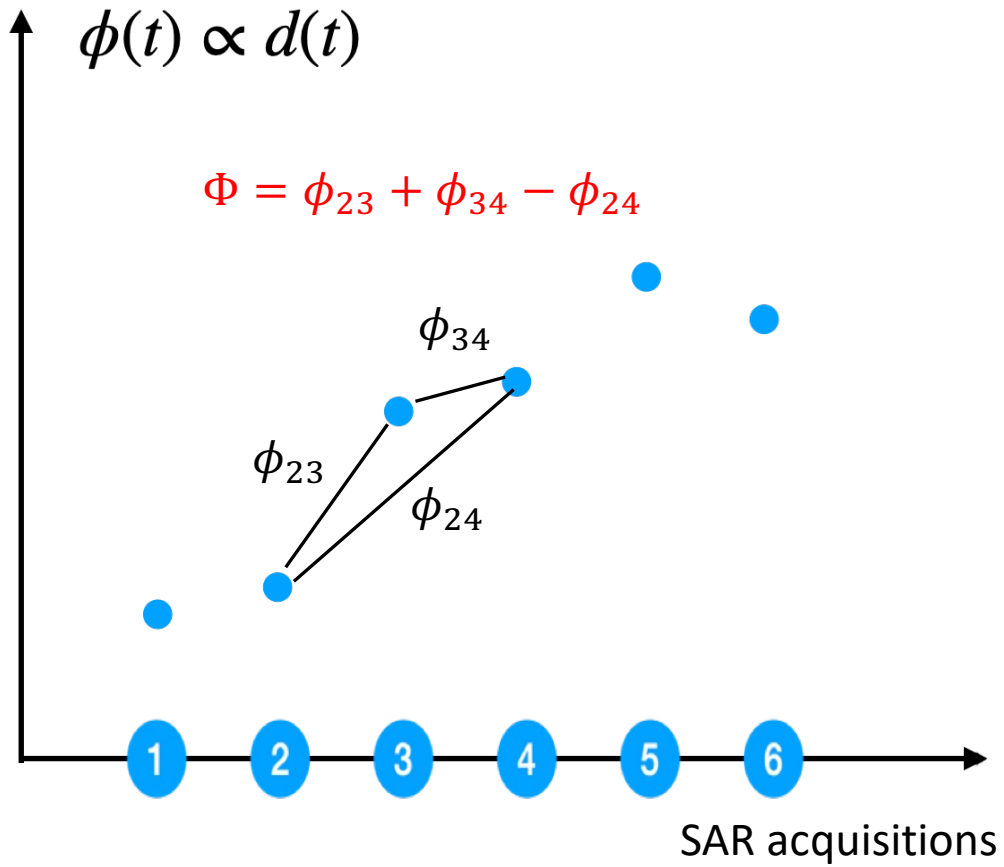
Closure phase bias: signal or noise?

Yujie Zheng(1), Heresh Fattahi(2), Piyush Agram(1), Mark Simons(1,2), Paul Rosen(2)

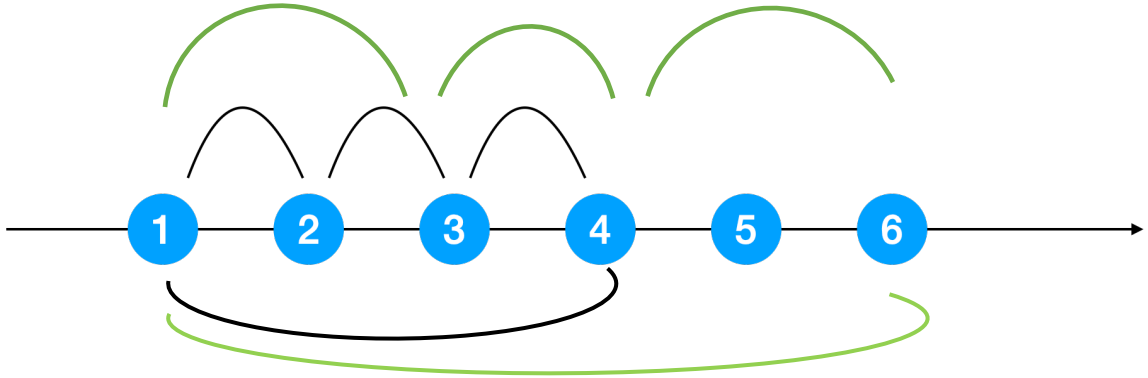
(1) California Institute of Technology, USA (2) Jet Propulsion Laboratory, California Institute of Technology, USA

2022 NiSAR Science Community Workshop

Closure phase measures the phase consistency among InSAR phase measurements



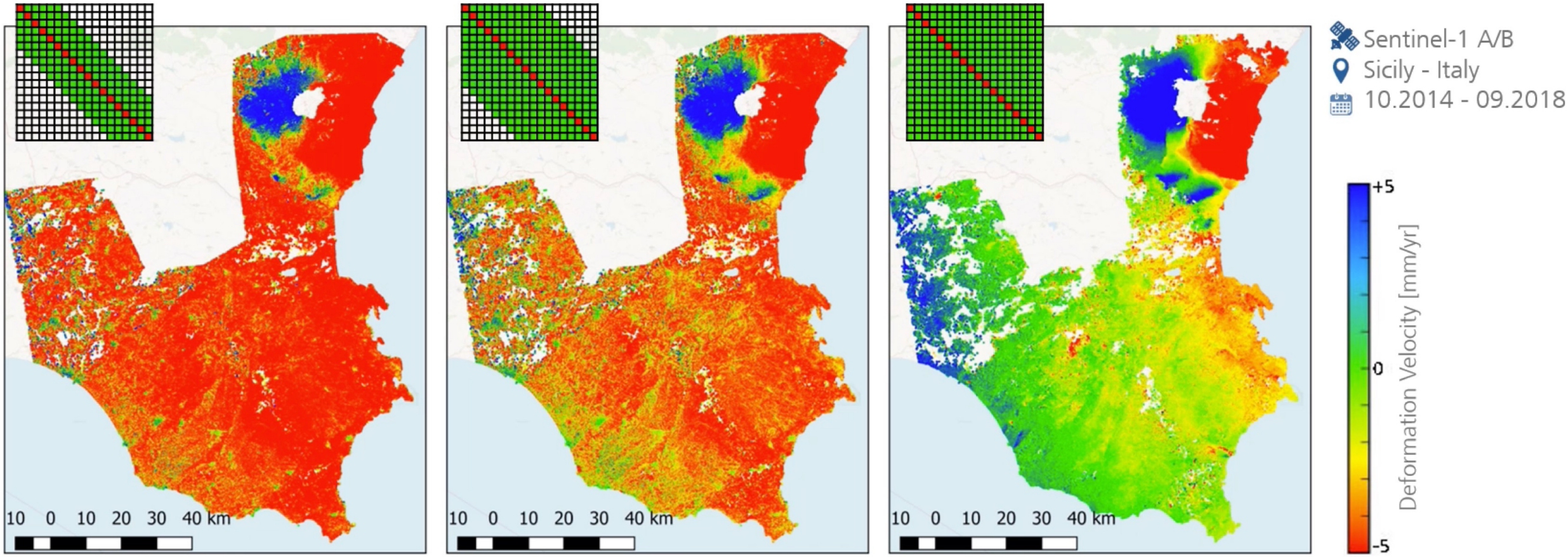
Closure phase can be defined on any closed loop.



