Closure phases and biases in InSAR products

Francesco De Zan

Contributions by Homa Ansari, Giorgio Gomba, Alessandro Parizzi

Remote Sensing Technology Institute
German Aerospace Center (DLR)

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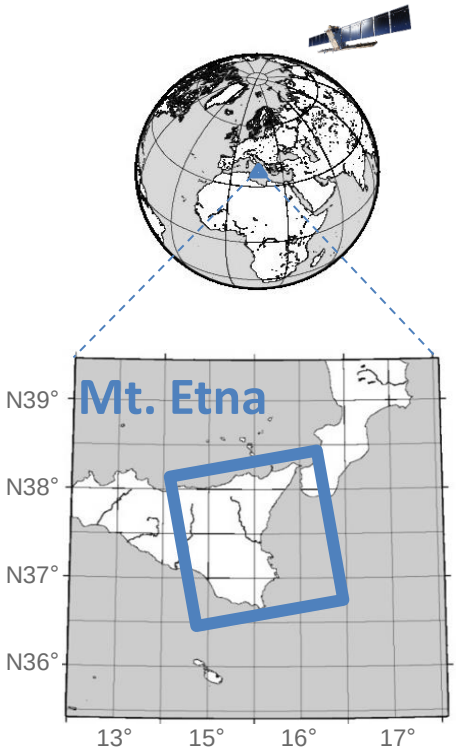
Performance comparison study

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	≈ 30000 km²
number of processed bursts	: 19



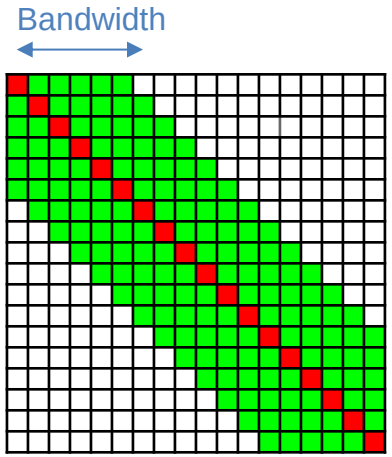
Benchmark: Persistent Scatterer Interferometry (PSI)

versus

StBas
Bandwidth **5**

StBas
Bandwidth **10**

EMI
Full Covariance



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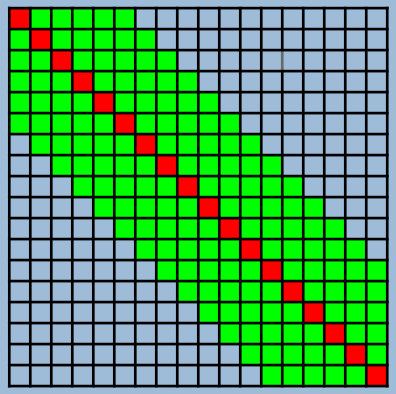
Mount Etna

StBAS
Bandwidth 5
905 Interferograms



-5 -4 -3 -2 -1 0 1 2 3 4 5
Deformation Velocity [mm/yr]

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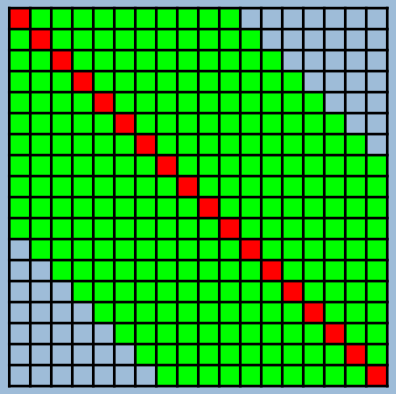
Mount Etna

StBAS
Bandwidth 10
1785 Interferograms



-5 -4 -3 -2 -1 0 1 2 3 4 5
Deformation Velocity [mm/yr]

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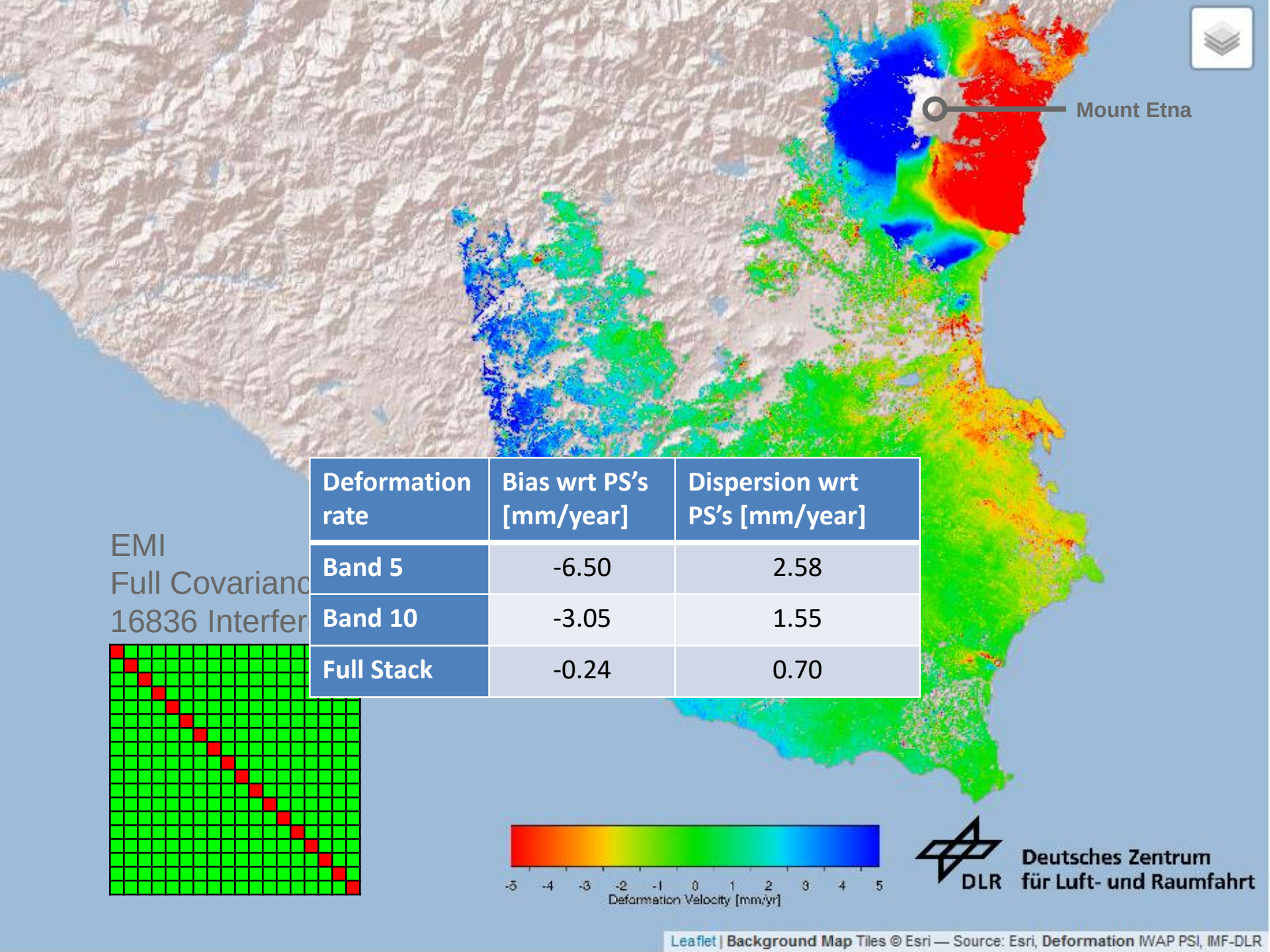
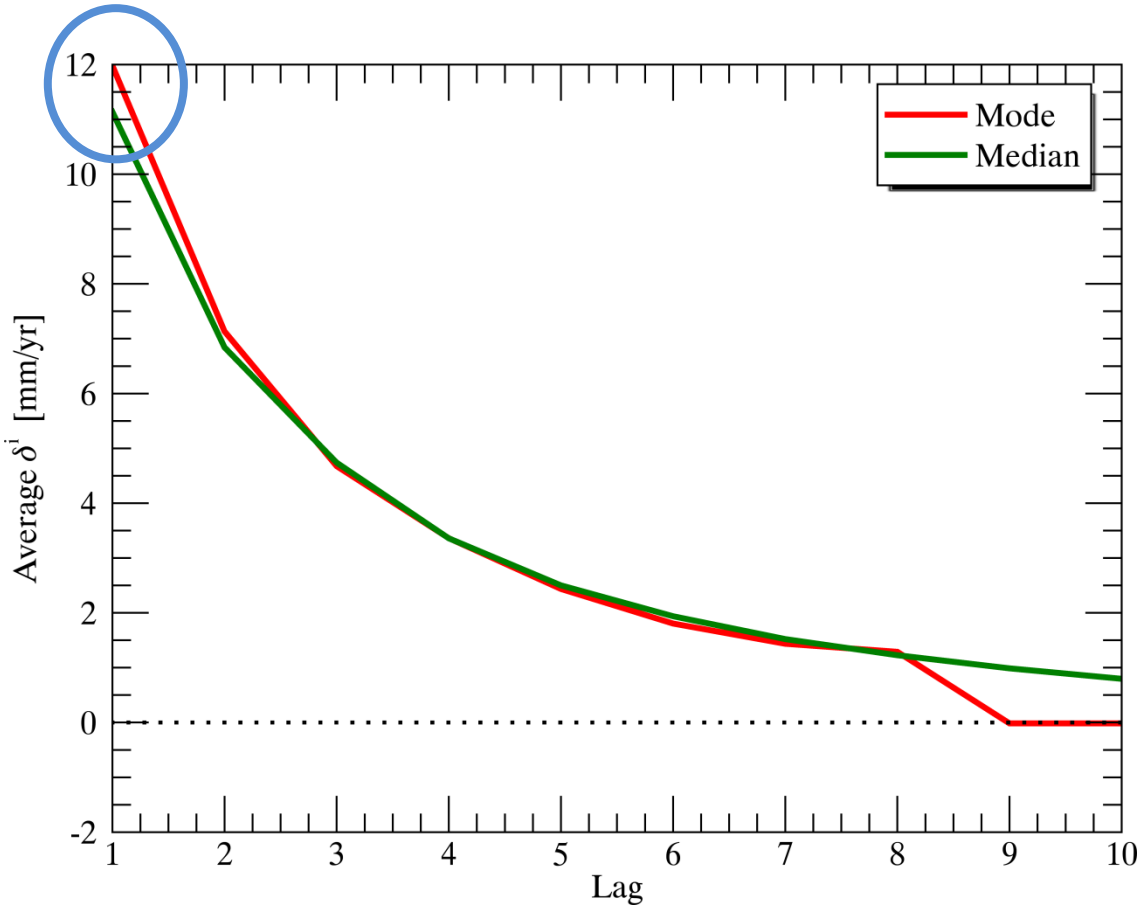


