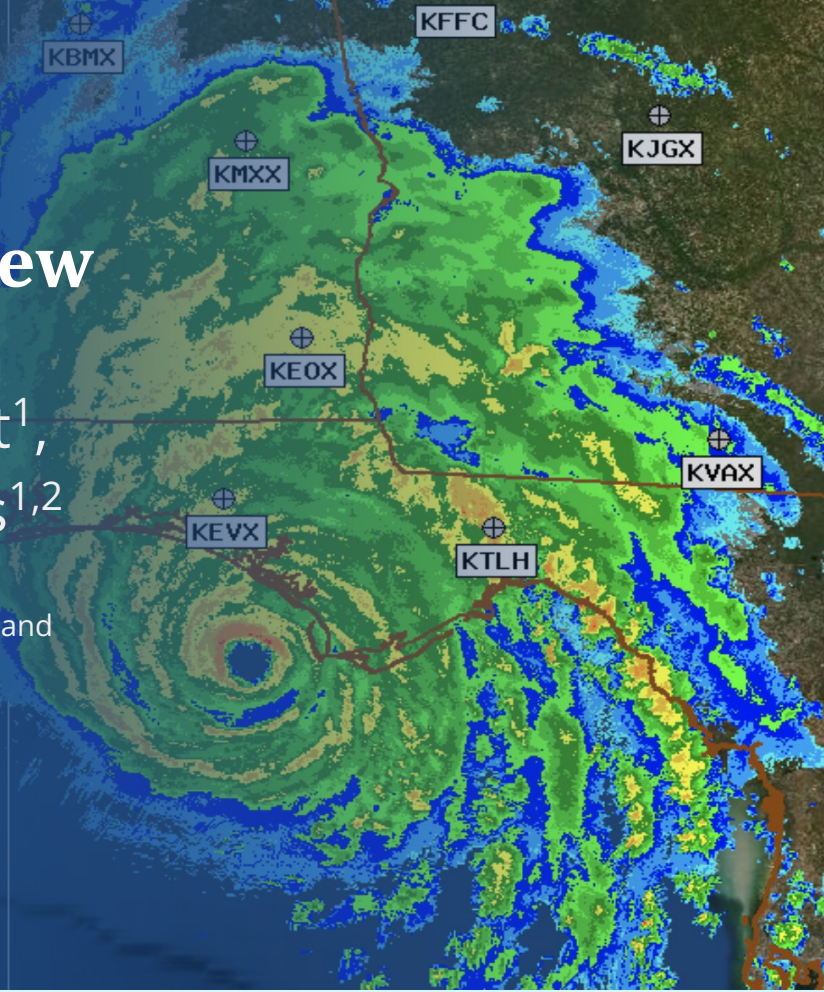
Multi-Radar Multi-Sensor Operational Product Overview



Heather Grams[1], Anthony Reinhart[1], Jian Zhang[1], and Steven Martinaitis[1,2]

[1]NOAA/OAR National Severe Storms Laboratory

[2]Cooperative Institute for Severe and High Impact Weather Research and Operations (CIWRO), University of Oklahoma

ROC Deeper Dive Webinar Series

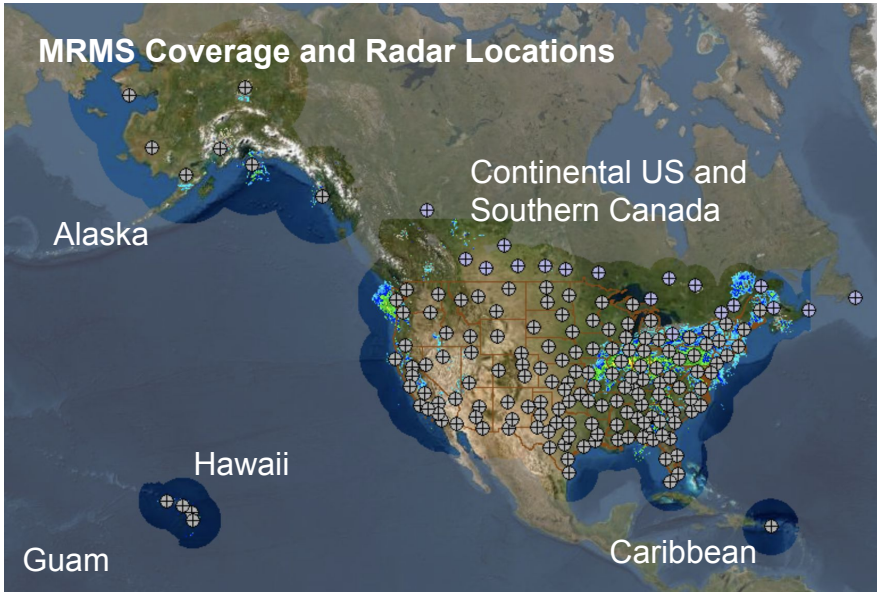
October 14, 2022

Multi-Radar Multi-Sensor (MRMS)

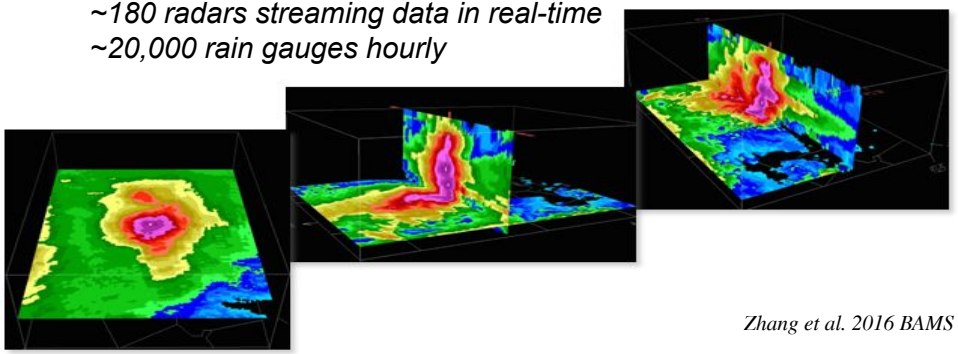
is an advanced remote sensing processing system that:

- Integrates radar, surface observations, satellite, lightning, and numerical weather prediction data into common reference grid

- Automatically generates complete seamless national 3D radar mosaic, storm attributes and multi-sensor quantitative precipitation estimates at high temporal and spatial resolution



~180 radars streaming data in real-time
~20,000 rain gauges hourly



Zhang et al. 2016 BAMS

Running operationally at NOAA/NCEP since 2014

Operational Product Viewer:
https://mrms.nssl.noaa.gov/qvs/product_viewer/

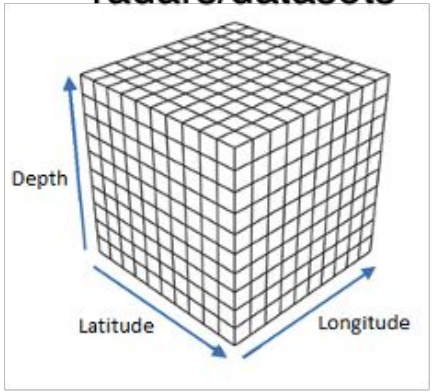
MRMS Training from WDTD:
https://training.weather.gov/wdtd/courses/MRMS/index.php

MRMS: Product Creation Process

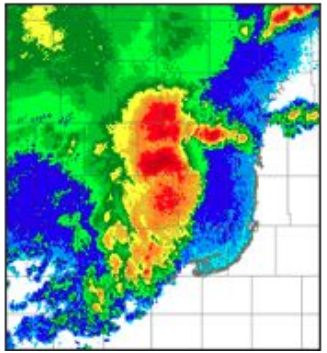
Data collection:
Active “listeners” that download data as soon as it becomes available

QC
Immediately processes data as soon as system ingest is finished

Interpolation & 3D Mosaic
Data is converted to regular grid and merged with other radars/datasets



Derivatives
Final products are computed from the mosaics (< 90 secs start to finish)



MRMS Radar Quality Control

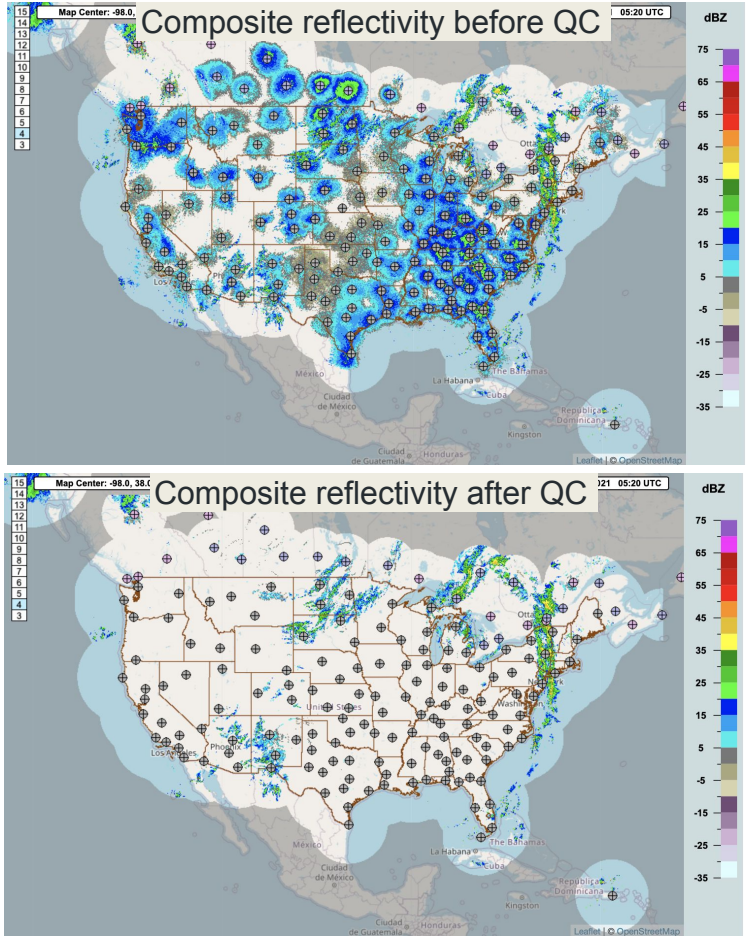
Mitigation of non-meteorological radar echoes:

- Ground clutter (terrain, trees, buildings, etc.)
- Biological returns (birds, bats and bugs)
- Sunspikes & electronic interferences
- Wind Farms

Mitigation of meteorological artifacts/influences in radar data:

- Bright banding from melting layer
- Three-body scatter spikes
- Virga and anvil overhang

Different QC measures used for different MRMS applications



0520 UTC 24 September 2021

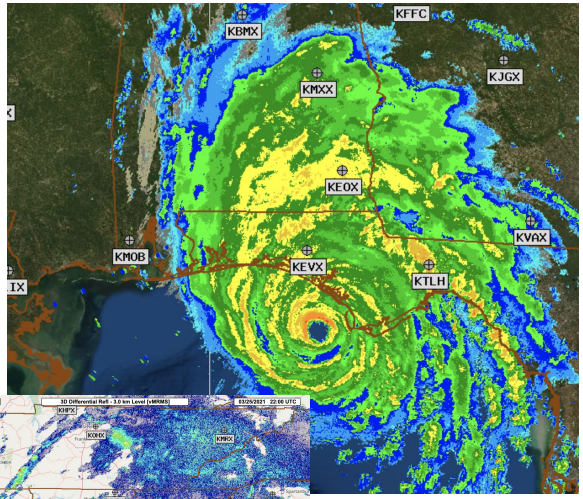
Tang et al. 2014 WAF
Tang et al. 2020 JTECH

MRMS Radar Mosaics

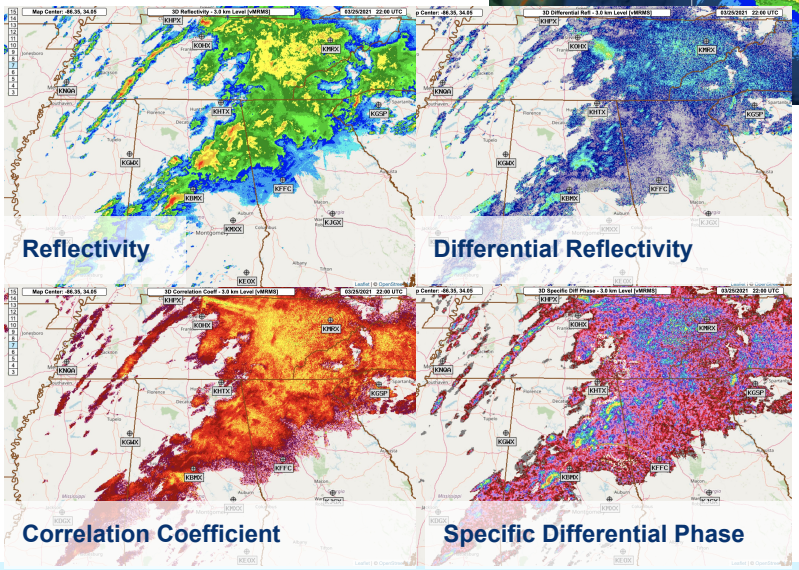
Creation of three-dimensional, multi-radar cubes of fundamental dual-polarization radar variables at a 2-minute resolution

- *Horizontal resolution of 1-km or 500-m*
- *33 vertical levels*

Two-dimensional multi-radar mosaics of derived radar values used to drive product development within the MRMS system



MRMS Composite Reflectivity from Hurricane Michael (2018)

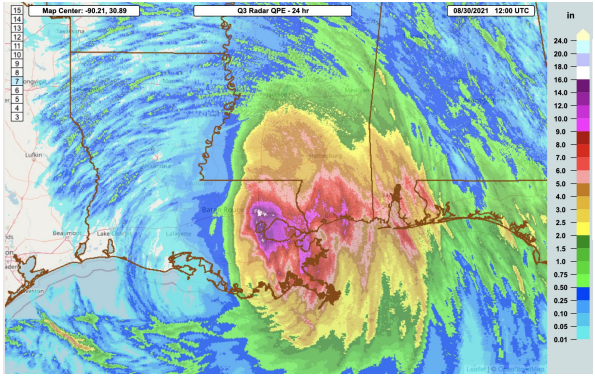


Dual-Polarization Variables at 3-km height level from 3-D mosaic

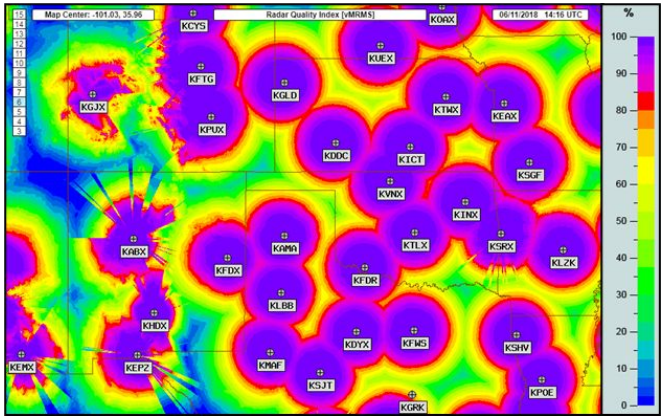
Zhang et al. 2016 BAMS

MRMS Radar-Based Precipitation Estimation Products

- **Radar-Only QPE:** Dual-polarization scheme that leverages radar variables to improve precipitation estimation and mitigate errors from partial beam blockage, brightband contamination, and other impacts
  - Instantaneous precipitation rates every two minutes
  - Accumulations from 15-min to 72-h
- **Radar Quality Index (RQI)** product shows best coverage of radar-based precip estimates based on radar beam height, beam blockage, and beam location with respect to the melting layer
  - Instantaneous RQI values
  - RQI accumulated over time

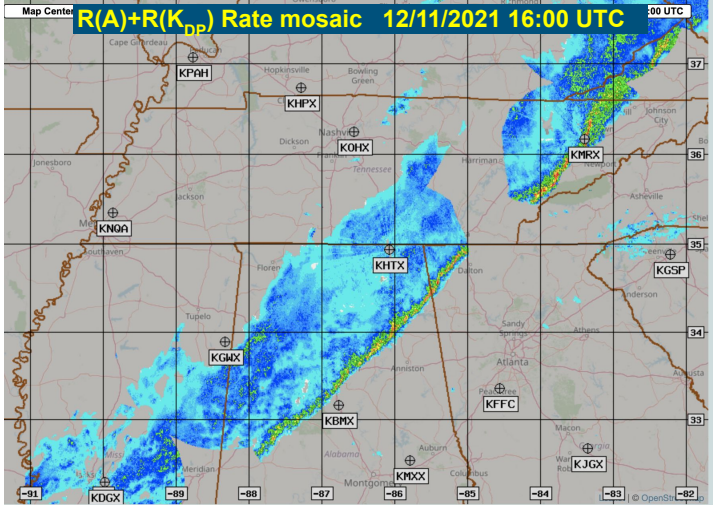


24-hour Rainfall Totals from Hurricane Ida (2021)



RQI over central CONUS - June 2018

Zhang et al. 2016 BAMS
Martinaitis et al. 2018 JHM


R(A)+R(K$_{DP}$) Rate mosaic 12/11/2021 16:00 UTC
KPAH
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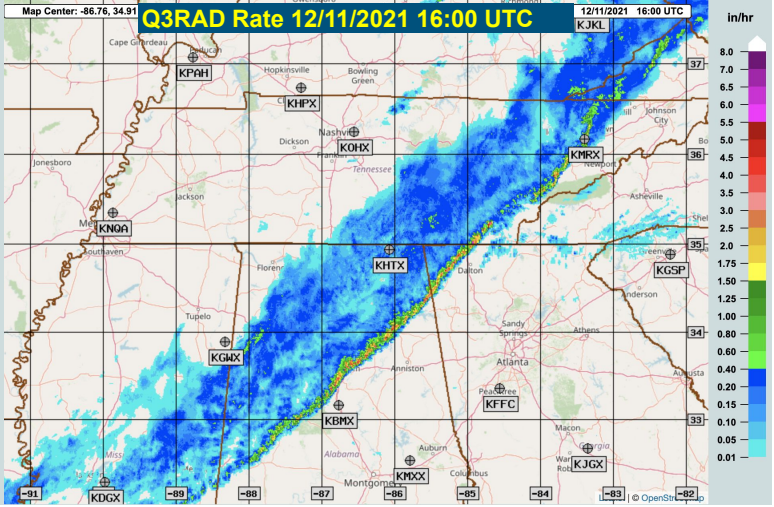
KGWX
KFFC
KBMX
KMXX
KJGX
KDGX


