Cal/Val approach for DInSAR Deformation Rates Products using GNSS data

Alessandro Parizzi, Ramon Brcic and Francesco De Zan

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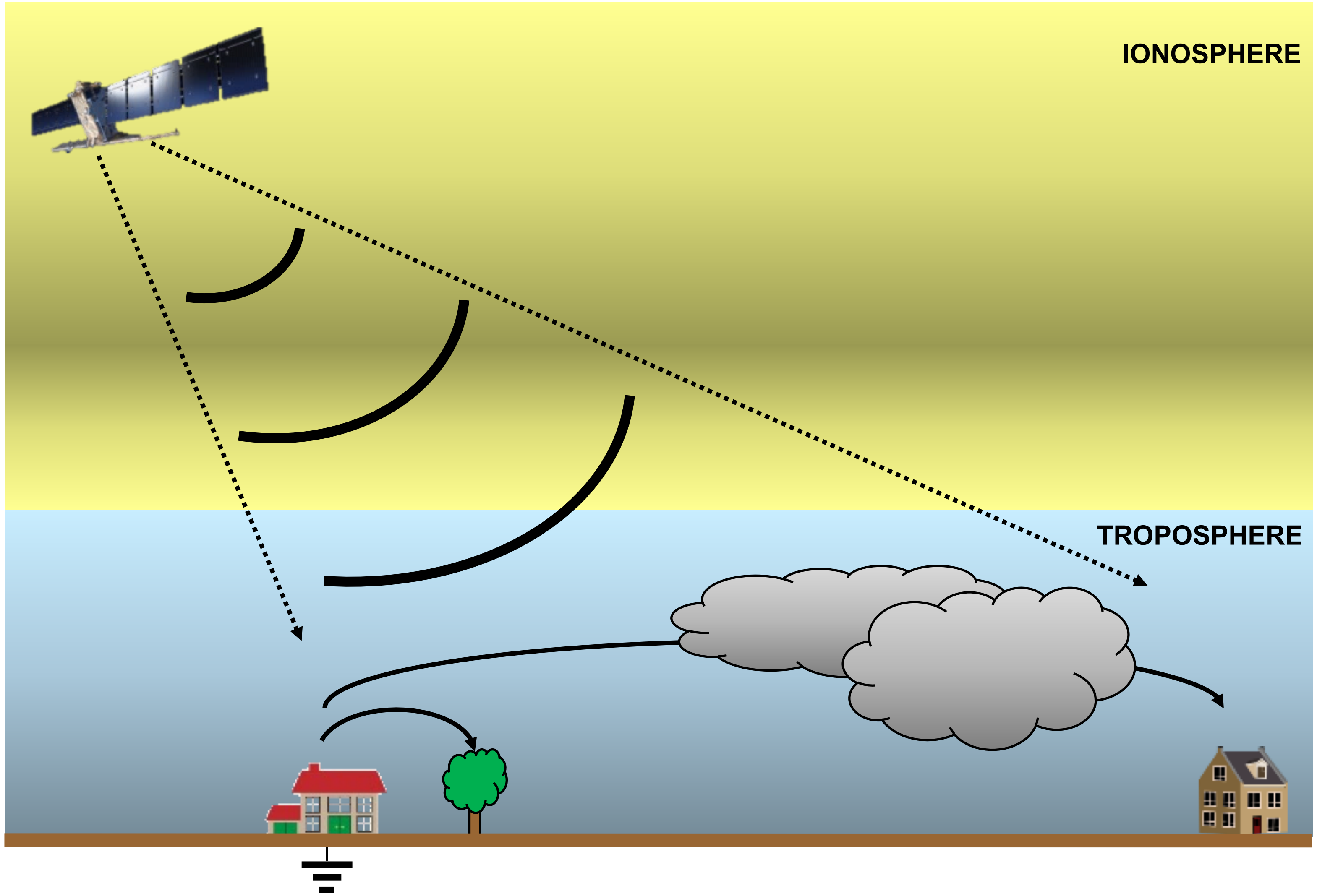
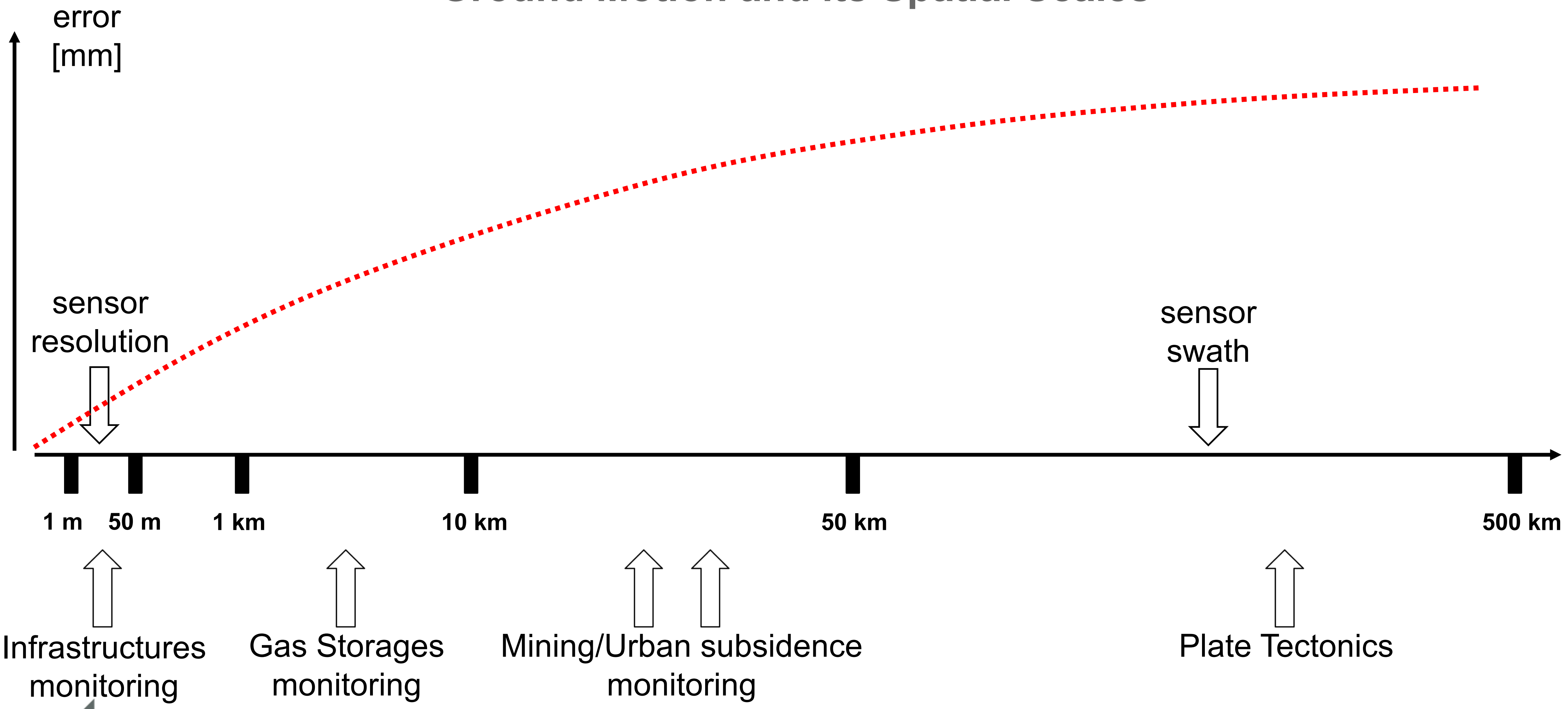
Knowledge for Tomorrow

