EUMETSAT
H SAF

Satellite-based snowfall detection and estimation: challenges and future perspectives within H SAF

Giulia Panegrossi, Daniele Casella, Andrea Camplani, Paolo Sanò
CNR-ISAC, Rome Italy
with
Jean-Franois Rysman (LMD, France), Mark Kulie (NOAA), Joe Turk (NASA JPL), Alessandro Battaglia (PoliTo), Kamil Mroz (Univ. of Leicester), Lisa Milani (NASA, GSFC)
and NASA PMM Science Team

MW radiometry and snowfall: A few key points

Satellite-based precipitation detection and estimation at higher latitudes (mainly snowfall) is one of the main challenges in precipitation retrieval from space

Golden age for spaceborne cloud/precipitation radars:

- ***GPM DPR (Ku/Ka band)***: good coverage but up to 65°N/S;
    - *valuable for medium/heavy snow conditions*;
    - low sensitivity, more suitable for heavy snowfall events

- ***CloudSat CPR (W band)*** **:** narrow swath (1.4 km) up to 82°N/S
    - considered reference for snowfall global monitoring
    - high sensitivity, more suitable for light-medium snowfall events (attenuation causes underestimation of heavy snowfall)

- Spaceborne radars have limited coverage

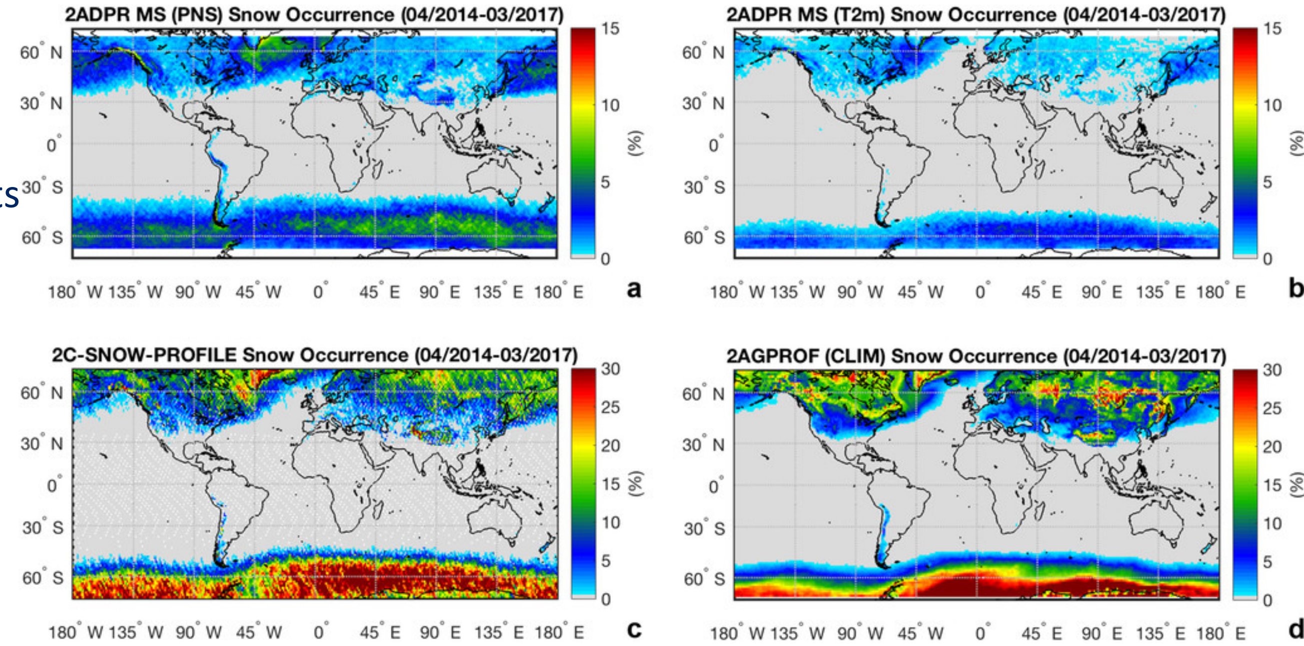
- Need to rely on PMW radiometers (GPM constellation and future EPS-SG mission)

- Current products show large discrepancies in snowfall climatologies (especially higher latitudes)

Large fraction of *higher latitudes snowfall* is missed by DPR (mostly due to sensitivity limits).

DPR vs. CPR (V04)	DPR-Ku	DPR – Ka MS
%missed snowfall events	92.5%	95.2%
% snowfall mass detected	28.08%	33.09%

(Casella et al., 2017, Atmos. Res.)



(Skofronick-Jackson et al., 2019)

MW radiometry and snowfall: challenges

Challenge 1

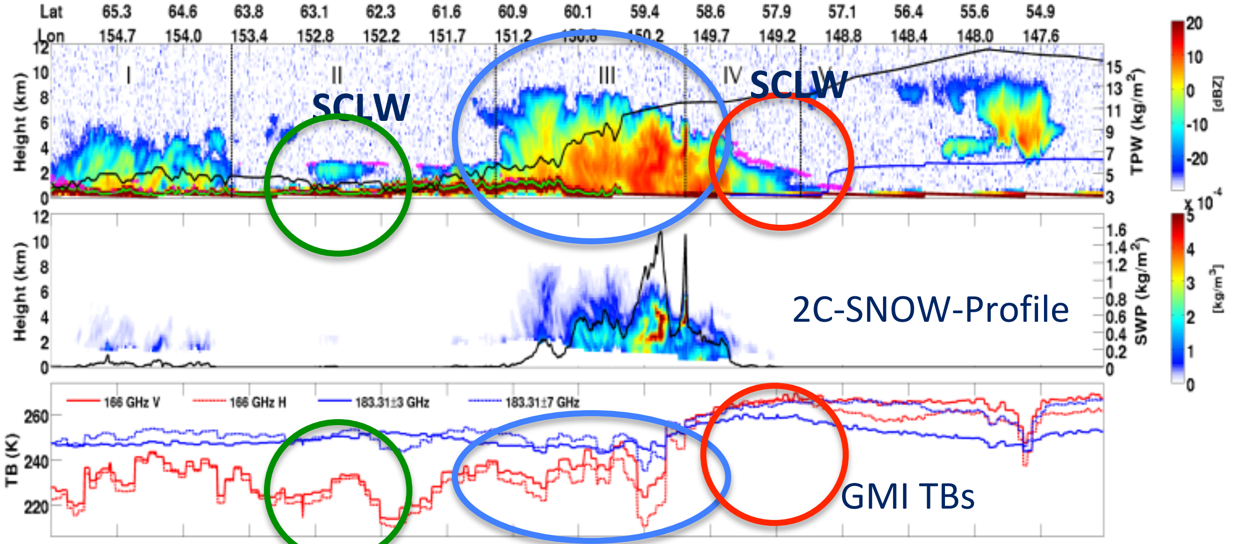
Snowfall scattering signal is weak and tends to be masked by the emission due to water vapor and supercooled cloud liquid water (SCLW*)*

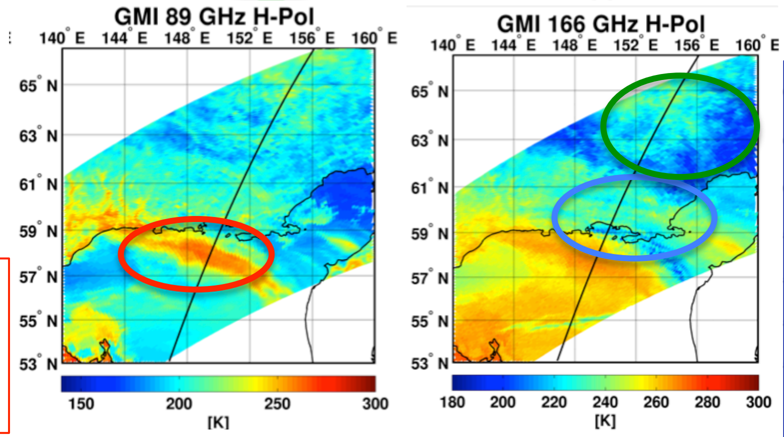
Need to characterize atmospheric moisture and SCLW at the time of the overpass

Strategy

– Model-based ancillary variables
– **Exploitation of all WV sounding channels and 90 GHz channels for SLWC and use of observational datasets providing information on cloud microphysics**

GMI/CloudSat-Calipso co-located observations Siberia 30 April 2014





Emission signal by supercooled liquid water at 89 GHz

Scattering signal at 166 GHz (hardly visible for light snowfall over snow-covered surfaces + emission due to SCLW)

Panegrossi et al. 2017 Rem. Sens.

