Lincoln Laboratory Dual Pol Algorithm Development Program

David J. Smalley

NEXRAD TAC

March 9, 2011

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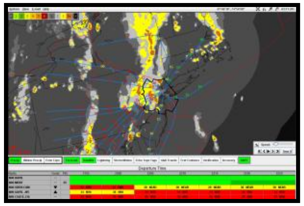
FAA Weather Systems Benefit from Improved NEXRAD Algorithms

Integrated Terminal Weather System

Weather And Radar Processor

Corridor Integrated Weather System

Consolidated Storm Prediction for Aviation



Route Availability Planning Tool

Functionality Gap	Algorithm	First Deployed
Legacy Algorithm Performance/Resolution	Precipitation Coverage - HRVIL	2002
	Echo Tops - HREET	2003
Data Quality	Data Quality Improvements - DQA	2003
Wind Shear Product	Gust Front Detection - MIGFA	2007
	Microburst Detection - AMDA	In development
Hydrometeor Identification	Icing Hazards - IHL	In development
	Hail Hazards - HHL	In development

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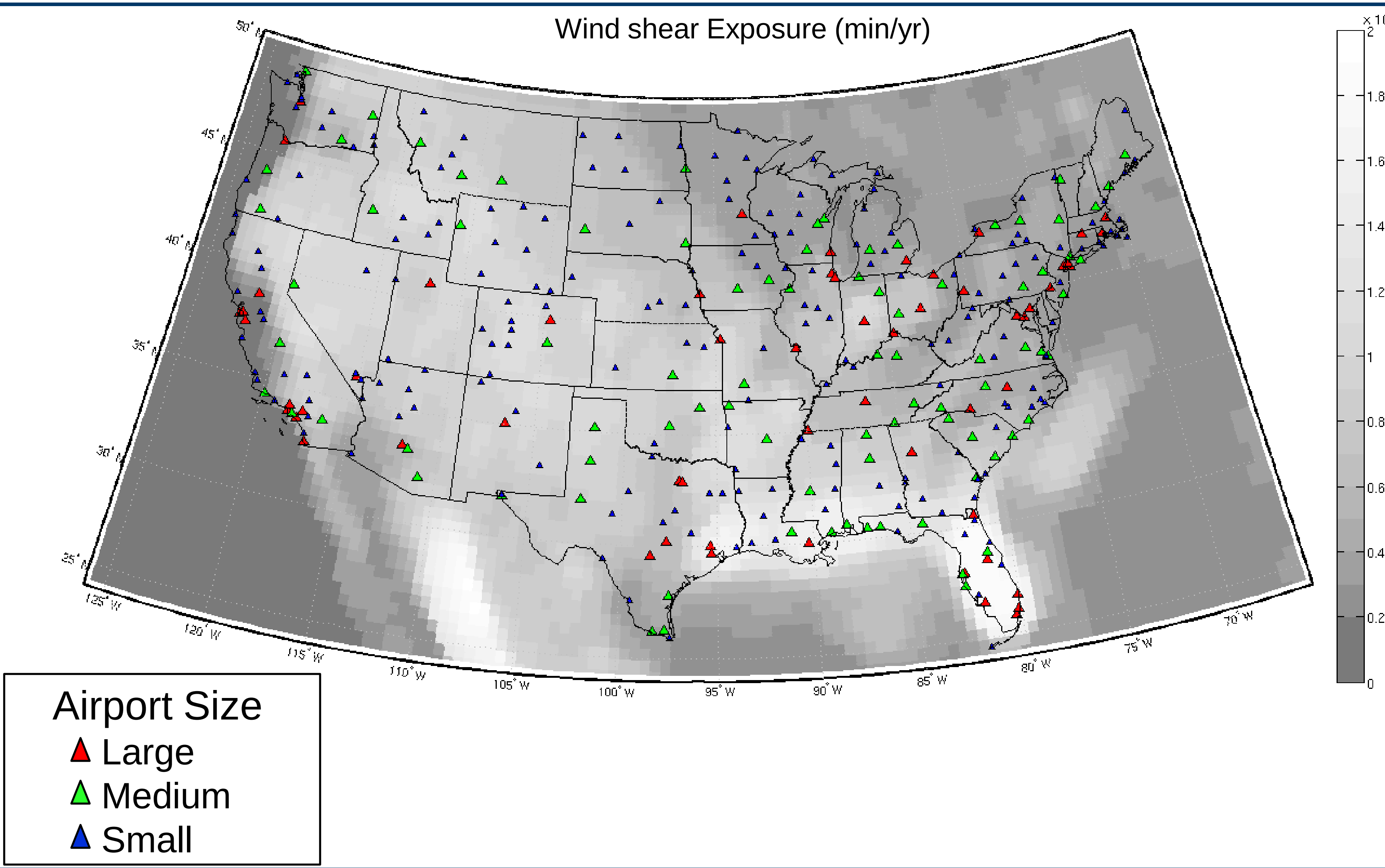
Outline

- Automated Microburst Detection Algorithm (AMDA)
- Dual Pol Algorithm Development Plan
- Icing Hazard
- Hail Hazard
- Data Quality Improvement
- High Res VIL Recovery

Airport Wind Shear Exposure



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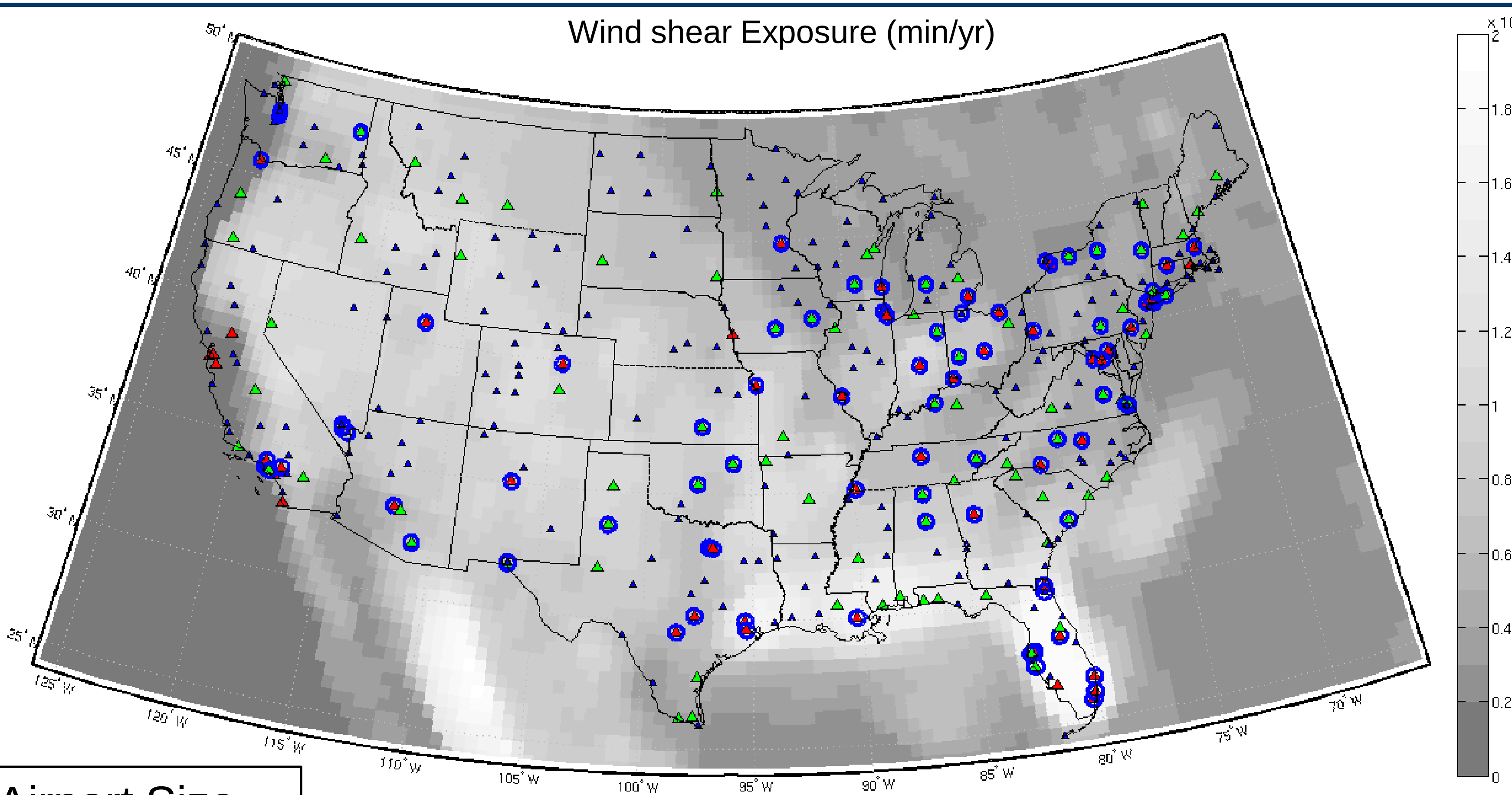
Current Airport Wind Shear Coverage



Airport Size
- Large
- Medium
- Small

Wide-area wind shear coverage

Current TDWR/WSP Airport Coverage

Circles Represent 30 KM Airport Coverage Area

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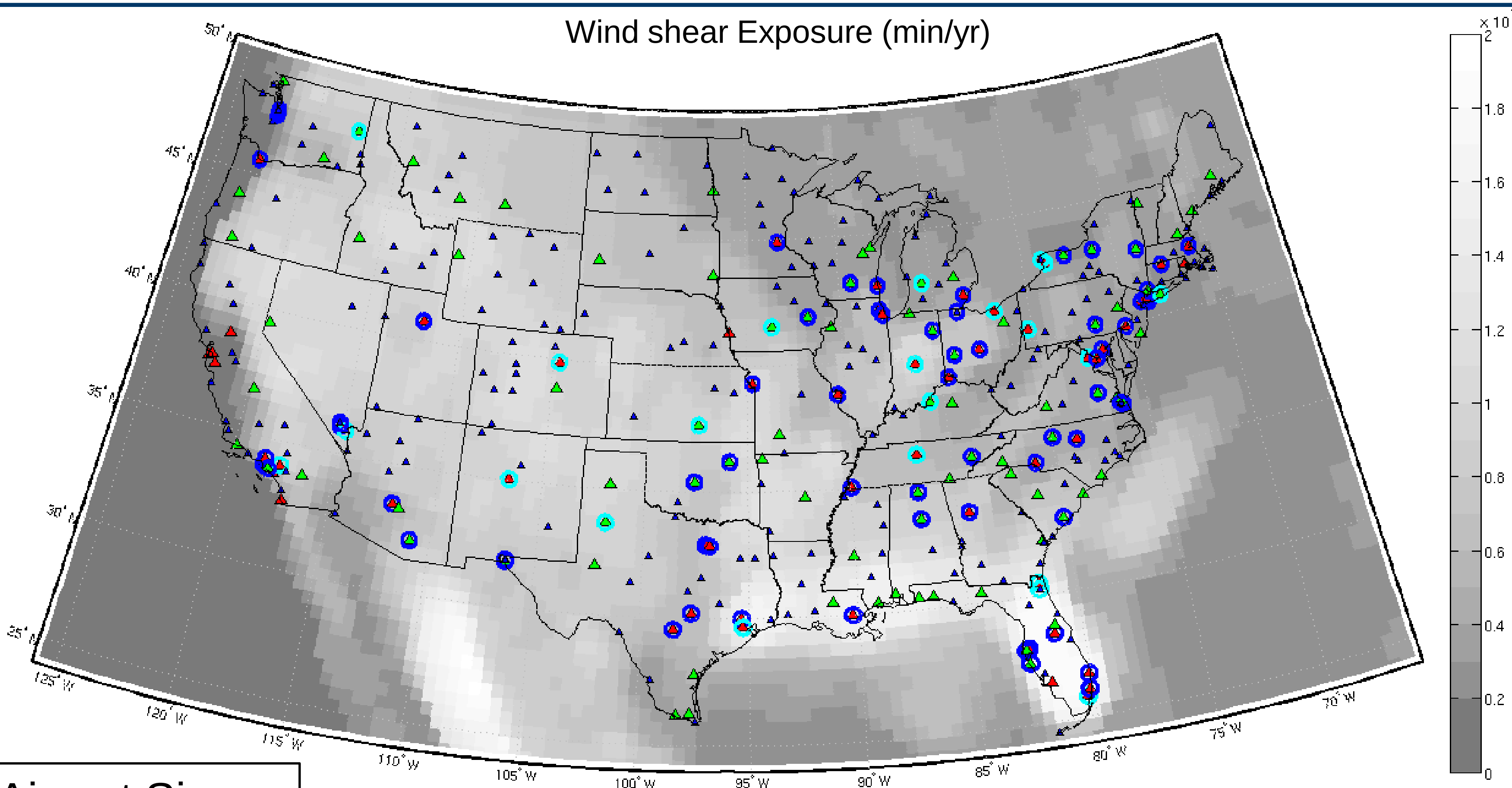
Complementary NEXRAD Enhanced Wind Shear Coverage



Airport Size

- Large
- Medium
- Small

Wide-area wind shear coverage

TDWR/WSP NEXRAD w/TDWR/WSP

Circles Represent 30 KM Airport Coverage Area

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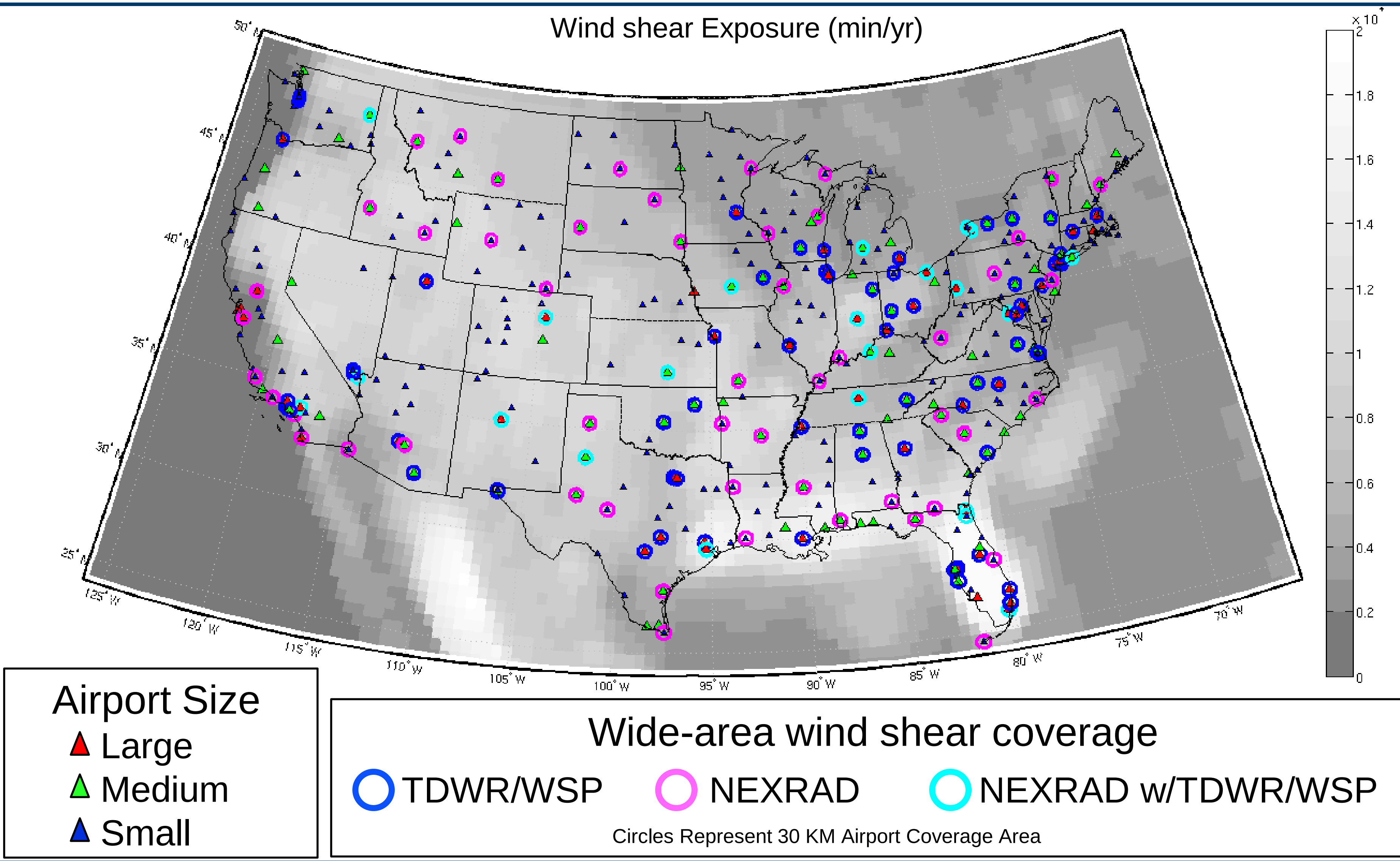
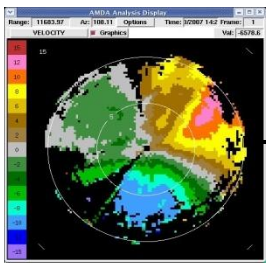
Potential NEXRAD Enhanced Wind Shear Coverage



Automated Microburst Detection Algorithm

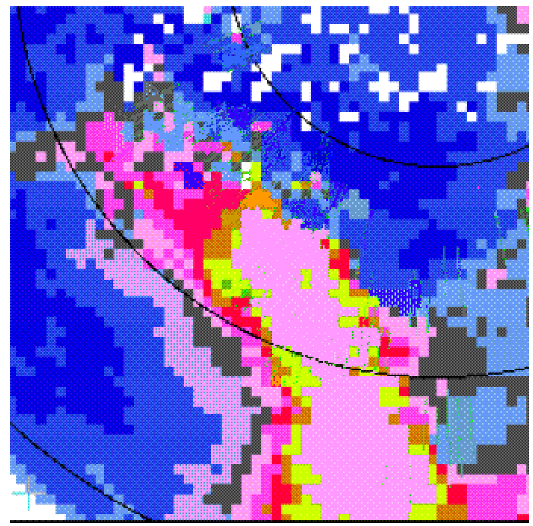
- TDWR benefits study identified NEXRAD as a cost effective alternative for wind shear detection
- NEXRAD does not currently have a microburst detection product
- There is a need for more wind shear products in NextGen
- NEXRAD AMDA based on AMDA concept for the ASR-9 WSP and lidar
- Does not require months of code development to determine if such a capability will be useful in the NEXRAD system

AMDA Overview



Read a Scan of Base Data

Segment Detection



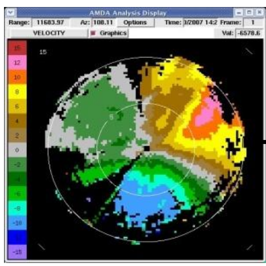
Segment Association

Segment Density Thresholding

Assimilate Evidence

MB Detections To Shape Algorithm & Display

AMDA Segment Detection



Read a Scan of Base Data

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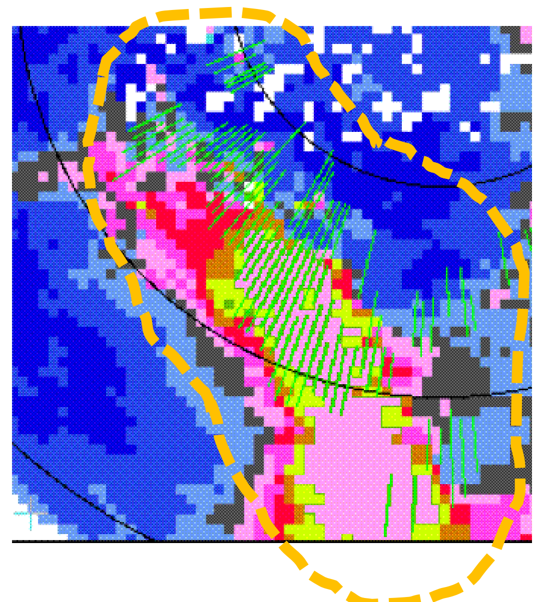

