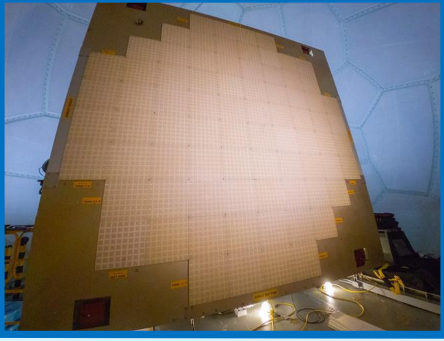
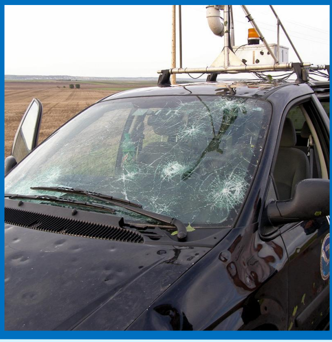
Forecast/Warning Tools and Techniques

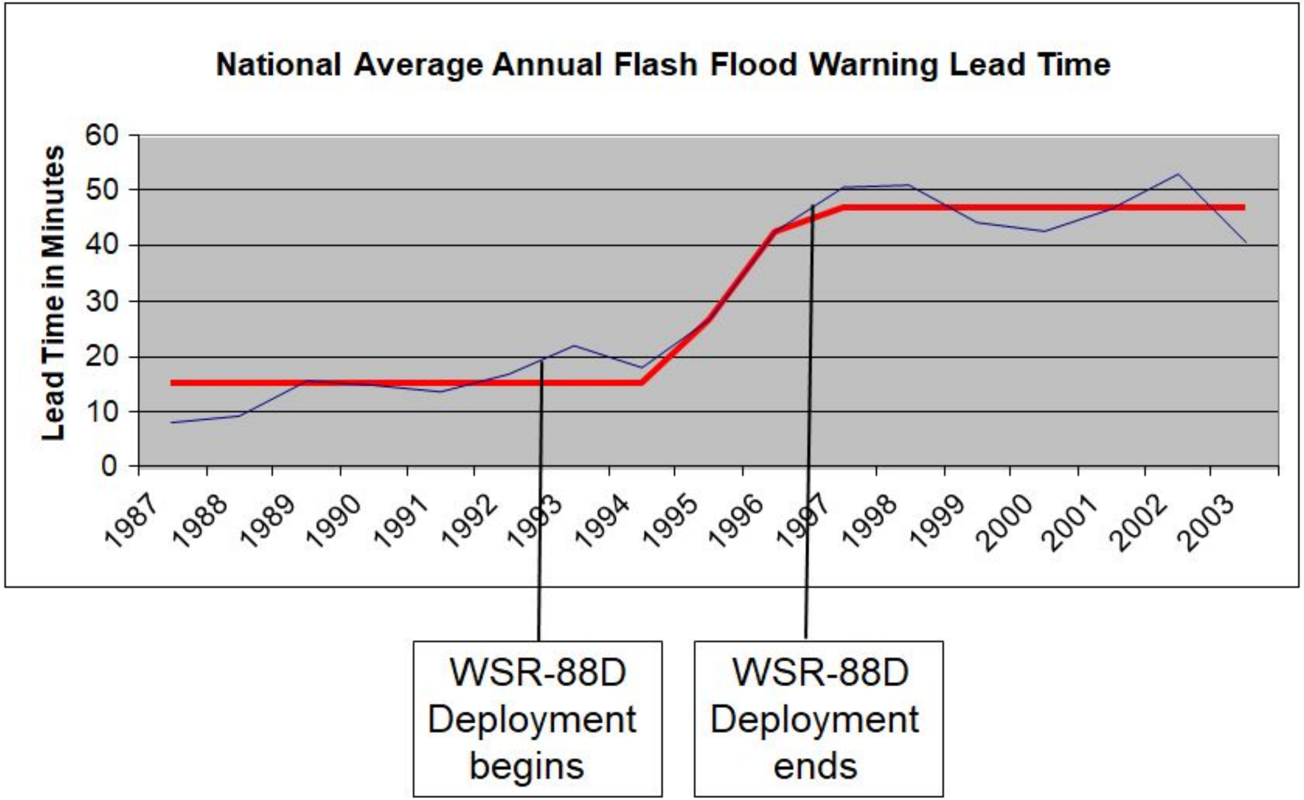
WSR-88D Science and Engineering R&D Overview

Dusan Zrnic, PhD, NSSL Senior Scientist, RRDD
Larry Hopper, PhD, NSSL Radar Division Chief, RRDD

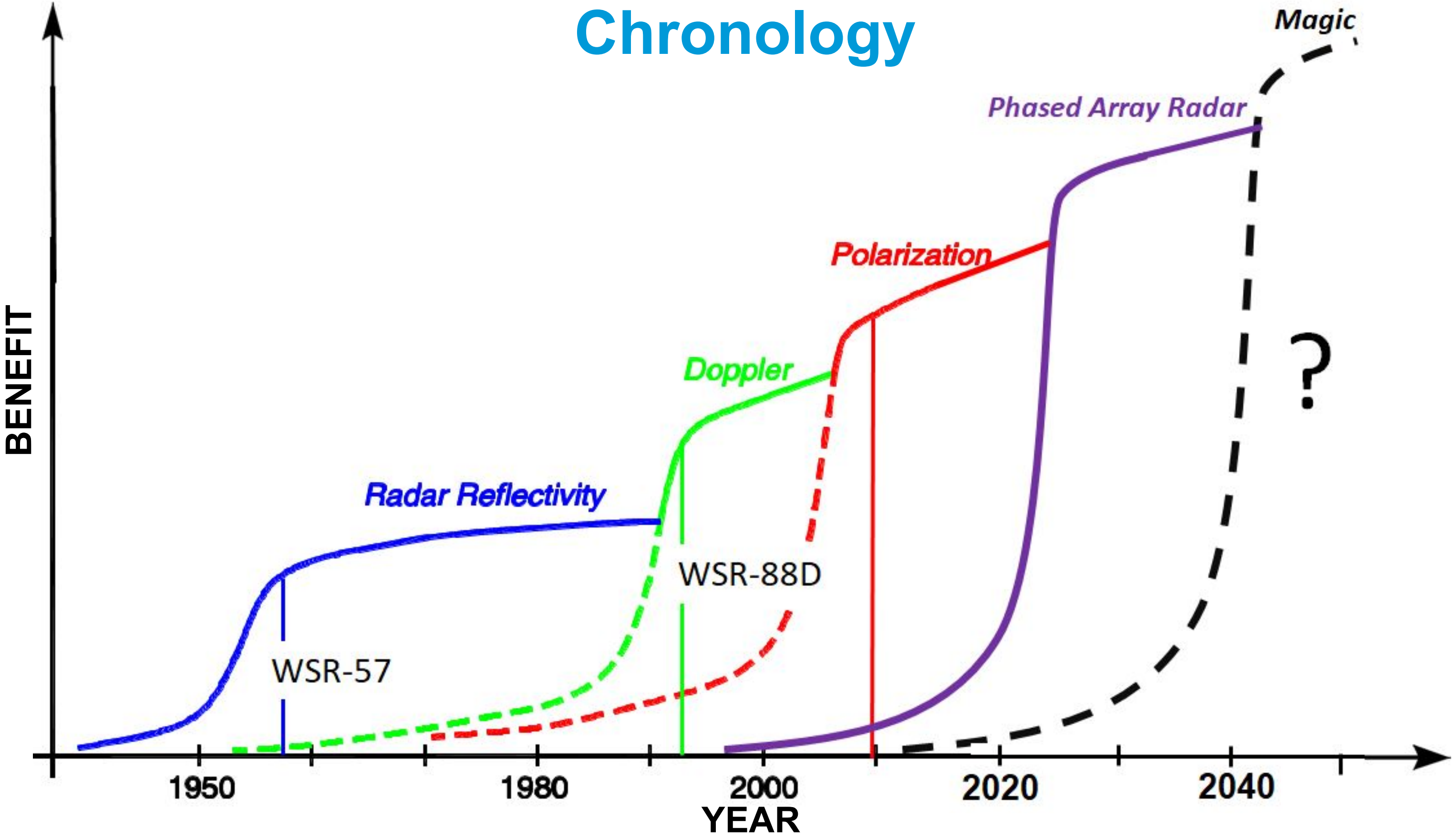


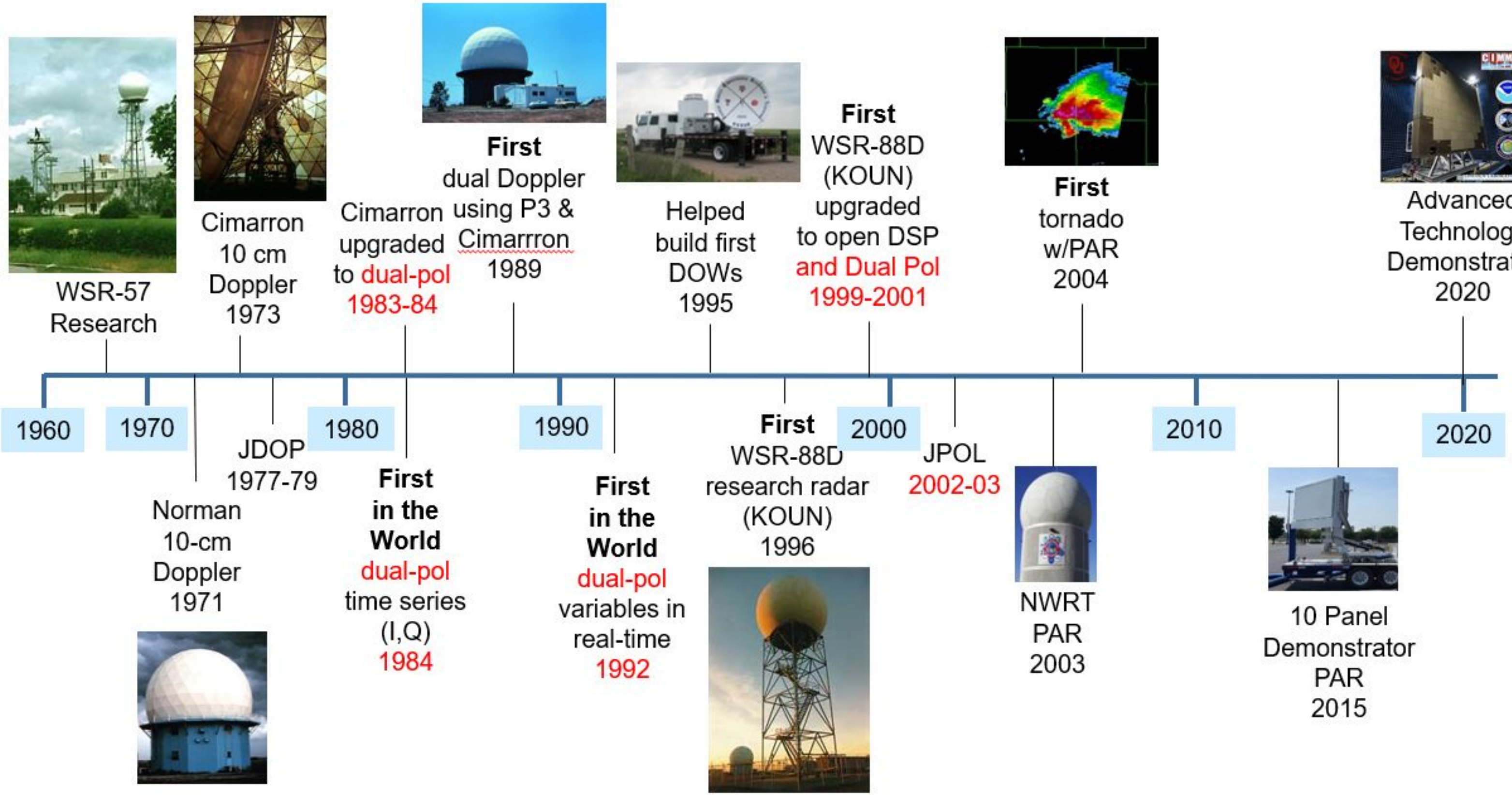
Impact of WSR-88D on Flash Flood Services



