Modeling soil moisture with closure phase bias

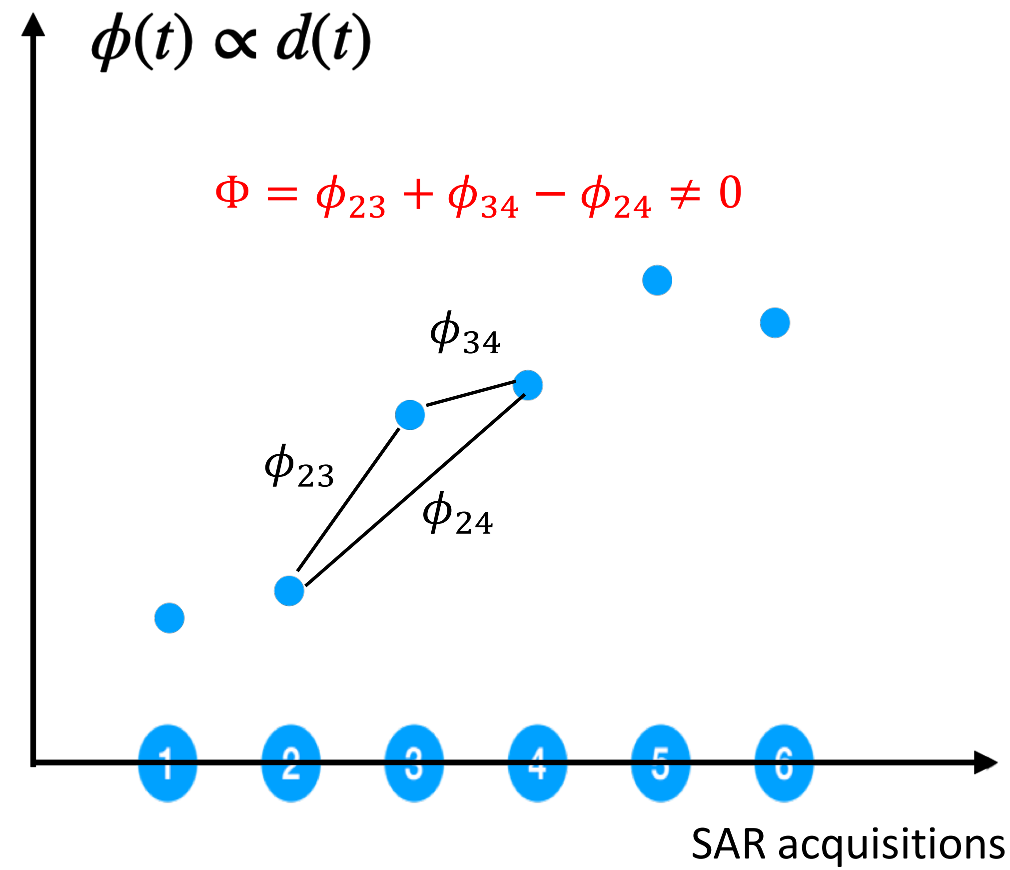
Yujie Zheng[1,2] and Heresh Fattahi[3]

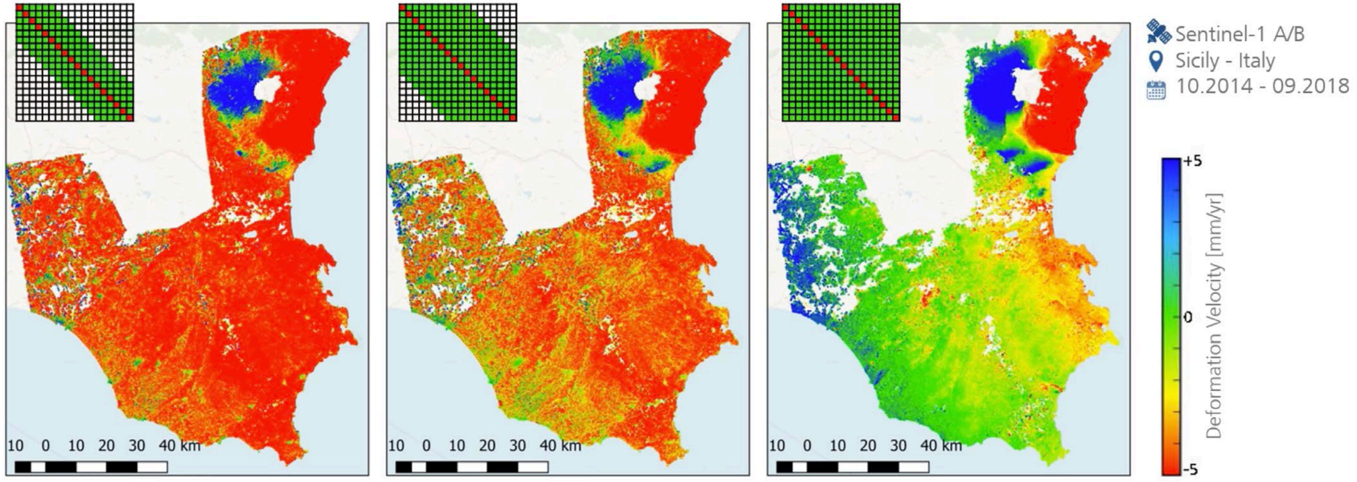
(1) California Institute of Technology, USA
(2) University of Texas at Dallas, USA
(3) Jet Propulsion Laboratory, California Institute of Technology, USA

FRINGE 2023

University of Leeds, UK | 11 - 15 September 2023.

Non-zero closure phase ⇄ Short Temporal Bias in time-series





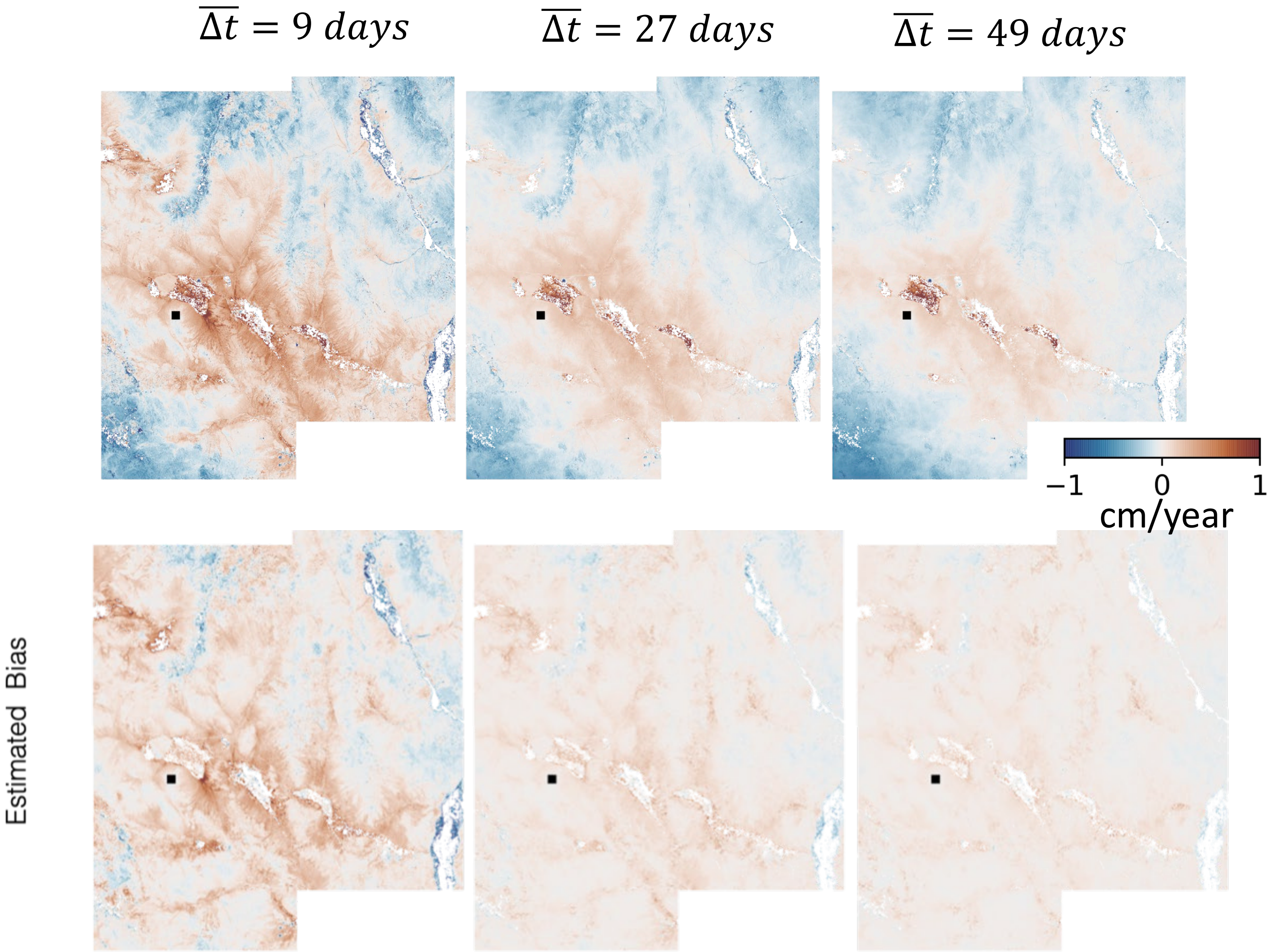
Ansari et.al. (2020)

Both phenomena are indicators of processes that induce complex changes of the interferometric measurements. (Zheng et al., 2022)

Bias correction methods :