Zero closure phase is always true for **single-look** measurements

Zero closure phase is generally NOT true for **multi-looked (spatially averaged)** measurements

Same Time-series — Different Deformation



Increasing maximum temporal baseline

Increasing velocity bias

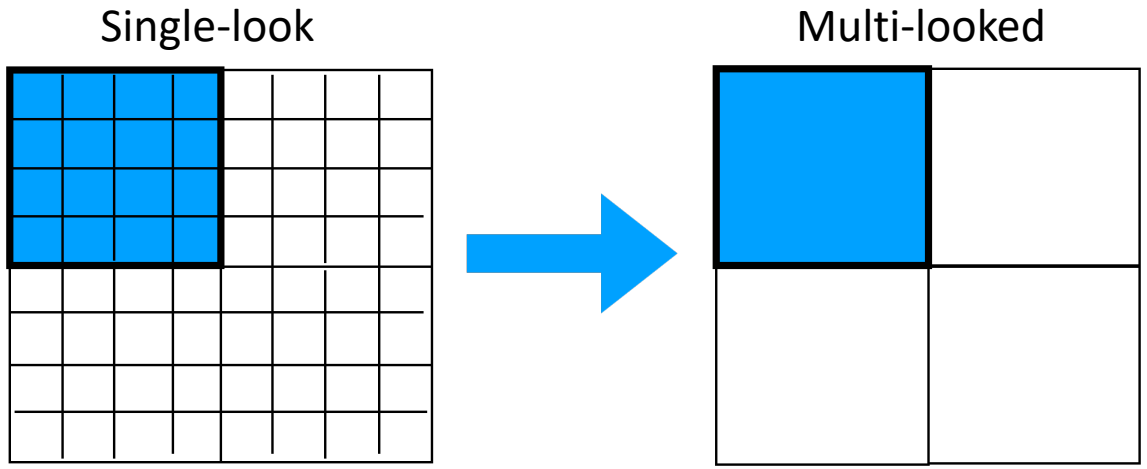
Ansari et.al. (2020): Study of Systematic Bias in Measuring Surface Deformation

Closure phase bias: signal or noise?

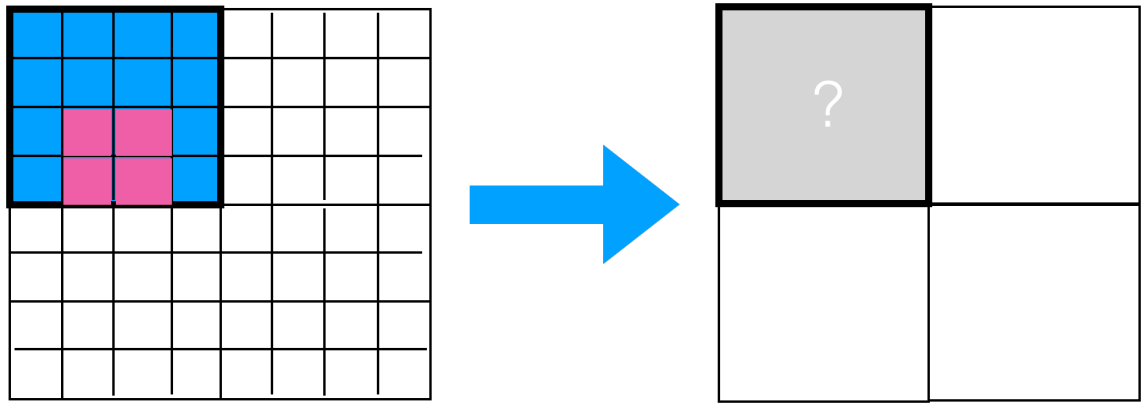
It is noise in the context of deformation modeling.

How to correct?

Multi-look : averaging single-look measurements



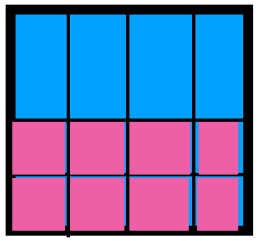
The Earth's surface is naturally heterogeneous.



Single-look		Multi-look
Amp	Phase	Phase
a	$\Delta\phi$	$\Delta\phi^m = \Delta\phi$

Amp	Phase	Phase
a^I	$\Delta\phi^I$	$\Delta\phi^m = \sum_i w_i \Delta\phi_i$
a^{II}	$\Delta\phi^{II}$	$w = f(a^I, a^{II})$

Closure phase bias signals the presence of temporally inconsistent processes (processes that change both the phase and the amplitude of the interferometric measurement)



$$\Delta\phi^{I} = \Delta\phi^{def}$$

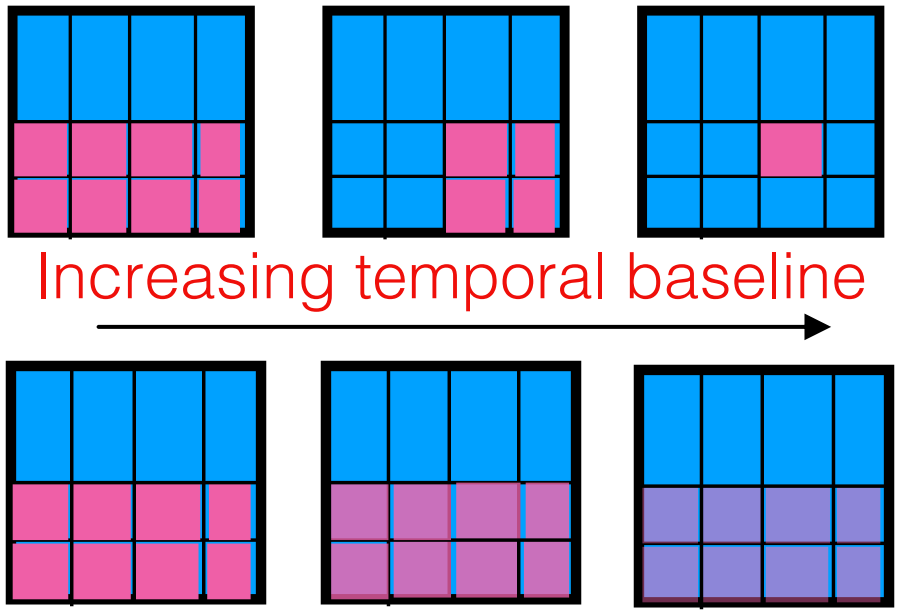
$$\Delta\phi^{II} = \Delta\phi^{def} + \Delta\phi^{x}$$

Multi-look

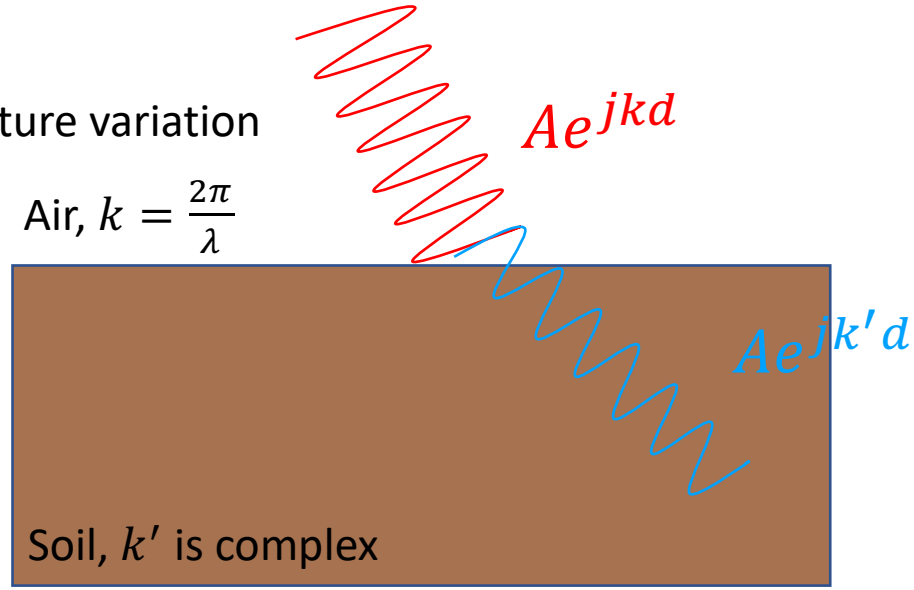
$$\Delta\phi^{m} = \Delta\phi^{def} + \boxed{w\Delta\phi^{x}}$$

