

# High-Latitude Remote Sensing and Learned Reanalysis: From Precipitation to Terrestrial Snow Storage

NASA Hydrosphere Investigator Meeting, Washington, DC, 2026



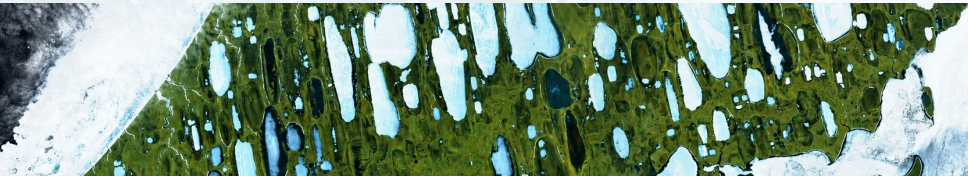
M. Prodhan, S. Fahim, S. Dahal, B. Subedi, A. Ebtehaj, *Univ. Minnesota.*

D. Kumawat, S. Kumar, R. Bindlish, *Goddard Space Flight Center.*

L. Milani, G. Hoffman *Goddard Space Flight Center.*

Y. Zhou, A. Colliander, M. Schwank, J.P. Wigneron, *WSL, FMI, INRAE*

Saint Anthony Falls Laboratory  
Dept. of Civil, Environmental, and Geo-Engineering  
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## Outline

### **The Problem**

### **Arctic Soil and Vegetation**

### **L- and C-band Snow Water Equivalent Retrievals**

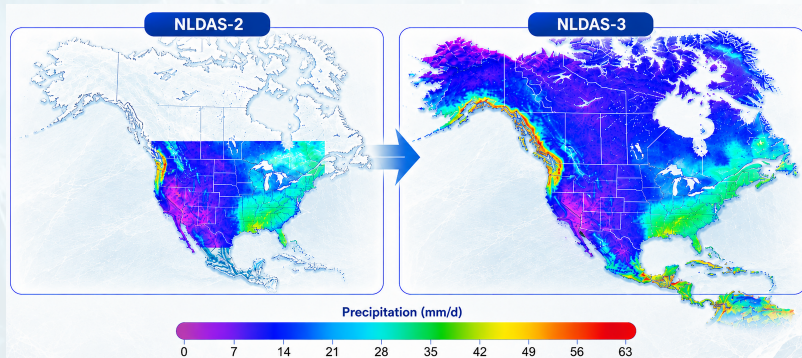
### **L-band and C-band Lake Ice Phenology**

### **References**



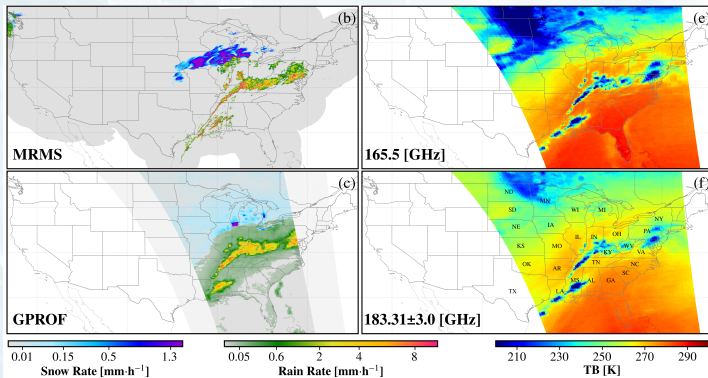
## North American Land Data Assimilation System (NLDAS-3)

- ✱ The third phase of the North American Land Data Assimilation System (NLDAS-3) is currently in development.
- ✱ Cloud covers roughly 50–60% of the Arctic Circle, and polar darkness lasts from late November to mid-January.
- ✱ Passive microwave snowfall retrievals, and thus the IMERG-V07 product is highly uncertain.
- ✱ There are an estimated 3.5 million lakes and ponds (400,000 km<sup>2</sup>) across the Arctic Circle.
- ✱ Boreal forests are covered with snow for more than 50% of the time from October to March.



