Assessment of multi-layer increment distributions in an EnKF system for land data assimilation

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1. Methodology

Experiments are performed from 2002 through 2019 over Europe with a resolution of 0.25°.

Land surface model (Noah-MP)

- Input: meteorological forcing, land cover, soil texture.
- Output: land surface states and fluxes.

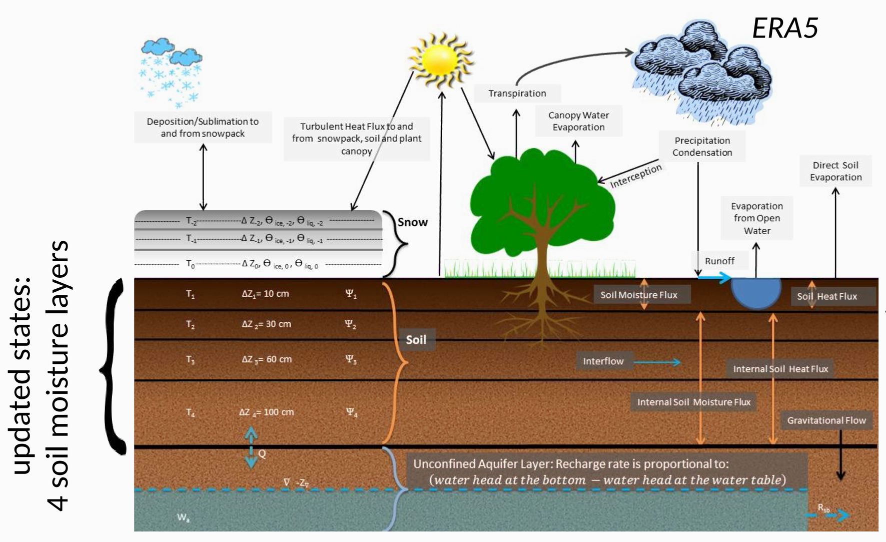

Fig. 1: The Noah-MP model (Niu et al., 2011).

Satellite retrievals (ESA CCI SM)

Observe the *surface* soil moisture (top layer of the model).

Data assimilation

- One-dimensional Ensemble Kalman Filter (EnKF) with 24 ensemble members.
- Differences between forecasted and observed surface soil moisture (innovations) are mapped to updates in soil moisture content in the four layers of the land surface model (increments).
- Perturbations applied to forcing and soil moisture states (Table 1), as well as to the observations.

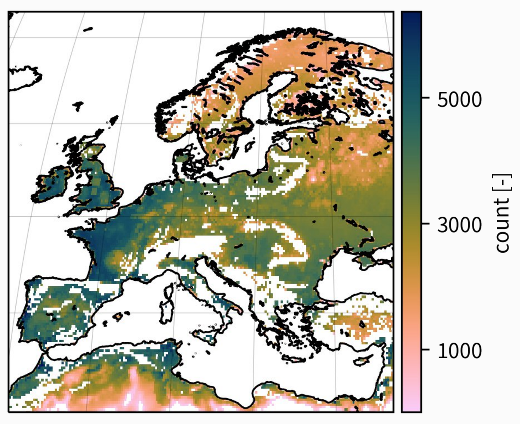

Fig. 2: Number of assimilated observations per pixel.

Table 1: Overview of ensemble perturbations.

	type	mean	std. dev.	cross correlations with other perturbations						
				SW	LW	P	SM_1	SM_2	SM_3	SM_4
SW	×	1	0.3		−0.5	−0.8				
LW	+	0	50 W m^{-2}	−0.5		0.5				
P	×	1	0.5	−0.8	0.5					
SM_1	+	0	0.00400 m^{-3} m^{-3}					0.6	0.4	0.2
SM_2	+	0	0.00007 m^{-3} m^{-3}				0.6		0.6	0.4
SM_3	+	0	0.00004 m^{-3} m^{-3}				0.4	0.6		0.6
SM_4	+	0	0.00002 m^{-3} m^{-3}				0.2	0.4	0.6	

2. Multi-layer increment distributions (MLIDs)

What are MLIDs?

They depict how increments of soil moisture from the surface layer and the deeper layers of the model correlate with each other (Fig. 3).

What can be learned from them?

- Two regimes can be discerned:
  1. Strong increment coupling regime (close to the vertical zero line).
  2. Weak increment coupling regime (close to the horizontal zero line).
- The regime dictates whether an update of the surface soil moisture state is propagated to the root zone or not.

