Recursive and robust InSAR Phase Estimation

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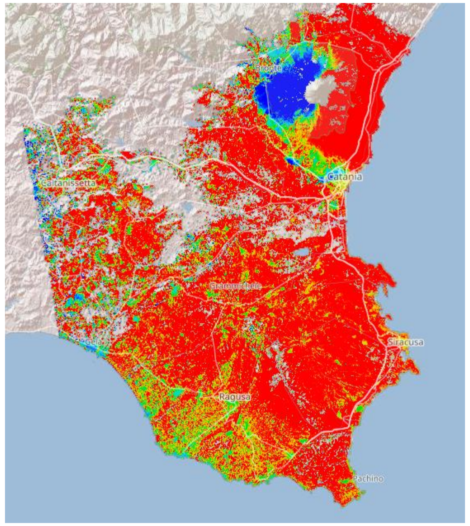
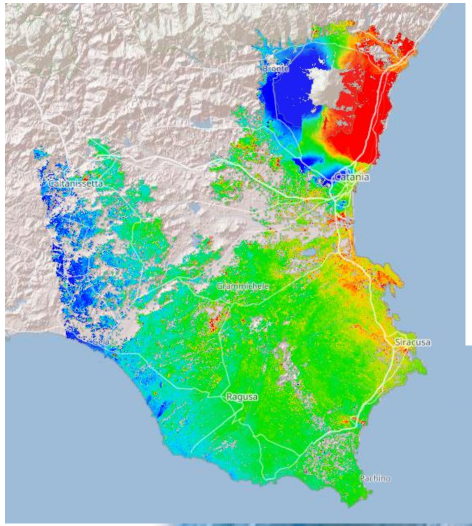
Closure phases and mean velocity biases

- 2015, TGRS, *Phase inconsistencies and multiple scattering in SAR interferometry*
  - Closure phase are among us, just compute them!
  - We predicted the existence of biases in InSAR deformation products

- 2020, TGRS, *Study of Systematic Bias in Measuring Surface Deformation with SAR Interferometry*
  - Sentinel-1 (C-band) data over Sicily (Italy)
  - Different temporal bandwidth for interferograms (~30 days, ~60 days, ~4 years)
  - We've observed different mean-velocity bias (**3-6 mm/yr**)
  - The bias depends on the temporal baseline (longer temporal baselines are less affected)





Deformation rate	Bias wrt PS's (mm/year)	Dispersion wrt PS's (mm/year)
Band 5 (~30 days)	**-6.50**	2.58
Band 10 (~60 days)	**-3.05**	1.55
Full covariance	**-0.24**	0.70

Phase estimation algorithms

Once could just recommend covariance-based algorithms

- Phase linking (Tebaldini 2008), EMI (Ansari 2018), …

or adding some long-span interferograms (Doin)

or de-biasing solutions

- Zheng 2022, Maghsoudi 2022

and proceed with feeding the phases to a e.g. PS-like chain to derive deformation products

However… this is not fully satisfying, as we would like to have:

- <u>Continuous updates</u> for a phase product (Analysis Ready Product)
- <u>Automatic long-term stability & short term quality</u>

I'm trying to develop a new approach

- Generation of simple interferograms
- Linear combination ("filtering") of acquisitions in time
- Recursive implementation
- Special care for long-term phase quality

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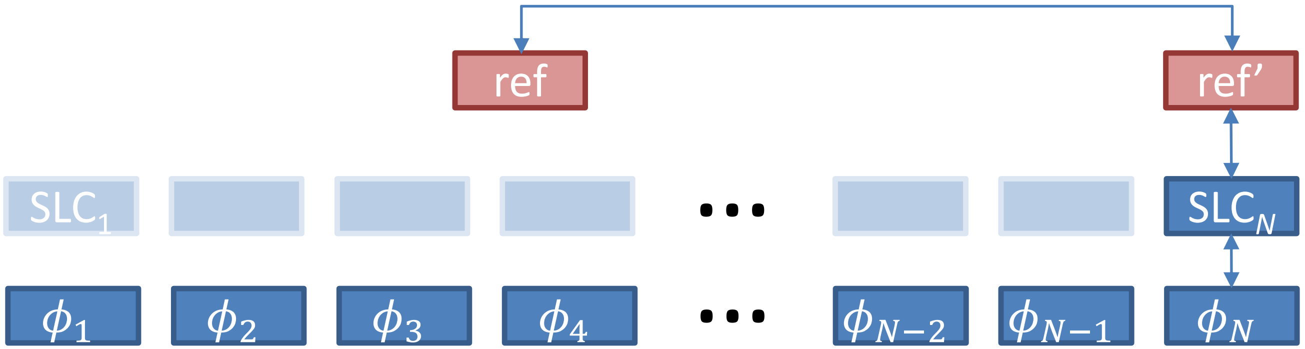
Recursive InSAR Phase Estimation

- A new phase estimation algorithm
  - Simple & Fast
  - Minimal I/O requirements



$\phi_N = \angle \langle SLC_N, ref' \rangle$

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Recursive InSAR Phase Estimation

