# InSAR Error Budget for Large Scale Deformation

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## Motivation:

- **Providing a performance analysis for large scale deformation**
- **Validating the performance prediction with Sentinel-1**
- **Highlighting contributions expected at long wavelengths**

## Troposphere

Tropospheric delays are caused by variations of temperature, pressure and humidity of the earth atmosphere. According to our experience, once numerical weather prediction models are used to correct the tropospheric delay, the absolute residual variation is in the order of **0.5 - 3 cm** depending on the geographical location, using the latest ECMWF products (see also Cong et al., Rem. Sens., 2018).

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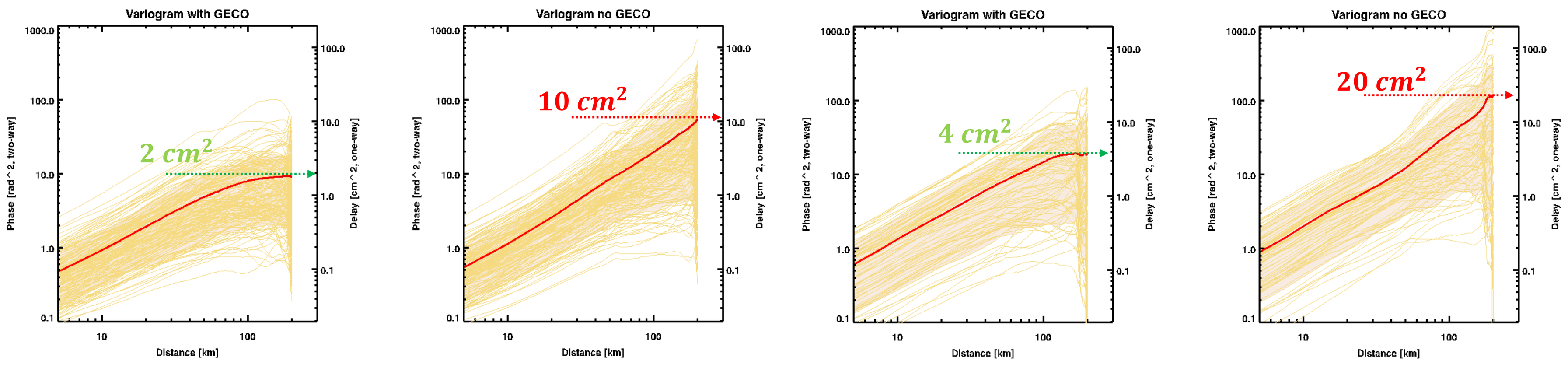


Fig. 1 Variograms of S-1 unwrapped phase over Germany and Pakistan. Despite the different levels of noise saturation the benefit of ECMWF-ERA5 corrections is evident.

