Quantitative Investigation of Radiometric Interactions between Snowfall, Snow Cover, and Cloud Liquid Water over Land

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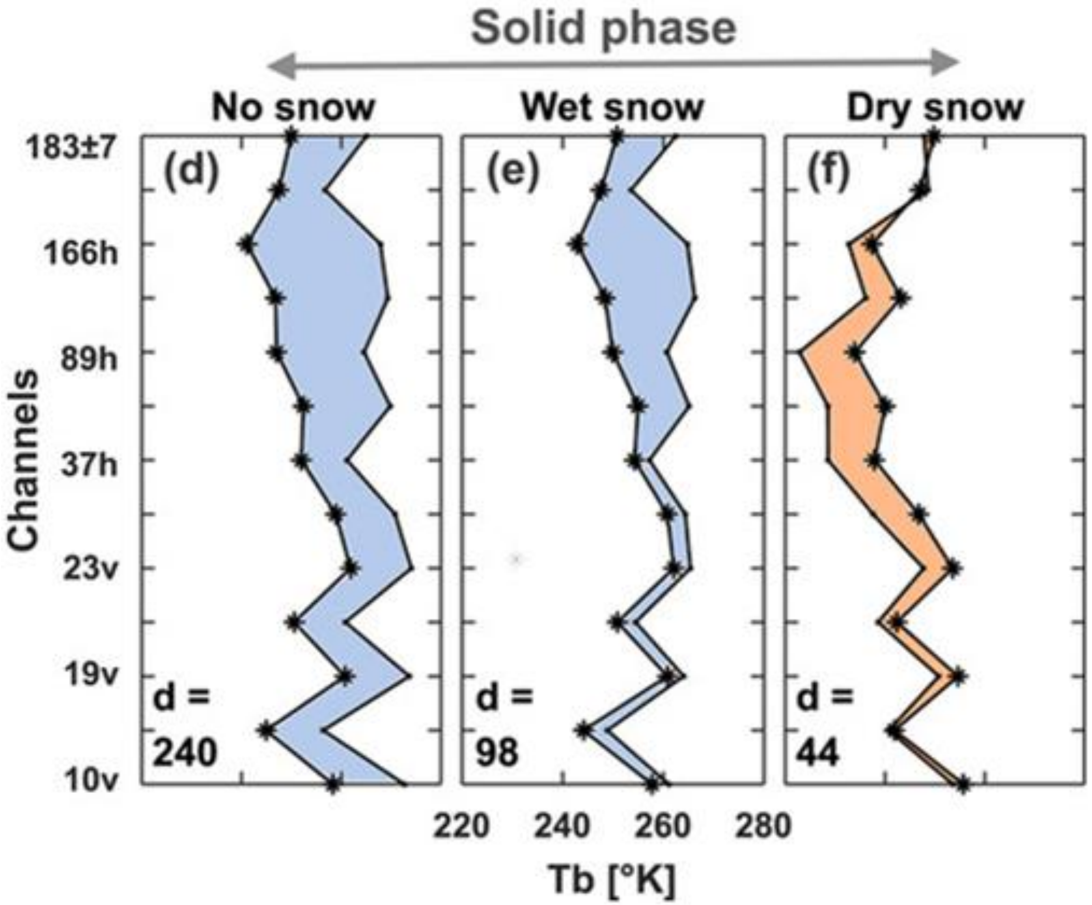
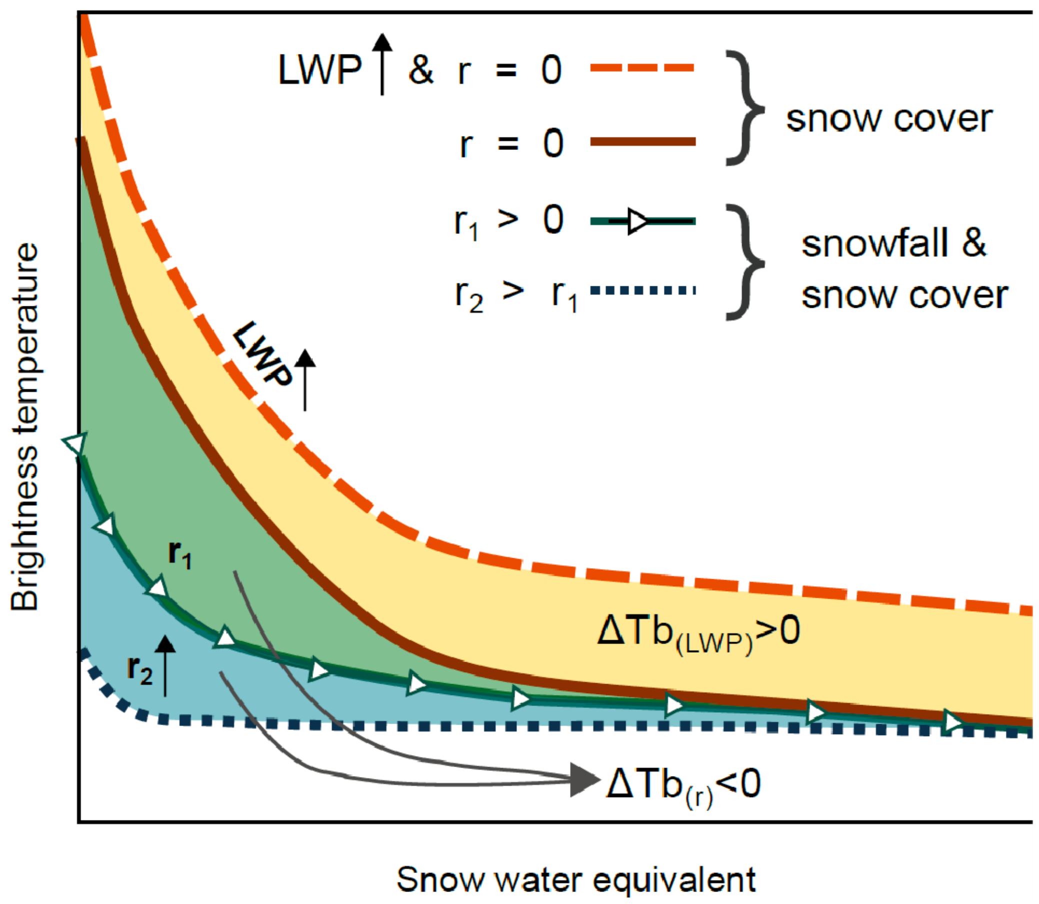
Challenges in the passive microwave snowfall retrievals