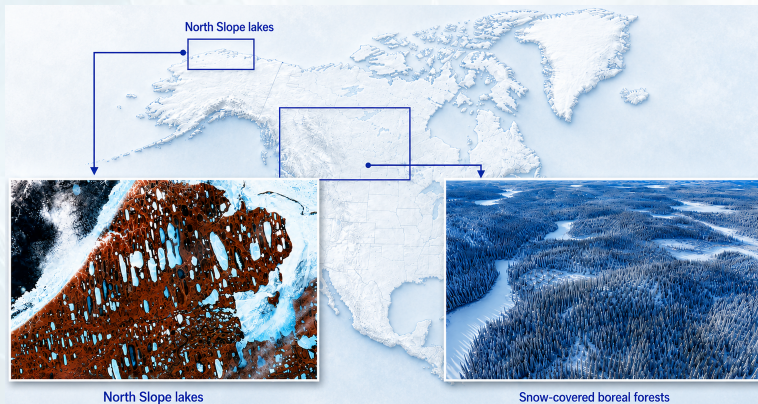
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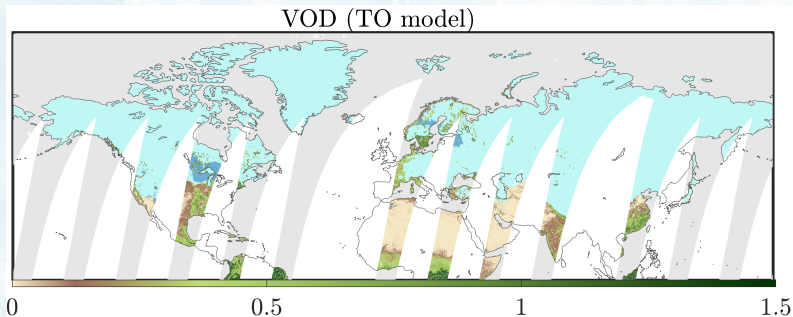
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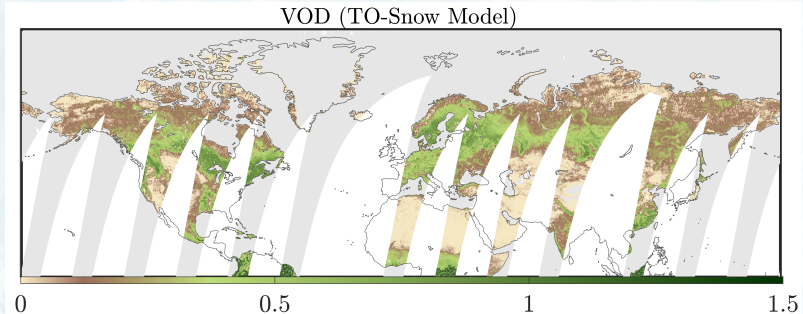
## Snow-covered Boreal Forests and Tundra

- \* Soil moisture and VOD under snow cover using SMAP Observations.
- \* A coherent L-band RT model is deployed to retrieve all-season L-band soil dielectric constant and VOD.
- \* Configured LIS domains over two high-latitude regions for assimilation into Noah-MP.



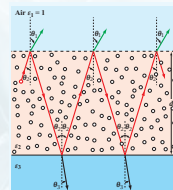
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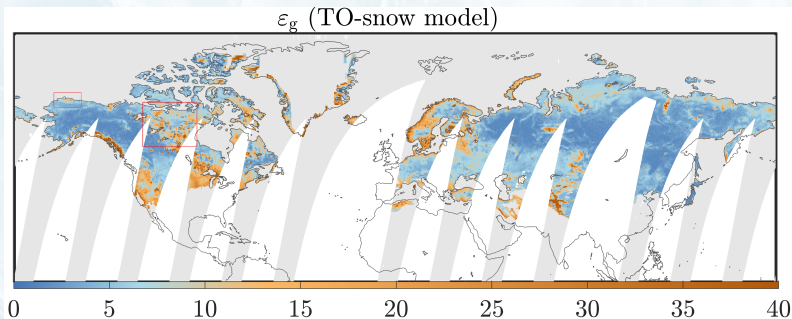
$$\rho^p = \frac{\rho_{12}^p + \rho_{23}^p \exp^{-2\gamma_2 d \cos \theta_2}}{1 + \rho_{12}^p \rho_{23}^p \exp^{-2\gamma_2 d \cos \theta_2}}$$

