Systematic Retrieval of Vegetation Structure and Biochemistry from Sentinel-2 MSI Imagery

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INTRODUCTION

Sentinel-2 (S2) mission requirements include fraction cover (FCOVER), leaf area index (LAI), leaf chlorophyll and water content (Cab, Cw) Level 2B products.[1]

ESA S2 Toolbox includes the Simplified Level 2 Product Prototype Processor (SL2P) for Level 2B products.[2] FCOVER generally meets specifications but other parameters indicate biases at high LAI. [3,4]

Can SL2P estimates of LAI, FCOVER and CWC=LAIxCw be improved by different training or inversion strategies?

Hypotheses

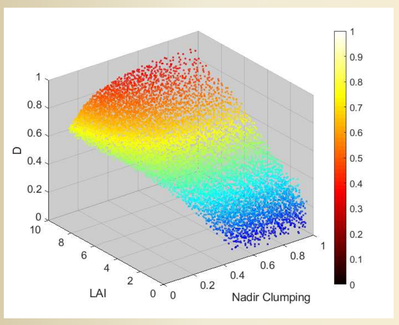
H1: Uniform LAI, Cw, Cab priors will decrease bias but increase RMSE.

H2: UNIFORM priors + constrained inversion using Directional Area Scattering Factor will decrease bias and RMSE.

METHODS

Directional Area Scattering Factor

- canopy directional reflectance for foliage albedo ω=1.
- for black soil, requires no prior knowledge of ω[5]
- closely related to LAI, FCOVER, clumping[6]



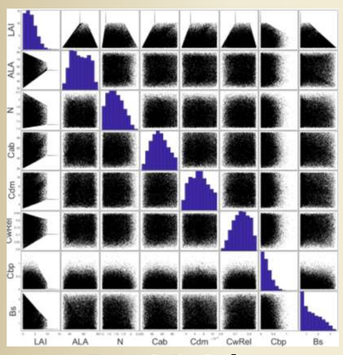
Modelled D using PROSAILH for one selected soil, foliage and geometry over a range of LAI and clumping.

Algorithms

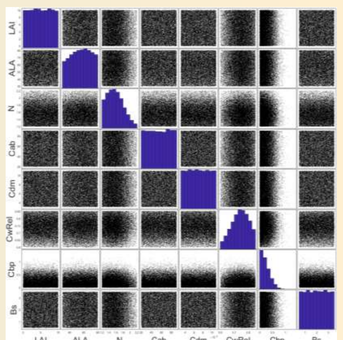
- Single hidden layer backprop. neural net per variable
- Training/valid. database using PROSPECT+SAILH
- UNIFORM-D: multiple networks for subsets of D

Treatment	Geometry PDF	Canopy PDF	#Networks	Training
SL2P	Global S2A Annual Cycle	Global Heuristic	FCOVER LAI, CWC, D: 1 net each	>40,000 random samples/net 1/3 cross-validation, 1/3 hold out
Uniform	Global S2A Annual Cycle	Uniform LAI, Cab, Cw, Cdry	FCOVER LAI, CWC, D: 1 net each D: 1 net FCOVER LAI, CWC: 20 nets spanning D=[0,1]	
Uniform-D	Global S2A Annual Cycle	Uniform LAI, Cab, Cw, Cdry		