Errors in InSAR Data

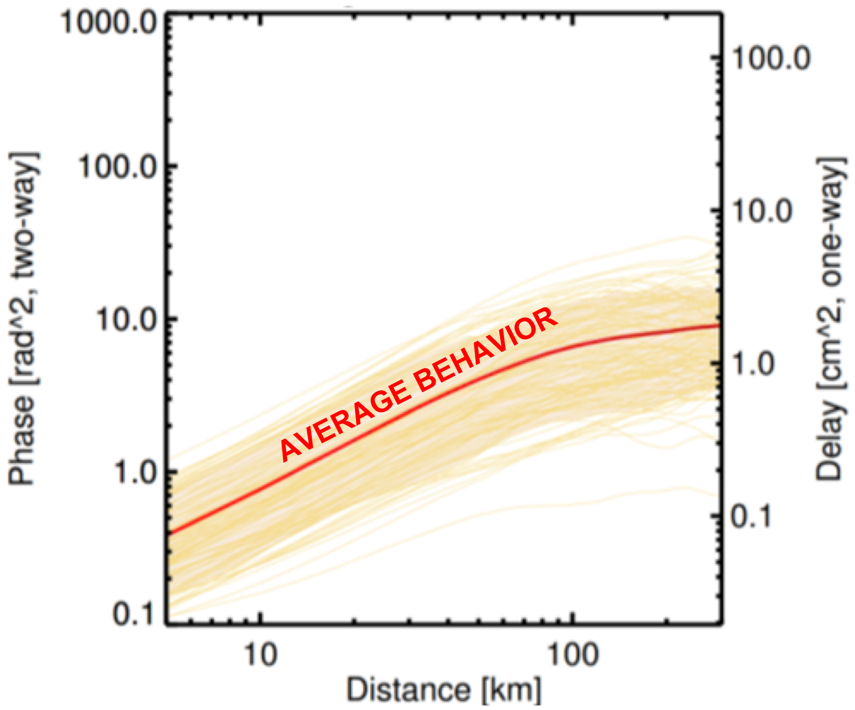
- ❑ Targets' Noise (Radar Clutter):
  - Spatially Uncorrelated
  - Depends on targets/backscatter quality
- ❑ Atmospheric Error
  - Spatially correlated
  - Power increase with the distance

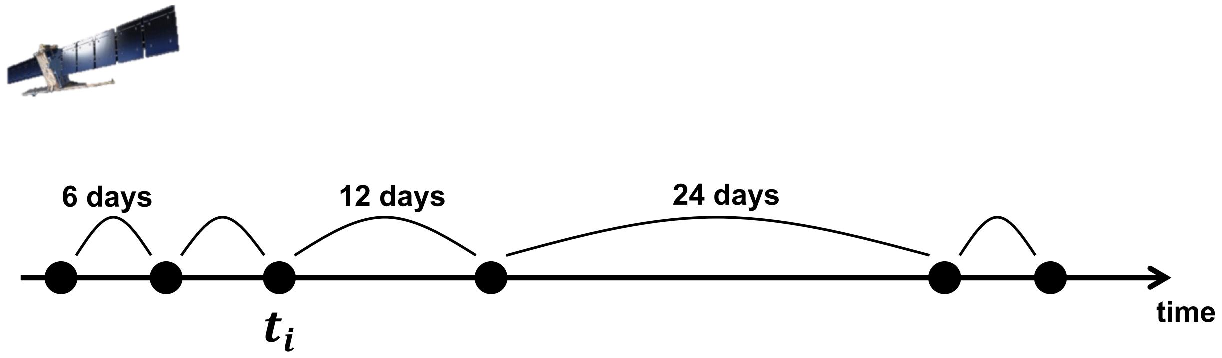


Ground Motion and its Spatial Scales



Compute the Residual Atmospheric Error Covariance After ECMWF Tropospheric Corrections (1)

