Quality Assessment of Space-Borne Active and Passive Microwave Snowfall Products Over the Continental United States

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Abstract

Surface snowfall rate estimates from the Global Precipitation Measurement (GPM) mission's core satellite sensors and CloudSat radar are compared to those from the Multi-Radar Multi-Sensor (MRMS) radar composite product generated over the continental United States (CONUS). The considered algorithms include: Dual-Frequency Precipitation Radar (DPR) product and its single frequency counterparts (Ka- and Ku-only); the combined DPR and multifrequency microwave imager (CORRA) product; the CloudSat SnowProfile product (2C-SNOW-PROFILE); two passive microwave products i.e. the Goddard PROFiling algorithm (GPROF) and the Snow retrievaL ALgorithm fOr gMi (SLALOM). The spaceborne and ground-based snowfall products are collocated spatially and temporally and compared at the spatial resolution of spaceborne instruments over the period spanning from January 2016 to March 2020 (4 winters). Detection capabilities of the sensors is assessed in terms of the most commonly used forecast metrices (Probability of Detection, False Alarm Ratio, etc.) whereas precision of the products is quantified by the mean error (ME) and root-mean-square-error (RMSE). 2C-SNOW product agrees with MRMS by far better than any other product. Passive microwave algorithms tend to detect more precipitation events than the DPR and CORRA retrievals, but they also trigger more false alarms. Due to limited sensitivity, DPR detects only approx. 30% of the snow events. All the retrievals underestimate snowfall rates, for the detected snowstorms they produce approximately only a half of the precipitation reported by MRMS. Large discrepancies (RMSE from 0.7 to 2.5 mm/h) between spaceborne and ground-based snowfall rate estimates is the result of limitations of both systems and complex ice scattering properties. The MRMS product is based on a power law relation and it has difficulties in detecting precipitation at far ranges; the DPR system is affected by low sensitivity while the GPM Microwave Imager (GMI) measurements are affected by the confounding effect of the background surface emissivity for snow-covered surfaces and of the emission of supercooled liquid droplet layers.

Cross validation of Space-Borne Active and Passive Microwave Snowfall Products Over the Continental United States

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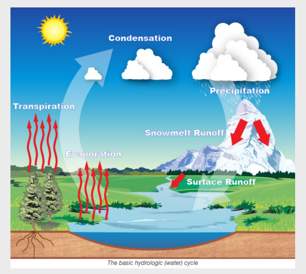
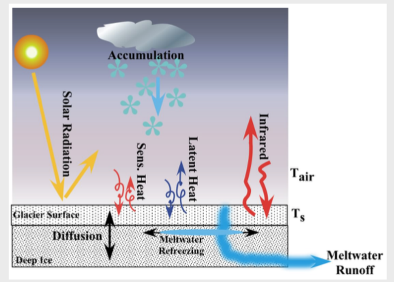
MOTIVATION

Why snowfall estimates are important:

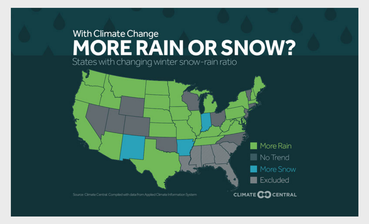


- Water budget. Snow represents a reservoir of fresh water and its quantification is extremely important as an input of the hydrological cycle.



- Energy budget. Snow cover plays a very important role in the climate system modifying the global and regional energy budget since its high albedo.
- Hazards Snow falls often represents an hazard to several public services (e.g.: transportations, energy distribution networks) as well as private belongings.

- Energy production: e.g. Snow accumulations is important for hydropower and water resource management needs
- Climate change: Solid precipitation and climate change connections need a better compression (Eg. polar processes, ocean (Thermohaline) circulation.



GOAL

Perform and *extensive evaluation* of satellite microwave radar and radiometer snow products

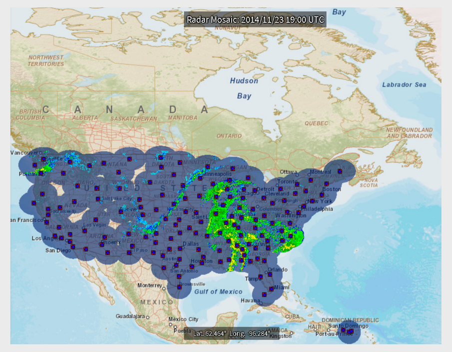
- **TARGET AREA**:
  - Continental United States (CONUS)
  - 130°W - 60°W; 22°N - 55°N
- **TIME PERIOD**
  - 5 winter seasons Jan 2016 - Mar 2020
  - plus data from 2006 to 2011 for CPR comparisons only
- **SENSORS AND ALGORITHMS**

