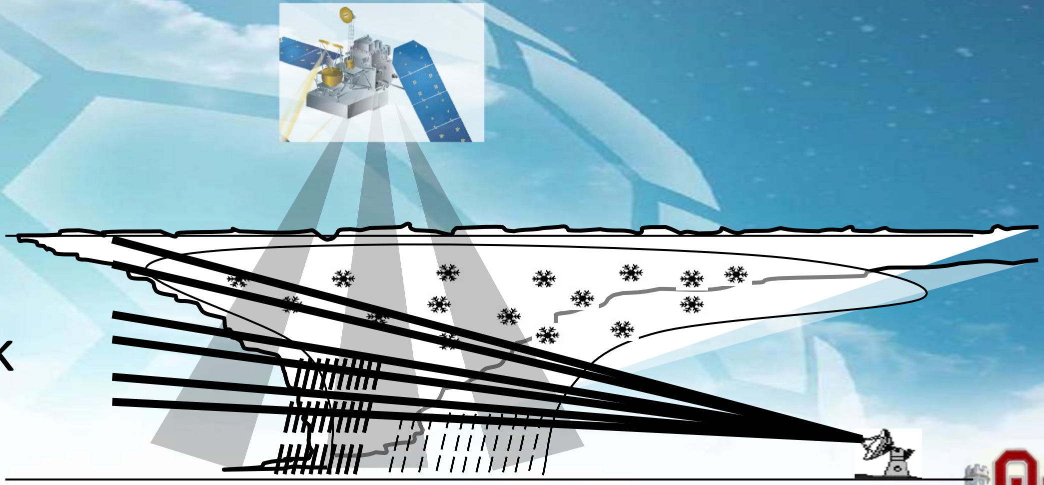
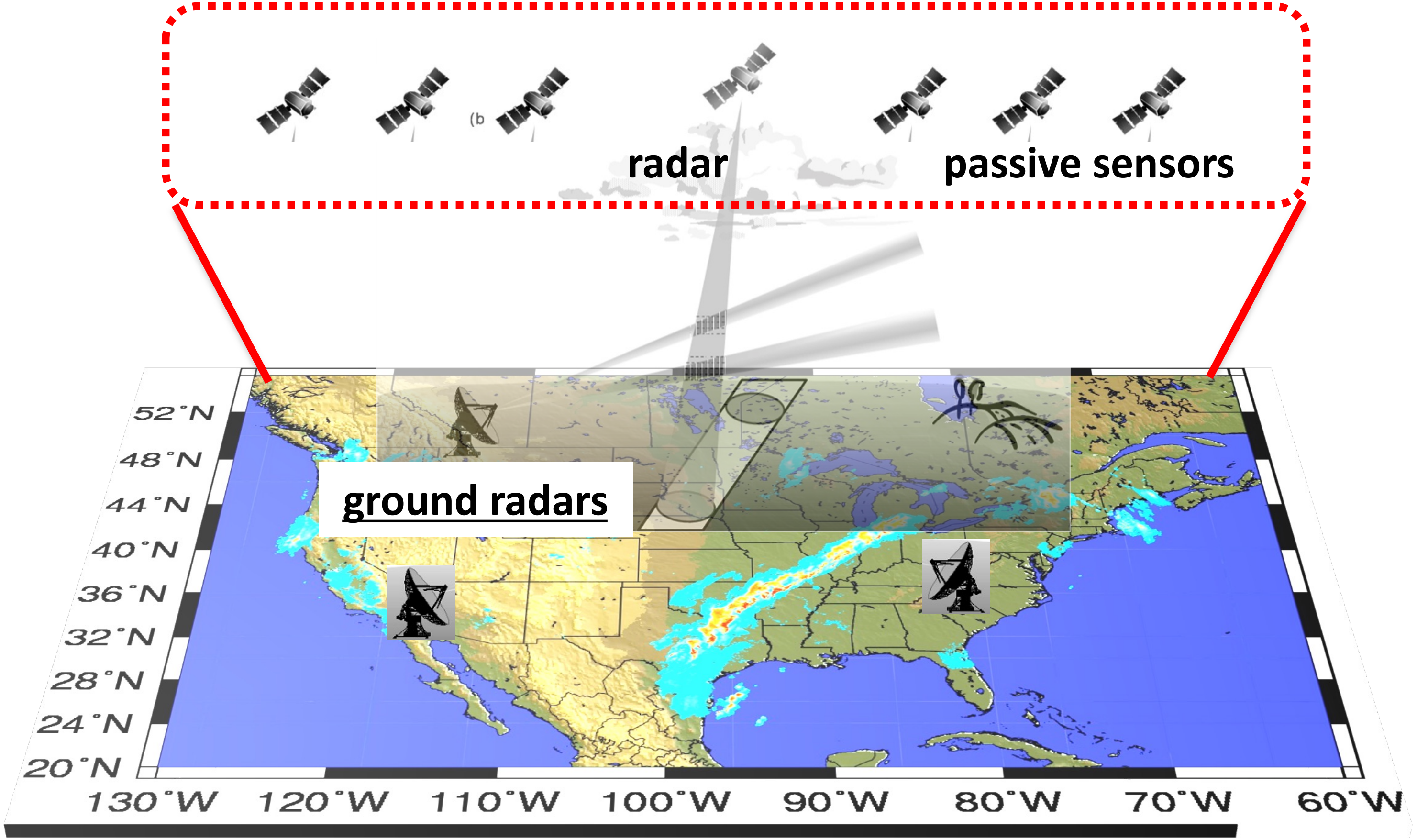
Probabilistic Quantitative Precipitation Estimation with Radars

Pierre Kirstetter

with contributions of:
Micheal Simpson, Jian Zhang, Jonathan J. Gourley, Steven Martinaitis and Nathaniel Indik

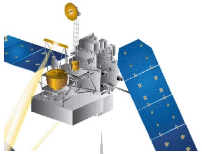


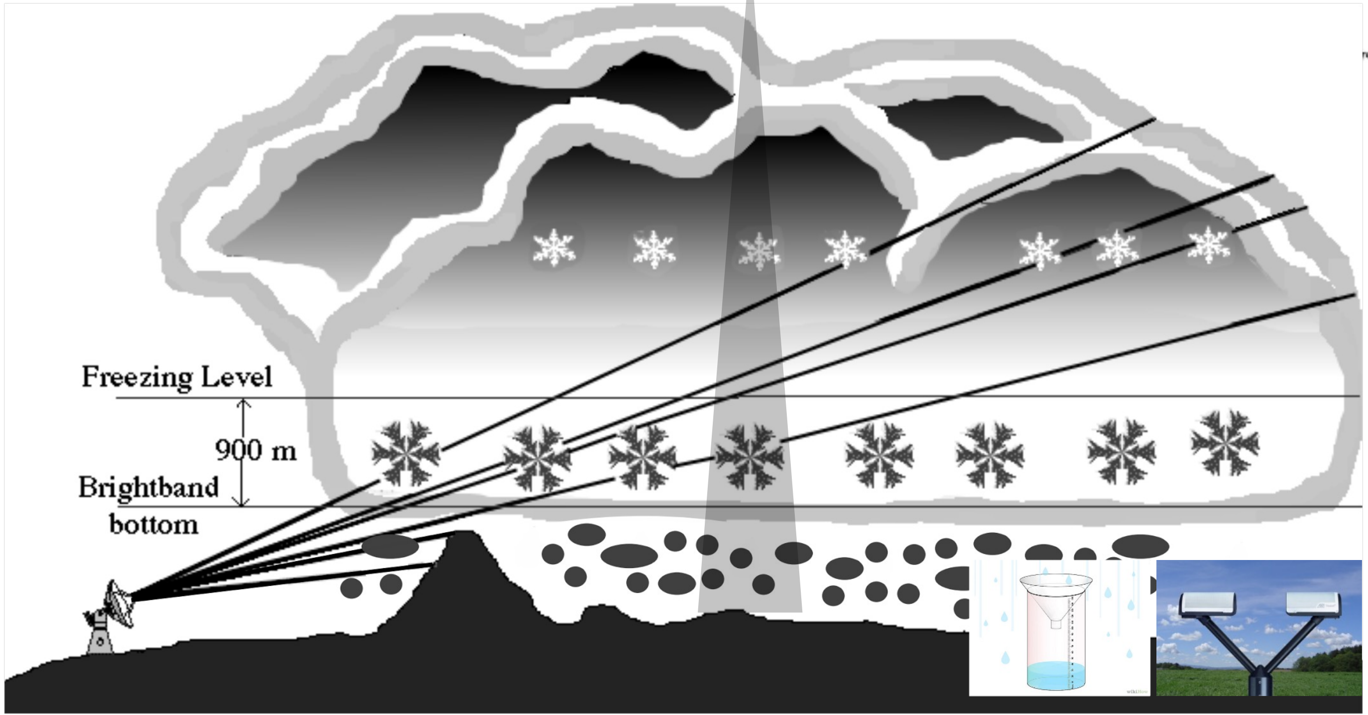
Remote sensing & Quantitative Precipitation Estimation

