National Research Council of Italy

Institute of Atmospheric Sciences and Climate

H SAF-GPM collaboration activity on precipitation retrieval: SLALOM (and PNPR)

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PMM Science Team Meeting

Phoenix (AZ) 8-12 October 2018

H SAF Support to Operational Hydrology and Water Management

Introduction

NASA PMM – EUMETSAT H SAF collaboration since 2014
H SAF current phase: CDOP-3 (2017-2022)

Current main activity:

- Use of GPM to characterize and monitor heavy precipitation systems in the Mediterranean region (*Panegrossi et al, 2016, Marra et al. 2017*)

Poster #200 on Wed.!!!

- Develop *global* PMW precipitation products exploiting datasets from coincident overpasses of spaceborne precipitation radars [*GPM DPR and CloudSat CPR*] and PMW radiometers. Focus on GMI and ATMS (for future EPS-SG MWS and MWI day-1 products) ***and* on snowfall (detection and retrieval)**

1. **Passive microwave Neural network Precipitation Retrieval (PNPR) applied to GMI** (*Sanò et al., 2018, Rem. Sensing*).
   - Training Dataset: GMI/DPR V04 (2B-CMB) 01/04/2014 – 08/06/2016 ($50x10^6$ rain, $150x10^6$ no rain); *GPM Global Area (68°S - 68° N)*
2. **Evaluation of DPR capabilities to observe snowfall with respect to CPR**, assessment of global snowfall mass estimate by DPR vs. CPR (*Casella et al., 2017, Atmos. Res.*):
   - DPR (V04) detects 29-34% of the global snowfall mass with respect to CloudSat CPR
3. **Analysis of GMI sensitivity to snowfall using CloudSat CPR coincident observations** (*Panegrossi et al., 2017, Rem. Sensing*)
4. **SLALOM**: snowfall detection and retrieval algorithm for GMI based on Cloudsat CPR (*Rysman et al., 2018, Rem. Sensing*)

GMI/CPR snowfall dataset

Based on the NASA 2B-CSATGPM product (J. Turk, JPL)

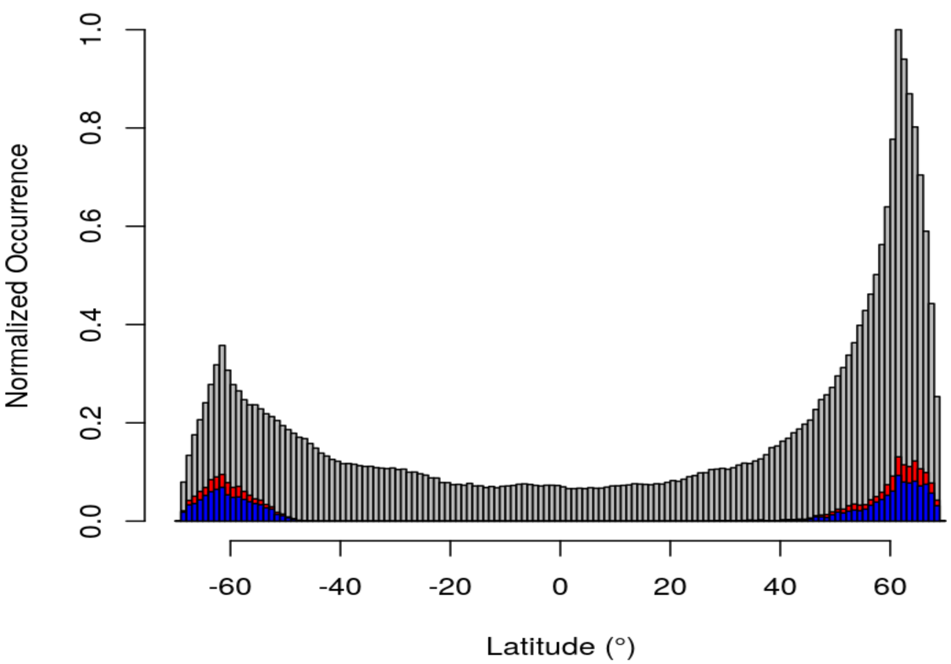
- GMI brightness temperatures/CPR reflectivity
- ***CPR 2C-SNOW-PROFILE (SWC, surface snowfall rate)***
- Environmental variables (TPW, T2m), vertical profiles (T, spec. hum., rel. hum.)

\+ AMSR2 daily Sea Ice

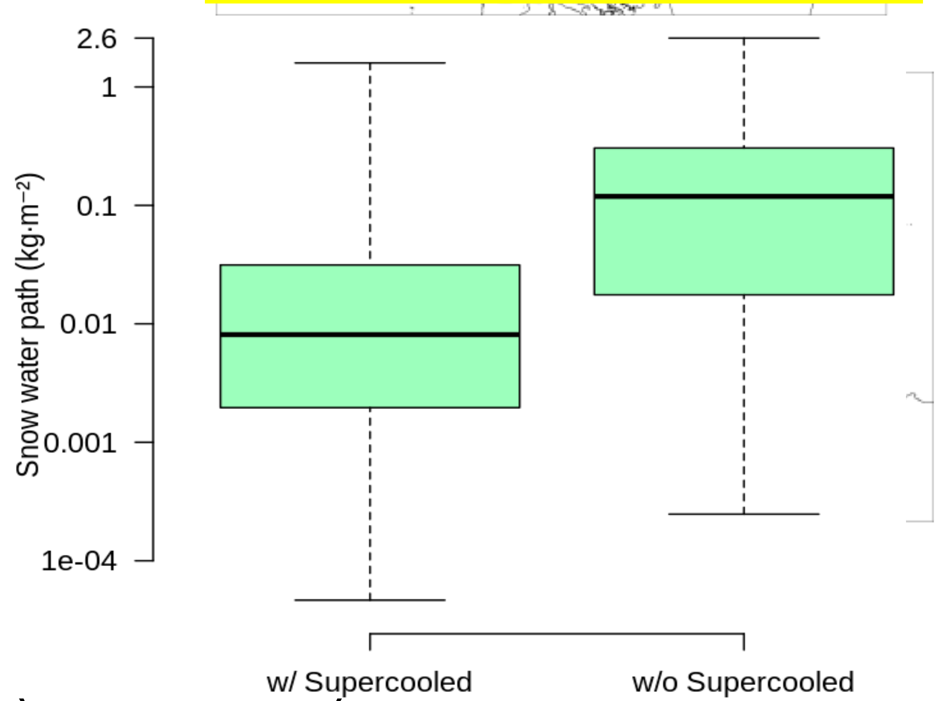
\+ **Supercooled droplet occurrence (CloudSat/Calipso *DARDAR*)**

What is a snowfall event?

- Snow probable or certain or liquid fraction < 15% (dry snow)
- Conditions based on ECWMF model temperature at the NS CFB
- Equivalent reflectivity factor Z at CFB > -15 dBZ
- CFB is not at the surface
- CPR profiles are averaged to match GMI resolution.



