# Enhancing Surface Data Assimilation and Near-Surface Weather Forecasts in NGGPS through Improved Coupling between the Land Surface and Atmosphere

*Principal Investigator*
**Zhaoxia Pu**
***Department of Atmospheric Sciences, University of Utah***

*Student/postdoc Participants*
**Dr. Liao-Fan Lin, Mr. Junkai Liu**
***Department of Atmospheric Sciences, University of Utah***

*NOAA Collaborators*
**Dr. Vijay Tallapragada, EMC/NCEP**
**Dr. Micheal Ek, *EMC/NCEP and UCAR***

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# Outline

## (Summary of the progress)

- Evaluating near-surface weather forecast errors

- Understanding covariances between soil and atmospheric states
  - Observational analysis
  - A single column model study
  - A strongly coupled land-atmospheric system (e.g., WRF-Noah)

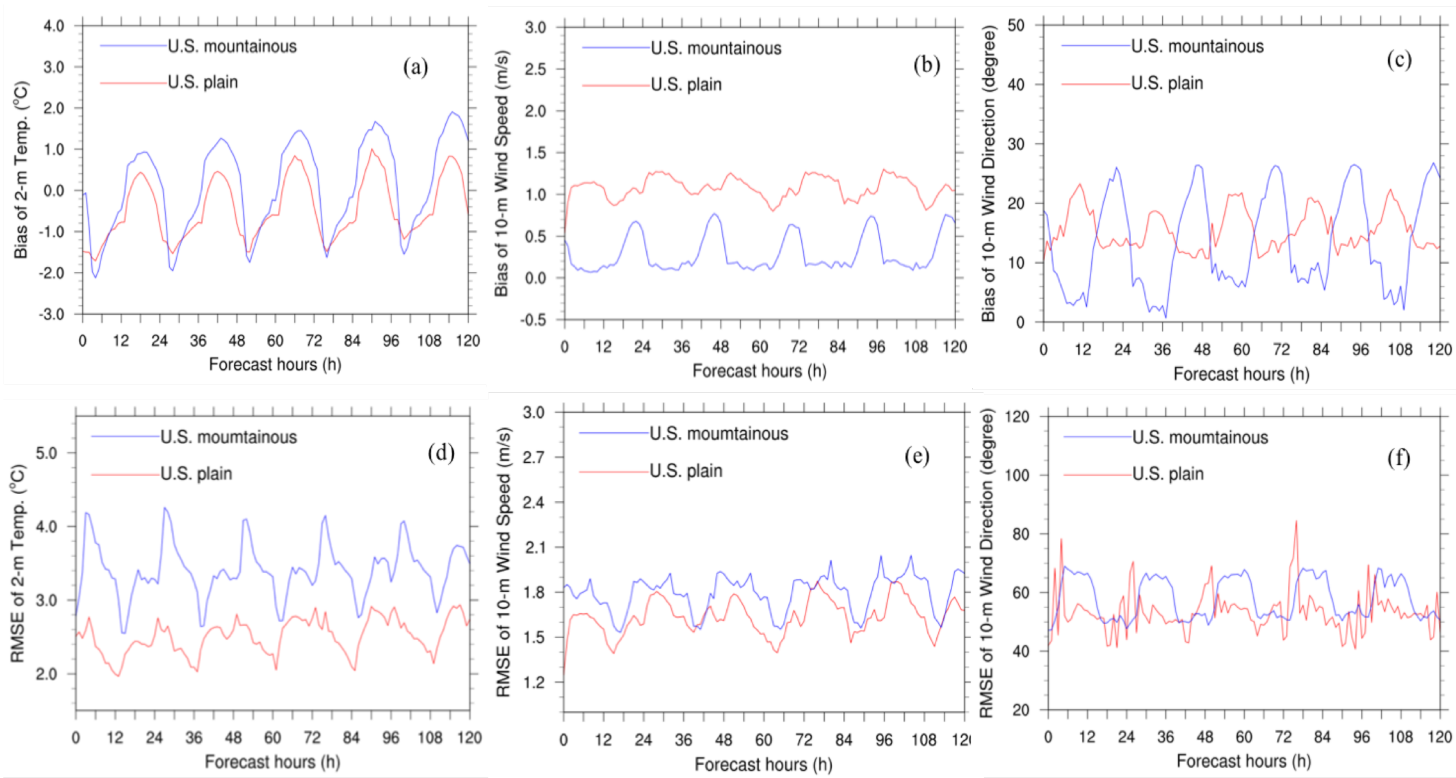
- Examining the influence of SMAP satellite soil moisture data on short-range weather forecasting: Strongly vs. Weakly coupled land-atmosphere data assimilation

- Developing a strongly coupled land-atmosphere data assimilation system with GSI-based EnKF

# Evaluating near-surface weather forecast errors

## Mean bias and RMSE for 2-m temperature and 10-m winds

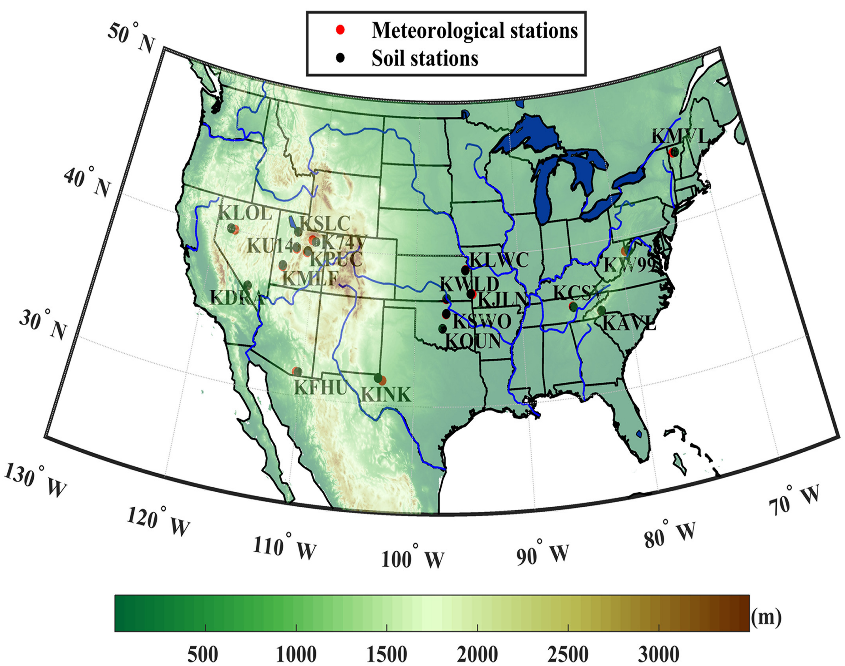
GFS. - U. S. Mountainous vs. U. S. Plains
00UTC FCST, June 2016



# Understanding covariances between soil and atmospheric states

## Observational analysis

- The meteorological observations, soil moisture data, and soundings from surface Mesonet, Climate Reference Network (CRN), Soil Climate Analysis Network (SCAN) network, and University of Wyoming sounding databases
  - **The correlation coefficient (R)**
  - **Information flow analysis (Liang, 2014 and 2015)**




**16 soil moisture, 16 meteorological stations, 2 sounding stations (2008-2016)**

KPUC, KU14, KMLG, and K74V: **mountain area with shrubland and grassland**.
KWLD, KSWO, KJLN, and KLWC: **plain area with grassland**.
KINK, KFHU, KDRA and KLOL: **desert area with shrubland**.
KW99, KAVL, KCSV and KMVL: **mountain area with forest**.
2 sounding stations: KSLC (Intermountain West) and KOUN (Great Plain)

- Liu, J., and Z. Pu, 2019: Does Soil Moisture Have an Influence on Near Surface Temperature? *Journal of Geophysical Research - Atmospheres*, 124, 6444-6466. https://doi.org/10.1029/2018JD029750

## Liu and Pu (2019) JGR

## ( 9-yr statistics with in-situ data; the WRF single column model)

- Soil moisture at all levels and the near-surface atmospheric temperature have weak to moderate causality with seasonal variability.
- Distribution of soil moisture depends on land use and land cover, and this dependence decreases with soil depth.
- There is a strong interaction between top soil layer and atmosphere; Impacts of soil moisture on near-surface temperature are significant.

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### Does Soil Moisture Have an Influence on Near-Surface Temperature?