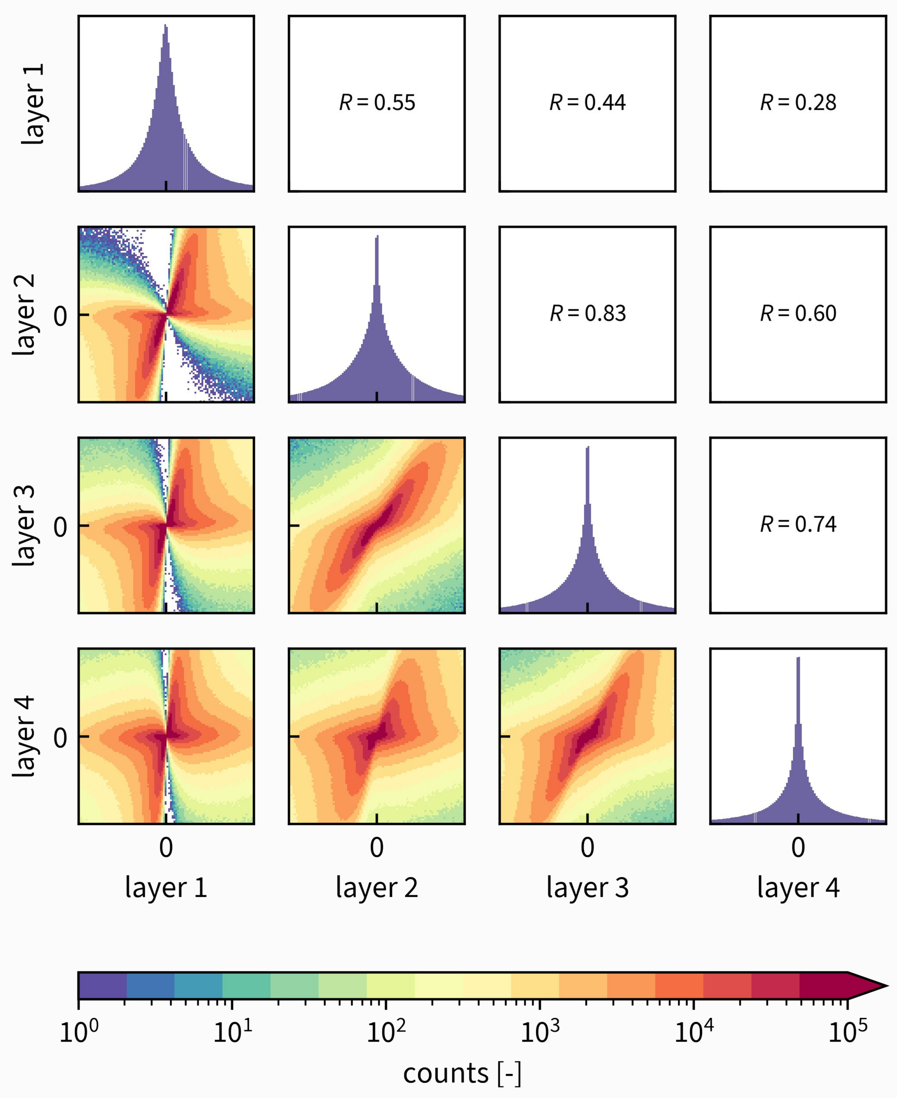

Fig. 3: Histograms on the diagonal show the univariate distributions of soil moisture increments for each layer. Panels below the diagonal show the bivariate distributions (MLIDs) between increments of the respective layers. Pearson correlations of these distributions are shown above the diagonal.

Ranges of the axes:

- layer 1: [-0.0069, 0.0069] m^3 m^{-3}
- layer 2: [-0.0012, 0.0012] m^3 m^{-3}
- layer 3: [-0.0005, 0.0005] m^3 m^{-3}
- layer 4: [-0.0003, 0.0003] m^3 m^{-3}

3. Influence of environmental factors on the MLIDs

Figures show the relation between layers 1 and 2; other layers have similar results (Fig. 4).

(a) Vertical coupling strength (VCS) of the model

- Anomaly correlation between time series of surface and root-zone soil moisture.
- Smaller (larger) VCS = weak (strong) regime.

(b) Evapotranspiration (ET)

- Smaller (larger) ET fluxes = weak (strong) regime.

(c) Runoff

- More (less) runoff = weak (strong) regime.

