Utilizing SMAP Soil Moisture Data to Improve Irrigation Parameterizations in Land Surface Models

MICHIGAN STATE UNIVERSITY

AGU100 ADVANCING EARTH AND SPACE SCIENCE

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1. INTRODUCTION

- **Irrigation** water, which accounts for **~90% of consumptive water** use globally, increased significantly over the past decades, accompanied by increasing interest in better simulating irrigation processes in LSMs which are highly **simplified**.

- Our **hypothesis** is that the **assimilation of SMAP** satellite soil moisture (SM) data into the irrigation module of the global land surface models (LSMs) to set the target SM can **significantly improve** the simulation of **irrigation water** and **SM**, thus enabling advancements in representation of irrigation toward better understanding the impacts of irrigation on land hydrology and climate system over large scales.

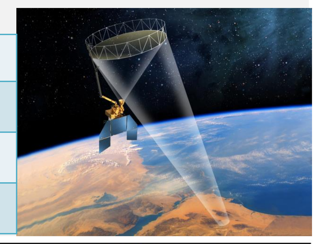
- The irrigation application trigger in LSMs, which is based on the **SM deficit mechanism**, is enhanced by utilizing SMAP SM data.

- Regional simulations are performed over the entire **High Plains Aquifer (HPA) region** and for 2000-2016 period. Four sets of simulations are conducted using the Community Land Model v4.5 (**CLM4.5**) with: (1) the default CLM4.5 irrigation scheme (CTRL), and with the modified irrigation schemes by (2) directly integrating raw SMAP data (SMAP_raw), (3) assimilating SMAP data using 1-D Kalman Filter (KF) (SMAP_KF), and (4) assimilating bias-corrected SMAP data using 1-D KF (SMAP_KF_BC).

2. SMAP SATELLITE

- Launched January 2015.
- It measures the amount of water in the top 5 cm of soil everywhere on Earth's Surface.
- This large swath coverage allows SMAP to make complete soil moisture maps of the Earth repeated every 2 to 3 days.
- The satellite's radar system failed in July 2015.

Temporal coverage	03/2015
Antenna size	6 m
Radar ground resolution	1-3 km
Radiometer ground res.	30 km



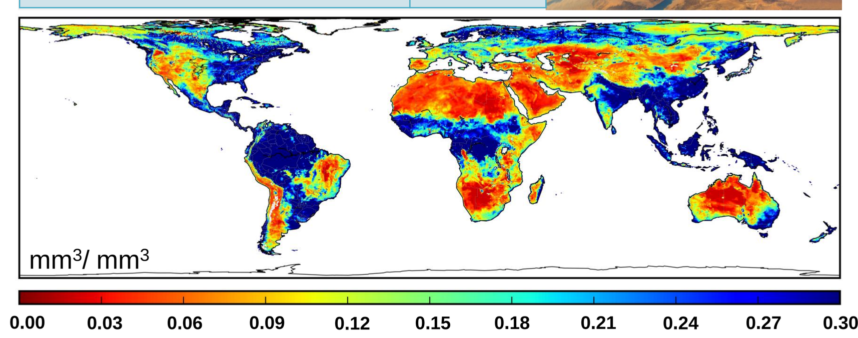
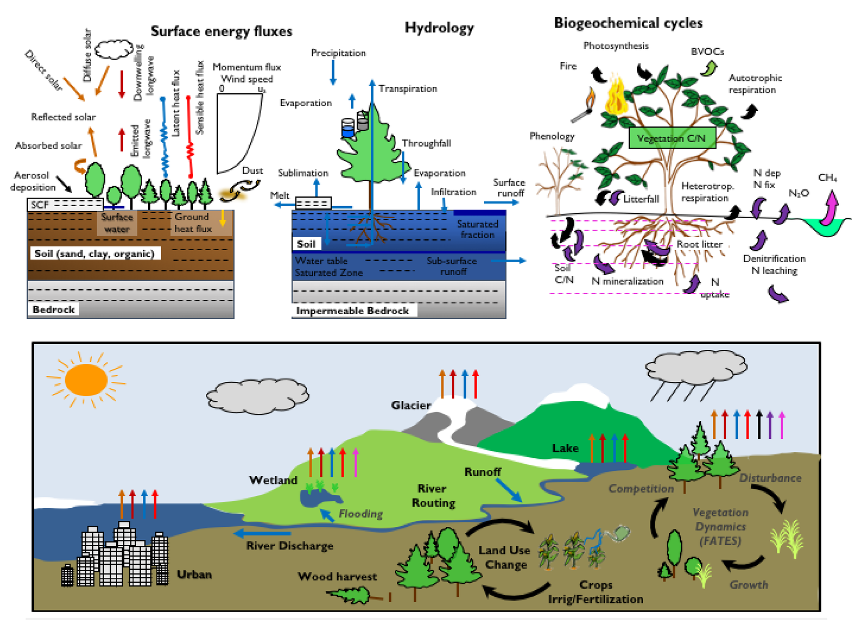