Junkai Liu, Zhaoxia Pu

First published: 30 May 2019 | https://doi.org/10.1029/2018JD029750

This article has been accepted for publication and undergone full peer review but has not be
the copyediting, typesetting, pagination and proofreading process, which may lead to differe
between this version and the Version of Record. Please cite this article as doi: 10.1029/2018J

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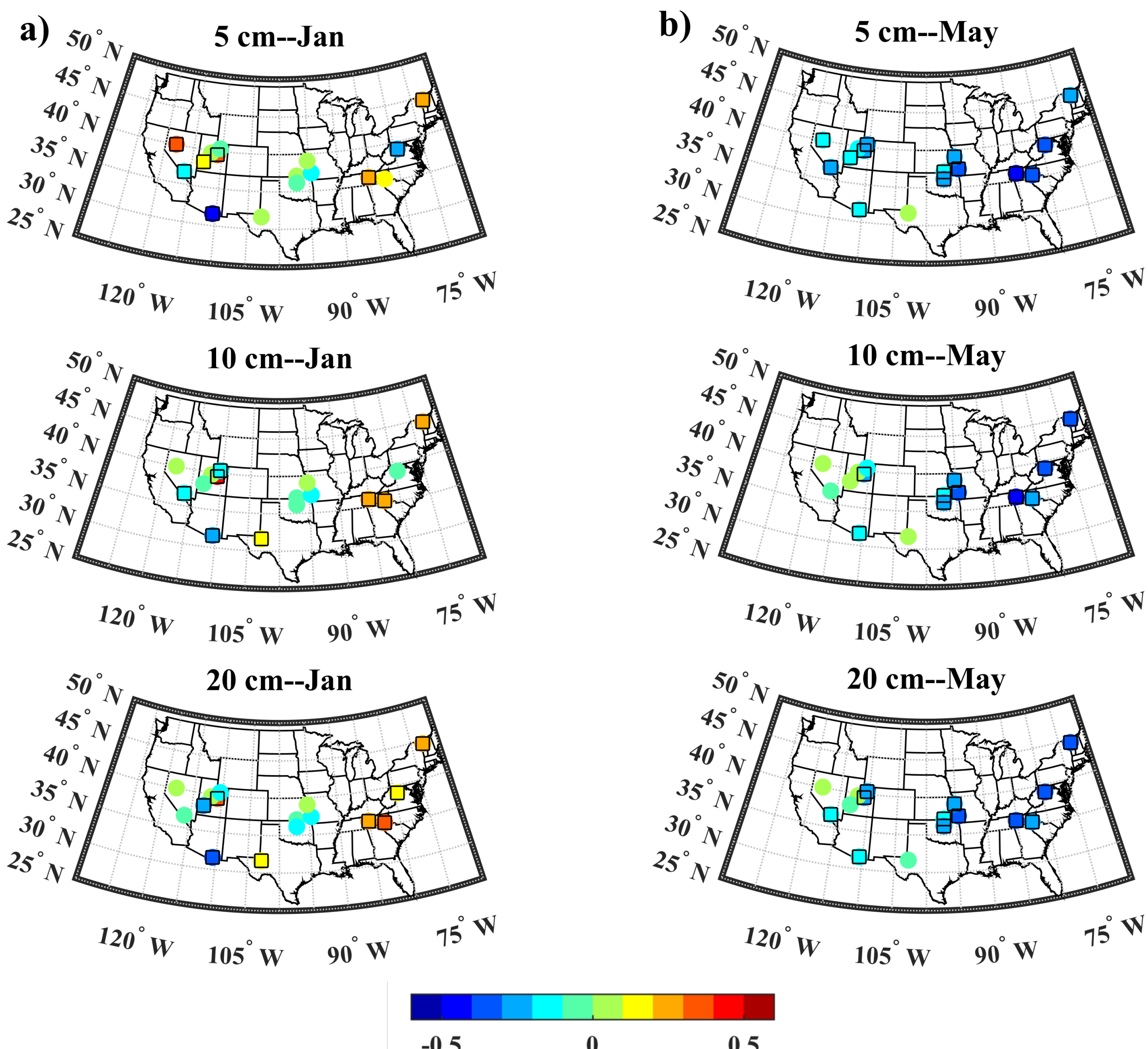
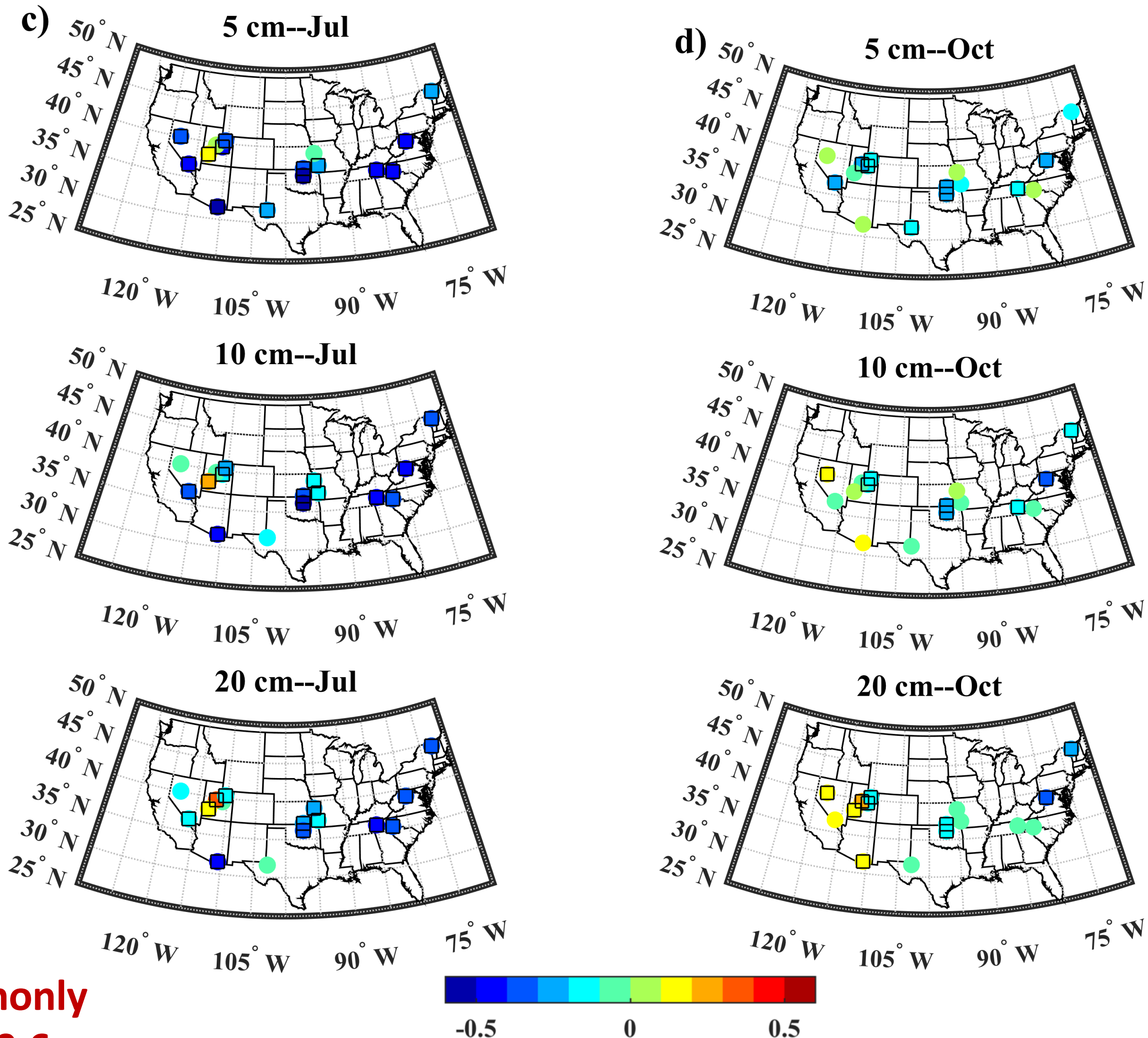
#### Abstract

The relationship between soil moisture (SM) and temperature at 2-m height (T
examined with long-term meteorological and soil observations and a single-c
model (SCM). With the information flow (IF) and correlation analysis methods,
show that the distribution of SM depends on land use and land cover, while a
in vegetation fraction corresponds to an increase in SM, and this dependence
with soil depth. There is causality between T2 and SM at all soil levels. Compa
those in deeper soil, higher IF values and correlations appear in the top soil le
implying a stronger interaction between the top soil layer and the atmospher
Meanwhile, most correlation coefficient values rank weak or moderate, and n