Radar Technology: Revolutionary Advancements Chronology

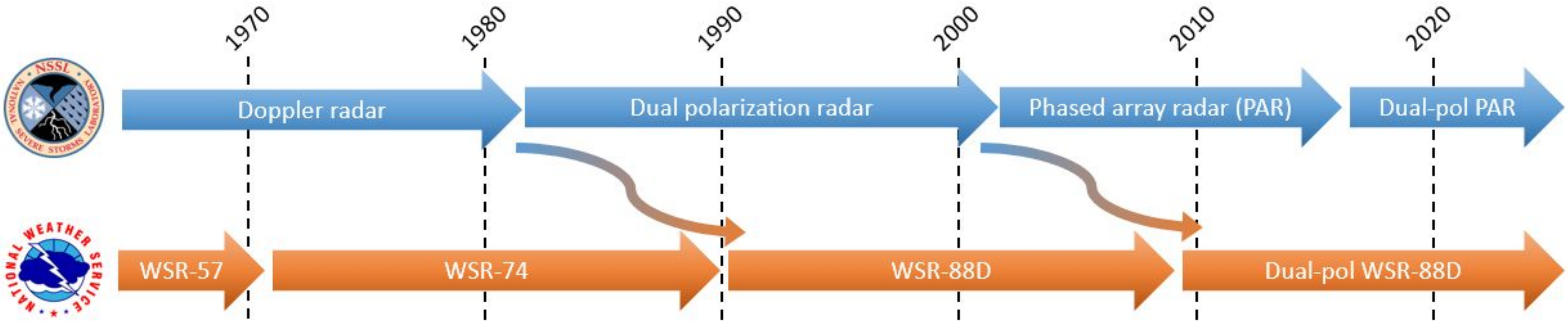


Radar Developments by NSSL



NSSL Radar Program Legacy

- Leading NOAA Lab in development of weather radar science and technology
- Supports NWS mission through novel research product improvement and technological advances
- Explores futuristic technologies for revolutionary changes in weather radar applications



1973 Union City tornado research motivates Doppler development for future NWS radars

1973 First WSR-74 fielded in Lubbock, Tx

1984 NSSL's Cimarron Doppler radar is converted to dual-polarization

1988 WSR-88D radar prototype (KOUN) erected at Operational Support Facility

1996 NSSL received from NWS a R&D WSR-88D (KOUN) and begun conversion to dual-polarization

1997 WSR-88D deployment is completed

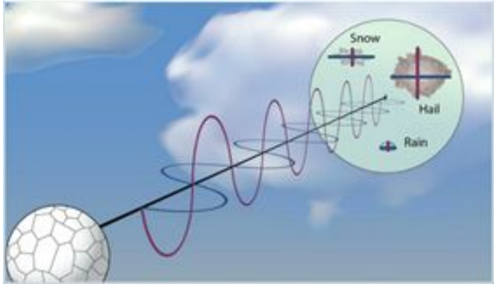
2004 Data collection with SPY-1A phased array radar begins

2004 NEXRAD PMC approves upgrade of its WSR-88D network to dual polarization

2013 NSSL begins work on the proof of concept for dual-pol phased array radar

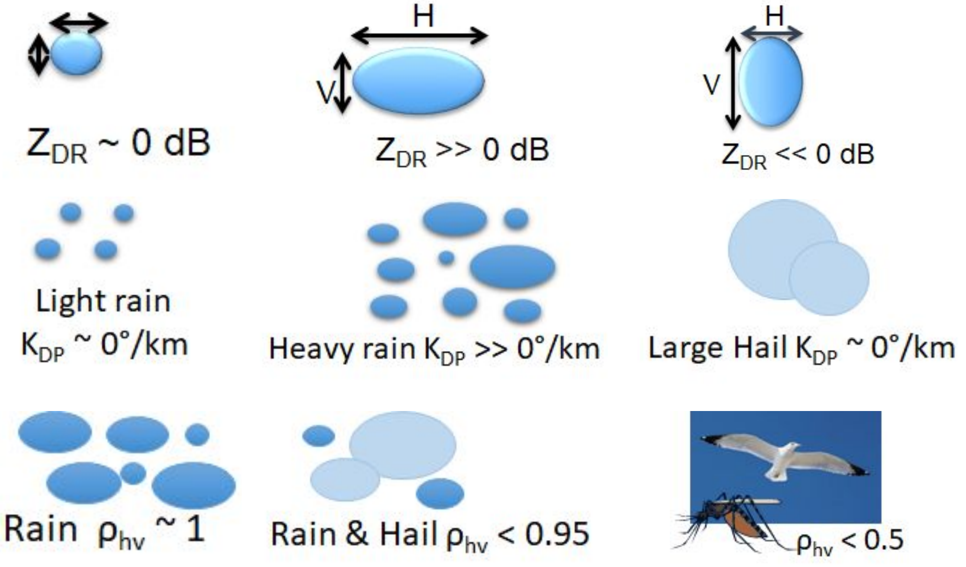
2013 Upgrade to dual polarization of WSR-88Ds is completed

Dual Polarization: Latest Technology Transferred to NWS



- Polarization is defined by the orientation of the E field in the plane perpendicular to the propagation direction
- The differences in interaction of the H and V fields with particles is characterized by the polarimetric variables

- Polarimetric variables:
  - Differential Reflectivity ($Z_{DR} = Z_H - Z_v$)
  - Differential Phase (Φ_{DP}) and Specific Differential Phase (K_{DP})
  - Co-polar correlation coefficient (ρ_{hv})



WSR-88D Science and Engineering R&D at NSSL

- **Chief organization conducting basic and applied R&D to explore and validate the operational utility of advances in weather radar science and technology, with accumulated expertise in:**
  - Evolutionary signal processing techniques
  - Analysis of radar and microphysical data
  - Scientific algorithm design & development
  - Use of radar data in NWP models

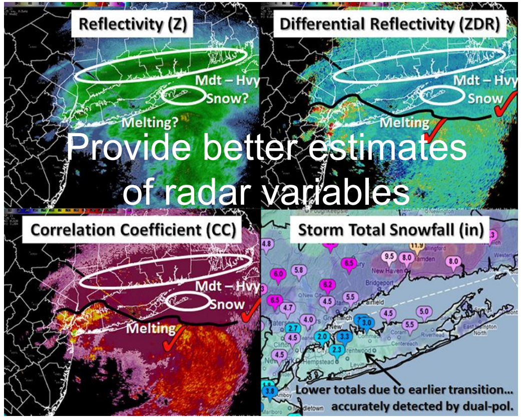
- NSSL Radar Research and Development Division (RRDD) scientists and engineers utilize this expertise to support the evolution of the WSR-88D network through the NWS Radar Operations Center (ROC)

What Do We Do?

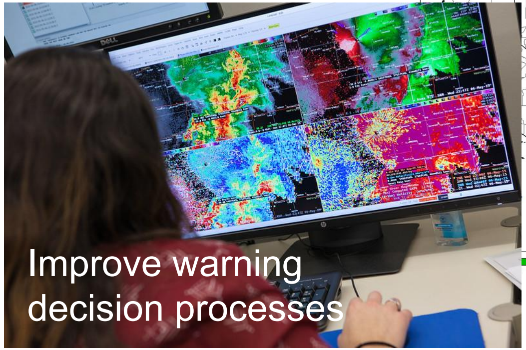
- **Two RRDD teams support WSR-88D science and engineering R&D:**

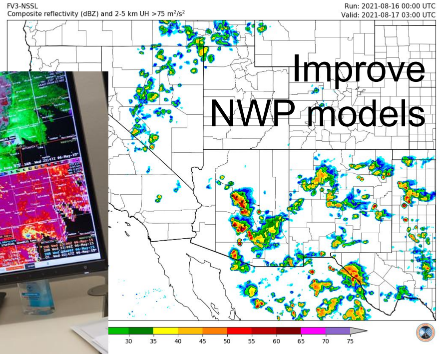
Advanced Radar Techniques (ART) Team develops advanced signal processing techniques to:

Improve radar data quality



Doppler Radar and Remote Sensing Research (DRARSR) Team conducts basic and applied polarimetric radar to:

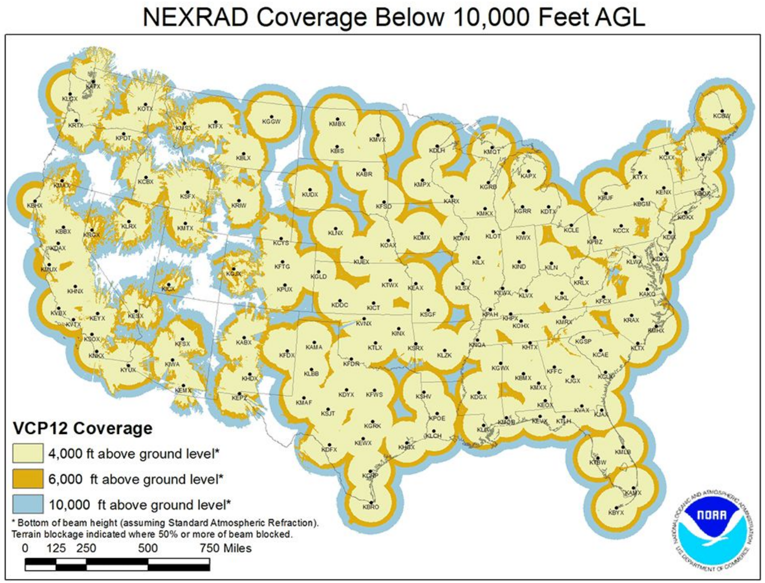




- Support the WSR-88D network as Subject Matter Experts to the ROC

Why Do We Invest in WSR-88D R&D?

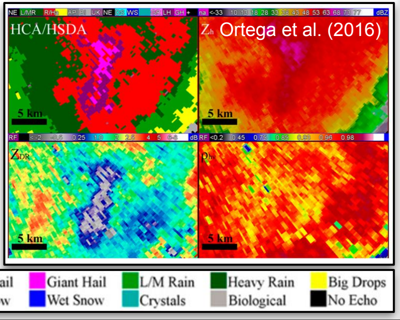
- **WSR-88D Science and Engineering R&D needed to:**
  - Improve and evolve the performance and utility of the WSR-88D network through 2040, its projected lifespan
  - Provide foundation for enhancements and capabilities to support the NWS, FAA, and DOD Air Force forecast and warning missions during this time
  - Support the domestic and global weather enterprise via basic research, operational applications, and informing the private sector of novel technological developments



How Do We Measure Quality and Success?

