ESTIMATION AND CORRECTION OF WET ICE ATTENUATION FOR X-BAND RADAR

Proposal Presentation

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PRESENTATION OUTLINE

- INTRODUCTION AND MOTIVATION
  - Research Objectives
- BACKGROUND THEORY
- METHODOLOGY
  - Data Sources
- PRELIMINARY RESULTS
- FUTURE WORK PLAN

INTRODUCTION

- **X-band** Radars in the past
  - Early 50's
  - Early 70's dual-wavelength (S/X) for hail detection
    - National Hail Research Experiment – NE Colorado (CP-2 and CHILL)
- **Large Attenuation**
  - S-band/C-band
  - Recent dual-polarization development

Motivation: CASA Radar Network

- NSF-ERC – Collaborative Adaptive Sensing of the Atmosphere (CASA) Radar Network in Oklahoma (2003) at X-band
  - Low cost, adapts real time with changing weather
  - Sense areas NOT observed by NEXRAD network
- May 2006 Integrative Project 1 (IP1) Southwest, OK
  - RSP, CYR, LWE, SAO
- Oklahoma environment:
  - 10 days of hail a year
  - Supercell activity

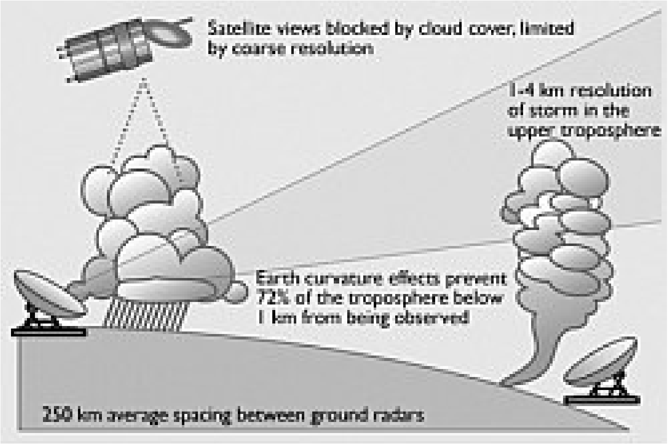
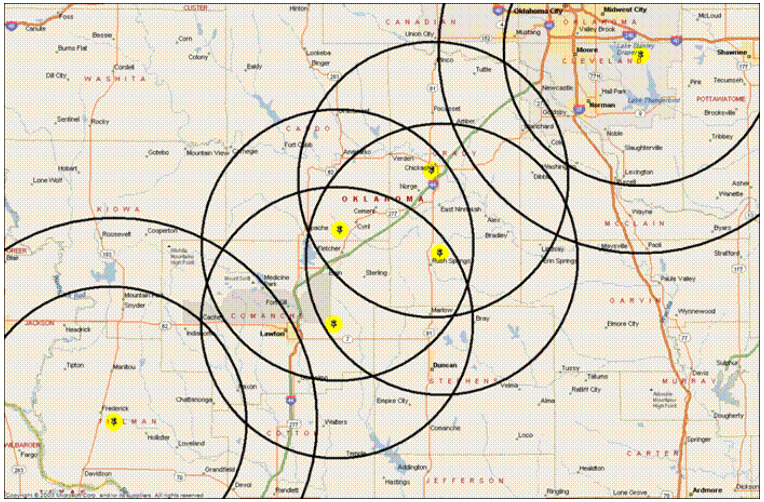


Figure 1. Limitations of Existing Observation System



Attenuation Correction…

- Real-time Attenuation Correction
  - Dual-polarized techniques (Φ_{DP} based)
- Wet ice attenuation
  - Φ_{DP} based methods does not help
  - High Reflectivities (Z)
  - Has been observed
    - Theoretically: Battan 1971 – Mie theory (S, C and X-band)
    - Skipped (i.e. Tuttle and Rinehart 1983)
    - Flagged (i.e. Tabary et al 2008)
- EXPLORE WET-ICE ATTENUATION CORRECTION
  - Quantify wet ice attenuation – convective storms
  - *k*-*Z* relationships

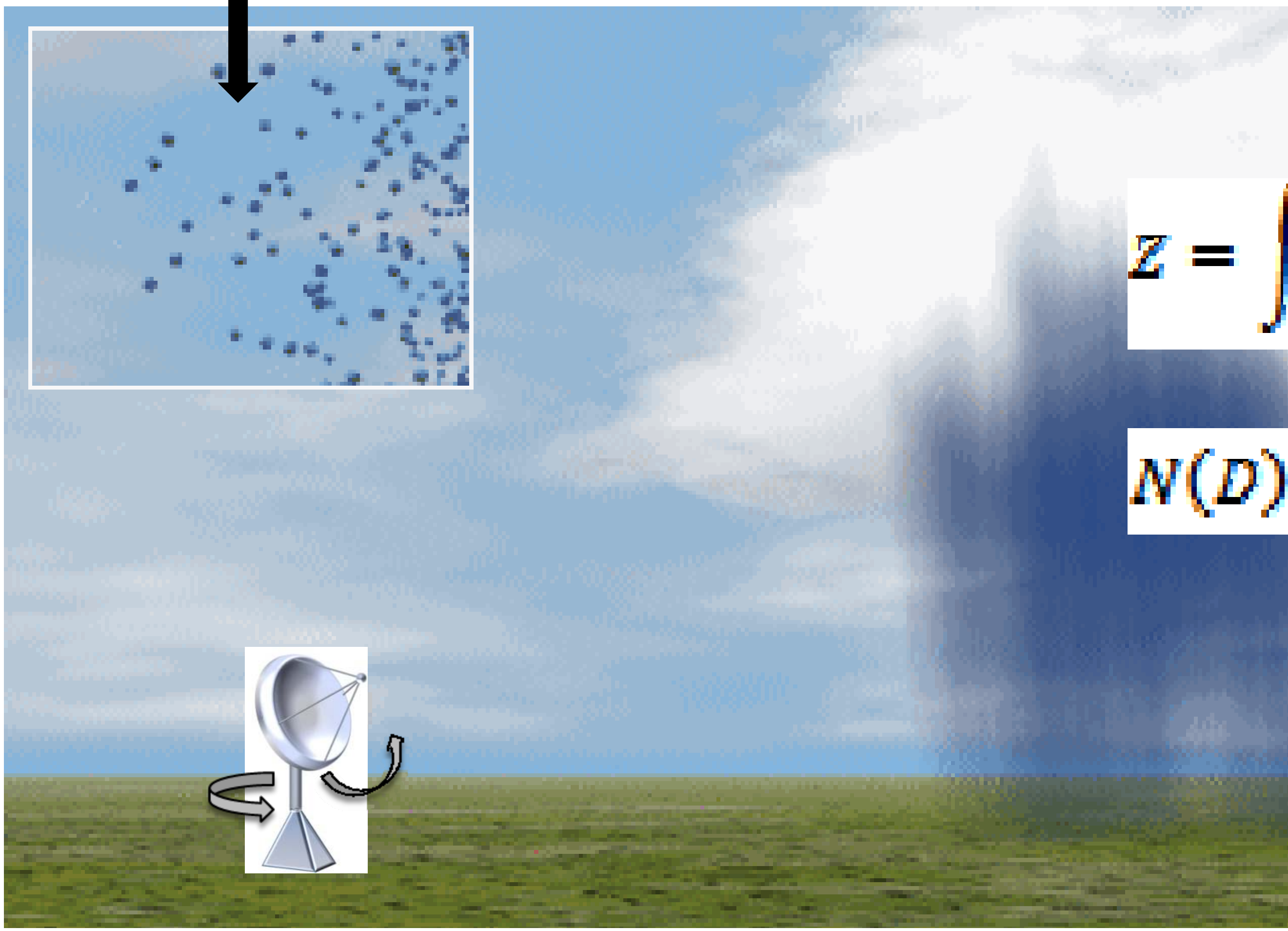
Research Objectives

- **Wet Ice Attenuation Correction**
  - Can the wet ice attenuation component be corrected for using the SRT-like technique?
- **Wet Ice Specific Attenuation Estimation**
  - Can the wet ice attenuation component be estimated separate from the rain attenuation component?
- **Wet Ice Attenuation Estimation with no reference**
  - Can the wet ice attenuation be estimated without using the un-attenuated reference signal?

BACKGROUND THEORY

- Radar Theory Review
- Radar Signal Interaction with Particles
- Radar Signal Attenuation and Correction Methods

$$Z = CP_r r^2 \qquad C = \left(\pi^3 P_t G^2 \theta \phi c t |K^2| / 1024 \ln(2) \lambda^2\right)^{-1}$$



$$Z = \int N(D) D^6 dD$$

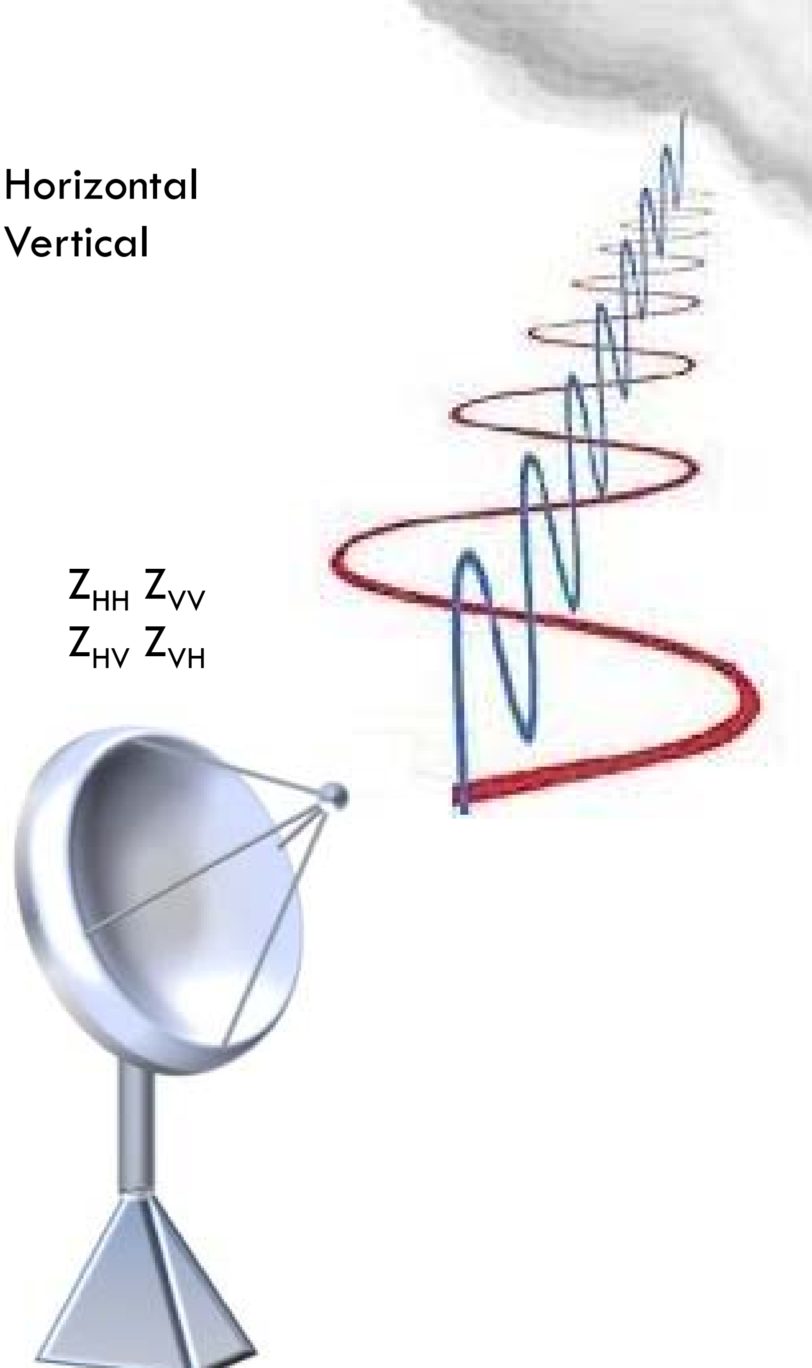
$$N(D) = N_o e^{4.1 R^{-0.21} D}$$

N_o=8,000

Marshall-Palmer

Horizontal
Vertical

Z_{HH} Z_{VV}
Z_{HV} Z_{VH}



Hail Signal (HS)