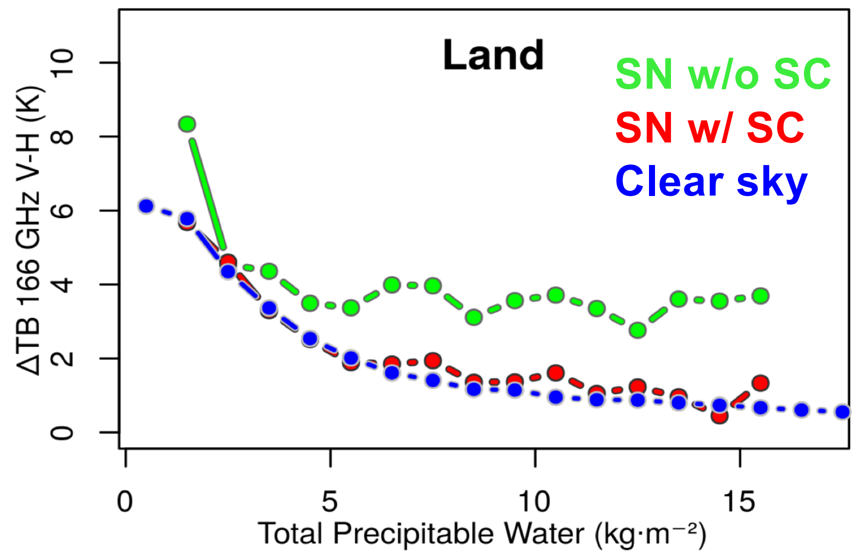
Zonal distribution of GMI/CPR coincidences: all (grey), snowfall (red), and snowfall with supercooled droplets (blue) (66% of snowfall events)



GMI sensitivity to *CPR* snowfall

(Panegrossi et al. 2017 Rem Sens.)

- We identified the **environmental conditions** favourable to snow detection with GMI
- We showed that the impact of **supercooled droplets** on GMI snowfall related signal can be critical depending on environmental conditions



- ***Lesson from case studies***: Important interconnnection of background surface characteristics, atmospheric water vapor content, and presence and vertical distribution (at cloud top or embedded) of supercooled cloud water on the GMI TB (and ΔTB) relation to snowfall.

- **Lesson from Global Analysis of TB sensitivity to CPR snowfall:**
  - *Regression tree statistical analysis* allows to ***quantitatively*** define critical thresholds of various parameters (e.g., sea ice concentration, TPW, SWP) towards the optimal use of GMI channels and their combination (e.g. 166 GHz ΔTB) for snowfall detection;

→ Need to take this into account to retrieve snowfall with GMI

SLALOM *(Rysman et al., 2018, Rem. Sens.)*

Snow retrievaL ALgorithm fOr gMi

Training dataset (70% of total): 408254 observations, with 38331 2CSP-defined snowfall events

For Sc module only Sc on cloud top are selected (not embedded). Sc are found for 2/3 of snow events

- **Input variables for detection modules:** T2m, TPW, T and moisture profiles, 13 GMI channels (***no surface variables***)

Random Forest

SLALOM consists of 3 modules

Snowfall detection

Output: probability of snowfall occurrence at each GMI pixel

Supercooled droplets (Sc) detection

Output: probability of supercooled droplets occurrence at each GMI pixel

Snow water path (SWP) retrieval

Output: SWP at each GMI pixel

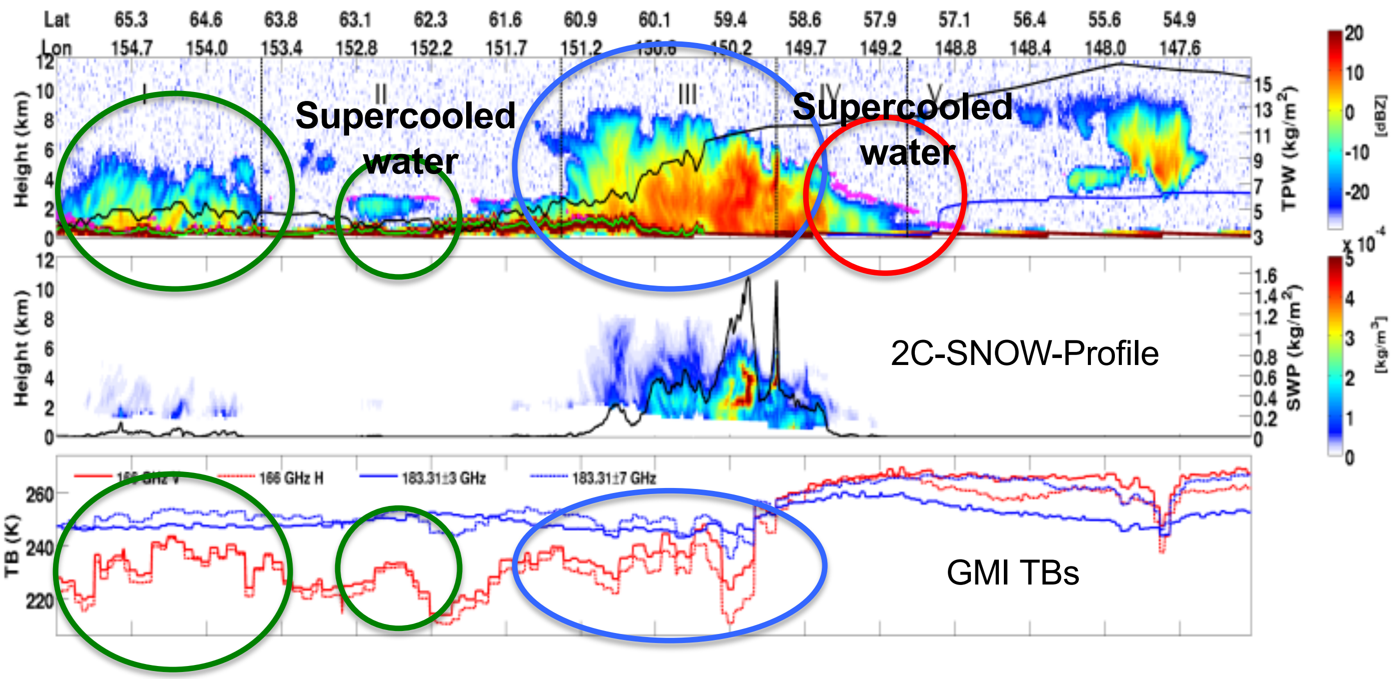
Segmented multi-linear regression:

- 46 subsets were found using as input: T2m, TPW, Sc flag, and low-frequency GMI channels (regression tree analysis);
- different linear regression models between **GMI high-frequency channels and SWP** for the different subsets

Surface snowfall rate retrieval **Under development**

GMI sensitivity to snowfall

Frontal snowfall event - Eastern Siberia 30 April 2014

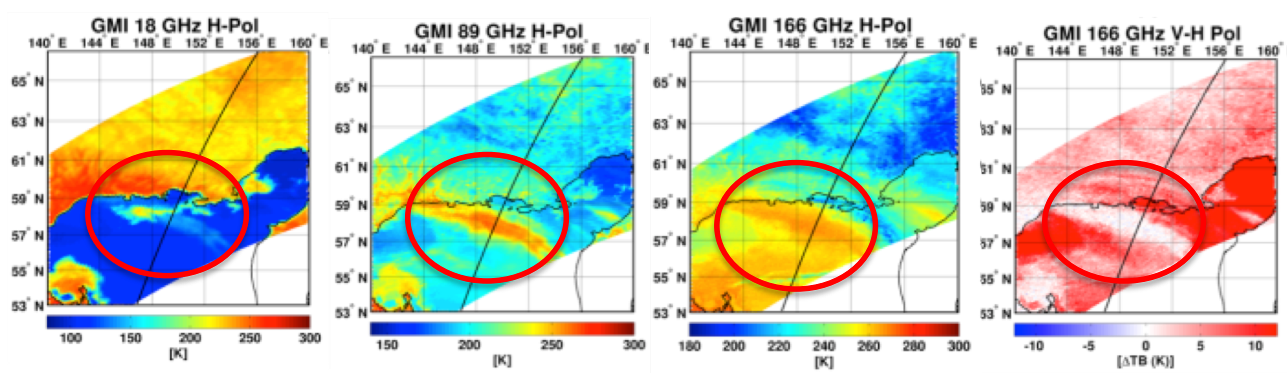


Land/snowcover
Very cold and dry env.

