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Joint assimilation of soil moisture and vegetation satellite retrievals into the Noah-MP land surface model

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Land Data Assimilation for Improved Model Output
104th AMS General Meeting
1 February 2024

1. Approach
2. Evaluation with reference data
3. Innovations and increments
4. Conclusions

1 Approach

2 Evaluation with reference data

3 Innovations and increments

4 Conclusions

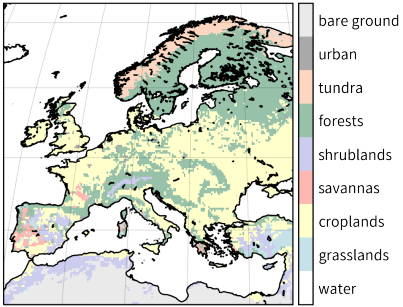
Approach

LSM:
Noah-MP 4.0.1

Forcing:
ERA5

DA approach:
1D EnKF

Experiments:
0.25° grid over Europe, Jan 2015 - Dec 2022



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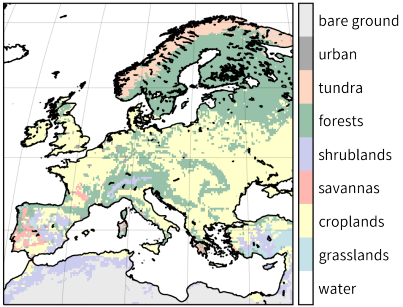
	SMAP L2 sfsm	CGLS LAI	AMSR2 X-VOD	$SM_1, \ldots, SM_4$	LAI
OL					



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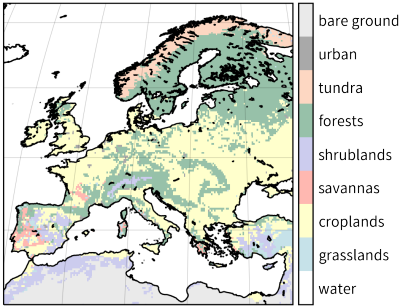
OL					
DA_{SM}	•			•	



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DA_{SM}	•			•	
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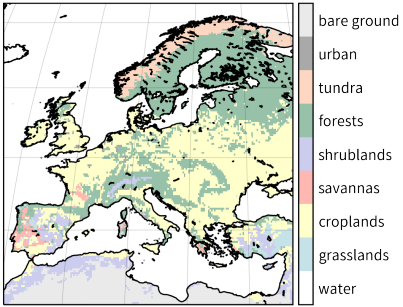

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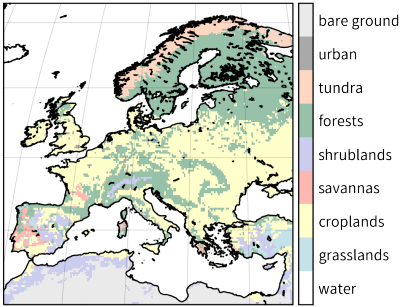

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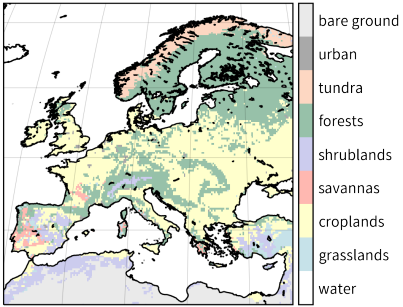
OL					
DA_{SM}	•			•	
DA_{LAI}		•			•
DA_{VOD}			•	•	•
DA_{SM+LAI}	•	•		•	•
DA_{SM+VOD}	•		•	•	•



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DA_{VOD}			•	•	•
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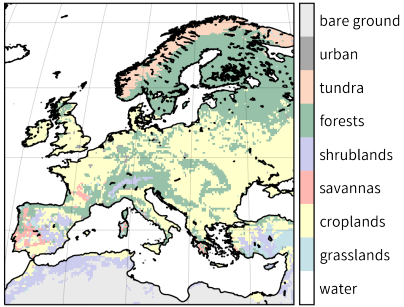
DA_{SM+VOD}	•		•	•	•



Research question
Can improvements from **surface soil moisture (sfsm)** and **vegetation (LAI/VOD)** DA be combined in a multi-sensor, multivariate setup for land DA?

