Translating the Physics of Snowfall to Radar-Based Validation of GPM

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Objective: Validate GPM estimates of Snow Water Equivalent Rate (SWER)

- Original GPM requirement is for "detection" of falling snow rates, but desire is to reliably estimate SWER
- Reliable satellite-based remote sensing of SWER is hard- but also the case for ground-based instrumentation (a "validation" source).
- How do we assess agreement between distributed (i.e., multiple footprints) GV-radar and near instantaneous satellite-based SWER estimates?

Approach(es)

Construct deterministic (e.g., S(Z), S (KDP,Z), etc.) and probabilistic (PQPE) radar-based SWER with minimum bias (random error accepted for large sample).
(1) Use multi-regime "reference" networks to obtain "best" footprint area estimators;
(2) Assess/correct radar SWER biases relative to reference network and physical character of snowfall
(3) Compare reference-based radar-diagnosed SWER to GPM satellite DPR and GMI estimates.

Hyytiälä, Finland. Case-specific Z-S constructed based on snow physical properties per **von Lerber et al. 2017, 2018** (JAMC), applied to Ikaalinen (IKA) C-band radar, compared to GPM, winters 2014-18

Grid and average GV data within DPR / GMI pixel

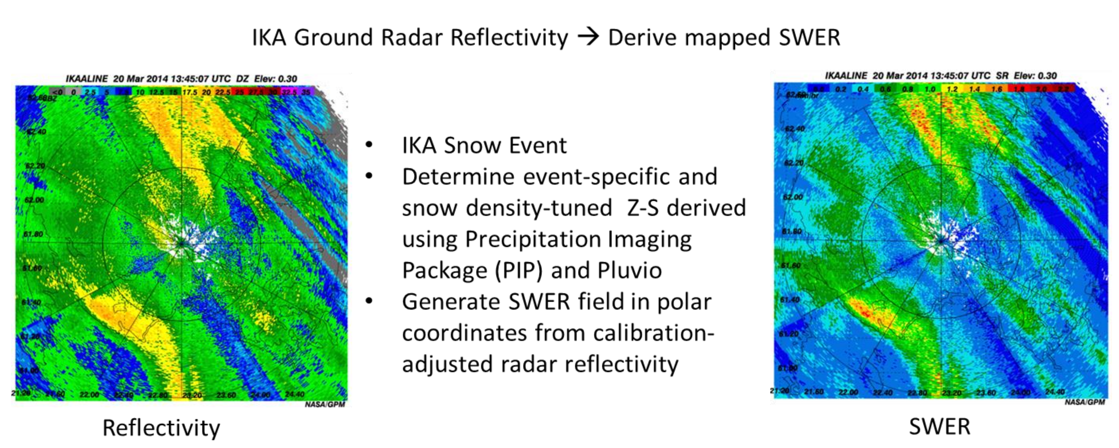
Gridded GV height: 0.5 km Horiz Res: 1.0 km;Vertical Res: 0.25 km	Average GV SWER in DPR/GMI pixels DPR/CMB: 5 x 5 km^2; GMI: 25 x 25 km^2

Generate precipitation rate data "Pairs"

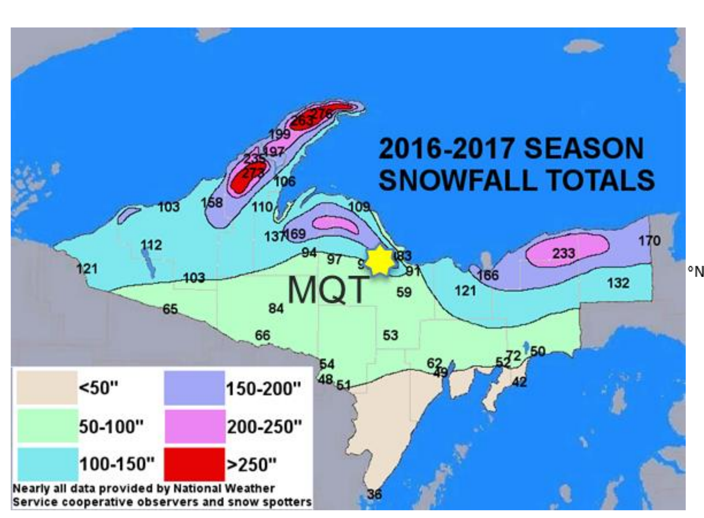
Snapshot data matched in time/space Multiple overpass dates combined.	GV scan and GPM overpass coincidence within 6 minutes (adjustable).