MW radiometry and snowfall: challenges

Challenge 2

PMW multi-channel measurements respond to both snowfall and background surface properties

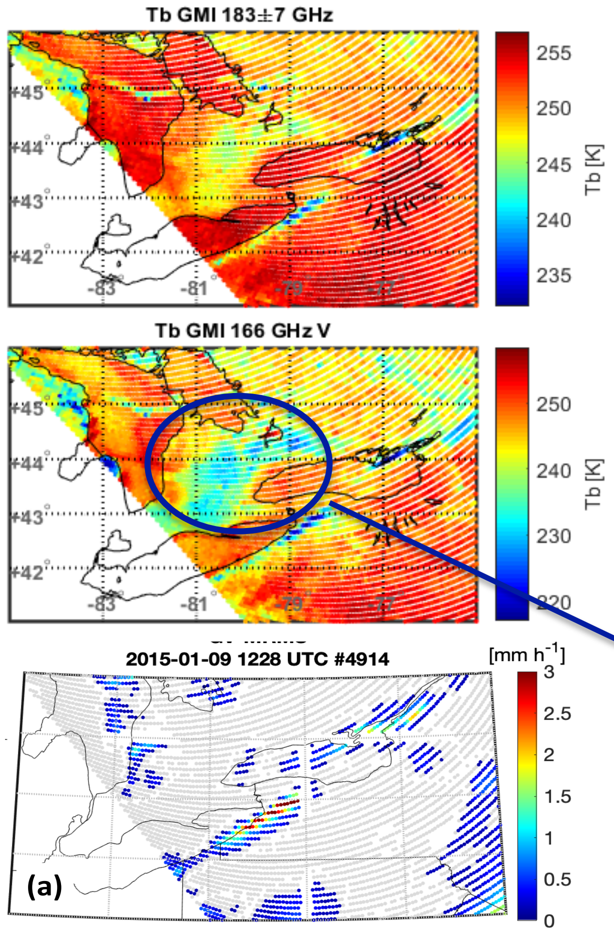
Sea ice and snow-covered land surface emissivity is extremely variable (sea ice properties, snow cover extent, accumulation, metamorphism)

Significant effect on the microwave measurements in presence of snowfall (especially in dry conditions/high latitudes) which is difficult to interpret

Need for better characterization of frozen surface (sea ice and snow cover) conditions

Strategy:

Exploitation of low frequency MW channels at the time of the overpass which are mostly affected by surface radiative properties



Measured TBs (including high-frequency channels in very dry conditions) are affected by snow cover (and sea ice) properties

Snowfall or Snow at the surface?

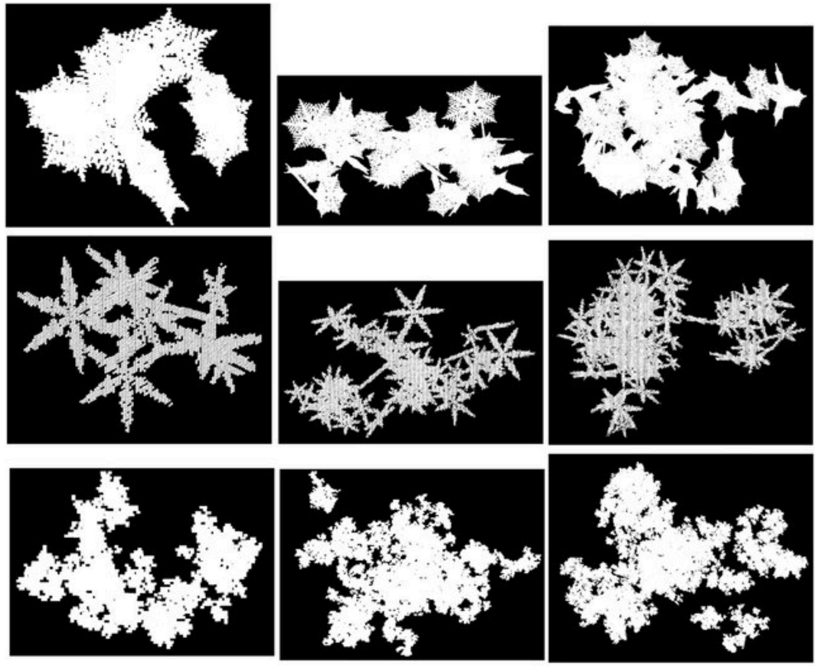
GMI overpass at 12:26 UTC for Extreme Lake Effect Snow event on 9 January 2015 (Milani et al., JHM, 2020)

MW radiometry and snowfall: challenges

Challenge 3

The PMW multichannel snowfall signal is highly dependent on the complex scattering properties of snowfall

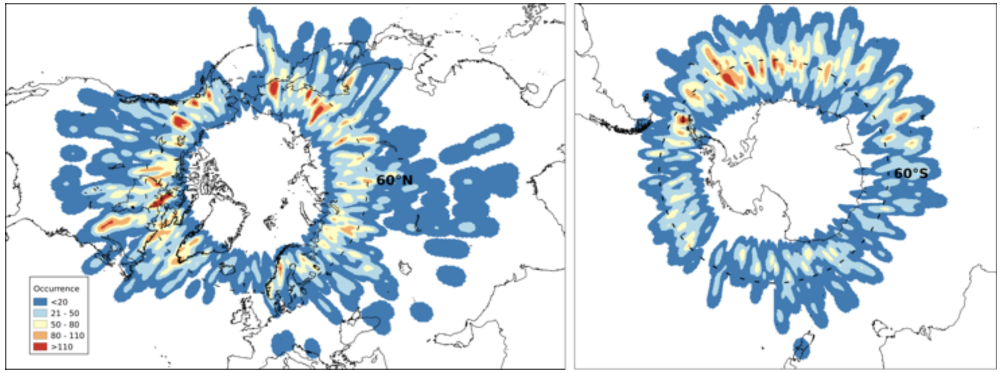
Need to have a high-quality, global snowfall database to be used as a priori or training information in the PMW retrieval process



Highly sophisticated single scattering models and cloud microphysics models are now available, but still large uncertainties in cloud-radiation model simulations

Strategy: Use of observational datasets relating surface snowfall estimates available from spaceborne radars with PMW measurements

CloudSat/Calipso-GMI coincidence dataset (extension of NASA 2B-CSATGPM, J. Turk, JPL)



Geographical distribution of GPM/CloudSat coincidences *(Panegrossi et al., 2017)*

SLALOM: CloudSat-based PMW snowfall retrieval

(in preparation for EUMETSAT H SAF EPS-SG day-1 precipitation product)

Machine Learning approach based on the GMI/CloudSat/Calipso coincidence observational dataset used for training (CPR 2C-SNOW product for snowfall with *liquid fraction < 15%* ***(no mixed phase or liquid precip.)*** **(extended 2B-CSATGPM dataset developed by J. Turk)**

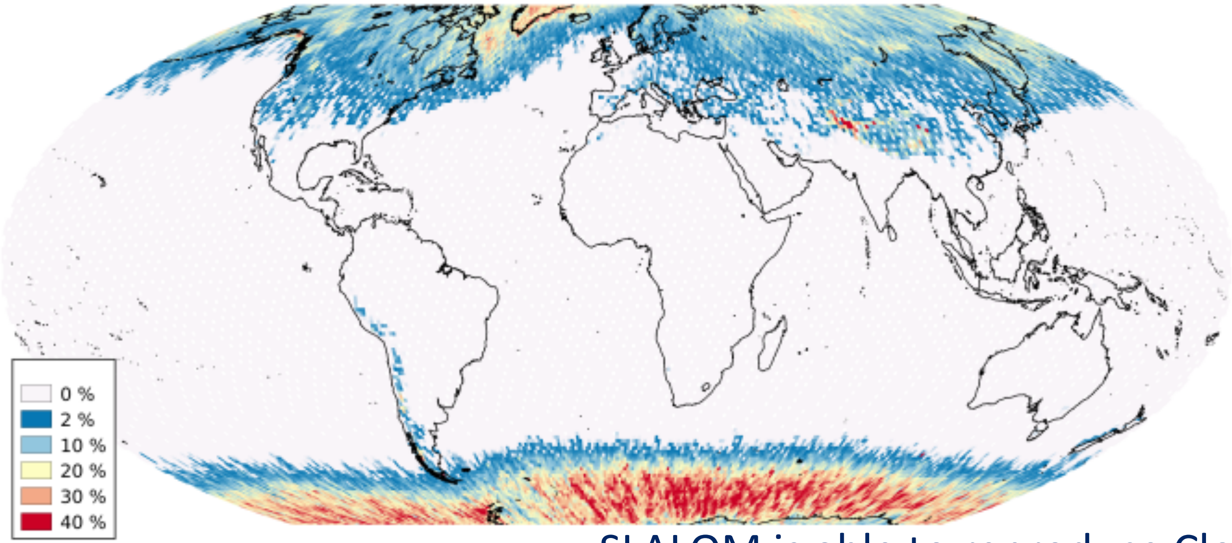
Input: GMI L1c TBs (all channels) and auxiliary ECMWF analysis variables on atmospheric state (T2m, moisture profiles)