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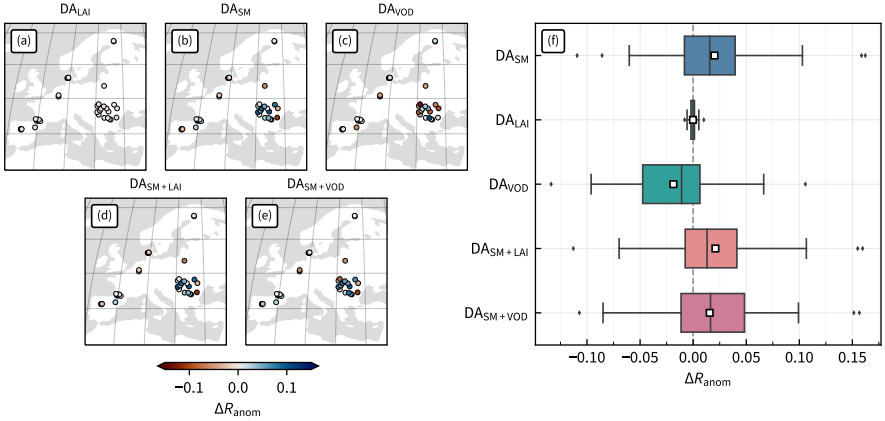
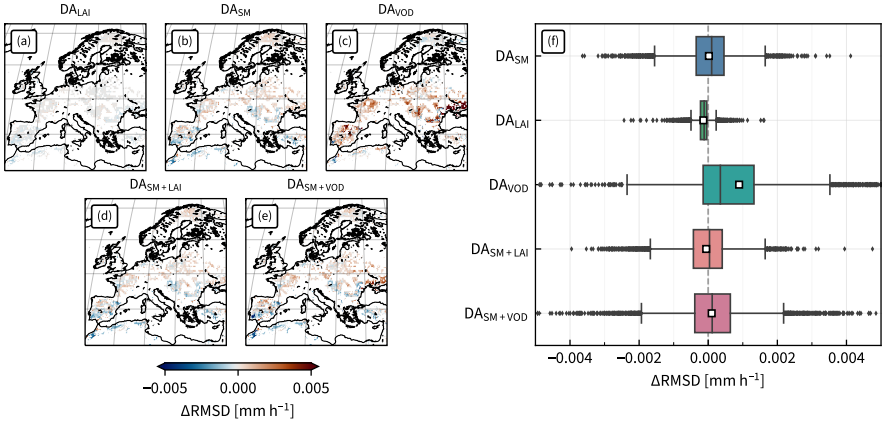
Evaluation of surface soil moisture

- Surface soil moisture (sfsm): top 10 cm of soil.
- Evaluated with ISMN in situ data.
- Maps show ΔR_{anom}: blue denotes improvement w.r.t. OL.
- **Similar skill for sfsm-only DA and joint DA.**