Satellite Platforms	Sensors	Single Snowfall products	Combined Dual Frequency radar product	Combined Radar/Radiometer
GPM	DPR	Ku-Only V06 *Iguchi & Meneghini 2017*	DFR V06 *Iguchi & Meneghini 2017*	CORRA *Grecu et al. 2016*
		Ka-Only V06 *Iguchi & Meneghini 2017*		
	GMI	GPROOF V05 *Kummerow et al. 2015*		
		SLALOM *Rysman et al. 2018*		
CLOUDSAT	CPR	2C-SNOW-PROFILE Wood & L'Ecuyer 2018		

Ground reference	Sensors	Snowfall products
MRMS V11	NEXRAD CANADA S/C band radars	Ordinary Z-S conversion Zhang et al. 2016

REFERENCE GROUND RADAR: MRMS

- **MRMS features**
  - Cartesian gridded level II and III radar products over US and Canada
  - Resolution: 0.01° x 0.01° km horizontal, 2 min time sampling
  - Domain: 130°W – 60°W; 22°N – 55°N
  - Time range: 5 winter seasons Jan 2016 - Mar 2020 (2min time sampling and dual pol. quality controlled data) plus: Jan 2006 - Dec 2011 for CPR comparisons only (5 min time sampling and single pol. quality controlled data)



- **Snowfall retrieval**
  - $PR_{MRMS} = 0.12\,Z^{0.5}$

  Only Z >5 dBZ (i.e. PRMRMS >0.2 mm/h) to avoid Bragg scattering

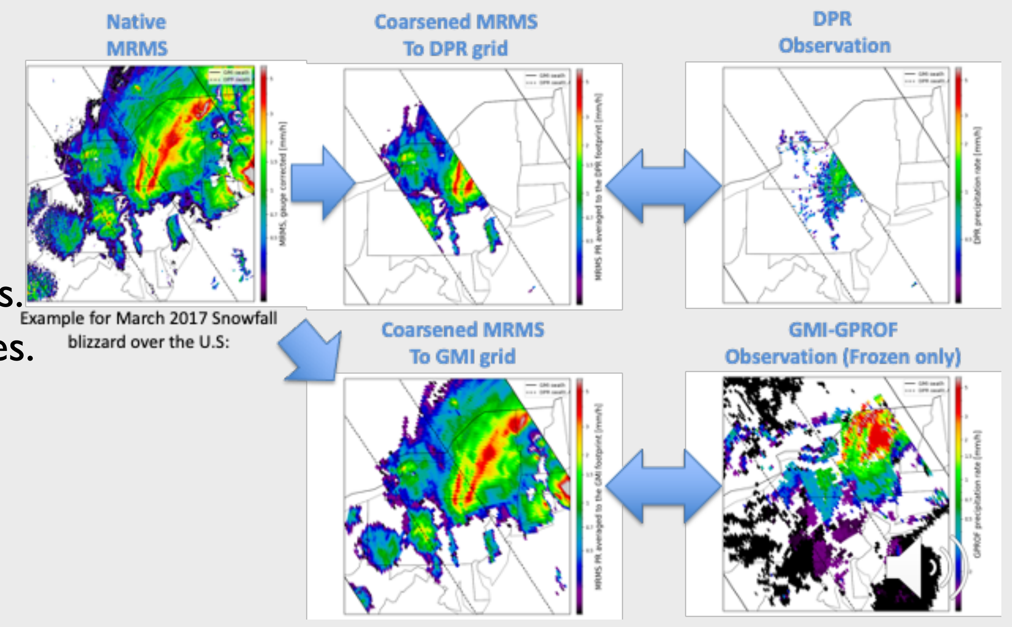
  Only Ts<2°C & Tw<0°C, derived from hourly model analyses, to identify snowfall.
- **Data quality checks**
  - PRMRMS >21.3 mm/h are removed (equivalent to Z>45dBZ) to mitigate hail and residual ground clutter contamination.
  - Distance > 110 km from the closest radar site are not considered to reduce impact of blind zone, sensitivity and bin size

METODOLOGY: TIME AND SPATIAL COLOCATIONS

Temporal colocation
- closest satellite overpass within the 2min update MRMS

Spatial colocation
- MRMS 1x1 km² is coarsened to
- 5×5 km² DPR/CORRA Hor. res.
- 15×9 km² GMI, 36GHz ch. Hor. res.
- 1.4×1.7 km² CPR, Hor. res.

