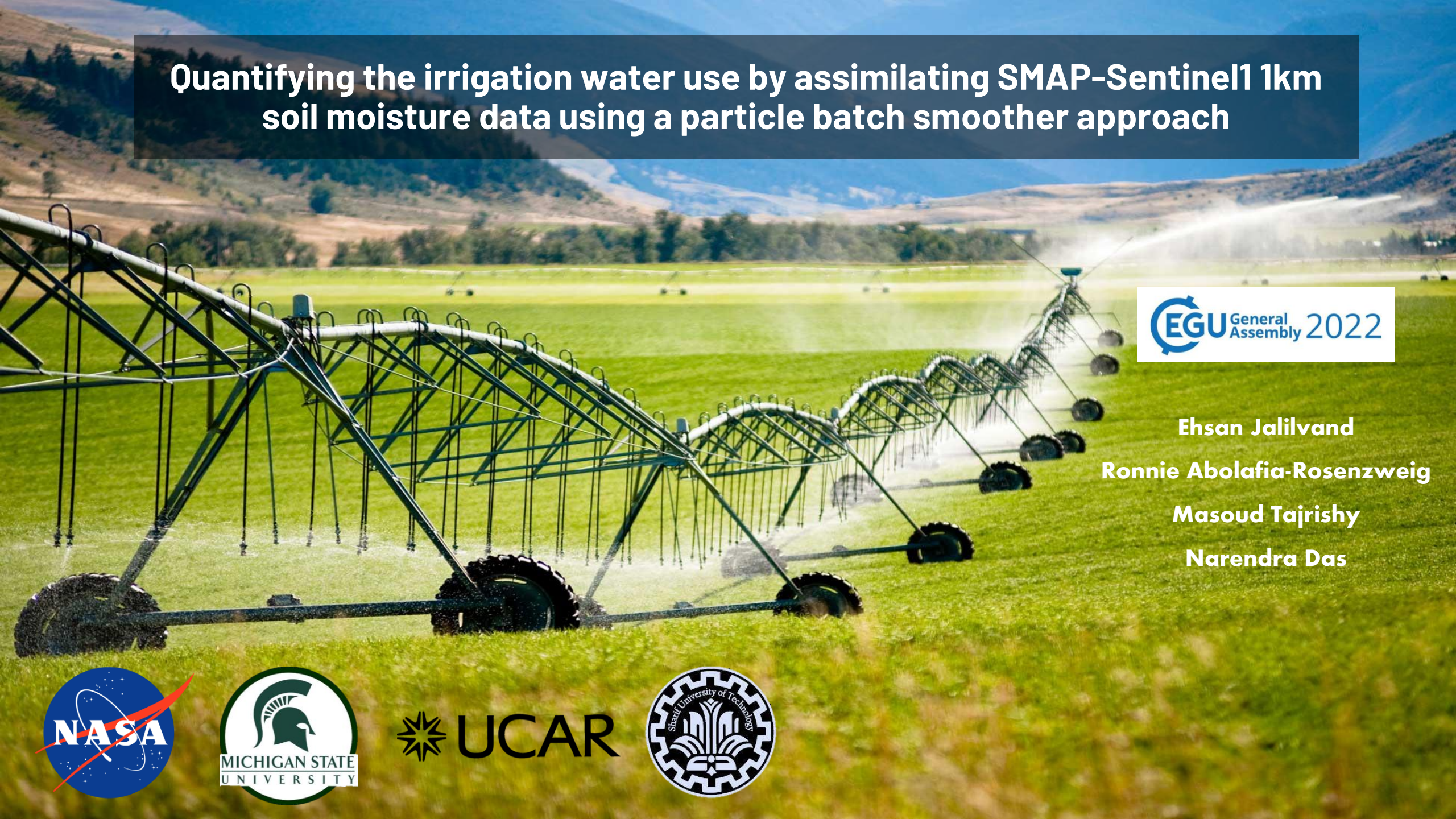
Quantifying the irrigation water use by assimilating SMAP-Sentinel1 1km soil moisture data using a particle batch smoother approach



EGU General Assembly 2022

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UCAR

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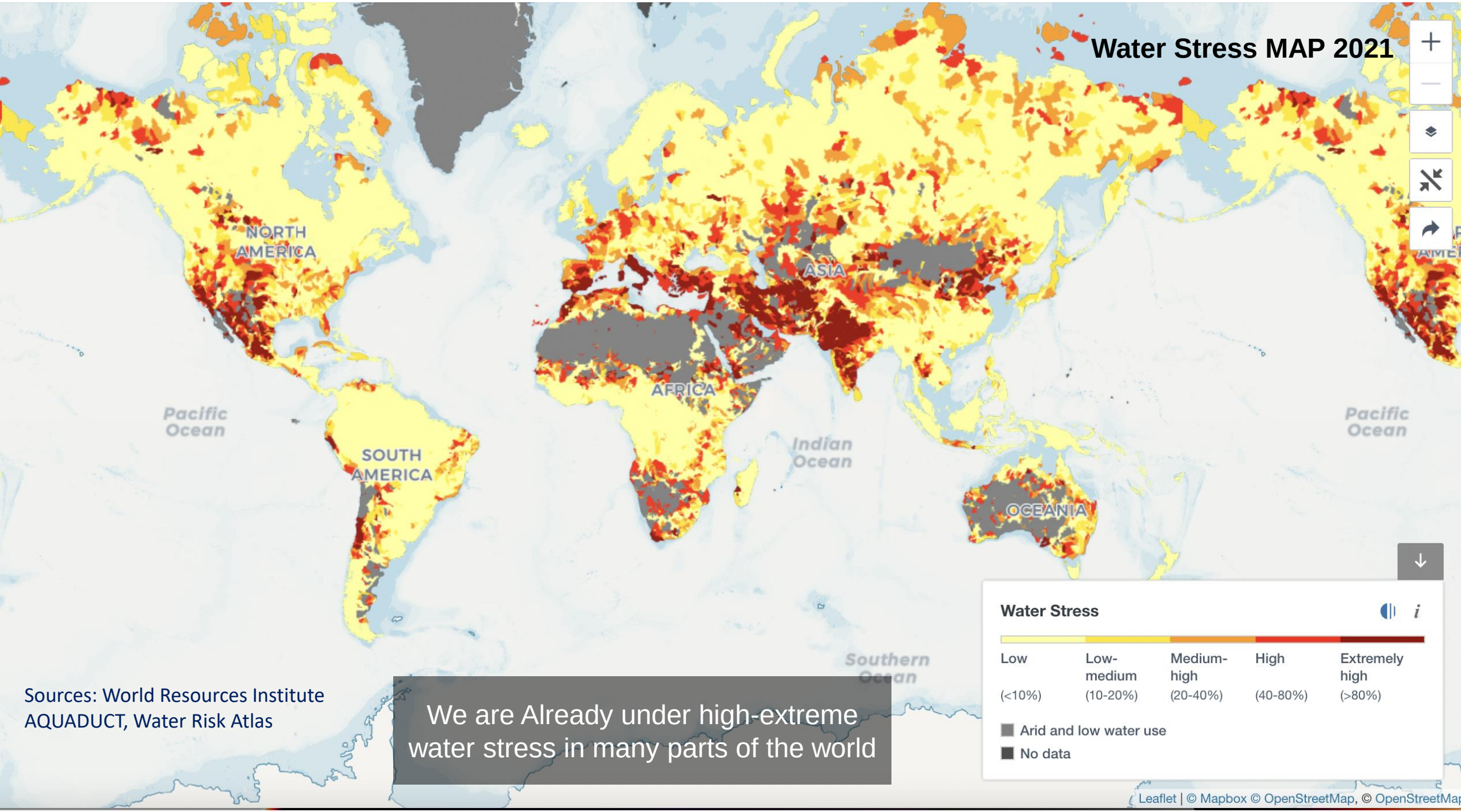
Motivation

- The global food demand is projected to be **doubled by 2050 (causes: population growth (30%)**, **dietary shift mainly toward Meat (70%)!** (Tilman and Clark , 2015)
- Irrigated agriculture is at least **twice as productive per unit of land** as rainfed agriculture! (world bank, water in agriculture)
- **80–90% of freshwater consumptive uses** are devoted to irrigation globally! (Foley, et al., 2009)

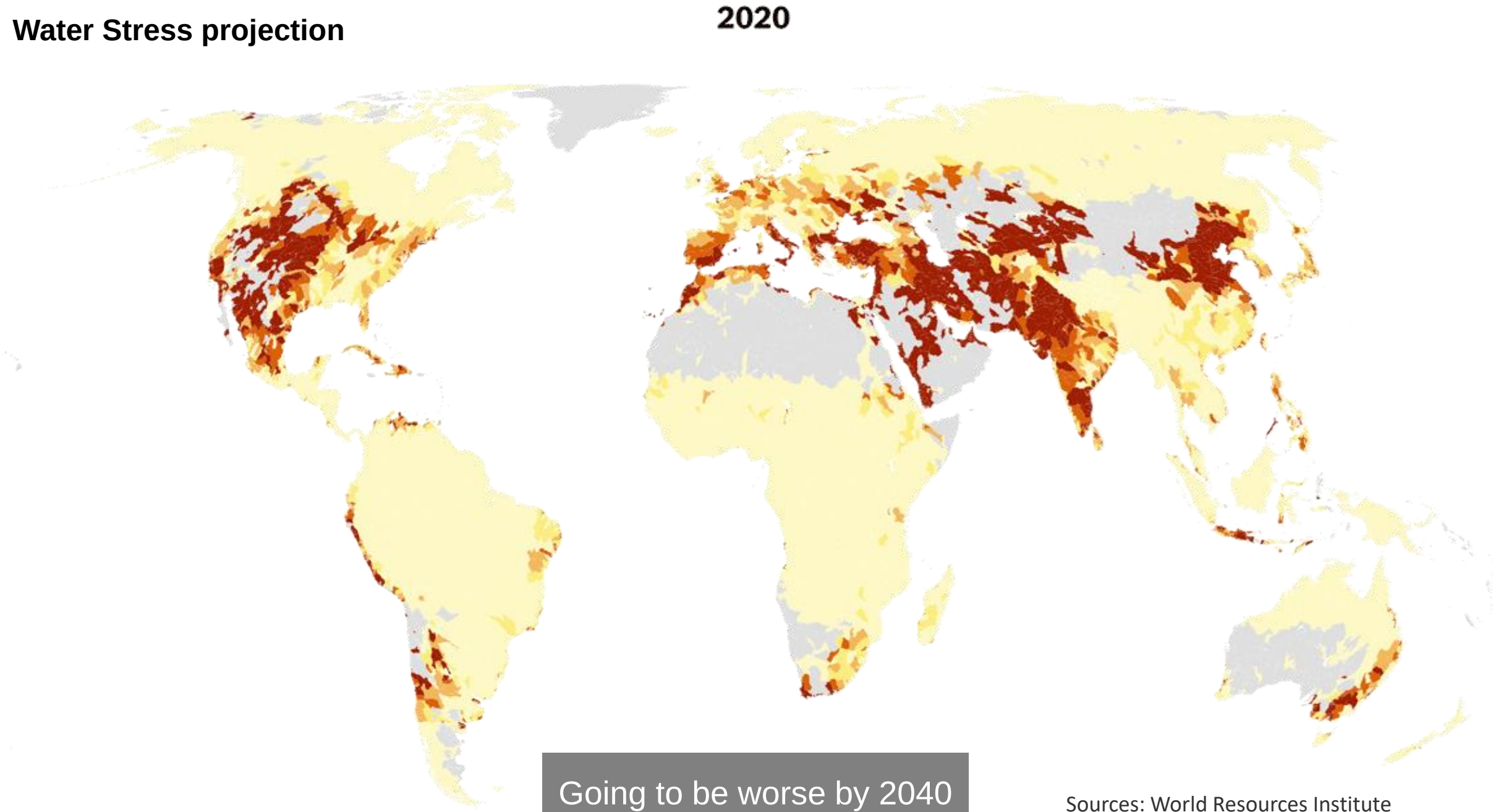
2 × food production ≅ 2 × freshwater withdrawal