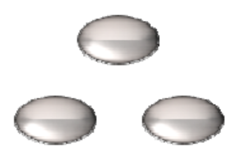
$HS = Z_h(S) - Z_h(X)$

Doppler
Dual Polarized
Tx and Rx
H vs. V

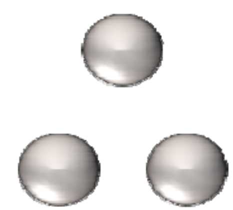
$$\Phi_{DP} = \Phi_{HH} - \Phi_{vv}$$

$$K_{DP} = \frac{\Phi_{DP}(r_2) - \Phi_{DP}(r_1)}{2(r_2 - r_1)}$$

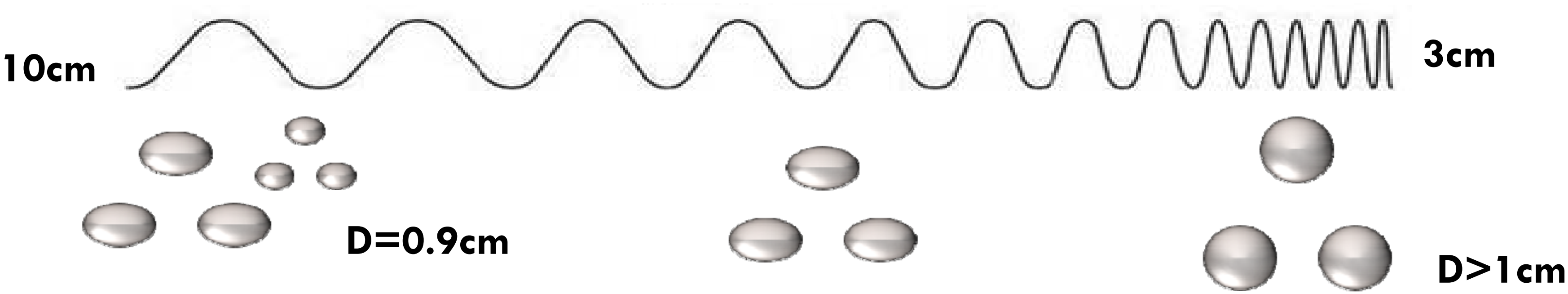
RAIN



Wet Ice



$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{64\pi^3 r^4}$$



Rayleigh

$$\sigma = \frac{\pi^5 |K|^2 D^6}{\lambda^4}$$

$$\sigma = \pi r^2$$

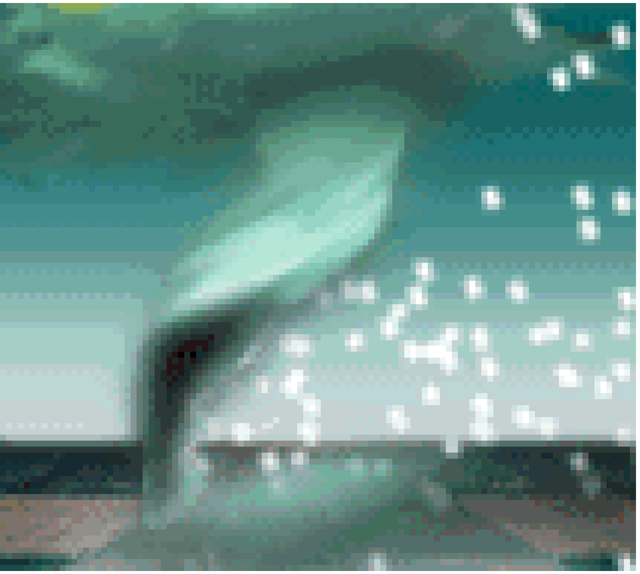
Mie

Hail Signal (HS)

$HS = Z_h(S) - Z_h(X)$

HS > 3dB
HS=20dB
HS<0

Radar Signal Interaction with Particles



Mixed rain and wet ice

Convective Storms

Battan 1971

Two-way attenuation [dB/km]

S-band	C-band	X-band	Water Shell Thickness (cm)
0.38	2.24	6.92	0.01
1.2	5.64	8.06	0.05
2.36	5.2	7.58	0.1

8.06 dB/km

Attenuation Correction

- Gases
- Cloud particles
- Precipitating Particles

$$Z_m(r) = Z_c(r)e^{-0.2\ln(10)\int_0^r k(s)dS}$$

$$PIA = \int_0^r k(s)dS$$

$$Z_c(r) = \frac{Z_m(r)}{\left[C - 0.2\beta\ln(10)\int_0^r \alpha(s)Z_m^{\beta}(s)dS\right]^{1/\beta}}$$

Hitchfeld-Bordan (HB)

SRT - TRMM

C: calibration constant

Assuming $Z_m(r=0)=Z_c(r=0)$ then C=1

σ_o -Clear Air

-Rainy Area

PIA

METHODOLOGY

- Simple Attenuation Correction → **RAIN**

$$Z_h^{attenuated} = Z_h^{unattenuated} - 2\int_0^r A_h(s)dS$$

$$Z_h^{attenuated} = Z_h^{unattenuated} - \alpha[\Phi_{DP}(r) - \Phi_{DP}(0)]$$

α=0.25 dB/°

HB-SRT Hybrid

- 1994
- Compares PIA_{SRT} and PIA_{HB}

$$Z_c(r) = \frac{Z_m(r)}{\left[C - 0.2\beta\ln(10)\int_0^r \alpha(s) Z_m^{\beta}(s)\,dS\right]^{1/\beta}}$$

Chosen and ADJUSTED → **α-adjustment method**

Proposed Algorithm…

- Wet Ice Attenuation Correction: SRT-like Modified Method

$$Z_h^{corrected} = \frac{Z_m(r)}{\left[1 - 0.2\ln(10)\,\varepsilon\beta\int_0^{r_s}\alpha(s)Z_m^{\beta}dS\right]^{\frac{1}{\beta}}}$$

$\Delta Z = Z_h(S) - Z_h(X)$

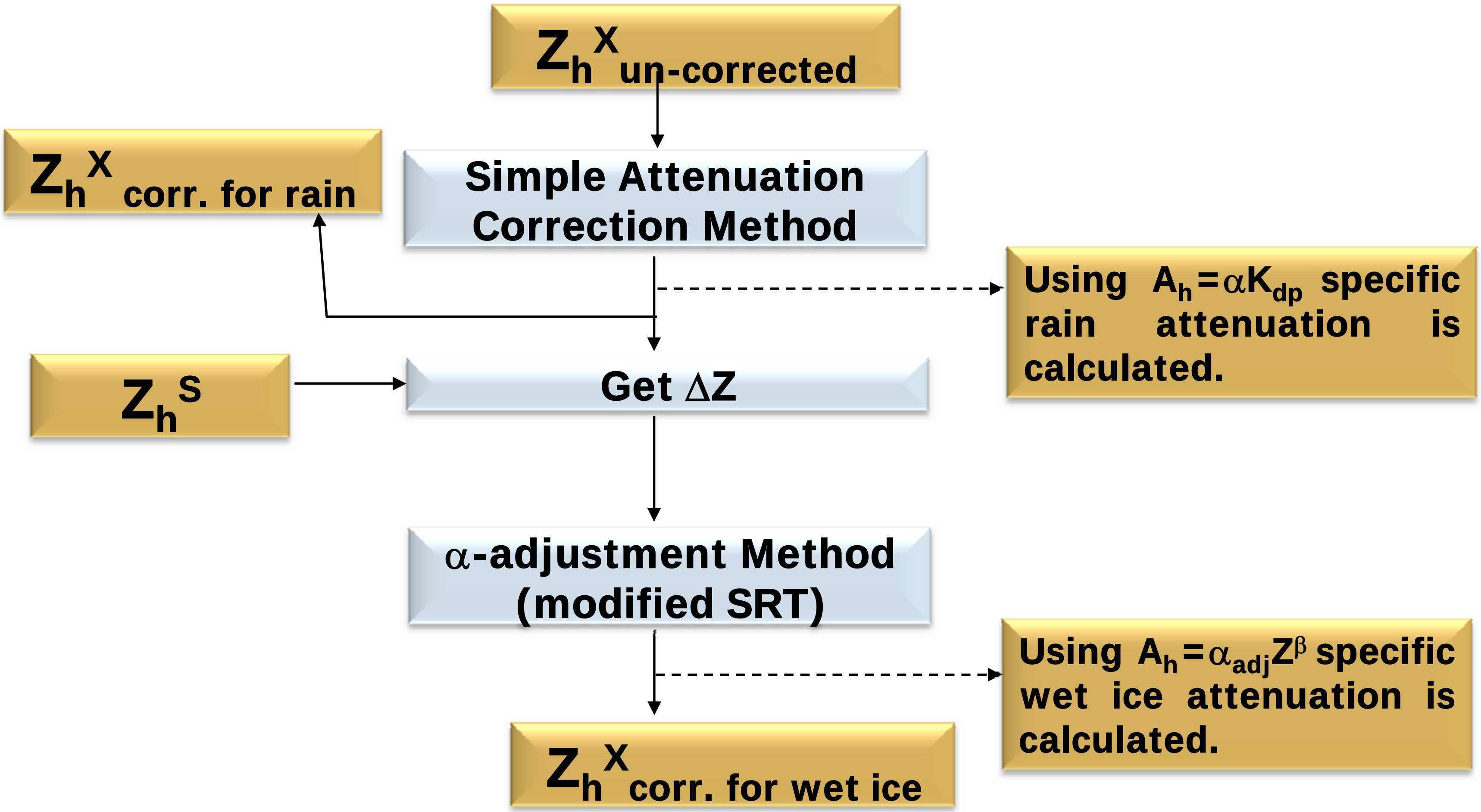
SRT – TRMM

σ_o

$$\varepsilon = \frac{1 - 10^{\beta\Delta Z/10}}{0.2\ln(10)\beta\int_0^{r_s}\alpha(s)Z_m^{\beta}dS}$$