Deformation rate	Bias wrt PS's [mm/year]	Dispersion wrt PS's [mm/year]
Band 5	-6.50	2.58
Band 10	-3.05	1.55
Full Stack	-0.24	0.70

Bias for each lag (Mt. Etna dataset)

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

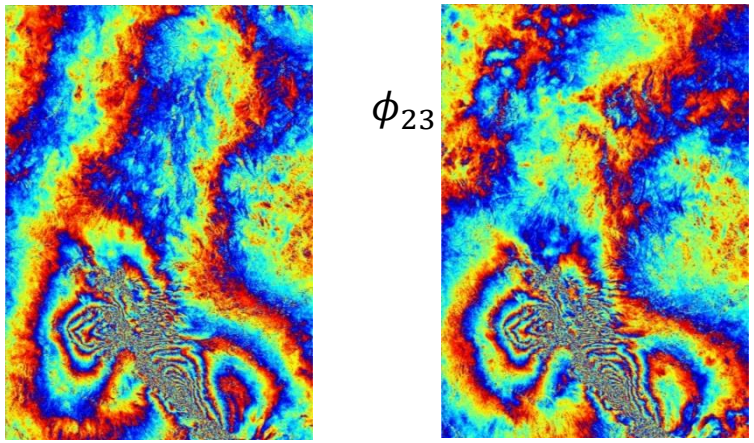


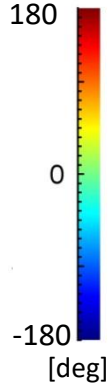
12 mm / 365 days * 6 days = 0.2 mm = 2.6 deg

Interferograms vs. closure phase

3 images
3 interferograms

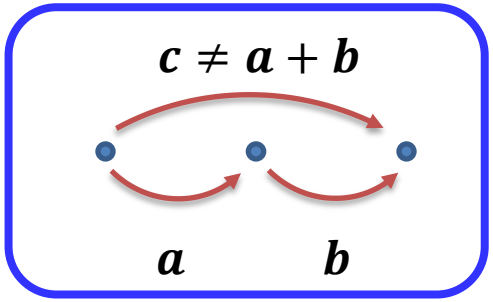
ϕ_{12} ϕ_{23} ϕ_{31}

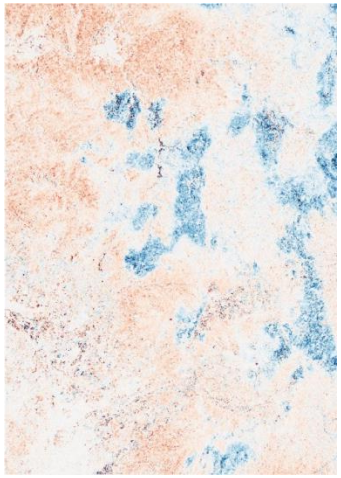


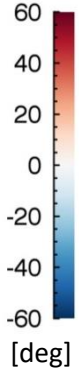


1 closure phase

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







Mis-closures are possible only with spatial averaging!

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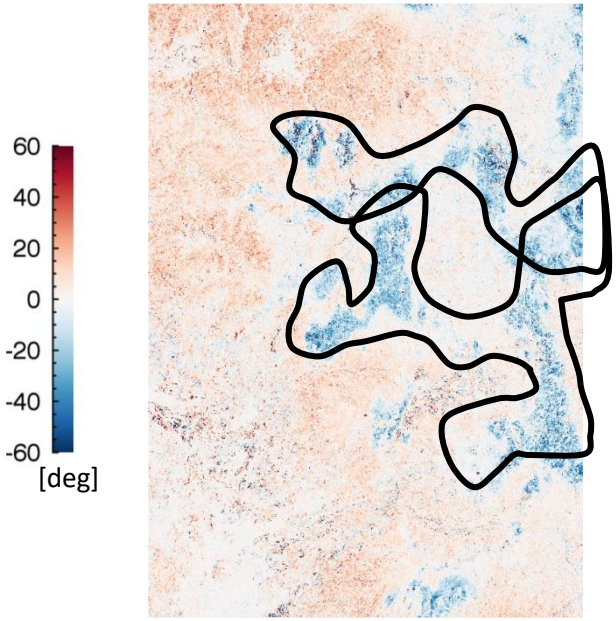
F. De Zan, M. Zonno and P. López-Dekker, "*Phase Inconsistencies and Multiple Scattering in SAR Interferometry*," in *IEEE Transactions on Geoscience and Remote Sensing*, 2015.

