Passive Microwave Retrieval of Soil Moisture below Snowpack at L-band using SMAP Observations

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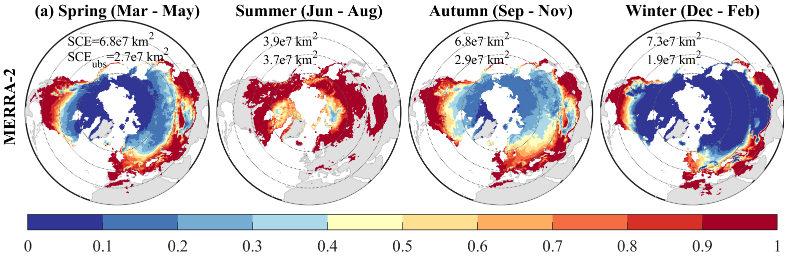
Outline

Problem statement and Hypothesis

- **Motivation:** Soil beneath the snowpack is unfrozen 30% of the time (Gao et al., 2022)



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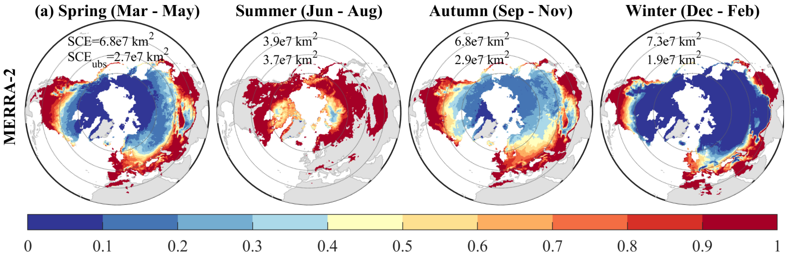
  ① The omission of snow in the retrieval of soil moisture typically result in 30% underestimation of soil dielectric constant (Schwank et al., 2015).
  ② There are no global observations of SM and VWC in the presence of snow cover at the moment.



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- **Hypothesis:** Soil moisture below dry snow-cover can be sensed in L-band. The **rationale** is the dry snow is a low-loss medium in L-band, however affects the propagation phase.

Research Questions

Question 1: How does snow cover affect soil emission in L-band?

Question 2: How can we account for the reflected downwelling canopy emission?

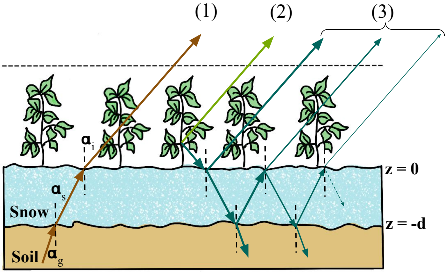
Question 3: What are the effects of snowpack physical properties including depth and density?

Question 4: Which SMAP channel is more robust to the induced uncertainties?

Forward Model

$$T_b^p = \overbrace{T_{bs}^p \gamma}^{(1)} + \overbrace{T_c(1-\omega)(1-\gamma)}^{(2)} + \overbrace{T_c(1-\omega)(1-\gamma) r_s^p \gamma}^{(3)}$$

- T_{bs}^p: bottom soil emission translated through snow (Mironov + DMRT)
- r_s^p: snow surface reflectivity
- T_c: canopy temperature.
- γ: vegetation transmissivity.
- ω: vegetation single scattering albedo.



Reflectivity of the downwelling vegetation temperature

- We use wave approach to model the reflectivity of the downwelling brightness temperature.

$$r_s^p = \left| \frac{\xi_{cs}^p + \tilde{\xi}_{sg}^p . e^{-2\gamma_s d \cos\alpha_s}}{1 + \xi_{cs}^p \tilde{\xi}_{sg}^p e^{-2\gamma_s d \cos\alpha_s}} \right|^2$$

$$\xi_{cs}^h = \frac{\eta_s \cos\alpha_i - \eta_i \cos\alpha_s}{\eta_s \cos\alpha_i + \eta_i \cos\alpha_s} \qquad \xi_{sg}^h = \frac{\eta_g \cos\alpha_s - \eta_s \cos\alpha_g}{\eta_g \cos\alpha_s + \eta_s \cos\alpha_g}$$