- Snowfall scattering is much weaker than rainfall and depends on complex microphysics of snowflakes.
- The cloud liquid water increases the brightness temperature, thus masks the snowfall scattering signal.
- Snow cover weakens the snowfall scattering. Snow cover and snowfall scattering are similar at high frequencies.
- **How can we unmix snow-cover, cloud liquid water and snowfall signals?**

Snow Cover & Snowfall Interactions

$$\mathbf{Tb_{obs} \approx Tb_{surface} - Tb_{snow\ cover} - Tb_{snowfall} + Tb_{cloud\ water}}$$



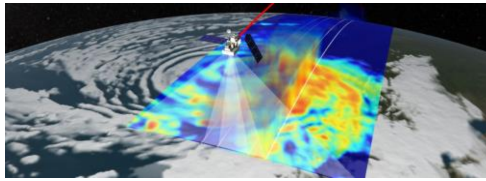
Key Questions:

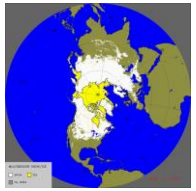
- How does the snow-cover scattering affect GMI brightness temperatures?
- To what extent the liquid water content of snowy clouds can mask the snowfall signals?
- At which boundary conditions can the snow cover obscure the snowfall signatures?
- Are there any land-atmospheric blind spots for GPM microwave snowfall retrievals?

Datasets

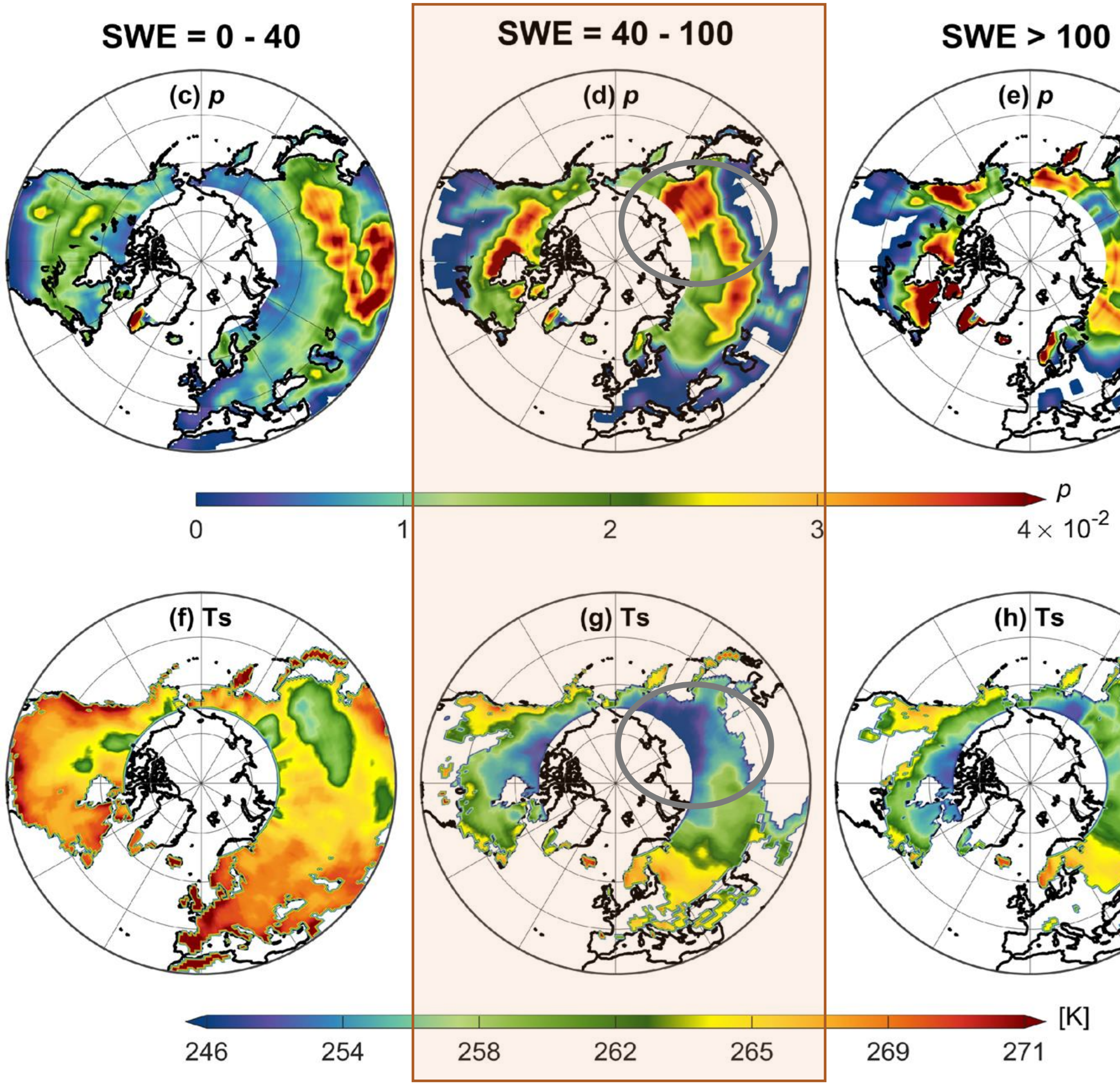
Table 1. Abbreviations, data, and products.