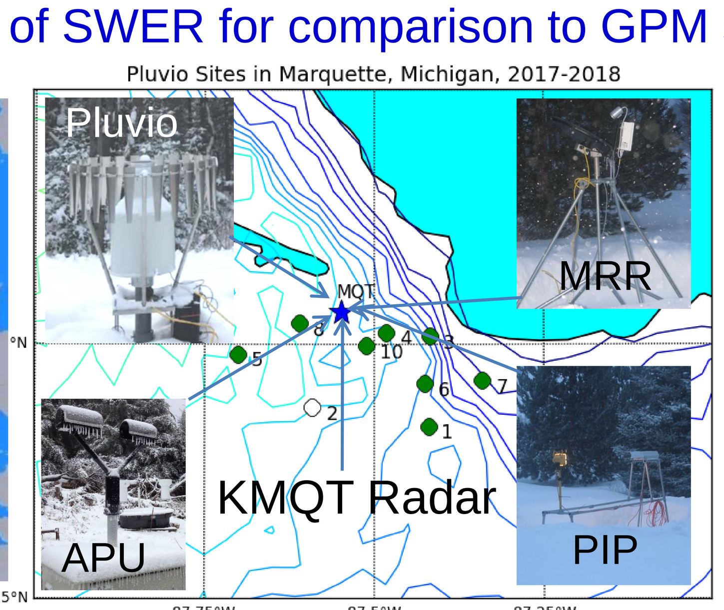
Generate plots (Bias/NMAE; Scatter; Density)

Conditional Analysis: GV mean rate and DPR/GMI pixel > 0 mm/hr	Beam-Filling at 50% or 90%: GV data must fill DPR/GMI pixel at required %.



2. Marquette (MQT) Reference Pluvio Network (RPN) and NWS measurement site. Ten GPM-GV Pluvio weighing gauges (single Alter fence) in 15-20 km footprint within 20 km of WSR-88D (KMQT) radar. Micro Rain Radar-2 (MRR) and Precipitation Imaging Package (PIP) installed at the NWS Forecast Office MQT. The RPN provides SWER "reference", MRR and PIP provide physics, KMQT provides "regional scale" distributed pixel measurements of SWER for comparison to GPM swath data.

