Impact of soil moisture data assimilation on short-term numerical weather prediction

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Land-atmosphere interactions and climate extremes
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15 April 2024

Introduction

- Soil moisture impacts the evaporative fraction.
- Plays an important role in the water and energy budgets at the land surface.

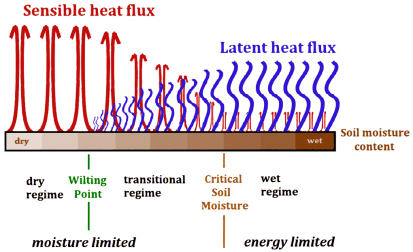

Figure from Hsu and Dirmeyer (2023).

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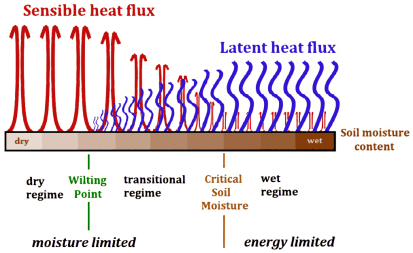

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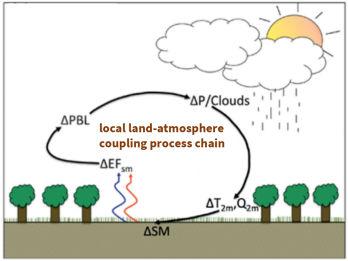
- Sensible and latent heat in turn are linked to atmospheric temperature, humidity, and even precipitation.



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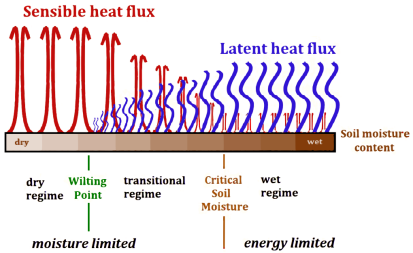

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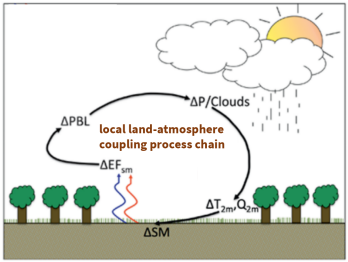

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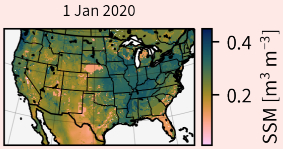
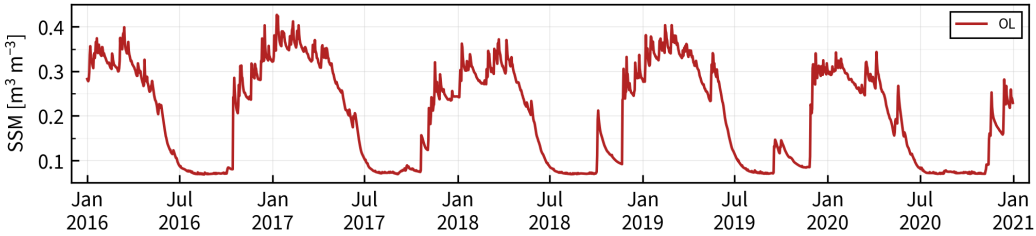
Research question
How are **meteorological forecasts** impacted by **assimilating surface soil moisture (SSM)**?

Land surface modeling

— Noah-MP 4.0.1 (18 km)
— MERRA-2 atmospheric forcing
— Gap-free estimates of SSM, ET, ...