- A new phase estimation algorithm
    - Simple & Fast
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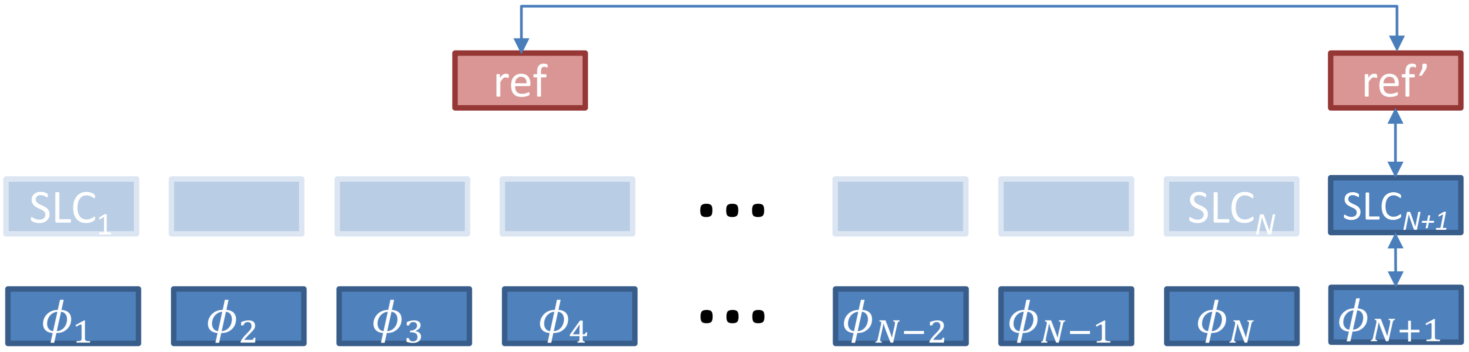


$\phi_{N+1} = \angle \langle SLC_{N+1}, ref' \rangle$

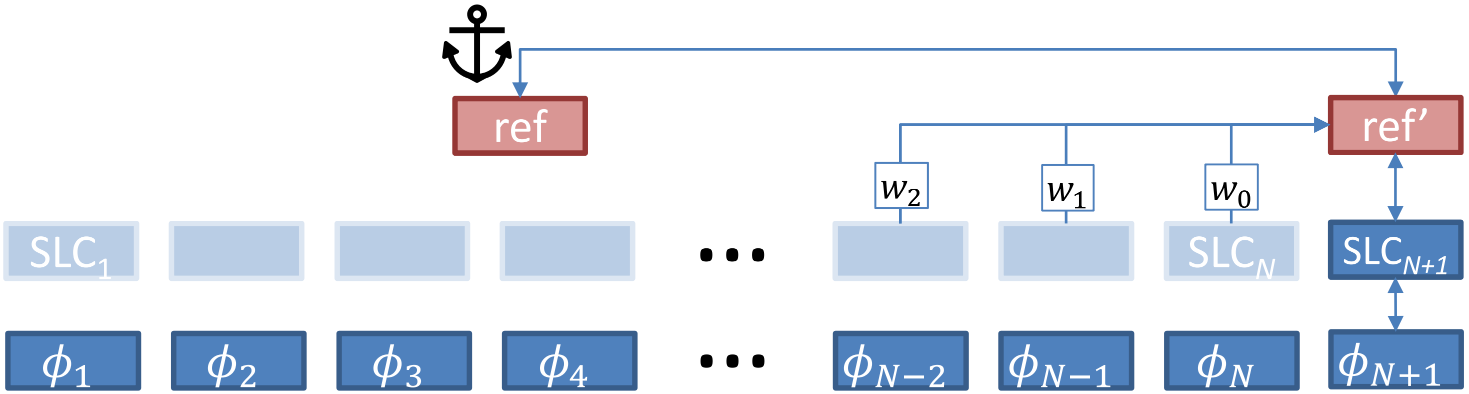
Recursive InSAR Phase Estimation

- A new phase estimation algorithm
  - Simple & Fast
  - Minimal I/O requirements
  - Good short-term quality (like 6-day interferograms)
  - Good long-term quality (like full covariance)