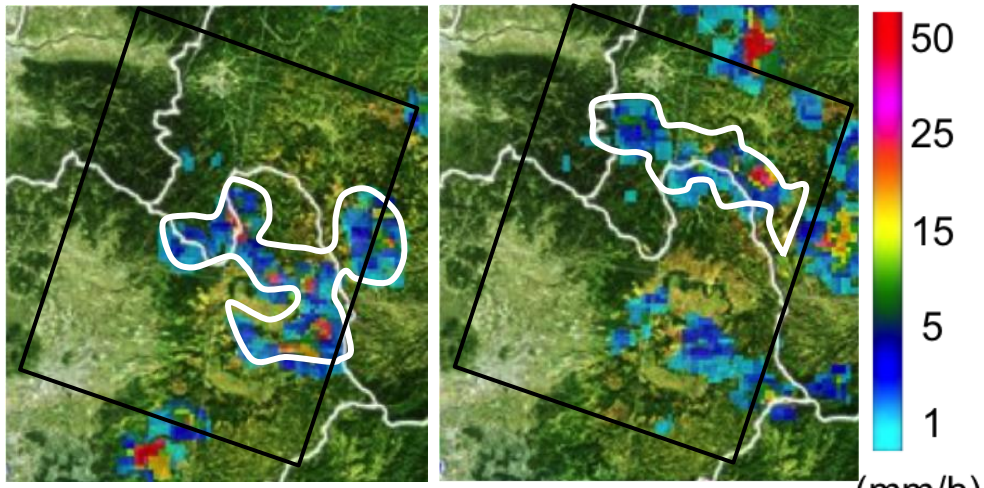
Rain event in Japan (Kumamoto)

