right panel), and AMSR-JAXA(bottom panel).

The two satellite estimates are closer to each other than to the NEXRAD estimate

Case 2: Widespread Precipitation-Isabel Rain Rate comparisons

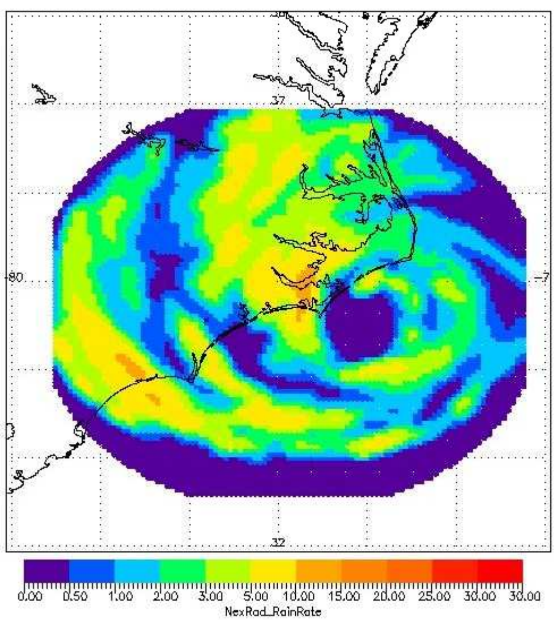


Sources of Uncertainties in the comparisons

- DSD assumptions in converting “Z” to “R”
- size of the averaging window
- radar calibration

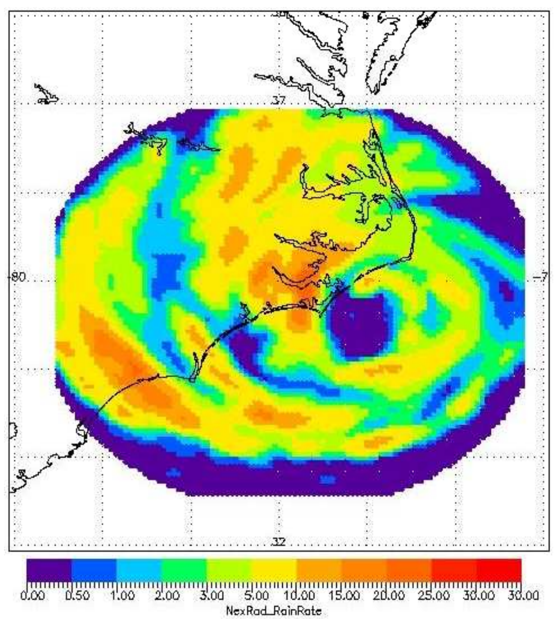
see differences in estimated rainrate below

