The Impact of Closure Phases on InSAR Processing

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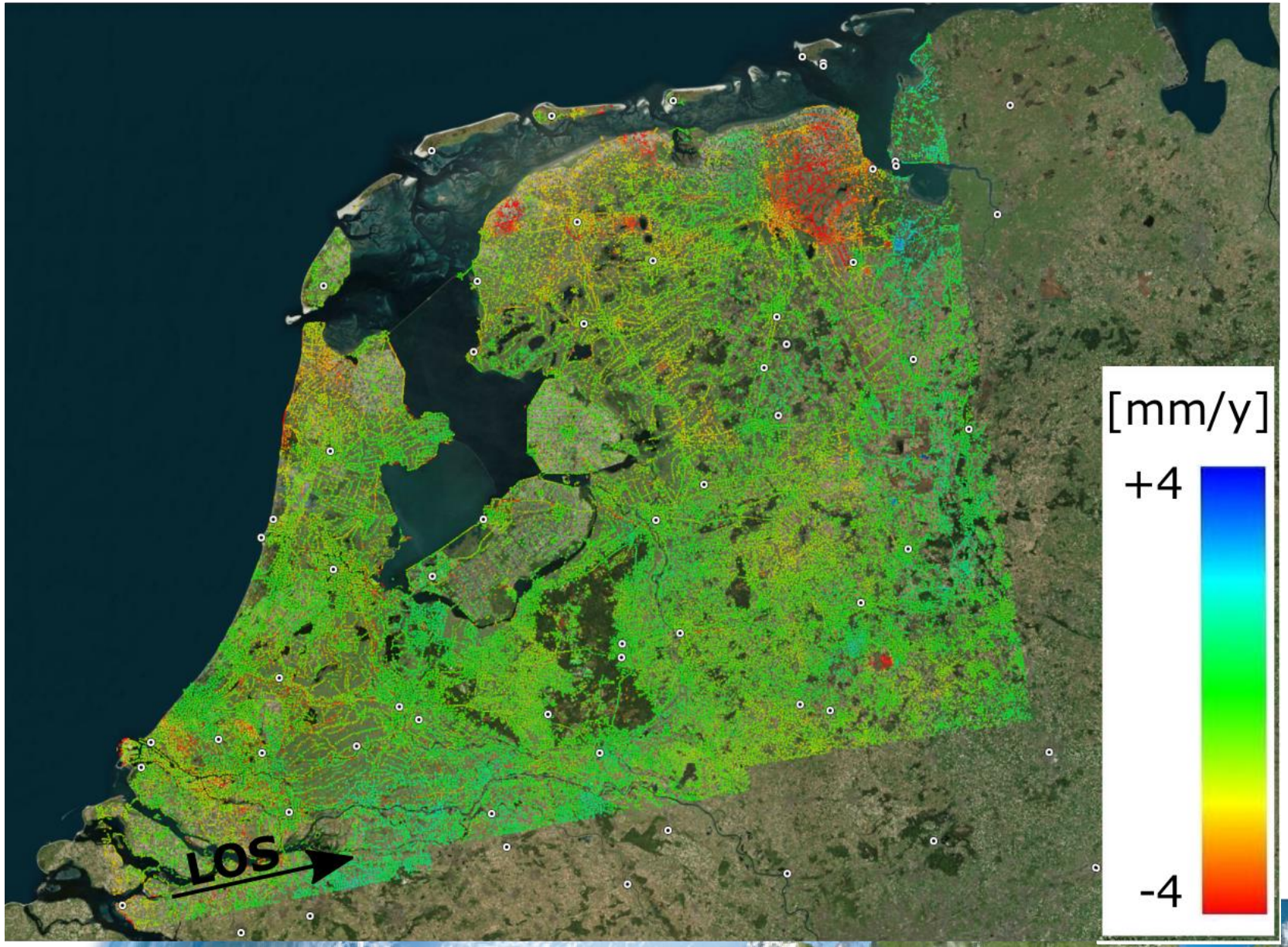
PSI vs. GPS std: 0.86 mm/yr