bias

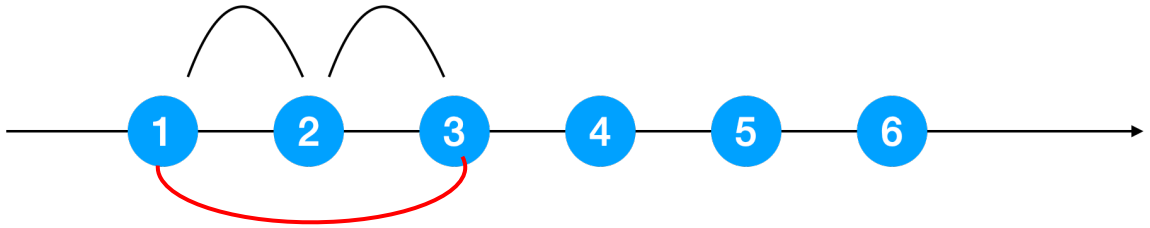
$$w = w(\Delta t)$$



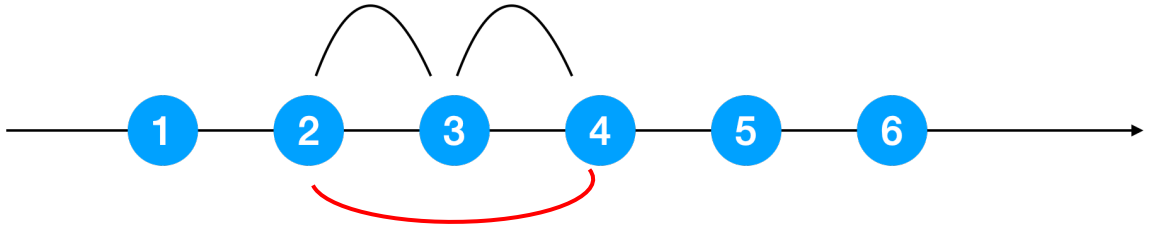
Example:
Soil moisture variation



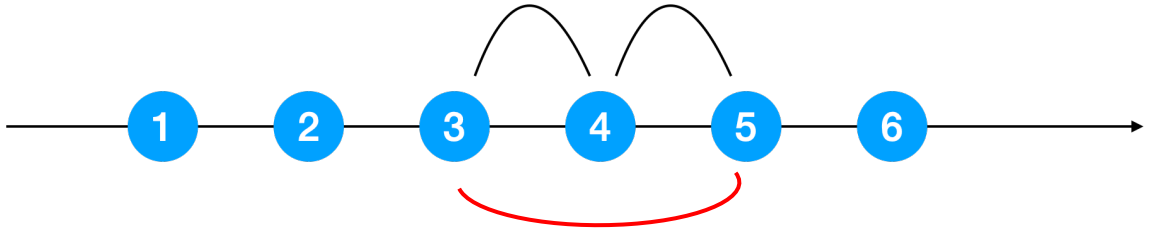
We can use sequential closure phase to reconstruct the phase history of the temporally inconsistent process



$$\Phi_{123} \propto \Delta\phi_{13}^{x}$$



$$\Phi_{234} \propto \Delta\phi_{24}^{x}$$

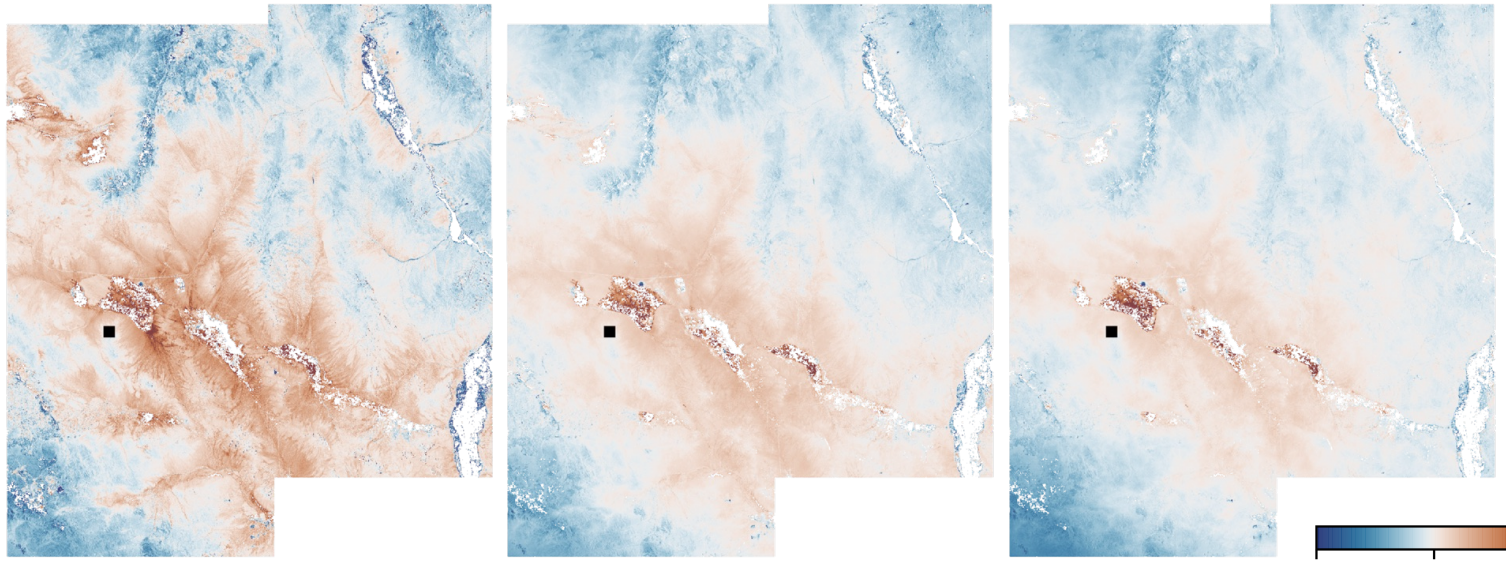


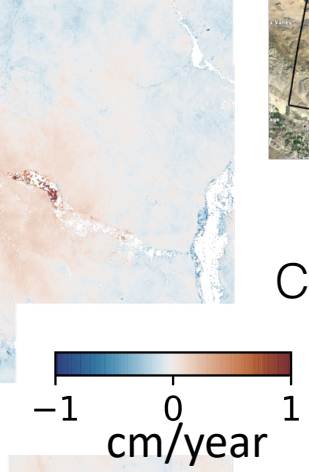
$$\Phi_{345} \propto \Delta\phi_{35}^{x}$$

- Sequential Closure phase is only sensitive to temporally inconsistent processes.
- Sequential Closure phase is only sensitive to the phase difference between the first and the last date of the loop.

