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on Earth System Modelling

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für Meteorologie

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Strongly-coupled ensemble data assimilation of boundary-layer observations for the atmosphere-land interface

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What should you take home?

Strongly-coupled ensemble data assimilation of boundary-layer observation for the atmosphere-land interface is possible in perfect twin experiments

We show advantages of strongly-coupled data assimilation compared to weakly-coupled data assimilation

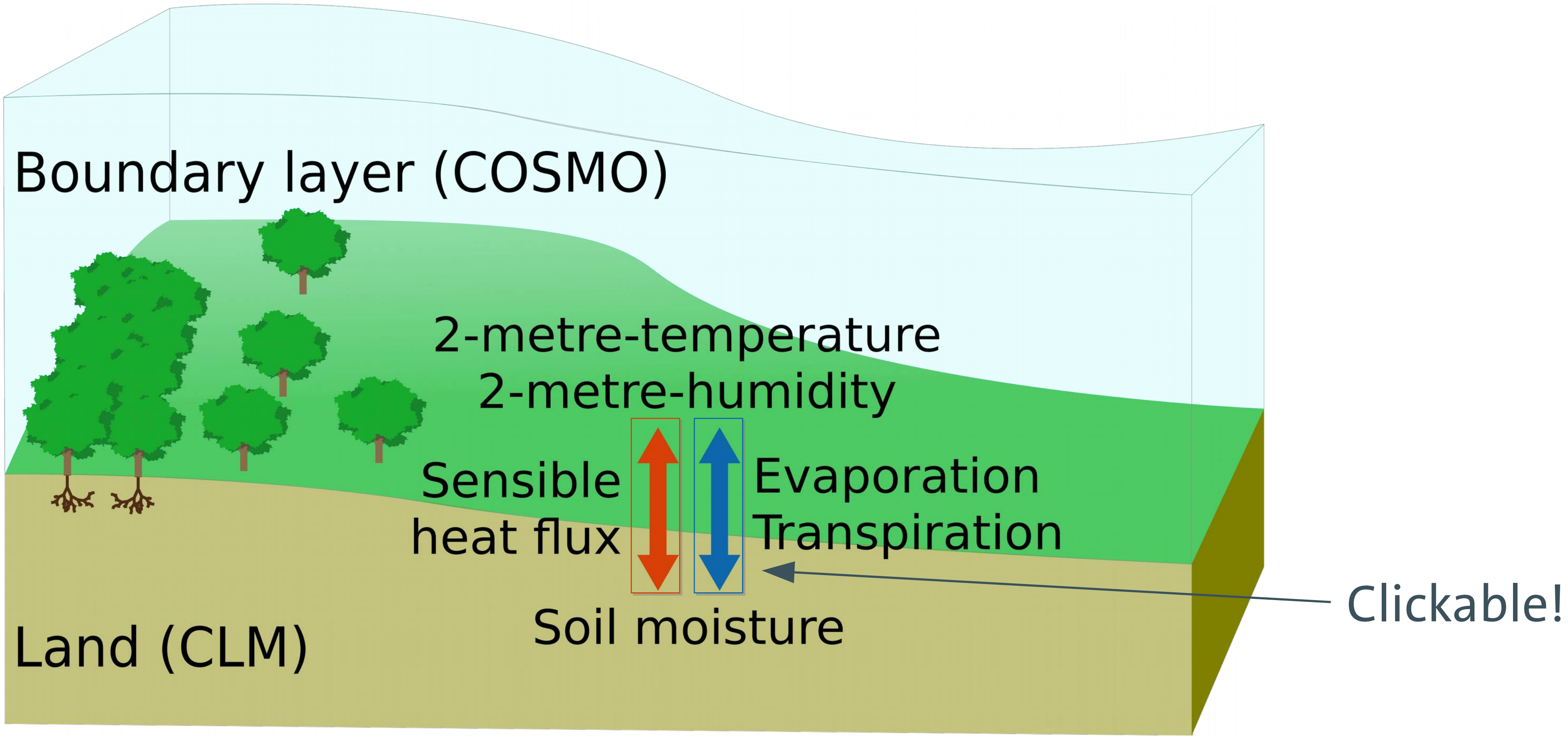
We show control mechanisms for the assimilation of the 2-metre-temperature into soil moisture

Clickable!

If you are interested, please continue

Or you can directly jump to sections

Fluxes couple atmospheric boundary layer to soil moisture



Boundary layer (COSMO)

2-metre-temperature
2-metre-humidity

Sensible heat flux

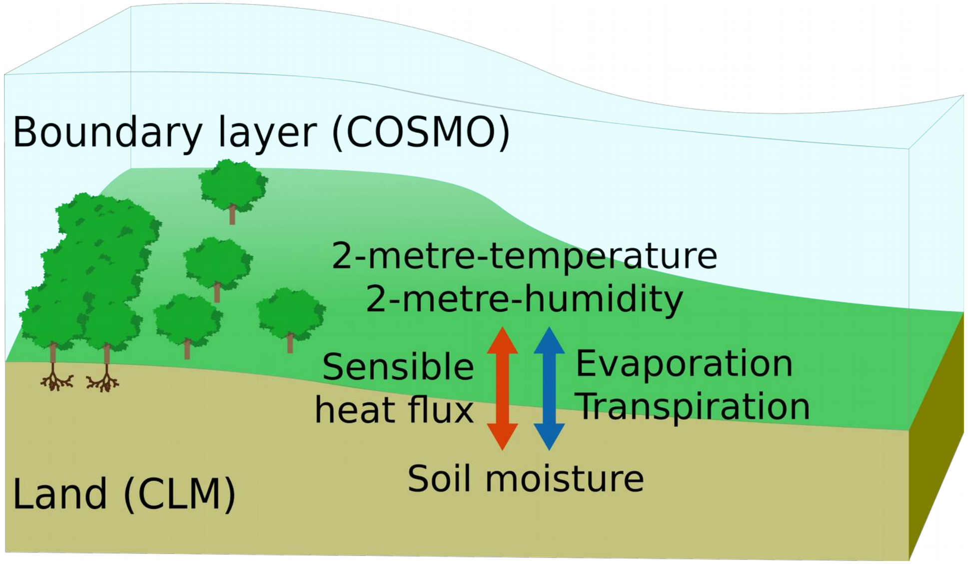
Evaporation
Transpiration

Clickable!

Soil moisture

Land (CLM)

Assimilation of boundary-layer observations for soil moisture



Current state of the art

Weakly-coupled data assimilation
(e.g. Carrera et al., 2015)

Simplified extended Kalman filter
(e.g. Hess et al., 2001; Rosnay et al., 2013)

Updating of soil moisture to correct biases in atmospheric boundary layer

Negative assimilation impact on soil moisture
(e.g. Muñoz-Sabater et al., 2019; Carrera et al., 2019)

What is the impact of strongly-coupled ensemble data assimilation on the assimilation of the 2-metre-temperature into soil moisture?

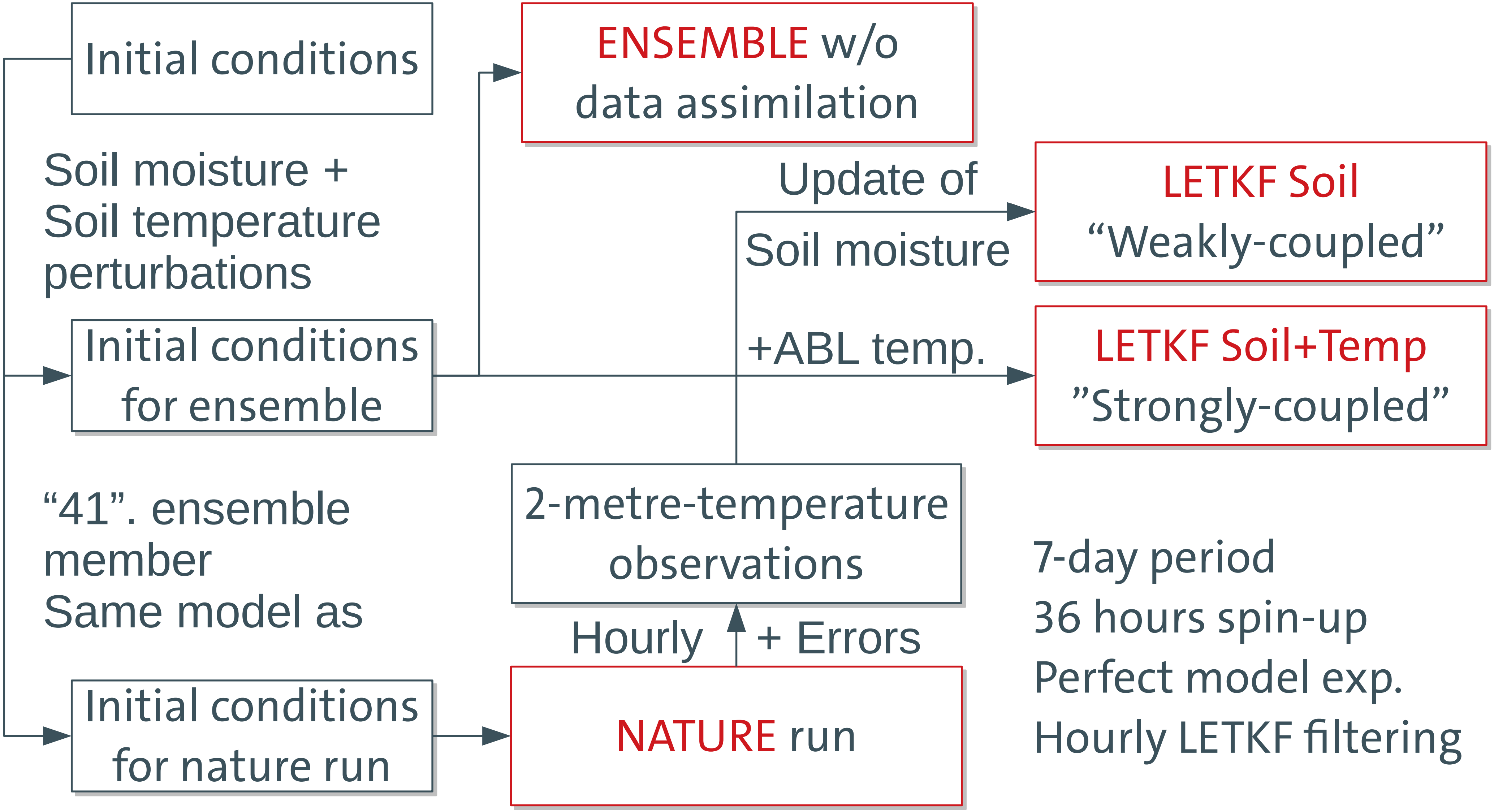
Our plan

Compare strongly-coupled data assimilation with weakly-coupled data assimilation for the atmosphere-land interface

Use an state-of-the-art 3D ensemble data assimilation system together with a fully-coupled model system

Use simple perfect twin experiments with initial soil perturbations only

Differences are driven by initial soil perturbations and data assimilation only



Initial conditions

Soil moisture +
Soil temperature
perturbations

Initial conditions
for ensemble

“41”. ensemble
member
Same model as

Initial conditions
for nature run

ENSEMBLE w/o
data assimilation

Update of
Soil moisture
+ABL temp.

