Terrestrial Carbon Community Assimilation System

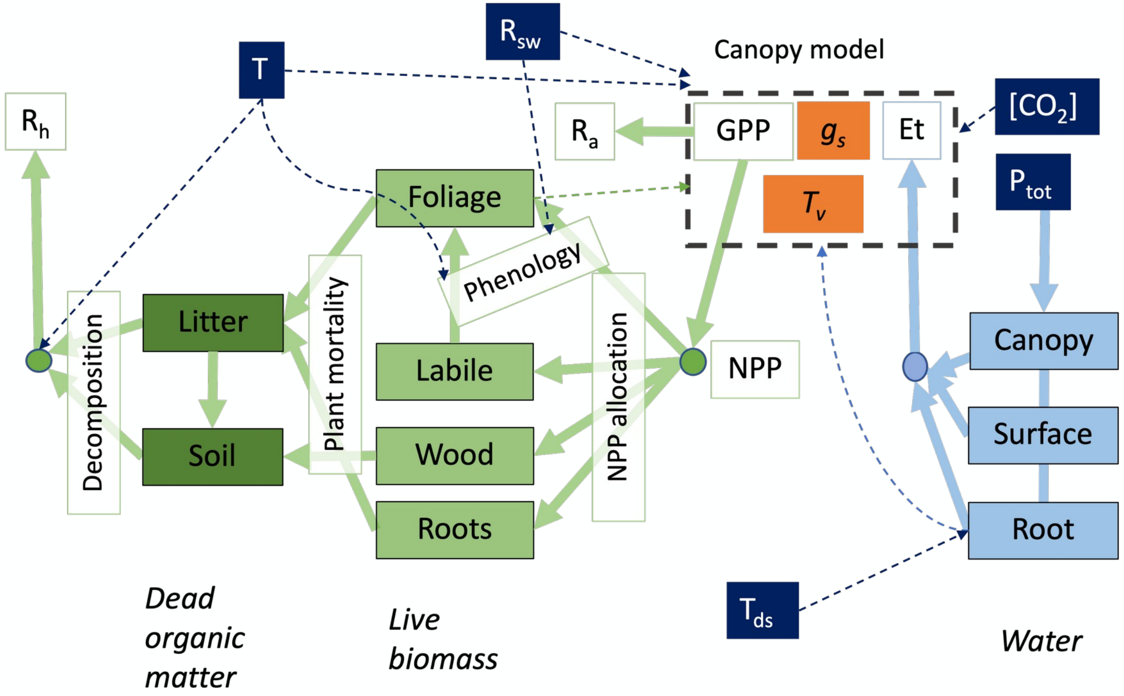
Thomas Kaminski[1], Tea Thum[2], Wolfgang Knorr[1], Michael Voßbeck[1], Mathew Williams[3], Timothy Green[3], Luke Smallman[3], Marko Scholze[4], Tristan Quaife[5], Sönke Zaehle[6], Peter Rayner[1], Susan Steele-Dunne[7], Mariette Vreugdenhil[8], Mika Aurela[2], Alexandre Bouvet[9], Emanuel Bueechi[8], Wouter Dorigo[8], Tarek S. El-Madany[6], Marika Honkanen[2], Yann H. Kerr[9], Anna Kontu[2], Juha Lemmetyinen[2], Hannakaisa Lindqvist[2], Arnaud Mialon[9], Tuuli Miinalainen[2], Amanda Ojasalo[2], Shaun Quegan[10], Pablo Reyez Muñoz[11], Nemesio Rodriguez-Fernandez[9], Mike Schwank[12], Jochem Verrelst[11], Matthias Drusch[13], and Dirk Schüttemeyer[13]

[1]The Inversion Lab, Hamburg, Germany
[2]FMI, Helsinki, Finland
[3]University of Edinburgh, UK
[4]University of Lund, Sweden
[5]University of Reading, UK
[6]MPI BGC Jena, Germany
[7]TU Delft, The Netherlands
[8]TU Wien, Austria
[9]CESBIO Toulouse, France
[10]University of Sheffield, UK
[11]University of Valencia, Spain
[12]Swiss Federal Institute for Forest, Snow and Landscape Research, Switzerland
[13]ESA, ESTEC, The Netherlands

FLEX Nutzerseminar
7. June

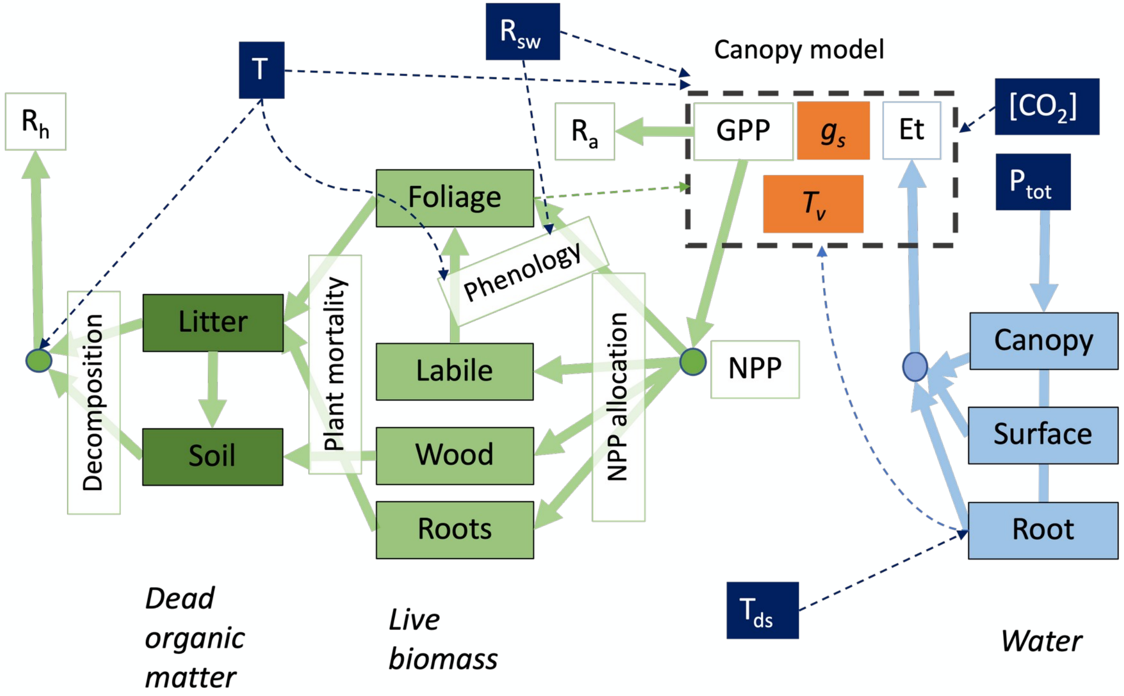
What is TCCAS?

- The Terrestrial Carbon Community Assimilation System (TCCAS) is built around the newly developed D&B terrestrial biosphere model.
- The focus of TCCAS is the combination of a diverse array of observational data streams with the D&B model to yield a consistent picture of the terrestrial carbon, water and energy cycles.
- The development of TCCAS is being funded through the carbon cluster of the European Space Agency



Outline

- Model
- Observation Operators
- Validation
- Assimilation System
- Assimilation at site level
- Analysis of information content
- Assimilation at global scale
- Computational Performance
- Training
- Further Information

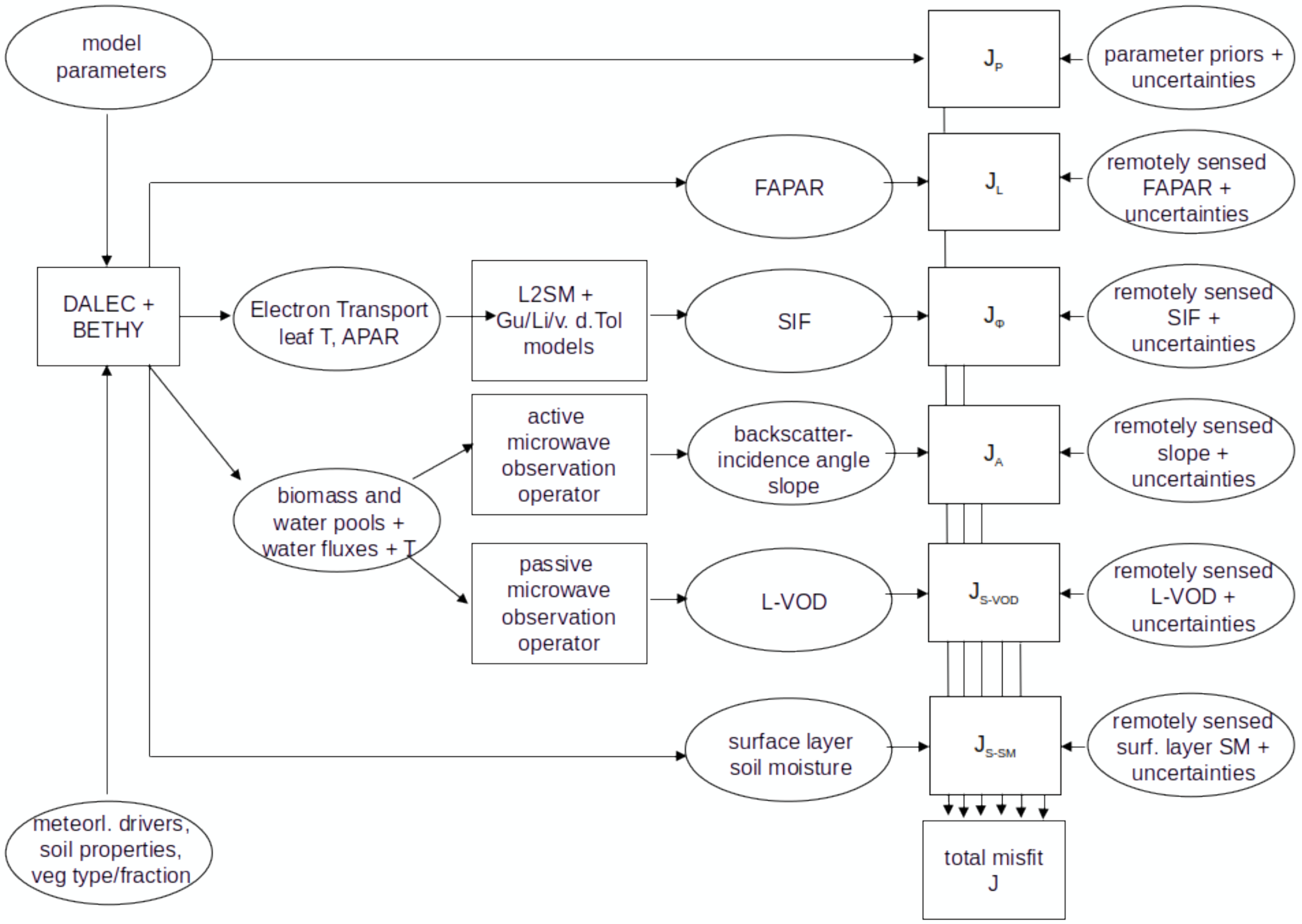


Developed and tested at site and regional scales

- Within the Landsurface Carbon Constellation Study: https://lcc.inversion-lab.com/
- Relied on comprehensive data base of satellite and Field Data
- Collected over two sites/regions:
  - Sodankylä, Finland
  - Majadas de Tietar, Spain

What does TCCAS offer?

- Open source community system
- Observation operators for optical as well as active and passive microwave observations
- Assimilation on the footprint
- Tangent and adjoint codes
- Modular setup
- Computational efficiency
- Tested on point to regional scales
- Experienced developer team
- Documentation
- User support and training



Model and Observation Operators

SIF

- Leaf level source: Gu et al. (2019)
- RT: L2SM, Tristan Quaife
- Spectral conversion: Oak or Pine spectra observed by Magney and Frankenberg (2019)

$$S_n = s_{SIF} J_n \frac{1 - \psi_{PSIImax}}{q_L \psi_{PSIImax} (1 + k_{DF})}$$

- Alternative Leaf level source:
  - Van der Tol et al. (2014) or
  - Li et al. (2019)

A comprehensive land surface vegetation model for multi-stream data assimilation, D&B v1.0

Wolfgang Knorr[1], Matthew Williams[2], Tea Thum[3], Thomas Kaminski[1], Michael Voßbeck[1], Marko Scholze[4], Tristan Quaife[5], T. Luke Smallman[2], Susan C. Steele-Dunne[6], Mariette Vreugdenhil[7], Tim Green[2], Sönke Zähle[8], Mika Aurela[3], Alexandre Bouvet[9], Emanuel Bueechi[7], Wouter Dorigo[7], Tarek S. El-Madany[8], Mirco Migliavacca[8,9], Marika Honkanen[3], Yann H. Kerr[10], Anna Kontu[3], Juha Lemmetyinen[3], Hannakaisa Lindqvist[3], Arnaud Mialon[10], Tuuli Miinalainen[3], Gaetan Pique[10], Amanda Ojasalo[3], Shaun Quegan[11], Peter. J. Rayner[1], Pablo Reyez-Muñoz[12], Nemesio Rodríguez-Fernández[9], Mike Schwank[13], Jochem Verrelst[12], Songyan Zhu[2], Dirk Schüttemeyer[14], and Matthias Drusch[14]

[1]The Inversion Lab, Tewessteg 4, D-20249 Hamburg, Germany
[2]University of Edinburgh, Edinburgh, UK
[3]Finnish Meteorological Institute, Helsinki, Finland
[4]Lund University, Lund, Sweden
[5]University of Reading, Reading, UK
[6]Department of Geosciences and Remote Sensing, Delft University of Technology, The Netherlands
[7]Vienna University of Technology, Wien, Austria
[8]Max-Planck Institute for Biogeochemistry, Jena, Germany
[9]DG Joint Research Centre, European Commission, Ispra, Italy
[10]Centre d'études Spatiales de la Biosphère (CESBIO), Université de Toulouse 3 Paul Sabatier, Centre National de la Recherche Scientifique, Centre National d'Etudes Spatiales, Institut de Recherche pour le Développement, Institut National de Recherches pour l'Agriculture, l'Alimentation et l'Environnement, Toulouse, France
[11]University of Sheffield, Sheffield, UK
[12]University of Valencia, Valencia, Spain
[13]Swiss Federal Institute for Forest, Snow and Landscape Research, Birmensdorf, Switzerland
[14]European Space Agency, ESTEC, Noordwijk, The Netherlands

Correspondence: Wolfgang Knorr (wolfgang.knorr@inversion-lab.com)