Falabella and Pepe, 2022; Maghsoudi et al., 2022; Zheng et al., 2022

Bias Correction with Sequential Closure Phase



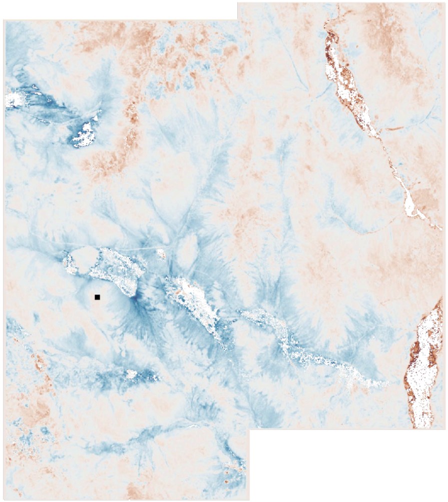
Sentinel-1A/B

Barstow-Bristol Trough, CA, United States

Feb 2017 - Jan 2021

SBAS, MintPy

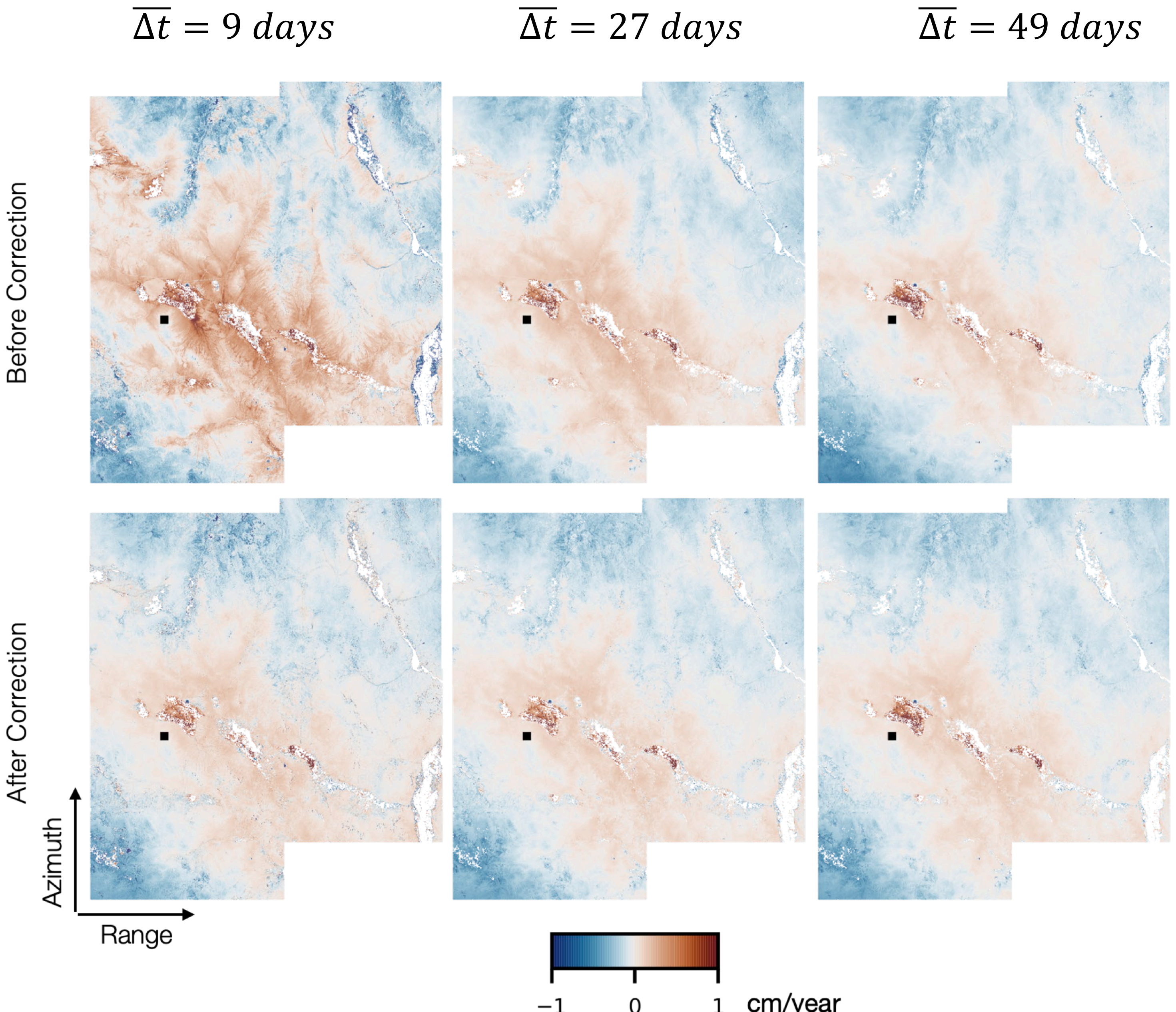
Cumulative Sequential Closure Phase



Zheng et al., 2022

Correction code available in MintPy

Bias Correction with Sequential Closure Phase



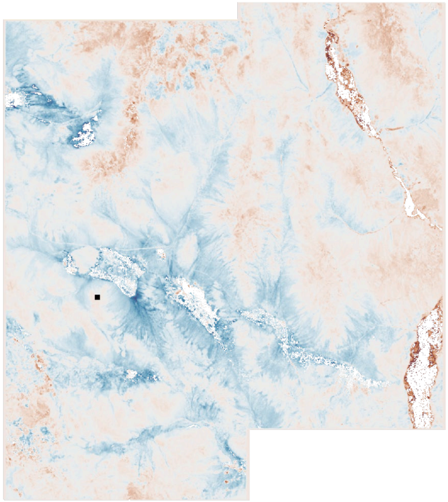
Sentinel-1A/B

Barstow-Bristol Trough, CA, United States

Feb 2017 - Jan 2021

SBAS, MintPy

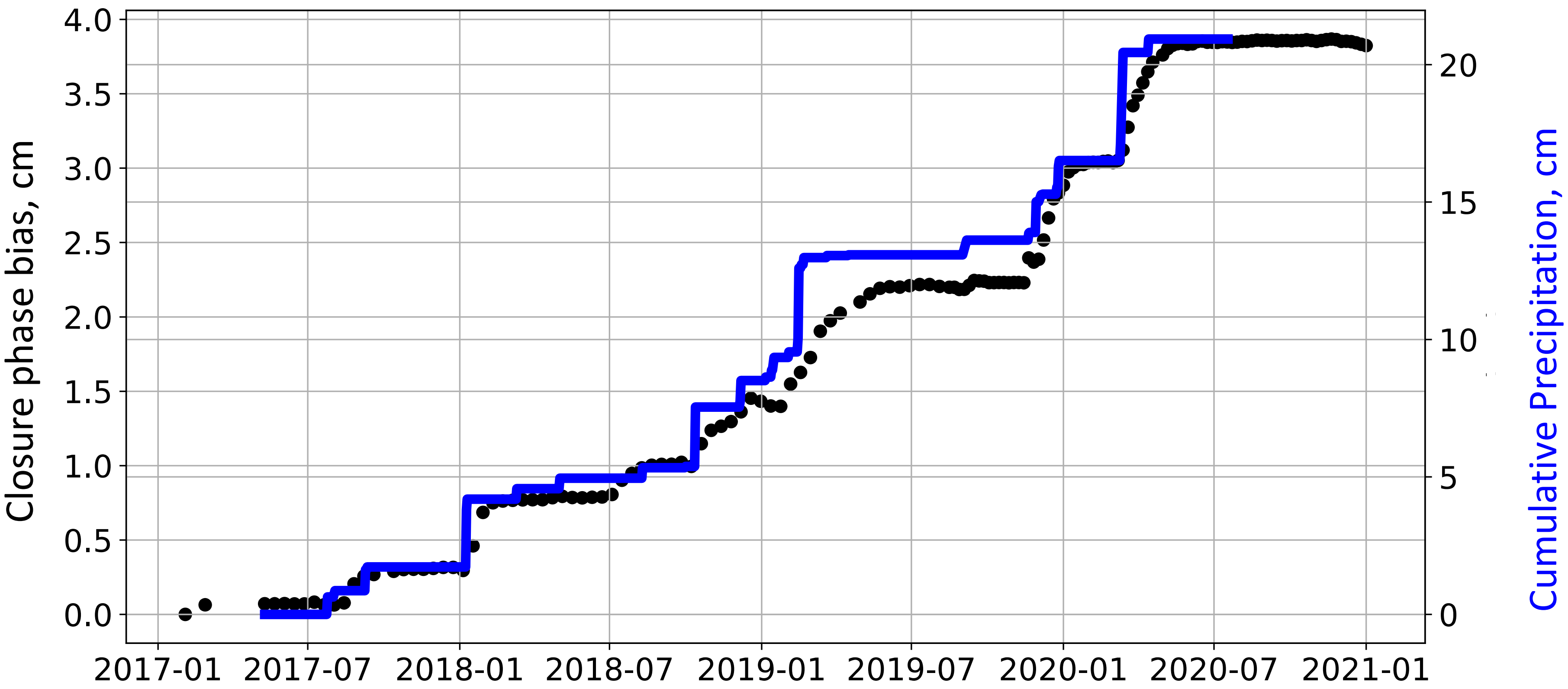
Cumulative Sequential Closure Phase