Data assimilation

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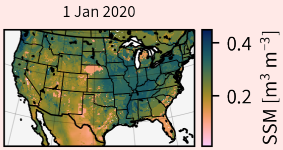
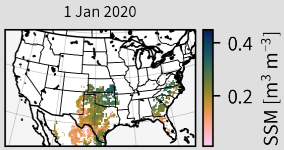
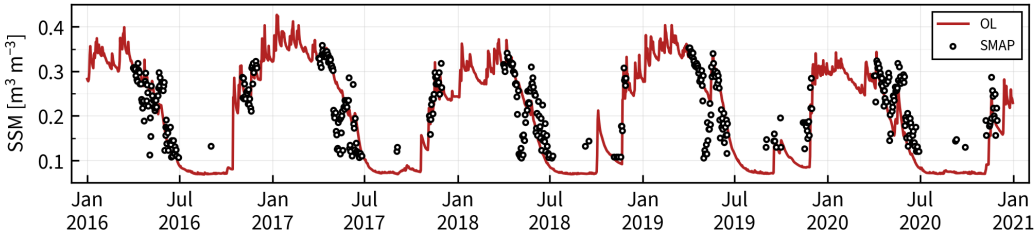


Remote sensing

— SMAP L2 SSM retrievals (36 km)
— Rescaled to model climatology
— Gaps in space and time





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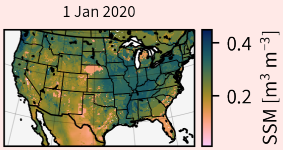

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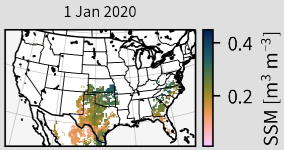
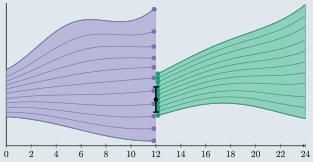


Data assimilation (DA)

Optimally combine models and observations (Ensemble Kalman Filter).



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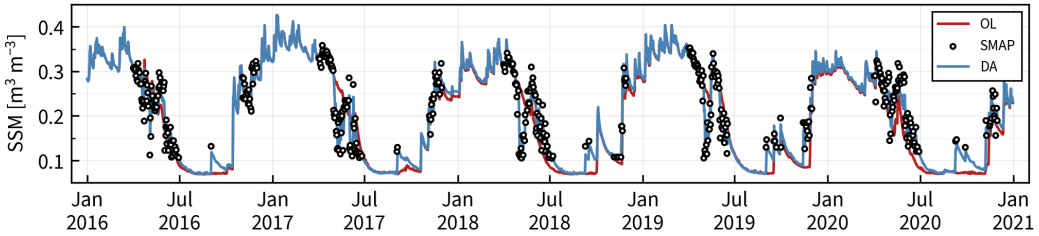
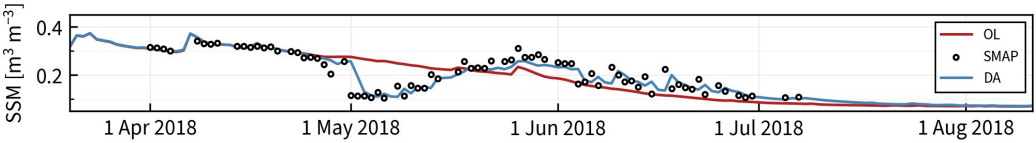
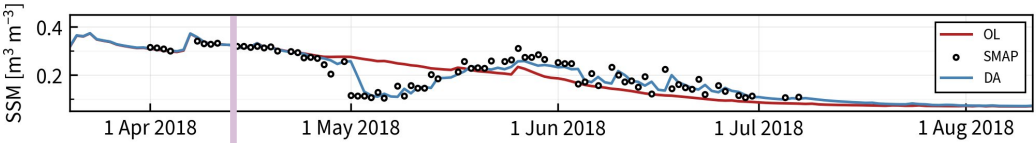


Experimental design



Noah-MP (MERRA-2 forcing)