Assumptions
- Gaussian anttenna pattern

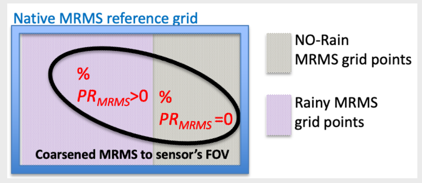


METODOLOGY: QUANTITATIVE COMPARISON STRATEGY

Verification point selection

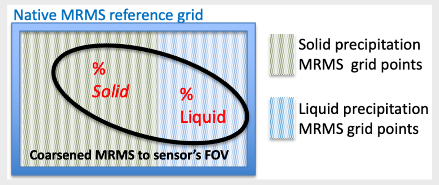
- **Snow MRMS. Coarsened MRMS having:**

  [% PRMRMS>0] ≥ 50% and
  [% solid precipitation] =100% and
  PRMRMS < 21.3 mm/h and
  Distance to the nearest NEXRAD radar<110 km



- **NO-Snow MRMS. Coarsened MRMS having:**

  ECMWF ERA5 T2m <0°C and
  [% PRMRMS=0] =100% and
  Distance to the nearest radar <110 km

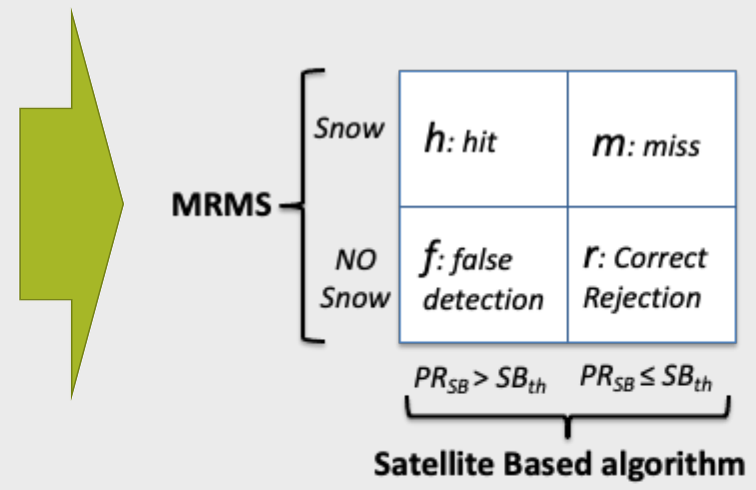


Snow detection

Any Satellite-based precipitation retrievals > SBth (see next slide) over the coarsened MRMS "snow verification points" is treated as snowfall
→ POD, CSI and HSS metric is calculated.

Snow quantitative evaluation

It is performed on the subset of hits (h) i.e. where coarsened MRMS and satellite products both detect solid phase
→ mean error, RMSE, etc. are calculated

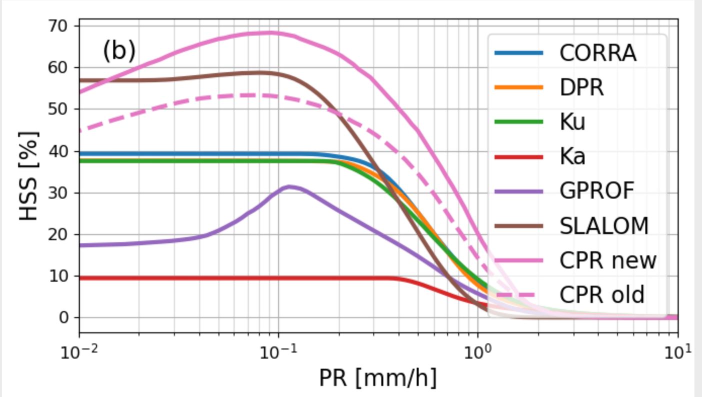


METODOLOGY: QUANTITATIVE COMPARISON STRATEGY

Ground based vs. spaceborne sensitivity

- A spaceborne (SB) instrument that is more sensitive than MRMS could detect snowfall where the reference indicates no-snow;
- Such an occurrence, would be misleadingly recorded as a false alarm whereas it is caused by differences in the sensors sensitivities.
- The sensitivity of each SB product is adapted to that of MRMS by introducing an optimal filtering minimum threshold (SBth).

  PRSB< SBth are put in the No-Snow class



$$HSS = \frac{2(hr - fm)}{(h+m)(m+r)+(h+f)(f+r)}$$

h: # correct detections (hits)
f: # false alarms
m: # missed detections
r: # correct rejections

Spaceborne sensitivity threshold identification

- SB_{th} is identified by maximising the Heidke Skill Score (HSS) vs. *PR*, see figure

	SLALOM	GRPOF	CORRA	DPR	Ku	Ka	2C-SNOW
SB_{th} (mm h⁻¹)	0.08	0.11	0.13	0.10	0.16	0.35	0.09