$\alpha_{adj} = \alpha\,\varepsilon$

Flow Diagram…



Assumptions:

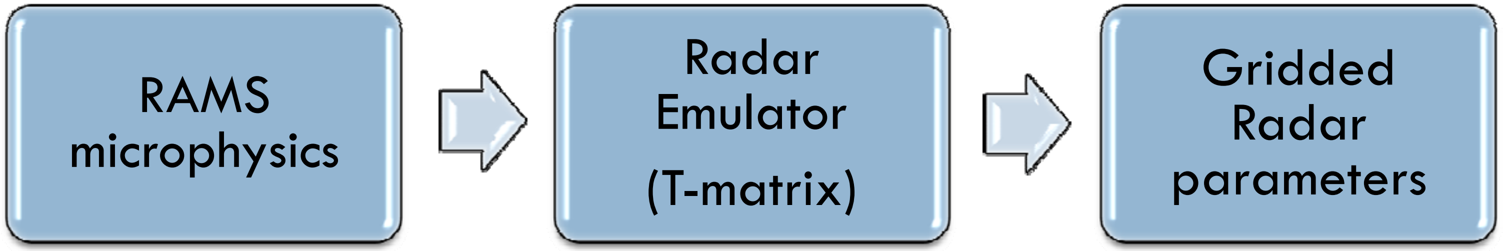
- While correcting the X-band reflectivity Z_h^X we assume that we have available Z_h^S at the end of the beam.
- In the simple attenuation correction method we are assuming α=0.25 dB/° for rain
- In the α-adjustment method we are assuming a fixed β=0.6 and an initial α=0.00045 dB/°

Data Sources

- RAMS
  - 2-moment scheme Supercell simulation
- IHOP
  - June 16th, 2002
- CASA
  - CASA/KTLX: June 20th, 2007, Stratiform Case
  - CASA/KOUN: June 10th, 2007, Convective Case
- CP-2
  - March 26th, 2008
  - October 21st, 2008

CSU-RAMS Model Supercell

- 2-moment microphysical parameterization
- Predicts number of concentration N_t and mixing ratios r
- Temperature provided for each grid point



Regional Atmospheric Modeling System (RAMS)

Assumptions…

Rain Case

- N_o fixed to 8,000 M-P relationship
- Oblate with B-C shape model
- Canting angle Gaussian with σ=5°

Hail/Graupel

- Oblate shape
- Axis ratio of 0.8 with random orientation
- Dry or Wet? – Liquid Fraction RAMS

X-band: Z_h K_{DP} A_h $A_{h\ rain}$ $A_{h\ dry\text{-}ice}$ $A_{h\ \text{wet-ice}}$ $A_{h\ \text{graupel}}$
S-band: Z_h

→

PPI & RHI Scans Assuming Radars in Same Place

IHOP: International H2O Project

2002 Campaign: June 16th ; Western Oklahoma

- NCAR's SPOL
  - Dual Polarized, Z_h
- NOA's XPOL (transportable)
  - Dual Polarized

•Rain Attenuation was corrected

NOA: National Observatory of Athens NCAR: National Center of Atmospheric Research

CASA

Stratiform Case

- KTLX- Single Polarized
- Rush Springs Data (RSP)
- June 20th, 2007

Convective Case

- KOUN – Dual Polarized
- Cyril Data (CYR)
- June 10th, 2007

•Latitude / Longitude / Height
•Average around gate
•Rain Corrected data was used
•SNR of 5dB filter was used

CP-2

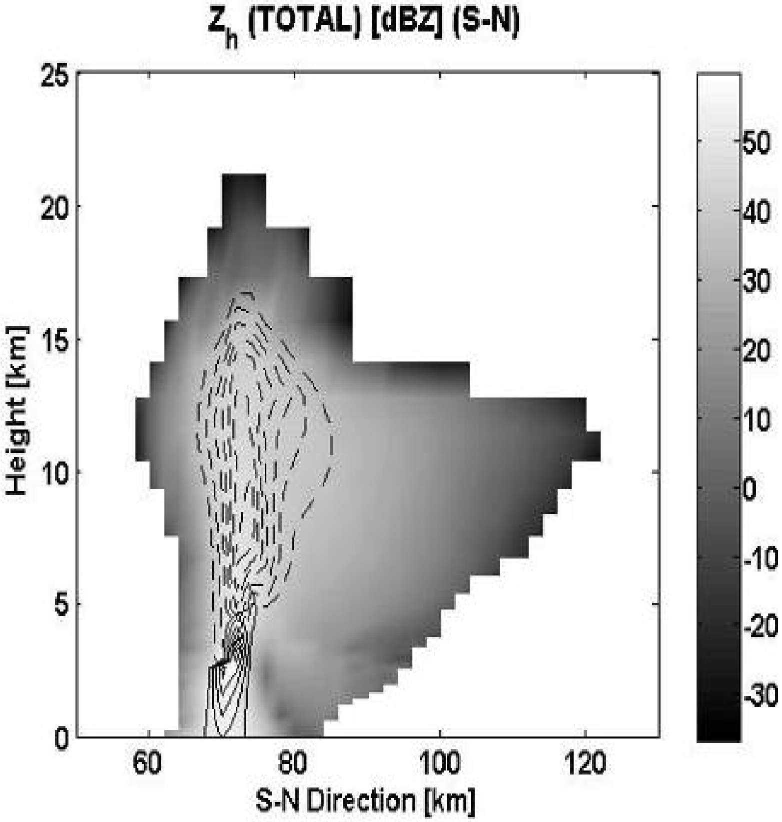
- Located at Brisbane, Australia
- X-band Doppler
- S-band Doppler/dual-polarized capability
- Thunderstorm Season
- PPIs 2008: March 26th (at 3.77°), October 21st (at 2.4°)

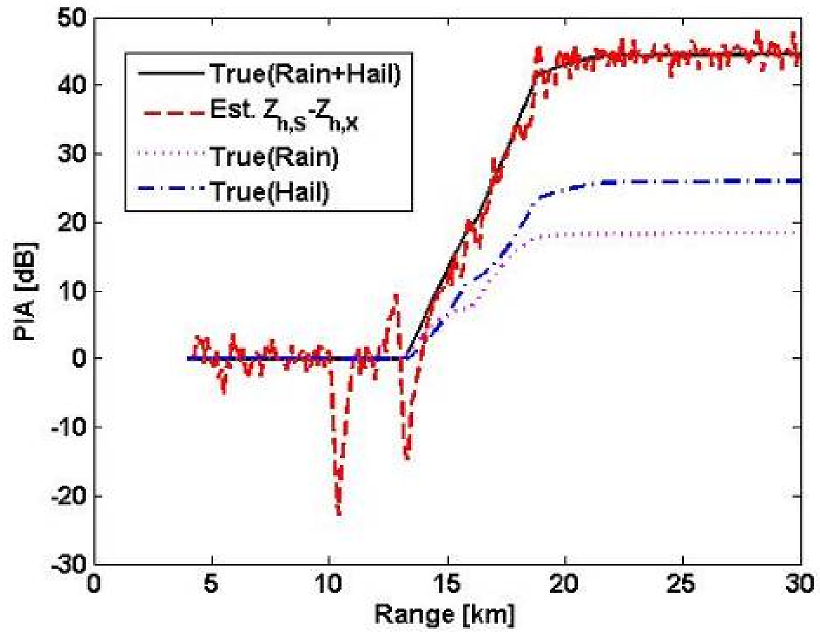
•**Rain Attenuation was corrected using:**

K_{DP} (S-band)