LETKF Soil
“Weakly-coupled”

LETKF Soil+Temp
”Strongly-coupled”

2-metre-temperature
observations

Hourly + Errors

NATURE run

7-day period
36 hours spin-up
Perfect model exp.
Hourly LETKF filtering

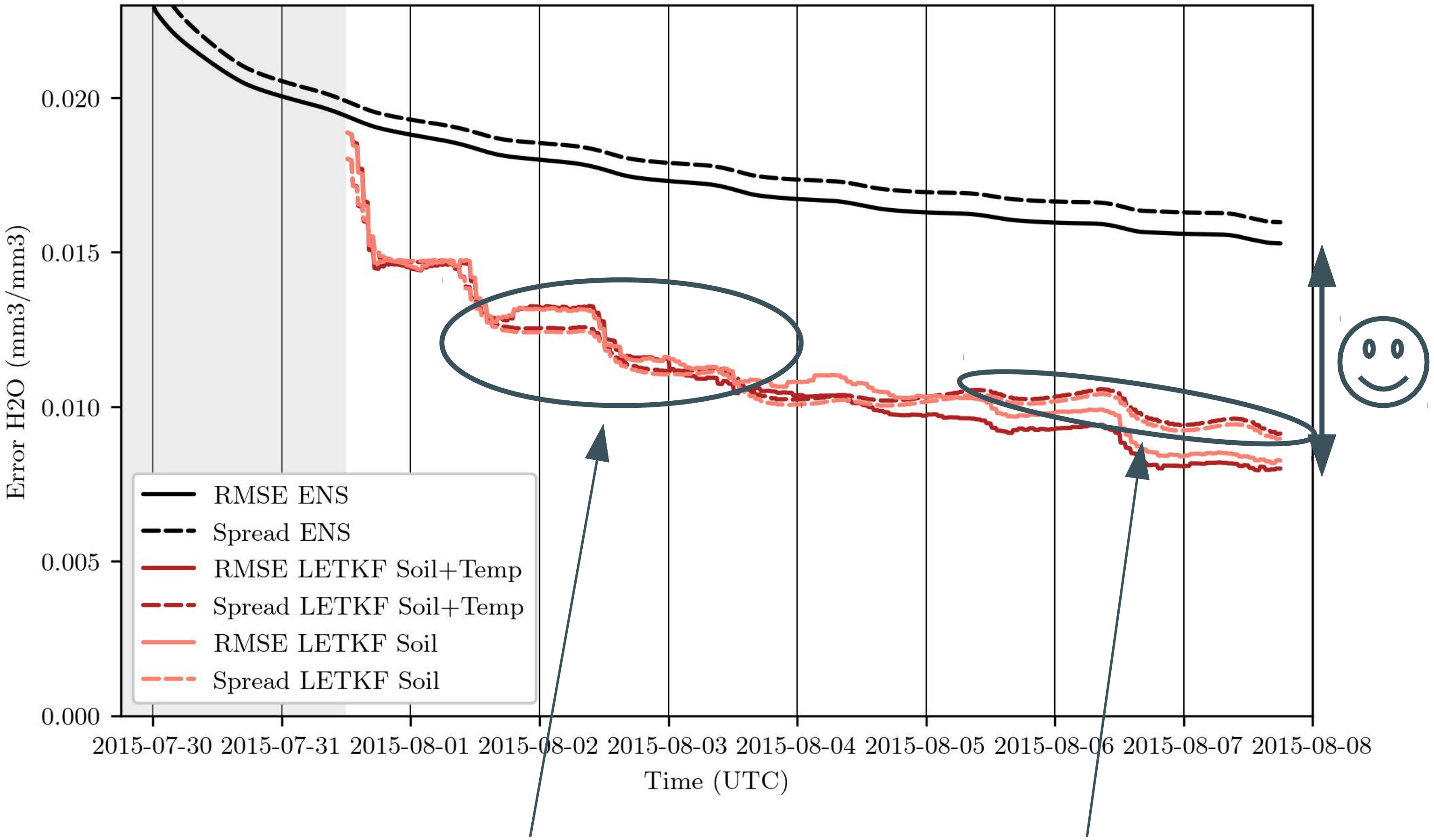
Results overview

LETKF Soil+Temp experiment has lower errors than the LETKF Soil experiment

Strongly-coupled data assimilation is more consistent across the interface compared to weakly-coupled assimilation

Processes within the atmospheric boundary layer have an impact on the data assimilation for soil moisture

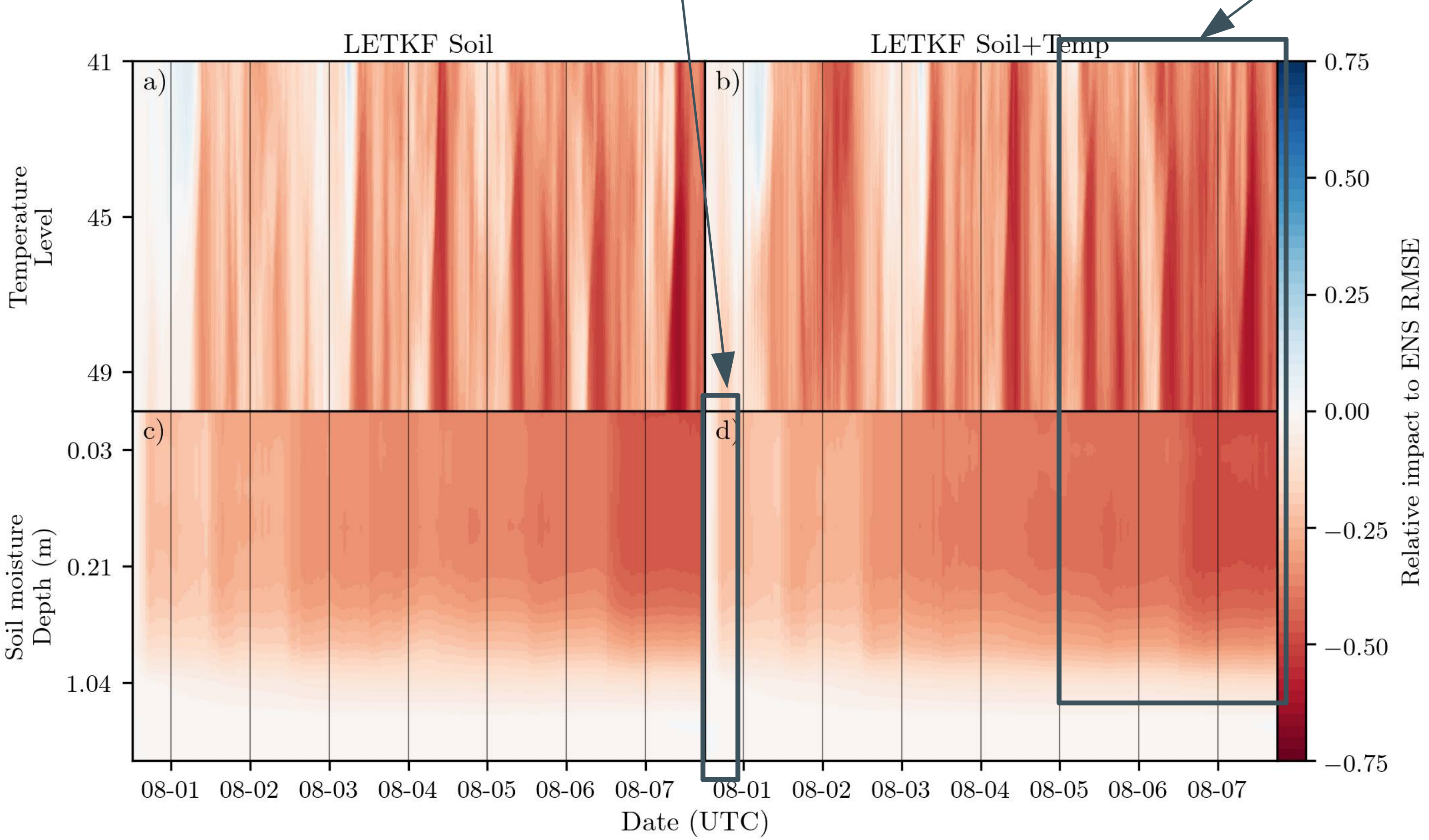
Assimilation of the 2-metre-temperature improves the soil moisture analysis



Inflation too small? Inflation too large?

Problems defining the right inflation → Process-dependent inflation?

Strongly-coupled data assimilation has a more consistent assimilation impact


More consistent increments at the first day

Improved representation of T2m for soil moisture

Positive impact caused by theoretical and practical advantages of consistent updates

Theory

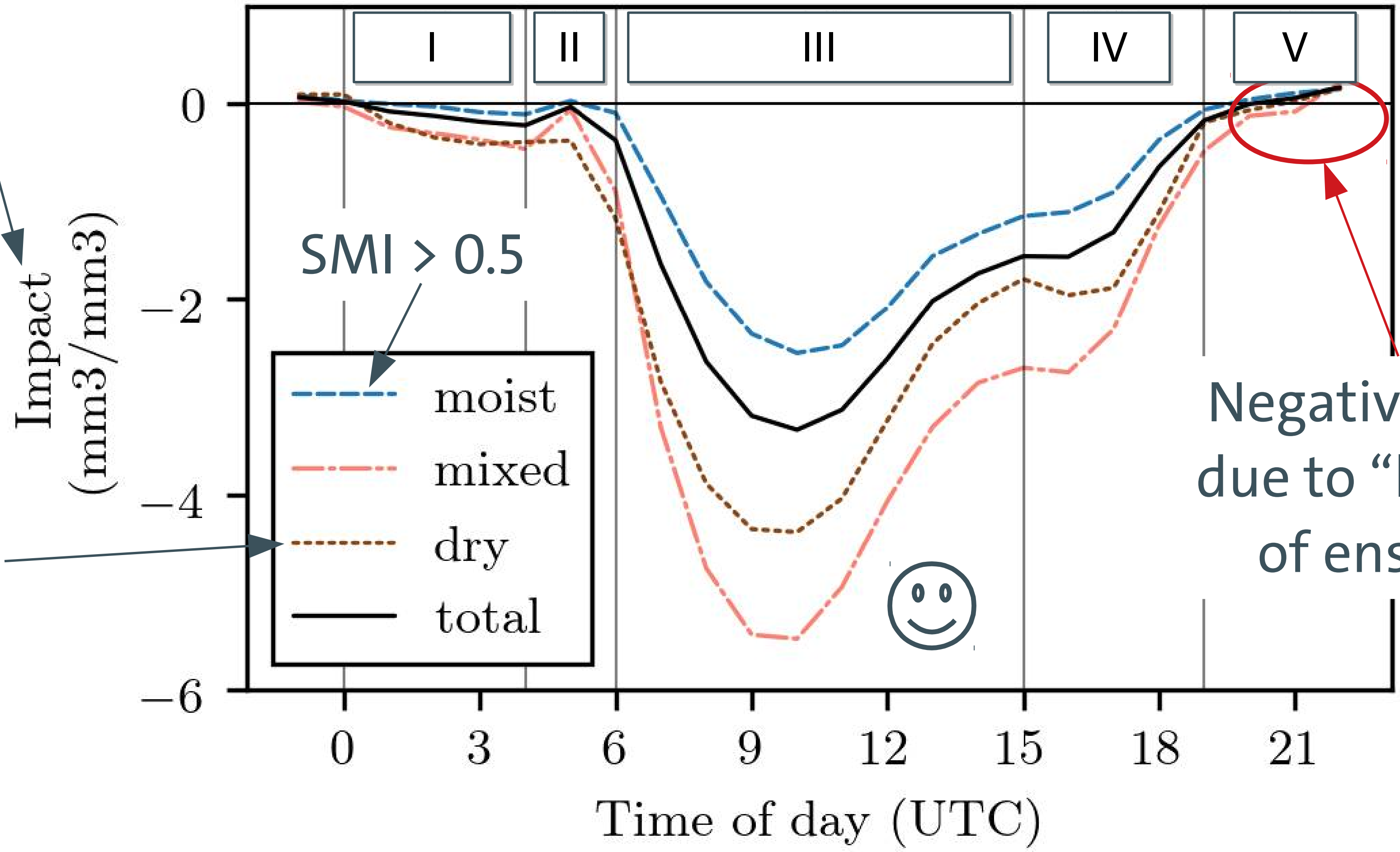
Strongly-coupled data assimilation improves consistency and reduces chances of “correcting the same error twice”

Decreased magnitude of innovations

Increased covariances across compartments

Processes in boundary layer have an impact on soil moisture

Error decrease due to assimilation



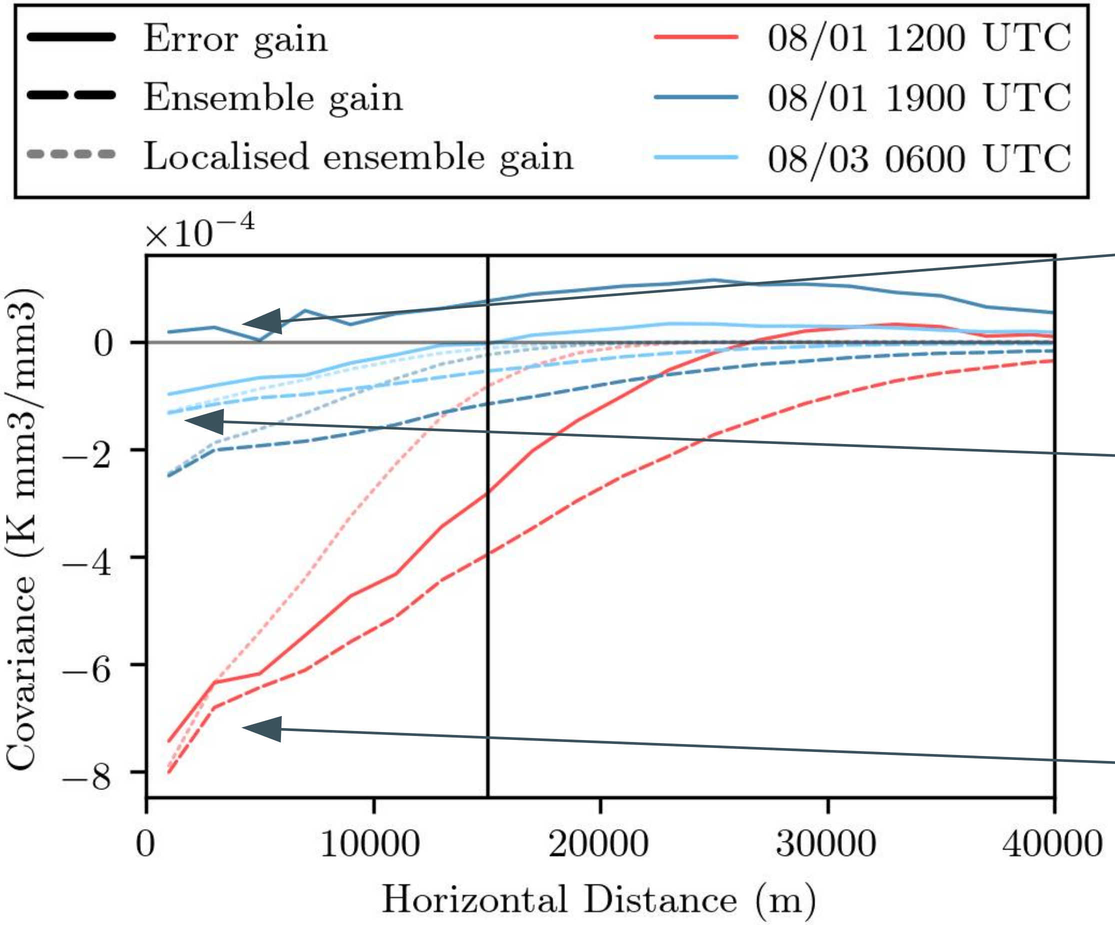
SMI > 0.5

SMI < 0.2

Negative impact due to “lazyness” of ensemble

Diurnal cycle over the 7 days and all grid points

Localisation has to be process-dependent



Best option: No assimilation
→ Localisation = 0

Localisation perfect

Localisation too small

Covariance between T2m and soil moisture dependent on distance between grid points