Closure phase



~12:18 11Jul-25Jul-8Aug

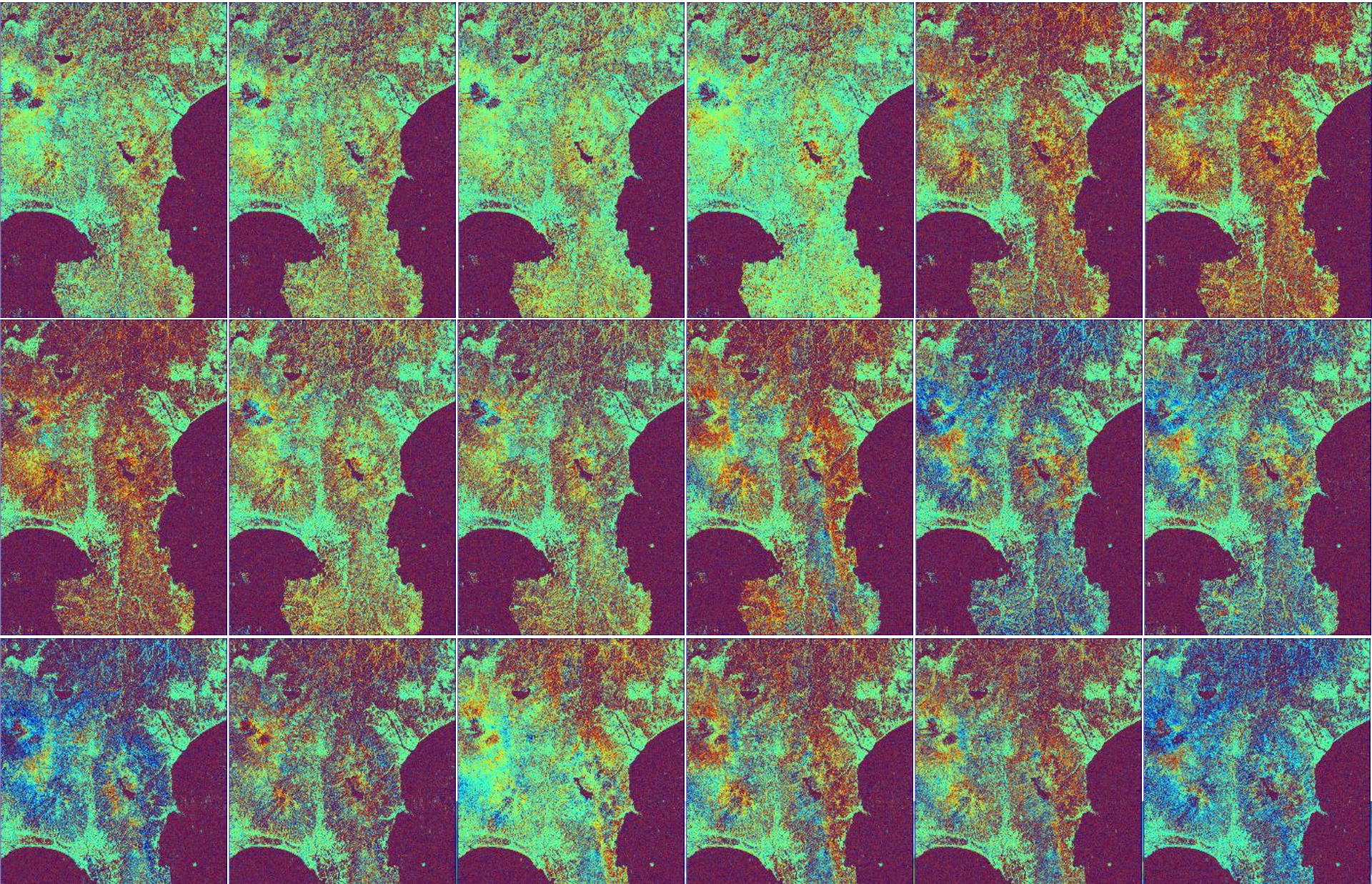
Weather radar images



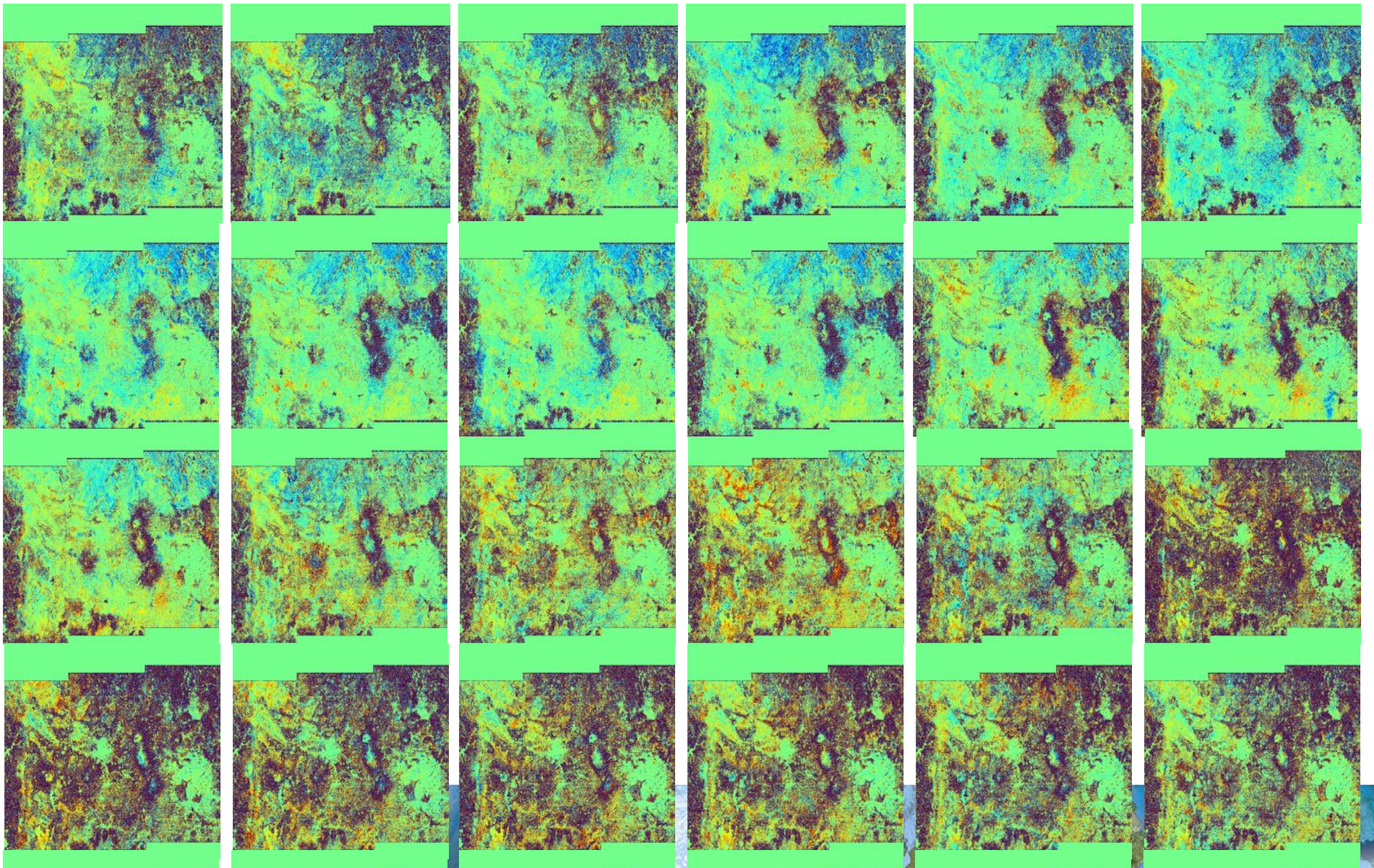
11:00 25Jul

12:00 25Jul

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

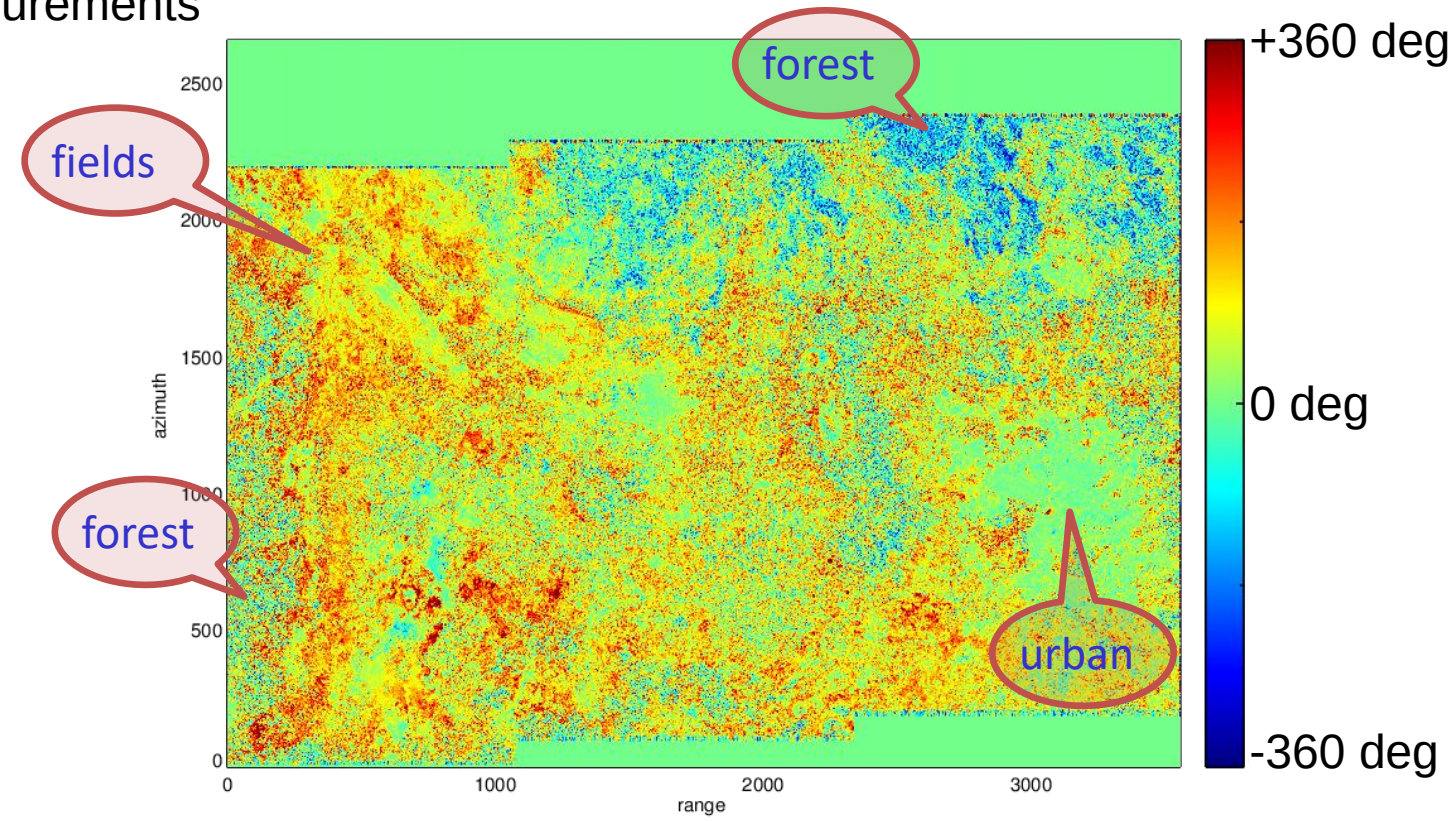


Mexico, Sentinel-1, Descending, Closure Phase +/- 30 deg, 2014-2016



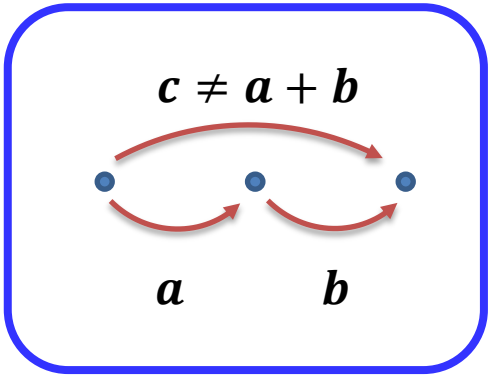
One-year deviation between 12-day and 24-day S1 interferograms

- Colorscale: +/- 360 deg => 28 mm/yr
- Far away from 1 mm / year target : necessity of log-span interferometric measurements



Interferometric phases and velocities are biased

- The presence of closure phases means that there is a **path dependency** in the temporal integration

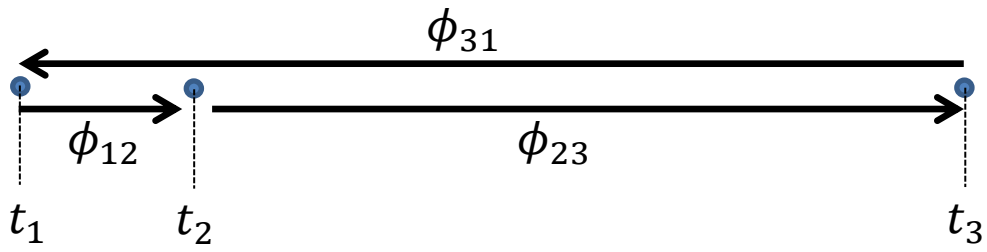


- Presence of **systematic closure phases** means that
  - the interferometric phases are biased, at least some of them
  - velocity estimates are biased

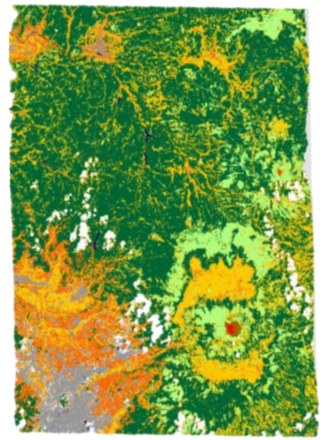
- We now know that **short term** interferograms are the culprit!