Q3RAD Rate 12/11/2021 16:00 UTC
12/11/2021 16:00 UTC
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in/hr
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1.00
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0.40
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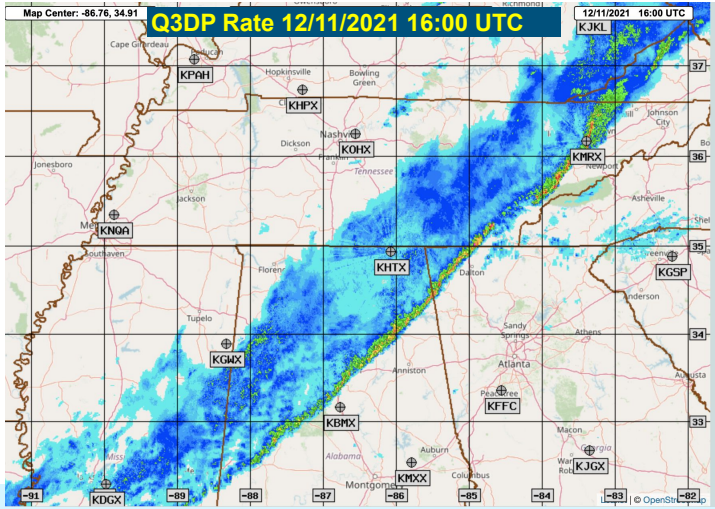
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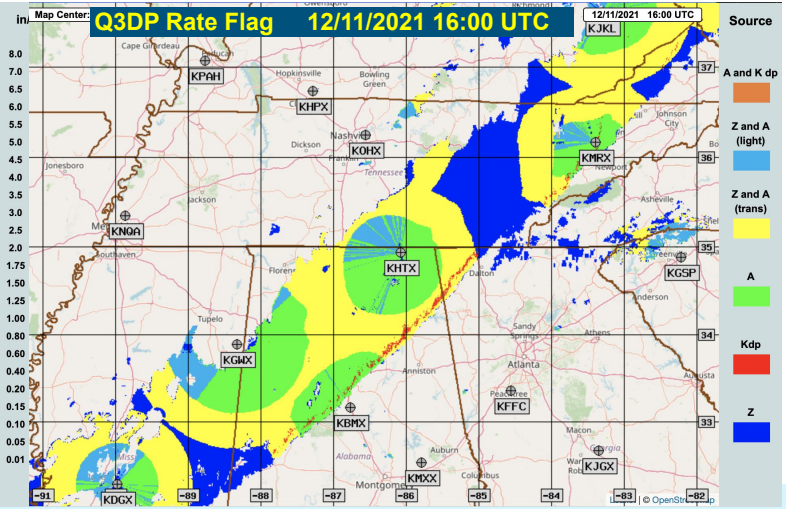
Q3DP Rate Flag 12/11/2021 16:00 UTC
12/11/2021 16:00 UTC
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Source
A and K dp
Z and A (light)
Z and A (trans)
A
Kdp
Z
KPAH
KHPX
KOHX
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KMXX
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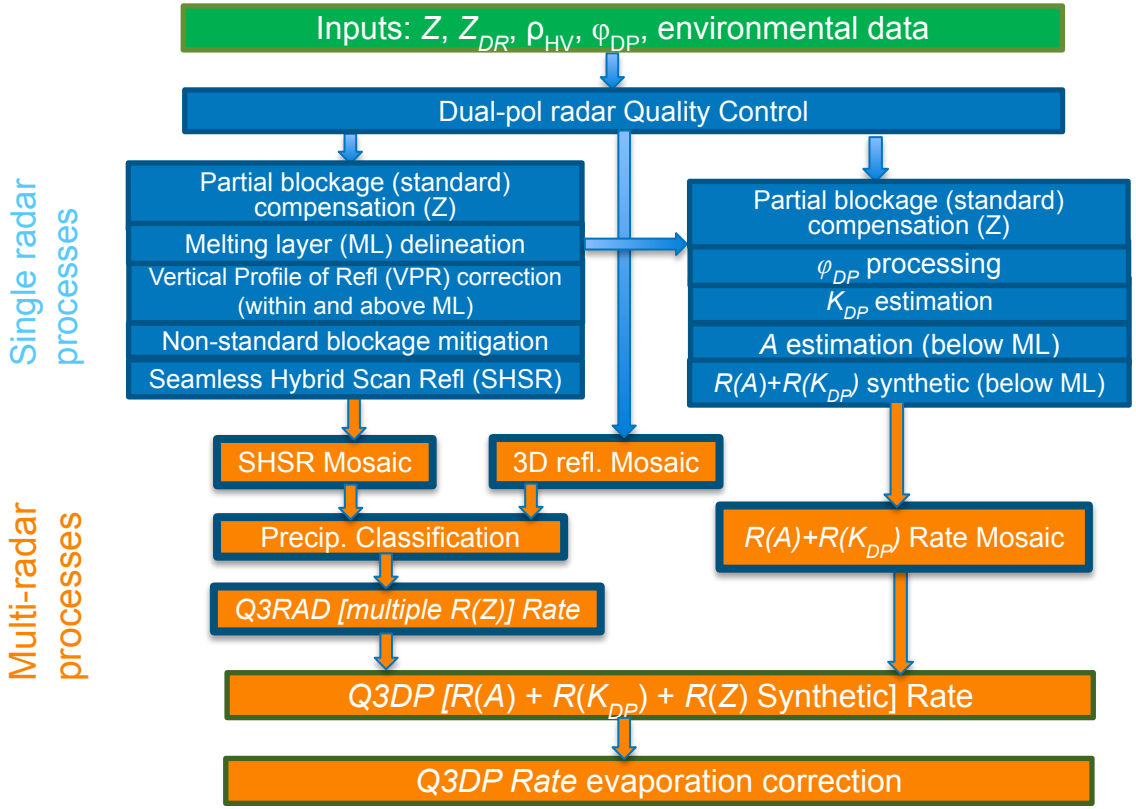
MRMS Radar-Only QPE Processing



Z: reflectivity;
Z_{DR}: differential reflectivity;
ρ_{HV}: correlation Coefficient;
φ_{DP}: differential phase;
K_{DP}: specific differential phase;
A: specific attenuation

Zhang et al. 2020 JHM

MRMS Dual-Pol Radar Synthetic QPE

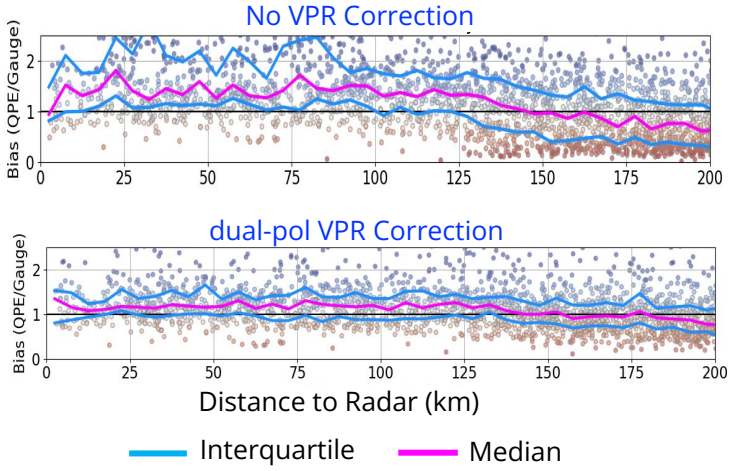
Advancements in radar QPE and their impacts

Techniques	Impacts
Specific attenuation based QPE	Significantly lowered dry biases and uncertainty in heavy to extreme rainfalls
Dual-pol VPR correction	Reduced range dependent biases and random errors (see Figure to the right)
Evaporation correction	Reduced false light precipitation; Improved QPE accuracy in semi-arid environments
Non-standard blockage mitigation	Reduced discontinuities and underestimation in QPE
Improved precipitation classification	Reduced false convective rain identification in bright band and reduced overestimation errors

Wang et al. 2019 JHM
Zhang et al. 2020 JHM
Cocks et al. 2019 JHM
Martinaitis et al. 2018 JHM