We can reach 1 mm/yr at 100's km with S1 by correcting

- Troposphere (ERA-5)
- Ionosphere
- Solid Earth tides



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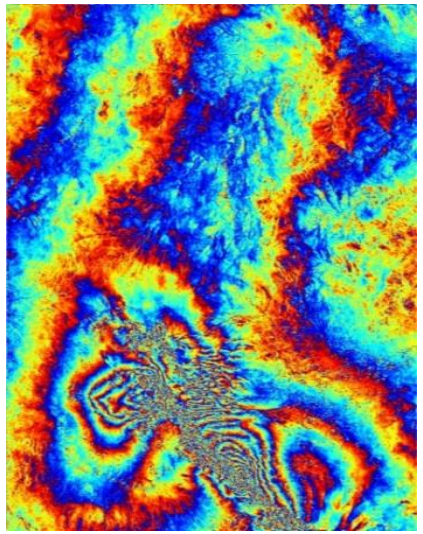
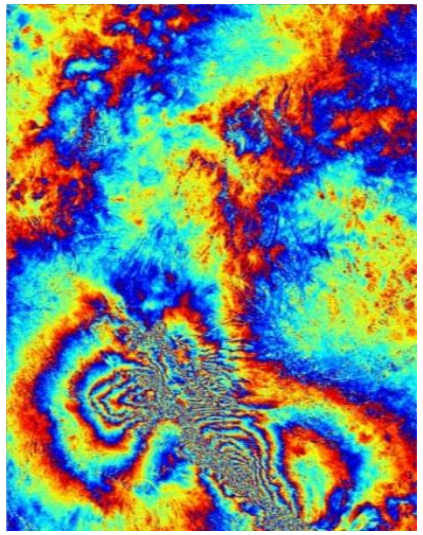
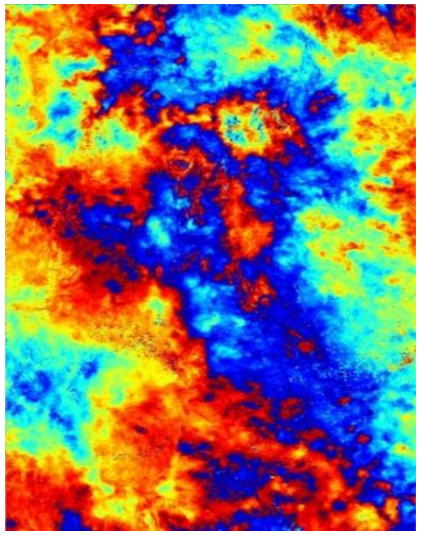
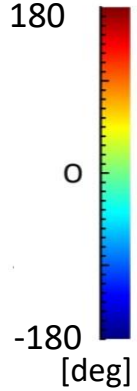
Interferograms vs. closure phase

3 images
3 interferograms

ϕ_{12} 

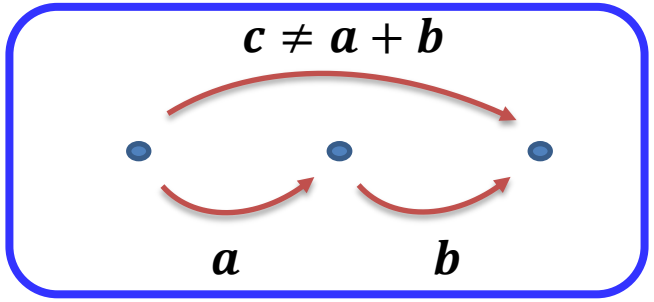
ϕ_{23} 

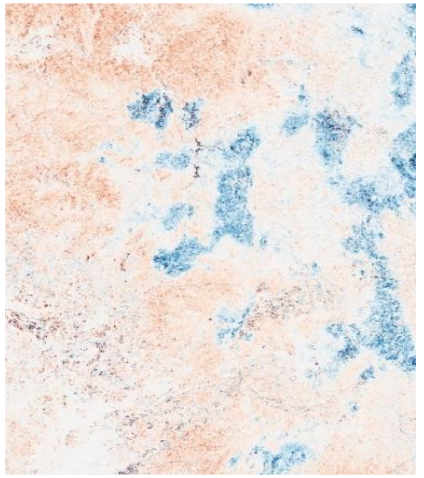
ϕ_{31} 

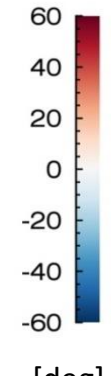


1 closure phase

$$\Phi_{1,2,3} = \operatorname{atan} \exp[j(\phi_{12} + \phi_{23} + \phi_{31})]$$