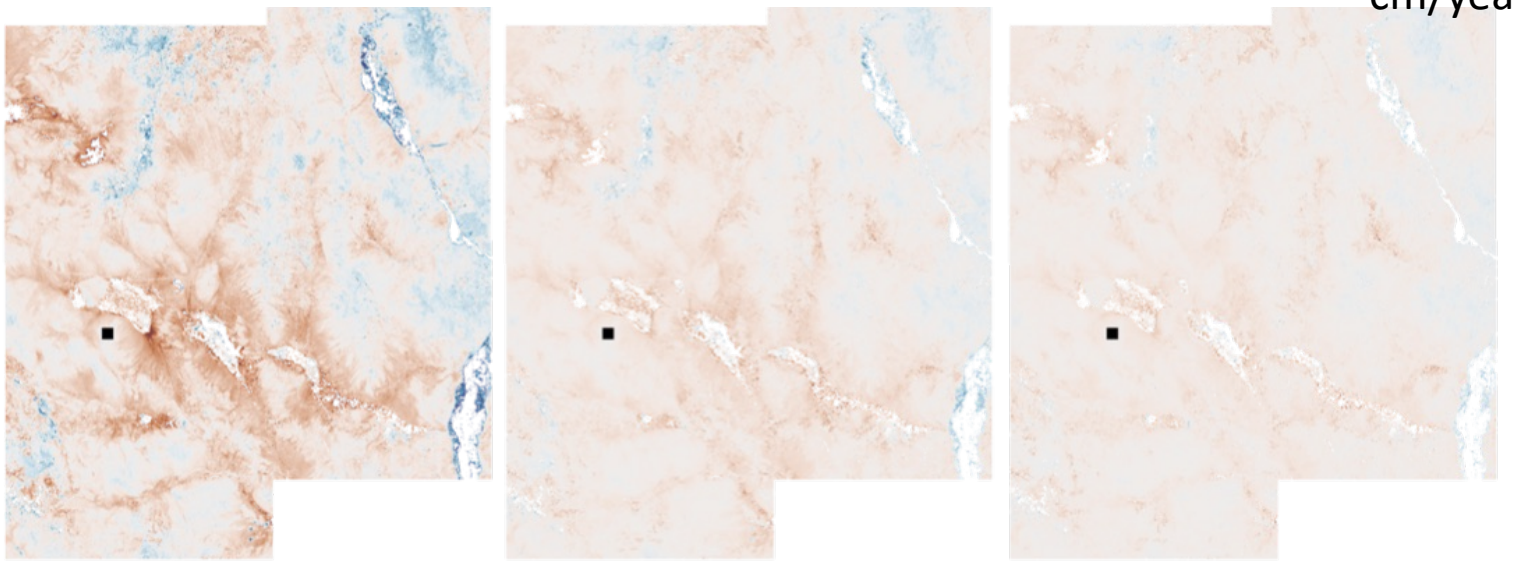
Bias Correction with Sequential Closure Phase

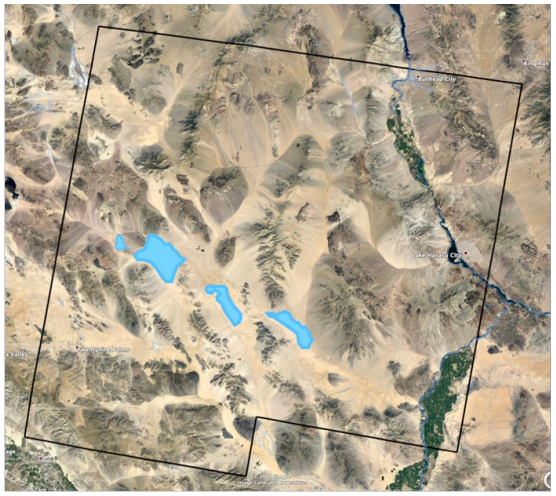
$\overline{\Delta t} = 9\ days$ $\overline{\Delta t} = 27\ days$ $\overline{\Delta t} = 49\ days$





Estimated Bias





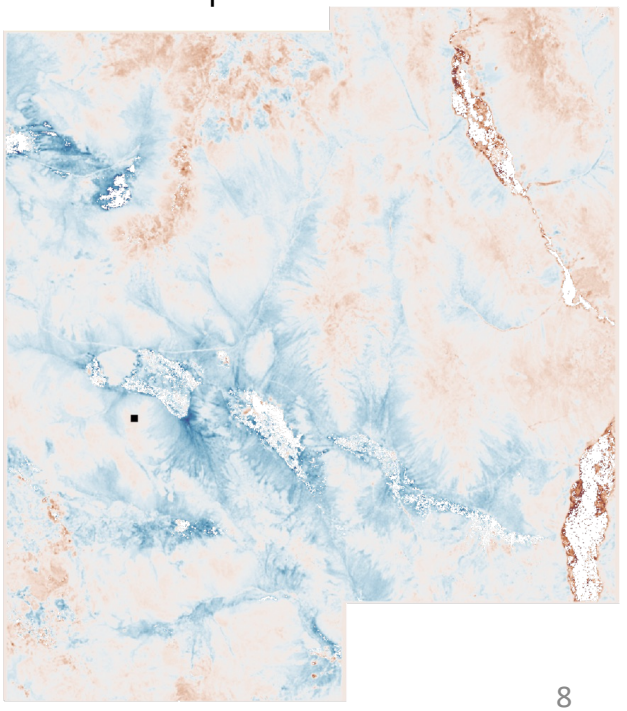
Sentinel-1A/B

Barstow-Bristol Trough, CA, United States

Feb 2017 - Jan 2021

SBAS, MintPy

Cumulative Sequential Closure Phase



Bias Correction with Closure Phase

$\overline{\Delta t} = 9\ days$ $\overline{\Delta t} = 27\ days$ $\overline{\Delta t} = 49\ days$

Before Correction

After Correction

Azimuth

Range

−1 0 1 cm/year

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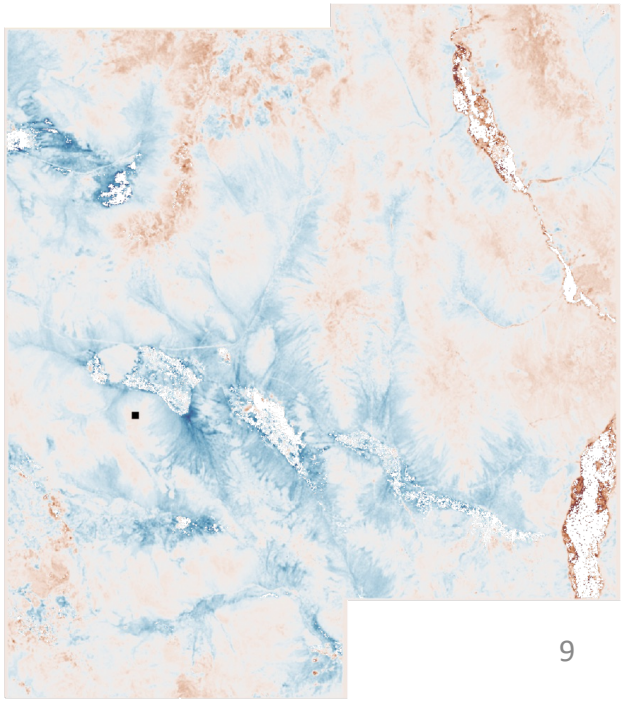
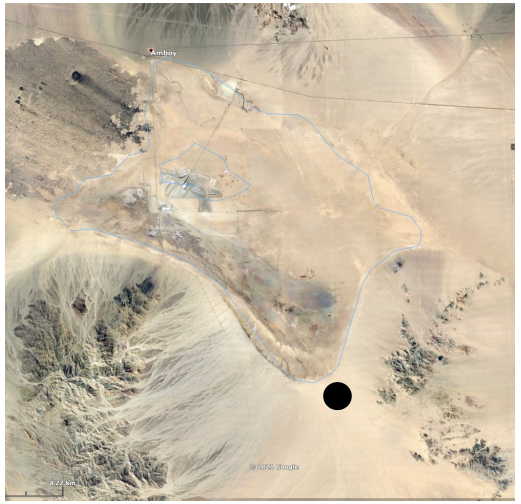
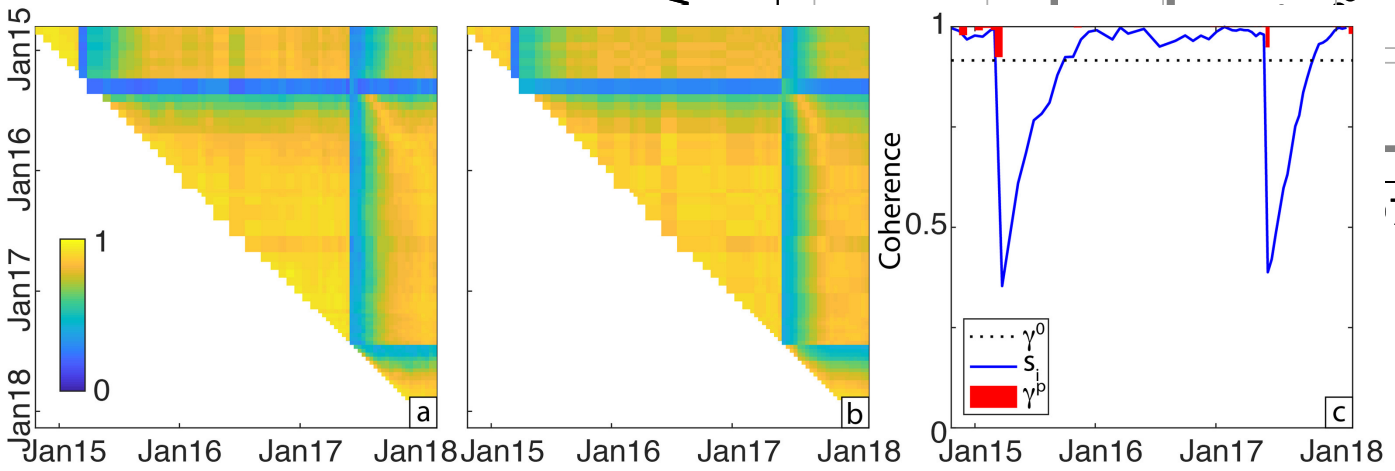
Cumulative Sequential Closure Phase