Conclusion overview

Summary: 3D LETKF assimilation of T2m into soil moisture improves soil moisture in perfect twin experiments

Tackling of negative assimilation impact caused by ensemble and non-linearities with fingerprinter operators + smoothing

Strongly-coupled data assimilation of boundary-layer observations improves consistency for the atmosphere-land interface

Summary

Simple perfect twin experiments with initial soil perturbations only
→ Assimilation with LETKF of T2m into soil moisture

Positive assimilation impact on soil moisture and atmospheric boundary layer

Additional updating the atmospheric temperature decreases error in soil moisture

Process-based disentanglement of assimilation impact shows impact of boundary-layer on assimilation

Inflation and localisation have a slightly negative impact on assimilation → How to choose right tuning parameters?

Outlook

Delayed impact of soil moisture on boundary-layer observations → Smoothing instead of filtering

“Lazyness” of ensemble comparable to spin-up problem
→ Running-in-place or no-cost-smoother approach

(Kalnay and Yang, 2010)

Use of derived observations (e.g. temporal T2m gradient) to tackle lazyness and non-linearities → Fingerprint operators

Process-dependent localisation and inflation
→ Additional statistical models for localisation and inflation

Conclusions

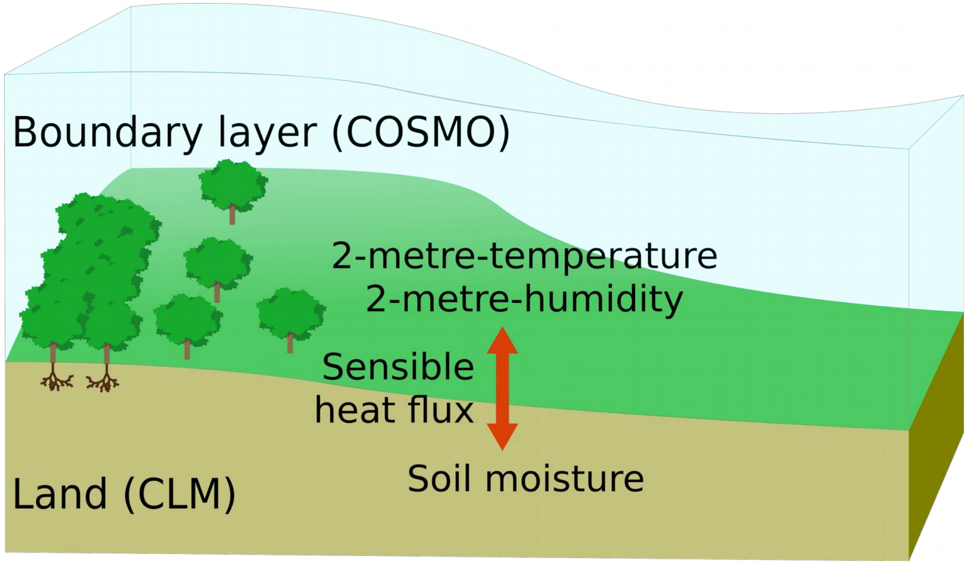
Strongly-coupled data assimilation improves consistency in atmosphere-land interface → Positive assimilation impact

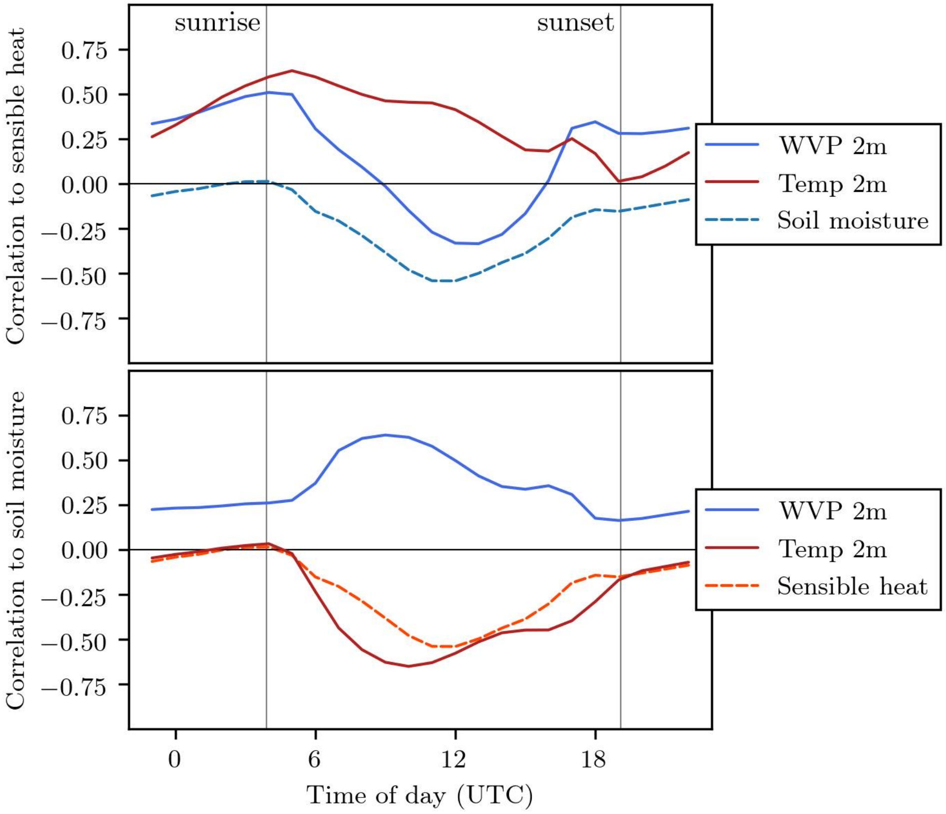
We can use boundary-layer observations in a fully-coupled hydrology model to infer soil moisture with 3D assimilation

Processes in the boundary-layer have a major impact on assimilation at the atmosphere-land interface
→ We need new ideas for “real-world” data assimilation

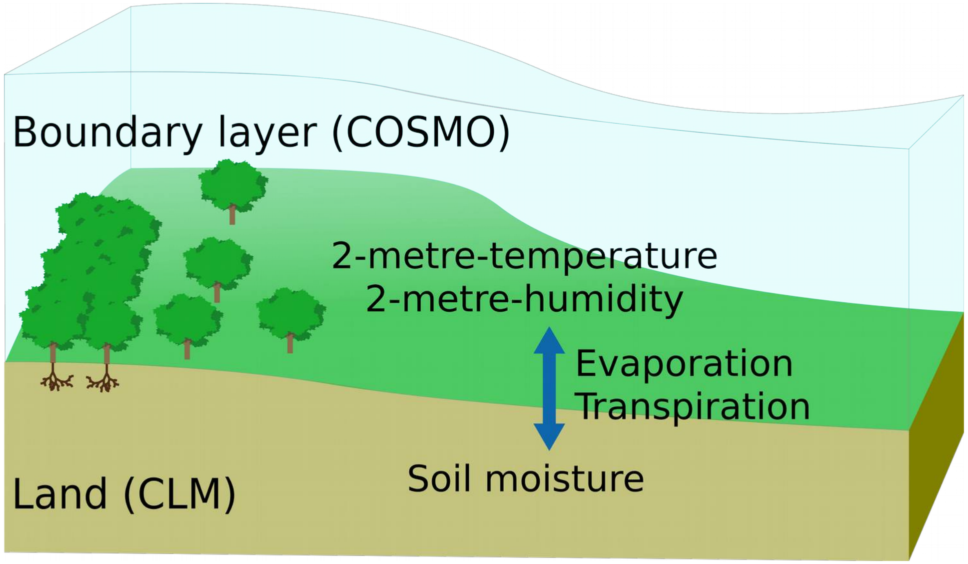
Do you have questions?

Sensible heat flux couples atmospheric temperature to soil moisture during day-time





Latent heat flux couples atmospheric humidity to soil moisture



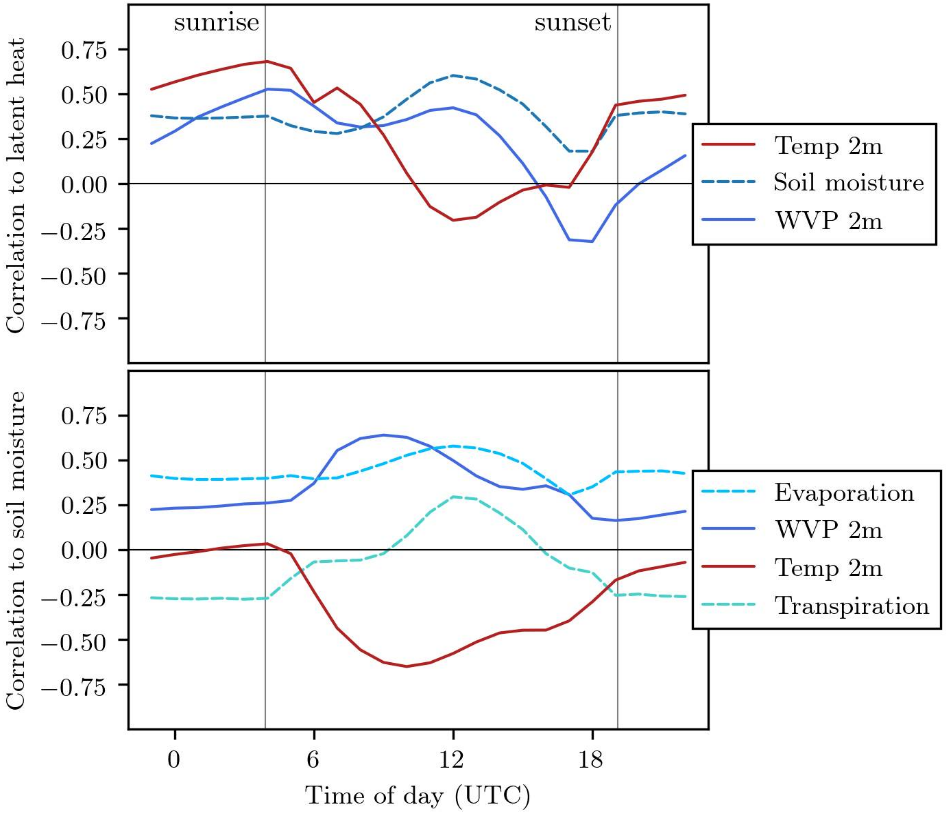
Boundary layer (COSMO)

2-metre-temperature
2-metre-humidity

Evaporation
Transpiration

Soil moisture

Land (CLM)



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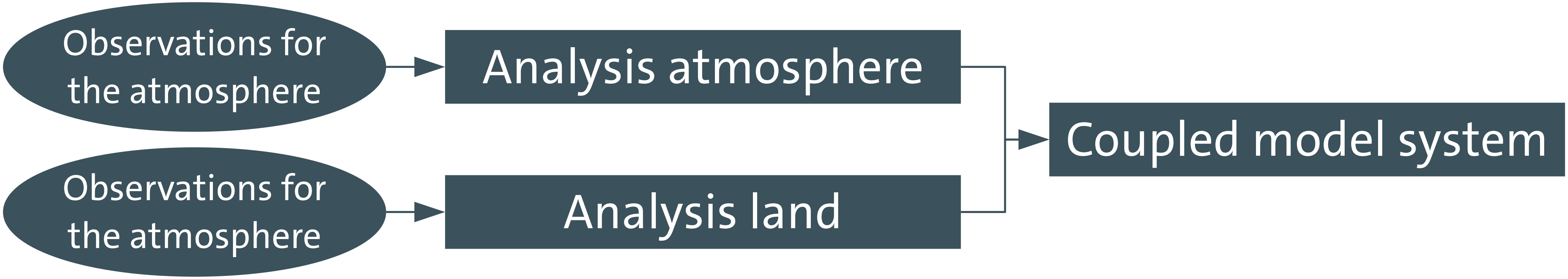
Introduction | Setup | Results | Conclusion