Abstract. Advances in Earth Observation capabilities mean that there is now a multitude of spatially resolved data sets available that can support the quantification of water and carbon pools and fluxes at the land surface. However, such quantification ideally requires efficient synergistic exploitation of those data, which in turn requires carbon and water land-surface models with the capability to simultaneously assimilate several of such data streams. The present article discusses the requirements for such a model and presents one such model based on the combination of the existing DALEC land vegetation carbon cycle model with the BETHY land-surface and terrestrial vegetation scheme. The resulting D&B model, made available as a community model, is presented together with a comprehensive evaluation for two selected study sites of widely varying climate. We then demonstrate the concept of land surface modelling aided by data streams that are available from satellite remote sensing. Here we present D&B with four observation operators that translate model-derived variables into measurements available from such data streams, namely: fraction of photosynthetically active radiation (FAPAR), solar-induced chlorophyll fluorescence

Model and Observation Operators

SIF

- Leaf level source: Gu et al. (2019)
- RT: L2SM, Tristan Quaife
- Spectral conversion: Oak or Pine spectra observed by Magney and Frankenberg

Electron Transport in Canopy Layer n

Leaf level SIF in Canopy Layer n

$$S_n = s_{SIF} J_n \frac{1 - \psi_{PSIImax}}{q_L \psi_{PSIImax}(1 + k_{DF})}$$

Tunable Scaling Coefficient

Combination of Parameters in Gu model

- Alternative leaf level source models:
  - Van der Tol et al. (2014) or
  - Li et al. (2019)

where J_n is the electron transport in canopy layer n (SI Equ. 16), $\psi_{PSIImax}$ is the maximum photochemical quantum yield of photosystem II, q_L is the fraction of open photosystem II reaction centres and k_{DF} the ratio of the first order rate constants

D&B (uncalibrated) against FloX at Majadas de Tietar
Grass (left), Trees (right); far red (top) and red (bottom)

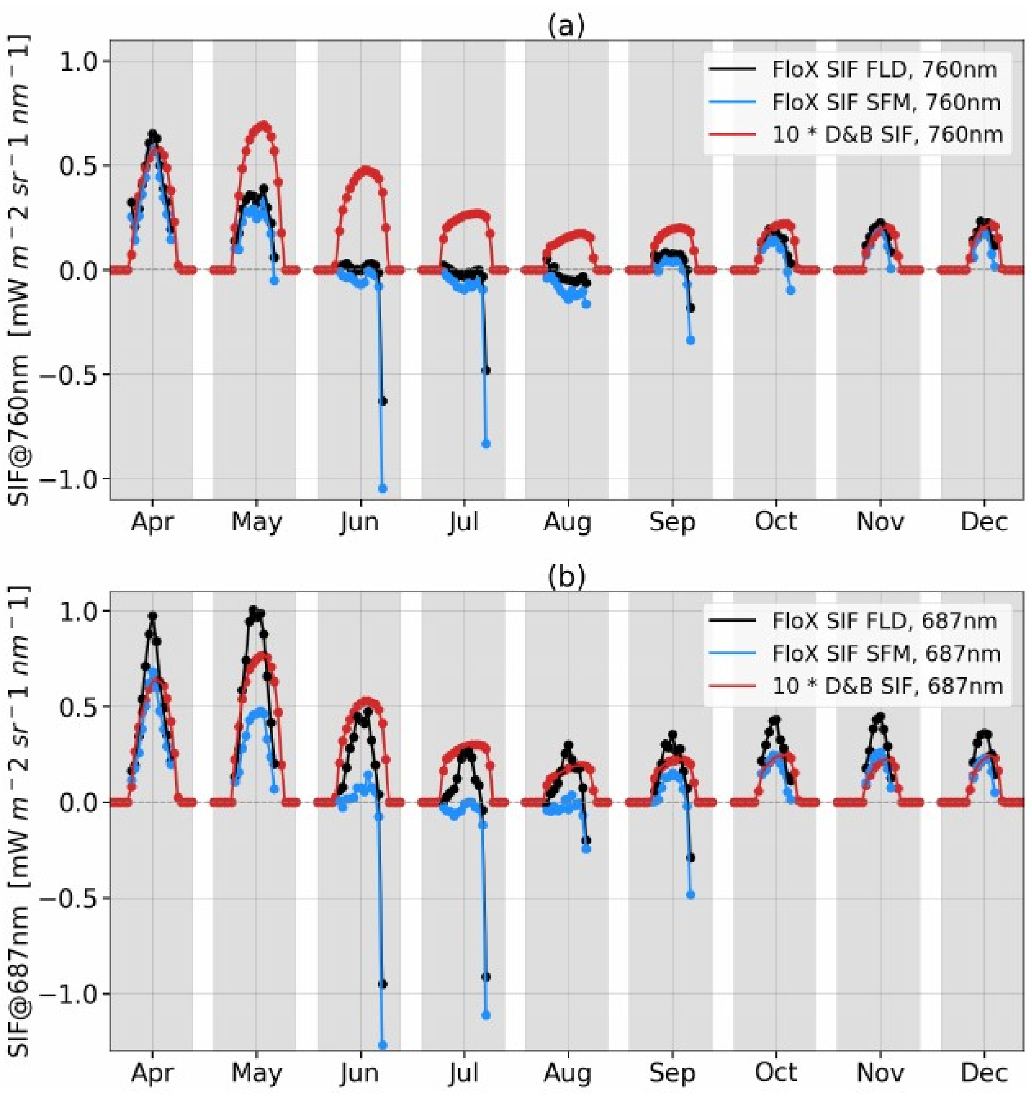


Figure 11. Average hourly diurnal cycle by month of SIF in the far-red (a) and red (b) for C3 grass (PFT 9) at Majadas de Tietar for months April to December in 2021. D&B simulations (red) against measurements: retrievals made with Frauenhofer line discrimination (black) and spectral fitting method (blue).

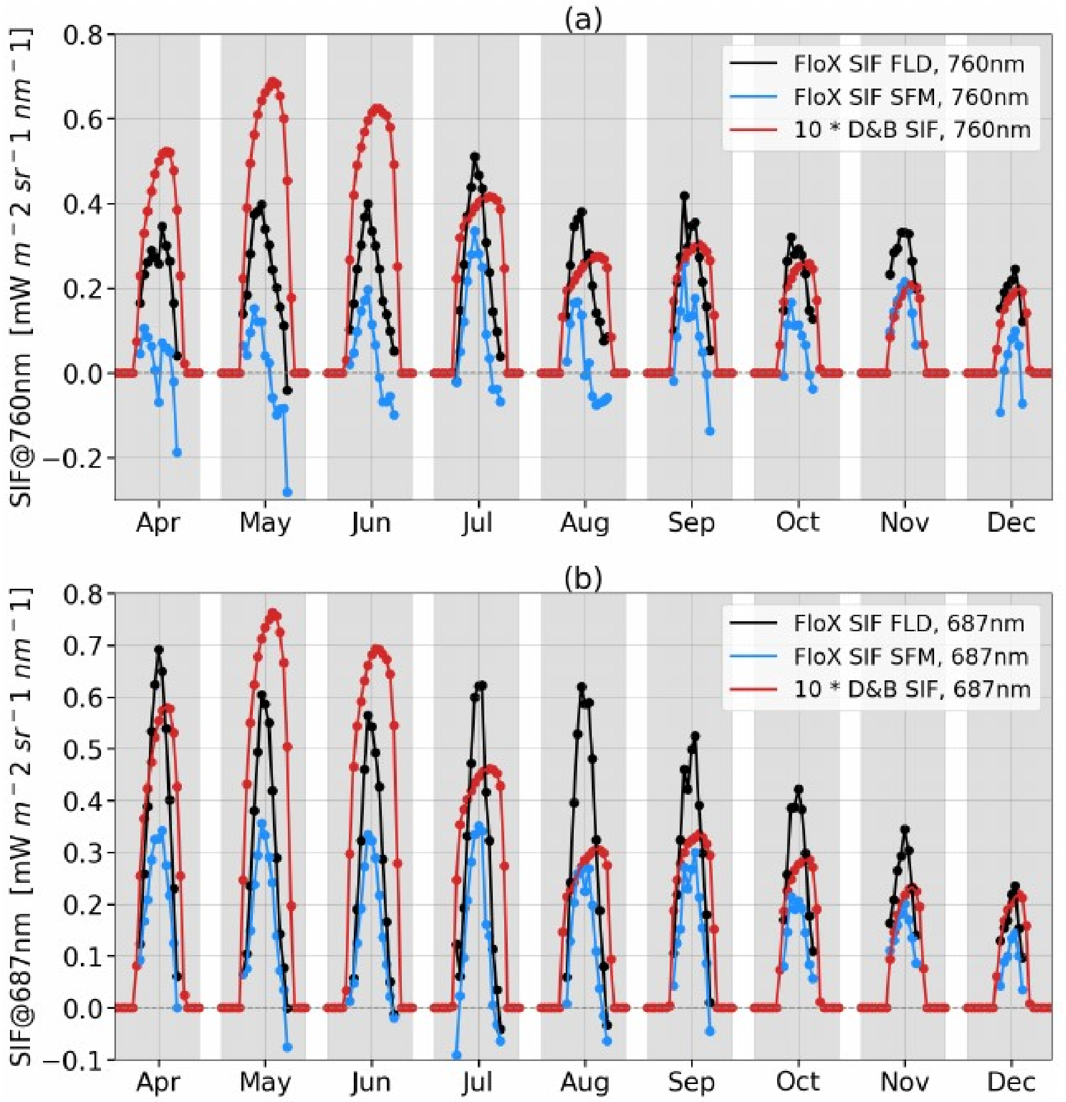
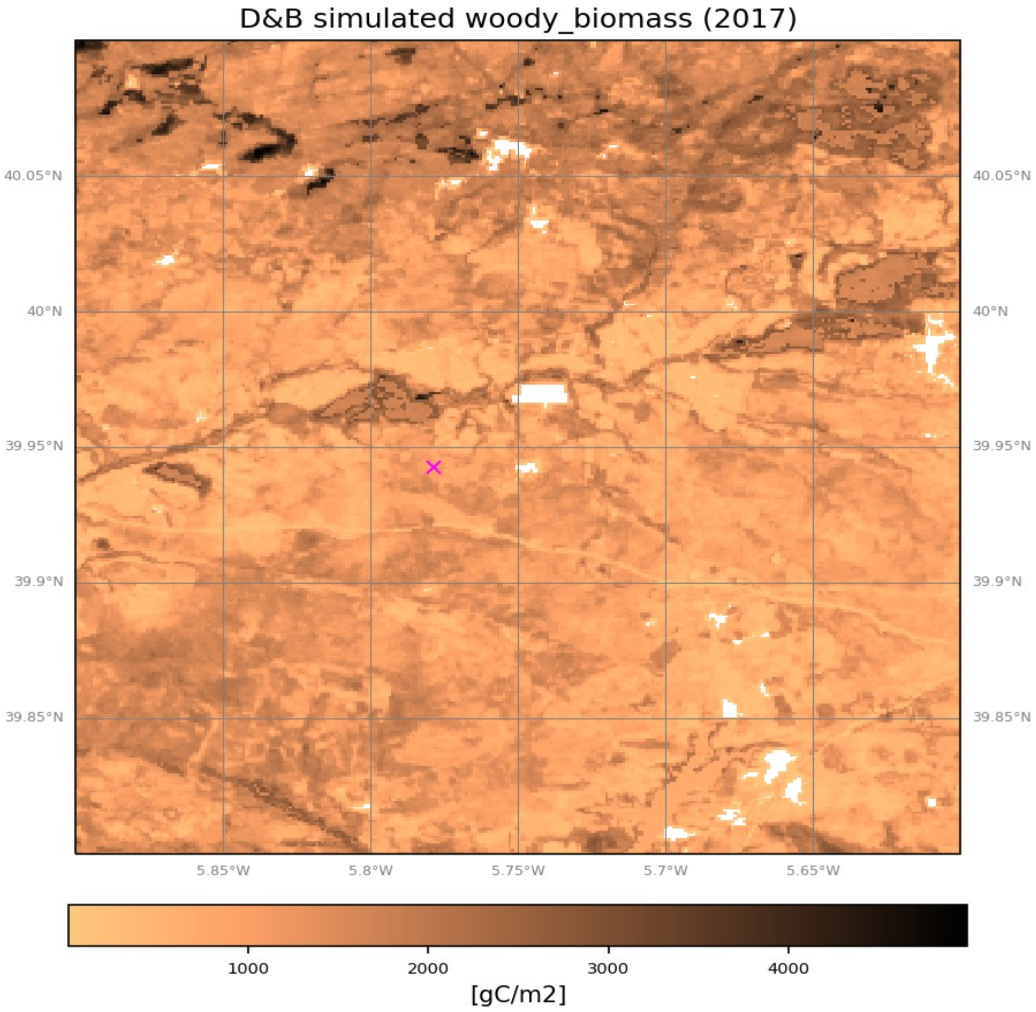
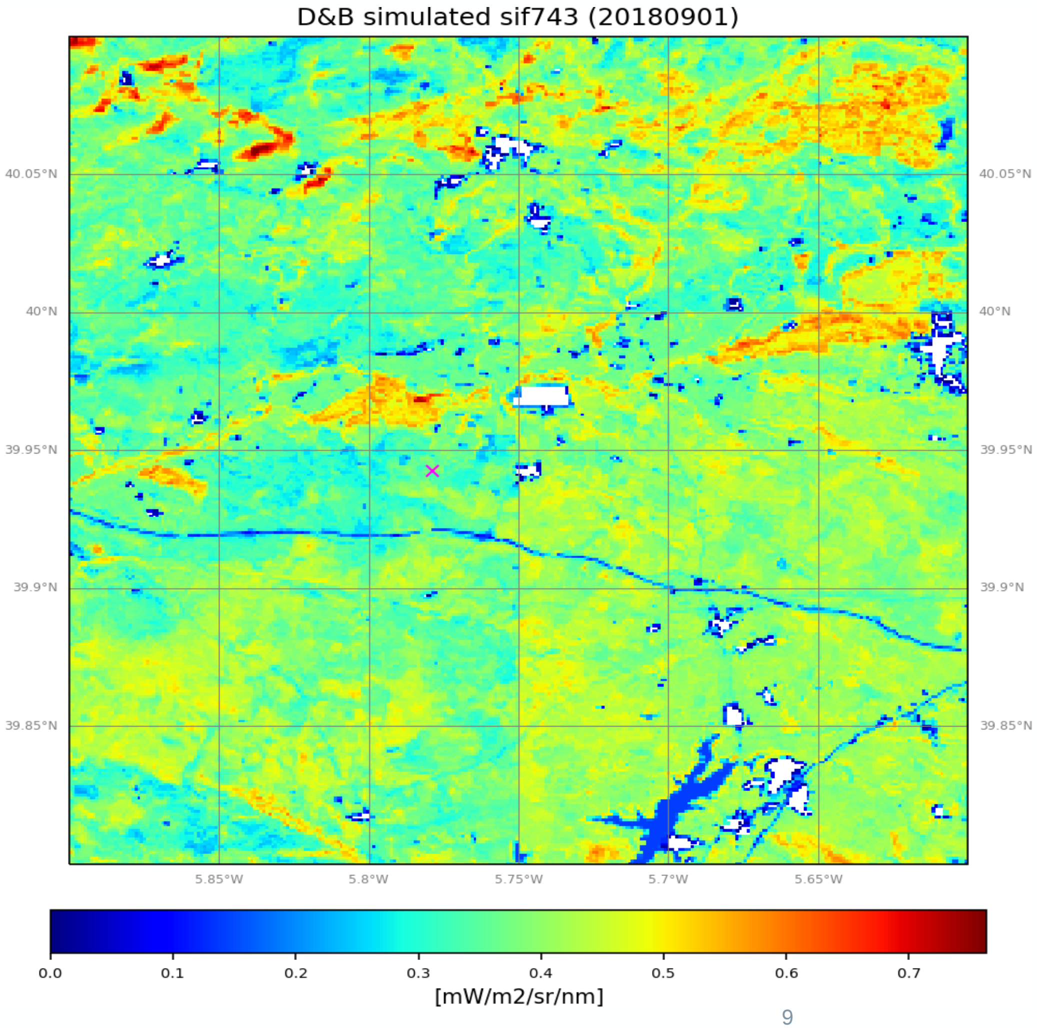