Radar QPE/gauge bias ratios vs. range

14 cases of different melting layer heights across CONUS



Hanft et al. 2022 JHM

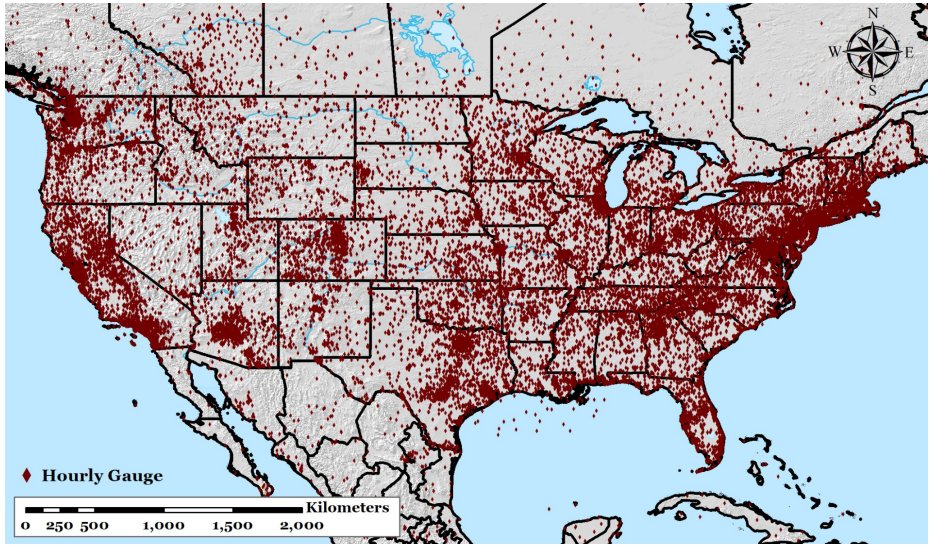
Gauge Quality Control

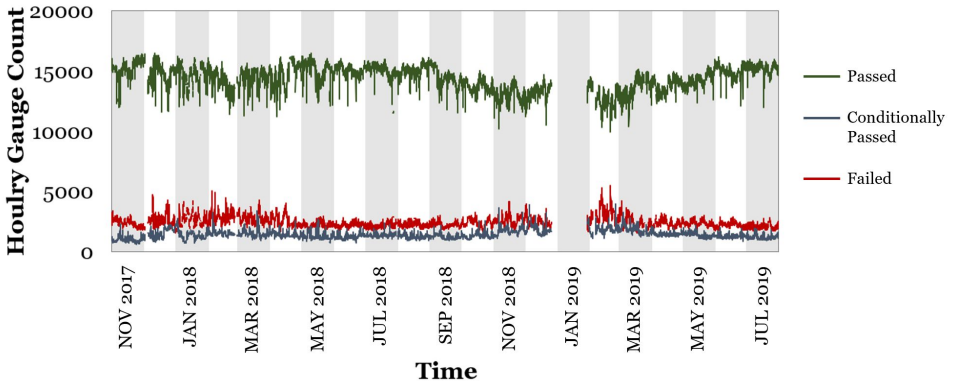
Ingest over 20,000 hourly automated gauge observations per hour across all MRMS domains

Complex decision trees leveraging radar and model data to remove erroneous observations

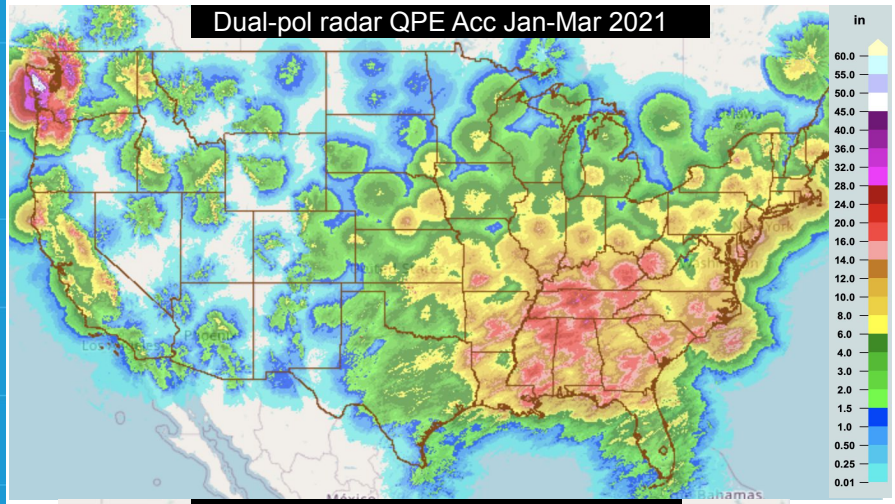
Average of 86% of all observations are retained per hour (Varies seasonally)

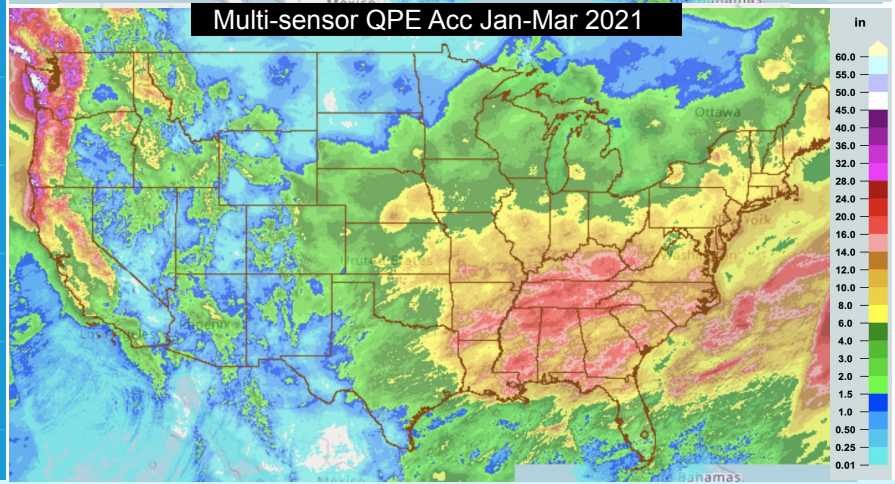
Automated gauge QC conducted in MRMS system correctly matches manual QC > 99%





Qi et al. 2016 JHM
Martinaitis et al. 2021 JHM



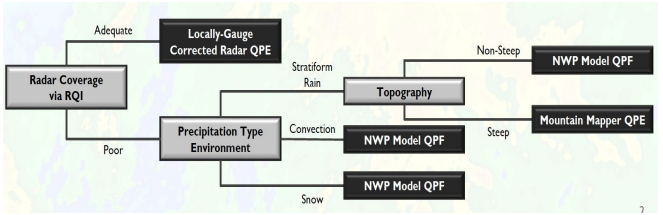


Multi-Sensor QPE

Seamlessly blend different precipitation information sources via physically-based methodology for optimal coverage and accuracy.

The blending scheme is based on the following information:

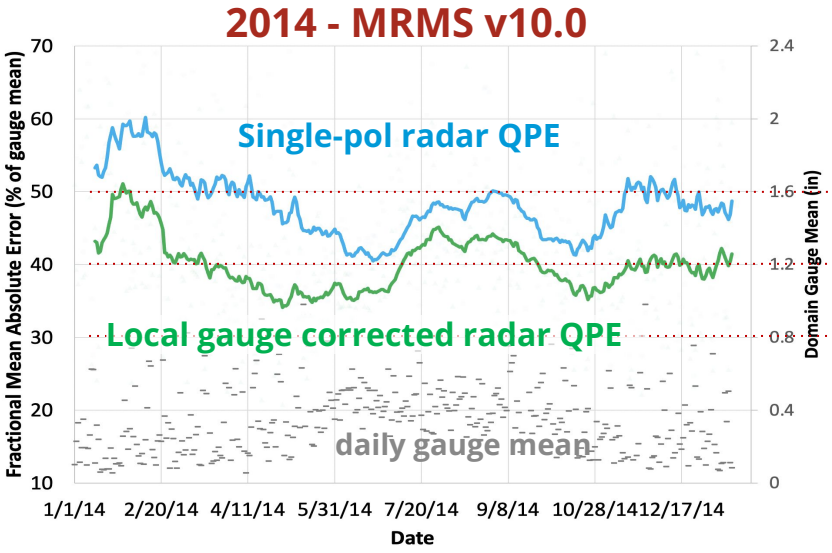
- Radar QPE Quality Index (RQI)
- Topography
- Precipitation Type
- MRMS Locally Gauge-Corrected Radar QPE
- MRMS Mountain Mapper QPE
- Model 1-hr Quantitative Precipitation Forecasts (QPFs)

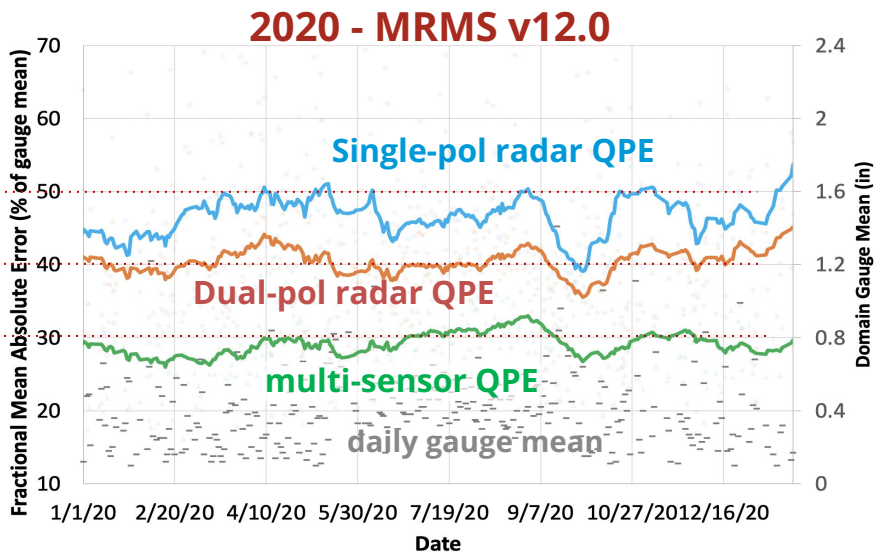


Martinaitis et al. 2020 JHM

MRMS QPE Evolution and Improvement

30-day Running Mean of Daily Fractional Mean Absolute Errors of MRMS QPEs
(with respect to CoCoRaHS Gauges over CONUS)