Experimental design



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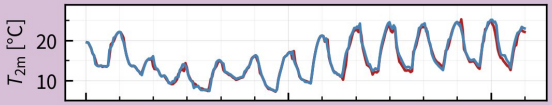
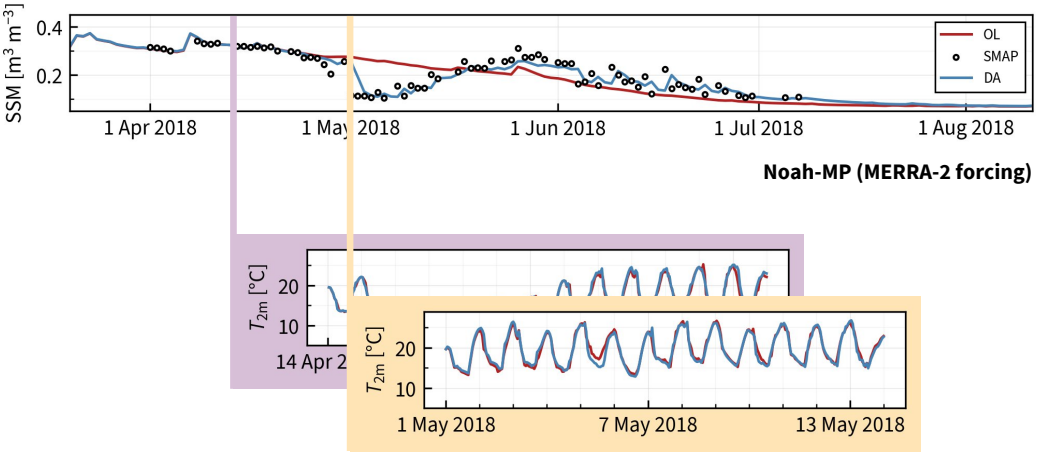


Noah-MP + WRF

Two-week forecast: 14 April - 27 April 2018

Experimental design



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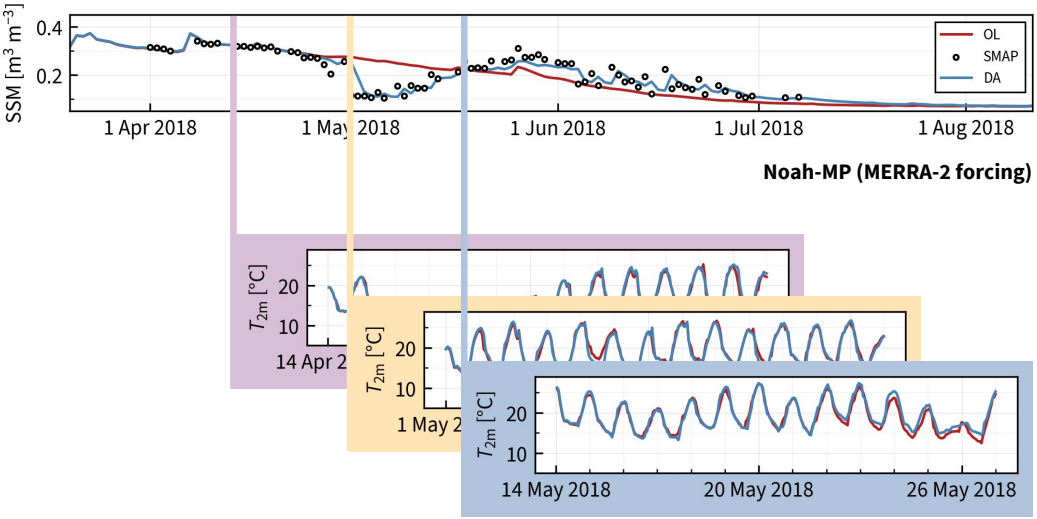
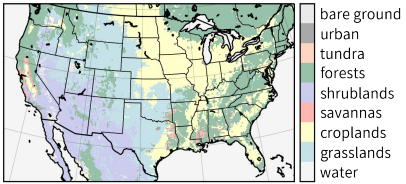
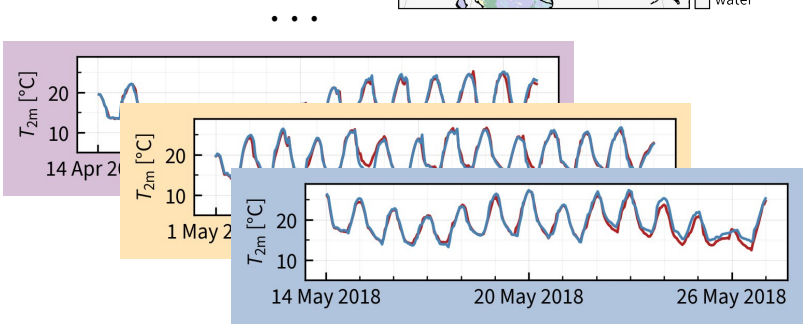