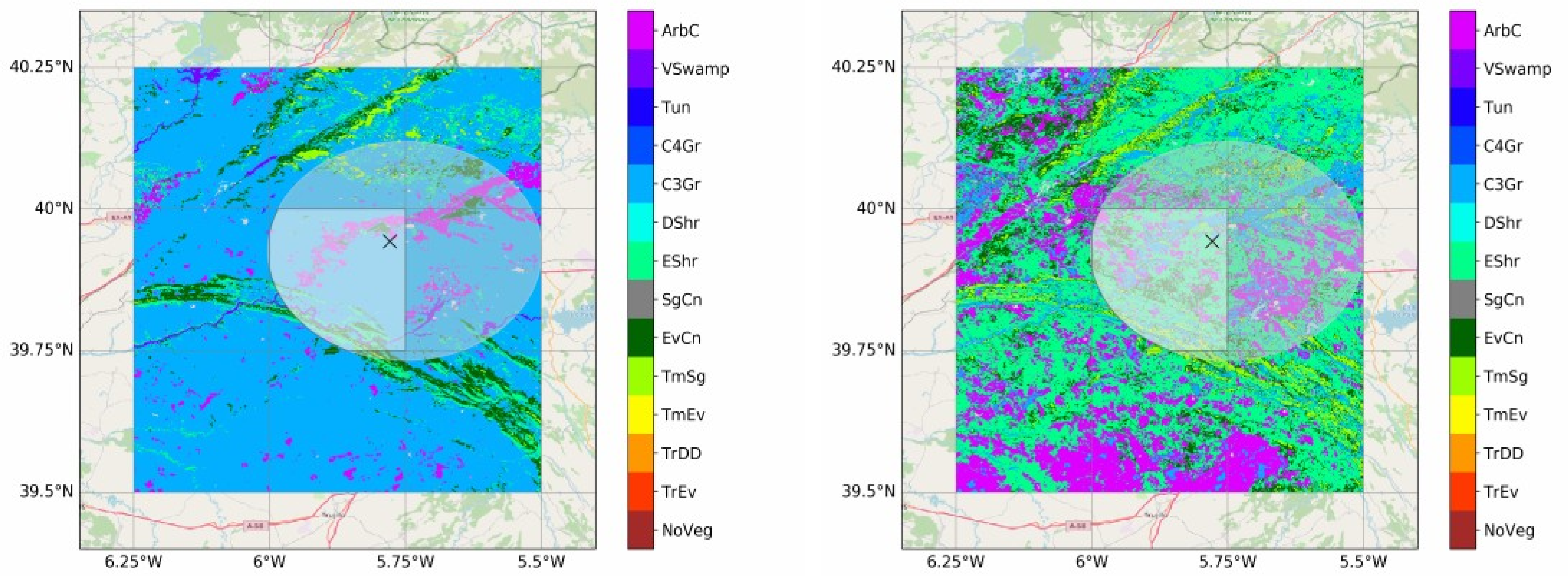
Figure 10. Average hourly diurnal cycle by month of SIF in the far-red (a) and red (b) for evergreen trees (PFT 3) at Majadas de Tietar for months April to December in 2021. D&B simulations (red) against measurements: retrievals made with Frauenhofer line discrimination (black) and spectral fitting method (blue).

Spatial Detail
Examples: Woody biomass (left) and SIF (right) around Majadas de Tietar





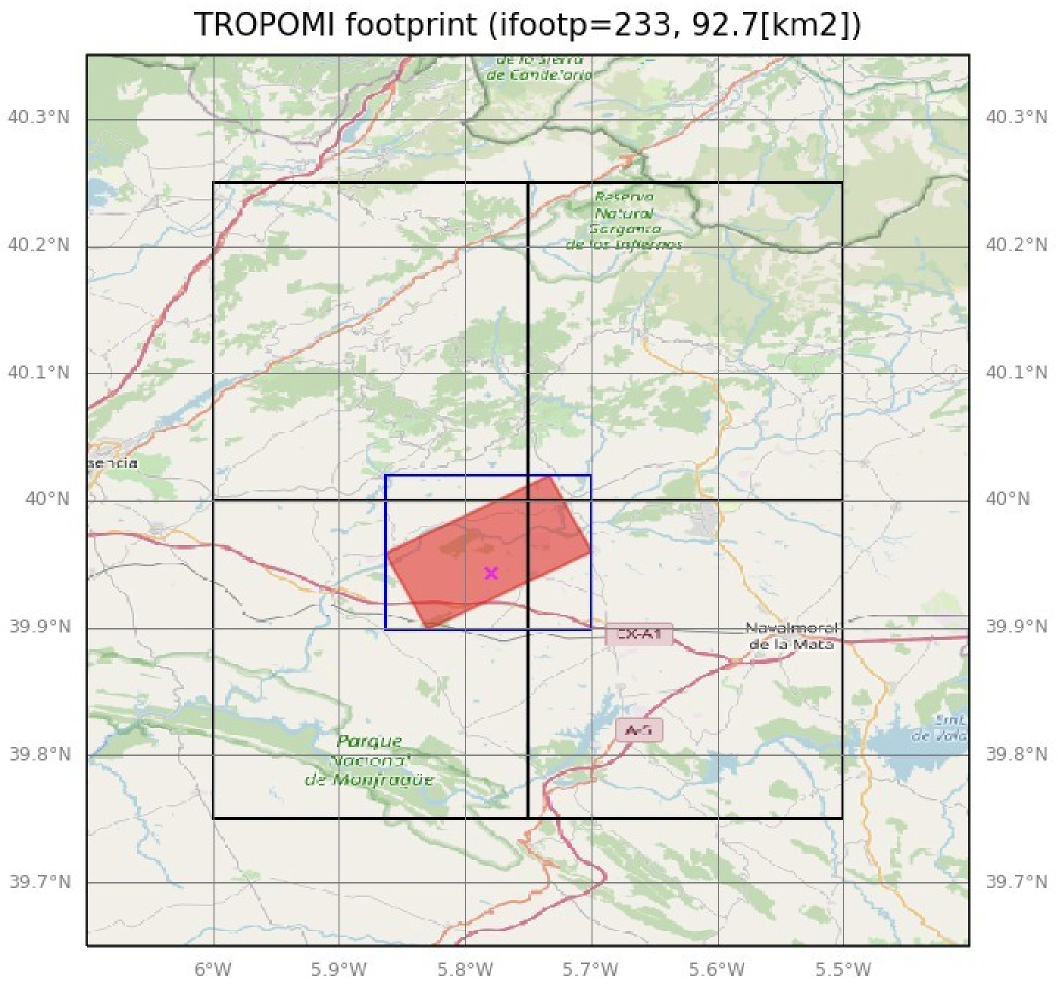
Simulation on the footprint/target area Example: SMOS

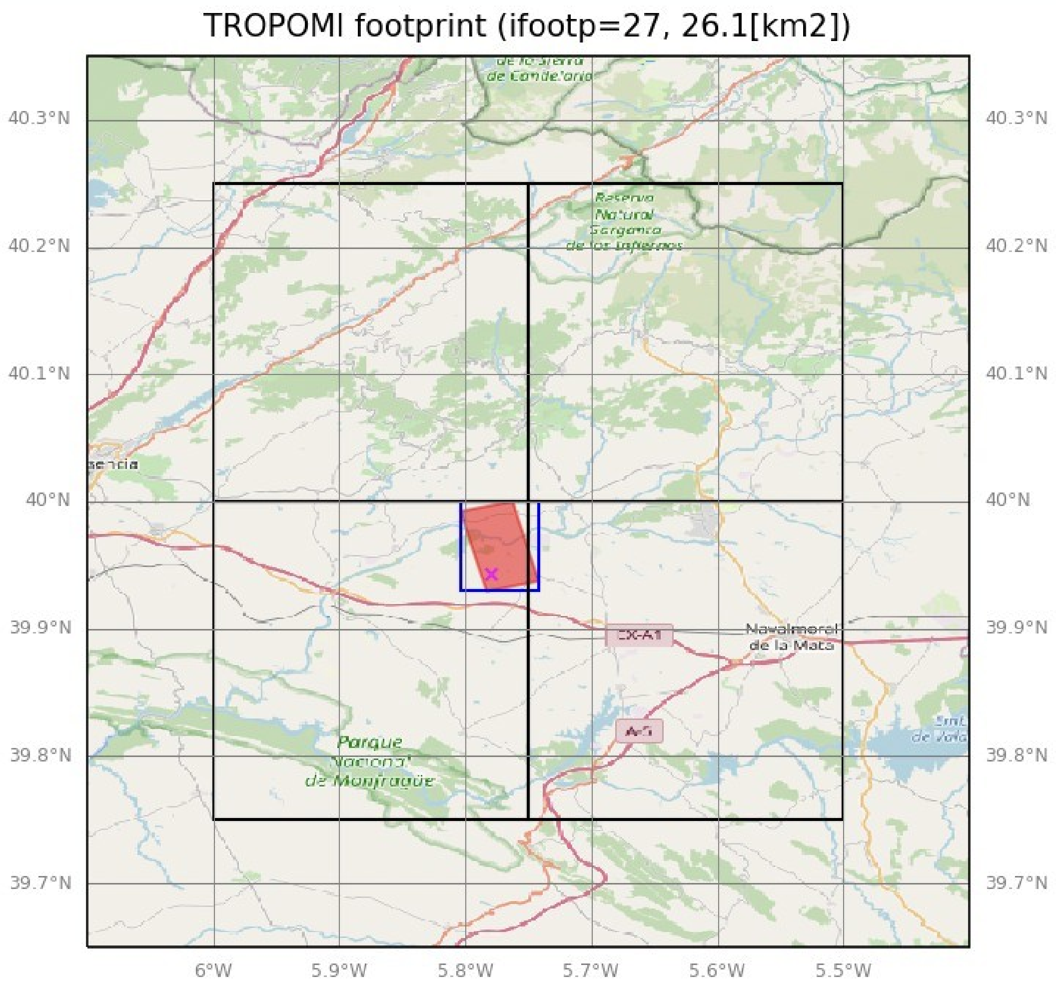


100m Landcover: Copernicus Land, Buchhorn et al. (2019)

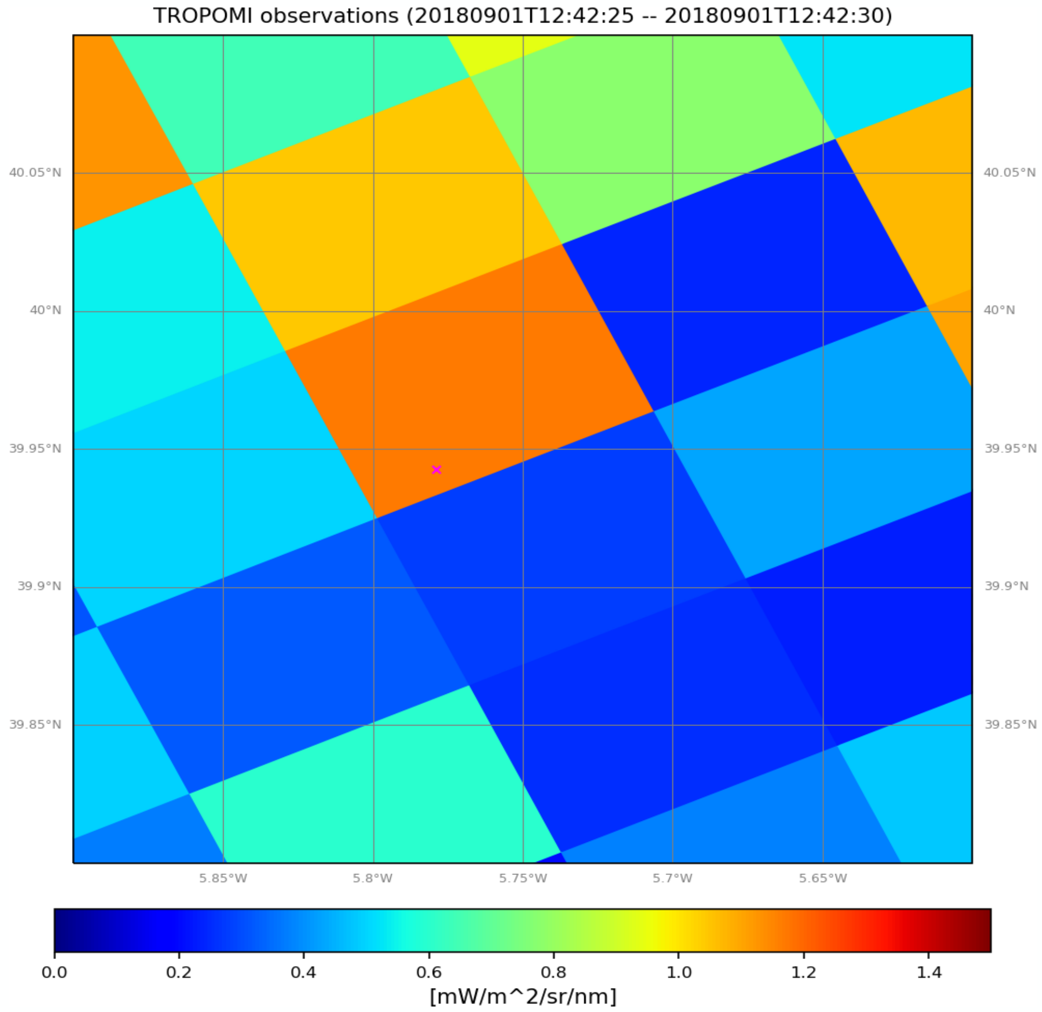
Figure 3: SMOS footprint (ellipse) along with the primary (left) and secondary (right) PFT over the grid defined by the meteorological driving data, with the location of the LM1 site indicated by a cross.