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AMDA Segment Association

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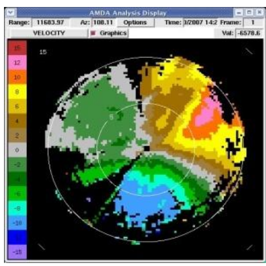
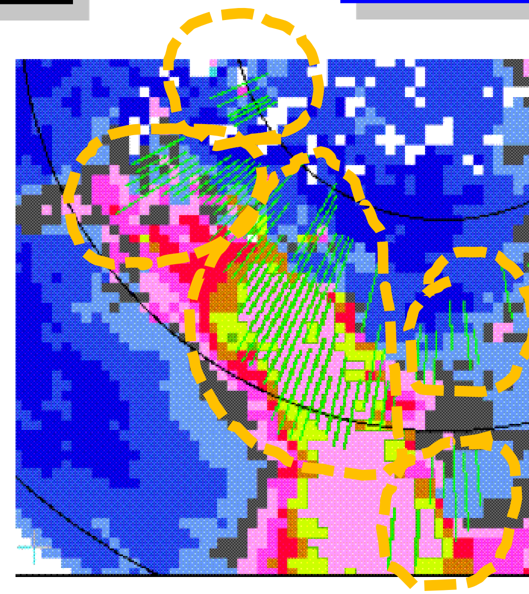
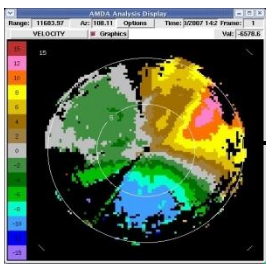


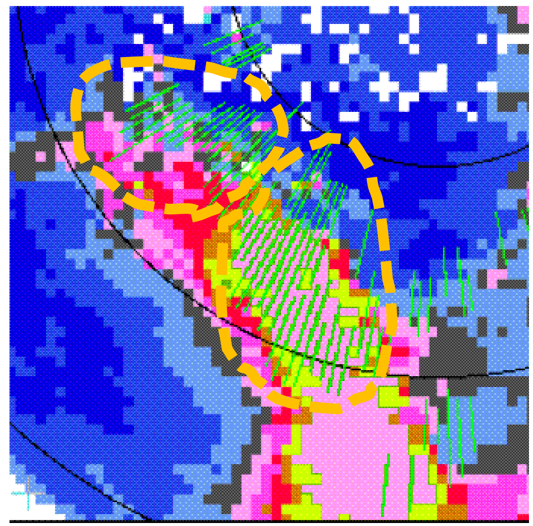


AMDA Segment Density Thresholding



Read a Scan of Base Data

Segment Detection



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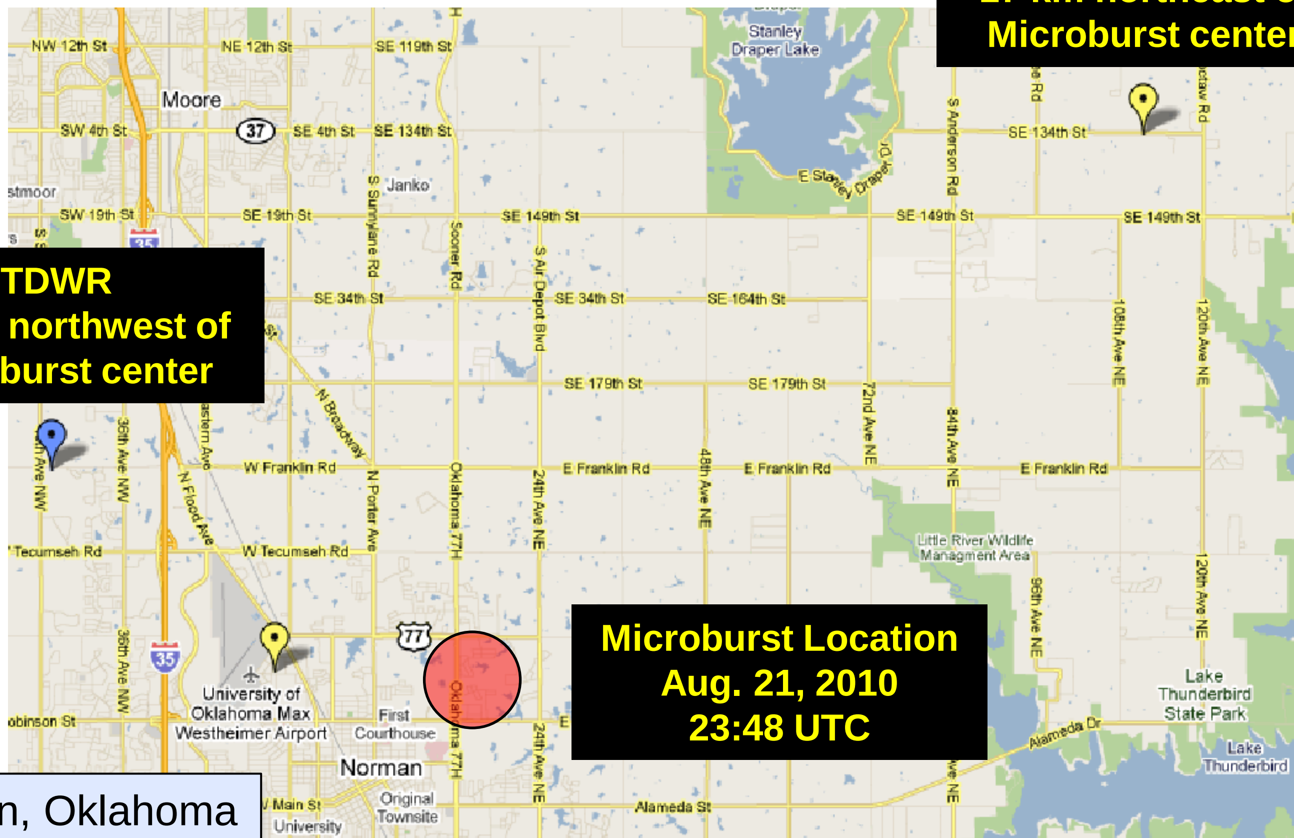
NEXRAD AMDA Implementation Progress

- Generate NEXRAD AMDA results to compare to TDWR/ITWS microburst algorithm results at a few live sites
  - Dallas area with two TDWRs
  - Indianapolis area with a TDWR and NEXRAD running AVSET
- Comparison warrants integration of AMDA into ORPG CODE
  - Approx. 85% detection when verified in NEXRAD data
  - Approx. 25 – 30% of TDWR detections not visible to NEXRAD
- NEXRAD surface (0.5^{o}) scanning likely too infrequent
  - Best max. return to surface scan every ~4.3 minutes (AVSET help?)
  - Other AMDA and TDWR/ITWS microburst algorithm based on 1 minute or less return to surface scan
- No predictive component for NEXRAD AMDA
  - TDWR/ITWS microburst algorithm has predictive component
  - NEXRAD AMDA may need such to augment infrequent surface scanning

Microburst Comparison Study TDWR and NEXRAD

NEXRAD
17 km northeast of
Microburst center

TDWR
6.5 km northwest of
Microburst center



Microburst Location
Aug. 21, 2010
23:48 UTC

Norman, Oklahoma

First Phase is to compare TDWR and NEXRAD microburst detections

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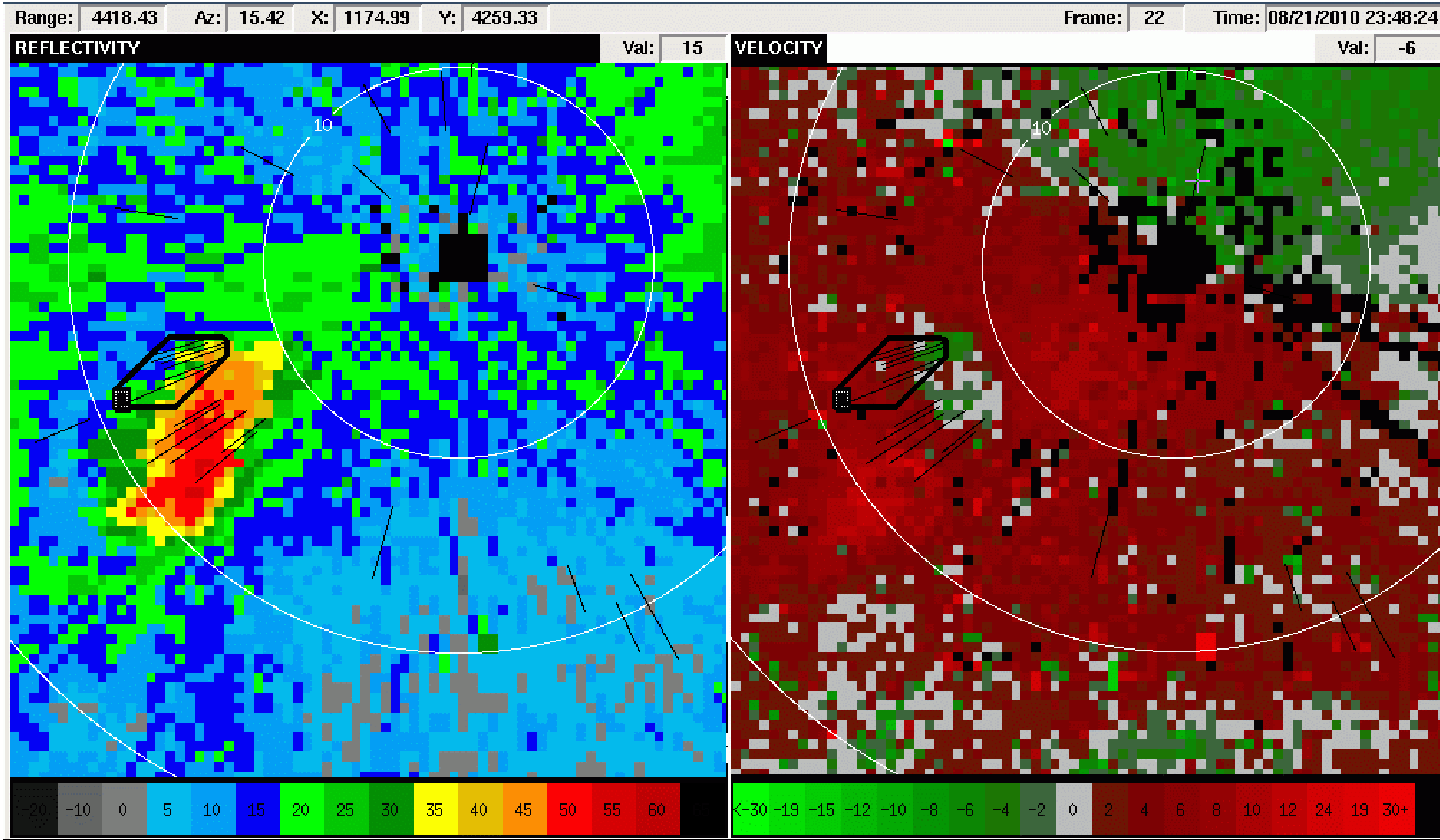
NEXRAD Detection of Norman, OK Microburst



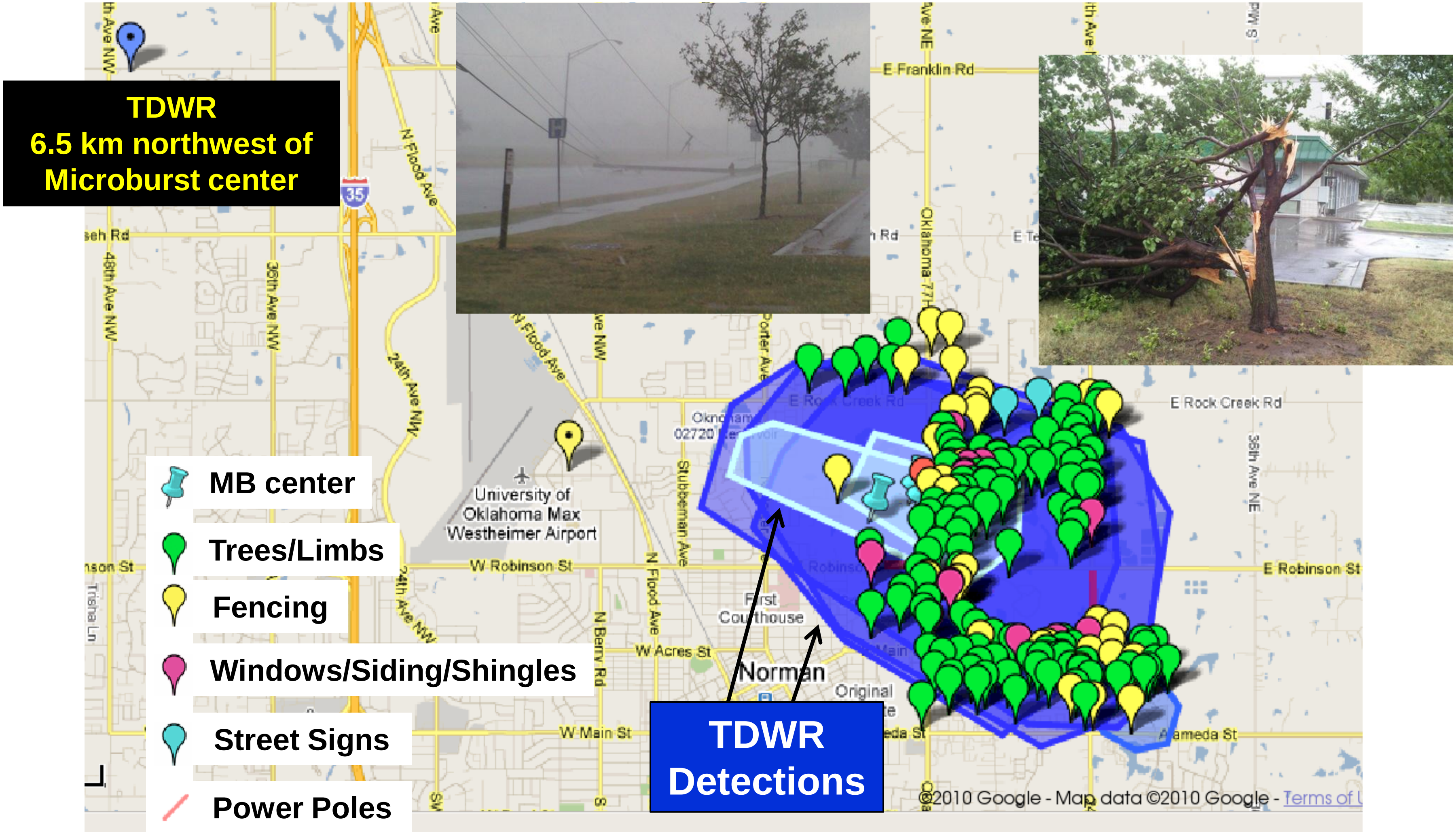
Reflectivity (dBZ)

Radial Velocity (m/s)

Damage Survey From Microburst Event in Norman Oklahoma

NEXRAD
17 km northeast of Microburst center

August 21, 2010 23:48 UTC



Damage Survey Mapping Courtesy of Paul Schlatter, NOAA

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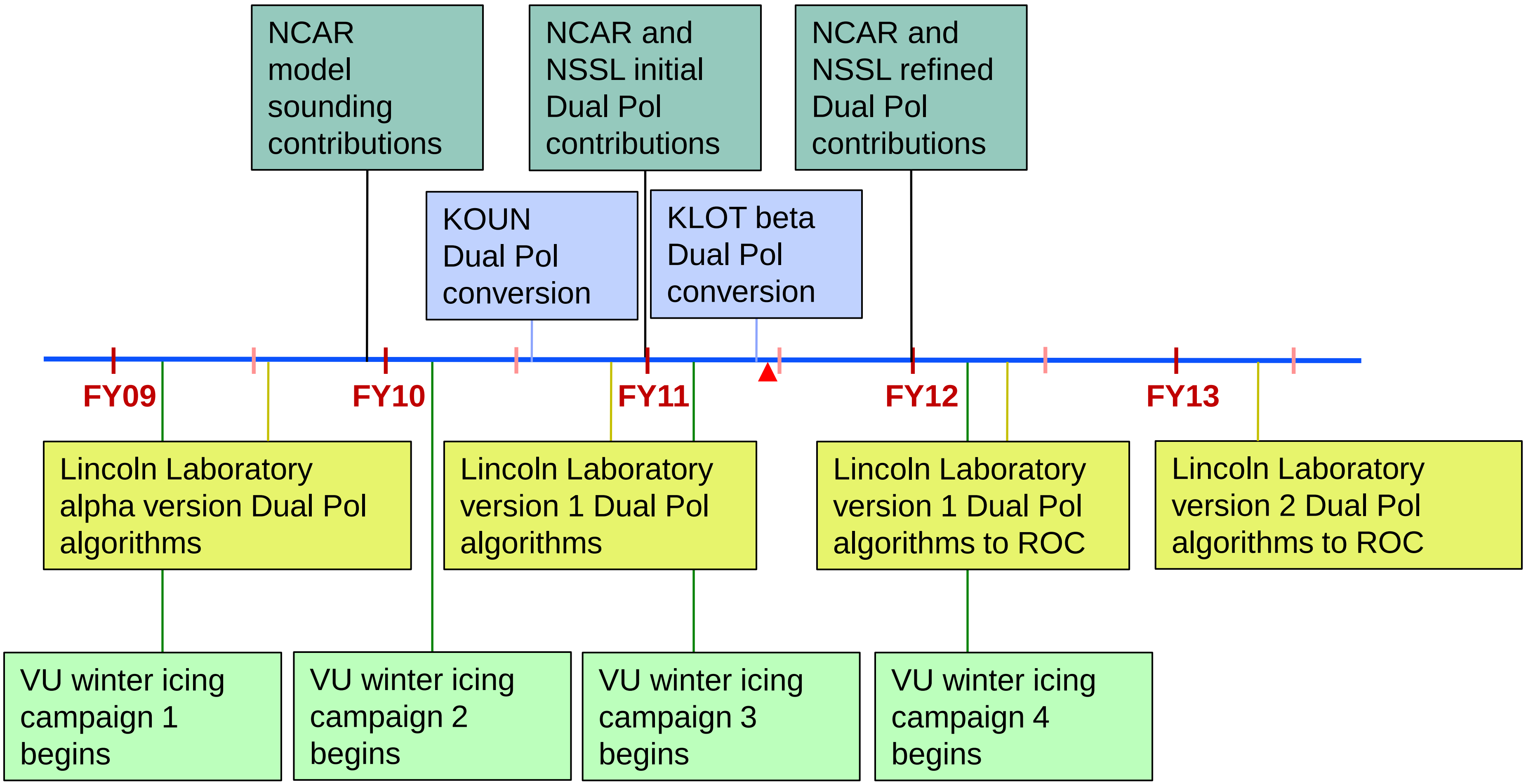
Partnerships Contribute to LL Development of Dual Pol Algorithm Products

- FAA supports LL partnership plan with subject matter experts (SMEs) on dual pol radar from national laboratories and universities
- Contributions from SMEs to be incorporated into real-time dual pol algorithms in development at LL for FAA weather systems
- Proxy data sources being used prior to NEXRAD upgrade
  - Valparaiso University's C-band Dual Pol radar
  - KOUN (Norman, OK) prototype and beta site dual pol data
- Identify strategies to bolster determination of the melting layer altitude and hydrometeor classification
- Incrementally more robust products from increasingly sophisticated algorithms
  - Current Source: NEXRAD Open Radar Product Generator
  - Future Added Source: NextGen Weather Processor

