Improving the monitoring of vegetation and drought by land surface models through the assimilation of satellite data

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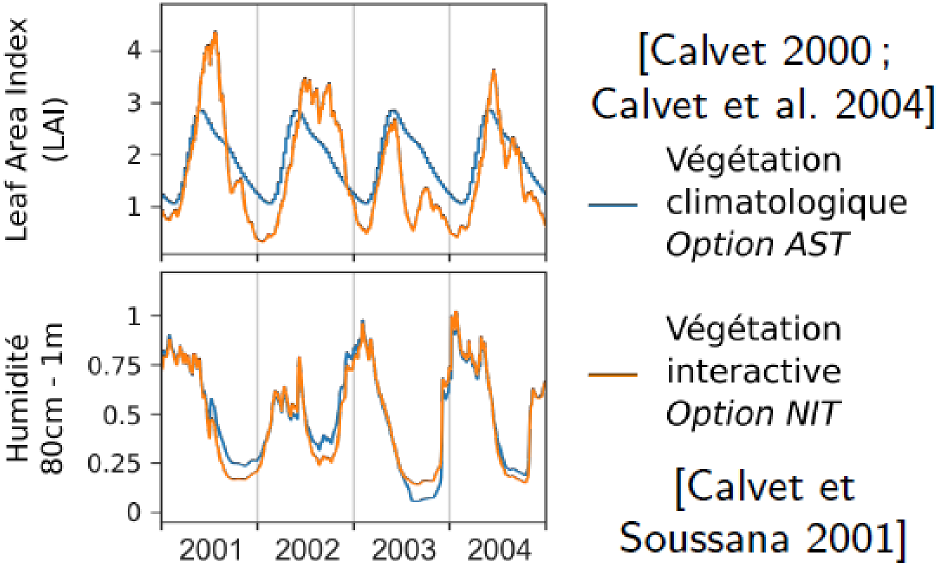
with contributions by Bertrand Bonan, Yann Baehr, Timothée Corchia, Oscar Rojas-Munoz, Pierre Vanderbecken, Jasmin Vural

Bonn, 8 April 2025

Vegetation provides biological control of evapotranspiration and carbon fluxes

- Complex processes
  - Agricultural practices
  - Transpiration vs. evaporation split
  - Land cover and plant species heterogeneity
  - …
- Uncertainties propagate to the water, energy, carbon budgets
- **Leaf Area Index** is key:
  - Seasonal / interannual variability
  - Root-zone soil moisture



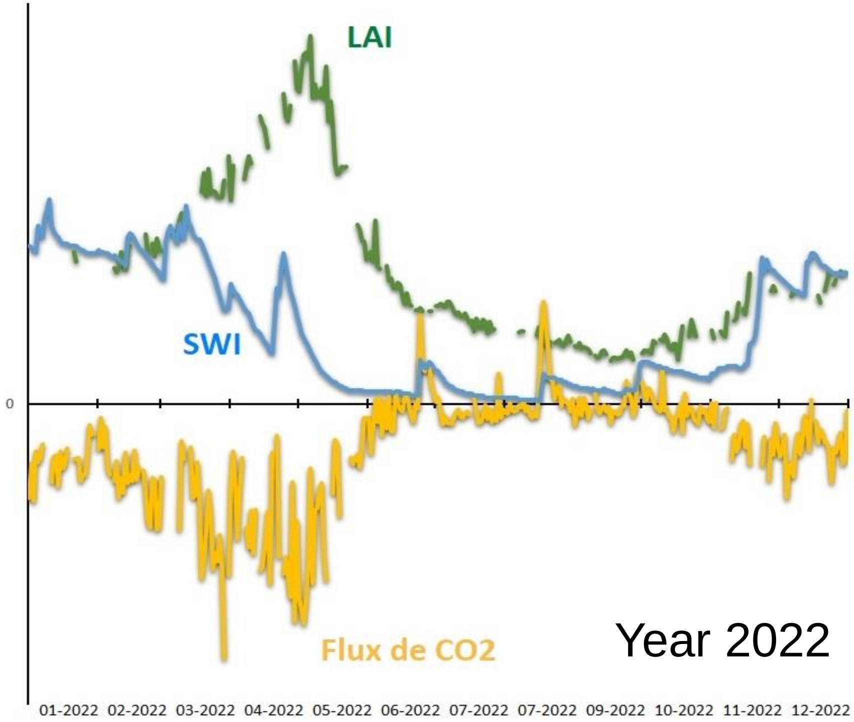
Barthelemy et al. 2024

Vegetation provides biological control of evapotranspiration and carbon fluxes

- Evapotranspiration, carbon storage and release

  - **Leaf Area Index**
    Spring growth followed by senescence
  - **Soil Wetness Index**
    drying caused by evapotranspiration
  - **CO_2 flux (at noon)**
    marked CO_2 pulses after rainfalls

ICOS FR-Tou site, Toulouse



https://doi.org/10.57932/5223fd82-10ce-490c-a4b0-1106b5511554

How to monitor terrestrial surfaces?

In-situ observations

- Used as ground truth
- Essential for validation
- High temporal frequency
- Limited spatially

Satellite observations

- Global coverage
- Unprecedented amount of observations
- Gaps in the observations
- Can only observe certain variables

Land surface models

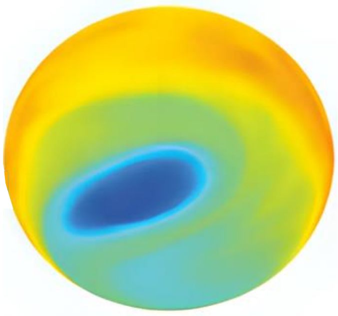
- Continuous coverage (No gaps)
- Can be used to forecast variables
- Some processes are too complex to represent

Data assimilation

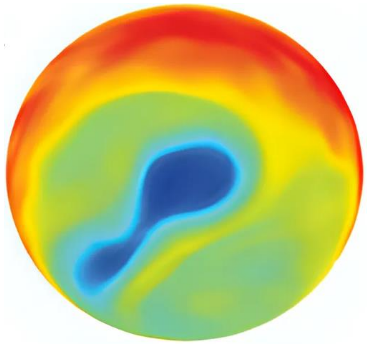
Data Assimilation System

models

Satellite observations



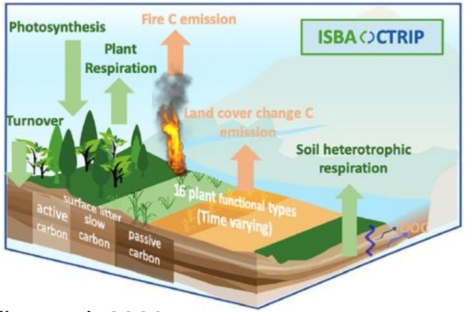
Analysed simulations



Adapted from Lahoz et al. 2014

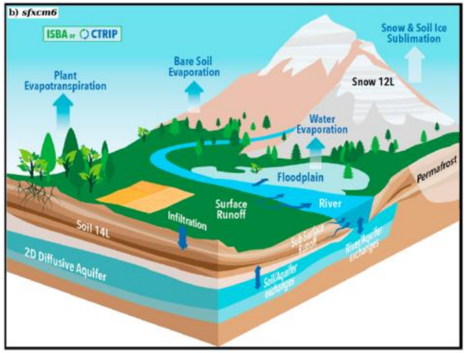
ISBA land surface model, as part of SURFEX