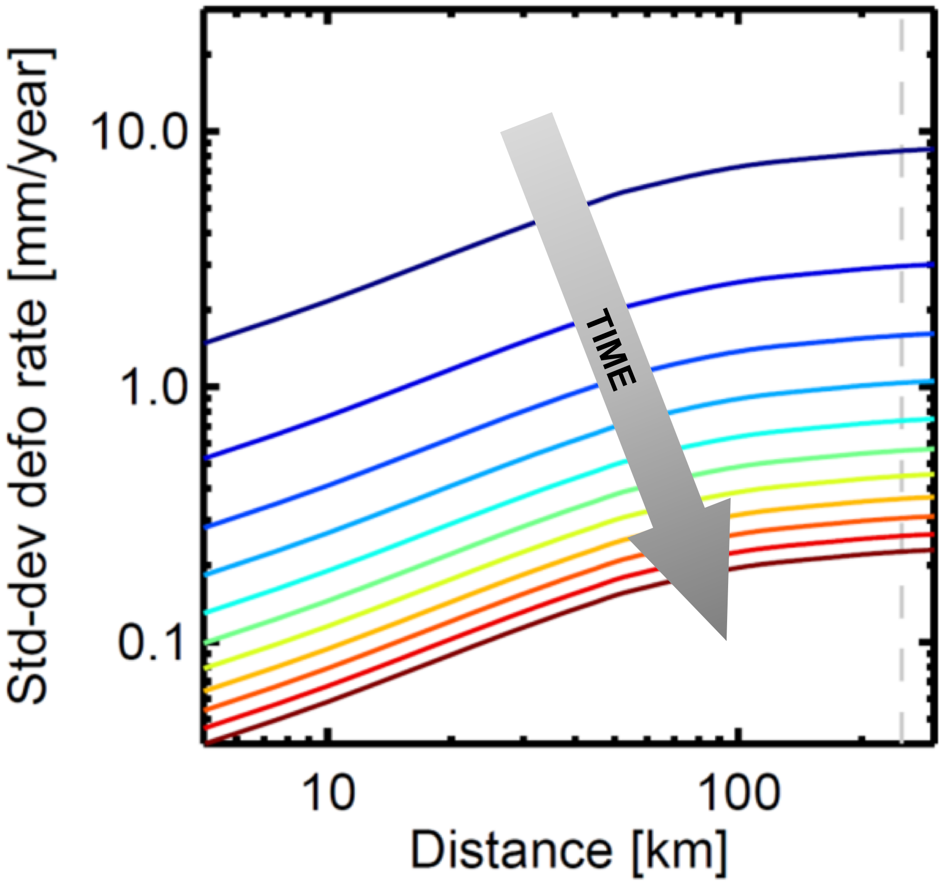




<u>Reduced effect of the motion only atmospheric noise measured (always in centimeter order of magnitude)!</u>

F. R. Gonzalez, A. Parizzi and R. Brcic, "Evaluating the impact of geodetic corrections on interferometric deformation measurements," *EUSAR 2018; 12th European Conference on Synthetic Aperture Radar*, Aachen, Germany, 2018, pp. 1-5

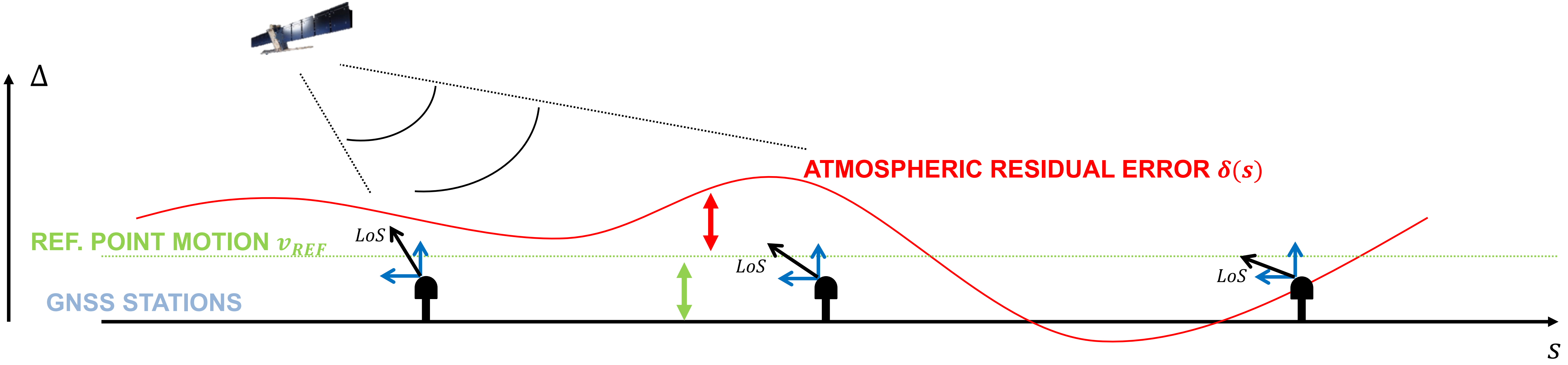
Compute the Residual Atmospheric Error Covariance After ECMWF Tropospheric Corrections (2)



The average Variogram is scaled according to the linear regression variance

F. R. Gonzalez, A. Parizzi and R. Brcic, "Evaluating the impact of geodetic corrections on interferometric deformation measurements," *EUSAR 2018; 12th European Conference on Synthetic Aperture Radar*, Aachen, Germany, 2018, pp. 1-5

Offsets between InSAR and GNSS rates: Problem Statement in radar LoS



$$\Delta(s) = v_{PS} - v_{GPS} = \delta(s) + v_{REF}$$

Hypothesis: the Offsets Δ between InSAR and GNSS (projected in LoS) represents the sum between the reference point displacement rate (constant) an the residual atmospheric error (space variant)

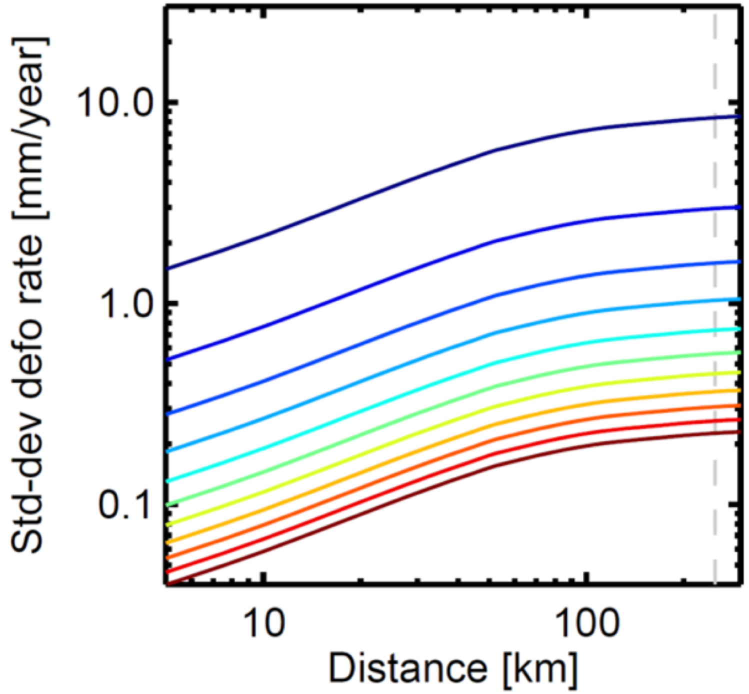
Statistic of the Offset Vector $\underline{\Delta}$