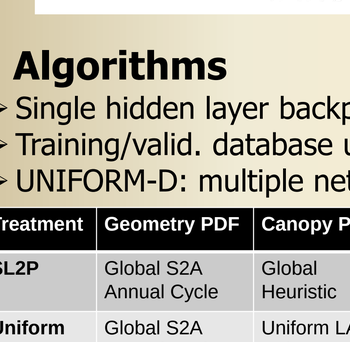
SL2P **UNIFORM,UNIFORM-D**



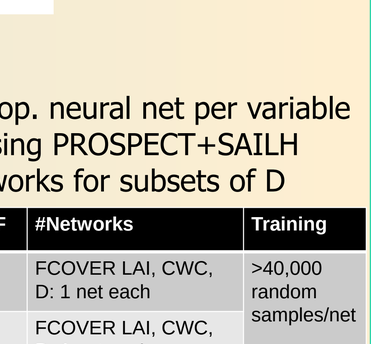
Input Database



Input Database



Output Database



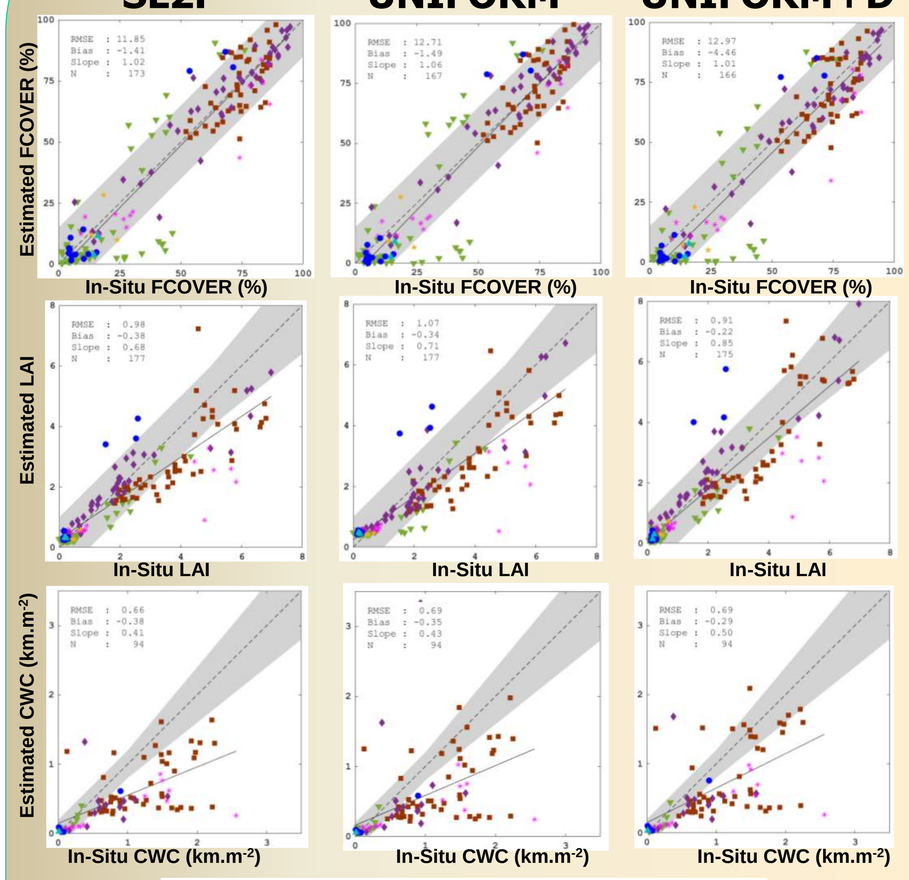
Output Database

Validation

- **In-Situ**: SMAPVEX16-MB crops (Manitoba, Canada)[3]
  - CANEYE DHP for LAI, FCOVER, destructive CWC
  - RMSE and BIAS for all crops,
  - Comparison to S2 User requirements (shaded)
- **Synthetic**: Hold out PROSAILH cross-validation
  - RMSE, BIAS as a function of actual value