No auxiliary info on background surface conditions but exploitation of all GMI low frequency channels

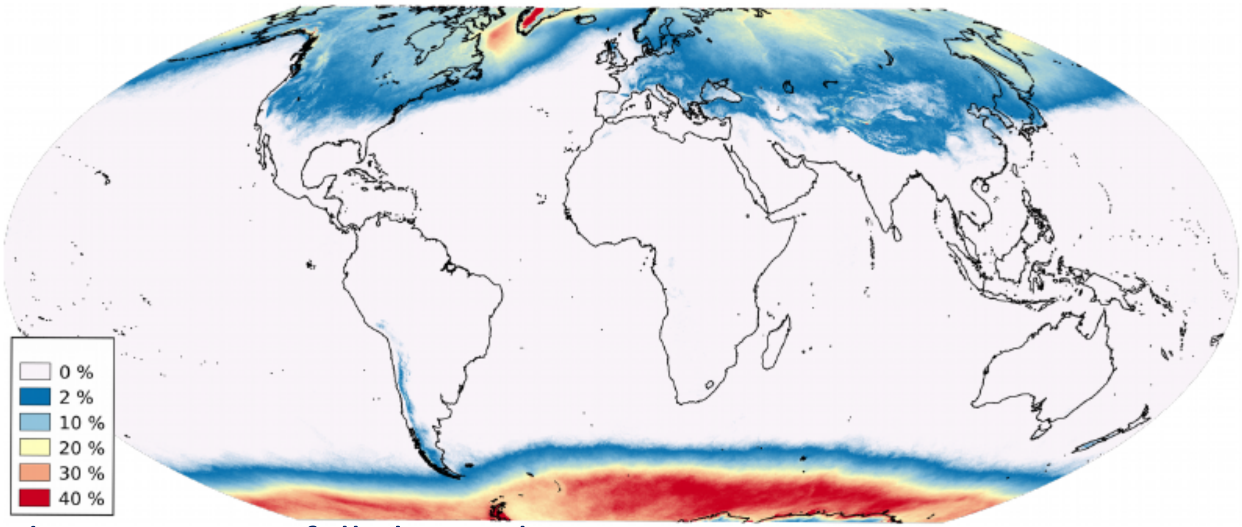
- **Random forest modules** for snowfall detection and supercooled liquid water detection;
- **Multi-linear regression module**: snow water path (SWP) estimates
- **Gradient boosting module**: Surface snowfall rate (SSR)

Global snowfall Occurrence 05/2014 - 05/2016

CPR



SLALOM



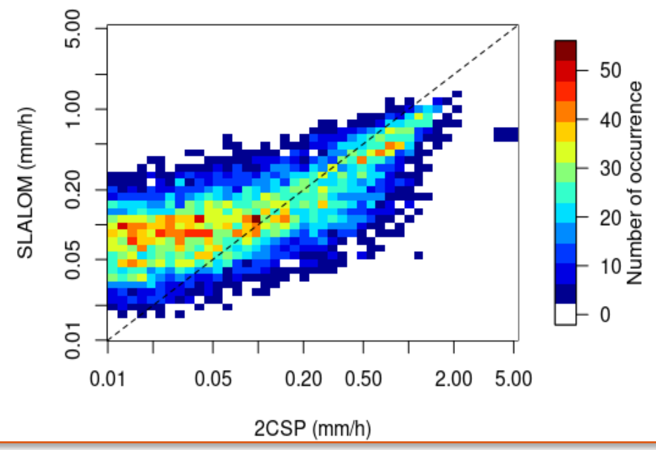
SLALOM is able to reproduce CloudSat CPR snowfall climatology

SLALOM: CloudSat-based PMW snowfall retrieval

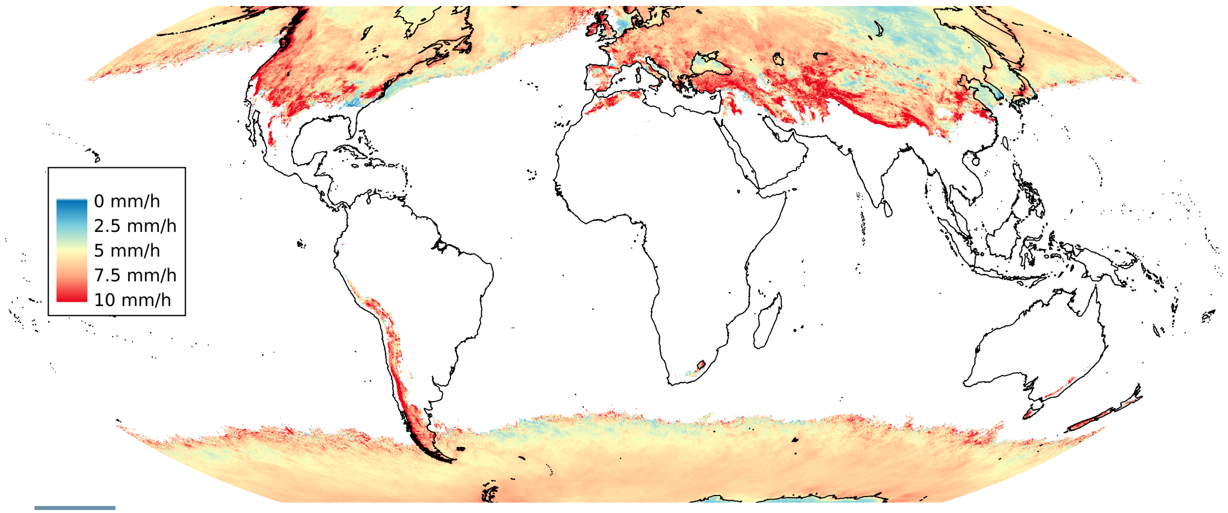
(in preparation for EUMETSAT H SAF EPS-SG day-1 precipitation product)

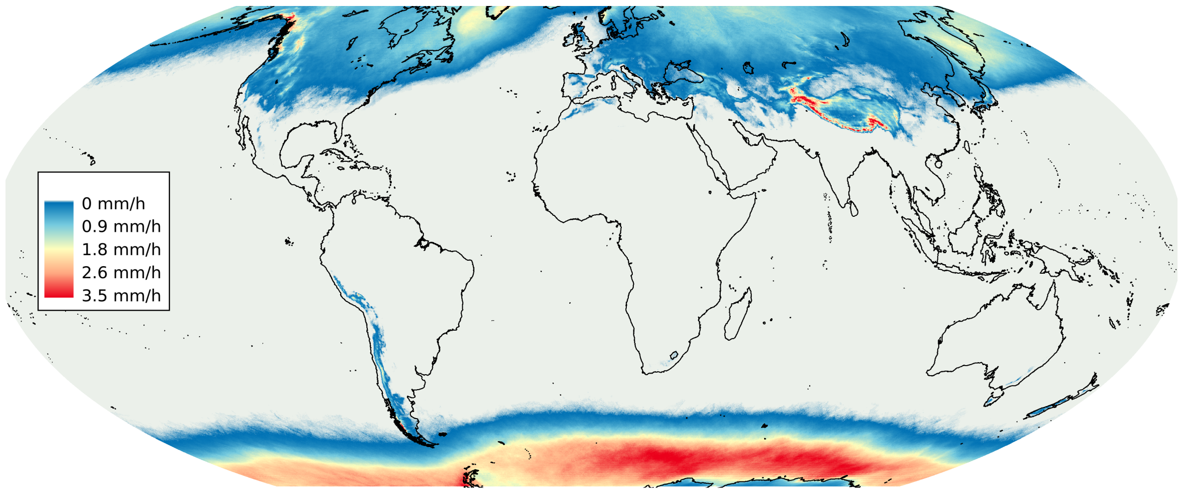
SLALOM main limitations:

- **SLALOM fully relies on the 2C-SNOW-PROFILE CPR product (V04);**
- GMI/CPR observations mostly occur around 60°N/S;
- Overestimation lower snowfall rates (< 0.1 mm/h) (sensitivity issues) and **underestimation of higher rates (not well represented in the training dataset)**



Conditioned (SSR > 0 mm/h) **Mean SSR (mm/h) between May 2014 and May 2017** **Unconditioned**

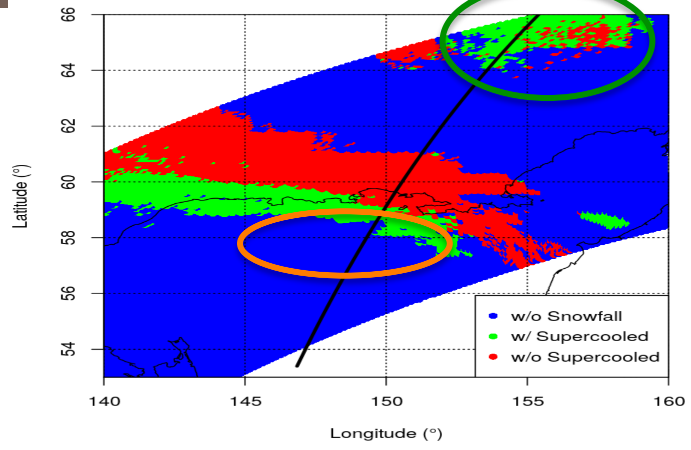


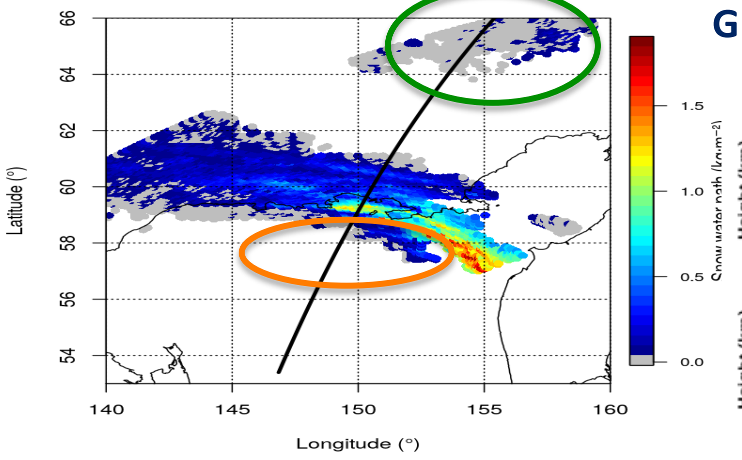


(Rysman et al., 2018,2019)

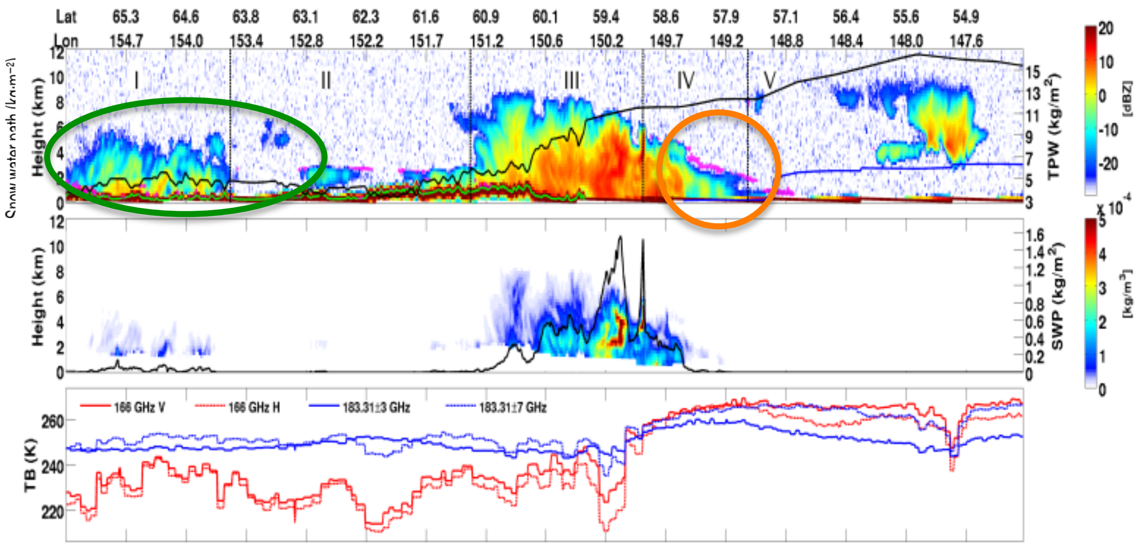
SLALOM: CloudSat-based PMW snowfall retrieval

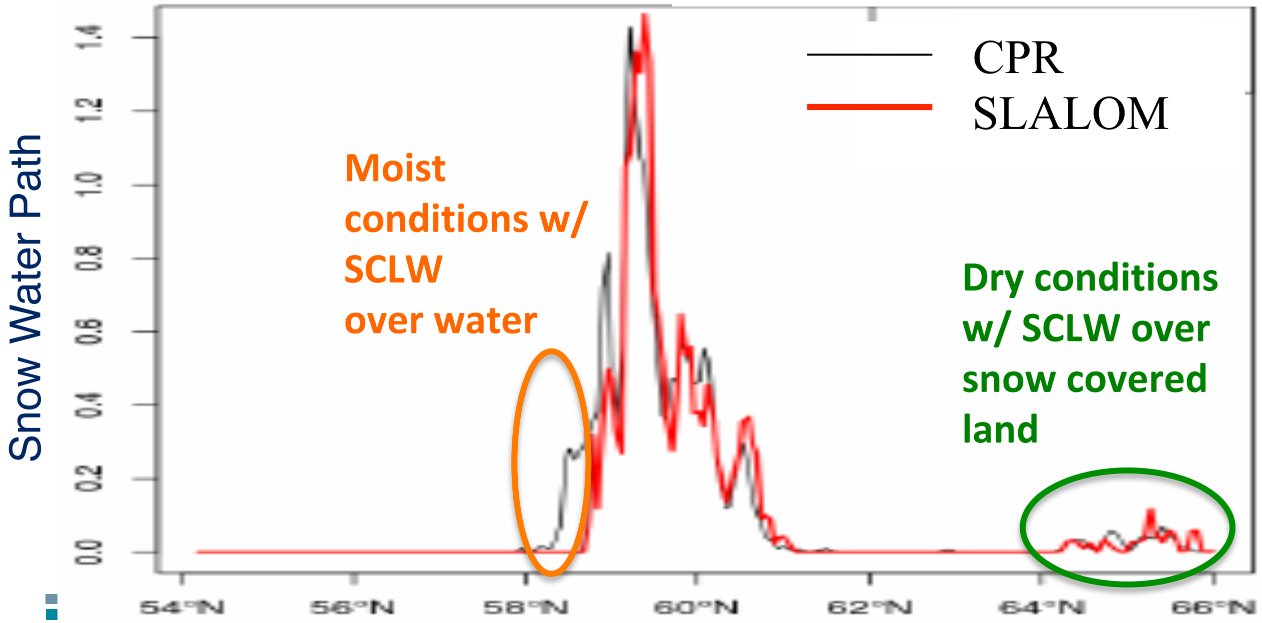
(in preparation for EUMETSAT H SAF EPS-SG day-1 precipitation product)





GMI/CloudSat co-located observations Siberia 30 April 2014





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

SLALOM misses snowfall in moister conditions over ocean (scattering signal masked by WV emission)

SLALOM matches the SWP in drier conditions over snow-covered land

(Rysman et al., 2018,2019)