Partner Dual Pol Product Development Timeline



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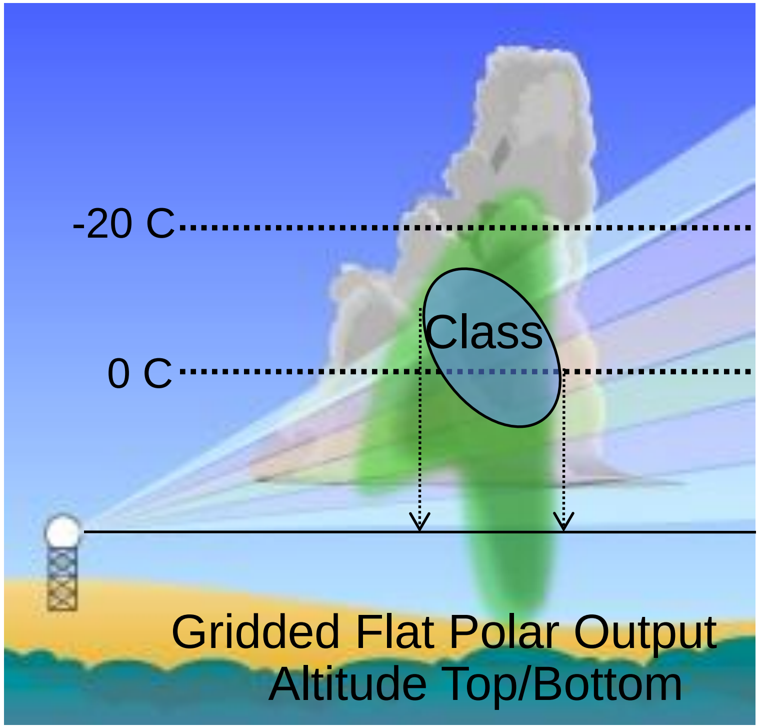
Icing Hazard and Hail Hazard Products



- 1^{o} x 1 km grid to 300 km range
- Top/bottom altitude of hazard per grid point
- Severity and confidence indices in final version

- Identify 3D hazard regions in radar volume
- Version 1 with NEXRAD hydrometeor classification, T/RH model soundings, and dual pol fields (target summer 2011)
- Version 2 with added techniques from Lincoln Laboratory and partner labs (target delivery in out years)
- *Will need surface data and/or additional sounding fields*

- LL/FAA readiness decision in 2011
- Hand off to ROC in early 2012

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Complete Icing Hazard Coverage

A. ICING HAZARDS WITHIN RADAR VOLUME FOR EN ROUTE APPLICATIONS

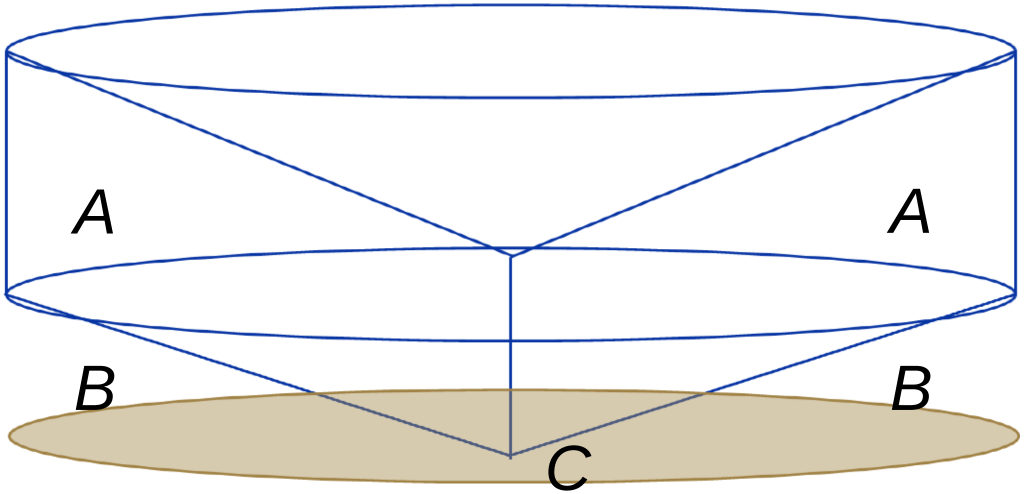
Supercooled water, ice crystals

B. ICING HAZARDS BENEATH LOWEST SCAN AND ABOVE SURFACE

Snow, sleet, rain, freezing rain, supercooled water

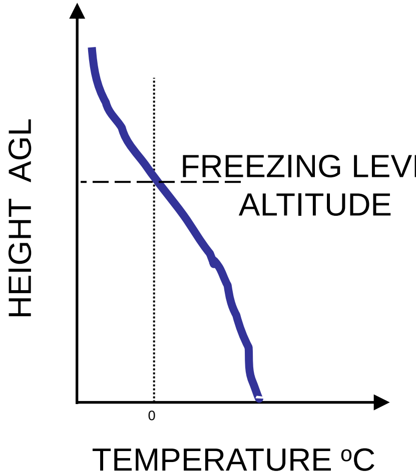
C. ICING HAZARDS AT SURFACE FOR TERMINAL APPLICATIONS

Snow, sleet, rain, freezing rain



Radar Volume

PLUS



Thermodynamic Sounding

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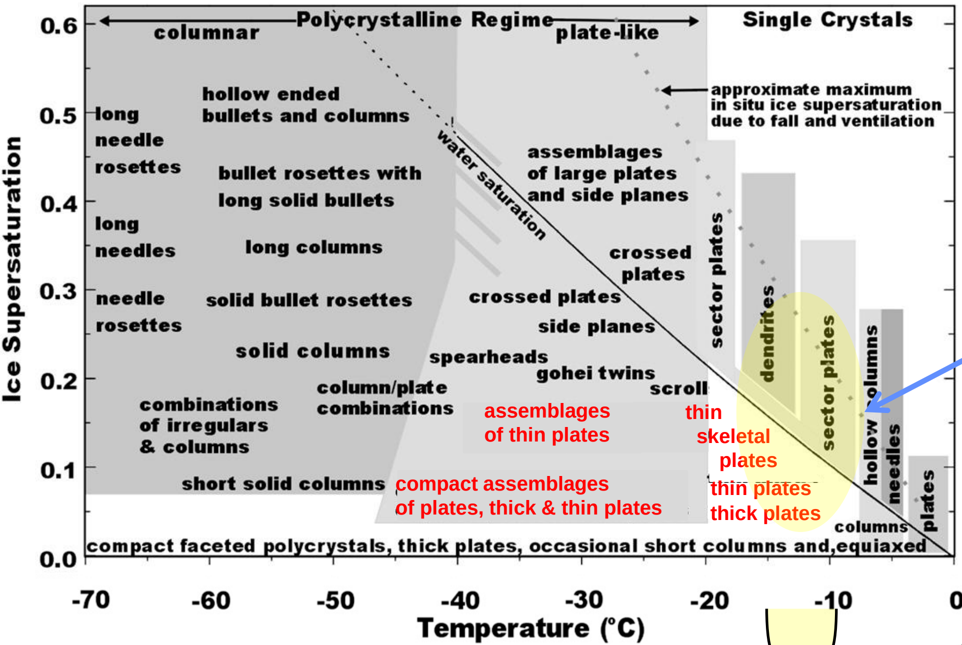
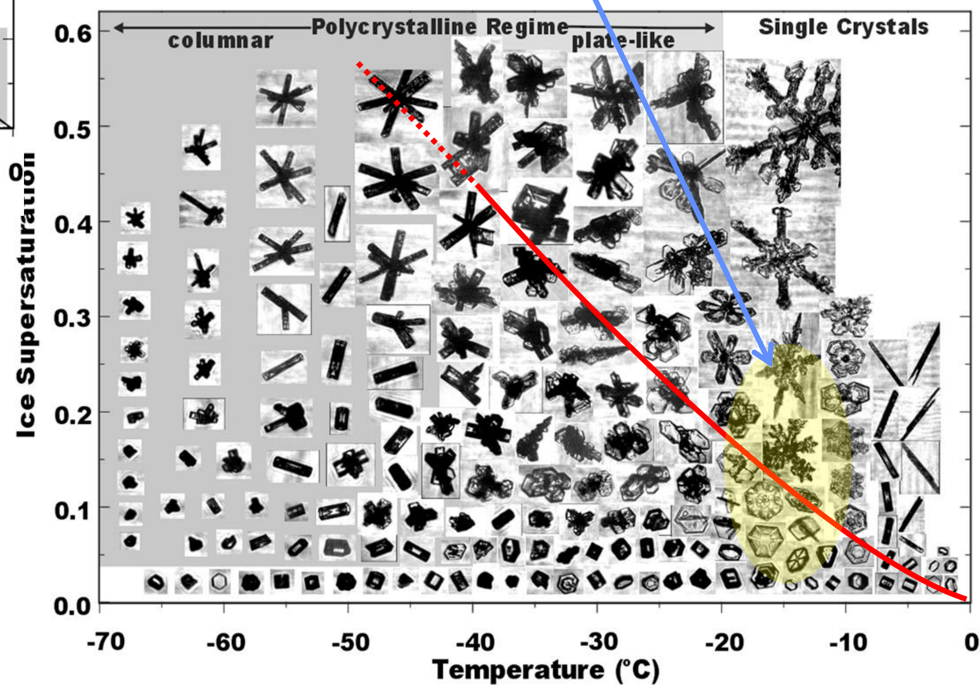
Discover Supercooled Water in Dual Pol Data

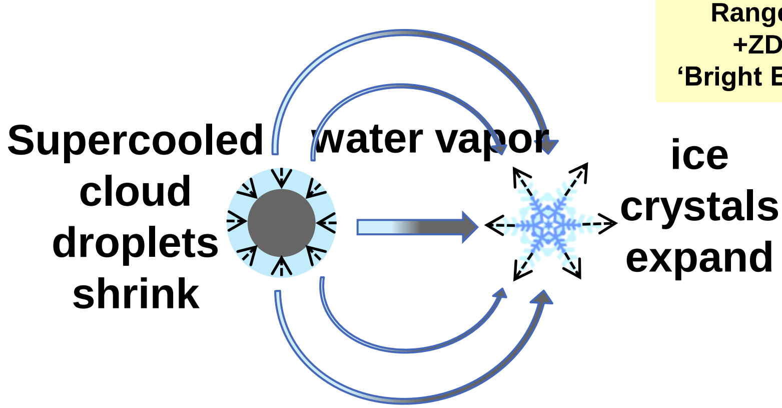


Range of +ZDR 'Bright Bands'

(from: Bailey and Hallett (2009)

The dendrite and plate regimes respond differently to supercooled water (icing) and yield different dual pol signature combinations





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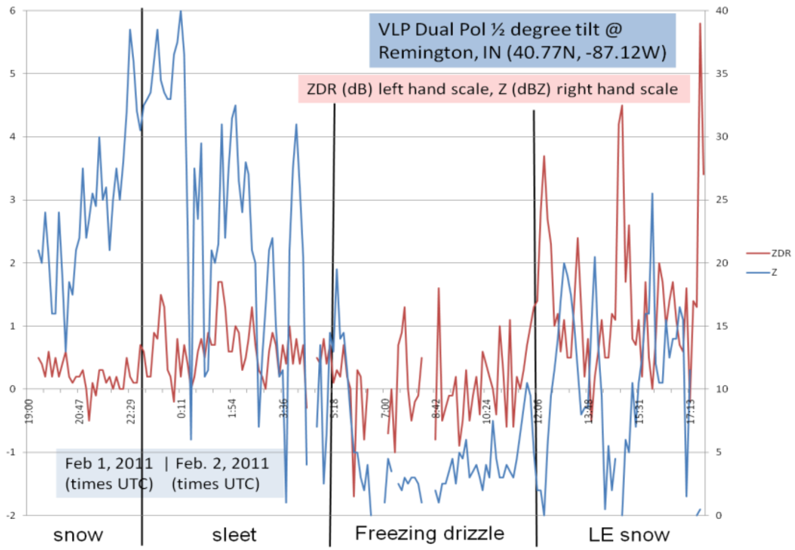
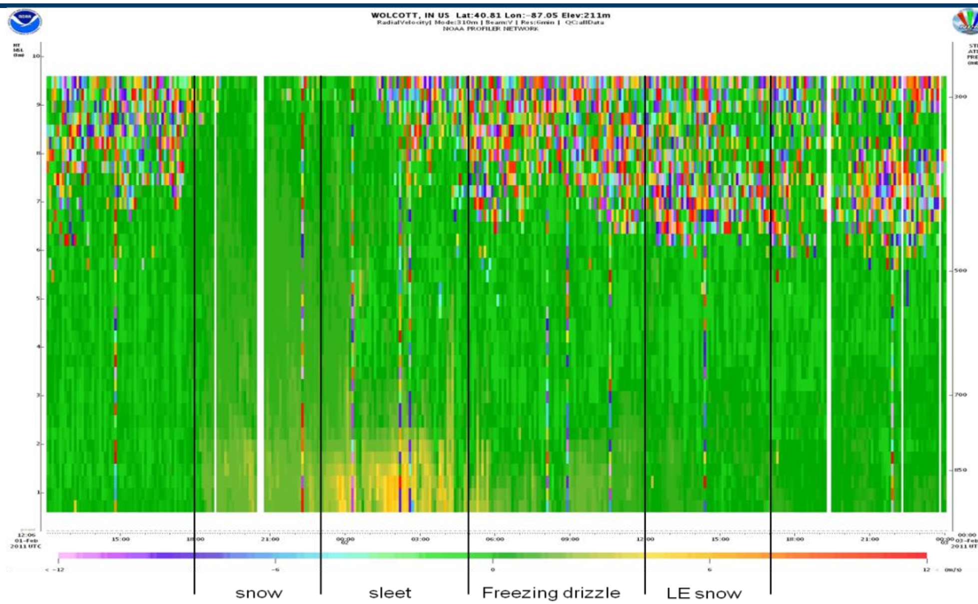
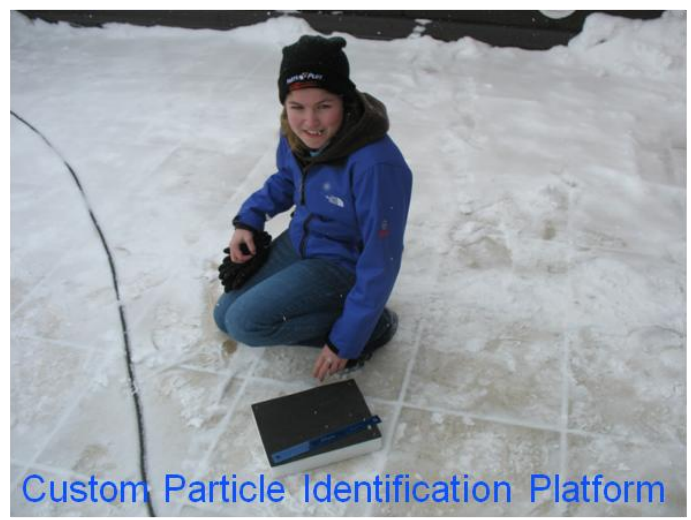
Valparaiso University's Winter Weather Verification Campaigns



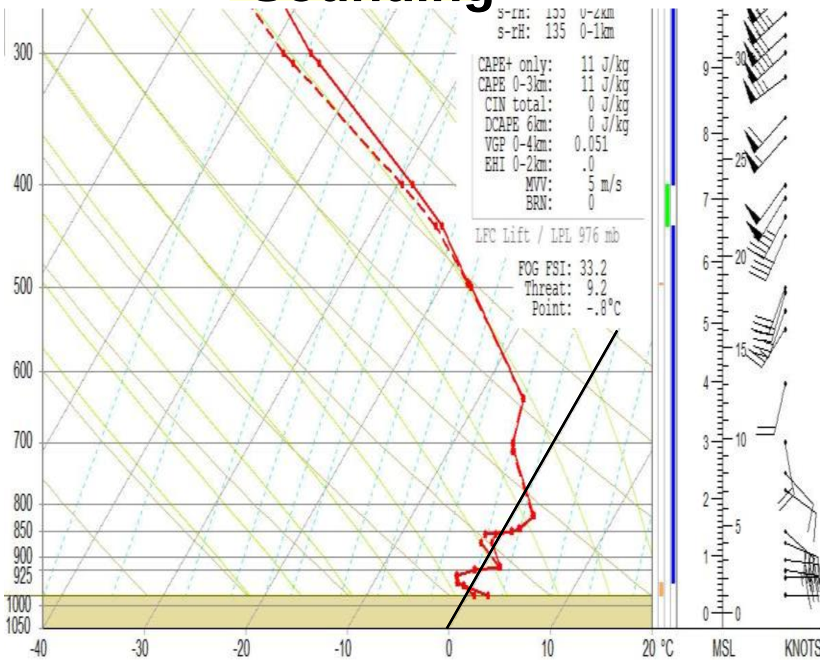



Targeted Radiosonde Soundings

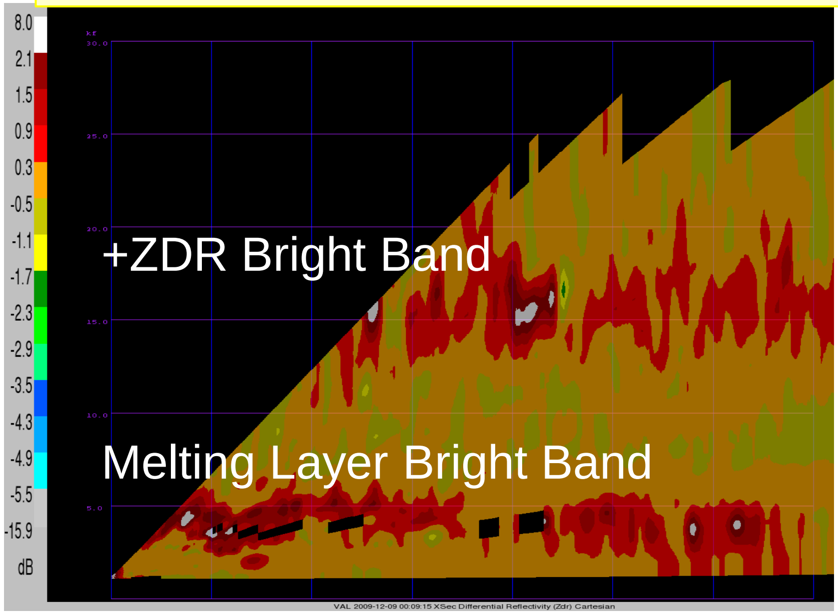

Custom Particle Identification Platform

Sounding Augments +ZDR Bright Band Interpretation

Sounding



VLP Dual Pol C-band ZDR RHI



- +ZDR Bright Band often noted within the -9º to -15º C temperature range
- Moderate rime icing PIREPs often associated with the -9º to -15º C altitude
- LL, NSSL, and NCAR discussing relevance of this feature to the icing hazard
- Plan to integrate +ZDR Bright Band concept into Icing Hazard product

NSSL – Surface Typing Technique

- Determine background winter weather classifications using RUC or HRRR model thermodynamic vertical profiles
- Add dual polarization identification of elevated warm layer (bright band) to get final surface classification
- Extends range from radar that surface classifications will be possible

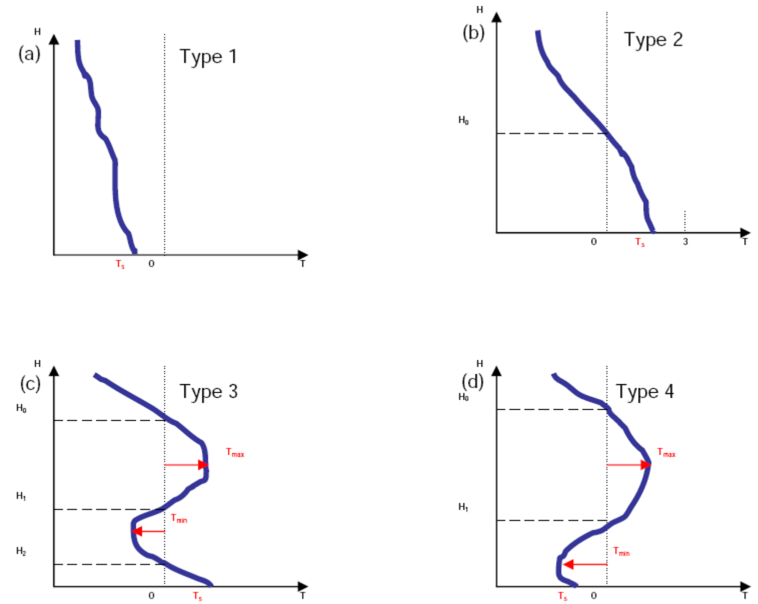


Fig. 3: Four types of vertical profiles of wet bulb temperature (T_w) for which the surface temperature wet bulb temperature (T_{ws}) is less than 3°C.