Stratiform DSD
25 km horizontal averages



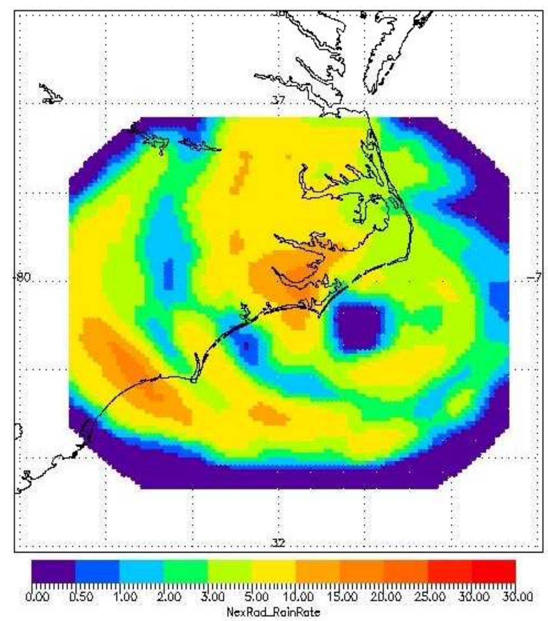
NexRad data

Convective DSD
25 km horizontal averages

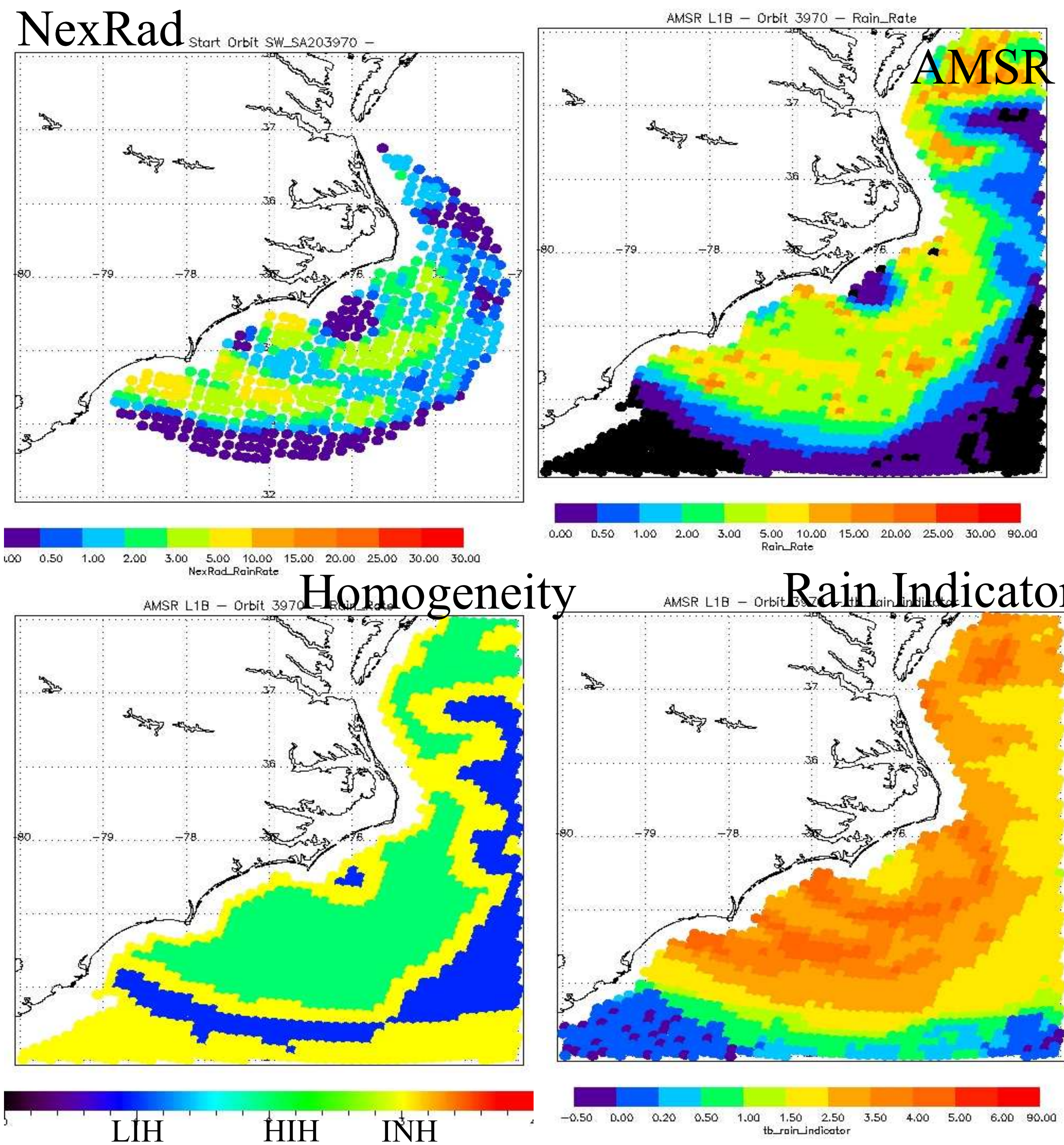


NexRad data

Convective DSD
35 km horizontal averages



NexRad data



Case 2 -Areas for improvement

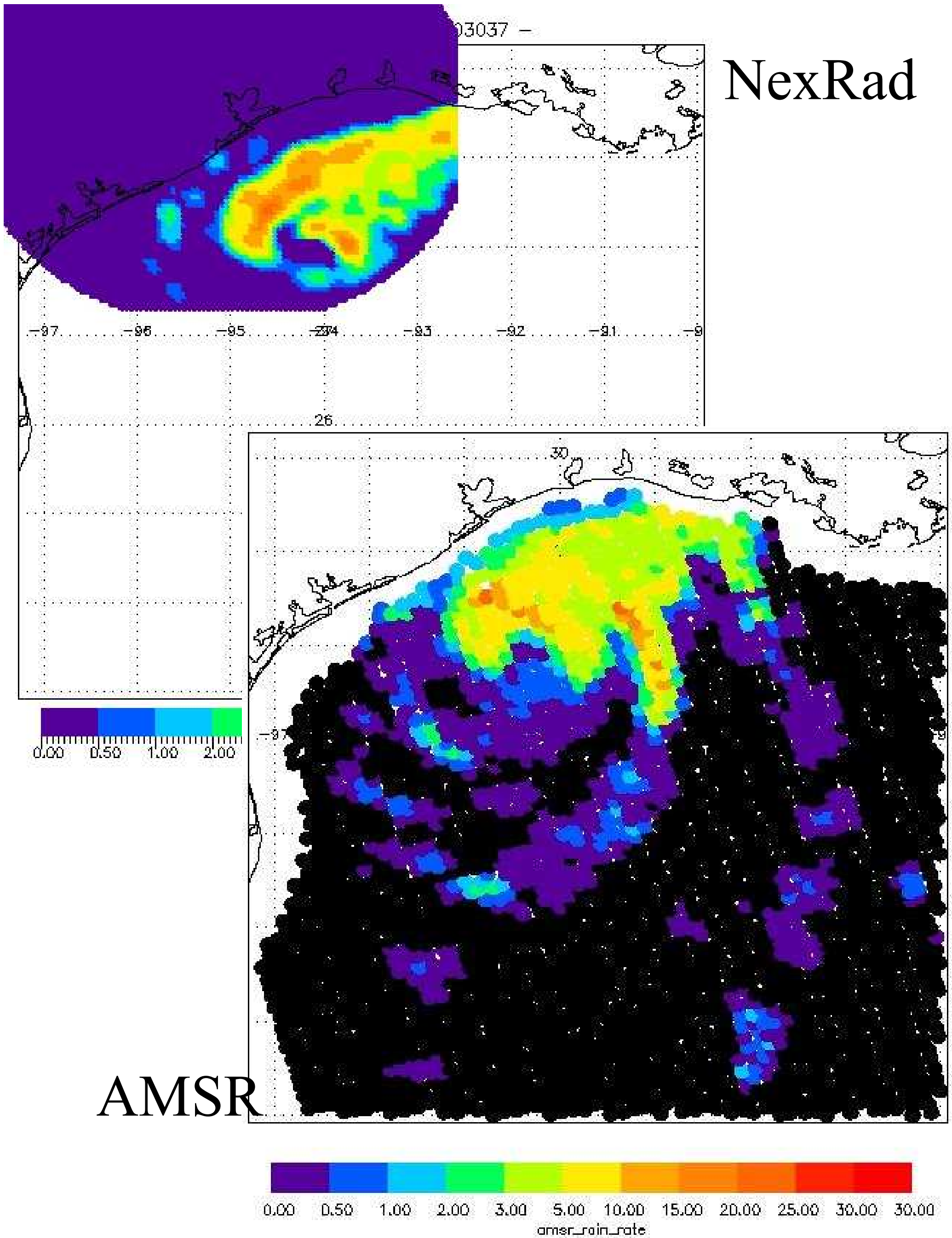
AMSR rain rates – somewhat noisier

Homogeneity classification – too flat

HIH class covers large area

AMSR Rain Indicator – shows much better ability to capture the NexRad features

Proposed improvement - Further break down of the HIH class into 2 or 3 more classes

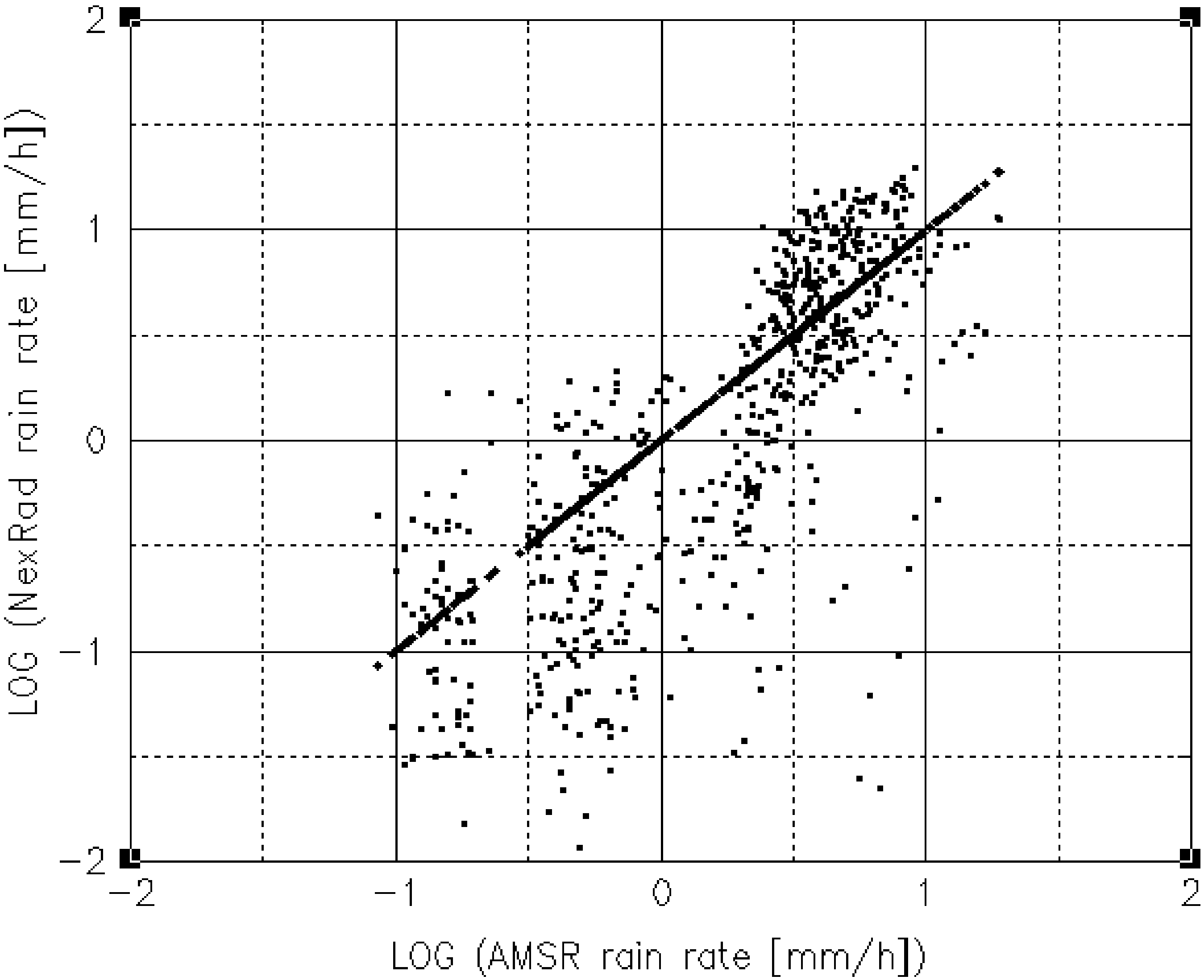


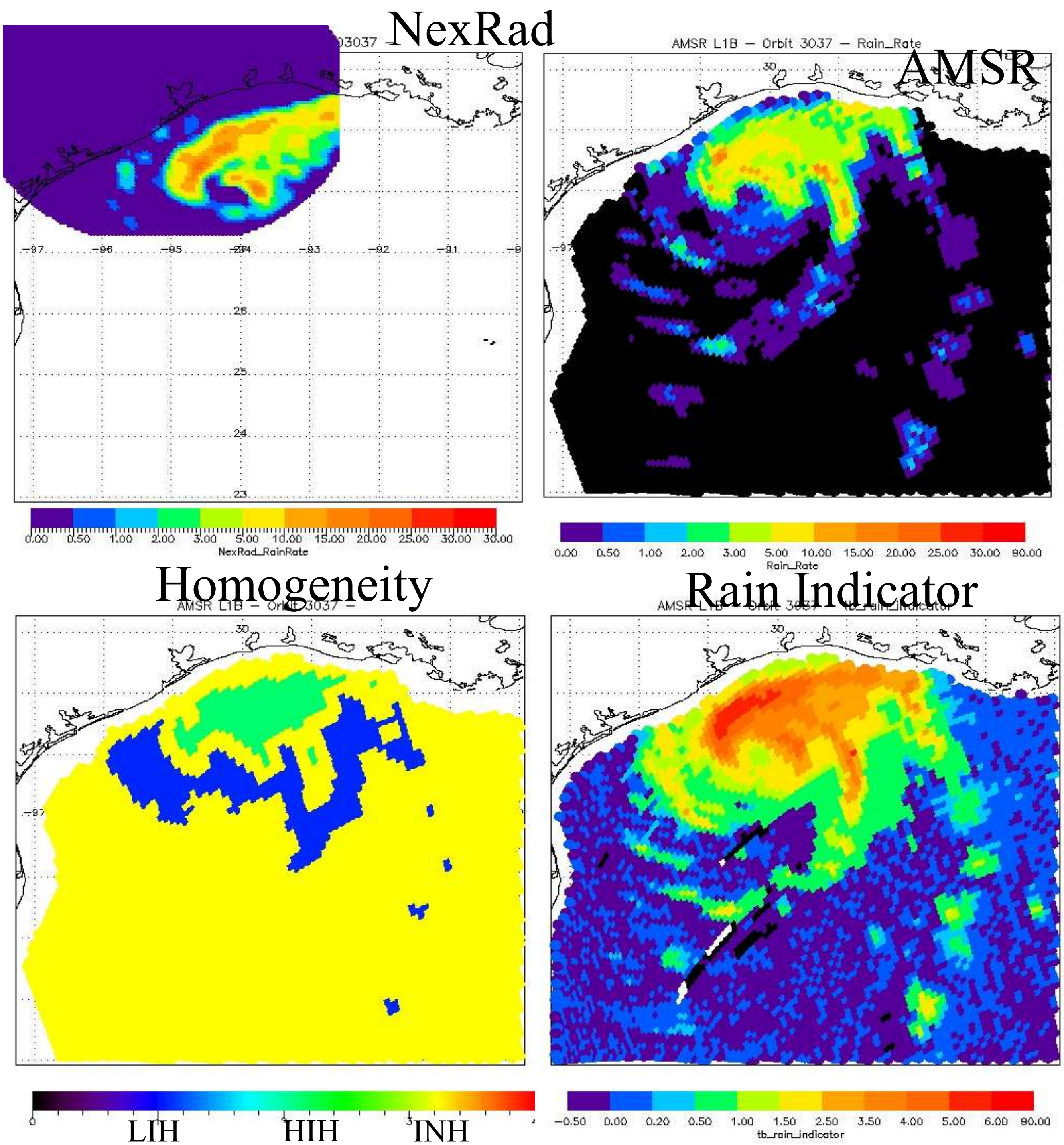
Case 3: Widespread Intense Precipitation