Strongly-coupled data assimilation uses an unified data assimilation across comparments

Weakly-coupled



Observations for the atmosphere

Analysis atmosphere

Observations for the atmosphere

Analysis land

Coupled model system

Strongly-coupled

Combined observations

Coupled analysis

Coupled model system

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3D-Ensemble Data Assimilation system with a fully-coupled model system

Data assimilation

Localised Ensemble Transform Kalman filter

- Gaspari-Cohn localisation – Horizontal radius: 15 km
- Small multiplicative inflation: $\gamma = 1.006$
- Python-based: https://gitlab.com/tobifinn/torch-assimilate

Fully-coupled model system

TerrSysMP (Shrestha et al., 2014, doi:10.1175/MWR-D-14-00029.1)

- Atmosphere: COSMO 4.21
- Land: Community Land Model 3.5
- Coupler: Oasis 3 MCT

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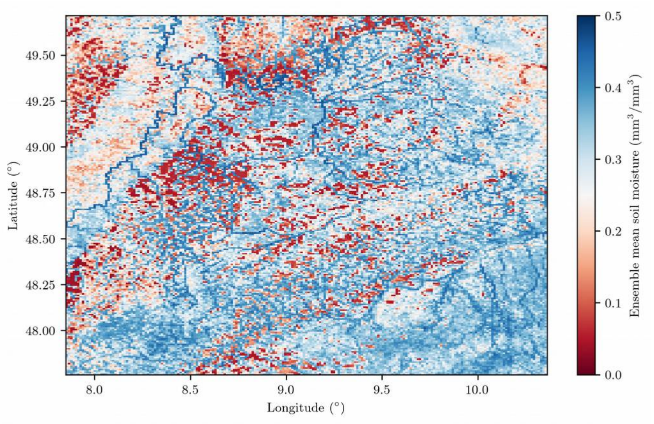
Correlated perturbations in soil moisture and soil temperature



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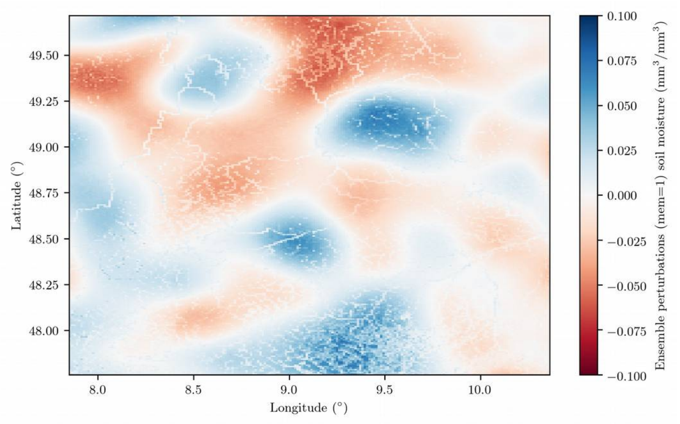

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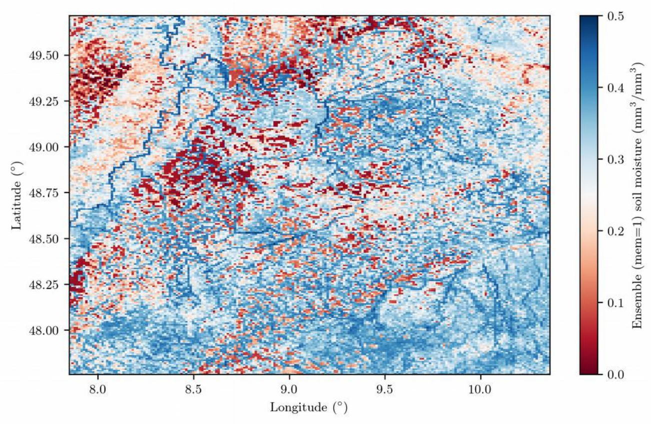

Soil moisture σ = 6 %
Soil temp. σ = 1 K

Horizontal and vertical Gaussian correlation structures

Creation of 40 ensemble members
+ Creation of nature run

All members have same initial + lateral atmospheres

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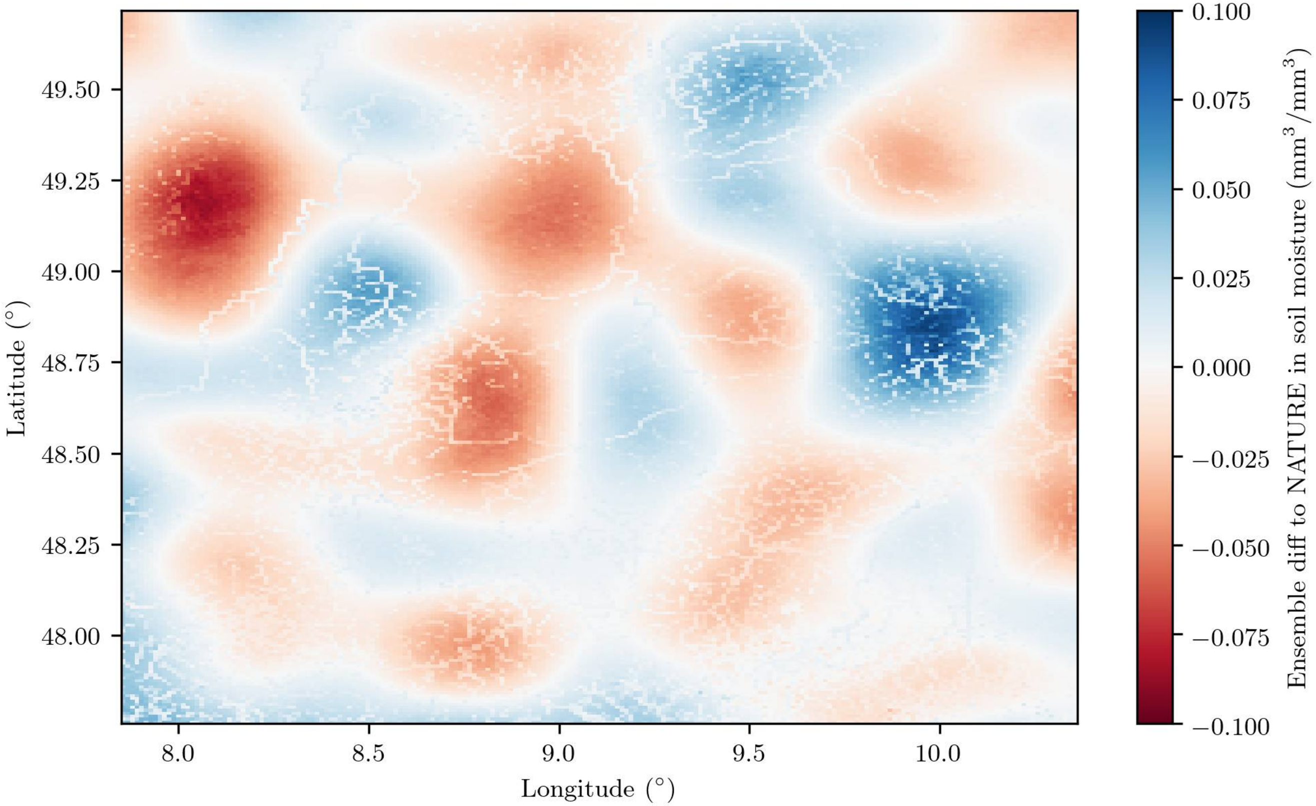
Introduction | Setup | Results | Conclusion

NATURE run is initialised as a single additional ensemble member

Initial soil moisture perturbations compared to ENSEMBLE mean



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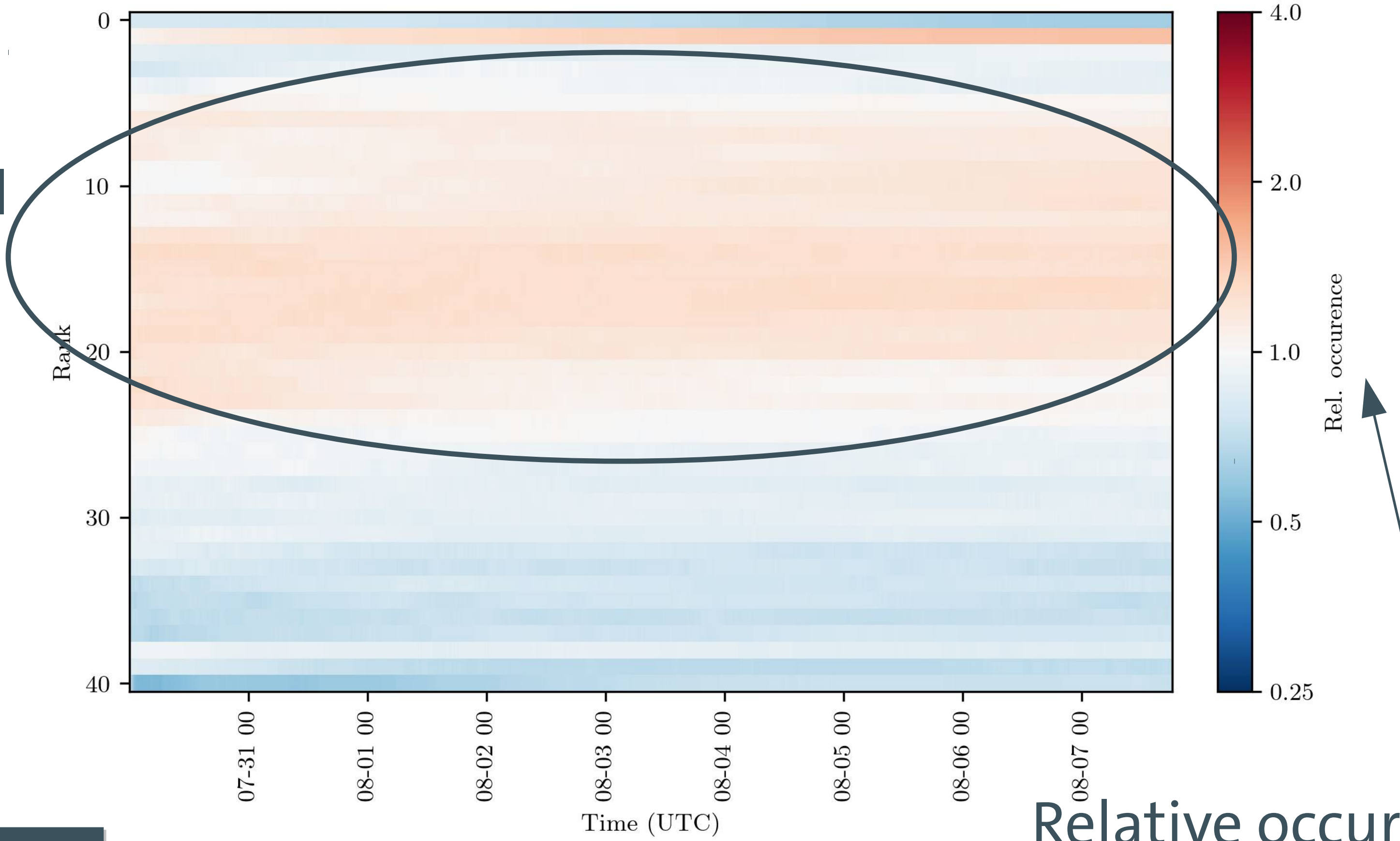
ENSEMBLE spread is representative for error to NATURE run