Sources: World Resources Institute
AQUADUCT, Water Risk Atlas

We are Already under high-extreme water stress in many parts of the world

Water Stress projection



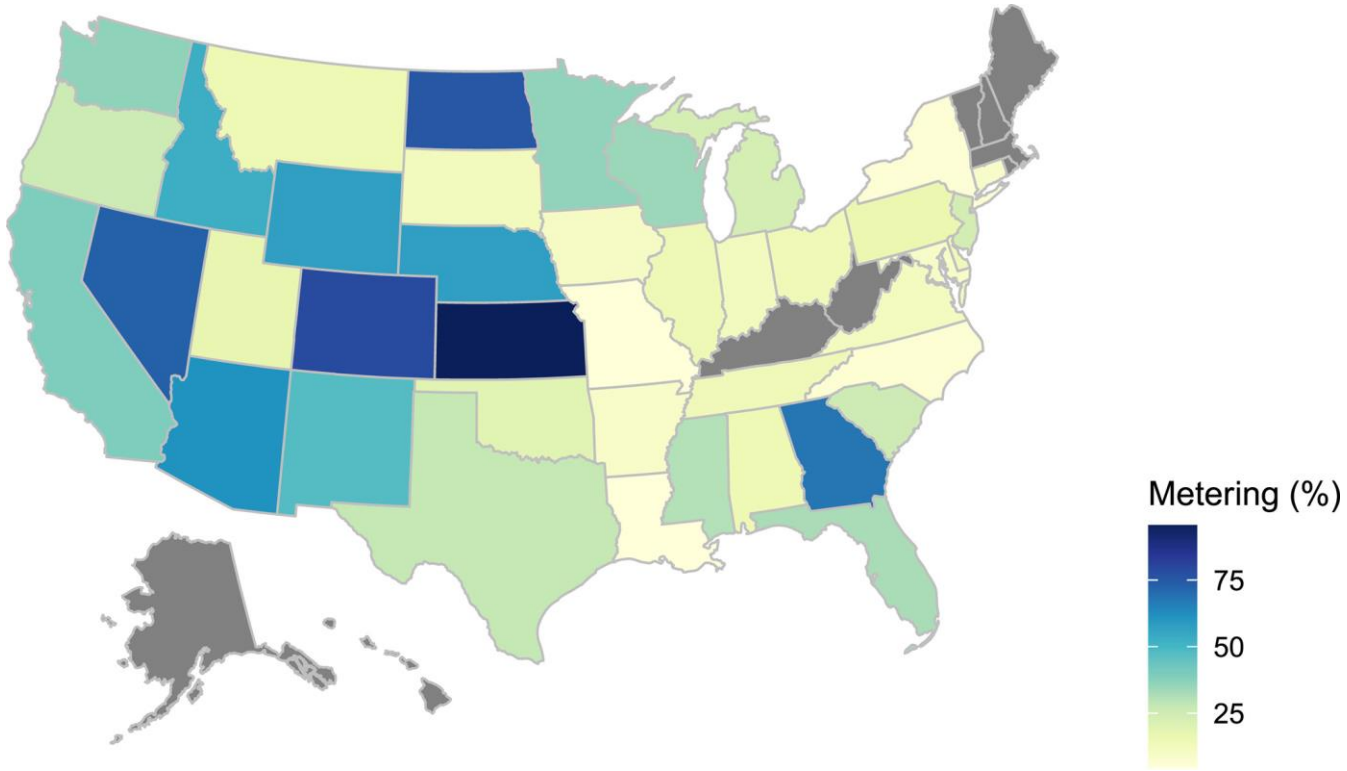
Going to be worse by 2040

Sources: World Resources Institute

Problem statement

- Water withdrawal needed to be limited by policymakers
- Enforcing any Agricultural Water Management Policy needs monitoring water withdrawal

Only **36%** of US well are equipped with a flowmeter



Percentage of groundwater irrigation wells with an attached flow metering device for each state in the United States (Foster, et al., 2020)

Problem statement

- Irrigation is poorly represented in land surface and hydrologic models (Why?)

Many information are needed for irrigation parametrization:

- Irrigation method
- Land use/cover
- Irrigation timing and frequency
- Crop phenology

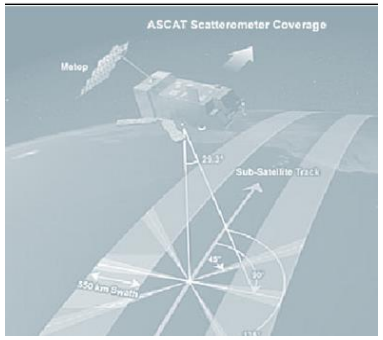
These information are usually not available!

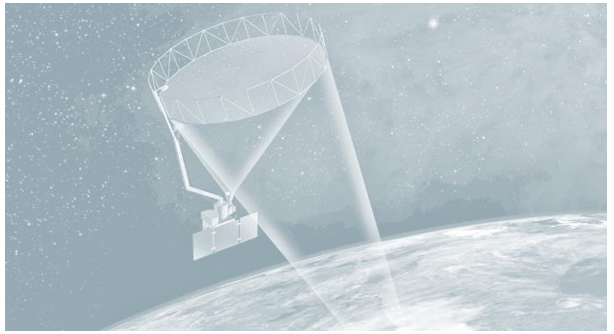
A simpler way to account for irrigation in the modeling …

Irrigation change the soil moisture → Use soil moisture as a proxy for the irrigation in the modeling

Soil Moisture remote sensing

Soil moisture can be detected through passive and active microwave remote sensing

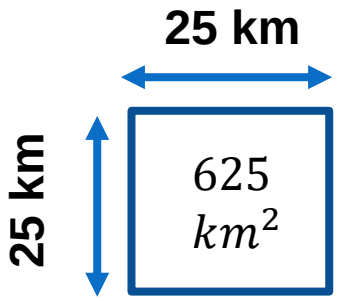




C-Band MW (6.9-10.65 GHz)