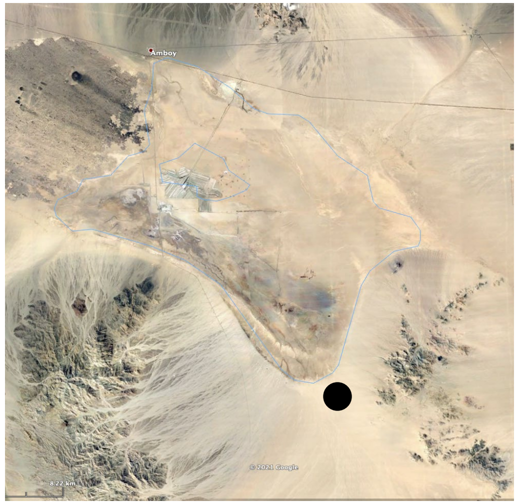


Zheng et al., 2022

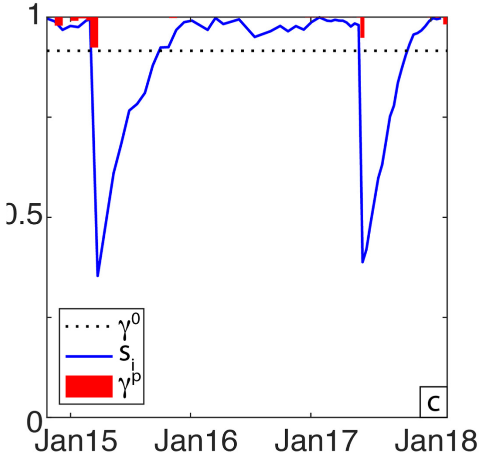
Correction code available in MintPy

Closure Phase Bias as SIGNAL





Bristol Dry lake, CA



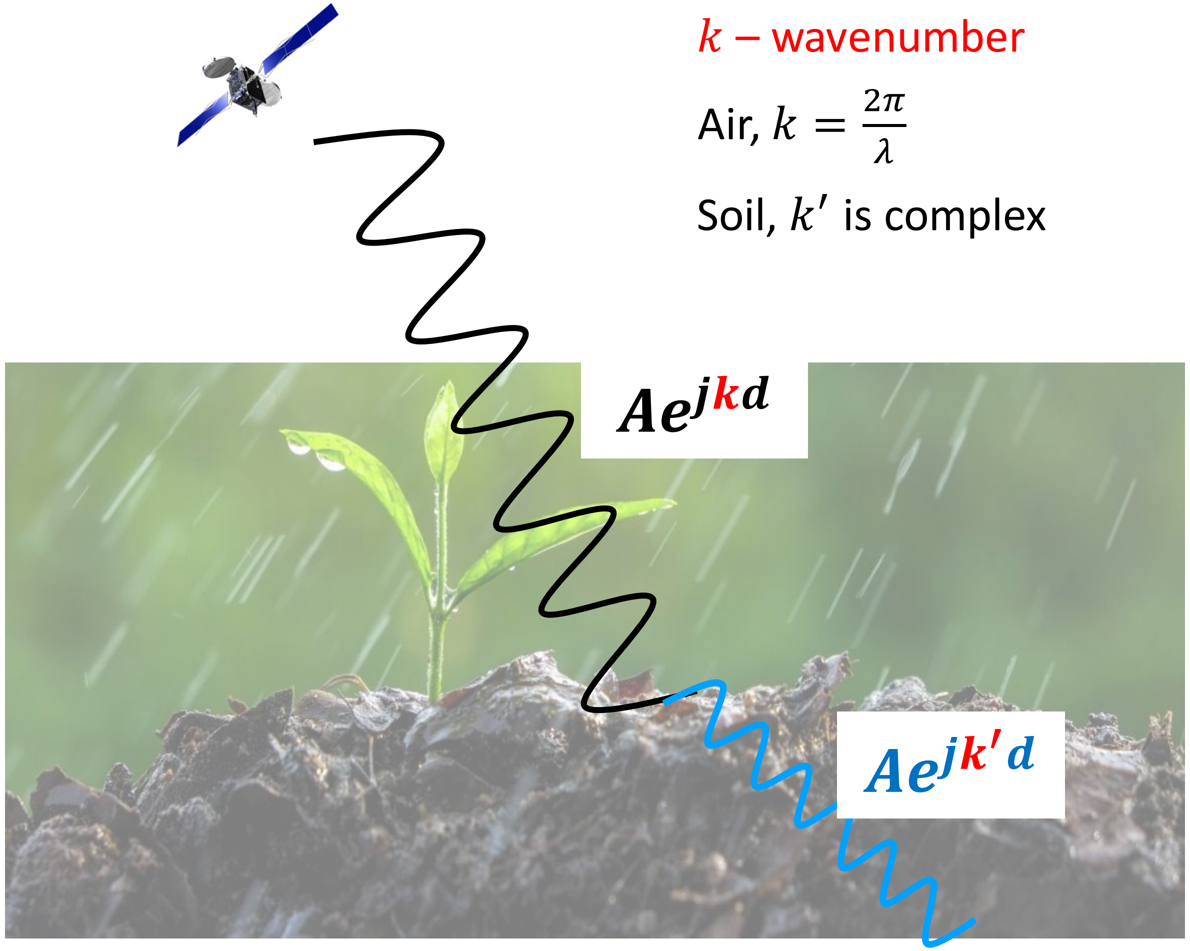
Jordan et al., (2020

A discrete interferometric model for soil moisture

k – wavenumber

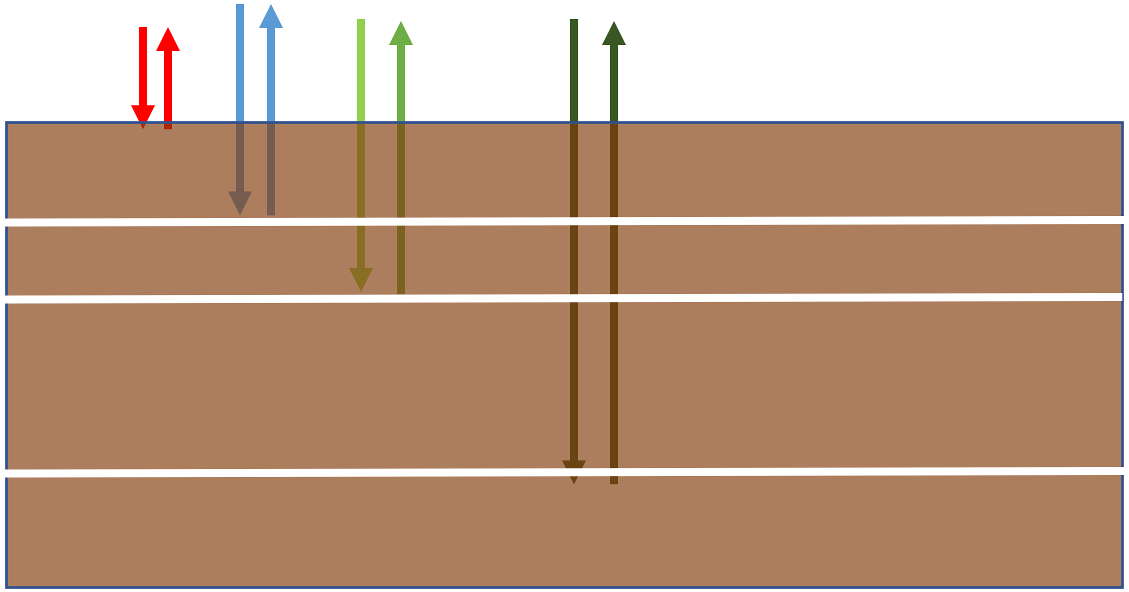
Air, $k = \frac{2\pi}{\lambda}$

Soil, k' is complex



Analytical model for soil moisture
e.g., De Zan et al., 2014; Michaelides, 2020

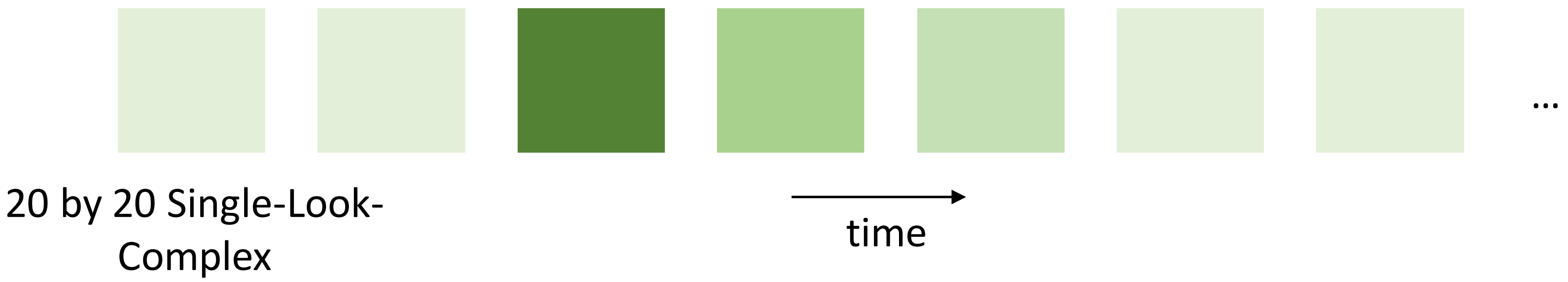
Easy to implement for numerical simulation.
Easier to adapt to more realistic scenarios.
Can start from single-look radar return.