Hurricane Claudette: In this case the AMSR estimates appear to be closer but slightly lower than the NEXRAD estimates that used stratiform DSD parameters.

Note that NEXRAD collects precipitation measurements only within ~200 km range from the radar. This, in addition to heavy precipitation along the radar beam, are the likely reasons why NEXRAD does not see the multiple precipitation bands observed by AMSR .

Case 3- Widespread Intense Precipitation Claudette Rain Rate comparisons





Case 3:

Widespread Intense Precip.

Areas for improvement

Same conclusions as for Isabel:

- the AMSR Rain Indicator carries information that has not been used yet.
- devising more inhomogeneity classes should help AMSR retrievals come closer to that from NexRad

Hurricane Dennis, July 10, 2005 t=10:50 Z

Near Cedar Key, FL., NEXRAD is “KTLH”, Tallahassee

Dr. Steven Morey – COAPS performed the storm surge calculation

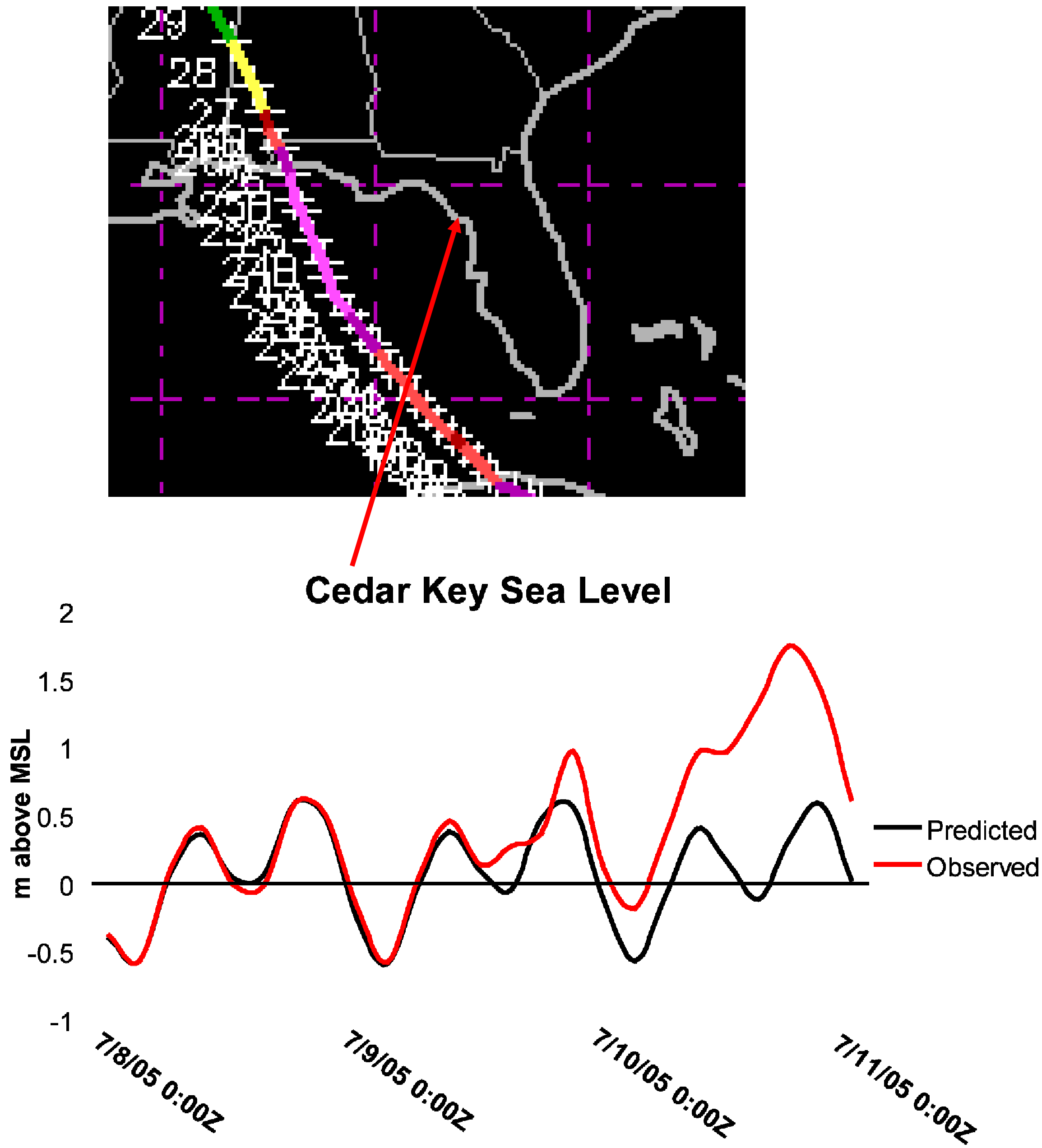
Dr. Mark Bourassa – Executed the corrected wind vector calculations

THE PROBLEM:

Well to the east of the storm track, Cedar Key experienced a storm tide of over 1.5m.

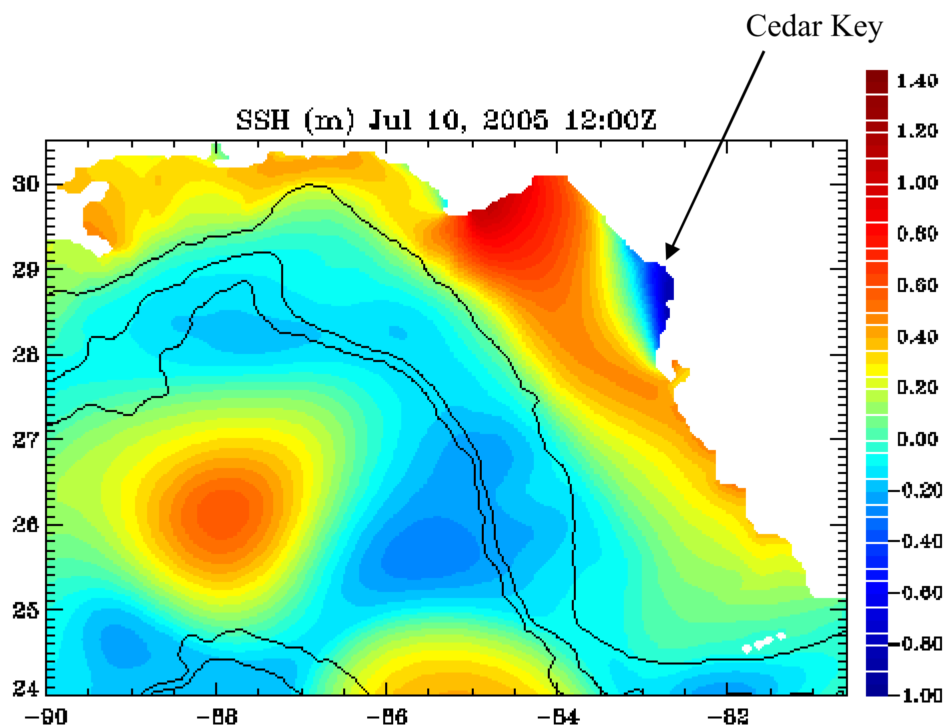
1m greater than predicted.

Why?



A numerical ocean model forced by gridded scatterometer fields (*Morey et al., 2005 JGR*) reproduced the storm surge across the northern Florida coastline, but there was an anomalous *low* sea level near Cedar Key.

Modeled storm surge was less than NOAA's underestimated prediction!