Observation frequency: 1-2 day

Pixel size: $\mathbf{25 \times 25 km^2}$

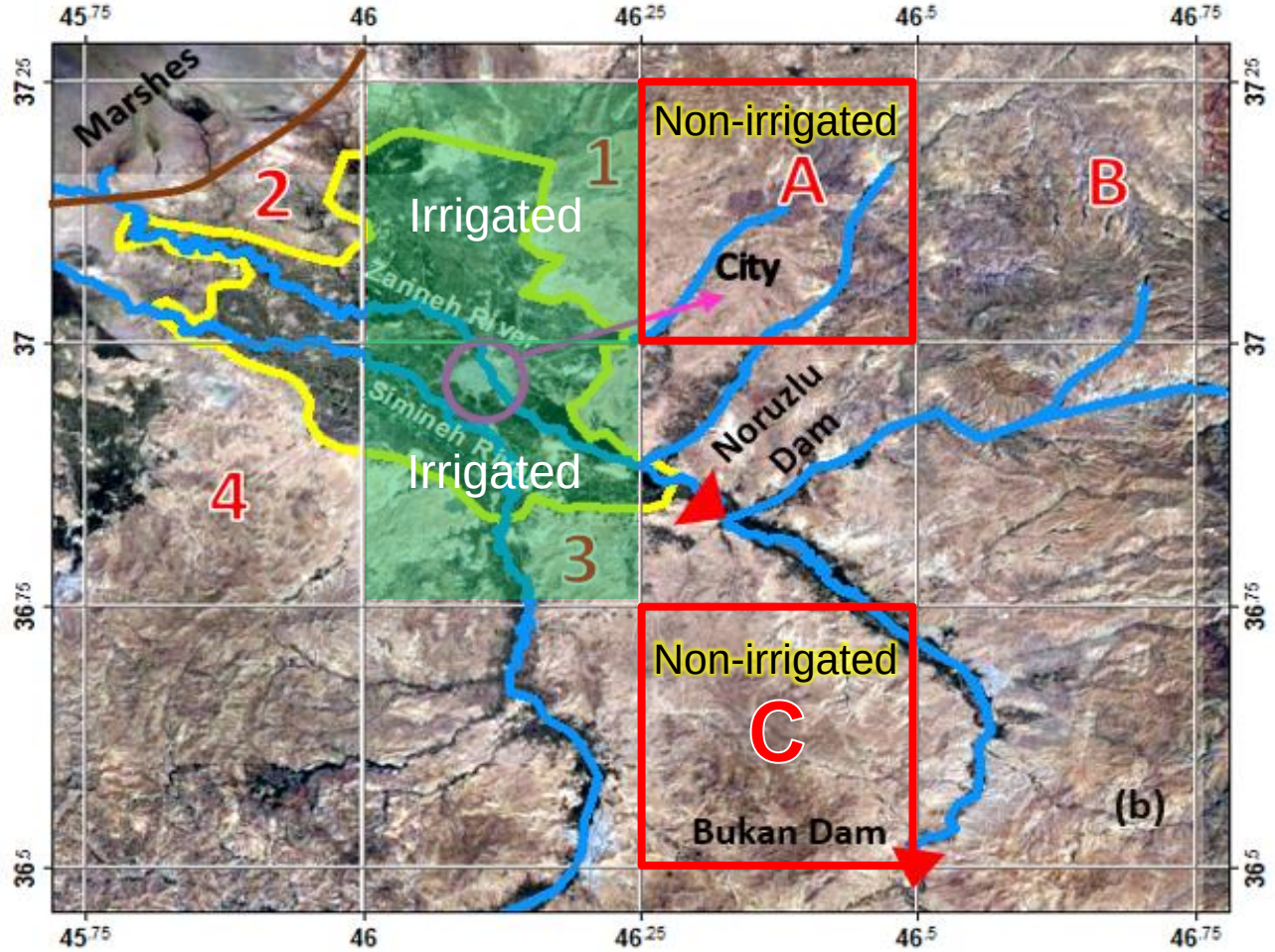


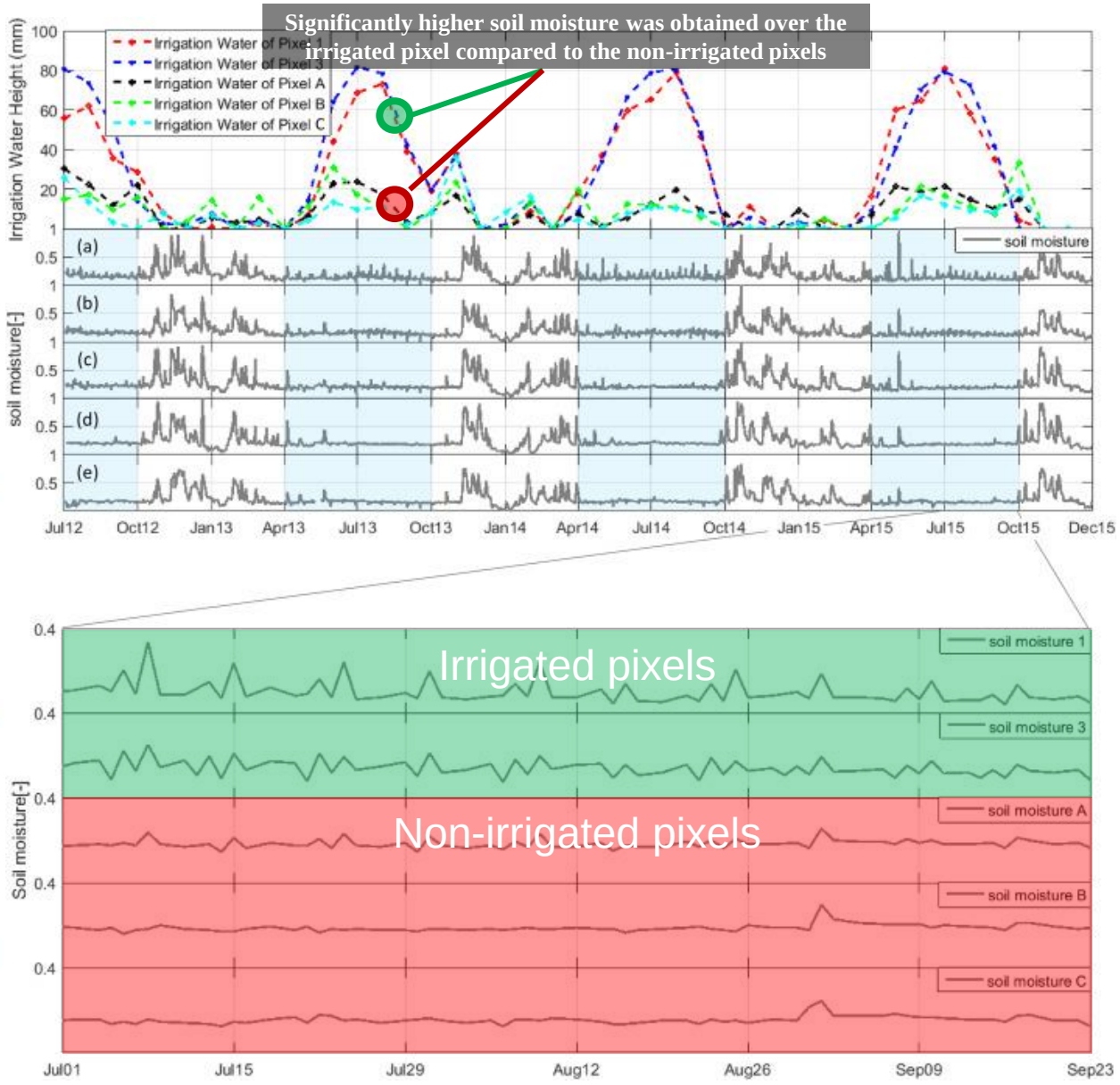
We used the changes in the AMSR2 25 km soil moisture data in an inverted water balance model (SM2RAIN) to quantify the irrigation water use

Remote Sensing of Environment
Volume 231, 15 September 2019, 111226

Quantification of irrigation water using remote sensing of soil moisture in a semi-arid region

Ehsan Jalilvand [a], Masoud Tajrishy [a], Sedigheh Alsadat Ghazi Zadeh Hashemi [a], Luca Brocca [b]





Higher soil moisture variation is observed over the irrigated pixels compare to the non-irrigated during the irrigation season

Remote Sensing of Environment
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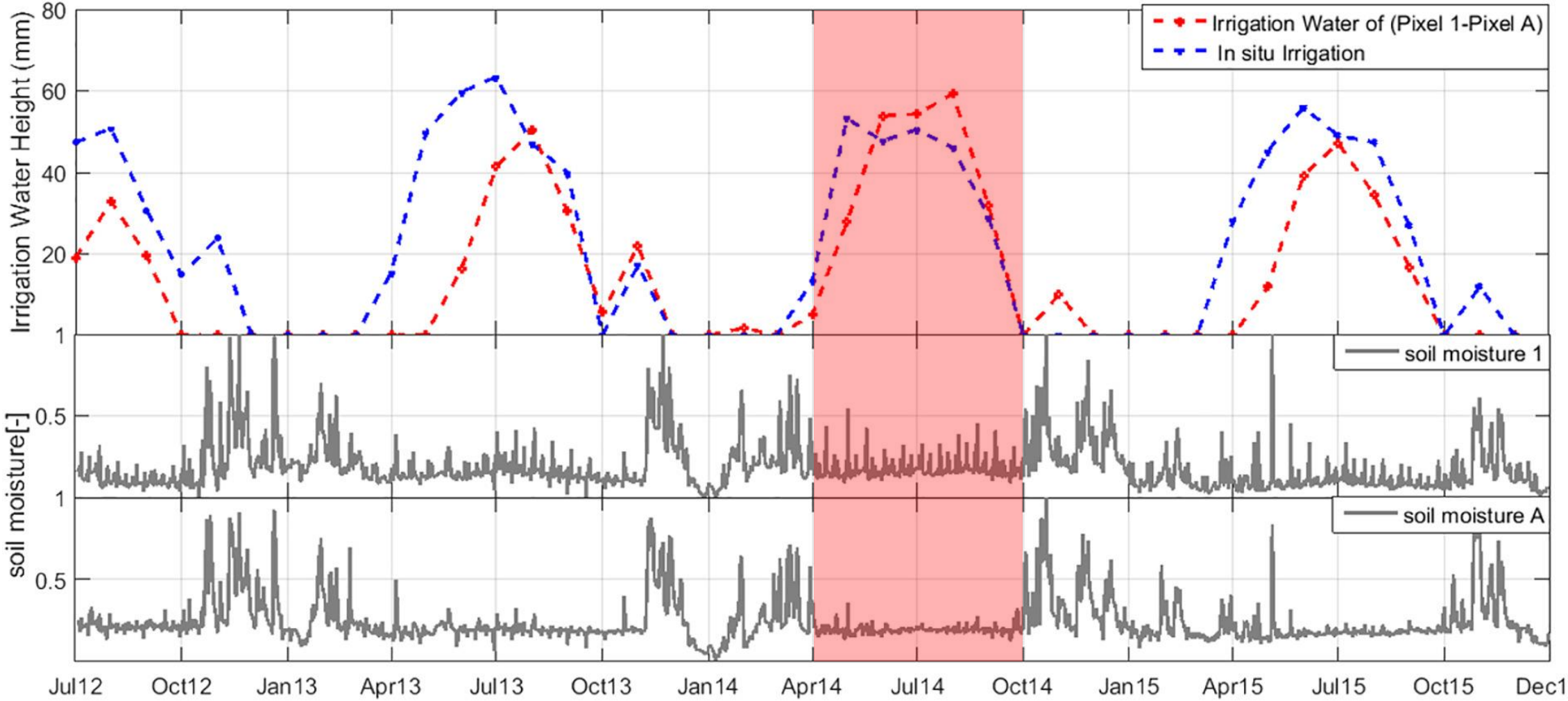
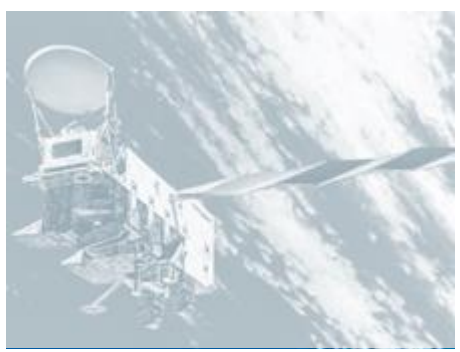
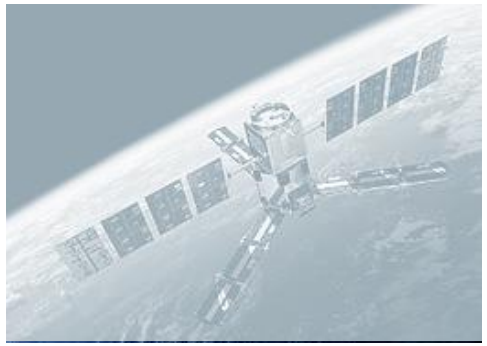
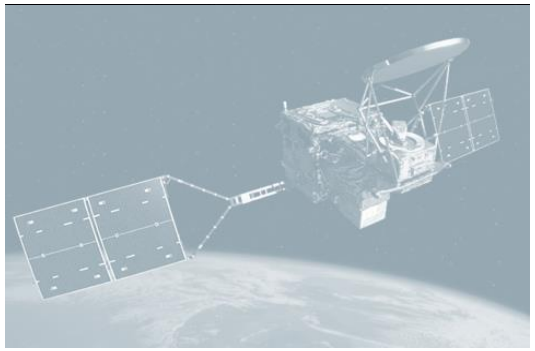
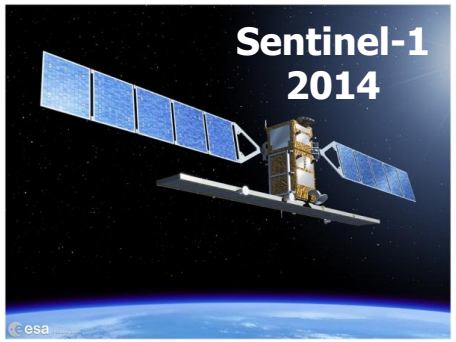


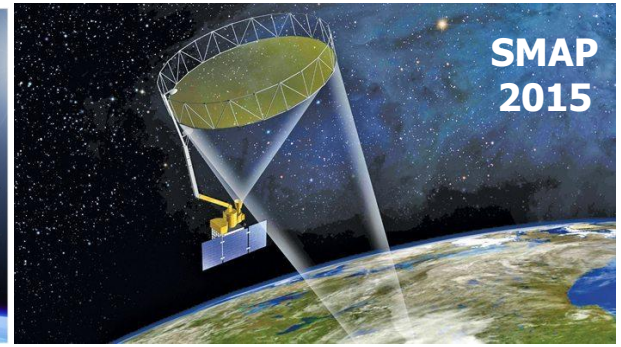
Spatial miss match between the plot scales and soil moisture observation

The water balance method is only applicable when:

1. The majority of the land in the pixel are irrigated
2. cropping and land management is homogenous

Trying a higher resolution product…



Passive: Spatial resolution: >25 km Much larger than an agricultural field!