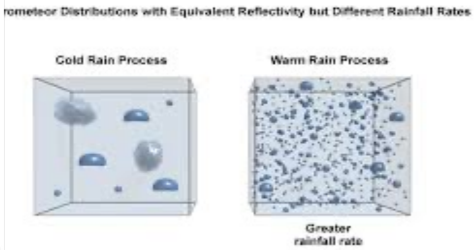


Challenges in remote sensing hydrometeorology

Example: **deterministic** QPE … but **indirect and often underdetermined relationship** between observations and precipitation







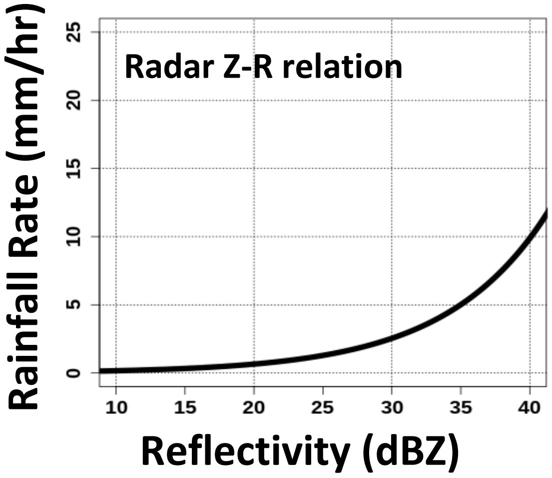
Challenges in remote sensing hydrometeorology

- **Remote sensing, atmospheric sciences, and hydrology:**
  - precipitation variability is ignored;
  - partially resolved / mixtures of precipitation processes;
  - limited characterization of extremes;
  - impacts hazard applications.
- **Classical parameterization approach is insufficient: deterministic, based on averaged properties.**

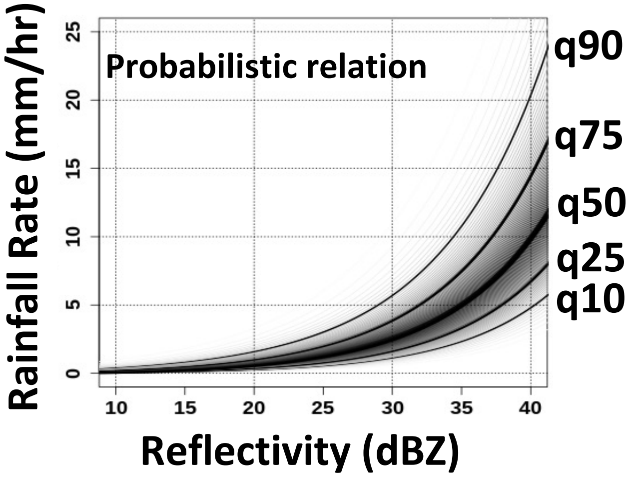
Moving forward: increase the information content

- **Use uncertainty as an integral part of precipitation estimation**
  - data fusion
  - data assimilation
- **Quantify the likelihood of weather and water extremes**
  - hazard information
  - risk analysis

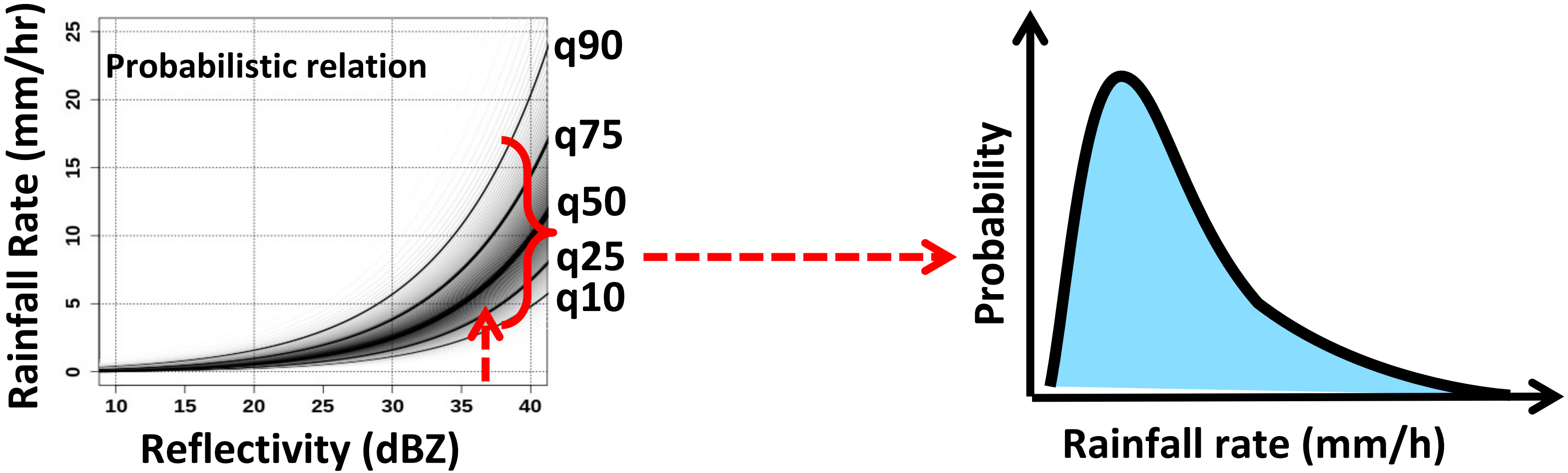
Space outside the deterministic relation = space of error