# Correlations between soil moisture and 2-m temperature (January and May)

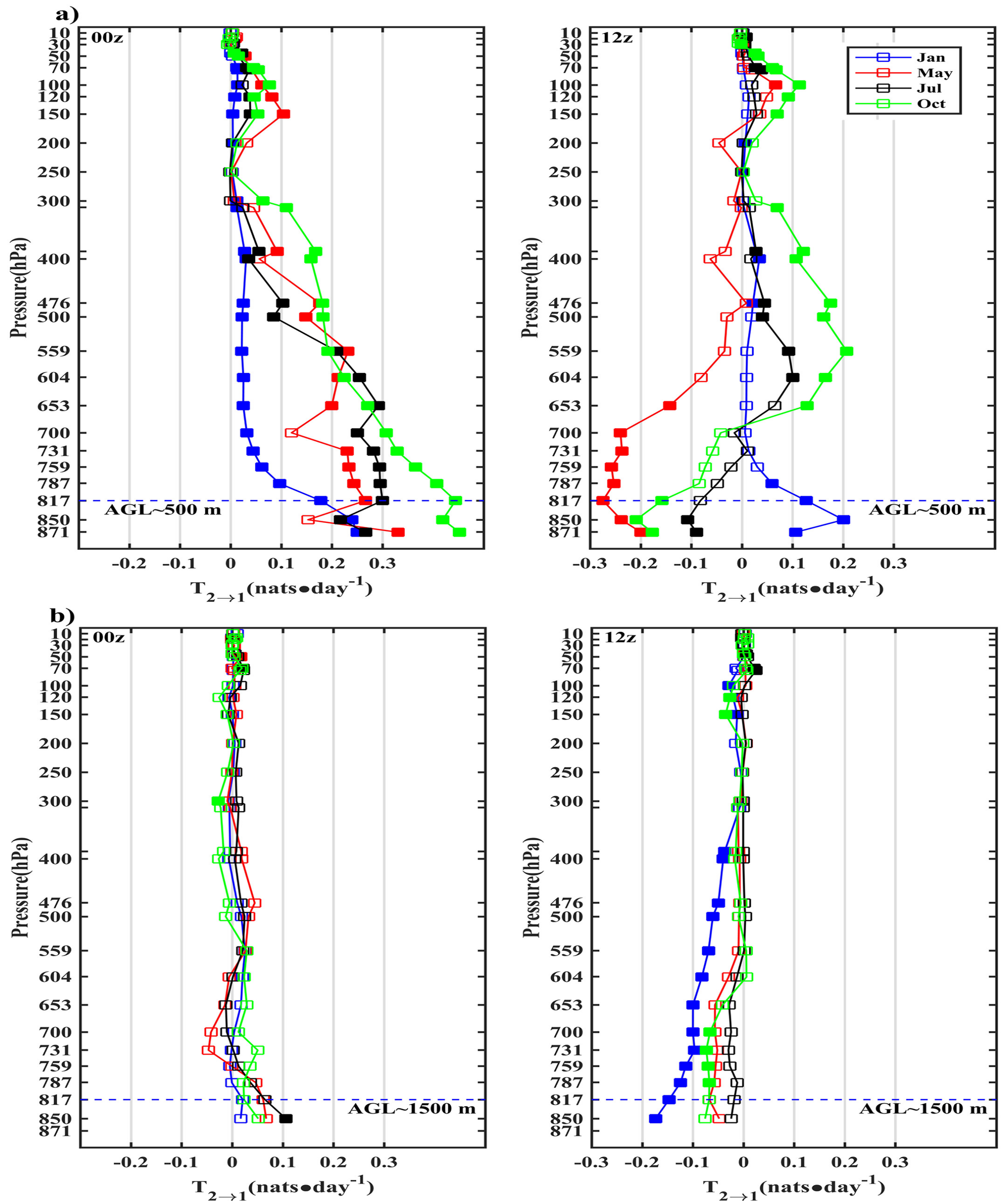


# Correlations between soil moisture and 2-m temperature (July and October)




**R is commonly less than 0.6**

**The information flows from sounding temperature to temperature at 2-m height.**

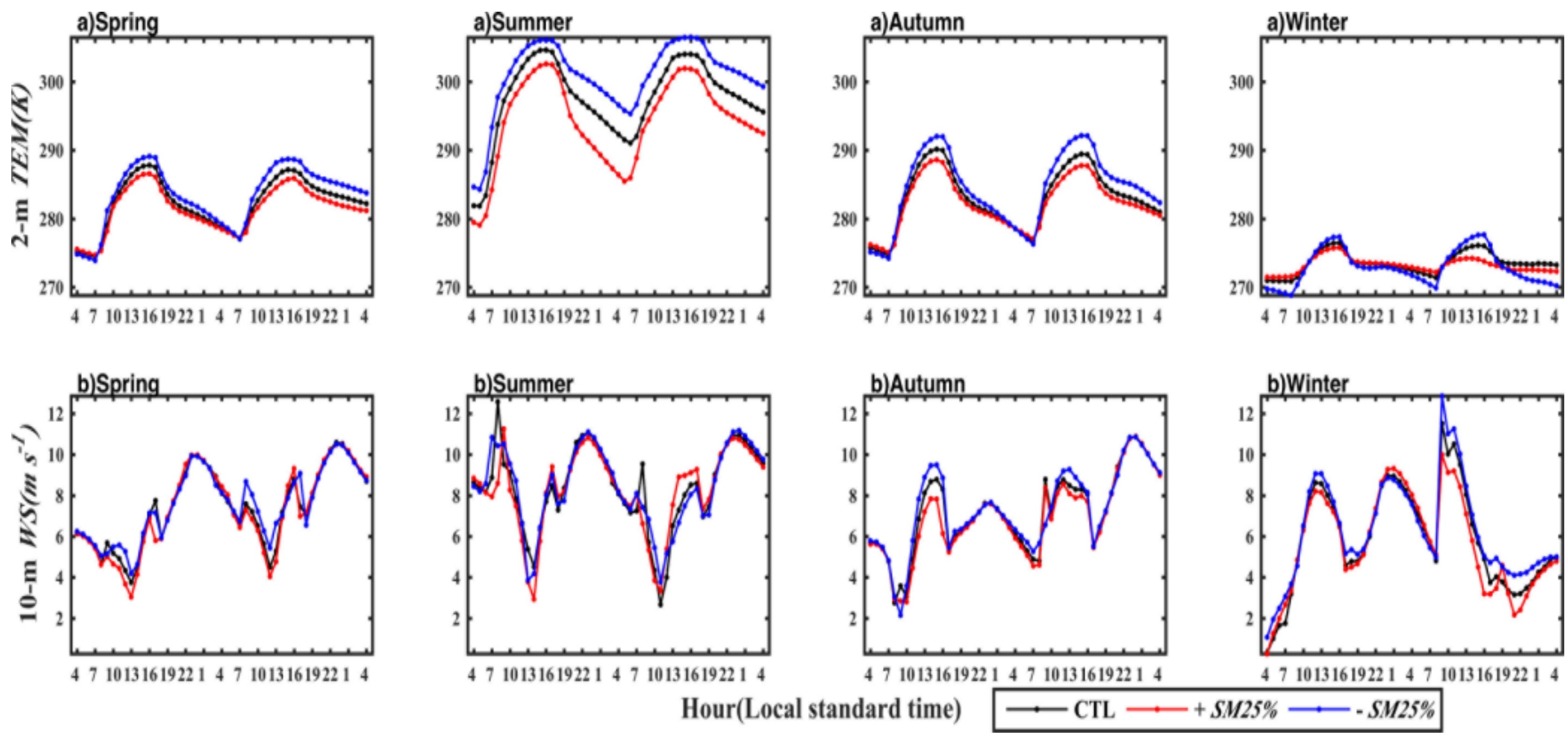


# Understanding covariances between soil and atmospheric states

A single column model study

- WRF single column model; WRF Version 3.8.1
- RRTM longwave radiation/ Dudhia shortwave radiation/ **Noah Land Surface model** / YSU PBL / WSM-6 microphysics

**Sensitivity of near-surface variable forecasts to the changes in soil moisture and land use**

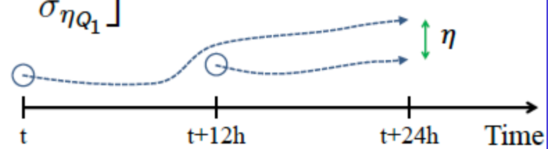


# Lin and Pu (2018) JAMC
## (WRF model with NOAH LSM)

**Variational Approach:** $\mathbf{B} = \overline{\eta\eta^{\mathrm{T}}} = \mathbf{\Sigma C \Sigma}$

$$\mathbf{C} = \begin{bmatrix} 1 & \rho_{\eta SM_1,\eta T_1} & \rho_{\eta SM_1,\eta Q_1} \\ \rho_{\eta T_1,\eta SM_1} & 1 & \rho_{\eta T_1,\eta Q_1} \\ \rho_{\eta Q_1,\eta SM_1} & \rho_{\eta Q_1,\eta T_1} & 1 \end{bmatrix}$$

$$\mathbf{\Sigma} = \begin{bmatrix} \sigma_{\eta SM_1} & 0 & 0 \\ 0 & \sigma_{\eta T_1} & 0 \\ 0 & 0 & \sigma_{\eta Q_1} \end{bmatrix}$$




Monthly estimates of B for 2015-2017 simulations

- The forecast errors in top-10-cm soil moisture and near-surface air potential temperature and specific humidity are correlated and relatively large during the daytime in the summer.

