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TAKING THE PULSE
OF OUR PLANET FROM SPACE

The ESA RainCast Study For Global Snowfall Monitoring: New Concepts And Perspectives in view of the Arctic Weather Satellite mission

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PMW Remote Sensing of Snowfall: Challenges and synergistic approach

Detection and quantification of snowfall by passive microwave observations remains among the most challenging tasks in global precipitation retrieval

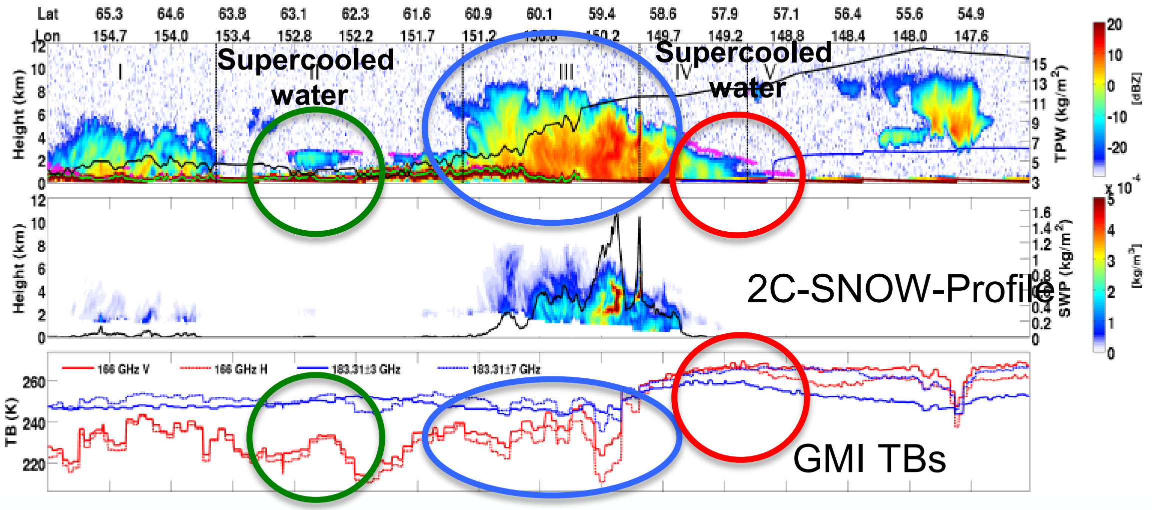
Challenges:

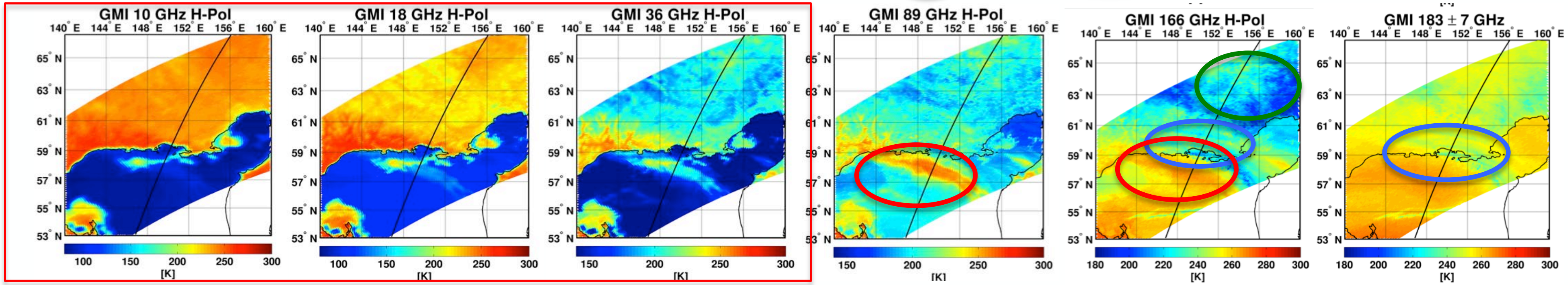
The *PMW spectral signature in presence of snowfall* is highly dependent on the complex scattering properties of snowfall

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

Sea ice and snow-covered land surface emissivity is extremely variable *due to rapid changes of sea ice properties of snow cover extent, snow accumulation on the ground, and snowpack and sea ice physical properties.*

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





Mostly affected by bakground sfc (and liquid precipitation emission over sea)

Panegrossi et al. 2017 Rem. Sens.

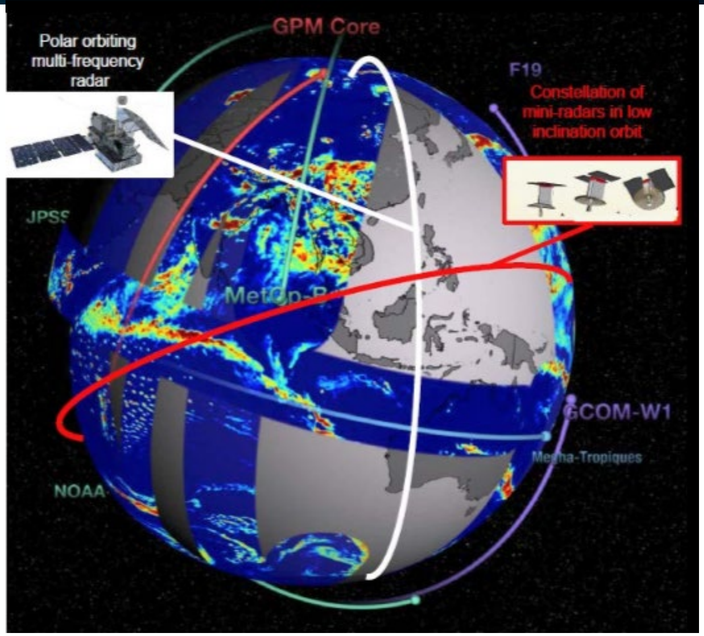
RainCast – Scientific Evaluation of Future Atmospheric Mission Concepts to Monitor Precipitation

(in response to ESA ITT TT 1-9324/18/NL/NA)

The study aims at identifying and consolidating the science requirements for a **European precipitation satellite mission** that could complement the existing space-based precipitation observing system

(fits the purposes of Earth Observation Science for Society https://eo4society.esa.int)