$\varphi = \angle\langle ref', ref\rangle$

$ref' \leftarrow ref' \cdot \exp(-j\,\varphi)$

$ref' \leftarrow w \cdot ref' + SLC_N \cdot \exp(-j\,\phi_N)$

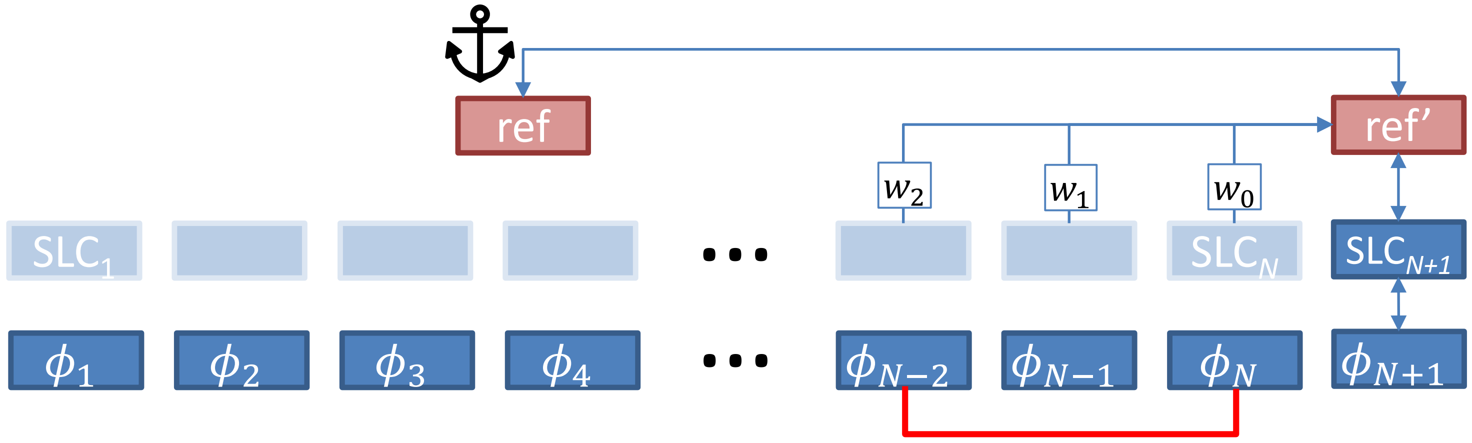


Usage of phase product

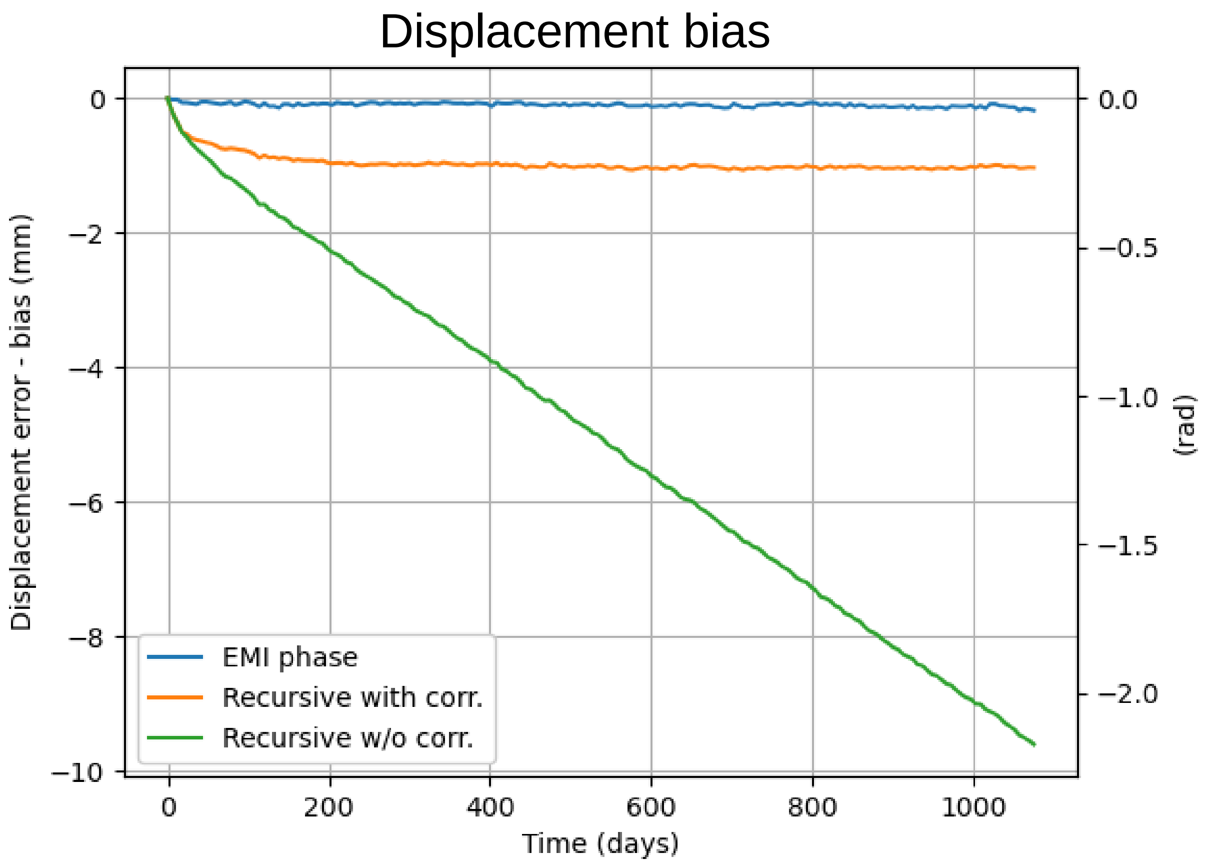
- Nominally, all interferograms are referred to the same reference
- Computing any "interferogram" is easy:

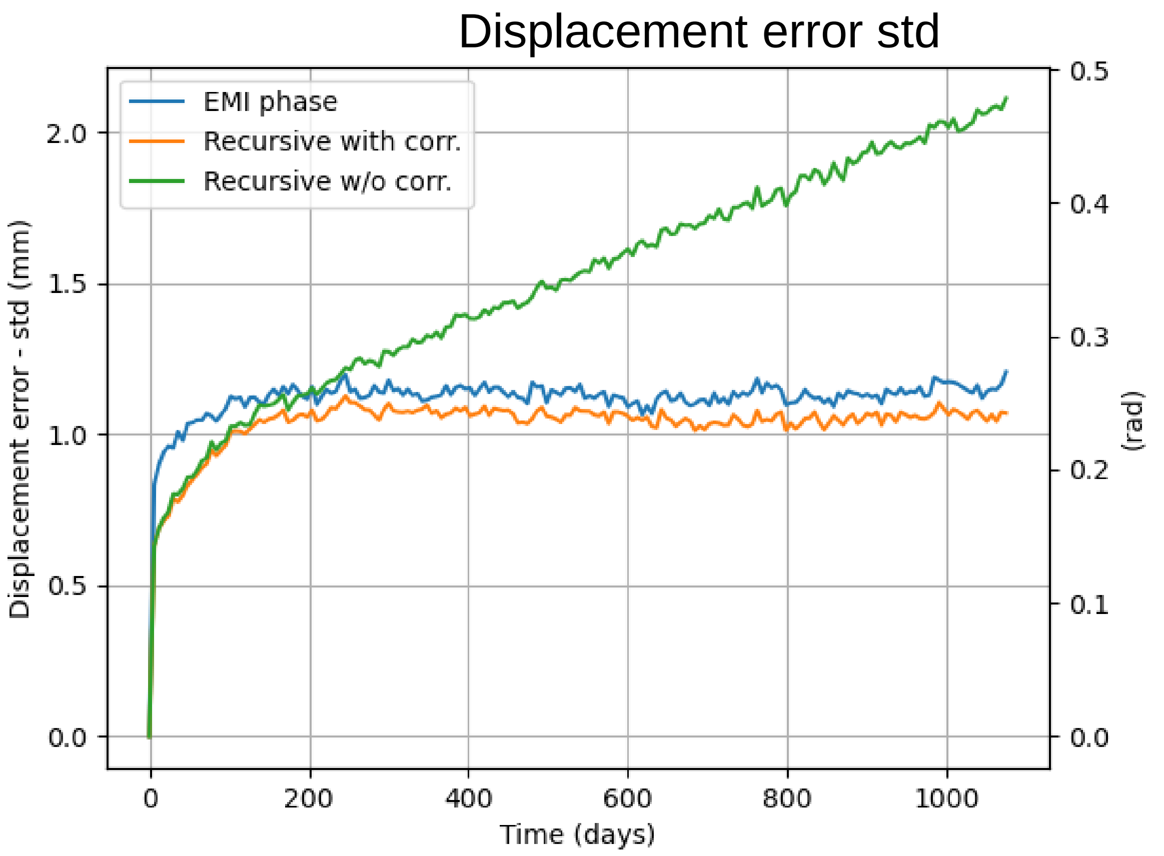
$$\phi_{ab} = \phi_a - \phi_b \pmod{2\pi}$$

- Users will still have to do the phase unwrapping
- Long- and short-term coherence as quality measures