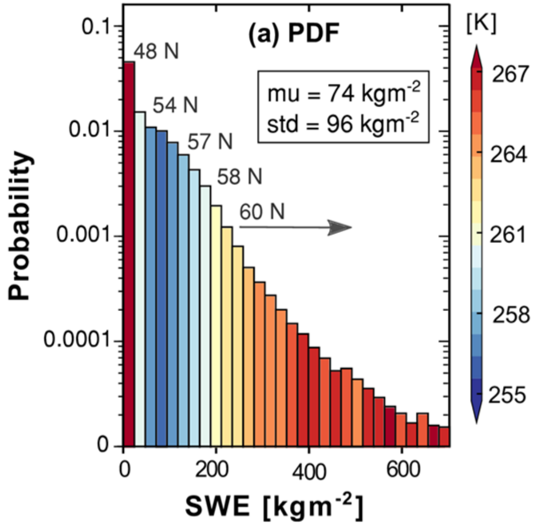
Variable	Symbol	Unit	Source
89 GHz brightness temperature	Tb_{89}	K	1C-R GMI V05 satellite observation product
166 GHz brightness temperature	Tb_{166}	K	1C-R GMI V05 satellite observation product
183 ± 3 GHz brightness temperature	$Tb_{183\pm3}$	K	1C-R GMI V05 satellite observation product
183 ± 7 GHz brightness temperature	$Tb_{183\pm7}$	K	1C-R GMI V05 satellite observation product
Snowfall rate	sr	$\mathrm{mm\ h^{-1}}$	2ADPR-V06 satellite observation product
Total precipitable water vertically integrated on 0–20 km	TPW	$\mathrm{kg\ m^{-2}}$	2ADPR-V06 satellite observation product
Skin temperature	T_{skin}	K	MERRA-2 reanalysis
2-m temperature	T_{2m}	K	MERRA-2 reanalysis
Snow cover extent	IMS	Dimensionless	United States National Ice Center
Snow water equivalent on the ground	SWE	$\mathrm{kg\ m^{-2}}$	MERRA-2 reanalysis
Cloud liquid water path	LWP	$\mathrm{g\,m^{-2}}$	MERRA-2 reanalysis
Ice water path	IWP	$\mathrm{g\,m^{-2}}$	MERRA-2 reanalysis
Water vapor path	WVP	$\mathrm{g\,m^{-2}}$	MERRA-2 reanalysis
Air temperature averaged on 0–20 km	T_{air}	K	GANAL analysis
Clear sky land emissivity	ε_s	dimensionless	$\varepsilon_s = \frac{\mathrm{Tb_s}}{\mathrm{T_{skin}}}$
Cloud liquid water emissivity	ε_{lwp}	dimensionless	$\varepsilon_{lwp} = \frac{\mathrm{Tb_{obs}} - \varepsilon_s \mathrm{T_{skin}}}{\mathrm{T_{air}}}$
Total atmospheric emissivity	ε_a	dimensionless	$\varepsilon_a = \varepsilon_{sr} + \varepsilon_{lwp}$