Rank histogram for all grid points compared to NATURE run

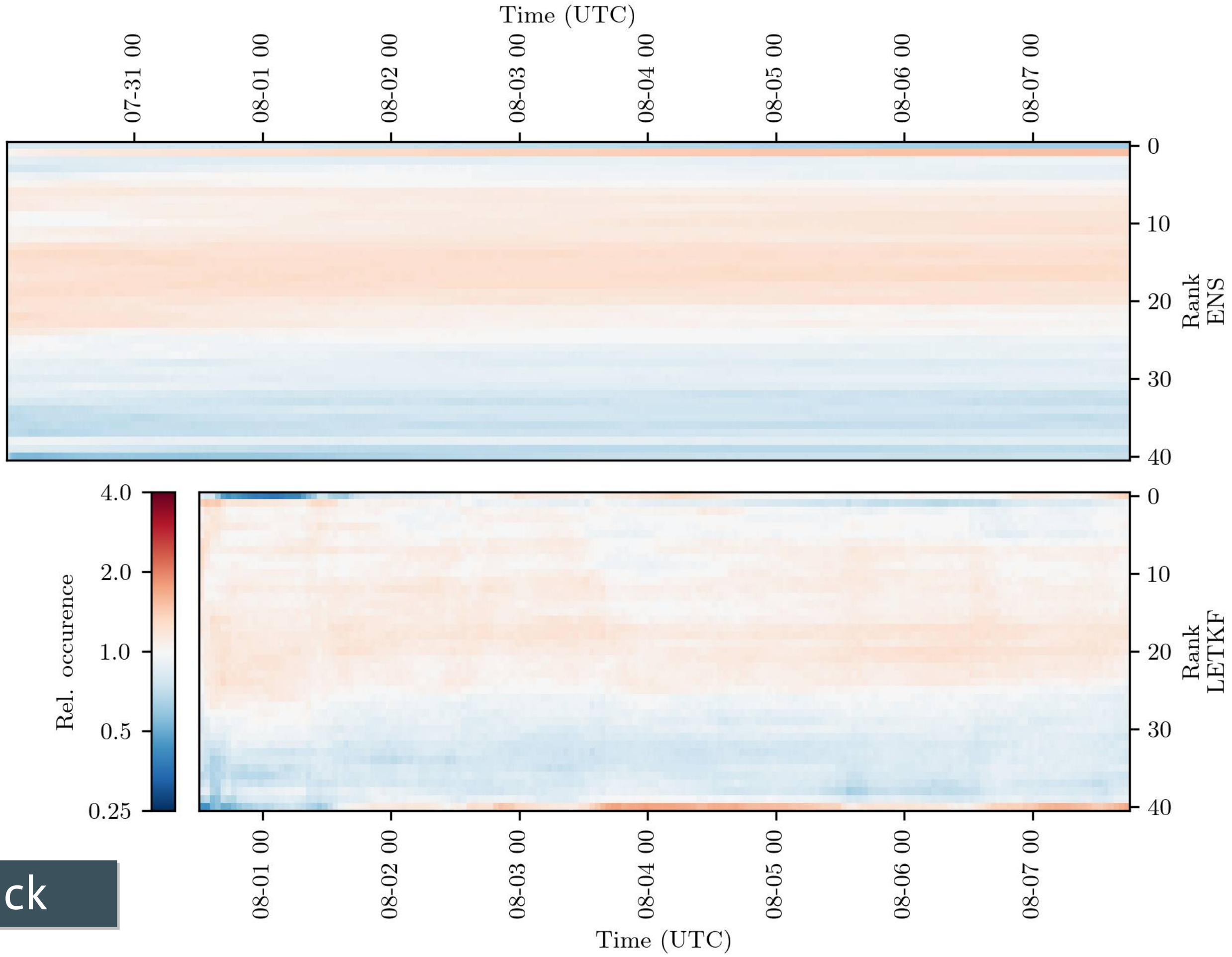


Small bias

Relative occurrence compared to uniform distribution

LETKF Soil has a similar spread as ENSEMBLE experiment

Rank histogram for all grid points compared to NATURE run

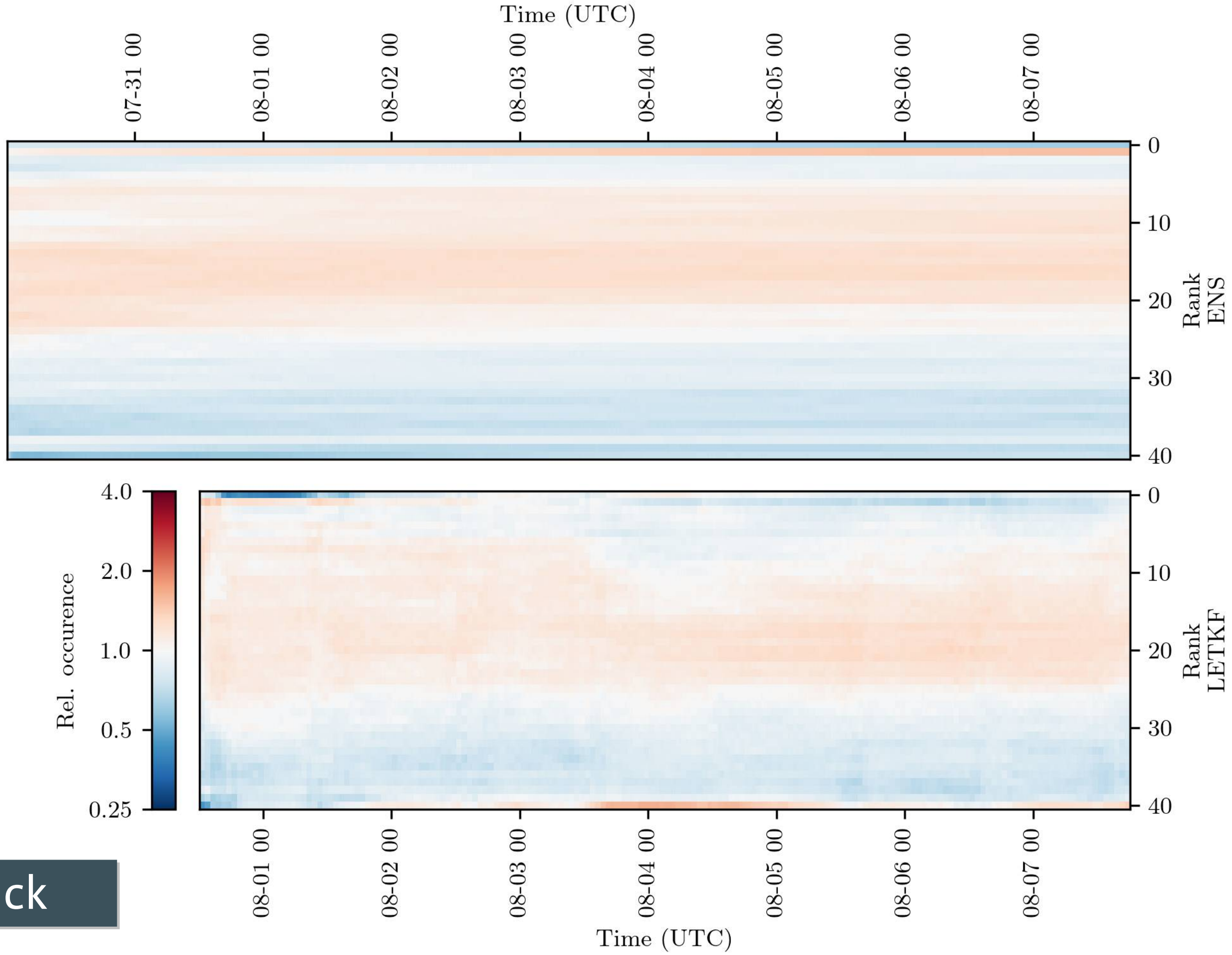


Multiplicative inflation

γ=1.006

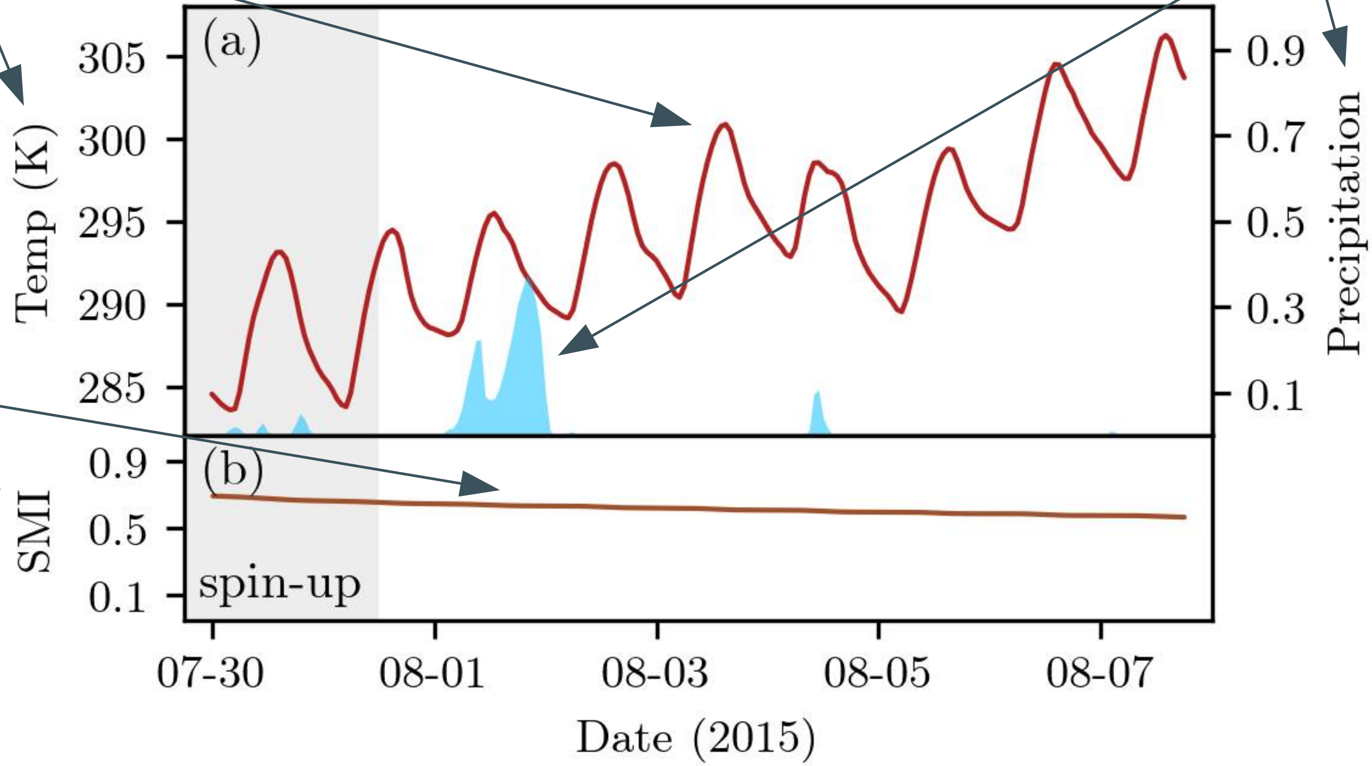
LETKF Soil+Temp has a similar spread as ENSEMBLE experiment

Rank histogram for all grid points compared to NATURE run



Multiplicative inflation
γ=1.006

Mainly sunny and dry weather conditions



Area mean temperature

Fraction of grid points with precipitation

Area mean soil moisture saturation

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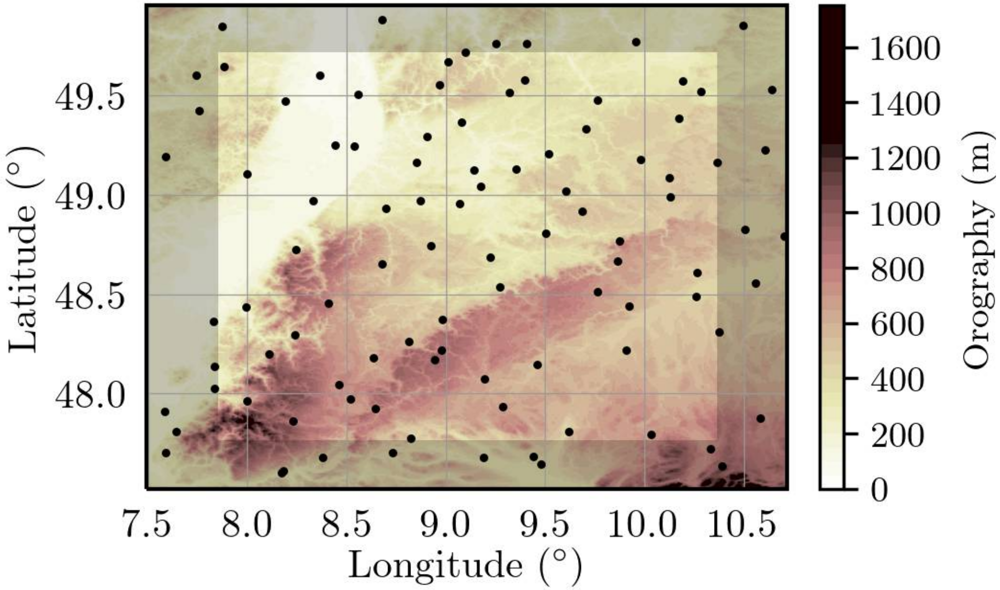
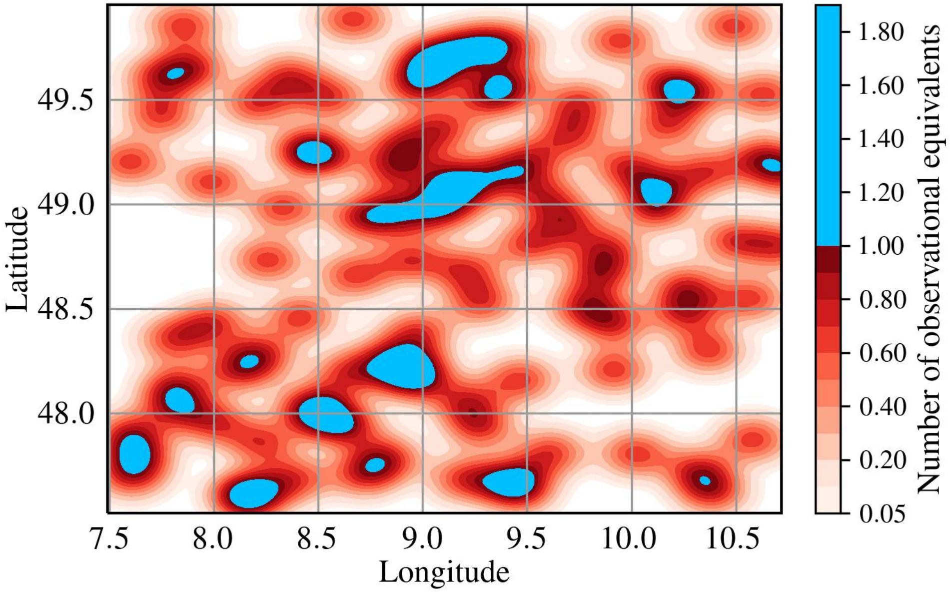
99 Virtual observation at DWD measurement sites

