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

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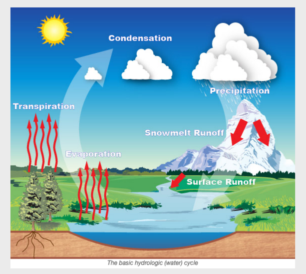
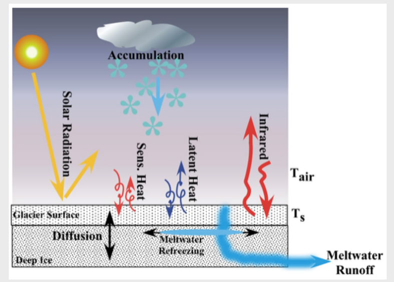
MOTIVATION

Why snowfall estimates are important:

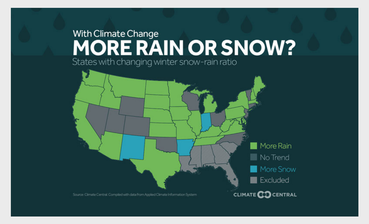


- Water budget. Snow represents a reservoir of fresh water and its quantification is extremely important as an input of the hydrological cycle.



- 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

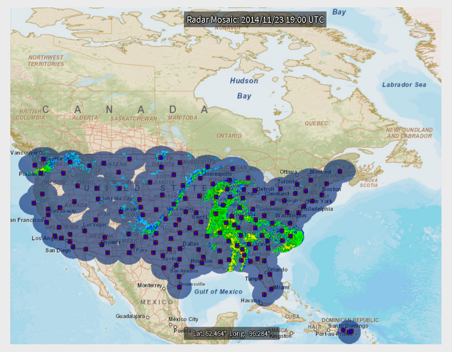
➢ **SENSORS AND ALGORITHMS**

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.

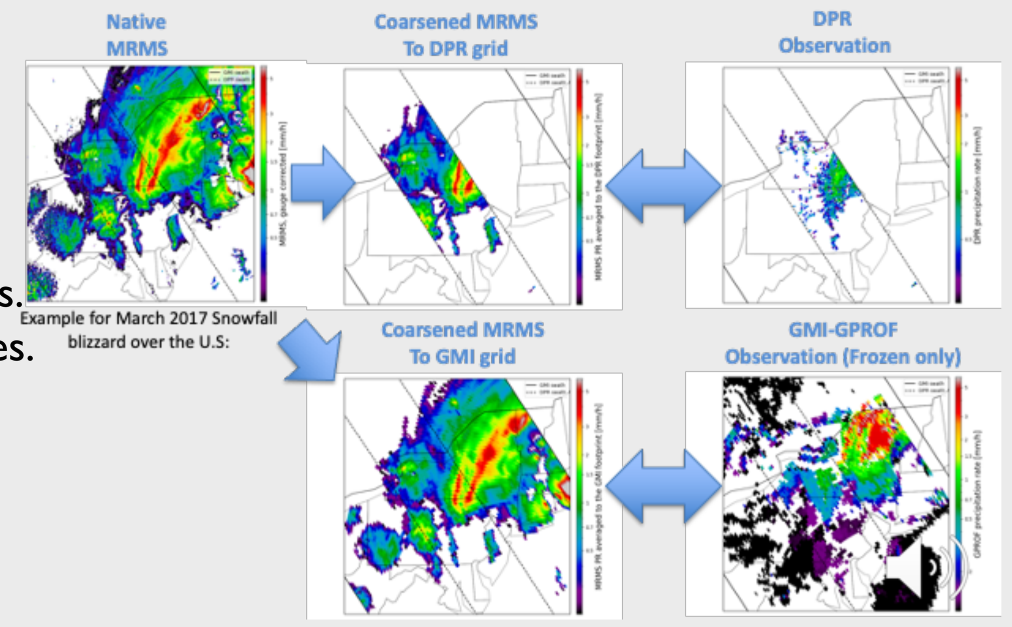
➢ **Data quality checks**
- PRMRMS >21.3 mm/h are removed (equivalent to Z>45dBZ) to mitigate hail and residual ground clutter contamination.
- Distance > 110 km from the closest radar site are not considered to reduce impact of blind zone, sensitivity and bin size

METODOLOGY: TIME AND SPATIAL COLOCATIONS

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

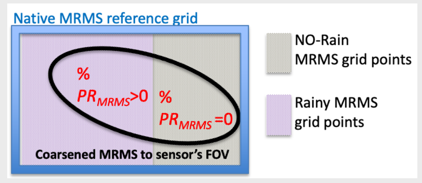
Spatial colocation
- MRMS 1x1 km^2 is coarsened to
- 5×5 km^2 DPR/CORRA Hor. res.
- 15×9 km^{2}GMI, 36GHz ch. Hor. res.
- 1.4×1.7 km^2 CPR, Hor. res.