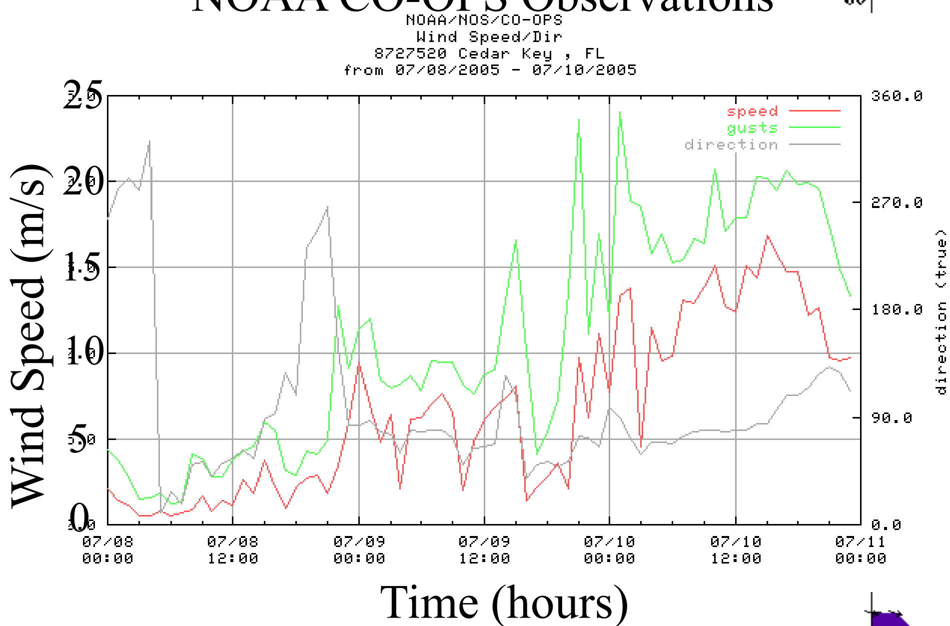


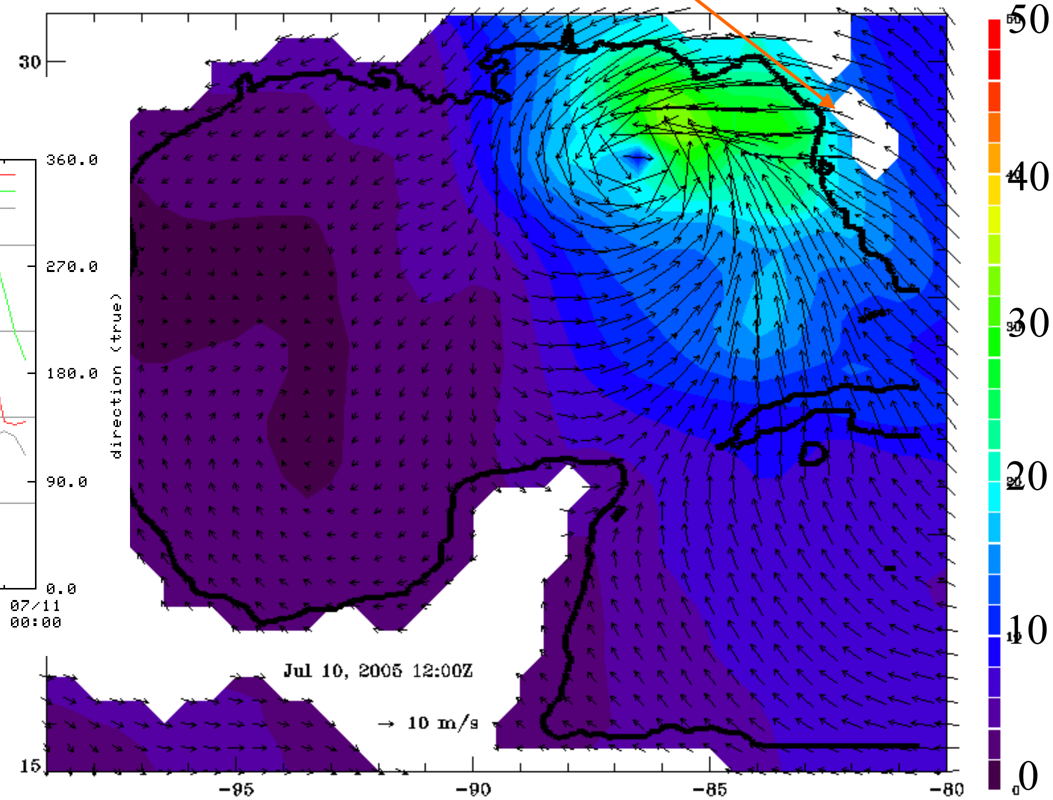
Analysis of the gridded wind field showed anomalously large offshore winds at Cedar Key due to erroneous scatterometer data. This offshore wind resulted in the local sea level low.

Gridded winds are east at 25-30 m/s, observed winds are roughly 15 m/s.

SeaWinds/NCEPR gridded winds

NOAA CO-OPS Observations



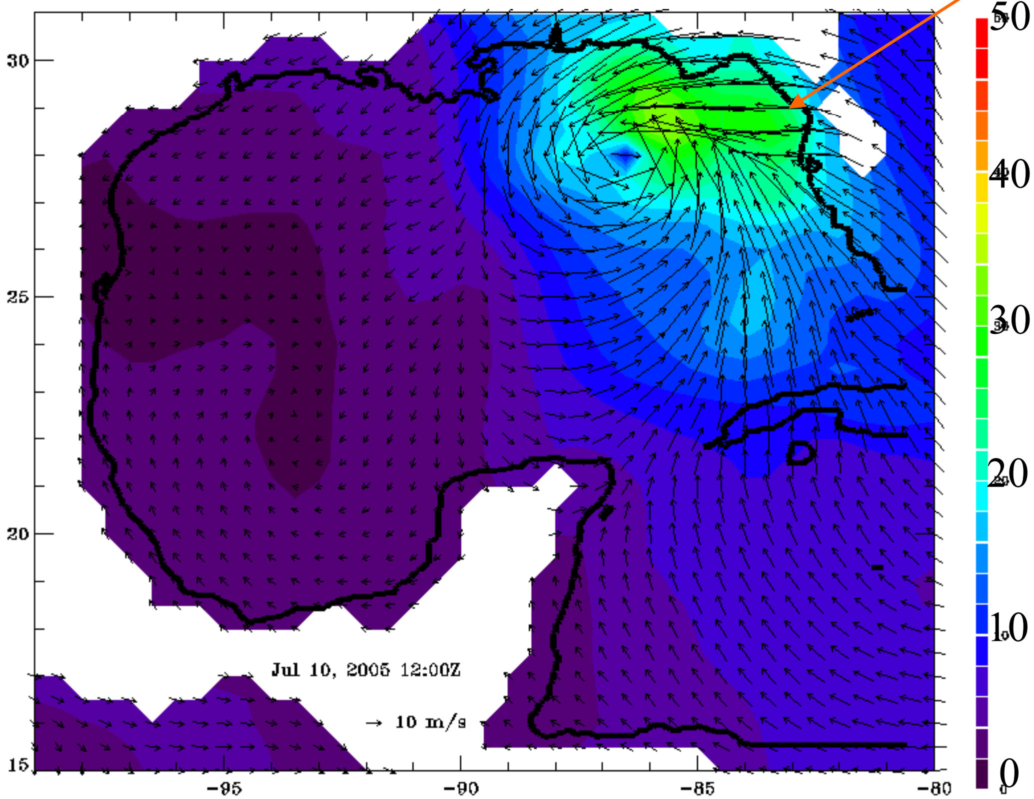


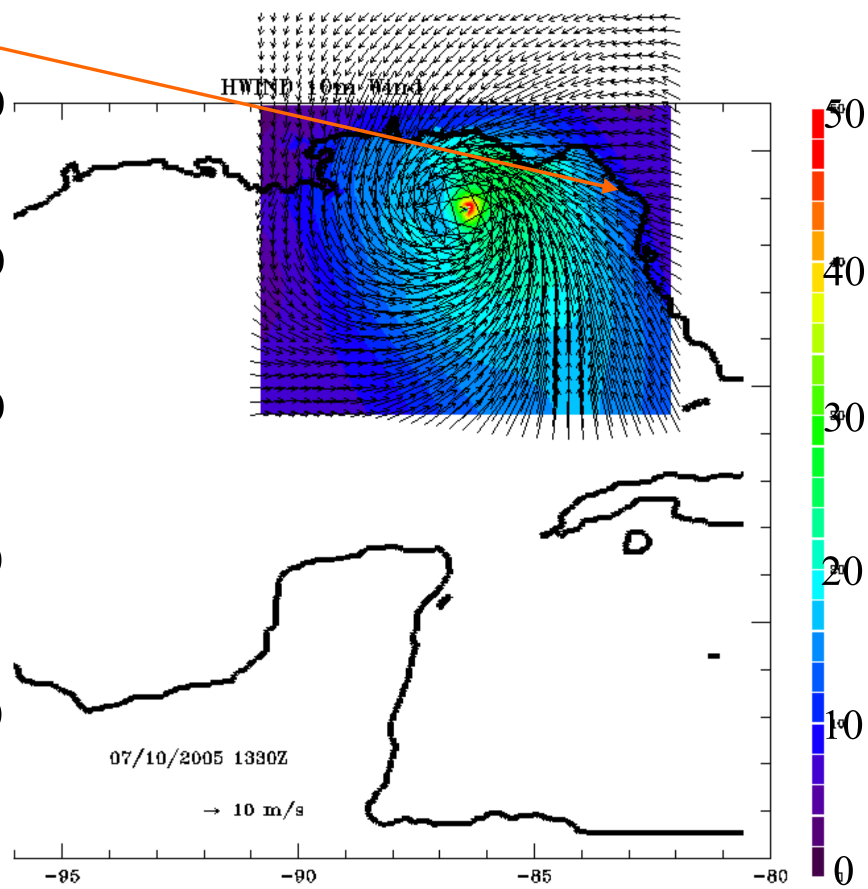
Speed is shown by red line.