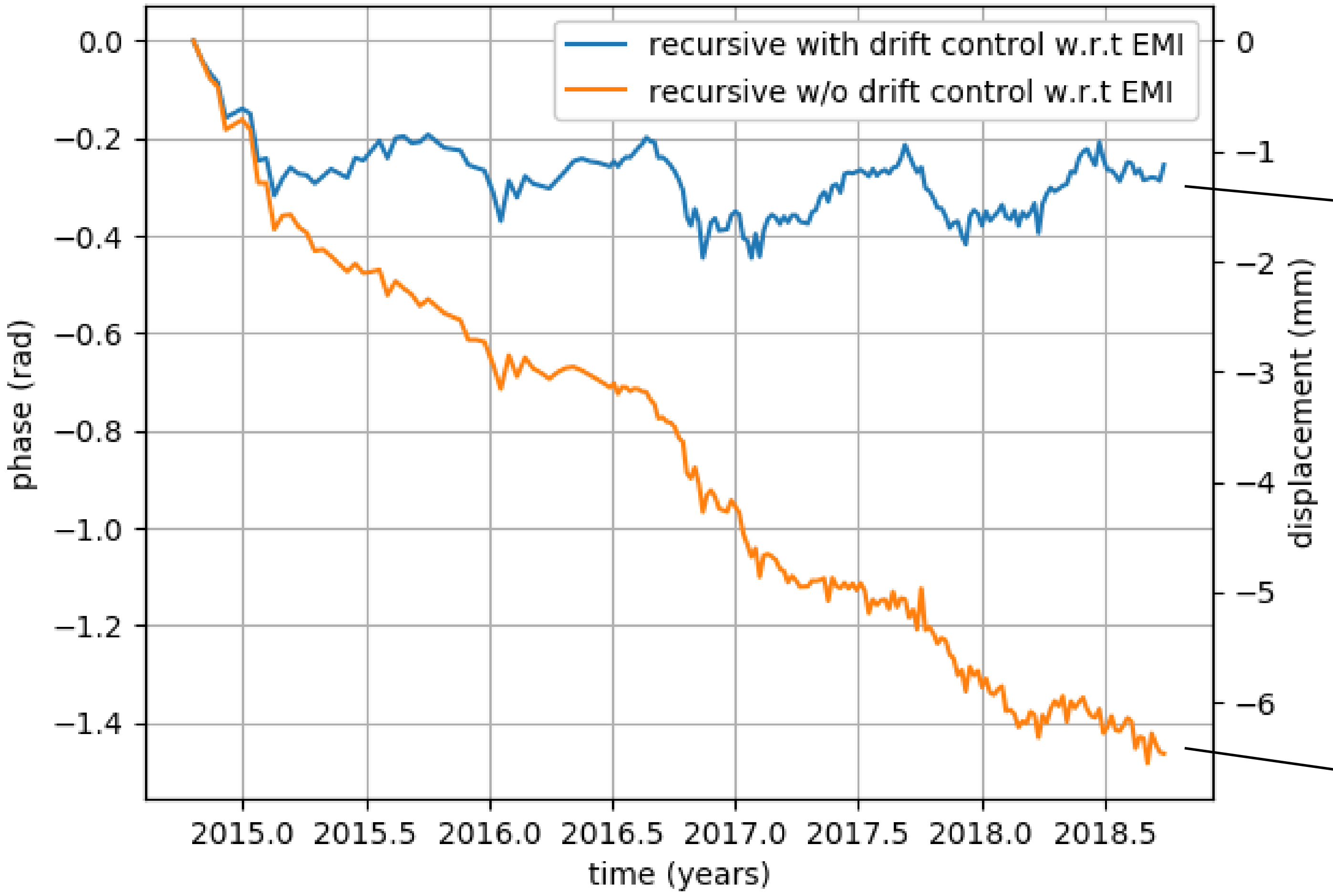


Simulations based on complex coherence model

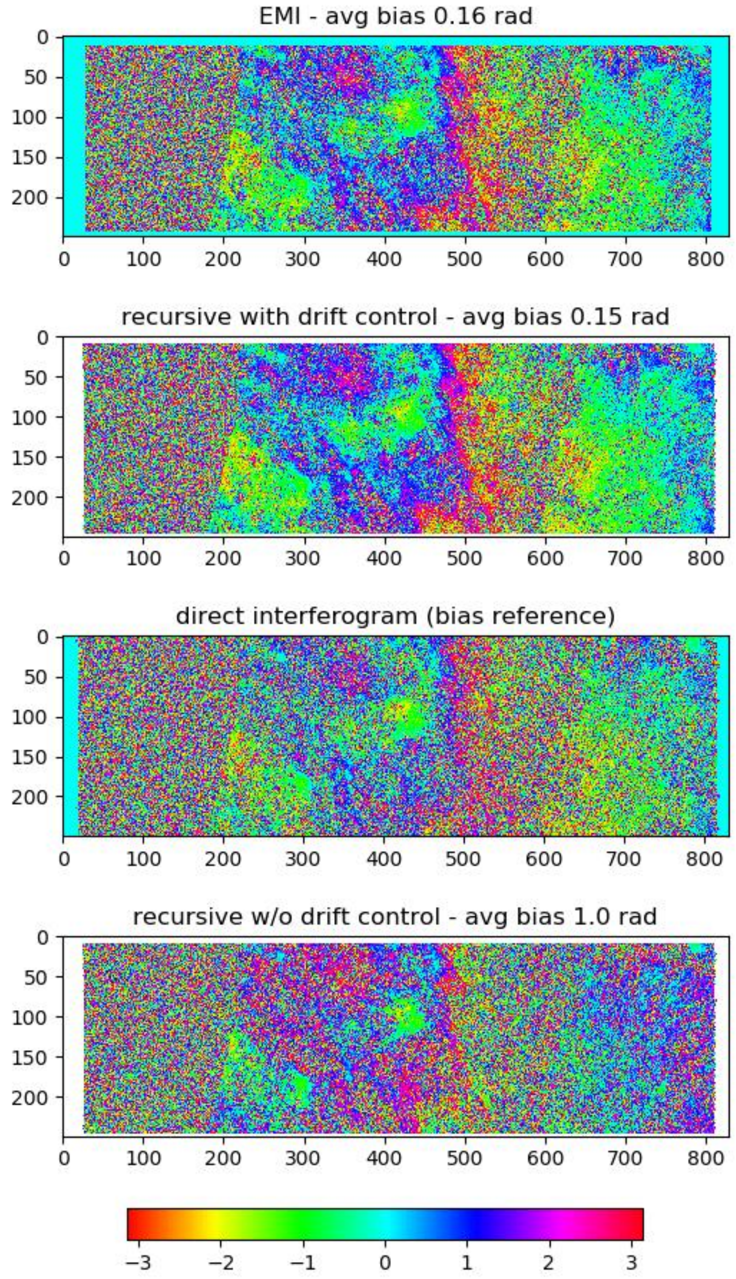