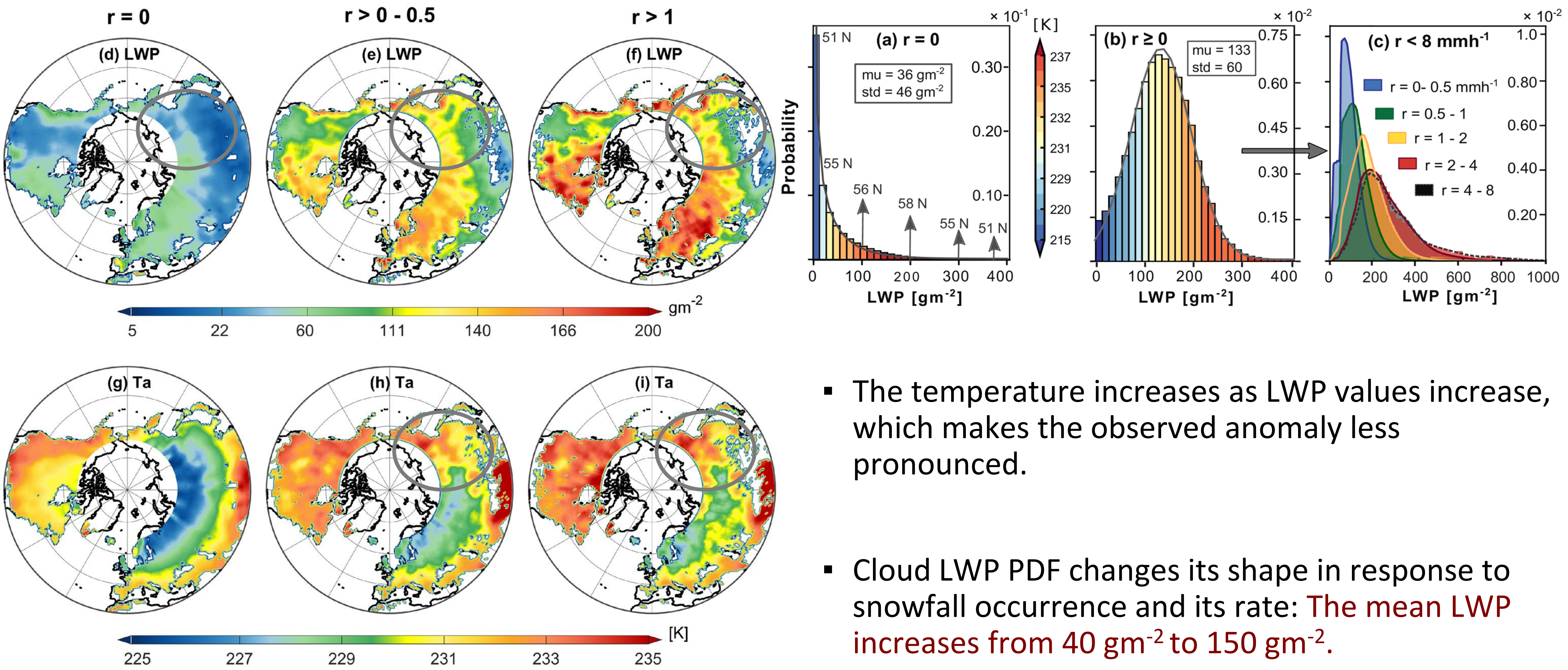
Spatial and Marginal Distributions of SWE & Average Surface Temperature (Ts)