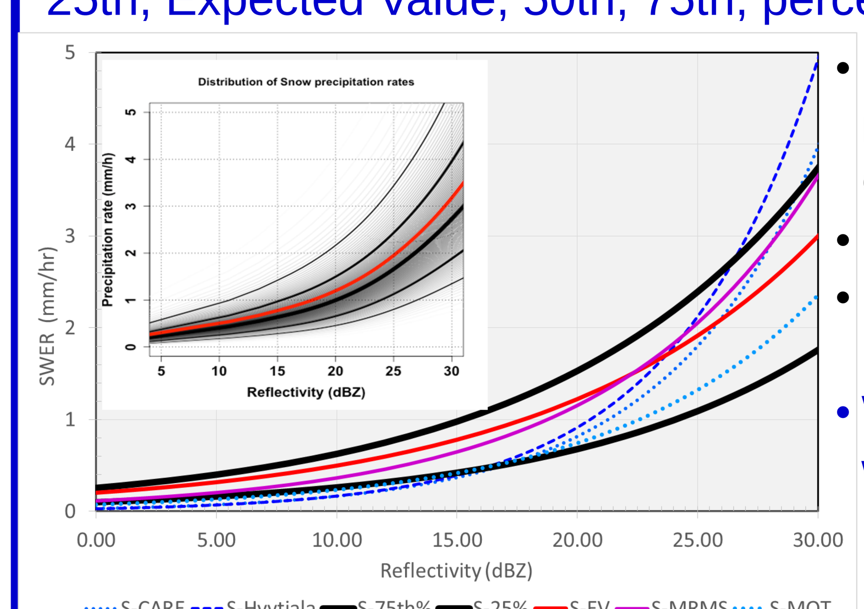




MQT RPN: Pluvio gauges (green dots) SWER "reference" sampling of KMQT estimators; Physics instruments located at MQT,

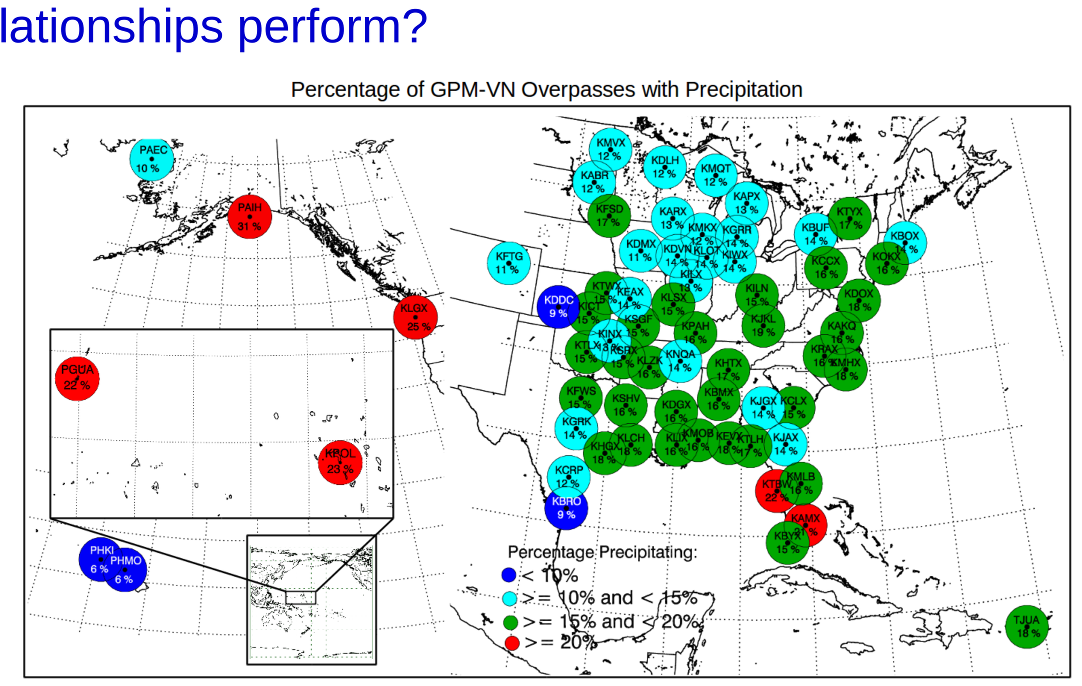
Dataset collection for winters 2017/18 and 2018/19 *(2017/18 analyzed so far)*

3. Probabilistic QPE (PQPE) approach (Kirstetter et al, 2015, Water Resources Research). Capture range of Z-S behavior that minimizes bias while providing an estimate of error. Compare PQPE range of Z-S (e.g., 25th, Expected Value, 50th, 75th, percentiles) against those diagnosed in other regimes.



- Left: PQPE Z vs. SWER relationships (inset) for the Expected (S-EV, red, bold), 25th, and 75th percentile (bold black) plotted against CARE, Hyytiälä, and WFO-MQT local KMQT Z-S relationships.
- Note all Z-S fit broadly within PQPE envelope.
- KMQT WFO relationship most similar to PQPE 25th% behavior.
- When used with KMQT radar and verified against the MQT RPN how well do the Z-S relationships perform?