Model orography with observation points (grey: boundary area)



3D LETKF observational equivalents per grid point estimated based on localisation



Blue: more "observations" at grid point than 1D assimilation (e.g. SEKF)

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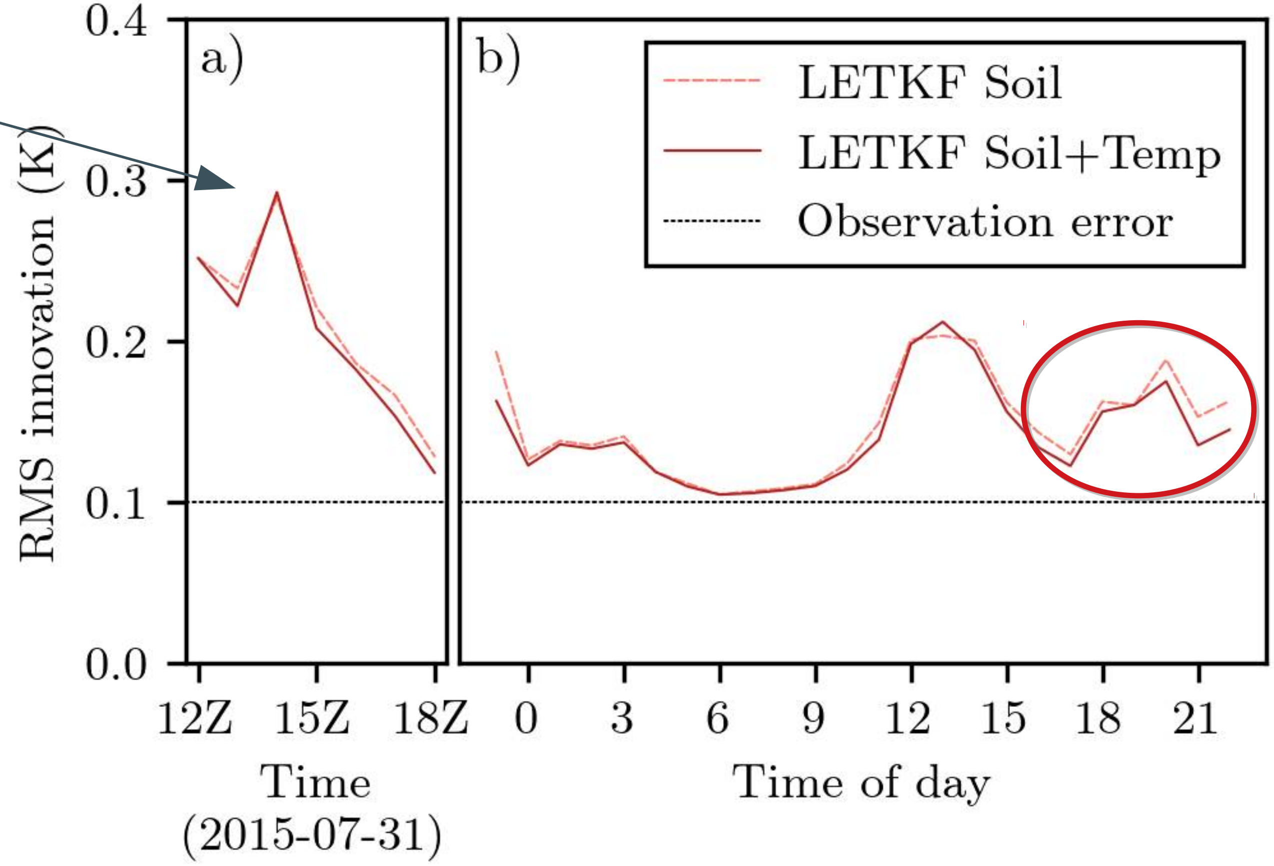
Innovations are decreased due to additional temperature updates



First 7 analysis cycles

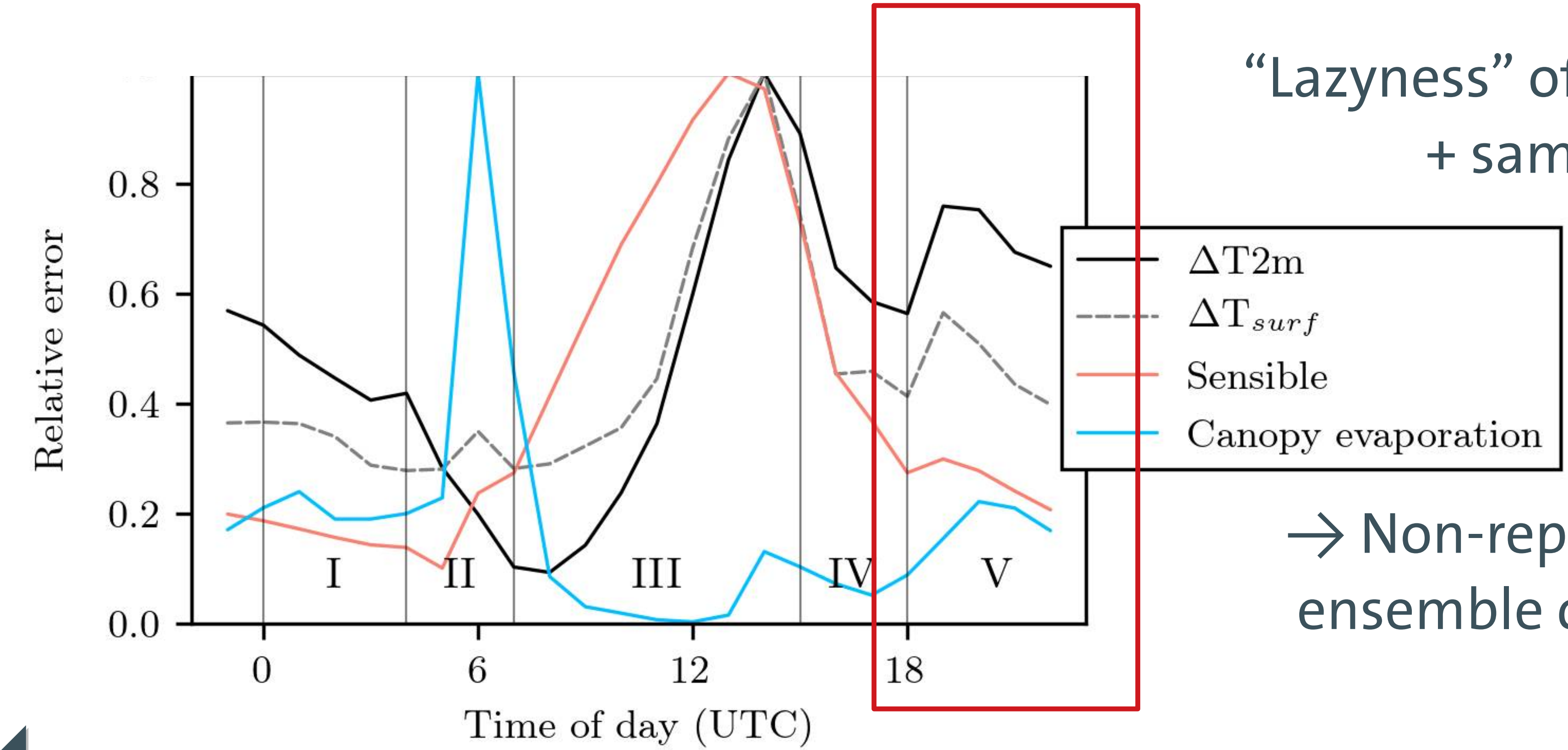
?

Diurnal cycle over the 7 days and all observations

Negative impact due to nocturnal boundary layer transition

Transition from weakly-stratified to strongly-stratified boundary layer

“Lazyness” of ensemble + sampling error



→ Non-representative ensemble covariances

Diurnal cycle over the 7 days and all grid points

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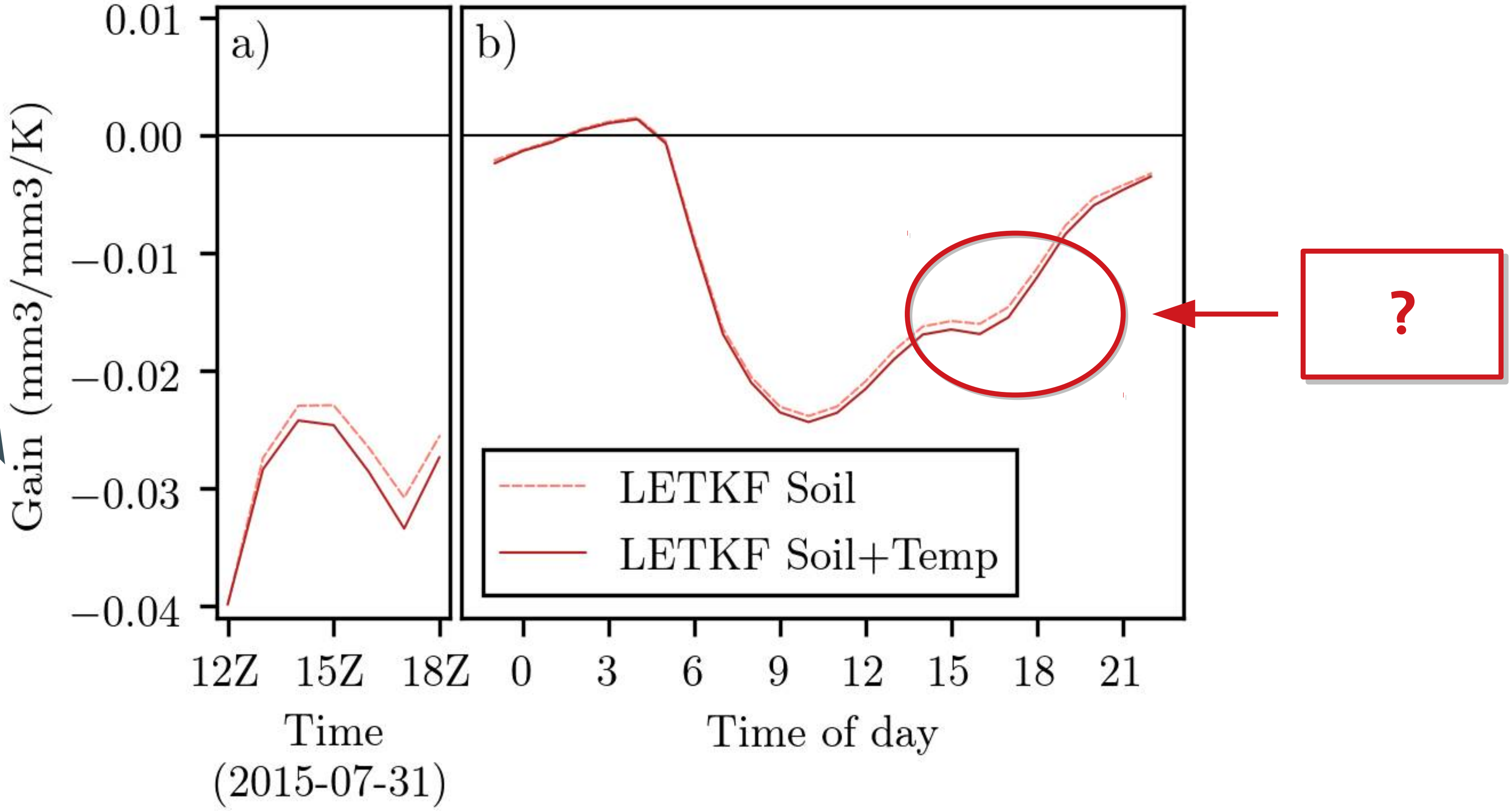
Increased magnitude of gain
→ T2m perturbations are more representative