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Characteristics of Background Error Covariance of Soil Moisture and Atmosph…

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### Characteristics of Background Error Covariance of Soil Moisture and Atmospheric States in Strongly Coupled Land–Atmosphere Data Assimilation


Liao-Fan Lin *and* Zhaoxia Pu
*Department of Atmospheric Sciences, University of Utah, Salt Lake City, Utah*



*https://doi.org/10.1175/JAMC-D-18-0050.1*
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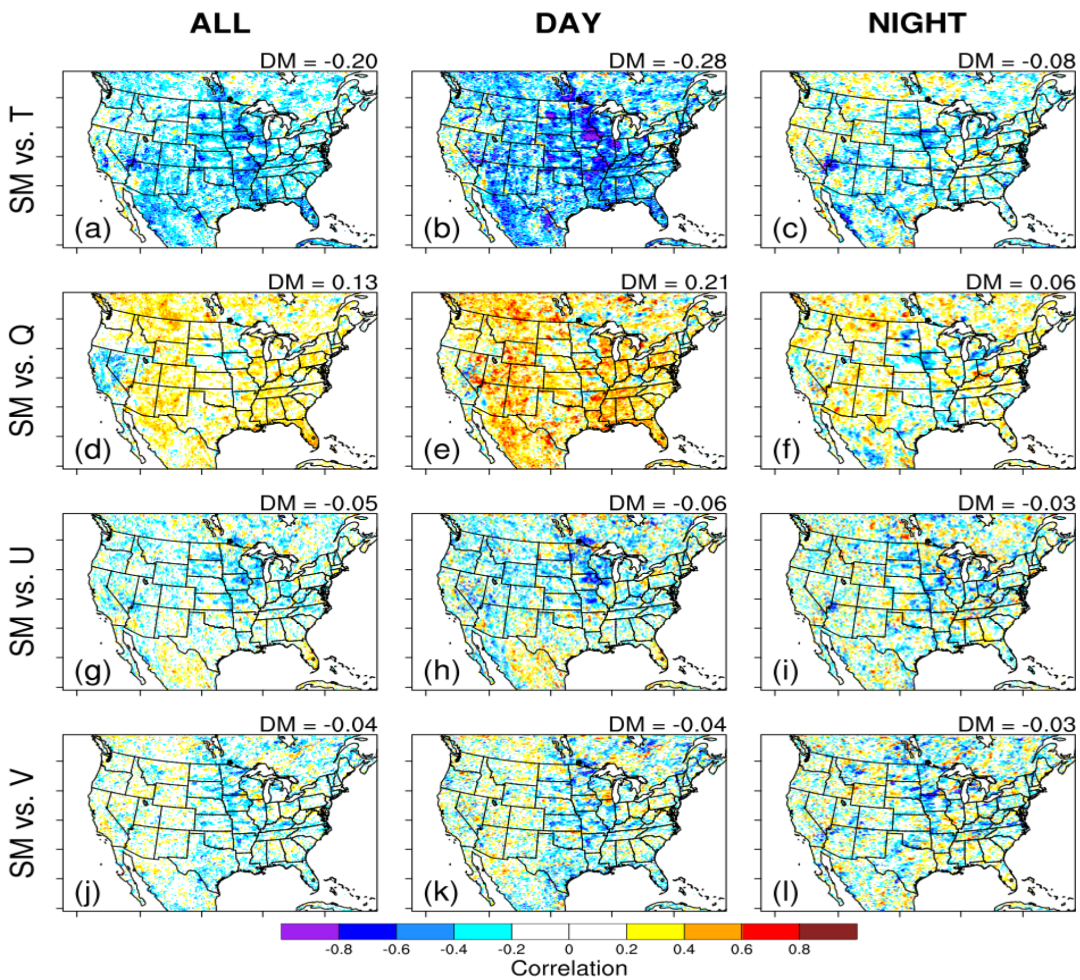
Abstract | Full Text | References | PDF


### Abstract

This study characterizes the spatial and temporal variability of the background error covariance between the land surface soil moisture and atmospheric states for a better understanding of the potentials of assimilating satellite soil moisture data under a framework of strongly coupled land–atmosphere data assimilation. The study uses the Noah land surface model coupled with the Weather Research and Forecasting (WRF) Model and the National Meteorological Center (NMC) method for computing the land–atmosphere background error covariance from 2015 to 2017 over the contiguous United States. The results show that the forecast errors in

# Understanding covariances between soil and atmospheric states

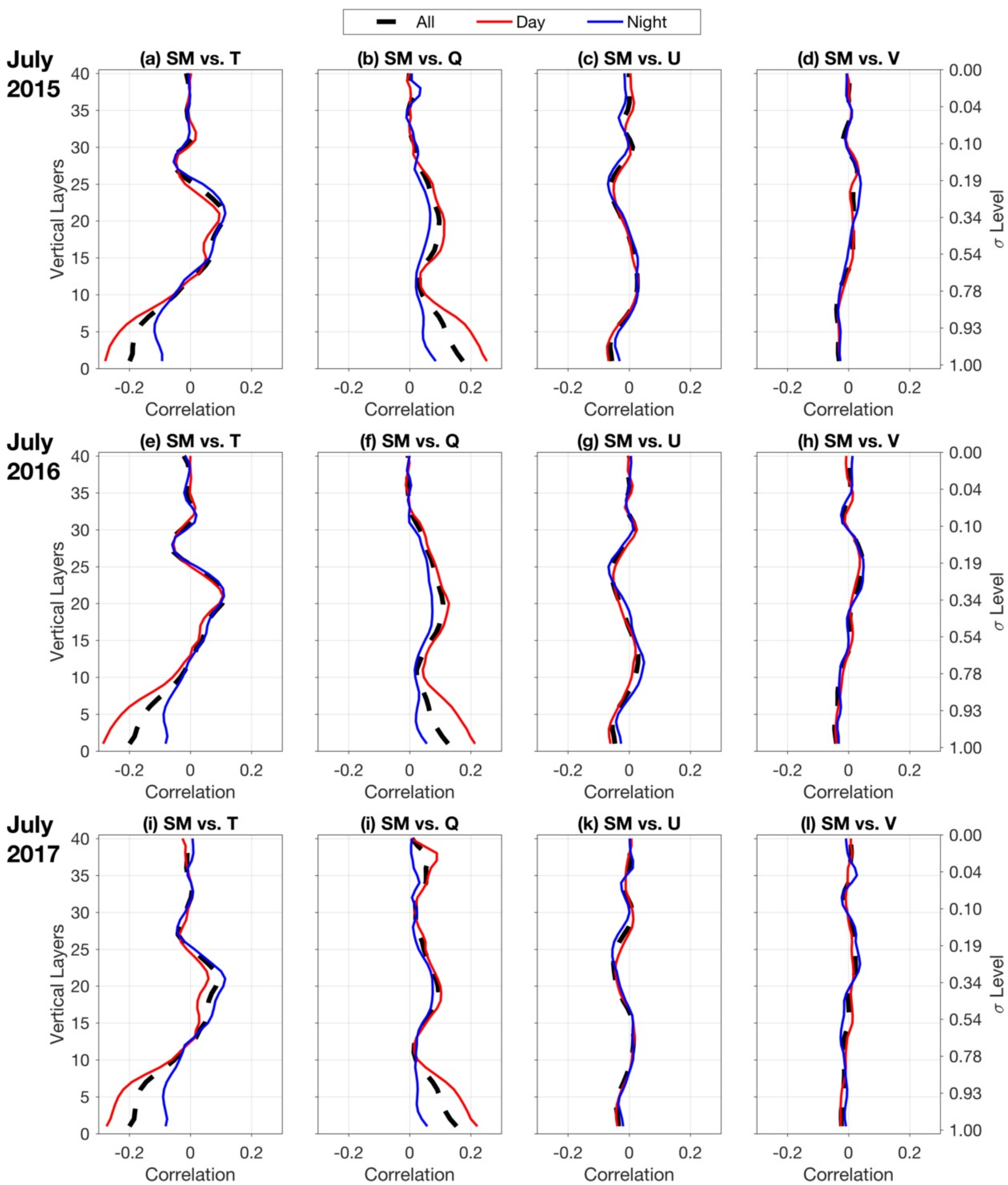
A strongly coupled land-atmospheric system (WRF-Noah)




"NMC-method"

**The error correlations between top-layer soil moisture (SM) and bottom-layer atmospheric T, Q, U, and V in July 2016.**

Lin, L-F, and Z. Pu, 2018: Characteristics of Background Error Covariance of Soil Moisture and Atmospheric States in Strongly Coupled Land-Atmosphere Data Assimilation. *Journal of Applied Meteorology and Climatology*, **57**, 2507-2529. https://doi.org/10.1175/JAMC-D-18-0050.