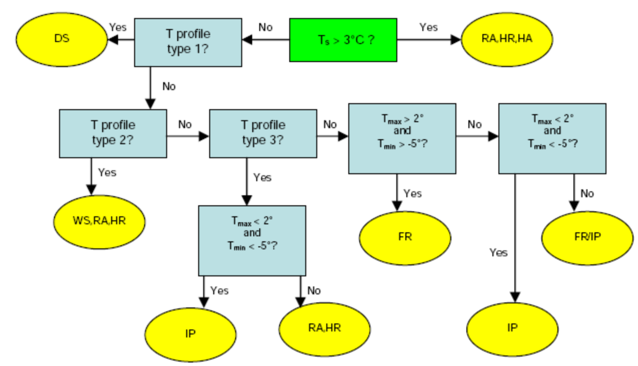


Fig. 4: Flow chart showing logistic for determination of precipitation types depending on vertical profile of wet bulb temperature.

Elevated warm layer	yes	yes	yes	yes	yes	yes
Background class	SN		All class except for RA	IP	FR/IP	RA
Condition	T_{wmin}< -7 °C	T_{wmin}>-7 °C	Median BBH < 1km			
Surface ID (final)	IP	FR/IP	WS	IP	FR/IP	RA

Elevated warm layer	No		No	No	No	No	No
Background class	SN		IP	FR/IP	RA	FR	WS
Condition	Z_{DR}>0.6 and Z<20 dBZ	otherwise					
Surface ID (final)	CR	DS	IP	FR/IP	RA	FR	WS

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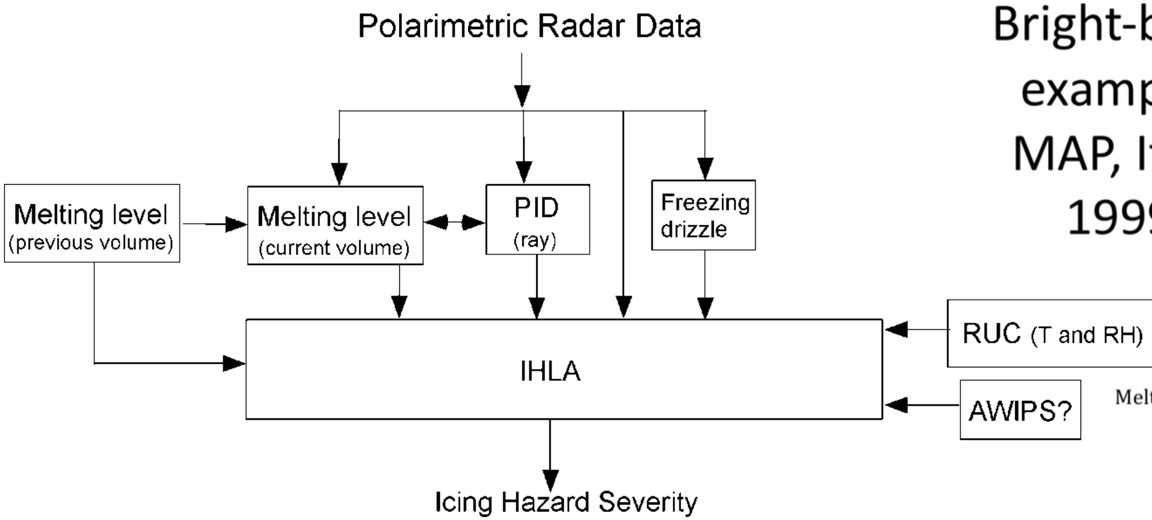
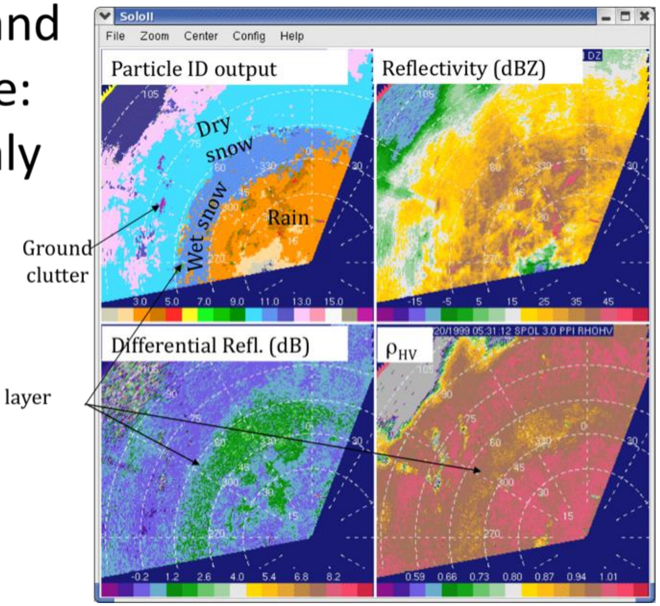
NCAR – Non-constrained Icing Hazard Levels (IHL) Algorithm Development



Bright-band example: MAP, Italy 1999



- **Two IHL approaches**
  - **Using current HCA augmented with CIP-like use of model thermodynamic profiles etc.**
  - **Using additional NCAR components (above) for later version(s)**

    Will NEXRAD ORPG environment support?
    Will NextGen Weather Processor be more appropriate?

- **Data sources**
  - **MAP via NCAR SPOL with in situ aircraft**
  - **CHILL radar**
  - **NEXRAD DP**

CIP = NCAR Current Icing Potential product
PID = NCAR Particle Identification algorithm

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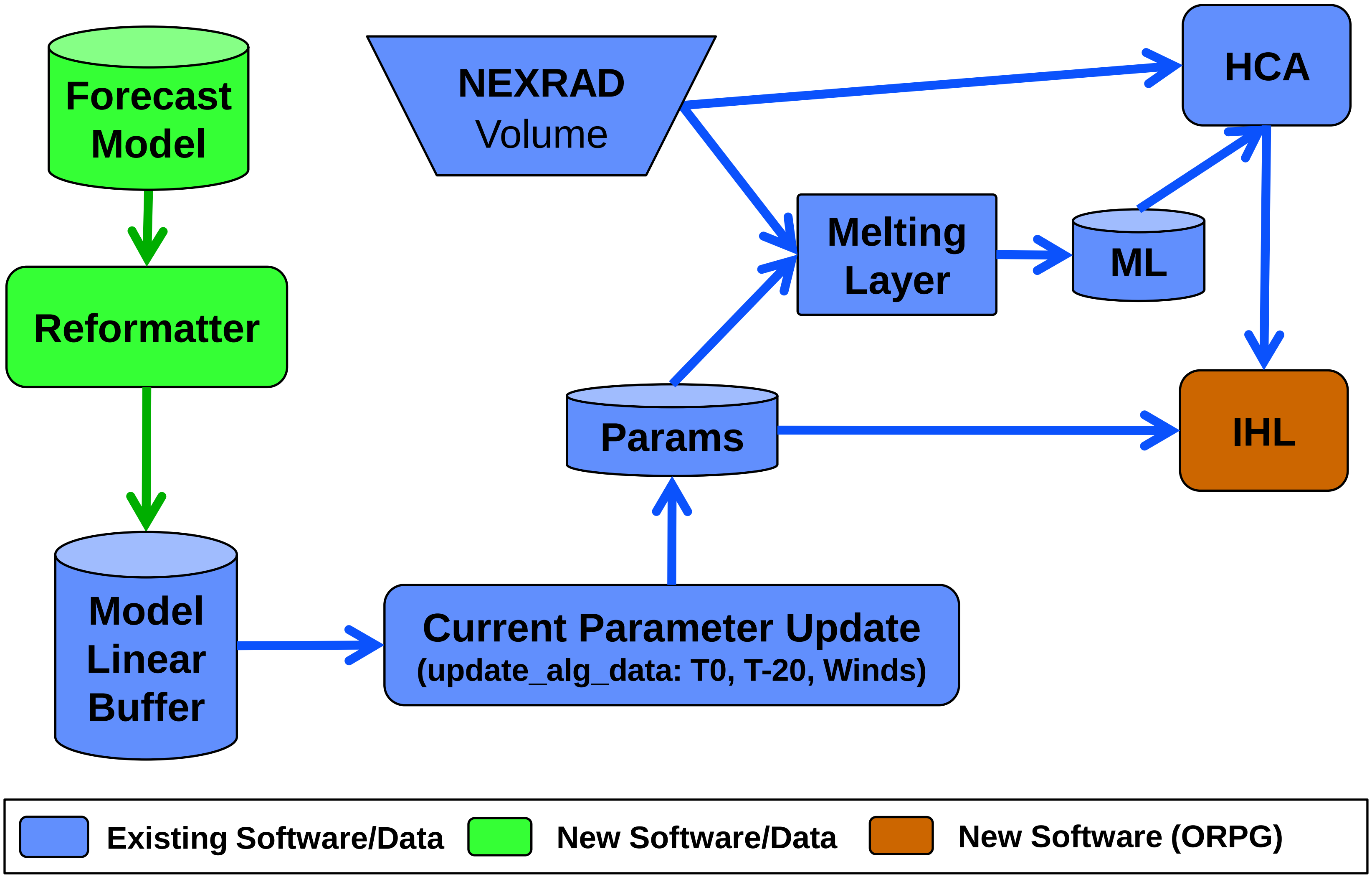
Icing Hazard Levels (IHL)
Initial Operating Capability



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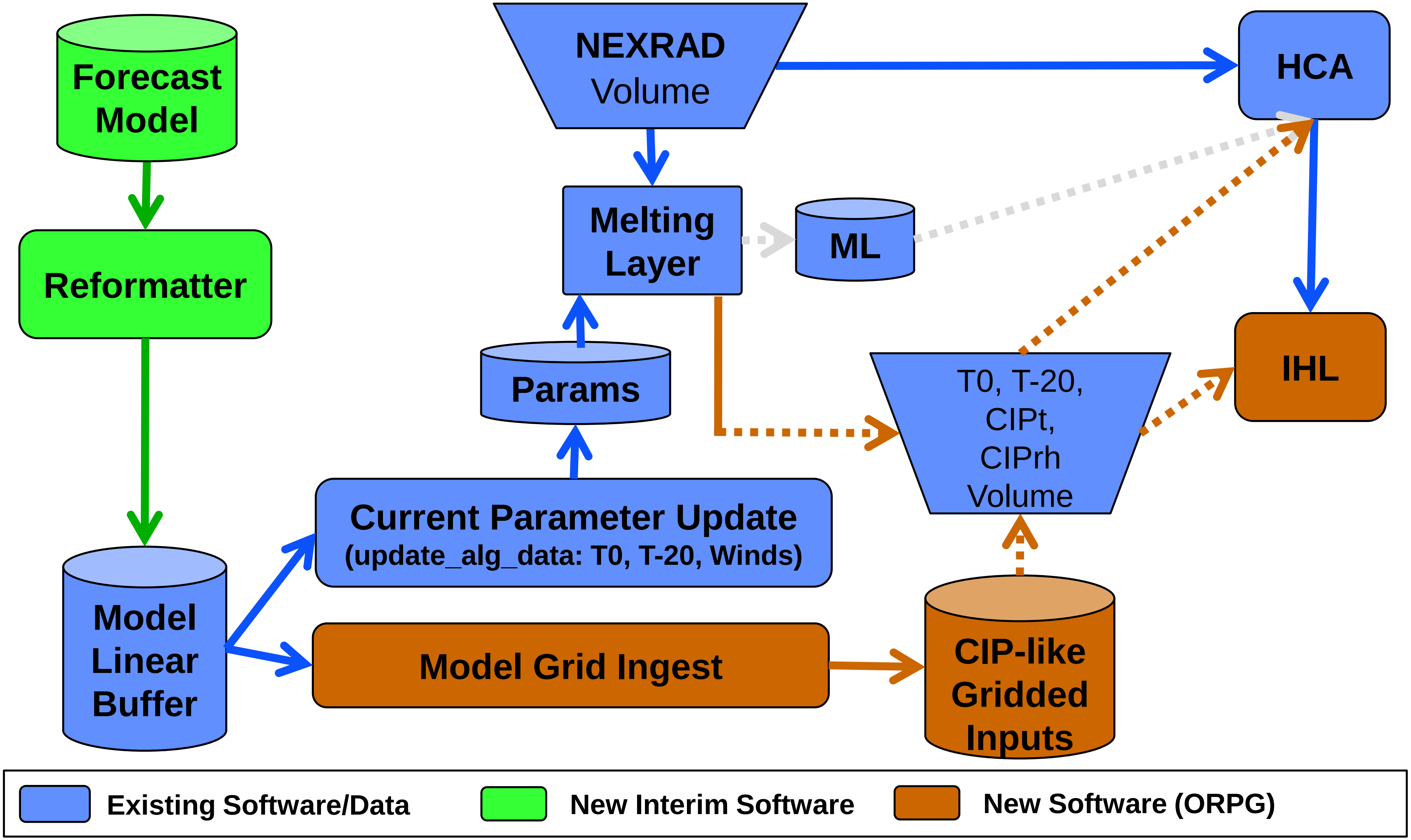
Icing Hazard Levels (IHL)
CIP-Enhanced Environmental Support



CIP = NCAR Current Icing Potential product

Icing Hazard Levels (IHL) Development Challenges

- Melting Layer Detection Algorithm
  - Some minor errors in the MLDA layer calculation
  - Default freezing level important
    - Updated to ingest RUC model data for defaults
  - Spatial changes are important in icing situations
    - Freezing level or levels evolve during the storm
    - Current algorithm uses only the radar location for freezing level
    - Updating to create dynamic freezing level from merging model and MLDA over entire grid
- Hydrometeor Classification Algorithm categories
  - Thresholding based on melting level limits flexibility
  - Icing algorithm may benefit from understanding ‘confusion matrix’ rather than single category
- Verification
  - Hail and differentiation of liquid/frozen categories are easily verified based on ground observations
  - Refining verification of graupel, wet snow, dry snow, etc. more challenging
    - Working on utilizing manual/automated techniques to verify frozen categories with greater differentiation

HCA Relationship to Icing Hazard

Thresholds \ Categories		No Echo NE	Dry Snow DS	Wet Snow WS	Ice Crystals IC	Graupel GR	Big Drops BD	Light/Mod Rain RA	Heavy Rain HR	Rain and Hail RH	Ground Clutter/AP GC	Biological BI	Unknown UK
Melting Layer	Above	Unknown	None	None	Icing	Icing	Icing	Icing	Icing	Icing	Unknown	Unknown	Unknown
	Mostly Above	Unknown	None	None	Icing	Icing	Icing	Icing	Icing	Icing	None	Unknown	Unknown
	Within	Unknown	None	None	Unknown	Icing	Conditional	Conditional	Conditional	Icing	None	None	Unknown
	Mostly Below	None	None	None	Unknown	Conditional	None	None	None	None	None	None	None
	Below	None	None	None	None	None	None	None	None	None	None	None	None

HCA Classification Key
Current HCA Category
Not in HCA
Not enough information to classify

Icing Hazard Key	
Icing:	Definitive icing region
Conditional:	Potential hazard based on fluctuations in freezing level
None:	No icing
Unknown:	More research is needed

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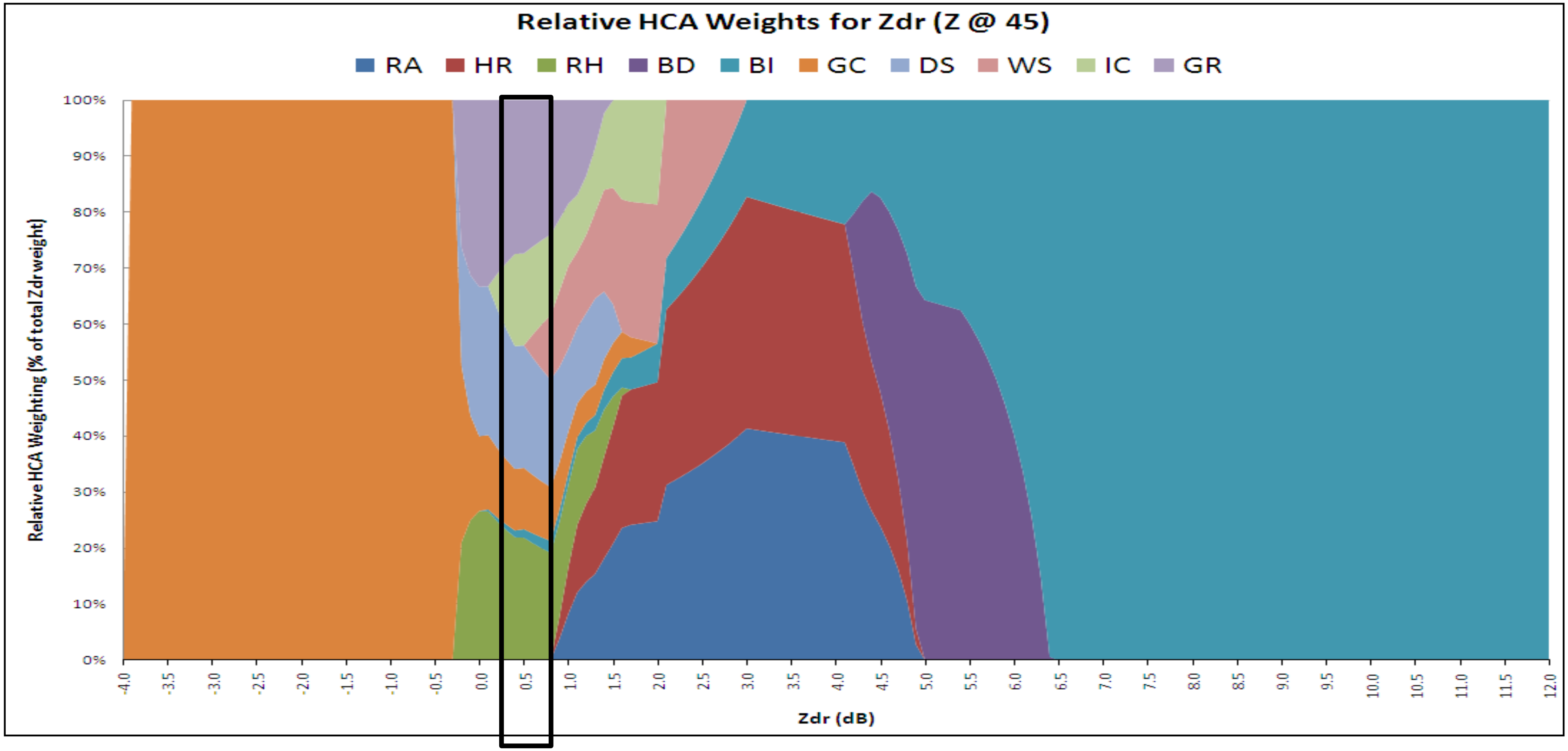
Sensitivity of HCA Parameter Weighting Functions



Zdr = 0.5	RA	HR	RH	BD	BI	GC	DS	WS	IC	GR	Sum
HCA Weight	0	0	0.8	0	0.06	0.4	0.8	0	0.6	1.0	3.66
%	0	0	22%	0	2%	11%	22%	0	16%	27%	100%