Grid-point-based gain between T2m and soil moisture



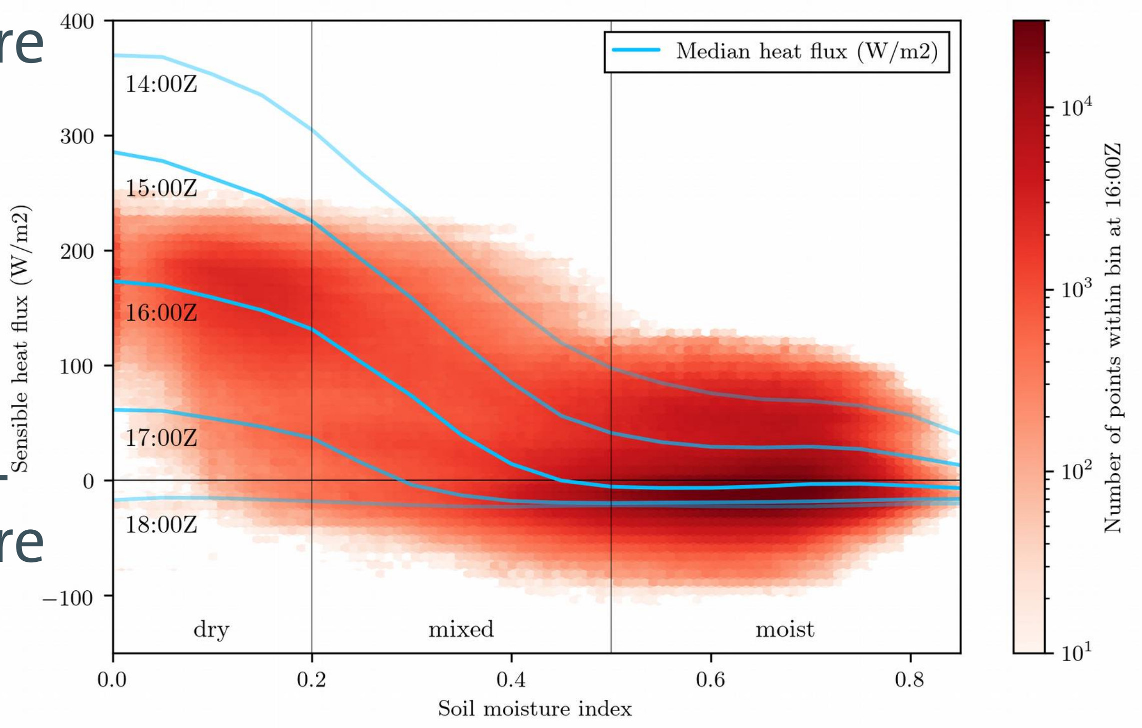
Diurnal cycle over the 7 days and all grid points

Covariance reinforcement mechanism caused by non-linear sensible heat flux

Time of inversion is soil moisture dependent

Atmosphere
↑
Surface

Atmosphere
↓
Surface



Cooler temperatures have earlier inversion

Stronger differences in temperature perts.

Increased covariance

Binned over the 7 days, all grid points and all ensemble members

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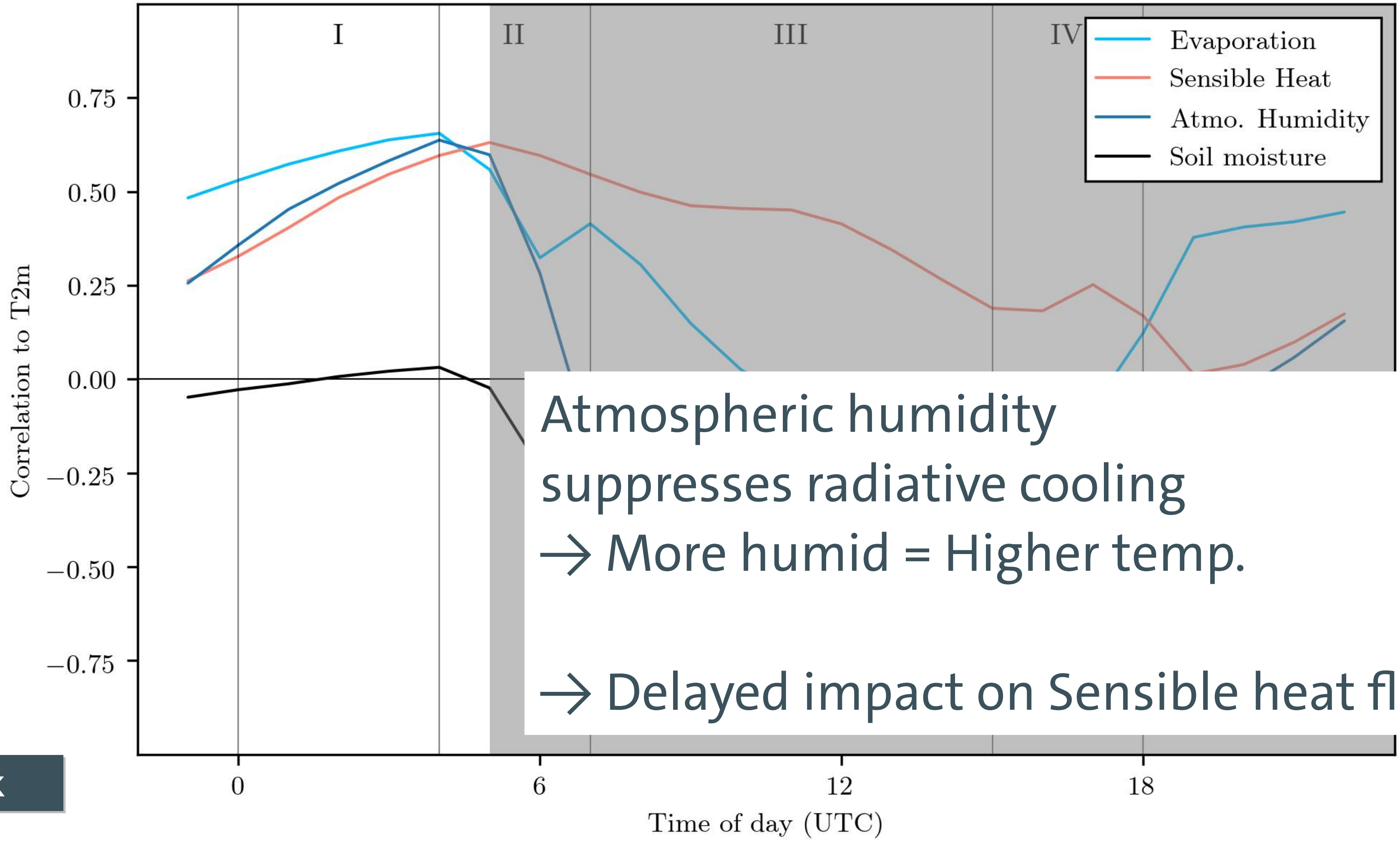
I – Positive coupling between T2m and soil moisture due to humidity

Diurnal cycle over the 7 days and all grid points



Atmospheric humidity suppresses radiative cooling

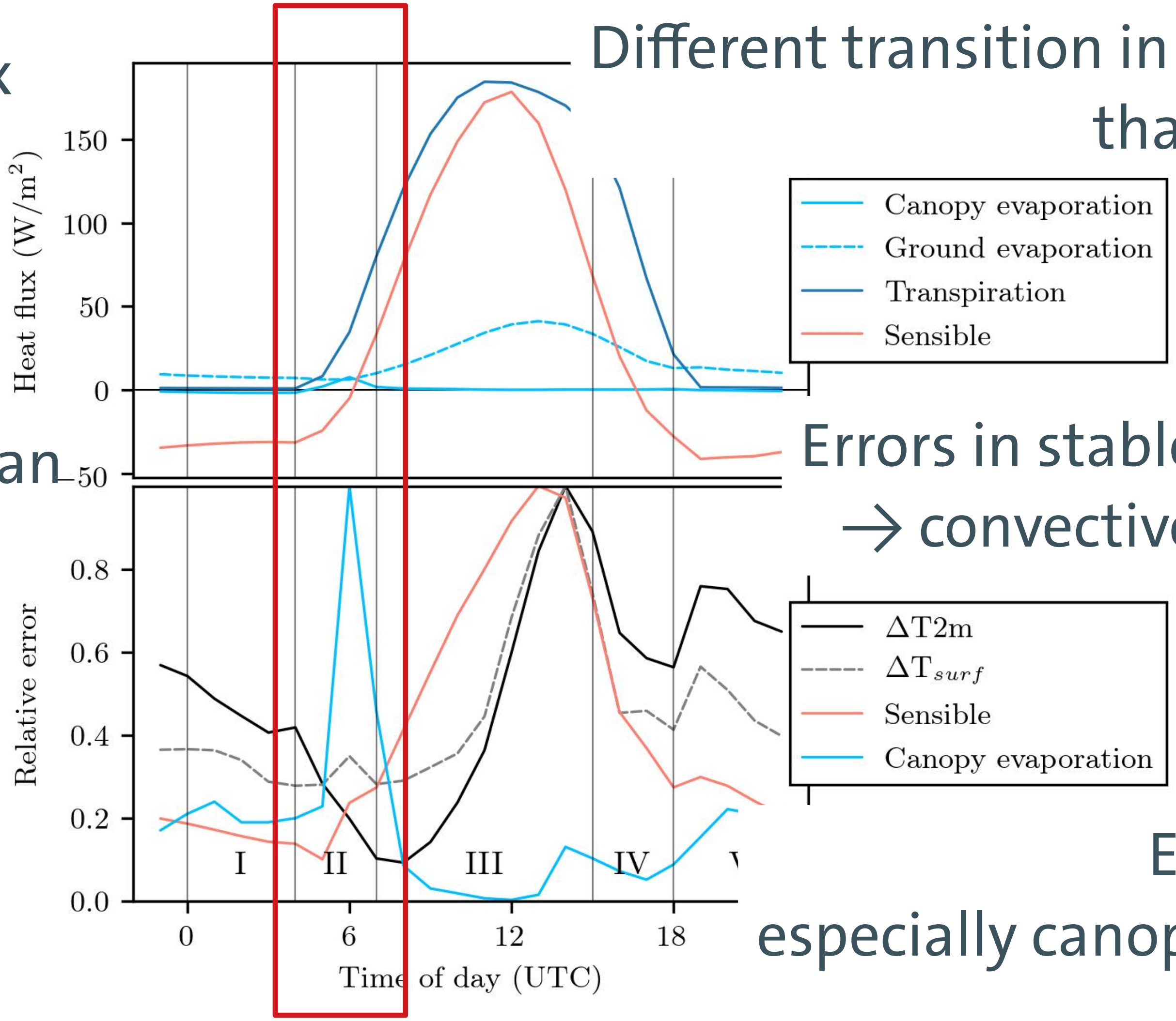
→ More humid = Higher temp.

→ Delayed impact on Sensible heat flux

II – Negative impact due to morning transition and canopy evaporation

Mean heat flux

RMSE of ENS mean to NATURE / maximum



Different transition in ENS members than NATURE run

Errors in stable stratification → convective stratification

Errors in fluxes, especially canopy evaporation

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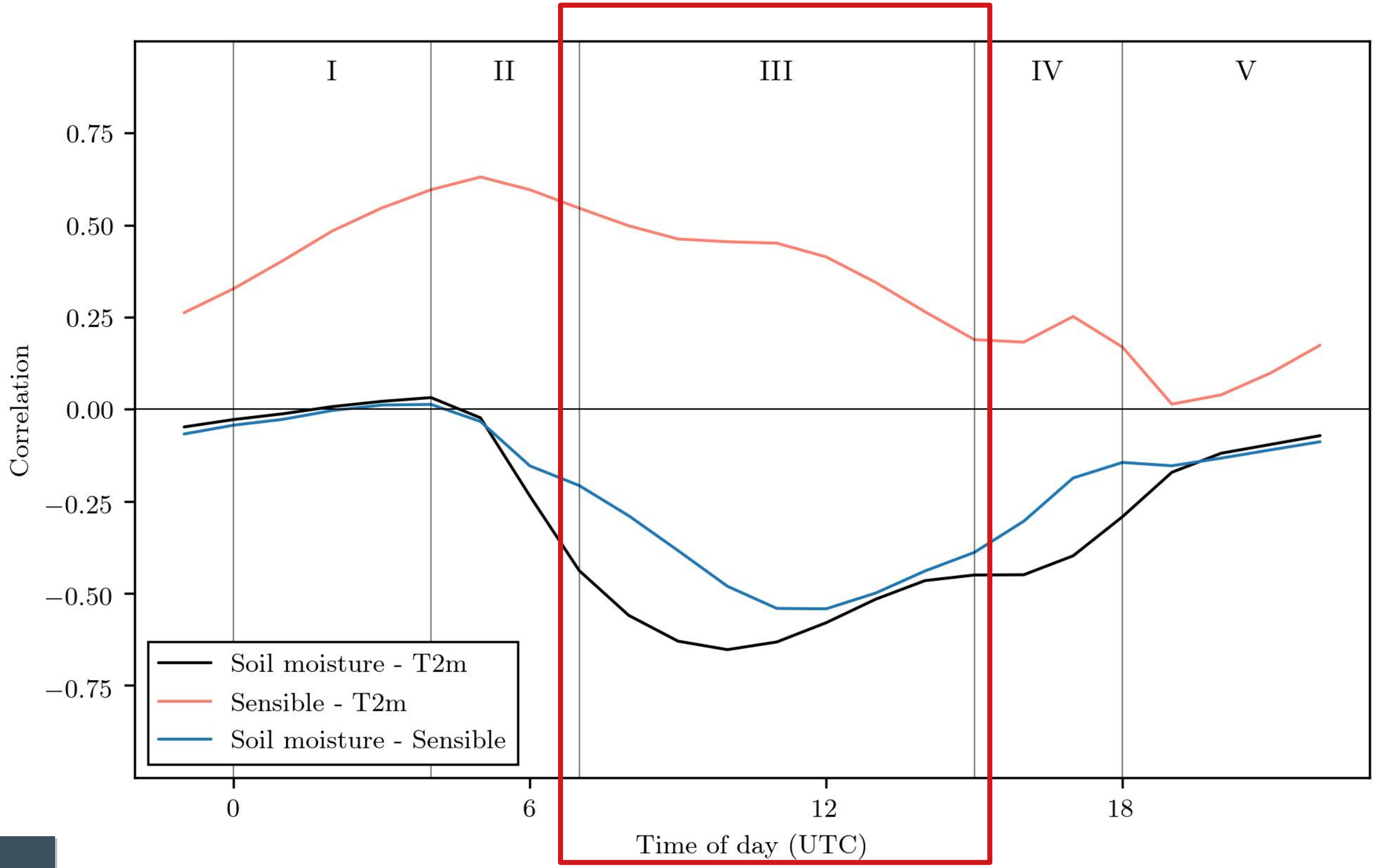
Diurnal cycle over the 7 days and all grid points

