SOIL MOISTURE RETRIEVAL FROM MULTI-INSTRUMENT AND MULTI-FREQUENCY SIMULATED MEASUREMENTS IN SUPPORT OF FUTURE EARTH OBSERVING SYSTEMS

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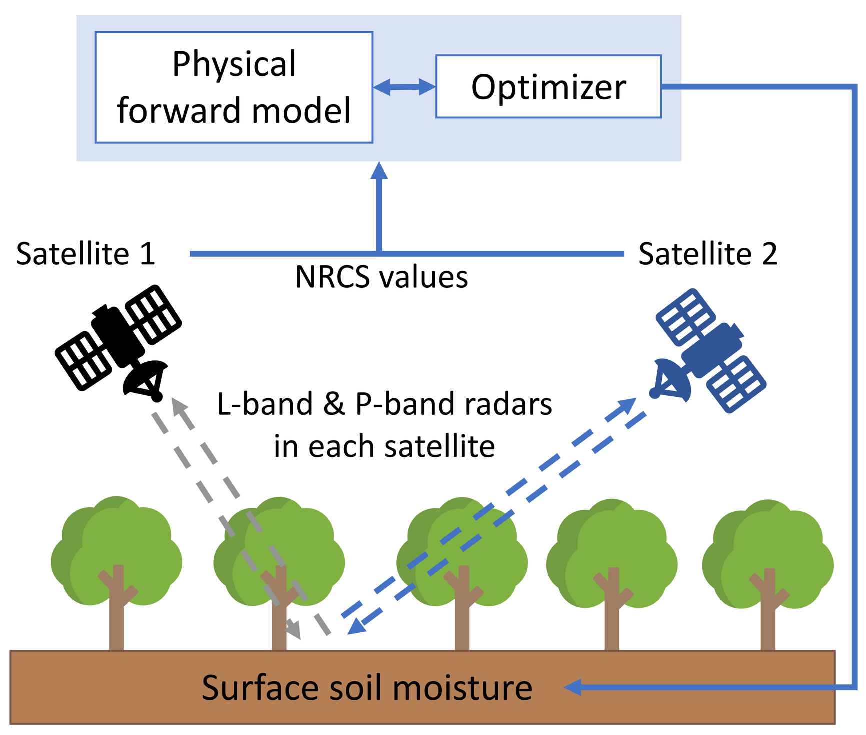
Overview: Determining the performance of soil moisture retrieval from multiple observations of different instruments is essential for optimizing the schedule of future earth observation spacecraft constellations. This poster presents a method that retrieves the soil moisture value from multiple instruments with different frequencies and polarizations and calculates their performance metrics. All measurements are used jointly in the soil moisture retrieval. The method utilizes a physical forward model and a global optimizer. The forward model calculates the normalized radar cross section (NRCS) from soil moisture value and other stationary parameters. The NRCS values of both the radars and the forward model are used by the optimizer to estimate soil moisture. We tested the method on simulated data with various vegetation terrains. The performance metrics calculated by this method are used in D-SHIELD, a future earth observation system, to aid the schedule and task of the satellites.

Retrieval Algorithm

- **Optimizer:** Multi-directional hybrid local and global optimization method, based on simulated annealing
- **Forward model:** Calculate NRCS value from soil moisture, vegetation parameters, and radar specifications



Cost function

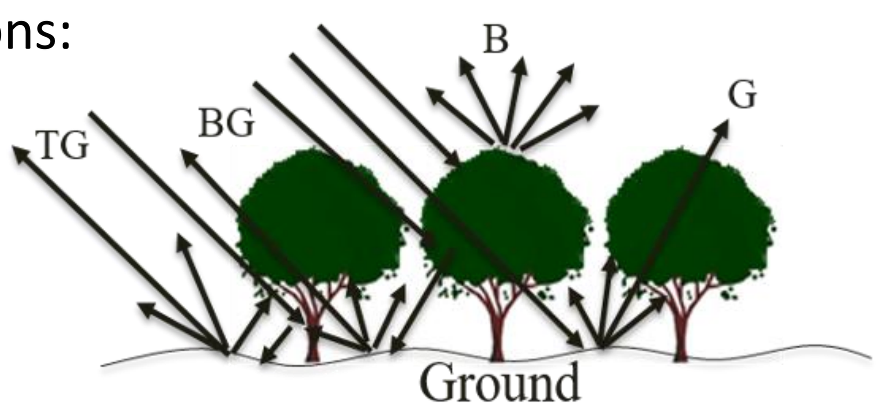
$$f^2 = \sum_{i,p} w[p] \left(\frac{\sigma_0^{sim}[p,i] - \sigma_0^{fwd}[p,i]}{\sigma_0^{sim}[p,i]} \right)^2$$