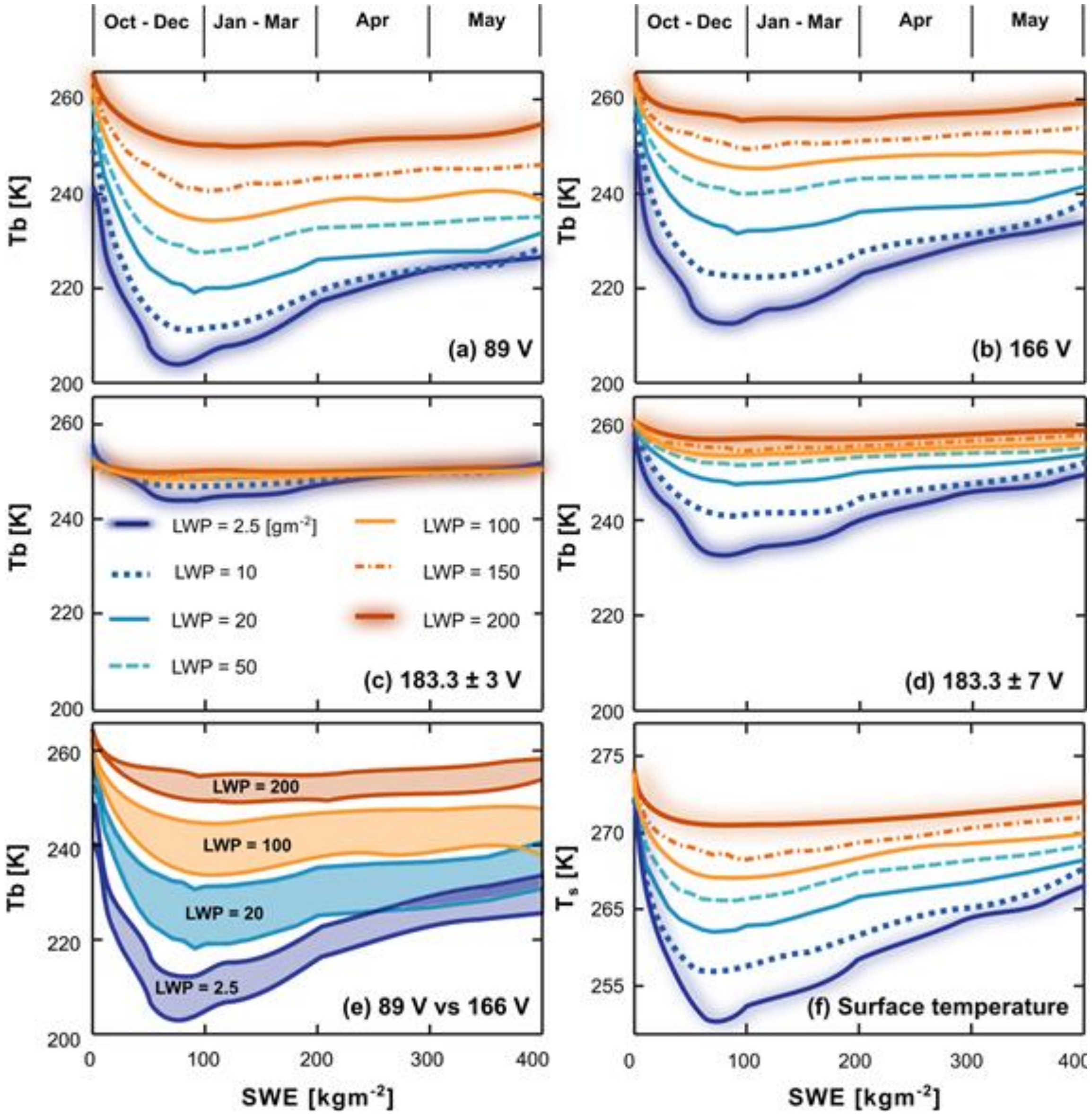
- SWEs 0-40 kgm^{-2} are for early wintertime fresh snow over Himalayas.
- SWEs 40-100 kgm^{-2} are largely from Siberian plateau and northern Canada with extremely colder surface temperature.
- SWEs >100 kgm^{-2} are for late winter and early spring with warmer surface temperature.

Multi-year average of Cloud LWP & Atmospheric Temperature (Ta)



- The temperature increases as LWP values increase, which makes the observed anomaly less pronounced.
- Cloud LWP PDF changes its shape in response to snowfall occurrence and its rate: The mean LWP increases from 40 gm^{-2} to 150 gm^{-2}.

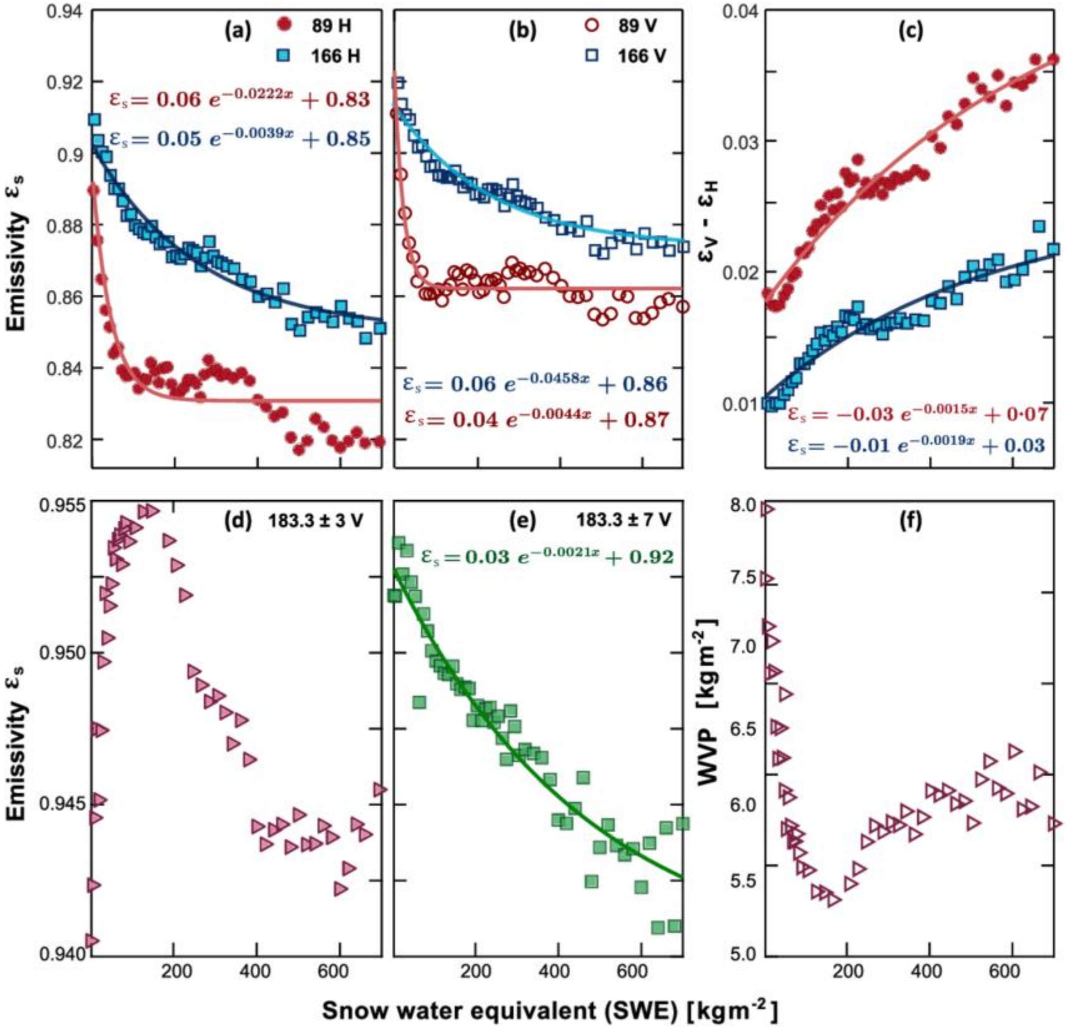
Snow Cover, LWP, & Snowfall Radiometric Interactions