Sector I/II: Shallow/weak snow clouds; sensitivity at 166 GHz *and* impact of **supercooled droplets**

Sector III: Deeper snowfall segment; scattering effects at 166 GHz and 183 GHz (lower TBs up to 30K); 166ΔTB polarization signal up to 12 K

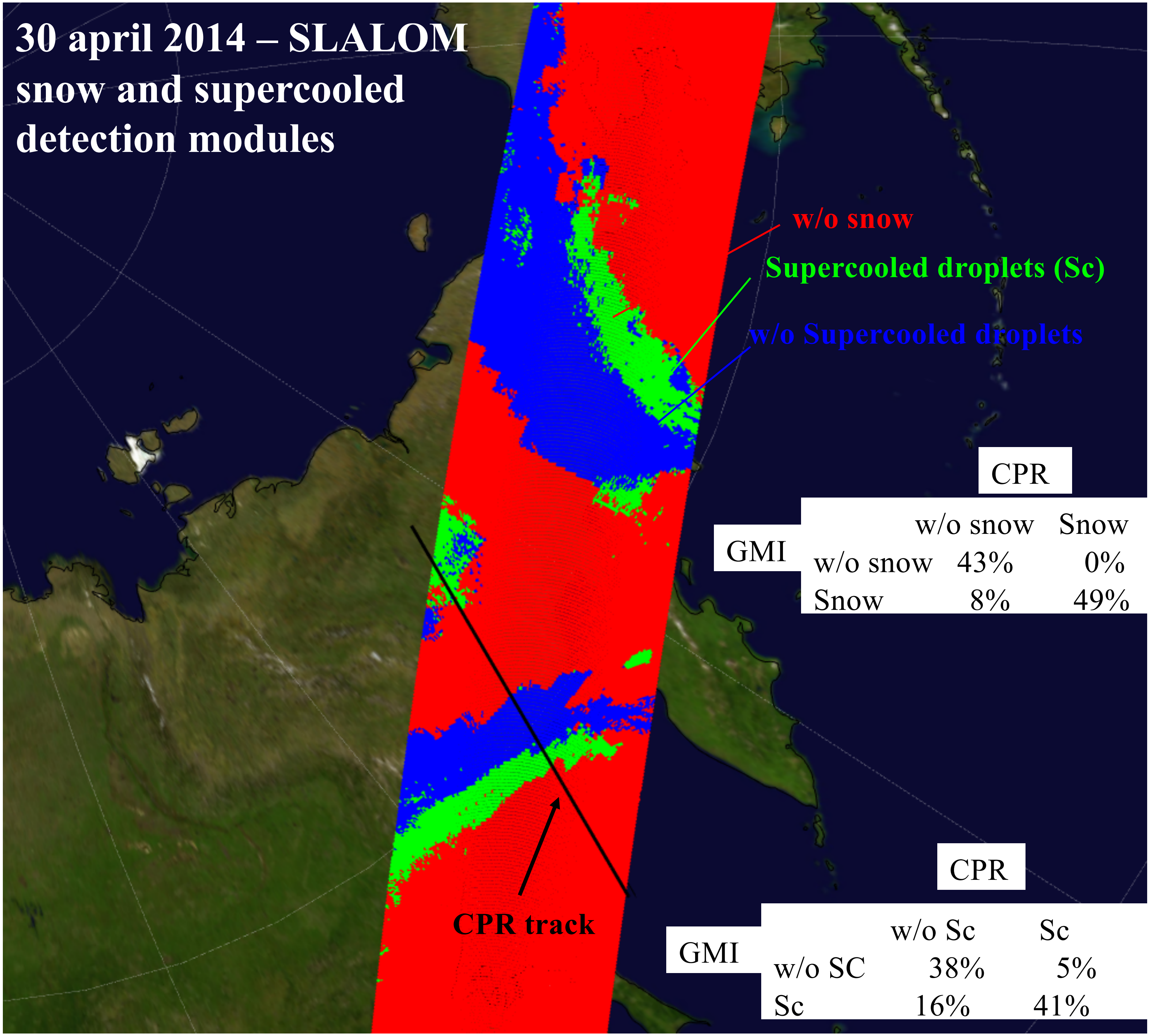
Ocean
Moist and warmer env.
Sector IV/V: Effect of **supercooled droplets** visible mostly at 89 GHz; presence of low-level mixed phase precipitation (2C-SNOW does not retrieve snowfall). Upper level cloud with strong signal at 166 and 183 GHz



GMI TB maps at 18.7, 89 (H-pol) and 166 GHz (H-Pol), and 166 ΔTB ; black line indicates the CloudSat track

Panegrossi et al. 2017 Rem Sens

30 april 2014 – SLALOM snow and supercooled detection modules



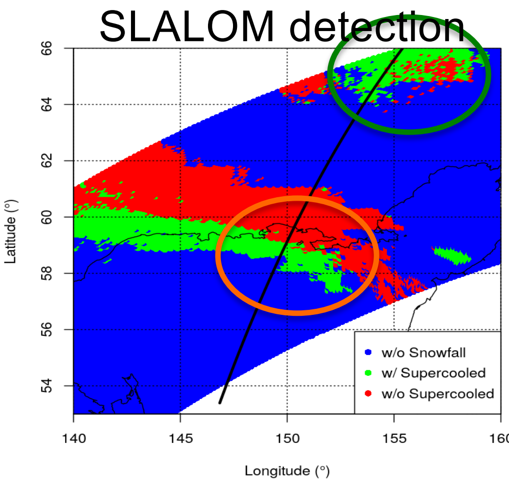
SLALOM predicts two distinct snowfall regions in the frontal system

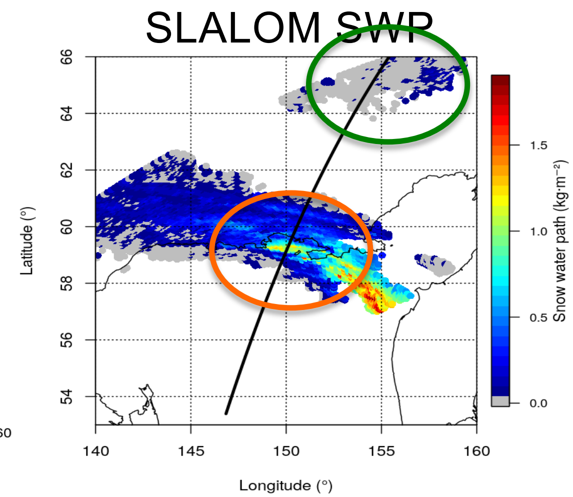
GMI \ CPR	w/o snow	Snow
w/o snow	43%	0%
Snow	8%	49%