Active: Spatial resolution: <1km Noisy retrieval!/lower temporal resolution

Passive + **Active** → **Higher Spatial resolution/ Less noise!**

SMAP-Sentinel1

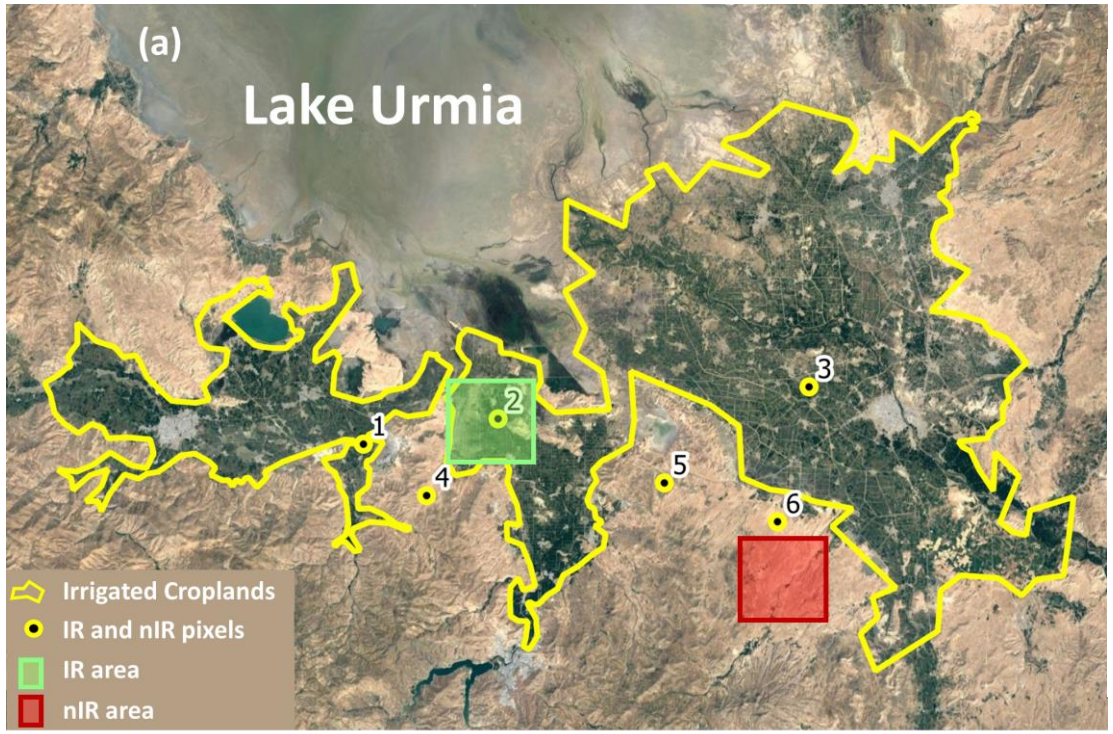
But, does SMAP Sentinel 1 Soil moisture data contain the irrigation signal?

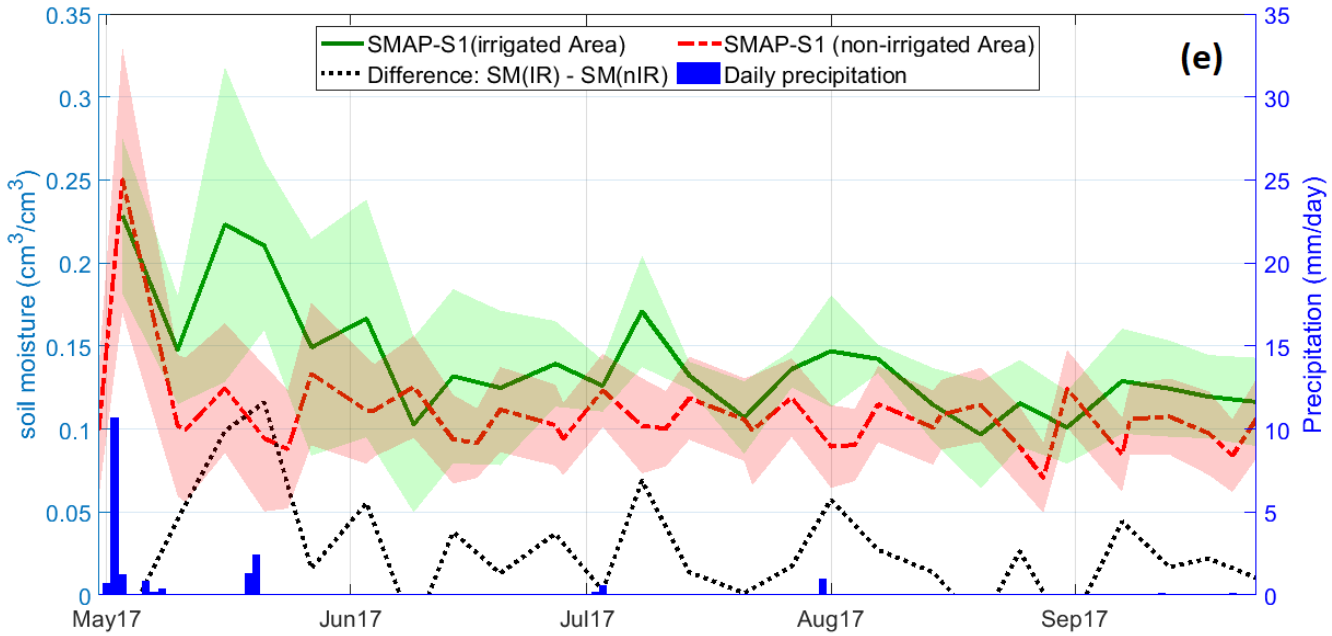
Detecting IR

Does SMAP-S1 soil moisture data contain irrigation signal over agricultural domain?

Irrigation signal is observed in the 1st moment (mean) of SMAP-S1 soil moisture timeseries

Higher soil moisture value and spatial variability is observed over an **Irrigated region (green box)** relative to a **Non-irrigated region (red box)** during the irrigation season of 2017



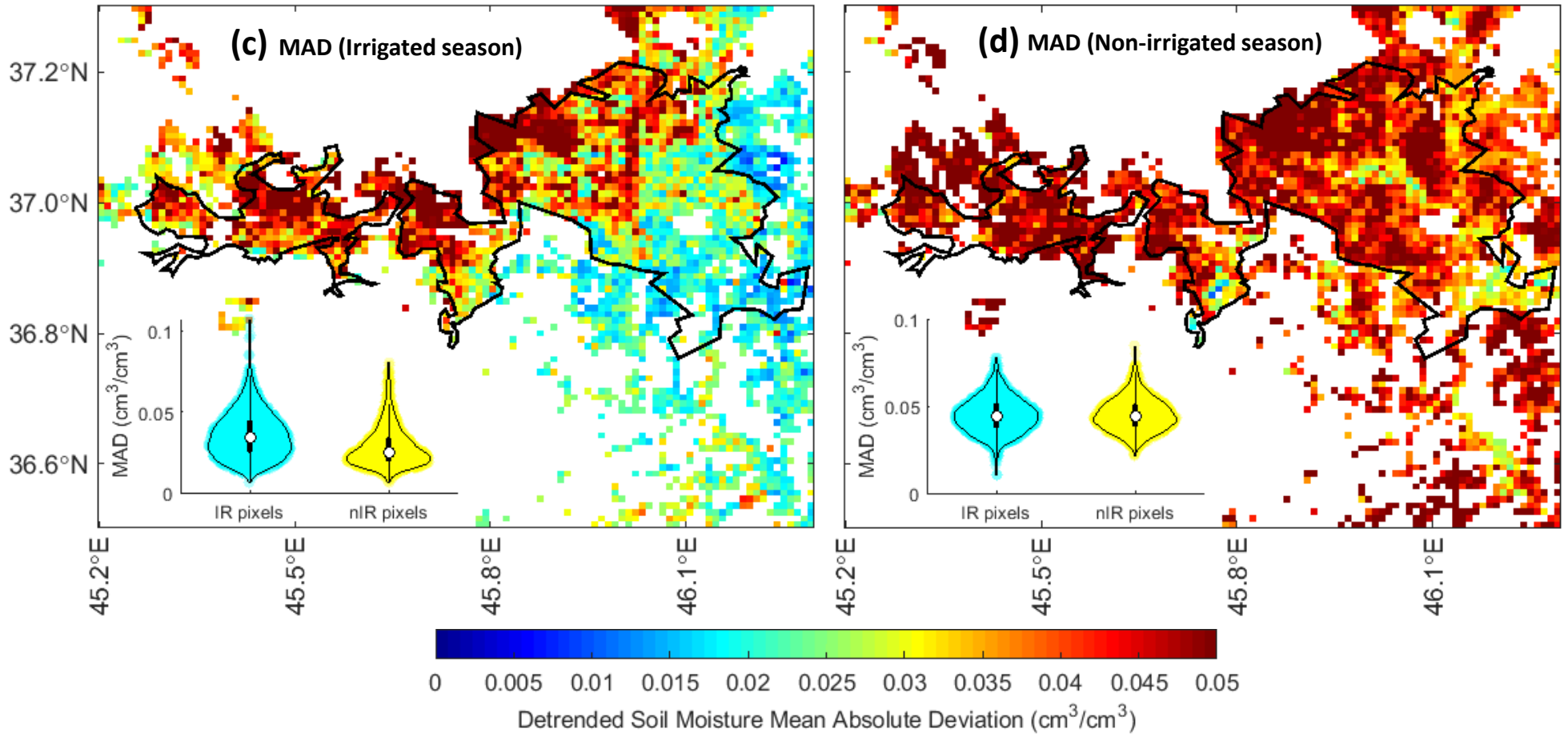


E. Jalilvand, R. Abolafia-Rosenzweig, M. Tajrishy and N. N. Das, "**Evaluation of SMAP/Sentinel 1 High-Resolution Soil Moisture Data to Detect Irrigation Over Agricultural Domain**," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 14, pp. 10733-10747, 2021, doi: 10.1109/JSTARS.2021.3119228.