EXPECTED VALUE

- $\mathrm{E}[\underline{\Delta}] = v_{REF}$

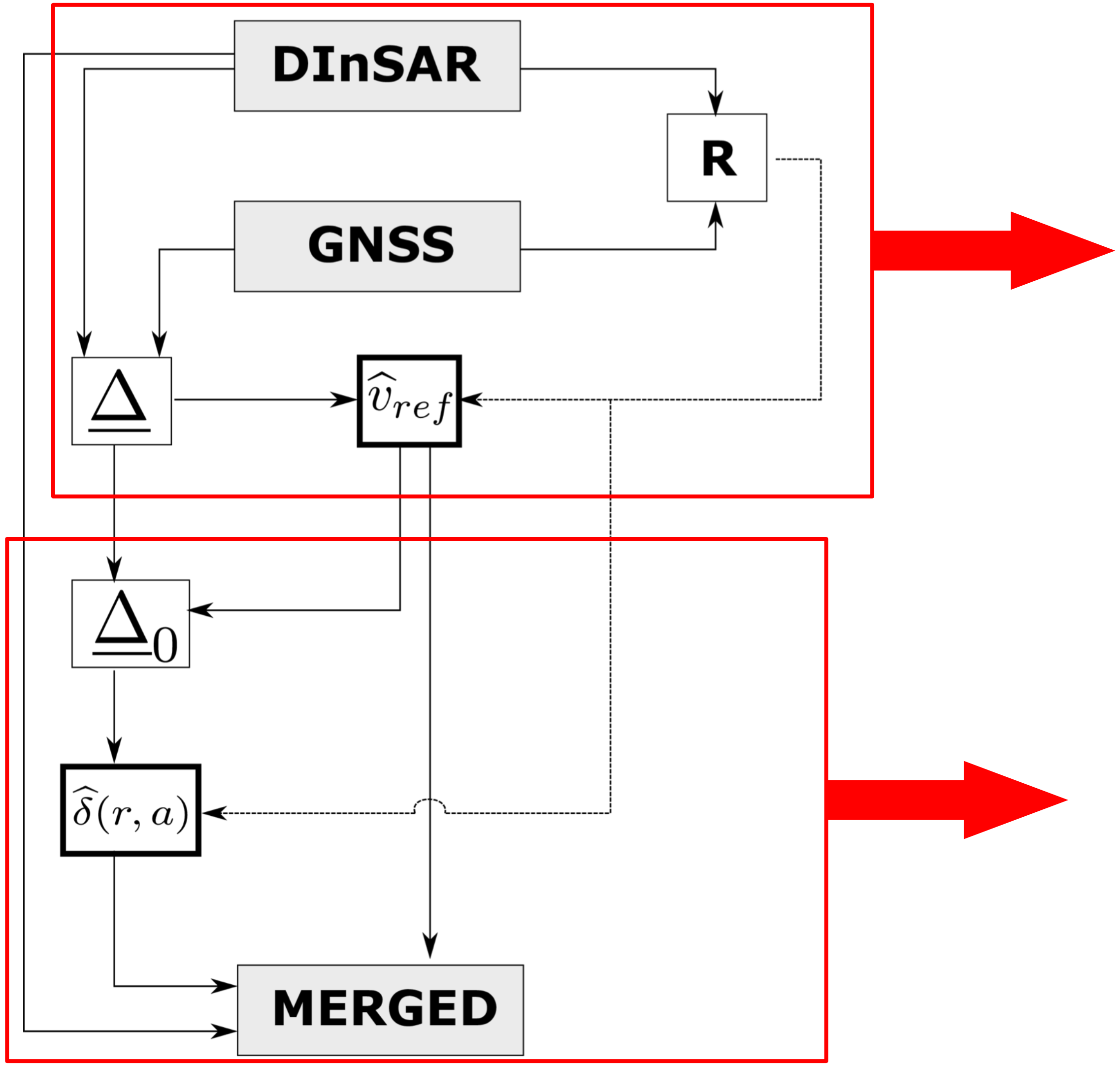
VARIANCE/COVARIANCE MATRIX

- $\mathrm{E}[\underline{\Delta}\,\underline{\Delta}^T] = \boldsymbol{R}_{\Delta} = \begin{bmatrix} \sigma^2_{GPS,1} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & \sigma^2_{GPS,N} \end{bmatrix} + \begin{bmatrix} \sigma^2_{clut,1} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & \sigma^2_{clut,N} \end{bmatrix} + \boldsymbol{R}_{\alpha}$ →



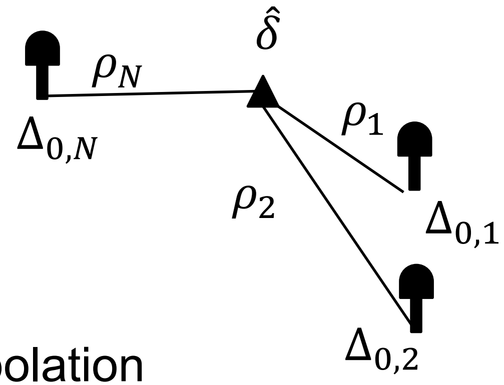
Calibration

Merging/Calibration Procedure



$$\hat{v}_{ref} = \langle \underline{\boldsymbol{\Delta}} \rangle_{weighted}$$

$$\begin{cases} \hat{\delta} = \underline{c}\, \underline{\boldsymbol{\Delta}_0} \\ \underline{c} = \boldsymbol{R}^{-1} \underline{\rho} \end{cases}$$

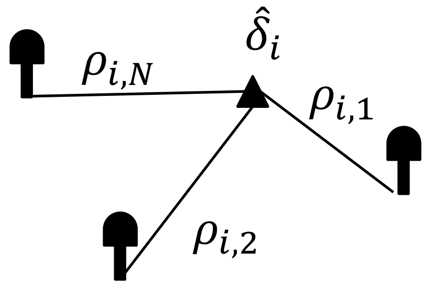


Kriging Interpolation

Variance/Covariance of the Merged/Calibrated Data

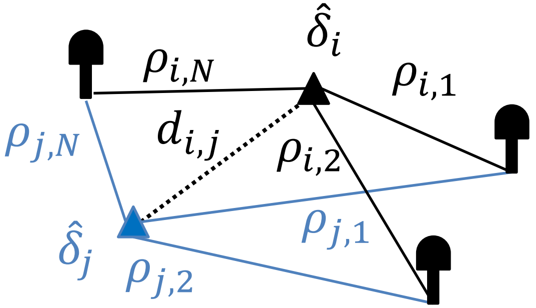
- The error in the estimation of $\hat{v}_{ref}$ generate a bias on the whole dataset. The accuracy of the final absolute comes from the accuracy of the weighted average $\sigma^2_{v_{ref}}$