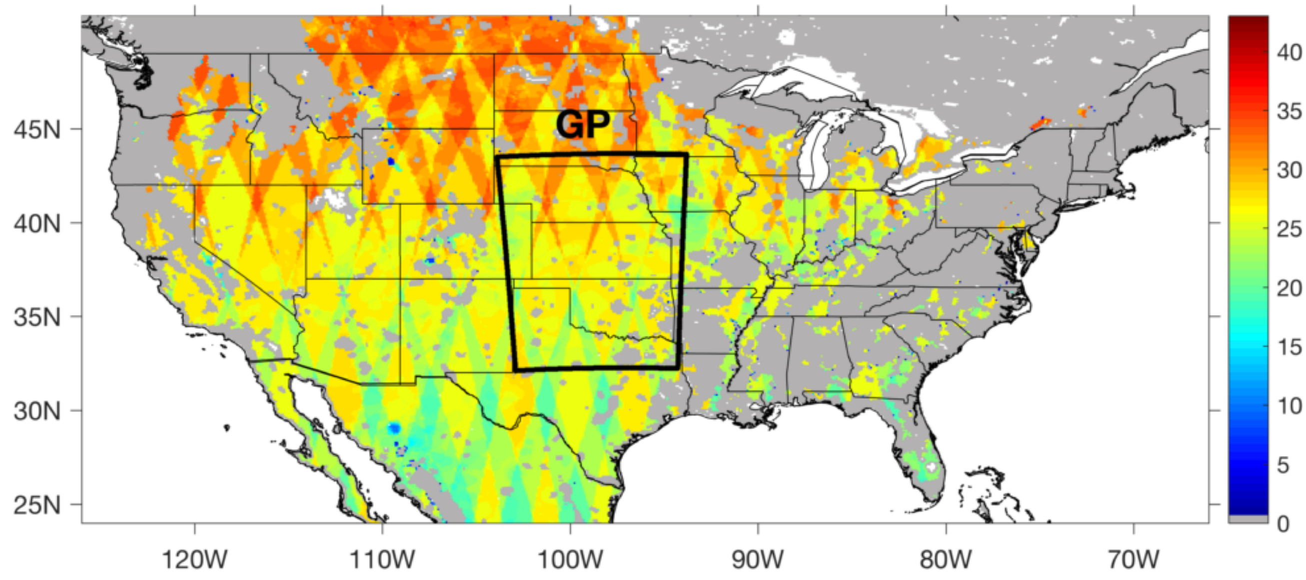

**The domain mean error correlation between the top 10-cm WRF-Noah soil moisture (SM) and atmospheric states including potential temperature (T), specific humidity (Q), zonal wind (U), and meridional wind (V) in July from 2015 to 2017.**

# Examining the influence of strong coupling on soil moisture data assimilation with SMAP satellite data: WRF-Noah

**L.-F. Lin and Z. Pu, 2018 (Mon. Wea. Rev. – minor revision)**

- Using Version 01 NASA SMAP 9-km enhancement soil moisture with quality control (removing data over surface types of vegetation, urban, water, and snow).

The sample of both descending and ascending data from SMAP, 1-27 July 2016



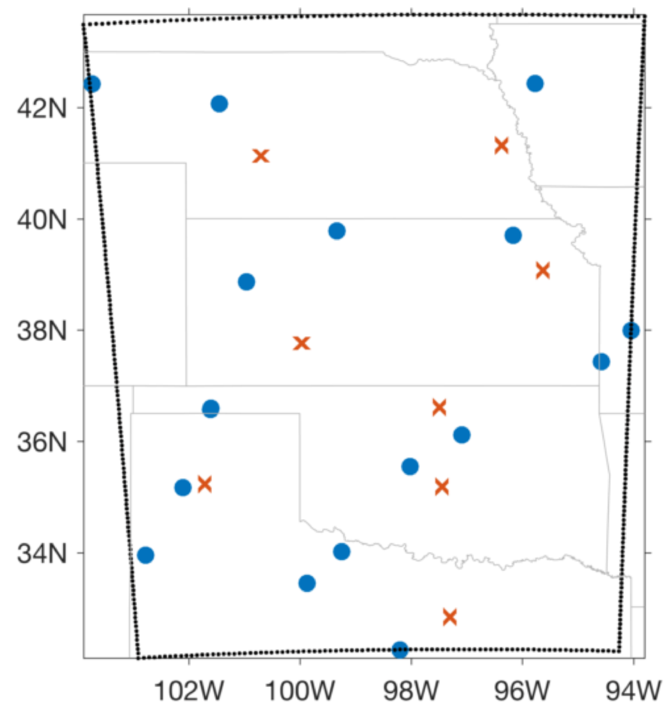
# Experiment Design

All the experiments were performed from 1-28 July 2016

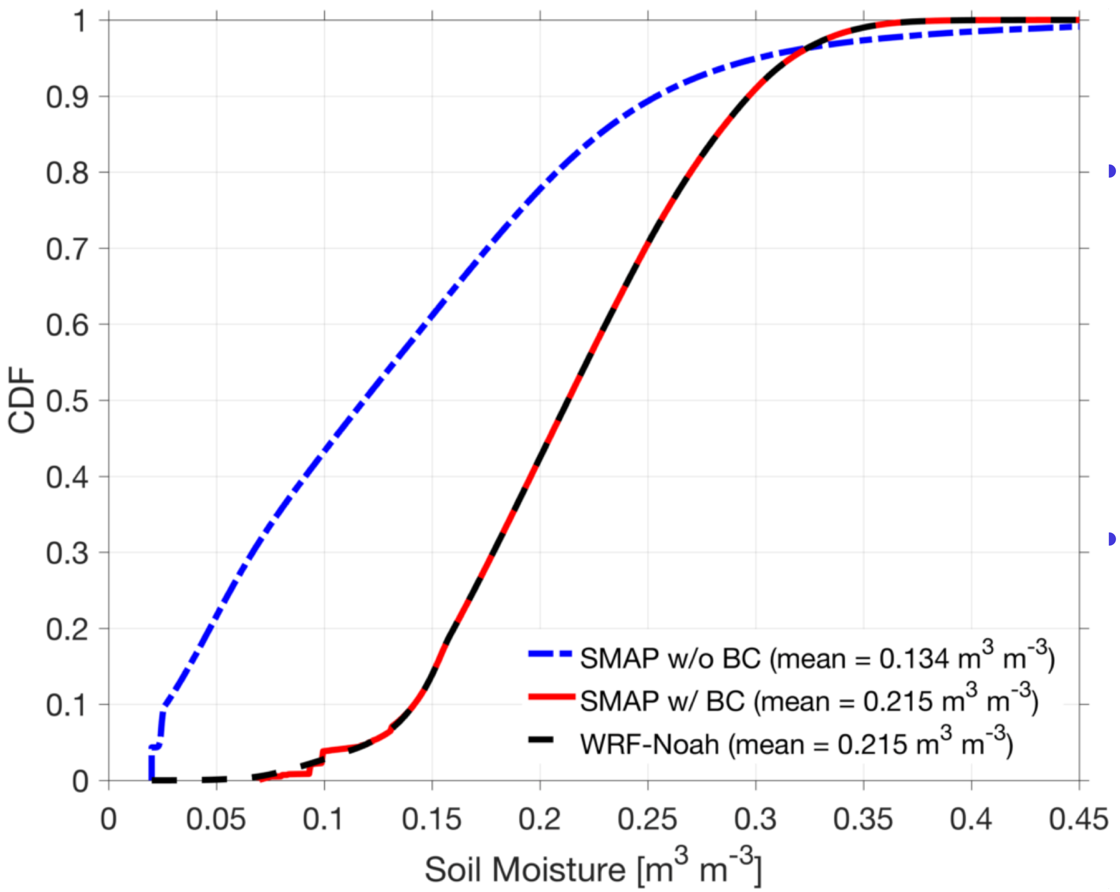
- OPL: no data assimilation
- WCDA: update only top-layer SM using bias-corrected SMAP SM
- SCDA: update SM and T/Q using bias-corrected SMAP SM

Evaluation with Reference datasets:

SM: SCAN and CRN gauges

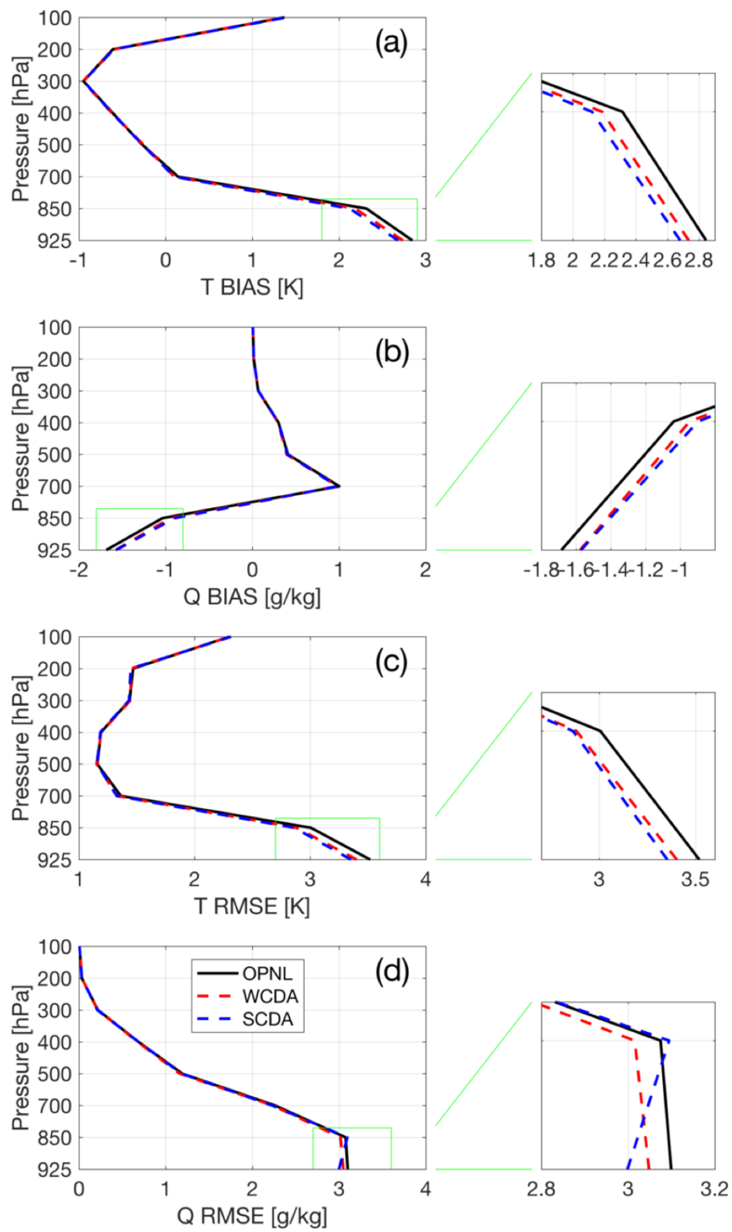



SCAN/CRN soil moisture gauges (blue dots) and the sounding data (red crosses)

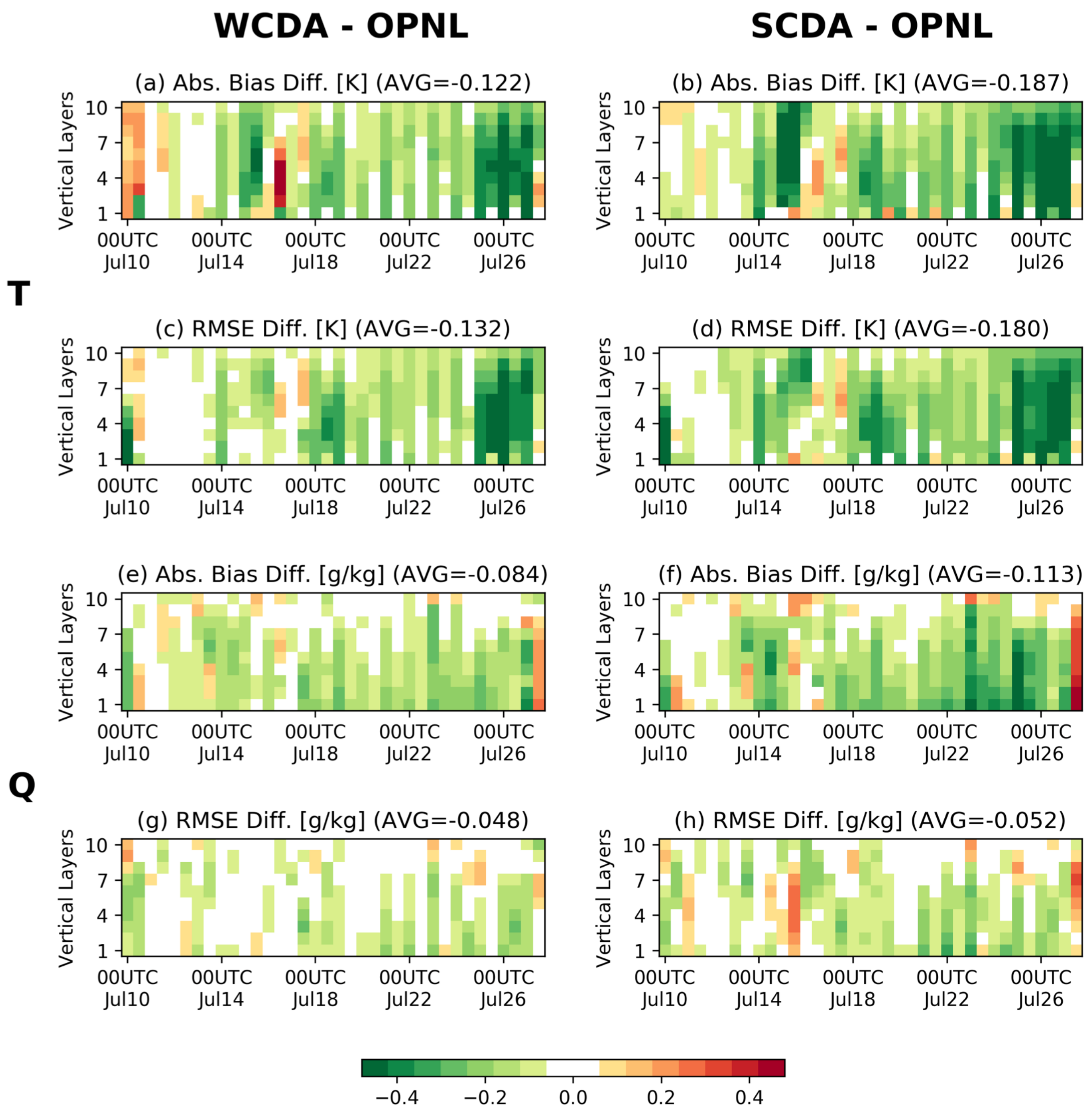



- **The soil moisture from Noah and SMAP SM before and after rescaling in July 2016 over the regions of interest**
- **Cumulative distribution function (CDF) matching**

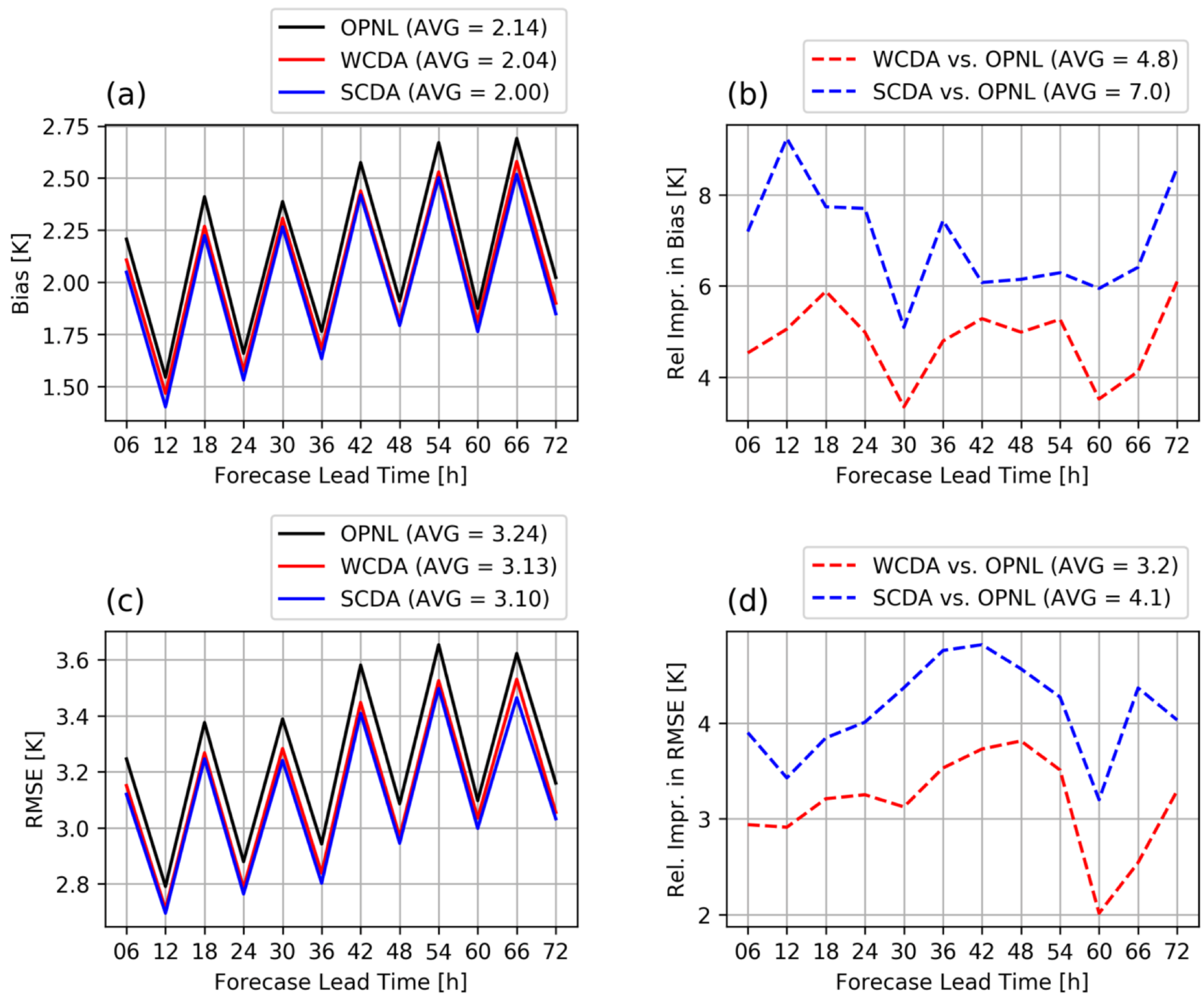
The verification of temperature (T) and specific humidity (Q) forecasts of a lead time of 12, 24, 36, 48, 60, and 72 hours that are initialized at 00 and 12 UTC during 10-27 July 2016 against the sounding data.