Error reductions:

Dual-pol vs. single-pol radar QPE: ~5-10%

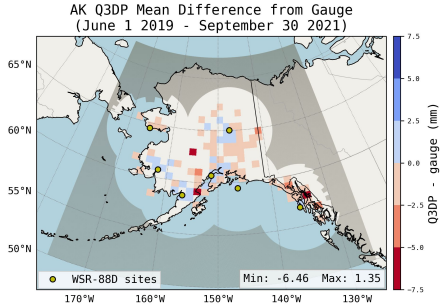
Multi-sensor vs. dual-pol radar QPE: ~10-13%

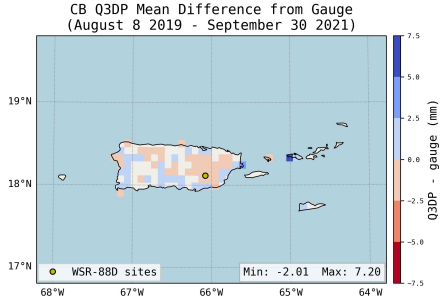
MRMS oCONUS Domains

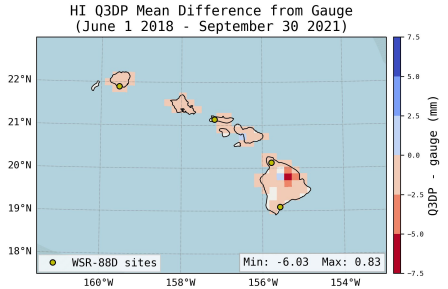
All MRMS precipitation products and tools are also available across four oCONUS domains: Alaska, Hawaii, the Caribbean, and Guam

These regions have diverse climates and stakeholder needs

- In Alaska, a lack of radar coverage necessitates assessing geostationary and polar-orbiting satellite information, as well as improvements to snow QPE
- In the other three domains, identification and quantification of “tropical” precipitation has a major impact
- Hawaii’s complex terrain degrades radar coverage and drives small-scale variations in orographic precipitation, which may be addressed by AI/ML techniques





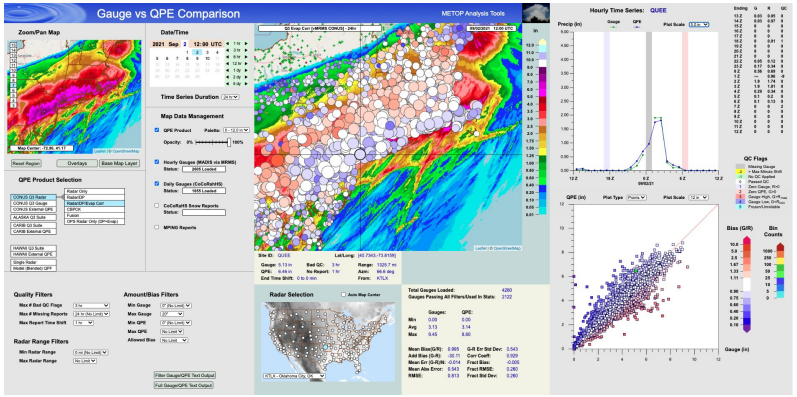


Product Testing/Validation

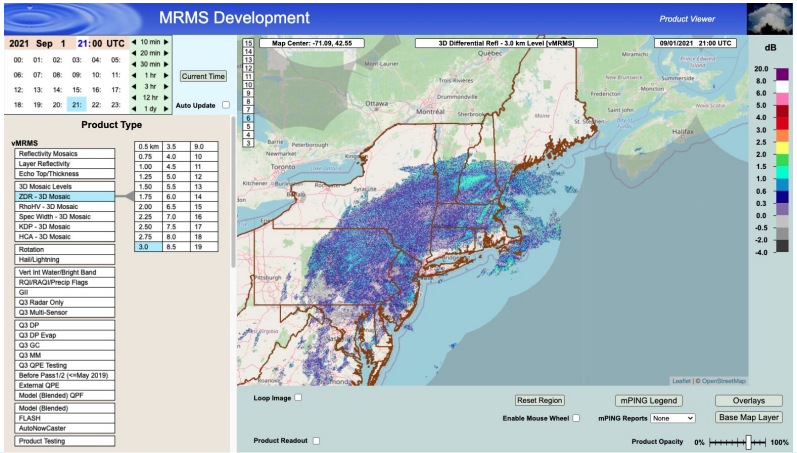
Operational and experimental MRMS are evaluated in real-time on the NSSL development system to verify product stability and quality

- Real-time products are displayed on internal web pages to allow scientists and software developers to monitor their quality
- Internal displays of products under development are made available for key external stakeholders for additional quality assurance and feedback prior to operational transition

Rain Gauge vs. QPE Comparisons



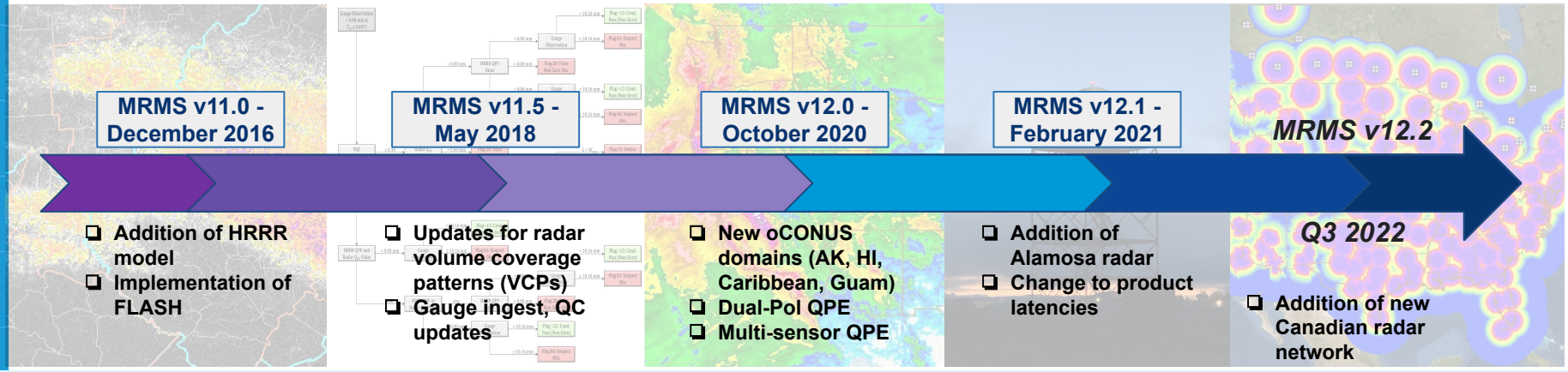
Real-Time Display of Internal and Operational Products



MRMS Process for Operational Updates

- NSSL team works directly with the NWS National Centers for Environmental Prediction (NCEP) Central Operations staff on the operational implementation for the NWS, including on-site training and interactions
- NSSL built and maintains a real time MRMS system processing environment nearly identical to the NCEP system, in addition to a second real-time system in the Cloud