How to estimate the bias magnitude? (without doing all the processing)

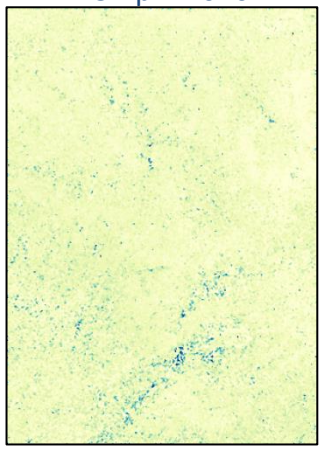
- Average closure phases with short and long arms
- Assumption: the long arms have little bias
- The asymmetric mis-closure should represents mostly the short-term bias



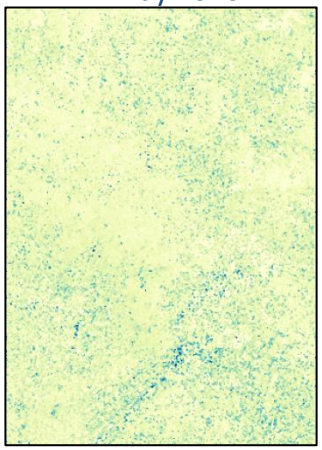
Moisture inversion (Kumamoto, ALOS-2)