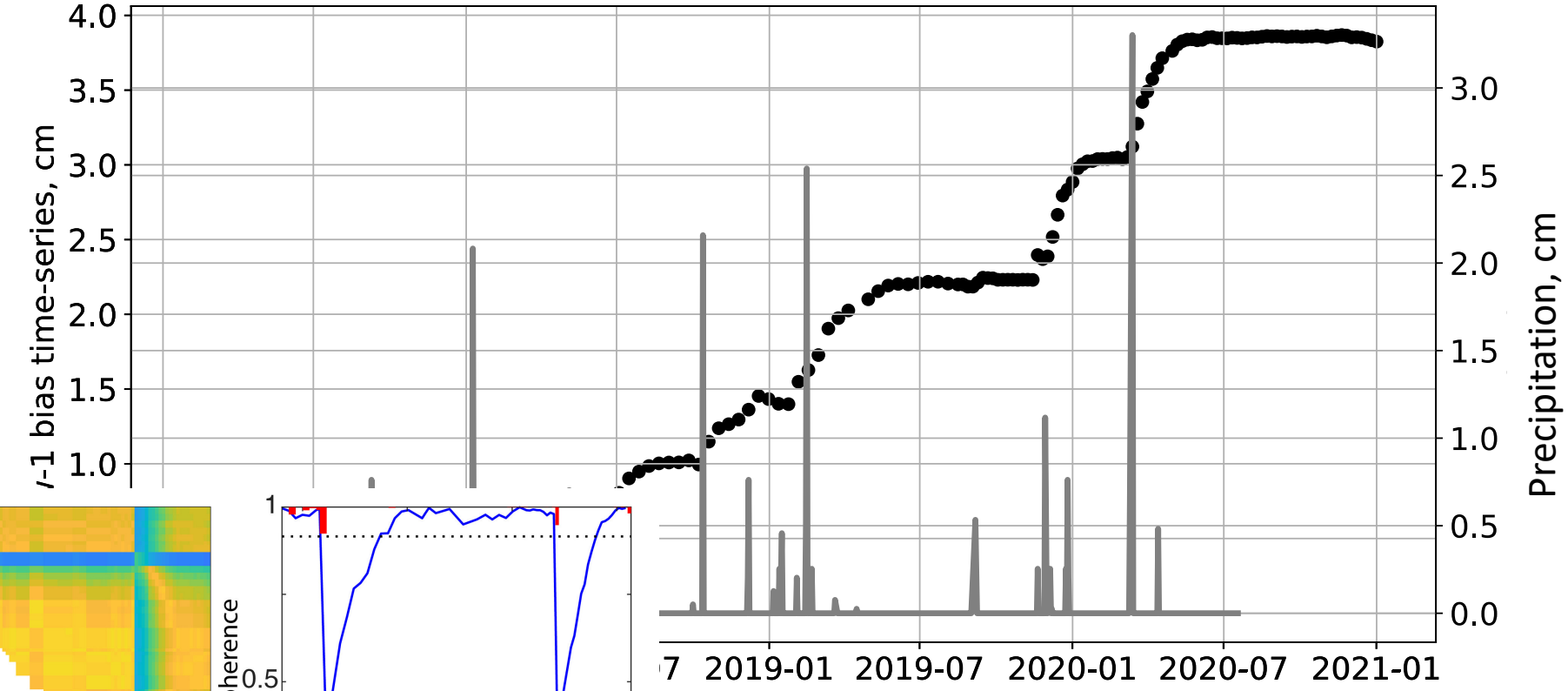


Bias time-series correlate with cumulative precipitation



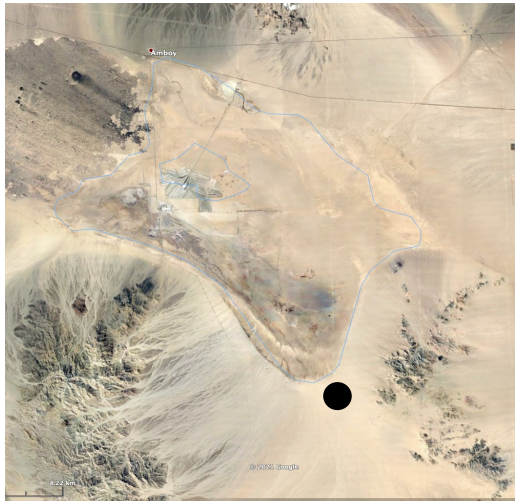
Bristol Dry lake, CA





Jordan et al., (2020). Surface materials and landforms as controls on InSAR permanent and transient responses to precipitation events in a hyperarid desert, Chile.