Notable MRMS Builds over the Past Five Years



MRMS Product Impacts

Part 1: Situational Awareness

MRMS radar mosaics in nationwide decision support displays

NWS

- radar.weather.gov
- SAFER Hazard Dashboard

NOAA

- nowCOAST

FAA

- Flight Information System for pilots

DOD

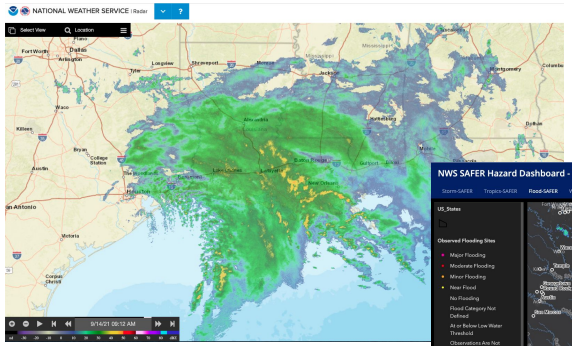
- AFW-WEBS

USGS

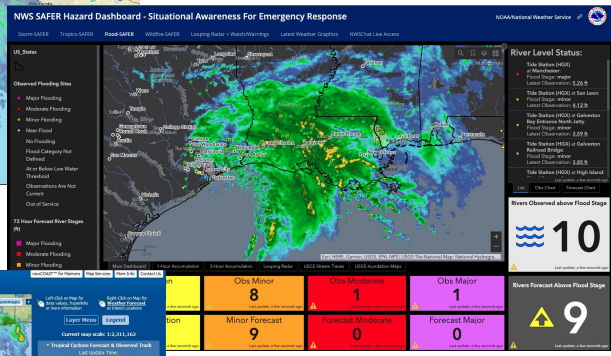
- National Water Dashboard

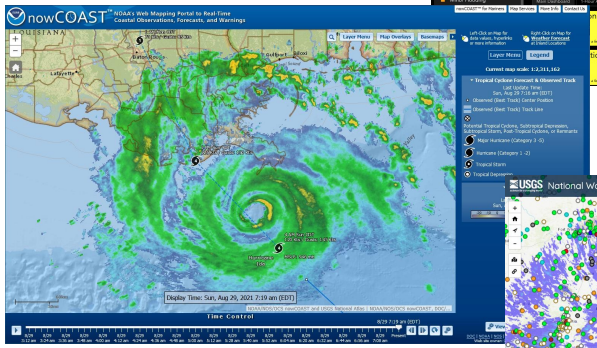
Private Sector

- GR-Earth, mobile radar apps, and many others

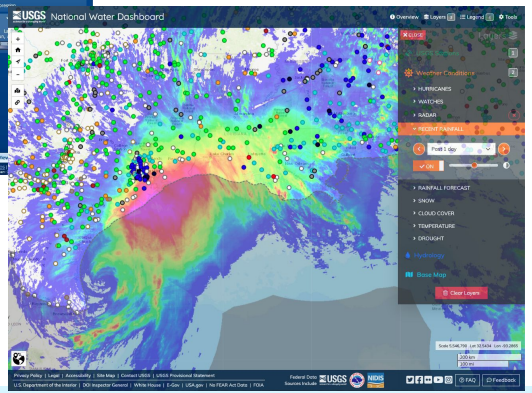


NWS





NOAA



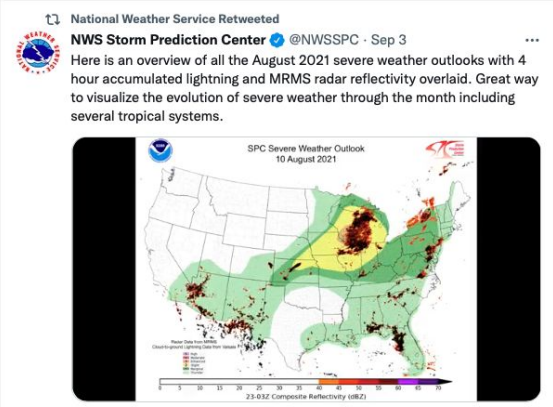
USGS

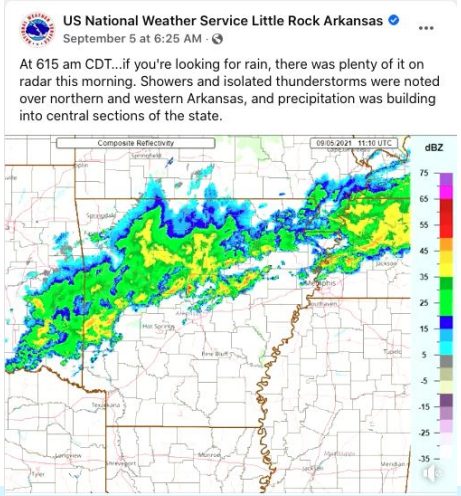
MRMS Product Impacts

Part 2: Improving Warnings and Public Messaging

- MRMS reflectivity, hail, precipitation, and FLASH products used routinely in NWS severe weather operations and public messaging
- MRMS rotation tracks used for post-event emergency response and for tornado damage surveys

NWS Houston Office Social Media Messaging for Tropical Storm Imelda (2019)





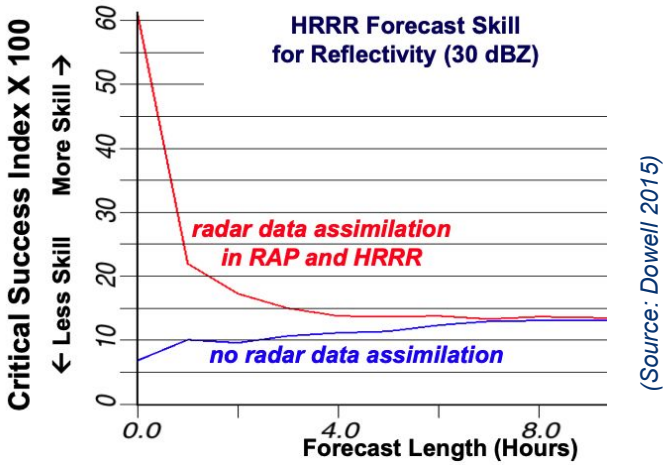
Northeast US Flash Flooding from Remnants of Hurricane Ida (2021)

MRMS Product Impacts

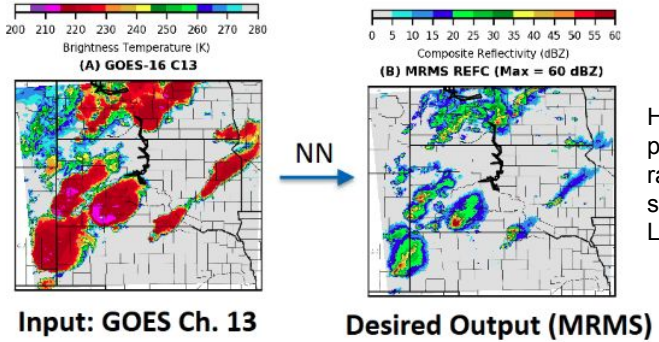
Part 3: Improving NWP

- MRMS reflectivity and precipitation used for weather model data assimilation (e.g., WoFS and HRRR/RRFS) and verification
- MRMS precipitation used as driver for NWS National Water Model and as starting point for NWS River Forecast Center precipitation analysis
- Growing adoption within machine learning community as input for training and validation

Impact of Radar Data Assimilation on NWP Skill

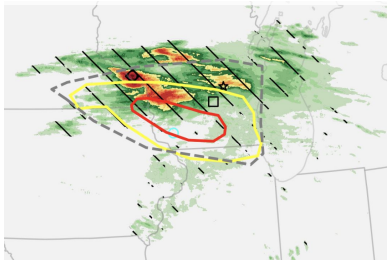


(Source: Dowell 2015)

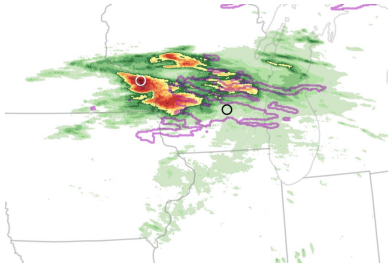


Hilburn et al. (2020) predicting MRMS radar from GOES-16 satellite using Deep Learning AI/ML

2021 FFaIR Experimental Product and Model Verification



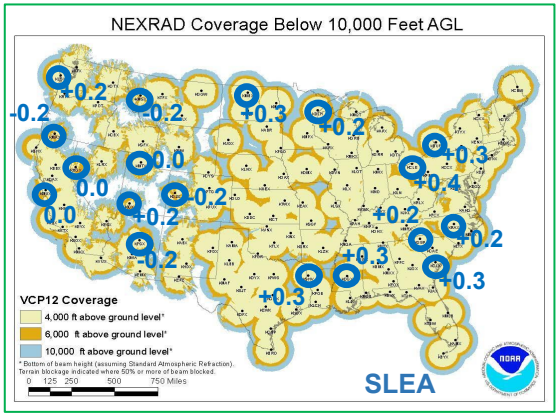
Experimental Rainfall Outlook

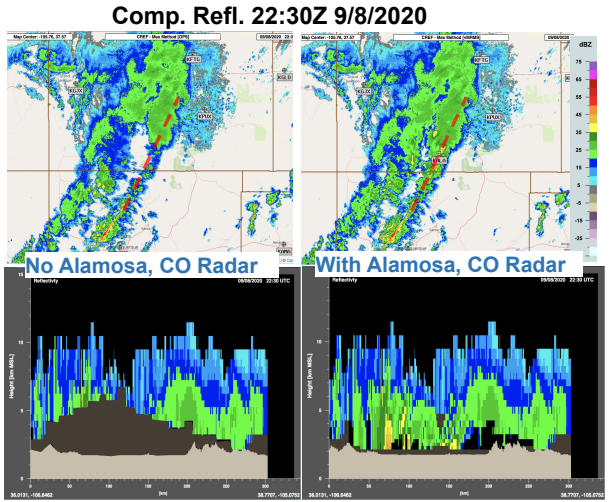


Purple = Model-Forecasted Precipitation

MRMS Development (2022 and beyond)

- Integration of new data and new radars, e.g.,
  - WSR-88D supplemental low angles
  - New dual-pol Canadian radar network (complete)
  - Terminal Doppler Weather Radars
  - Radars deployed by private sector and local governments
- Machine Learning-based QPE and Severe
- Satellite QPE (active and passive)
- Multi-Sensor Pass 3 Daily QPE
- Short-Term QPF for FLASH
- Multi-Radar Velocity Products for NWP data assimilation
- Continued upgrades for all MRMS domains