NOAA HWIND analysis fields (From the National Hurricane Center) had more realistic wind speeds and directions over the Florida "Big Bend" waters than the gridded SeaWinds fields (NDBC offshore buoys used for comparison as well).

AOML HWIND Analysis

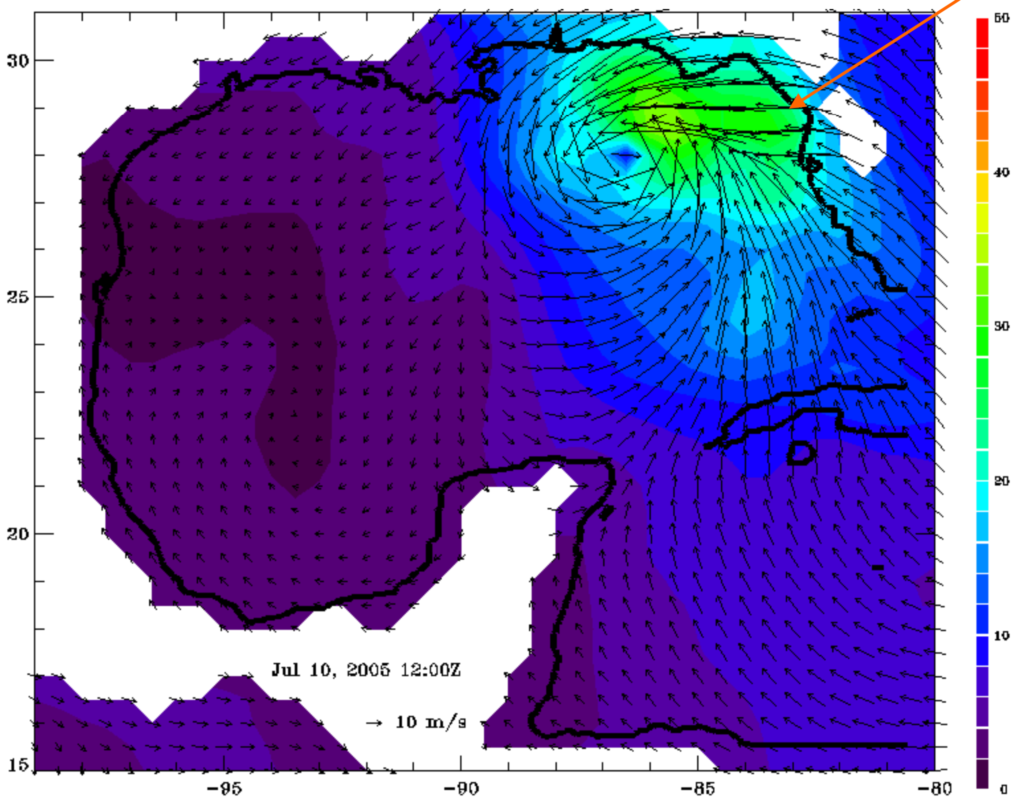
SeaWinds/NCEPR gridded winds



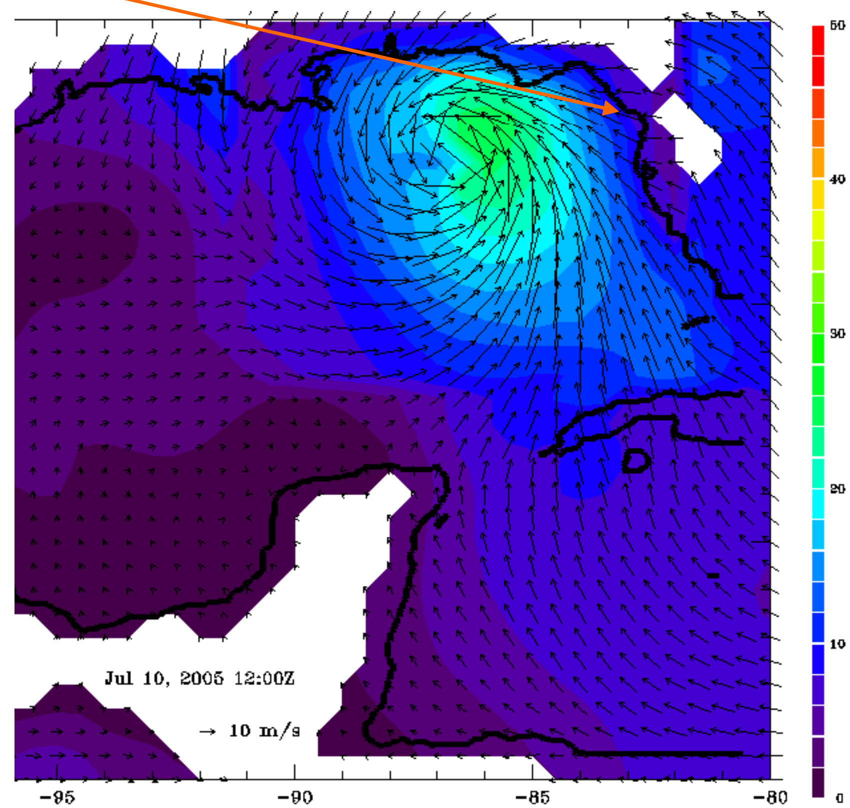


Adding HWIND data as “observations” with the SeaWinds data in the objective gridding technique seems to produce a more realistic “far field” for the storm (but with too-low wind speeds near the eye).

SeaWinds/NCEPR gridded winds



SeaWinds/HWIND/NCEPR gridded winds

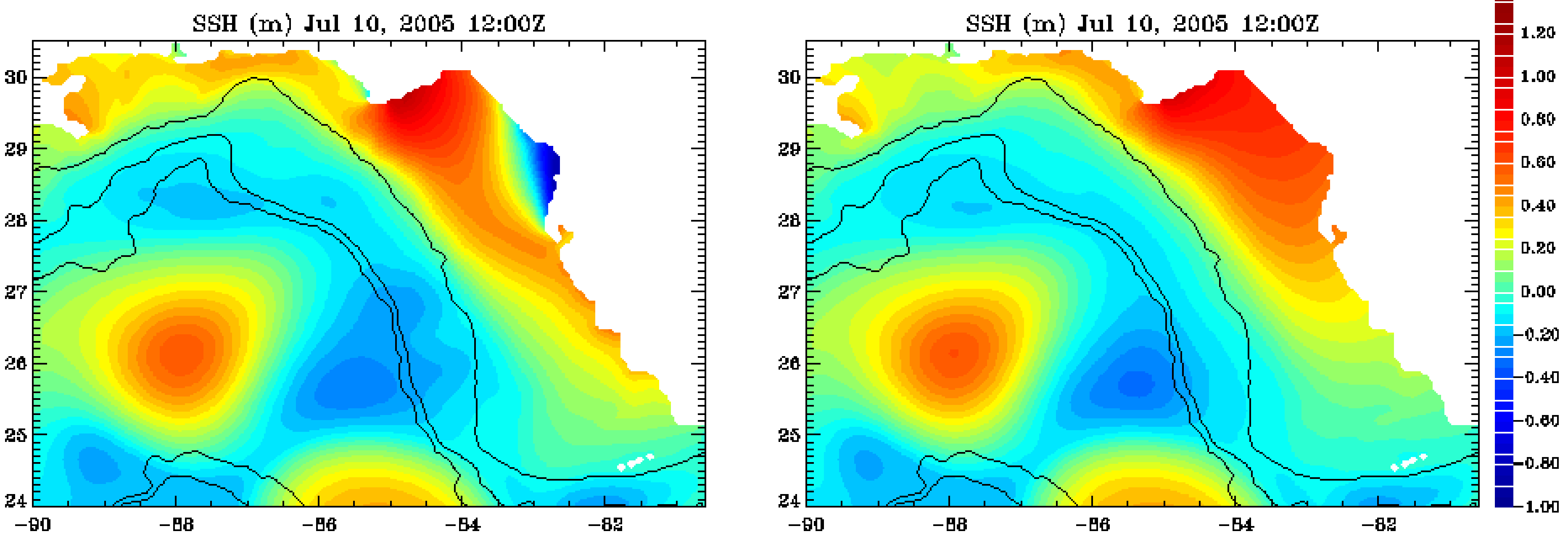


The HWIND corrected wind fields produce an ocean model solution that more closely matches observations, correcting a dramatic error in the simulated storm surge.