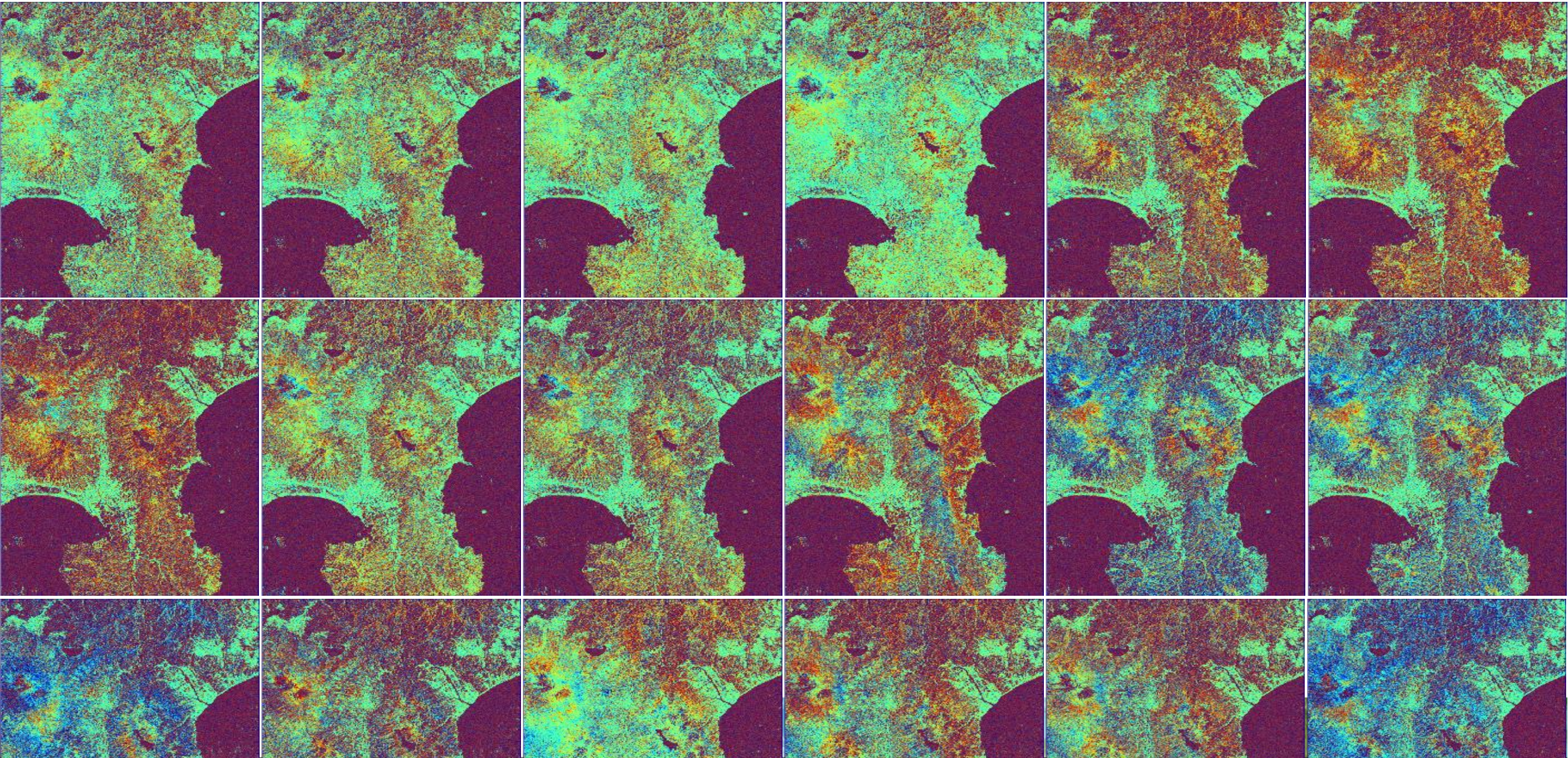




Mis-closures “require” spatial averaging!

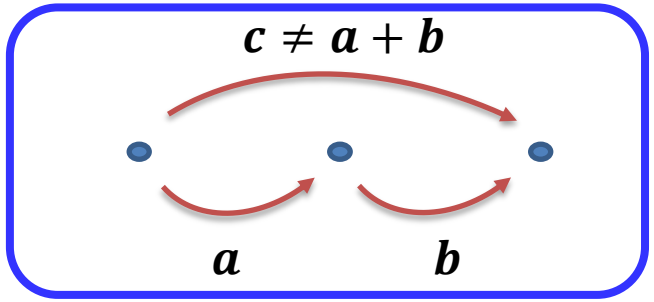
F. De Zan, M. Zonno and P. López-Dekker, "*Phase Inconsistencies and Multiple Scattering in SAR Interferometry*," in *IEEE Transactions on Geoscience and Remote Sensing*, 2015.