Small variations in Zdr result in large impacts to HCA

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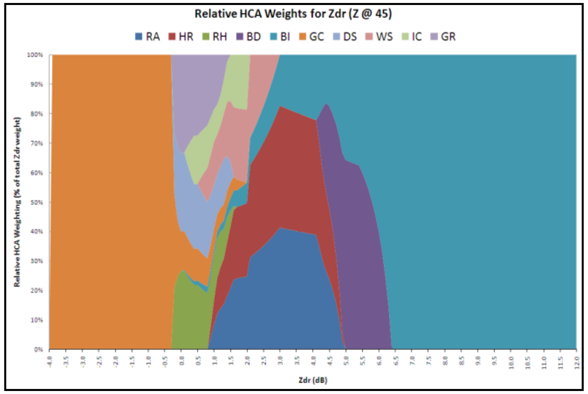
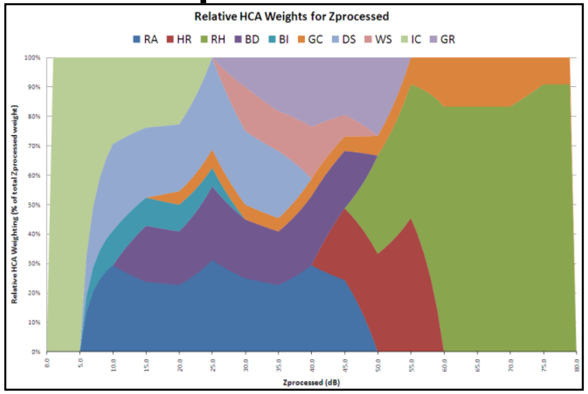
Sensitivity of HCA Parameter Weighting Functions

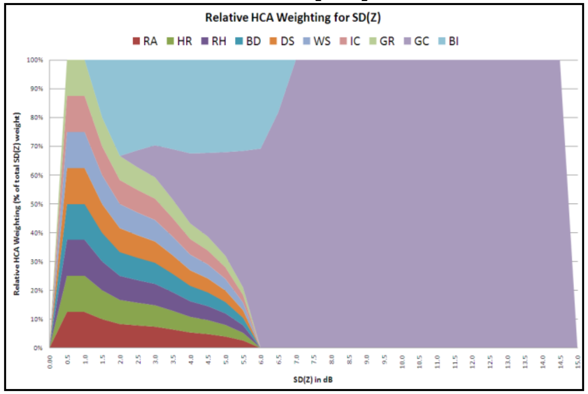
Zdr



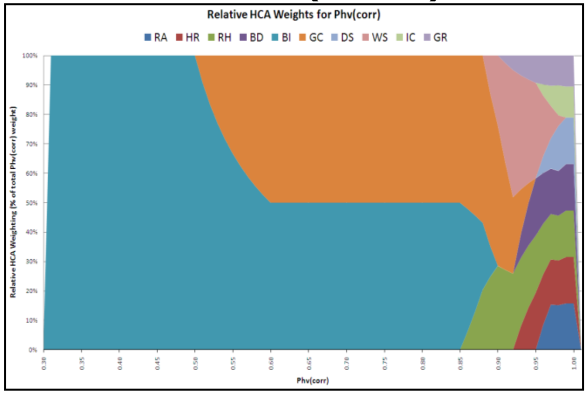
Zprocessed



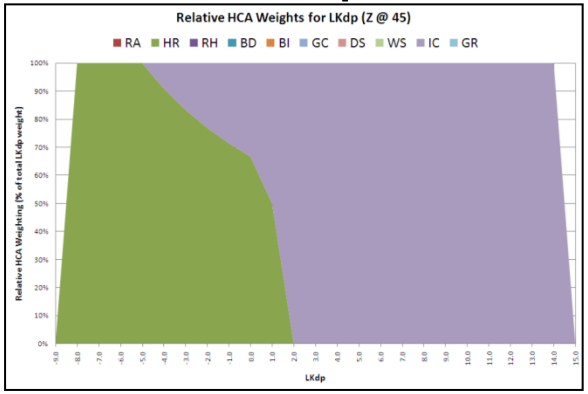
SD(Z)



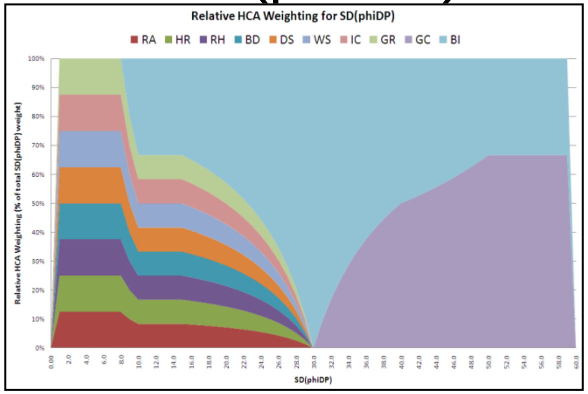
Rhohv(corr)



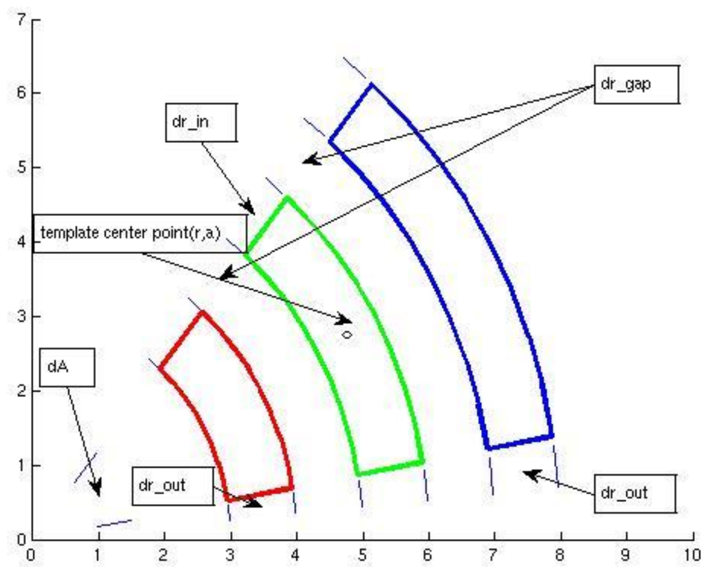
LKdp

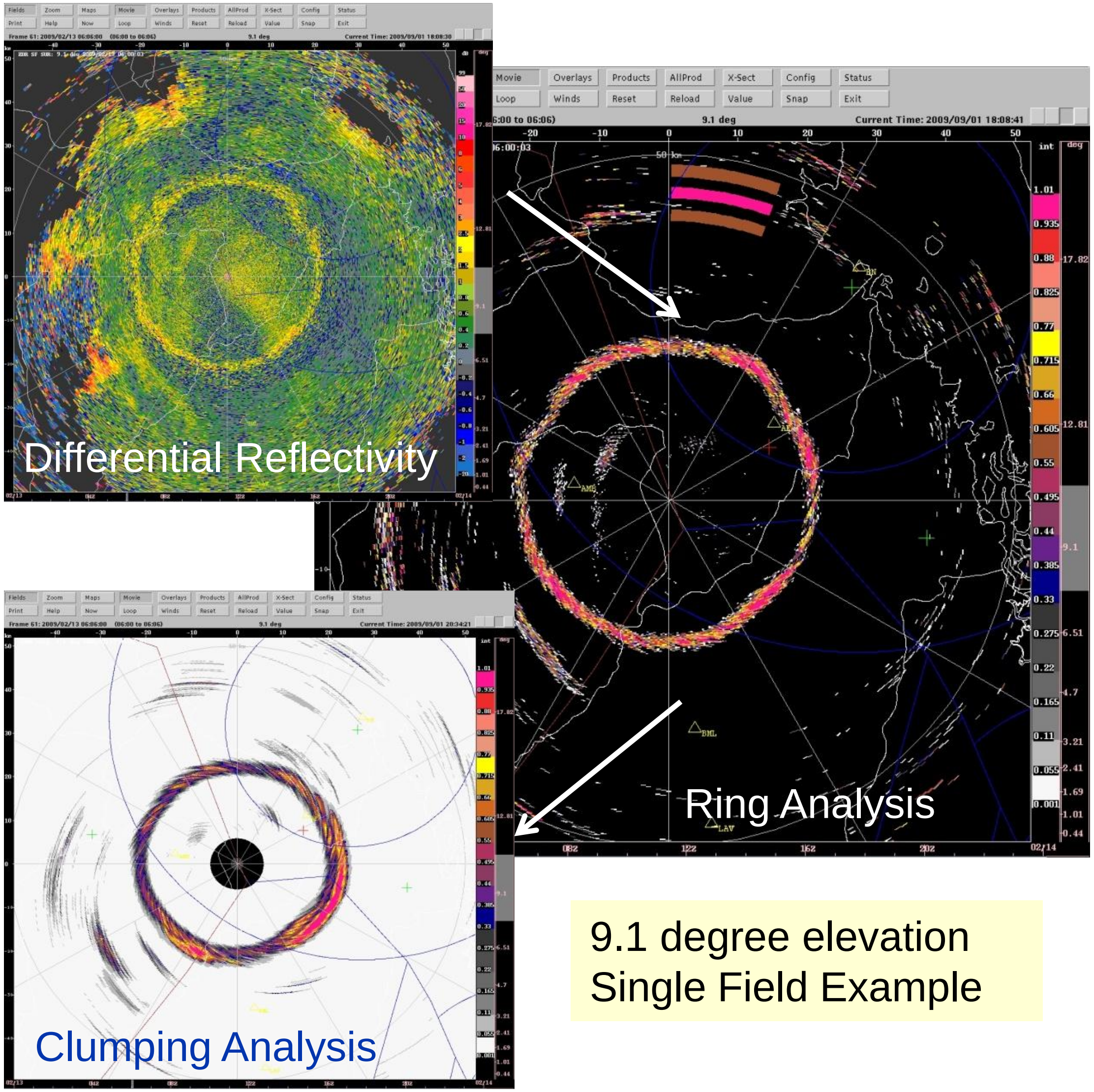


SD(phiDP)



NCAR Method for Detection of Melting Level Altitude





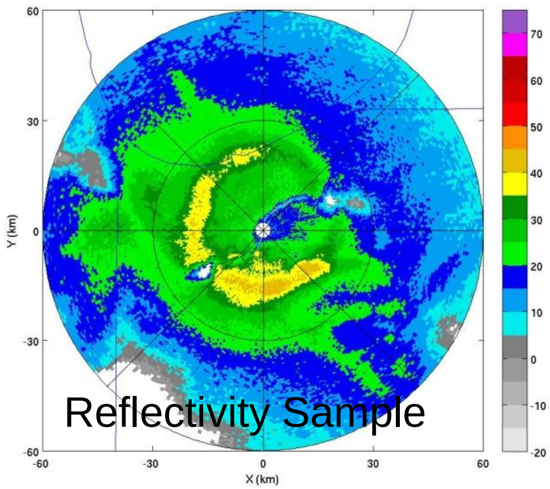
The data difference between the center (green) region and the non-center (blue and red) regions are computed and a derived value 'Ring(r,a)' is computed fo that point

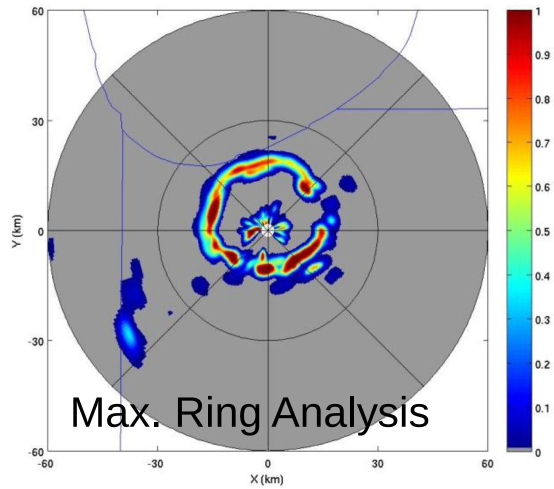
NCAR method is applied to Z, ZDR, ρ_{hv} for all elevation angle scans and then combined for consensus

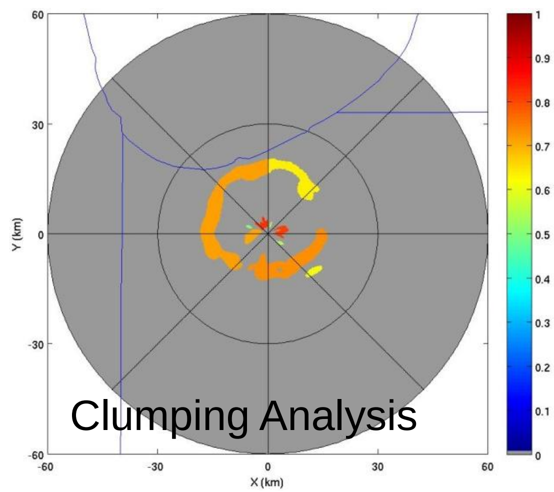
9.1 degree elevation
Single Field Example

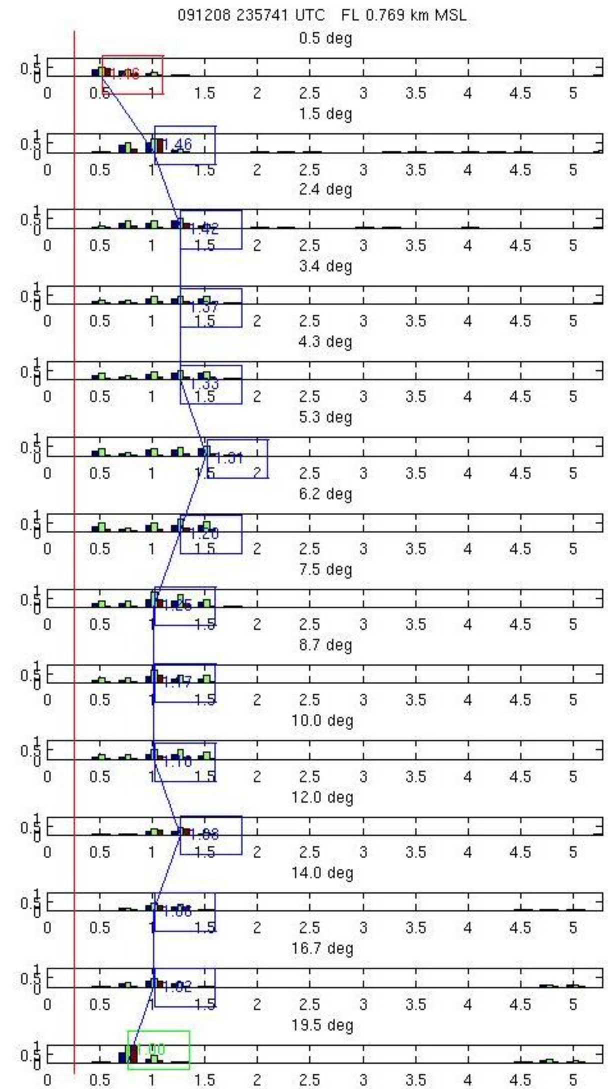
LL Implementation of NCAR Detection of Melting Layer Altitude

4.3 degree elevation Multi-Field Example





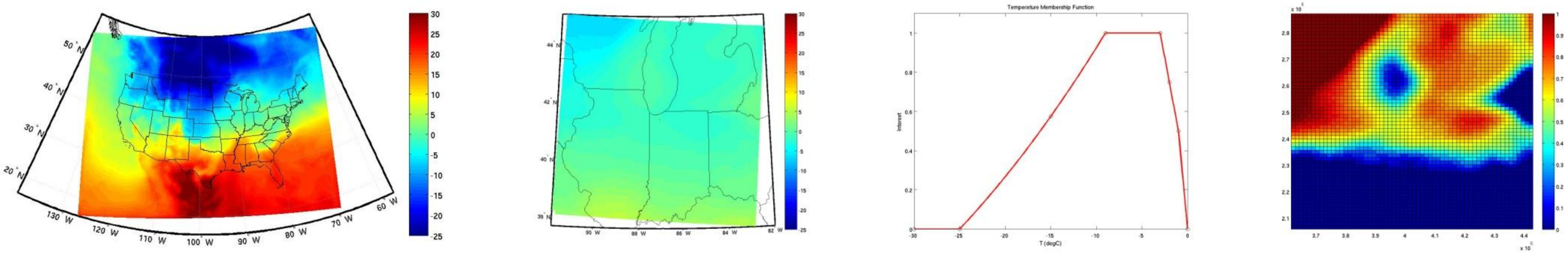




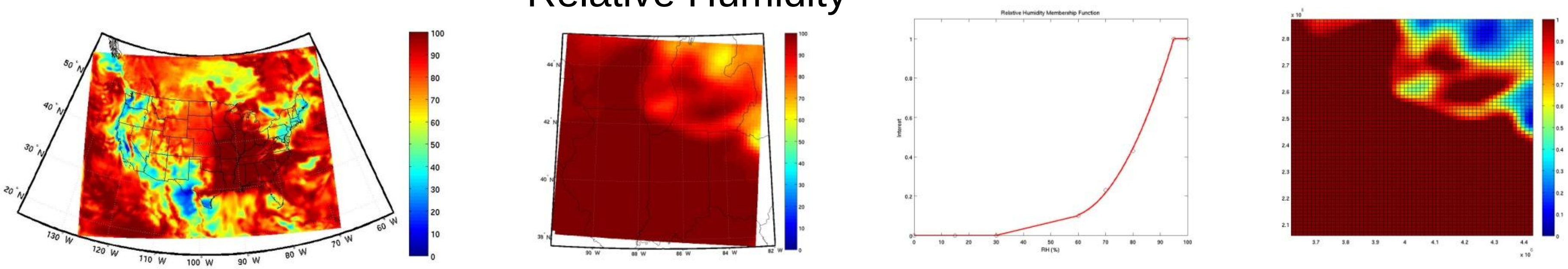
- **Valparaiso University dual pol data used**
- **Challenging double melting layer case**
- **Extend logic to other challenging cases and possibly +ZDR bright band**

Transform Model Data to NCAR CIP Interest Products Centered at Valparaiso

Temperature



Relative Humidity

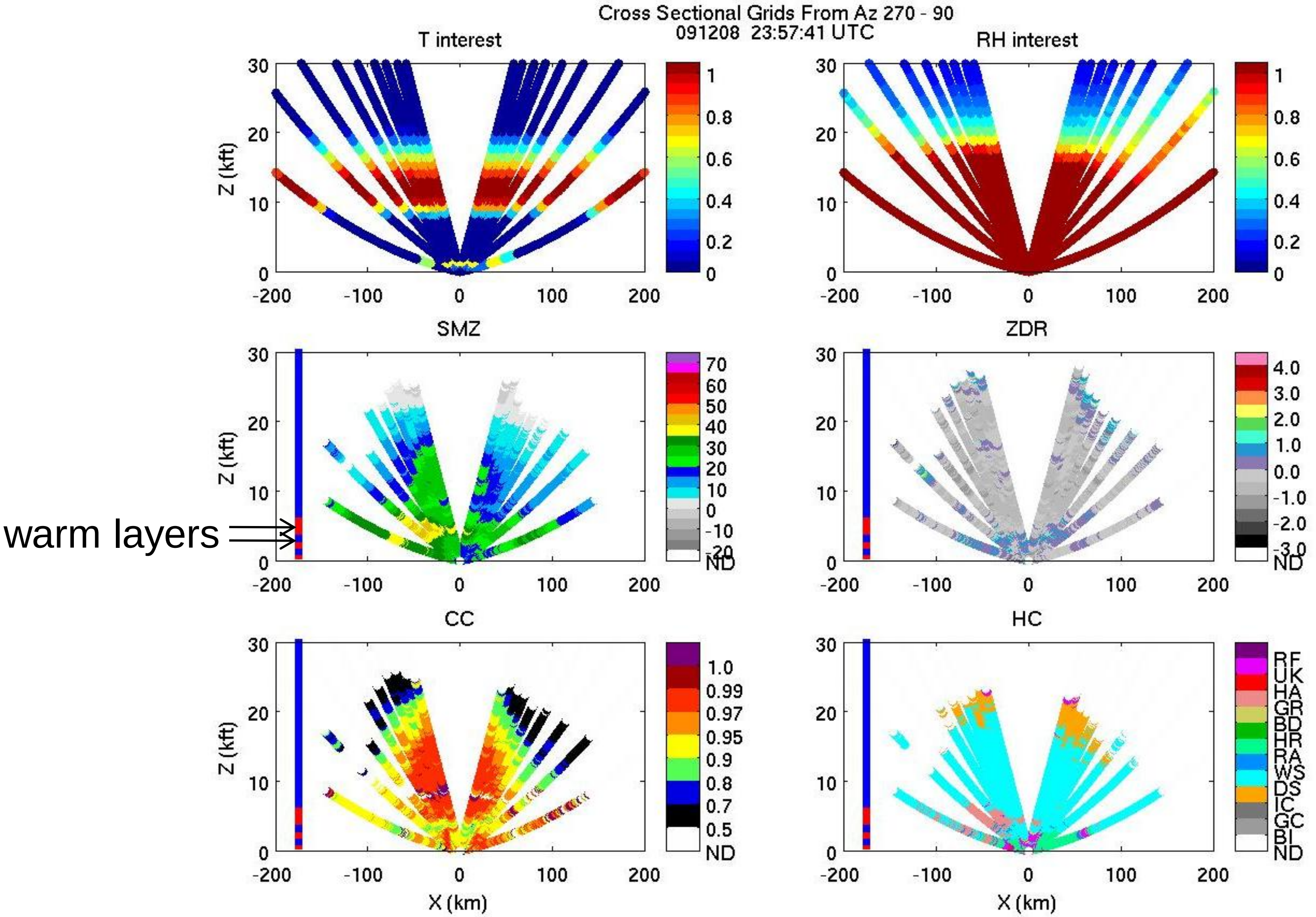


RUC-13 km Full Grid → Subsample ~800 km^2 → Membership Functions → Interest Grids