The goal is to investigate the cause for the erroneous scatterometer data and find physical methods of correcting the data.

SeaWinds/NCEPR gridded winds

SeaWinds/HWIND/NCEPR gridded winds



CORRECTING THE SCATTEROMETER RADAR DATA FOR RAIN EFFECTS

Objective:

1. a. Create corrected SIGMA0's (L2A values) over the rain affected area;

   b. Then use this modified data set, with JPL/COAPS wind retrieval algorithm to produce corrected wind vectors in the L2B data product

2. Learn what level of rain spatial resolution is sufficient to obtain satisfactory corrections (Can the AMSR corrections perform as well as those based on the NEXRAD rain data?)

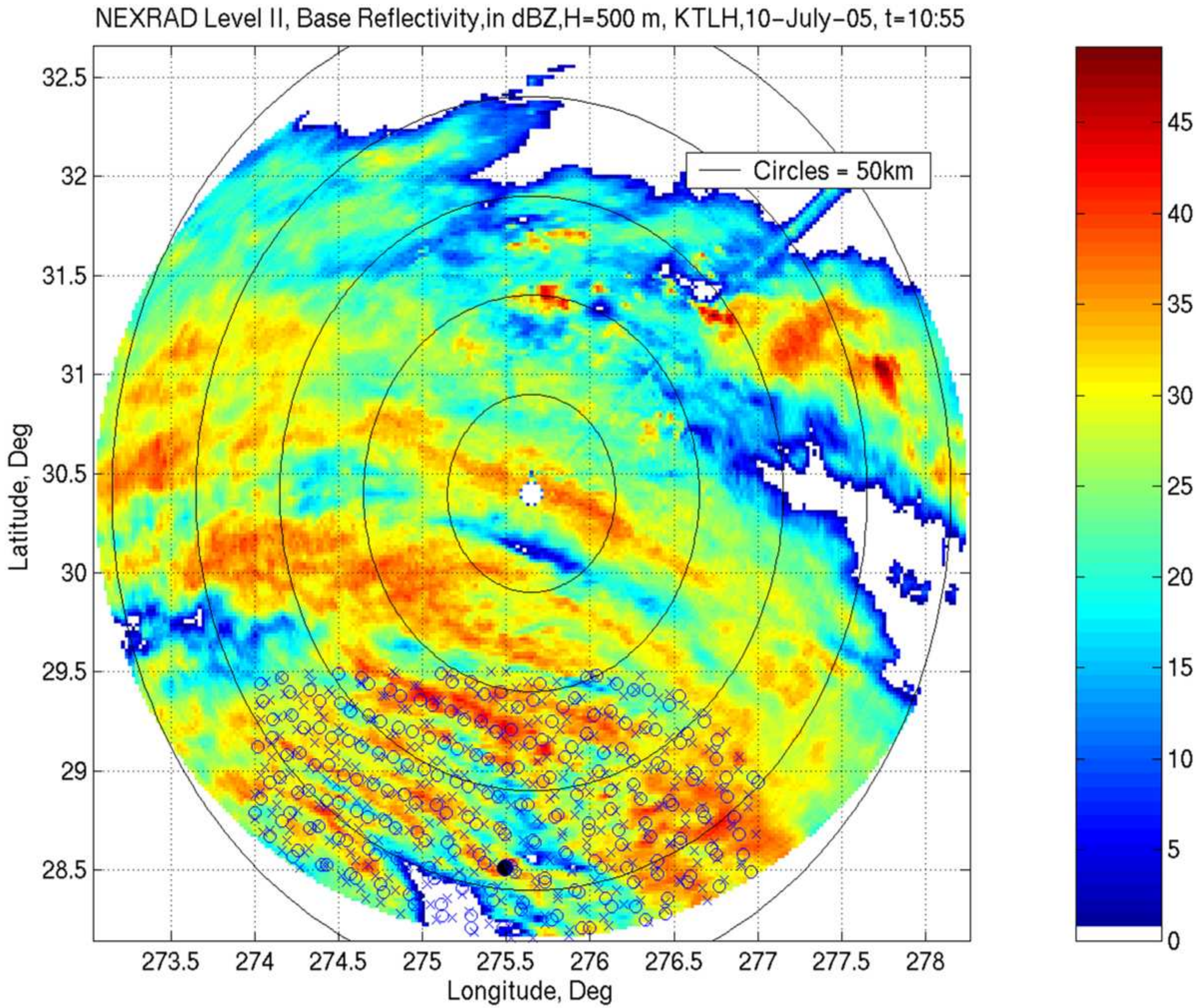
Approach: Use a physically based electromagnetic model which includes volumetric scattering, attenuation and surface splash, to correct each SIGMA0 measurement for the effects of rain volume backscatter and two-way attenuation

Technique:

1. Use coincident and collocated 3-D rain measurements that provide volumetric S-Band radar reflectivity, Z_s, from the NEXRAD

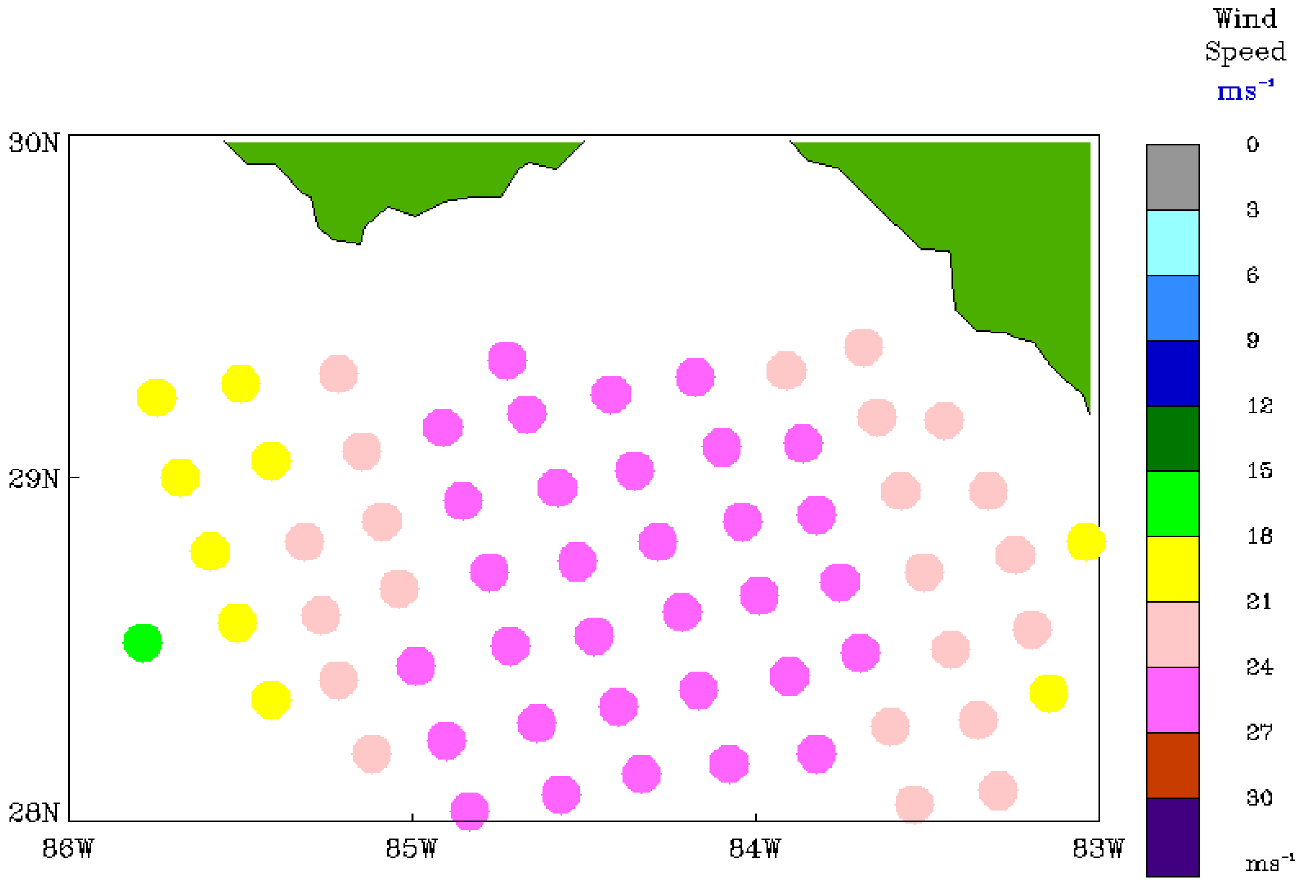
2. Use this "Z_s", (NEXRAD) to permit estimation of the K_u-band reflectivity and attenuation (2-km horizontal resolution)

3. Use an estimate for the effect of rain-impact splash on the surface NRCS based on the measurements of Contreras and Plant (2004)



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

10-July-05 Wind Magnitudes Estimated by NCEP / Model Winds provided by the L2B data product for Hurricane Dennis at t=11:00Z