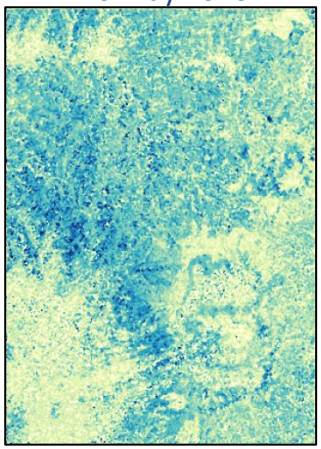
18 April 2016



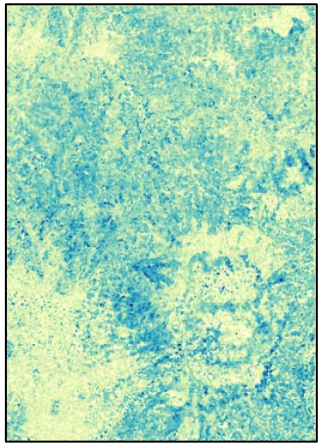
2 May 2016



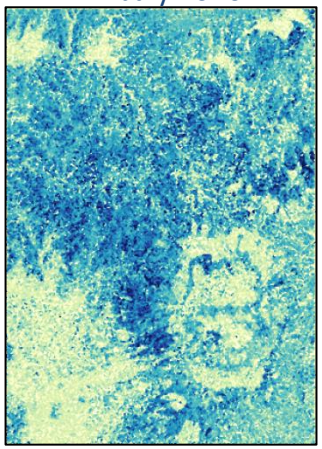
16 May 2016



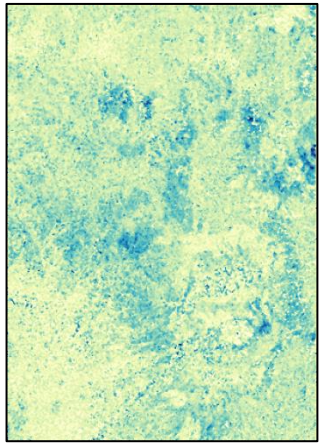
13 June 2016



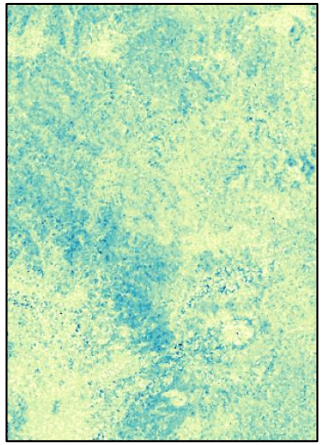
11 July 2016



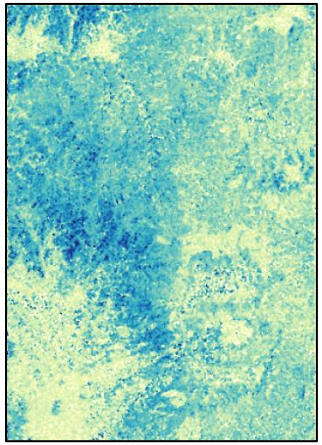
25 July 2016



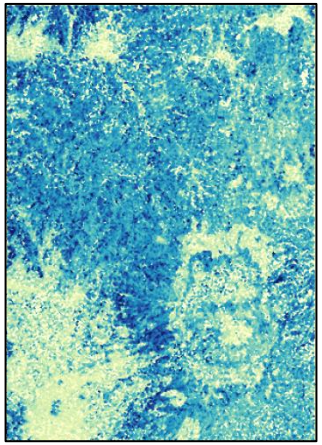
8 August 2016



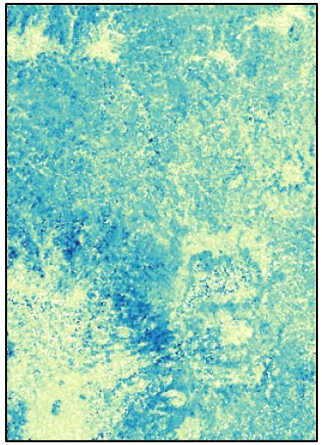
5 September 2016



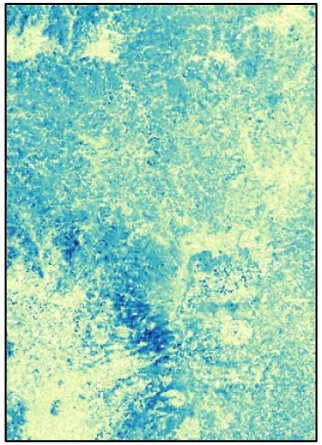
19 September 2016

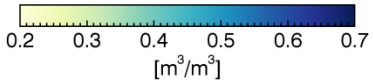


3 October 2016



31 October 2016





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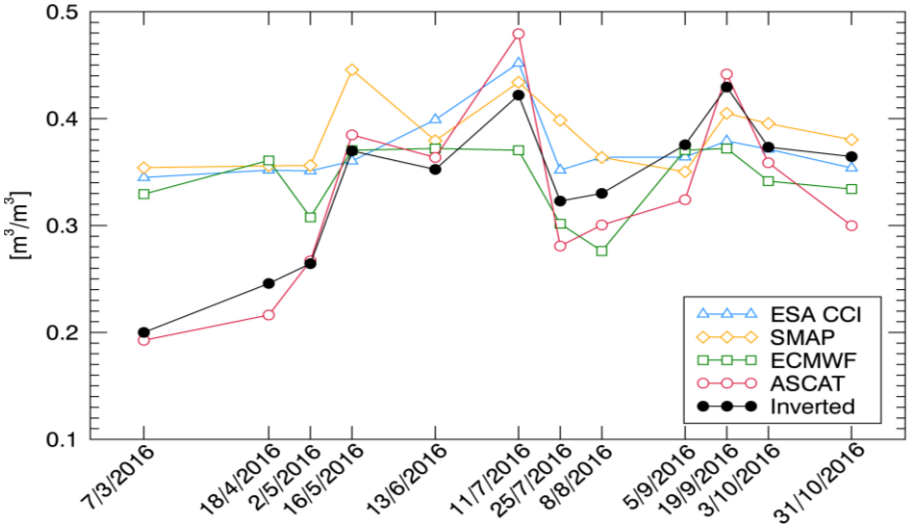
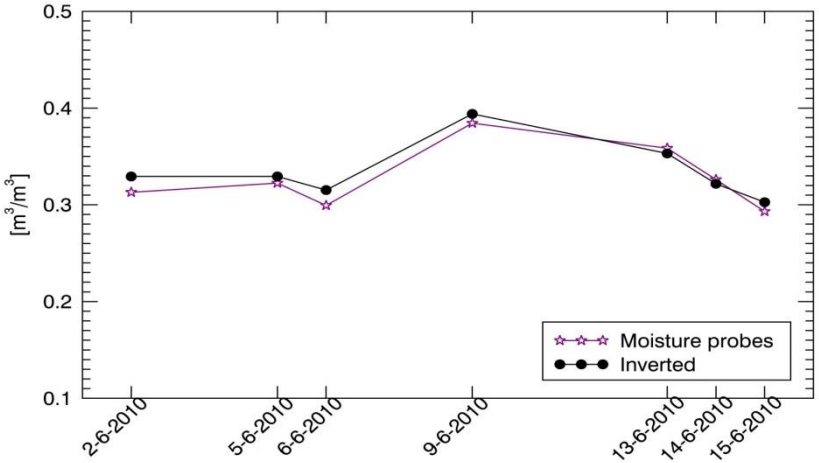
F. De Zan and G. Gomba, *Vegetation and soil moisture inversion from SAR closure phases: first experiments and results*, Remote Sensing of Environment (2018)

We have some validations…

Kumamoto, ALOS-2



CanEX-SM10, UAVSAR, JPL



G. Gomba and F. De Zan, *Estimating soil moisture from SAR Interferometry with Closure Phases*, IGARSS 2019 (poster)

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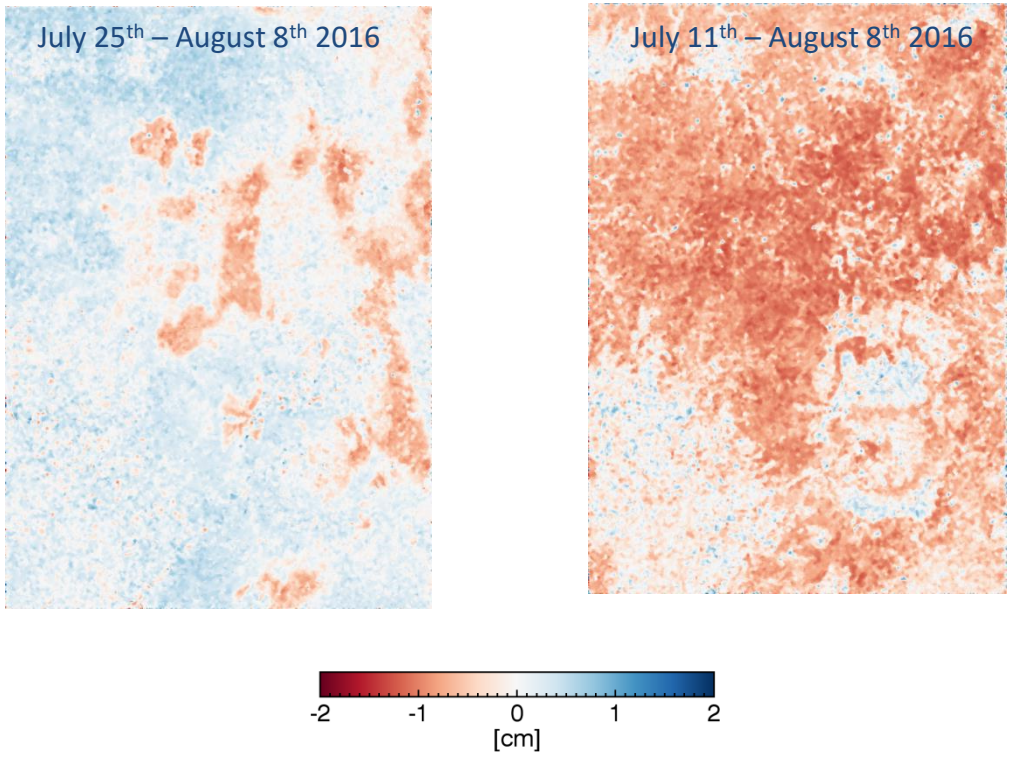
Moisture signal in SAR interferograms (L-band)

- Magnitude: a few centimeters in L-band (10-20 % of wavelength, S. Zwieback)
- Corrections for InSAR: two examples over Kumamoto with our model



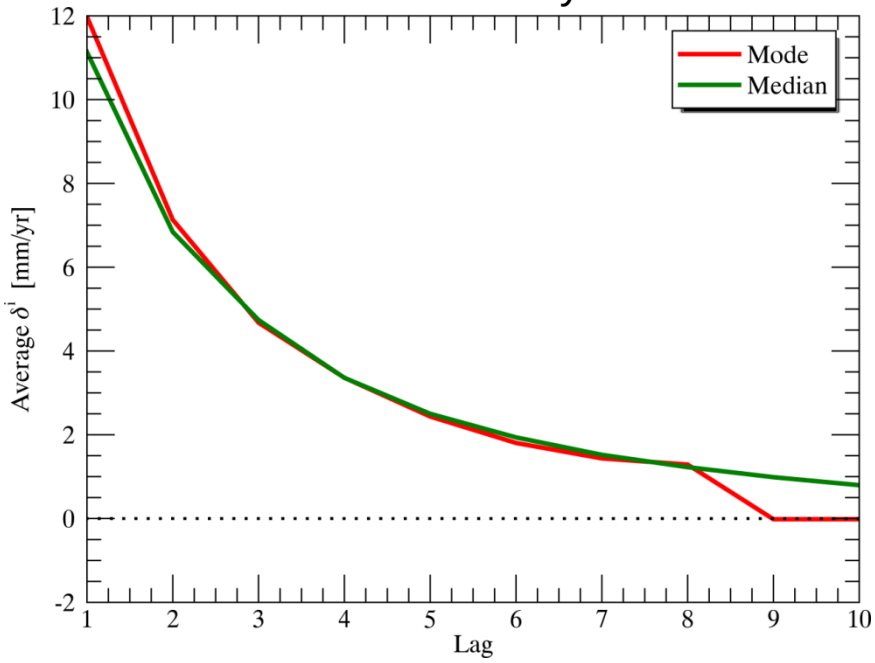
Modeling the velocity bias

- The moisture model seems not to describe the bias (wrong sign, more seasonal)
- Some scatterer electrically moving away from the satellite at 0.1 mm / day
- Biomass growth?