LL has added operational model capability to NEXRAD ORPG Common Operations and Development Environment

CIP = NCAR Current Icing Potential product

Apply NCAR CIP Interest Products to Valparaiso Data



CIP = NCAR Current Icing Potential product

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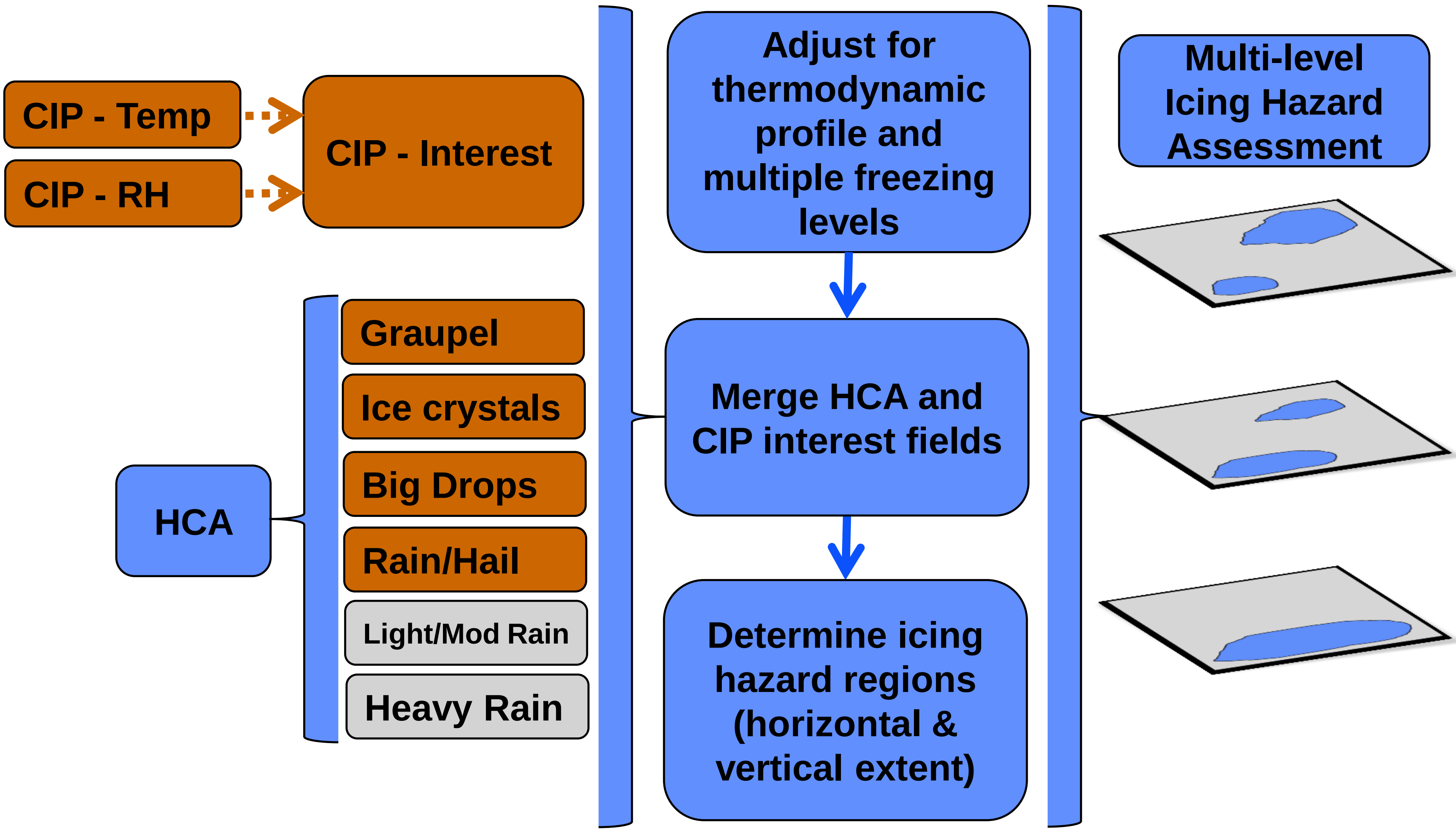
Icing Hazard Levels (IHL) Flow Revisited



CIP = NCAR Current Icing Potential product
HCA = NEXRAD Hydrometeor Classification Algorithm

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Icing Hazard Levels Example

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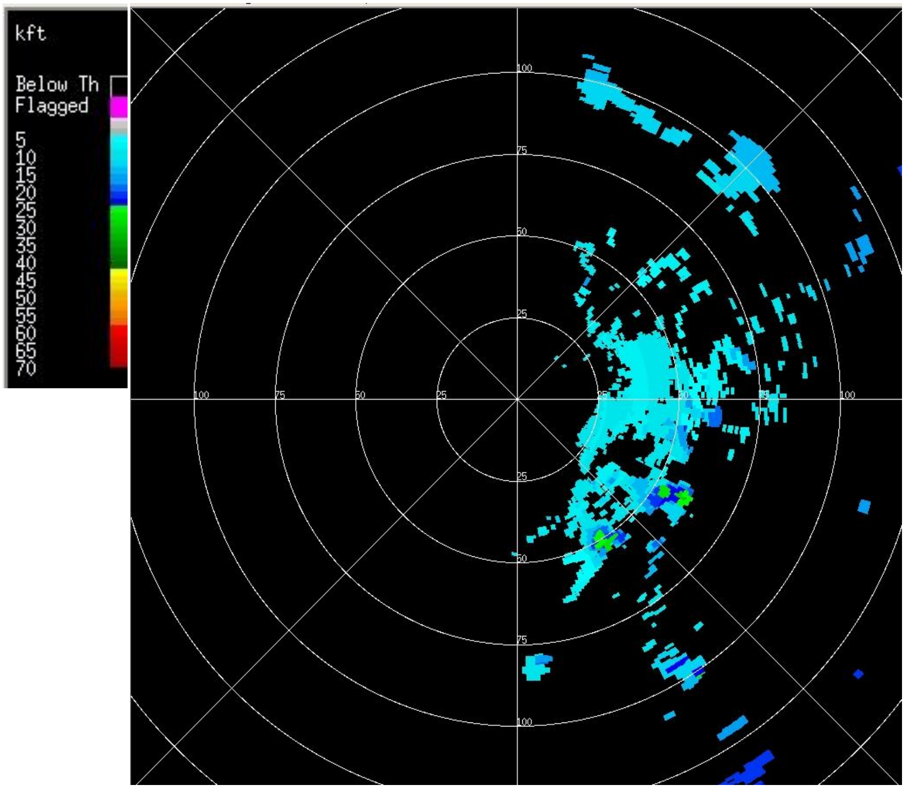
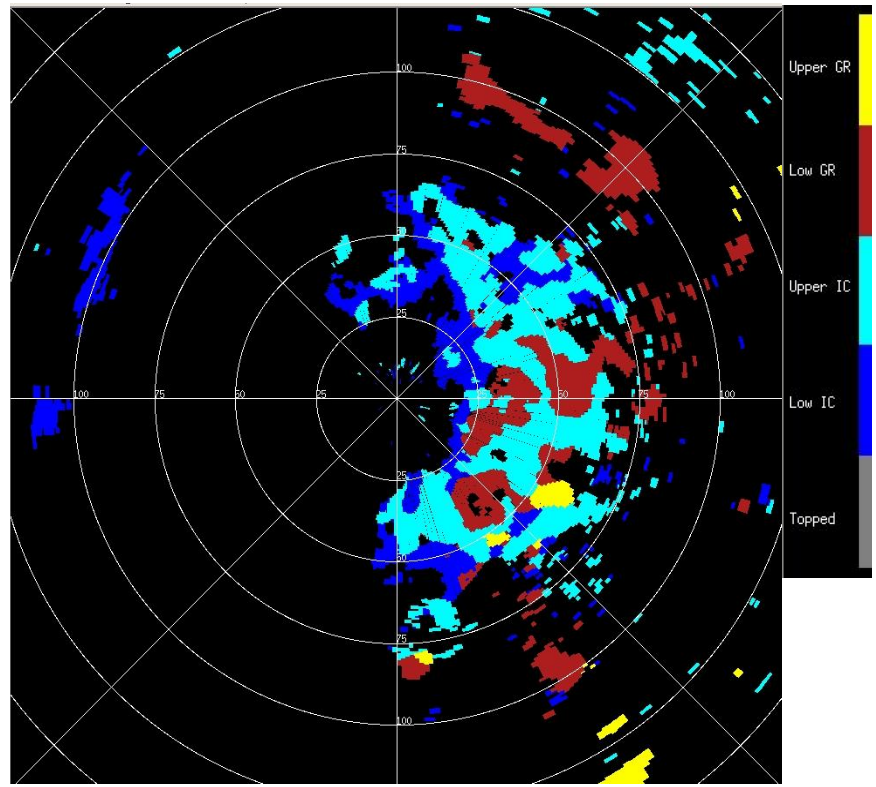
02/24/2011
1653 UTC



IHL – Graupel Tops



IHL – Dual Hazard Synthesis

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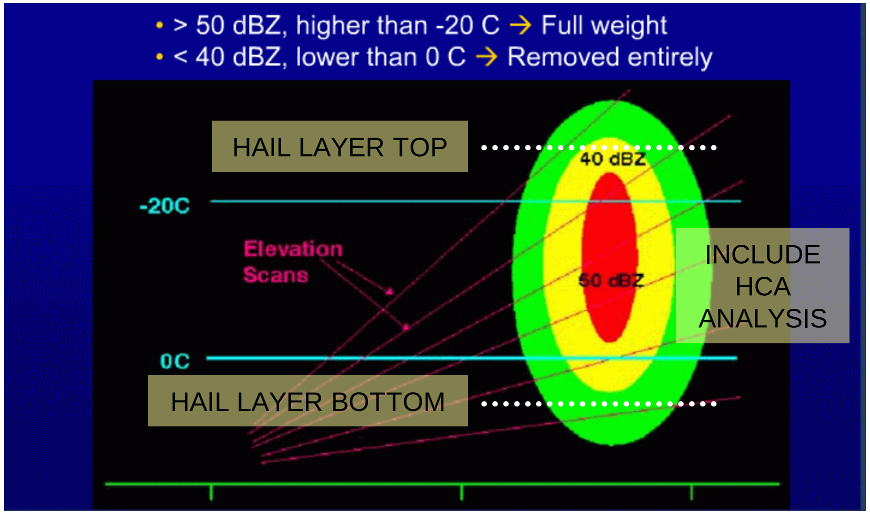
Outline

- Automated Microburst Detection Algorithm (AMDA)
- Dual Pol Algorithm Development Plan
- Icing Hazard
- Hail Hazard
- Data Quality Improvement
- High Res VIL Recovery

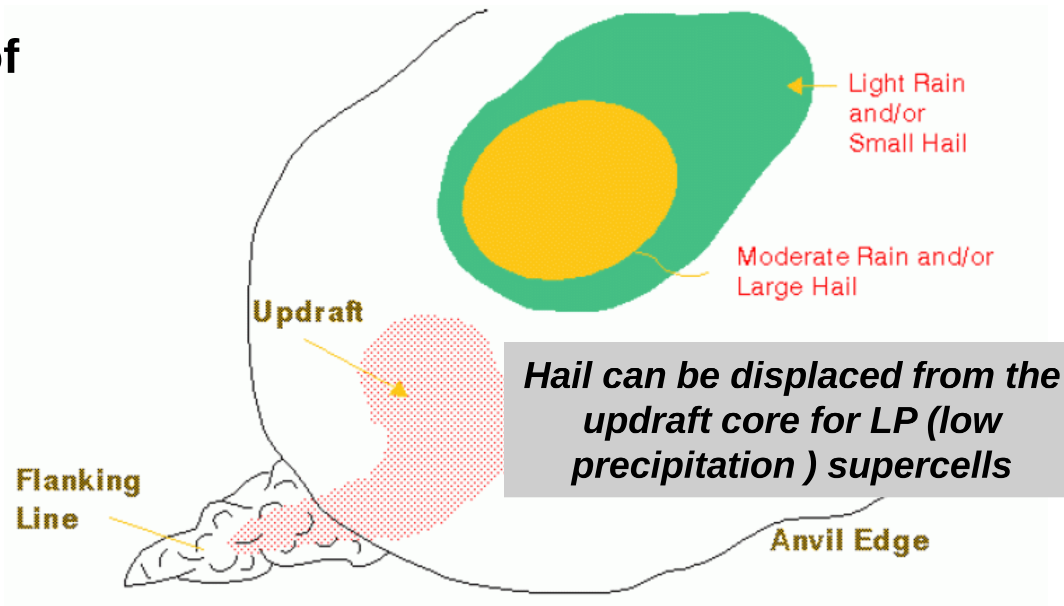
Hail Hazard Layers (HHL) Product

- **HHL Addresses**
  - **Unexpected hail aloft**
  - **Identify early hail potential (indicator of future cell intensity)**

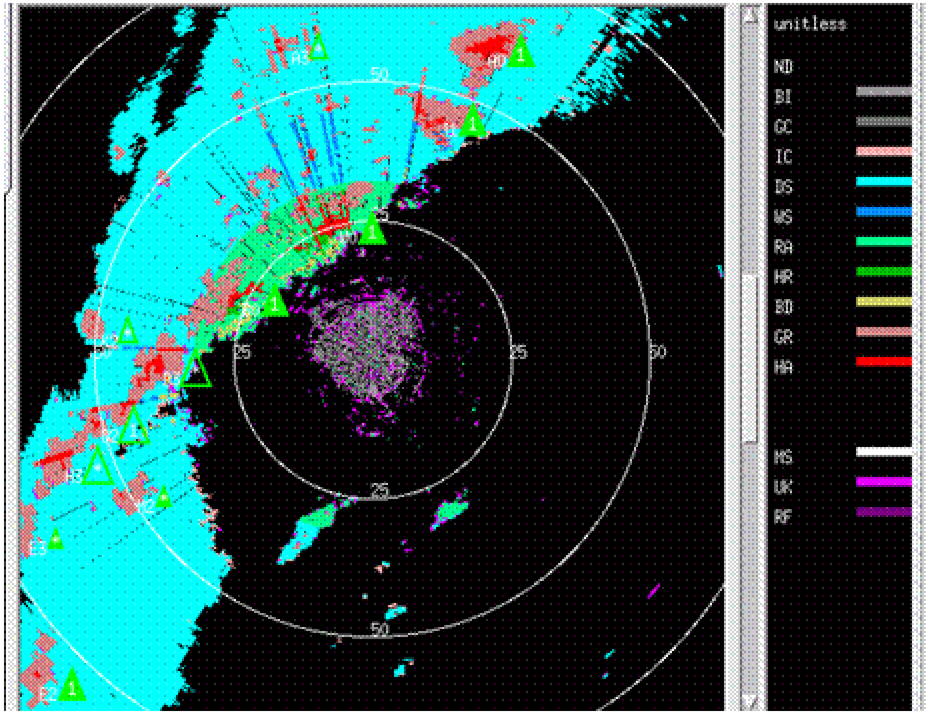
- **Supplement use of current NEXRAD hail algorithm by FAA weather systems**
  - **Provide vertical extent of hazard**
  - **ITWS operational use**
  - **WARP receives product**



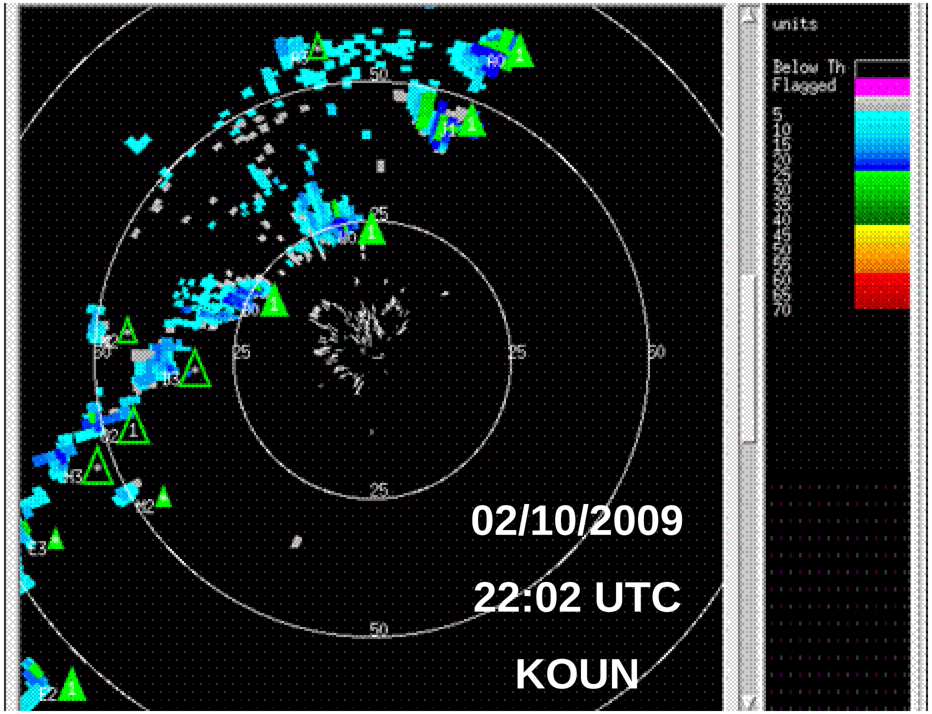
Heinselman and Ryzhkov (2006) show hail class algorithm with CSI of 89% vs. 56% for traditional algorithm



Hail Hazard Layers (HHL) Product Comparison



Hydrometeor Classification for mid-level scan of radar volume (red indicates rain/hail class)



HHL volume product depicting top altitude of hail found in radar volume by azimuth and range

Triangles are storm cells with hail identified by the legacy Hail algorithm. Large triangles represent greater hail likelihood. Filled triangles represent greater severe hail likelihood.