- There is an anomaly in the response of the Tb values for SWE.
- The anomaly is due to snow-cover metamorphism and global climatology of snow-cover and surface and atmospheric temperature.
- To separate the snowfall and snow-cover signals, land and atmospheric emissivity values need to be studied.

Snow-Cover Emissivity -- Clear Sky

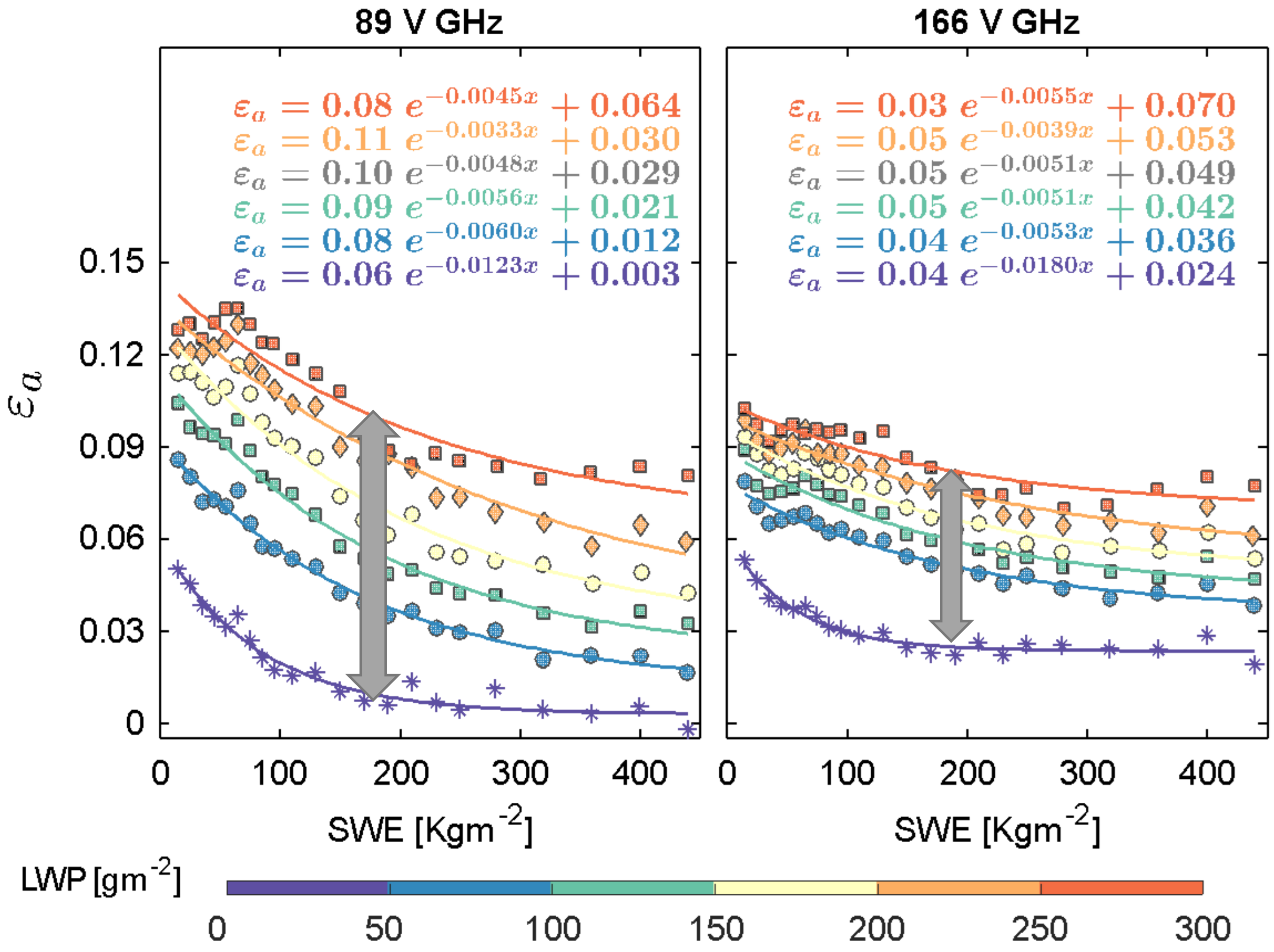
$$\varepsilon_{sc} = Tb_{obs}/T_s$$



- Precipitation and cloud liquid water are close to zero.
- Exponential function can explain well the emissivity values as a function of SWE at GMI frequencies.
- As the SWE increases, the emissivity of 166 GHz channels is decreasing with a lower rate compared to the emissivity of 89 GHz.
- 89 GHz reaches a plateau at SWE ≈ 100 kgm^{-2}, while 166 GHz continues to respond to changes with SWE.