(d) Rainfall

- Stronger increment coupling during (heavy) rainfall.
- Note: no assimilation takes place during extreme precipitation events.

(e) Root-zone soil moisture (rzsm)

- Drier (wetter) soils = weak (strong) regime.

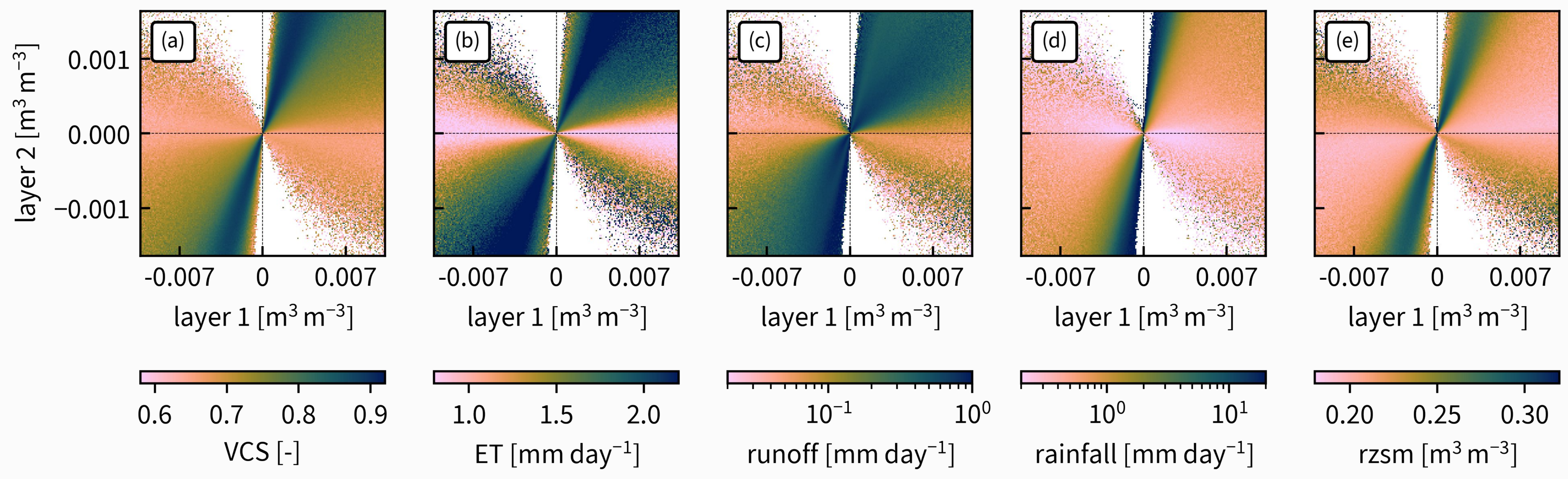

Fig. 4: Same bins as in Fig. 3 but the colors represent the average value of the environmental factors discussed above.

4. Influence of design choices on the MLIDs

Influence of design choices is examined by comparing a reference experiment with other experiments (Table 2).

(a) Observation perturbation size S

- Represents error (uncertainty) applied to the observations.
- Larger S = smaller increments (surface and deeper layers).

(b) Rescaling technique

- Observations are rescaled to model climatology through CDF matching.
- Either monthly (12 CDFs) or climatologically (1 CDF).
- Monthly rescaling = smaller increments.

Table 2: Overview of the performed experiments.

	observation pert. size S	rescaling	met. forcing
DA_{ref}	0.025 m^3m^{-3}	monthly	ERA5
DA_1	0.050 m^3m^{-3}	monthly	ERA5
DA_2	0.025 m^3m^{-3}	climatological	ERA5
DA_3	0.025 m^3m^{-3}	monthly	MERRA-2

(c) Meteorological forcing

- Weak increment coupling regime is more pronounced when forced by MERRA-2, strong coupling regime when forced by ERA5.
- Higher number of heavy rainfall events for ERA5.