ROC Deliverables & Products

Ex: Hail Size Descrimination (HSDA) & MetSignal Algorithms implemented in RPG Build 17.0



Technical Publications

(algorithms & upgrades for WSR-88D radars)

Applications of an Expanded ZDR Scale

Valery Melnikov*, Richard Murnan+, and Donald Burgess*

Target	Observed ZDR interval, dB
Precipitation and clouds	-4 to +15
Attenuation effects	-2 to 0
Dust storms	-2 to +12
Ground clutter	-20 to +20
Sea clutter	-15 to +15
Atmospheric biota	-12 to +17
Chaff	Less than -8 to more than +8
Wild fire smoke	-5 to +8 dB

Peer-Reviewed Publications

Quasi-Vertical Profiles—A New Way to Look at Polarimetric Radar Data

ALEXANDER RYZHKOV, PENGFEI ZHANG, AND HEATHER REEVES

Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma, and NOAA/OAR/National Severe Storms Laboratory, Norman, Oklahoma

MATTHEW KUMJIAN

The Pennsylvania State University, University Park, Pennsylvania

TIMO TSCHALLENER, SILKE TRÖMEL, AND CLEMENS SIMMER

Meteorological Institute, University of Bonn, Bonn, Germany

(Manuscript received 22 January 2015, in final form 26 December 2015)

ABSTRACT

A novel methodology is introduced for processing and presenting polarimetric data collected by weather surveillance radars. It involves azimuthal averaging of radar reflectivity Z, differential reflectivity Z_{DR}, cross-correlation coefficient ρ_{hv}, and differential phase Φ_{DP} at high antenna elevation, and presenting resulting quasi-vertical profiles (QVPs) in a height-versus-time format. Multiple examples of QVPs retrieved from the data collected by S-, C-, and X-band dual-polarization radars at elevations ranging from 6.4° to 28° illustrate advantages of the QVP technique. The benefits include an ability to examine the temporal evolution of microphysical processes governing precipitation production and to compare polarimetric data obtained from the scanning surveillance weather radars with observations made by vertically looking remote sensors, such as wind profilers, lidars, radiometers, cloud radars, and radars operating on spaceborne and airborne platforms. Continuous monitoring of the melting layer and the layer of dendritic growth with high vertical resolution, and the possible opportunity to discriminate between the processes of snow aggregation and riming, constitute other potential benefits of the suggested methodology.

1. Introduction

Polarimetric radars provide unique insight into microphysical processes in clouds and precipitation. This knowledge will create opportunities for better microphysical parameterizations in numerical weather prediction (NWP) models and for assimilation of dual-polarization data into storm-scale models. Different microphysical processes (size sorting, evaporation, melting, freezing, riming, aggregation, diffusional growth, etc.) are characterized by specific "polarimetric fingerprints" (e.g., Kumjian 2012). These can be used to evaluate and eventually improve the models via converting their outputs into fields of polarimetric radar variables and adjusting parameterizations in a way that the observed polarimetric fingerprints are adequately reproduced.

The routine presentation of radar data in the plan position indicator (PPI) mode is not convenient for linking polarimetric radar signatures aloft, associated microphysical processes, and precipitation near the surface. Most convenient for the latter are scans along vertical planes in the so-called range–height indicator (RHI) mode; however, such scans typically are not available from operational systems due to time constraints. In principle, vertical cross sections of different radar variables can be obtained from a series of PPIs at different elevations (i.e., reconstructed RHIs), but their quality and vertical resolution are usually worse than that of "genuine" RHIs. On the other hand, genuine RHIs yield information only in selected azimuthal directions and thus do not represent the general structure of the storm or its evolution.

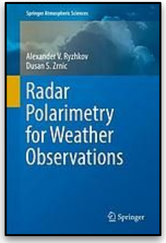
To get a better understanding of the microphysical processes that govern precipitation generation and evolution, it is beneficial to complement polarimetric

Corresponding author address: Alexander Ryzhkov, CIMMS, University of Oklahoma, 120 David L. Boren Blvd., Ste. 2100, Norman, OK 73072.
E-mail: alexander.ryzhkov@noaa.gov

DOI: 10.1175/JTECH-D-15-0020.1

Awards

Alexander Ryzhkov and Dusan Zrnic:



2019 ASLI Choice Award: Best Sci & Tech Book

Jeff Snyder: 2019 Presidential Early Career Award for Scientists and Engineers (PECASE)

THE WHITE HOUSE

NSF

Stakeholder Engagement

Numerous interactions with domestic and international partners, including:

- TAC and DQ/IRT meetings
- NWS ROC & Regions
- Conferences
- Invited Talks and Visits

Who Do We Collaborate With to Increase Performance?

- **NSSL recognized as a domestic and international leader in radar engineering and science, with numerous collaborations resulting in:**
  - Basic science advancements and associated resources supporting radar algorithm development and improvement
  - Additional support through external funding and participation in field projects

KMA Korea Meteorological Administration

Met Office

UNI BONN

Environment Canada

KYUNGPOOK NATIONAL UNIVERSITY 경북대학교

Australian Government Bureau of Meteorology

LUNDS UNIVERSITET

University of Colorado Boulder

Stony Brook University

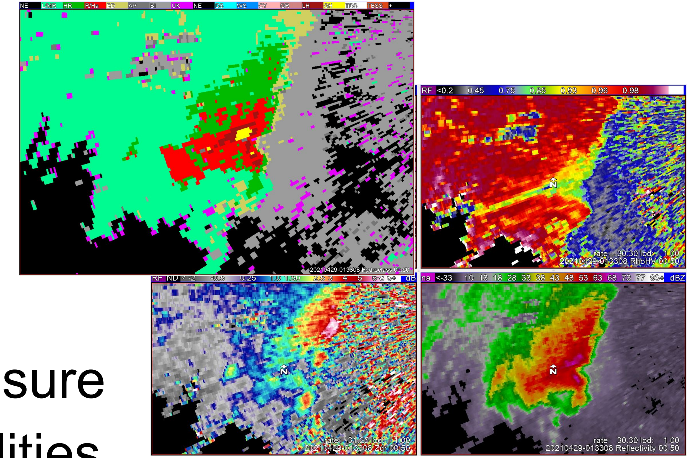
Pacific Northwest NATIONAL LABORATORY

MIT Lincoln Laboratory

האוניברסיטה העברית בירושלים
THE HEBREW UNIVERSITY OF JERUSALEM

How Do We Impact Stakeholder Goals & Performance?

- By developing **evolutionary signal processing techniques** and **new diagnostic capabilities** for the WSR-88D network, focusing on **using dual-polarization data** for improving:
  - Hydrometeor classification
  - Quantitative precipitation estimates (QPE)
  - Severe weather nowcasting



- Work collaboratively with the NWS to ensure forecasters have the knowledge, capabilities, and technologies to effectively communicate accurate, timely, and actionable forecasts

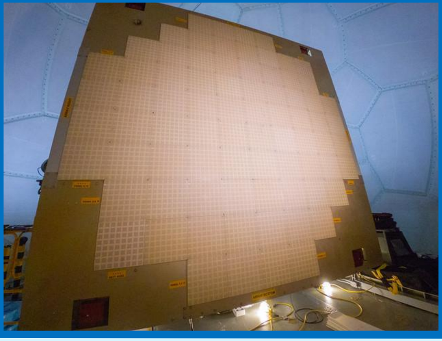
Weather-Ready Nation

Forecast/Warning Tools and Techniques: RADAR

WSR-88D Upgrades and Radar Product Improvement

Terry Schuur, PhD, CIWRO Research Scientist, RRDD






WSR-88D Upgrades and Radar Product Improvement

- The Radar Product Improvement (RPI) program
  - Established to evolve and improve the WSR-88D
  - Provides a foundation for future WSR-88D enhancements and new capabilities

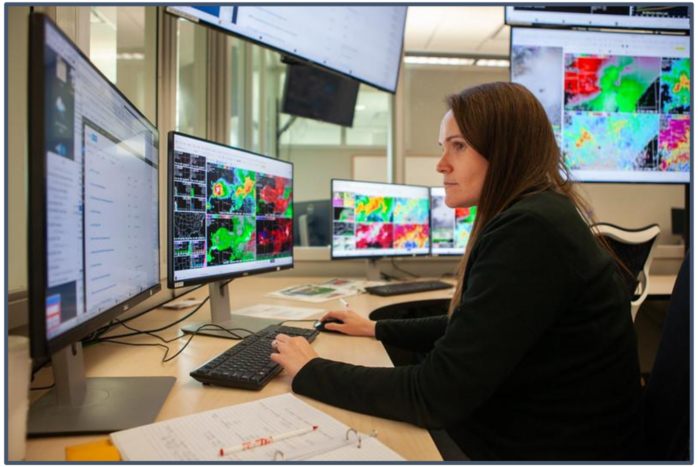
- Supported by:
  - Department of Commerce (NWS)
  - Department of Transportation (FAA)
  - Department of Defense (Air Force)

- NSSL annually coordinates with the NWS, FAA, and Air Force to produce a Statement of Work that includes research tasks that address their needs. Research results are then reported to the agencies throughout the year by technical reports, technical interchange meetings, presentations, and software deliveries.

The Radar Product Improvement (RPI) Program

Why RPI?

- Artifacts in the radar have historically had a negative impact on data quality, thereby impeding a forecaster's ability to correctly interpret the radar data.
- Forecasters rely heavily on radar observations in the warning decision process and research is needed to better understand how polarimetric radar data can best be utilized in the forecast office.



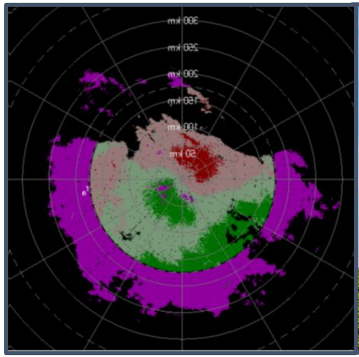
The deployment of polarimetric capabilities across the WSR-88D network provides an opportunity to:

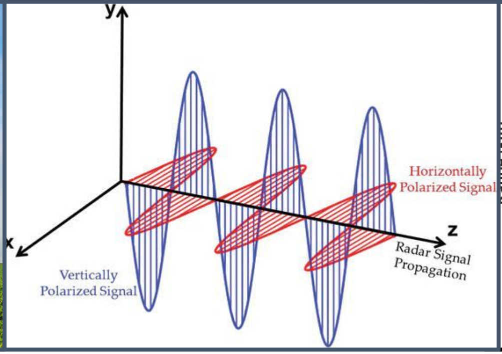
- Develop new signal processing techniques that improve radar data quality.
- Develop polarimetric algorithms that better estimate precipitation accumulation, predict precipitation type, and increase warning lead times for weather hazards in both cold- and warm-season storms.

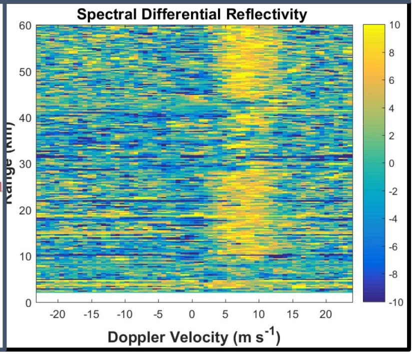
RPI Accomplishments and Goals: Signal Processing

<u>RPI-supported Data Quality Improvement Work:</u>

- Mitigate contamination from non-meteorological scatterers (trees, buildings, wind farms, biological, etc.).
- Mitigate ambiguities in range and velocity.
- Improve estimates of radar variables.
- Support ROC implementation, validation, and testing.







RPI Accomplishments and Goals: Meteorological

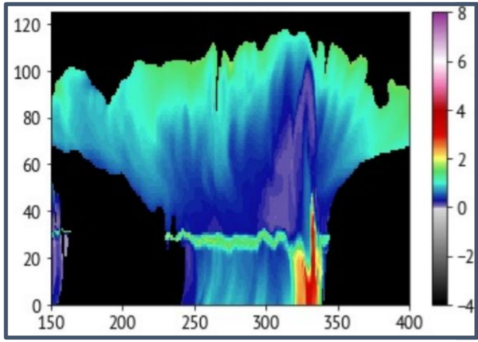
RPI-supported Dual-Polarization Enhancement Work:

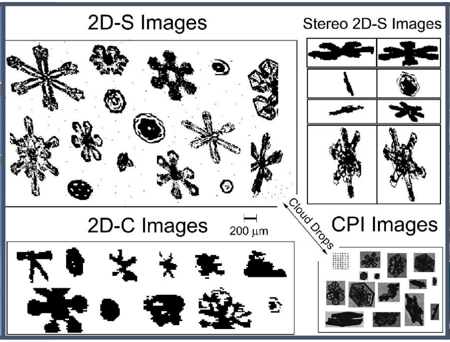
- Improve radar estimation of rain and snow intensity.
- Enhance the detection of the height and intensity of the melting layer in winter storms.
- Detect/predict precipitation type at the surface in winter storms.
- Use radar signatures aloft to predict the future location of heavy snow at the surface.
- Detect growing hail aloft and improve the lead time for the prediction of large hail at the surface.
- Use radar signatures aloft to predict which storms might produce damaging downbursts/microbursts.