Preliminary Results

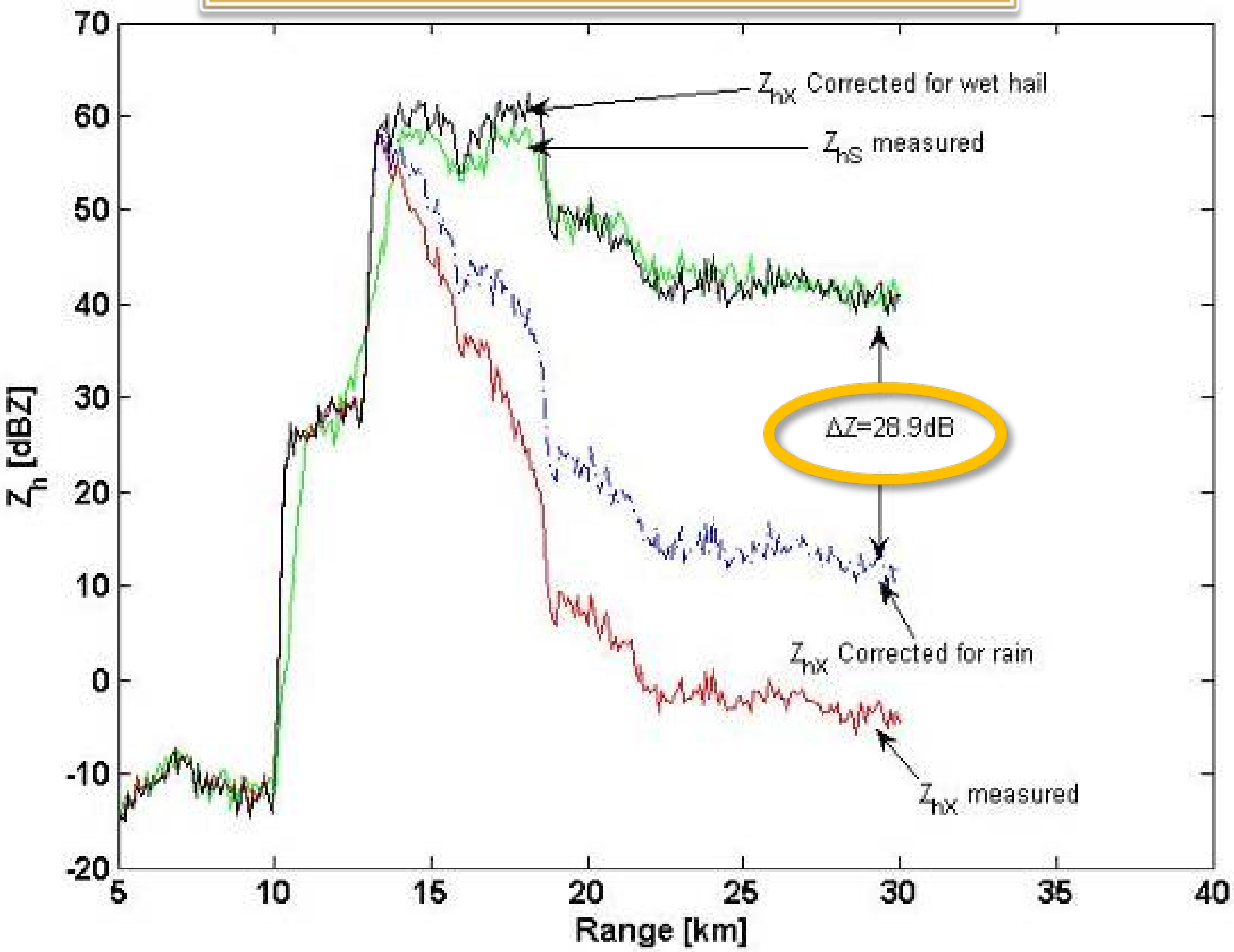
RAMS





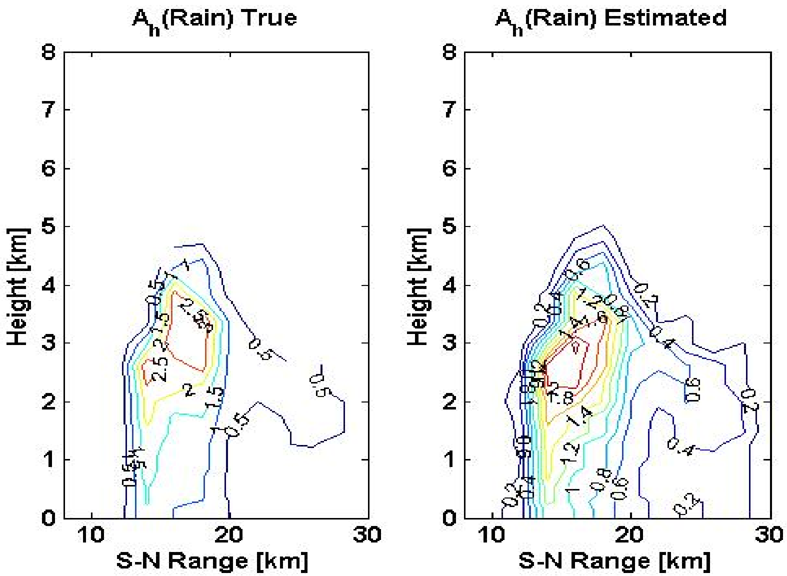
Z(X)(measured)=Z(X)(true)-PIA(total)