Phase 1 Closed on May 2021



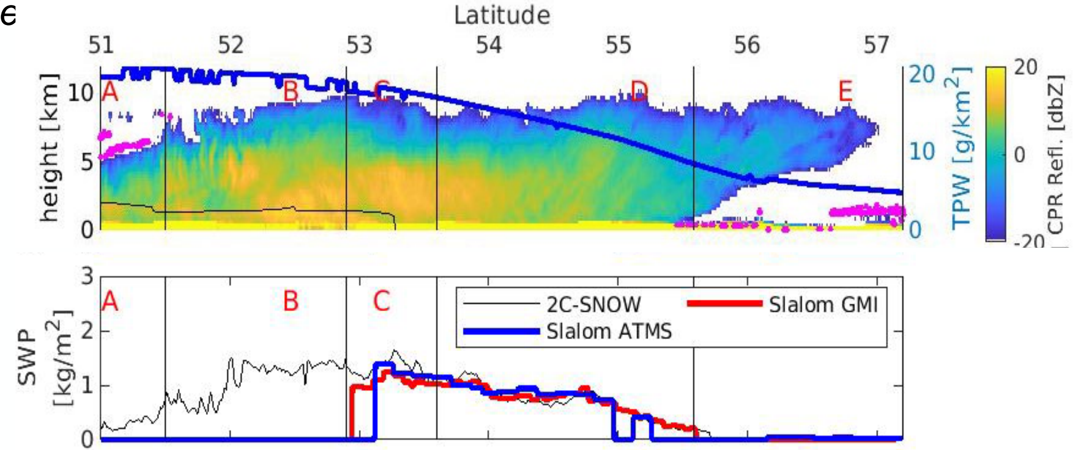
GOAL (WP3200)

Assessment of snowfall observation capability of spaceborne active and passive sensors

We focused on
***CloudSat CPR** and the two most advanced microwave radiometers currently available*
***GMI** (conically scanning) and **ATMS** (cross-track scanning)*
(in view of MWI and MWS for EPS-SG mission)

SLALOM (GMI)
SLALOM-CT (ATMS)

Algorithms for snowfall retrieval from PMW
- Based on ML
- Based on Observational data (Coincident CPR –Radiometer OBS.)



Turk et al. 2021 Rem. Sens.

SLALOM-CT Snow retrievaL ALgorithm fOr gpM – Cross Track

ATMS channels
23.8 GHz
31.4 GHz
13 Ch, in 50- 60 GHz
89.5 GHz
165.5 GHz
5 ch at 183.31 GHz

- Brightness Temperatures
- NWP Model Derived Variables
- Surface Characterization

CLASSIFICATION

Snowfall Detection

Supercooled Droplet Detection

ESTIMATE

Snow Water Path estimate

Snowfall Rate estimate

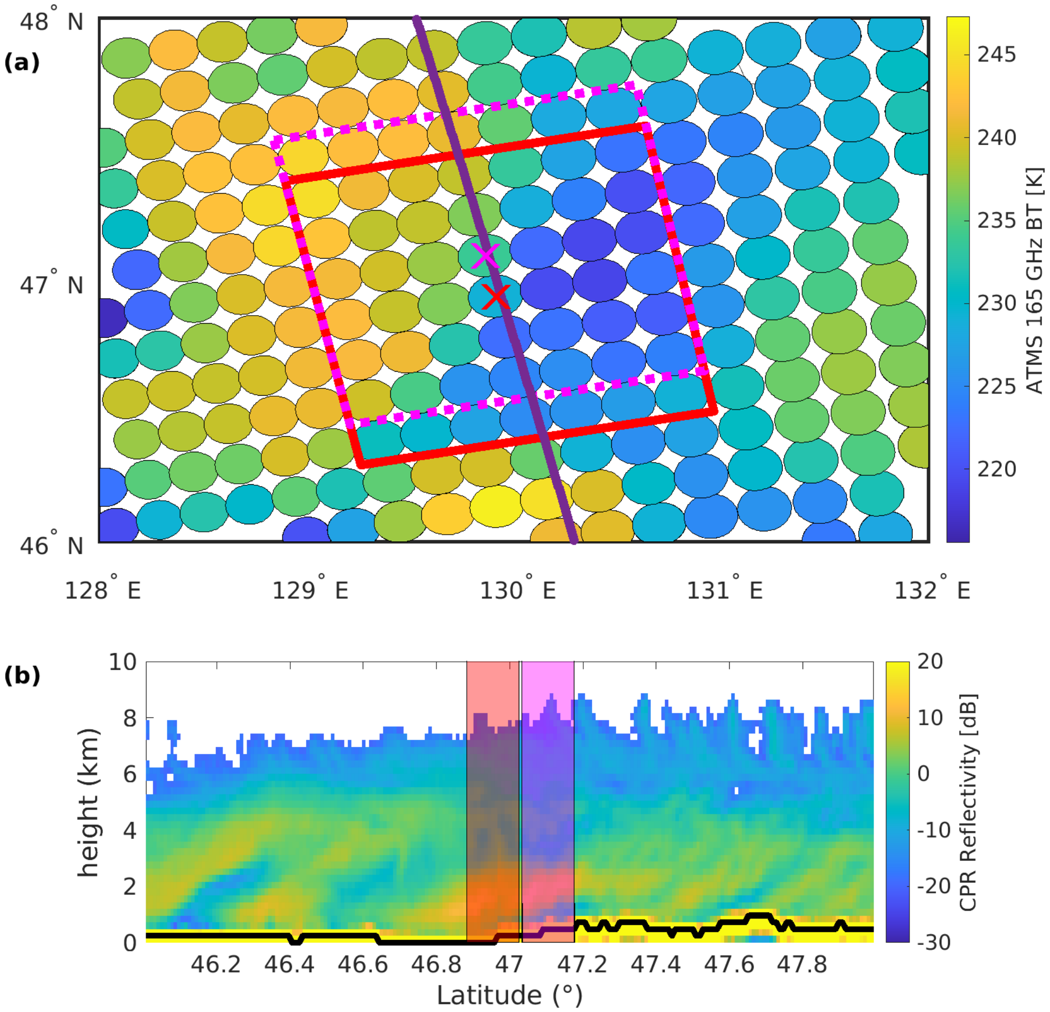
- **Shallow Neural Network** → Pixel Based
- **Convolutional Deep Neural Network** → Image Based

Sanò et al. 2021 Rem. Sens.