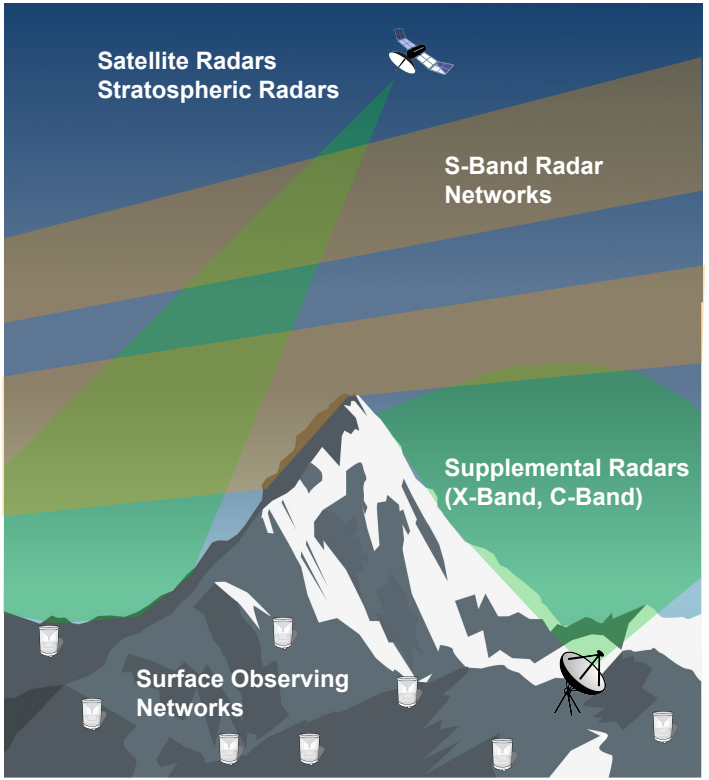




MRMS as an R2O Platform for new Observations

MRMS is ideally positioned to serve as the R2O gateway for new and emerging observing systems.

- Initial successes demonstrated with Canadian radar networks and supplemental radars
- Established processes for ingest, quality control, and optimized merging of widely varying data sources
- Established pathway to model data assimilation and operational agencies

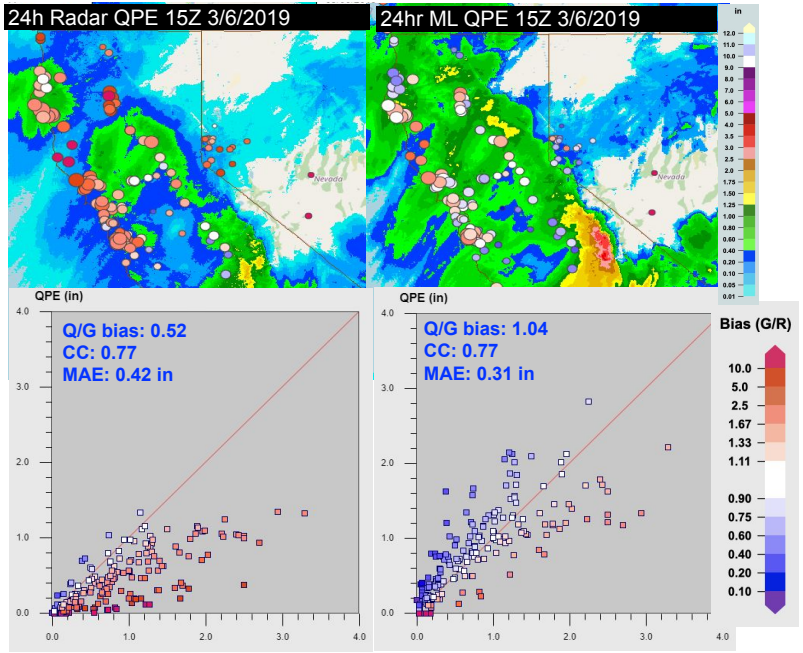


Machine Learning Development for QPE

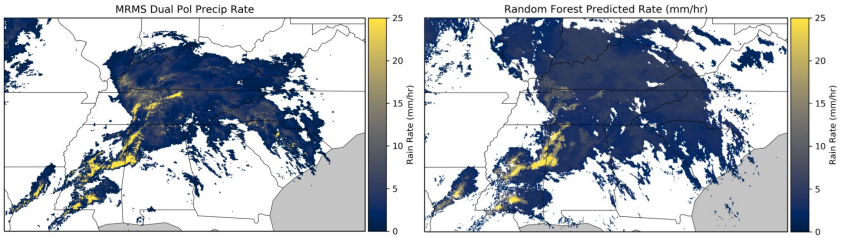
MRMS Surface Precipitation Estimates:

- Estimating rates and accumulations at surface in areas where observing networks are sparse.
- Estimating orographic enhancement below radar level

Convolutional Neural Nets and LSTM estimation of precipitation in complex terrain

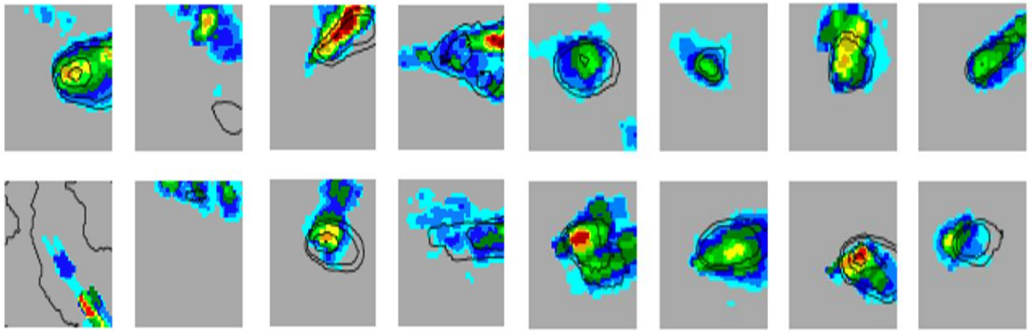


Estimating Radar-Based Precip Rates with GOES-16

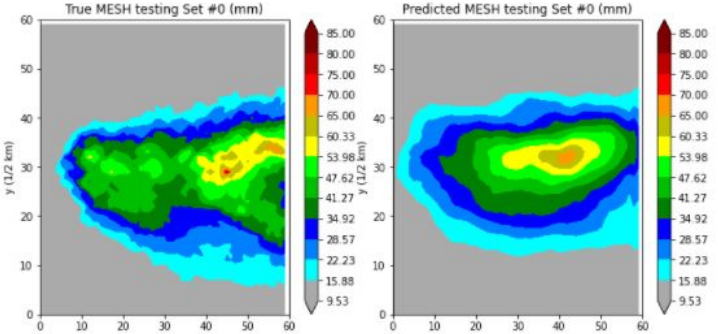


Machine Learning Development for Hail

- Precise measurements of the hail-output of a storm have been difficult to measure. This has led to the use of the Maximum Estimated Size of Hail as both a diagnostic tool and measure of ground truth for hail-sizing algorithms (such as the HSDA)
- U-nets (a type of CNN) for MESH swath prediction up to 30 minutes
- Inputs are MESH swaths with statistics from other MRMS and NSE fields

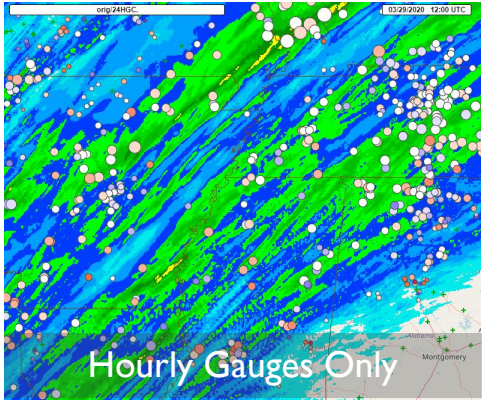


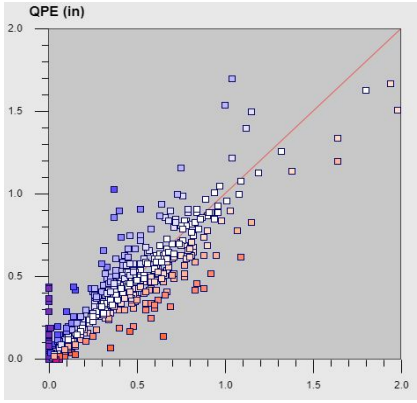
20, 25, 30 mm Predicted contours in black for 30-min MESH swaths