CARBON CYCLE



Delire et al. 2020

WATER CYCLE

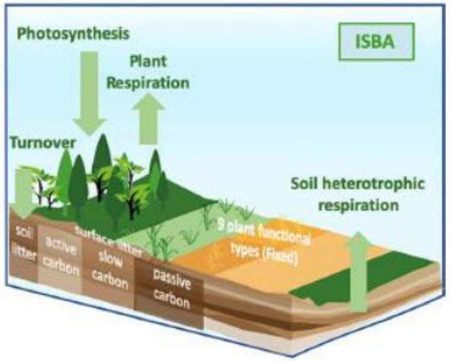


Decharme et al. 2019

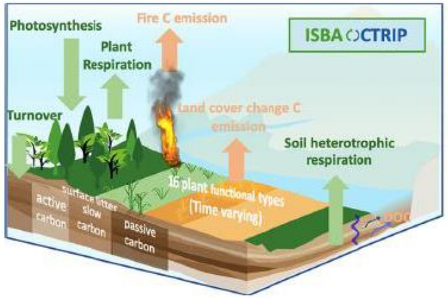
ISBA	Soil	Force restore (2 or 3 layers) Diffusion (14 layers)
	Vegetation	Noilhan and Planton 1989 (~Jarvis) A-gs (photosynthesis and CO2 fluxes) A-gs and interactive LAI Carbon storage (soil, wood and roots)
	Hydrology	No subgrid process Subgrid surface runoff Subgrid drainage Flooding and coupling with CTRIP
	Snow	1 layer 12 layers

ISBA land surface model, as part of SURFEX

- **Multilayer soil:** 14 layers up to 12m depth for water and energy [Boone *et al.*, 2000; Decharme *et al.*, 2013]
- **Multilayer snow:** explicit scheme with 12 layers [Boone and Etchevers, 2001; Decharme *et al.*, 2016]
- **Coupling with river routing system CTRIP** [Decharme *et al.*, 2019]
- **ISBA-NIT** [Calvet *et al.*, 1998; Gibelin *et al.*, 2008]:
  - Photosynthesis-driven phenology based on Goudriaan approach and prescribed parameters
  - Plant water stress: tolerant vs avoiding
  - 9 Plant Functional Types (PFTs)
- **ISBA-NCB** [Delire *et al.*, 2020]:
  - Updated phenology and 16 PFTs compared to NIT
  - Improved carbon cycle (fire, carbon leaching, …)



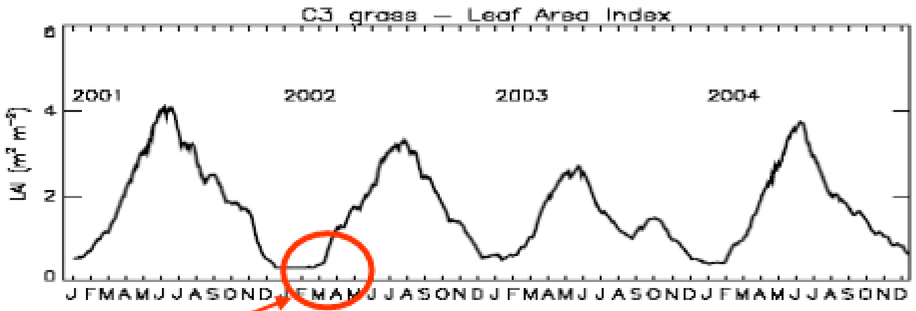
ISBA-NIT (top) and ISBA-NCB (bottom) adapted from Delire *et al.* (2020)

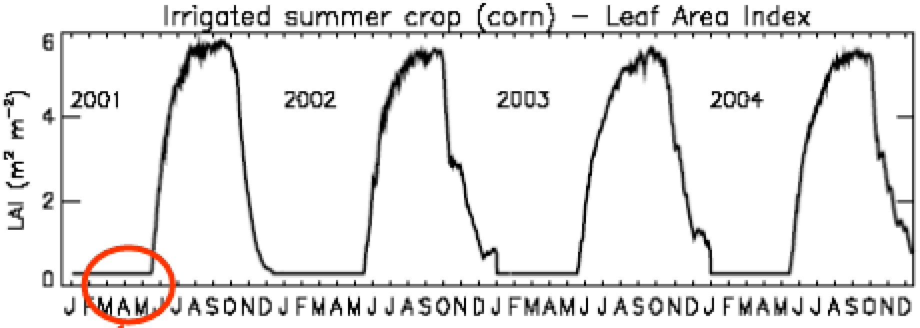


ISBA land surface model, as part of SURFEX

Photosynthesis-driven phenology

- LAI is linearly related to the **active biomass** (parameters = **SLA**, derived from leaf nitrogen concentration and 2 plasticity parameters)
- A minimum value of LAI, **LAI_{min}**, is prescribed (e.g. 0.3 for annual vegetation), permitting a self restart of the vegetation when photosynthesis becomes active
- Possibility to cut the vegetation or to maintain LAI at its minimum value, for agricultural applications

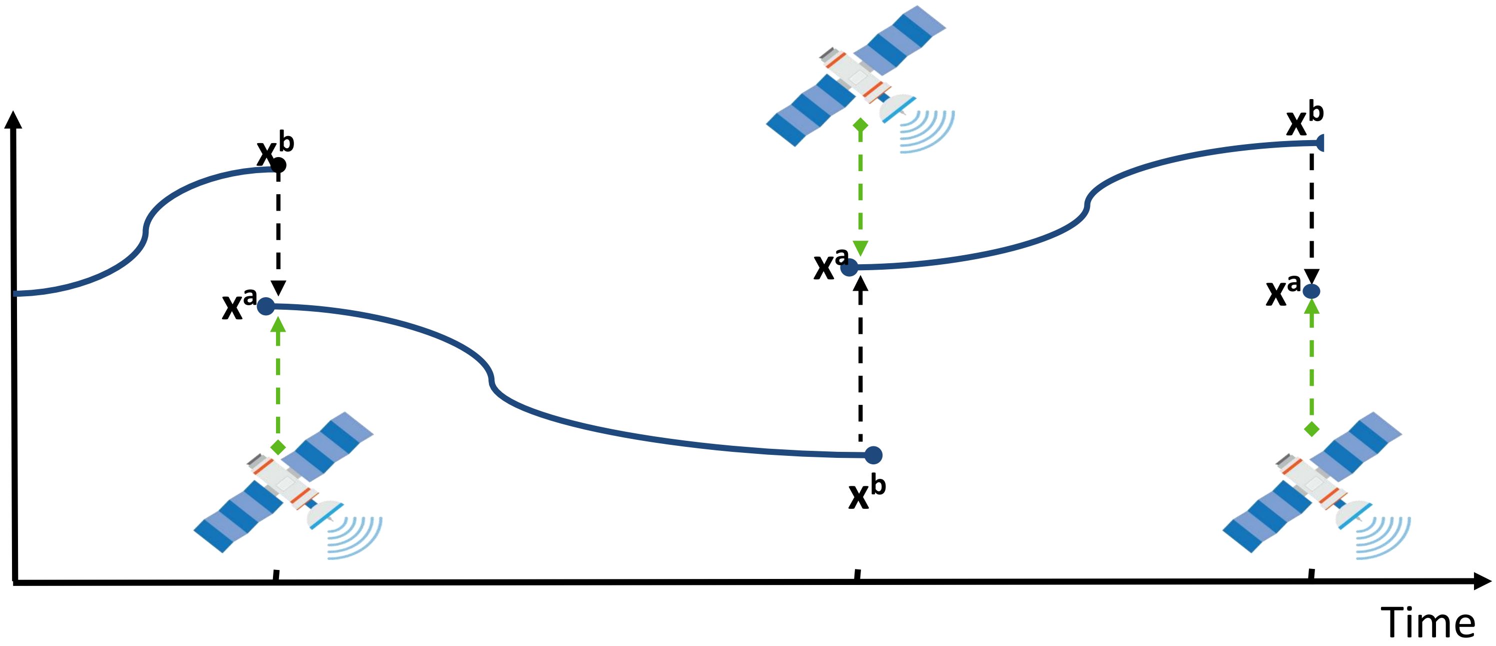




Sequential data assimilation in SURFEX

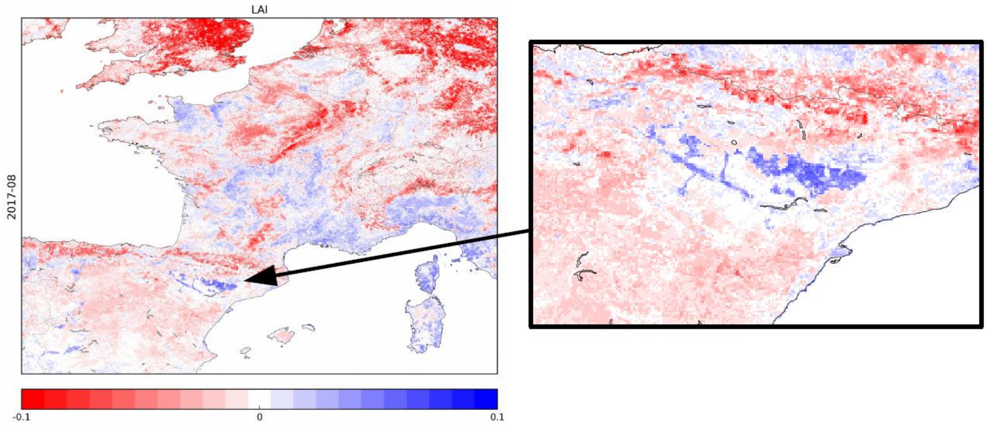
LDAS - Kalman filter (24h assimilation window)