SLALOM-CT: Coincidence dataset

Period	**16/01/2014 – 31/08/2016**
Geographical area	82°S–82°N, 180°W–180°E
Number of database points	6.5 M
Number of database points with snowfall	1.1 M
Horizontal resolution (Km)	15.8 x 15.8 (nadir) 30 x 68.4 (scan edge)

INPUT Variables	**Data source**
ATMS BTs	NOAA
ATMS Scan angle	
Temperature @ 2m	ECMWF
Total column integrated water vapor	
Freezing level Height	
Temperature profile	
Relative humidity profile	
Absolute humidity profile	
REFERENCE	**Data source**
Supercooled Droplet	DARDAR (raDAR/liDAR) LATMOS-Reading Univ.
Snowfall Rate	2C-SNOW-PROFILE (CPR product)
Snow Water Path	2C-SNOW-PROFILE (CPR product)



SLALOM-CT: Cold Surfaces Characterization

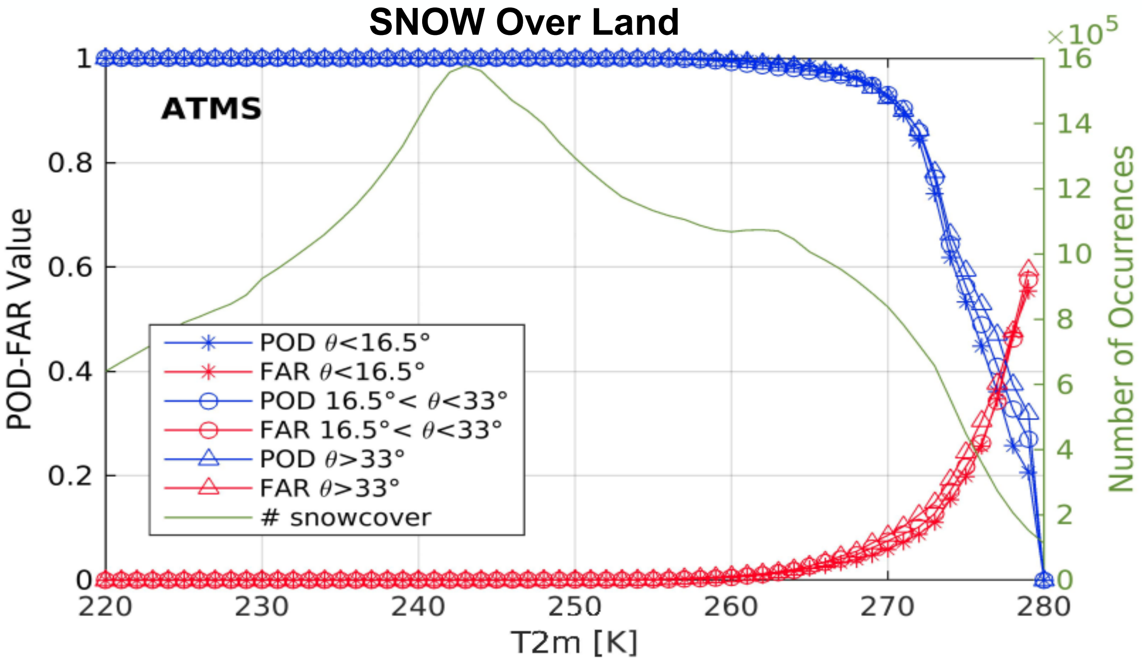
Passive Microwave Empirical Cold Surfaces Classification Algorithm (**PESCA**)

Characterization of surface emissivity is supposed to be very important for snowfall estimate

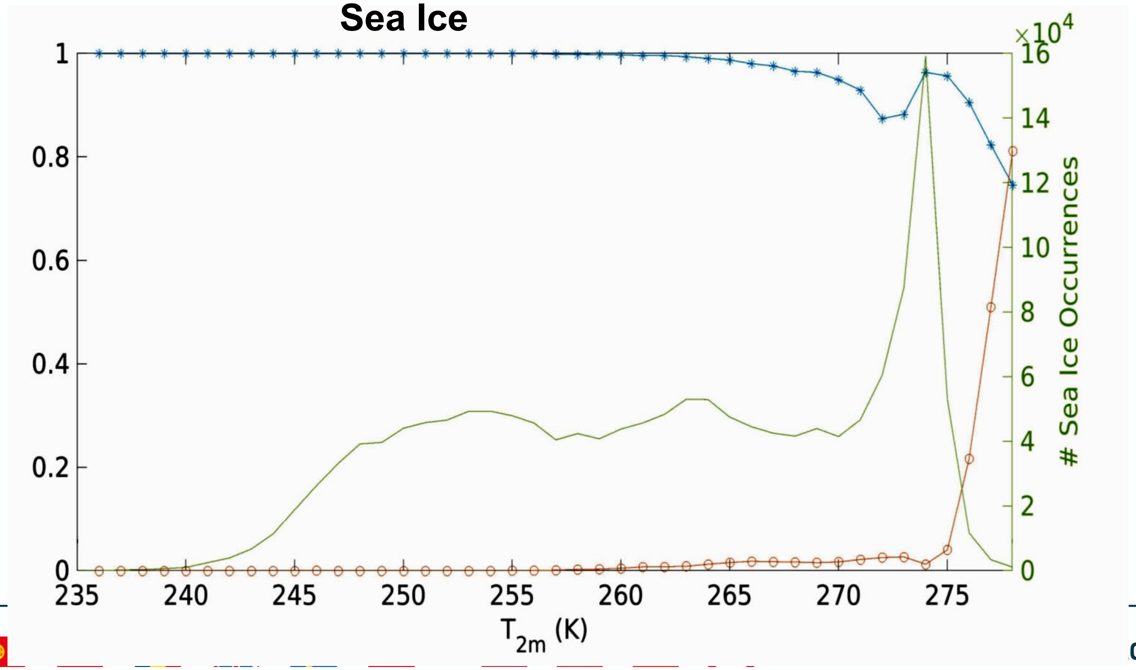
variable emissivity and light signals

PESCA algorithm identifies 4 classes of **Snow over Land** and 3 classes of **Sea Ice**
- at the time of the MW overpass
- using low frequency channels (almost unsensitive to ice clouds)
- Applicable to both Cross Track (ATMS) and Conically Scanning (GMI)