4-year SLALOM and GPM products validation over CONUS

Ground-based radar reference data

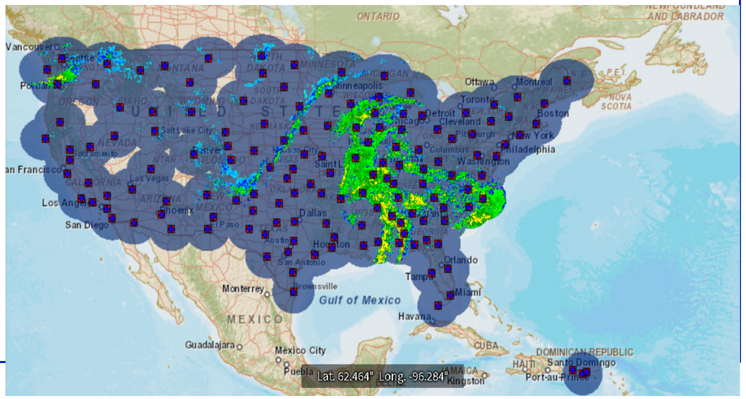
MRMS: Multi-radar-multi-sensor (*Zhang, et al. 2011, Zhang, et al. 2016; Tang et al. 2020*) https://blog.nssl.noaa.gov/mrms/

- ***Products***: Cartesian gridded level II and III radar products over US and Canada
- ***Resolution***: 1 x 1 km horizontal, 2 min time sampling

Variables considered:

- Instantaneous precipitation rate (*S*)
- Radar quality index (RQI)
- Phase precipitation flag

- ***Statistical analysis: 4 year dataset from Jan 2016 to March 2020***



Satellite Snowfall products

SLALOM for GMI

NASA GPM products (GMI and DPR):

GPROF V05 for GMI (NASA GPM)

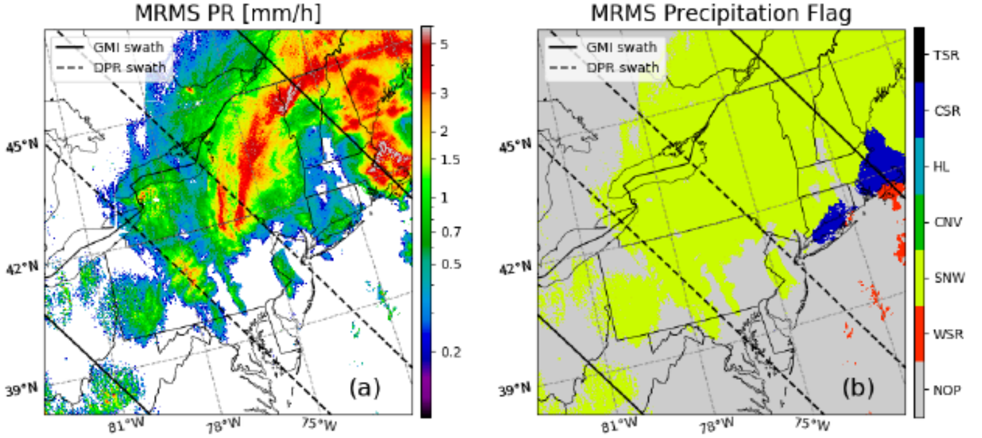
DPR, Ku, Ka V06 (NASA GPM)

CORRA (2B-CMB) V06 (NASA GPM)

CloudSat CPR product

2C-SNOW-PROFILE (NASA)

Snowfall event 14 March 2017 20:02 UTC



(Mroz et al., JHM, 2021)

4-year SLALOM and GPM products validation over CONUS

4-year analysis of snowfall retrieval over all surface types (2016-2020)

Score	GMI SLALOM	GMI GPROF	CPR 2C-SNOW
POD (%)	57.3	28.1	70.0
FAR (%)	26.3	39.6	25.5
HSS (%)	58.7	31.3	68.3
CSI (%)	47.6	23.7	56.4

In SLALOM the exploitation of low frequency channels allows to better constrain the snowfall retrieval (based on high frequency channels) over all surfaces

Sea ice

Snow cover

Surface type	HSS (%)		POD (%)		FAR (%)		no. of MRMS pixels	
	SLALOM	GPROF	SLALOM	GPROF	SLALOM	GPROF	"no-snow"	"snow"
Ocean	46.1	18.9	49.5	22.7	24.8	39.5	66219	30940
Sea-Ice	54.4	15.2	59.0	12.3	37.6	48.6	93201	15158
Maximum Vegetation	57.1	31.3	49.1	21.3	18.9	9.1	799283	113169
High Vegetation	54.6	31.3	45.1	21.0	19.2	11.2	1381112	154952
Moderate Vegetation	56.2	28.8	45.8	18.8	16.1	7.5	473357	51387
Low Vegetation	60.6	32.3	50.2	21.7	16.3	16.5	24855	2007
Minimal Vegetation	63.4	24.4	53.0	16.9	12.4	30.3	8109	857
Maximum Snow	58.0	14.0	68.5	26.8	41.7	77.8	309380	38151
Moderate Snow	58.8	30.5	63.0	33.1	33.1	52.3	1641016	291043
Low Snow	60.5	28.2	63.9	29.6	30.9	51.7	1404417	258627
Minimal Snow	61.2	37.3	61.0	33.9	24.0	32.4	3448465	798754
Standing Water and Rivers	53.8	30.5	45.1	21.5	17.1	13.7	203484	33633
Water/Land Coast Boundary	49.4	19.0	45.9	14.1	20.7	12.9	731055	225411
Water/Ice Boundary	54.1	12.3	54.0	8.4	27.1	11.1	80445	20491

(sfc classes are based on GPROF surface classification)

(Mroz et al., JHM, 2021)

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PESCA

Passive microwave Empirical cold Surface Classification Algorithm

The microwave signal related to snowfall is strongly influenced by the **extremely variable frozen surface conditions**. Need to characterize background surface radiative properties at the time of the satellite overpass to better constrain snowfall retrieval

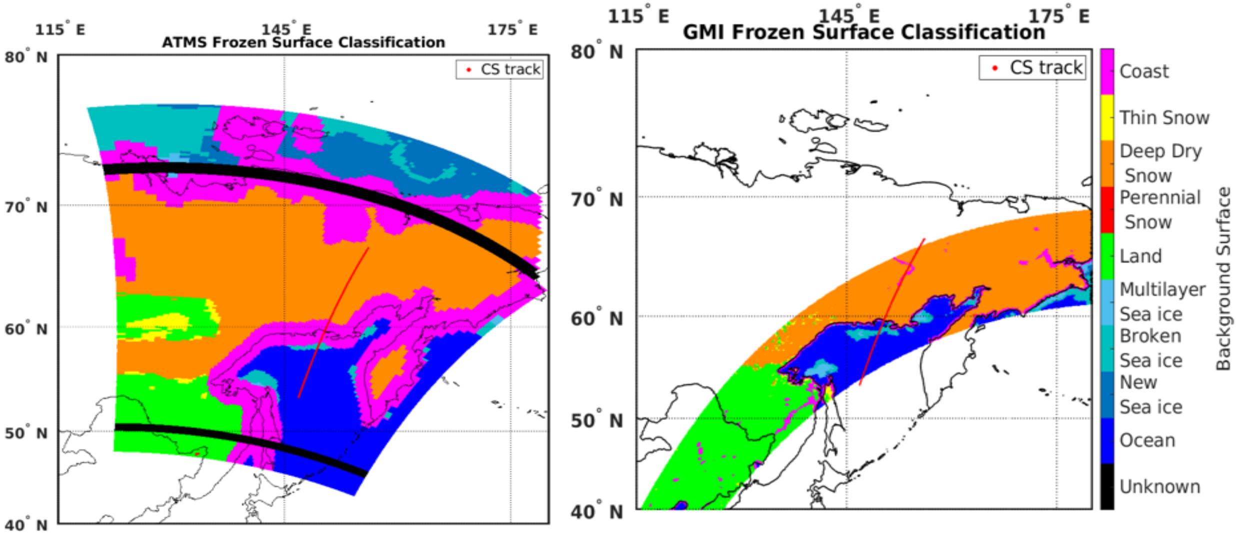
PESCA has been developed for ATMS and GMI

Empirically-based algorithm for frozen background surface characterization (different types of sea ice and snow cover)