- The variance of the estimation of $\hat{\delta}$ can be derived: $\langle \epsilon_i^2 \rangle = C_\alpha(0) - \underline{\rho}_i^T \boldsymbol{R}^{-1} \underline{\rho}_i$



➡ The error is no longer stationary, no variogram available

- The covariance of the estimates $\hat{\delta}$ can be derived: $\langle \epsilon_i \ \epsilon_j \rangle = C_\alpha(d_{i,j}) - \underline{\rho}_i^T \boldsymbol{R}^{-1} \underline{\rho}_j$

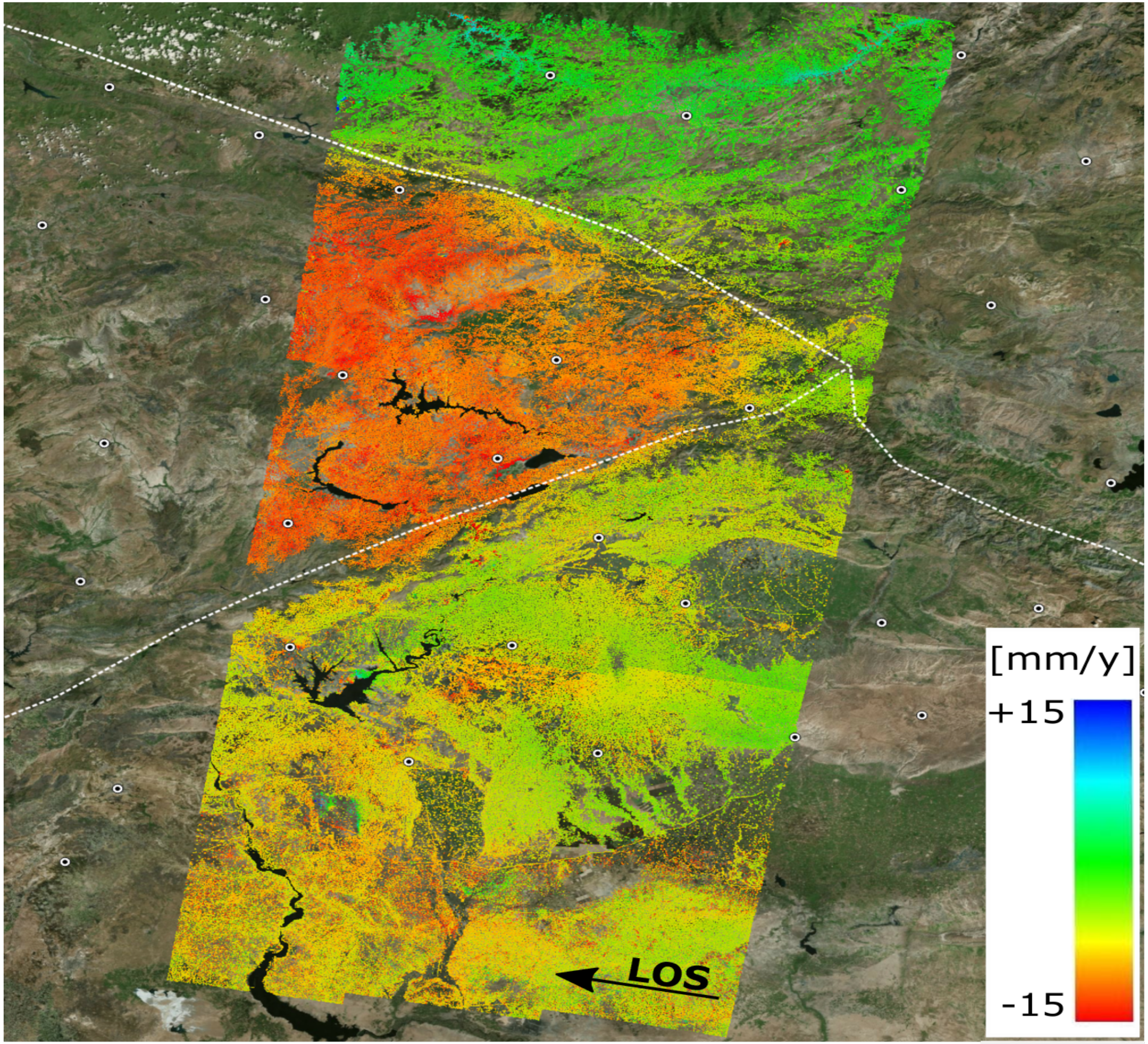


CEOS

North Anatolian Fault

- Junction between NAF and EAF
- 3 Sentinel 1 A/B Frames ~ 700 X 250 km²
- $T_{obs} = 3.3\ years$
- $N_{slcs} = 133$
- $N_{GPS} = 15$