Mts. Hakone & Fuji (Japan), ALOS-2, 2014-2015
Closure phase +/- 40 deg



Interferometric phases and velocities are biased

- The presence of closure phases implies a **path dependency** in the temporal integration



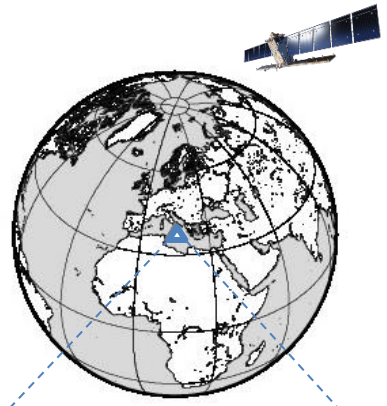
- Presence of **systematic closure phases** means that
  - the interferometric phases are biased, at least some of them
  - velocity estimates are biased

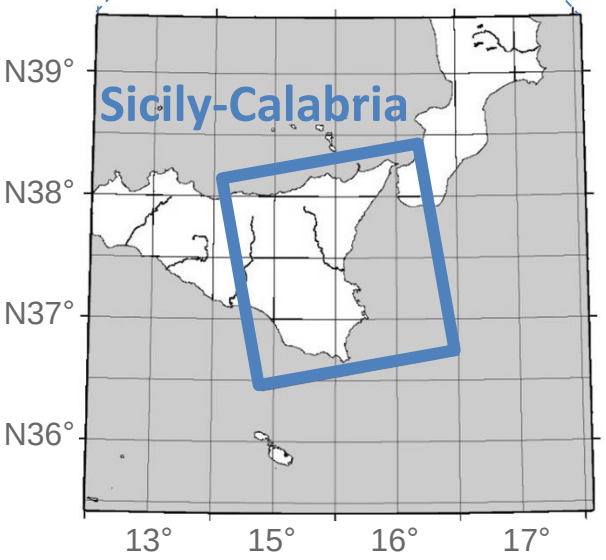
- We now know that **short term** interferograms are the culprit!

Performance Comparison Study

Data set:

Sentinel-1 A/B time series	: IW mode
acquisition time span	: 4 years (Oct. 2014-Sep. 2018)
size of the time series	: 184 SLCs
extent of the chosen area	≈ 30,000 km²





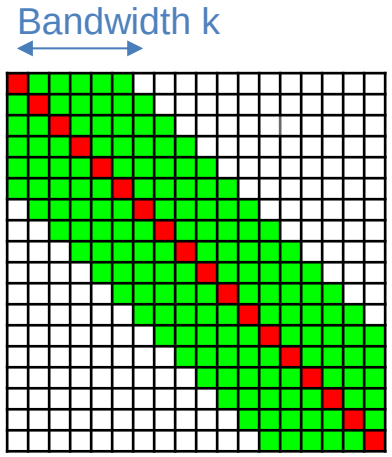
Benchmark: Persistent Scatterer Interferometry (PSI)

versus

StBAS Bandwidth **5**

StBAS Bandwidth **10**

EMI Full Covariance



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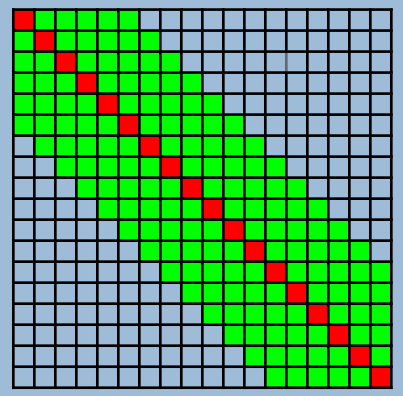
Mount Etna

Reference Point

Syracuse

Ragusa

StBAS
Bandwidth 5
905 Interferograms



-5 0 5

Deformation Velocity [mm/yr]

DLR Deutsches Zentrum für Luft- und Raumfahrt

20 km

Lat: 36.62214 Lng: 18.94867

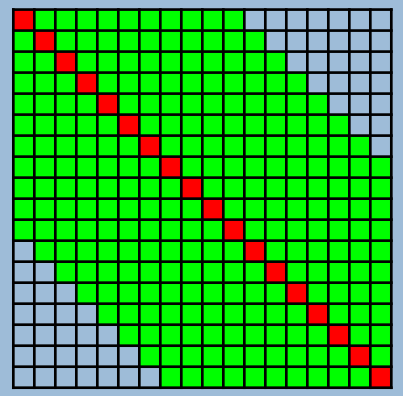
Mount Etna

Reference Point

Syracuse

Ragusa

StBAS
Bandwidth 10
1785 Interferograms



-5 0 5

Deformation Velocity [mm/yr]

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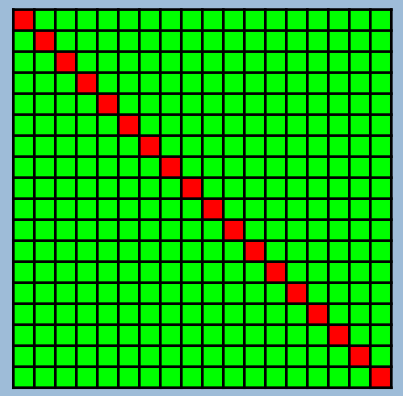
Mount Etna