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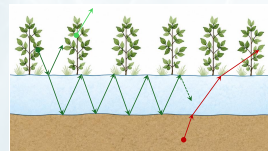


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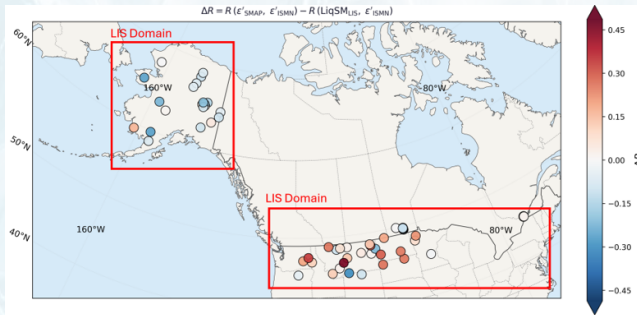
$$T_B^p = T_g e^p \gamma + T_c (1 - \omega) (1 - \gamma) + T_c (1 - \omega) (1 - \gamma) r^p \gamma.$$

$$e^p = \text{sgn}(1 - |\xi_{cs}^p| |\tilde{\xi}_{sg}^p|) \left( \frac{|\xi_{cs}^p|^2 + |\tilde{\xi}_{sg}^p|^2 - |\xi_{cs}^p|^2 |\tilde{\xi}_{sg}^p|^2 - 1}{|\xi_{cs}^p|^2 |\tilde{\xi}_{sg}^p|^2 - 1} \right)$$



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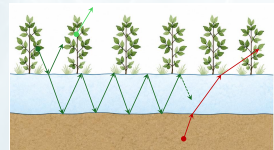


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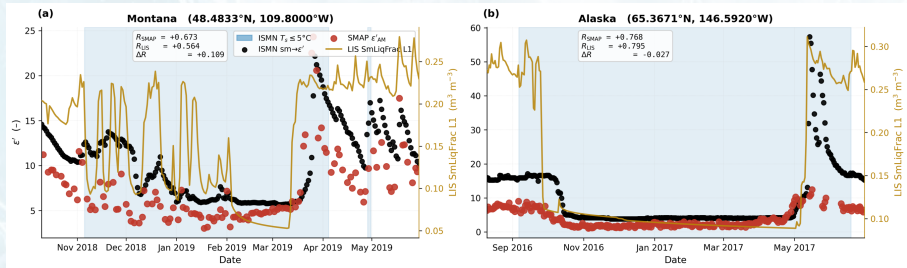
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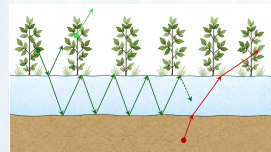


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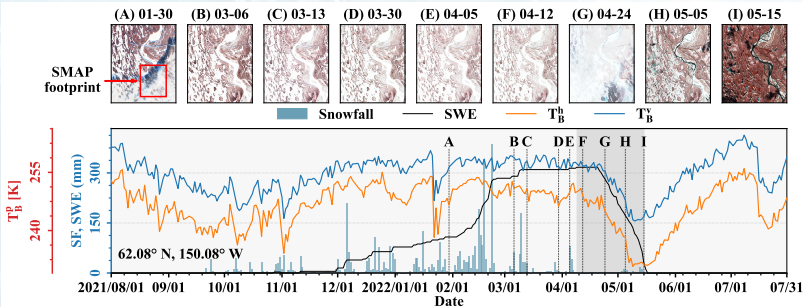
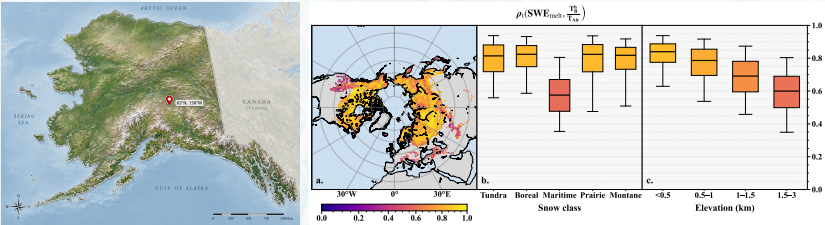
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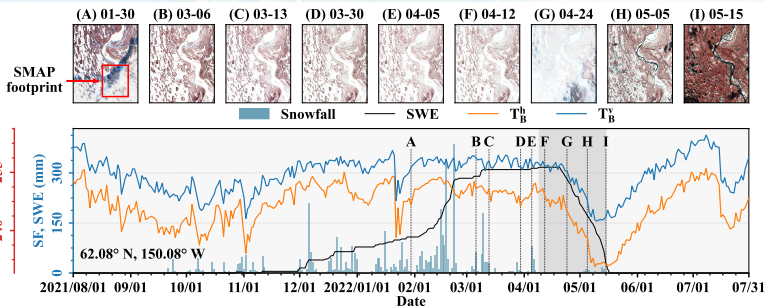
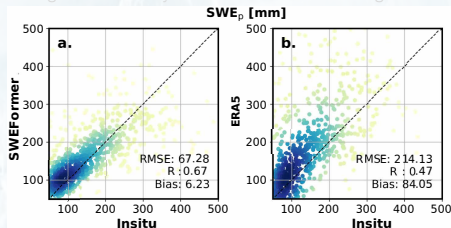
# Learned Reanalysis of SWE using L-band Radiometry