Assumptions
- Gaussian antenna pattern

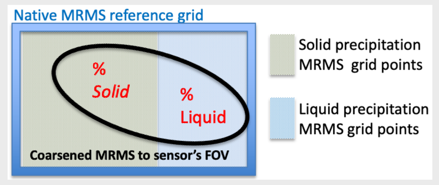


METODOLOGY: QUANTITATIVE COMPARISON STRATEGY

Verification point selection



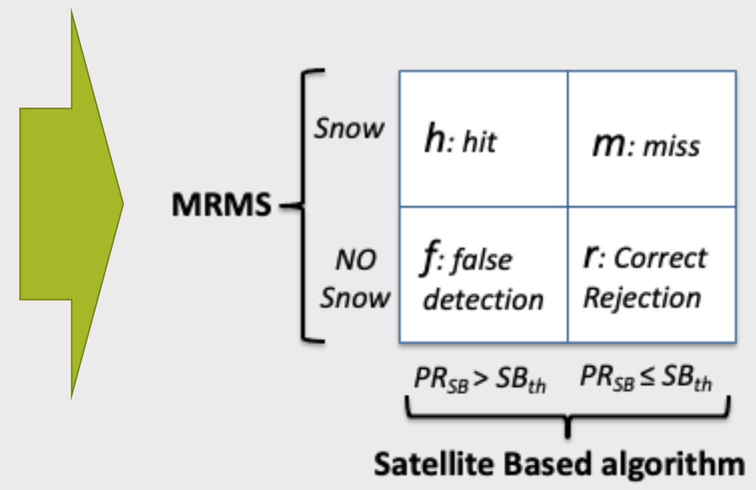
- **Snow MRMS. Coarsened MRMS having:**
  [% PRMRMS>0] ≥ 50% and
  [% solid precipitation] =100% and
  PRMRMS < 21.3 mm/h and
  Distance to the nearest NEXRAD radar<110 km



- **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.***



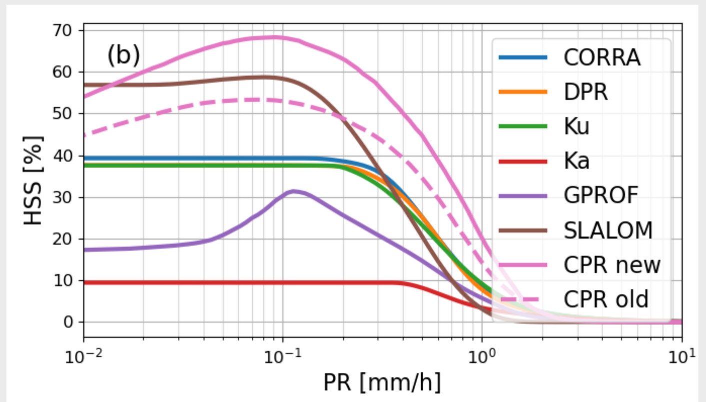
Snow quantitative evaluation

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

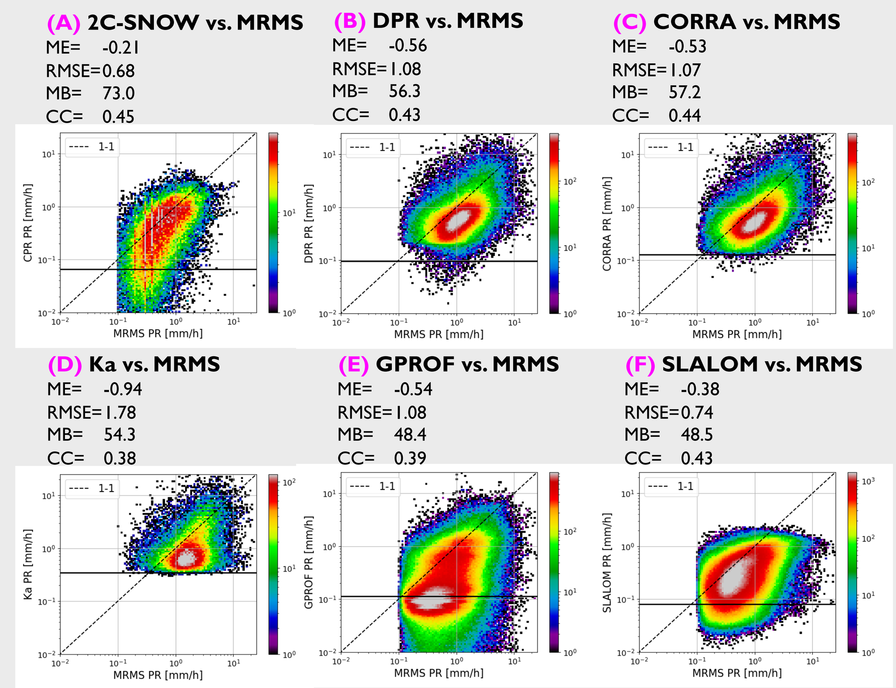
RESULTS: SNOWFALL DETECTION CAPABILITIES

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.

ACKNOWLEDGMENTS

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