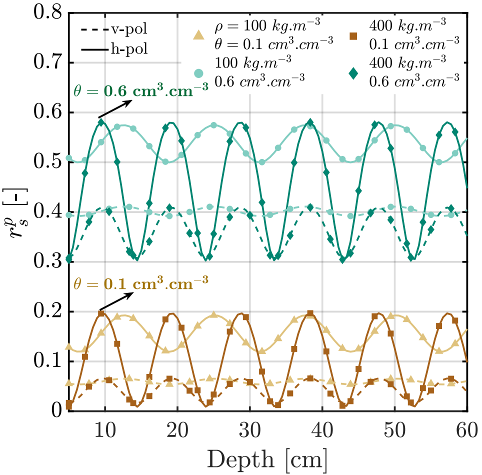
$$\xi_{cs}^v = \frac{\eta_s \cos\alpha_s - \eta_i \cos\alpha_i}{\eta_s \cos\alpha_s + \eta_i \cos\alpha_i} \qquad \xi_{sg}^v = \frac{\eta_g \cos\alpha_g - \eta_s \cos\alpha_s}{\eta_g \cos\alpha_g + \eta_s \cos\alpha_s}$$

where η_i, η_s and η_g are the intrinsic impedance of incident medium, snow and ground.

- Reflectivity is a function of dielectric constants of snow, soil and depth of the snow layer.

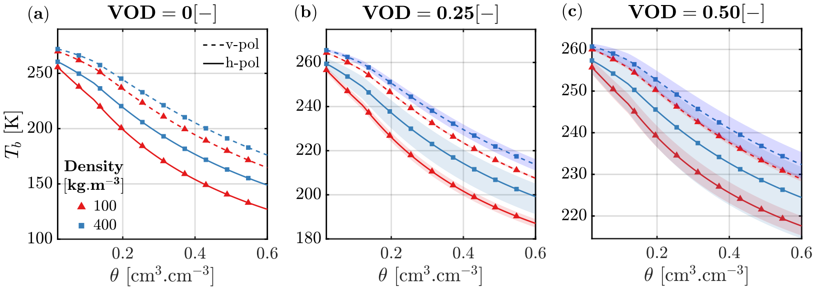
Reflectivity of the downwelling vegetation temperature

- Variation of the effective snow reflectivity r_s^p with respect to depth of the snowpack at density 100 and 400 $\mathrm{kg\,m^{-3}}$ for soil moisture values 0.1 and 0.6 $\mathrm{cm^3\,cm^{-3}}$.



Sensitivity: density, soil moisture and vegetation optical depth

- The shaded region represents the minimum and maximum bounds of the brightness temperatures in response to changes in snowpack depth.

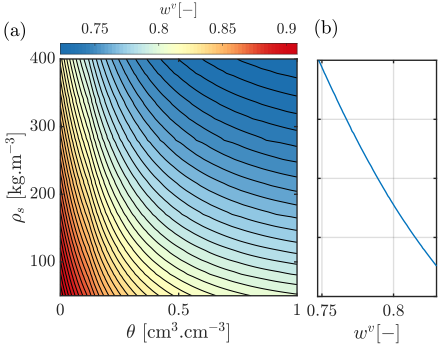


Inverse Model

The retrieval scheme searches for the minimum of the weighted sum of squared differences between the observed $\mathbf{y}^p_{Tb}$ and simulated $T^p_b = f^p(\phi)$ brightness temperatures as follows:

$$\phi^* = \underset{\phi}{\operatorname{argmin}} \sum_p \left[w^p \left(\mathbf{y}^p_{Tb} - f^p(\phi) \right) \right]^2 \qquad \text{subject to} \qquad \boldsymbol{\phi}_\mathbf{l} \leq \boldsymbol{\phi} \leq \boldsymbol{\phi}_\mathbf{u},$$