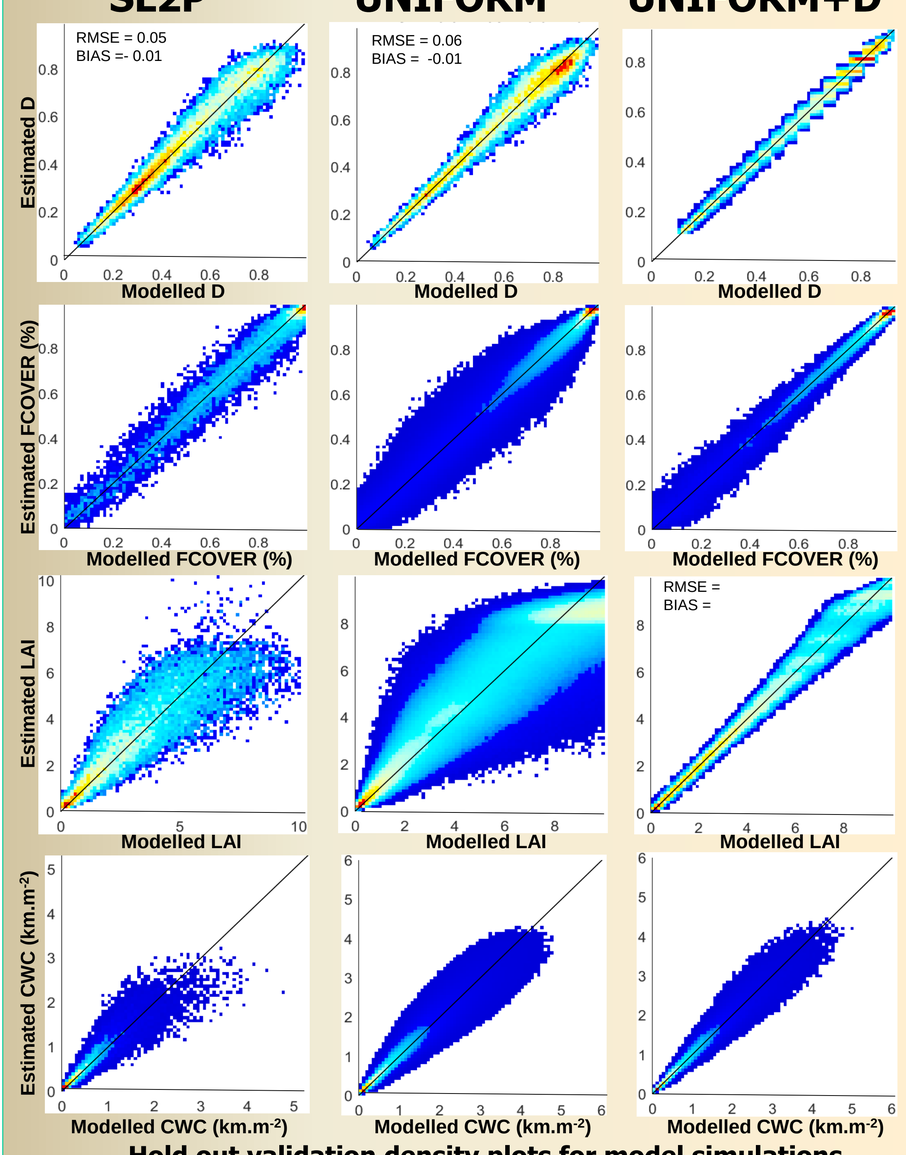
RESULTS: IN-SITU

SL2P **UNIFORM** **UNIFORM+D**

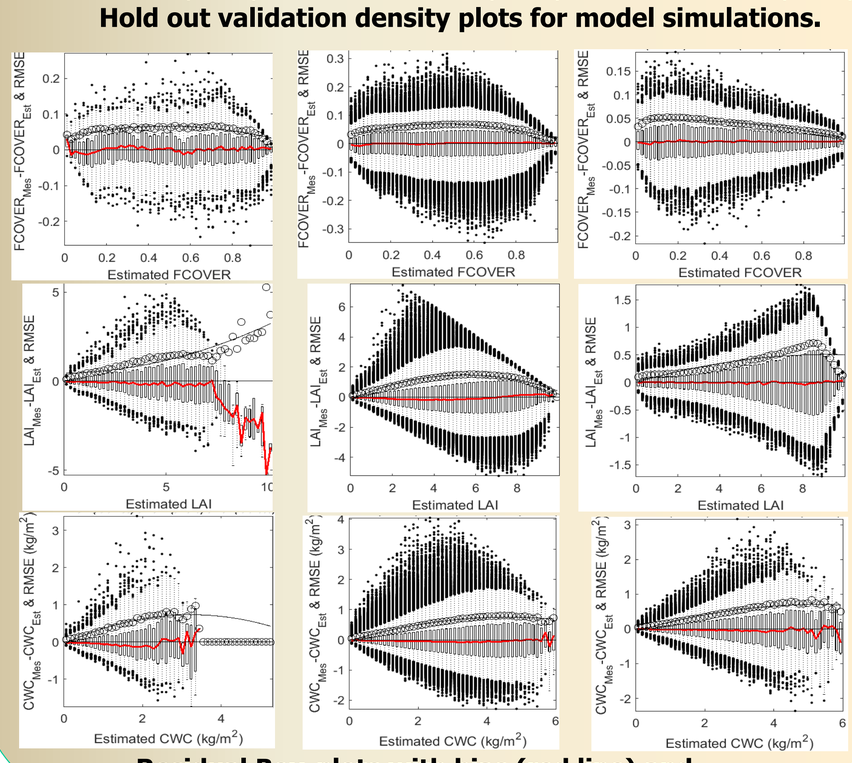


RESULTS: SYNTHETIC

SL2P **UNIFORM** **UNIFORM+D**



Hold out validation density plots for model simulations.



Residual Box-plots with bias (red line) and absolute residual (black line).

CONCLUSIONS

For LAI and FCOVER

H1: Uniform priors decreased bias and increased RMSE for in-situ comparisons.

H2: Uniform priors + Directional Area Scattering Factor reduced bias and RMSE for in-situ and synthetic comparisons.

For CWC, results inconclusive for in-situ; cross-validation agrees with LAI and FCOVER.

RECOMMENDATIONS

1. Directional Area Scattering Factor should be a new Level 2B product for Sentinel 2.
2. Uniform priors + Directional Area Scattering Factor constraint should be provided in SNAP.
3. Further validation required for canopy water and chlorophyll content retrieval constrained with D.

DISCUSSION

Methodology

SMAPVEX16 data represents a strong test of sensitivity to crop structure and soil conditions but has limited acquisition geometry and no forest cases.

In-situ Validation

Large LAI and FCOVER residuals at LAI>3 were expected. Large FCOVER residuals for some oat Samples likely due to biased DHP sampling.