- **Use of low-frequency (<= 90 GHz) channels common to most radiometers**
- Environmental conditions: dry (TPW < 10 mm), low elevation (DEM < 2500 m); T2m < 280 K
- Applicable to both cross-track and conically scanning spaceborne microwave radiometers (including EPS-SG MWS and MWI)

Siberia 30 April 2014

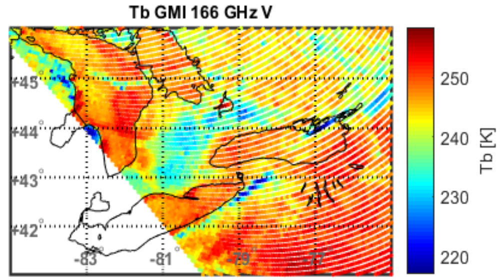
ATMS-based GMI-based

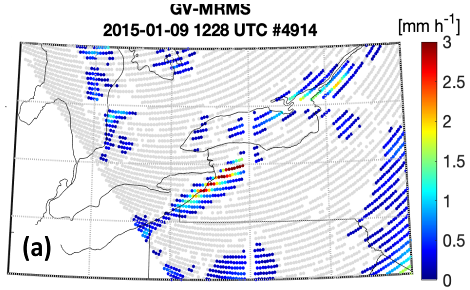


(Camplani et al., JHM, 2021)

PESCA: Snowfall vs. background surface

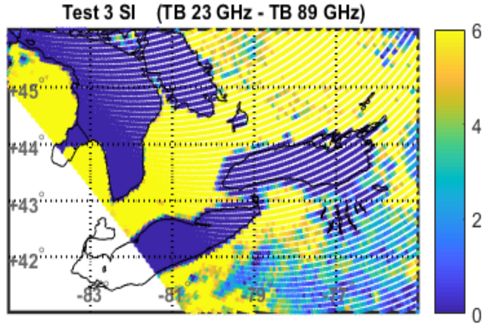
GMI 9 January 2015 at 12:26 UTC

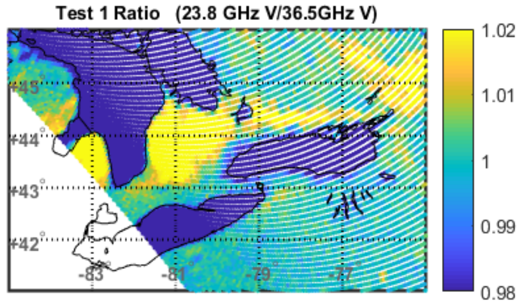


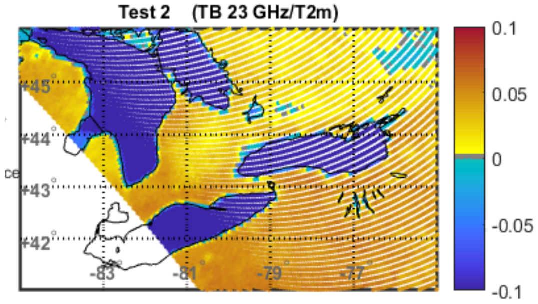


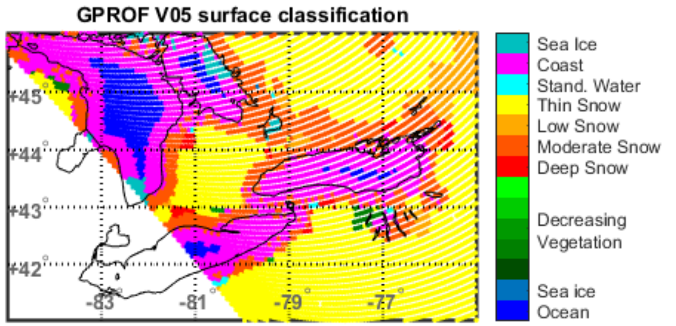
Extreme Lake Effect Snow event on (Milani et al., JHM, 2020)

Low-frequency channels combinations are used in PESCA to identify different types of sea ice and snow cover with distinct radiative properties

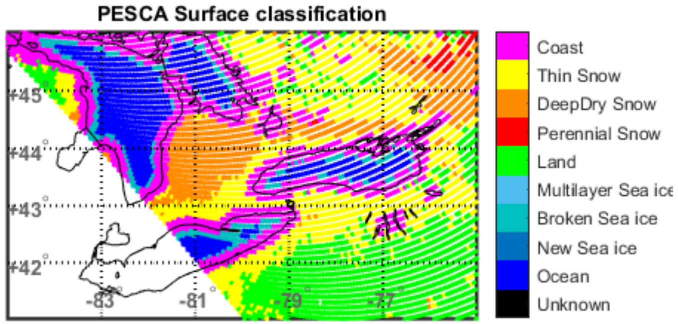




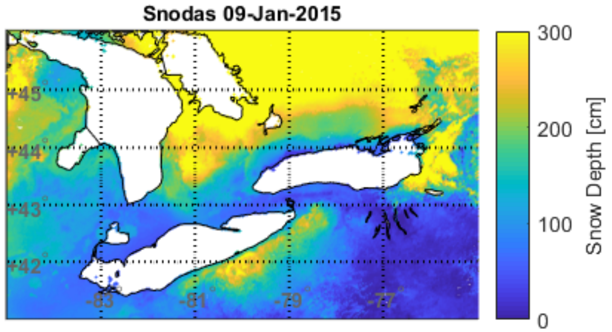




GPROF classification based on climatological and daily snow cover product



PESCA classification at the time of the GPM overpass.



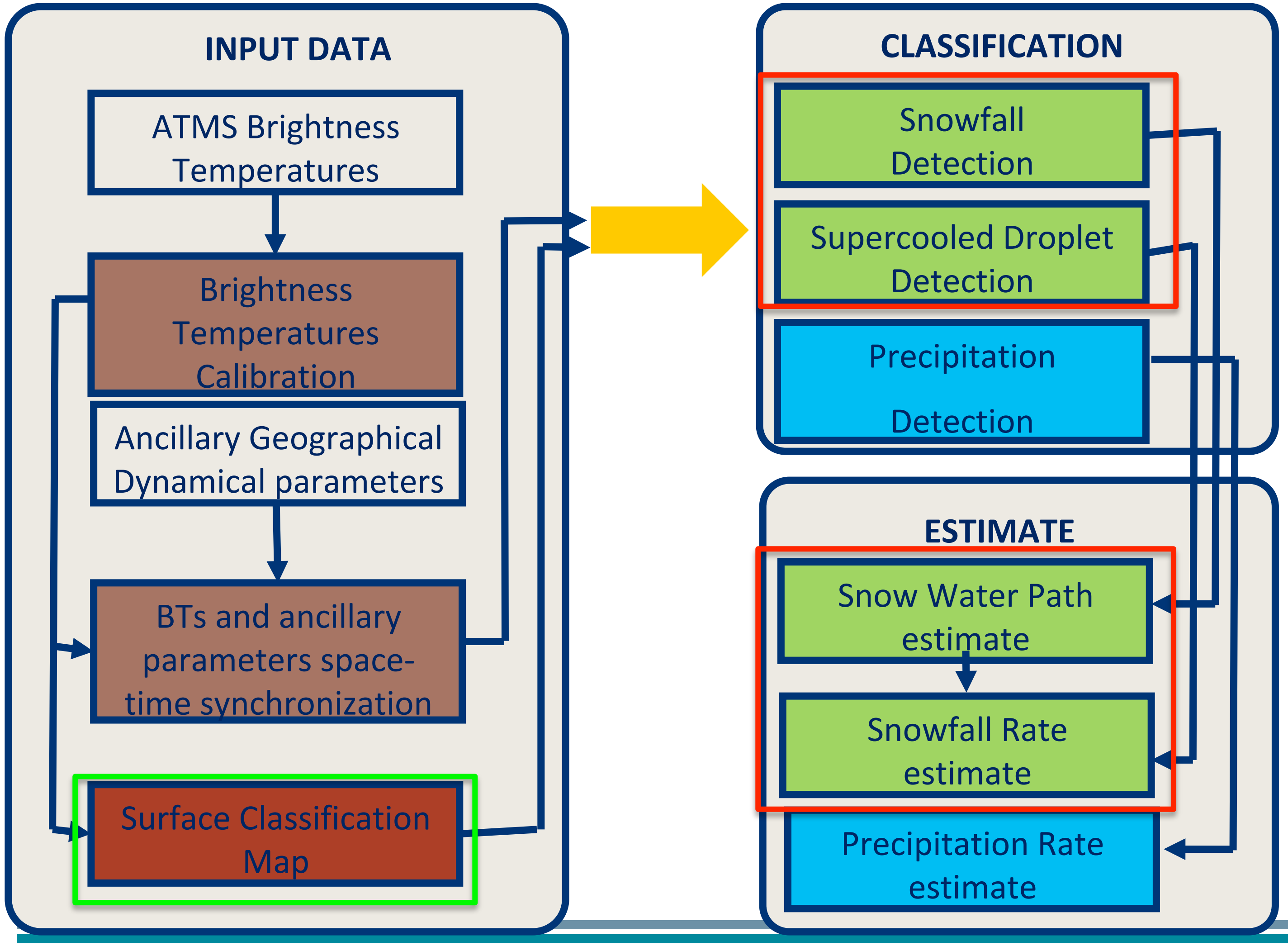
Snow Depth from NOAA NOHRSC SNOw Data Assimilation System (SNODAS) https://nsidc.org/data/g02158