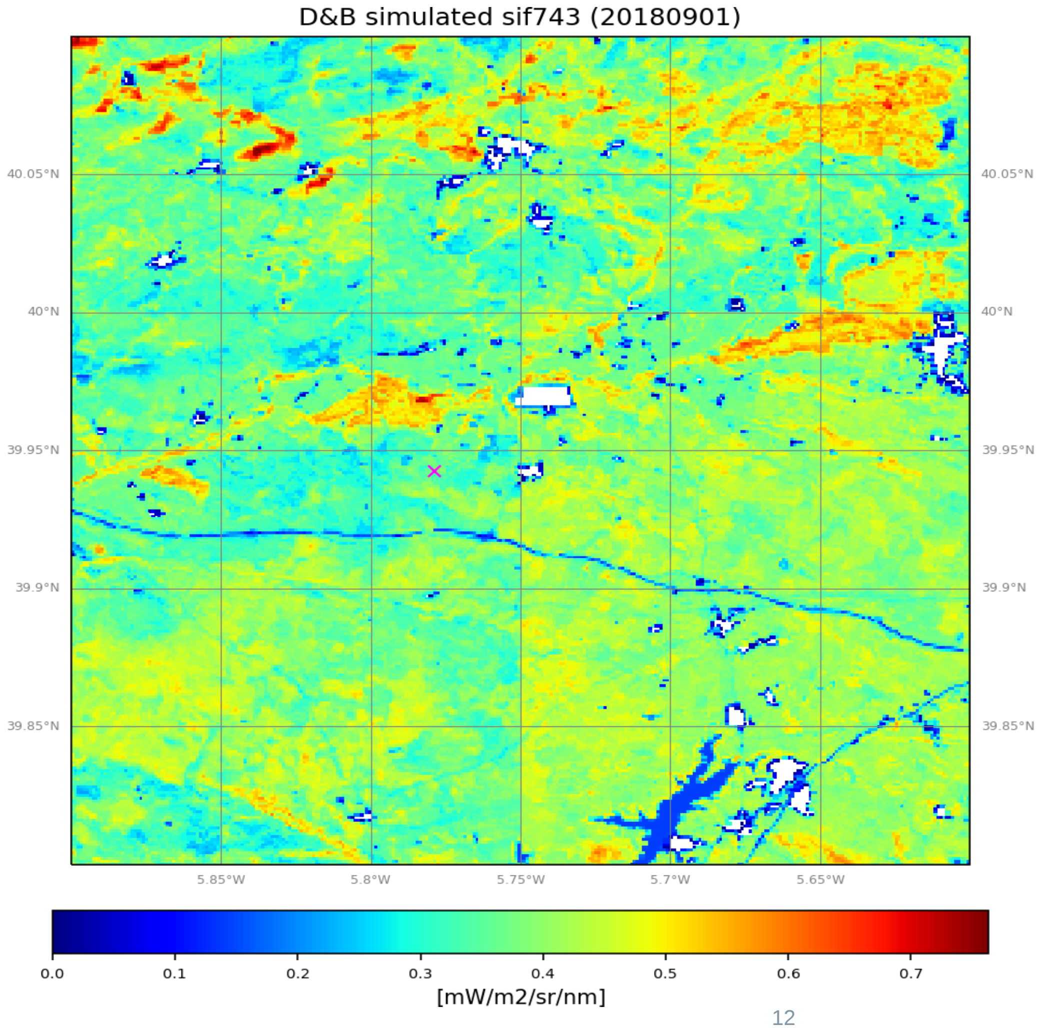
Simulation on the footprint/target area
Example: TROPOMI



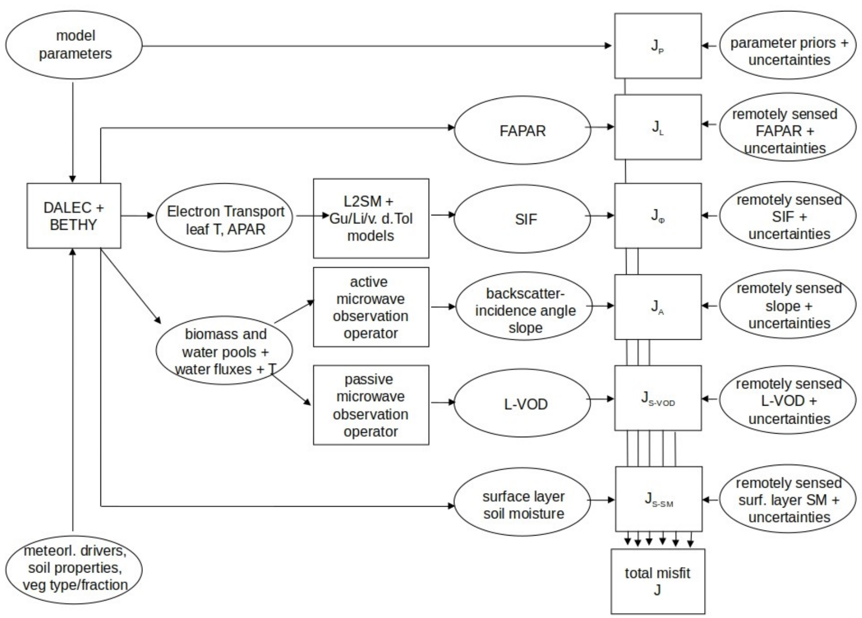


Spatial Detail
Examples: TROPOMI (left) and simulated (right) SIF

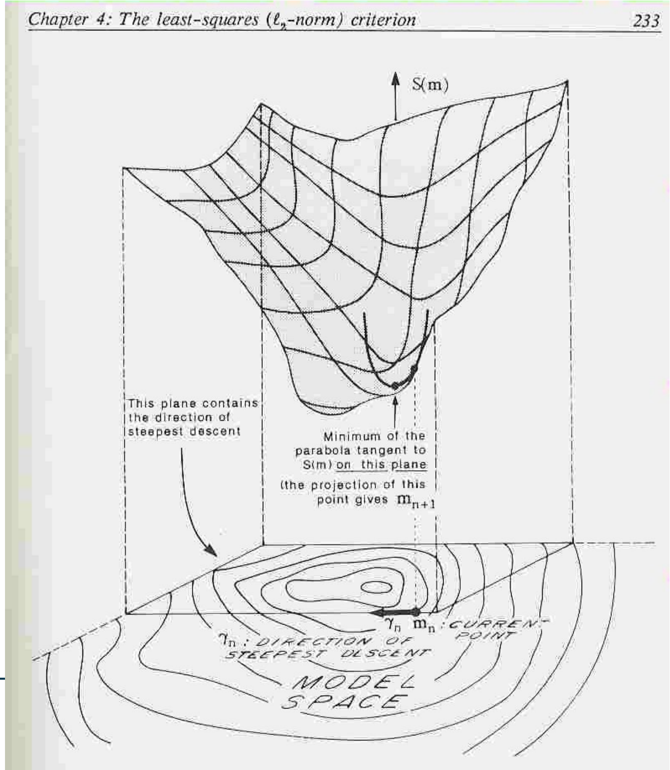




Variational Data Assimilation

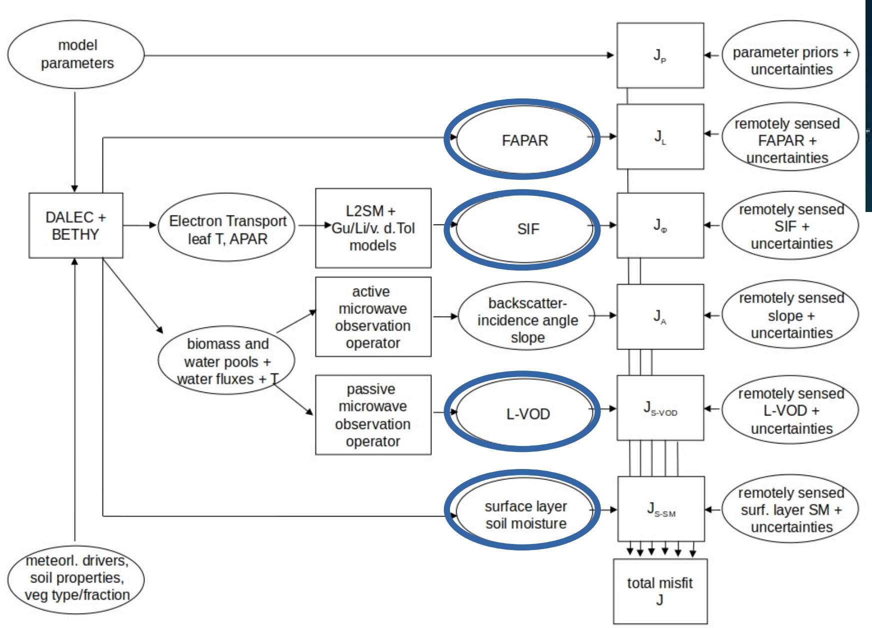


- Assimilating all data in one long assimilation window (need to constrain slow processes)
- Minimisation of a cost function J(x) of a set of process parameters (in core model and observation operators) and initial pool sizes
- Minimisation algorithm uses gradient of J(x) with respect to x
- Gradient efficiently provided by adjoint of D&B

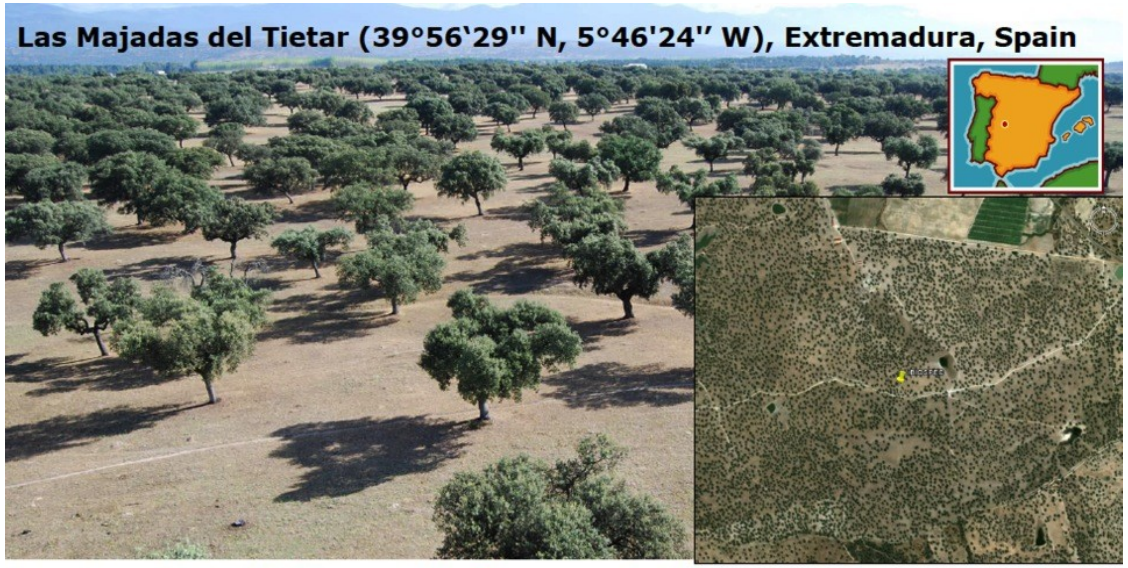


Tarantola 1987

Example: Majadas de Tietar



- Savannah site in Extremadura, Spain
- C3 grass and temperate evergreen trees
- Spin up 2015+2016
- Assimilation window 2017-2021
- Joint assimilation of:
    - FAPAR: JRC-TIP, twostream RT
    - SIF: TROPOSIF, Gu model
    - L-VOD: SMOS, empirical
    - surface layer soil moisture: SMOS



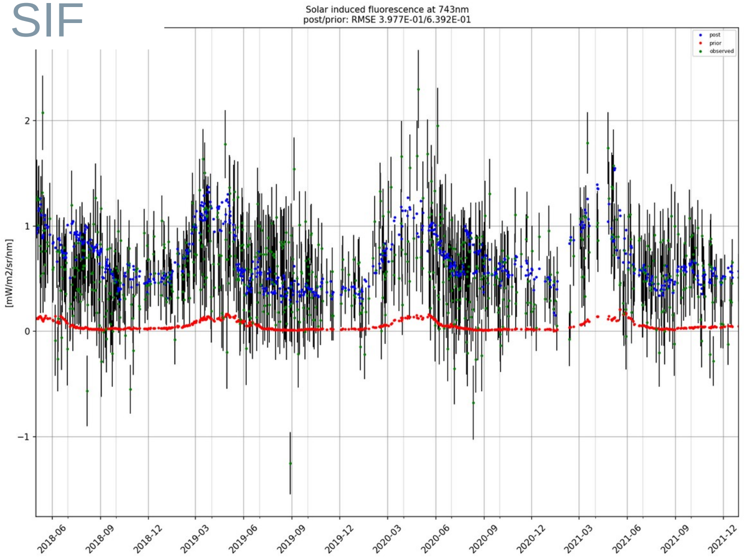
Ecosystem: ***dehesa*** Mediterranean Holm Oak open woodland (Savanna)

Example: Las Majadas de Tietar

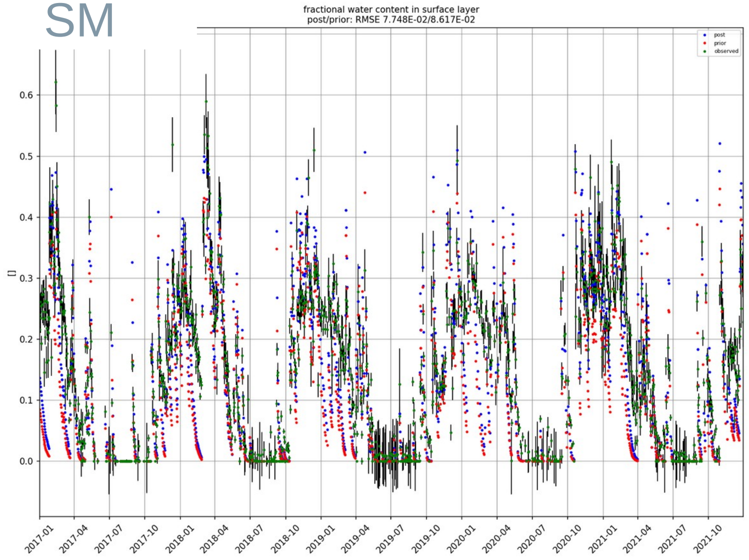
scots pine spectra, new observation operator for L-VOD