$$\underbrace{x^a}_{\text{Analysis}} = \underbrace{x^b}_{\text{background}} + \overbrace{K}^{\text{Kalman gain}}(\underbrace{y^o}_{\text{Observation vector}} - \overbrace{H}^{\text{Observation Operator}}(x^b))$$

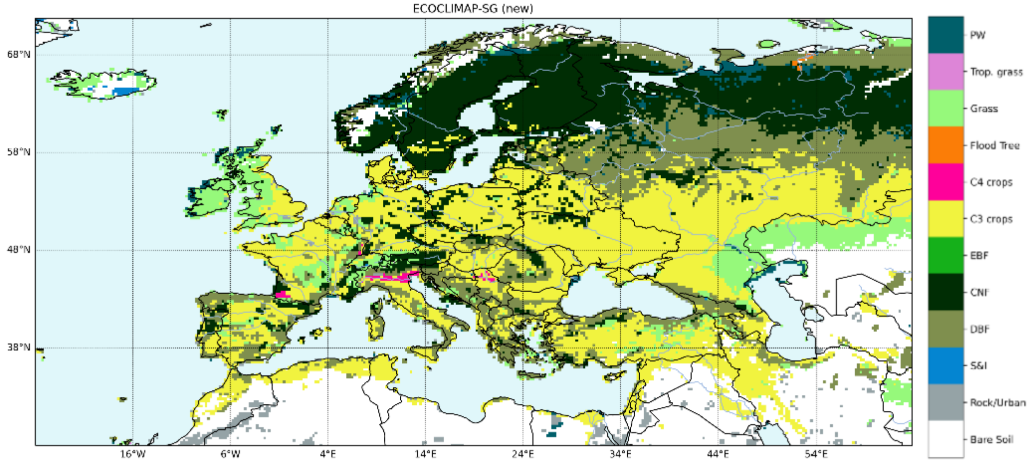


Integration of geographical information in SURFEX

- **Offline sequential assimilation of satellite-derived LAI**
  - **LDAS-Monde**
    - e.g. LAI increments highlighting irrigated areas in Spain (August 2017)

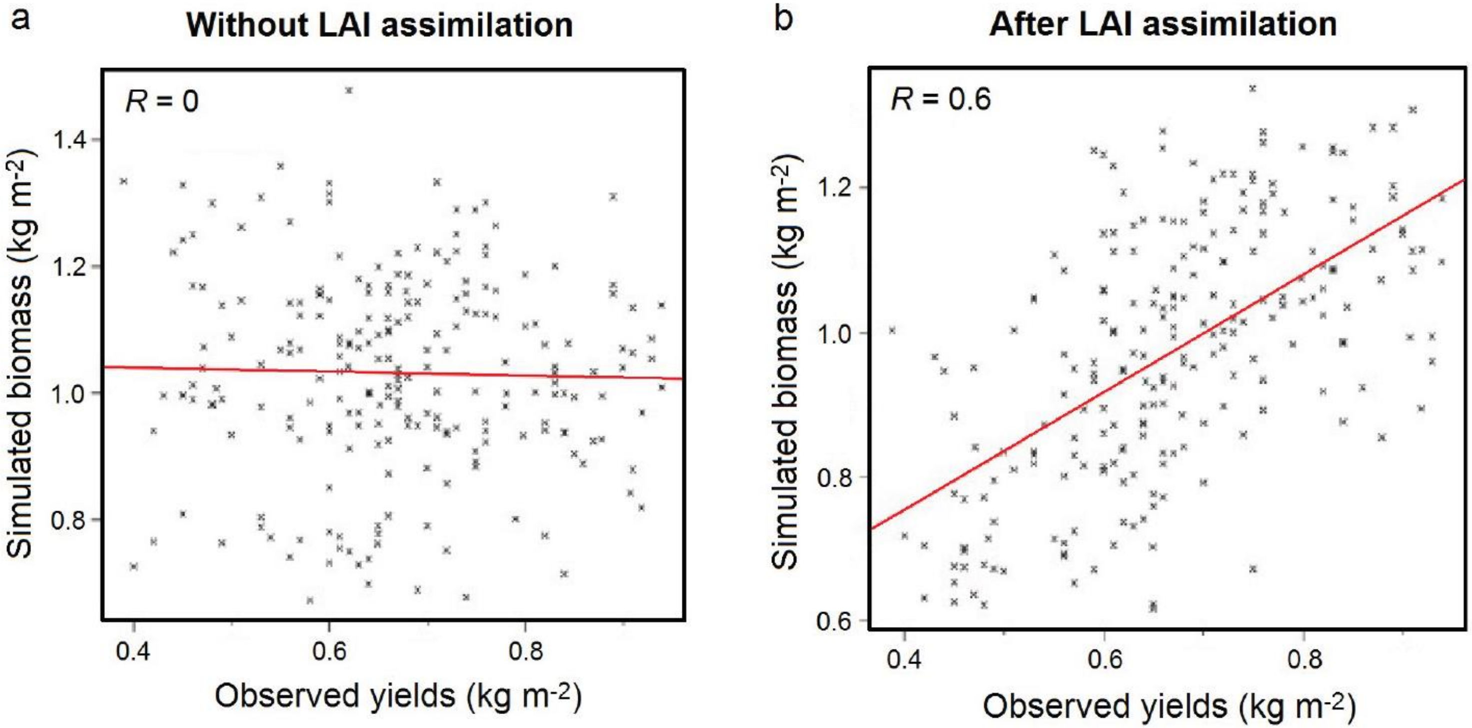


- **Land cover and model parameter mapping**
  - **ECOCLIMAP**
    - e.g. surface types in southwestern France
    - ECOCLIMAP-SG includes ESA-CCI LC

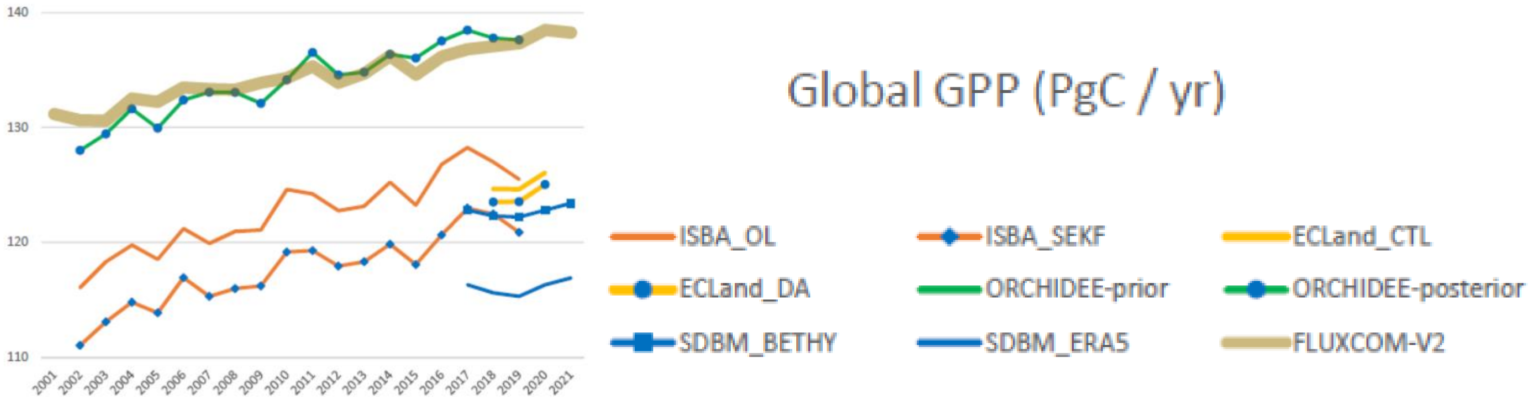


Integration of geographical information in SURFEX

– Straw cereal yields over France (Dewaele 2017)



