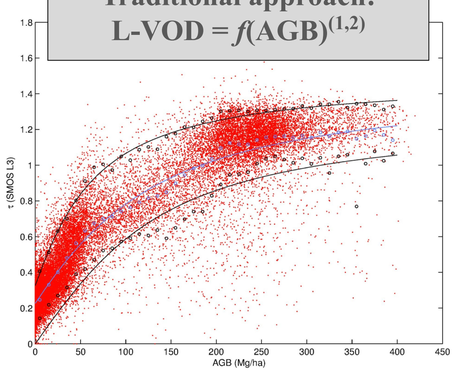
A Novel Observation Operator for Assimilating Microwave Vegetation Optical Depth into Vegetation / Carbon Cycle Models

W. Knorr(1), M. Williams(2), T. Thum(3), T. Kaminski(1), M. Vossbeck(1) and TCCAS Team*
(1) The Inversion Lab, Hamburg; (2) University of Edinburgh; (3) Finnish Meteorological Institute

Summary

- Large-scale monitoring capabilities for biomass, carbon and water fluxes of land vegetation are needed for carbon accounting.
- Satellite-based sensors can monitor the attenuation of microwave radiation by terrestrial plants as Vegetation Optical Depth (VOD), together with surface-level soil moisture.
- VOD depends on the mass and water status of stems, branches and leaves as well as on temperature. Here, we focus on VOD in the L-band (21 cm or 1.4 GHz).
- So far, L-VOD has been interpreted as a proxy for above-ground biomass (AGB) using empirical non-linear functions. This approach ignores the effects of water status or temperature and discards information contained in the temporal profile of the VOD-signal.
- We present a novel observation operator (model) that predicts L-VOD on the basis of woody and leaf biomass, plant water status and temperature. Coupled to simulations with the D&B terrestrial biosphere model, the observation operator successfully captures temporal variability at a study site in northern Finland.
- With this new L-VOD obs. operator, we assimilate[2] SMOS L-VOD, surface soil moisture and solar-induced fluorescence (SIF) during 2017-2021 into D&B for a region in Iberia..
- Thus simulated L-VOD captures the annual cycle and some of the high-frequency variation of the SMOS data.
- In this way, remotely sensed L-VOD can be used to improve estimates of regional carbon fluxes.
- We also refine parameters of the L-VOD obs. operator. However, we underestimate observed biomass. Final parameterisation of the observation operator is still under way.

Traditional approach: L-VOD = f(AGB)[1,2]



New Approach: Observation Operator[3]

biomass multiplier — water status multiplier

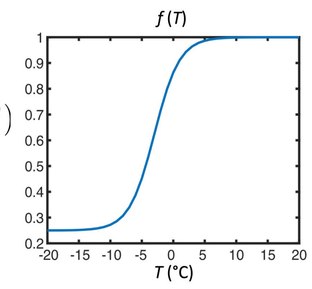
$$\tau_\lambda = f(T)(l_{wd}C_{wd} + l_{fol}C_{fol})(l_s f_{soil} + l_f f_E + l_0)$$

C in wood; C in foliage; plant-available soil water, fraction of field capacity; actual / potential evapotranspiration

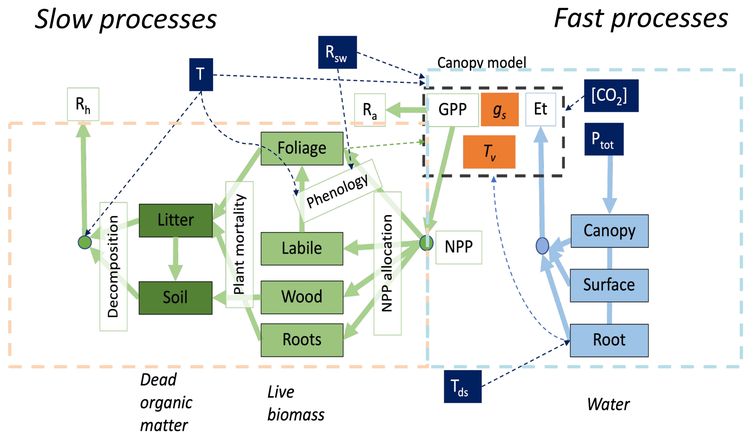
l_x: parameters

temperature function (4)