Probabilistic relation = possible precipitation rates

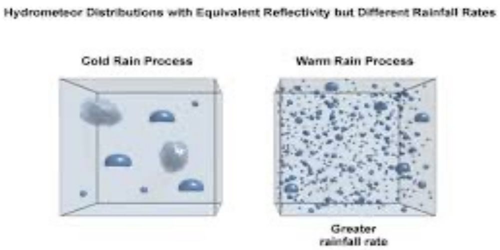


Estimating distributions of possible precipitation rates



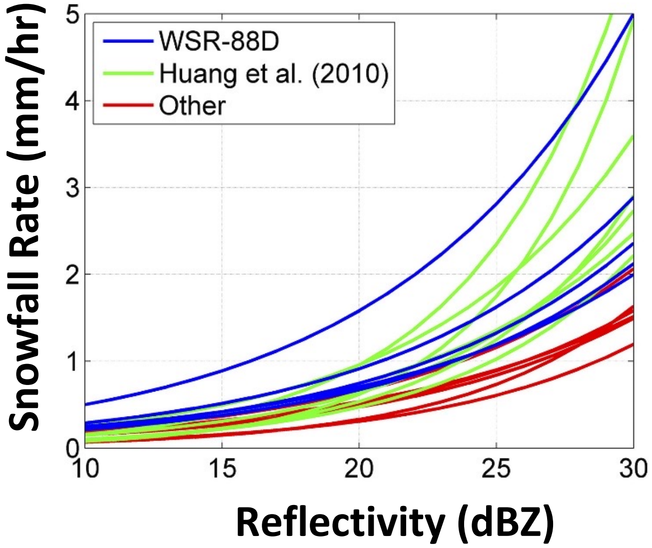
Same reflectivity $$Z_{\infty} = \int_{0}^{\infty} D^{6} N(D)\, dD$$

2 different rain rates $$R_{\infty} = \frac{\pi}{6} \int_{0}^{\infty} w_t D^{3} N(D)\, dD$$

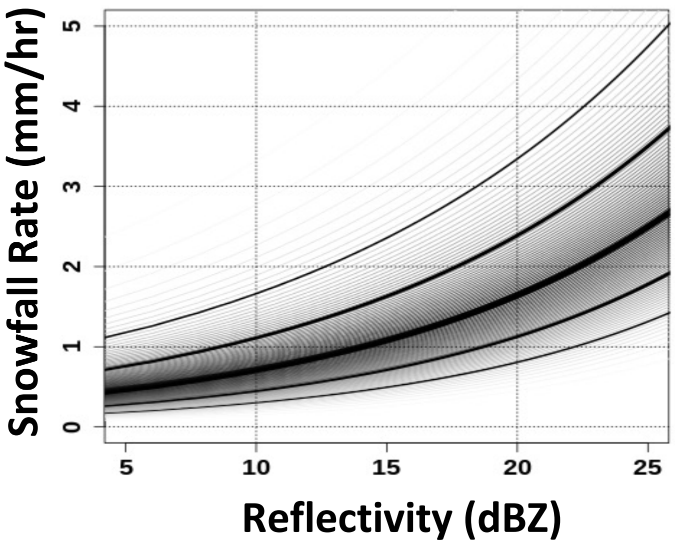


Distribution of precipitation rates: Snow

Deterministic Z-S relations: compilation



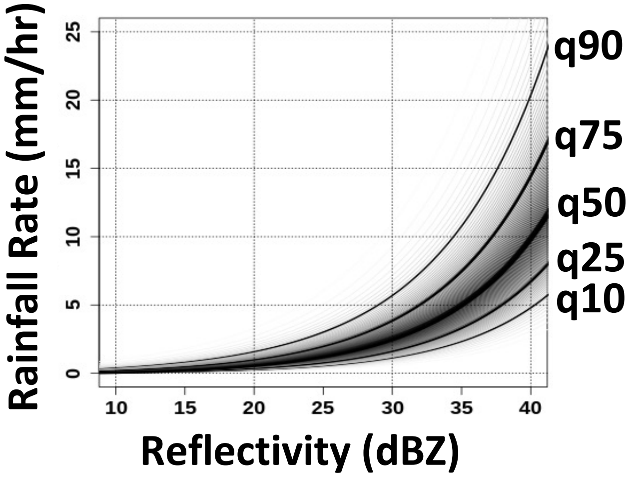
Snow PQPE

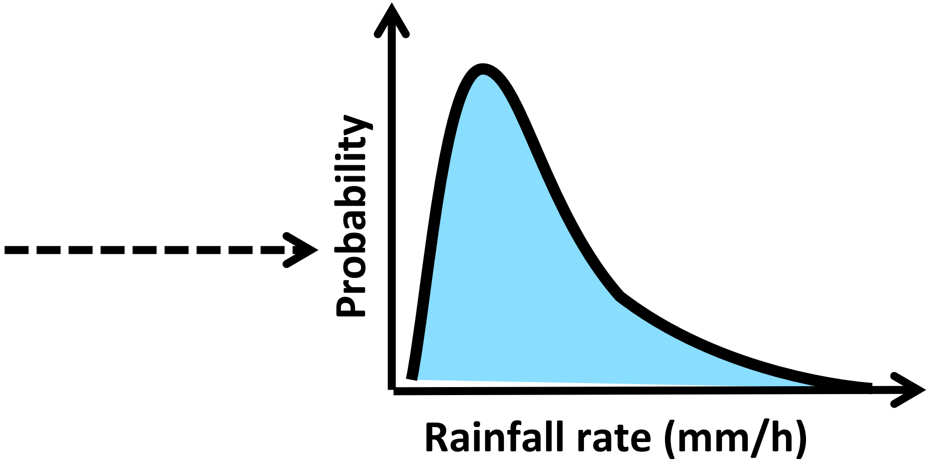


Source	$Z(S)$ relation for dry snow
Gunn and Marshall (1958)	$Z = 448S^2$
Sekhon and Srivastava (1970)	$Z = 399S^{2.21}$
Ohtake and Henmi (1970)	$Z = 739S^{1.7}$
Puhakka (1975)	$Z = 235S^2$
Koistinen et al. (2003)	$Z = 400S^2$
Huang et al. (2010)	$Z = (106\text{–}305)S^{(1.11\text{–}1.92)}$
Szyrmer and Zawadzki (2010)	$Z = 494S^{1.44}$
Wolfe and Snider (2012)	$Z = 110S^2$
WSR-88D, Northeast	$Z = 120S^2$
WSR-88D, north plains–upper Midwest	$Z = 180S^2$
WSR-88D, high plains	$Z = 130S^2$
WSR-88D, Intermountain West	$Z = 40S^2$
WSR-88D, Sierra Nevada	$Z = 222S^2$

Courtesy Bukovčić et al. (2018)