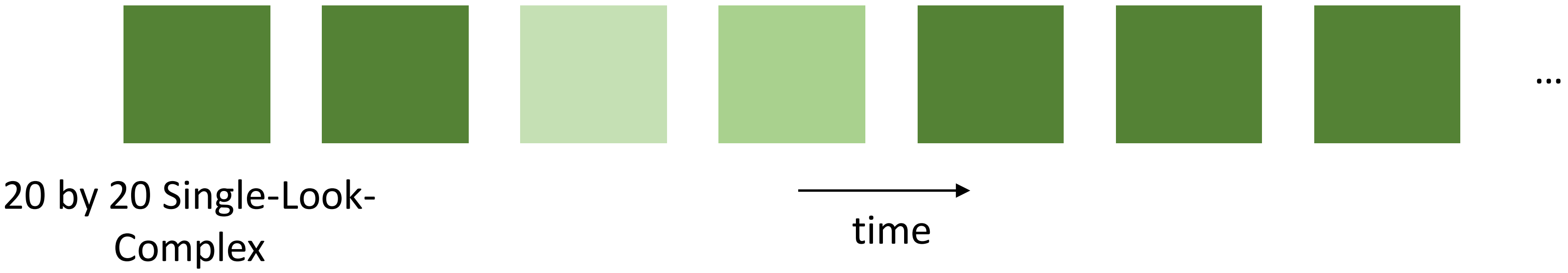
Discretized model for soil moisture

From soil moisture to closure phase bias – Numerical Simulation

Case I – Arid environment

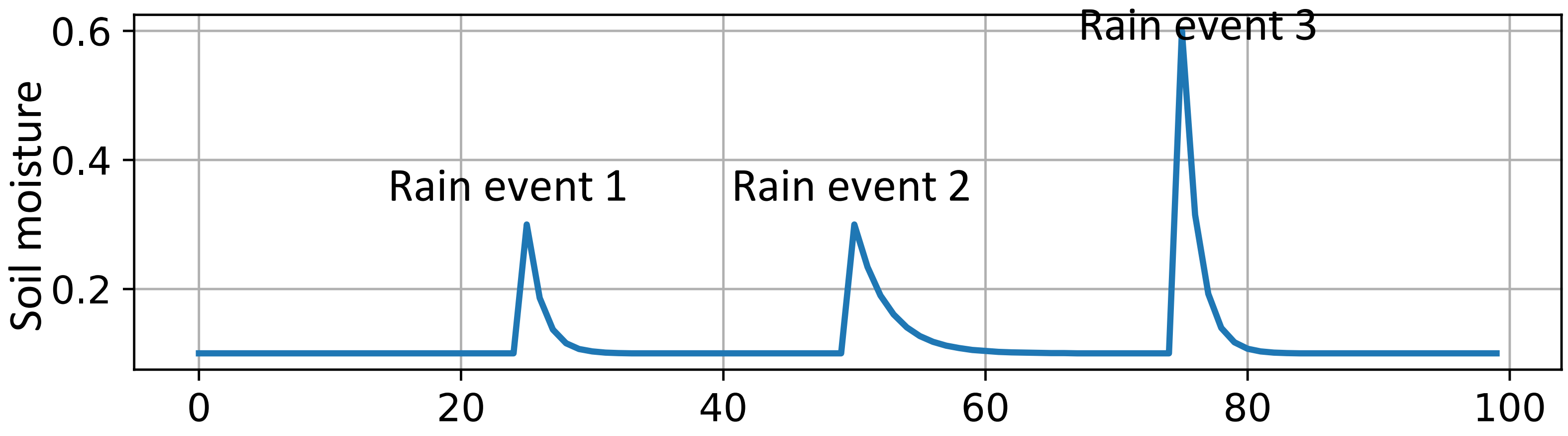


Case II – Wet environment

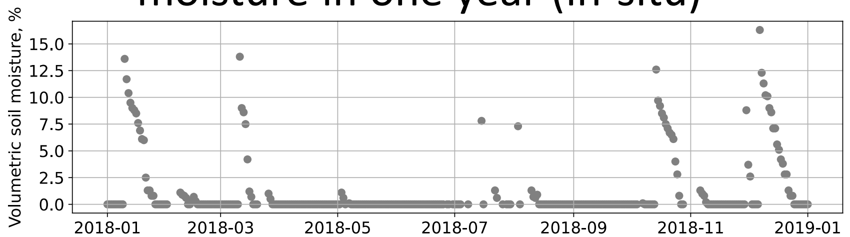


From soil moisture to closure phase bias – Numerical Simulation

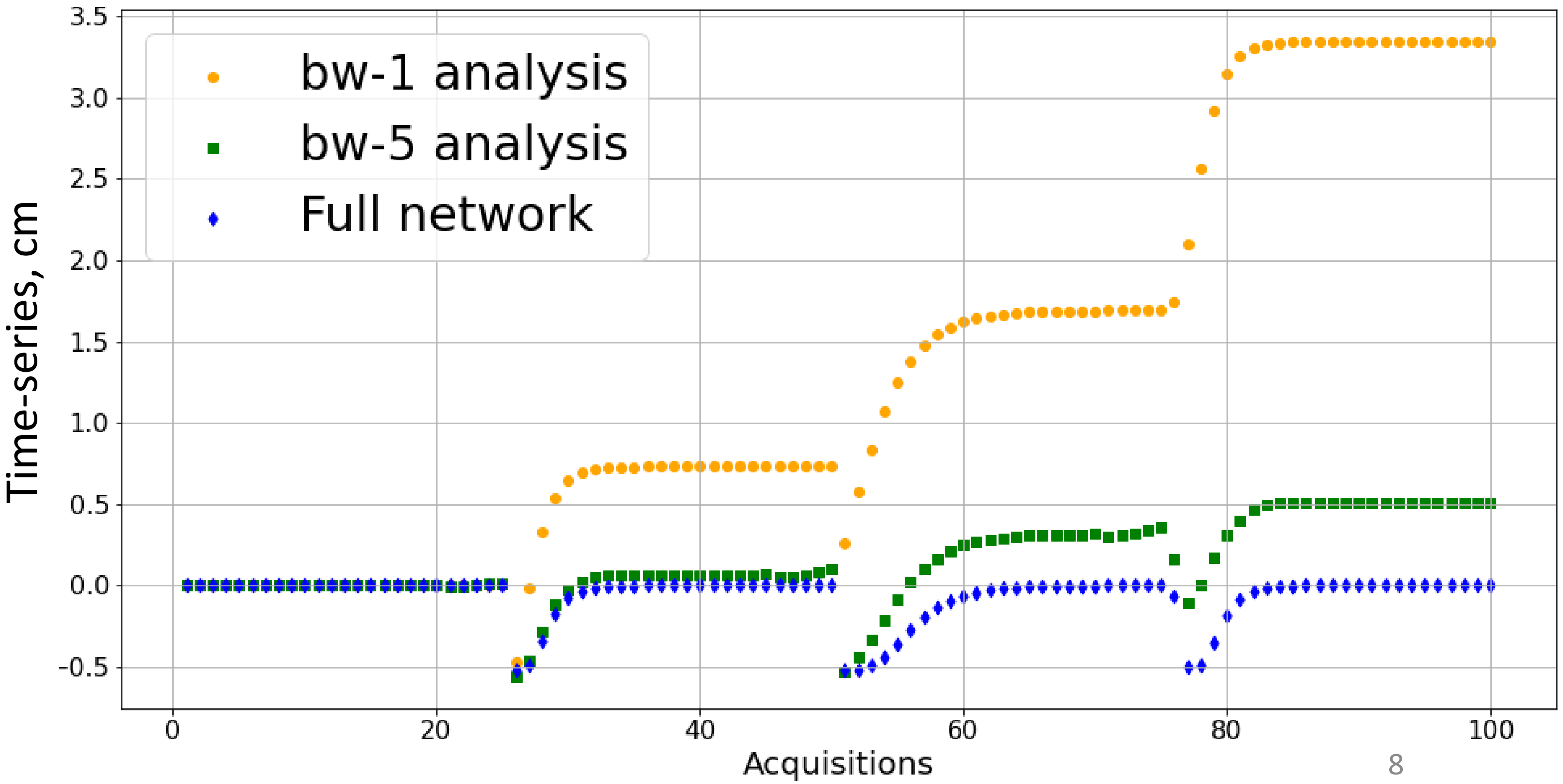
Case I – Arid environment



Example of arid environment soil moisture in one year (in-situ)



Step 1: Simulate 100 SAR acquisitions, each acquisition contains 400 pixels
Step 2: Form interferograms and multi-look by 400
Step 3: Time-series analysis of different bandwidth

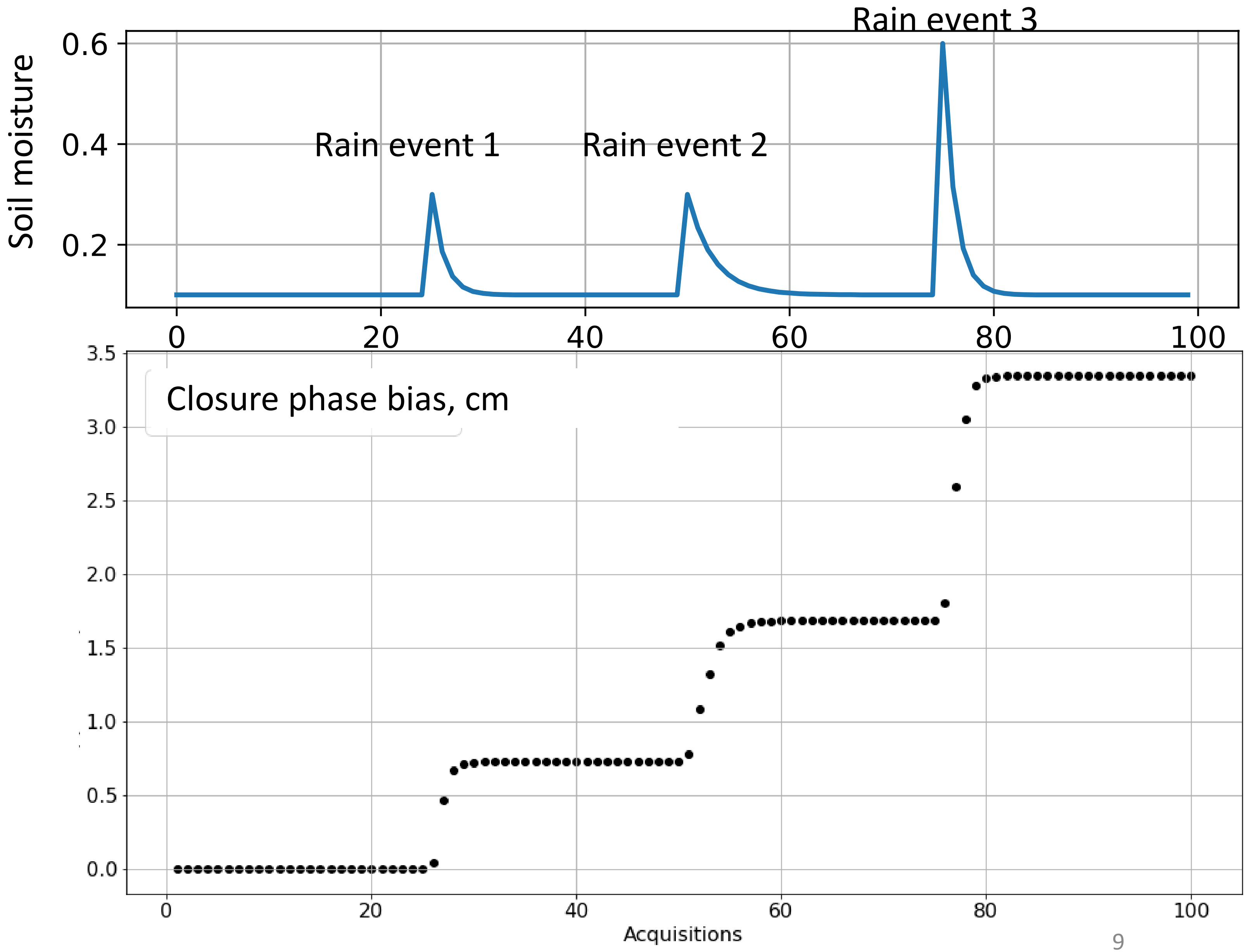


From soil moisture to closure phase bias – Numerical Simulation

Case I – Arid environment

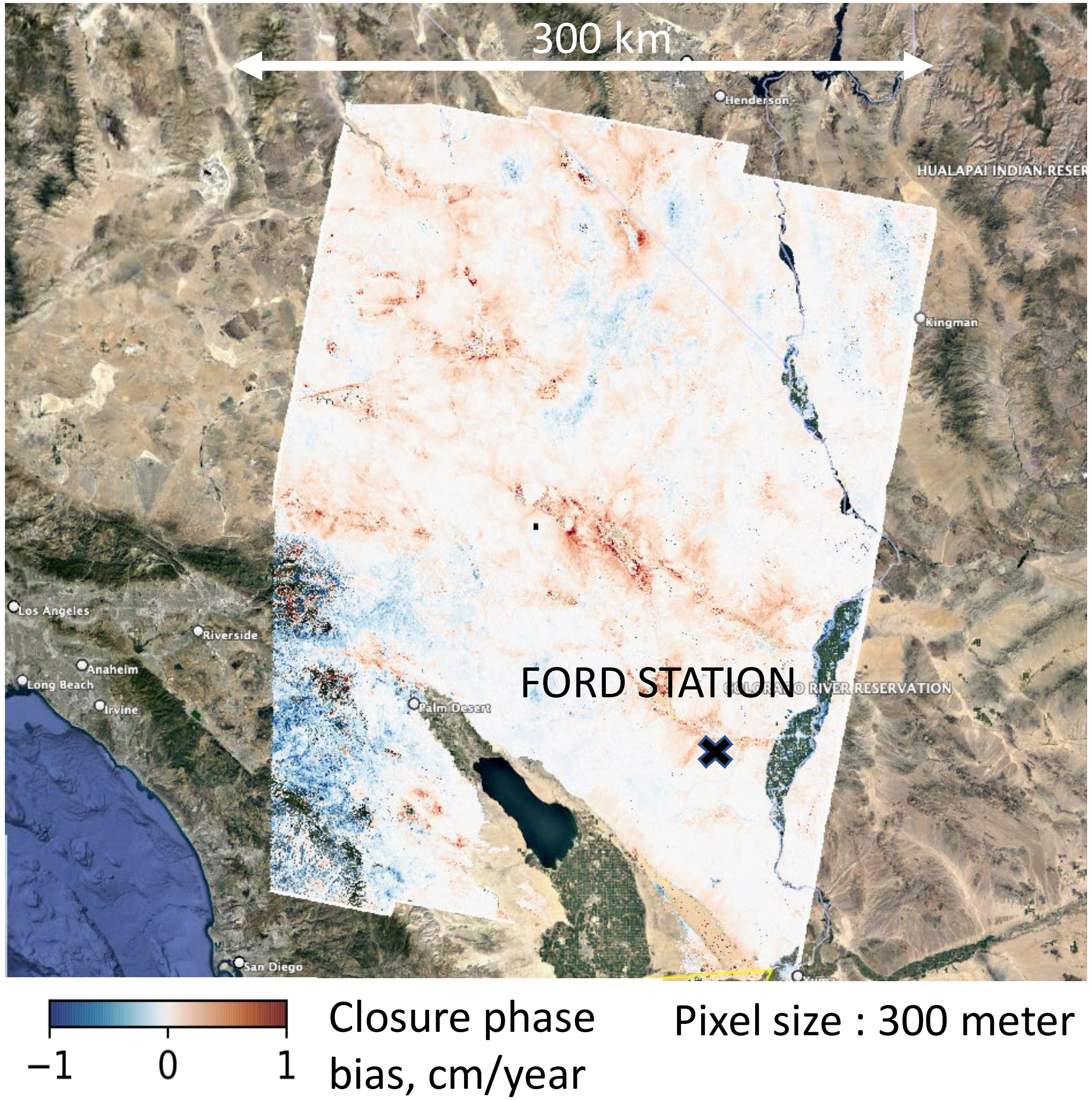
Key findings:

1. “Uplift” in closure phase bias corresponds to soil drying after rainfall.
2. Uplift magnitude depends on soil moisture decay rate and variation
3. Slower decay and greater variation result in larger uplift