$$f(T) = 0.25 + 0.75/(1 + e^{-0.5(T+3)})$$

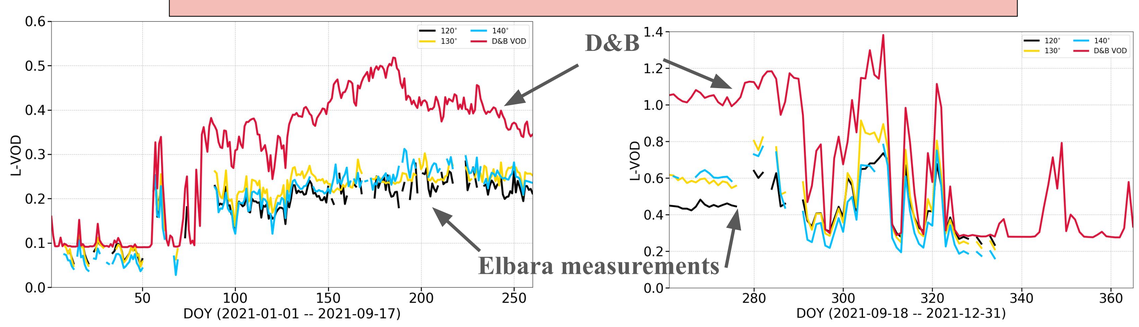


DALEC: *Slow processes* — **BETHY:** *Fast processes*

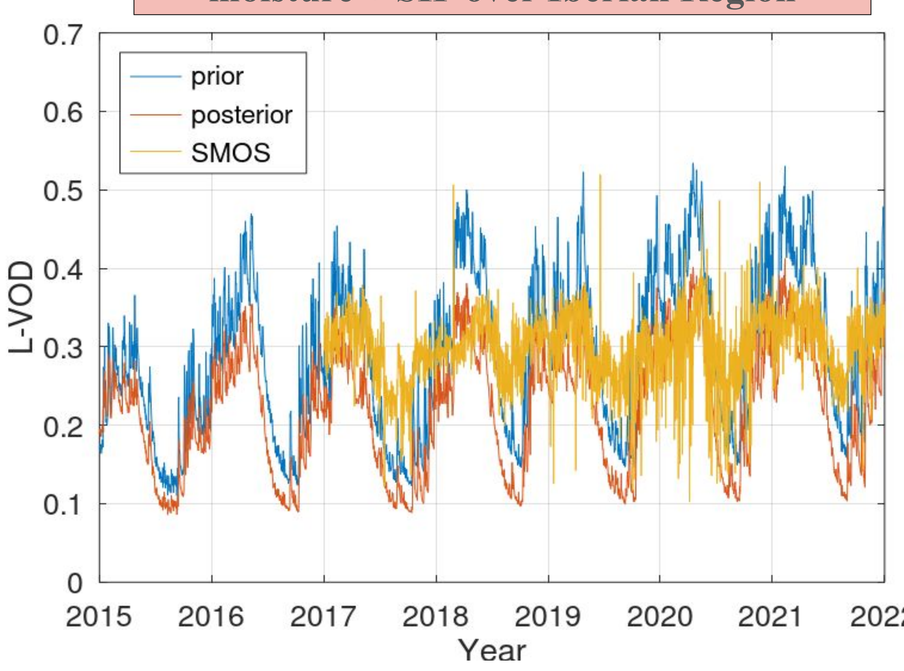


D & B The DALEC-BETHY Terrestrial Ecosystem Model

Validation of L-VOD at Sodankylä, Finland[4]



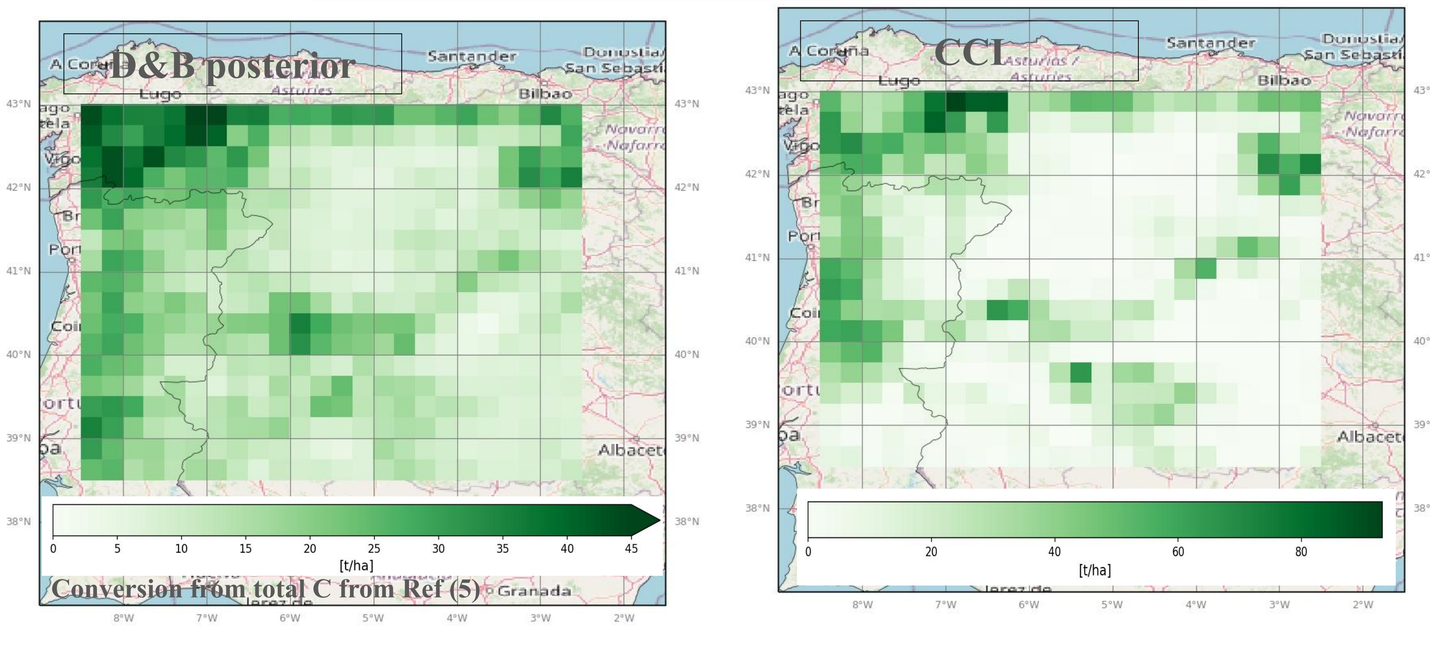
Assimilation of SMOS L-VOD & soil moisture + SIF over Iberian Region