Turk et al., JHM, 2021

EUMETSAT H SAF

Outlook to EPS-SG mission: H SAF Level 2 precipitation products

MWS and MWI day-1 Level 2 Precipitation rate products



ML apporach (SLALOM-based)

PESCA-based

MetOp-SG-A (MWS) Q1 2024
MetOp-SG-B (MWI/ICI) Q1 2025

Day-1 precipitation products expected operational after EPS-SG commissioning phase

Observational training dataset built from global coincident measurements of existing PMW radiometers (ATMS for MWS) with GPM DPR (2B-CMB V06) and CloudSat CPR 2C-SNOW

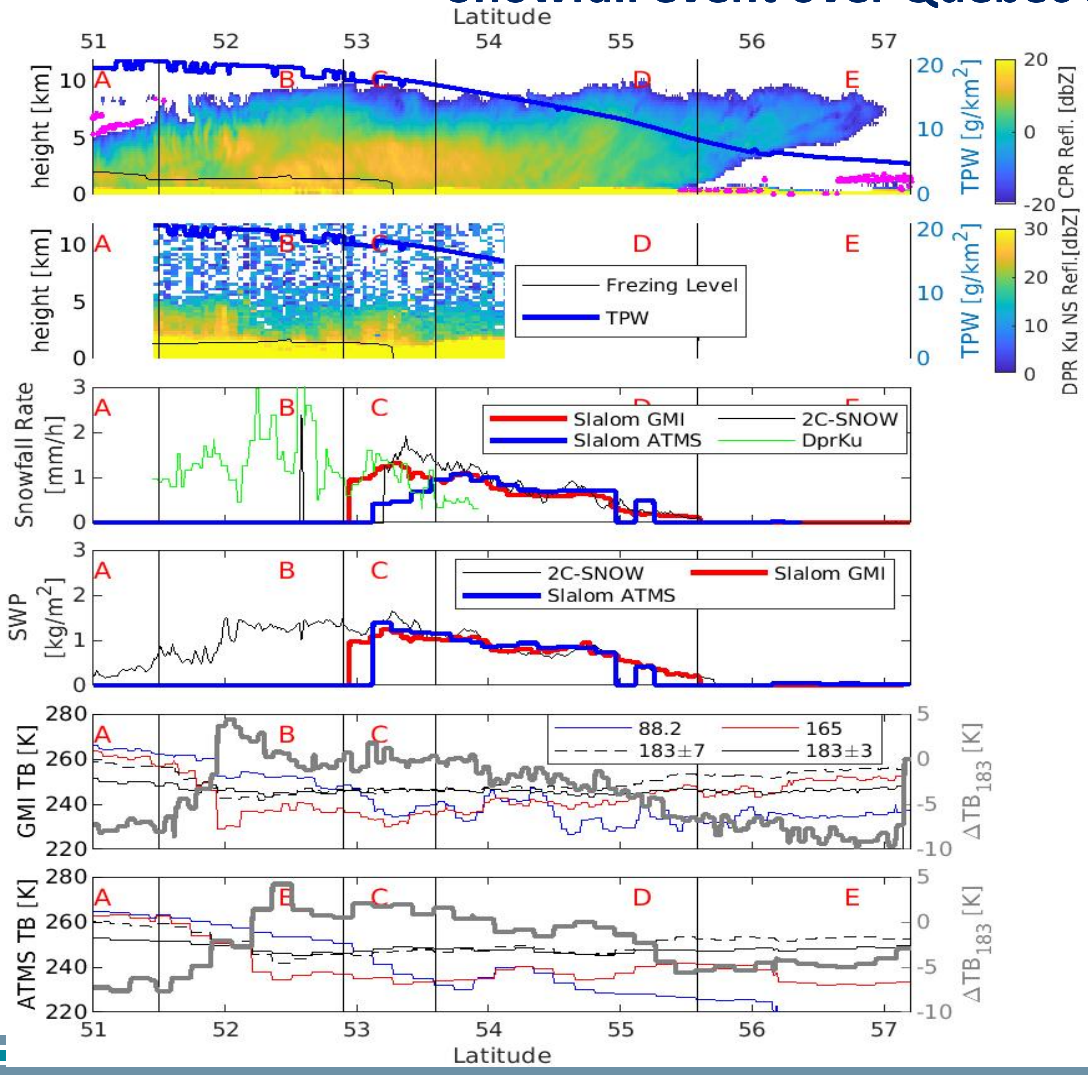
Day-2 EPS-SG products to be developed during H SAF CDOP-4 (2022-2027)

Next Presentation by D. Casella (CNR-ISAC)

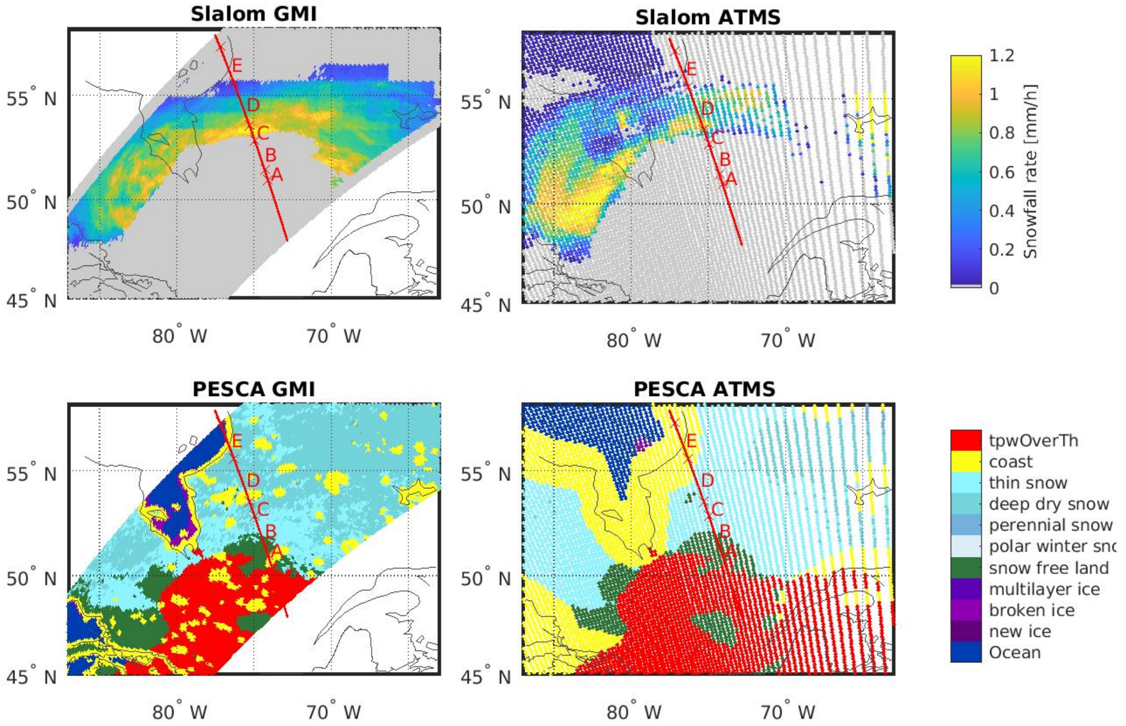
SLALOM and PESCA for ATMS and GMI

(in preparation for EUMETSAT H SAF EPS-SG precipitation products)