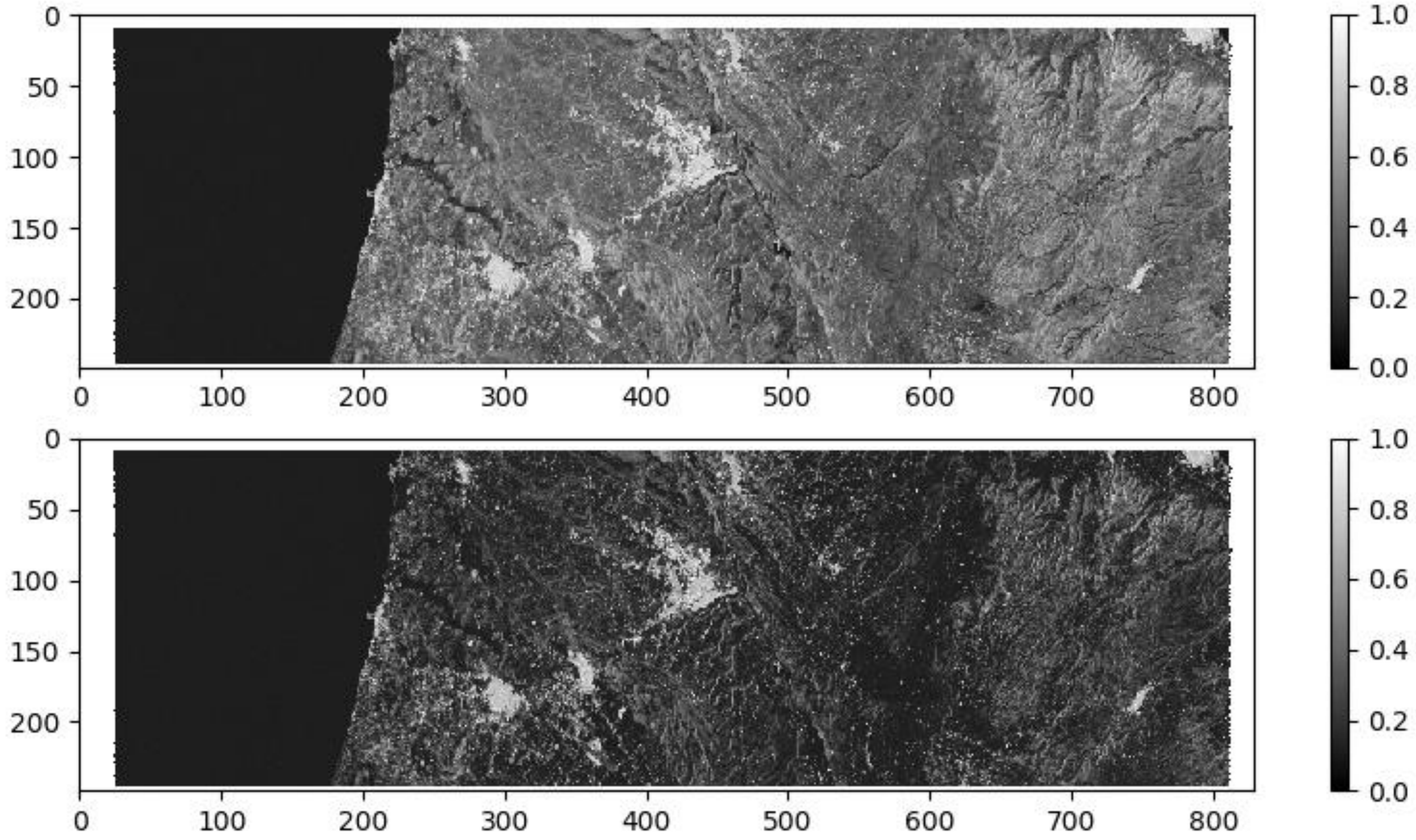
RIPE with and w/o anchoring