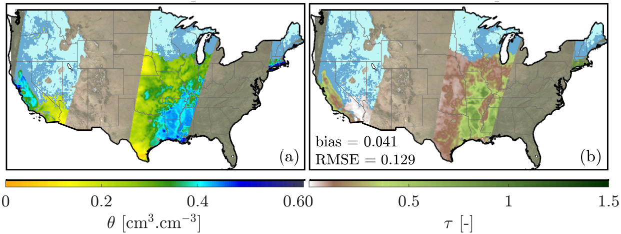
where $\phi = (\theta, \tau)$, $f^p(.)$ denotes a functional representation of the forward model, w^p is a weight characterizing the relative precision of each channel, and ϕ_l and ϕ_u encode the lower and upper bounds for the retrieved variables.



Orbital retrieval

The blue colored area indicates where the ground temperature was above 0 C but SMAP was unable to recover owing to snow cover.

SMAP product

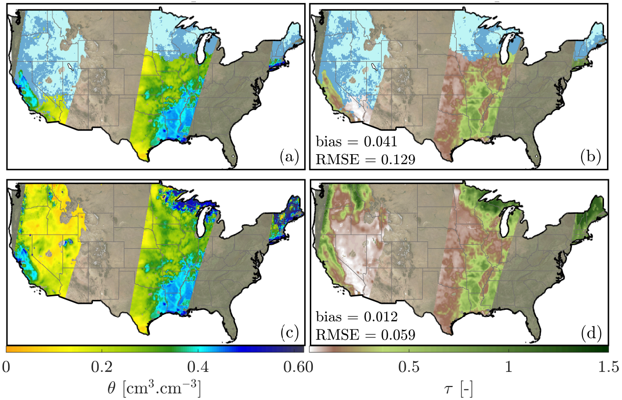


Orbital retrieval

Panels (c) and (d) shows the retrievals of SM and VOD over SMAP orbit using the proposed approach.

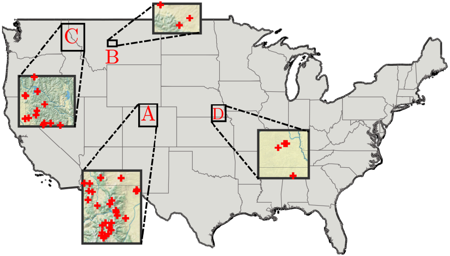
SMAP product

retrievals below snow cover



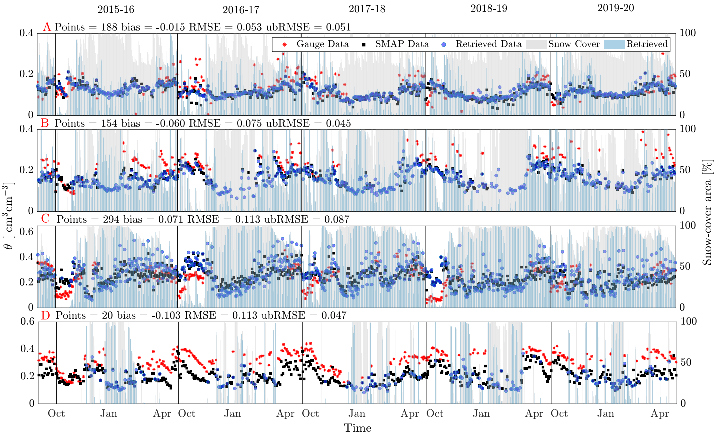
Time-series analysis using ISMN gauge data

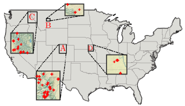
We chose four sites across the United States for our study, each with a different land cover type.



Time-series analysis using ISMN gauge data

This algorithm is capable of bridging the retrieval gap over snow-covered terrain.





Thank You

Entekhabi, Dara et al. (2014). "SMAP handbook–soil moisture active passive: Mapping soil moisture and freeze/thaw from space". In.

Gao, Lun et al. (2022). "Variability and Changes of Unfrozen Soils below Snowpack". In: *Geophysical Research Letters*, e2021GL095354.

Schwank, Mike et al. (2015). "Snow density and ground permittivity retrieved from L-band radiometry: A synthetic analysis". In: *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 8.8, pp. 3833–3845.