- ❖ The L-band brightness temperatures are highly correlated with SWE during melting.
- ❖ We retrieved peak SWE using deep Transformers.
- ❖ Extending to full SWE reconstruction using snowfall history and later SAR backscattering.



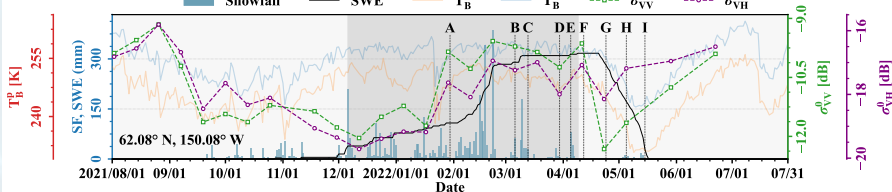
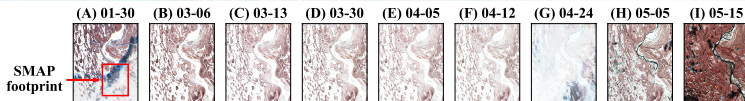
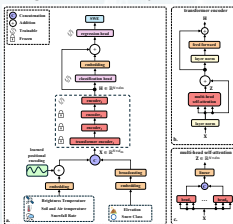
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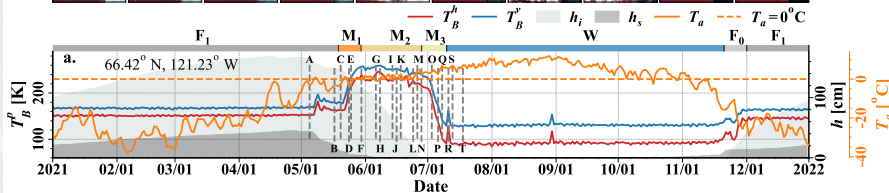
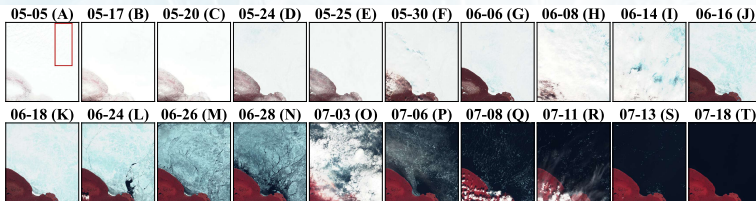
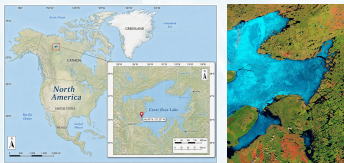
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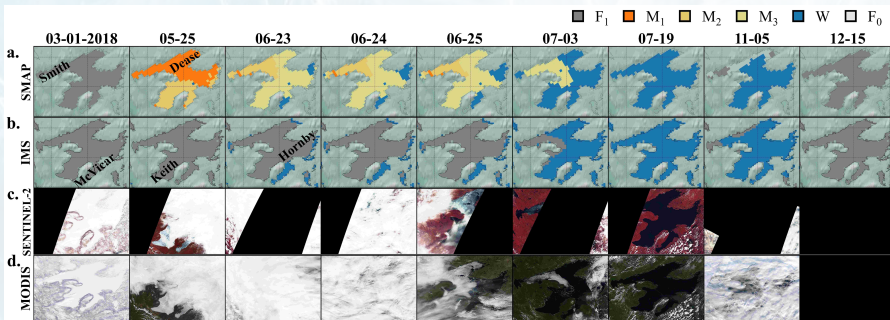
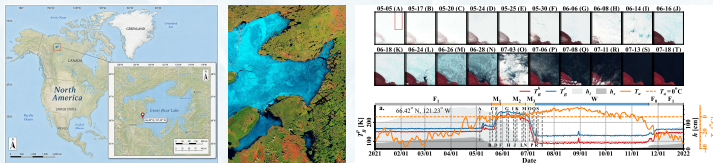
# L-band Radiometry of Lake Ice Freeze-Thaw Dynamics