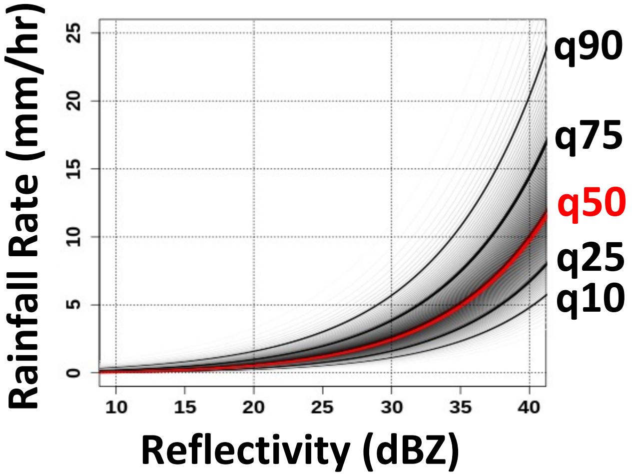
Enhance QPE information content

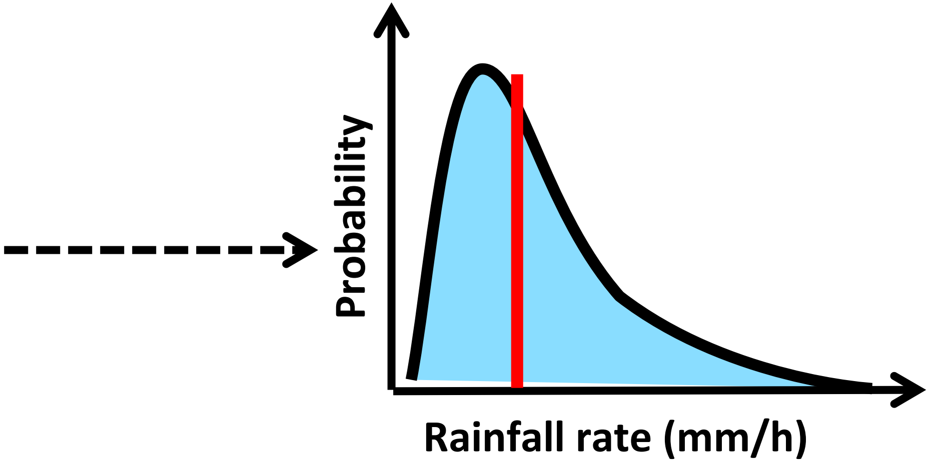




- **Provide the PDF of precipitation rates at radar measurement scale**

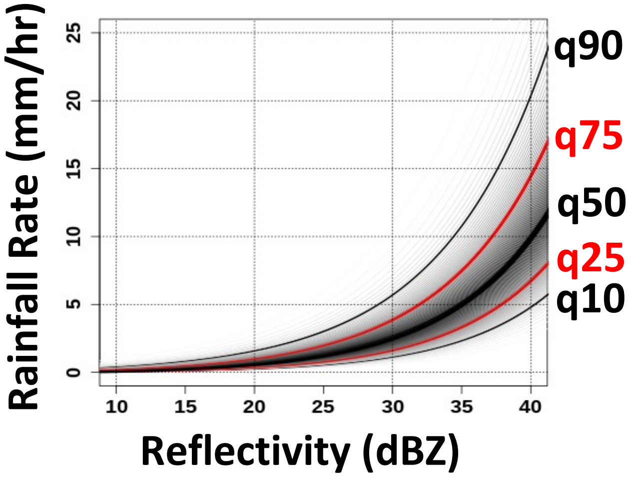
Most likely value – mitigate bias

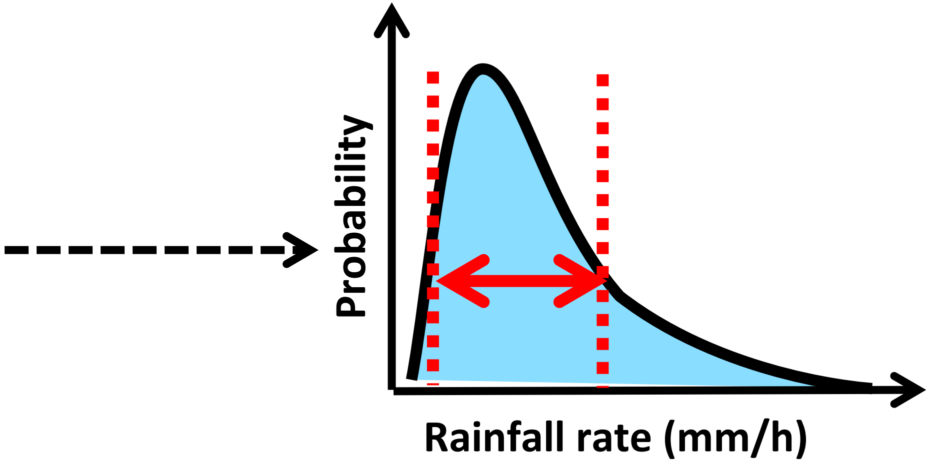




- **Provide the PDF of precipitation rates at radar measurement scale**
- **Depict the most likely value (deterministic users & applications)**

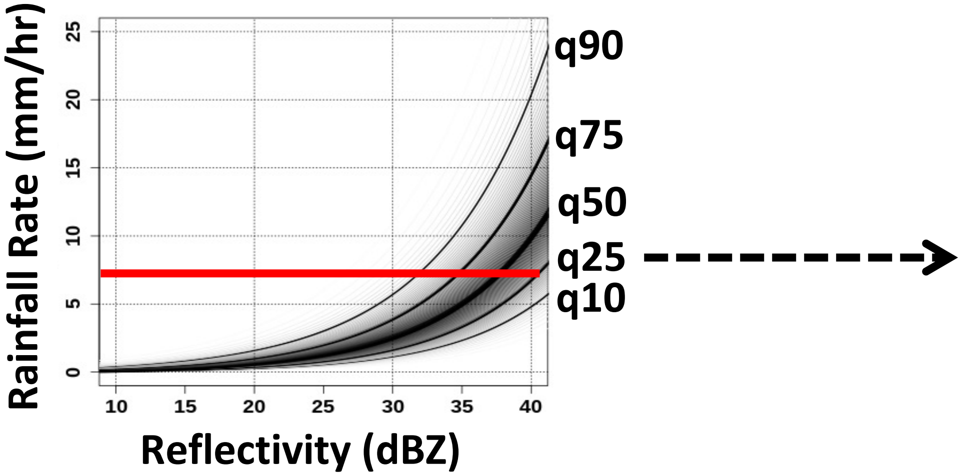
Uncertainty

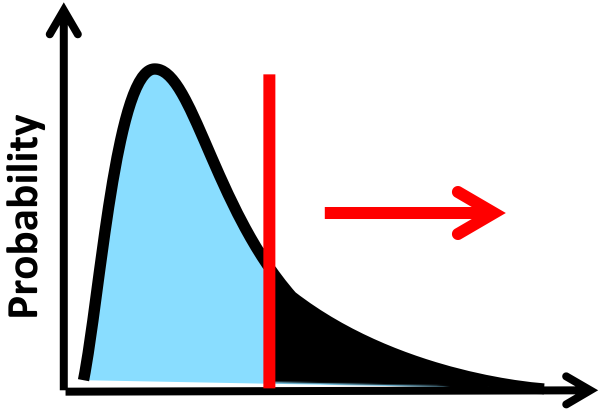




- **Provide the PDF of precipitation rates at radar measurement scale**
- **Depict the most likely value (deterministic users & applications)**
- **Quantify certainty bounds (data fusion & assimilation)**

Monitoring the likelihood of extremes - hazards



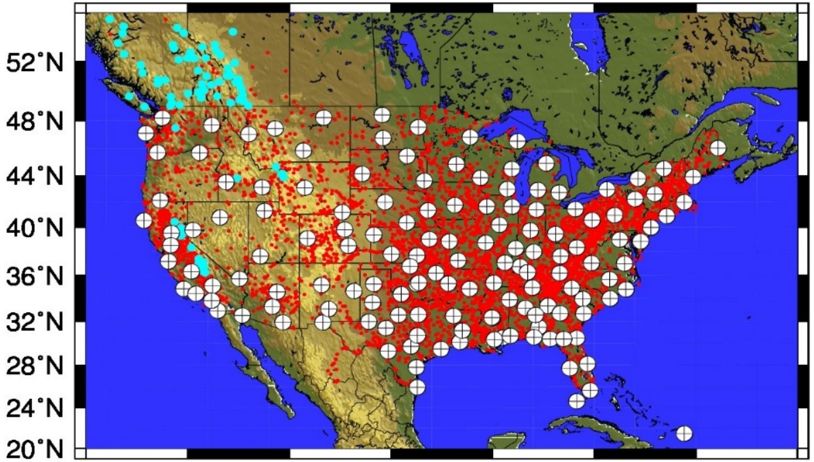


- **Provide the PDF of precipitation rates at radar measurement scale**
- **Depict the most likely value (deterministic users & applications)**
- **Quantify certainty bounds (data fusion & assimilation)**
- **Quantify the likelihood of extreme cases (risk analysis)**

Kirstetter, P.E., et al. , 2015: Probabilistic Precipitation Rate Estimates with Ground-based Radar Networks. *Water Resources Research*, 51, 1422–1442. doi:10.1002/2014WR015672

PQPE implementation in MRMS v11

Goal: implement PQPE in the MRMS system testbed
Time period: 2017
Temporal resolution: 2-min