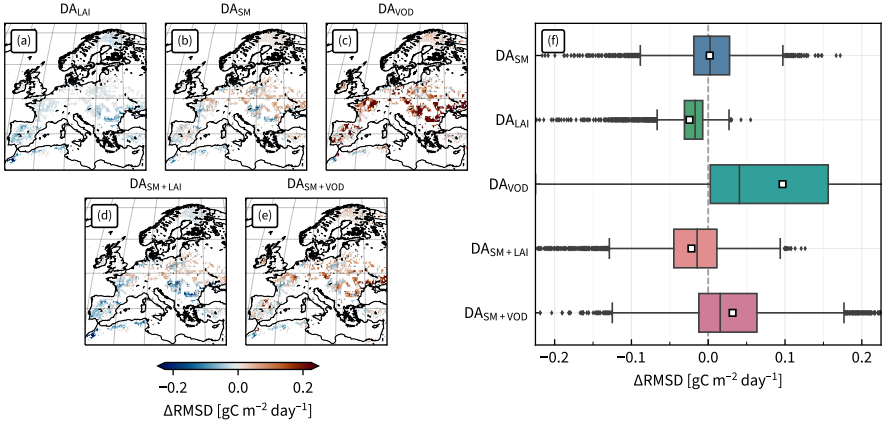
Evaluation of ET

- ET: evapotranspiration.
- Evaluated with the FLUXCOM-X dataset.
- Maps show ΔRMSD: blue denotes improvement w.r.t. OL.
- **Similar skill for sfsm-only DA and joint DA.**



Evaluation of GPP

- GPP: gross primary production.
- Evaluated with the FLUXCOM-X dataset.
- Maps show ΔRMSD: blue denotes improvement w.r.t. OL.
- **Joint DA skill in between sfsm- and vegetation-only DA.**



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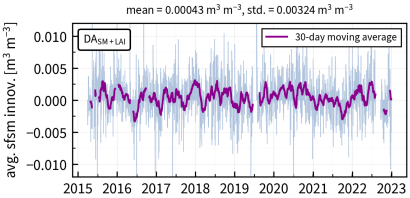
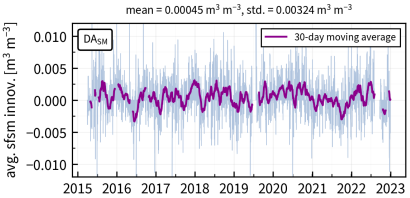
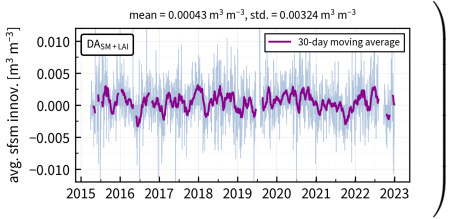
- Time series of **spatially averaged sfsm innovations** for DA_{SM+LAI} and DA_{SM}.





- Time series of **spatially averaged sfsm innovations** for DA_{SM+LAI} and DA_{SM}.

abs



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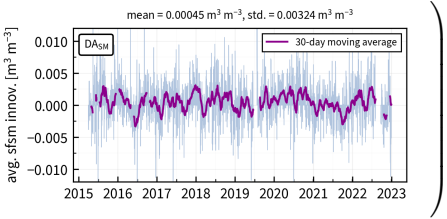
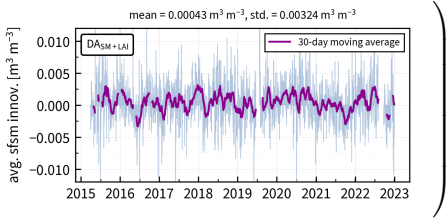


- Time series of **spatially averaged sfsm innovations** for DA$_{SM+LAI}$ and DA$_{SM}$.
- Difference of their absolute values: **no clear pattern**.

abs



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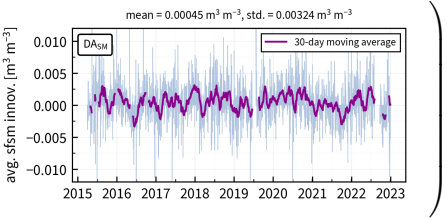

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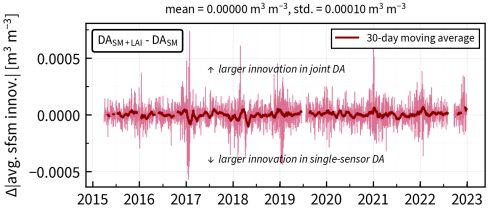
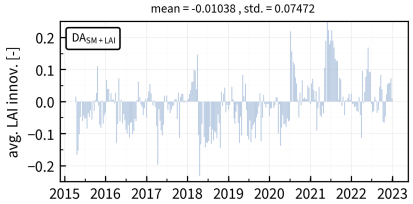
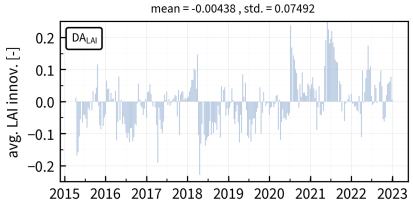
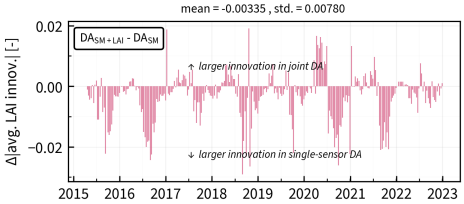