Electromagnetic Model of the NRCS (σ_{ax}) Measured by SeaWinds Scatterometer

Use of "*x*" subscript below will represent either "h" or "v" polarization
σ_{ax} =Total measured NRCS at Receiver;Contributions from Surface and Rain Volume

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

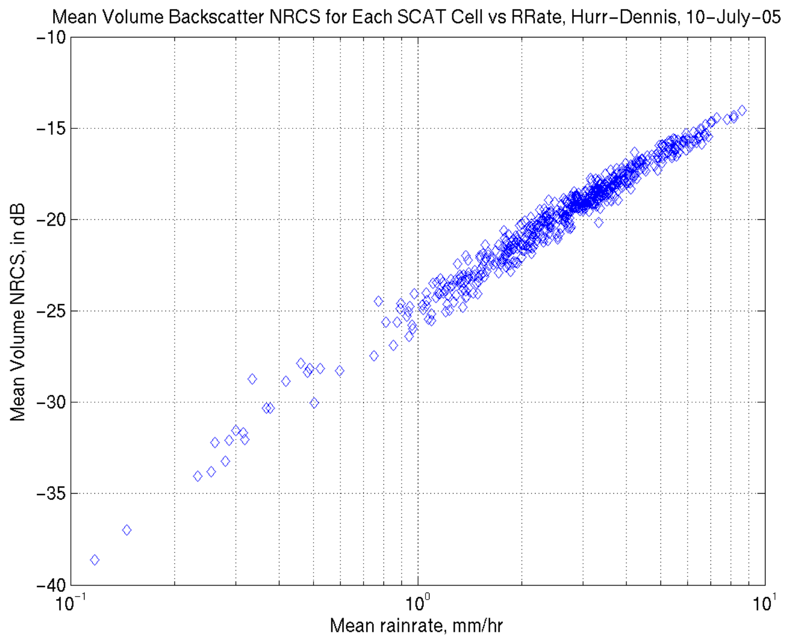
σ_{rnx} = sea surface NRCS due to rain impact roughness alone (rain-NRCS)
α_x(r)= attenuation, in nepers/m for each polarization, function of local volume rainrate or precipitation water content

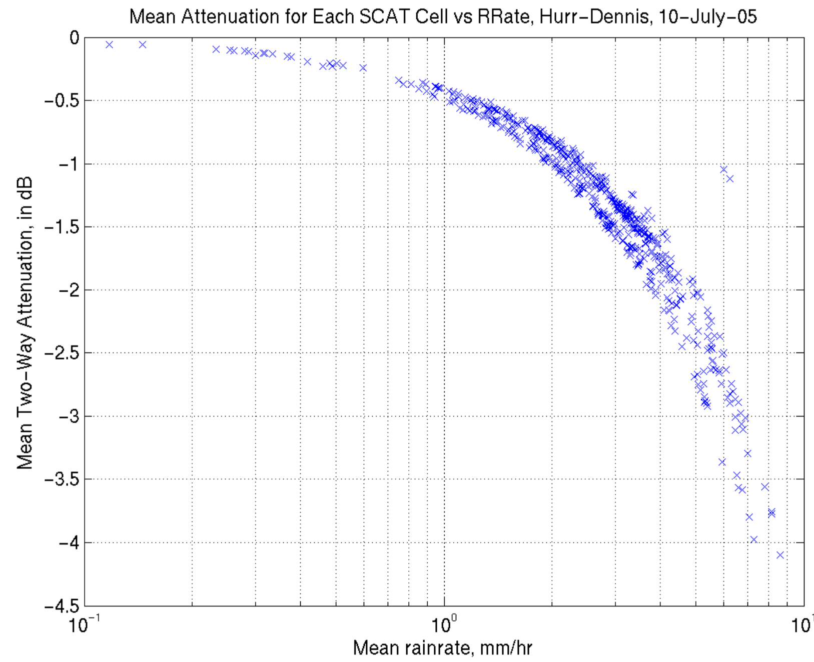
σ_{ox} (r)= surface equivalent of volumetric rain RCS, = constant * Zx (the radar reflectivity factor for Ku-band, Zx, varies with position, "r")

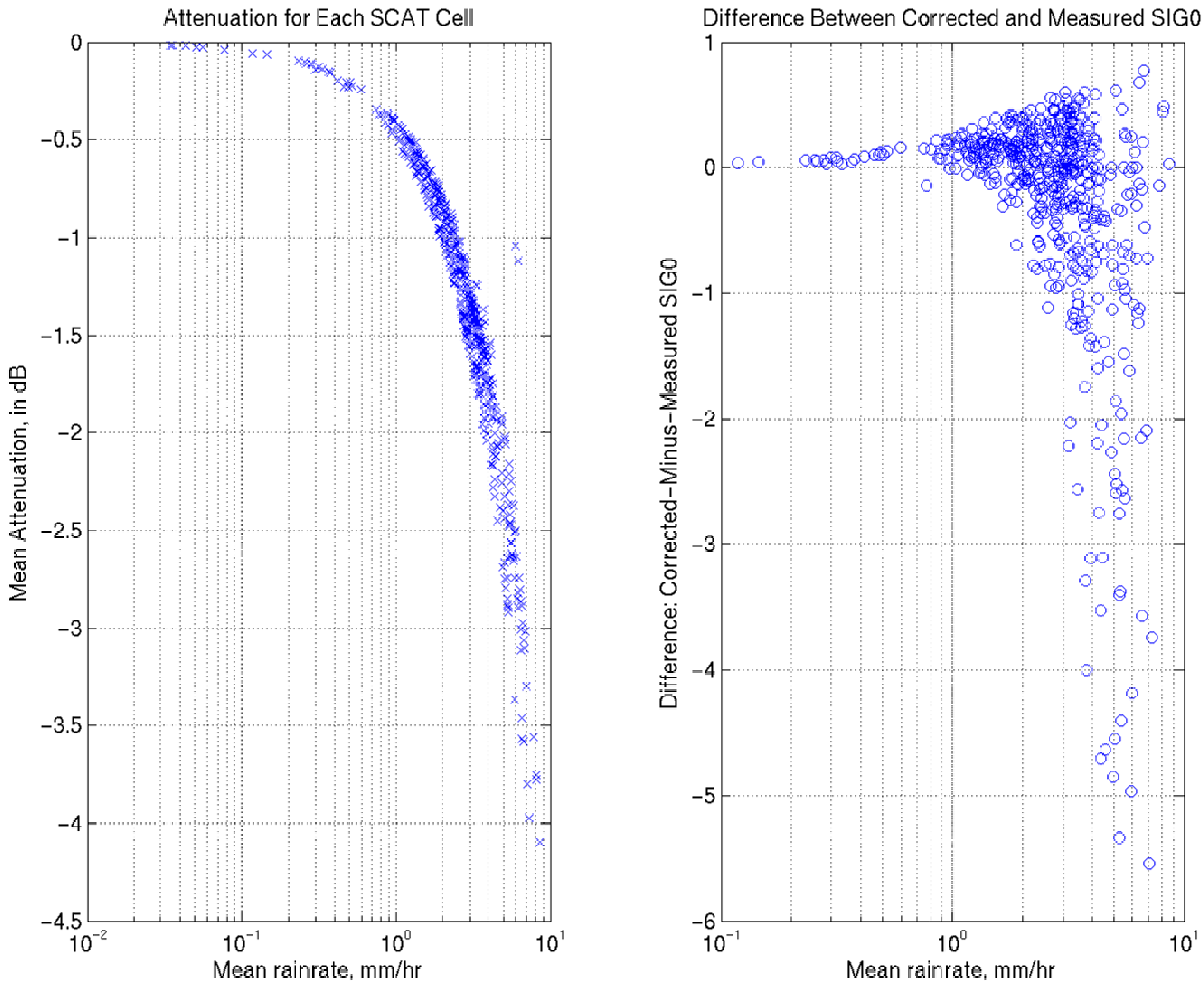
lenx=path length of radar beam for each polarization = len/Cos(θx)
(rain column height, over scatterometer footprint = len, θh=46^o & θv=54^o)