Detecting IR

Does SMAP-S1 soil moisture data contain irrigation signal over agricultural domain?

Irrigation signal is observed in the 2nd moment (variability) of SMAP-S1 soil moisture timeseries

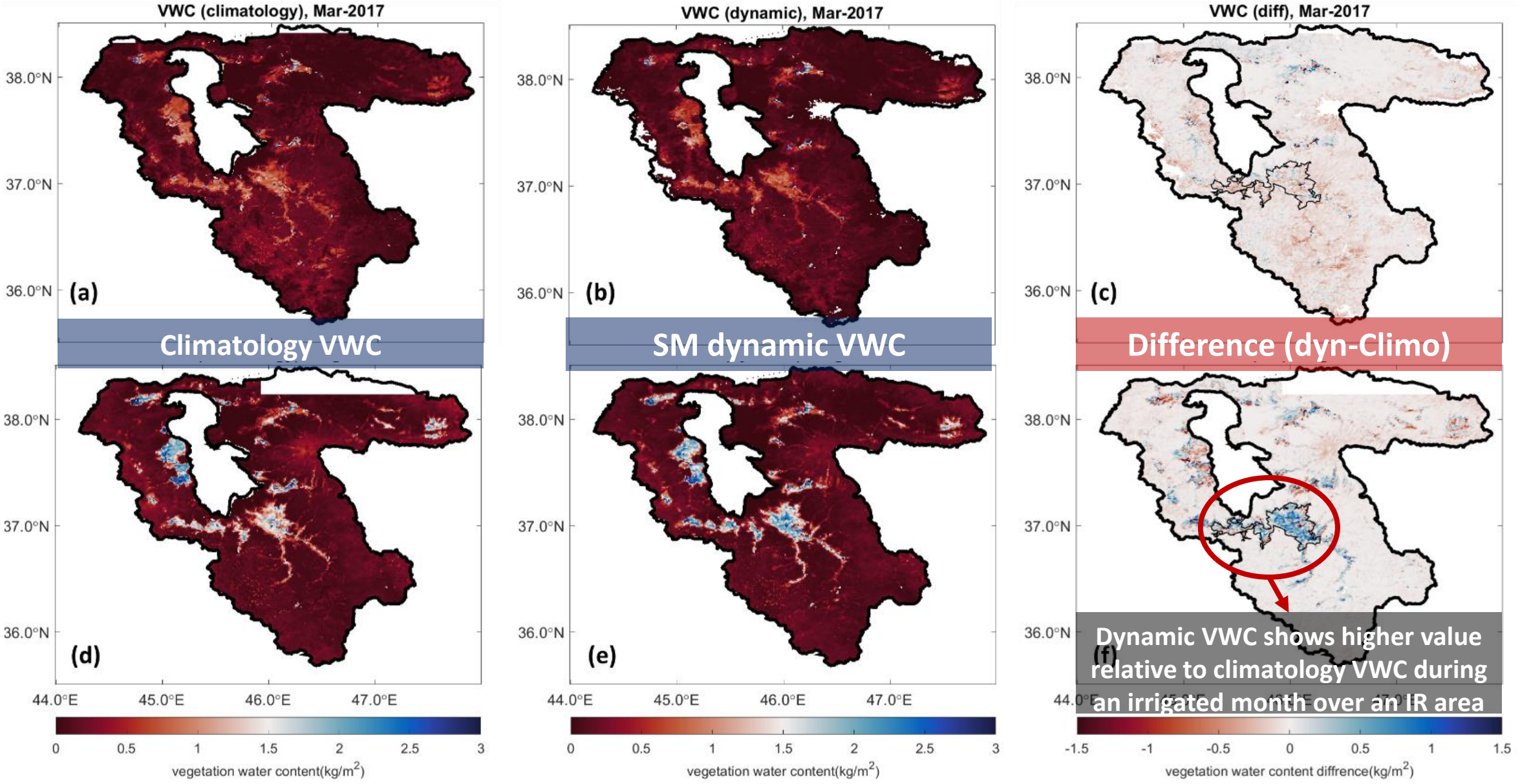


Detecting IR

Enhancing SMAP-S1 irrigation signal during the irrigation season by using dynamic VWC

Non-irrigated month
March 2017

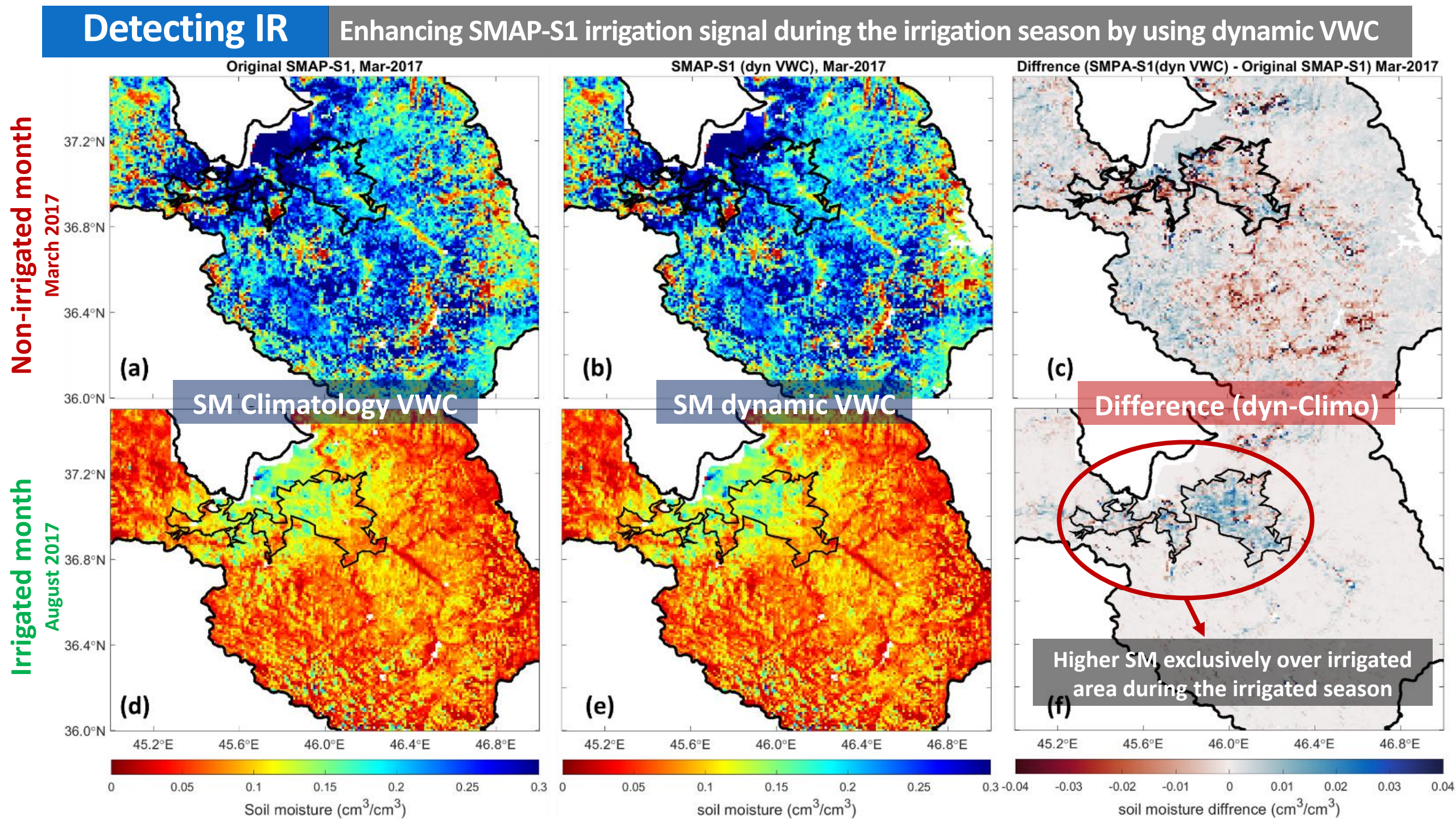
Irrigated month
August 2017



Dynamic and climatology VWC difference during and irrigated (August 2017) and a non-irrigated (March 2017) month

Detecting IR

Enhancing SMAP-S1 irrigation signal during the irrigation season by using dynamic VWC



Two problems

1. Does SM contain irrigation signal?

2. The temporal resolution is 6-12 days, and we might miss an irrigation event, how should we deal with that?

- The soil moisture data can be assimilated with a land surface model …
- Particle Batch Smoother Data assimilation method allows quantification of irrigation water use by assimilation of sparse observations (even every 10 days) in a batch (Abolafia, et al., 2019)

Abolafia-Rosenzweig, R., Livneh, B., Small, E.E. and Kumar, S.V., 2019. Soil moisture data assimilation to estimate irrigation water use. *Journal of advances in modeling earth systems*, *11*(11), pp.3670-3690.