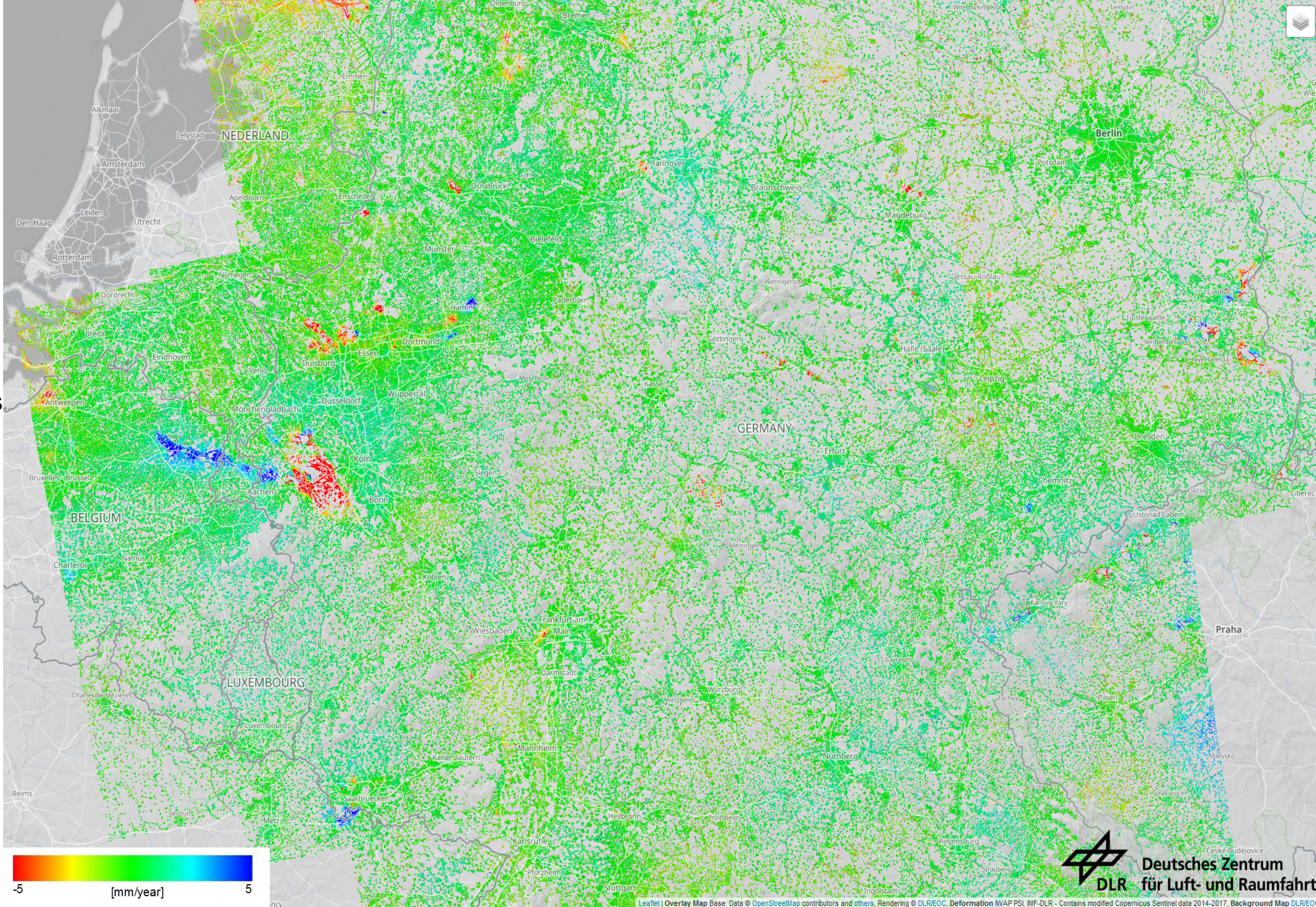
(*) GNSS data from Nevada Geodetic Laboratories (http://geodesy.unr.edu/)
Blewitt, G., C. Kreemer, W.C. Hammond, and J. Gazeaux
MIDAS robust trend estimator for accurate GPS station velocities without step detection, (2016) Journal of Geophysical Research



BGR BBD

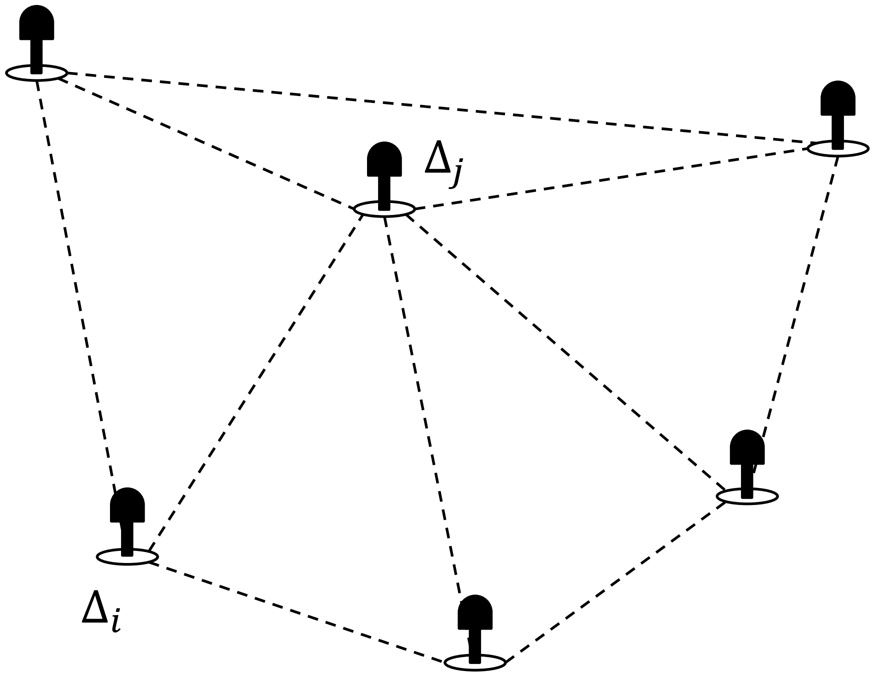
German Ground Motion Service

- Not the official BBD product !!!
- Same PSI raw-results
- Different calibration approach
- Different GNSS data
- Different projection (LoS)



Validation

Differences of InSAR/GNSS Offsets



- The Offsets Vector $\underline{\Delta}$ can be use to validate the error bars derived
- The statistic of the Offsets differences includes the error variograms

$$\left\langle \left(\Delta_i - \Delta_j\right)^2 \right\rangle = \sigma_{n,i}^2 + \sigma_{n,j}^2 + V(d(i,j))$$

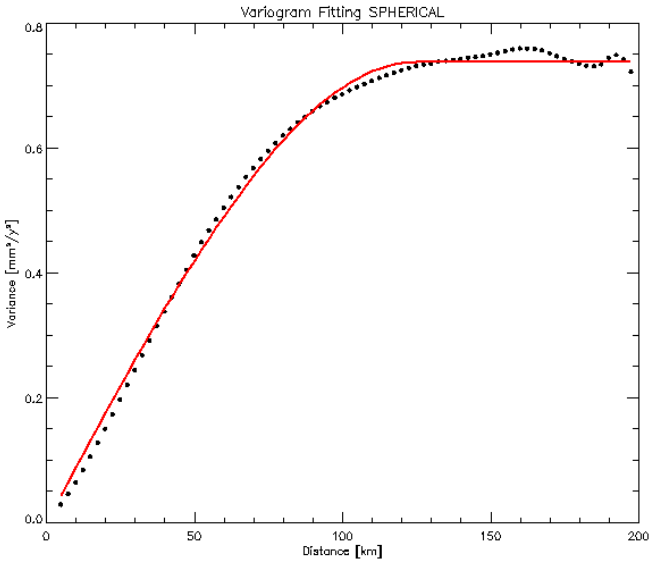
Standardized Differences of InSAR/GNSS Offsets