4. Continental-scale comparisons via application of SWER estimates in the GPM GV radar Validation Network (VN). Assess PQPE, KMQT Z-S and polarimetric SWER(KDP,Z) SWER estimators against GPM satellite estimates.

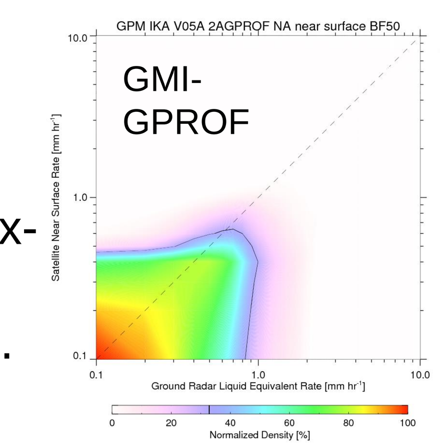


Radars in VN network. Colors indicate percentage of GPM overpasses of VN radars with precipitation (solid or liquid).

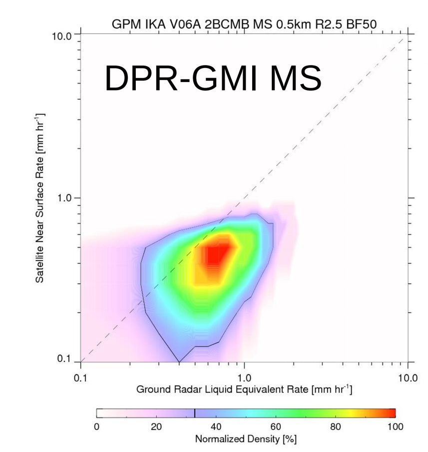
Results

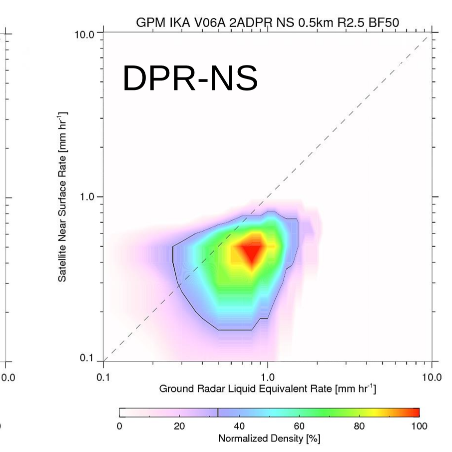
1. Example GPM SWER Comparisons over Hyytiälä Finland

(GMI-GPROF (V5) SWER (y-axis) vs. IKA Radar SWER (x-axis) Winter 2014/15, 17/18.



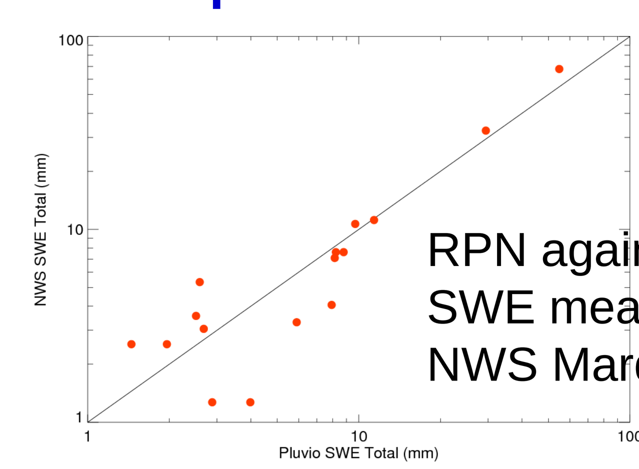
As in figure for GMI-GPROF but DPR-GMI MS product (left) and DPR NS product (right)- DPR Ku similar