Camplani et al. 2021 *Journal of Hydromet.*



SNOW Over Land

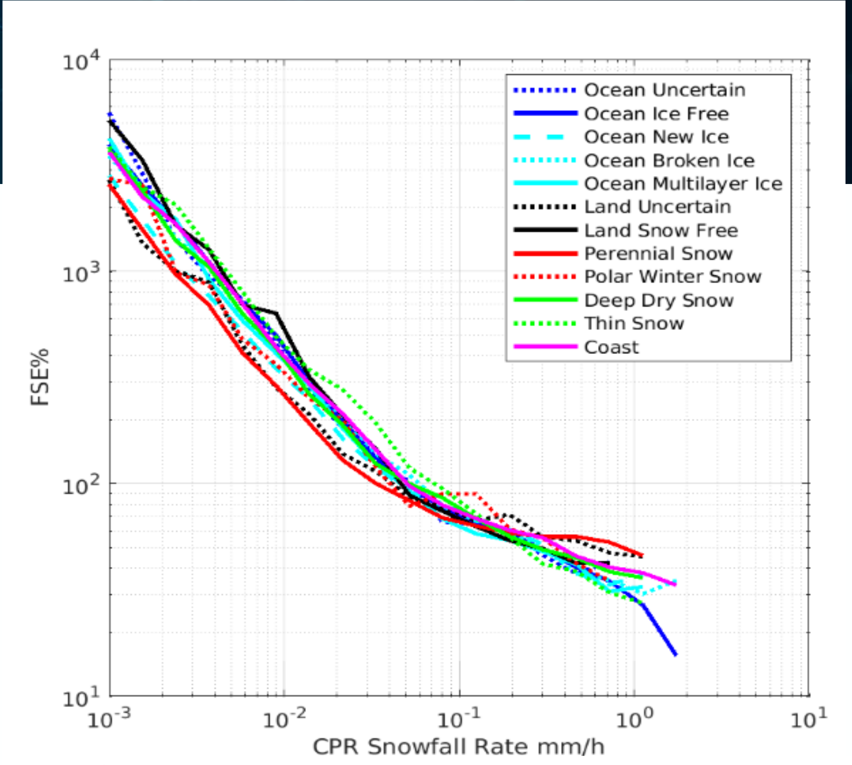


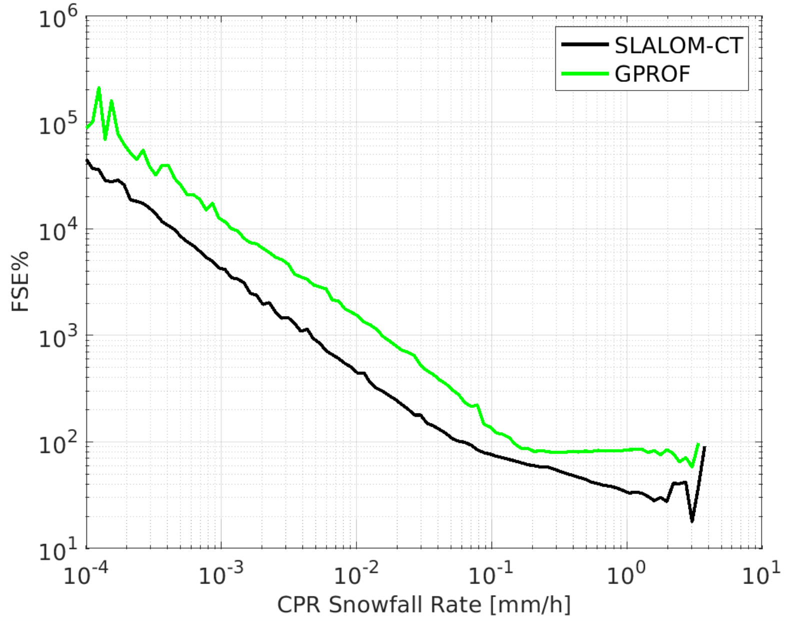
Sea Ice

SLALOM-CT: Comparison with GPROF

- Almost insensitive to surface
- Detection capabilities largely better than GPROF
- Very accurate Estimates (compared to GPROF, using CPR as reference)

Surface	SNOW		Ocean		Land	
	GPROF	SLALOM-CT	GPROF	SLALOM-CT	GPROF	SLALOM-CT
RMSE [mm/h]	0.18	0.10	0.24	0.09	0.24	0.10
ME [mm/h]	0.006	0.002	-0.006	-0.002	0.090	-0.01
Corr	0.55	0.80	0.04	0.84	0.47	0.79
POD	0.20	0.76	0.28	0.86	0.23	0.80
FAR	0.55	0.22	0.44	0.15	0.39	0.22
HSS	0.05	0.63	0.03	0.68	0.21	0.71





RainCast Phase 1 Final Recommendations

- PMW products benefit from calibration/training by spaceborne radars:
  - Demonstrated benefits of using CloudSat/Calipso-based Machine Learning SLALOM approach (mostly for higher latitudes) -> **Key role of EarthCare mission and NASA ACCP Radar**
  - **G-band** radar can assist both in water vapour sounding and in cloud microphysics characterization.

- **Frequency range**: 19 to 190 GHz available in most advanced PMW radiometers (e.g., EPS-SG):
  - 150-166 GHz highly recommended-> **Key role for shallow snowfall**
  - The full spectrum of T and WV sounding is needed -> **Definition of environmental conditions (T, WV)**
  - Lower frequency channels -> **characterization of the frozen background surface**
  - 85-90 GHz channels -> **key role in detection of supercooled liquid cloud droplets**

- Conically scanning is preferable (dual pol., high resolution) but only EPS-SG MWI will be available -> **Need to advance research on cross-track scanning radiometer capabilities (ATMS, MWS, AWS)**

RainCast – Phase 2

Offcially Started April 2022 !!

Objectives:

Arctic Weather Satellite (AWS) snowfall retrieval at high latitudes

W-G band Doppler radar for ice/snow retrievals

synergy between G-band radar and high-frequency radiometers.

RainCast – Phase 2

Objectives:

Arctic Weather Satellite (AWS) snowfall retrieval at high latitudes

- impact of the lack of low frequency window channels (< 60 GHz) for snowfall detection capabilities

W-G band Doppler radar for ice/snow retrievals

synergy between G-band radar and high-frequency radiometers.