Bias time-series correlate with cumulative precipitation



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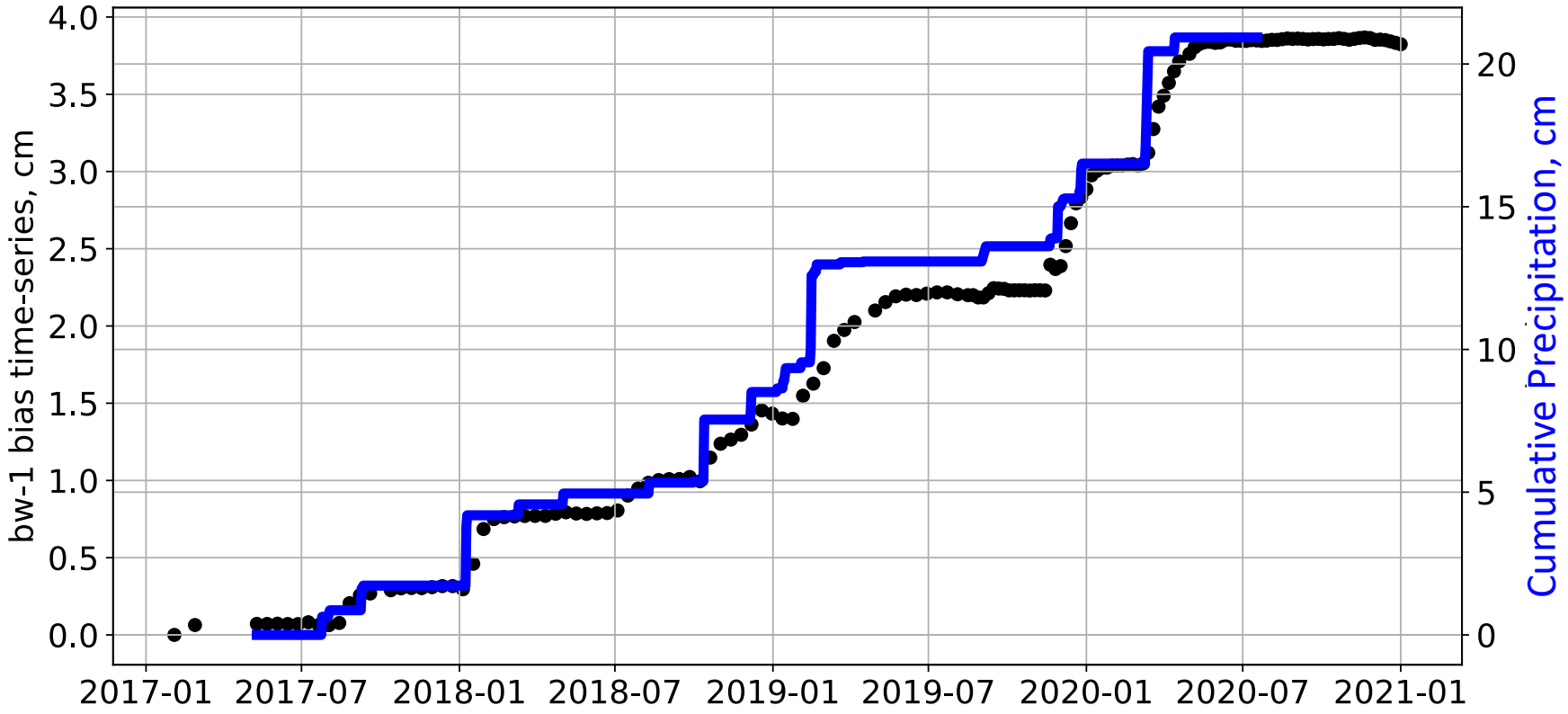
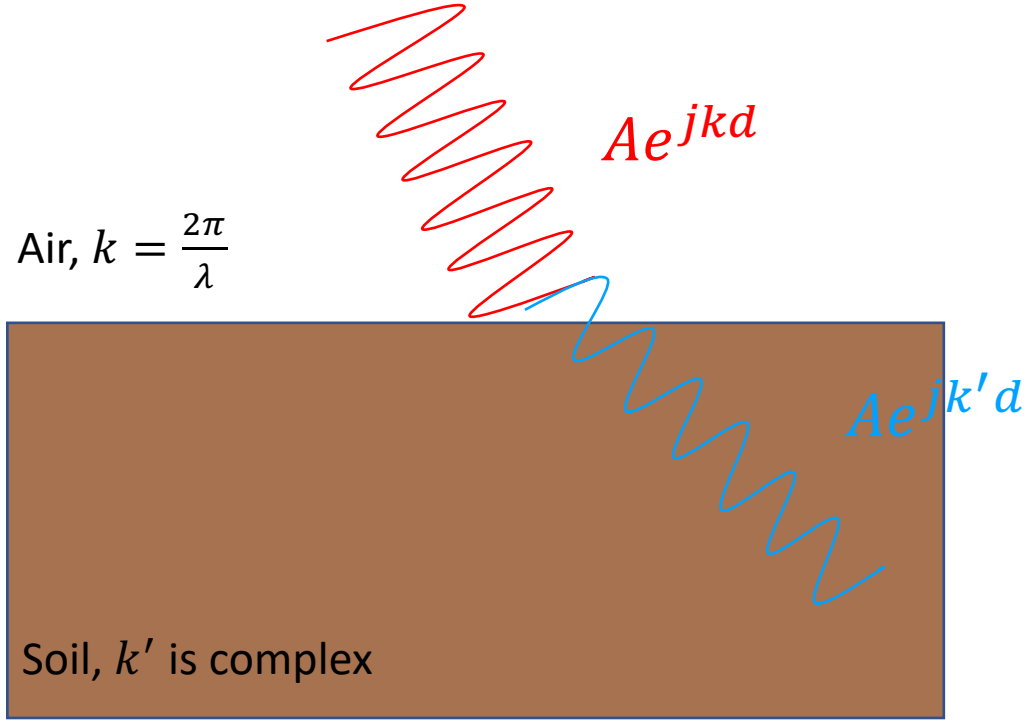


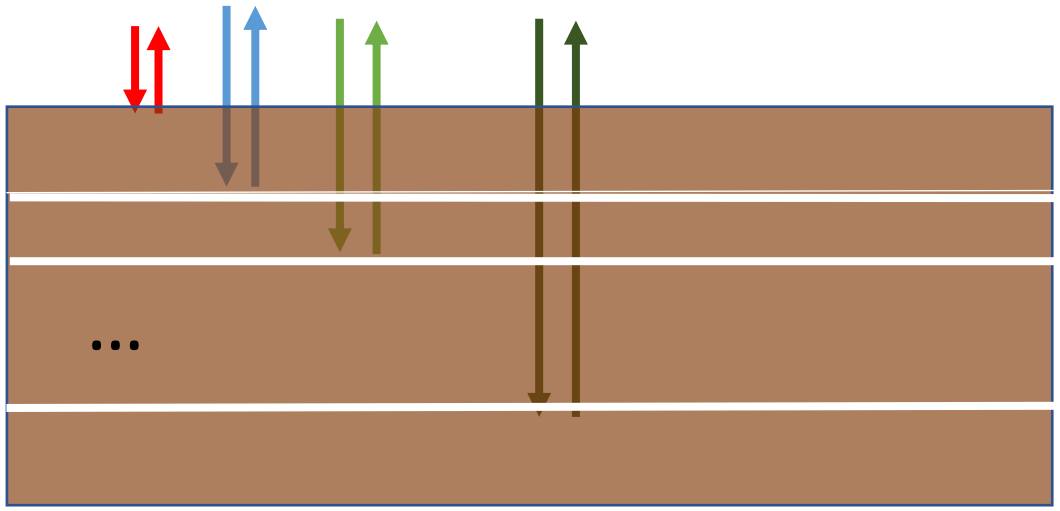
Closure phase bias: signal or noise?

It represents InSAR phase response to moisture variation in time ?