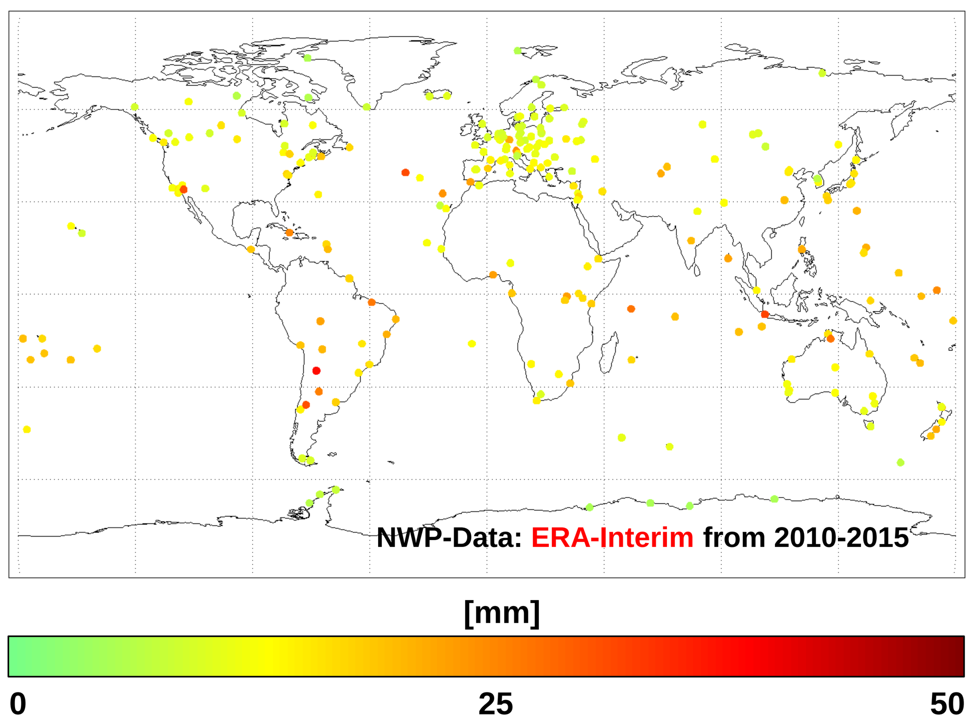


Fig. 2 Standard deviation between GPS and ECMWF ERA-Interim products. There is clear dependence on the geographical location. The performance is particularly good in areas where more data are available (Europe, North America) or in high plateaus (Tibet). Approaching the Equatorial belt the performance degrades.

## Ionosphere

Ionospheric range delays are very sensitive to the frequency: their magnitude is proportional to the square of the wavelength. GNSS models are in general not very reliable to mitigate the ionospheric effects and it is better to apply the split-spectrum technique on the SAR data (Gomba et al., 2016, TGaRS). The performance of split-spectrum depends on the range resolution. We normally achieve errors in the order of **~1 cm** by averaging areas of 1 km$^2$. This is enough to suppress the ionosphere error below the residual tropospheric error.

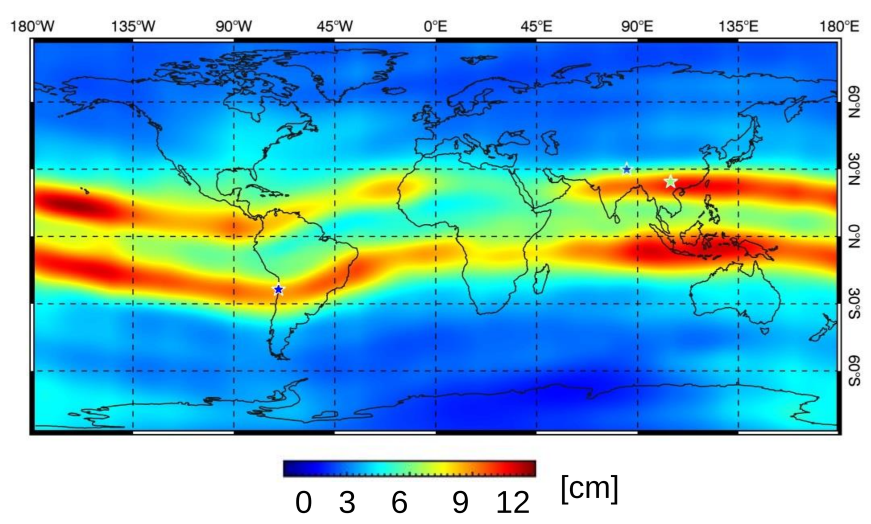


Fig. 3 Expected ionospheric error for uncorrected C-band ascending interferograms