Impact of LAI assimilation on carbon fluxes



CoCO2
Prototype system for a Copernicus CO_2 service

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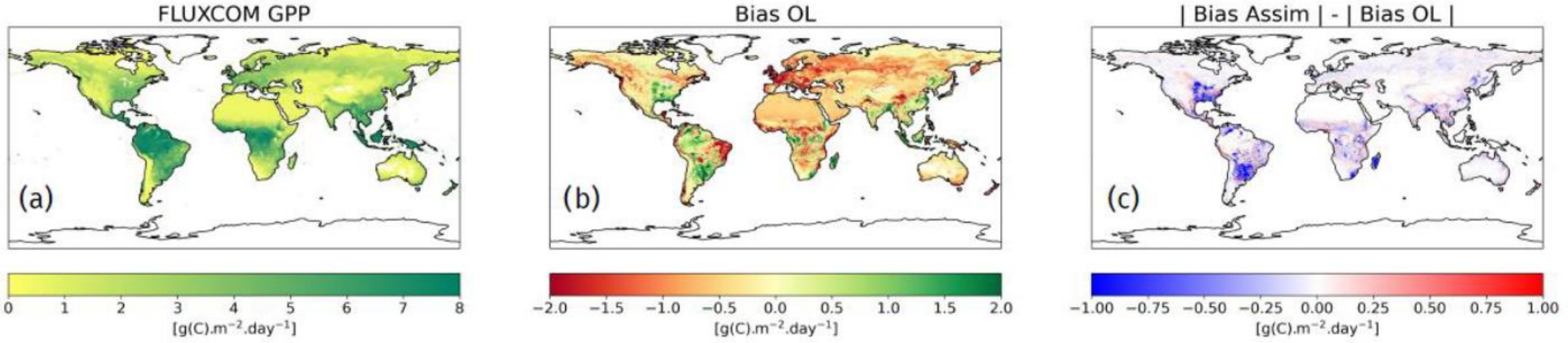
GPP source	Trend (PgC/yr)	SD of de-trended (PgC/yr)	Mean bias (PgC/yr)	R^2 (p-value)	R^2 of de-trended (p-value)
FLUXCOM-V2	0.36	0.62	0	1 (0)	1 (0)
ISBA_OL	0.58	1.28	-9.4	0.90 (0)	0.37 (0.008)
ISBA_SEKF	0.57	1.20	-13.8	**0.93 (0)**	**0.50 (0.001)**
ORCHIDEE_prior	0.58	1.39	35.0	0.91 (0)	0.44 (0.003)
ORCHIDEE_posterior	0.55	0.96	**0.3**	**0.93 (0)**	0.39 (0.005)

Impact of LAI assimilation on carbon fluxes

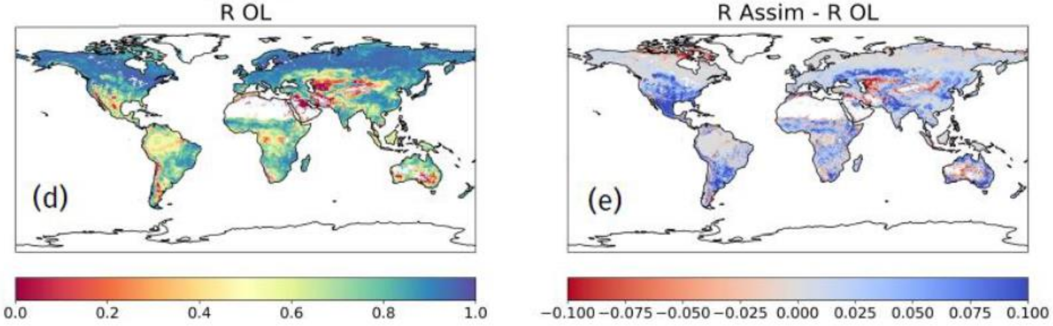


(a) mean FLUXCOM GPP 2018-2019

(b) Bias OL vs FLUXCOM mostly negative, positive for rainforests and culture areas

(d) R OL vs FLUXCOM above 0.8 in North of globe, below 0.5 in rainforests and low mean GPP

(c, e) Bias and R scores improved by assimilation **in blue**



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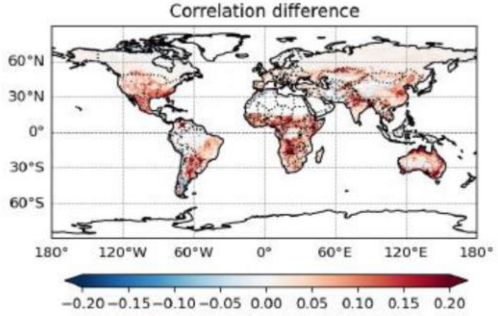
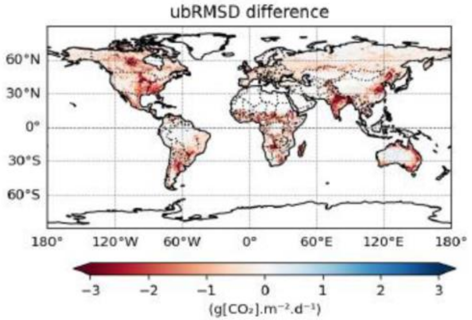
Bonan et al. 2023

Impact of LAI assimilation on carbon fluxes

Gross Primary Production

Benchmarking using GPP FLUXCOM 0.25° from 2001 to 2021





	Corr	Bias (g[Co2].m-2.d-1)	RMSD (g[Co2].m-2.d-1)	UbRMSD (g[Co2].m-2.d-1)
Winter	0.46 / 0.49	-0.69 / -0.44	3.09 / 2.61	1.96 / 1.71
Spring	0.66 / 0.68	-0.50 / -0.11	4.73 / 4.12	3.04 / 2.70
Summer	0.58 / 0.61	-0.37 / -0.09	6.41 / 5.75	4.10 / 3.71
Fall	0.64 / 0.68	-1.01 / -0.48	4.74 / 3.98	3.07 / 2.63
All	0.72 / 0.76	-0.84 / -0.40	5.55 / 4.85	4.53 / 4.01

Improvement of modeled GPP after LAI assimilation !