Studying the statistics of the standardized offsets allows to check if the provided error bars are reliable

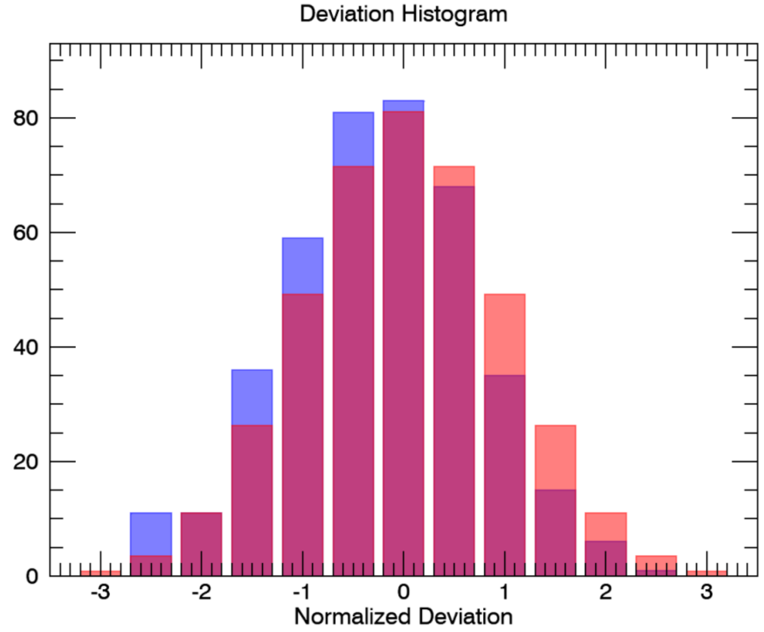
$$\frac{(\Delta_i - \Delta_j)}{\sqrt{\sigma_{n,i}^2 + \sigma_{n,j}^2 + V(d(i,j))}} \sim N(0,1)$$

Assuming the GNSS errors to be perfectly characterized verify if the set of standardized offsets is distributed as a standard normal *pdf* is validating the correctness of the Variograms V

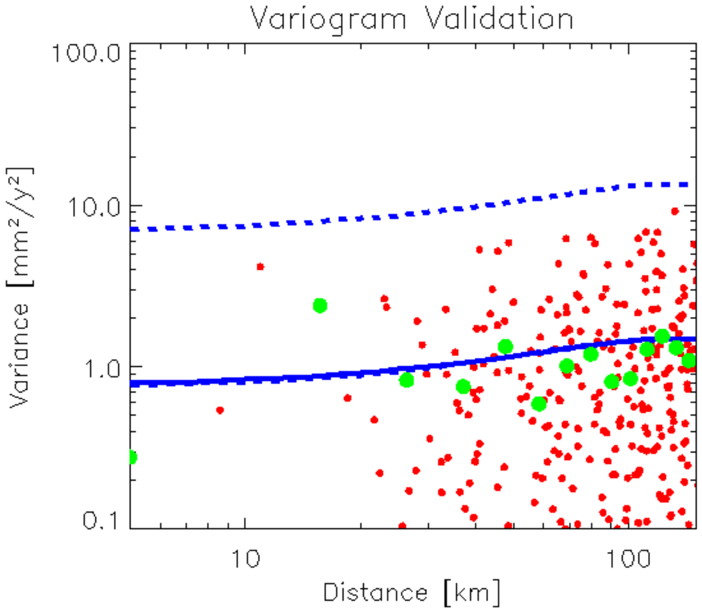
….some good examples (1)



Our fitted Accuracy Variogram



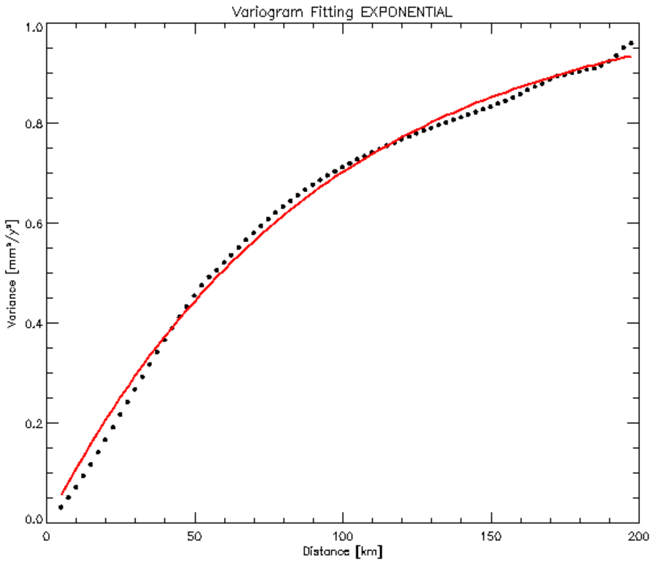
Histogram of the standardized Offsets w.r.t N(0,1)