Syracuse

EMI
Full Covariance
16836 Interferograms



Deformation rate	Bias wrt PS's [mm/year]	Dispersion wrt PS's [mm/year]
Band 5	-6.50	2.58
Band 10	-3.05	1.55
Full Stack	-0.24	0.70

-5 0 5

Deformation Velocity [mm/yr]

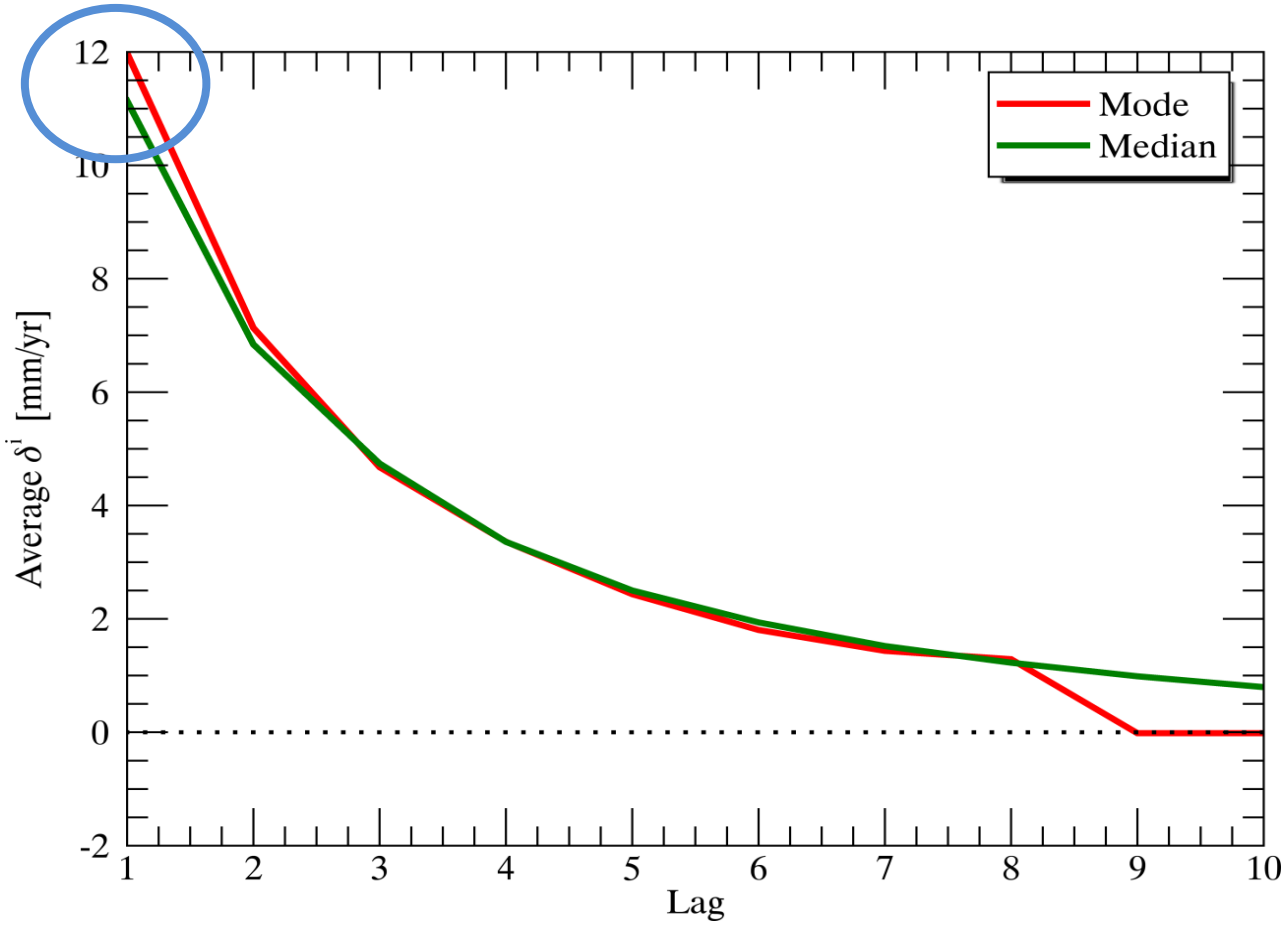
DLR Deutsches Zentrum für Luft- und Raumfahrt