CWC residuals larger and less systematic for crops with substantial stem biomass or flowers (wheat, oat, canola). Suggests results may improve for canopies with high LAI to plant area index ratio.

Cross-Validation

D was estimated with <5% RMSE and low (<0.01) bias. Suggests D can be estimated from Sentinel-2 without knowing leaf, soil or view/illumination parameters.

Cross-validation overoptimistic for LAI for UNIFORM-D. Suggests clumping more complex in-situ in comparison to SL2P approach (PROSAILH with variable vegetation cover fraction. A discrete radiative transfer model may improve uncertainty estimates.

REFERENCES

[1]ESA, 2007, GMES Sentinel-2 Mission Requirements Document, European Space Agency. , EOP-SM/1163/MR-dr.

[2]Weiss, M.; Baret, F., 2016. S2ToolBox Level 2 Products. Version 1.1. Accessed at: step.esa.int/docs/extra/ATBD_S2ToolBox_L2B_V1.1.pdf.

[3]Djamai, N., Fernandes, R., Weiss, M., McNairn, H., Goita, K., 2019. Validation of the Sentinel Simplified Level 2 Product Prototype Processor (SL2P) for mapping cropland biophysical variables using Sentinel-2/MSI and Landsat-8/OLI data. Remote Sens. Environ. 225, 416-430.

[4]Upreti, D., et al., 2019, A Comparison of Hybrid Machine Learning Algorithms for the Retrieval of Wheat Biophysical Variables from Sentinel-2, Remote Sensing, 11, https://doi.org/10.3390/rs11050481

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