Fig. 1: *SMAP SM retrievals averaged over June to August of 2015*

3. THE MODEL: CLM



Irrigation calculations in CLM4.5 based on SM deficit mechanism:

$$SM_{deficit} = \sum_{i=1}^{soil\ layers} SM_{target,i} - SM_{simulated,i}$$

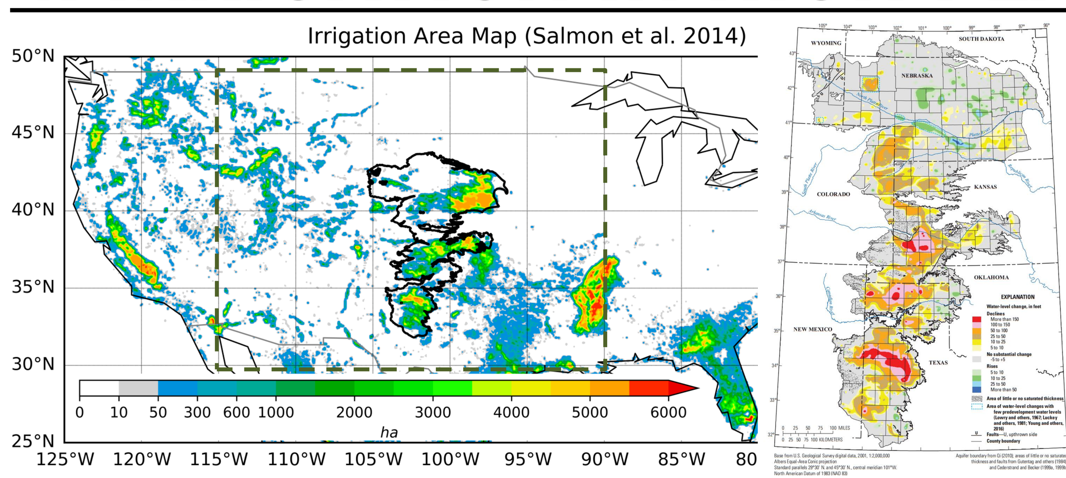
$$SM_{target} = (1 - F_{irrig}) \times SM_{min} + F_{irrig} \times SM_{max}$$

* F_{irrig} is an empirical factor that is set globally at 0.7

* SM_{min} and SM_{max} set based on the soil type

Fig. 2: *Schematic representation of primary processes and functionality in the Community Land Model (CLM). Abbreviations: SCF-snow cover fraction; BVOC-biogenic volatile organic compounds; C/N-carbon and nitrogen (Lawrence et al., 2011. J. Adv. Model. Earth Syst.[1])*

4. IRRIGATION IN HIGH PLAINS AQUIFER



- The US bread/grain basket.
- 1950 is the beginning of the substantial irrigation with groundwater

Fig. 3: *Left: Irrigated areas across the US. Right: Water-level changes in the High Plains aquifer, predevelopment (~1950) to 2015 (showing more than 150 feet over red regions).*

5. EXPERIMENTAL DESIGN

- We conduct four sets of offline simulations (activating different irrigation schemes) forced by the North America Land Data Assimilation System phase II (NLDAS2) data.
- The typical spatial resolution for CLM4.5 is 0.5°; here we set up the model at a higher resolution (3 arc-minute or 0.05°) to capture the fine-scale details of irrigation processes.
- SMAP simulation are conducted using daily climatology of SM data observed by SMAP satellite. The SMAP data are re-gridded from the 36 km EASE projection to 0.125° Cylindrical Equidistant grid. Then, a 1-D KF is used to assimilate the SMAP data into the CLM.
- The U.S. Geological Survey (USGS) census data of irrigation amount at county level is used to compare with the model irrigation water amount (**Fig. 5**).