PQPE products:

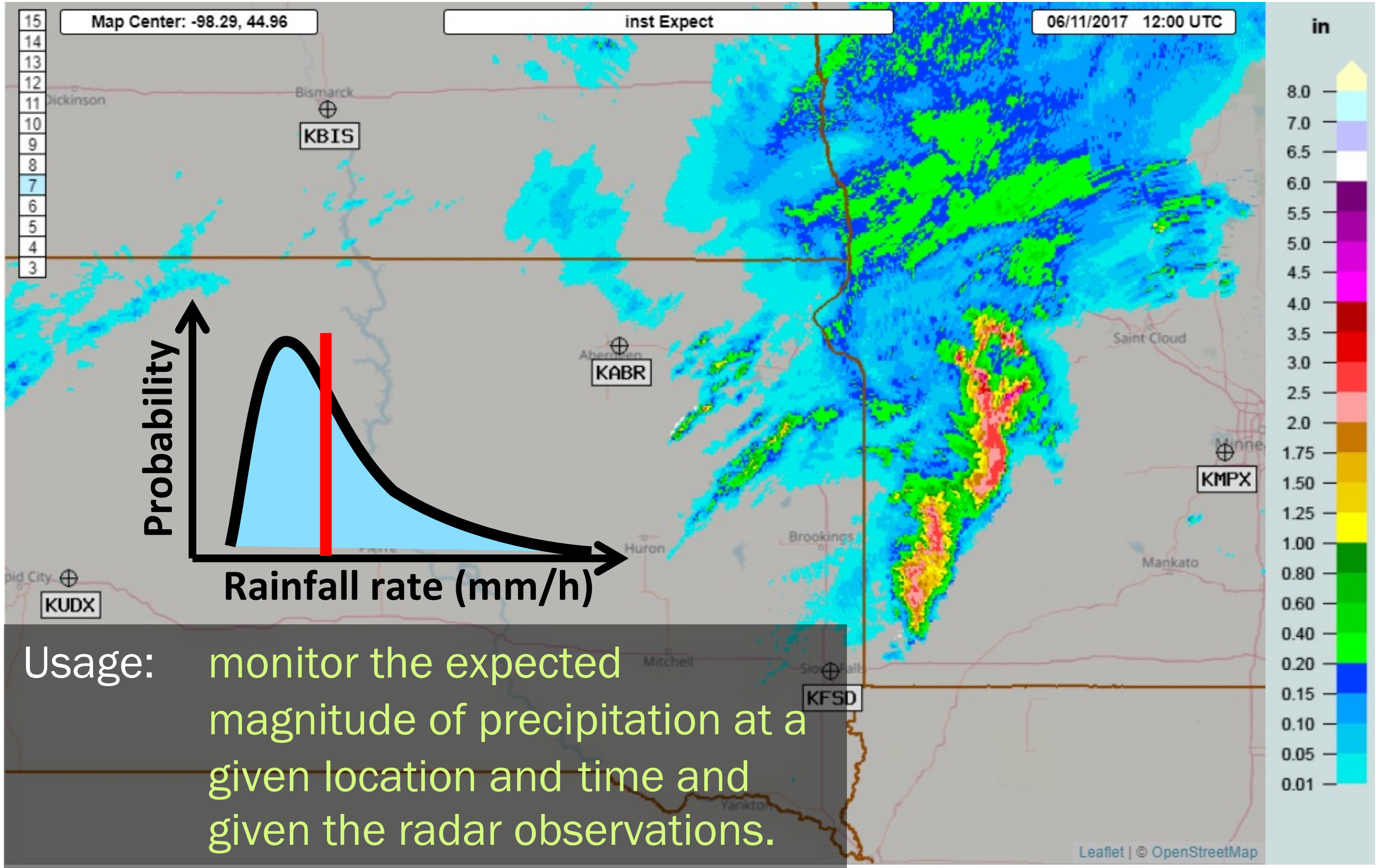
- Expectation
- Uncertainty
- Probability of exceeding thresholds

Computational efficiency:

- 2 mins to process a full day (using parallel computation)

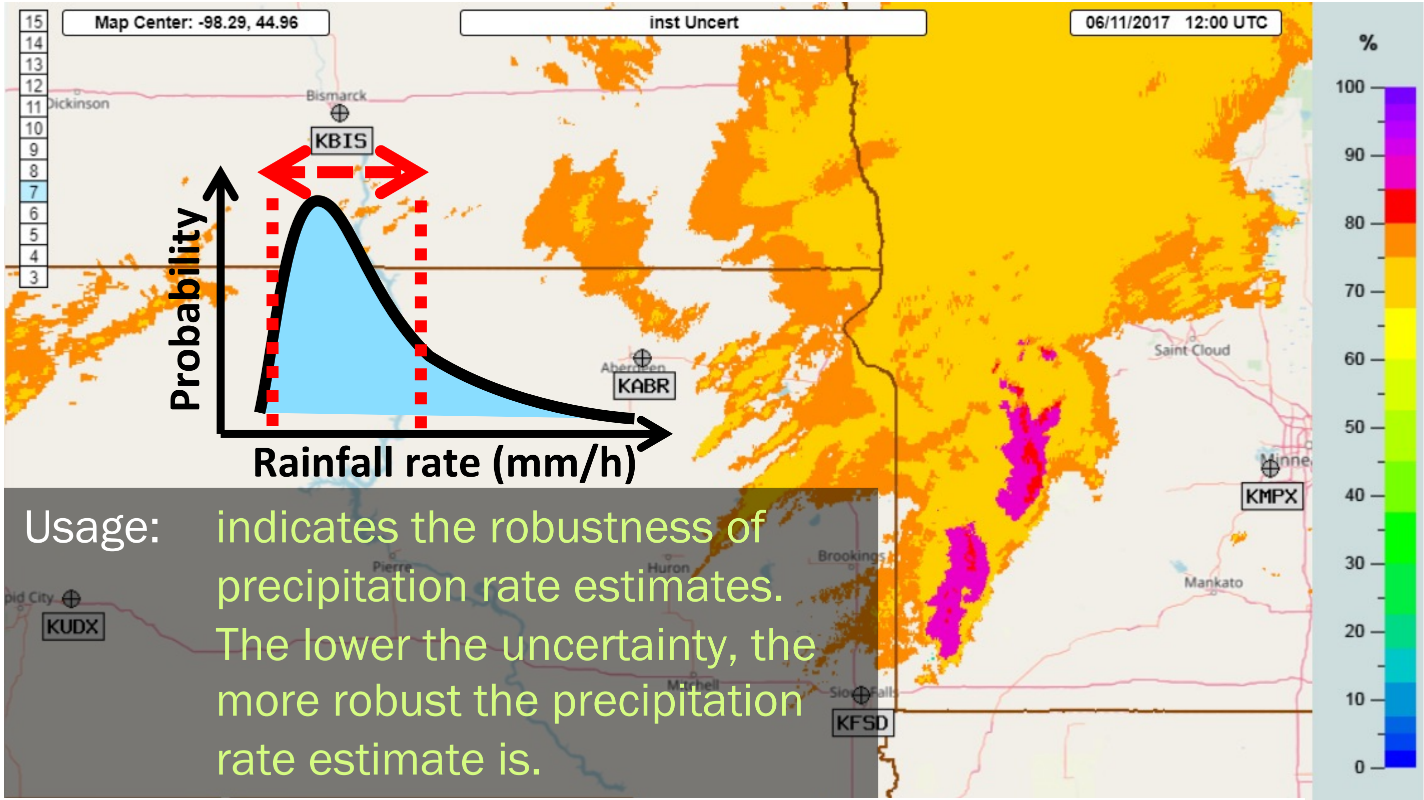
→ **suitable for operational implementation in MRMS.**

PQPE expectation



Usage: monitor the expected magnitude of precipitation at a given location and time and given the radar observations.