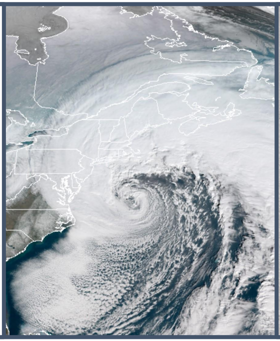
Additional Accomplishments and Goals

In addition to RPI-supported research, domestic and international collaborations and competitive funding obtained from other agencies such as NSF and DoE contribute to NOAA's mission by supporting:

- Graduate student research
- Participation in field projects and the collection of validation and verification data sets
- Research leading to improvements in the retrieval of microphysical and thermodynamic from polarimetric radar data
- Investigations into how to better utilize information obtained by polarimetric radar data in numerical models







Future Work

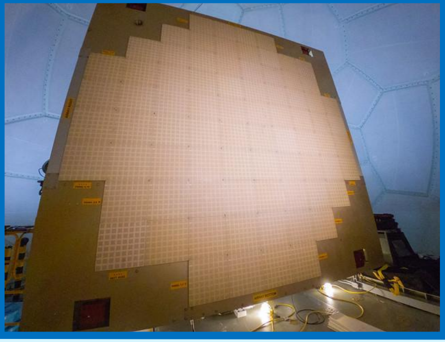
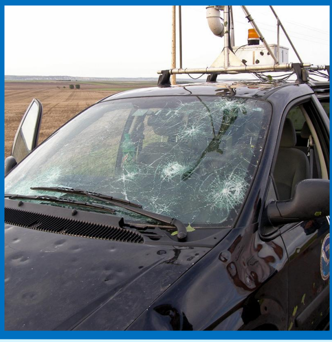
- Continue the development and testing of evolutionary signal processing techniques to improve data quality and provide better estimates of radar variables.
- Conduct basic and applied research to improve existing algorithms, develop new algorithms, and/or provide guidance to forecasters on how to best utilize polarimetric radar data in warning operations for a variety of weather hazards.
- Investigate how data from other observation platforms can be integrated into algorithms to improve performance.
- Use observational data sets to verify/validate algorithm performance.
- Work to better understand how thermodynamic and microphysical information obtained from polarimetric radar observations can be used to improve numerical simulations of both winter and warm-season storms.

Forecast/Warning Tools and Techniques: RADAR

Signal Processing Techniques

Christopher Curtis, PhD, CIWRO Research Scientist, RRDD

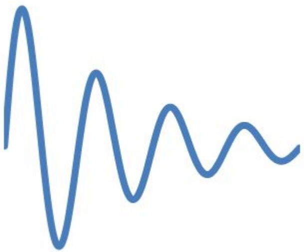


Weather Radar Signal Processing

- Radar is the most important observing system supporting NWS warning decisions and short-term forecasts, for which clean radar data is essential.

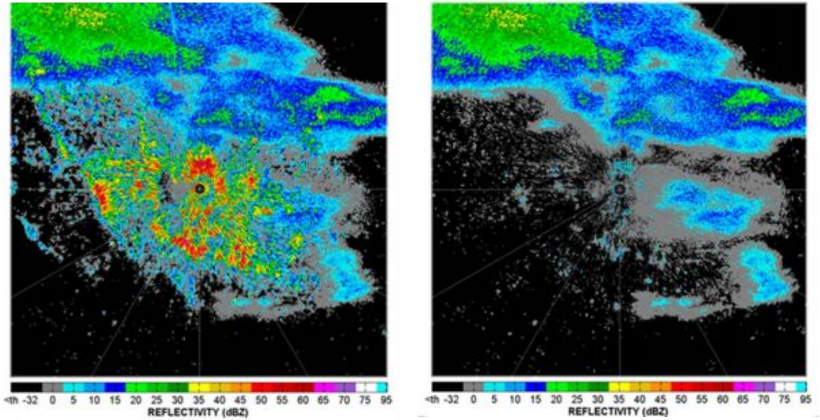
- When left unprocessed (or poorly processed), radar data may
  - Be contaminated by non-meteorological echoes
  - Not precisely represent the weather characteristics being measured
  - Not capture important characteristics of quickly evolving storms
  - Not capture both the location and the movement of weather



- The goal of weather radar signal processing is to separate and classify radar echoes from different sources and to mitigate radar sampling artifacts so that consumers of radar data have relevant information to support the NOAA mission of saving lives and protecting property.

Why Are We Doing Weather Radar Signal Processing?

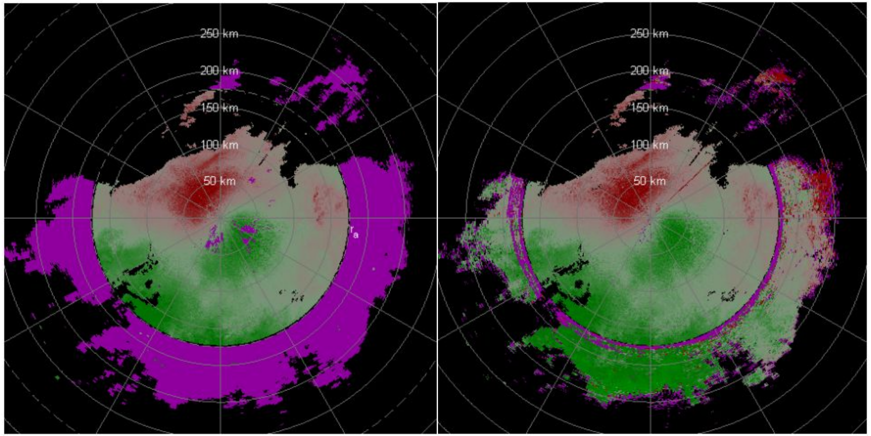
- NOAA has and continues to invest in the development and operational deployment of new radar technologies.
  - The improvements from radar hardware upgrades cannot be fully realized without radar software upgrades. (you wouldn't load Windows 95 on a modern high-performing computer)
  - Signal processing techniques must complement hardware upgrades.
- Signal processing techniques can improve weather observations by providing:
  - Effective quality control
  - Faster updates
  - Better accuracy and precision
  - Greater coverage
- Improvements are at the source.
  - Raw radar signals contain more information.
  - Benefits carry over downstream.



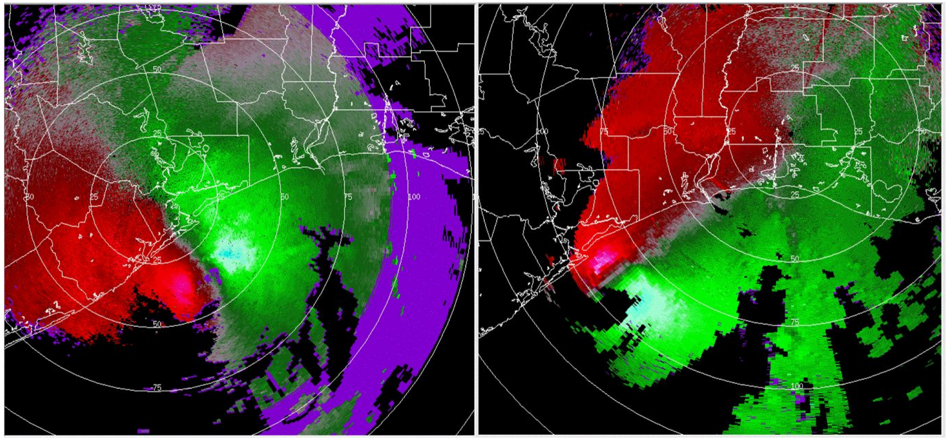
Improvements to Range-and-Velocity Ambiguity Mitigation: Phase Coding

- Phase coding is currently operational on the WSR-88D.
- NSSL developed phase coding and continues to improve its performance.
  - Phase coding algorithm (SZ-2) uses pulse-to-pulse phase coding and spectral processing to separate overlaid echoes.
- Reduces the amount of “purple haze” for forecasters.

Before Phase Coding | After Phase Coding



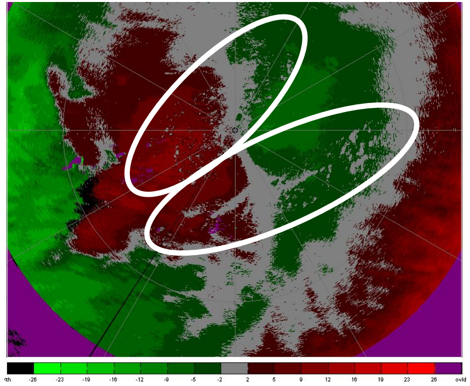
Before Phase Coding | After Phase Coding



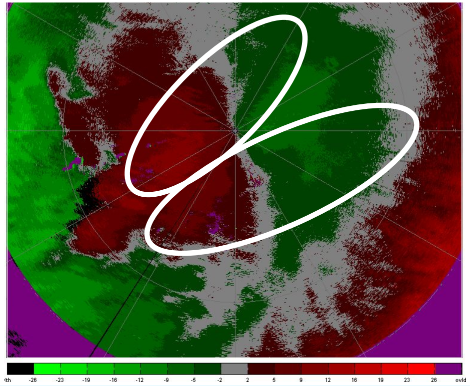
Improvements to Ground Clutter Mitigation: Weather Detection and Clutter Filtering (WET/CLEAN-AP)

- WET (Weather Environment Thresholding) uses the spatial variability of dual-polarization variables to identify weather that does not need clutter filtering.
- CLEAN-AP (Clutter Environment Analysis using Adaptive Processing) utilizes spectral processing (autocorrelation spectral density) to adaptively determine the notch size, to filter the spectrum, and to interpolate to minimize negative effects on radar variables.
- Currently being transferred to the WSR-88D.
- Improves mitigation of ground clutter and minimizes effects of ground clutter filtering on “pure” weather data.

Unfiltered

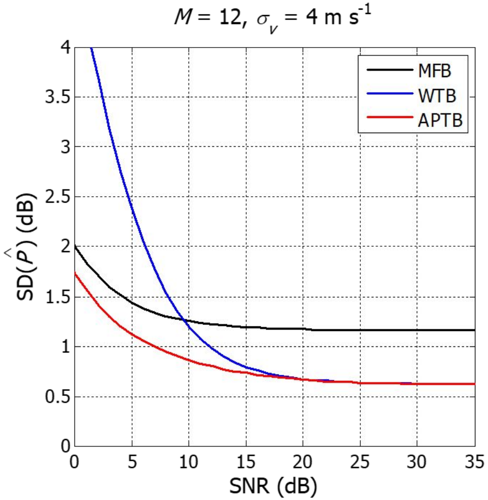


WET/CLEAN-AP

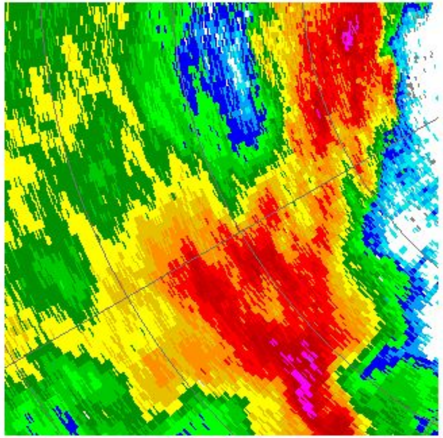


Improvements to Radar-Variable Estimation: Range Oversampling

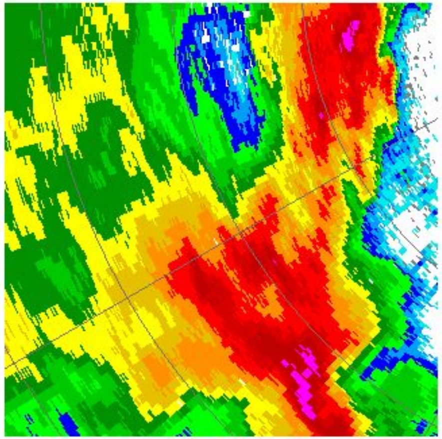
- Range oversampling will be transferred to the WSR-88D in the future.
- Adaptive pseudowhitening is used to combine oversampled correlations to minimize radar-variable estimate variance.