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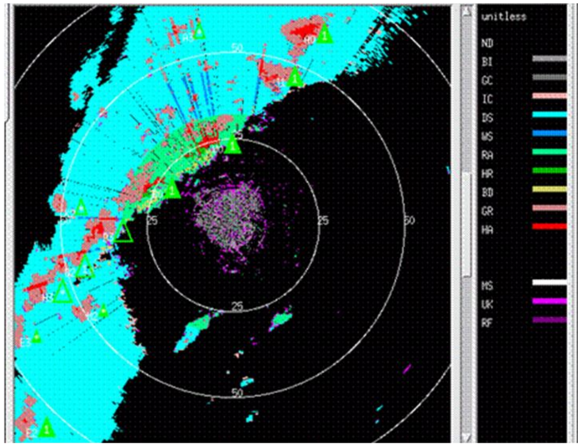
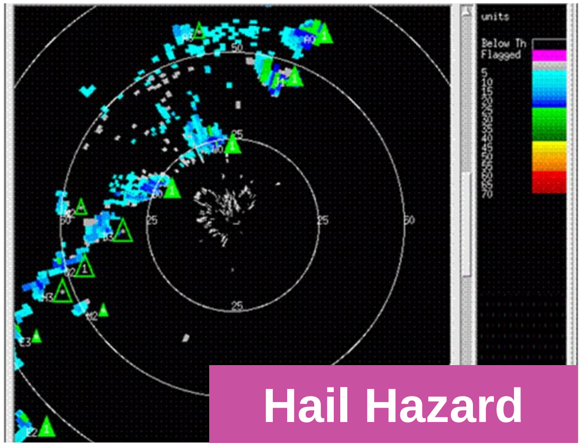
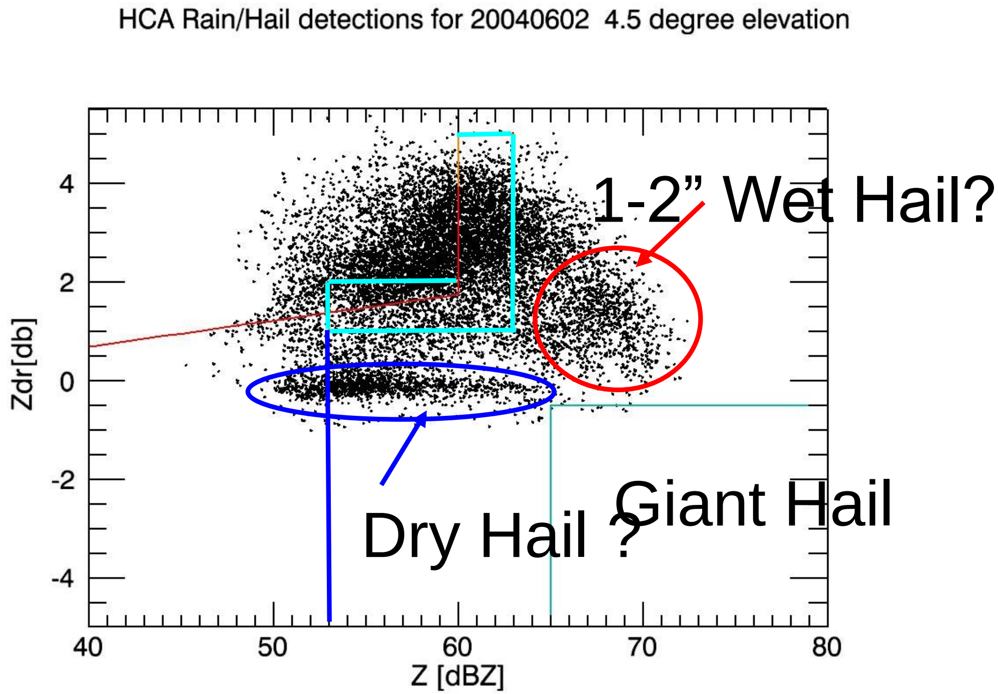
NSSL Large Hail Sizing Technique



Hydrometeor Classification for mid-level scan of radar volume (red indicates rain/hail class)



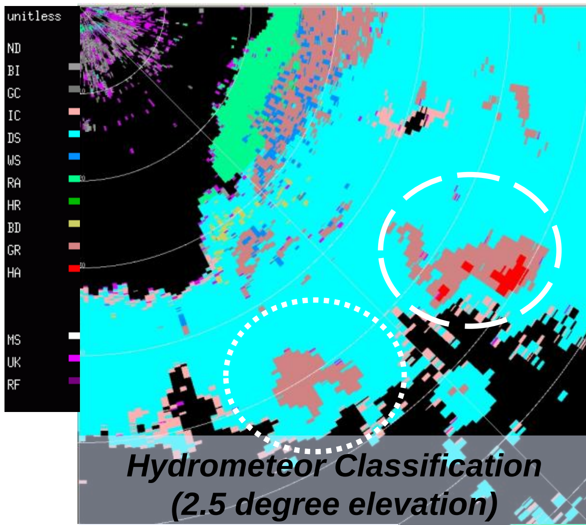
HHL volume product depicting top altitude of hail found in radar volume by azimuth and range

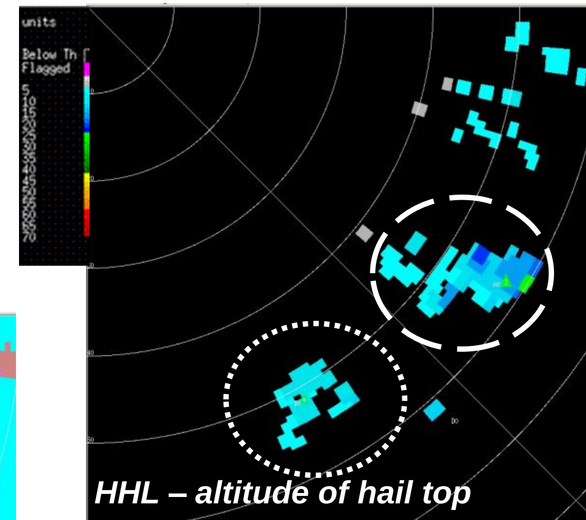


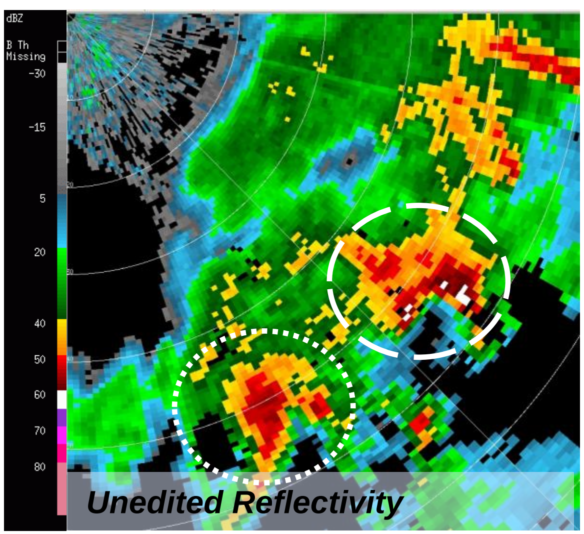
- **NEXRAD HCA rain/hail class is the basis for sizing of large hail**
- **NSSL method for large hail (> 2.5 cm dia.) uses Z, ZDR, ρ_{hv}, and height from melting layer**
- **Sizing logic will be a sidebar to NEXRAD HCA**
- **Small and giant hail sizing targeted for future**

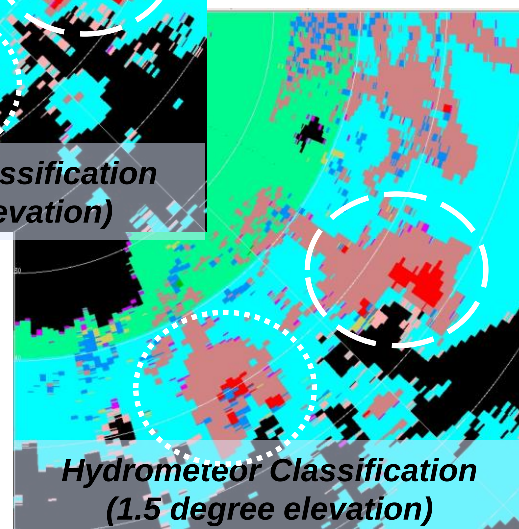
HHL Altitude Tops

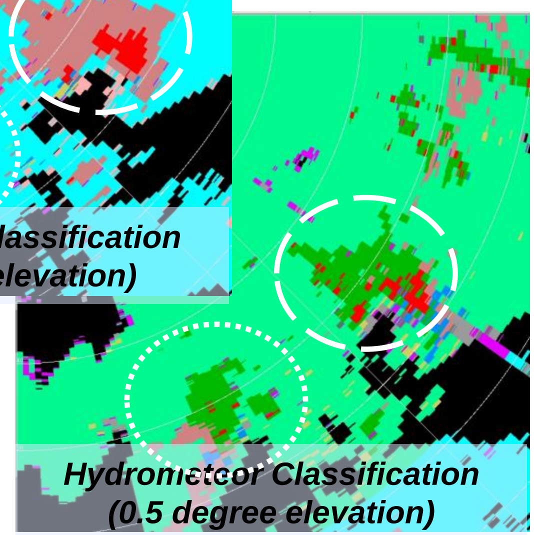
Note graupel class (pink) surrounds and caps rain/hail class (red) above freezing level











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02/24/2011
1653 UTC

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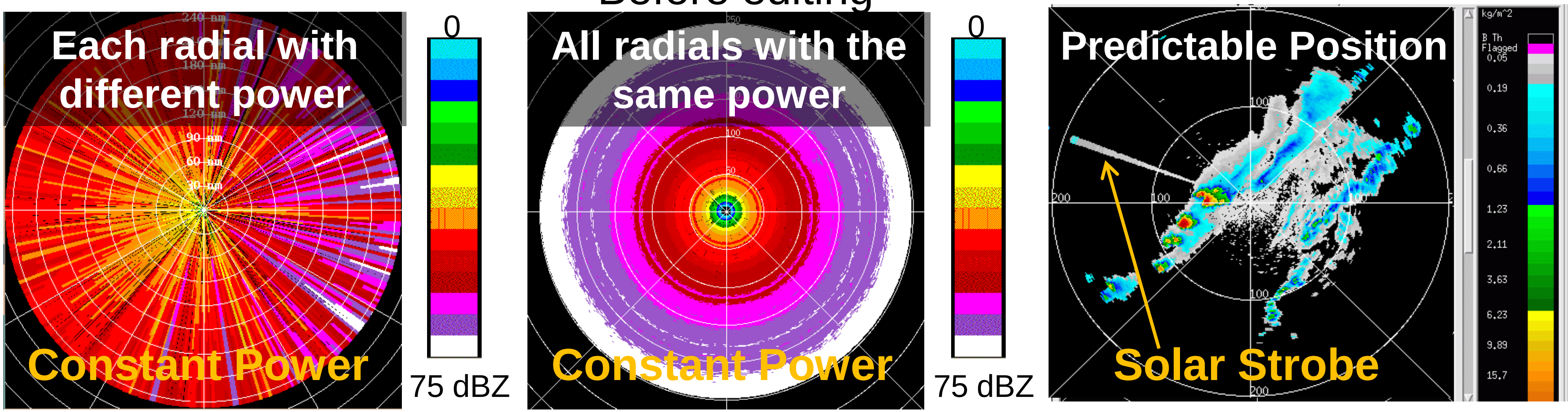
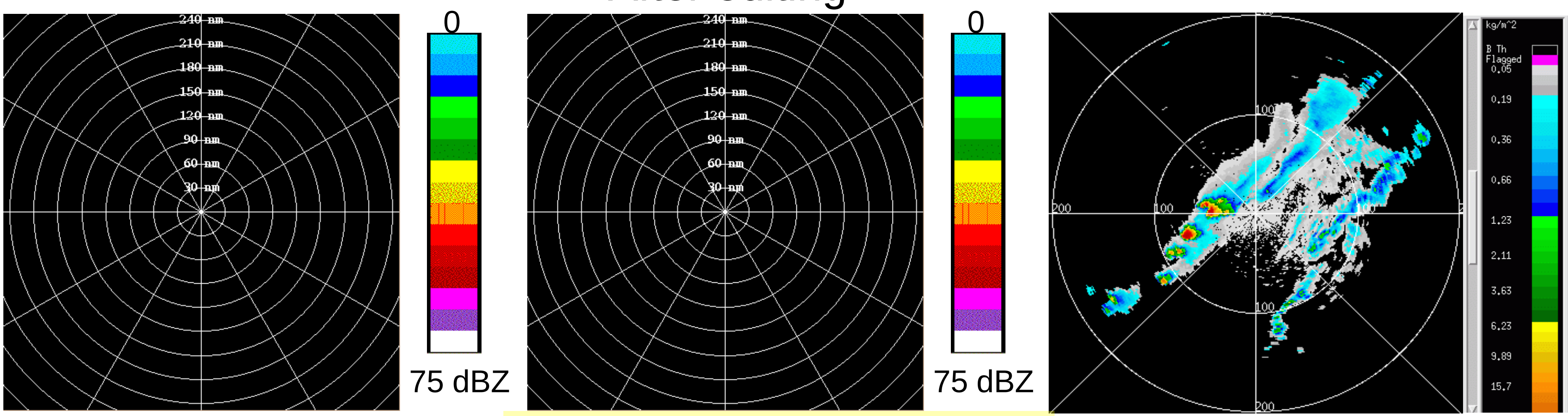
FAA Data Quality Assurance (DQA)
Radial Constant Power Removal Modules

Before editing



After editing



All images are precipitation products

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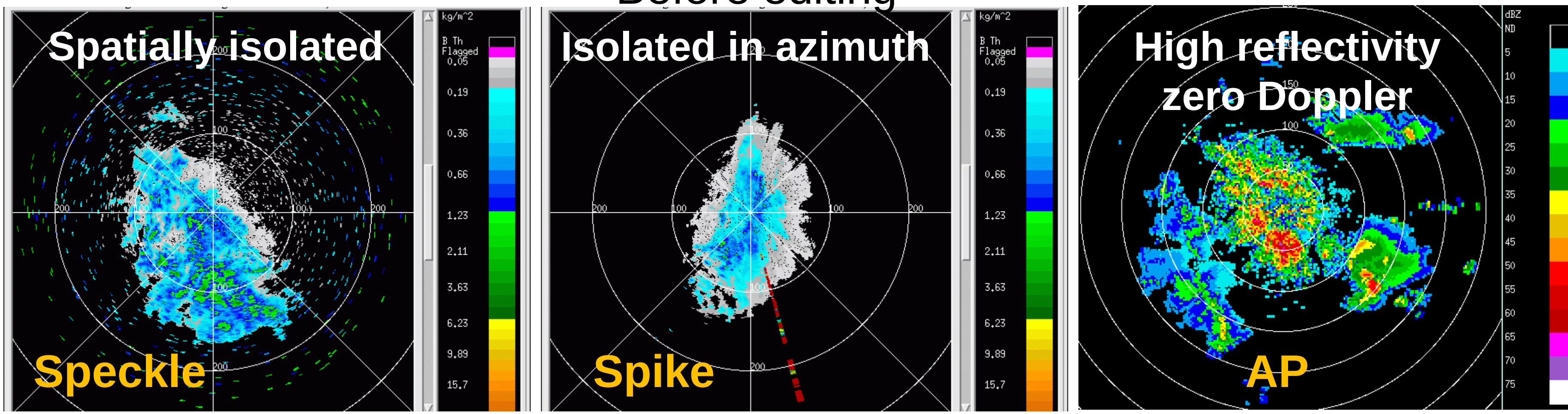
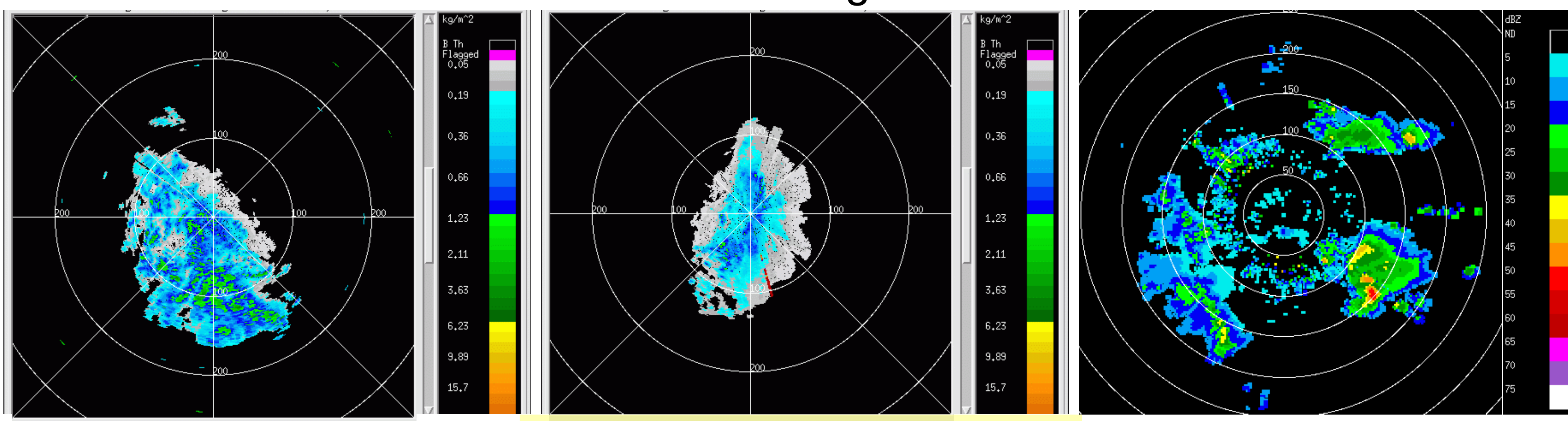
FAA Data Quality Assurance (DQA) Elevation tilt-based Removal Modules

Before editing



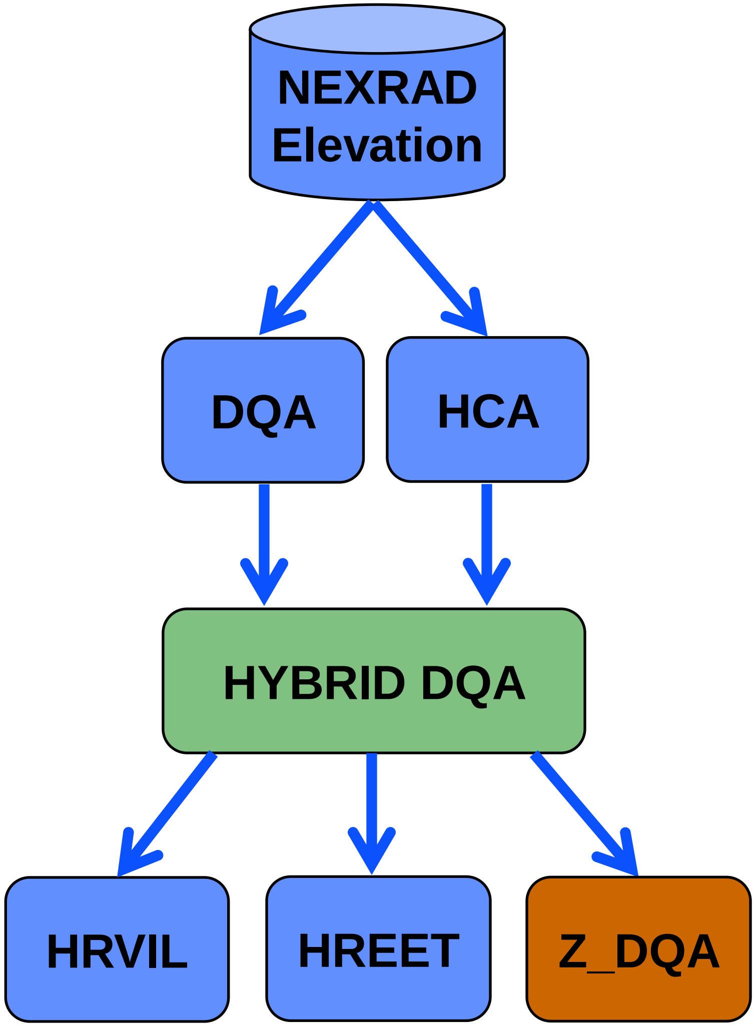
After editing



All images are precipitation products

Hybrid DQA Evolution

- **Up-convert logic modules to account for improved resolution data (¼ km, 1 deg. and ¼ km, ½ deg.)**
- **Integrate Dual Pol Hydrometeor Classification for removal of Ground Clutter and Biologicals**
- **Integrate up-convert and dual pol based modules into Hybrid DQA**
- **Work with NSSL, ROC, and Air Force to add class to Hydrometeor Classification Algorithm to *IDENTIFY CHAFF***