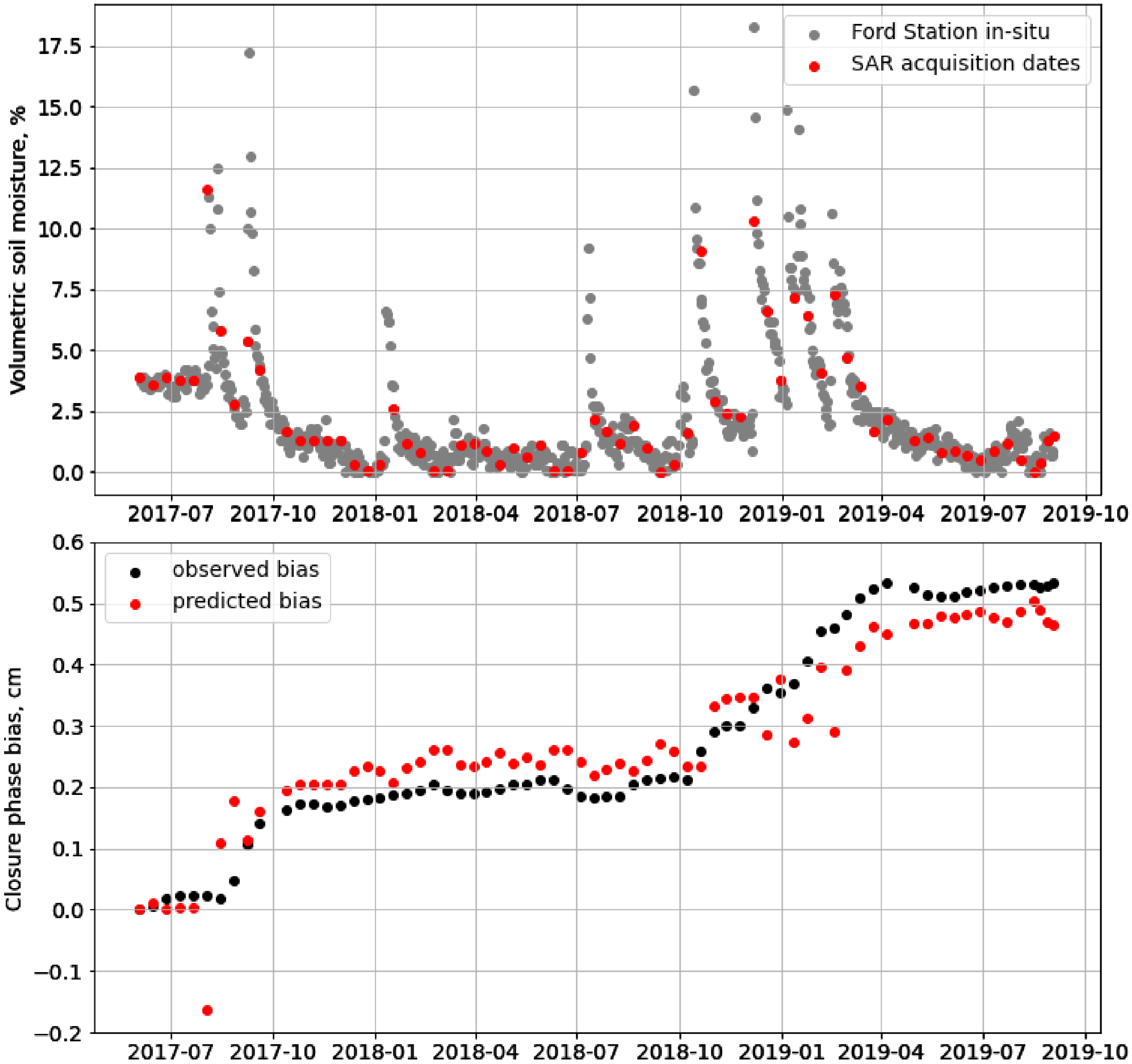
Forward model validated with in-situ measurements

Case I – Arid environment

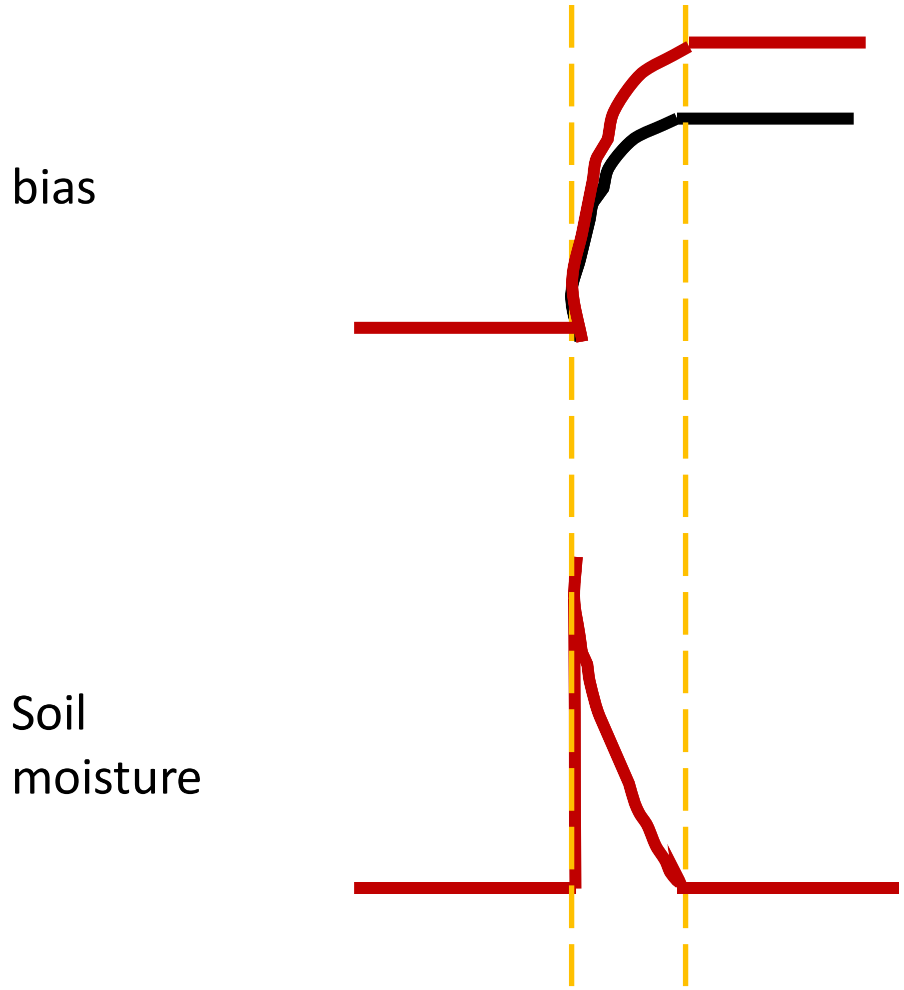


Closure phase bias, cm/year

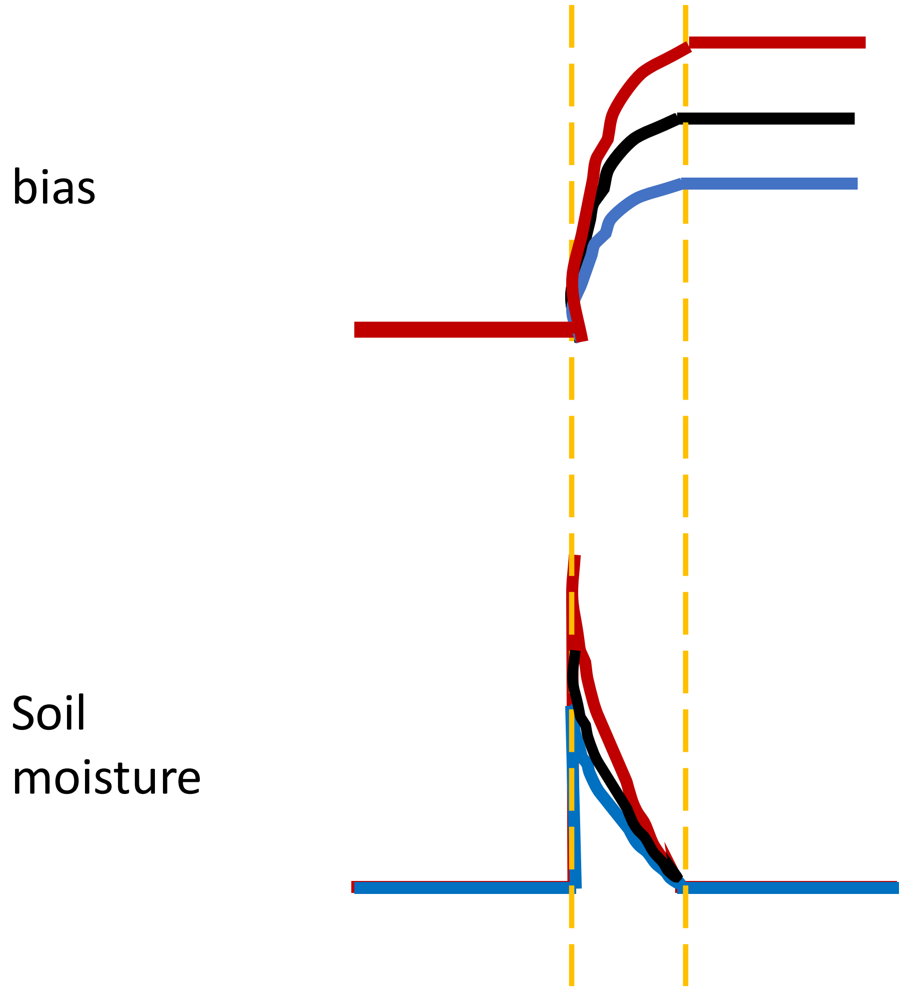
Pixel size : 300 meter



From closure phase bias to soil moisture: inversion scheme



From closure phase bias to soil moisture: inversion scheme



Step 1 – identify disturbance windows

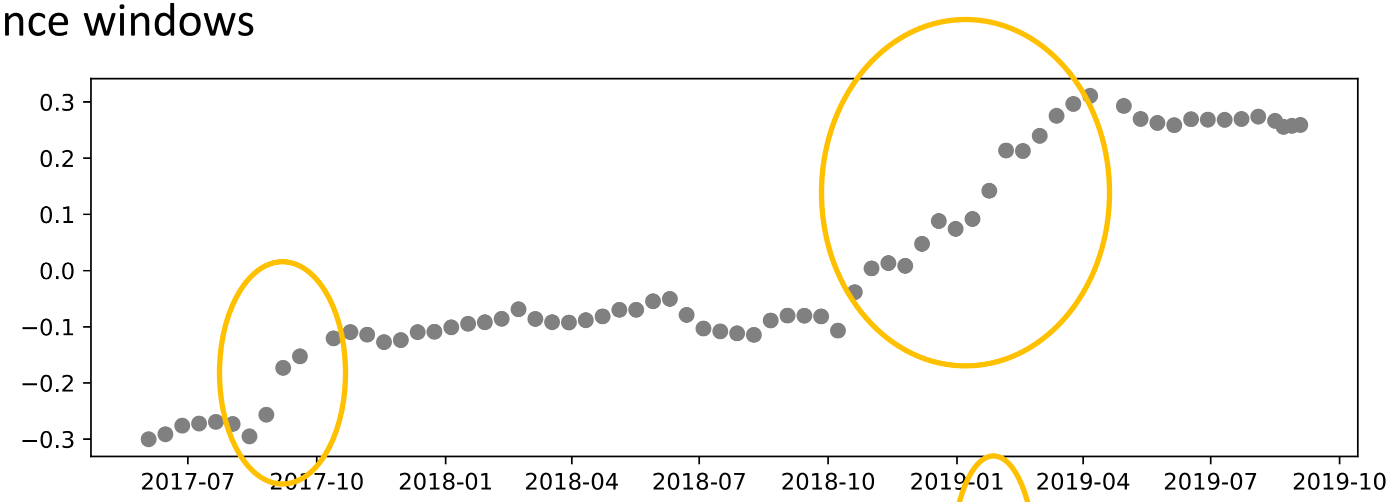
Step 2 – propose a soil moisture time-series with base value s_0 and an exponential decay model s $= s_0 e^{(-)t/\tau}$