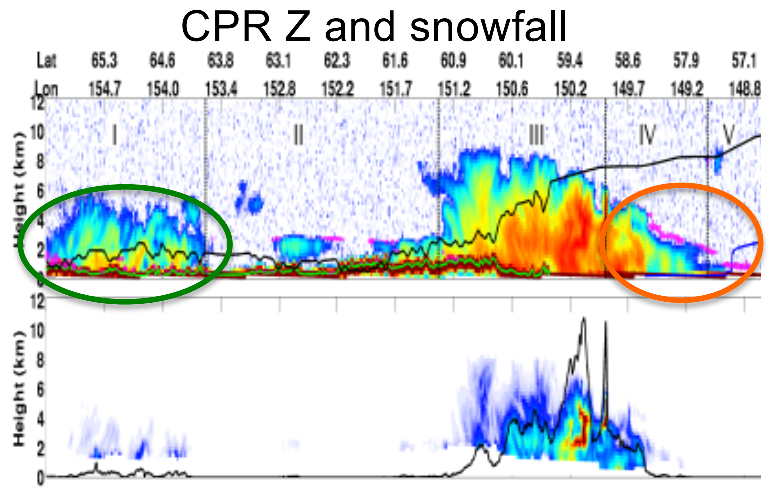
Supercooled droplets detection along CPR consistent with CloudSat/Calipso DARDAR product

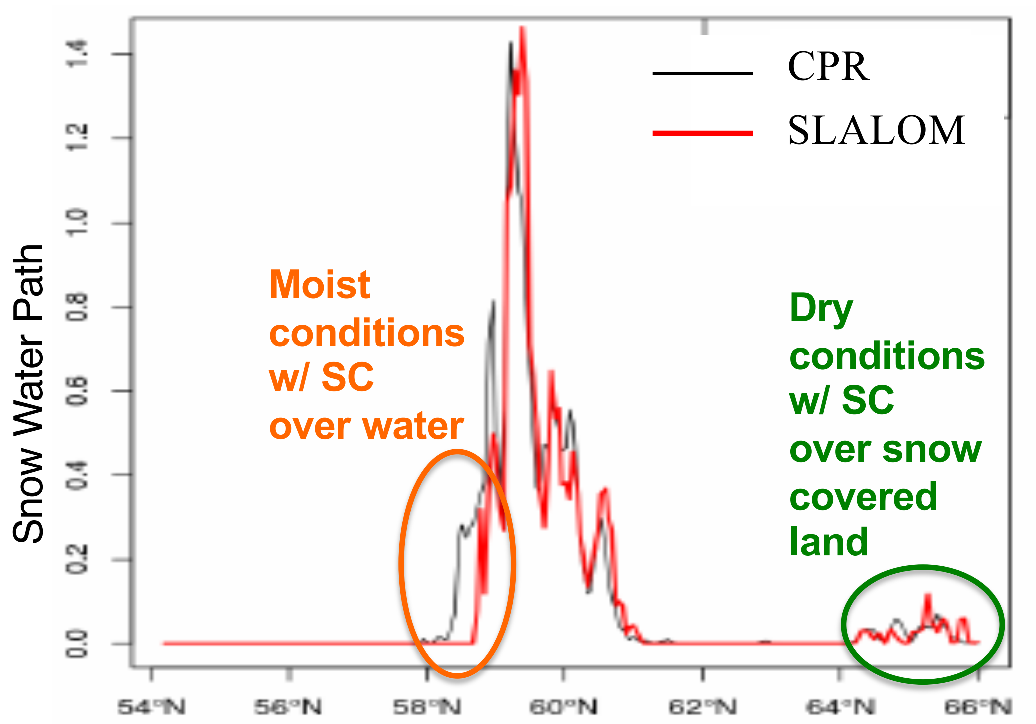
GMI \ CPR	w/o Sc	Sc
w/o SC	38%	5%
Sc	16%	41%