6. RESULTS

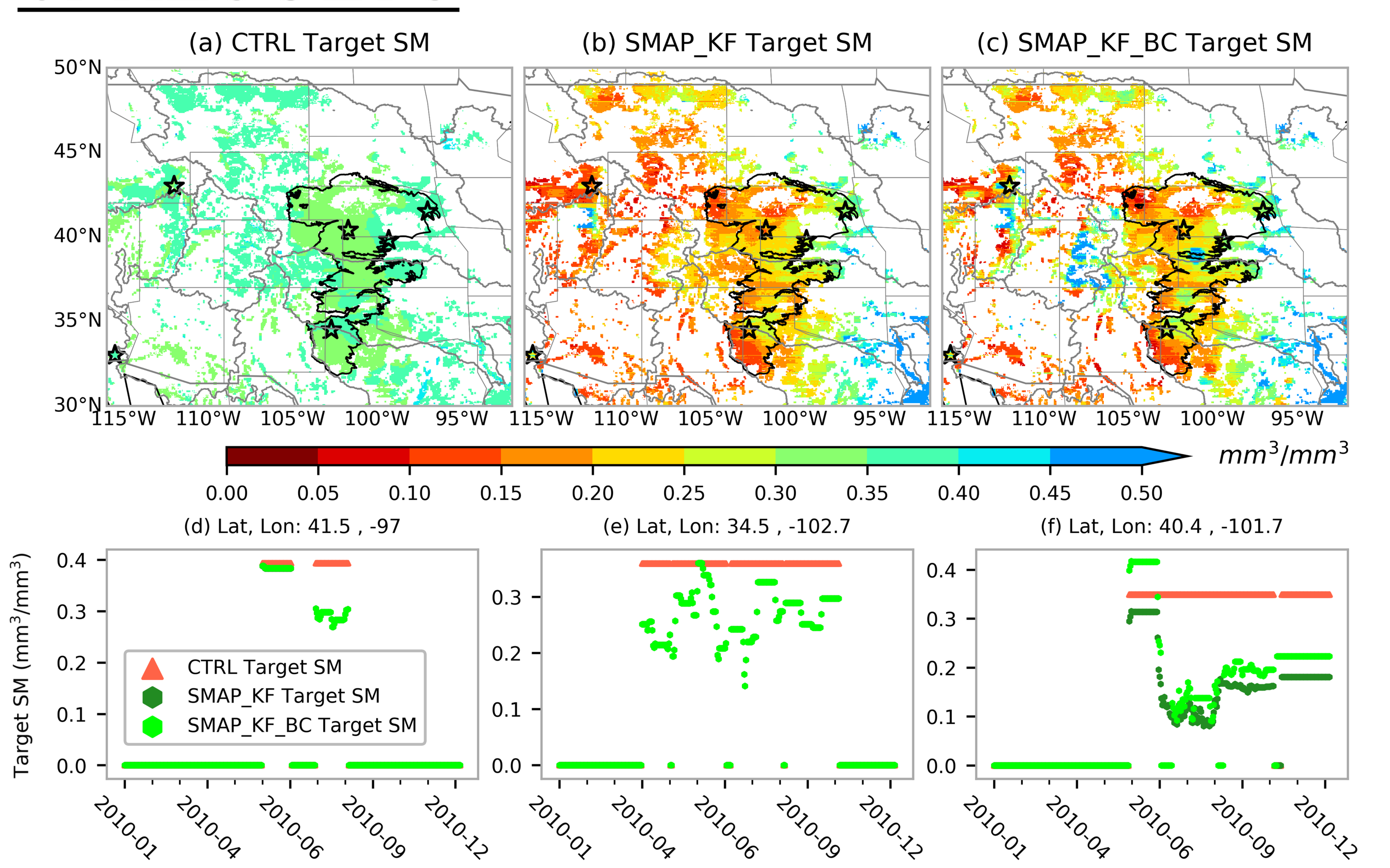


Fig. 4: *Spatial variability of target SM averaged in soil layers and for JJA of 2010 from CTRL (a), SMAP_KF (b), and SMAP_KF_BC (c) simulations. Temporal variability of target SM for sample grid cells (which are marked by stars in spatial maps a-c) is shown for the entire year 2010 (d-f). The target SM in the CLM4.5 irrigation scheme (CTRL) does not vary in time and its spatial variability, prescribed as a function of soil type, is generally small.*