Step 3 -- solve for s_0 and τ that gives the best fit to the bias time-series

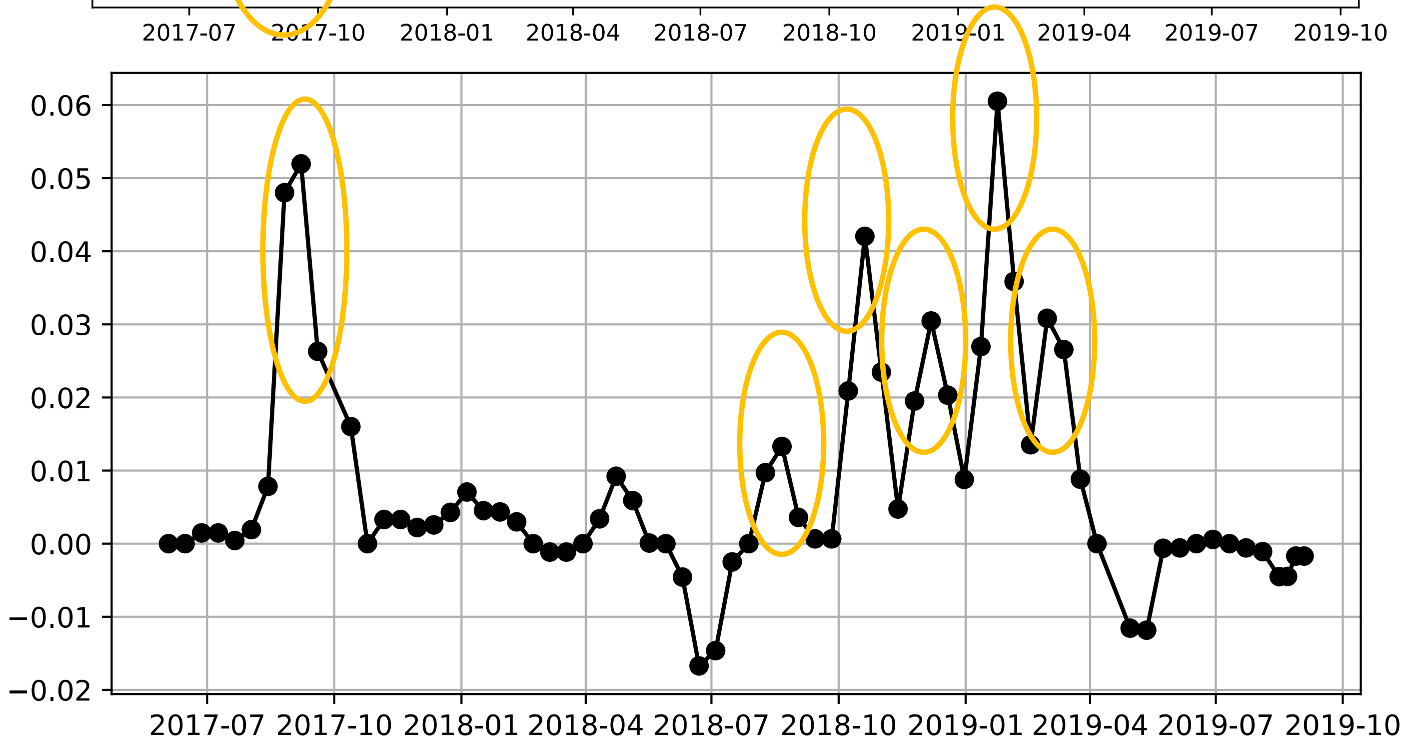
From closure phase bias to soil moisture: initial results

Step 1 – identify disturbance windows

Closure phase bias



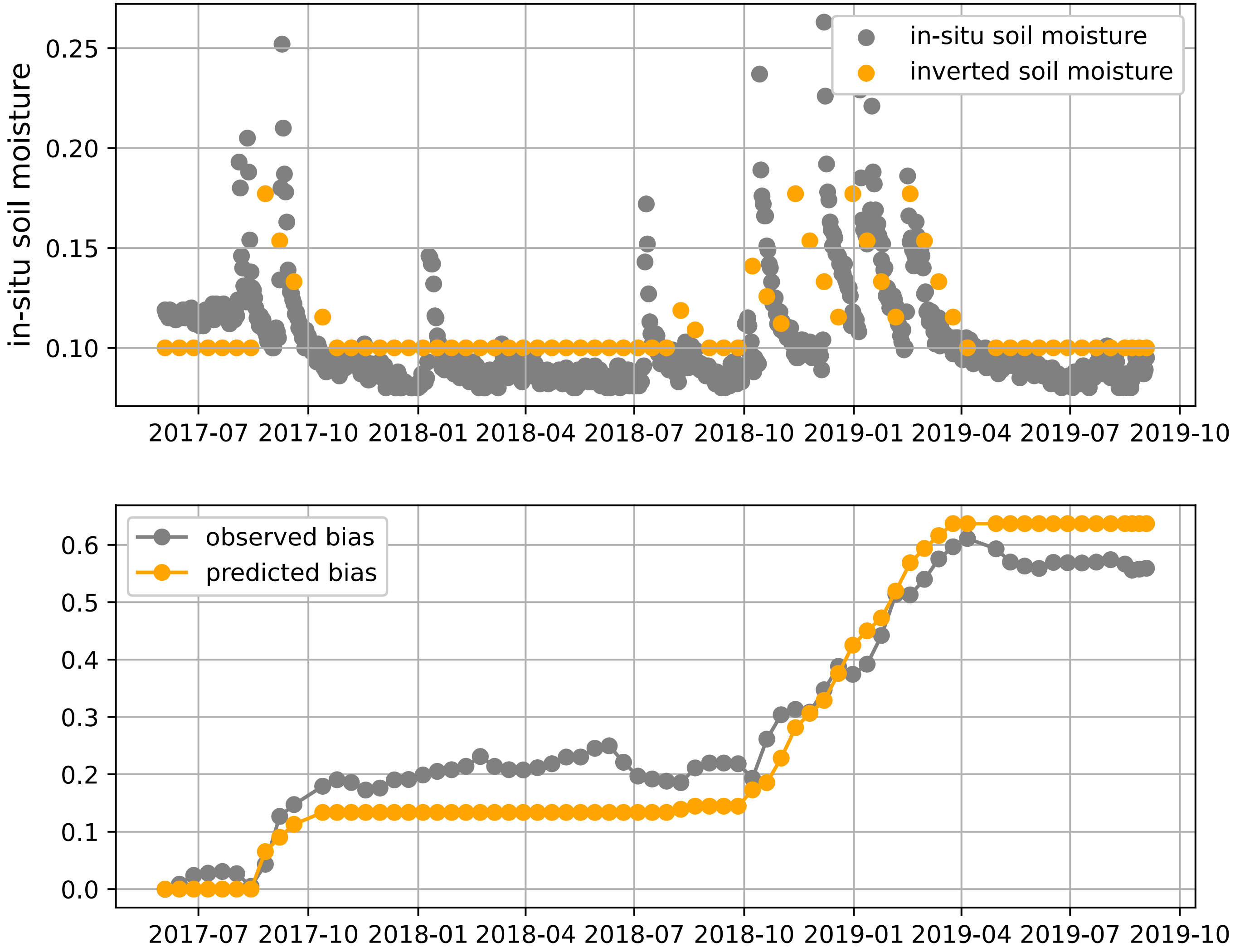
Closure phase bias gradient



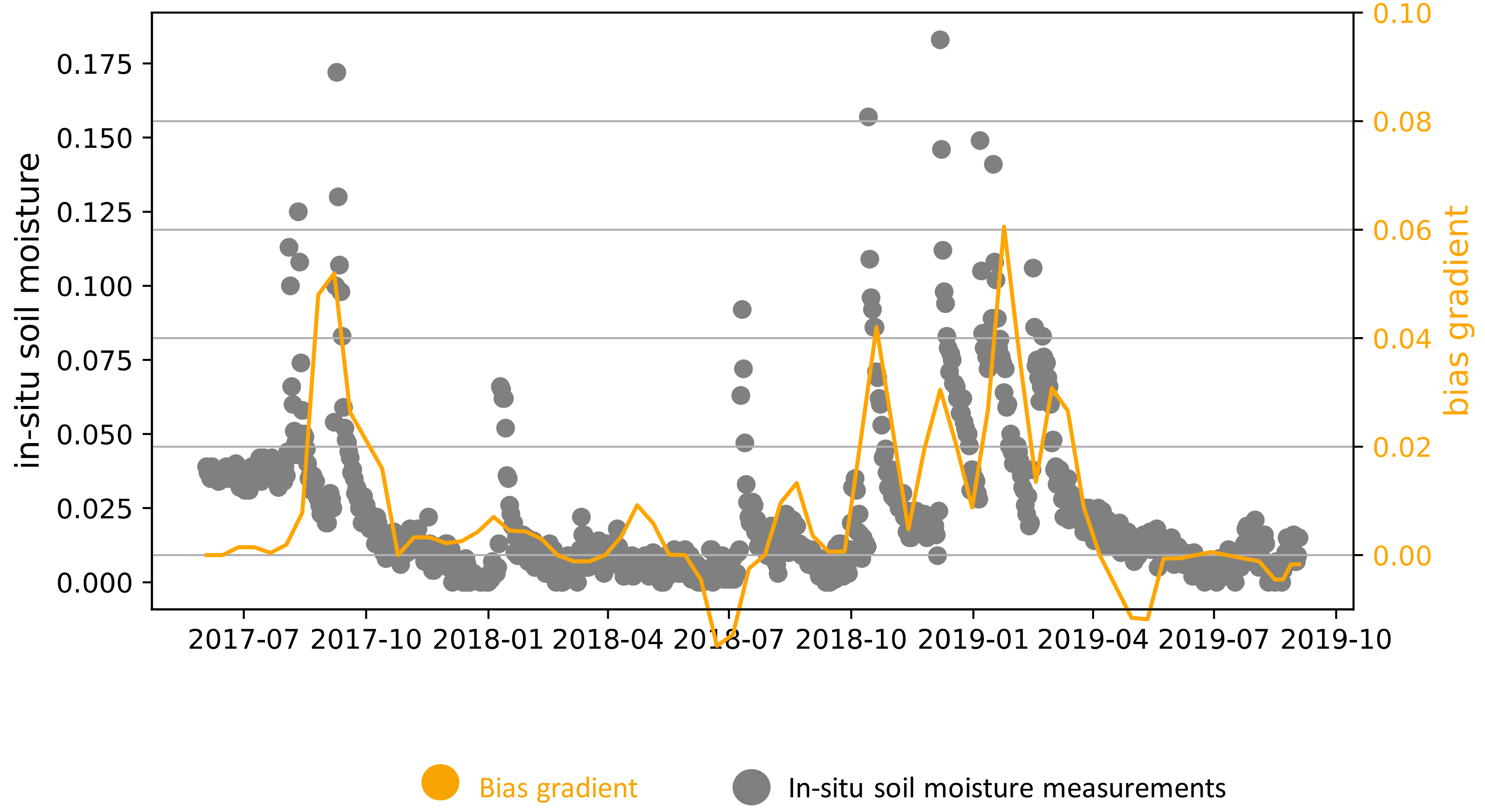
Six disturbance events detected

From closure phase bias to soil moisture: initial results

Step 2 & 3 – find the best fit soil moisture time-series



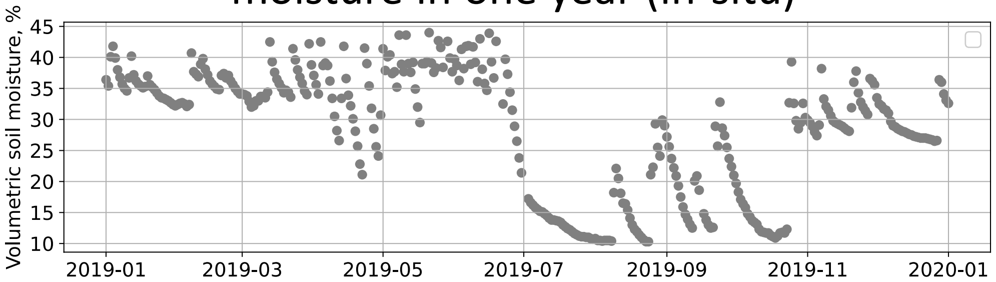
From closure phase bias to soil moisture: bias gradient as a proxy