A discrete model for soil moisture



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

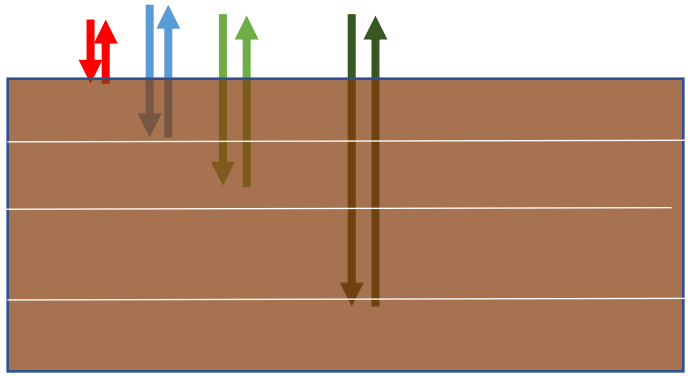


Discretized model for soil moisture

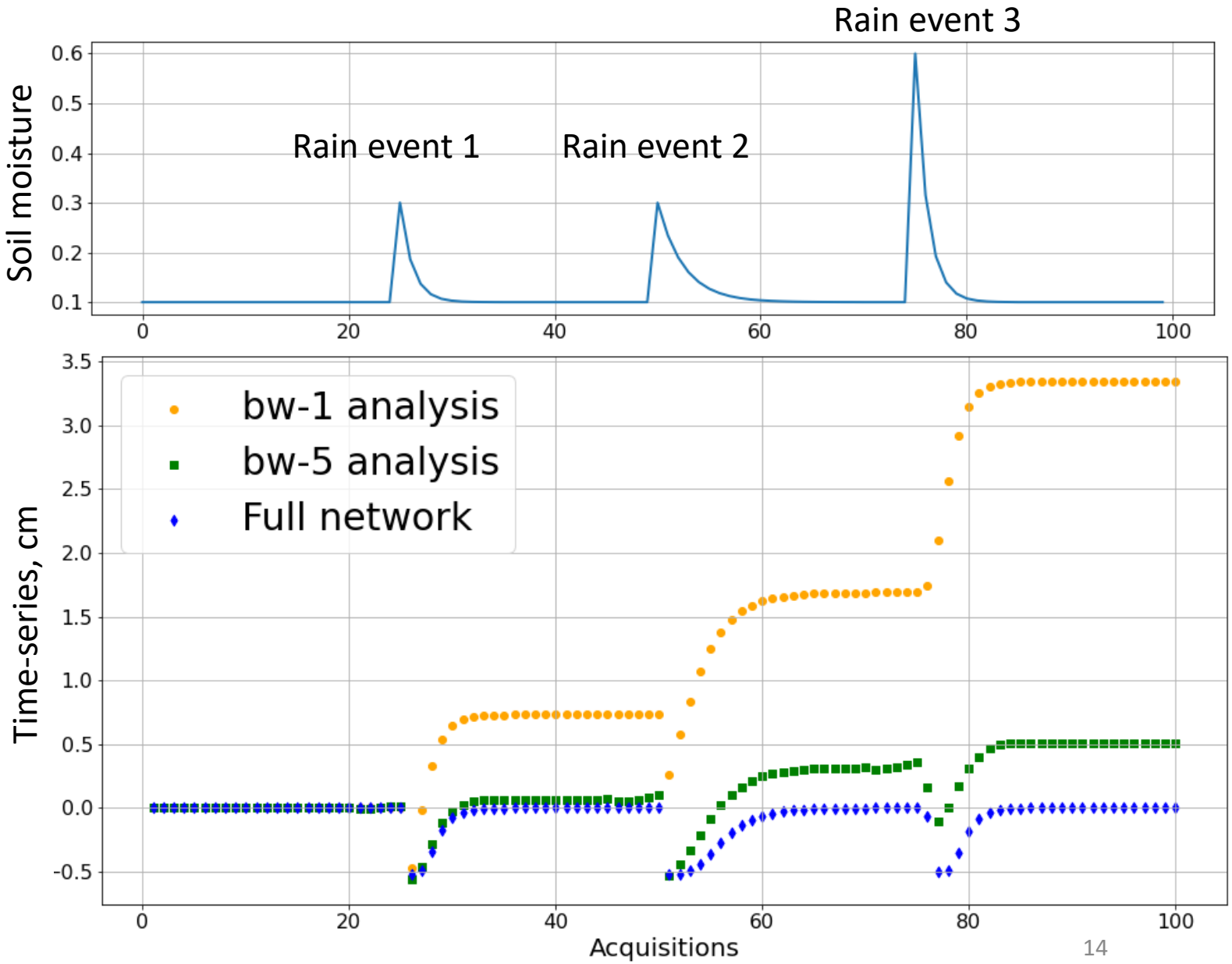
Closed form solution for interferometric phase only in simplified scenarios.

Easy to implement for numerical simulation. Can start from single-look radar return.

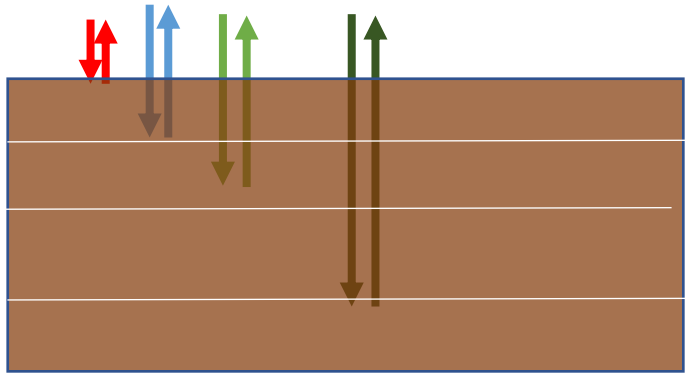
From soil moisture to closure phase bias : simulation



Step 1: Simulate 100 SAR acquisitions, each acquisition contains 200 pixels
Step 2: Form interferograms and multi-look by 200
Step 3: Time-series analysis of different bandwidth



From soil moisture to closure phase bias : simulation



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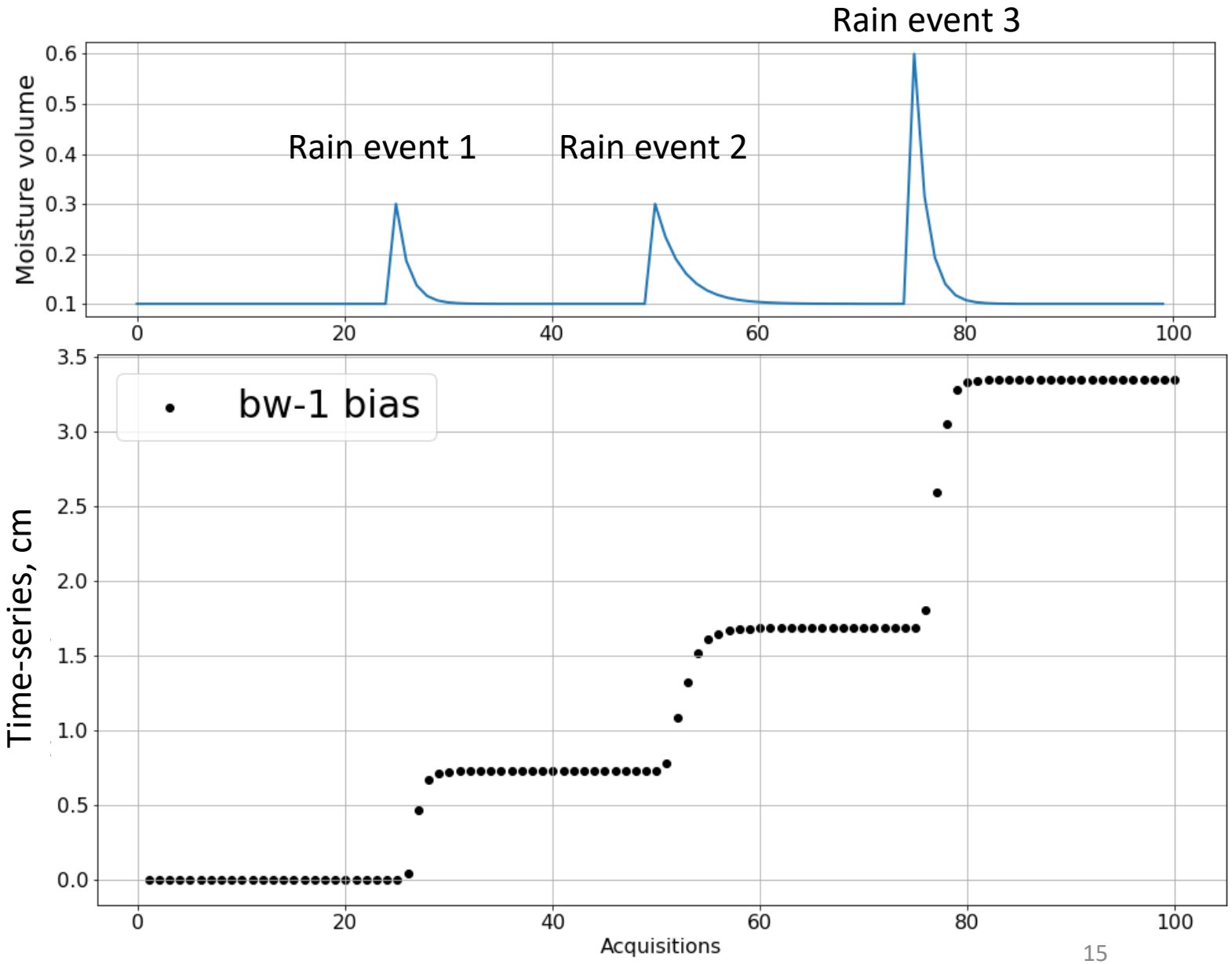
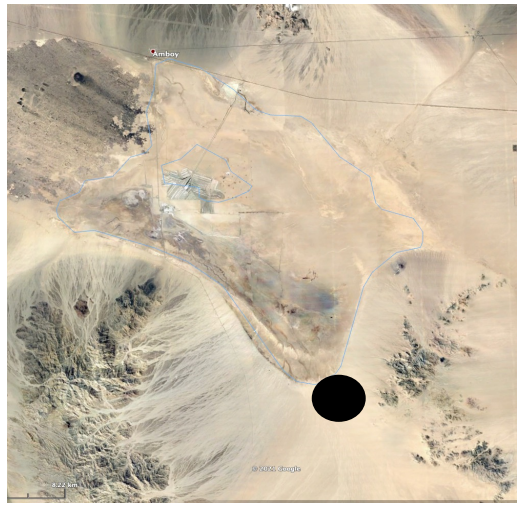