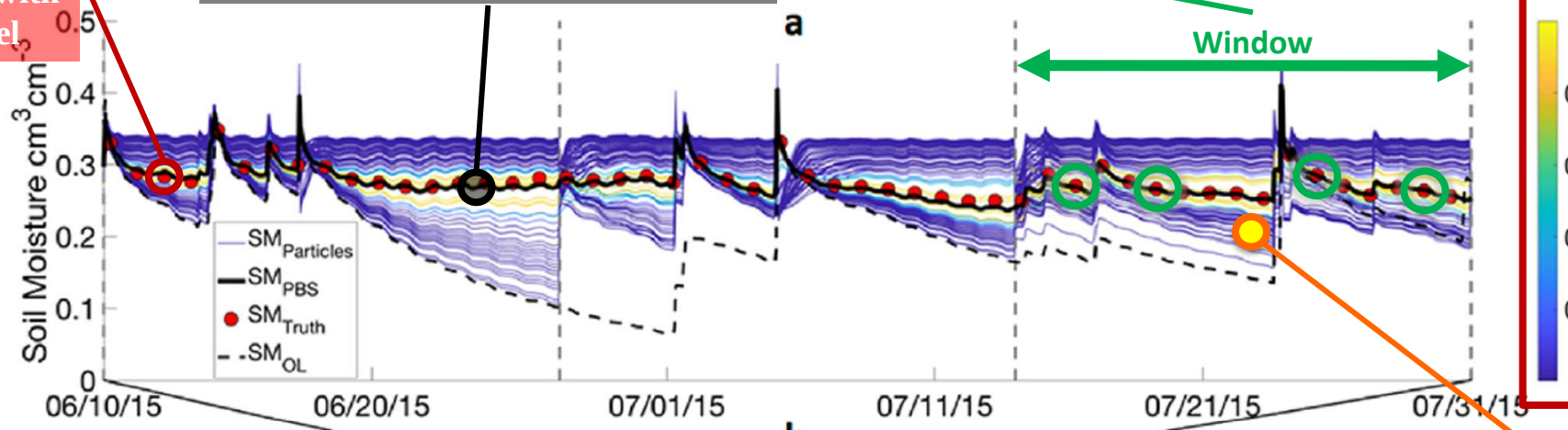
Quantifying IR | Using Particle Batch Smoother (PBS) to quantify the irrigation water use

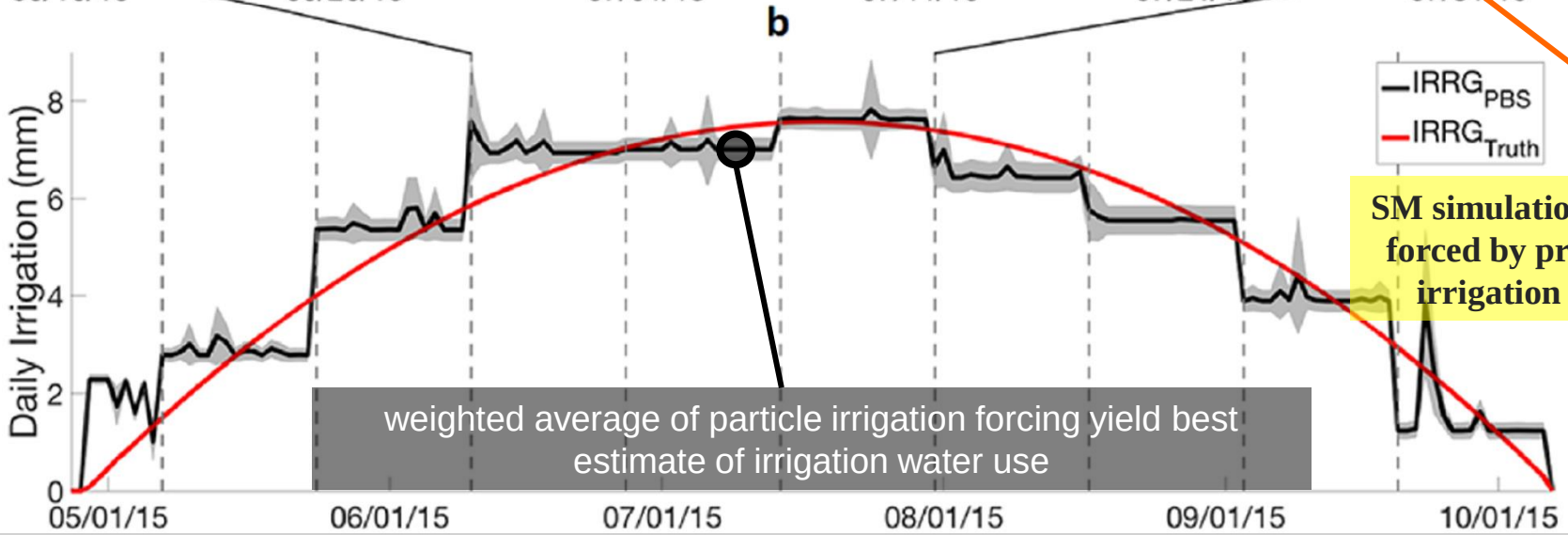
SMAP-S1 1km observations that are assimilated with the VIC model

Weighted average of all particles

SMAP observations are assimilated in a batch in each window

Particles are weighted based on their distance to SMAP observation in each smoothing window





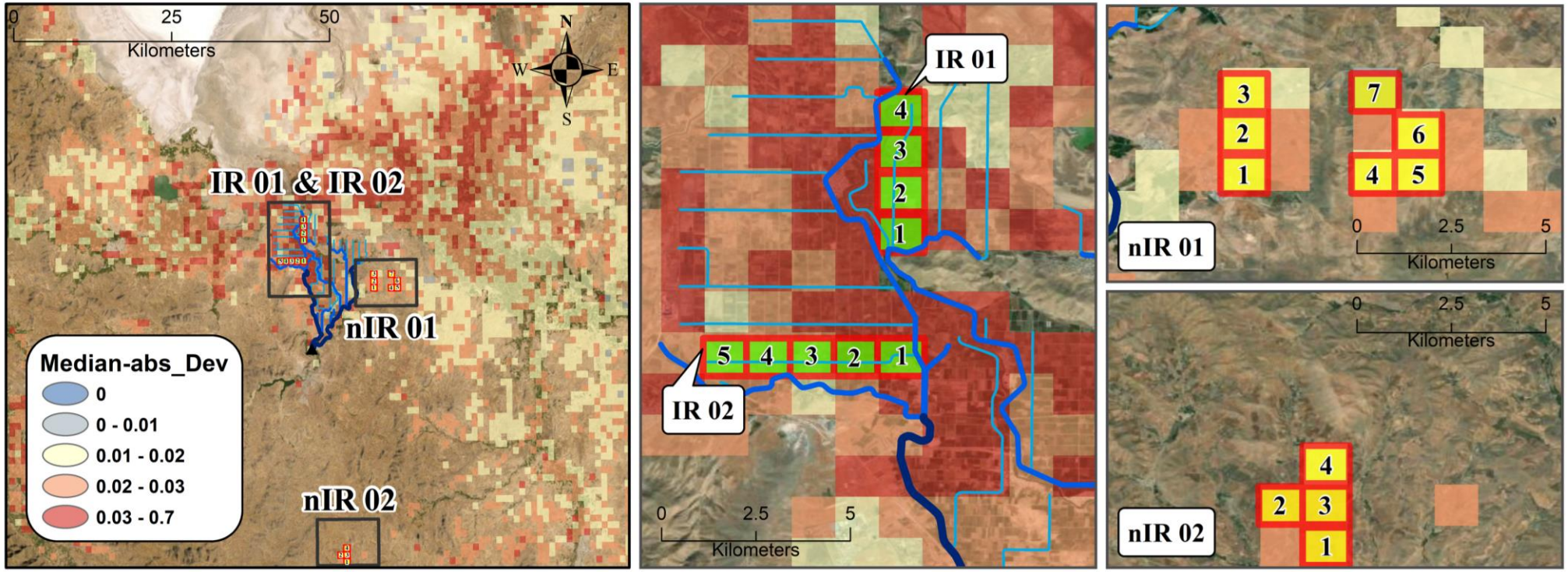
SM simulations with the VIC model (particles) forced by precipitation + random prescribed irrigation as a supplement to the rainfall

weighted average of particle irrigation forcing yield best estimate of irrigation water use

Abolafia-Rosenzweig, R., Livneh, B., Small, E.E. and Kumar, S.V., 2019. Soil moisture data assimilation to estimate irrigation water use. *Journal of advances in modeling earth systems*, *11*(11), pp.3670-3690.