Experimental design

- Two-week meteorological forecasts over the US.
- MERRA-2 initial and boundary conditions.
- 18 km Lambert conformal grid.

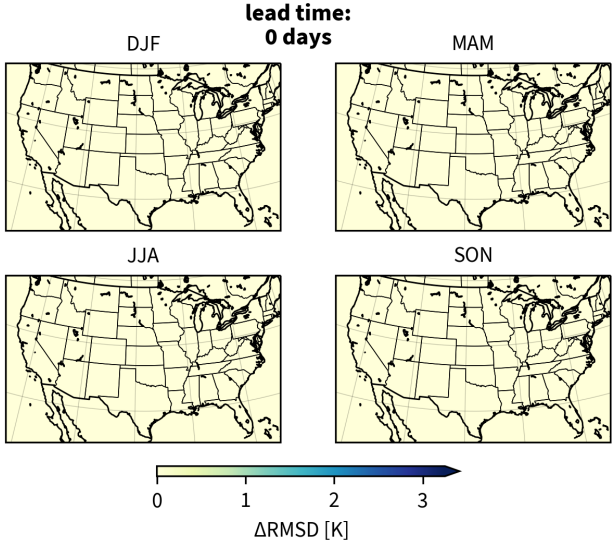


120 experiments
Noah-MP + WRF
Jan 2016 - Dec 2020



Impact of SSM DA on air temperature

- RMSD between OL and DA experiments shows the impact of SSM DA on T_{2m}.
- More impact during warmer seasons.
- OL and DA experiments diverge with longer lead times.