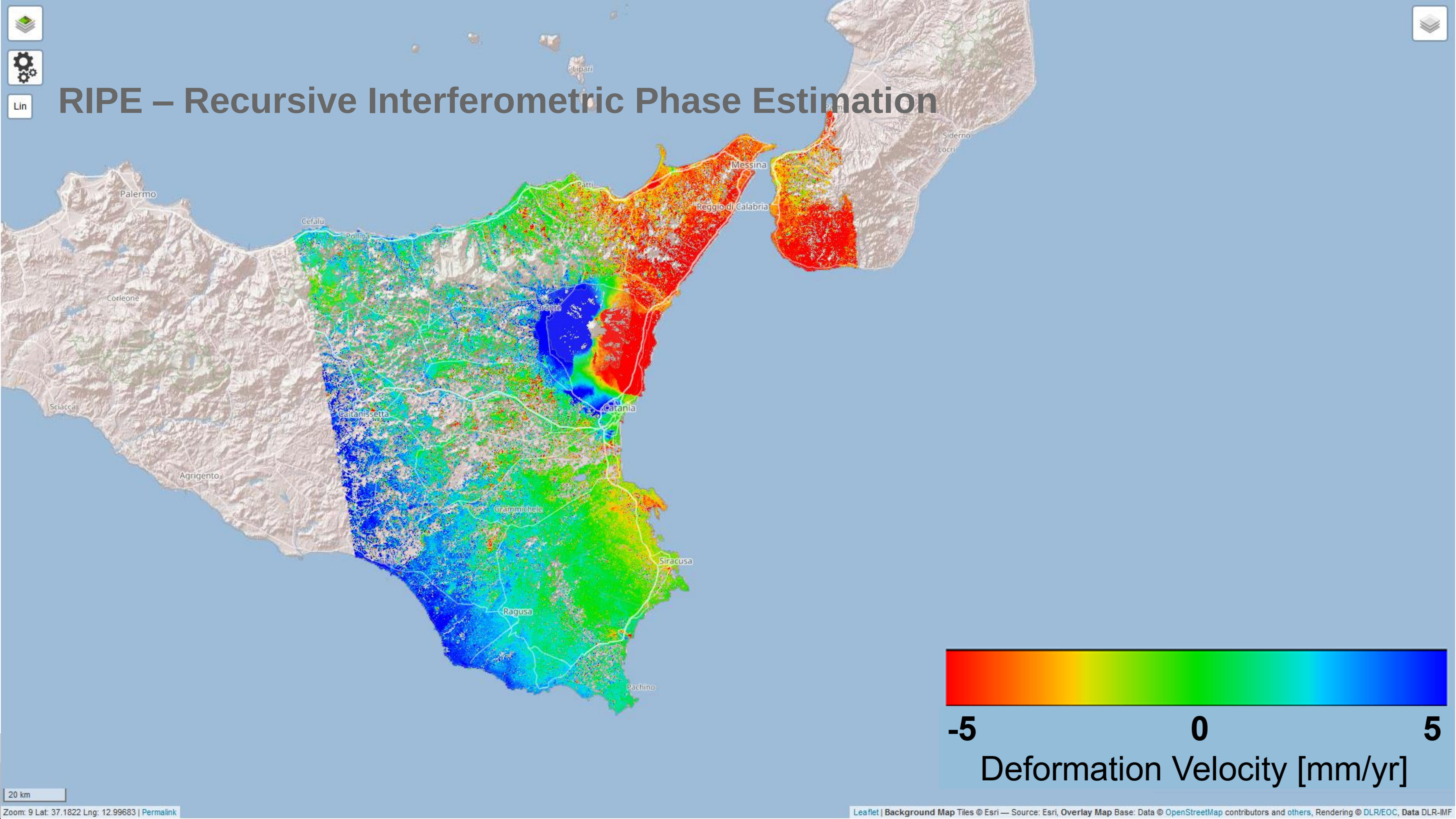
Temporal separation 1032 days



Short-term (top) and long-term coherence (bottom)