20 km

Lat: 36.62214 Lng: 18.94867

Bias for each lag: (multilooked interf. phase – full-cov phase)

≈ PS phase



12 mm / 365 days * 6 days = 0.2 mm = 2.6 deg

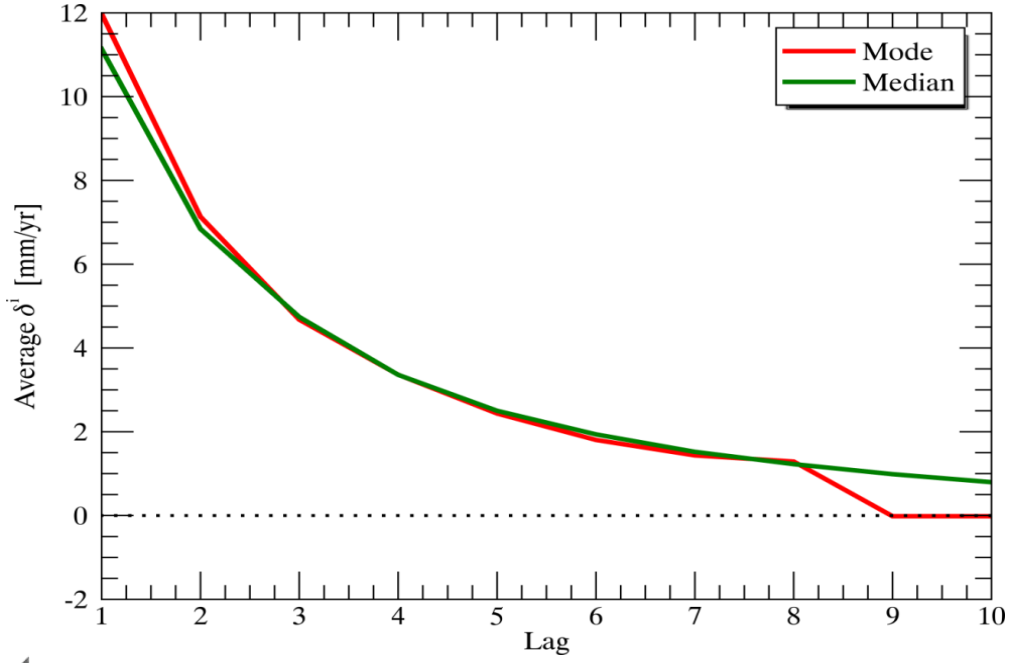
$\text{Lag}-1 \approx 6$ days
$\text{Lag}-2 \approx 12$ days
…

Modeling the velocity bias

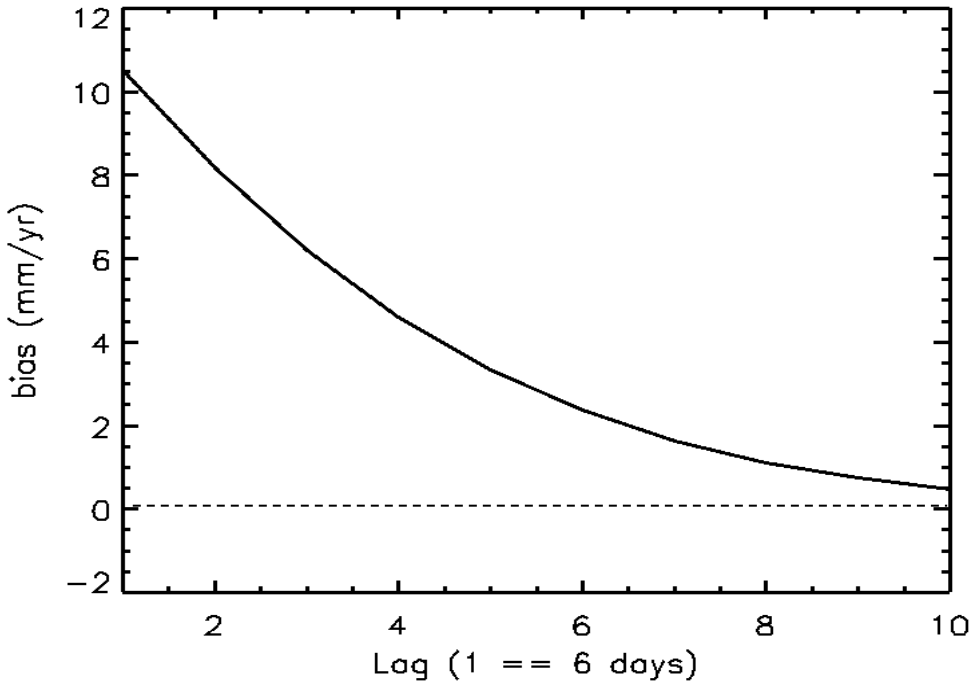
Complex coherence model $\gamma = 0.2 + 0.08 \cdot \exp(j \cdot 0.03 \cdot t) \exp\left(-\frac{t}{20}\right)$