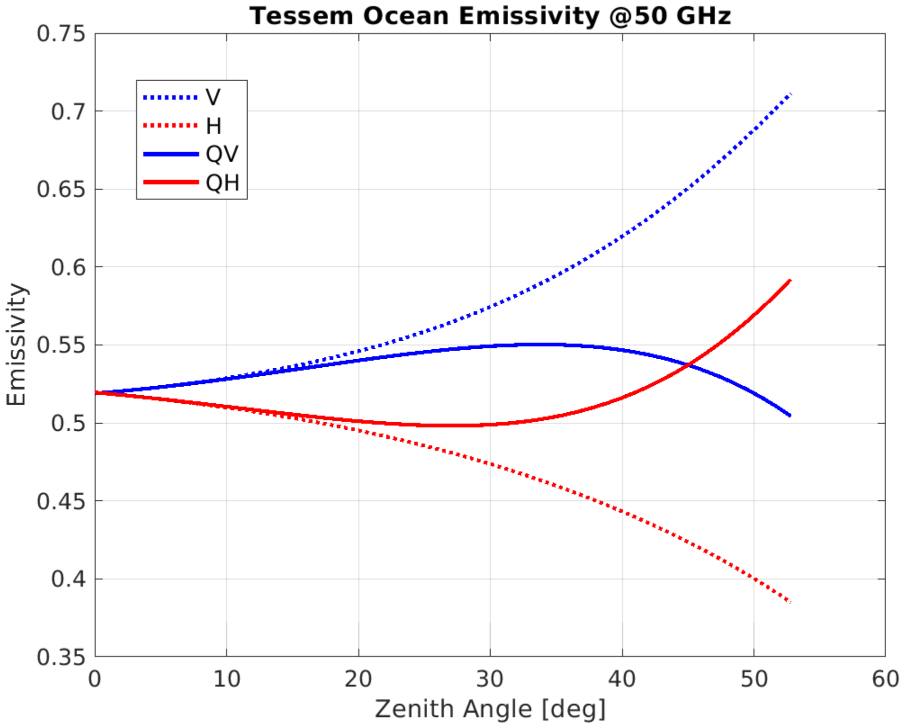
ATMS vs AWS channels

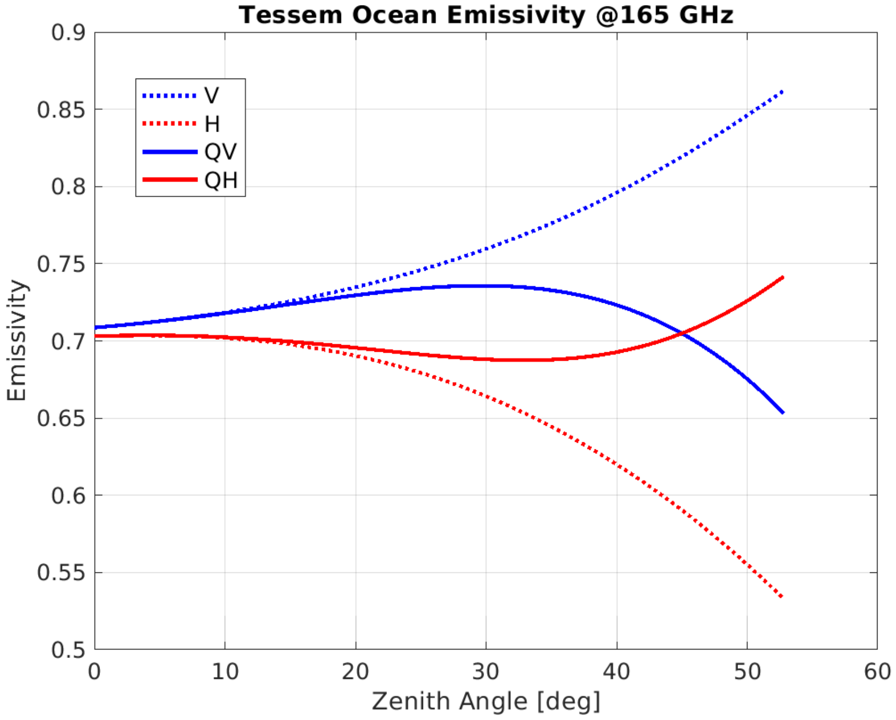
AWS				ATMS		
No.	Central frequency	Polarisation		No.	Central frequency (GHz)	Polarisation
				~~1~~	~~23.8~~	~~QV~~
				~~2~~	~~31.4~~	~~QV~~
1	50.3 GHz	**QV**		3	50.3	**QH**
				4	~~51.76~~	~~QH~~
2	52.8 GHz	**QV**		5	52.8	**QH**
3	53.246 GHz	**QV**		6	53.596 ± 0.115	**QH**
4	~~53.596 GHz~~	~~QV~~				
5	54.4 GHz	**QV**		7	54.4	**QH**
6	54.94 GHz	**QV**		8	54.94	**QH**
7	55.5 GHz	**QV**		9	55.5	**QH**
8	57.29 GHz	**QV**		10	f0 = 57.29	**QH**
				~~11~~	~~f0 ± 0.217~~	~~QH~~
				~~12~~	~~f0 ± 0.3222 ± 0.048~~	~~QH~~
				~~13~~	~~f0 ± 0.3222 ± 0.022~~	~~QH~~
				~~14~~	~~f0 ± 0.3222 ± 0.010~~	~~QH~~
				~~15~~	~~f0 ± 0.3222 ± 0.0045~~	~~QH~~
9	89 GHz	QV		16	89.5	QV
10	165.5 GHz	**QV**		17	165.5	**QH**
11	176.311 GHz	**QV**		18	183.31 ± 7.0	**QH**
12	178.311 GHz	**QV**		19	183.31 ± 4.5	**QH**
13	180.311 GHz	**QV**		20	183.31 ± 3.0	**QH**
14	181.311 GHz	**QV**		21	183.31 ± 1.8	**QH**
15	182.311 GHz	**QV**		22	183.31 ± 1.0	**QH**
~~16~~	~~325.15±1.2 GHz~~	~~QV~~				
~~17~~	~~325.15±2.4 GHz~~	~~QV~~				
~~18~~	~~325.15±4.1 GHz~~	~~QV~~				
~~19~~	~~325.15±6.6 GHz~~	~~QV~~				