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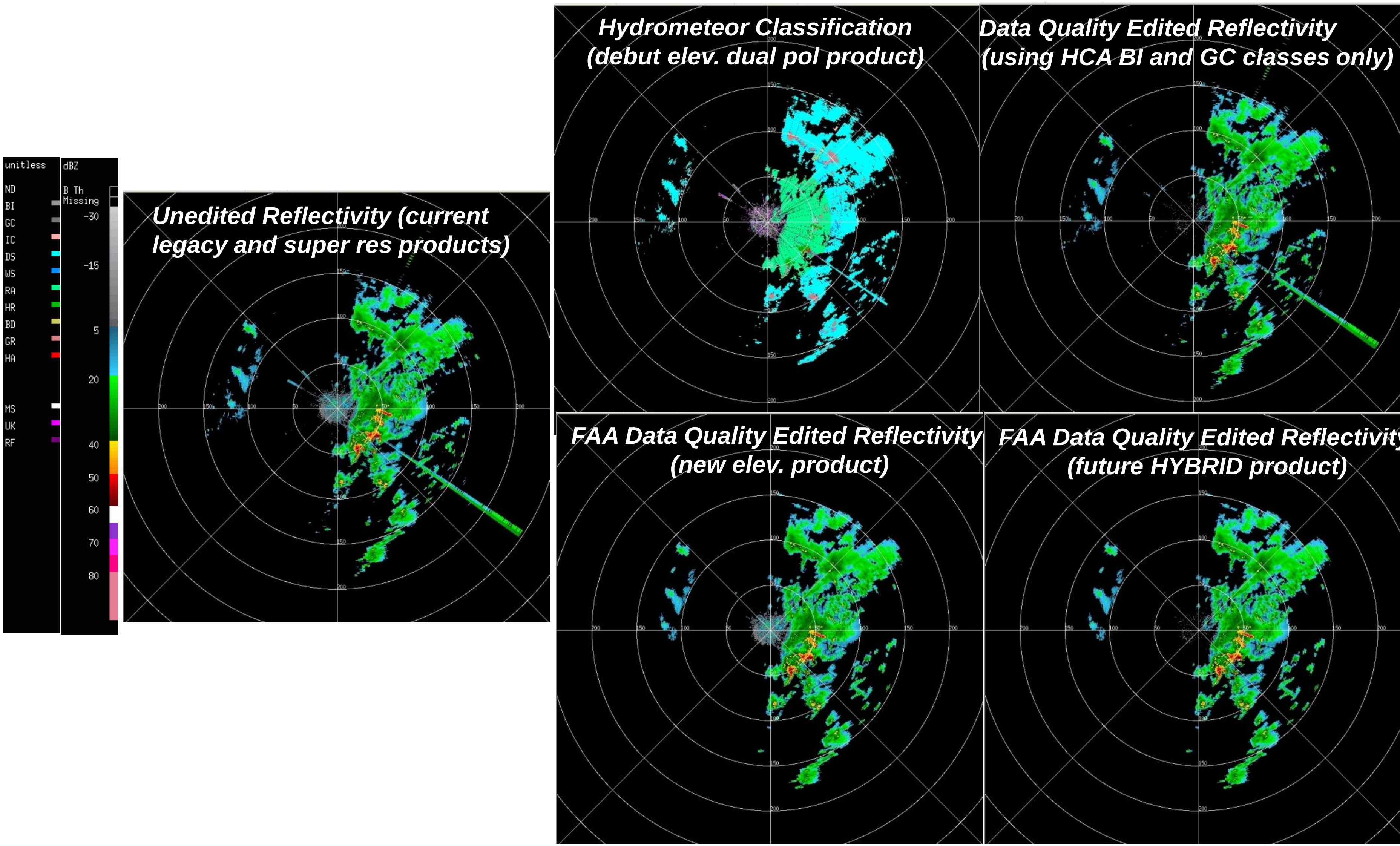
Hybrid DQA Example – KOUN Feb. 24, 2011 1653 UTC



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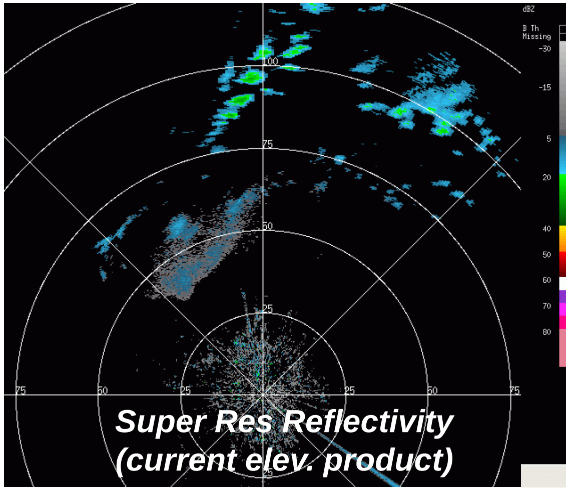
Path to the Future in NEXRAD Dual Pol Era



Super Res Reflectivity (current elev. product)

Super Res for Low Elevation Scans to 1.5^o

¼ km, ½^o

with ORDA CMDA

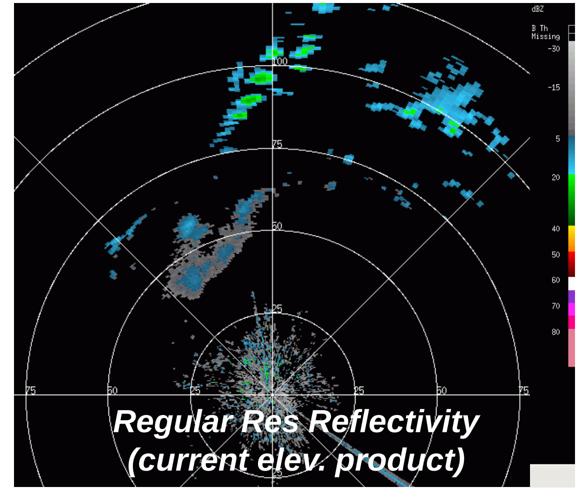
No ORDA CMDA with dual pol; to be restored circa 2014

Regular Res for Elevation Scans above 1.5^o

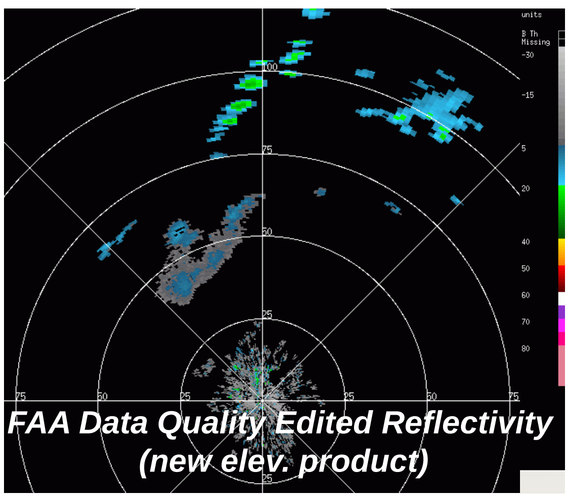
¼ km, 1^o

NO ORDA CMDA

Severe AP possible up to mid-volume scans



Regular Res Reflectivity (current elev. product)



FAA Data Quality Edited Reflectivity (new elev. product)

For All Scans

Best available res.

Possible for NextGen Segment 0

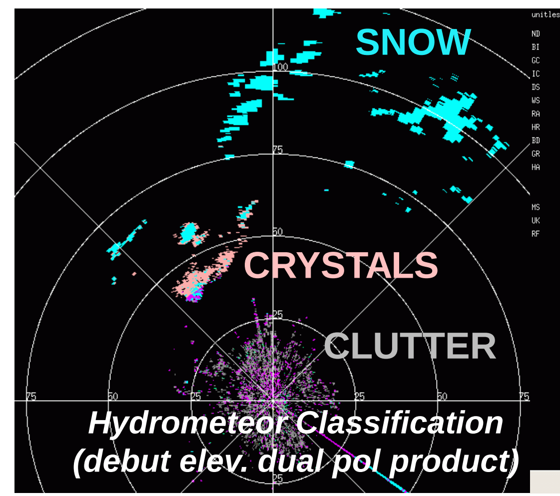
Will incorporate non-weather hydrometeor classes to further improve quality

For All Scans

¼ km, 1^o

Future new classes such as chaff

FAA likely needs aviation-specific classifier as HCA evolves for precip estimation use



Hydrometeor Classification (debut elev. dual pol product)

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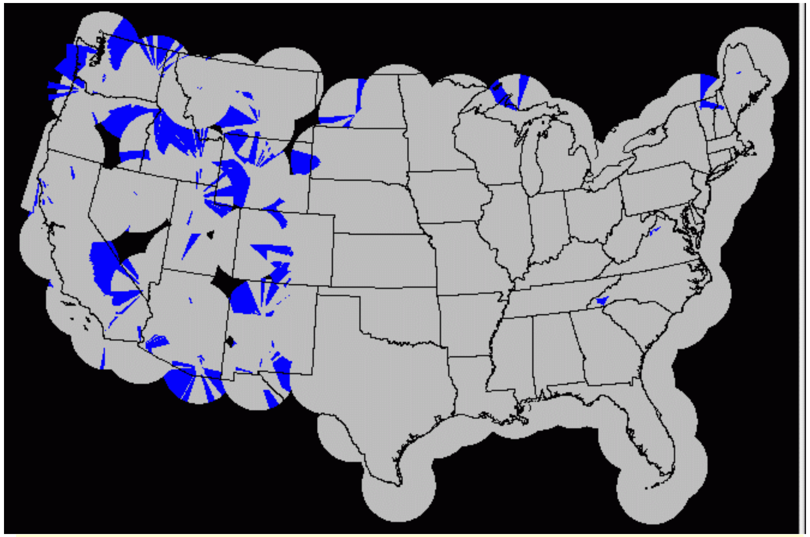
High Resolution VIL Recovery with Dual Pol Data

The western US NEXRAD network impacted by terrain blockage



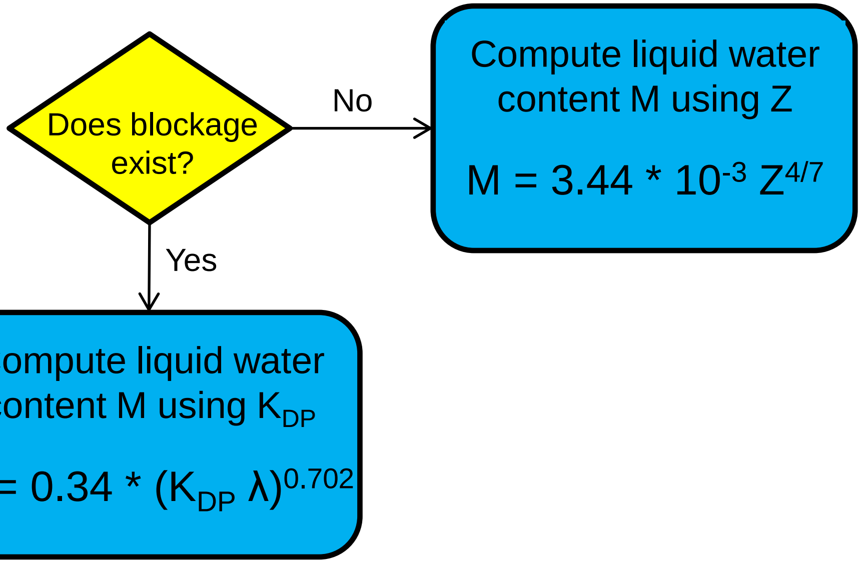
NEXRAD 230 KM COVERAGE (GRAY) WITH PARTIAL BLOCKAGE (BLUE)

- **HRVIL Recovery benefit**
  - **Recover VIL "lost" to beam blockage from natural and man-made obstructions**
  - **Removal of contaminants from HRVIL (hail, bright band)**
  - **Potential for "VIL" by type**

Partial Beam Blockage Mitigation Using Dual Polarization

- **Bias in Z due to partial beam blockage (PBB) negatively affects downstream algorithms (VIL, QPE)**
- **Dual polarization provides capabilities to mitigate PBB through specific differential phase (K_{DP}) derived from differential phase (Φ_{DP}), which is immune to blockage**

Example logic to mitigate PBB for VIL



- **LL and NSSL found NEXRAD K_{DP} product not satisfactory to mitigate partial beam blockage**

VIL = Vertically Integrated Liquid
QPE = Quantitative Precipitation Estimate

Z = reflectivity
λ = wavelength

NSSL Z-Φ_{DP} Method to Adjust Z for Partial Beam Blockage

- **Robust method is based on the general idea of consistency between reflectivity Z, specific differential phase K_{DP}, and differential reflectivity Z_{DR} in rain**
  - **NSSL method based in the power-law K_{DP} – Z relation (Ryzhkov *et al*. 1997)**

$$K_{DP} = a * Z^{b}$$

- **Variable intercept *a* is determined on the scan-to-scan basis using the data in unblocked azimuthal directions**
  - **Primary variability of factor *a is* due to changes in drop size distributions that will vary from storm-to-storm**
  - **A climatological beam blockage fraction map is created to cover all azimuths for elevation scans with blockage**

- **Radial integrals of K_{DP} (i.e., Φ_{DP}) and Z are computed for each radial**
  - **Ratio of integrals compared in regions with and without blockage and correction applied to Z**

- **Method has potential to work in areas of significant (> 50%) blockage and accounts for dynamic atmosphere and earth surface changes**

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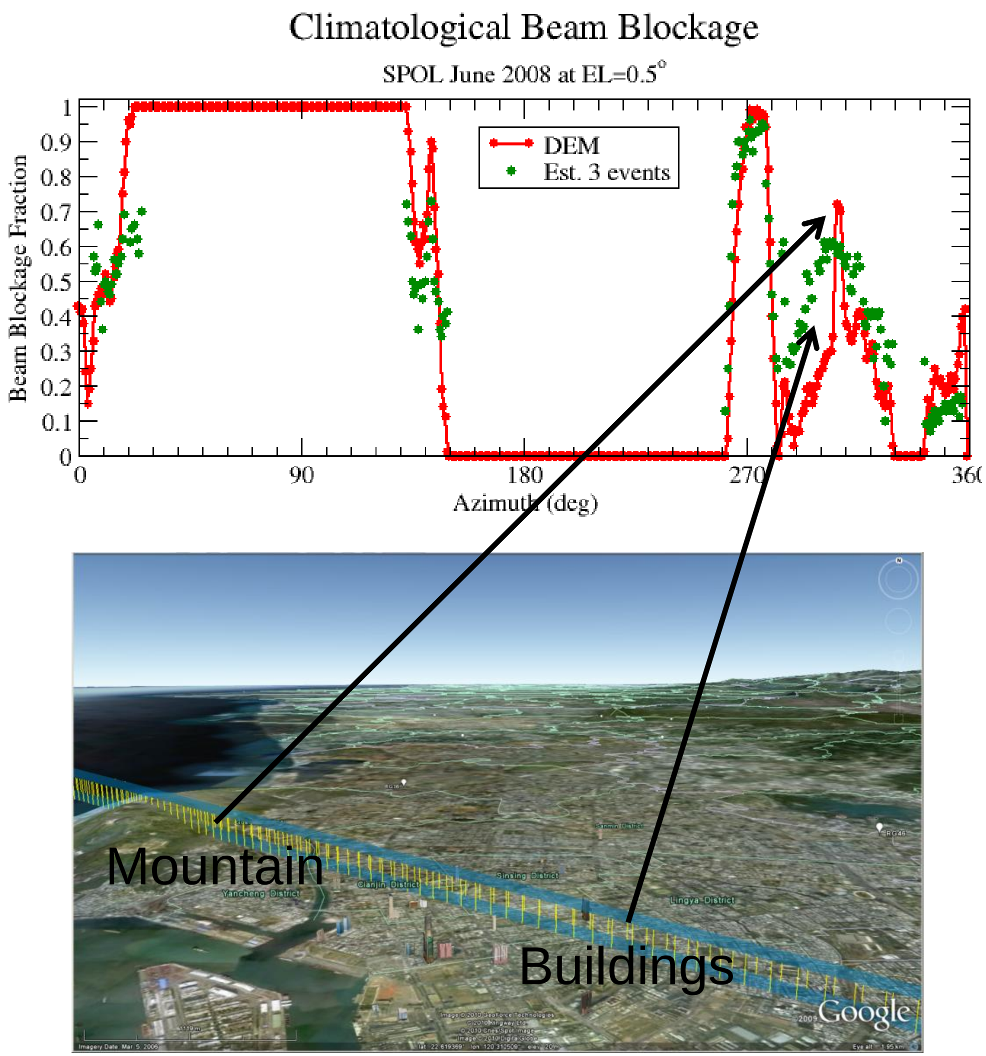
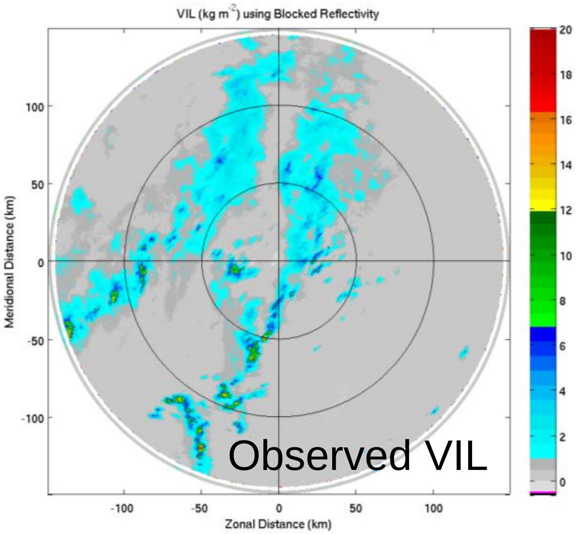
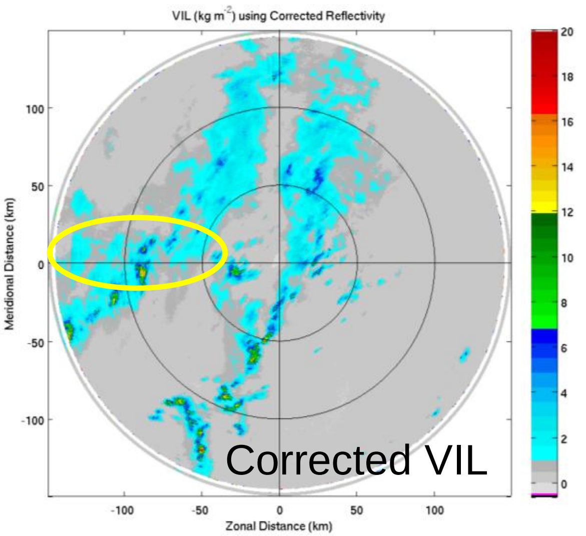
Climatological Beam Blockage







DEM = Digital Elevation Map

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Summary

- LL is operating and evaluating new dual pol algorithm products 24/7 live via KOUN data
  - Icing Hazard and Hail Hazard
  - Also hybrid dual pol data quality products
- Important contributions from partner scientists being evaluated and implemented to address multiple challenges
  - Additional contributions in development
- Collaborative discussion continues to relate the microphysics of mixed-phase conditions to robust dual pol signatures usable in real-time algorithms
- Spring/summer season will provide further opportunity to quantify performance of NEXRAD AMDA
- Version 1 dual pol algorithms could be transferred to the ROC by early 2012