The difference of the domain-mean absolute bias and RMSE in the analyses of temperature and humidity between OPNL and WCDA/SCDA.



(a, c) The bias and RMSE of 2-m temperature forecasts initialized every 12 hours during 10-27 July 2016 against the METAR weather stations; (b,d) The relative improvements



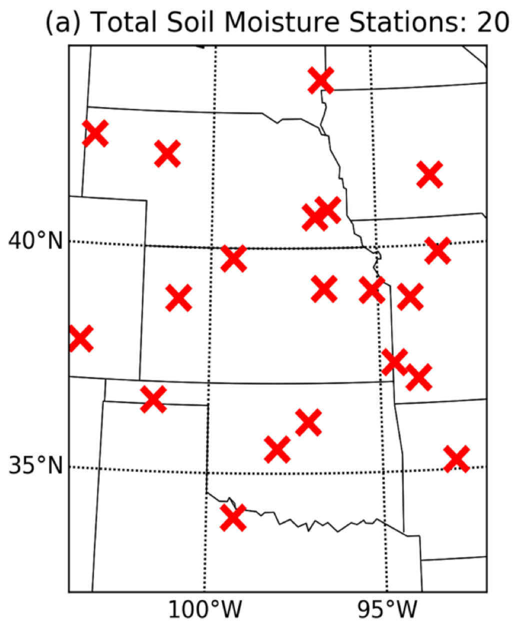
## New and ongoing development: Strongly coupled land-atmosphere data assimilation within the GSI-EnKF framework (Lin and Pu 2019, in prep.)

Two main implementations:

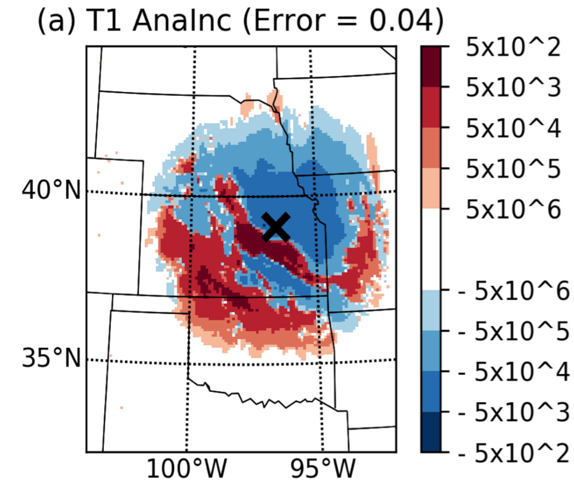
- Adding soil moisture of all four Noah soil layers as a control analysis state
- Assimilating soil moisture observations together with conventional atmospheric data simultaneously

| No. | Experiment | Control States | Assimilated Observations |
|---|---|---|---|
| 0 | OPNL | - | - |
| 1 | VarwoSM_CONV | T, Q, U, V, MU | Conventional data |
| 2 | VarwoSM_CONV_T2 | T, Q, U, V, MU | Conventional data + T2 |
| 3 | VarwoSM_CONV_Q2 | T, Q, U, V, MU | Conventional data + Q2 |
| 4 | VarwoSM_CONV_T2Q2 | T, Q, U, V, MU | Conventional data + T2 + Q2 |
| 5 | VarwSM_CONV | T, Q, U, V, MU, SM | Conventional data |
| 6 | VarwSM_CONV_T2 | T, Q, U, V, MU, SM | Conventional data + T2 |
| 7 | VarwSM_CONV_Q2 | T, Q, U, V, MU, SM | Conventional data + Q2 |
| 8 | VarwSM_CONV_T2Q2 | T, Q, U, V, MU, SM | Conventional data + T2 + Q2 |
| 9 | VarwSM_CONV_SM | T, Q, U, V, MU, SM | Conventional data + SM |
| 10 | VarwSM_CONV_T2Q2SM | T, Q, U, V, MU, SM | Conventional data + T2 + Q2 + SM |