Some scatterer (electrically) moving 0.1 mm / day **away** from the satellite

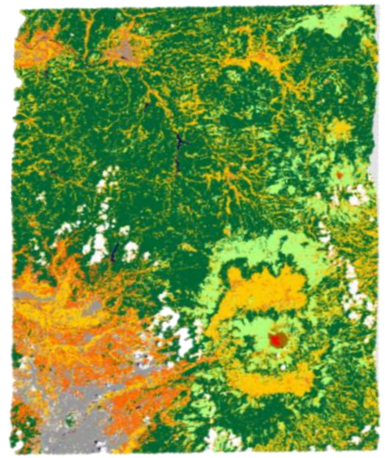
Observed velocity bias



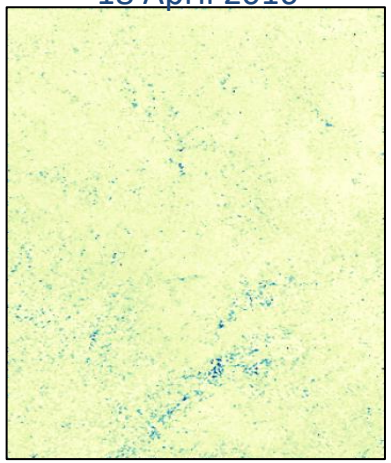
Modelled bias



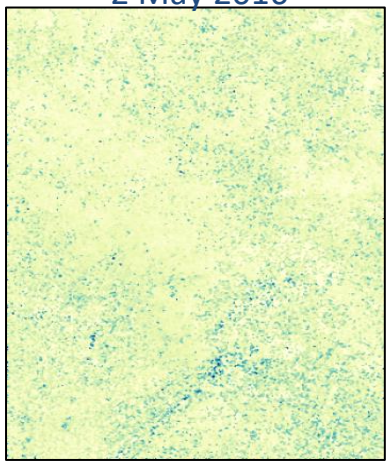
Moisture inversion (Kumamoto, ALOS-2)