30 april 2014 – SLALOM vs. CPR





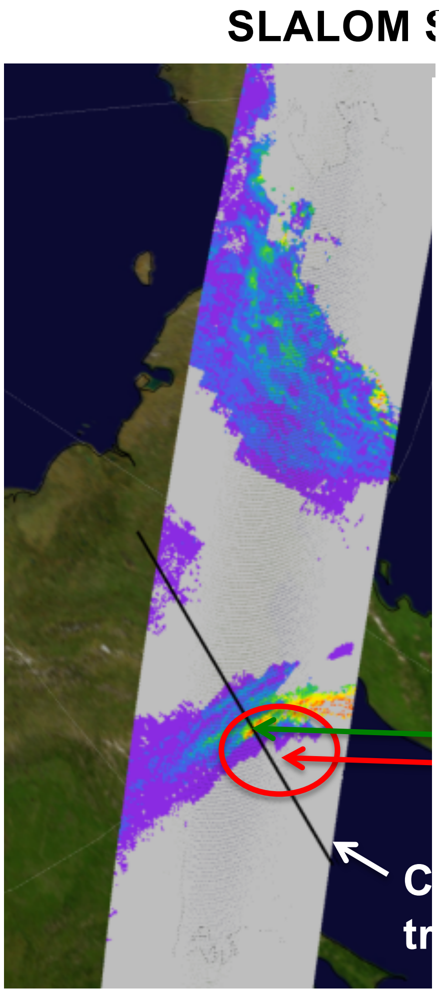


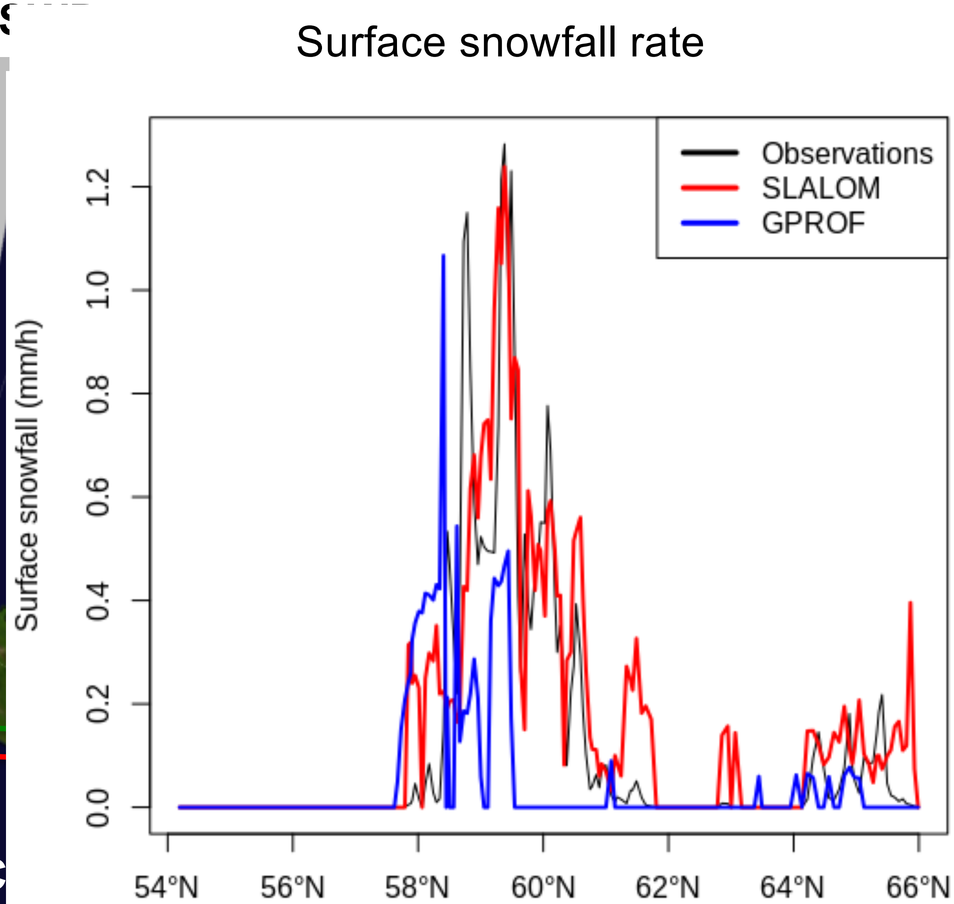


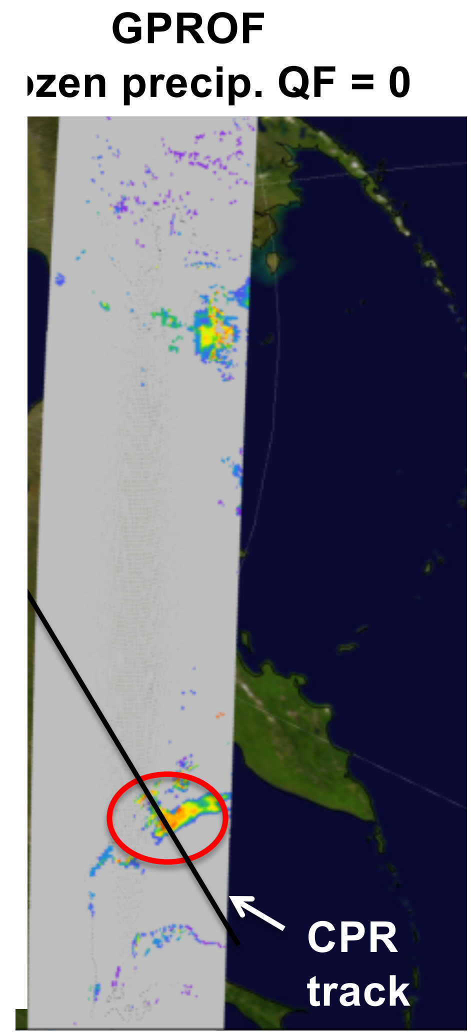
Predicted and observed SWP match very well, even in the weaker snow region (around 65 °N)

SLALOM misses snowfall in the region with high TPW and supercooled droplets, while it matches the SWP in the northern region with low TPW and supercooled droplets.

30 april 2014 – Comparison with GPROF V05







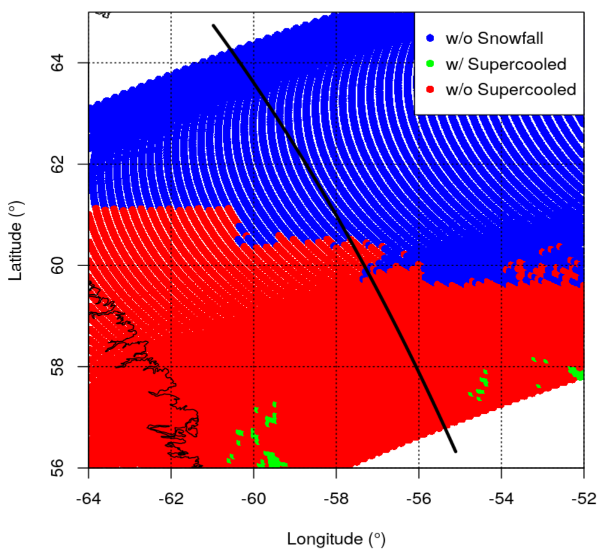
(Preliminary results for SLALOM surface snowfall rate!)

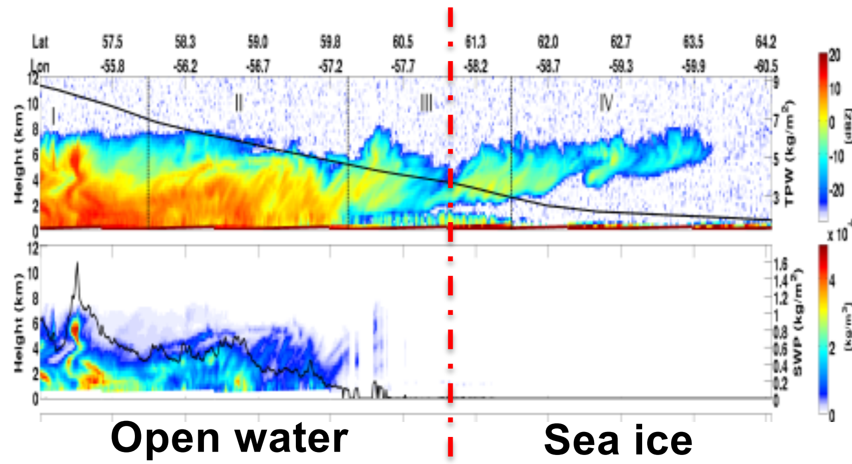
Snow water path vs. Surface precipitation rate!!

24 March 2014 – SLALOM vs. CPR

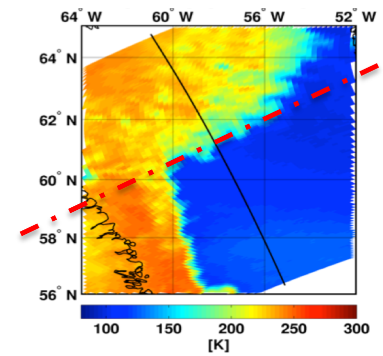
Synoptic snowfall event over the Labrador Sea

SLALOM detection



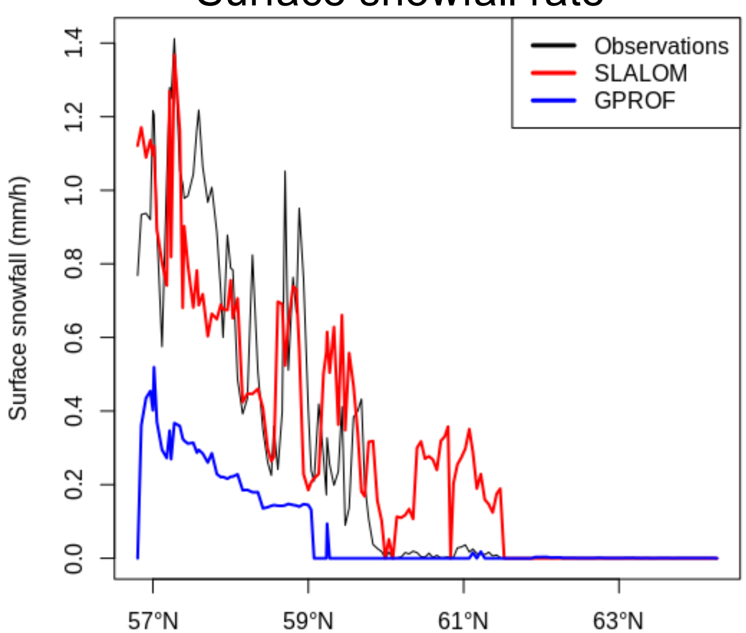


GMI TBs 18.7 GHz (H pol)