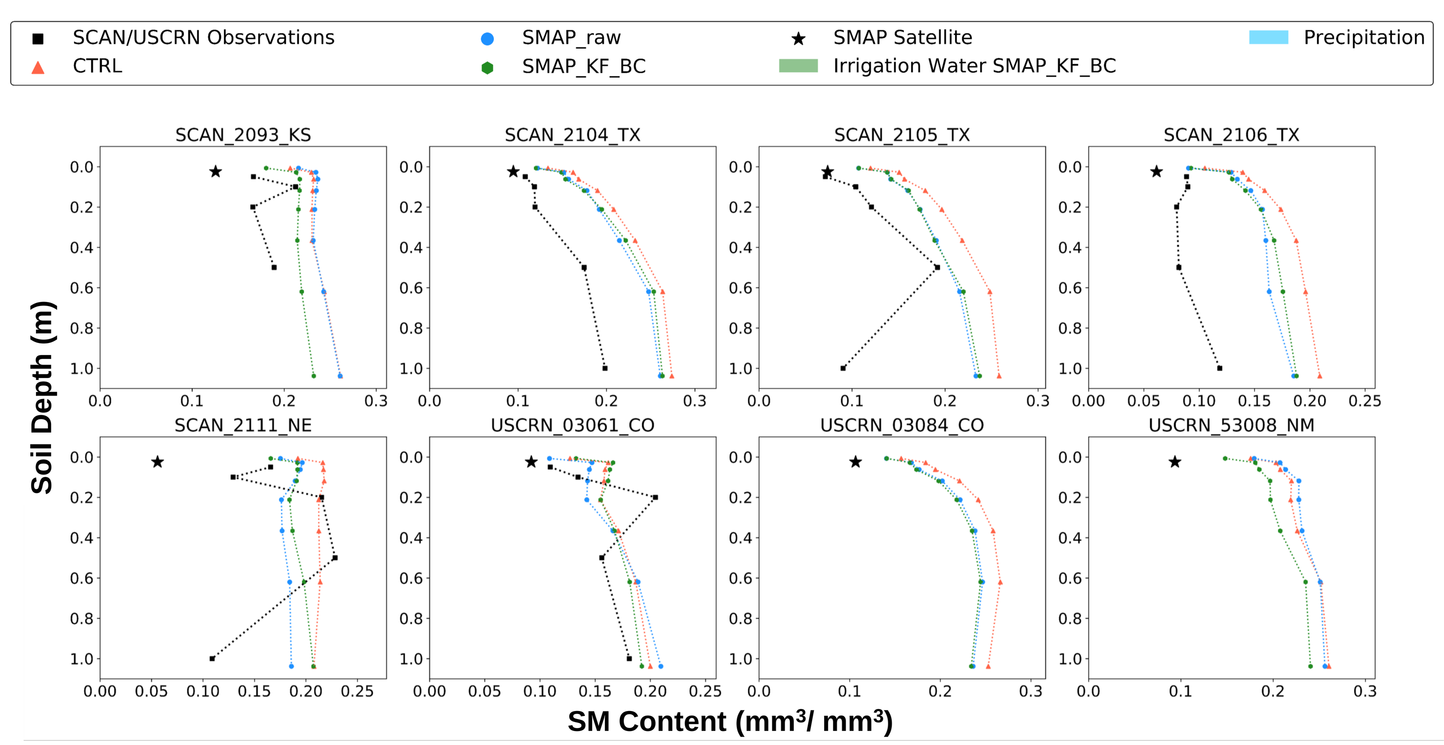


Fig. 6: *Vertical profiles of averaged SM over JJA during 2015-2016 from SMAP, ground observations (i.e., SCAN and USCRN stations), and CTRL, SMAP_raw, and SMAP_KF_BC simulations*