- Quad-pol measurements: $w[p{=}vh]$=1/5, $w[p{=}hh,vv]$=2/5
- Co-pol measurements: $w[p]$=1/2

p: Polarization index
i: Instruments index
σ_0^{sim}: Simulated measurement (NRCS)
σ_0^{fwd}: NRCS of forward model
$w[p]$: Measurement weight

Forward Model: Main scattering contributions:

1. Direct ground scattering (G)
2. Vegetation volume scattering (B)
3. Double-bounce scattering due to interactions between ground and vegetation (BG and TG)



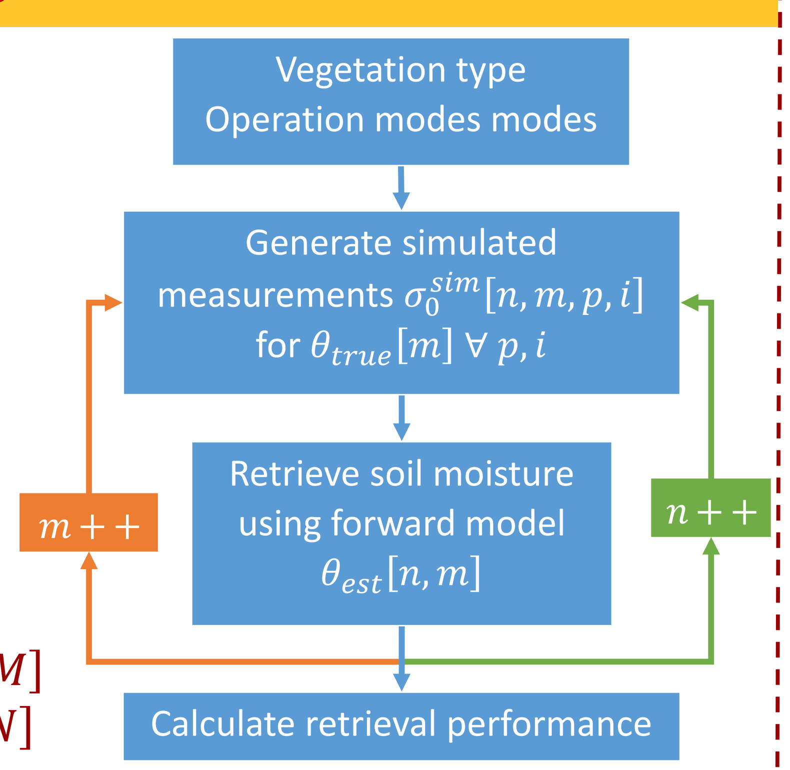
- Small perturbation method (SPM) used to compute ground scattering
- Finite discrete cylinders used to model vegetation components
- Mironov soil dielectric model used to map soil moisture to dielectric constants
- The interaction between vegetation and ground is considered by using scattering matrices of pertinent cylindrical distributions and the rough ground surface
- For double-bounce scattering, Kirchhoff approximation (KA) was used to model the coherent reflection from ground

Simulation Setup

- Monte Carlo simulation for multiple soil moisture values; from 0.16 to 0.3 m^3/m^3
- Maximum of 4 radars of D-SHIELD constellation considered in simulation: 2 L-band and 2 P-band radars
- Five classes of land cover types were considered

M: Number of soil moisture measurements
N: Number of Monte Carlo trails
θ_{est}: Estimated soil moisture

$M \in [1, M]$
$n \in [1, N]$



- Each radar has three operation modes with incidence angles: 35°, 45°, 55°
- 100 possible unique combinations of operating modes for D-SHILED radars
- Performance metrics were compared to retrievals from instrument with SMAP specification

Vegetation type	IGBP No.	Site name
Evergreen needleleaf forest	1	Metolius
Open shrublands	7	Walnut Gulch
Woody savannas	8	Tonzi Ranch
Croplands	12	Yanco
Barren	16	Las Cruces

*IGBP: International Geosphere-Biosphere Programme

Simulated NRCS:

$$\sigma_0^{sim} = \sigma_0^{fwd} \left(1 + \frac{0.523}{\sqrt{N_{look}}} w_1 \right) + k_p w_2$$

N_{look}: Number of looks
k_p: Noise equivalent sigma zero (NESZ)
$w_i \sim \mathcal{N}(0,1)$