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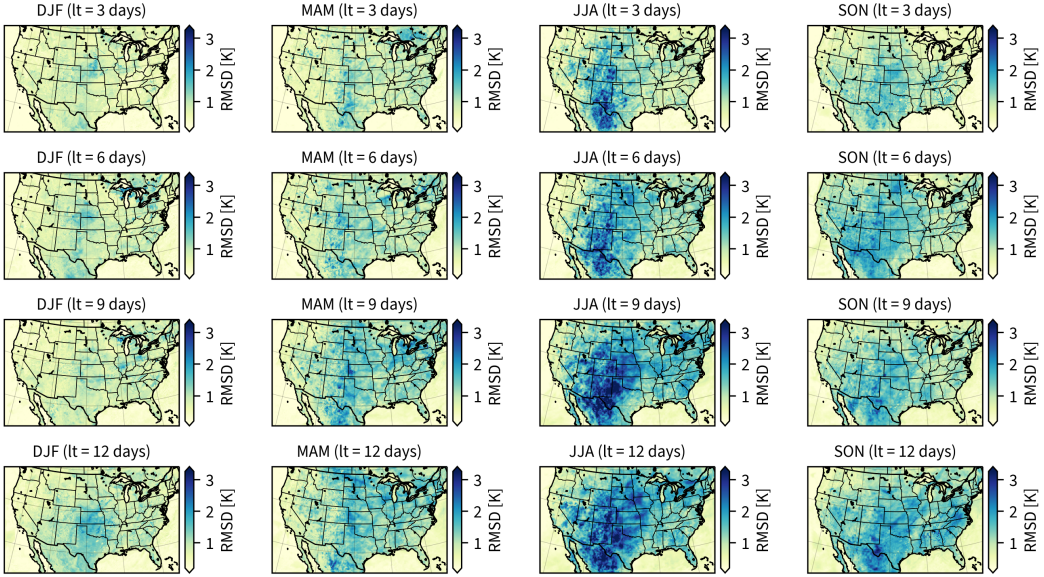
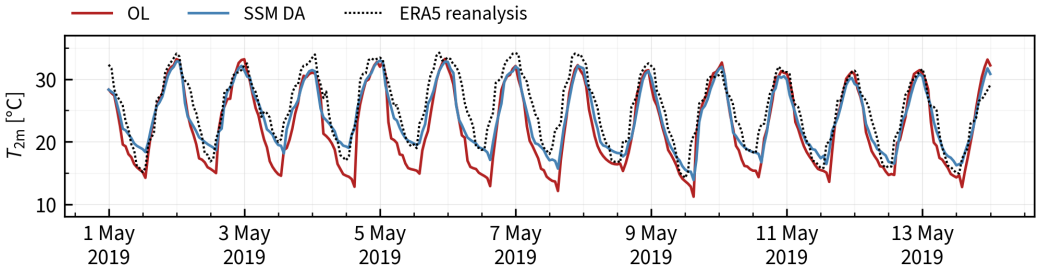


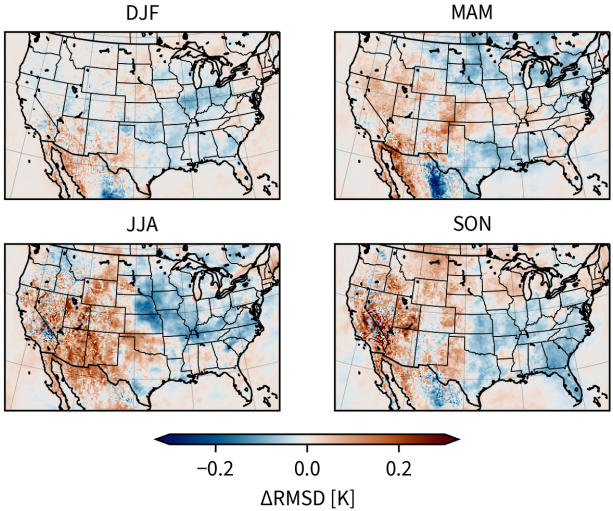
Evaluation with ERA5

- Which of the two experiments yields the **best meteorological forecast**?
- Compare T_{2m} predictions with the ERA5 reanalysis.



Evaluation with ERA5

- Evaluation of T_{2m}, aggregated over all lead times.
- Improvements in east of domain, degradations in west.
- Larger impacts during the warmer seasons.



Conclusions

- We initialized the land component of a coupled land-atmosphere simulation with
  1. an OL experiment;
  2. an SSM DA experiment.
- **Substantial differences** in forecasted air temperature.
- Evaluation: both **improvements and degradations** in air temperature comparing SSM DA to OL.

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What is next?

- Evaluate forecasts of other meteorological variables (humidity, precipitation, ...).
- **Improve results** in the west of the domain.
- Make the link with model-based **land-atmosphere coupling metrics**.

Thank you!

References I

Evensen, G., Vossepoel, F. C., and Van Leeuwen, P. J. (2022). Data assimilation fundamentals: A unified formulation of the state and parameter estimation problem. Springer Nature.

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Santanello, J. A., Kumar, S. V., Peters-Lidard, C. D., and Lawston, P. M. (2016). Impact of soil moisture assimilation on land surface model spinup and coupled land–atmosphere prediction. Journal of Hydrometeorology, 17(2):517–540.