III – Positive impact caused by strong coupling via sensible heat flux



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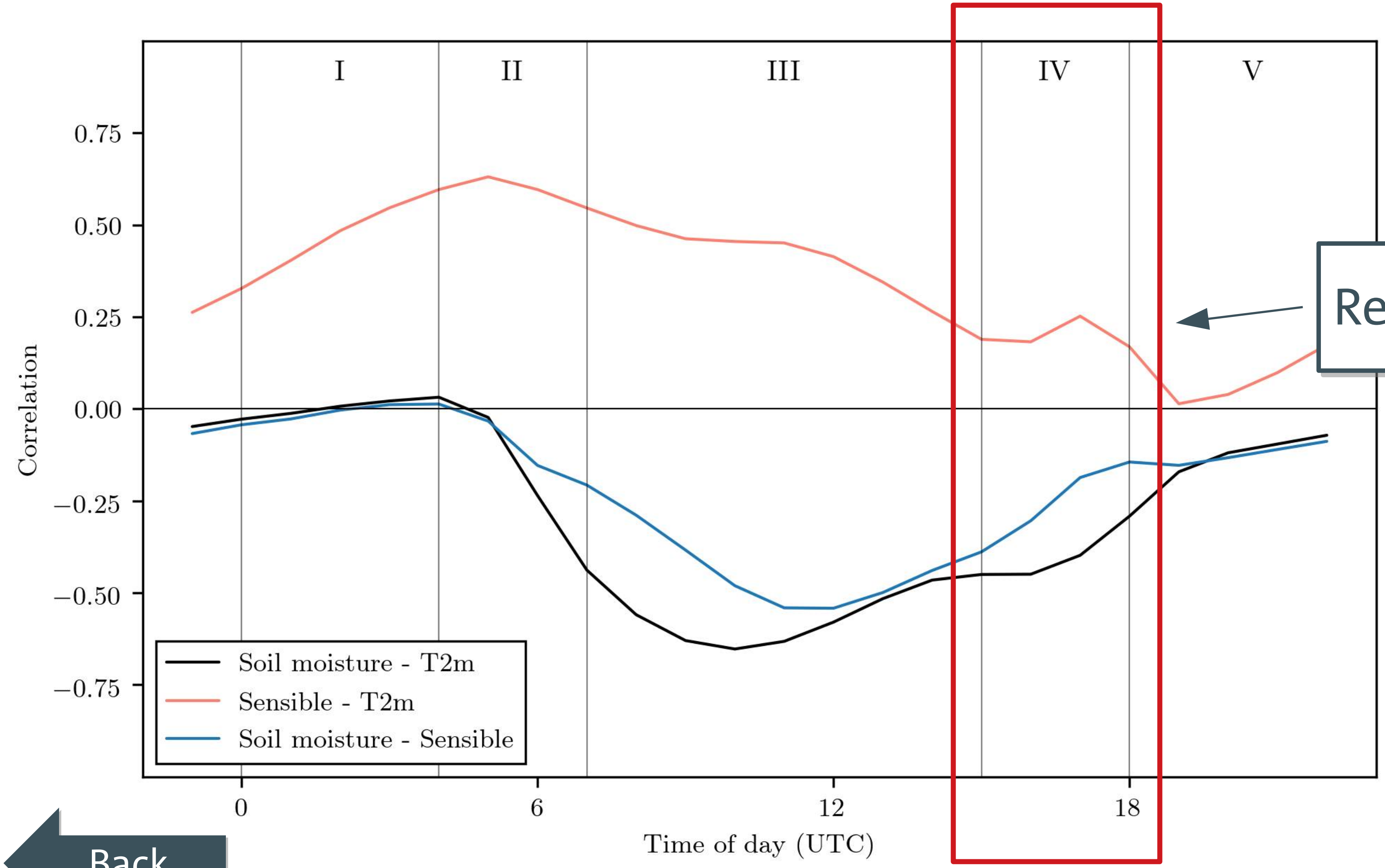
Diurnal cycle over the 7 days and all grid points

IV – Reinforcement mechanism increases correlation between T2m and soil moisture



Reinforcement

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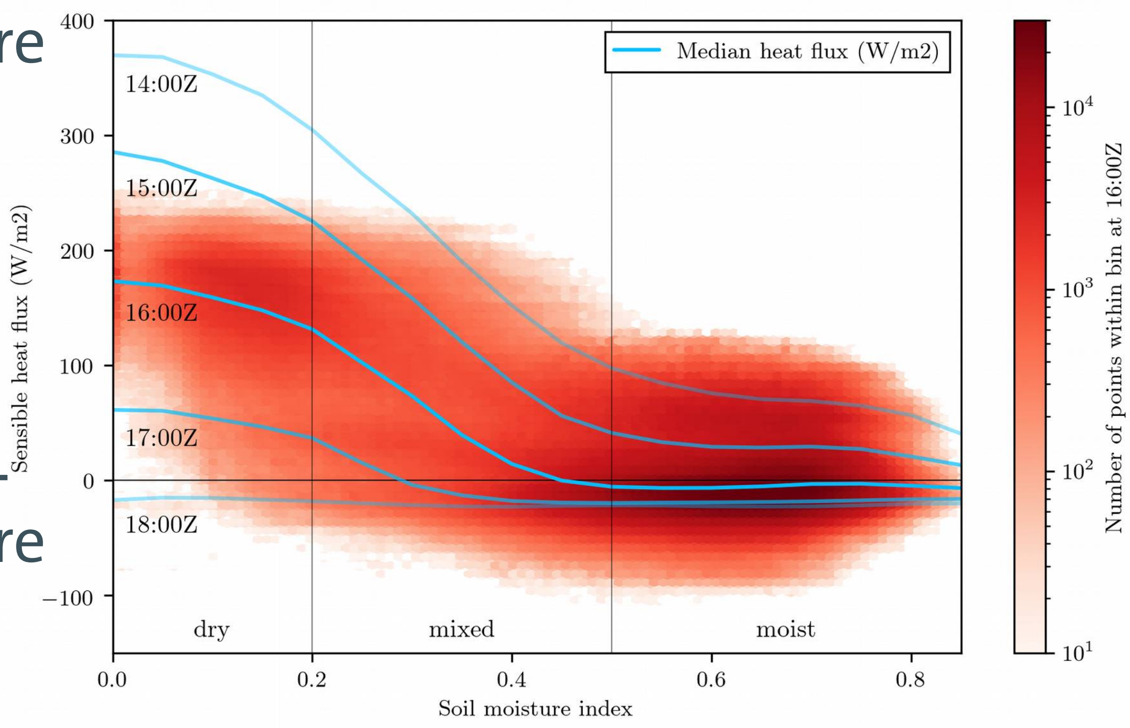
Diurnal cycle over the 7 days and all grid points

Covariance reinforcement mechanism caused by non-linear sensible heat flux

Time of inversion is soil moisture dependent

Atmosphere
↑
Surface

Atmosphere
↓
Surface



Cooler temperatures have earlier inversion

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Increased covariance

Binned over the 7 days, all grid points and all ensemble members

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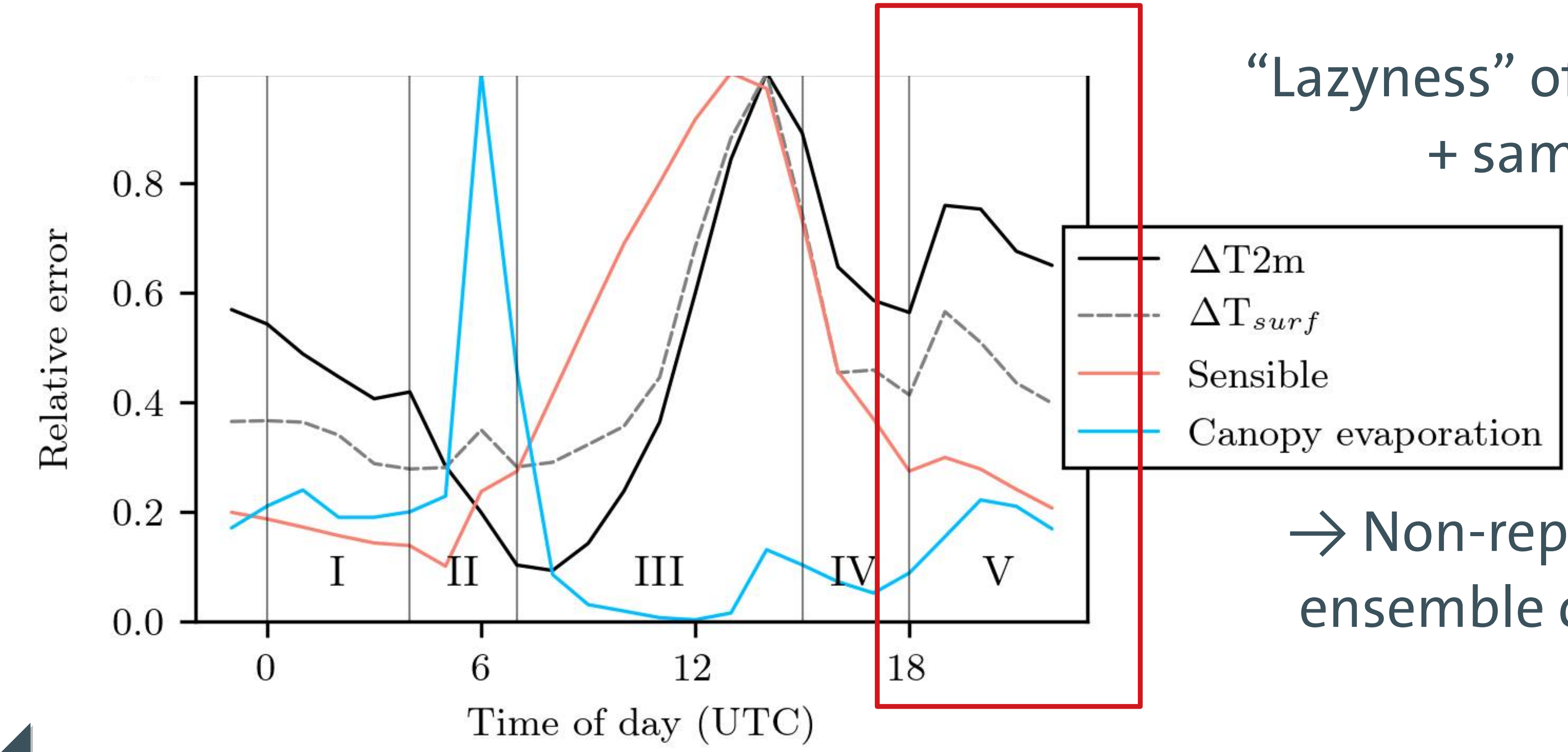
V – Negative impact due to nocturnal boundary layer transition

Transition from weakly-stratified to strongly-stratified boundary layer

“Lazyness” of ensemble + sampling error



→ Non-representative ensemble covariances

Diurnal cycle over the 7 days and all grid points

Contact and publication

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Publication (to be submitted, including comparison to SEKF):
Finn, Tobias Sebastian, Gernot Geppert, and Felix Ament. “Towards strongly-coupled ensemble data assimilation of boundary-layer observations for the atmosphere-land interface”, to be submitted to ”Hydrology and Earth System Science”, 2020.

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