Assimilation (left/middle) and validation (right) variables

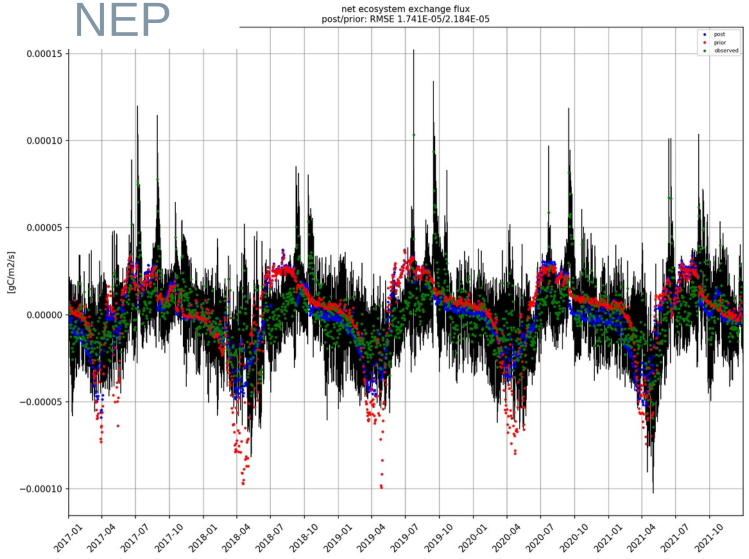
SIF



SM

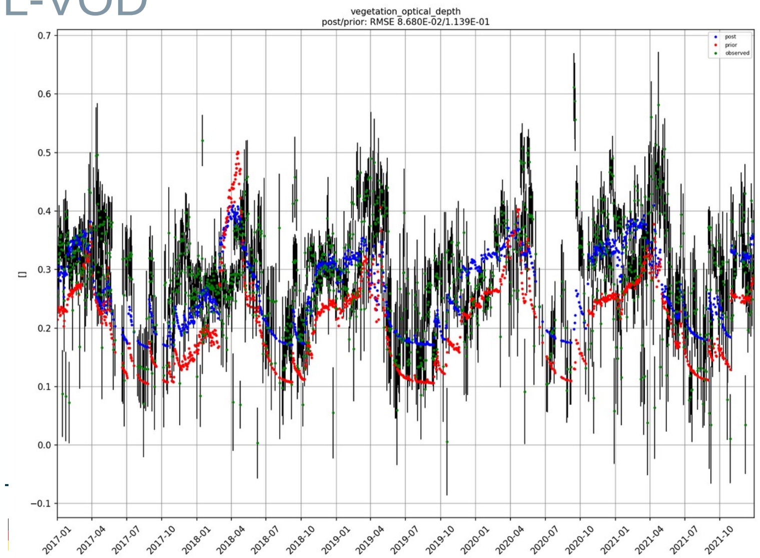


NEP

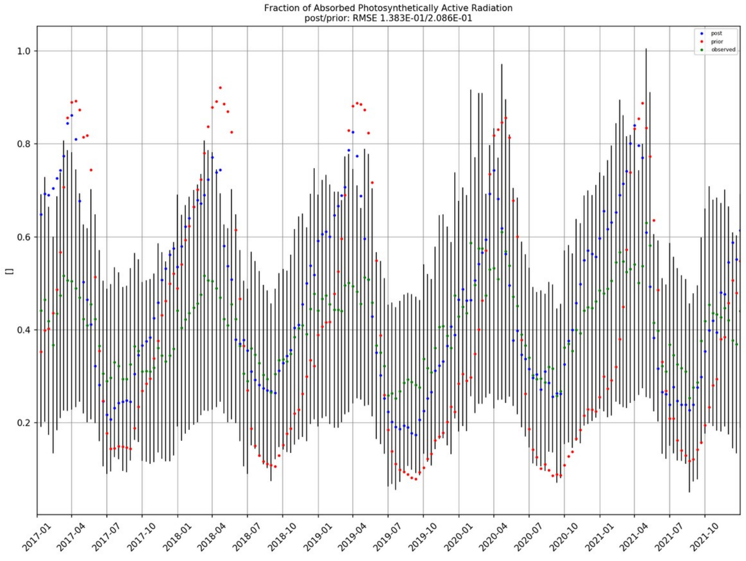


Obs (green), prior (red), posterior (blue)

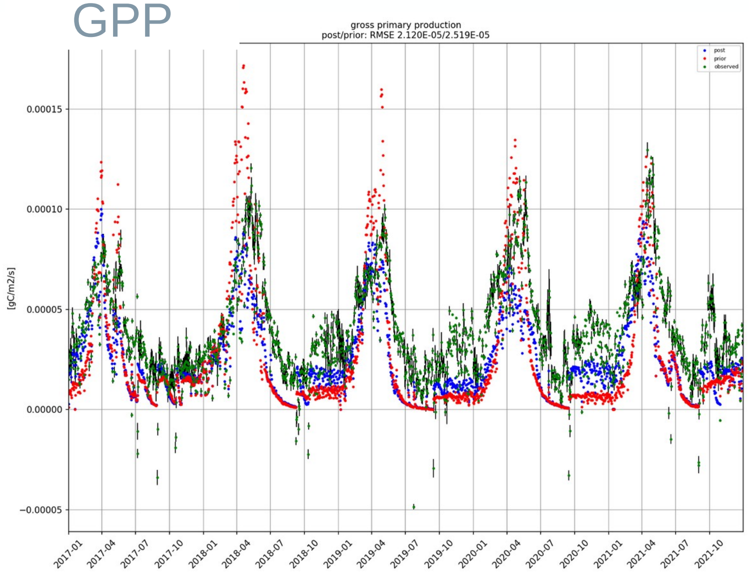
L-VOD



FAPAR

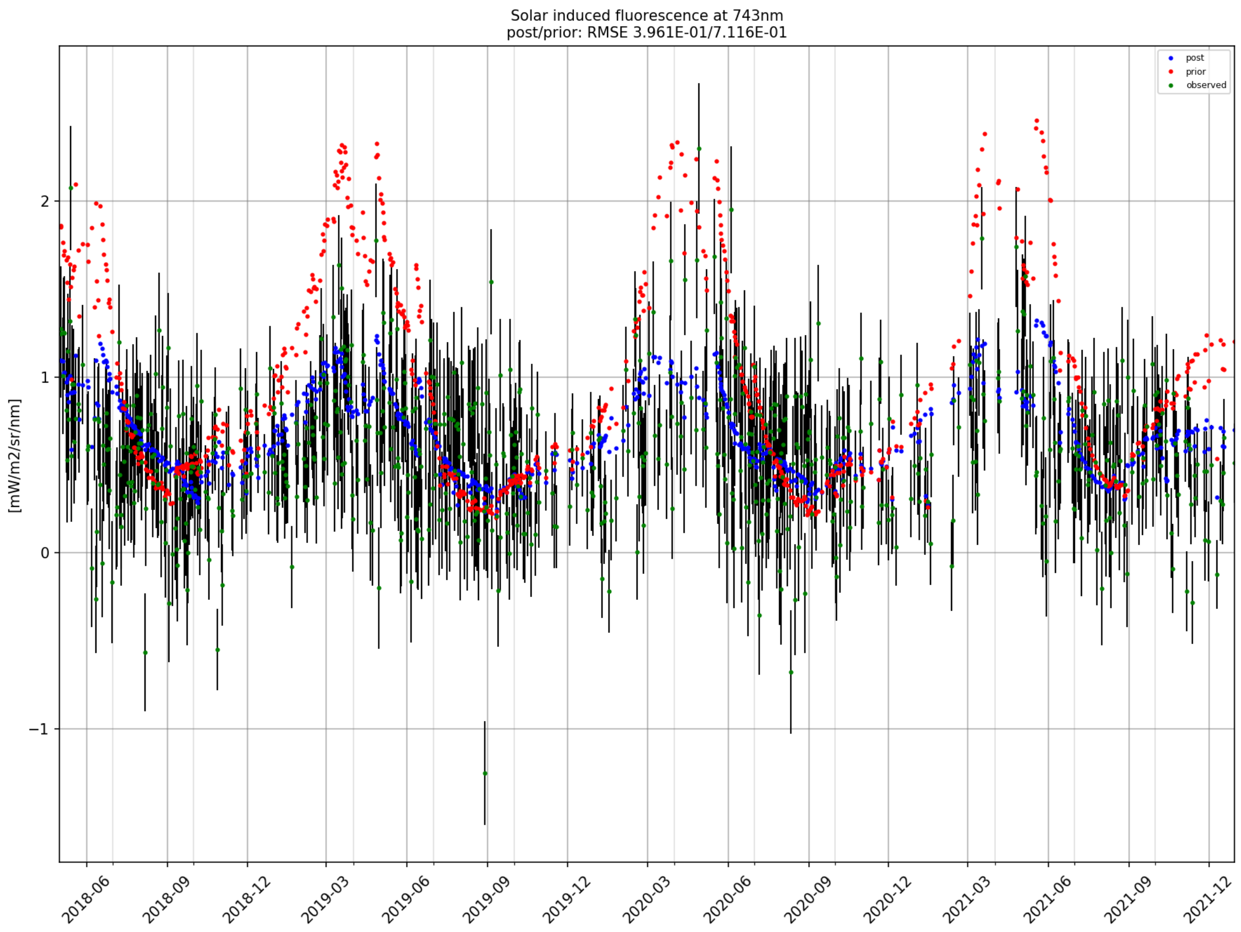


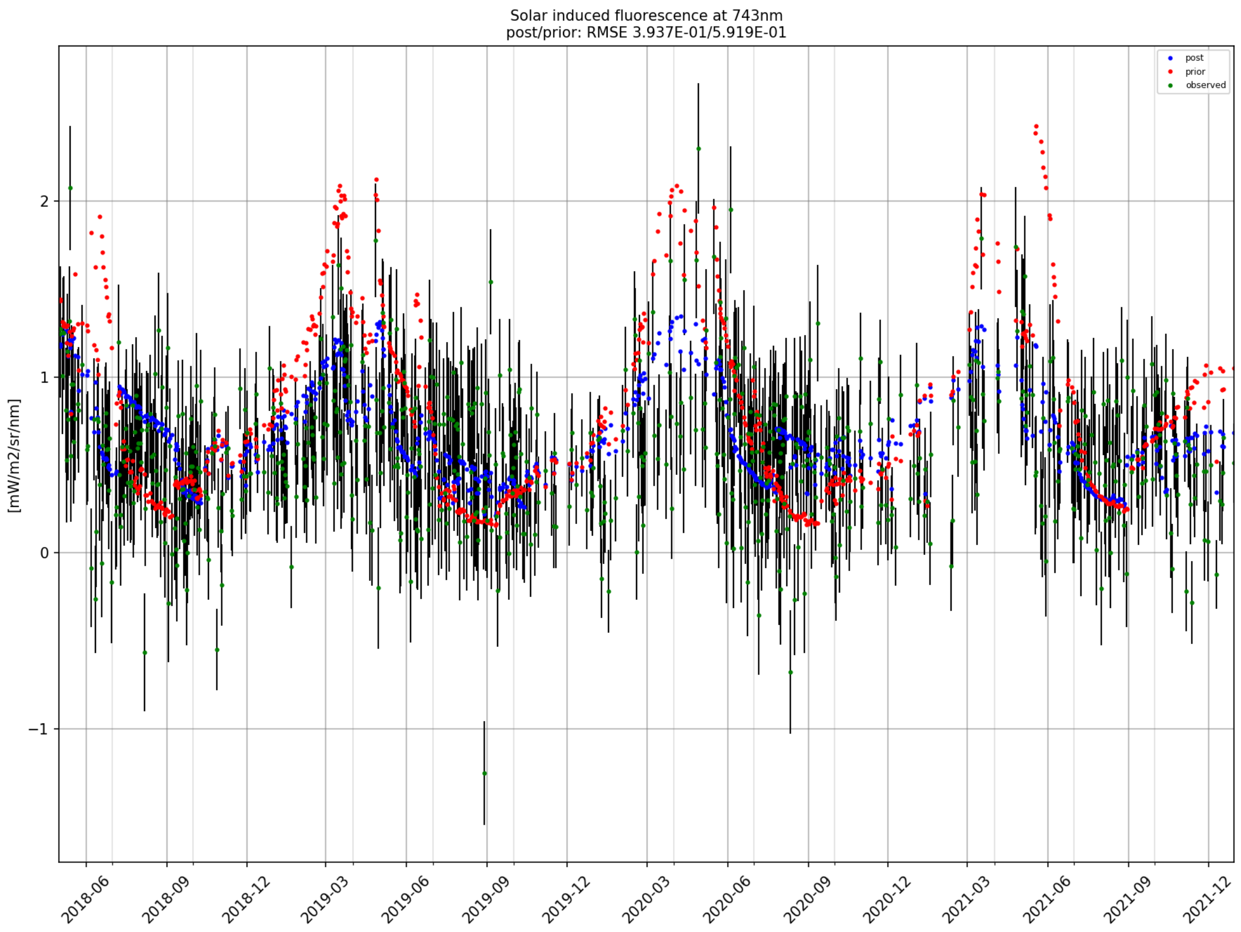
GPP



Example: Las Majadas de Tietar
Assimilation with van der Tol (left) and Li (right) source terms