P-band radar operation modes

Op. mode	θ_i	NESZ [dB]	N_{look}
1	35^o	-41	4,213
2	45^o	-38	5,195
3	55^o	-35	6,018

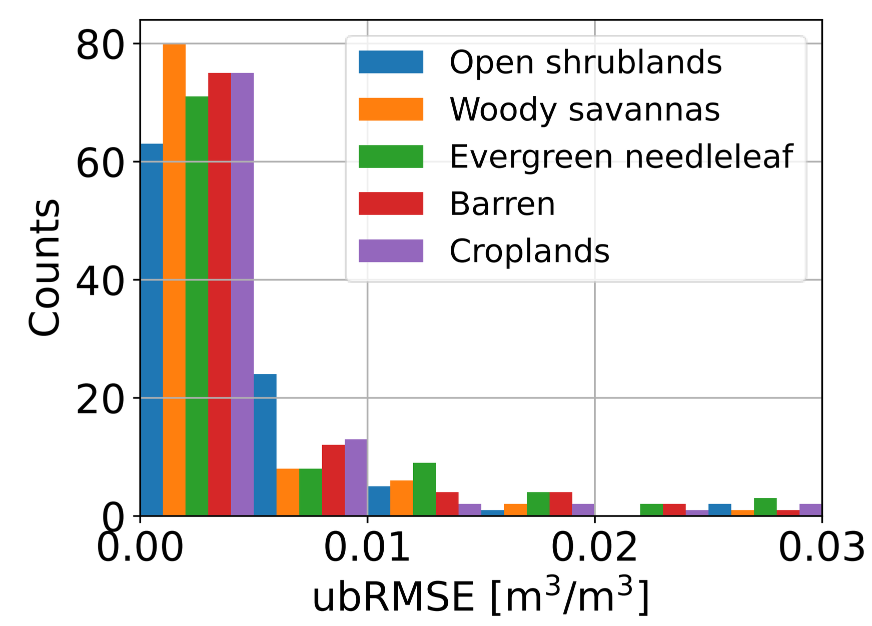
L-band radar operation modes

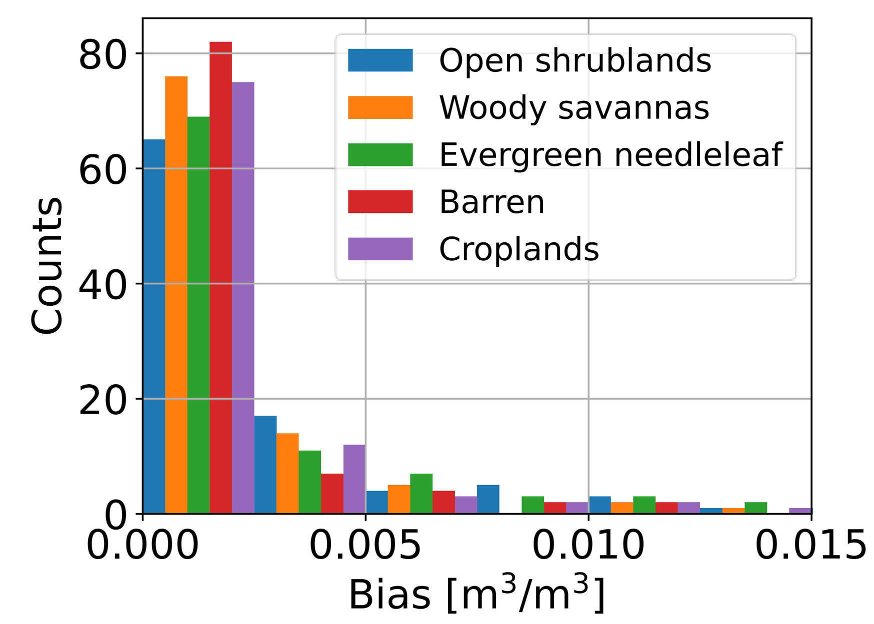
Op. mode	θ_i	NESZ [dB]	N_{look}
1	35^o	-41	411
2	45^o	-37	507
3	55^o	-33	587

Results

*ubRMSE: Unbiased root mean square error

- Retrievals metrics: RMSE, ubRMSE, bias
- Retrievals from D-SHIELD instruments outperformed retrievals from instrument of SMAP specification
- Both means of RMSE and bias were very small, for all vegetation types
- For over %80 of operation modes combinations, ubRMSE$< 0.01\ m^3/m^3$, which is very small ubRMSE
- RMSE values are used by the planner to optimize for satellites operation modes