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

Dependence of the Volume NRCS and Attenuation Versus RainRate

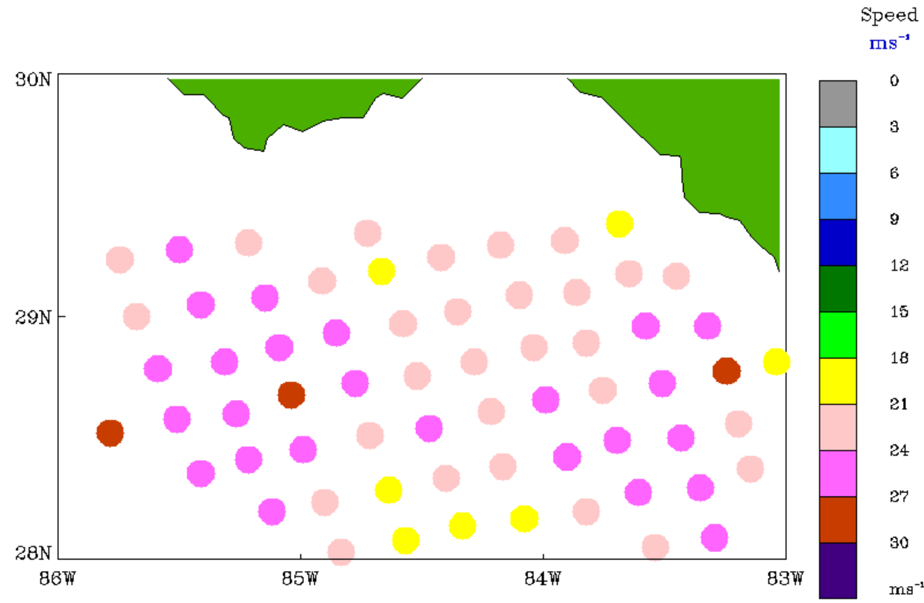




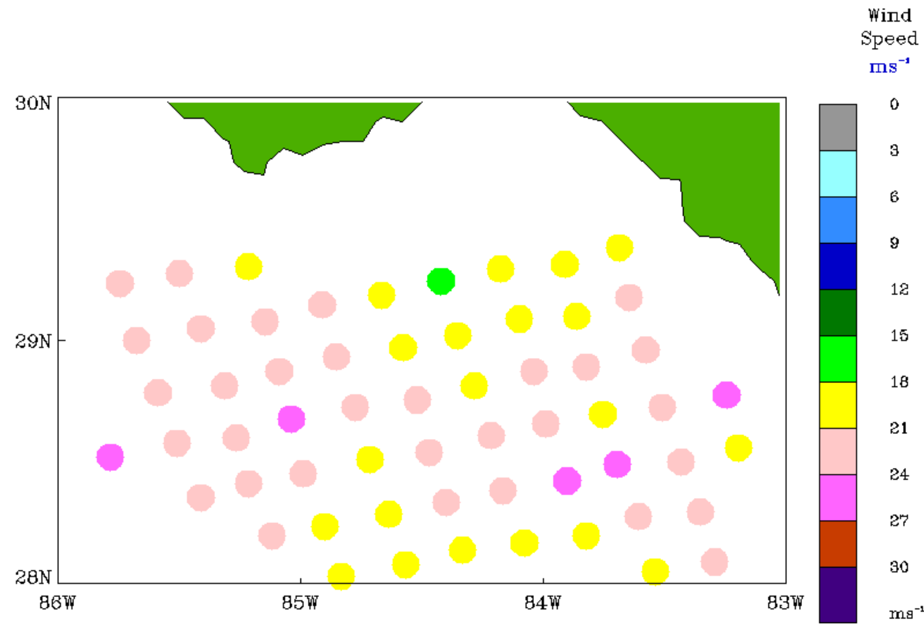


Attenuation for Each SCAT Cell
Mean Attenuation, in dB
Mean rainrate, mm/hr
0
−0.5
−1
−1.5
−2
−2.5
−3
−3.5
−4
−4.5
10^{-2}
10^{-1}
10^{0}
10^{1}
Difference Between Corrected and Measured SIG0
Difference: Corrected−Minus−Measured SIG0
Mean rainrate, mm/hr
1
0
−1
−2
−3
−4
−5
−6
10^{-1}
10^{0}
10^{1}

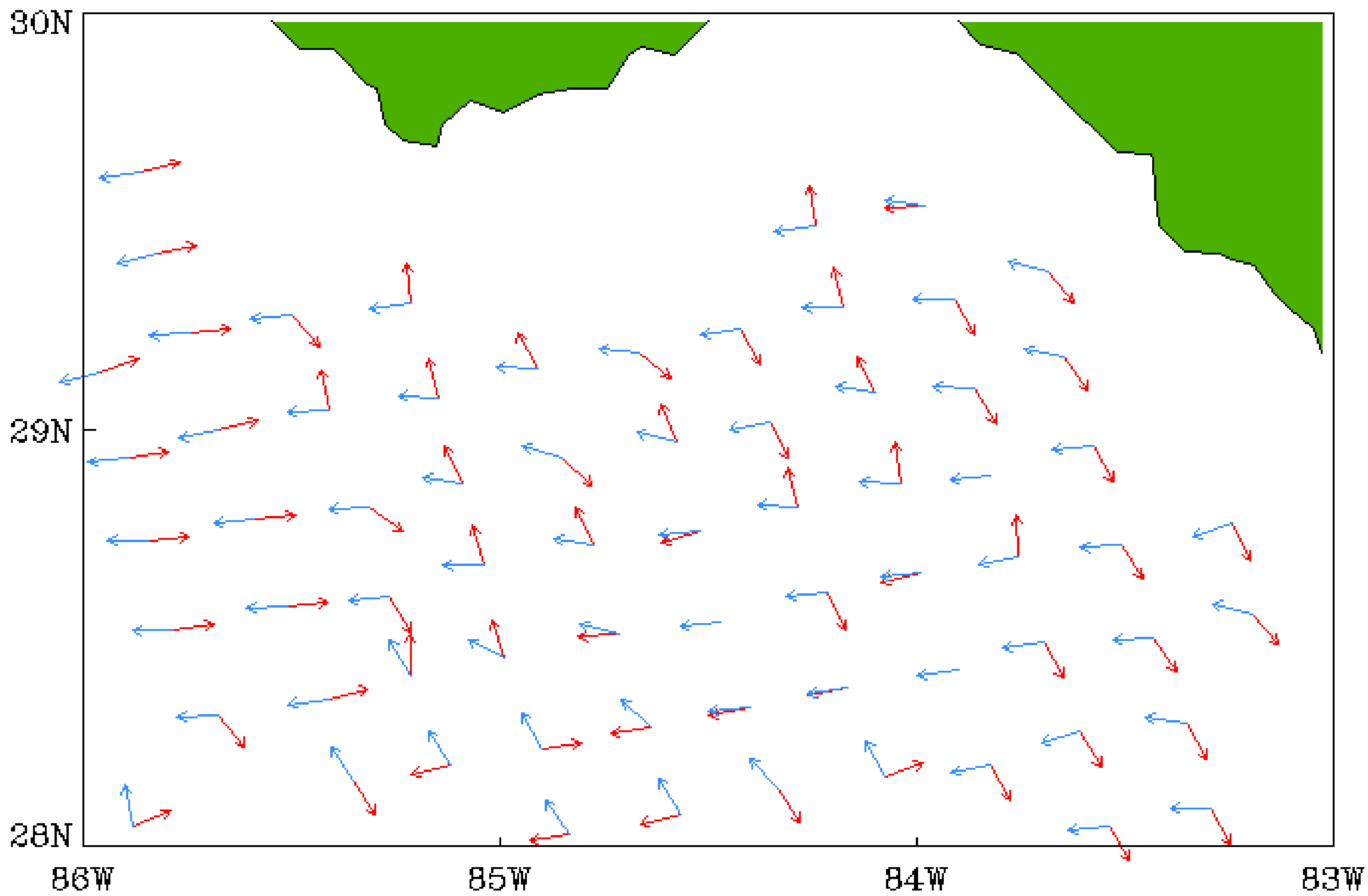
JPL-PODAAC L2B Product Wind Magnitude across area observed by NEXRAD during Hurricane Dennis (10-July-05, t=10:55)



Corrected Wind Magnitudes Using the Modified L2A SIGMA0 Values – Using volume backscatter and attenuation



Hurricane Dennis: Comparison between wind directions estimated from the SIGMA0's in the PODAAC L2A file (RED arrows) and directions computed from the Corrected SIGMA0's (BLUE Arrows) – Using COAPS Vector Wind Retrieval Algorithm



SUMMARY

GOAL 1:

The high resolution (~1 km) S-band reflectivity is used to model the volume reflectivity and attenuation for each L2A SCAT cell. NEXRAD estimate rain corrections are made to the measured scatterometer σ_o

2. The volume backscatter and the two way attenuation produce opposing effects on the total received power. The attenuation reduces the NRCS from the surface, while the volume NRCS is additive and increases the received signal. In the case of Hurricane Dennis, both effects are clearly seen in the variety of rain conditions.

3. The Wind Retrieval algorithm recalculates the wind magnitudes and direction at the same locations as the L2B winds.

The corrections are appreciable, and produce improved wind and direction estimates. These are supported by an in-situ buoy observation.

GOAL 2:

- AMSR and NEXRAD compare quite well when AMSR retrievals are done with INH and LIH classes

- when HIH is used the comparison is not so good

- this is encouraging because the statistics show that overall HIH class is used very infrequently
  > INH ~ 58% of cases
  > LIH ~ 40% of cases
  > HIH ~ 2% of cases

- the specially designed AMSR *Rain Indicator* appears to be very capable of capturing the structures observed by NEXRAD. It carries information that has not been used yet
- improved AMSR retrievals can be achieved by further break down of the HIH classes

FUTURE WORK:

- Evaluate AMSR performance in many more cases to cover a wide variety of precipitation conditions including mid-latitude frontal systems

- Improve and evaluate the new AMSR retrievals that use more homogeneity classes

- Address issues about DSD assumptions, radar calibration, and representative scale for the spatial scale

- Develop more wind-corrected cases for AMSR and NEXRAD