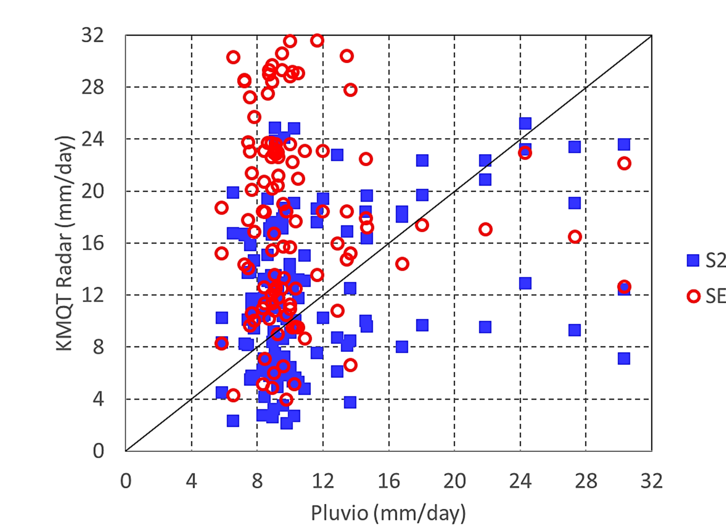
Compared to case-specific IKA radar Z-S (tuned for snow density)
- GMI-GPROF biased low ~60%
- Radar-based products (dual or single frequency) also biased low ~55%

2. Marquette



RPN against manual SWE measurement at NWS Marquette site

- Pluvio "reference" at NWS Site, single Alter shield, compares reasonably well with observer SWE (manual core)

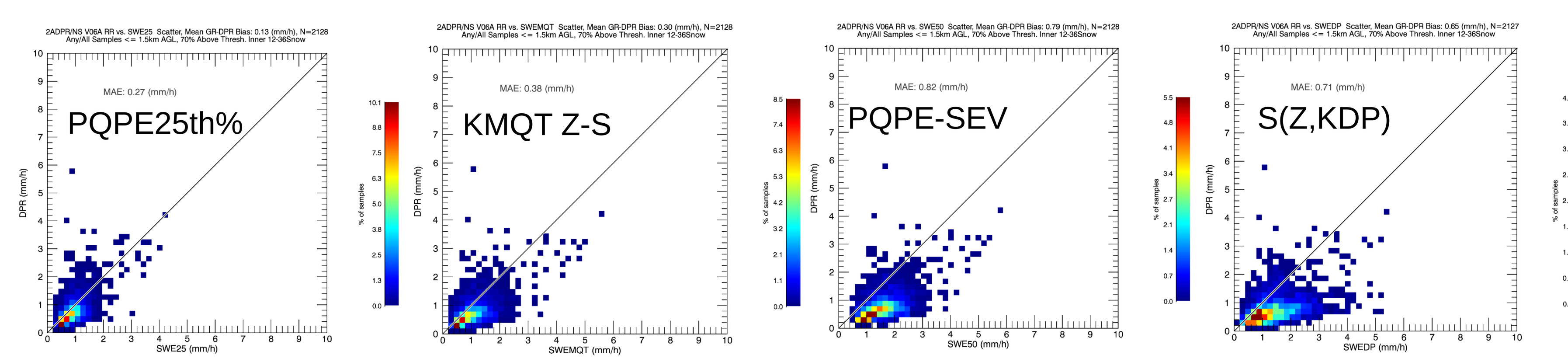


Daily accumulated KMQT Radar SWER using S25% and SEV Z-S plotted against RPN (lowest 3-tilts of KMQT volume scan- heights 100m - 700m above RPN).
- PQPE SEV (similar to MRMS): +85%,
- PQPE 75% *and* polarimetric estimator (S[Z, KDP], not shown) are biased ~100% high.
- Local KMQT (not shown) Z-S, SMQT: +4%
- PQPE 25th%: +23%

- KMQT radar comparisons against RPN very noisy.
- **"Best" bias is for local Z-S (SMQT) and PQPE 25th% Z-S**
- SEV PQPE Z-S is much higher for common events. Note that default MRMS Z-S (not shown) will exhibit a bias similar to PQPE EV Z-S.