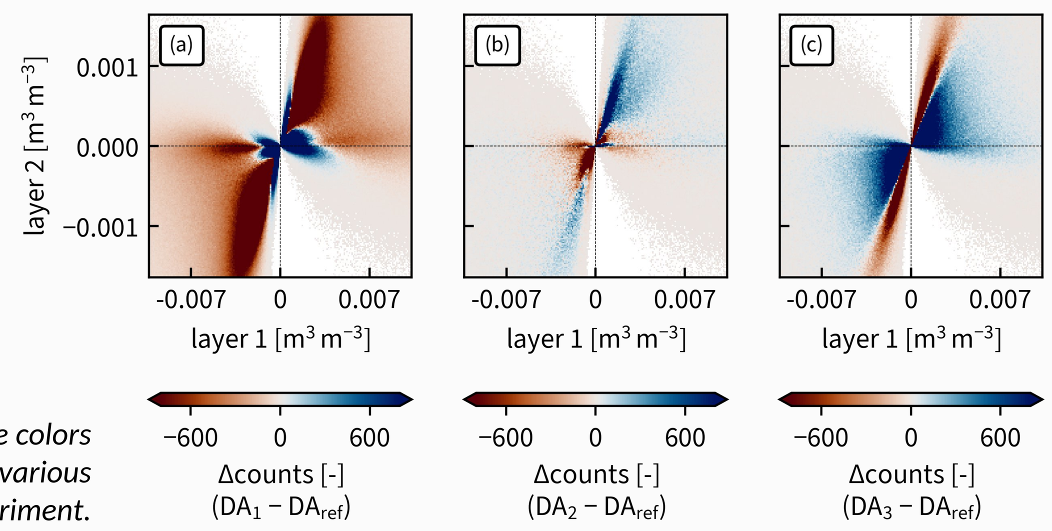

Fig. 5: Same bins as in Fig. 3 but the colors represent the difference in count between various DA experiments and the reference DA experiment.

5. Precipitation

- Surface increments are compared between DA experiments forced by MERRA-2 and ERA5 (Fig. 6).
- Some increments have opposite signs with a different forcing.
- DA may be correcting for rainfall events not captured well by the meteorological forcing (and thus the LSM).

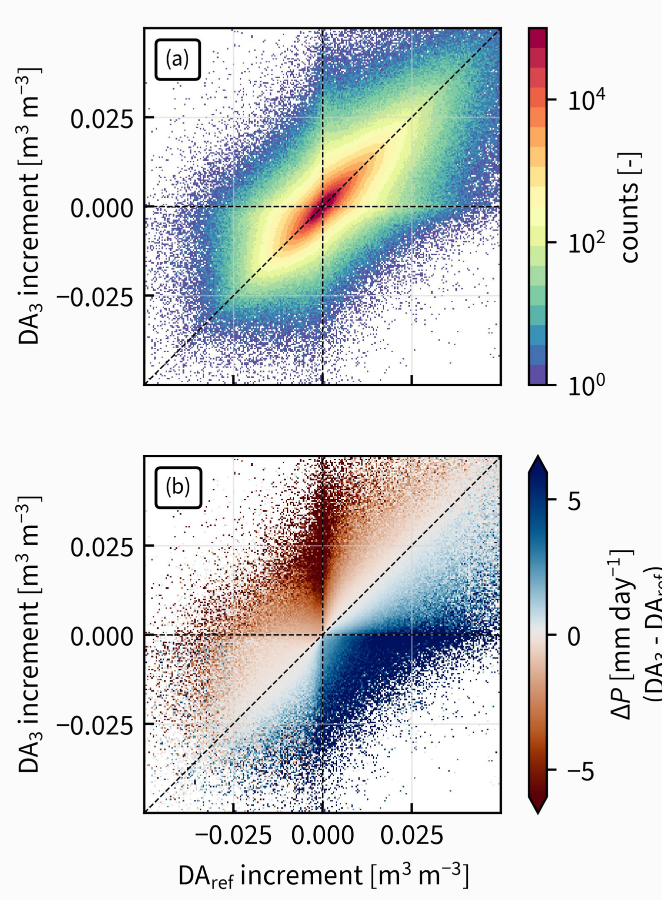

Fig. 6: (a) Relation between increments of DA_3 (forced by MERRA-2) and DA_{ref} (forced by ERA5) for the surface layer. (b) Same bins as (a), but the color represents the average difference in rainfall ΔP between both.

Conclusions

- Multi-layer increment distributions of a soil moisture DA system show **two distinct regimes**: one of strong and one of weak increment coupling between the soil layers.
- Strong increment coupling regime is linked to wetter soils and larger hydrological fluxes.
- Design choices of the DA system, ranging from the rescaling approach of the observations to the meteorological forcing, have an impact on which regime is more populated and on the increment sizes overall.
- The study provides additional insight into the **conditions that result in a substantial impact** of surface soil moisture DA **on the deeper model layers**.

References

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SCAN ME

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