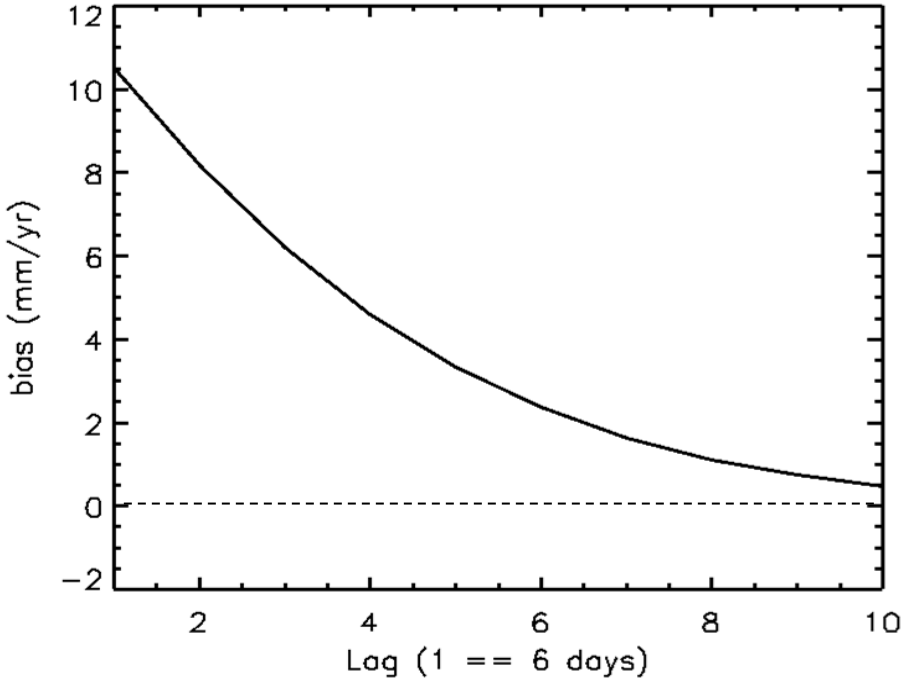
Modelled coherence

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

Observed velocity bias



Modelled bias



Current theoretical performance

- Assuming four years of Sentinel-1 with 60 acquisition / year

	Residual troposphere	Residual ionosphere	Instrument/ geometry	Total	Deformation rate
Germany	**1.0 cm**	1.0 cm	1.5 cm	**2.1 cm**	**1.3 mm/yr**
Indonesia	**3.0 cm**	1.0 cm	1.5 cm	**3.5 cm**	**2.1 mm/yr**

- To reach this performance at large scale (large distances) we need:
  - Good instrument / orbits
  - Tropospheric corrections (numerical weather models, e.g. ERA5)
  - Ionospheric corrections (e.g. from CODE model or split spectrum)
  - **Accurate processing!**

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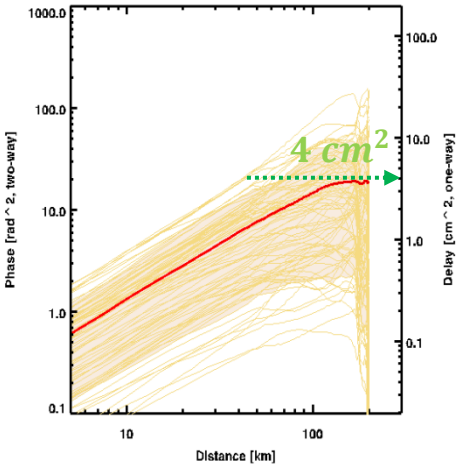
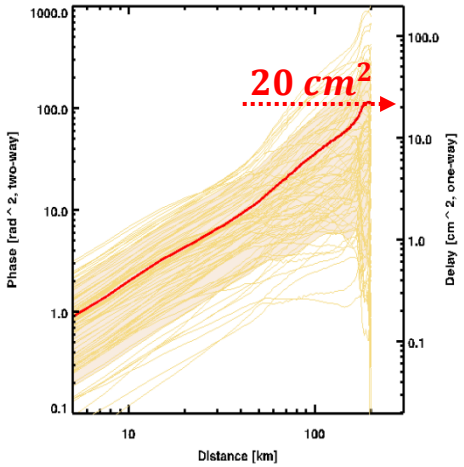
Performance of corrections with ECMWF ERA5