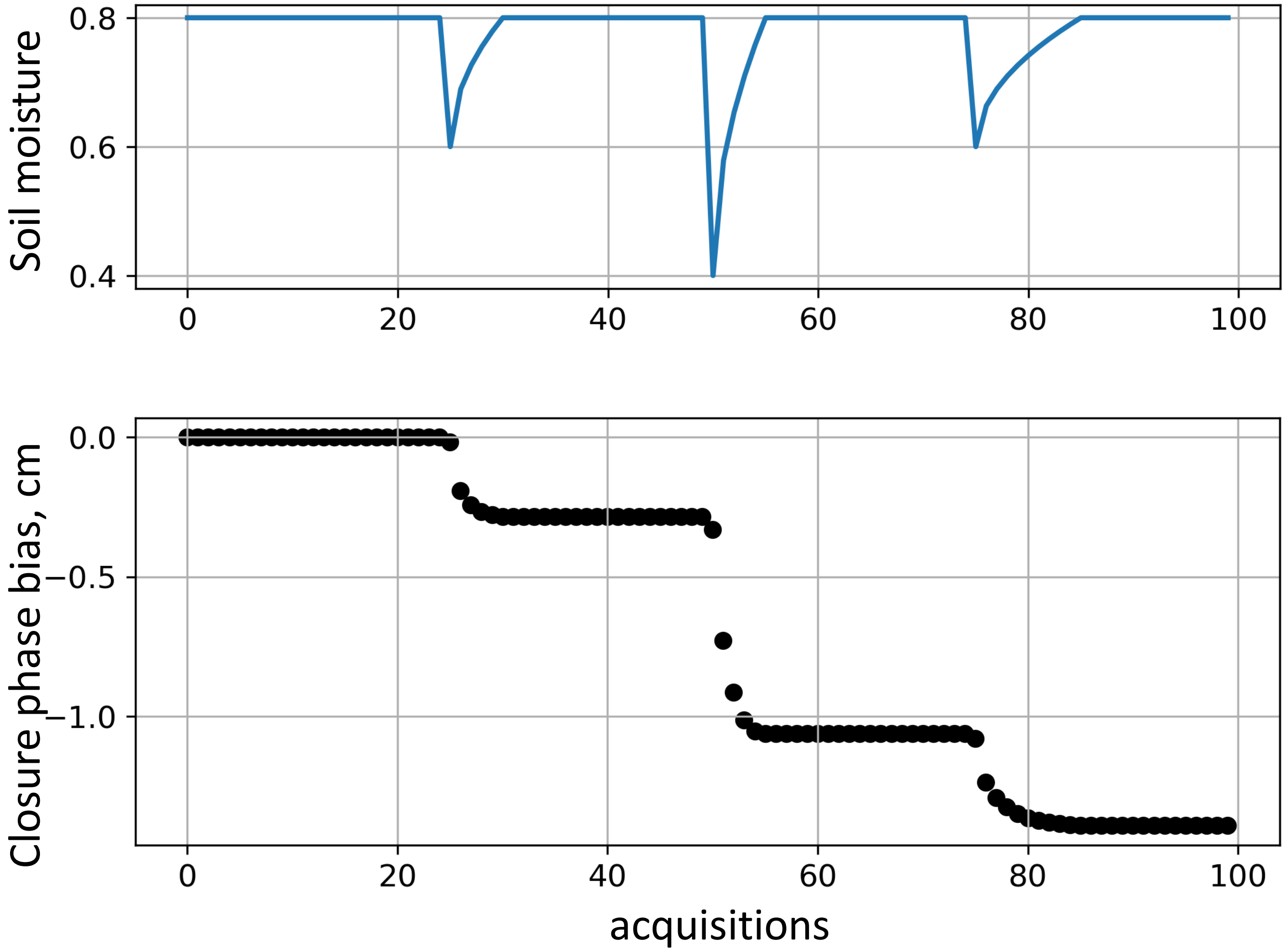


From soil moisture to closure phase bias – Numerical Simulation

Case II – Wet environment

Example of wet environment soil moisture in one year (in-situ)



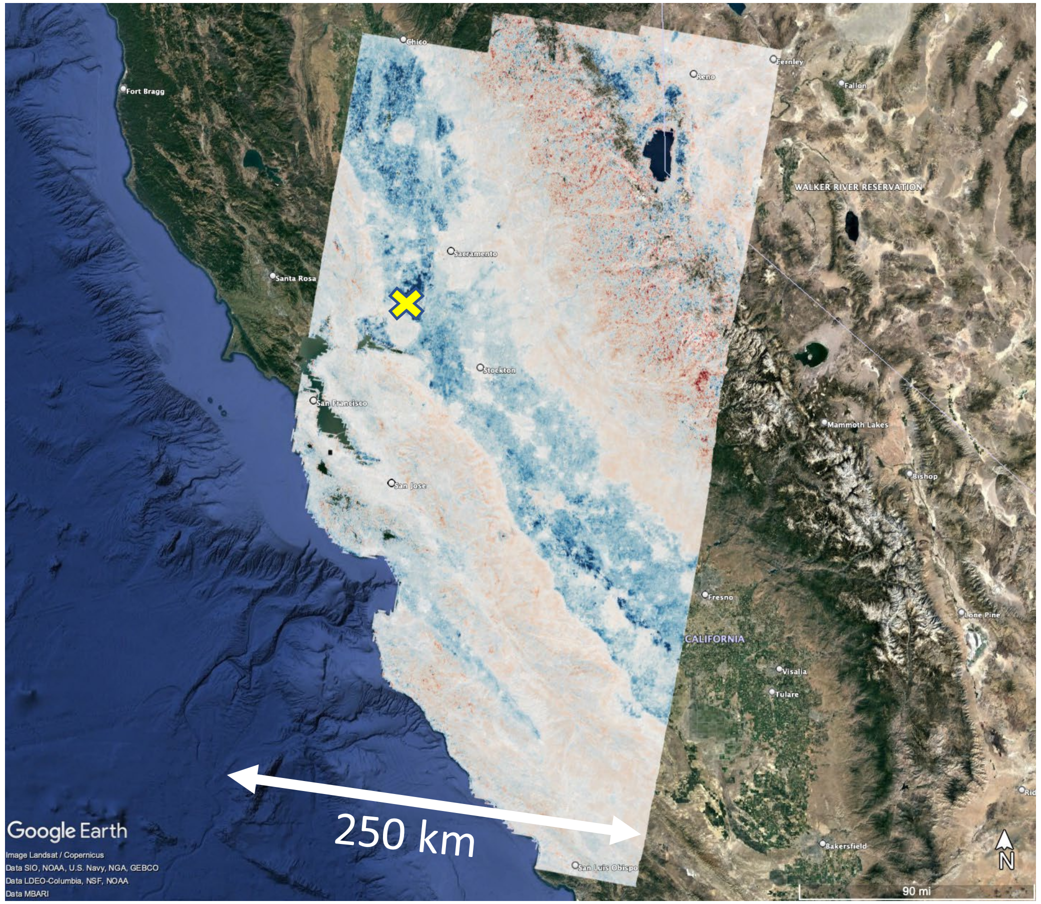


Key findings:

1. "Subsidence" in closure phase bias corresponds to soil moisture increase after irrigation.
2. subsidence magnitude depends on soil moisture increase rate and variation
3. Slower increase and greater variation result in larger subsidence

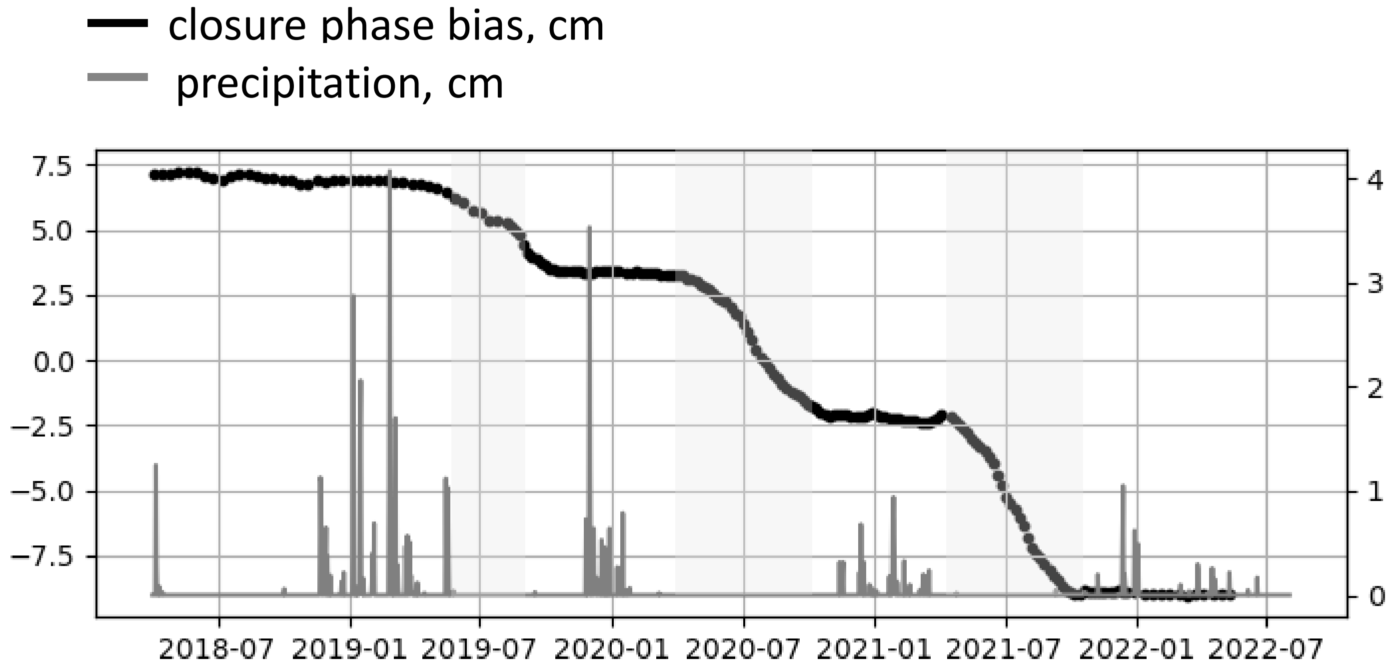
From soil moisture to closure phase bias – validation with data