Conventional Matched Filter



Adaptive Pseudowhitening



Future Work (next 1-3 years)

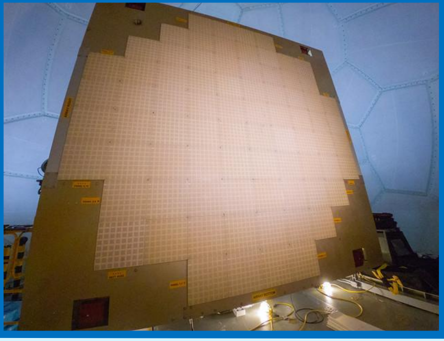
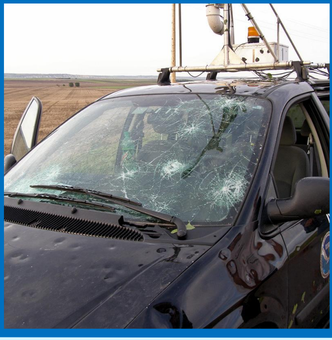
- Continue the development of evolutionary signal processing techniques in support of the WSR-88D dual-polarization upgrade.
  - Improvements to range-and-velocity ambiguity mitigation:
    - Validation and testing of SZ-2 algorithm with ground clutter filtering (GMAP/CLEAN-AP)
    - Support ROC implementation of staggered PRT (replacement for batch)
  - Improvements to ground clutter mitigation:
    - Wind turbine clutter mitigation
    - Support ROC implementation of weather detection and clutter filtering (WET/CLEAN-AP)
  - Improvements to radar-variable estimators:
    - Weighted Adaptive Range Averaging
    - Generalized Multi-Lag Estimators
    - Support ROC implementation of new correlation coefficient estimators
    - Support ROC implementation of Hybrid Scan Estimator
    - Support ROC implementation of range oversampling processing
  - Improved radar data quality control:
    - Integration of Coherency Based Thresholding with staggered PRT

Forecast/Warning Tools and Techniques: RADAR

Hydrometeor Classification and Winter Weather

Jacob Carlin, PhD, CIWRO Research Scientist, RRDD



Winter Weather Research at NSSL

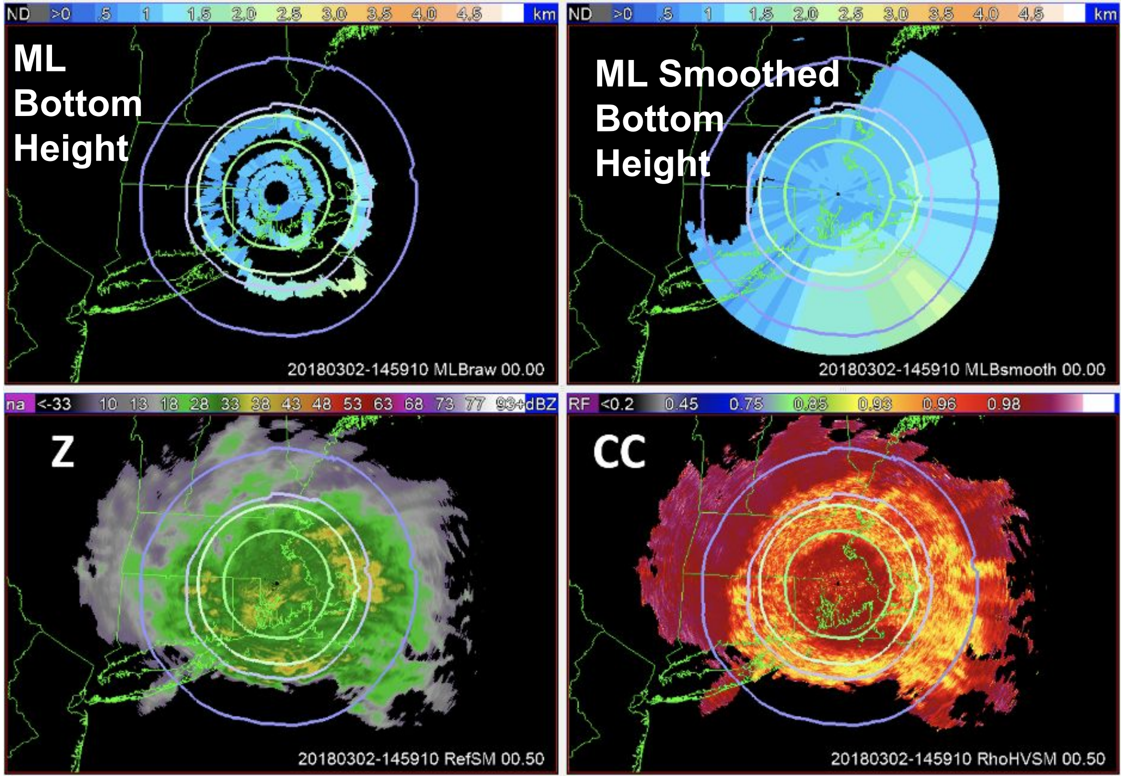
- The WSR-88D network has been a crucial tool for monitoring and warning for cold-season precipitation
- The introduction of dual-polarization radar vastly increased the amount of information available to characterize snow, freezing rain, ice pellets, etc. and ushered in an era of robust radar-based research on cold-season precipitation
- NSSL has exploited this newfound information content and explored:
  - Automated melting layer detection
  - Hydrometeor Classification Algorithms
  - Snow quantitative precipitation estimation
  - Improved rainfall estimation through better identification of brightband contamination
  - Radar-based microphysical retrievals
- Increasingly, radar observations and model simulations are being used synergistically to further interpret polarimetric radar signatures in cold-season precipitation (NSSL GSC2)

Relevance

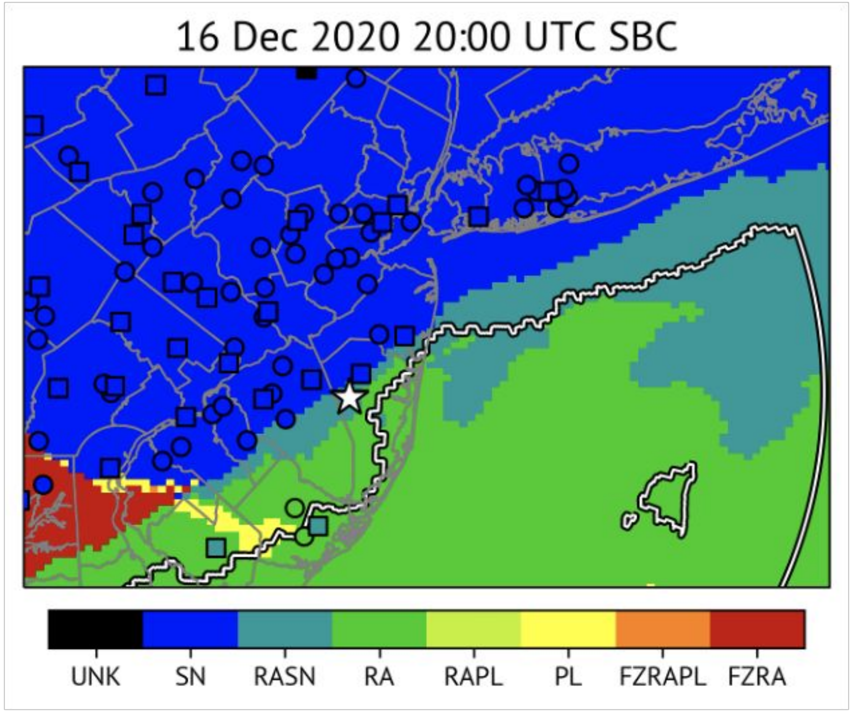
- Numerical weather prediction (NWP) models often struggle due to simplified microphysical assumptions and sensitivity to subtle but significant thermodynamic changes in the environment
    - These limitations also impact storm-scale convection forecasts
- Radar is an optimal tool for resolving these systems in real-time.
    - NWP models available hourly (at best)
    - Radar coverage is national

Research: Melting Layer Detection Algorithm

- Existing melting-layer detection assumes constant melting layer height in all directions from radar
  - Only valid close to the radar site
  - Neglects frontal boundaries, localized precipitation-type changes, and other heterogeneities further from radar
- NSSL has developed and tested a new algorithm that provides a spatially variable melting layer top and bottom
- Will help validate models, improve HCA, and aid forecasters in nowcasting precipitation-type transitions



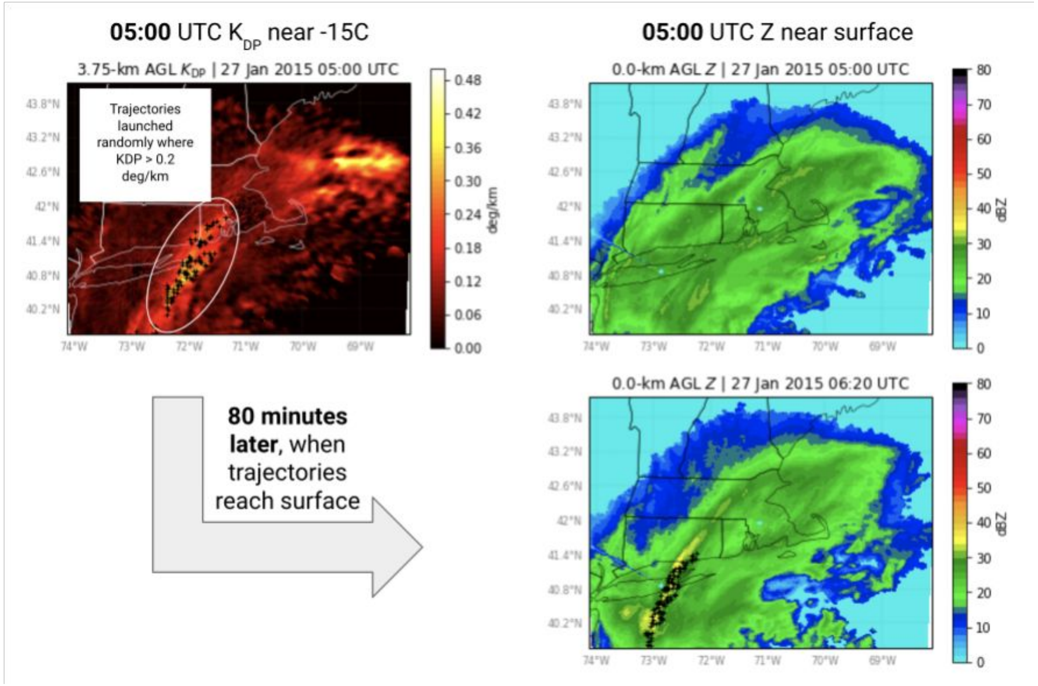
Research: Surface Precipitation-Type Classification



- It is challenging to know what the surface precipitation type is at all locations (e.g., sparse obs, below-beam effects, crude precipitation-type algorithms in models)
  - Particularly challenging to differentiate ice pellets vs. freezing rain
- NSSL has developed a Spectral Bin Classifier (SBC) that uses detailed microphysical calculations to determine a precipitation type at every model grid point.
- Research is underway to further improve the SBC using polarimetric radar data:
  - Incorporate MLDA observations
  - Vary precipitation intensity over model grid
  - Evolve on sub-hourly basis
  - Complement existing Hydrometeor Classification Algorithm

Research: Nowcasting Heavy Snowfall

- Recent research has found associations between high K_{DP} aloft and subsequent heavy snow at the surface.
- Due to slow fallspeed of snow, this can be exploited for advanced notice of impending heavy snow at >= 1 hour lead times
- Combining national radar mosaics (e.g., MRMS) with model wind/thermodynamic data has potential to pinpoint timing and location of heavy snowfall at the surface before it occurs.