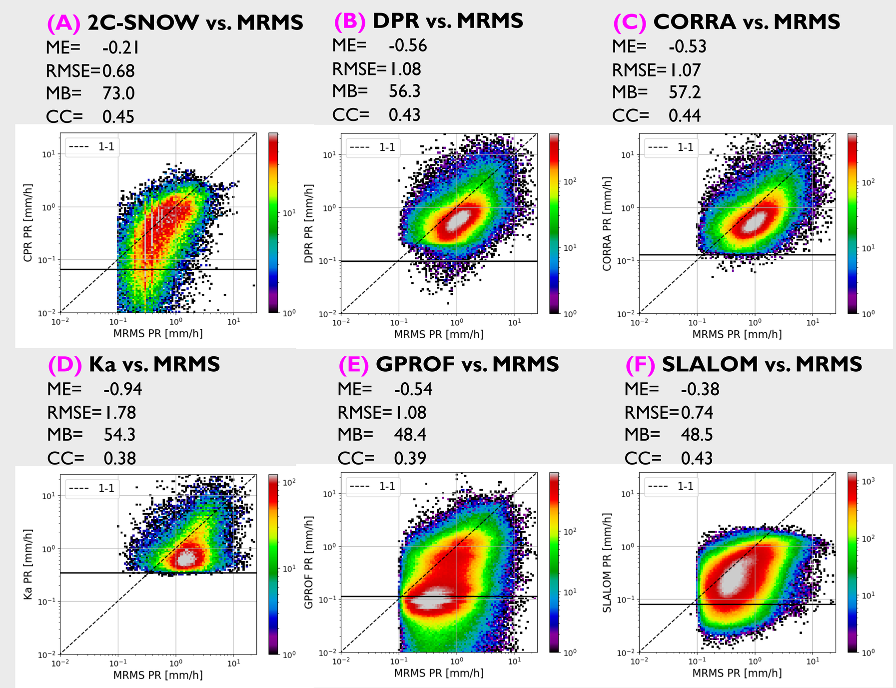
RESULTS: SNOWFALL DETECTION CAPABILITIES

SCORE	SLALOM	GPROF	CORRA	DPR	Ku	Ka	2C-SNOW
POD (%)	57.3	28.1	28.1	26.6	26.5	5.8	70.0 (59.1)
FAR (%)	26.3	39.6	5.1	4.3	4.2	2.8	25.5 (43.9)
HSS (%)	58.7	31.3	39.2	37.6	37.5	9.4	68.3 (53.3)
CSI (%)	47.6	23.7	27.7	26.3	26.2	5.8	56.4 (40.4)
SB_{th} (mm h^{-1})	0.08	0.11	0.13	0.10	0.16	0.35	0.09 (0.08)
no. of MRMS "no-precipitation" samples	10664398		4852871				91814 (689028)
no. of MRMS "snow" samples	2034580		841415				13183 (66846)

- Best performance in terms of CSI (>56%) and HSS (>68%) POD (70%) triggering 25% FAR
- Similar detection capabilities of DPR, Ku and CORRA but lower than 2C-SNOW (very low POD ~27%). Detection is mainly driven by the Ku radar (i.e the most sensitive of the DPR)
- Ka-only product performs worse likely due to its lower sensitivity (18 dBZ)
- SLALOM performs similarly to CPR 2C-SNOW, the data it was trained on, and it is significantly better than GPROF (with almost the double HSS) and DPR.

RESULTS: SNOWFALL QUANTITATIVE ESTIMATES

- All the considered products tend to underestimate precipitation with negative ME=[-0.94, -0.21] mm/h)
- All the considered products show moderate correlation coeff. (CC~0.45 with a peak of 0.53 for Ku-only) which reflects high degree of uncertainty in snowfall estimates.
- MB~50% for PMW products (E),(F) showing that the snow accumulation is only one half of the MRMS values for PMW.
- MB~55% in the GPM radar products and CORRA, (B), (C), (D)
- MB~73% for 2C-SNOW products (A)



CONCLUSIONS

- **SNOW DETECTION CAPABILITIES**: Upper limit 70% driven by CPR 2C-SNOW
  - **RADAR** sensitivity seems to be a key factor for the detection capabilities of snowfall
  - **PMW** snowfall rete detection capability can be improved by:
    - →Training retrievals on high quality data & using the potentials of machine learning algorithms
    - →Improving the surface type characterization close to the overpass time (this could reduce False Alarm Rate of 2 – 3 times)
- **SNOW QUANTITATIVE ESTIMATES** : 30% underestimation performed by CPR
  - **RADAR-CloudSat-CPR**. Depsite its limited coverage, it provides by far the most complete view of snow systems
  - **RADAR-DPR**. offers better coverage and it is certainly more valuable for medium/heavy snow conditions;
  - **PMW-products** perform better than DPR. SLAOM outperforms GPROF albeit both underestimate the total snowfall.

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