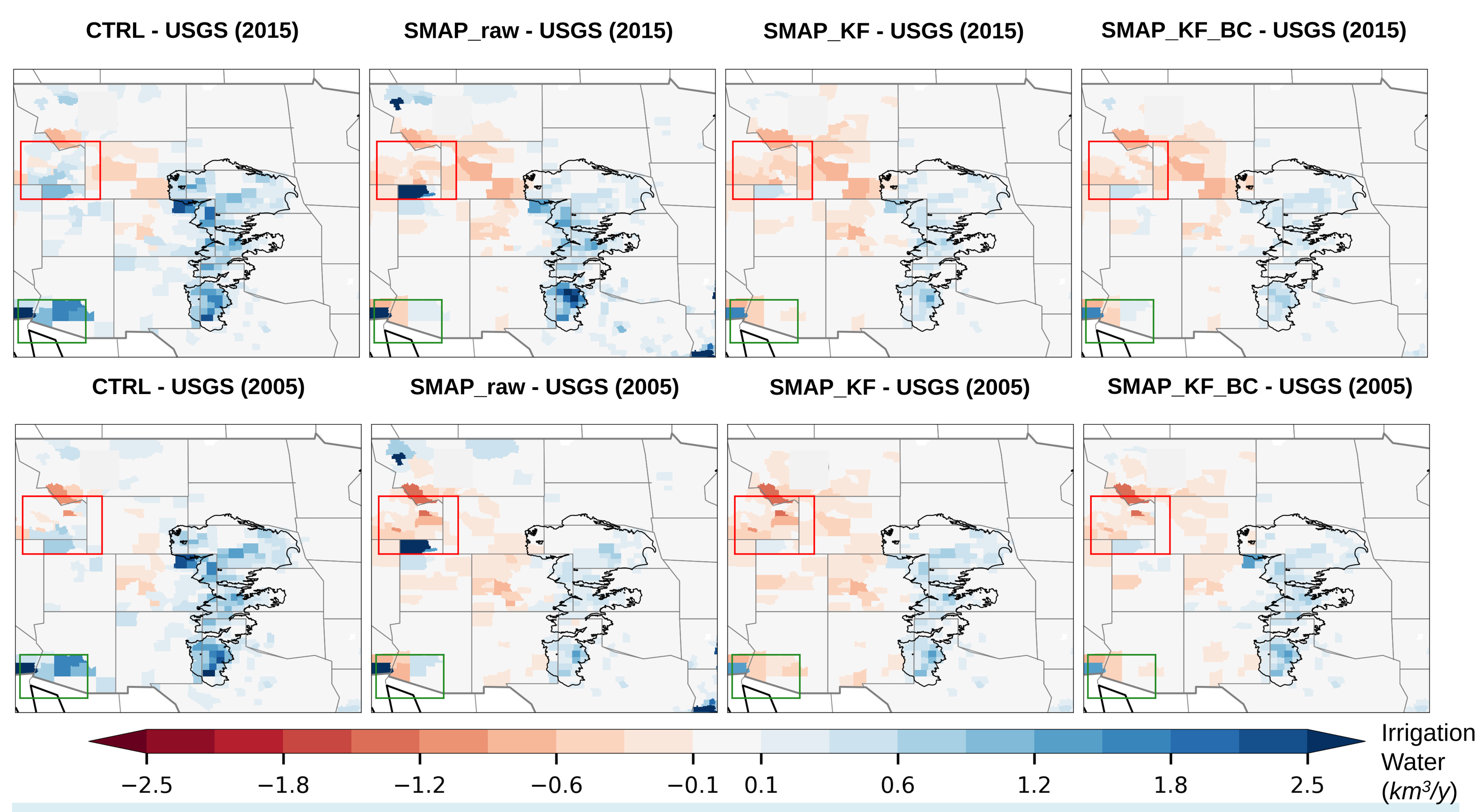


Fig. 5: *Difference between annual total irrigation water requirement simulated using different model settings and the census data of irrigation from the USGS for census years 2005 and 2015.*

7. SUMMARY and CONCLUSIONS

- **Figure 5** shows that highly **overestimated** irrigation water in the control simulation (particularly over HPA) is **significantly improved** by modified irrigation schemes (particularly in SMAP_KF and SMAP_KF_BC).

- **Figure 6** shows that in general, **a shift** in the SM profile **toward the observed profile** and SMAP data can be observed in the improved irrigation schemes, suggesting an **improvement** also **in SM simulations** due to SMAP data assimilation.

- We conclude that the use of **SMAP data** with **1-D KF** better represents the target SM, thus providing **robust improvements** in the simulation of irrigation water requirement and soil moisture, and generally reducing wet bias in irrigation water requirement in the control simulation. Thus, while this study is conducted regionally using CLM4.5, the new approach can be incorporated **into any LSM**, and applied and validated **globally**.

- **Figure 7** shows the **preliminary results** of our **ongoing research** which aims at coupling the irrigation scheme of CLM5.0 with an improved groundwater model and the river routing scheme to better simulate the source of irrigation and groundwater table dynamics which affects large number of hydrological variables.