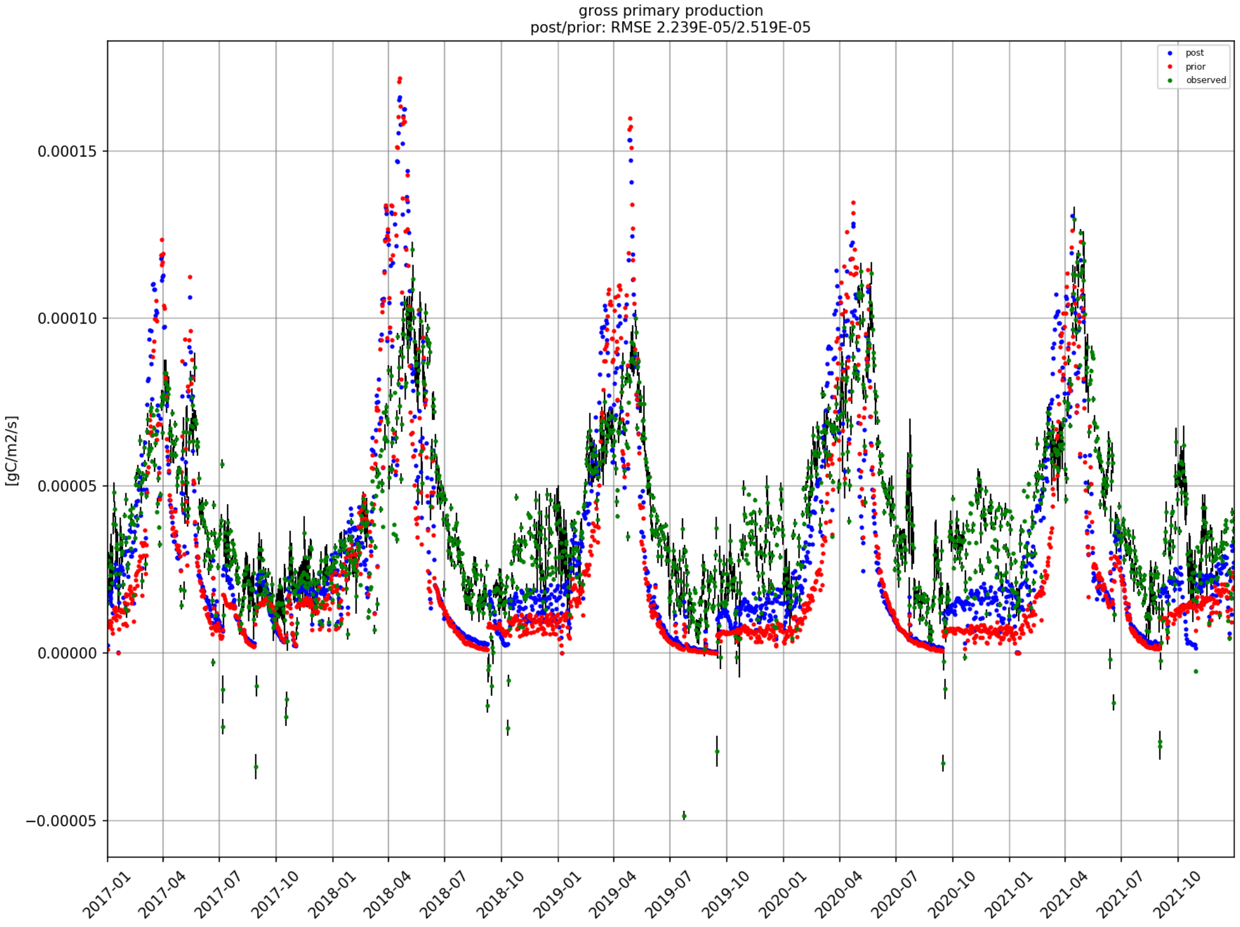
conversion with Oak spectra

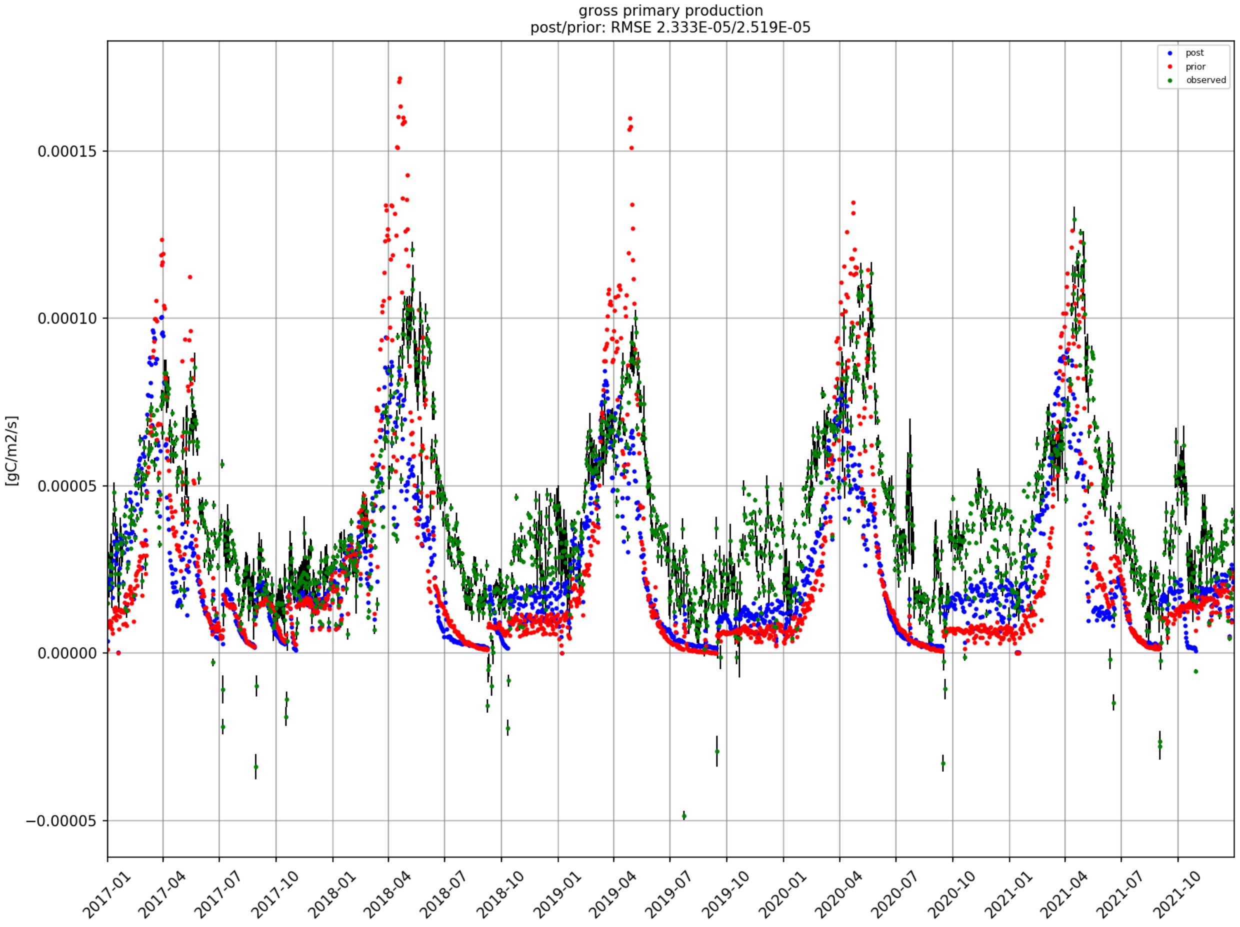




Example: Las Majadas de Tietar
Assimilation with van der Tol (left) and Li (right) source terms

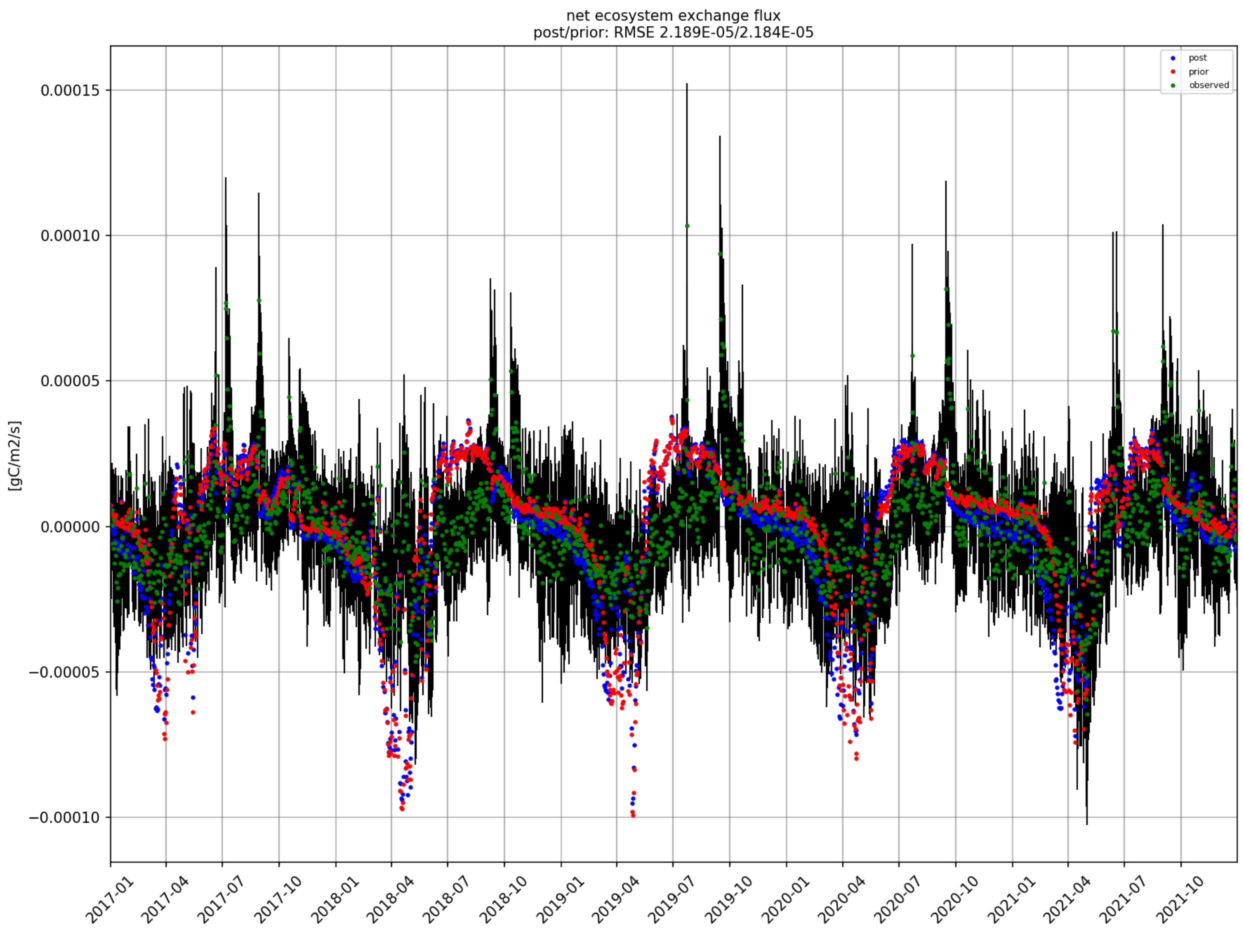
GPP

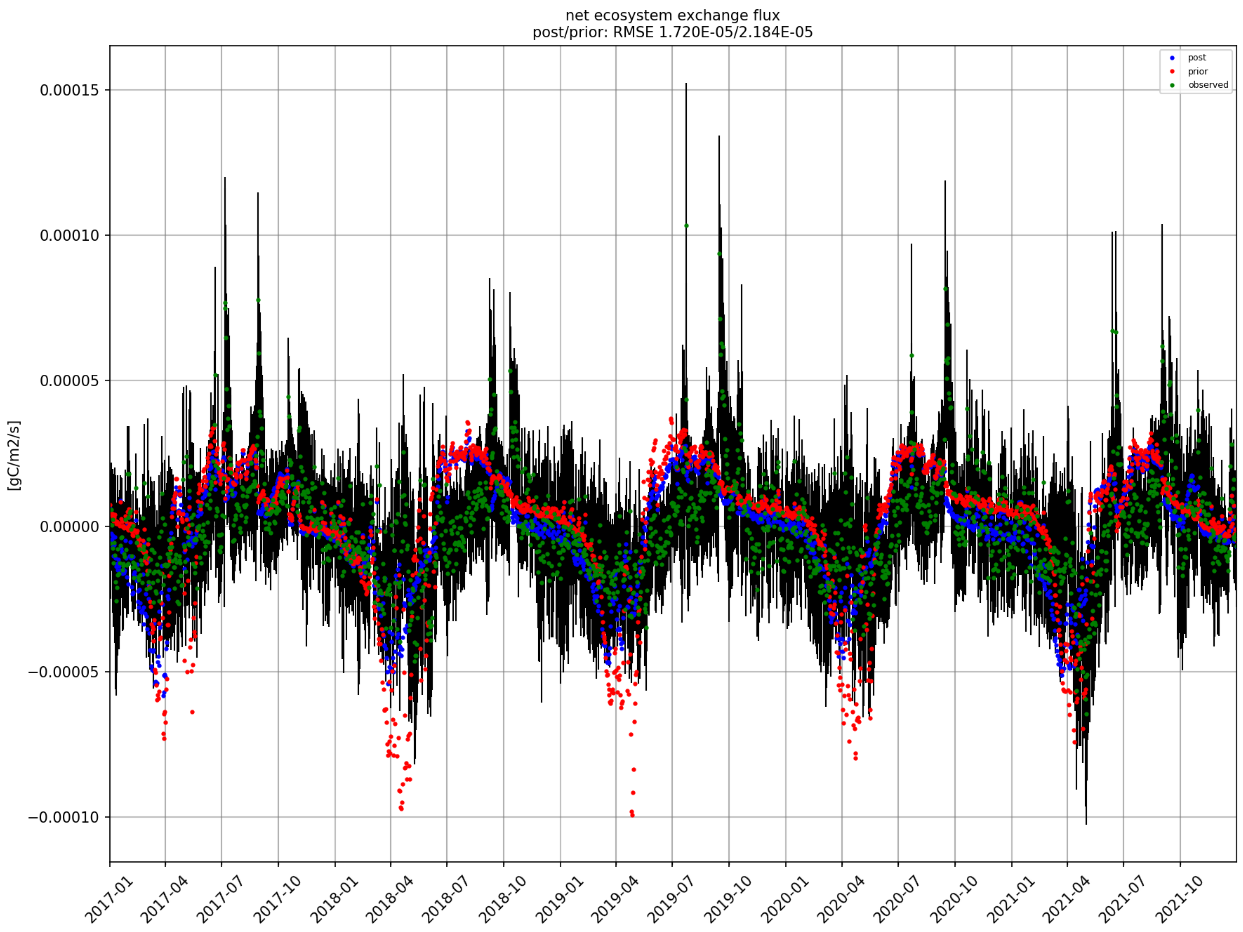




Example: Las Majadas de Tietar
Assimilation with van der Tol (left) and Li (right) source terms