Ray at 12.6° in elevation



Preliminary Results: RAMS

RAIN

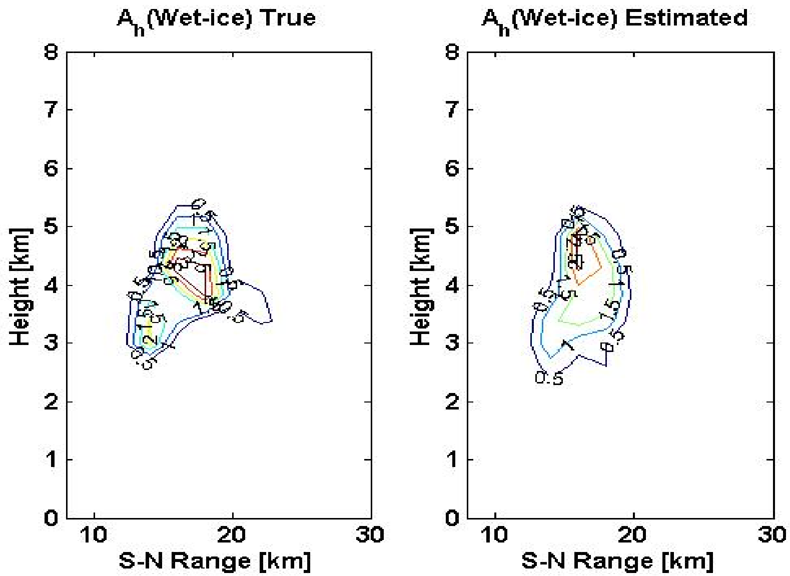


0.5 dB/km step   0.2 dB/km step

Both Max=2.5 dB/km

RMS Error
0.39 dB/km

WET ICE

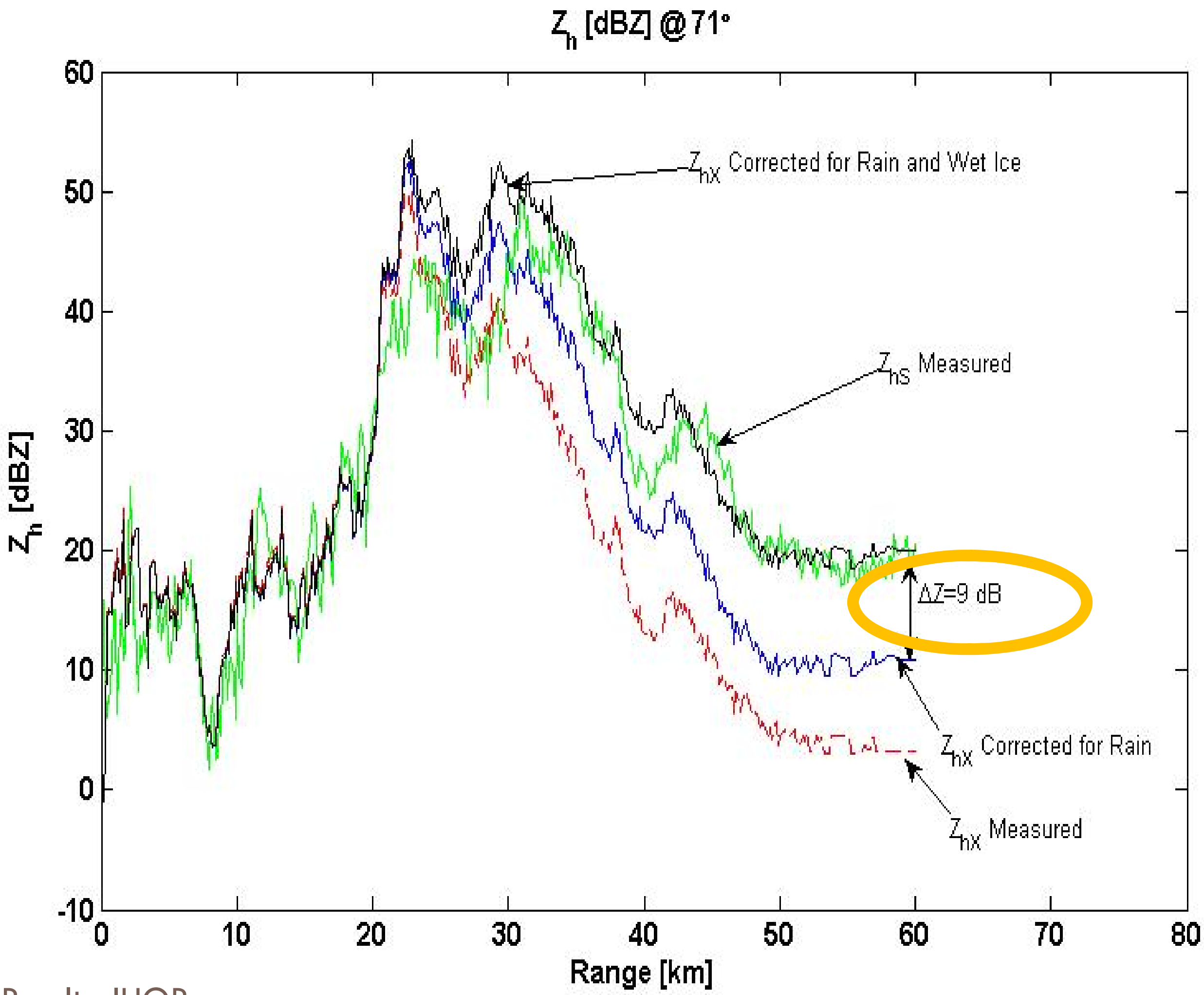


0.5 dB/km step   0.5 dB/km step

Both Max=2.5 dB/km

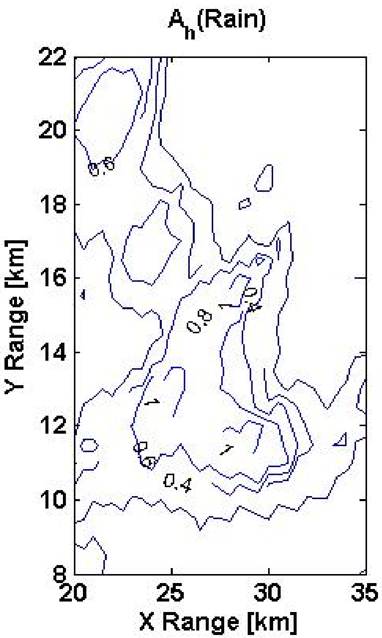
RMS Error
0.2 dB/km

IHOP: June 16th, 2000

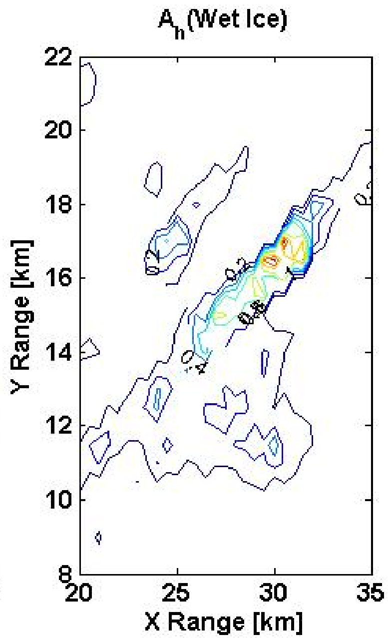


Preliminary Results: IHOP

RAIN

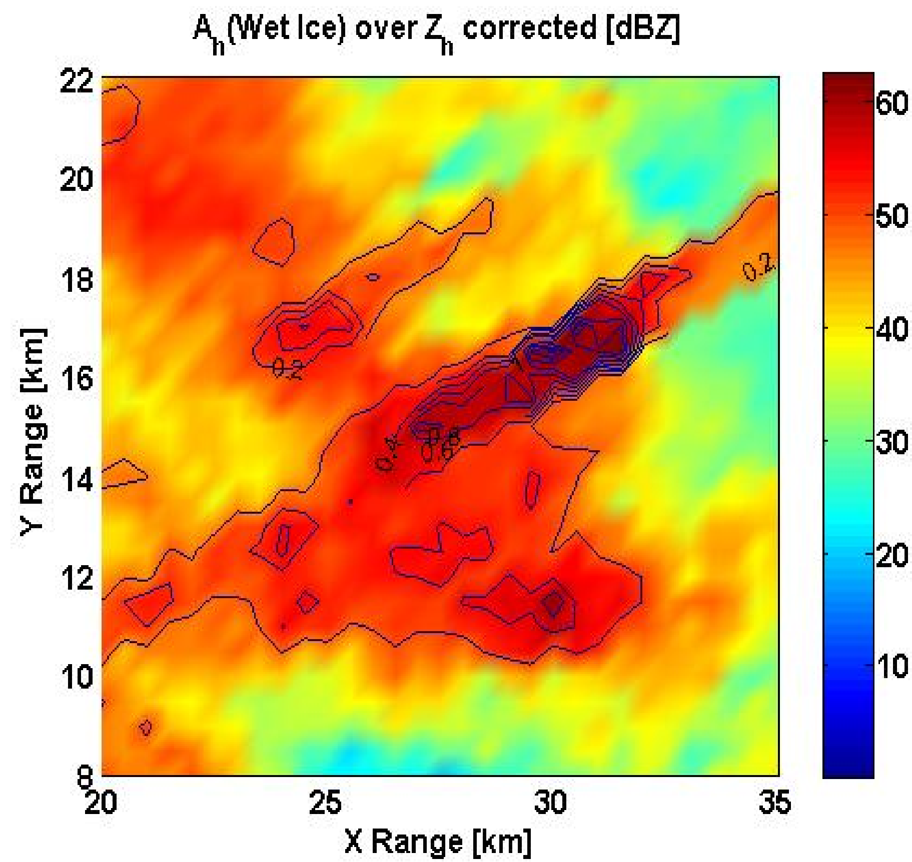