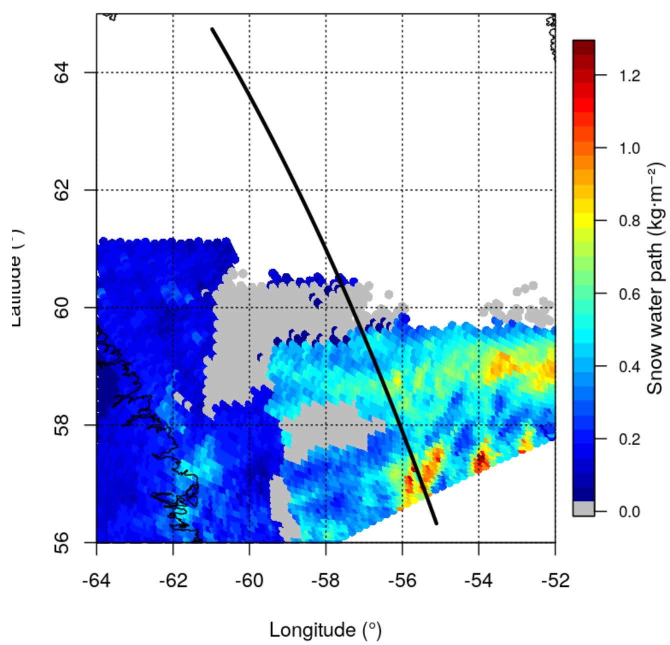


Transition from open sea to sea ice around 61° N-58° W, and from moister to extremely dry conditions

Surface snowfall rate



SLALOM SWP



Snowfall without supercooled droplets predicted by SLALOM south of 61° N

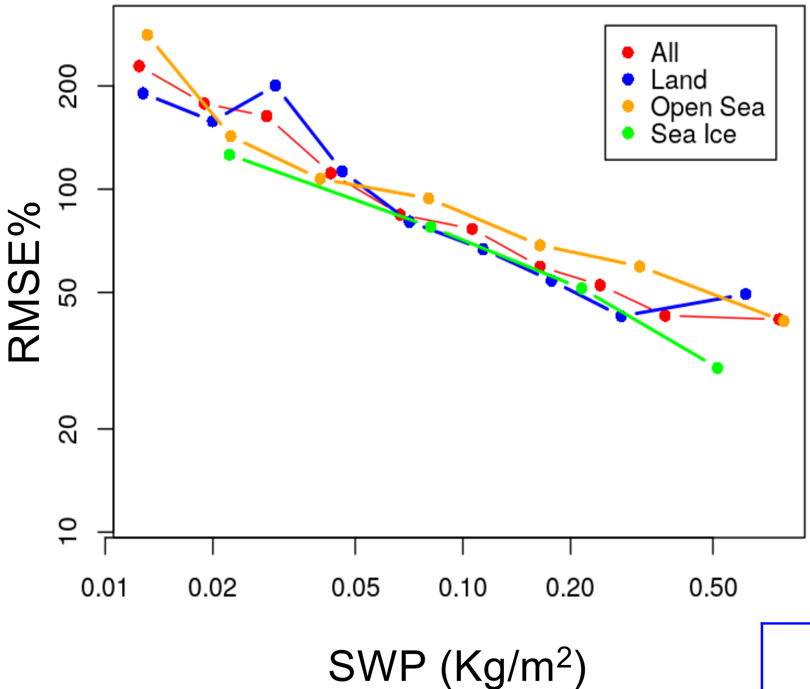
CPR and SLALOM SWP match very well

SLALOM statistical evaluation

Snow detection module
POD = 0.82 ; FAR = 0.12; HSS= 0.84
(17% misses on average mostly at T2m> 275K)
10% misses for SWP > 1×10^{-2} kg/m^2

Supercooled detection module
POD = 0.97; FAR = 0.05; HSS = 0.9
(misses around 5% mostly found at TPW <2.4 kg/m^2)

Similar results for all surface types



SWP retrieval module

Surface	Correlation	BIAS	RMSE (kg/m^2)
All	0.88	-16%	0.1
Land*	0.85	-13%	0.1
Open Sea	0.88	-21%	0.12
Sea Ice**	0.92	-15%	0.08

*(*land is 88% at T2m < 273K, **Sea Ice concentraion > 90%)*

SWP SLALOM (full algorithm)

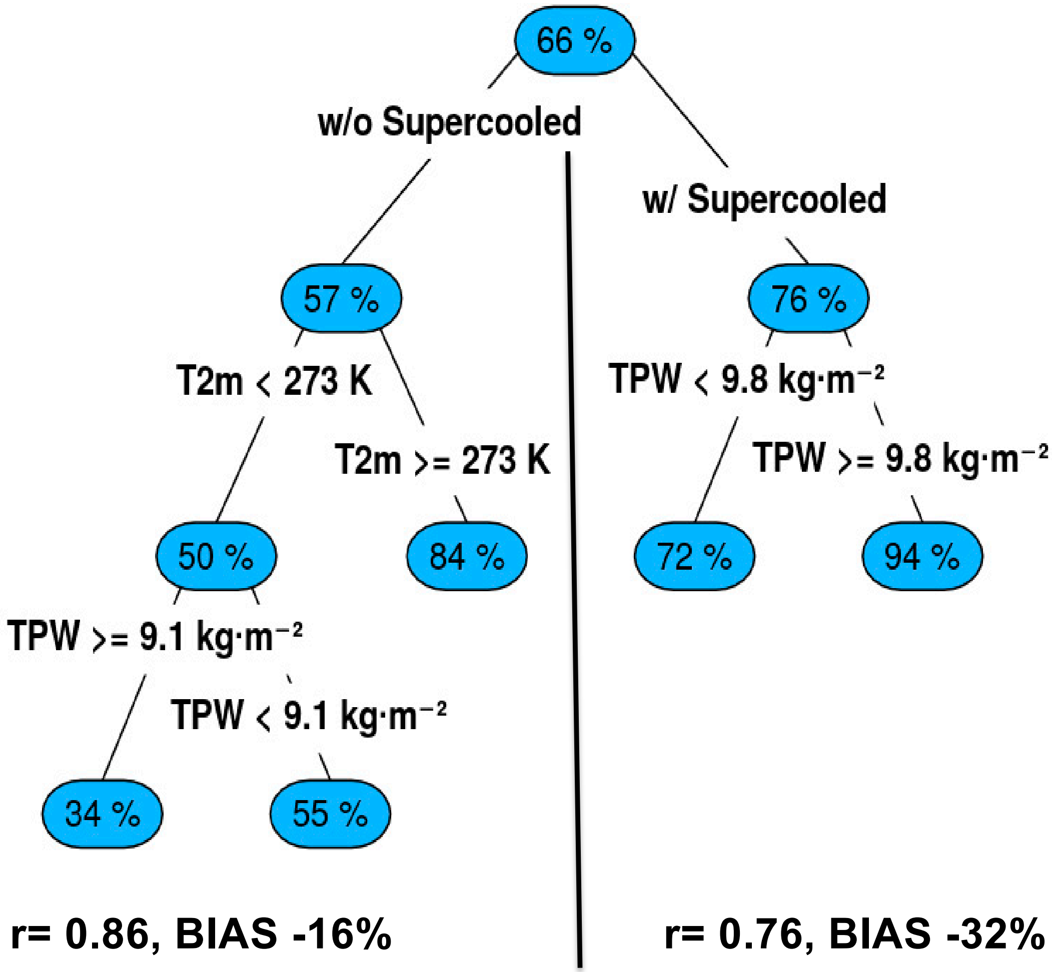
	Correlation	BIAS	RMSE (kg/m^2)
SLALOM	0.86	-20%	0.04
SLALOM w/o Sc	0.86	-18%	0.04
SLALOM w/o env.	0.61	-49%	0.13