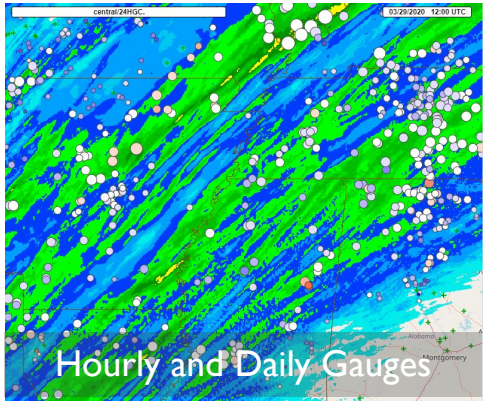
Multi-Sensor QPE - New Pass 3

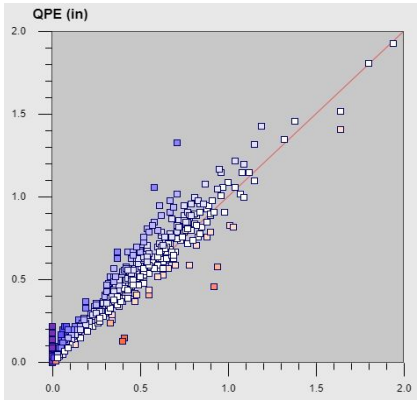
- Incorporate new longer duration or larger latency products into a Pass 3 version of the MRMS QPE
  - CoCoRaHS/COOP gauges
  - Satellite products
- Downscale 24-h gauge observations to be utilized in hourly QPE to create new accumulations
- Use satellite data to supplement radar coverage





Q/G Bias: .996
MAE: 0.095
Frac MAE: 0.216
CC: 0.905





Q/G Bias: 1.126
MAE: 0.077
Frac MAE: 0.175
CC: 0.965

Decadal MRMS Product Retrospective

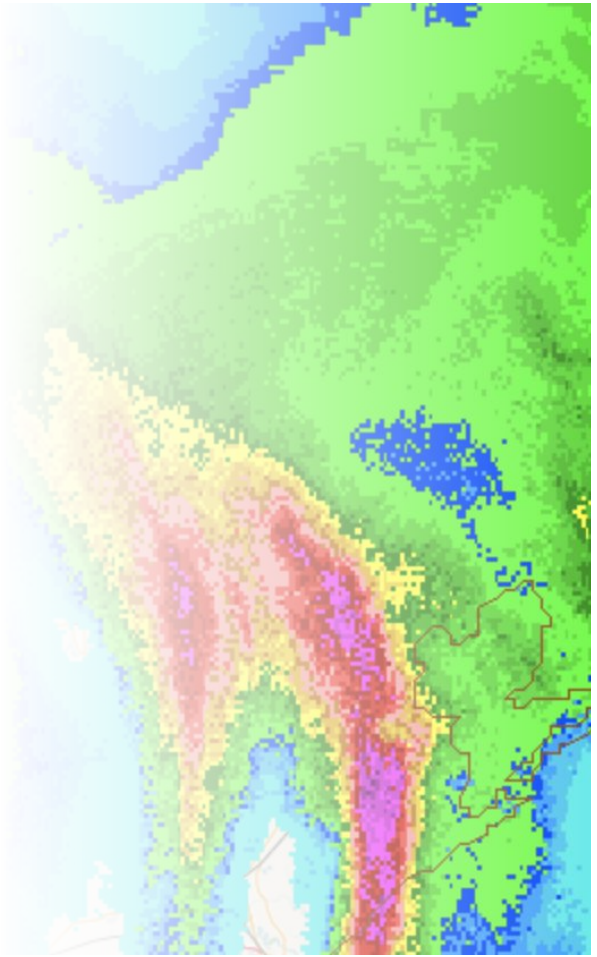
- Widespread need from stakeholders and users for a long-term, high-quality MRMS archive dataset
  - Precipitation climatology analysis at unprecedented scales
  - Hydrologic model calibration (including National Water Model)
  - Machine learning applications

- **Goal:** Reproduce all MRMS products since 2011 (WSR-88D Dual-Polarization era) using latest versions of algorithms from V12.2
  - Including national dataset of quality-controlled rain gauge accumulations for validation/ground truth

- Cloud-based workflow developed and optimized, and input datasets retrieved and processed

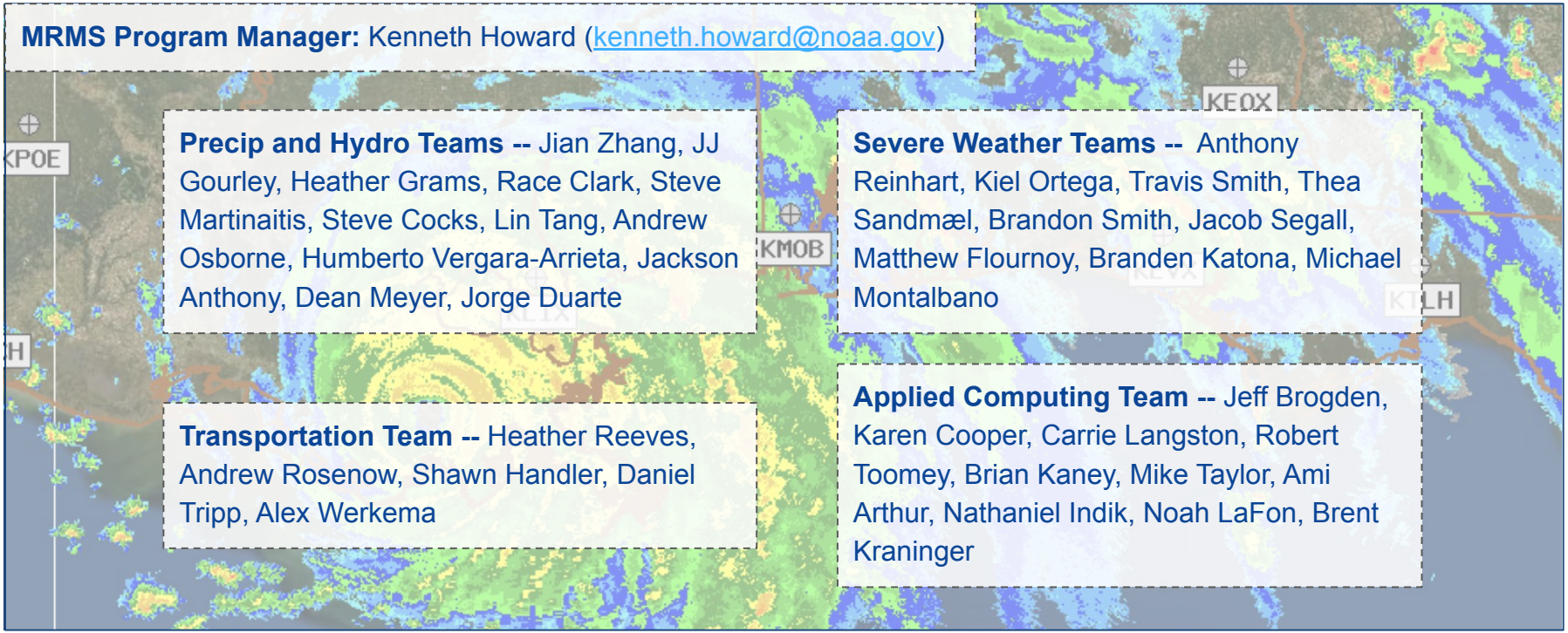
Summary

- MRMS products are a critical operational resource that is valuable to many hydrometeorological and severe weather applications
- MRMS is ideally positioned to serve as the central platform for integration of new emerging technologies in remote sensing
- NSSL will continue to explore and develop new innovations to improve product skill and accuracy



The MRMS Development and R2O Teams at NSSL

For MRMS questions: mrms@noaa.gov **For More Information:** https://mrms.nssl.noaa.gov/



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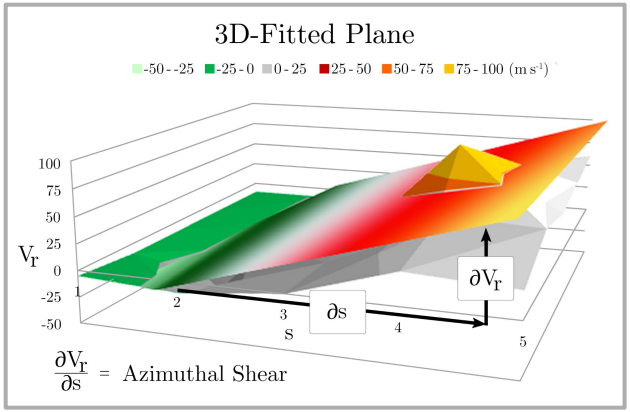
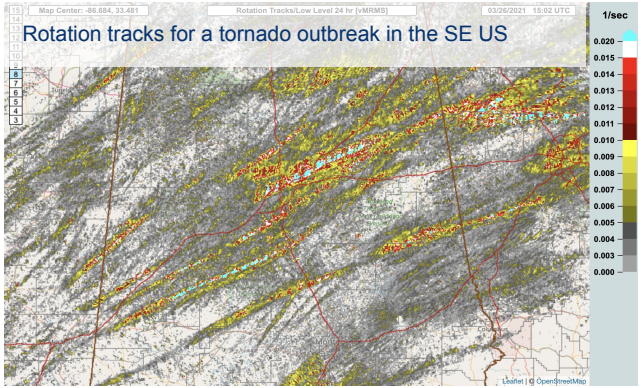
Linear Least-Squares Velocity Derivative Fields

- Azimuthal shear (AzShear)
- AzShear is layered producing 2 products a 0 - 2 km (low-level) and 3 - 6 km (mid-level)
- Layered products are then accumulated for rotation tracks
- This technique can be applied to products other than radial velocity





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