Future work

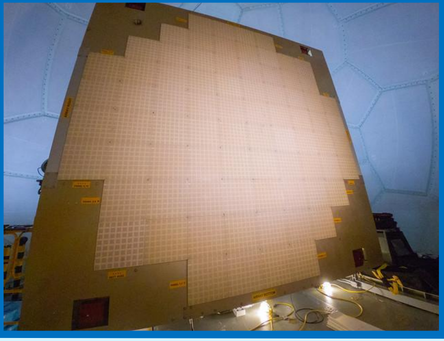
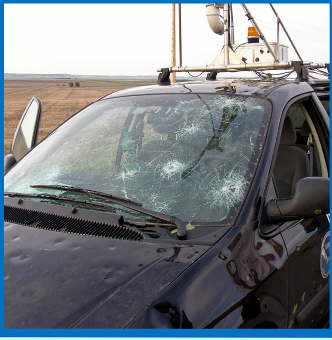
- Continued synergy of NWP models and polarimetric radar data for nowcasting
  - Improved radar retrievals, NWP model physics, and algorithms
  - Sub-hourly to short-term (0-1 hour) nowcasting
  - Direct applications for both *operational* forecasters (e.g., nowcasting) and for *research* seeking to further improve NWP models
- Unify existing efforts into sub-hourly precipitation type and intensity nowcasting tool and make available to NWS forecasters through displays

Forecast/Warning Tools and Techniques: RADAR

Quantitative Precipitation Estimation

Alexander Ryzhkov, PhD, CIWRO Research Scientist, RRDD



Recent progress in polarimetric radar quantitative precipitation estimation (QPE)

- A principally novel approach for radar rainfall estimation has been introduced and operationally implemented during last 5 – 7 years. It is based on the joint use of specific attenuation A and specific differential phase Kdp instead of the previous methods utilizing radar reflectivity Z or a combination of Z with differential reflectivity Zdr

- The R(A)/R(Kdp) algorithm has been operationally implemented on the MRMS platform and tested for a large number of rain events over the whole US territory. The MRMS version of the nationwide R(A)/R(Kdp) output is available in real time.

- A novel QPE method outperforms the algorithms currently utilized on the WSR-88D network and demonstrates particularly impressive performance for flash flood events associated with landfalling hurricanes

- For the first time, polarimetric radar methods have been used for QPE of snow. Their advantages compared to currently used multiple S(Z) relations have been demonstrated for a number of snowfall events and show a good promise

Relevance of accurate QPE

- As a result of global warming, the frequency and intensity of flash flood events and their societal impact dramatically increase in recent years. Therefore, providing accurate precipitation estimates over large areas is of great value for the nation.

- The new polarimetric radar QPE methods developed in the lab are particularly beneficial for the estimation of heavy rain associated with landfalling hurricanes and heavy snow caused by Nor'easters

- Accurate estimation of precipitation rates is very important for assimilation of the results of radar observations into the numerical weather prediction (NWP) models and for optimization of the microphysical parameterization of the NWP models.

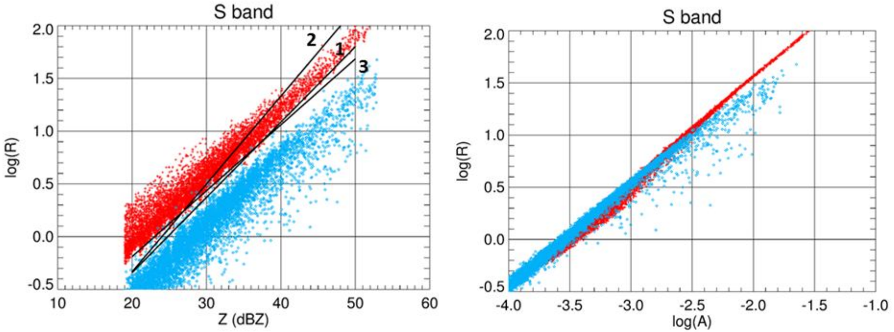
Tennessee, 08/21/21, 22 fatalities

New York City, 09/01/21, 45 fatalities

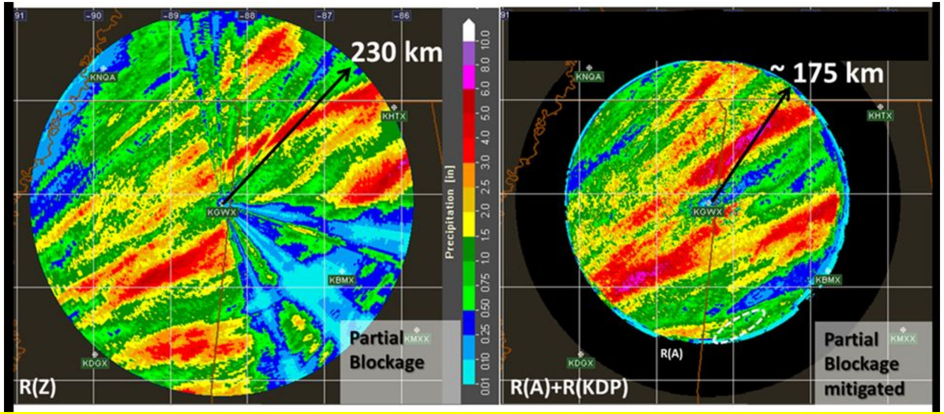
Snowstorm Gail, 12/21/20, 5 fatalities

A novel method for radar rainfall estimation based on specific attenuation R(A)

- A novel methodology for rainfall estimation based on specific attenuation A has been introduced
- Although attenuation is quite small at S band, it almost linearly depends on rain rate R. Therefore, the R(A) relation is less sensitive to the variability of drop size distribution than any other relation including conventional R(Z)
- Specific attenuation can be estimated by the polarimetric radar from the radial profile of Z and a total span of differential phase along the propagation path
- The R(A) estimate is immune to the radar miscalibration, attenuation, partial beam blockage, and impact of the wet radome.



Tropical rain – red dots, continental rain – blue dots

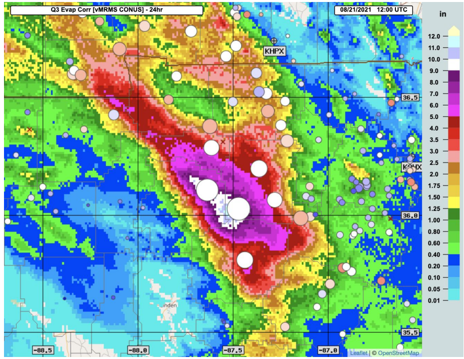


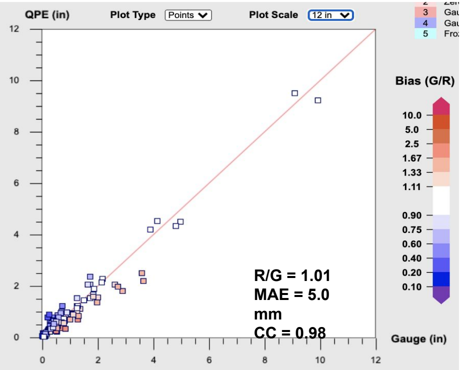
The impact of the partial beam blockage caused by nearby trees is completely eliminated in the rainfall map retrieved from A

Polarimetric QPE performance during past summer flash flood events

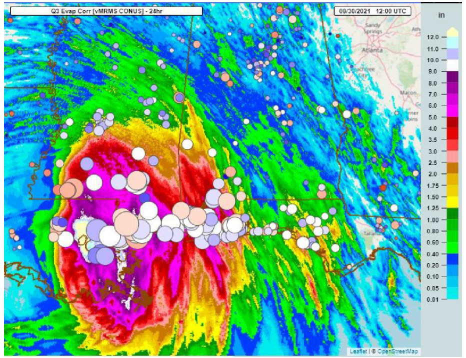
The R(A) / R(Kdp) algorithm. 24 –hour total

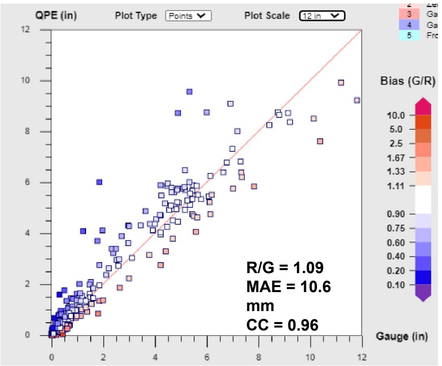
Tennessee flash flood



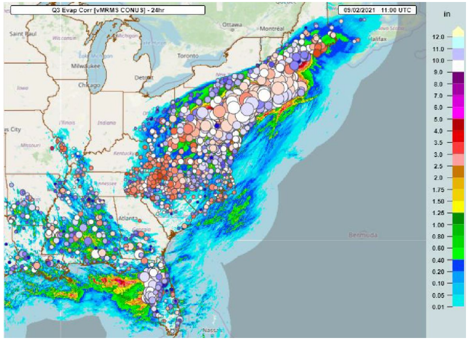


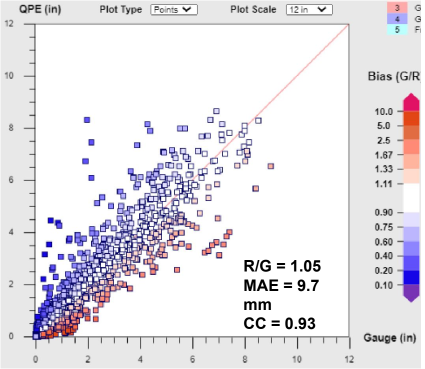
Ida. Louisiana, Mississippi





Ida. US Northeast

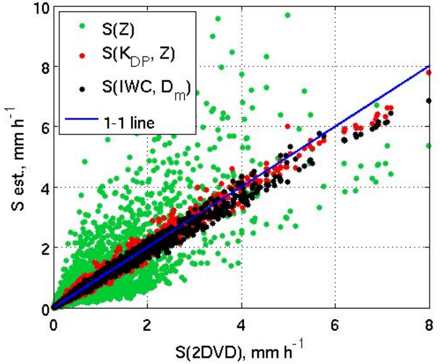




The color circles indicate comparisons with gauges so that the circle size is proportional to rainfall amount and its color indicates the sign / magnitude of the bias.