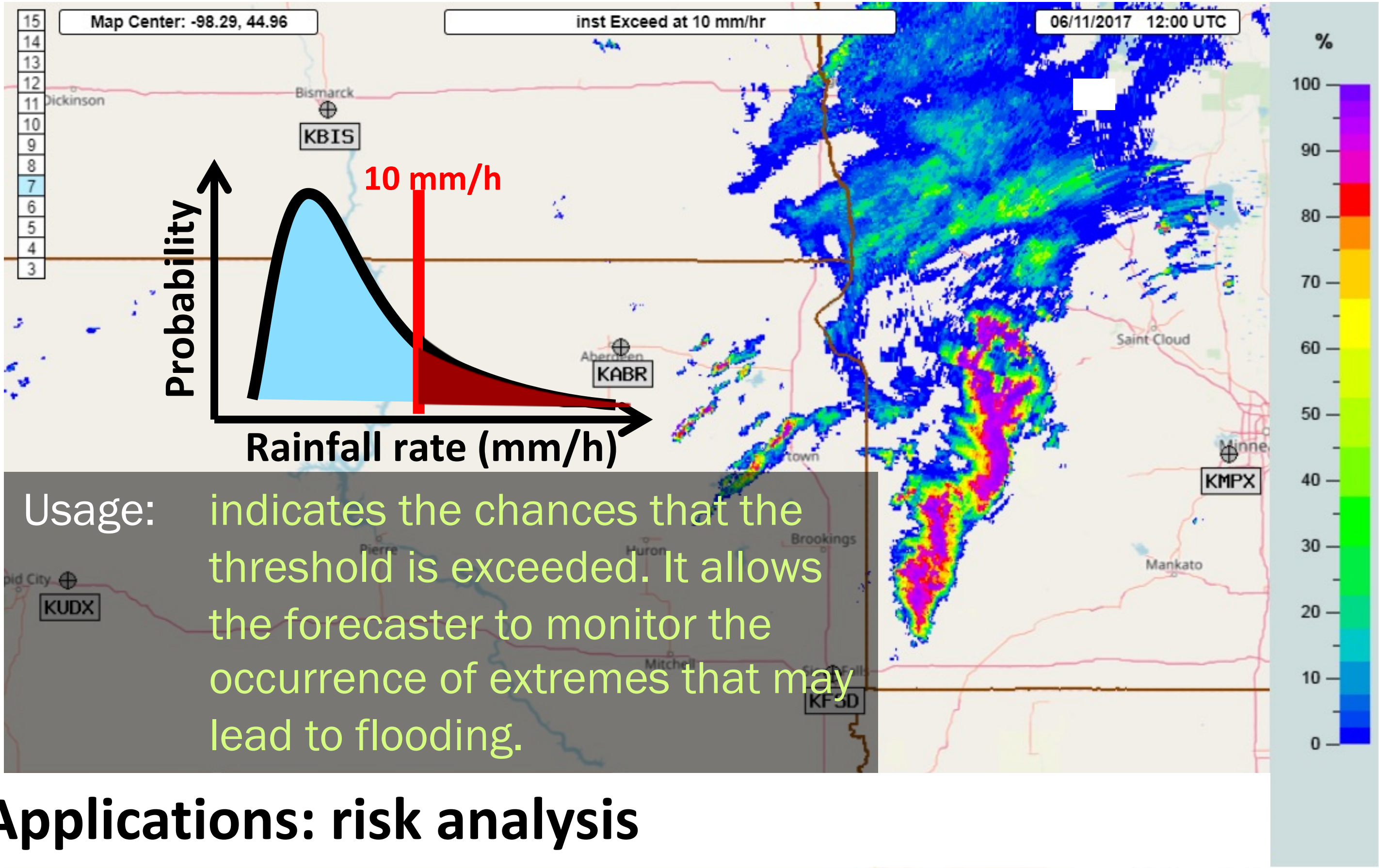
Uncertainty estimates



Usage: indicates the robustness of precipitation rate estimates. The lower the uncertainty, the more robust the precipitation rate estimate is.

- **Applications: data fusion & assimilation**

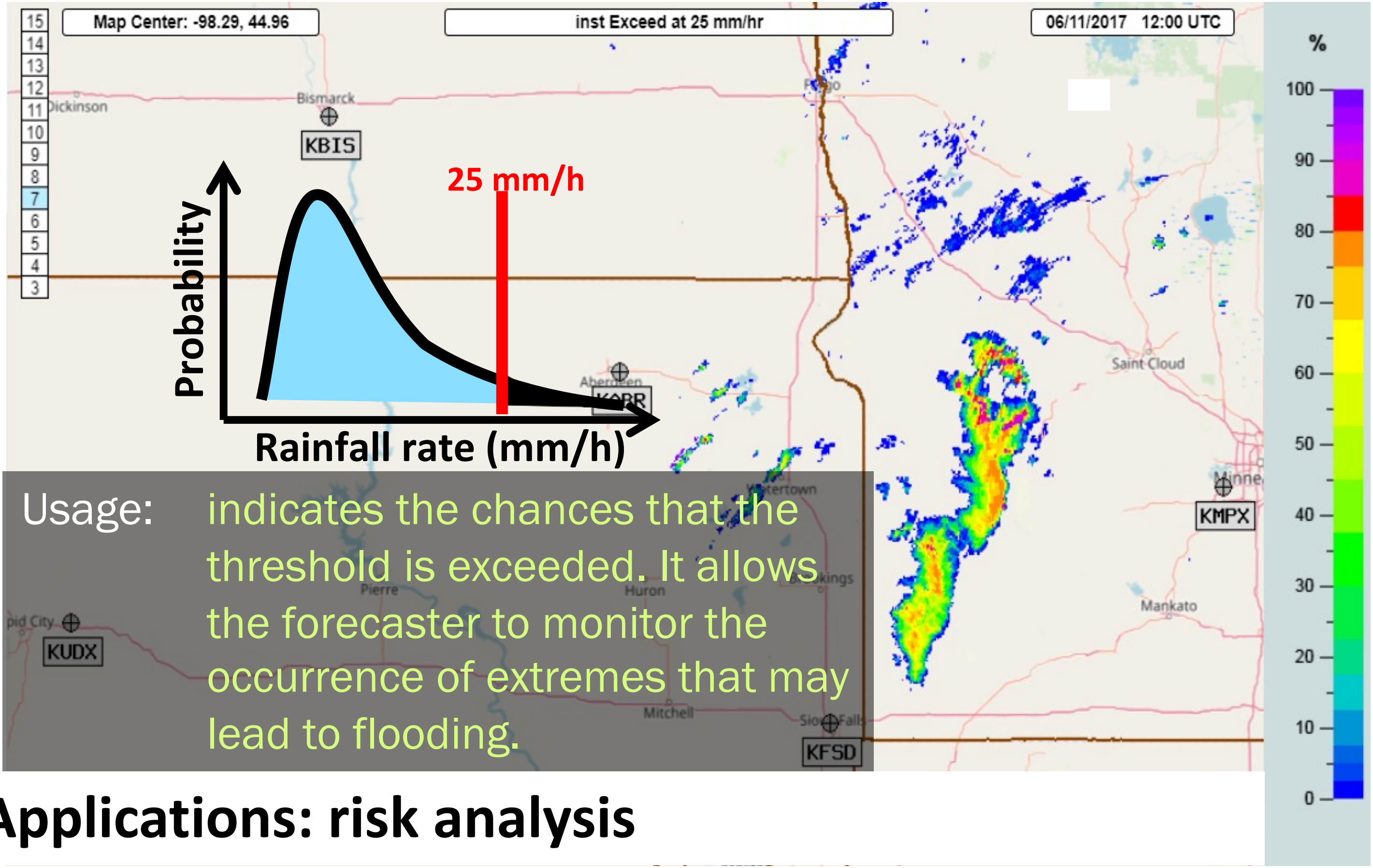
Probability of exceeding threshold (10 mm/h)



Usage: indicates the chances that the threshold is exceeded. It allows the forecaster to monitor the occurrence of extremes that may lead to flooding.