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- \* We can retrieve snow as well as ice wetness and the ice fraction with FOV.
- \* SAR high-resolution ice phenology using deep learning: why?.



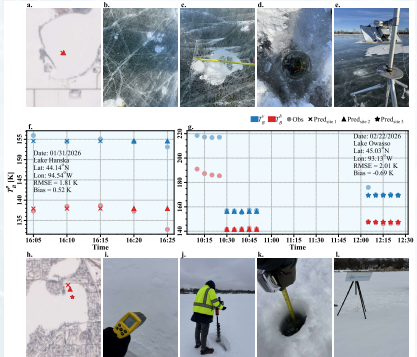
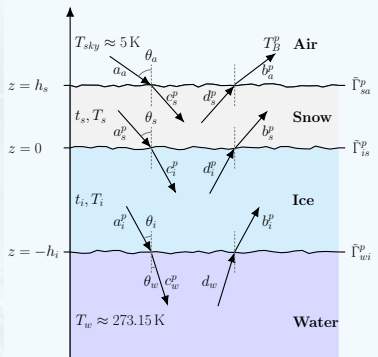
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$$T_B^p = T_w \zeta_w^p + T_i \zeta_i^p + T_s \zeta_s^p + T_{sky} \zeta_{sky}^p + T_{sky} \Gamma_{sa}^p$$

$$\zeta_w^p = \frac{1 - \Gamma_{sa}^p}{\delta \rho} \left[ t_i t_s (1 - \Gamma_{wi}^p) (1 - \Gamma_{is}^p) \right]$$

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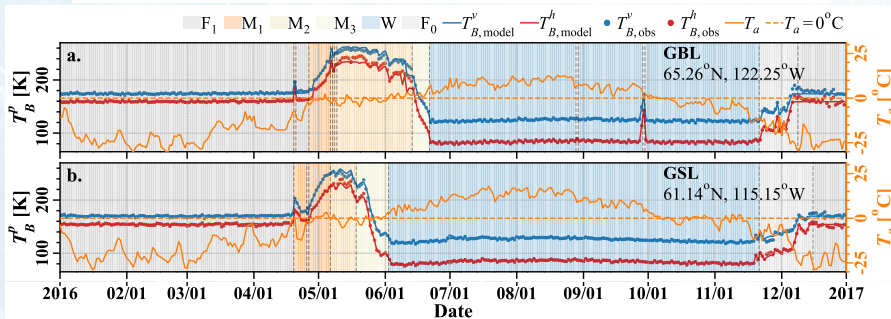
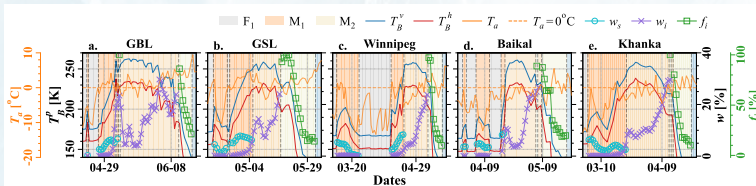
$$\zeta_s^p = \frac{1 - \Gamma_{sa}^p}{\delta \rho} \left[ t_i^2 t_s (1 - t_s) \Gamma_{wi}^p (1 - \Gamma_{is}^p)^2 + t_s (1 - t_s) \Gamma_{is}^p (1 - t_i^2 \Gamma_{wi}^p \Gamma_{is}^p) + (1 - t_s) (1 - t_i^2 \Gamma_{wi}^p \Gamma_{is}^p) \right]$$