Case II – Wet environment



Closure phase bias, cm/year

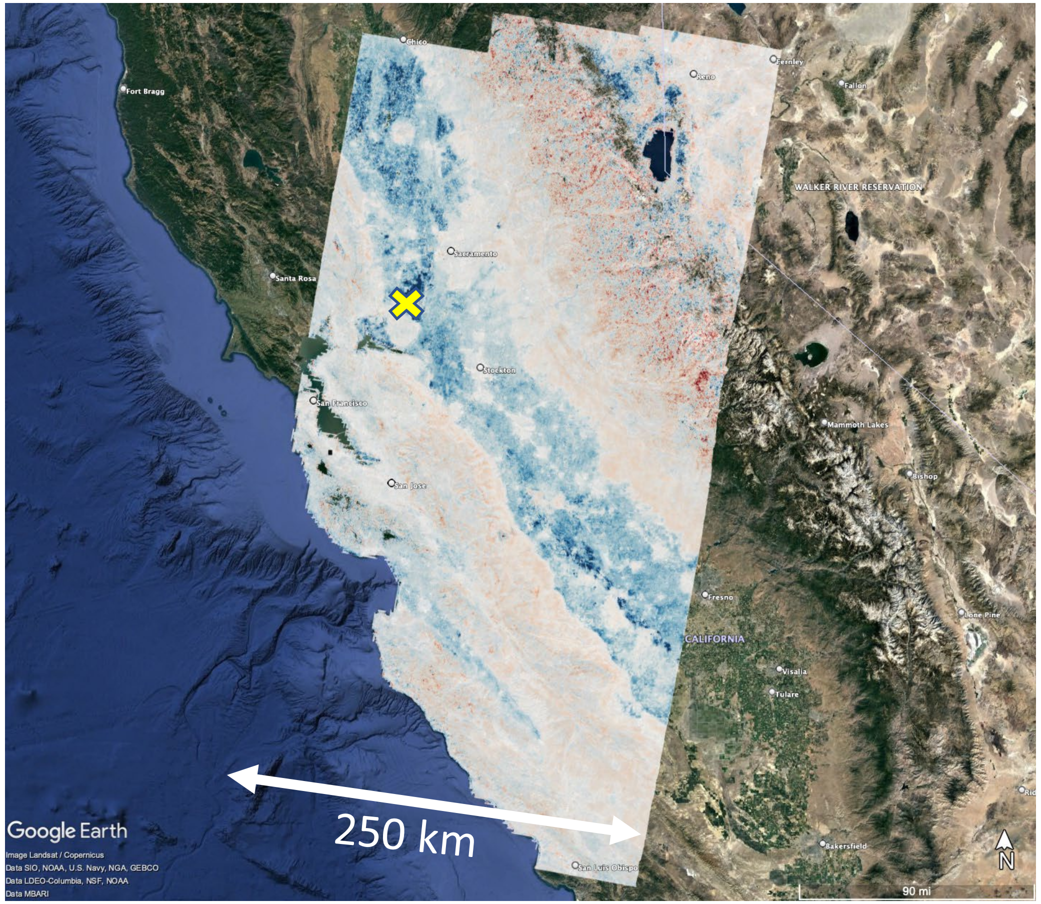
-3 0 3



* Processed Sentinel data courtesy of Zhen Liu, JPL, California Institute of Technology, USA

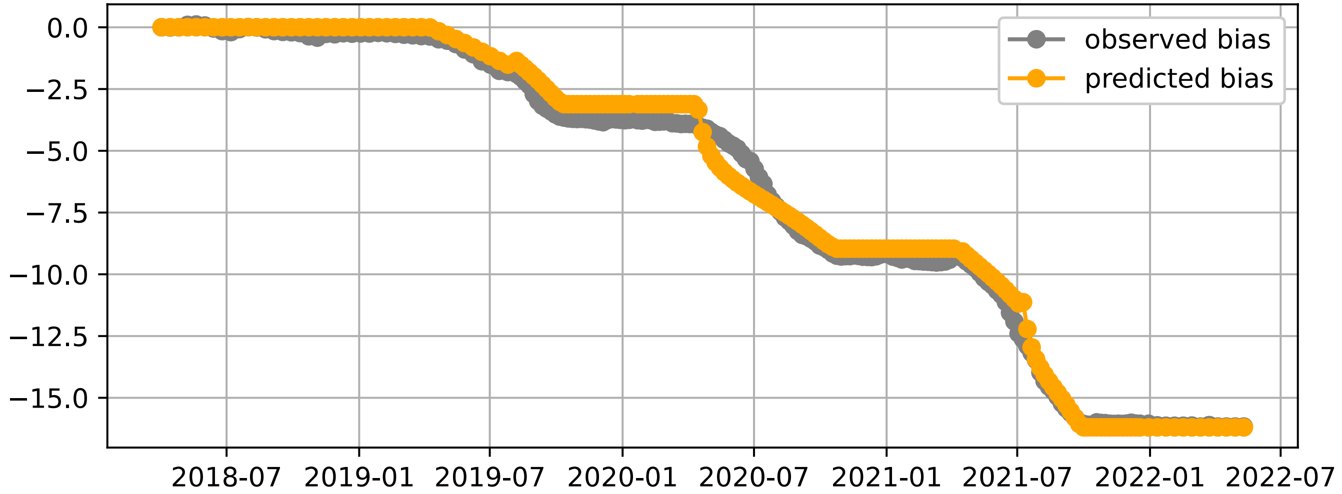
From closure phase bias to soil moisture – initial results

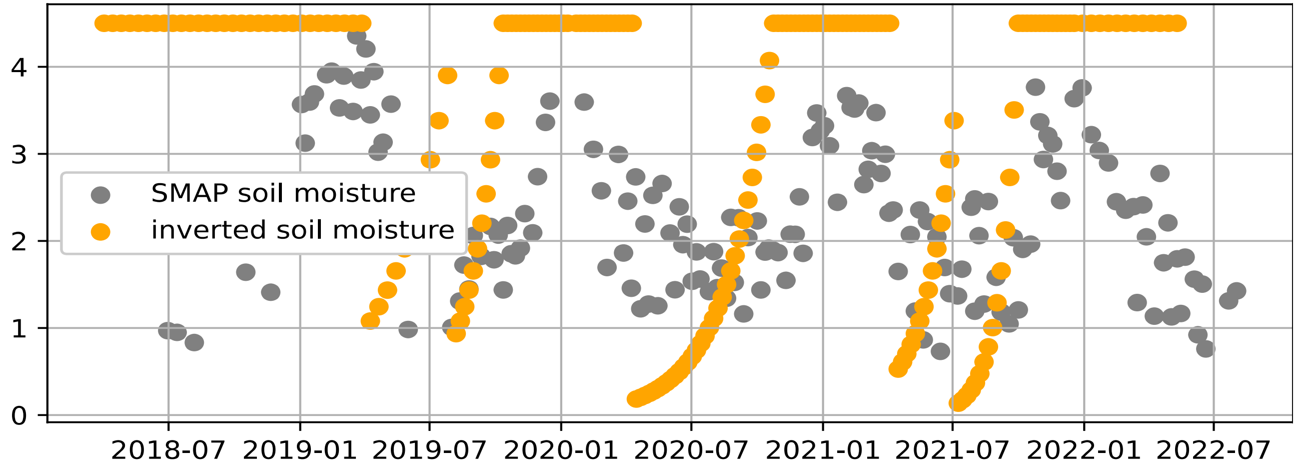
Case II – Wet environment



Closure phase bias, cm/year

-3 0 3

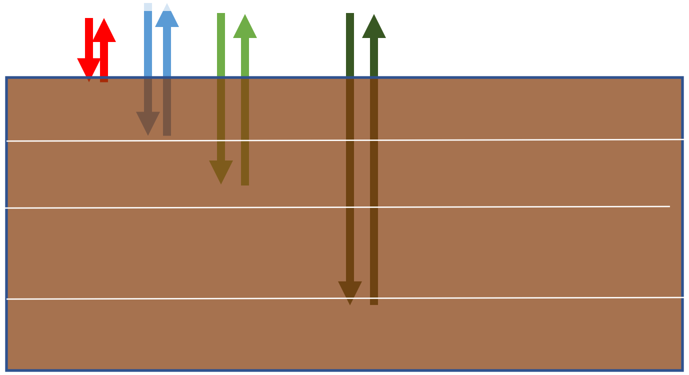




*Processed Sentinel data courtesy of Zhen Liu, JPL, California Institute of Technology, USA

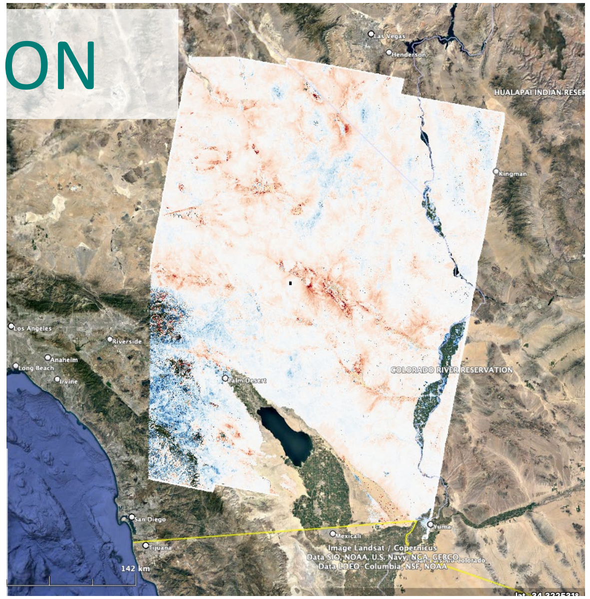
Modeling soil moisture from closure phase bias - Summary

MODEL

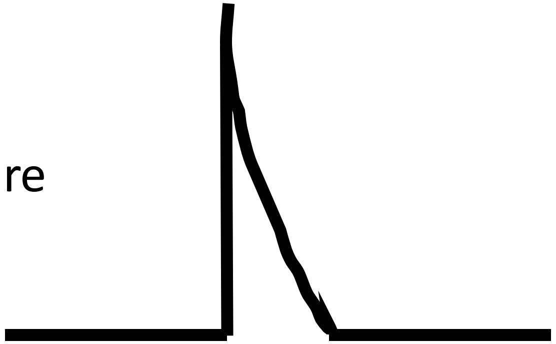


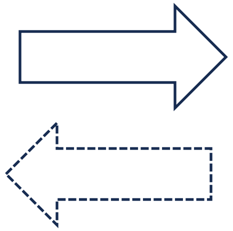
A discrete soil moisture model
soil moisture -> closure phase bias

OBSERVATION

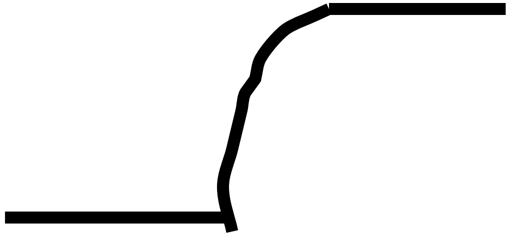


Soil
moisture





Bias



Modeling soil moisture from closure phase bias – Summary

Potentials

- Linking soil moisture variation to bias accumulation is straightforward relative to working directly with closure phase.
- It offers potential to detect drought onset, produce high-resolution soil moisture maps and scale with global time-series products

Limitations

- Limited temporal resolution (limited by SAR acquisition intervals).
- Inversion scheme has yet to be tested with extensive data.