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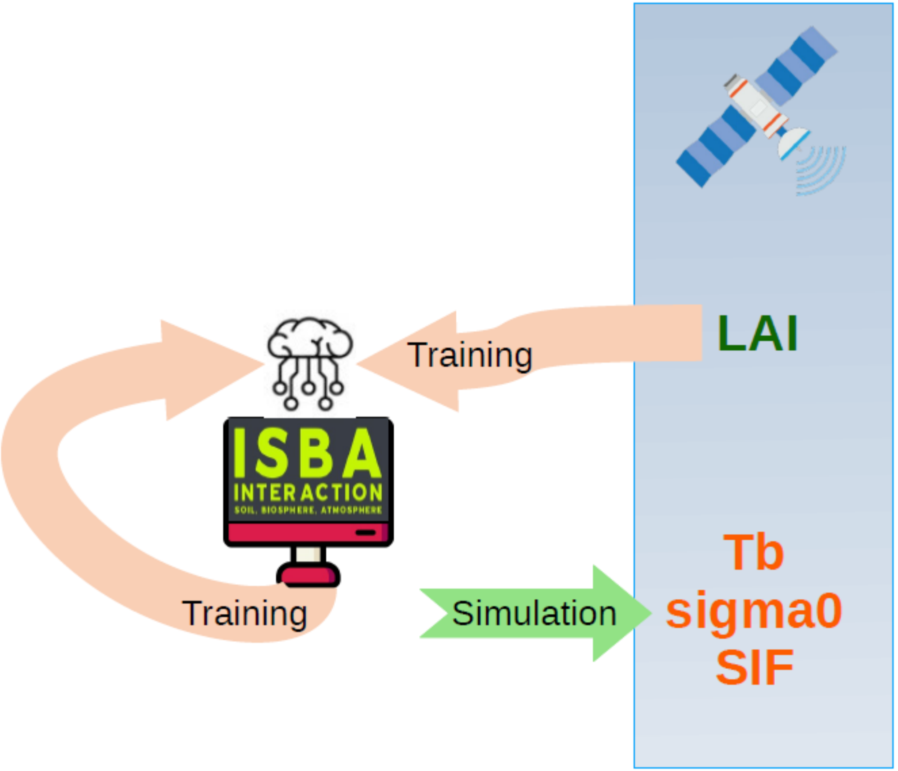
Rojas-Munoz et al. 2025

ML for the assimilation of new observations

SIF and microwave data



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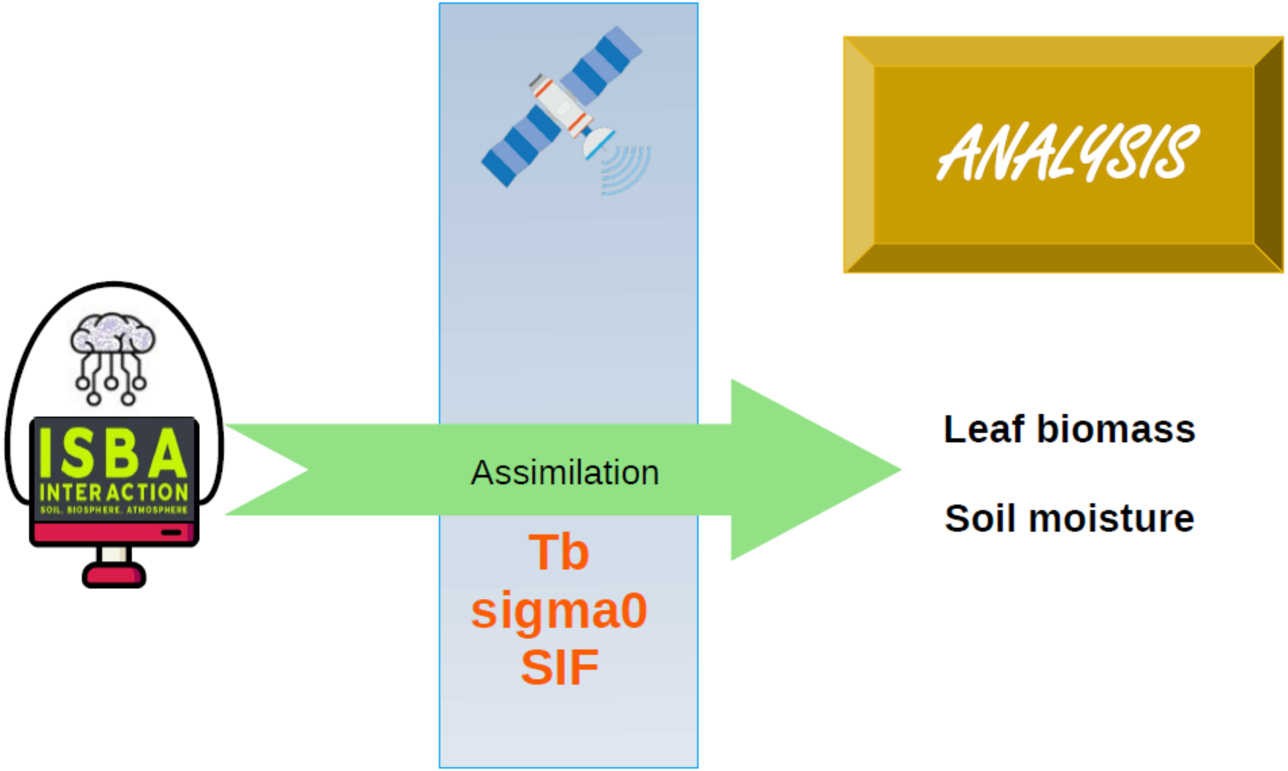
ML for the assimilation of new observations

SIF and microwave data



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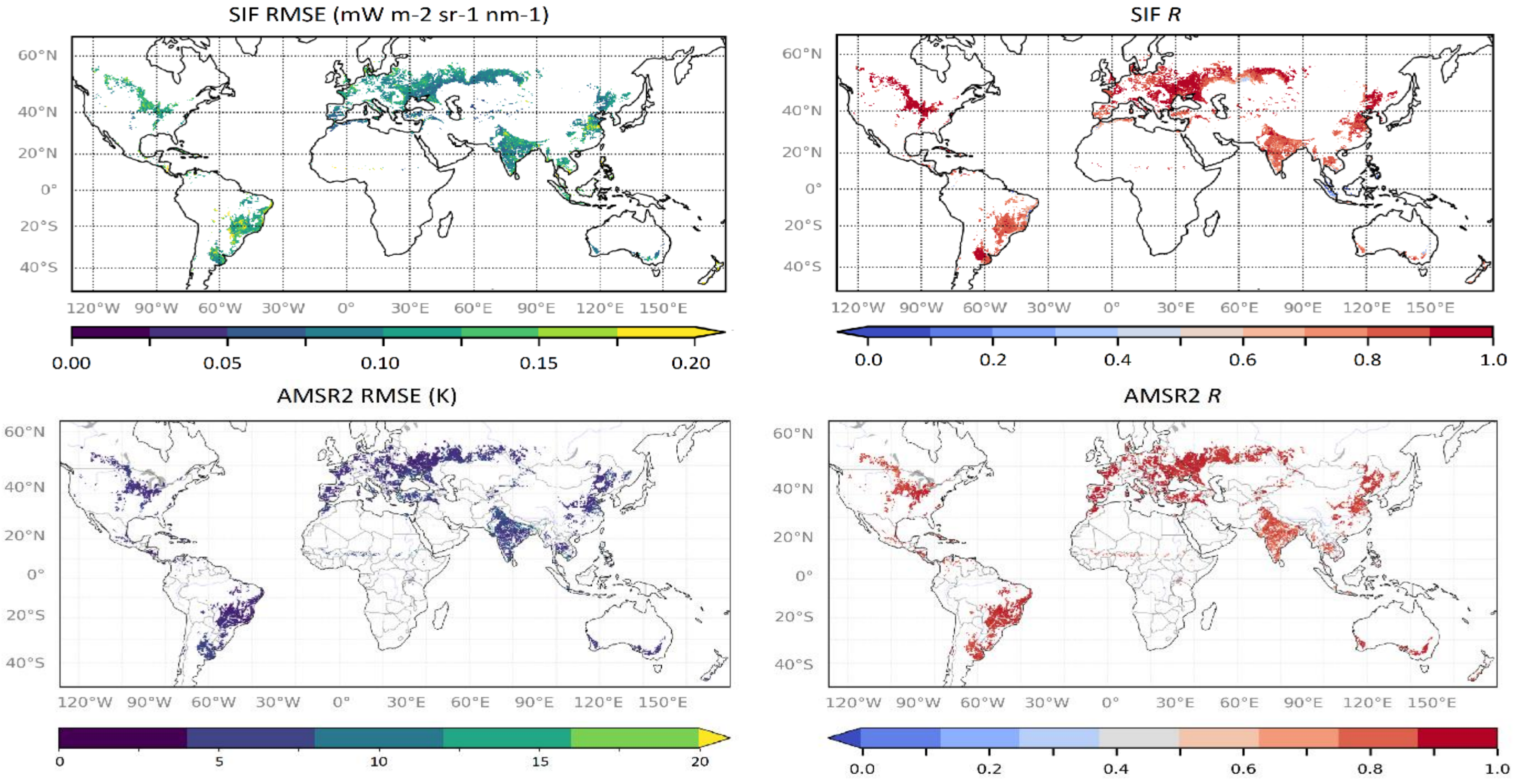