8. FUTURE: CLM5.0 IRRIGATION COUPLED with GROUNDWATER and SURFACE WATER

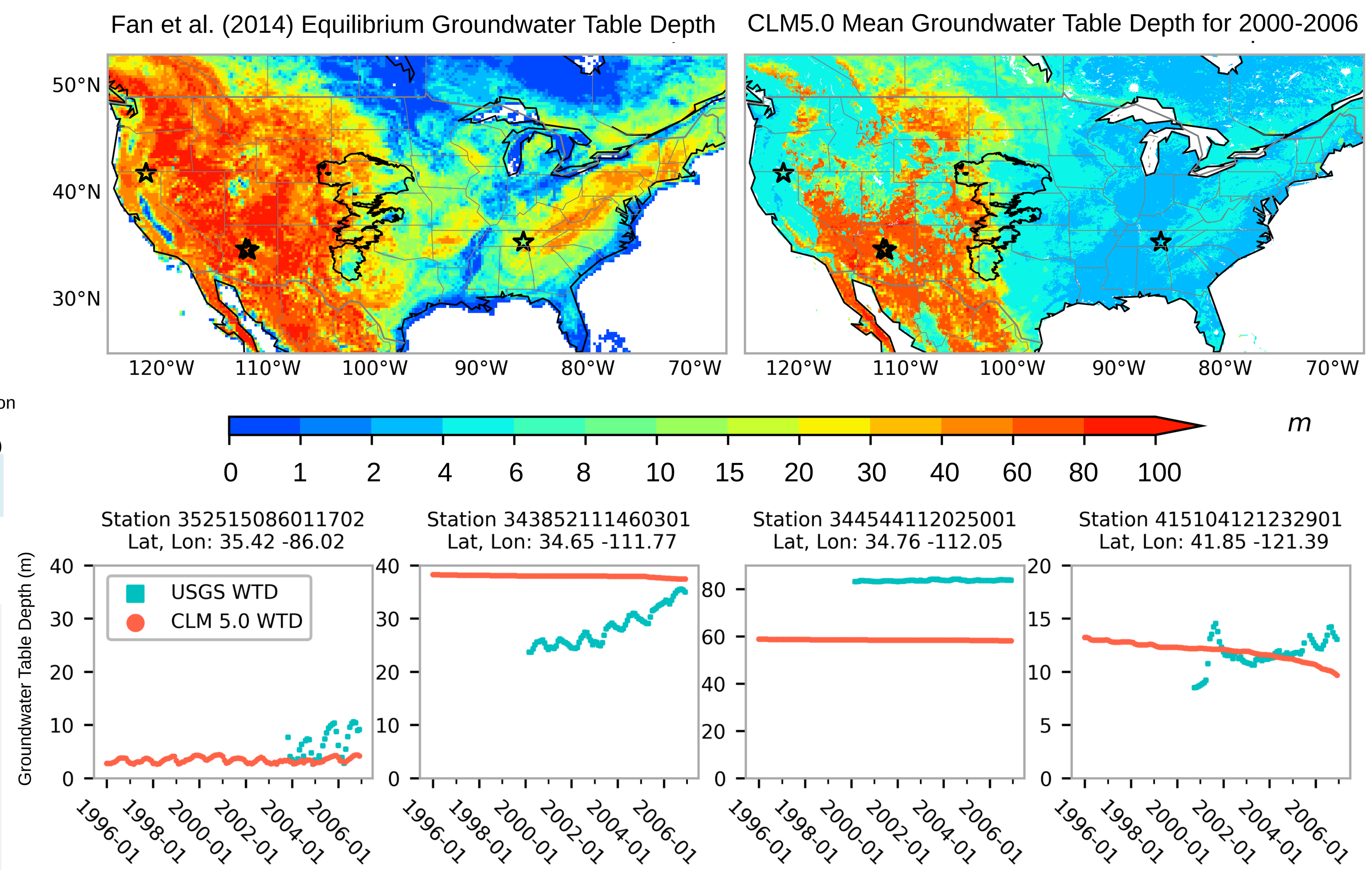


Fig. 7: Top) the equilibrium *groundwater table depth from Fan et al. (2014) and the simulated averaged groundwater table depth from CLM5.0 (as the control simulation) over contiguous U.S.. Bottom: comparison of temporal variability of groundwater table depth from CLM5.0 with USGS observational sites.*

KEY REFERENCES

1. Felfelani, F. et al. Utilizing SMAP Soil Moisture Data to Constrain Irrigation in the Community Land Model. ***Geophysical Research Letters*** **(2018)**
2. Lawrence, D.M. et al. Parameterization improvements and functional and structural advances in Version 4 of the Community Land Model. ***J. Adv. Model. Earth Syst.*** **(2011)**.
3. Felfelani, F. et al. Natural and human-induced terrestrial water storage change: A global analysis using hydrological models and GRACE. ***Journal of Hydrology*** **(2017)**.

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