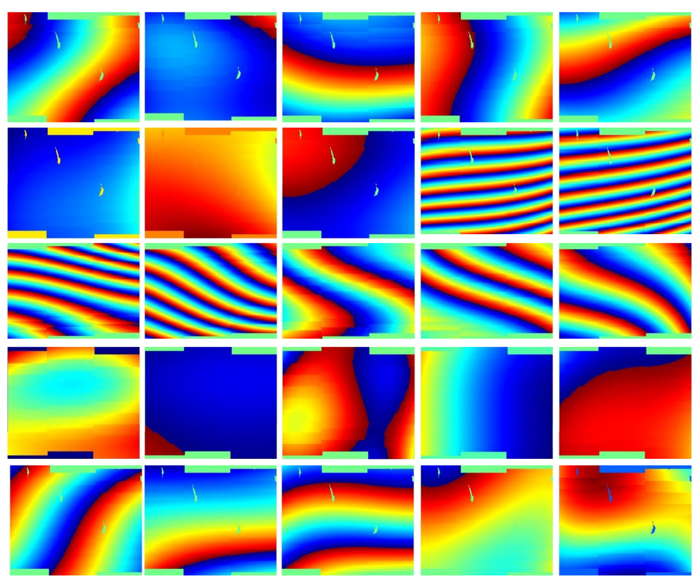

Fig. 4 Example of split-spectrum method estimated phase screens

## Moisture variations

Propagation in semi-transparent media, like many natural targets, is affected by the moisture status. Expected variable contributions to the delay are **2 - 4 cm** for a typical soil type when observed in L-band (Zwieback at. Al, 2015, RSE). A model developed by some of the authors predicts a magnitude proportional to the wavelength: in C-band the effects are expected to be 4 times smaller (De Zan et al., 2014, TGaRS).

We plan to model moisture-related phases, hoping to minimize the impact on deformation products. First experiment with moisture inversions from InSAR (closure) phases are promising (De Zan and Gomba, 2018, RSE).

## Interferometric processing

The presence of closure phases different from zero implies that the choice of interferograms to consider and their weighting is not trivial. First experiments show that limiting the processed pairs to 5 or 10 successive images entails biases in the deformation rate of 3-6 mm/yr. We recommend full-covariance methods, which seem to be rather robust to the effect of non-closure phases (Ansari at al., 2019, IGARSS & Ansari et al., 2018, TGaRS).

## Instrument and geometry

Errors in the orbit knowledge in the elevation translate into phase ramps across the swath. To have errors comparable to the troposphere residuals, the across track error should have a dispersion < 5 cm (< **1.5 cm** ramps across 300 km swaths). Fortunately Sentinel-1 is doing well enough.

In the past, long term oscillator frequency drifts have produced phase trends from near to far range. Considering a target of 1 mm/yr across 100 km (slant range), the oscillator drift knowledge requirement is $10^{-8}$/yr. Sentinel-1 is doing better than $10^{-9}$/yr, so this is not currently a concern (Larsen et al., 2017, IGARSS).

## Deformation rate error budget

The estimation of the deformation rate is essentially a line fit and the performance, for a regular acquisition scenario, is

$$\sigma_v = \frac{\sqrt{12}}{\sqrt{NT}}\sigma_r$$

Where $N$ is the number of acquisitions and $T$ the total time span. The $\sigma_r$ represents all contributions to the line-of-sight error mentioned in this poster. One can easily verify that with Sentinel-1 we expect to attain already a performance of **~1 - 2 mm/yr** under reasonable assumptions.

Tab. 1: Error budget excluding moisture and processing effects, for a Sentinel-1 case with 4 years of acquisitions and 50 acquisitions / yr.

| Residual troposphere | Residual ionosphere | Instrument geometry | $\sigma_r$ | $\sigma_v$ |
|---|---|---|---|---|
| 1.0 cm | 1.0 cm | 1.5 cm | **2.1 cm** | **1.3 mm/yr** |
| 3.0 cm | 1.0 cm | 1.5 cm | **3.5 cm** | **2.1 mm/yr** |
| 3.0 cm | 1.0 cm | 3.0 cm | **4.4 cm** | **2.7 mm/yr** |

## Validation

The results of a PSI processing (no moisture effects expected) have been calibrated using 47 GNSS stations. The results are displayed in Figure 5. The residual screen corrected varies in a range of ± 3 mm/yr that corresponds to a $\sigma \approx 1$ mm/yr.