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ML for the assimilation of new observations

SIF and microwave data

Instrument (observation)	RMSE			R		
	Mean	SD	RSD	Mean	SD	RSD
TROPOMI	0.11	0.03	30	0.83	0.15	18
(SIF)	(mw m^{-2} sr^{-1} nm^{-1})		(%)			(%)
ASCAT	0.68	0.29	43	0.63	0.17	27
(C-band sigma0)	(dB)		(%)			(%)
SMAP	9.7	7.3	75	0.76	0.18	24
(L-band TB)	(K)		(%)			(%)
SMOS	12.3	9.5	77	0.67	0.28	42
(L-band TB)	(K)		(%)			(%)
AMSR2	3.5	1.7	49	0.92	0.09	10
(X-band TB)	(K)		(%)			(%)

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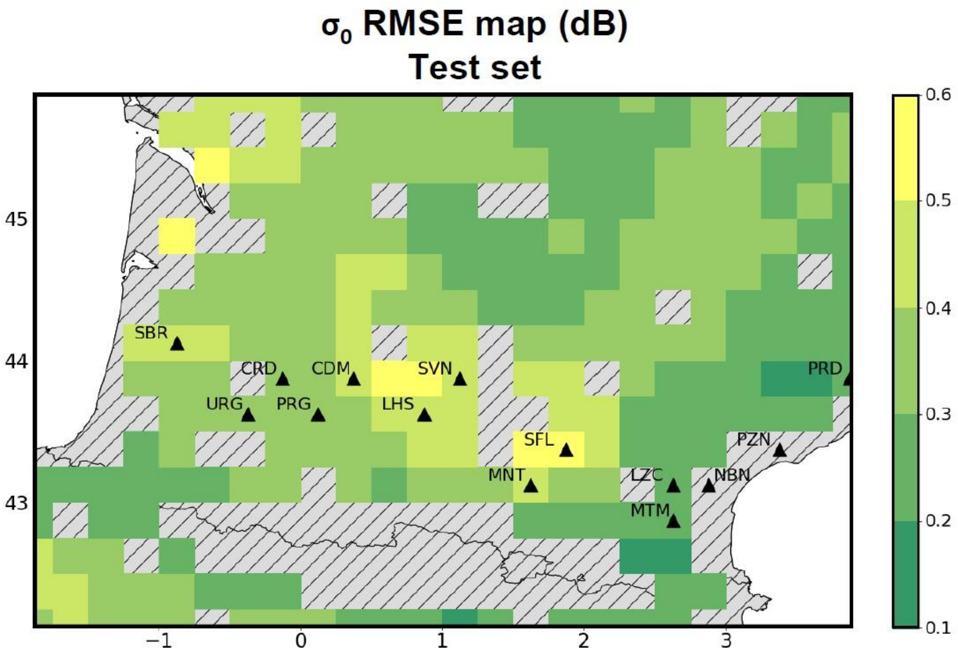
Assimilation of ASCAT sigma0



Good performance of the NNs

Higher RMSEs in agricultural areas

ASCAT σ_0 observation error ≈ 0.33dB

CORSO CO2MVS Research on Supplementary Observations

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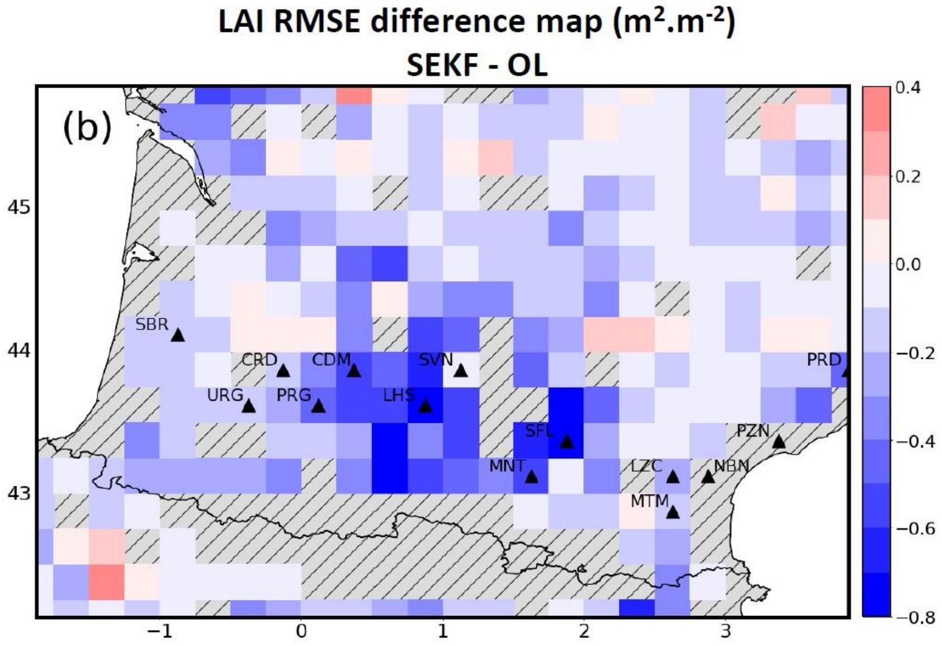
Corchia et al. 2023

Assimilation of ASCAT sigma0



Improvement of LAI RMSE in most grid-cells

Stronger improvement in agricultural areas

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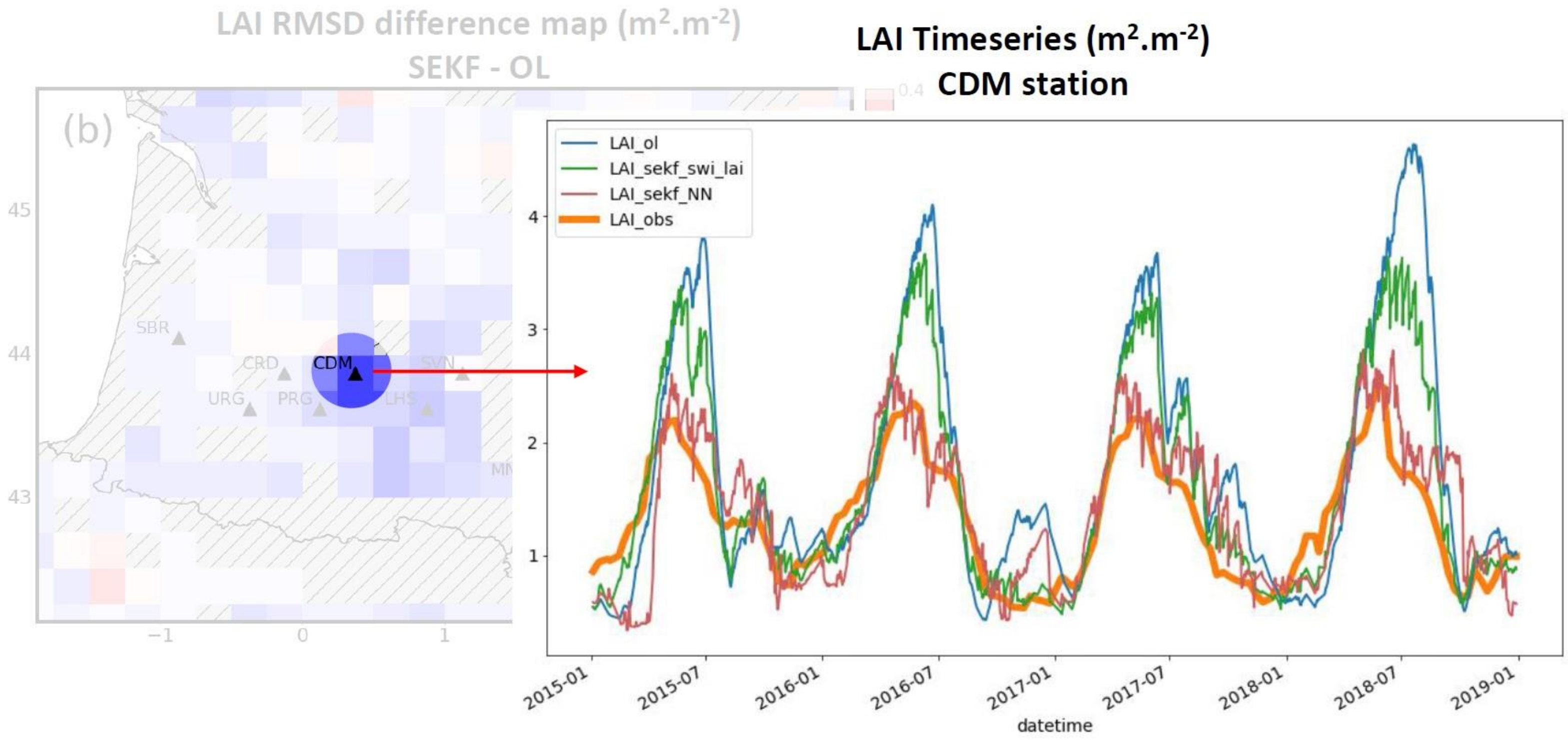
Assimilation of ASCAT sigma0