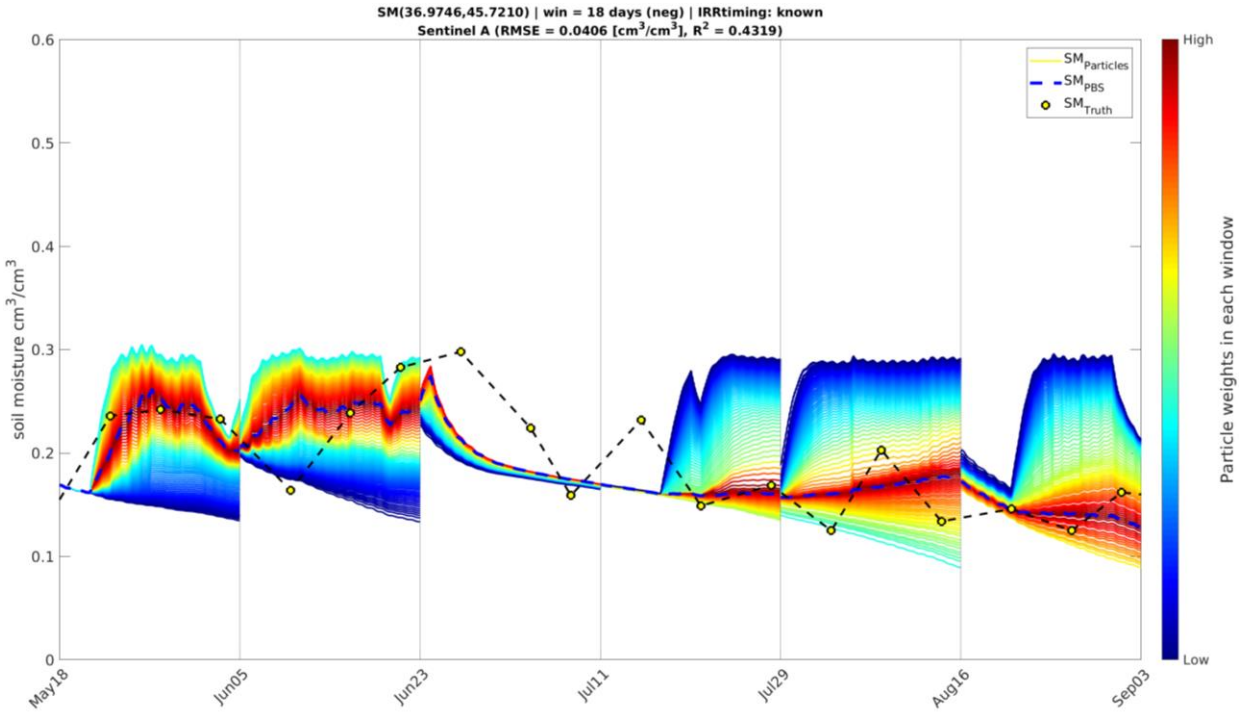
Real World Experiment

Irrigated and non-irrigated pixels location

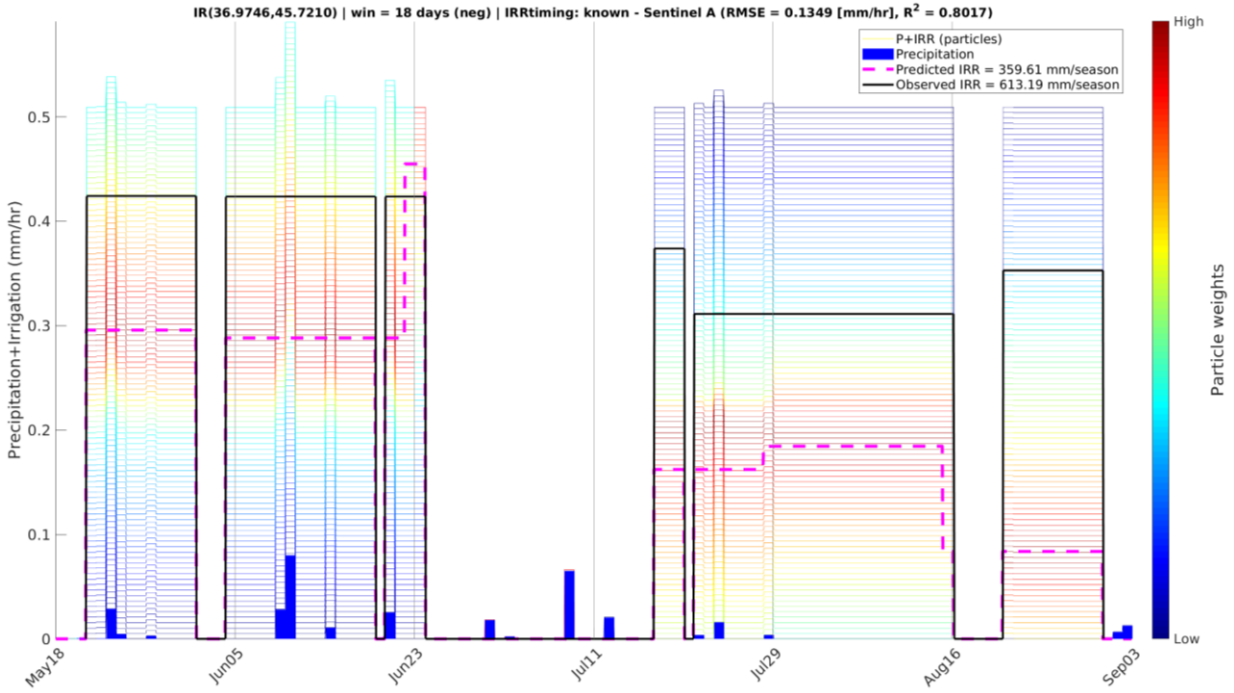


Real World Experiment | **Irrigated pixels** | **Known irrigation timing**

Soil moisture simulation

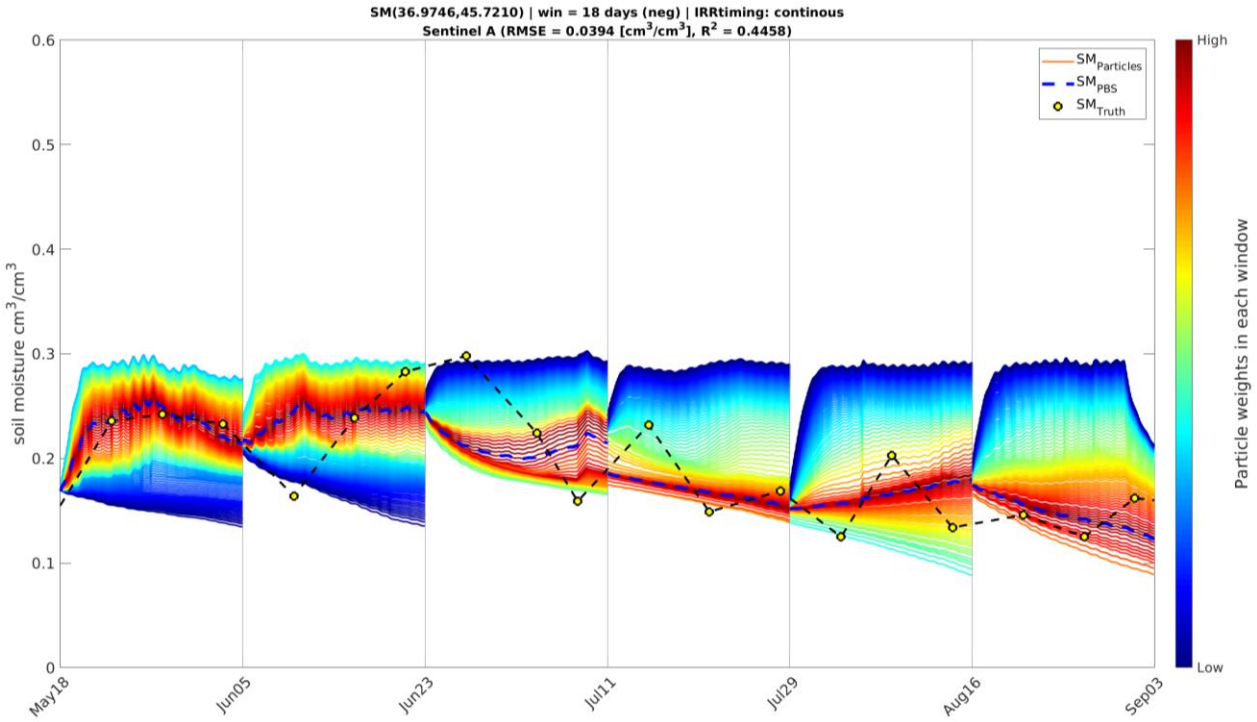


Irrigation simulation

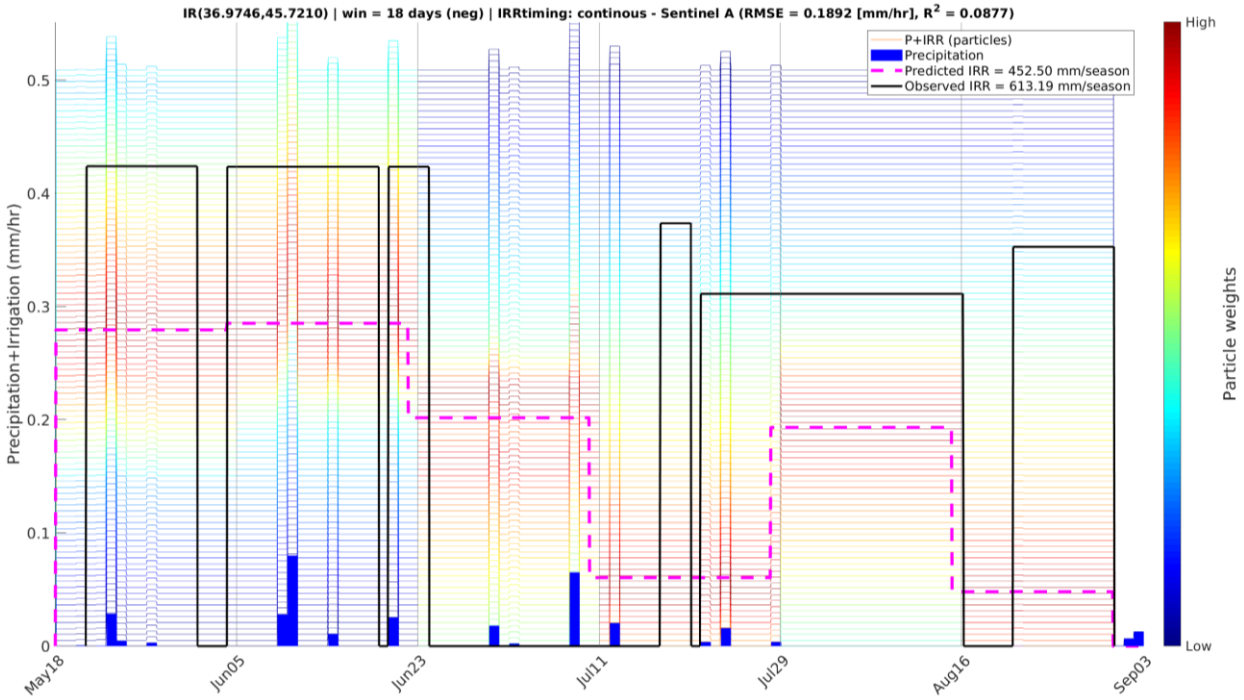


Real World Experiment | **Irrigated pixels** | **Unknown irrigation timing**

Soil moisture simulation

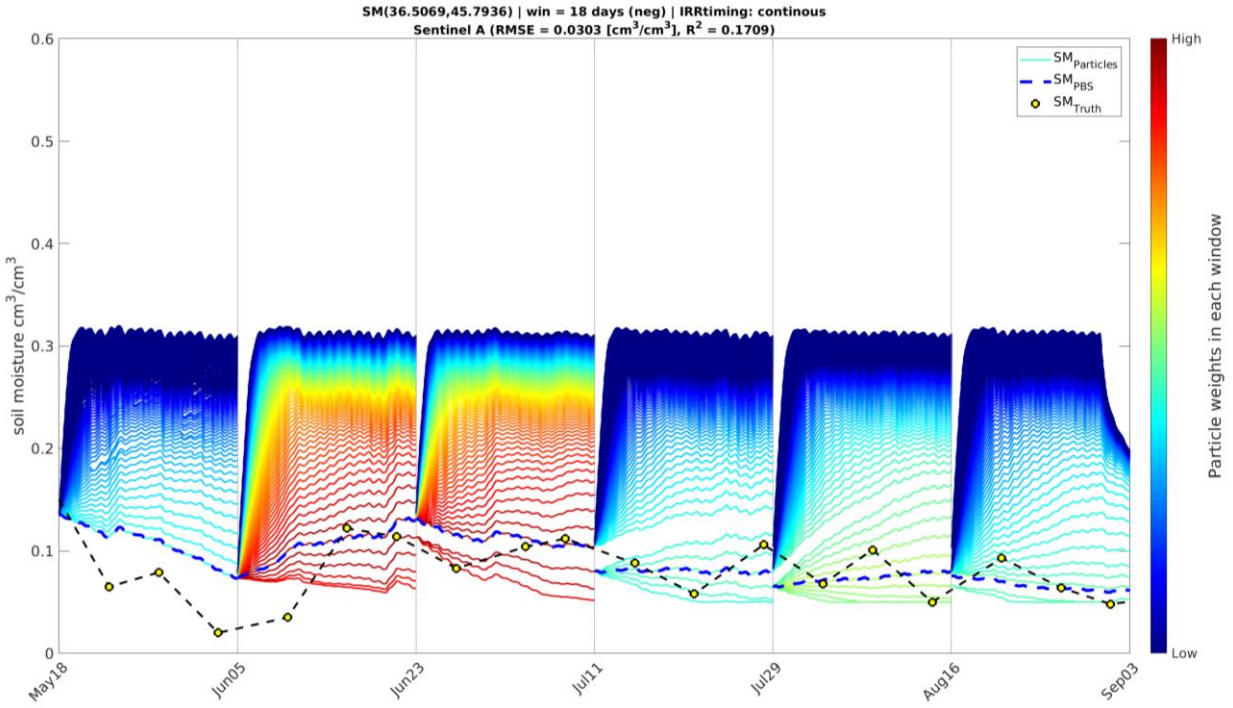


Irrigation simulation

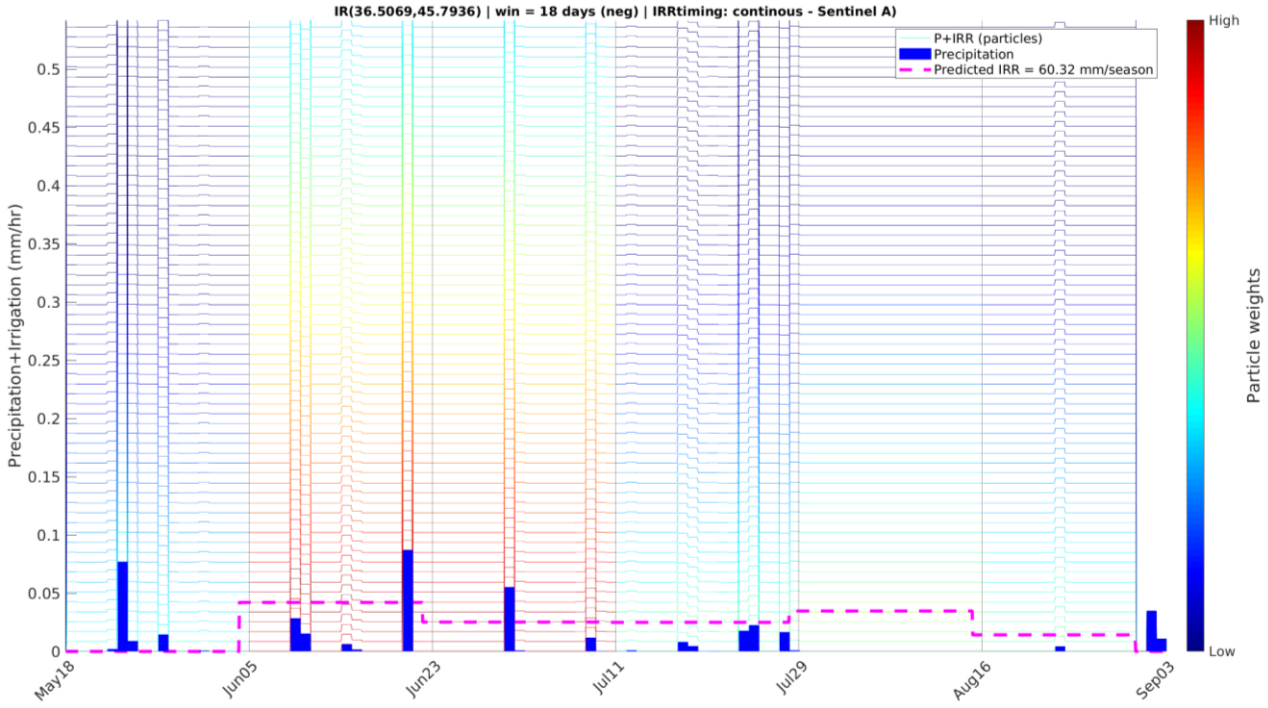


Real World Experiment | **Non-Irrigated pixels** | **Unknown irrigation timing**

Soil moisture simulation



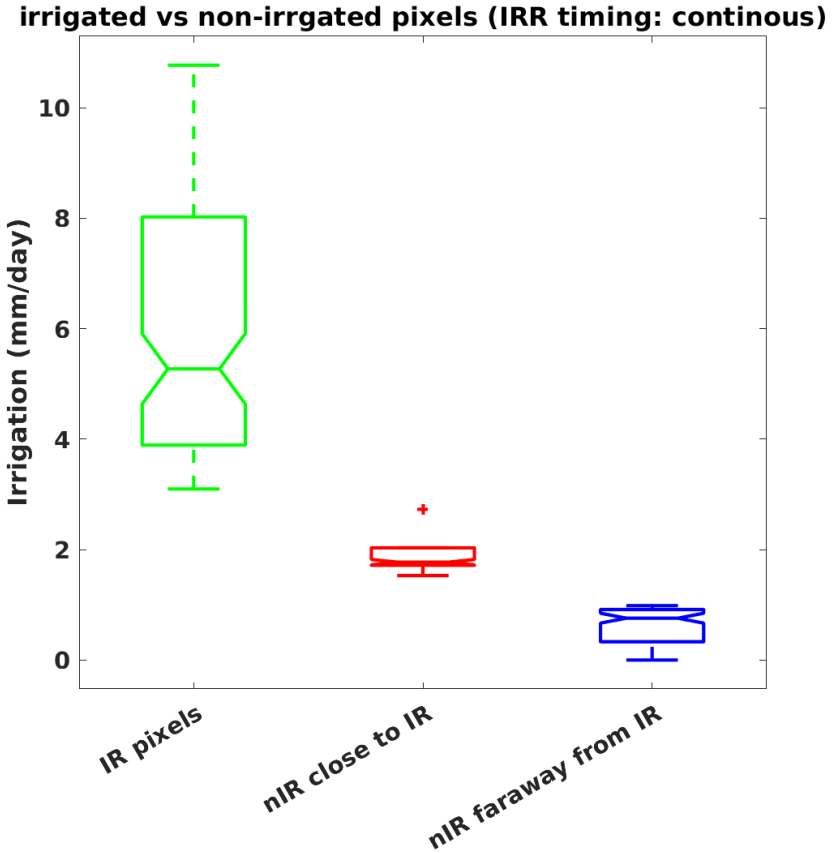
Irrigation simulation

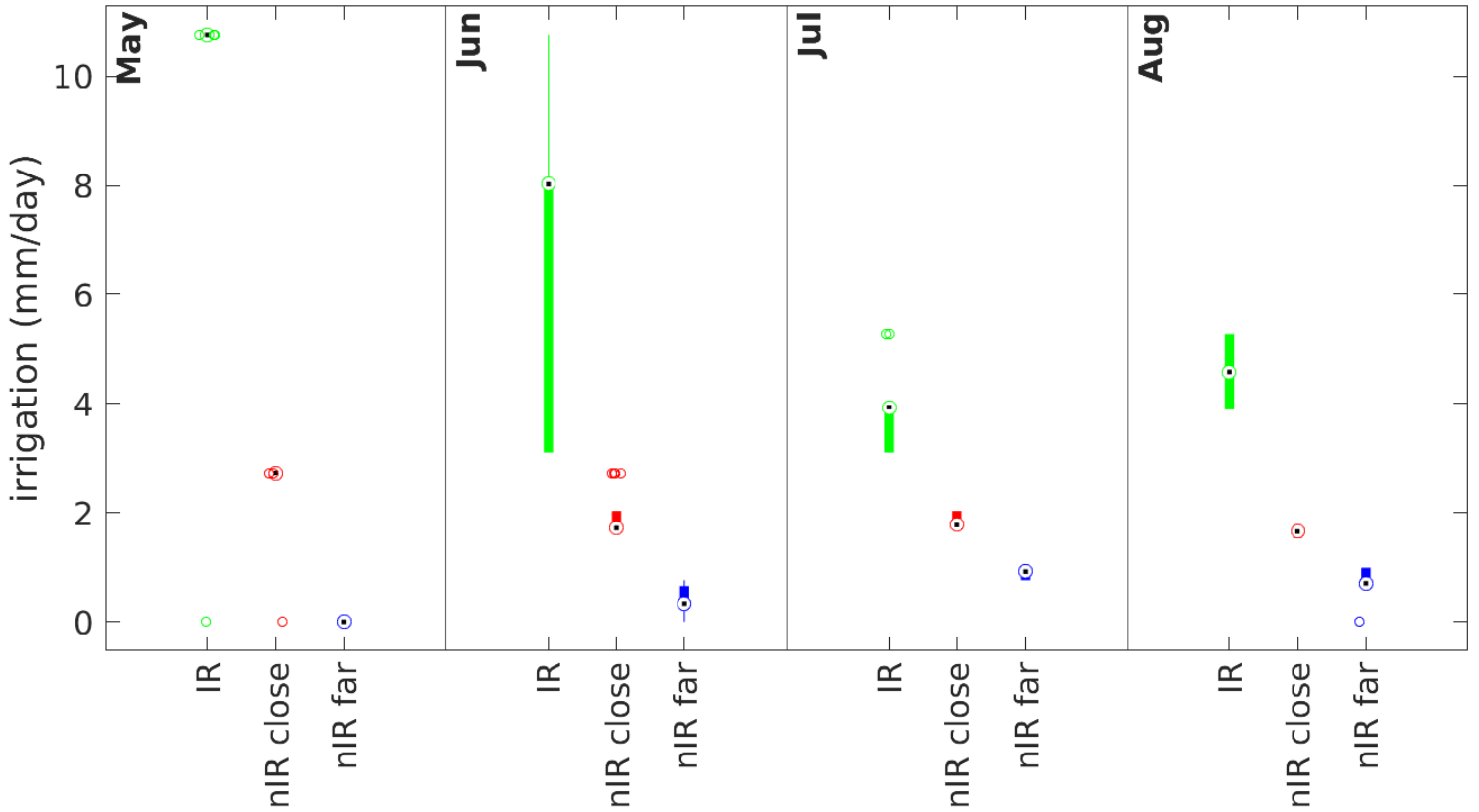


Real World Experiment

Non-Irrigated pixels

Irrigated pixels





Conclusion and Take home messages

1. SMAP-S1 1km soil moisture data contain irrigation signal (study #1)
2. PBS data assimilation approach is capable of quantifying the irrigation water use (synthetic experiment)
3. Assimilation of SMAP-S1 soil moisture data with VIC LSM using the PBS approach yield significantly higher irrigation amount over irrigated pixels as compared to the non-irrigated pixels
4. There is ~30% underestimation in the irrigation estimated over the irrigated pixels that can be explained by:
    1. Sparse retrieval of SMAP-S1 1km data (6-12 days)
    2. The coarse spatial resolution of SMAP-S1 relative to plot scale agriculture
    3. Part of the irrigation signal appears to be lost in the SMAP-S1 soil moisture retrieval

Conclusion and Take-home messages

5. The upcoming NASA and ISRO radar mission (NISAR) with 200 m resolution soil moisture data every 6 days can significantly improve the model simulation compared to SMAP-S1 (1km, 6-12 days)