30% of the original GMI/CPR dataset is used for the validation

SLALOM: statistical evaluation

Analysis of the mean normalized absolute difference between CPR SWP and SLALOM SWP (%)

*Regression (or decision) tree: a classification method that allows to identify the variable that hierarchically affect the parameter analyzed (in blue). It chooses recursively variables whose value (**branches**) splits the dataset into 2 groups (**leafs**) for which the variance is minimal.*



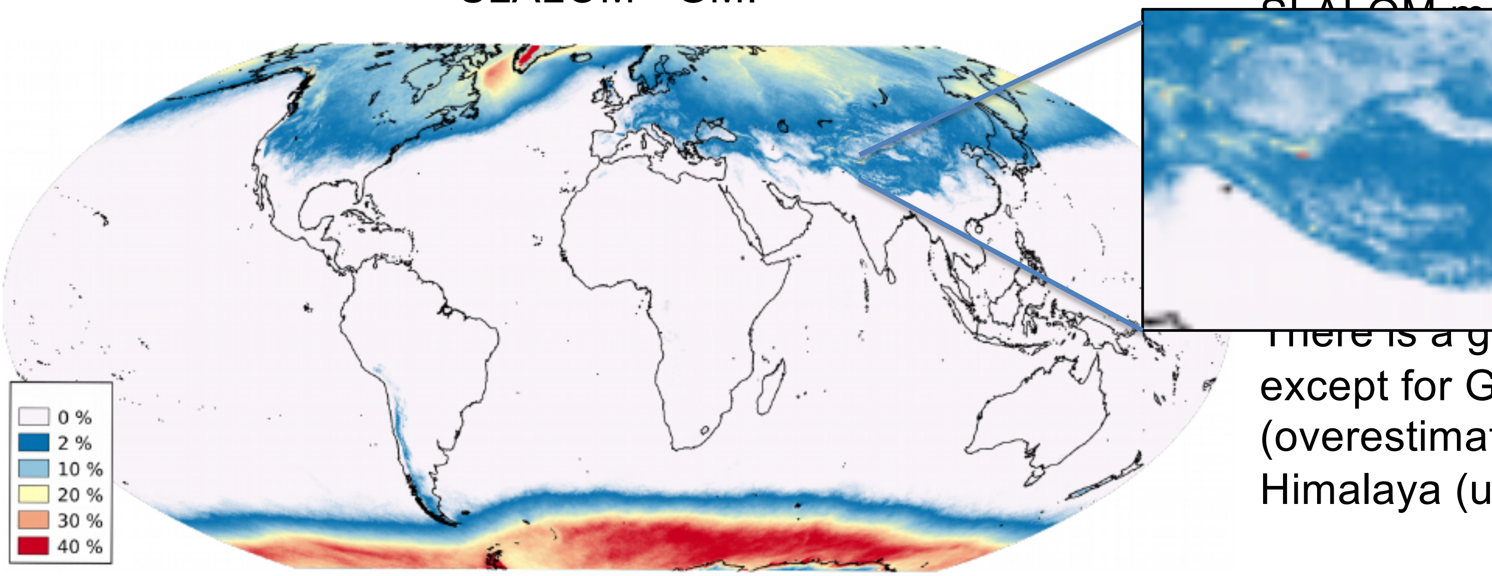
Partitioning variables considered are: TPW, T2m, surface type, flag for supercooled droplets (Sc)

1) Main variable is Sc flag
2) Normalized difference is lower w/o Sc
3) **w/o Sc (left side)** high T2m has big impact; low T2m and **high TPW** are most favourable
4) **w/ Sc (right side), low TPW** is more favourable

Sc events are associated with lower SWP (SWP w/ Sc is 10 times lower than w/o Sc). Therefore high TPW obscures snowfall signal in most cases.

Climatology of Snowfall occurrence 05/2014 - 05/2016

SLALOM - GMI



…ap was made
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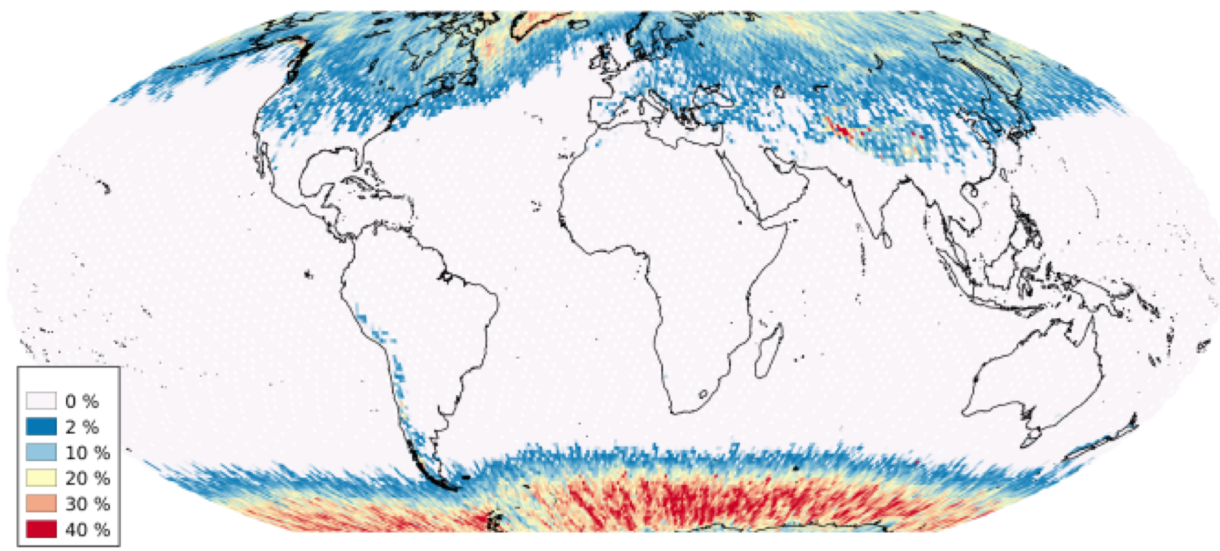
There is a good agreement except for Greenland (overestimation) and Himalaya (underestimation)