Emissivity dependence on scan angle

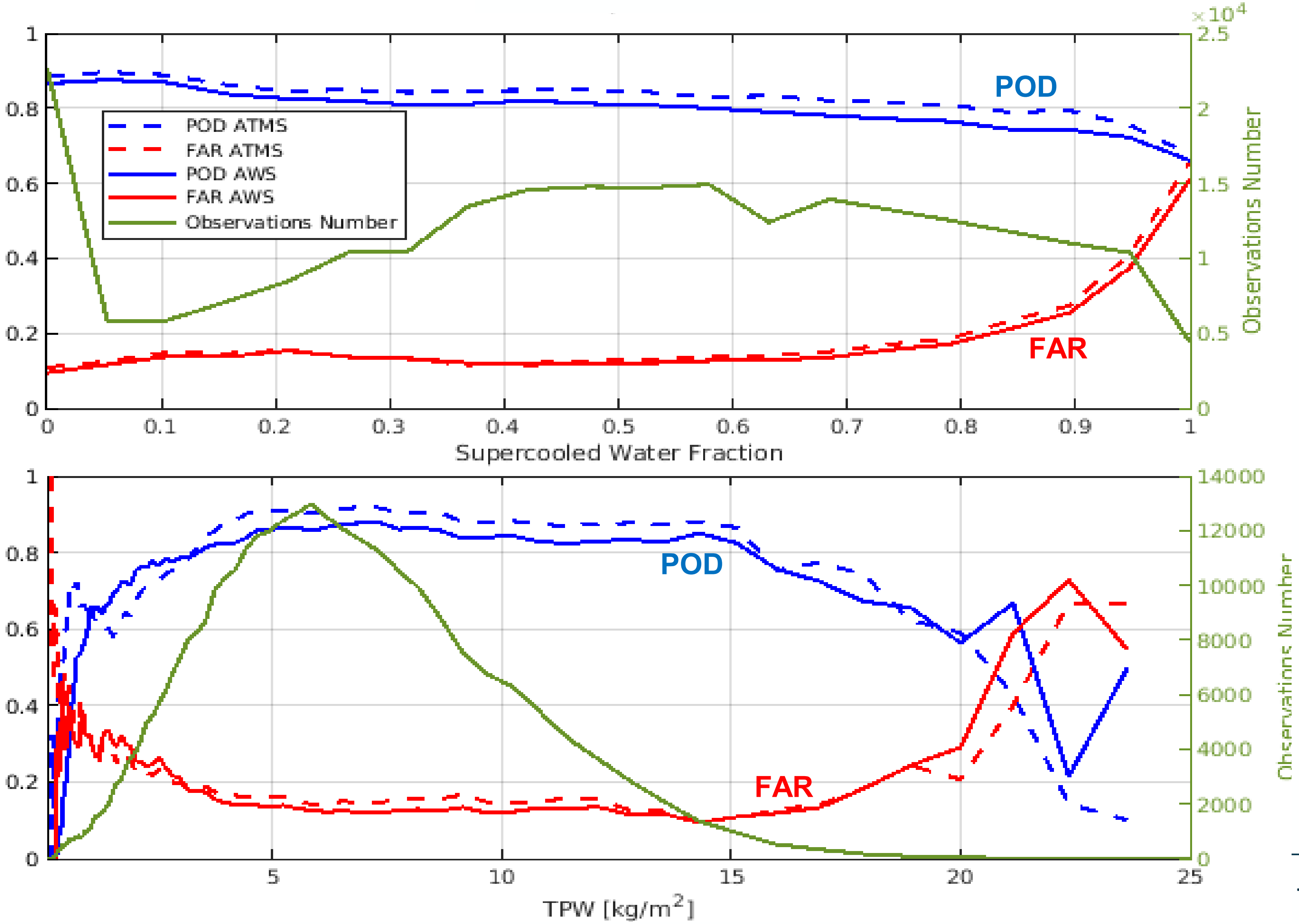
Cross track scanners mixed polarization with scan angle
Expected impact of QV-QH change should be further investigated

$$QV = ev \cdot cos^2(\theta) + eh \cdot sin^2(\theta)$$
$$QH = eh \cdot cos^2(\theta) + ev \cdot sin^2(\theta)$$





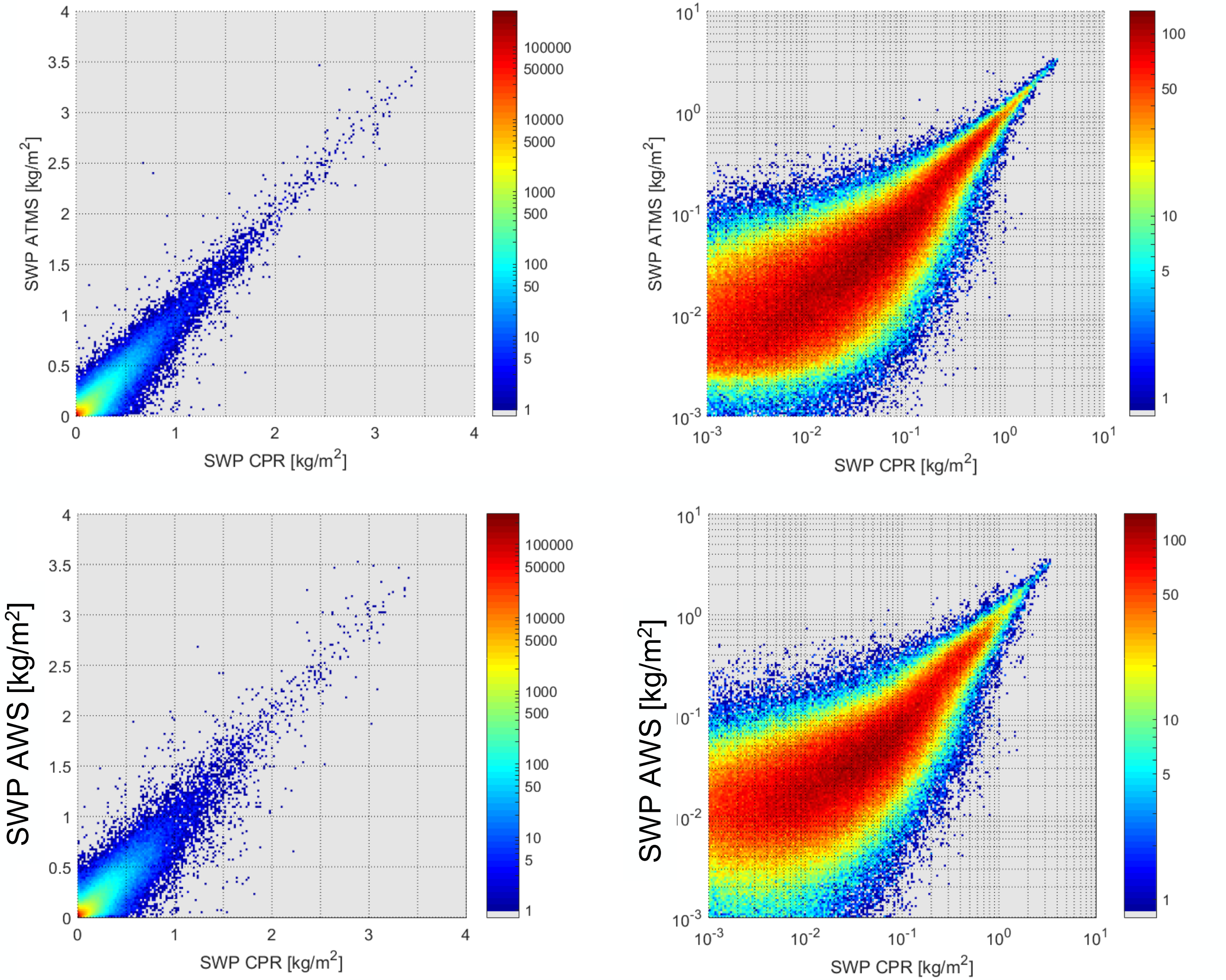
SLALOM-CT Snowfall Detection: AWS and ATMS:



SLALOM-CT SWP Estimate: AWS and ATMS:

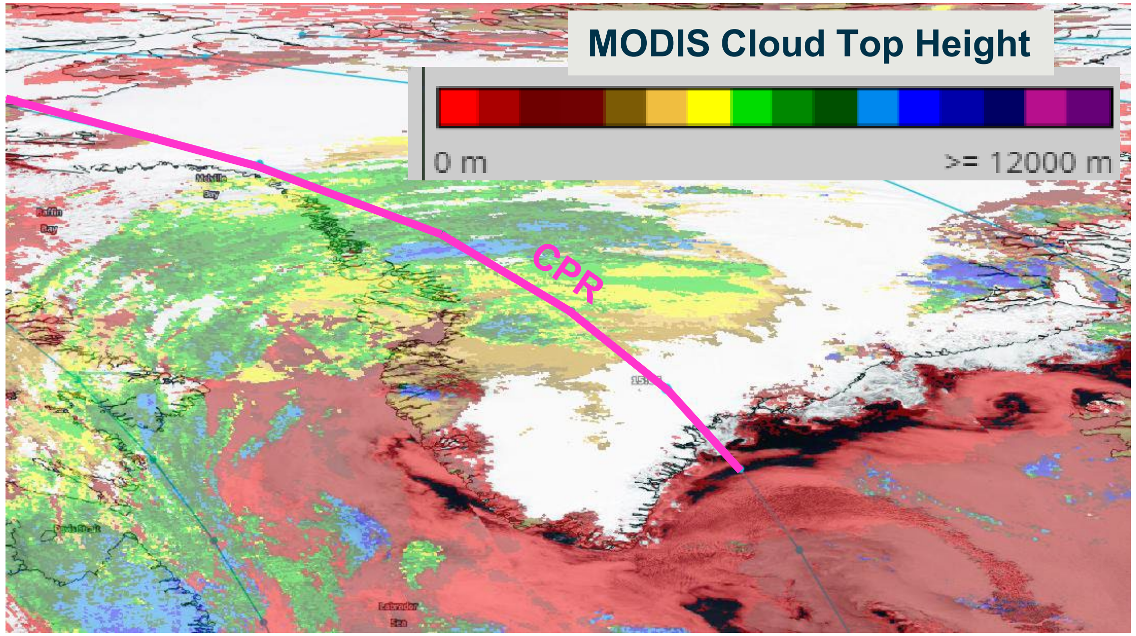
Comparison of SWP
SLALOM-CT (ATMS and AWS) y axis
and CPR x axis
In the test dataset

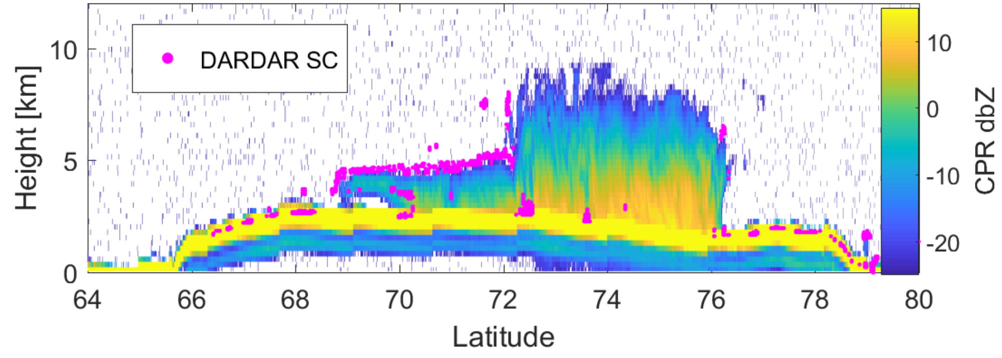
SWP	ATMS	AWS
RMSE [kg/m²]	0.050	0.061
R²	0.86	0.80
ME[kg/m²]	-1.6×10^{-5}	1.3×10^{-4}
CC	0.93	0.90