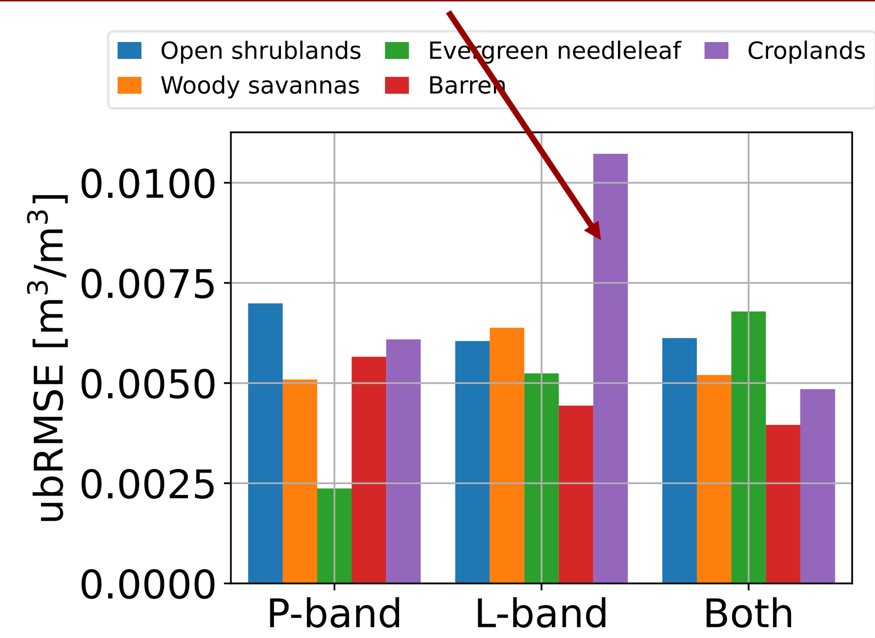


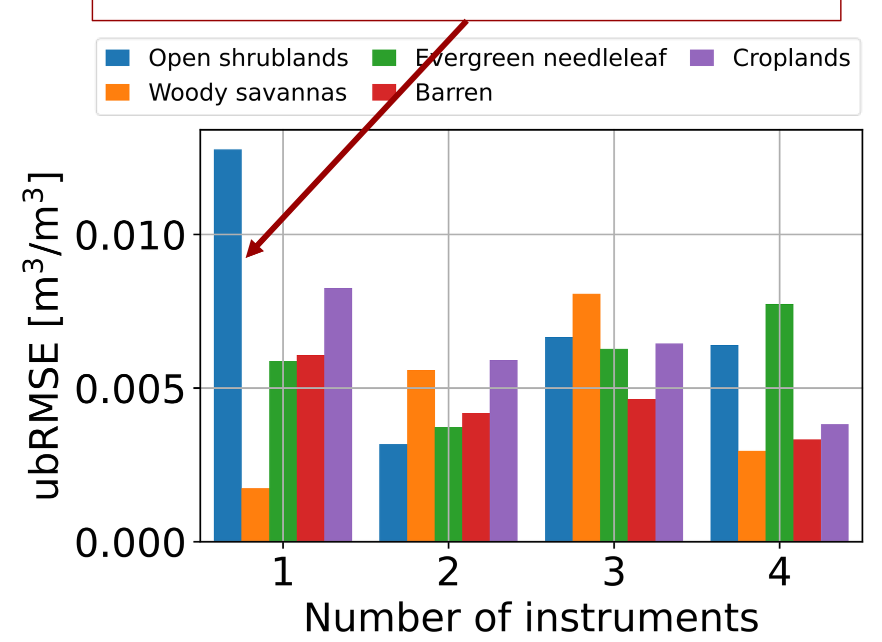
Retrieval performance of all operation modes

IGBP No.	ubRMSE $[m^3/m^3]$ Mean	std	SMAP	Bias $[m^3/m^3]$ Mean	std	SMAP
1	0.006	0.011	0.030	0.003	0.006	0.021
7	0.006	0.009	0.054	0.003	0.005	0.049
8	0.005	0.017	0.013	0.003	0.010	0.018
12	0.005	0.011	0.026	0.003	0.007	0.031
16	0.004	0.006	0.013	0.002	0.003	0.006

Retrievals using P-band radar have better or similar performance to retrievals using L-band radar

There is no significant performance improvement for using more than 2 observations in the retrieval





Future Directions

- The multiple observations can be used to retrieve other geophysical parameters such as surface roughness and vegetation water content
- By combining L- and P-band data, we expect to get enhanced vegetation characterization and increase the number of unknowns that the system can retrieve