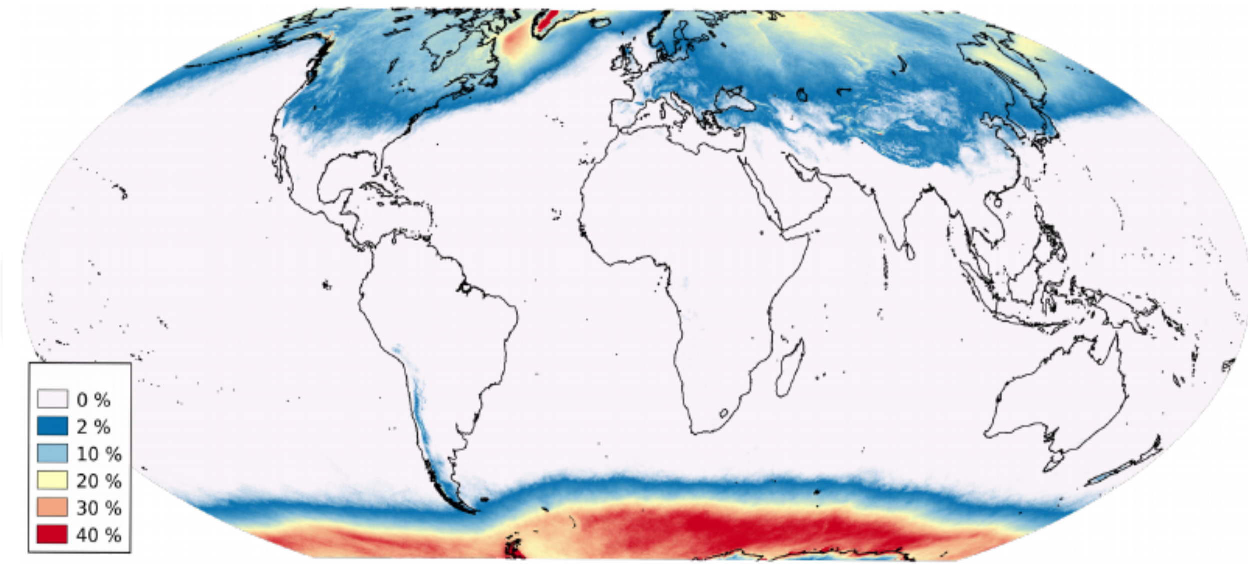
- Antarctica coast is region with highest occurrence up to 40%
- Values around 30% are found in Canada, Labrador Sea, Siberia
- Europe and western regions around 5%
- Mountain ranges show occurrences that can exceed 20% (a peak at 40% is found in Himalaya)

CPR 2C-SNOW-PROFILE (V04)



Climatology of Snowfall occurrence 05/2014 - 05/2016

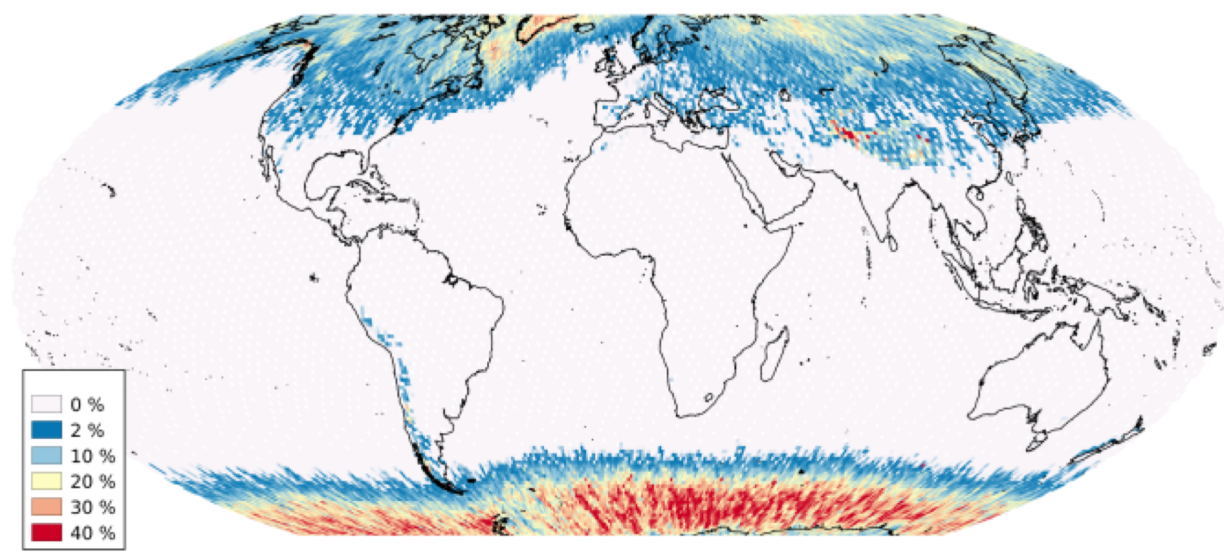
SLALOM - GMI



Comparison between snowfall products is very challenging:

- Different definition of "snowfall" (dry, partly melted, etc.)
- Phase determination (model based);
- Quality flags;
- Limitations/differences in reference datasets (DPR vs. CPR);

CPR 2C-SNOW-PROFILE (V04)



85% threshold for GPROF chosen to compare it with SLALOM and CPR dry snow

Conclusions

- SLALOM is a snowfall retrieval algorithm for GMI based on Cloudsat/CALIPSO products; it provides ***snowfall and supercooled droplets detection, and SWP*** in agreement with CPR;
  - The algorithm fully exploits all GMI channels and model-based atmospheric fields (***no information on the surface is provided***);
  - Temperature, moisture, and GMI low frequency channels play a key role in SLALOM, and define conditions where snowfall retrieval GMI is feasible, and how SWP is related to high-frequency channels;
  - Interesting interconnections are found between supercooled droplets (on top of the cloud) and moisture conditions, and their impact on SWP retrieval error.
- Random forest technique used for detection (snowfall and supercooled droplets) is very effective; the “simple” segmented multi-linear regression for SWP retrieval can be improved;
- Intercomparison between snowfall products can be quite challenging because of differences difficult to reconcile (“snowfall” definition, liquid/solid phase determination); need for an independent high-quality GV dataset.

SLALOM main limitations

- SLALOM fully relies on the 2C-SNOW, e.g., misses lower layers, ground clutter, dry snow only;
- GMI/CPR coincidences mostly occur at high latitudes (snowfall climatology is not complete);
- Effect of embedded supercooled droplets is not considered (30% of cases, they may affect the results)

Future development

1. Finalize development of surface snowfall rate retrieval
2. Analyze SLALOM skills on various regions using independent GV (i.e., Great Lakes;)
3. Participate to Intercomparison experiment (LSWG initiative, J. Turk)
4. Incorporate SLALOM in the **global neural network PNPR algorithm for GMI (Sanò et al., 2018)** (based on GPM observational dataset), developed recently within H SAF;
5. Extend study to ATMS, also in view of H SAF day-1 product for EPS-SG MWS:
   - exploit empirical datasets built from coincident observations with CloudSat to analyze ATMS snowfall observation capabilities (starting from 2B-CSATGPM V03B);
   - develop SLALOM-based algorithm for ATMS in order to have snowfall detection and retrieval to higher latitudes, and achieve global coverage of (dry) snowfall.

THANK YOU

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