Pakistan

with corrections

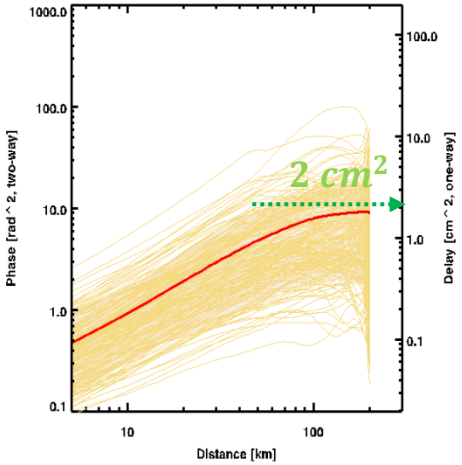


w/o corrections

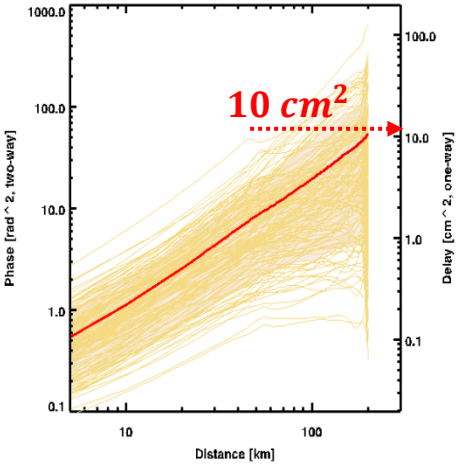


Germany

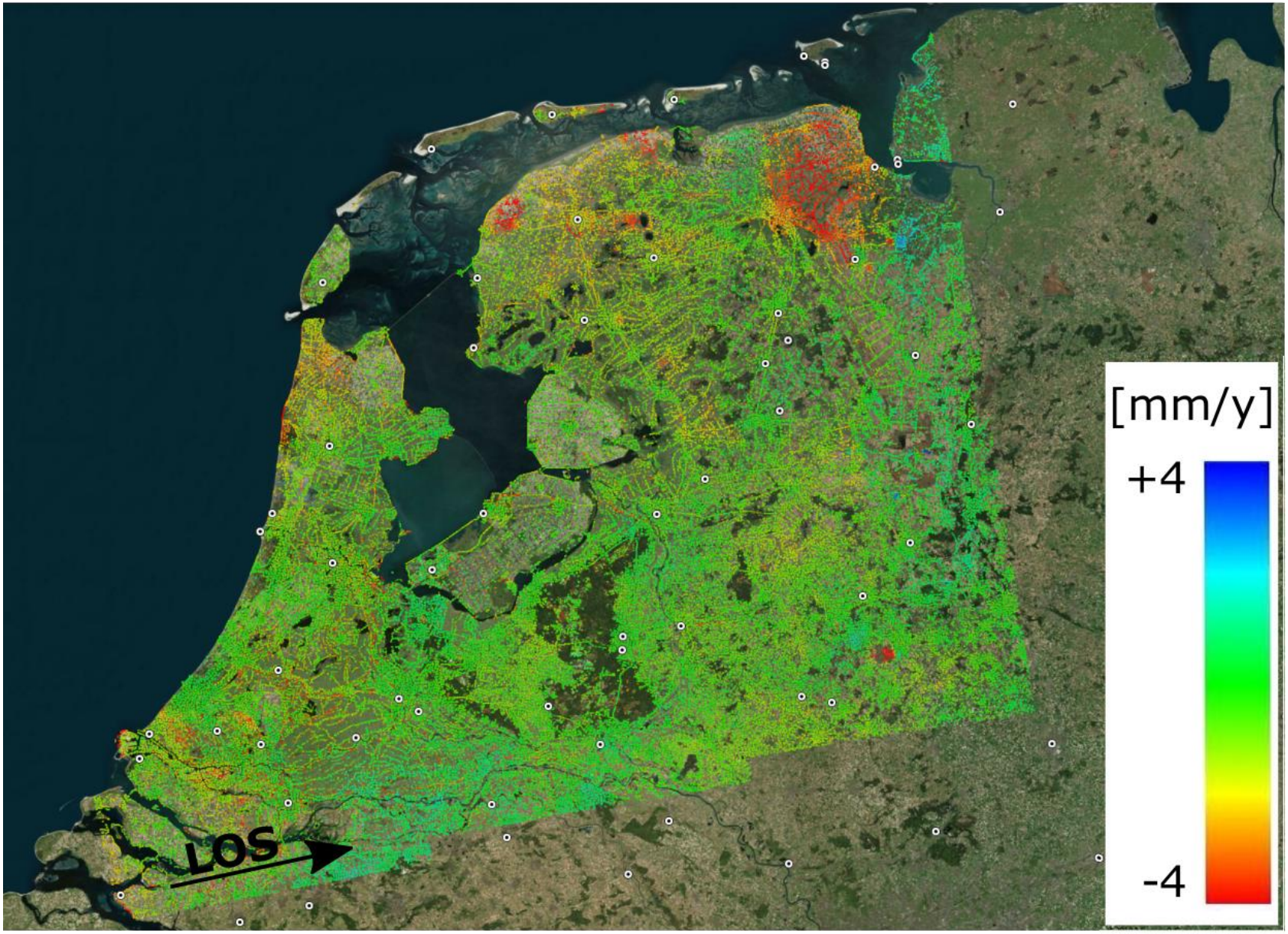
with corrections



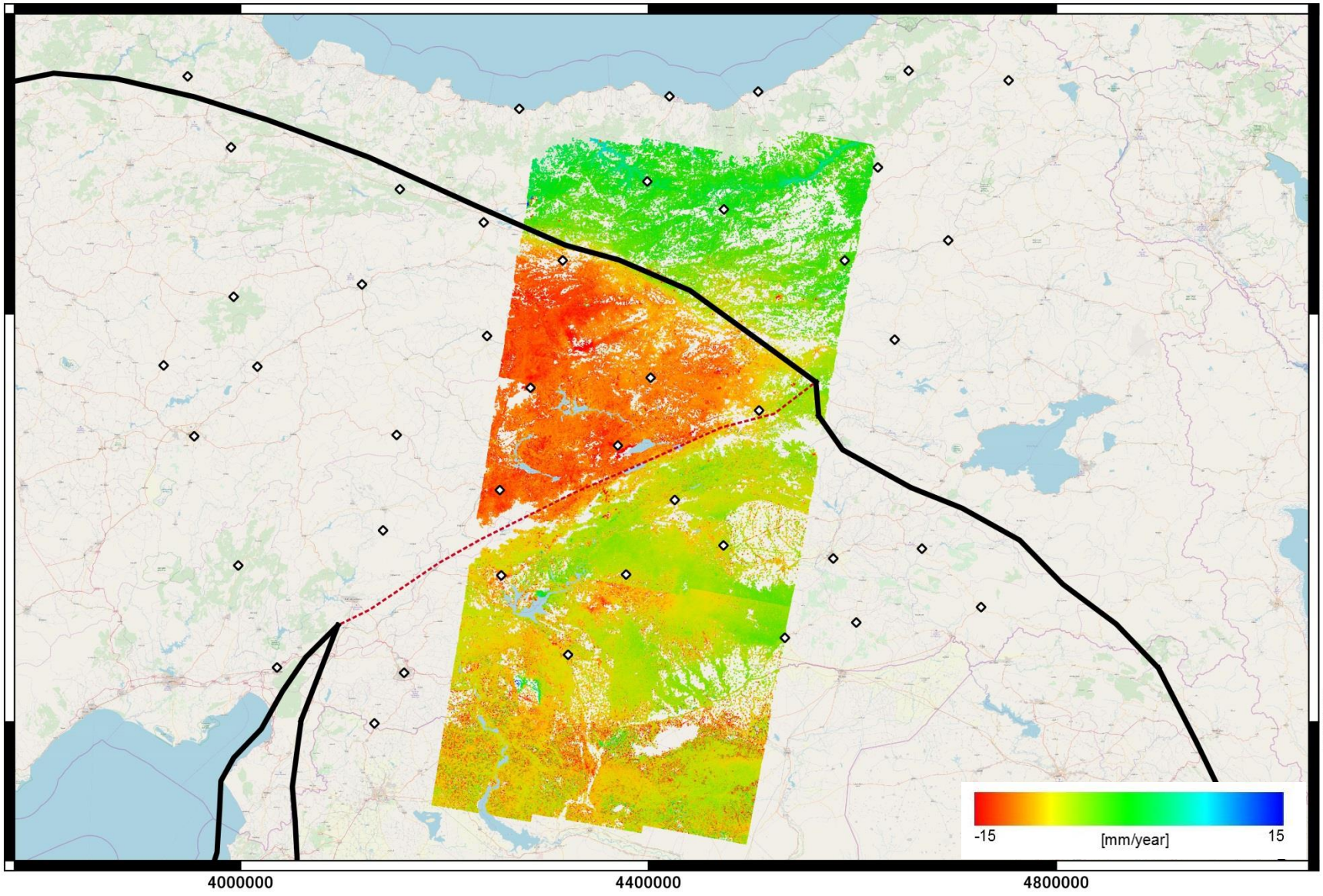
w/o corrections



PSI vs. GPS std: 0.86 mm/yr

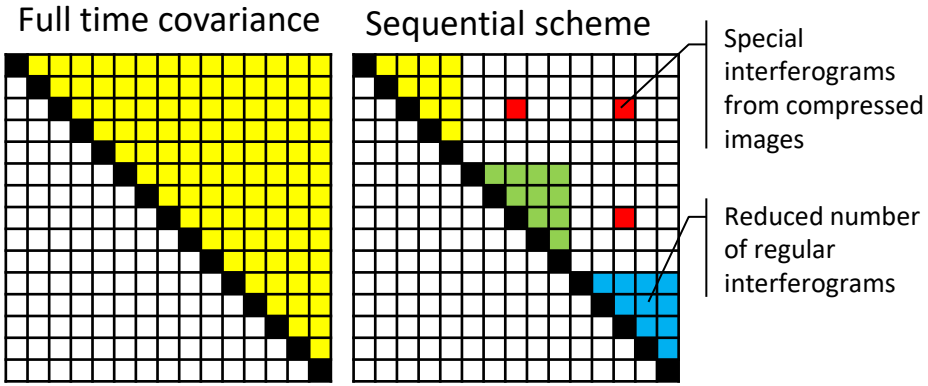


North and East Anatolian Faults – PSI



A phase product based on the full covariance matrix

- It would like to propose a **phase product** to be provided routinely (for instance by ESA)
  - Multilooked (100 m – 200 m) => much smaller than SLC's
  - Based on full covariance => long-term stable
  - Including correction layers (troposphere, ionosphere, SET…)
  - Wrapped



Monti Guarnieri & Tebaldini, *On the exploitation of target statistics for SAR interferometry applications,* TGaRS (2008)

Ferretti et al., *A New Algorithm for Processing Interferometric Data-Stacks: SqueeSAR*, TGaRS (2011)

Ansari et al., *Efficient phase estimation for interferogram stacks*, TGaRS (2018)

Ansari et al., *Sequential estimator: Toward efficient InSAR time series analysis,* TGaRS (2017)

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Conclusions and recommendations

- Velocity biases for short lags can reach 5-10 mm/yr (or more)
- Moisture related phases
  - Compensation for L-band interferograms (1-2 cm)
  - Do not seem to explain the velocity biases
- 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
- A phase product based on the full covariance matrix