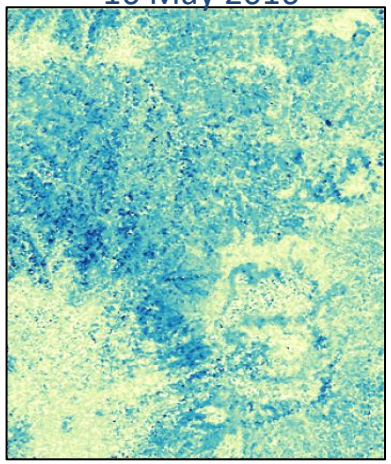
18 April 2016



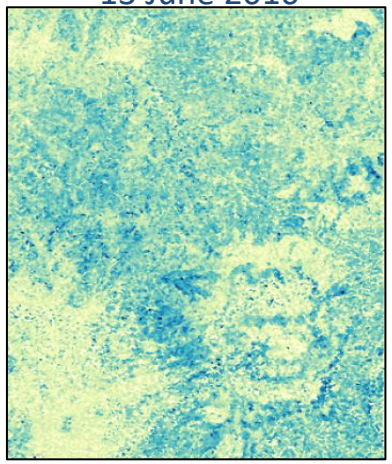
2 May 2016



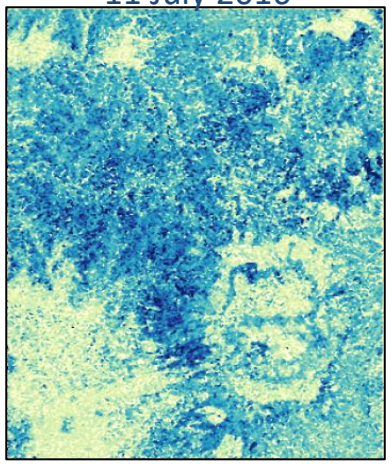
16 May 2016



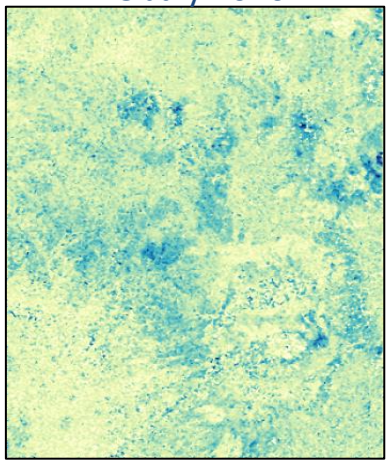
13 June 2016



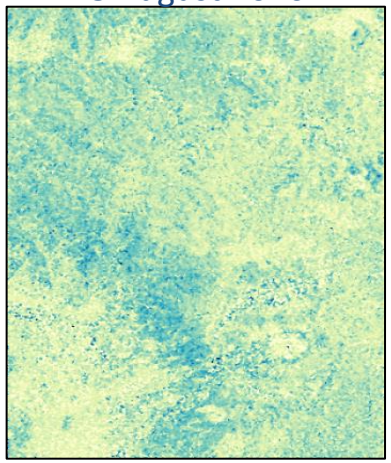
11 July 2016



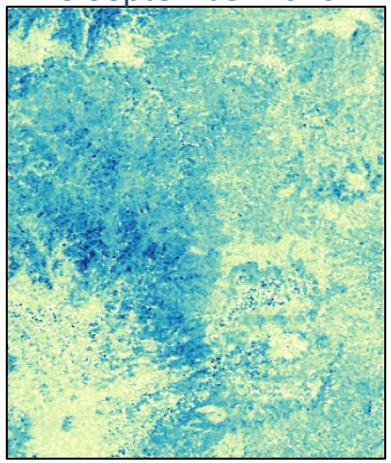
25 July 2016



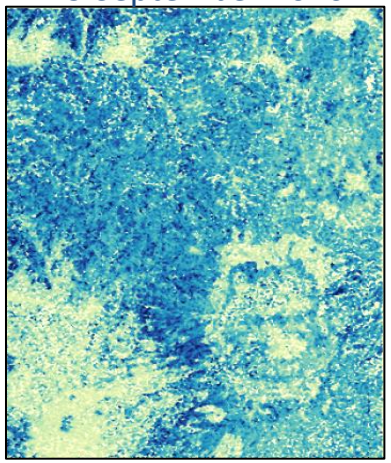
8 August 2016



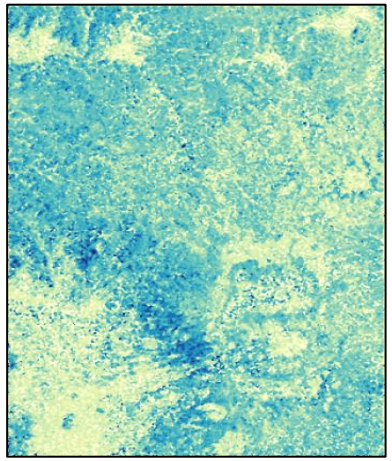
5 September 2016



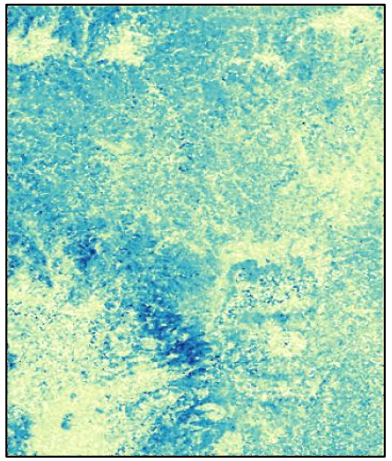
19 September 2016

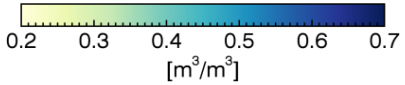


3 October 2016



31 October 2016





F. De Zan and G. Gomba, *Vegetation and soil moisture inversion from SAR closure phases: first experiments and results*, Remote Sensing of Environment (2018)

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Moisture cycle? Biomass accumulation?

- **Moisture cycle hypothesis: not really working!**
  - Typical moisture cycle is fast wetting and slow drying
  - My moisture model predicts that slow change dominates => drying dominates
  - Scatterers should apparently move **towards** the satellite

- Different hypothesis: **Biomass accumulation in plants** (water)
  - More biomass = more delay = motion **away** from the satellite
  - 0.03 rad /day = 47 mm/yr = 5.4 mm/yr (water)
  - To convert in tons/ha we need extra assumptions…

Conclusions and recommendations

- Depending on the choice of interferograms:
  velocity biases for short lags can reach 5-10 mm/yr (or more)

- Modeling the bias
  - Moisture related phases do not seem to explain the velocity biases
  - Biomass growth could explain the bias sign

- The velocity biases can easily be a performance bottleneck!
  - Modeling => compensation
  - Use of long-term interferograms, as in Phase Linking or EMI
  - Single-look interferometry (PSI)