Snowfall event over Quebec and Ontario on 24 November 2014



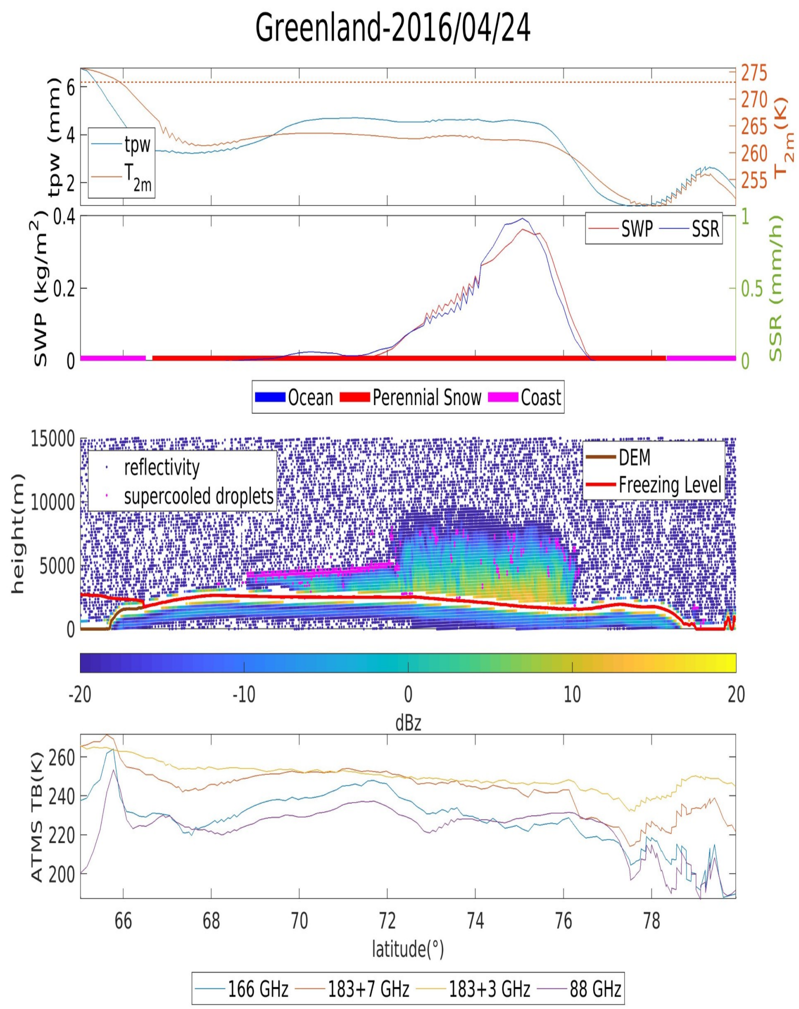
SLALOM: ML-based approach using low frequency channels for background surface characterization at the time of the overpass



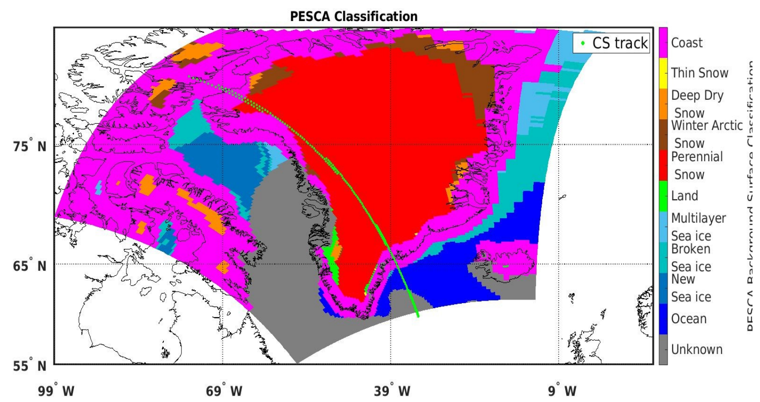
Turk et al., 2021, Rem. Sens.

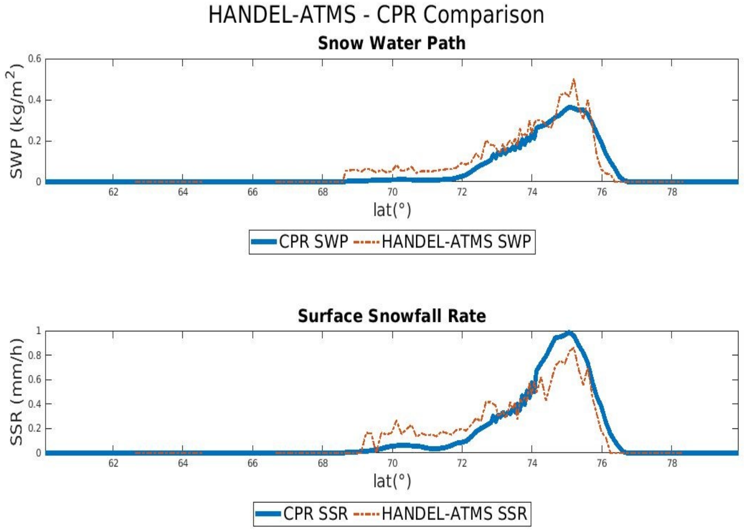
ATMS snowfall retrieval algorithm for High Latitudes (HANDEL)

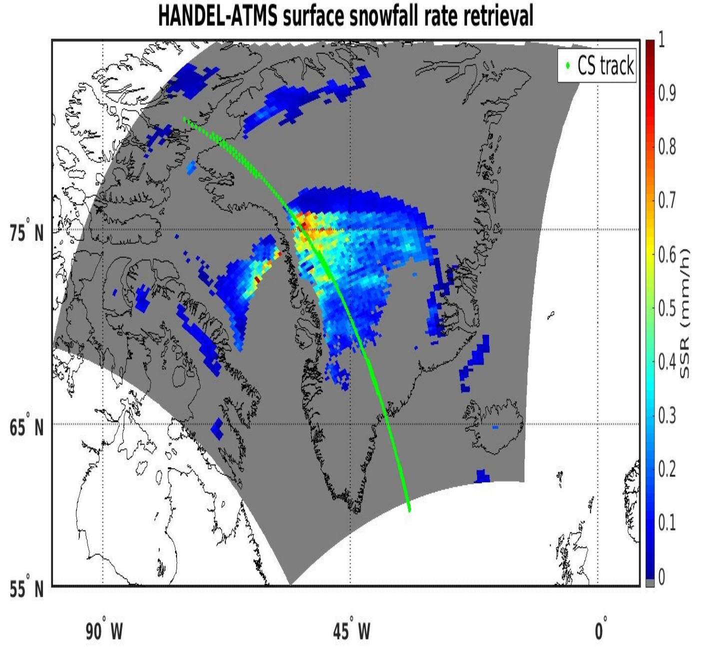
(in preparation for EUMETSAT H SAF EPS-SG precipitation products)



PESCA Surface Classification







Global validation against CPR 2C-SNOW

	RMSE	bias	POD	FAR
SWP	0.047	0.001	0.85	0.15
SSR	0.079	0.002	0.84	0.17

Conclusions and future perspectives

- **Detection and quantification of global snowfall must rely on PMW observations: very complex problem**
- **Paramount role of cloud/precipitation radars as calibrators for PMW snowfall detection/retrieval algorithms (fundamental at higher latitudes)**
- **Demonstrated benefits of using CloudSat/Calipso-based Machine Learning approach (mostly for higher latitudes) *exploiting all channels to better constrain environmental conditions*;**
    - *Crucial role of EarthCare CPR (W-band) (two year timeframe) and NASA ACCP radar (Ka and W band) (6-years time frame*
- **Low frequency channels can be used to correctly interpret background signal and better constrain snowfall detection and quantification**
- **Several challenges related to snowfall quantification are being addressed within H SAF towards the development of global Level 2 PMW products including EPS-SG day-1 and day-2 products foreseen in the next CDOP-4 (2022-2027)**
    - Multi-platform approach when low frequency channels are not available
    - Synergy of Copernicus Imaging Microwave Radiometer (CIMR) and EPS-SG for high latitude precipitation will be investigated

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