Atmospheric Emissivity -- Cloud LWP

- The rate of emissivity increase due to the increase of the liquid water path is higher at channel 89 GHz than that of channel 166 GHz.



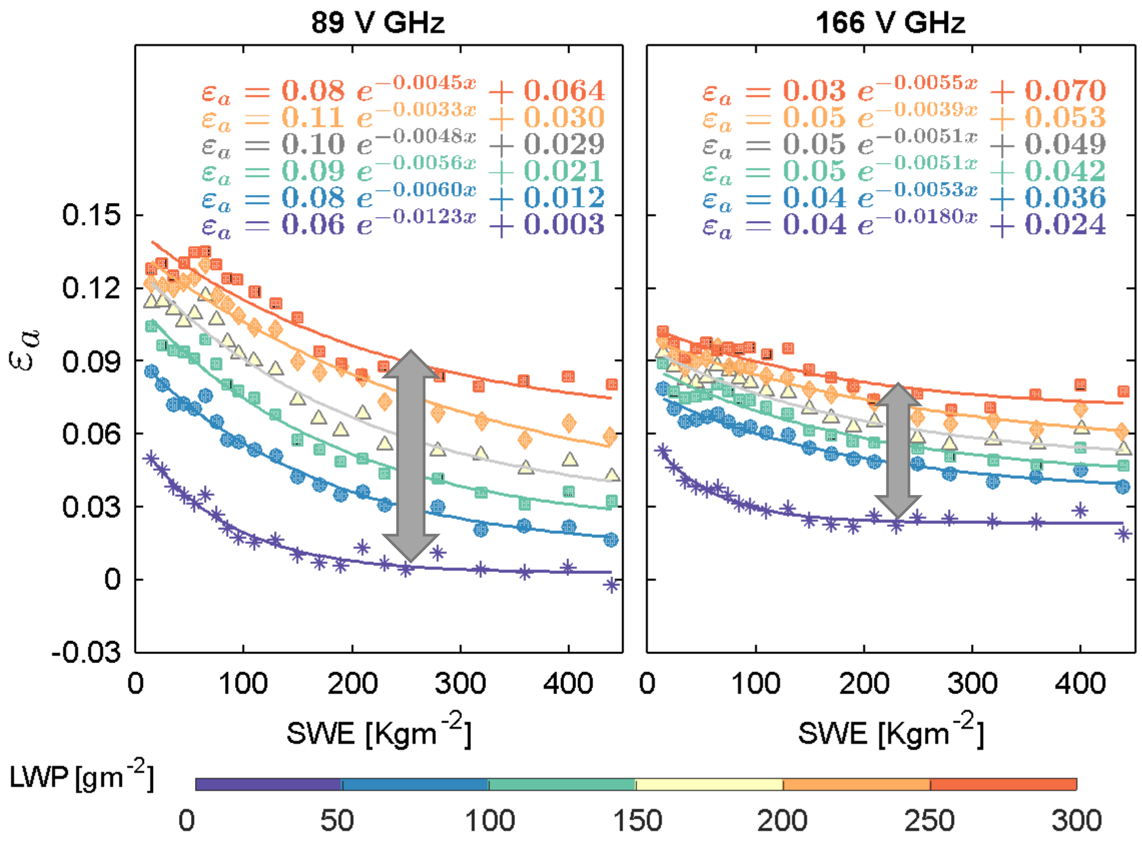
$$\varepsilon_{snow} = \frac{Tb_{obs}}{T_s}$$