NEE





Analysis of Information Content

A: posterior parameter uncertainty:

$$A = (M^T R^{-1} M + B^{-1})^{-1}$$

B: prior parameter uncertainty

R: data uncertainty

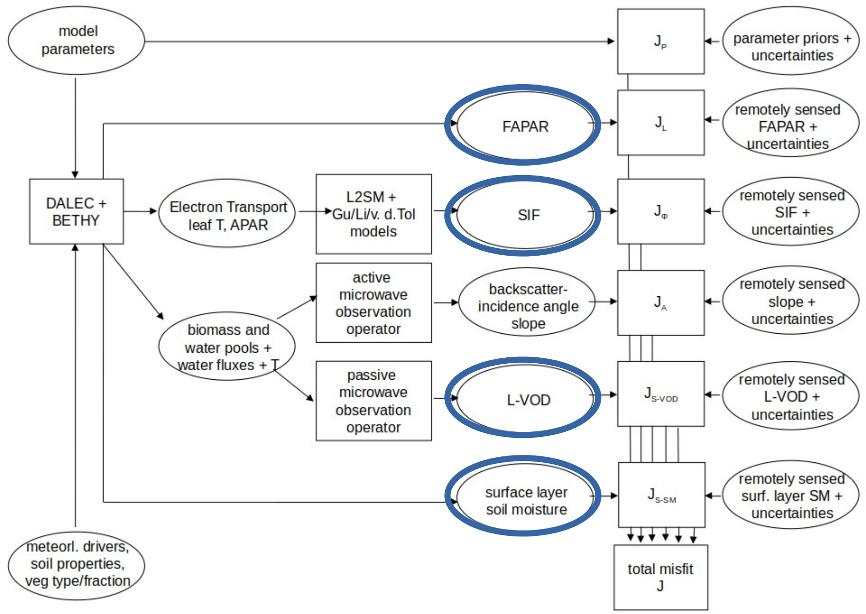
M: linearised model

Plots show unc. reduction:

$$(\sigma_{prior} - \sigma_{posterior}) / \sigma_{prior}$$

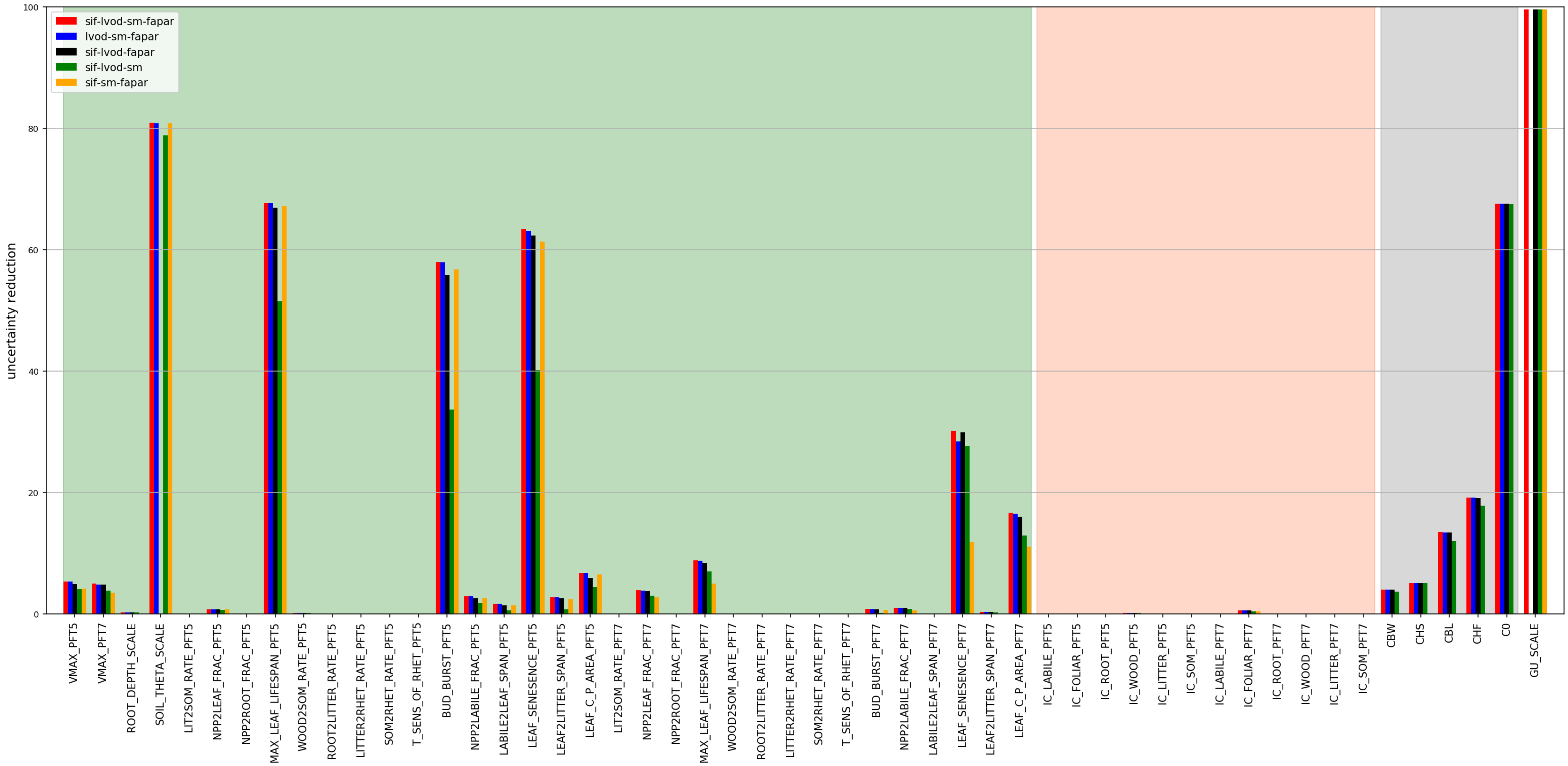
5 Experiments at Sodankylä (Everg. Conifer and understorey):

- First, joint assimilation of all 4 data streams
- Then, leaving one data stream out (in turn)

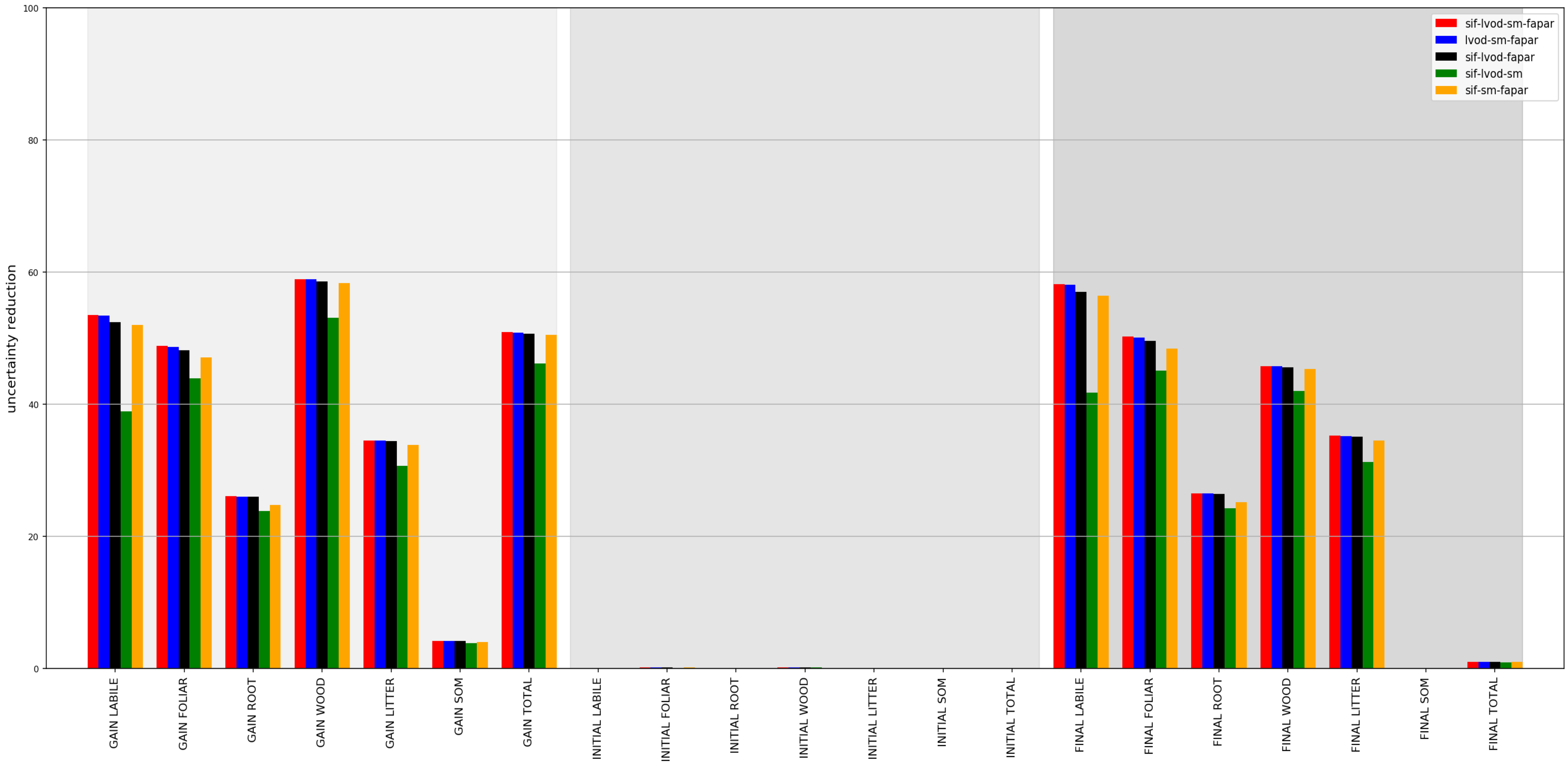


Analysis of Information Content

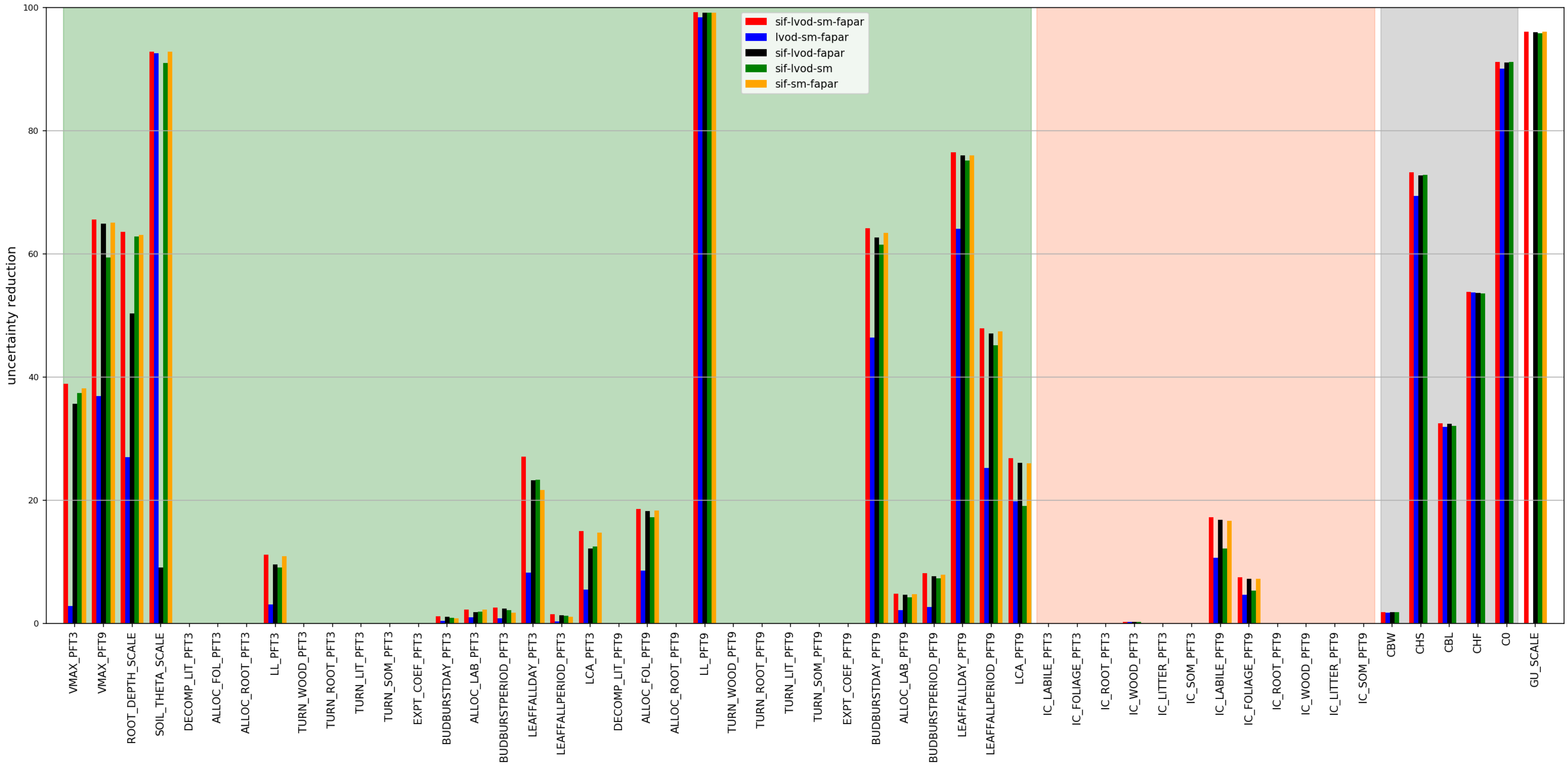
Example: Sodankylä; Uncertainty Reduction Parameters (left), Initial Pool sizes (middle) and Parameters of Observation operators (right)



Analysis of Information Content
Example: Sodankylä; Uncertainty Reduction Fluxes (left), initial (middle) and final (right) Carbon Pools