WET ICE



Max = 1 dB/km Max = 1.5 dB/km

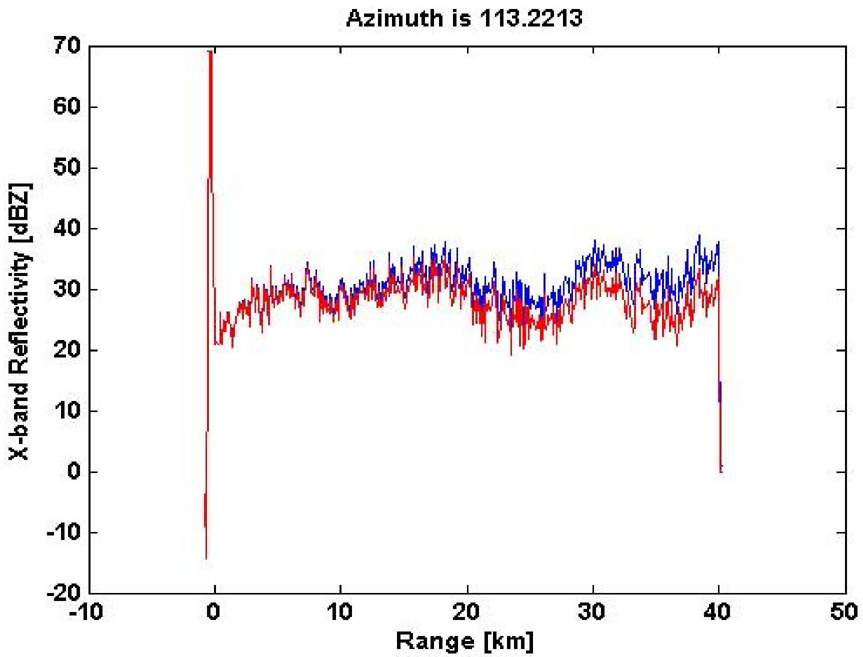
Both Step=0.2 dB/km

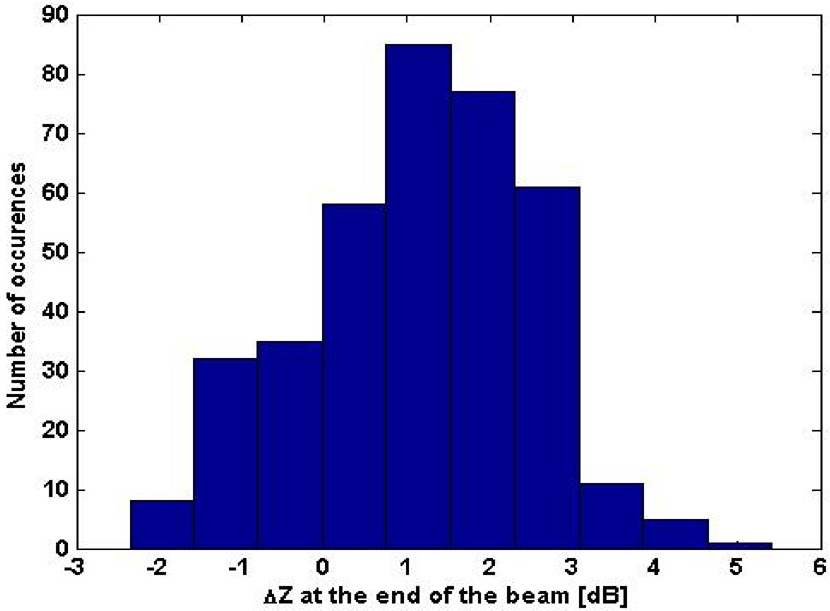


Preliminary Results: IHOP

CASA/TLX: June 20th, 2007

STRATIFORM CASE

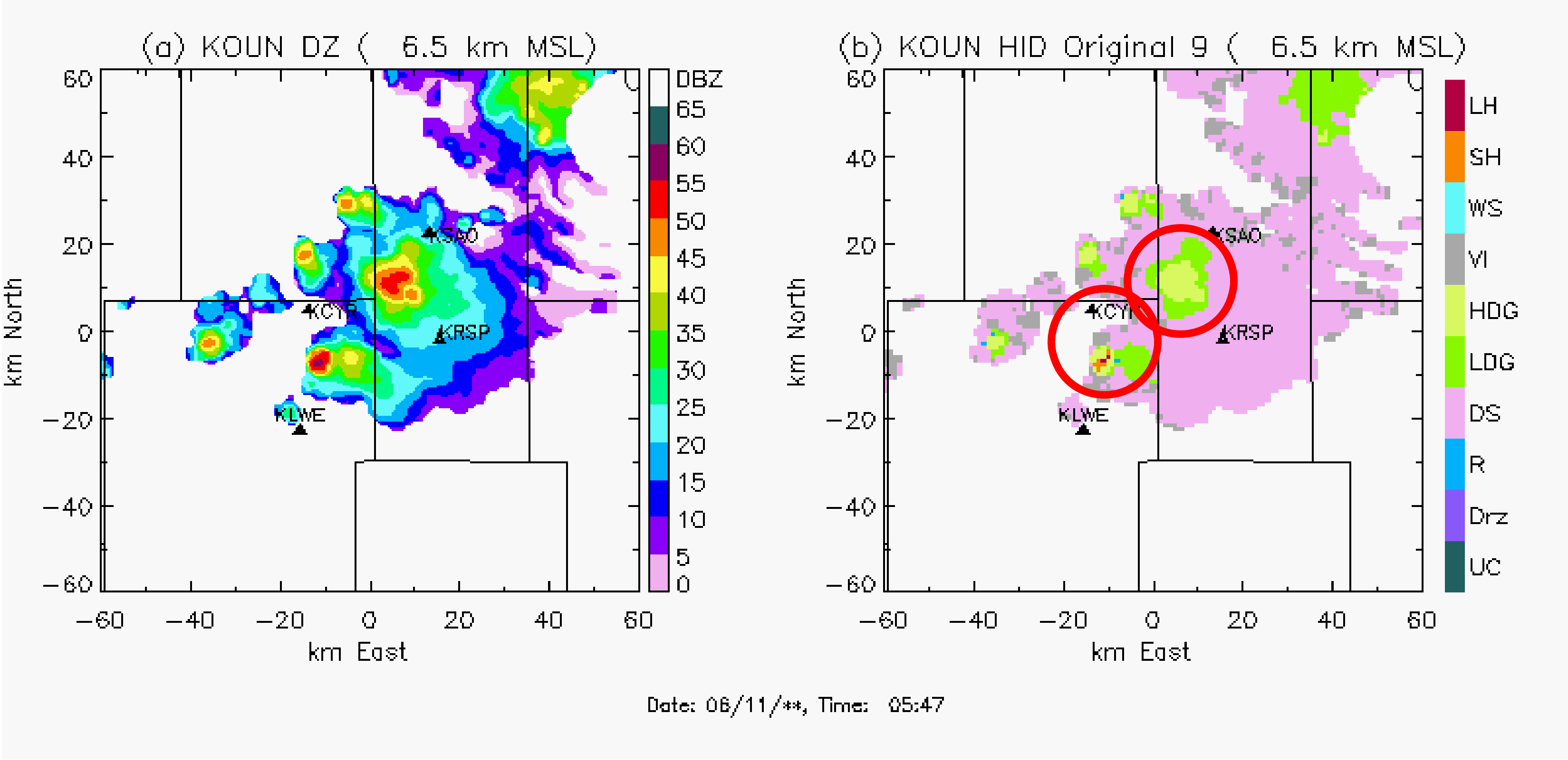


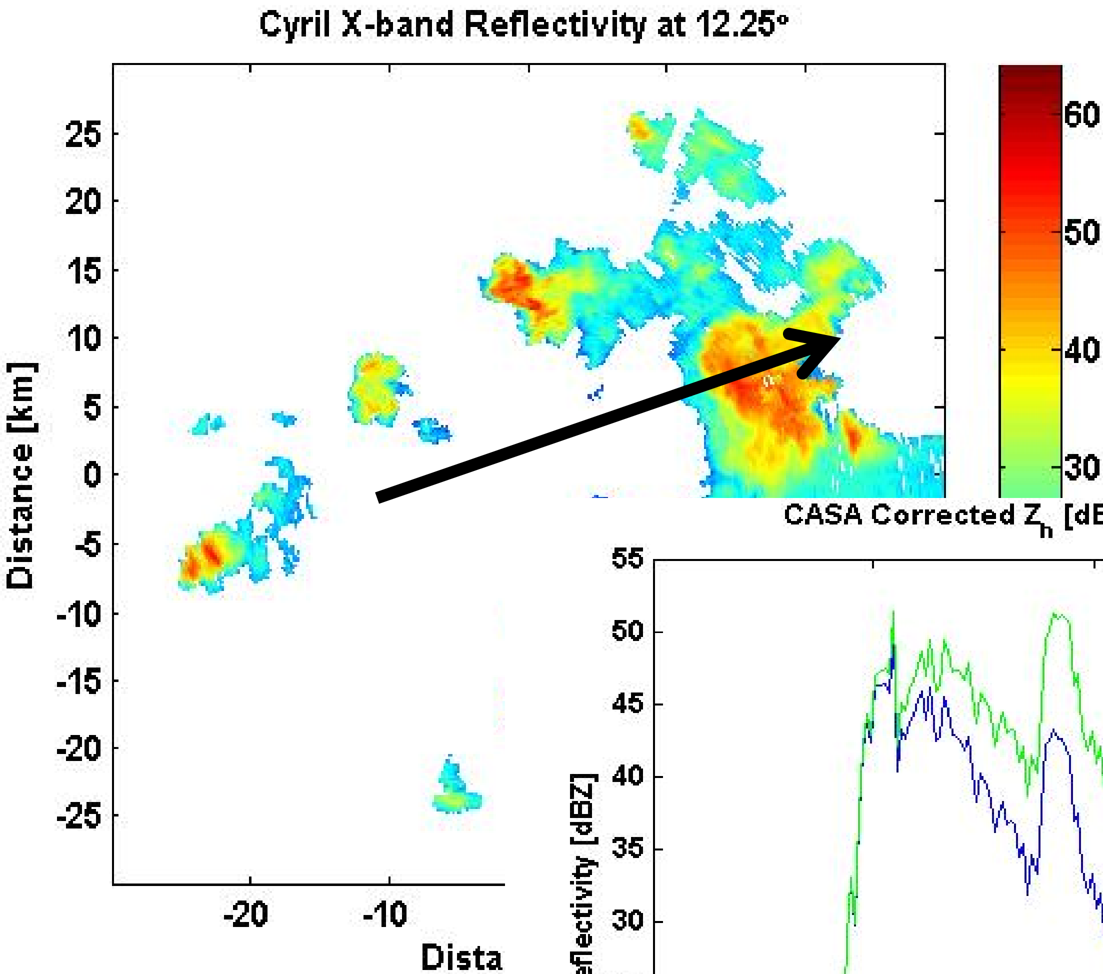


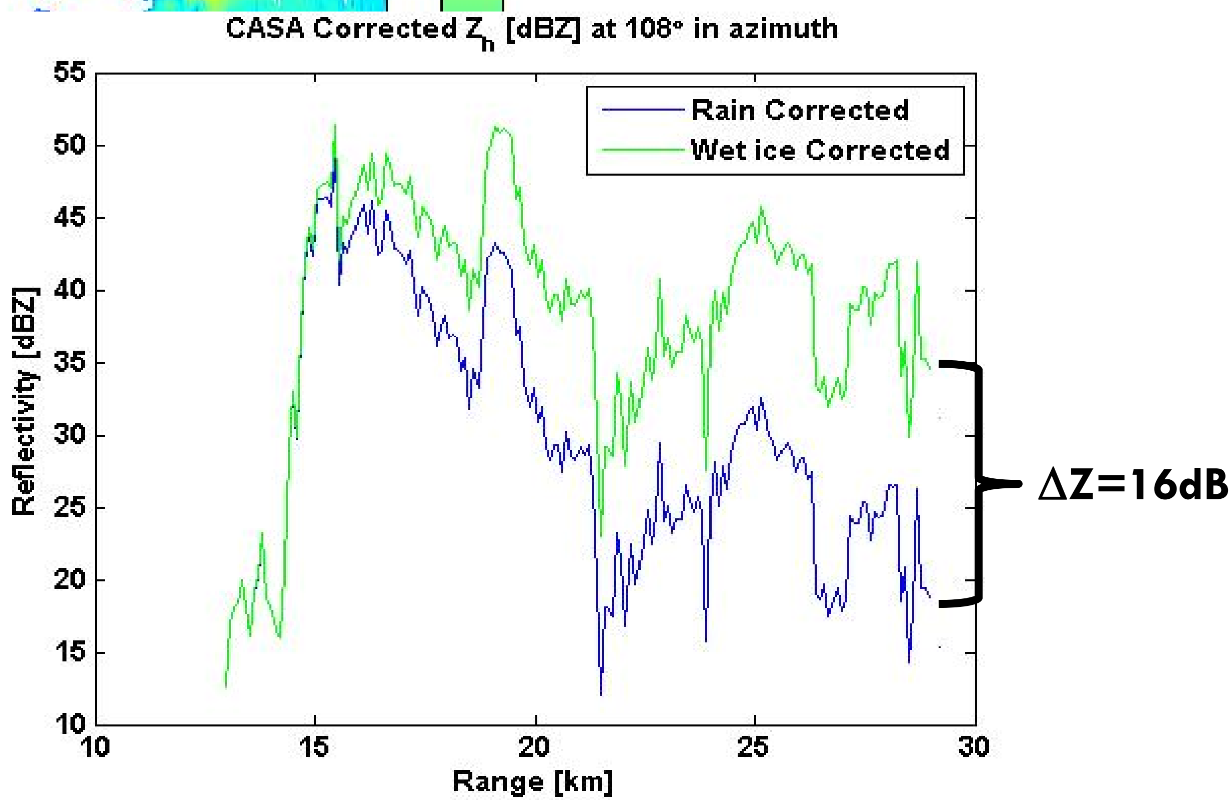
$-2 \leq \Delta Z \leq 4$

CASA/KOUN: June 10th, 2007

CONVECTIVE CASE

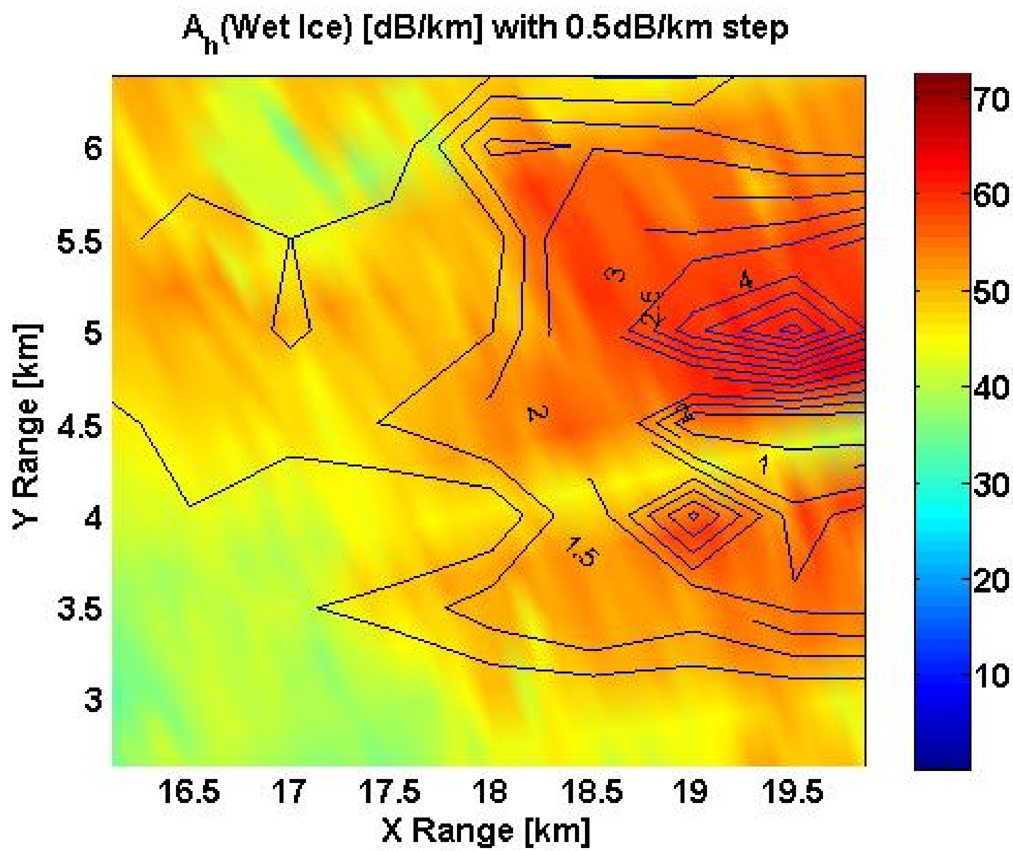






Corrected FOR RAIN!!!