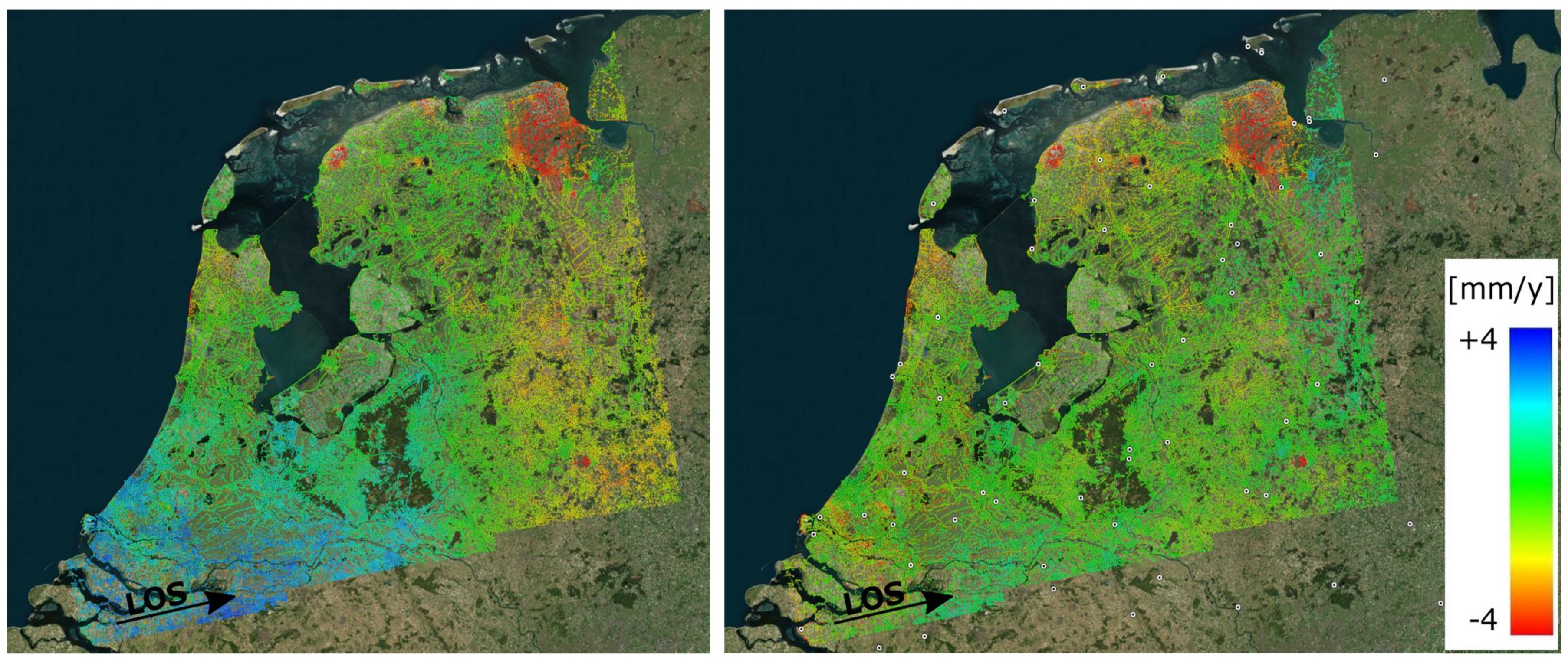


Fig. 5 Validation over the Netherlands, S1 data (left: only InSAR, right: with GNSS). The GNSS stations are shown with black/white dots.