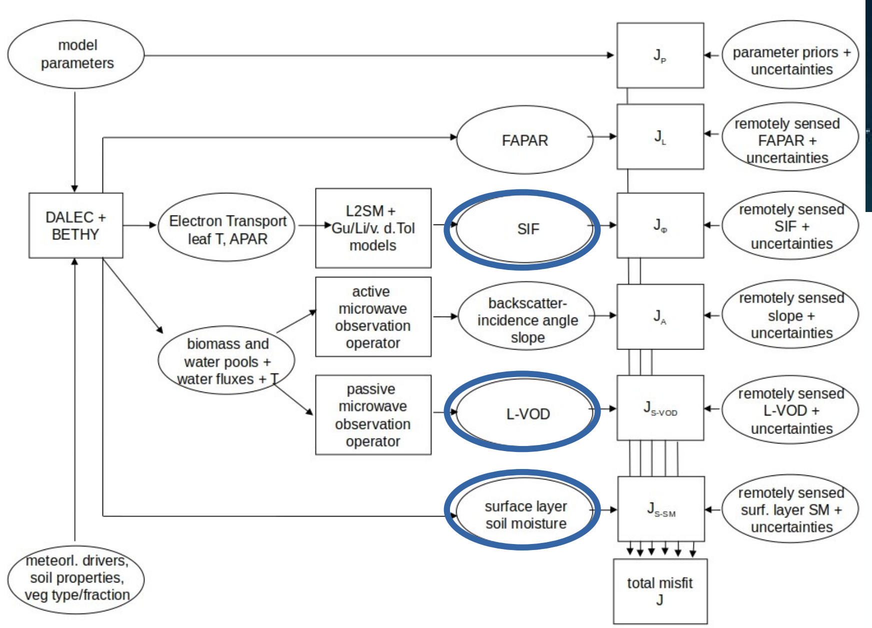


Analysis of Information Content
Example: Majadas de Tietar; Uncertainty Reduction Parameters (left), Initial Pool sizes (middle) and Parameters of Observation operators (right)



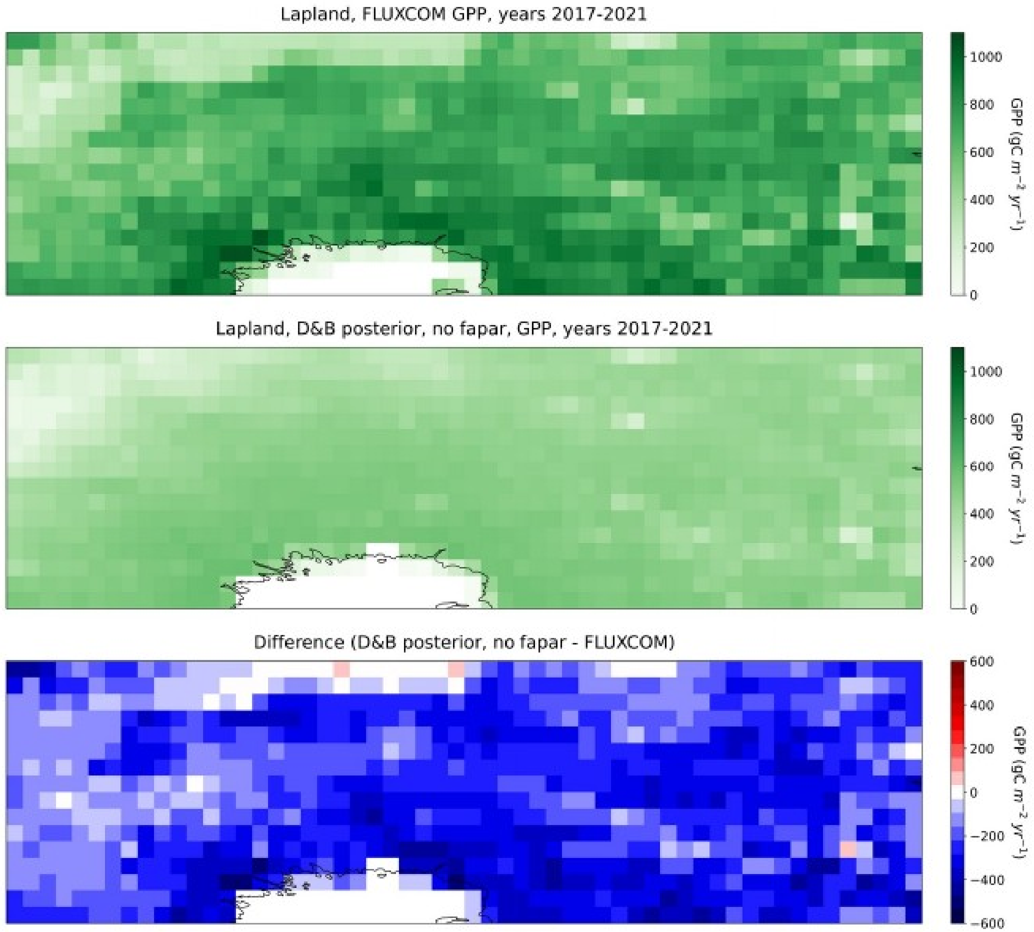
Example: Lapland

- Spin up 2015+2016
- Assimilation window 2017-2021
- Joint assimilation of:
    - FAPAR: JRC-TIP, twostream RT
    - SIF: TROPOSIF, Gu model
    - L-VOD: SMOS, empirical
    - surface layer soil moisture: SMOS

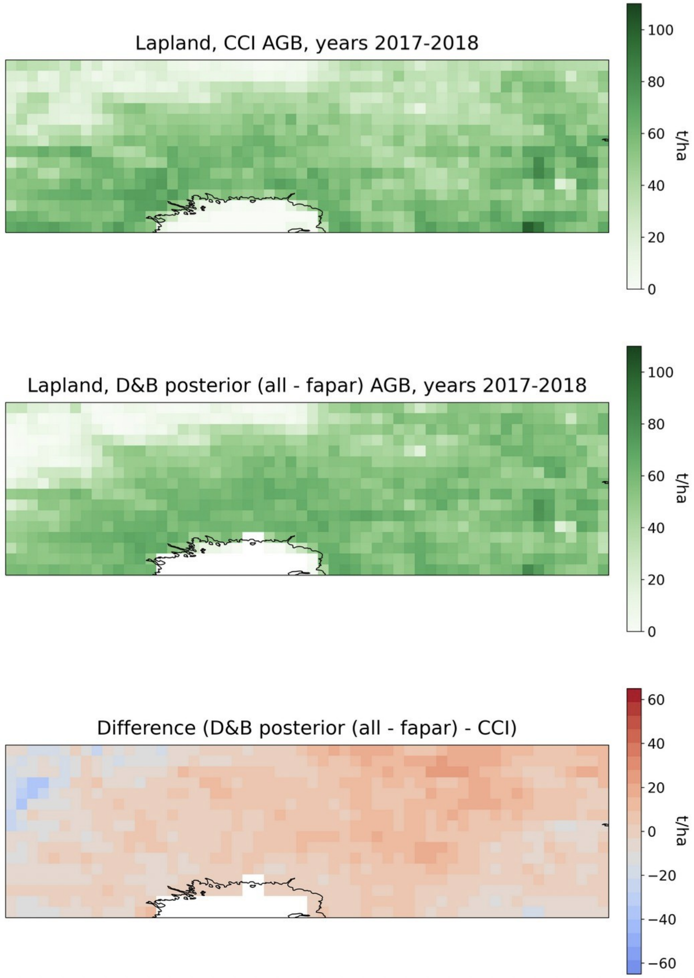


Example: Lapland
Validation of posterior GPP (left) and biomass (middle/right)

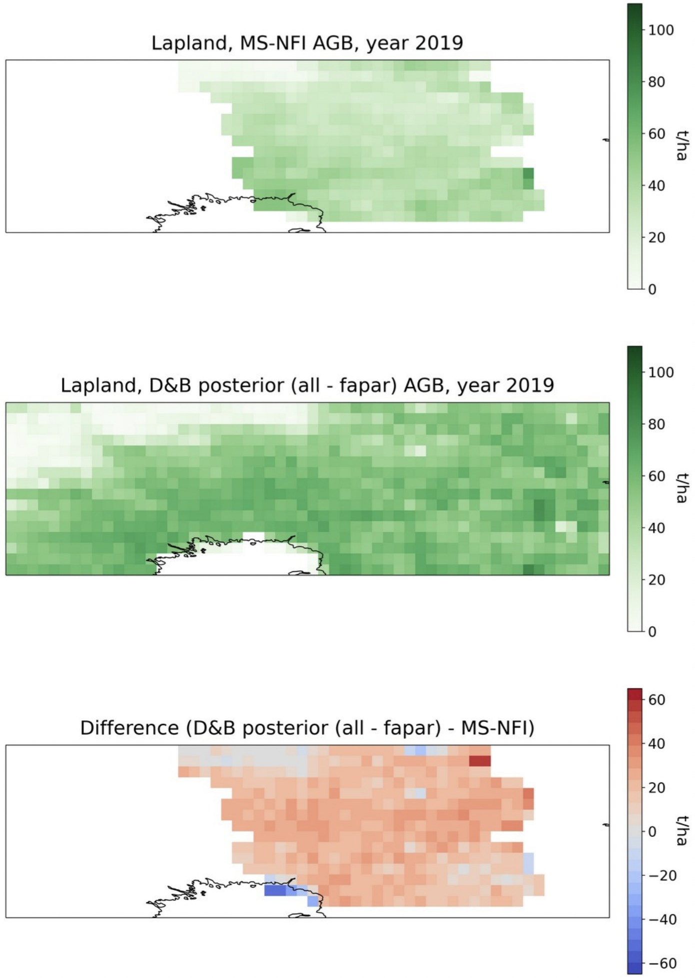
FLUXCOM V2: Martin Jung



CCI: Santoro et al. 2019

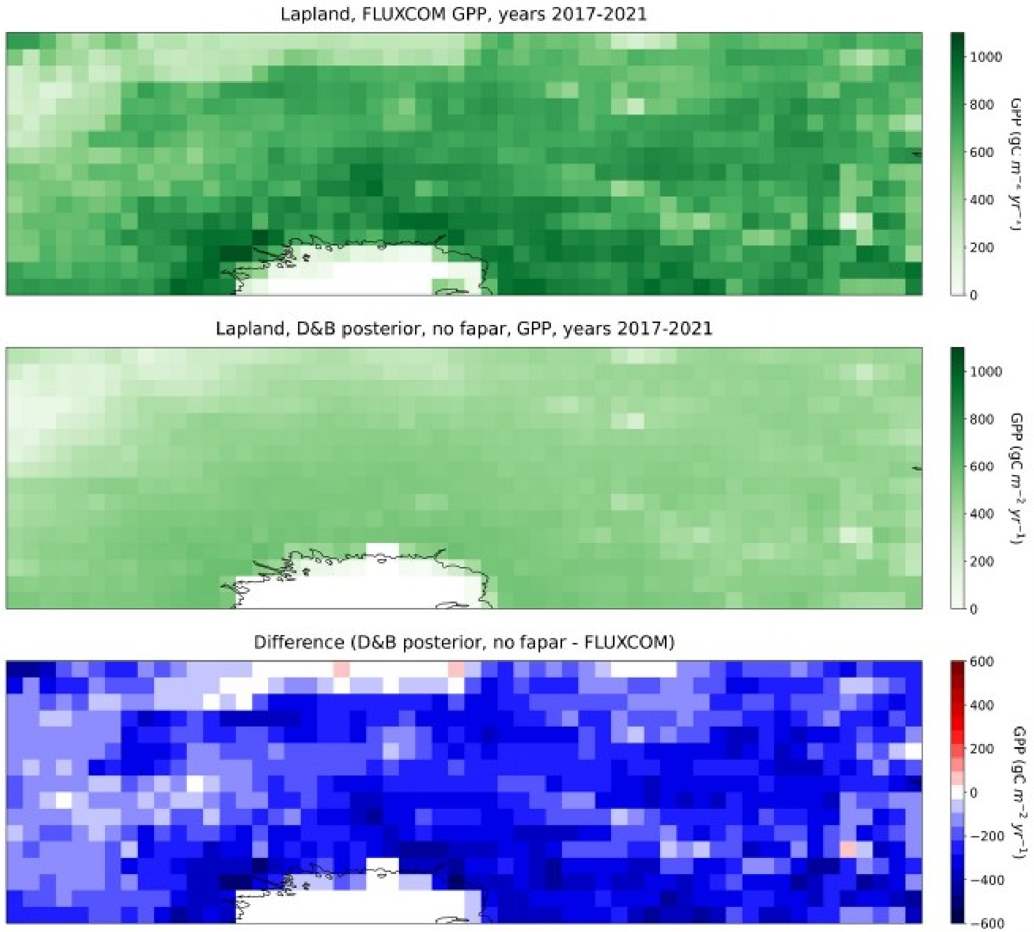


NFI: Tomppo et al., 2008

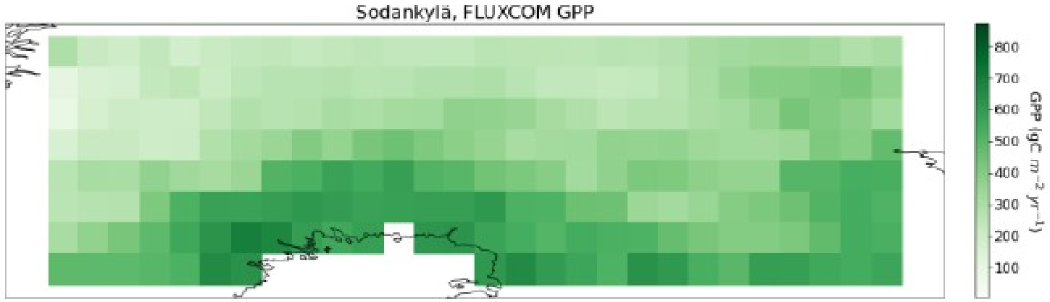


Example: Lapland
Validation of posterior GPP

FLUXCOM V2: Martin Jung



FLUXCOM V1 2011-2013: Jung et al. (2022)



Current TCCAS team

Terrestrial Carbon Community Assimilation System Study

Project | Partners | Publications | Internal | Contact

Partners

https://tccas-study.inversion-lab.com

The contact points for the individual partners are:

Contact	Company/Organisation	Country
Thomas Kaminski (coordinator)	The Inversion Lab	Germany
Marko Scholze	Lund University	Sweden
Tea Thum	Finnish Meteorological Institute	Finland
Tristan Quaife	University of Reading	UK
Mathew Williams	University of Edinburgh	UK
Sönke Zaehle	Max Planck Institute for Biogeochemistry	Germany

Training event

- October 7 and 8
- Hybrid: ESRIN science hub and remote
- Hands-on (Polar TEP) and lectures
- Topics:
  - Terrestrial Carbon Cycle
  - D&B
  - Data Assimilation Method
  - Data Assimilation with TCCAS
- Registration will open shortly
- In parallel: Started to work with test users

Further Information

- Hybrid user training event at ESRIN (Frascati, Italy) on October 7 and 8
- https://tccas-study.inversion-lab.com
- TCCAS@Inversion-Lab.com
- Thomas.Kaminski@Inversion-Lab.com