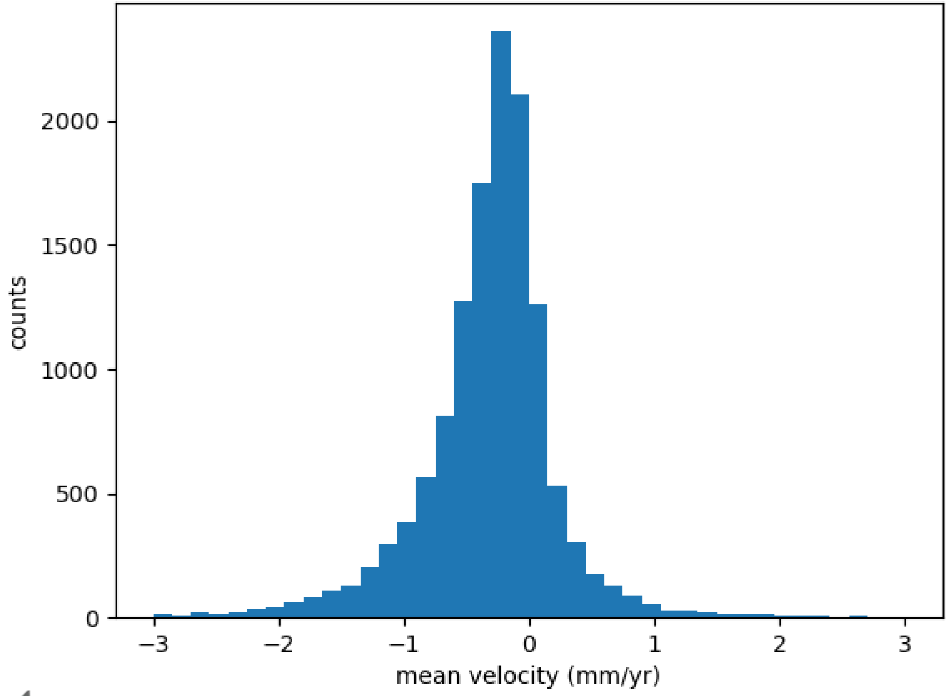


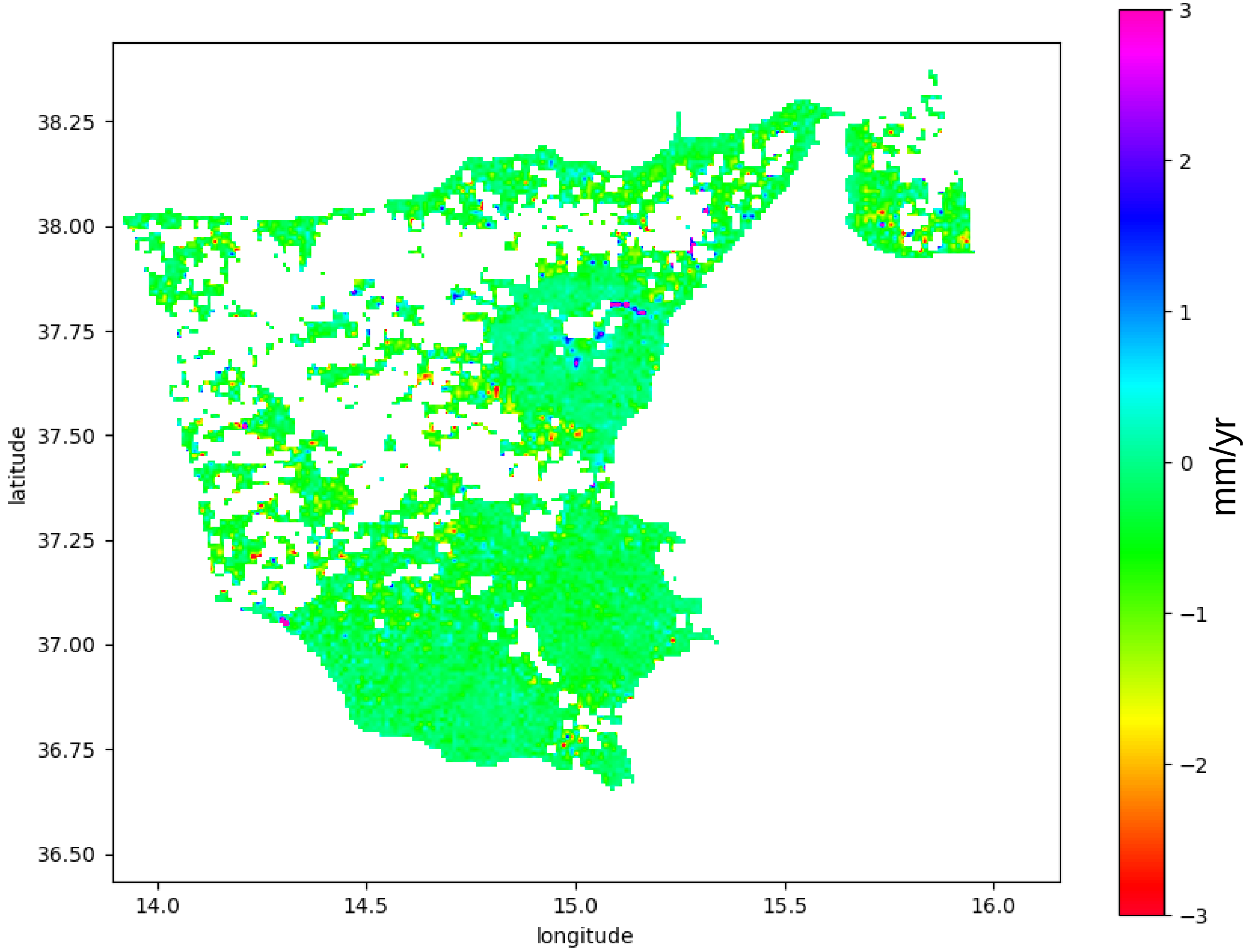
RIPE – Recursive Interferometric Phase Estimation



DS - PS mean velocity difference

- Average difference: -0.32 mm/yr
- Comparable to using full stack (-0.24 mm/yr for DS)
- It might be possible to reduce it further
- It’s going to be smaller with longer time series





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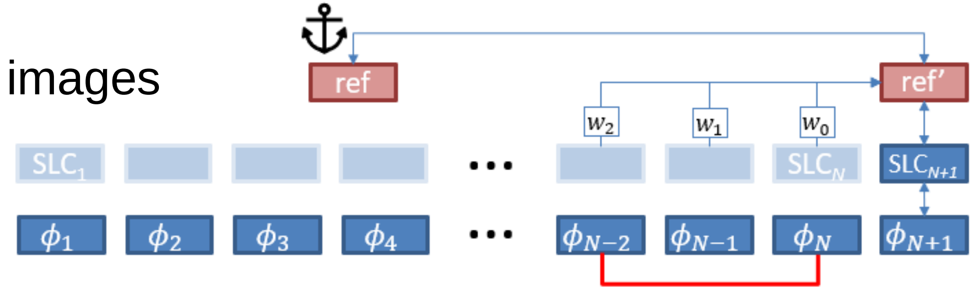
Towards an phase product

- Test and tune algorithm on different climates and land covers
- Design for forward compatibility with ESD, split-spectrum, etc.
- Probe product usability, users of this intermediate product should “just” unwrap the phases

To conclude…

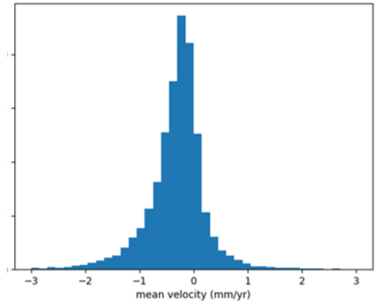
- New algorithm based on interferograms and linear combination of images
    - No covariance matrix
    - It’s possible to give continuous updates



- A recursive formulation minimizes the storage and I/O needs

$$\text{ref}' \leftarrow w \cdot \text{ref}' + SLC_N \cdot \exp(-j\,\phi_N)$$

- The algorithm tackles explicitly
    - Short term coherence
    - Long term stability (small velocity bias w.r.t. PS’s)



- The results on simulated and real data are meaningful