$$T_{obs} = T_s \times \varepsilon_{sc} + T_a \times \varepsilon_a$$

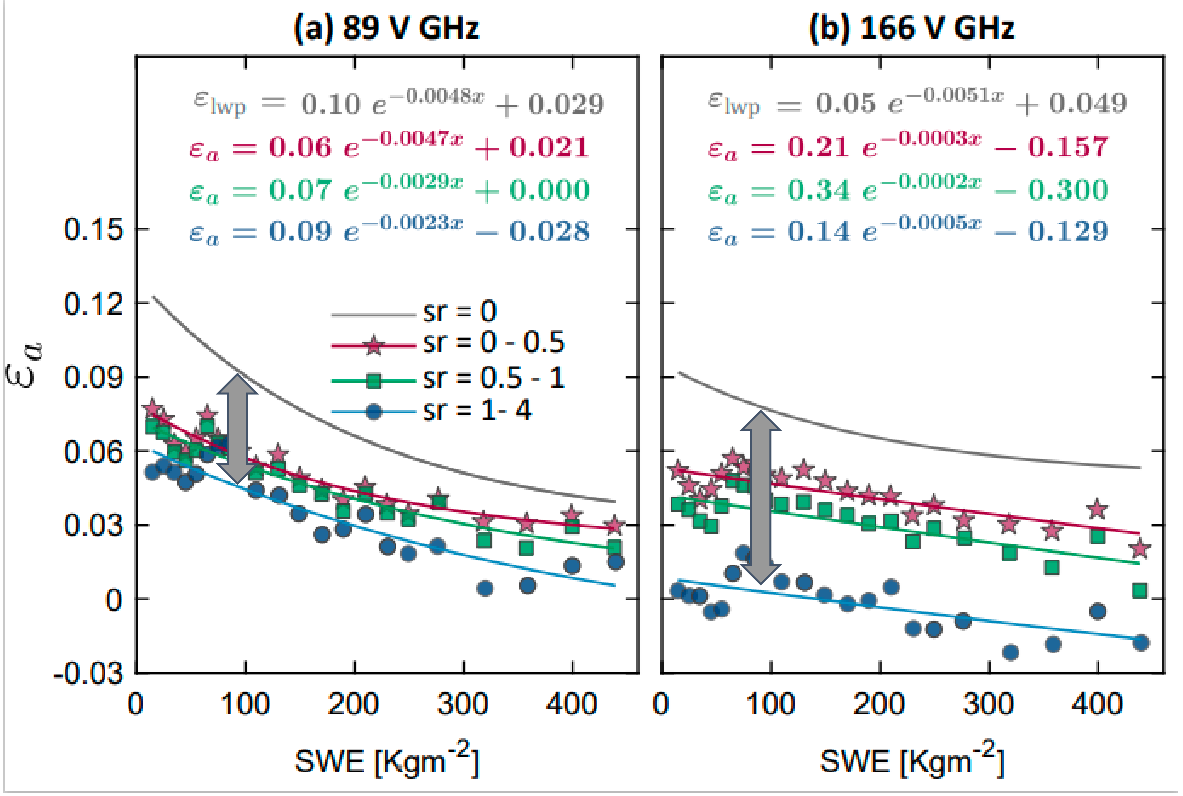
$$\varepsilon_a = (Tb_{obs} - T_s \times \varepsilon_{sc})/T_a$$

Atmospheric Emissivity -- Snowfall and Cloud LWP

Atmospheric emissivity of the cloud LWP



Atmospheric emissivity of the LWP and snowfall



Findings

- *The channel 166 GHz could better capture the scattering signature of light snowfall events* because it responds less strongly to the increase of the cloud LWP than the 89 GHz channel.
- Larger snowfall events could be captured better at 89 GHz when both LWP and SWE are small, while *166 GHz becomes more advantageous at capturing this scattering when LWP increases up to about 100–150 g m^{-2}.*
- Over deeper snow-cover regions (SWE > 200 kg m^{-2}) and larger LWP values (≥100–150 gm^{-2}), the scattering of snowfall, even with large intensity, is masked by the comparable scattering contribution from the large accumulation of snow cover and the emission from liquid water at both 89 and 166 GHz channels: the snowfall dominant signature becomes its emission that can be distinguished from the very low plateaued emissivity of the surface at channel 89 GHz.
- Over latitudes above 60°N with SWE > 200 kg m^{-2} and LWP < 100–150 g m^{-2}, the snowfall microwave signal could not be detected with GPM without considering a priori data about SWE and LWP. Our findings provide quantitative insights for improving retrieval of snowfall in particular over snow-covered terrain.

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Limitations

- At the daily or sub-daily time scales, large variability around these multi-year averages is expected.
- For instantaneous precipitation retrievals, one should consider the use of the dynamic surface emissivity database developed by Munchak et al., 2020.
- We acknowledge potential errors and inaccuracies in DPR measurements regarding light precipitation intensities. An additional investigation, if it does not require high space-time coverage, should consider measurements from CloudSat Cloud Profiling Radar (CPR, Turk et al., 2021).
- We only used total precipitable water to screen the clear-sky Tbs. This can add some uncertainties regarding the calculated emissivities of LWP and snowfall. Future research needs to investigate the effects of total precipitable water on the radiometric signal during the snowfall events (Milani et al., 2021).

References

1. Takbiri, Zeinab, Lisa Milani, Clement Guilloteau, and Efi Foufoula-Georgiou. 2021. "Quantitative Investigation of Radiometric Interactions between Snowfall, Snow Cover, and Cloud Liquid Water over Land" Remote Sensing 13, no. 13: 2641. https://doi.org/10.3390/rs13132641

2. Takbiri, Z., Ebtehaj, A., Foufoula-Georgiou, E., Kirstetter, P., & Turk, F. J. (2019). A Prognostic Nested k-Nearest Approach for Microwave Precipitation Phase Detection over Snow Cover, Journal of Hydrometeorology, 20(2), 251-274. https://journals.ametsoc.org/view/journals/hydr/20/2/jhm-d-18-0021_1.xml

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