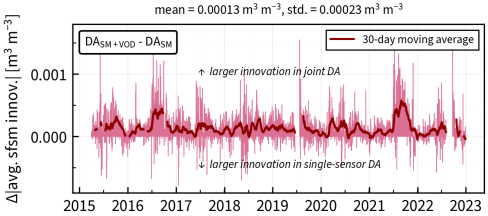
- Time series of spatially averaged LAI innovations for DA_{SM+LAI} and DA_{LAI}.
- Difference of their absolute values: **smaller LAI innovations in joint DA**.

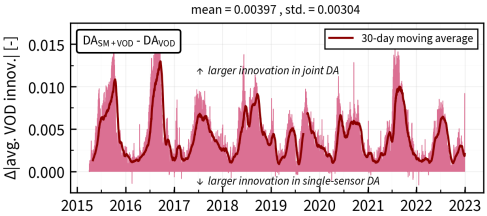




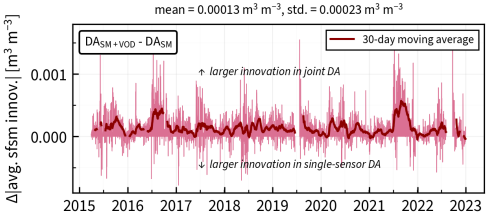


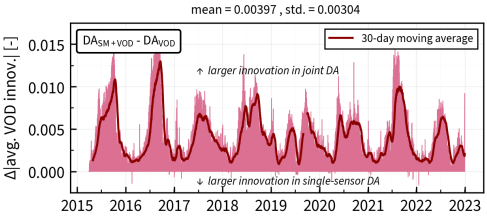
DA_{SM+VOD}



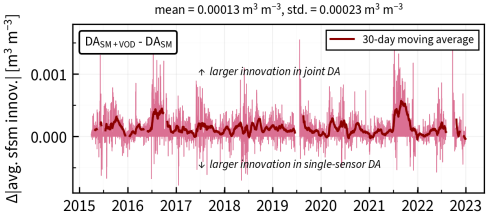


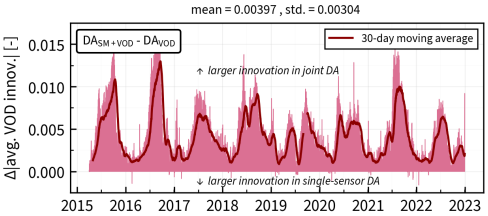
- Larger sfsm and VOD innovations in joint DA.



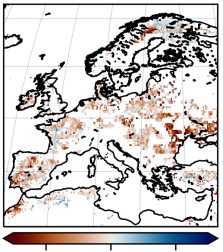


- Larger sfsm and VOD innovations in joint DA.
- Innovation of sfsm $\Rightarrow$ increment of $SM_1, \ldots, SM_4$.
- Innovation of VOD $\Rightarrow$ increment of $SM_1, \ldots, SM_4$ and LAI.





- Larger sfsm and VOD innovations in joint DA.
- Innovation of sfsm ⇒ increment of SM_1, …, SM_4.
- Innovation of VOD ⇒ increment of SM_1, …, SM_4 and LAI.
- **SM increments from sfsm and VOD innovations counteract each other.**



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Conclusions

Single-sensor experiments

- Soil moisture estimates mainly improved by assimilating sfsm.
- Vegetation estimates (e.g., GPP) mainly improved by assimilating LAI.