Polarimetric estimation of snow

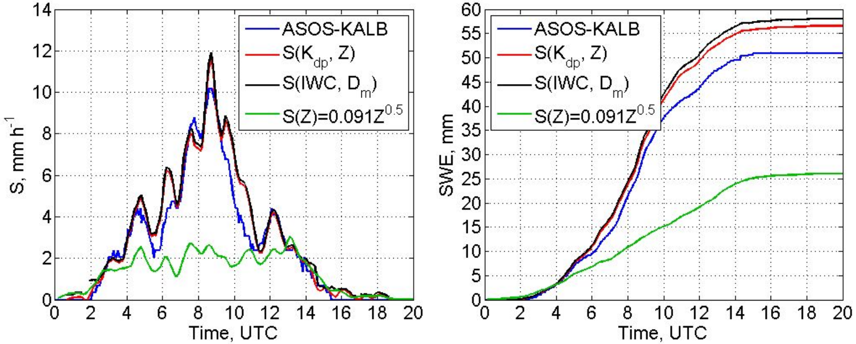
Simulations based on the disdrometer snow data



The polarimetric estimates of snow rate are much less sensitive to the variability of snow size distribution than the conventional S(Z) estimates

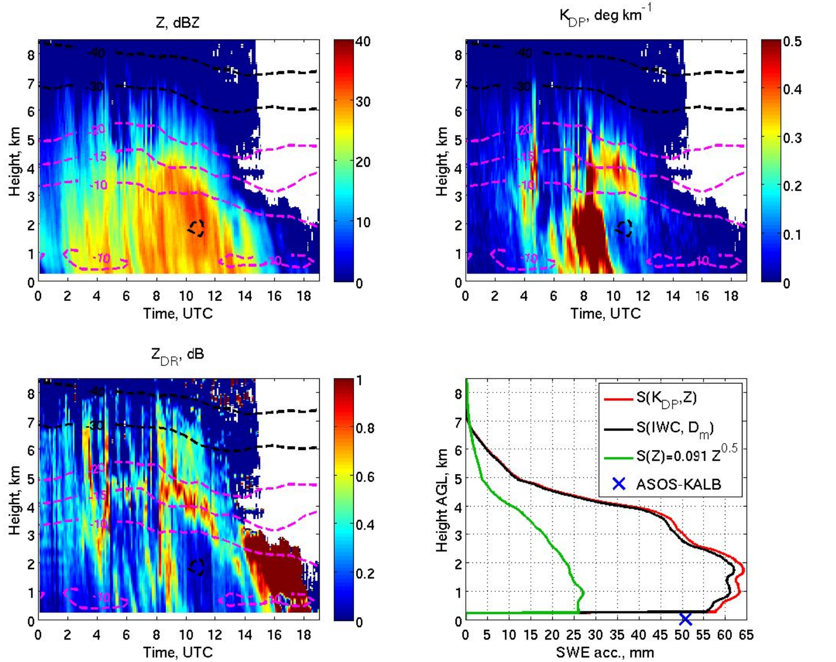
Nor'easter "Gail" on 17 Dec 2020. KENX WSR-88D

Instantaneous snow rates and accumulations



Nor'easter "Gail" on 17 Dec 2020. KENX WSR-88D

Columnar vertical profiles of radar variables and snow rate



Polarimetric estimates of snowfall better agree with the ASOS measurements than the S(Z) estimate

Future work

- Remaining issues of rainfall estimation at longer distances from the radar have to be addressed by taking into account strong vertical gradients of precipitation fluxes typical for warm tropical rain and rain affected by evaporation in the western US.

- Reliable methods for correcting effects of the QPE contamination at the distances where the radar resolution volume is filled with mixed-phase or ice hydrometeors will be developed

- Massive validation and refinement of the polarimetric algorithms for snow estimation is needed

- The quality of precipitation estimation in areas of poor WSR-88D radar coverage will be improved via integration with the information obtained from satellite retrievals and a forthcoming network of X-band gap-filling radars.

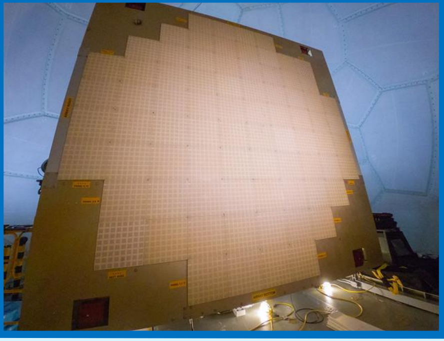
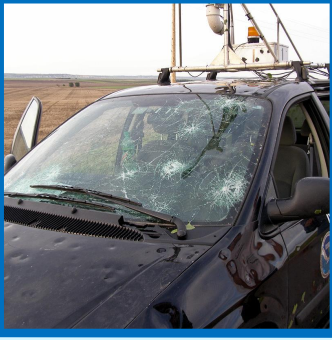
- The concept of nowcasting precipitation amount at the surface using simple Lagrangian cloud models with spectral microphysics coupled with polarimetric measurements aloft will be explored

Forecast/Warning Tools and Techniques: RADAR

Severe Weather Research

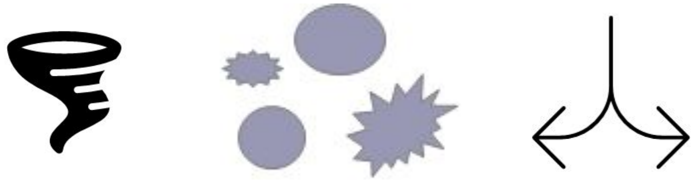
Jeffrey Snyder, PhD, NSSL Research Meteorologist, RRDD



Severe Weather Research Using WSR-88D

- Substantial progress has been made over the past 5–10 years to (1) *develop and implement* new research focused on hazards produced by severe convective storms and (2) *revisit and improve* legacy algorithms
- Examples of prominent areas of development include:
  - Tornado detection
  - Hail detection and size estimation
  - Downburst detection



- The goal for all work is to improve the detection and/or quantification of hazardous weather in order to provide more accurate and timely forecasts and warnings

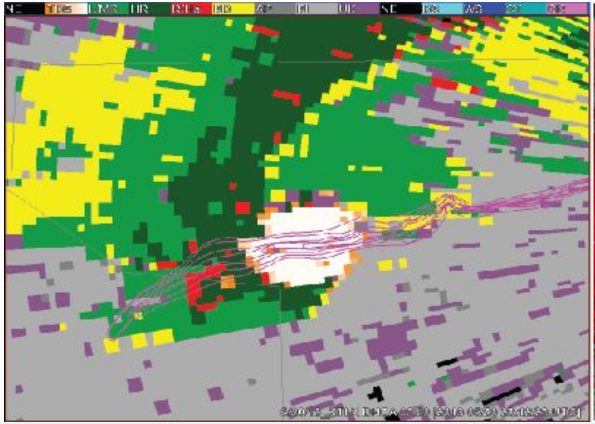
WSR-88D Severe Weather Research at NSSL

- Severe weather research, and in particular the use of weather radar to carry out such research, is **core to NSSL's mission**
- NSSL *pioneered the use of weather radar* to study severe convective storms and their hazards decades ago, and this tradition continues today
- Previous and ongoing projects span the full spectrum of scientific research (**R**) to operational algorithms/best practices (**O**)
- Operational implementation is the targeted end goal for much of our work

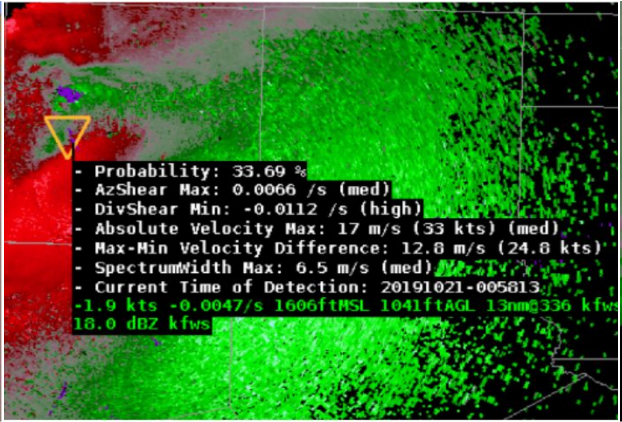
Severe Weather Science: Tornadoes

- Leverage dual-polarization radar and advanced shear detection (e.g., LLSD) to identify tornadoes or parent rotation
- Provide probabilistic information

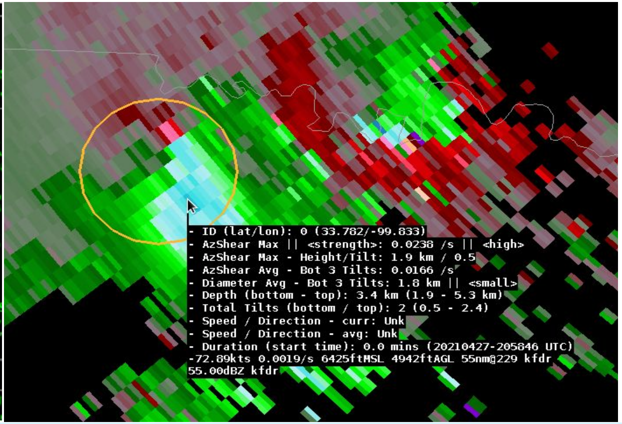
Tornado Debris Signature Algorithm



New Tornado Detection Algorithm

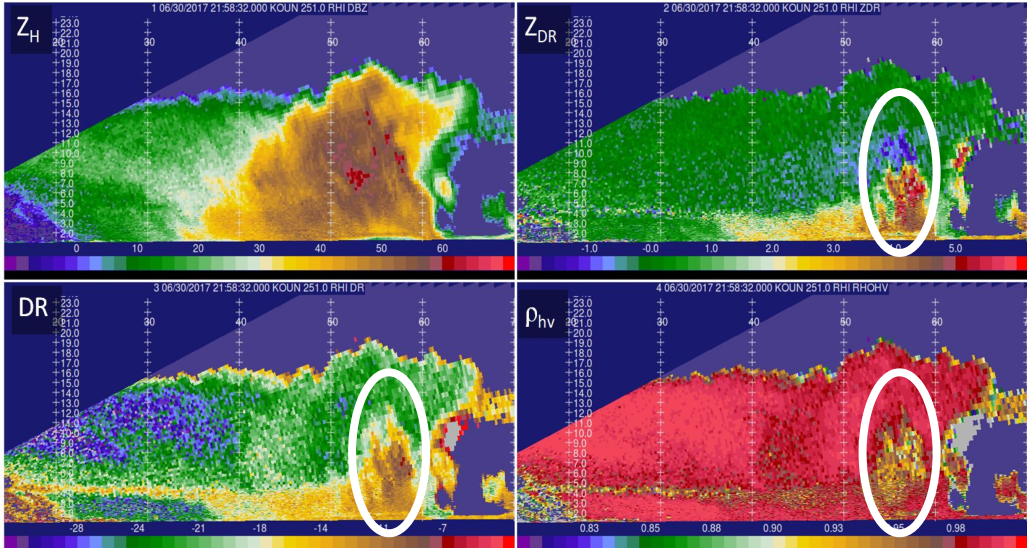


New Mesocyclone Detection Algo.