Preliminary Results: CASA/KOUN



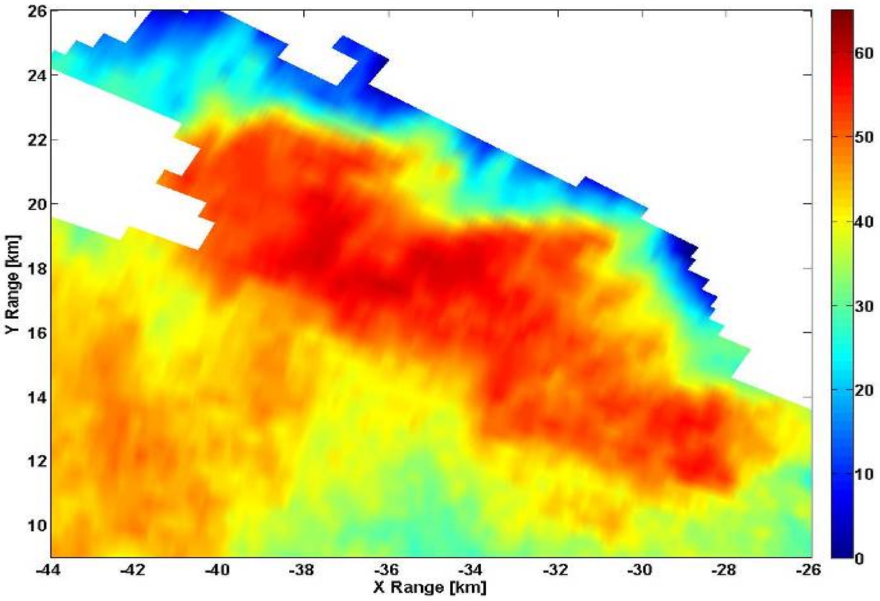
For wet ice:
Max A_H = 5 dB/km

Preliminary Results: CASA/KOUN

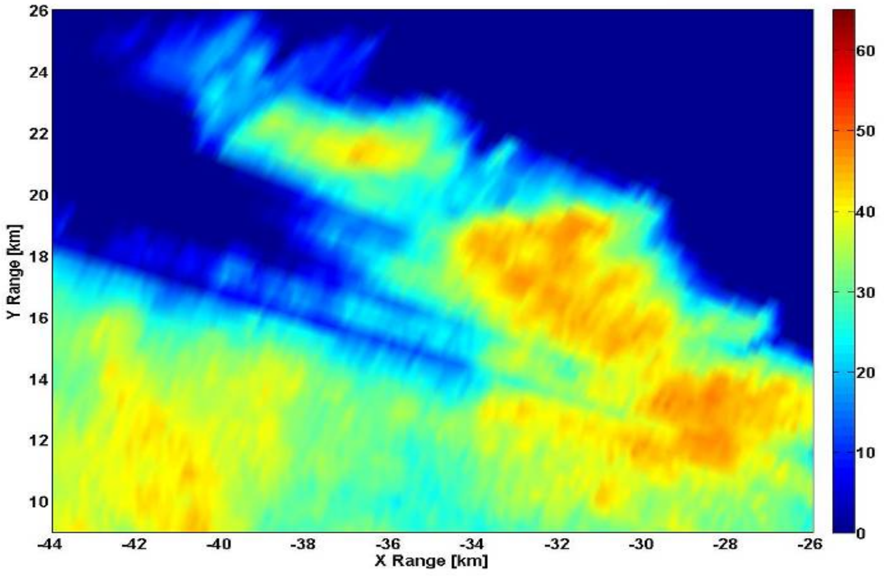
CP-2: Case March 26th, 2008

PPIs at 3.70° in elevation

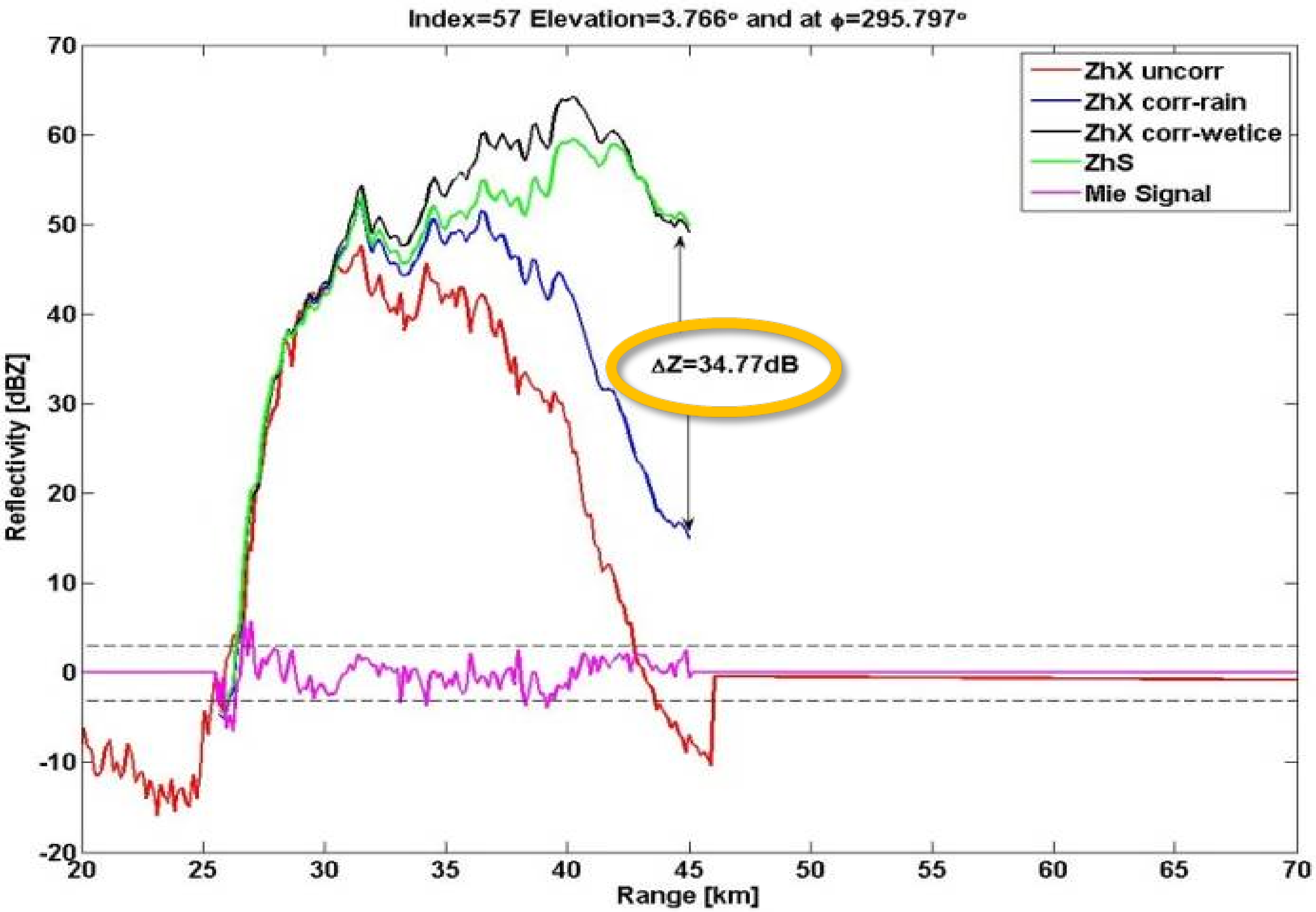
S-band Reflectivity



X-band Reflectivity



at X-band $$A_h^{rain} = 0.0917(K_{dp}^S)^2 + 0.6454K_{dp}^S + 0.1749$$

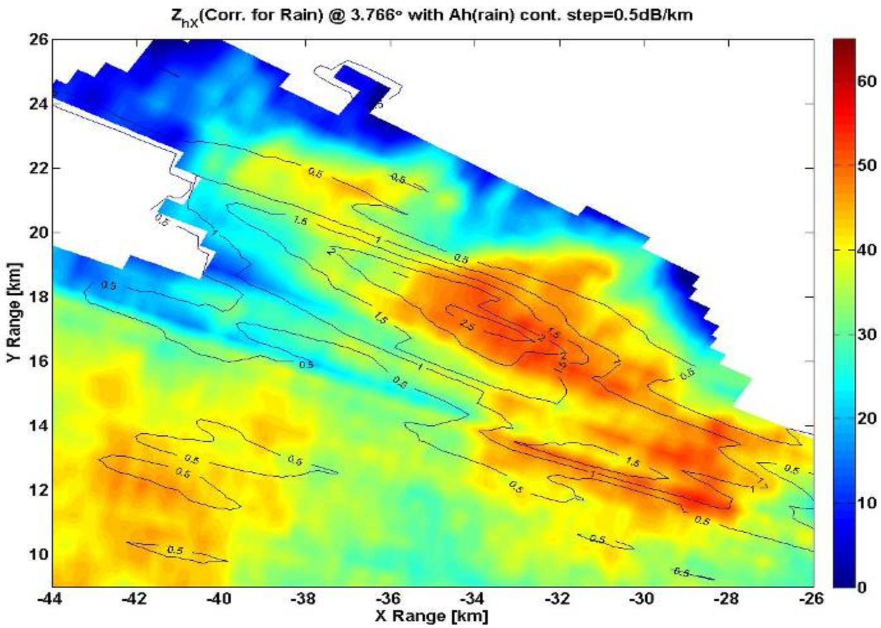


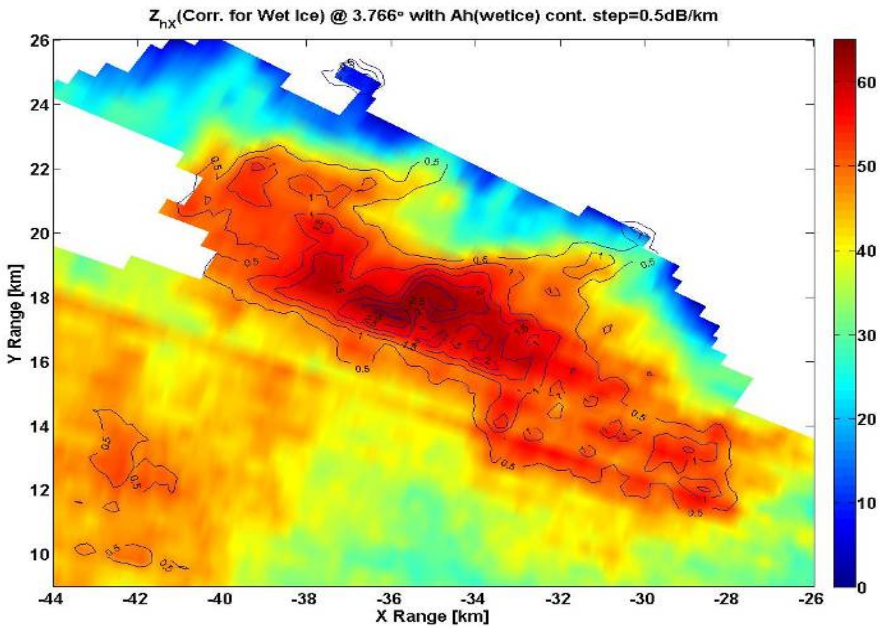
Preliminary Results: CP-2 March Case

PPIs at 3.7° in elevation

Corrected for Rain with A_h (rain contours)

Corrected for Wet ice with A_h (wet ice contours)