DA_{SM+LAI}

- 'Inherits' properties of DA_{SM} and DA_{LAI}: improvements in soil moisture and vegetation state variables.
- Slightly smaller innovations: observation and model estimates closer together.

DA_{SM+VOD}

- More complex interactions between updates from both sensors.
- Soil moisture increments actively try to counteract each other.
  $\rightarrow$ predominantly over areas where VOD DA does not perform well!

Heyvaert, Z., Scherrer, S., et al. (2024). Joint assimilation of satellite-based soil moisture and vegetation conditions into the Noah-MP land surface model. Submitted to *Science of Remote Sensing* (in review).

Preprint available at `http://dx.doi.org/10.2139/ssrn.4692442`.

PREPRINT

Thank you!

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AMS 2024

AMERICAN METEOROLOGICAL SOCIETY
104TH ANNUAL MEETING
28 JANUARY-1 FEBRUARY 2024
BALTIMORE, MD & ONLINE

VLAAMS SUPERCOMPUTER CENTRUM

Vlaanderen
is supercomputing

Appendix

Number of assimilated observations

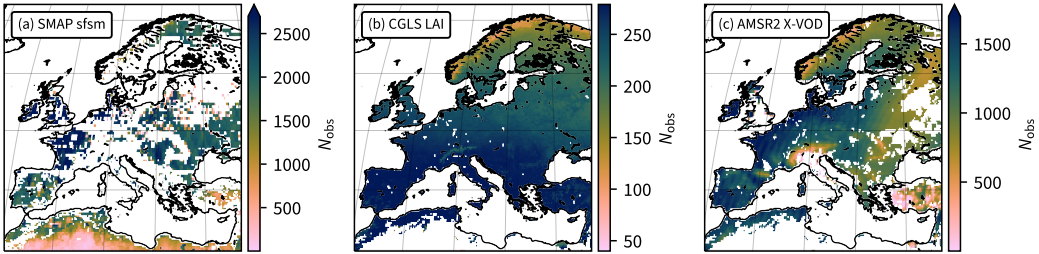


Figure: Number of assimilated observations N_{obs} for the three satellite products between 1 April 2015 and 31 December 2022: (a) SMAP sfsm, (b) CGLS LAI, and (c) AMSR2 X-VOD. No assimilation is performed over the white masked grid cells.

Rescaling of LAI observations

Rescaled observations LAI'_o at each day t are calculated as

$$\mathrm{LAI}'_\mathrm{o}(t) = \mu_\mathrm{m}(\mathrm{doy}(t)) + \frac{\sigma_\mathrm{m}}{\sigma_\mathrm{o}} \cdot (\mathrm{LAI}_\mathrm{o}(t) - \mu_\mathrm{o}(\mathrm{doy}(t))).$$

- $\mu_\star(\mathrm{doy}(t))$ is the mean modeled (m) or observed (o) LAI value for the given day of the year.
- Mean seasonal cycle via three-step procedure:
  1. apply smoothing with a 5-day window;
  2. average the values over the days of year across multiple years;
  3. smooth the obtained seasonal cycle using a window of 31 days.
- $\sigma_\star$ is the standard deviation of the modeled or observed LAI time series at individual grid cells.

VOD observation operator

- Linear regression model linking anomalies ($'$) of **leaf area index (LAI)** and **root-zone soil moisture (rzsm)** to anomalies of **vegetation optical depth (VOD)**:

$$\mathrm{VOD}' = \alpha \cdot \mathrm{LAI}' + \beta \cdot \mathrm{rzsm}'. \tag{1}$$

  The model was calibrated with VOD retrievals and model output of LAI and rzsm from July 2012 through December 2021.

- The parameter β is actually a function of LAI and rzsm:

$$\beta(\mathrm{LAI}, \mathrm{rzsm}) = \beta_0 + \beta_1 \cdot \mathrm{LAI} + \beta_2 \cdot \mathrm{rzsm} + \beta_3 \cdot \mathrm{LAI} \cdot \mathrm{rzsm}. \tag{2}$$

  This represents the fact that the relation between VOD anomalies and rzsm anomalies is itself dependent on moisture and vegetation conditions.