3. VN and GPM

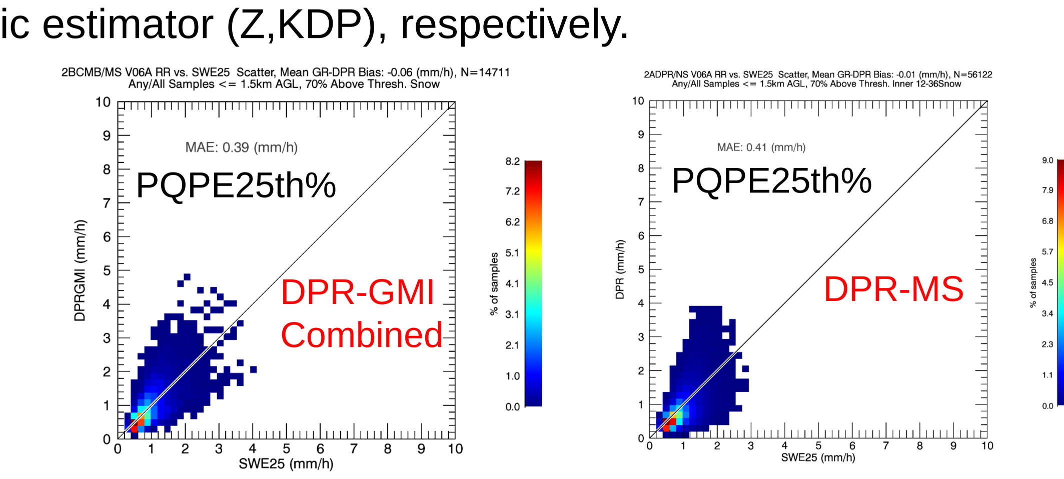
The PQPE 25th% and KMQT Z-S relationships are the "best" for the MQT network (from a purely bias perspective). How well do DPR-estimated SWERs compare to these estimates in the KMQT radar domain and subsequently over the Continental U.S. (CONUS) when using WSR-88 radars in the VN architecture?



KMQT VN radar domain (100 km range) [x-axis] vs. DPR MS footprint [y-axis] comparisons of SWER (mm/hr) for samples of PQPE Z-S (25th%), local KMQT Z-S, PQPE SEV (similar to MRMS), and KMQT polarimetric estimator (Z,KDP), respectively.

- DPR matched swath (MS) product: only slightly lower than "best" relationships (PQPE 25% and KMQT Z-S) *in the KMQT radar domain*. [Combined algorithm, similar, not shown].
- DPR Markedly lower for PQPE SEV and dual-pol KMQT (as expected based on RPN comparisons).

How well do PQPE and KMQT Z-S' compare to GPM DPR SWERs in the CONUS VN?



Left: PQPE 25th% results (KMQT Z-S similar) for the Combined (left) and DPR-MS algorithms (right). Remainder of PQPE and dual-pol Z-S are not shown, but exhibit much higher values compared to DPR and GPM Combined.

- For CONUS VN radars DPR estimates of SWER are very similar to the 25th% PQPE Z-S, and KMQT Z-S (though noisy, both of these Z-S' exhibited the least bias compared to the RPN).

Summary

- We have developed an ensemble of tools/approaches designed to provide physically-tuned/consistent and/or statistically optimal radar-based SWER estimates to validate instantaneous GPM estimates of SWER from the pixel to swath scale.
- Comparison of the GPM products to reference radar-based SWER estimates over Finland and the U.S. suggest that GPM GMI-GPROF and DPR SWER estimates may be biased low.
- Ongoing and future analysis work will include expansion of the case database in Finland and Canada, continued evaluation of snow physical properties defining regime Z-S behavior, examination of footprint to sub-footprint scale SWER variability.

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