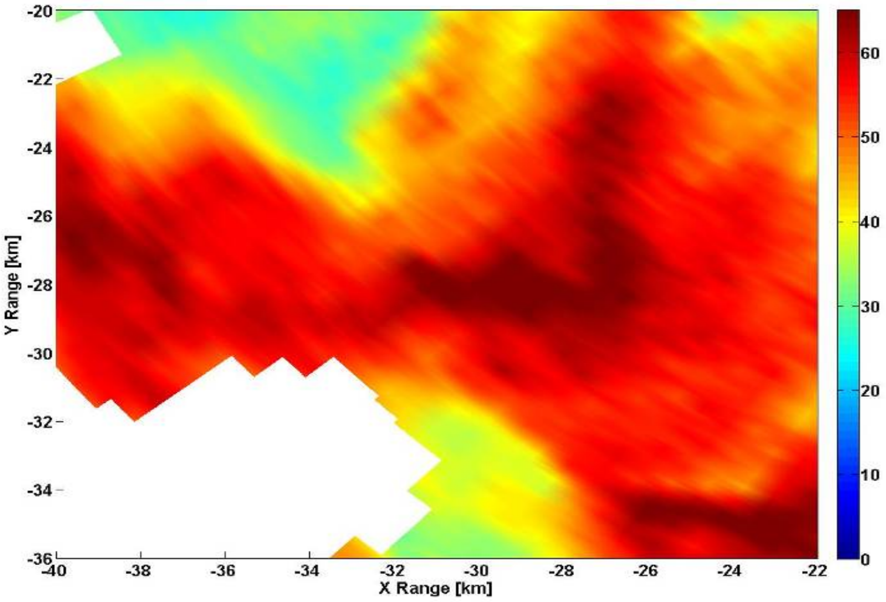
Max A_H= 2.5dB/km
Step=0.5 dB/km

Max A_H= 5dB/km
Step=0.5 dB/km

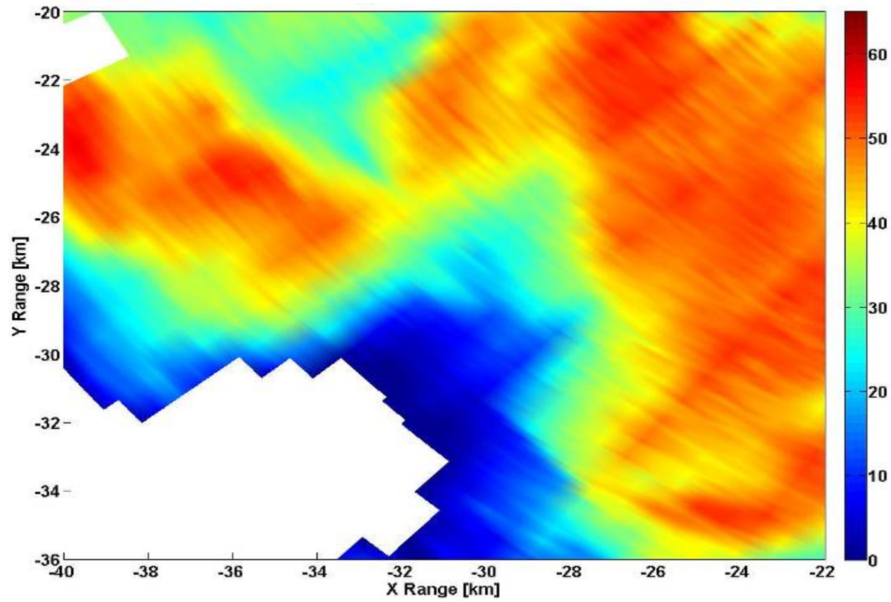
CP-2: Case October 21st, 2008

PPIs at 2.48° in elevation

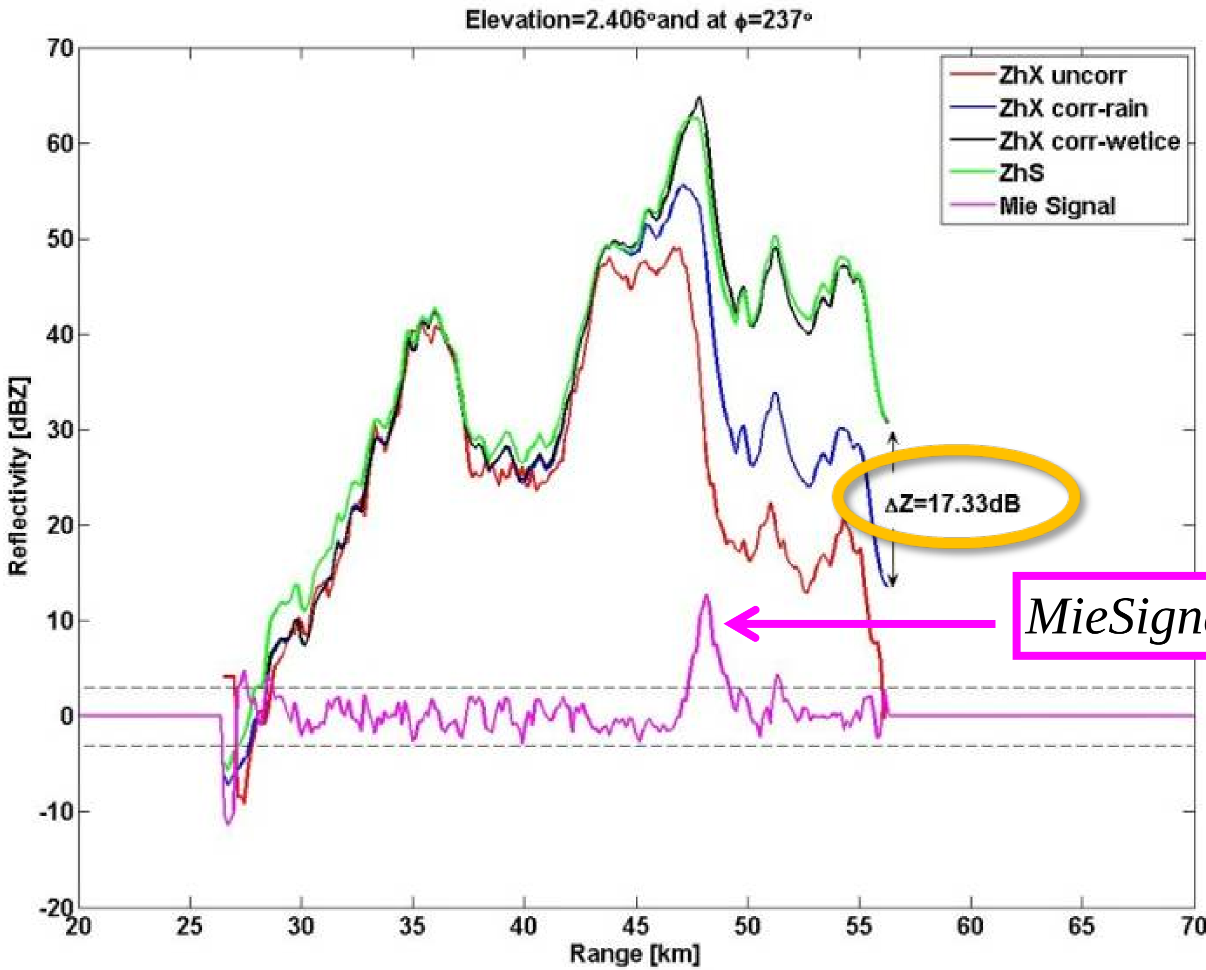
S-band Reflectivity



X-band Reflectivity

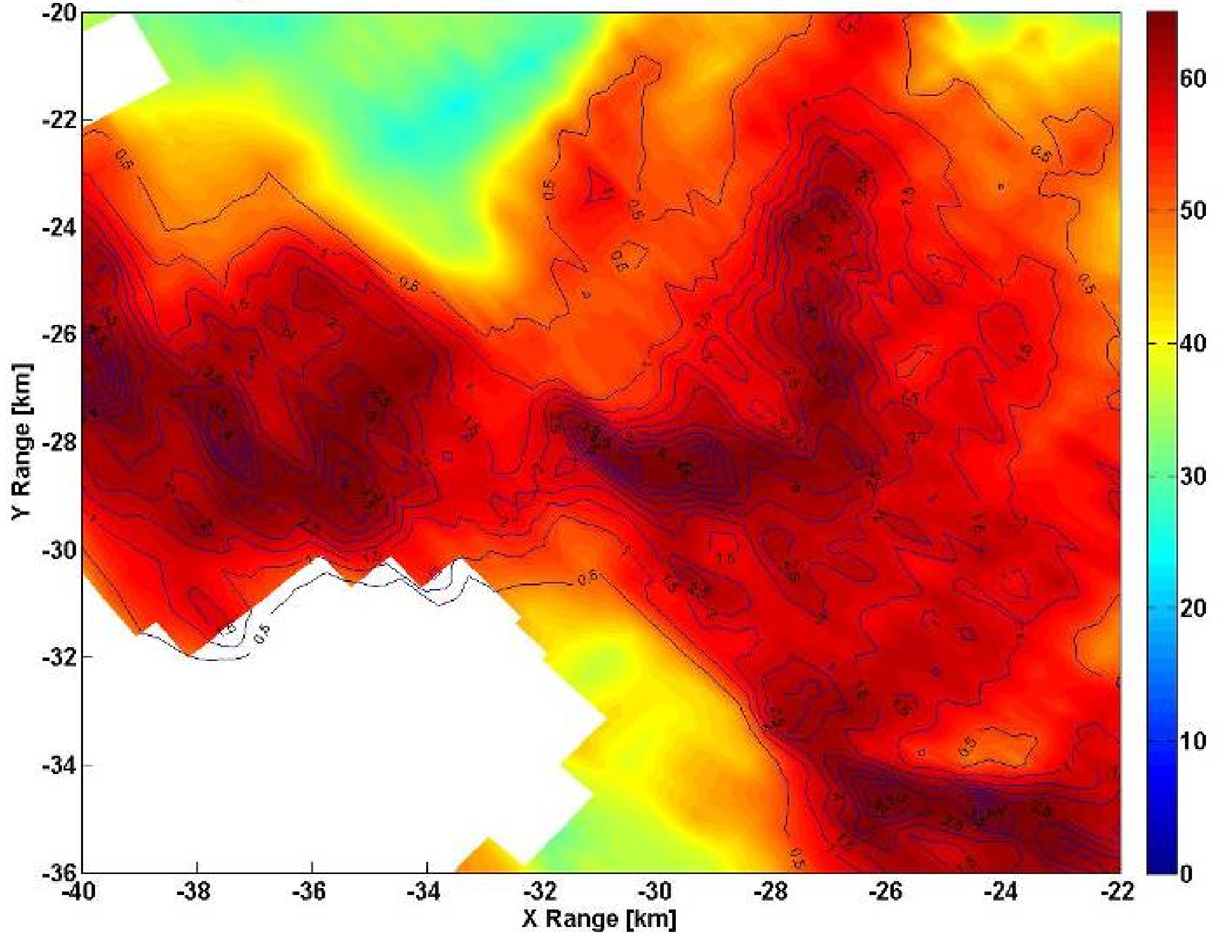


at X-band $$A_h^{rain} = 0.0917(K_{dp}^S)^2 + 0.6454K_{dp}^S + 0.1749$$

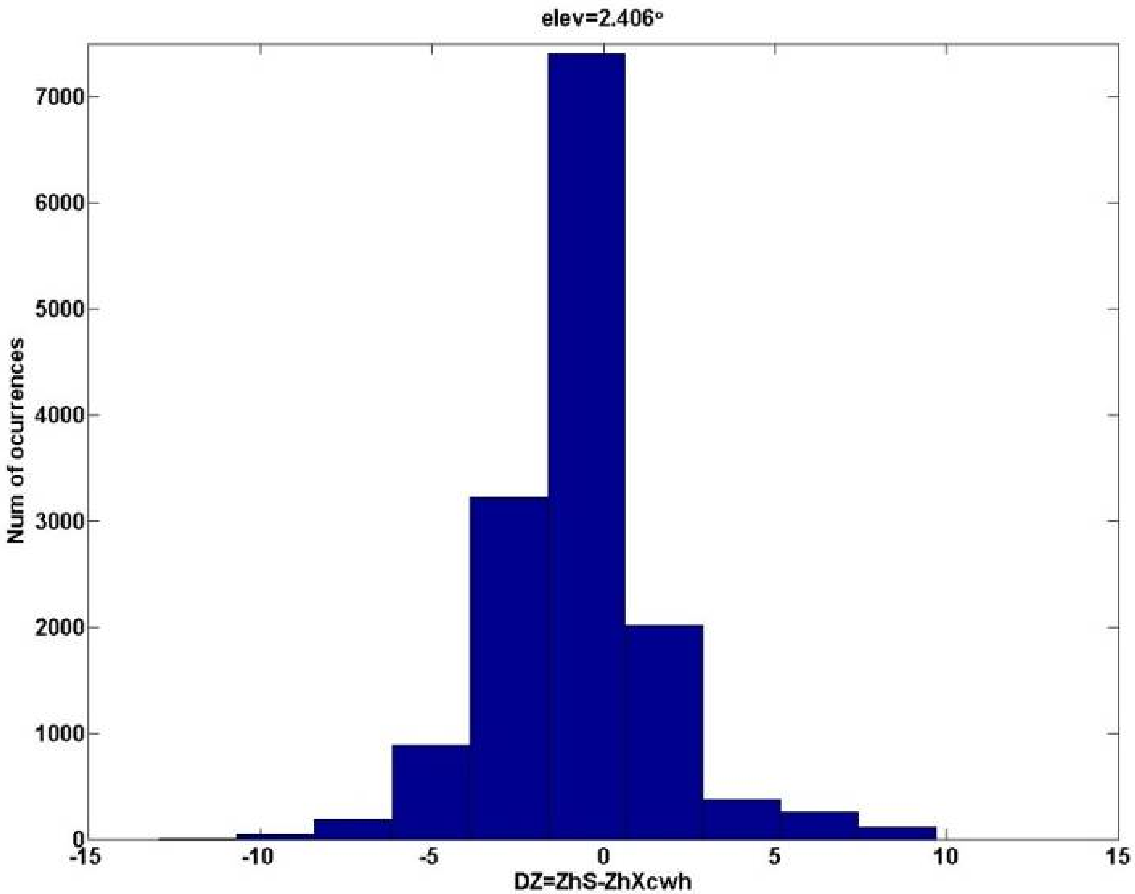


$$MieSignal = DWR - DWR^f$$

Corrected for Wet Ice with A_h (wet ice) contours at 0.5 dB/km step



Max A_H= 5dB/km
Step=0.2 dB/km



$-10 \leq \Delta Z \leq 9$

$\Delta Z = Z(\text{S-band}) - Z(\text{X-band corrected wet ice})$

Preliminary Results: CP-2 October Case

Future Work

- To analyze and apply the proposed algorithm to two CASA-IP1 network cases
  - Case May 8th,2007 – May 9th, 2007 / KOUN
  - Case June 1st, 2008 / KTLX
- To apply the HID algorithms to these datasets
  - HID-X and HID-S
- To eliminate the NEXRAD reference signal
  - Probability of Hail (POH)

Thanks for coming!

Any Questions?