VOD observation operator

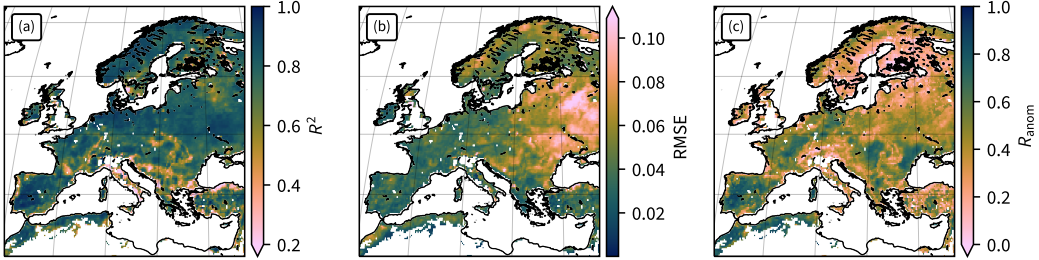
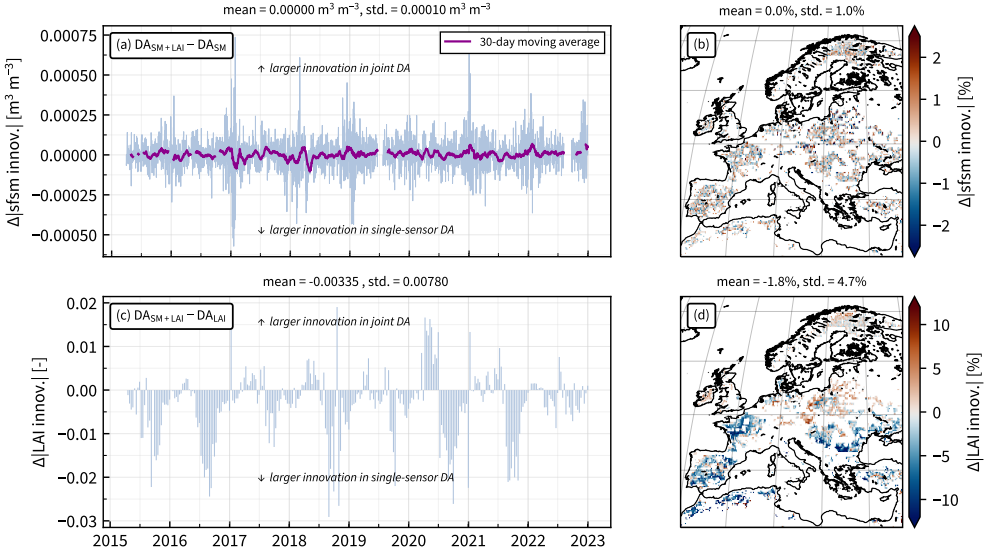
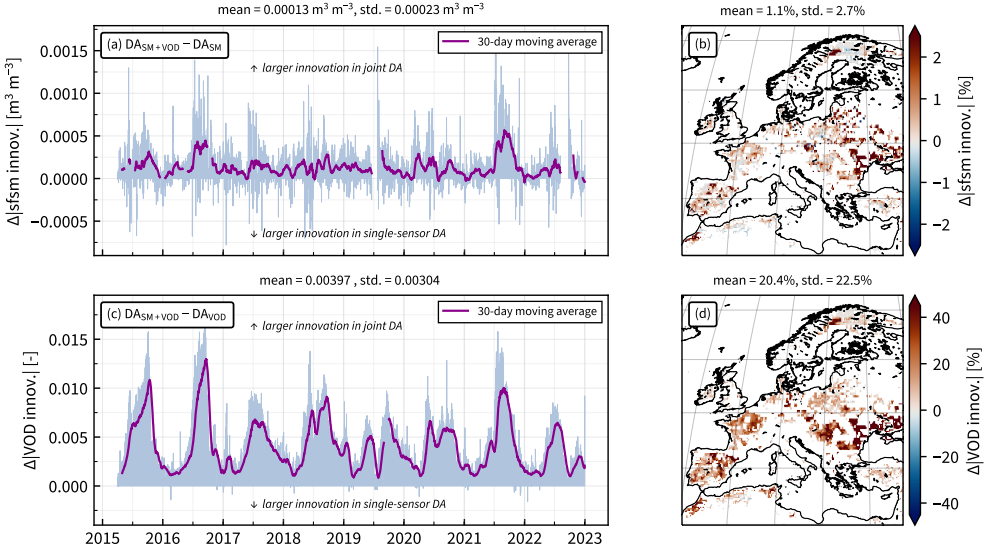