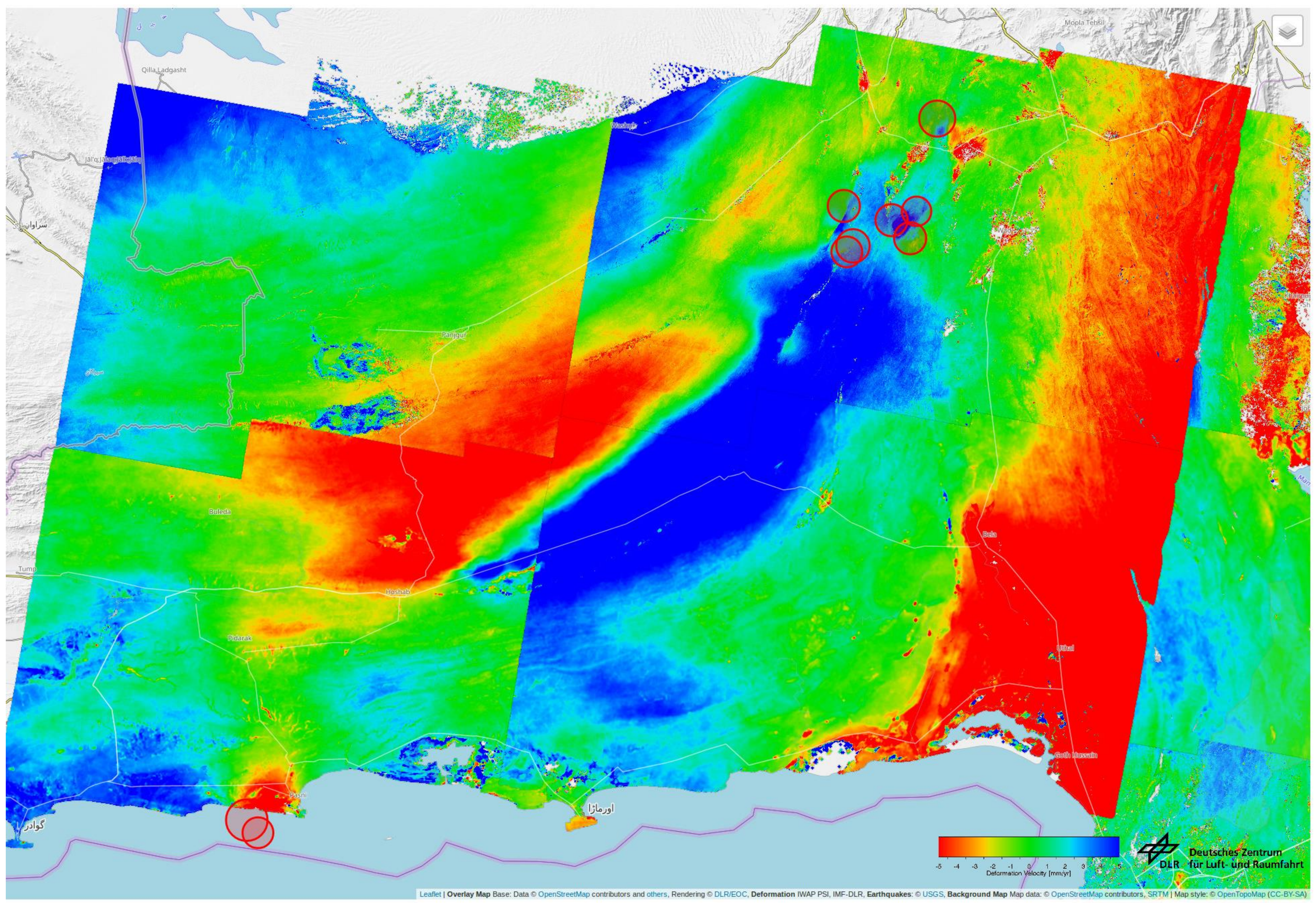

Fig. 6 Deformation rate seen by Sentinel-1 over Pakistan, where it is difficult to exploit permanent GNSS stations

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This work contains modified Copernicus Sentinel data 2014-2019. GPS data from Nevada Geodetic Laboratory.