$$\zeta_{sky}^p = \frac{1 - \Gamma_{sa}^p}{\delta \rho} \left[ t_i^2 t_s^2 \Gamma_{wi}^p (1 - \Gamma_{is}^p)^2 (1 - \Gamma_{sa}^p) + t_s^2 \Gamma_{is}^p (1 - \Gamma_{sa}^p) (1 - t_i^2 \Gamma_{wi}^p \Gamma_{is}^p) \right]$$



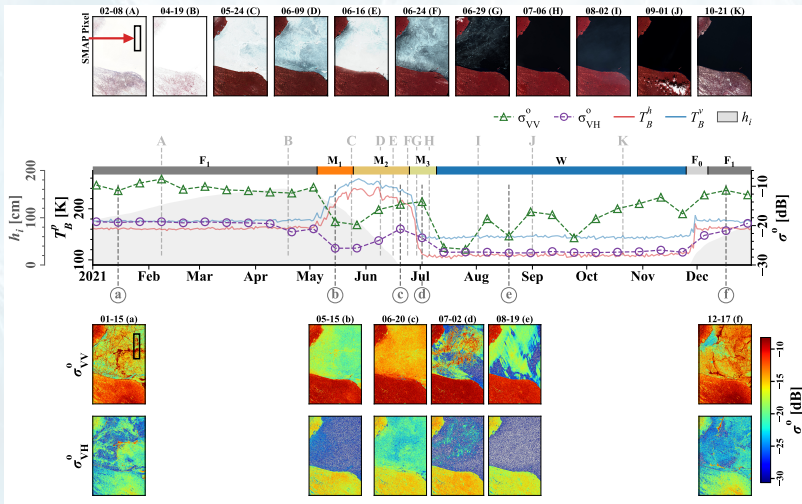
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# Thank You



Kumawat, D., A. Ebtehaj, X. Xu, A. Colliander, V. Kumar (2024)

An Autoencoder Architecture for L-band Passive Microwave Retrieval of Landscape Freeze-Thaw Cycle  
*IEEE Trans. on Geosci. and Remote Sens.*, 10.1109/TGRS.2025.3530356.



Repo View On Github



Open in Colab

<https://github.com/aebtehaj/FTCEncoder>



Kumawat, D., A. Ebtehaj, S. Kumar, A. Colliander (2025)

Deep Learning of Seasonal Peak Snow Water Content of Global Boreal Forest and Arctic using Spaceborne L-band Radiometry

*Remote Sensing of Environment, Remote Sensing of Environ.*, <https://doi.org/10.1016/j.rse.2025.114963>.



Repo View On Github



Open in Colab

<https://github.com/Divak14/SWEFormer>



Prodhan M., A. Ebtehaj, D. Kumawat, S. Kumar et al., (2026)

Learning Lake Ice Phenology and Freeze-Thaw Dynamics using L-band Radiometry: Insights from SMAP Satellite Observations

*under review, IEEE Trans. on Geosci. and Remote Sens.*



Repo View On Github



Open in Colab

<https://github.com/prodh004/LIMEM>



Subedi B., M. Garshasbi; A. Ebtehaj, L. Milani, N. Utsumi, G. Huffman (2026)

An Incremental Learning Framework Linking Reanalysis and Radar Data for Passive Microwave Precipitation Retrievals  
*IEEE Trans. on Geosci. and Remote Sens.* 10.1109/TGRS.2026.3713037



Repo View On Github



Open in Colab

[https://github.com/Buddha-subedi/PMWPrecip\\_TLP-R2S](https://github.com/Buddha-subedi/PMWPrecip_TLP-R2S)