Figure: Evaluation of the VOD observation operator model fit in terms of (a) R^2 [-], (b) RMSE [-], and (c) R_{anom} [-] between model predictions and observation data. Darker colors indicate better performance.

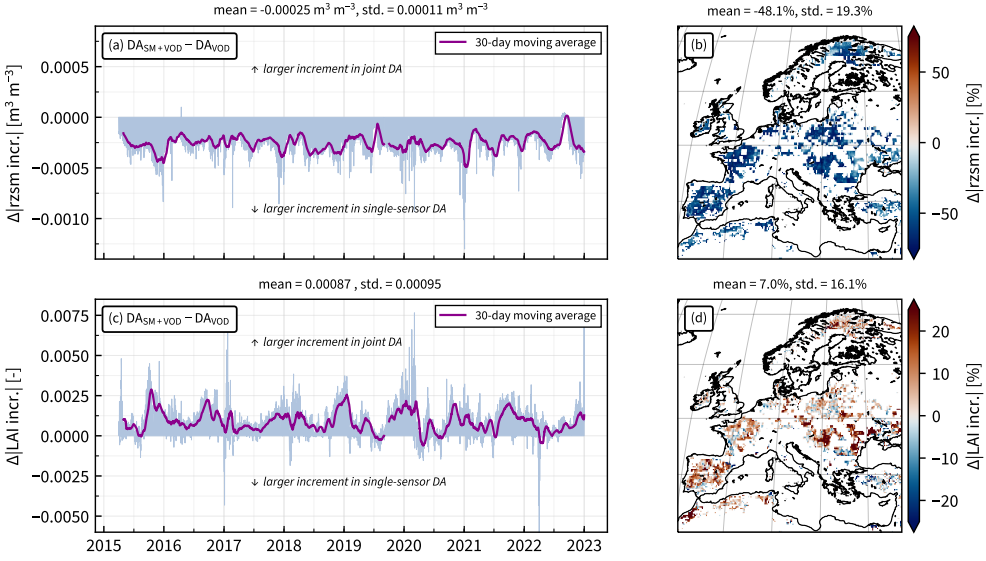
DA_{SM+LAI} innovations



DA_{SM+VOD} innovations



DA_{SM+VOD} **AMSR2 increments**



Perturbations applied to forcings and Noah-MP prognostic variables

	type	mean	standard deviation	temp. corr.	cross-correlations with other perturbations							
					SW	LW	P	SM_1	SM_2	SM_3	SM_4	LAI
SW	$\times$	1	0.3	24 h		−0.50	−0.80					
LW	$+$	0	50 W m^{-2}	24 h	−0.50		0.50					
P	$\times$	1	0.5	24 h	−0.80	0.50						
SM_1	$+$	0	0.00400 m^3 m^{-3}	0					0.60	0.40	0.20	0.08
SM_2	$+$	0	0.00007 m^3 m^{-3}	0				0.60		0.60	0.40	0.13
SM_3	$+$	0	0.00004 m^3 m^{-3}	0				0.40	0.60		0.60	0.19
SM_4	$+$	0	0.00002 m^3 m^{-3}	0				0.20	0.40	0.60		0.10
LAI	$+$	0	0.01	0				0.08	0.13	0.19	0.10	