- **Applications: risk analysis**

Probability of exceeding threshold (25 mm/h)

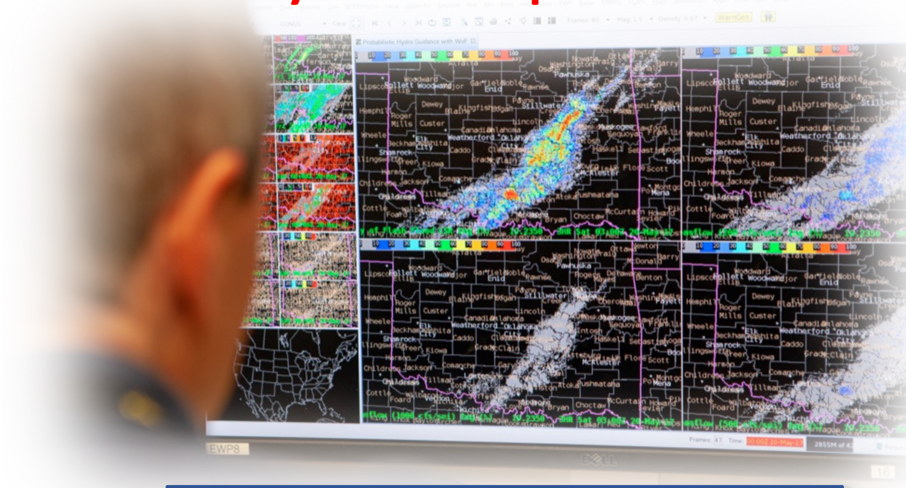


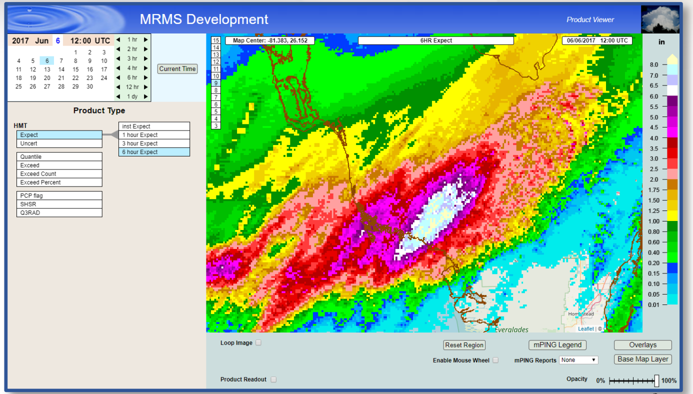
Usage: indicates the chances that the threshold is exceeded. It allows the forecaster to monitor the occurrence of extremes that may lead to flooding.

- **Applications: risk analysis**

Hydrometeorology Testbed MRMS Hydro Experiment

- **NSSL scientists and NWS forecasters collaborated on testing emerging hydrometeorological products for NWS operations.**
- **web interface with various PQPE product available: expected values, uncertainty products, exceedance probabilities**
- **June 24 – July 19, 2019**





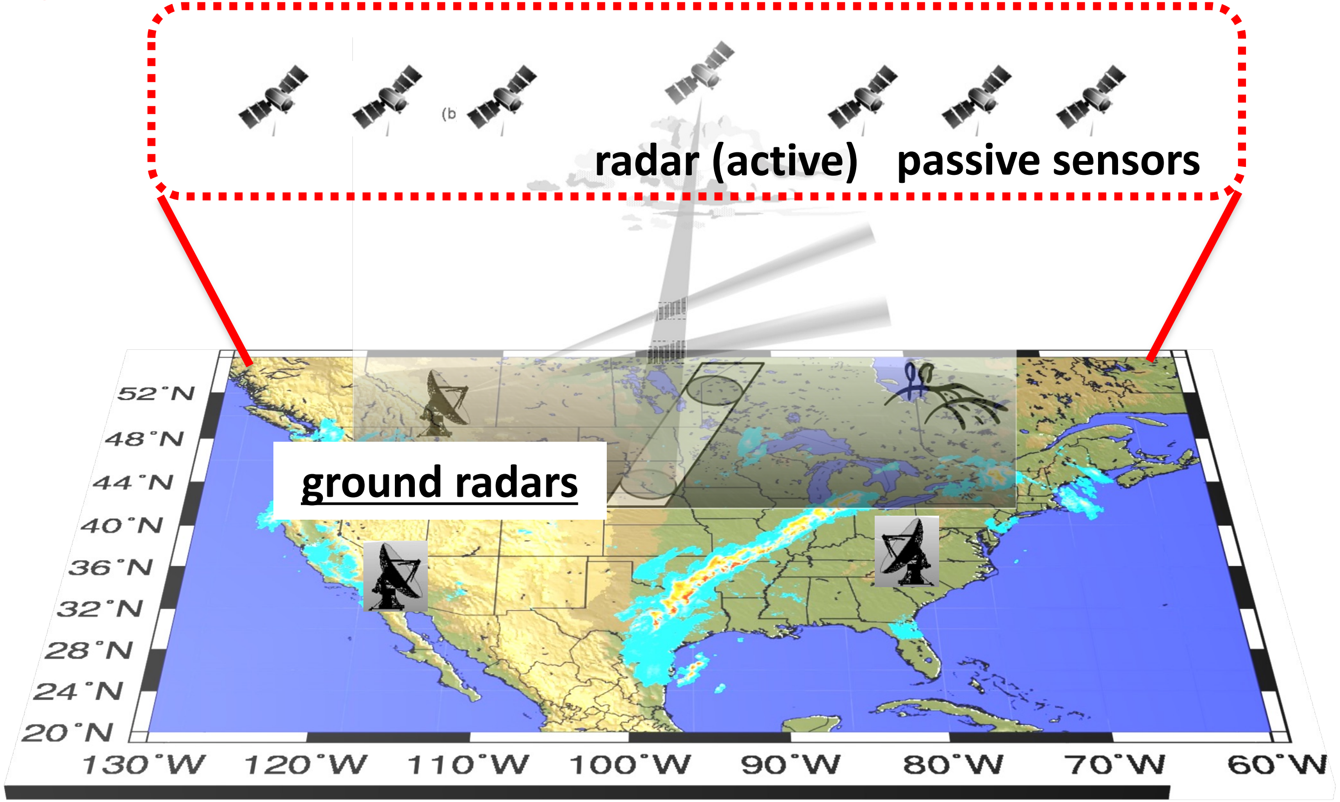
https://blog.nssl.noaa.gov/flash/hwt-hydro/

HMT-Hydro experiment: forecasters feedback

- **Forecasters found utility in the expected PQPE product and the probability of exceeding rainfall rate thresholds**
- **Uncertainty was not scored as favorably**
  - Context of the experiment favors information directly relevant to hazards
  - Suggestions were made to better convey uncertainty
  - "very useful in a facets/PHI framework […] input into flash flood models"

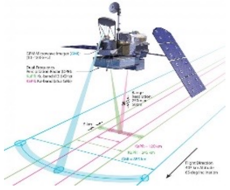
- **Suggestion: "0.5, 1, 3, 6 hour accumulated PQPE would be extremely helpful"**