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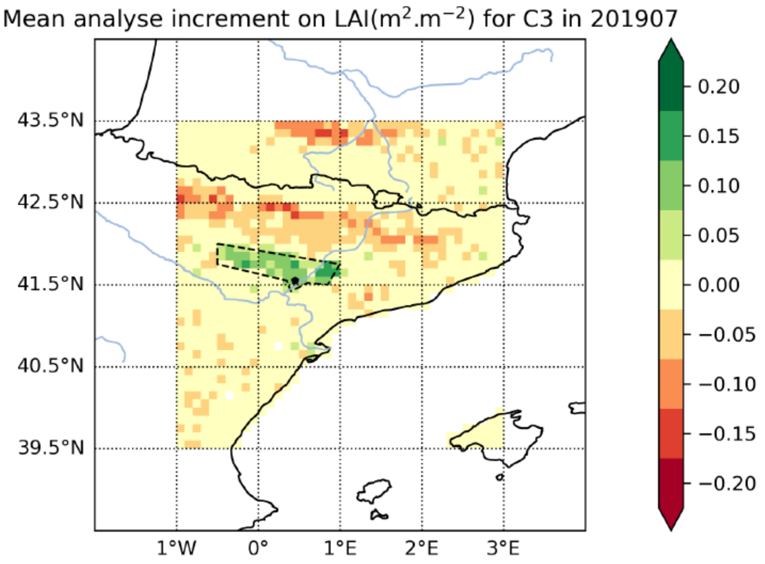
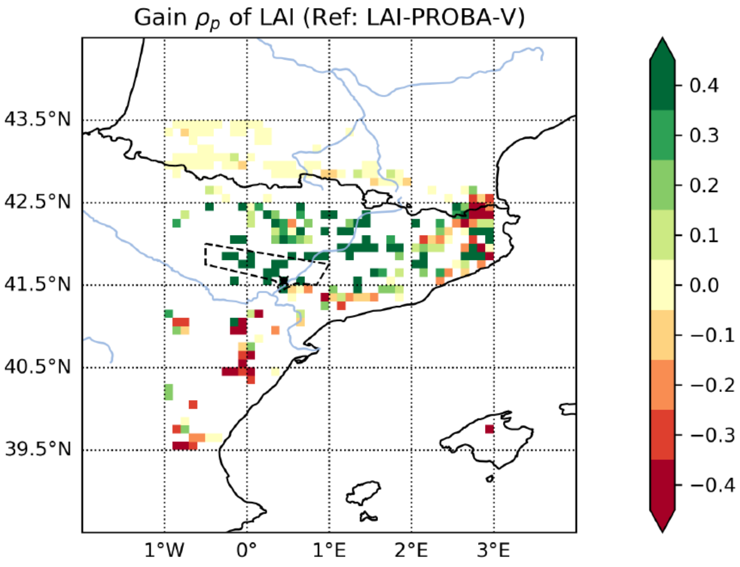
Assimilation of SIF





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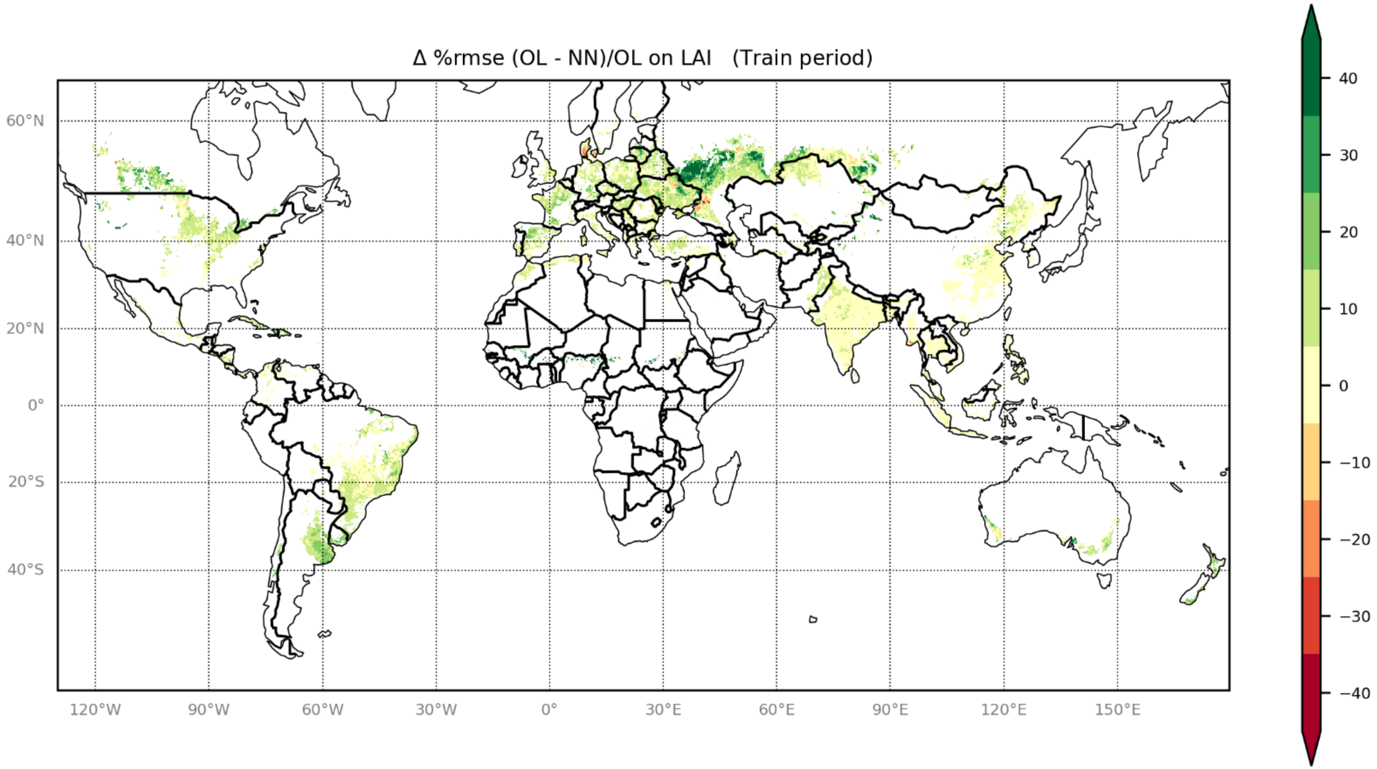
Assimilation of SIF



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Vegetation fire danger assessment