Iberia Total	Prior	Posterior	FLUXCOM V2
GPP [MtC/yr]]	559	397	223
NEE [MtC/yr]	-26	-3	-16

Parameter	Prior	Posterior	Description
l_{wd}	2.00 x 10^{-4}	1.70 x 10^{-4}	multiplier of wood carbon pool [m^2/gC]
l_{fol}	2.00 x 10^{-4}	1.30 x 10^{-4}	multiplier of leaf carbon pool [m^2/gC]
l_s	1.20	1.15	multiplier of slowly changing plant water status
l_f	2.00	1.37	multiplier of rapidly changing plant water status
l_0	0.40	0.44	offset

Validation against CCI Above-Ground Biomass



*Full Terrestrial Carbon Cycle Assimilation System (TCCAS) and author team: Knorr W , Williams M , Thum T , Kaminski T , Voßbeck M , Scholze M , Quaife T , Smallmann T , Steele-Dunne S , Vreugdenhil M , Green T , Zaehle S , Aurela M , Bouvet A , Bueechi E , Dorigo W , El-Madany T , Migliavacca M , Honkanen M , Kerr Y , Kontu A , Lemmetyinen J , Lindqvist H , Mialon A , Miinalainen T , Pique G , Ojasalo A , Rodríguez-Fernández N , Schwank M , Rayner P , Reyez-Muñoz P , Verrelst J , Zhu S , Quegan S , Schüttemeyer D , Drusch M

References

1) Rodríguez-Fernández, N. J., Mialon, A., Mermoz, S., Bouvet, A., Richaume, P., Al Bitar, A., Al-Yaari, A., Brandt, M., Kaminski, T., Le Toan, T., Kerr, Y. H., and Wigneron, J.-P.: An evaluation of SMOS L-band vegetation optical depth (L-VOD) data sets: high sensitivity of L-VOD to above-ground biomass in Africa, Biogeosciences, 15, 4627–4645, https://doi.org/10.5194/bg-15-4627-2018, 2018.
2) Scholze, M., Kaminski, T., Knorr, W., Voßbeck, M., Wu, M., Ferrazzoli, P., et al.. Mean European carbon sink over 2010–2015 estimated by simultaneous assimilation of atmospheric CO2, soil moisture, and vegetation optical depth. Geophysical Research Letters, 46. https://doi.org/10. 1029/2019GL085725, 2019.
3) Schwank, M., Kontu, A., Mialon, A., Naderpour, R., Houtz, D., Lemmetyinen, J., Rautiainen, K., Li, Q., Richaume, P., Kerr, Y. and Mätzler, C. Temperature effects on L-band vegetation optical depth of a boreal forest. Remote Sensing of Environment, 263, p.112542, 2021
4) Knorr, Wolfgang, Matthew Williams, Tea Thum, Thomas Kaminski, Michael Voßbeck, Marko Scholze, Tristan Quaife et al. "A comprehensive land-surface vegetation model for multi-stream data assimilation, D&B v1. 0." Geoscientific Model Development 18, 2137-2159, 2025.
5) Saatchi, S. S., Harris, N. L., Brown, S., Lefsky, M., Mitchard, E. T. A., Salas, W., Zutta, B. R., Buermann, W., Lewis, S. L., Hagen, S., Petrova, S., White, L., Silman, M., and Morel, A.: Benchmark map of forest carbon stocks in tropical regions across three continents., P. Natl. Acad. Sci. USA, 108, 9899–9904, doi: 10.1073/pnas.1019576108, 2011