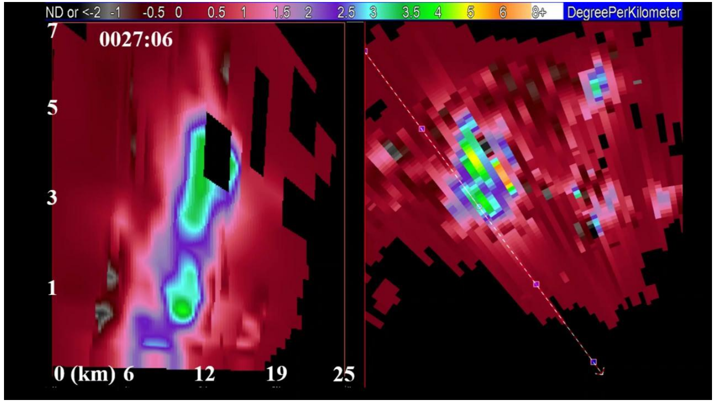
Severe Weather Science: Hail

- Dual-pol radar can usually discriminate hail from other scatterers
- The Hail Size Discrimination Algorithm was developed at NSSL and made operational in 2016-2017
- Current: Mid-level signatures
  - Large hail far above ground
  - Hail growth (identify *before* it gets large and threatens life/property)
- Updraft identification (e.g., Z_{DR} column, negative Z_{DR} cap) and storm cell tracking methods



Severe Weather Science: Downbursts

- Downbursts: areas of rapidly sinking air that spread out rapidly upon reaching the ground, producing violent straight-line winds and severe hazards for aviation
- Areas of high concentrations of melting hail + rain (“K_{DP} cores”) have been identified as prime regions for downburst development and occurrence
- Identifying these features may offer added lead-time and better real-time identification of intense downbursts



Kuster et al. (2021)

Severe Weather Research: Future Plans

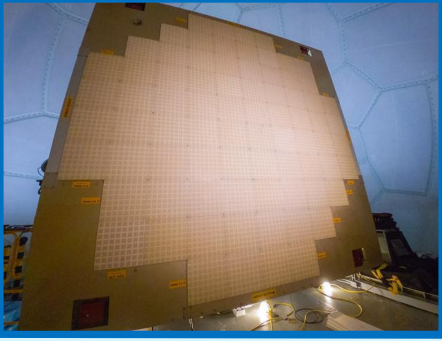
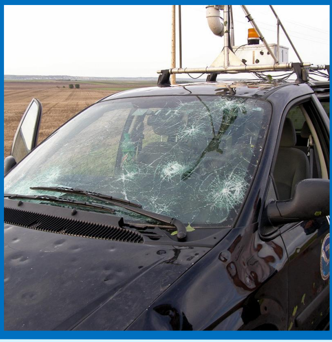
- *Improve* existing and *create* new algorithms that can identify severe weather hazards (tornadoes, hail, and straight-line damaging winds) earlier and more completely
- Focused research to identify hazards by providing best practices and guidance for forecasters remains an important goal when optimal result may not be an algorithm
- Research will fuse additional observing platforms (experimental measurements, satellite observations, etc.) with the existing, world-class radar network (the WSR-88D network) to help ensure NSSL serves its customers best

Forecast/Warning Tools and Techniques: RADAR

Linking Polarimetric Radar Observations and Numerical Models

Jeffrey Snyder, PhD, NSSL Research Meteorologist, RRDD

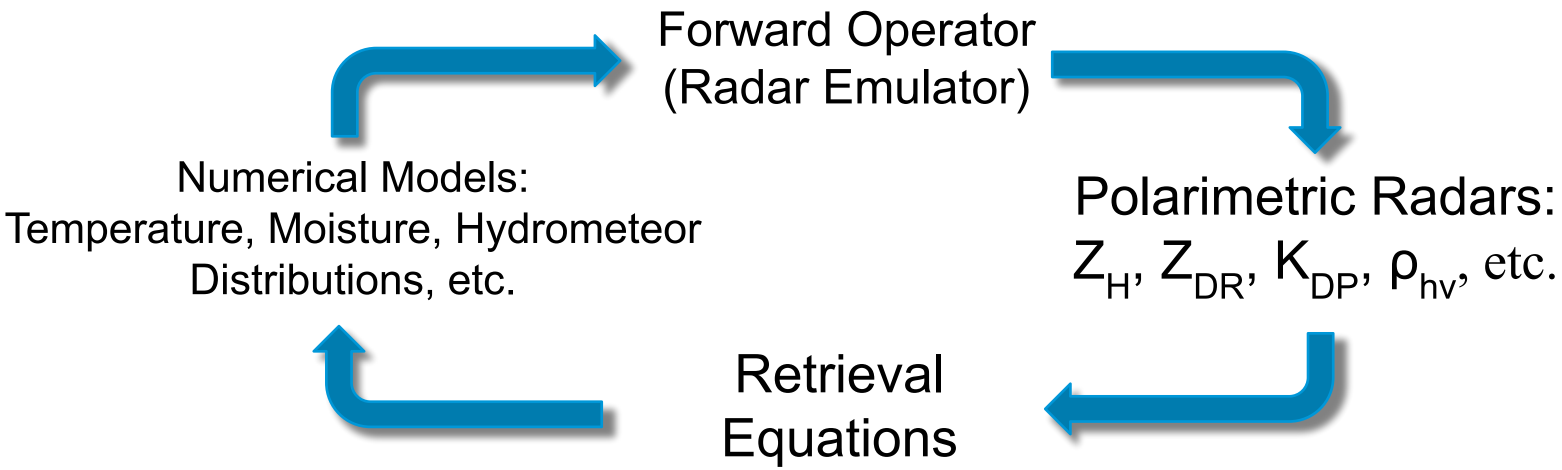


Why Radars and Models?

- **Weather radar** and **storm-scale numerical modeling** are **foundations** of NSSL research and development activities over past several decades
- Although models are getting more accurate (and complicated), there are a myriad of simplifications required to produce a simulation (parameterizations, etc.) -- lot of uncertainty and error
- Countless convective storms have been sampled by radar, but the radars measure a very small subset of the things that characterize the atmosphere
- We can use models to help us learn what the radar is seeing (e.g., microphysical fingerprinting), use radars to assess & improve models

Synthesizing Model and Radar Data

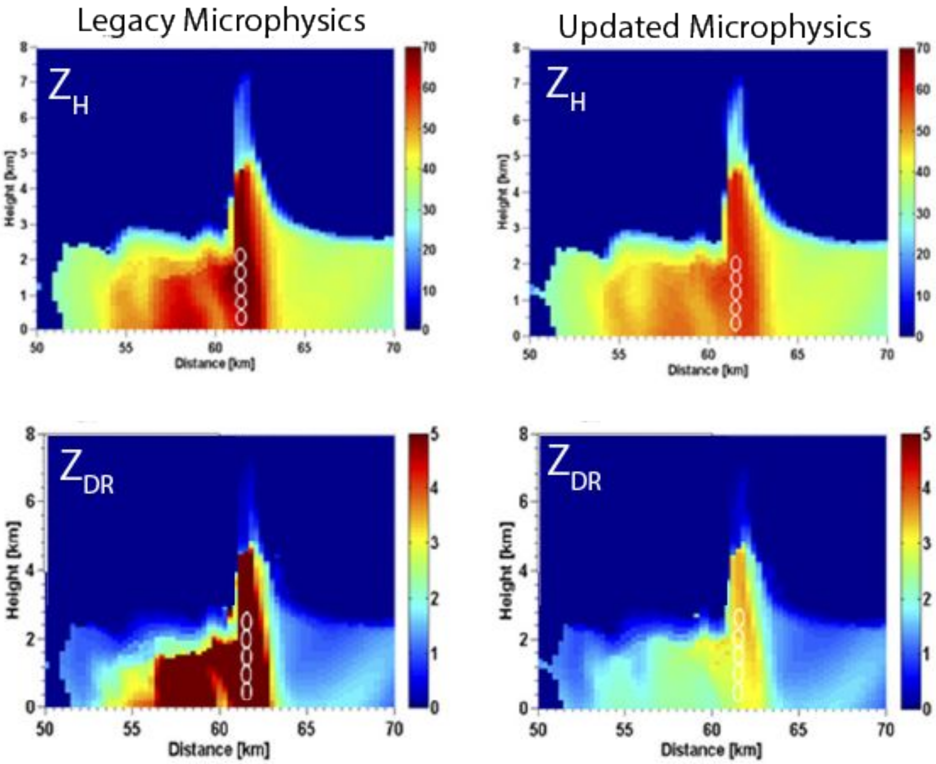


Many of the most "polarimetrically interesting" signatures occur where complexities and uncertainties are large. Need accurate forward operator to calculate accurate radar fields!

Radar quantities can be affected by
- Radar frequency
- Specific size distribution
- Liquid water fraction and distribution*
- Canting angle distribution*
- Particle density*
- Particle shape*

* Generally not predicted

Assessing Models Using Simulated Radar Data

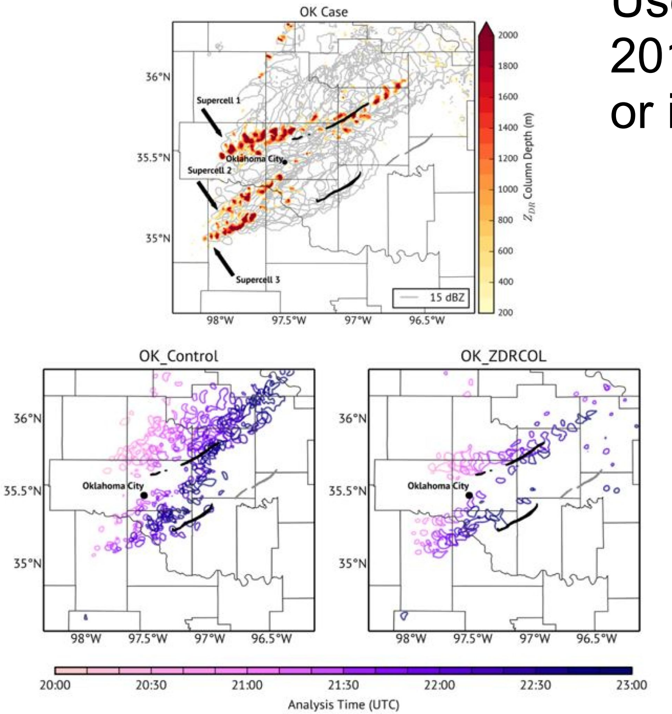


Adapted from Ilotoviz et al. (2018)

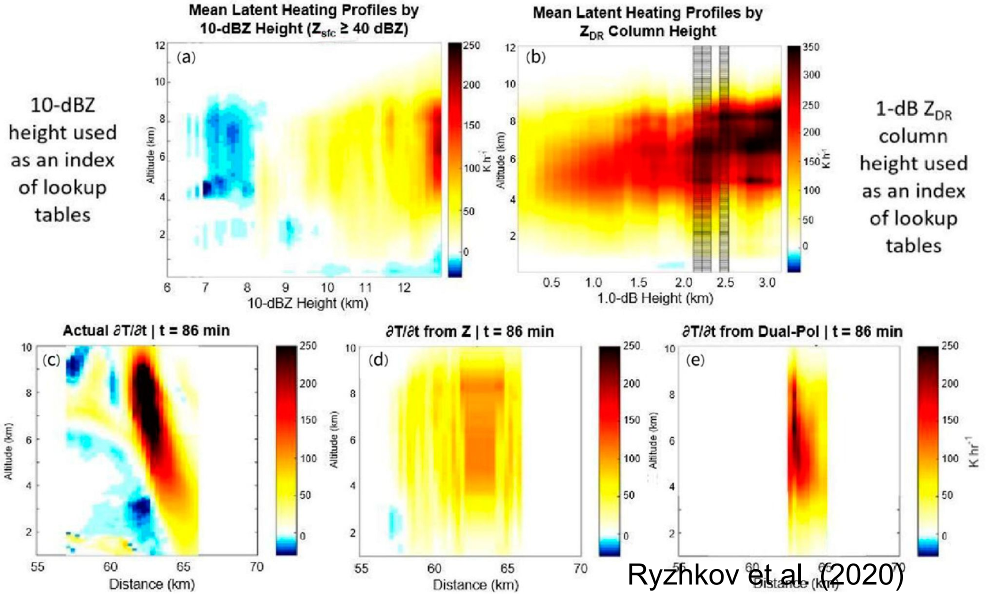
- “Simple” models coupled to a radar forward operator have been / are being used to study relationships between microphysical processes (evaporation, melting, etc.) and radar structure and evolution
- Radar observations can be used to assess a model. In this (left) case, Z_{DR} was found to be too high compared to observations. The microphysics was adjusted to bring it closer to observations.

Using Dual-Pol Radar Data in NWP: An Example

Use radar-identified Z_{DR} columns (e.g., Snyder et al. 2015) to localize storm updrafts, either directly (left) or indirectly through latent heat retrievals (bottom)



Carlin et al. (2017)



Ryzhkov et al. (2020)

Future Work: Improving PRFOs and Data Assimilation

- Continue porting over the advanced polarimetric radar forward operator (PRFO) to other high-resolution NWP models for community use
- Improvements to the PRFO will enable more accurate simulations of convective storms, thereby facilitating comparisons between observations and models
- How best to use the observations in models is an area of active research and will strongly impact how much observations can improve short-term forecasts