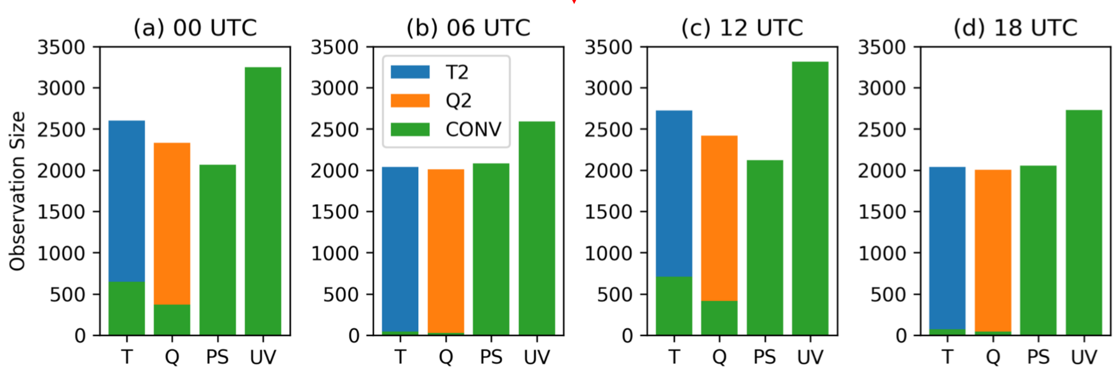
# Experiment Settings

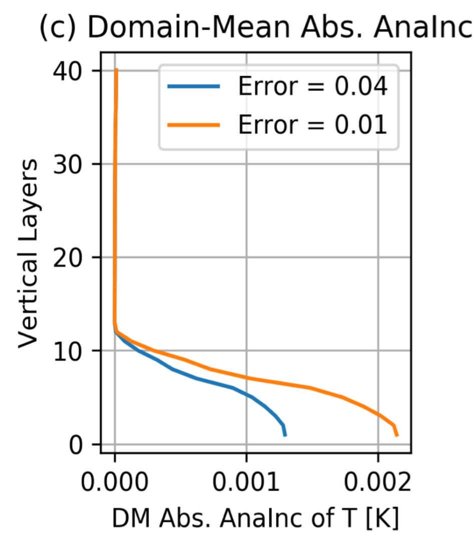



- Horizontal localization: 500 km
- Vertical localization: 0.4 scale height

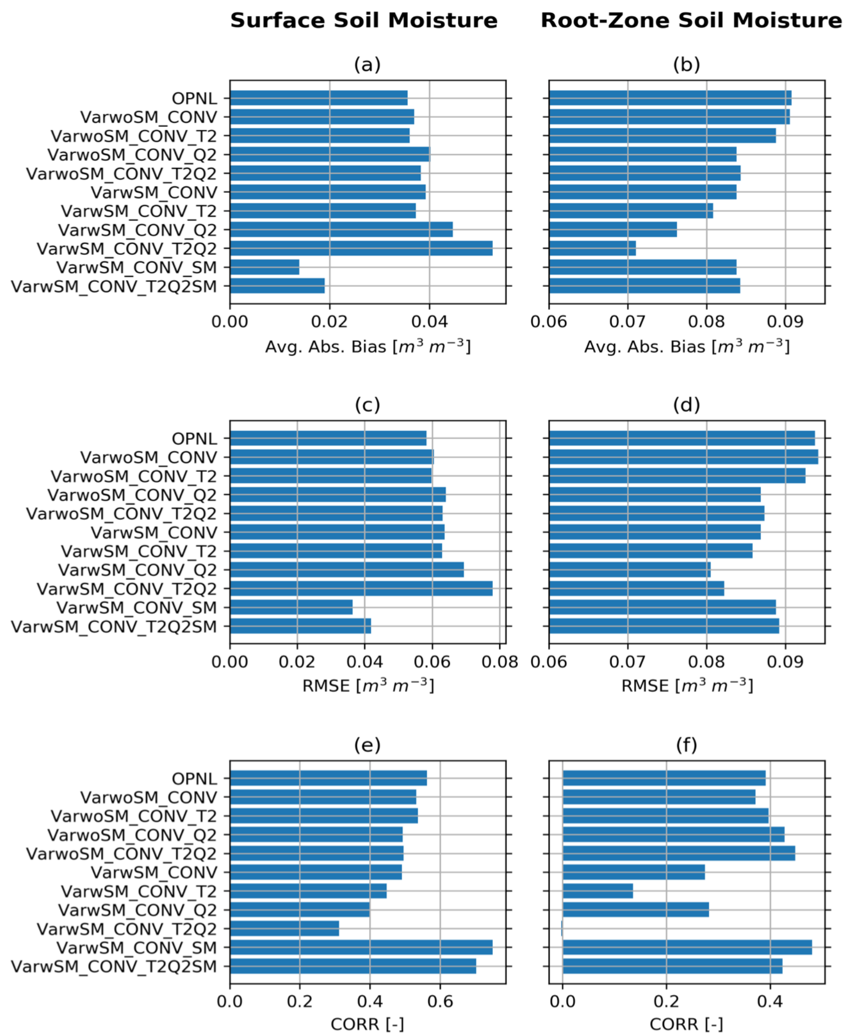



Averaged observation size during the experiment period in July 2018

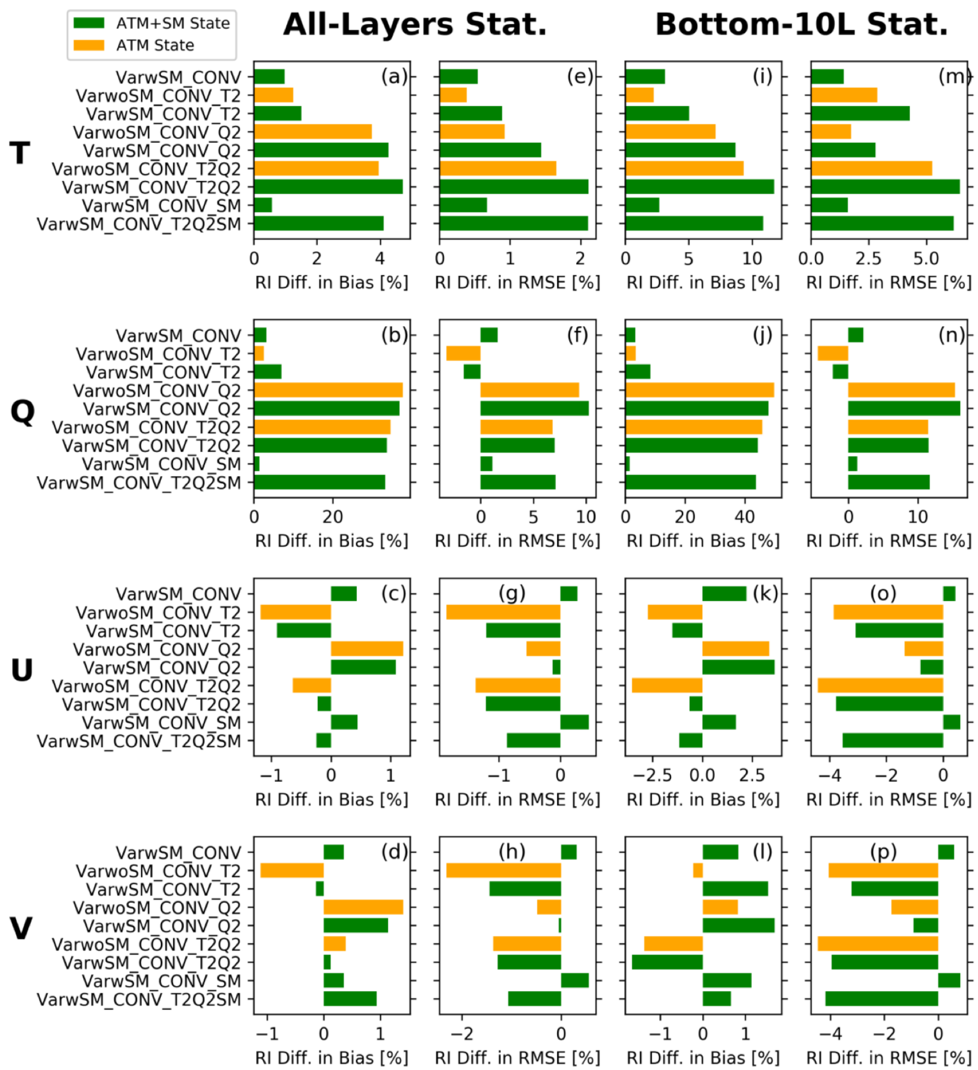


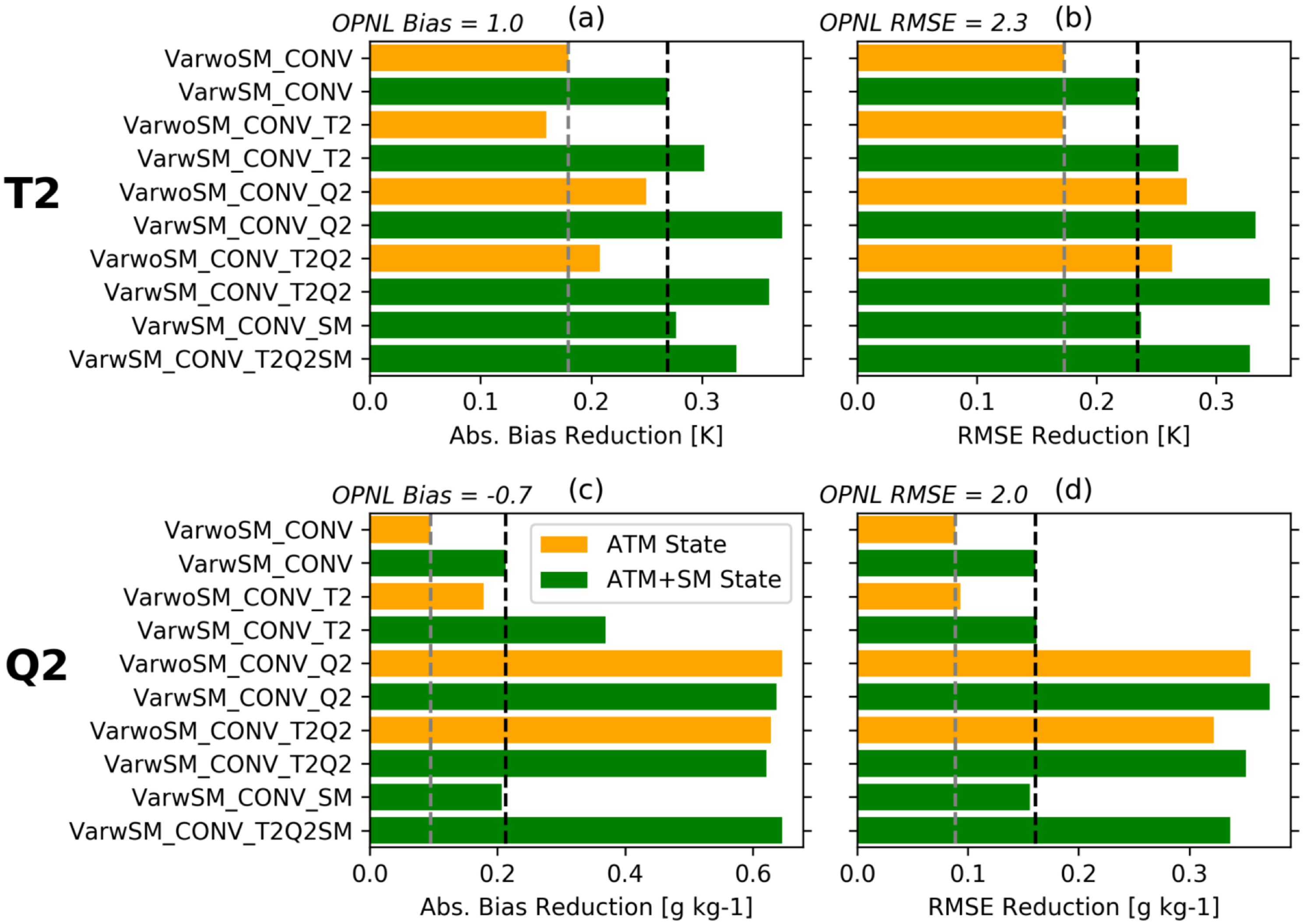
# Verification of Soil Moisture Analysis Against ISMN



# Verification of Atmos. Analysis Against NCEP NAM



# Verification of T2 and Q2 Against METAR Stations



# Concluding remarks

- Near-surface weather forecast remains a significant forecast challenge in NWP.
- There are correlations between soil and atmospheric states. A strongly coupled land-atmospheric data assimilation is recommended.
- With SMAP soil moisture data assimilation experiments, the strongly coupled land-atmosphere data assimilation outperforms the weakly coupled data assimilation.
- Preliminary development/evaluation of strongly coupled system with GSI-EnKF demonstrates some potential benefits on the improved prediction of near-surface atmospheric conditions and soil moisture.