Perspectives: space-based geostationary sensors – Shruti Upadhyaya

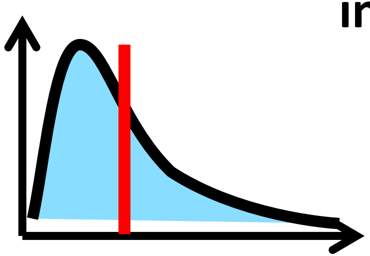


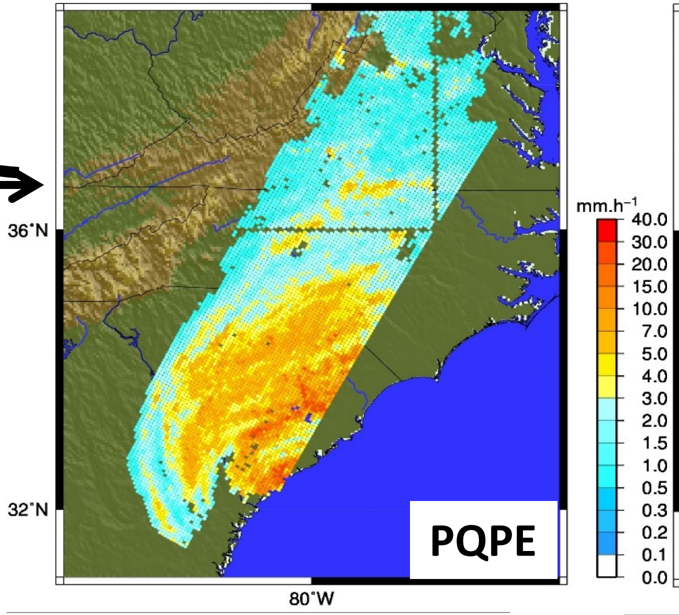
NOAA's GOES16 provides high-resolution passive observations of severe weather clouds and precipitation

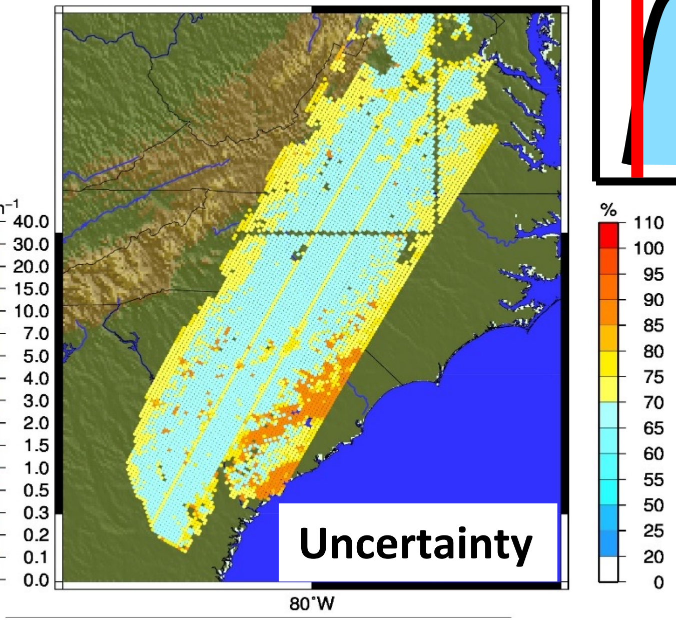
Perspectives: spaceborne radars

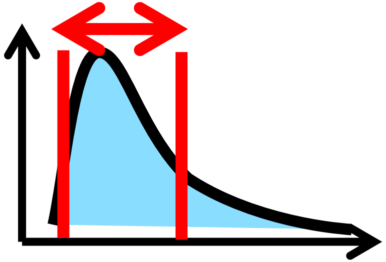


DPR PQPE = f (reflectivity, microphysics,
precipitation type,
incidence angle)









Hurricane Matthew at 09:15 UTC on 08 October 2016 in North Carolina

Probabilistic QPE: perspectives

Probabilistic Quantitative Precipitation Estimates:

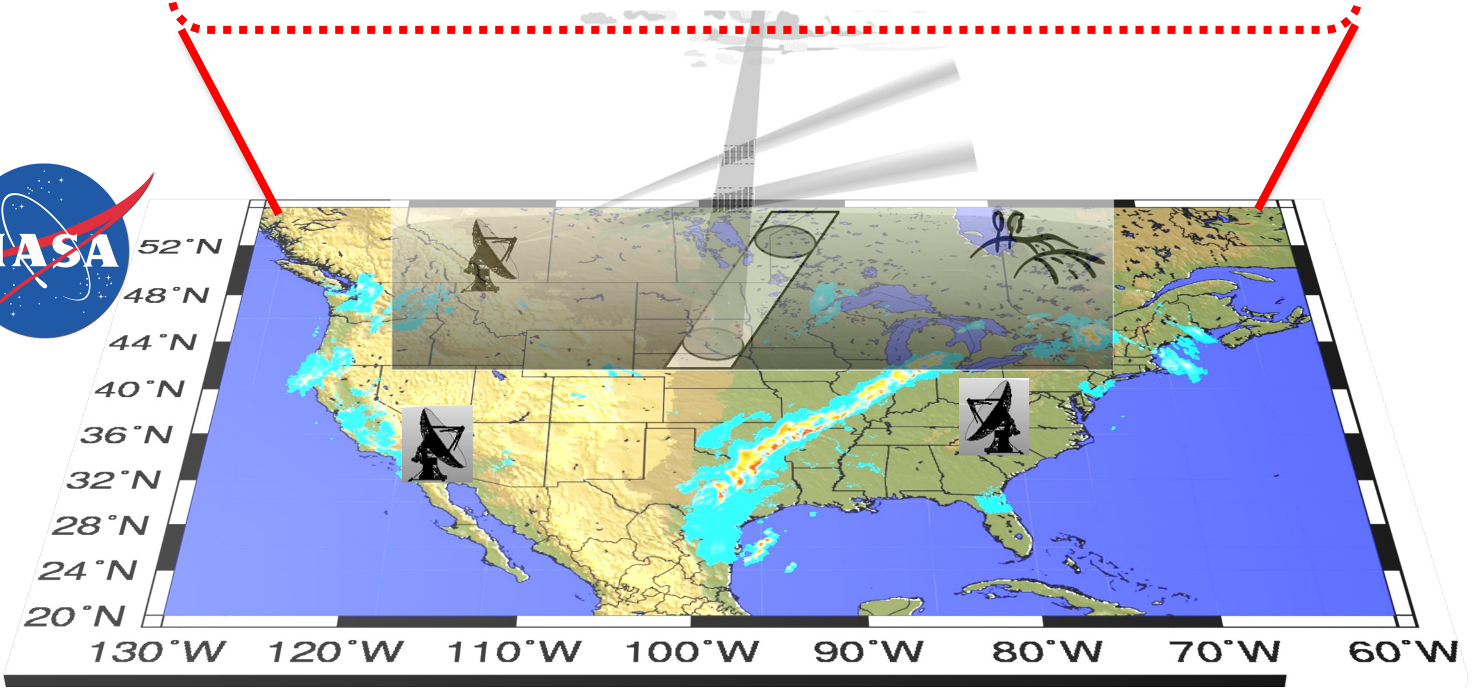
- ➔ **Ground-based radars**
- ➔ **Space-based radars**
- ➔ **IR-based (satellite) component of GPM**

Other applications/developments:

- ➔ **GOES16**
- ➔ **snow water equivalent**
- ➔ **flash flood risk monitoring**

Communicating probabilistic information is still an outstanding challenge.

THANK YOU



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through support by NOAA **JTTI** and **GOESR3** programs