From closure phase bias to soil moisture ? [Work in progress]



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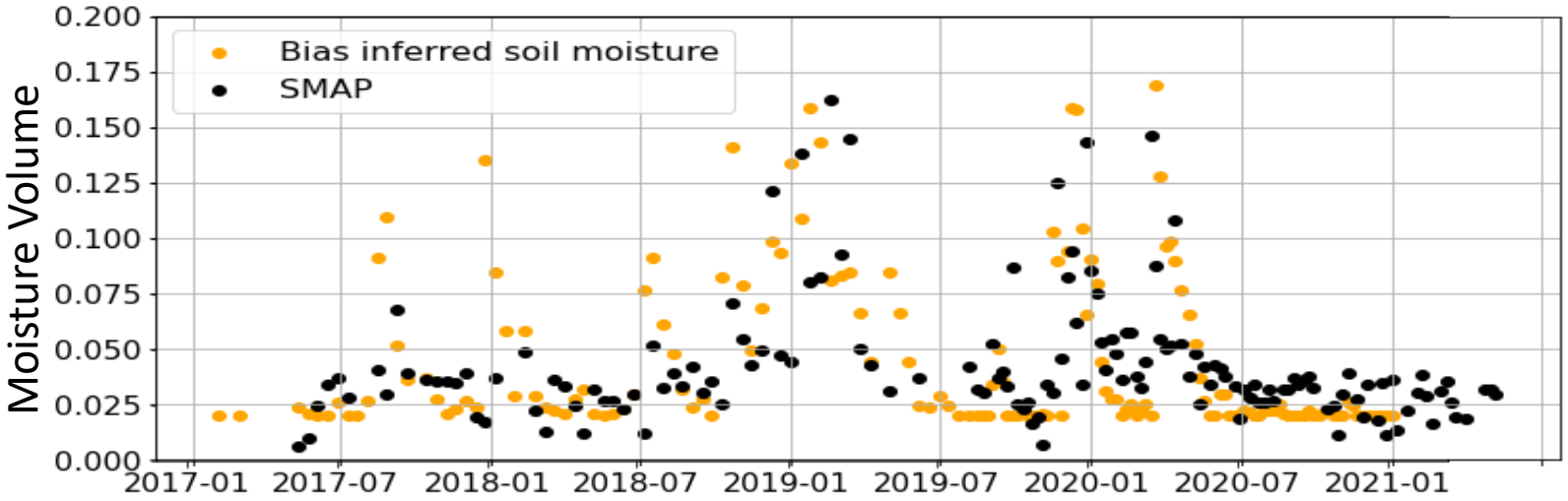

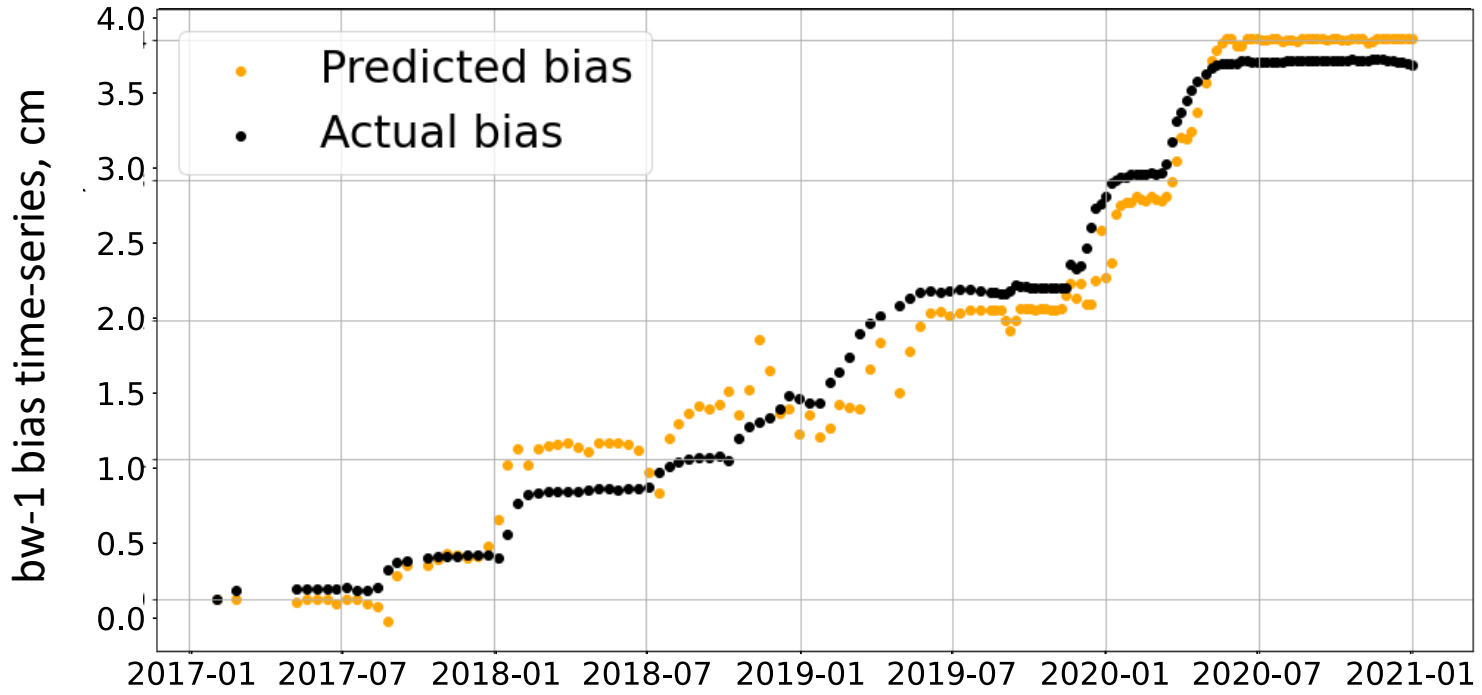

and

Closure phase bias: signal ~~or~~ noise?

It is noise in the context of deformation modeling.

Zheng et al., (2022), On Closure Phase and Systematic Bias in Multi-looked SAR Interferometry

Code:
https://github.com/insarlab/MintPy/blob/main/mintpy/closure_phase_bias.py
Tutorial (Jupyter notebook)
https://github.com/insarlab/MintPy-tutorial/blob/main/applications/closure_phase_bias.ipynb

Closure phase bias: signal ~~or~~ and noise?

It represents InSAR phase response to moisture variation.

InSAR is known to be sensitive to soil moisture in terms of :

- Amplitude
- Coherence
- Phase
  - Triplets
  - Closure phase bias time-series

Future looks very promising!