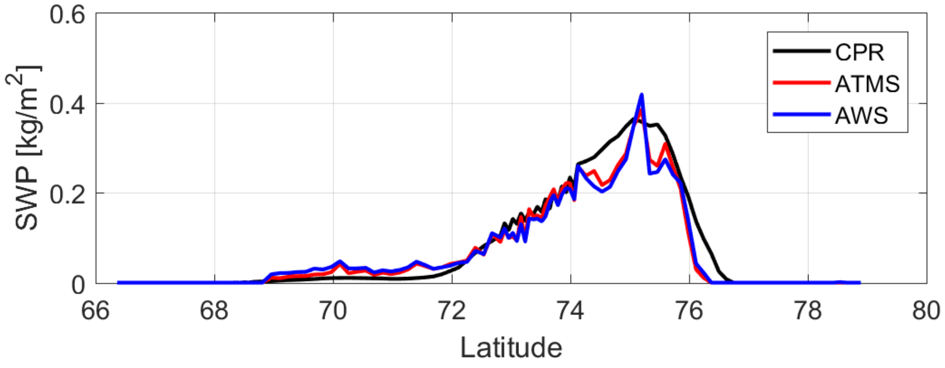


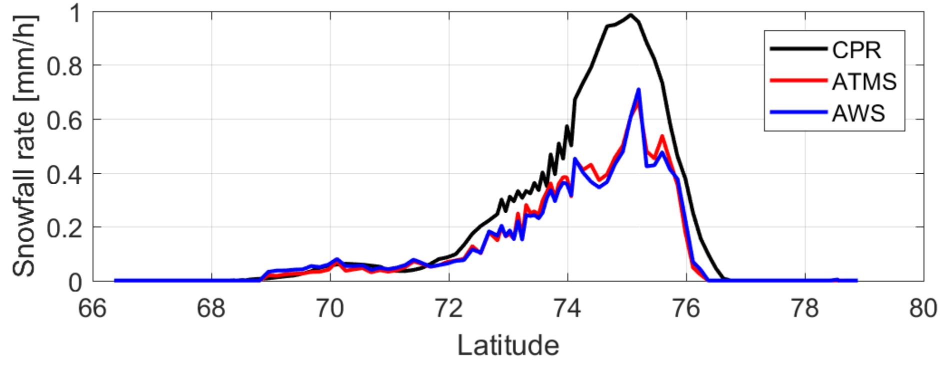
Case Study: Greenland 24 April 2016

Almost a Worst Case Scenario
No sensible impact of low frequency channels









RainCast – Phase 2

Objectives:

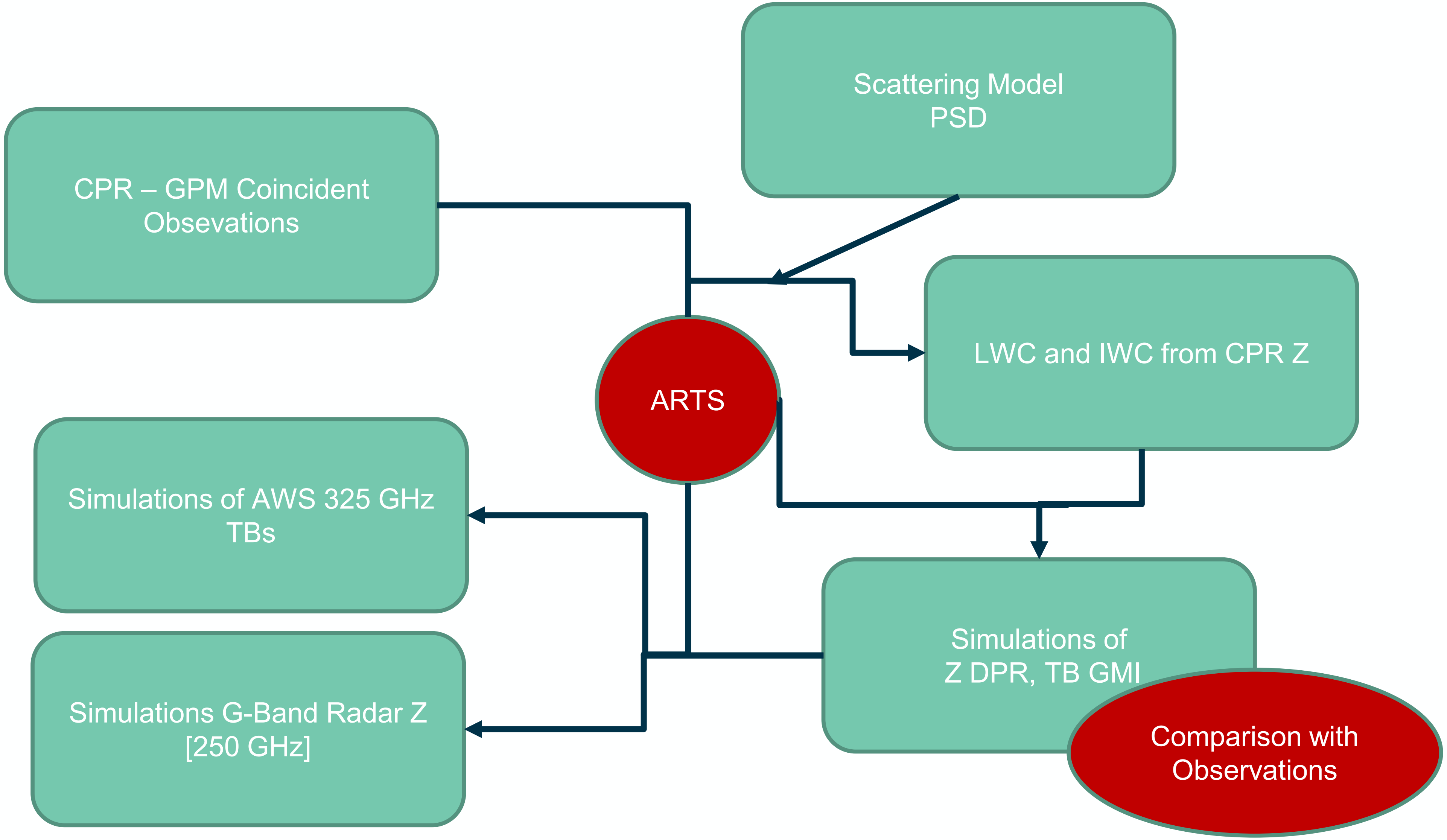
Arctic Weather Satellite (AWS) snowfall retrieval at high latitudes

- impact of the lack of low frequency window channels (< 60 GHz) for snowfall detection capabilities
- Analysis on the combined use of the 325 GHz -183.31 GHz channels to improve very light snowfall retrieval at high latitudes.

W-G band Doppler radar for ice/snow retrievals

synergy between G-band radar and high-frequency radiometers.

Simulation Strategy: AWS and G-Band Radar



Scattering Model
PSD

CPR – GPM Coincident
Obsevations

LWC and IWC from CPR Z

ARTS

Simulations of AWS 325 GHz
TBs

Simulations of
Z DPR, TB GMI

Simulations G-Band Radar Z
[250 GHz]

Comparison with
Observations

RainCast – Phase 2: Next Steps

Objectives:

Arctic Weather Satellite (AWS) snowfall retrieval at high latitudes

- Sinergy with other radiometers for background surface characterization (CIMR, MWI)
- Exploitation of the full spectrum of the AWS T and WV sounding channels to reduce the dependence on model-derived auxiliary Variables

- Analyze the combined use of the AWS channels to improve supercooled water droplets detection.

W-G band Doppler radar for ice/snow retrievals

synergy between G-band radar and high-frequency radiometers.

Some References

Thank you

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