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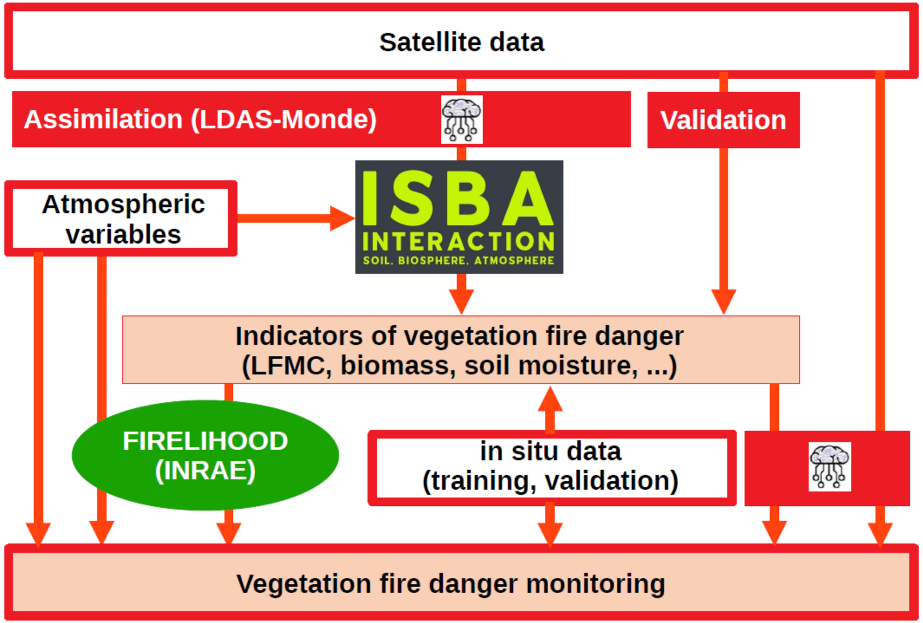
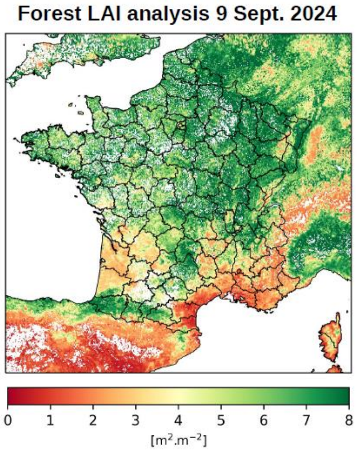
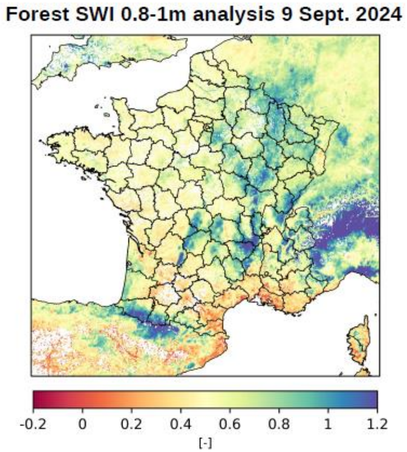




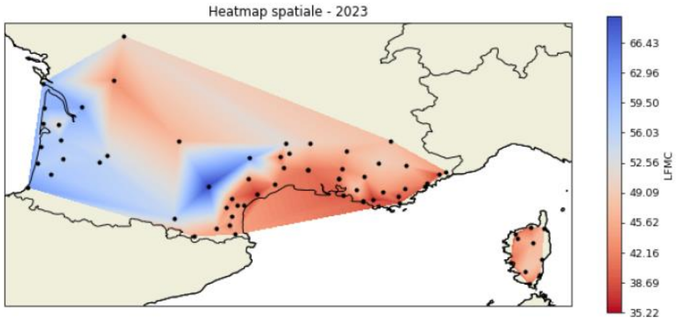


Vegetation fire danger assessment

Since 1996, the ONF has been collecting LFMC (Living Fuel Moisture Content) values in France.
(Yebra, M. et al., 2013)[1]

$$LFMC(\%) = \frac{FreshMass - DryMass}{DryMass}$$

- Fire ignition (Chuvieco et al., 2004b)[2]
- Fire propagation (Rossa, 2017; Pimont, 2019)[3,4]



GreenEO

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OBSERVATION DE LA TERRE ET TERRITOIRES EN TRANSITION

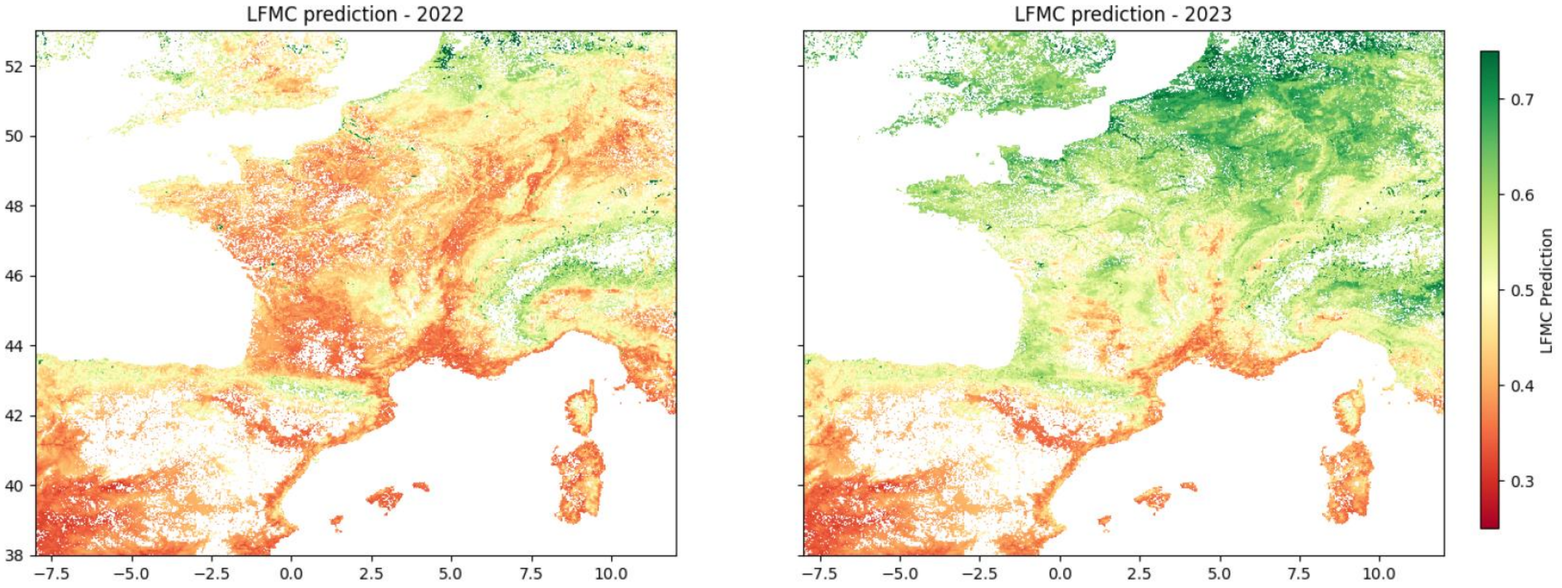
Défis Clés OCCITANIE

La Région Occitanie Pyrénées - Méditerranée

Université de Toulouse

Baehr et al. 2025

Vegetation fire danger assessment



LFMC Maps of the 10th of August 2022 and 2023

Baehr et al. 2025

CONCLUSIONS

- LAI assimilation
  - Leaf biomass and soil moisture profile analysis
  - CLMS LAI can be used for NRT applications (RT1 vs. consolidated RT6)
    - But only one observation every 10 days
  - Assimilating new observations is needed
    - Align other LAI products on CLMS (e.g. EUMETSAT LSASAF)
    - Assimilate SIF and microwave data
- Potential applications of improved vegetation and drought monitoring
  - Vegetation fire danger assessment
  - Hydrology and water resources
  - NWP?

Thank you for your attention