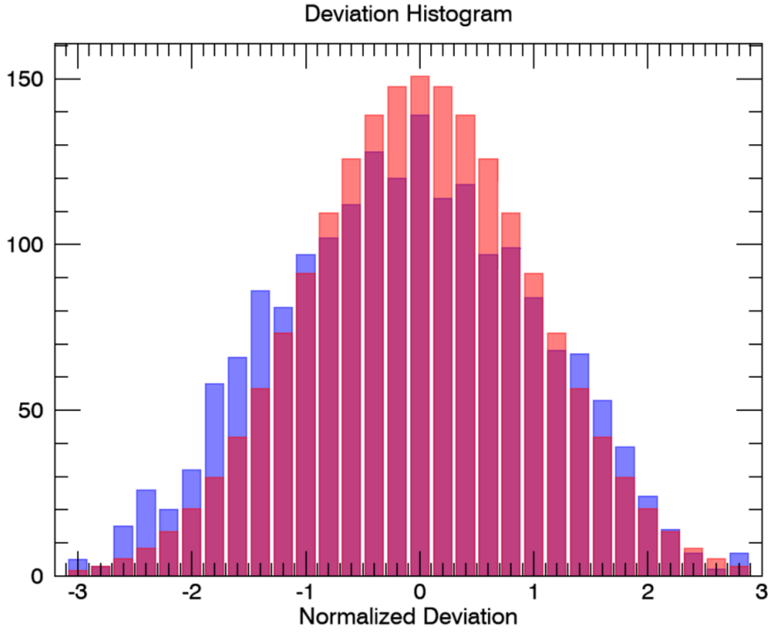


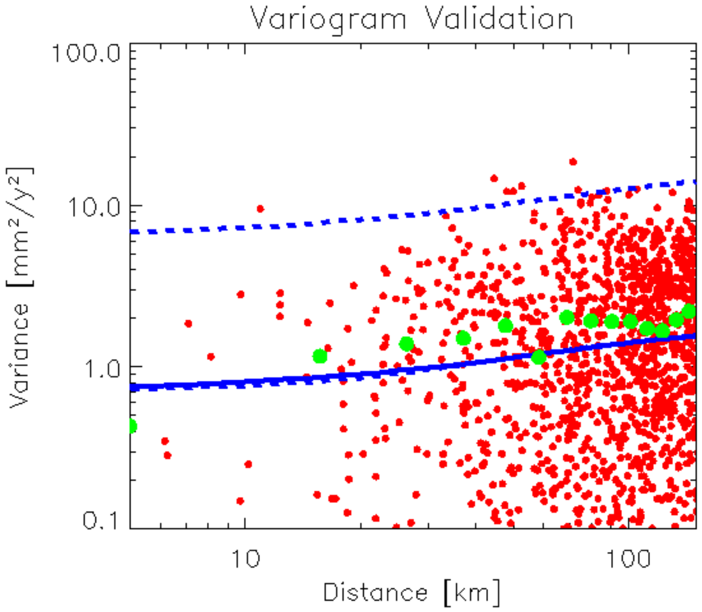
Variogram Offsets Comparison.

- red = single quadatic Offsets
- blue bold = our variogram + GNSS errors
- green = quadratic offsets averaged in bins

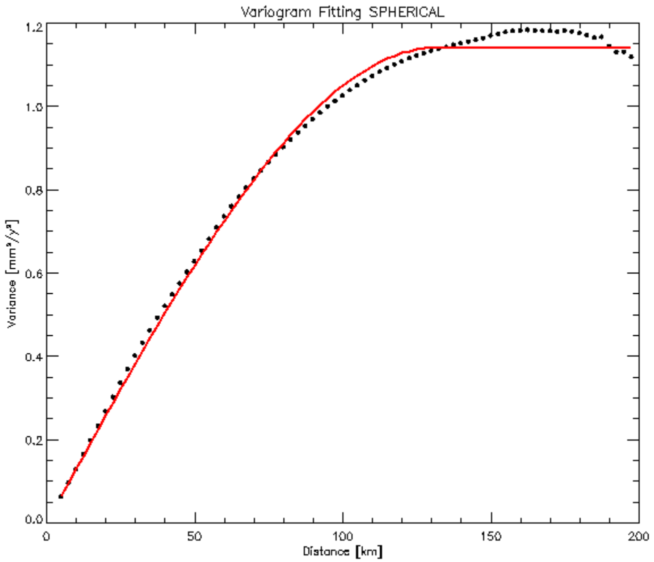
….some good examples (2)

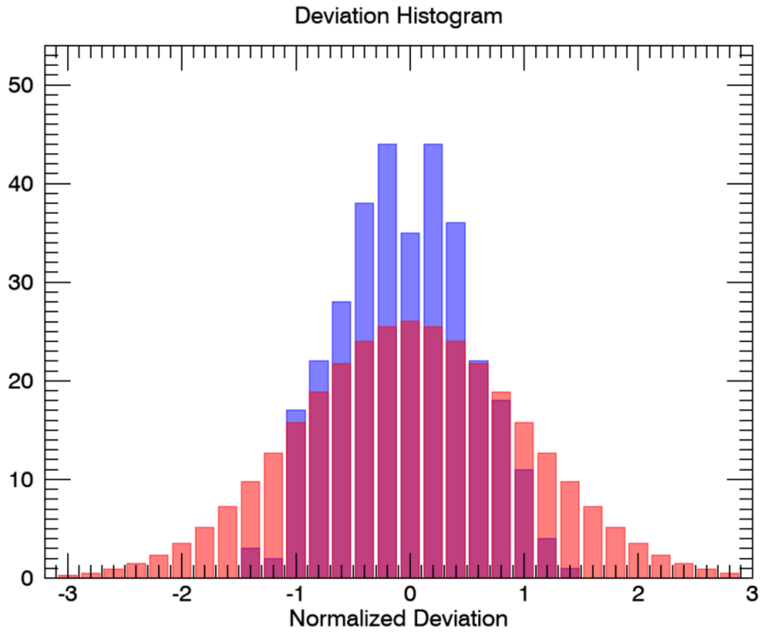


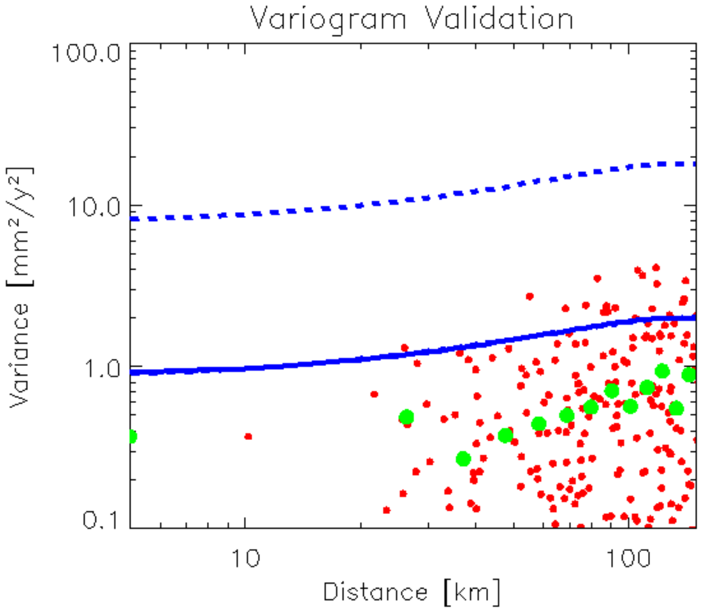




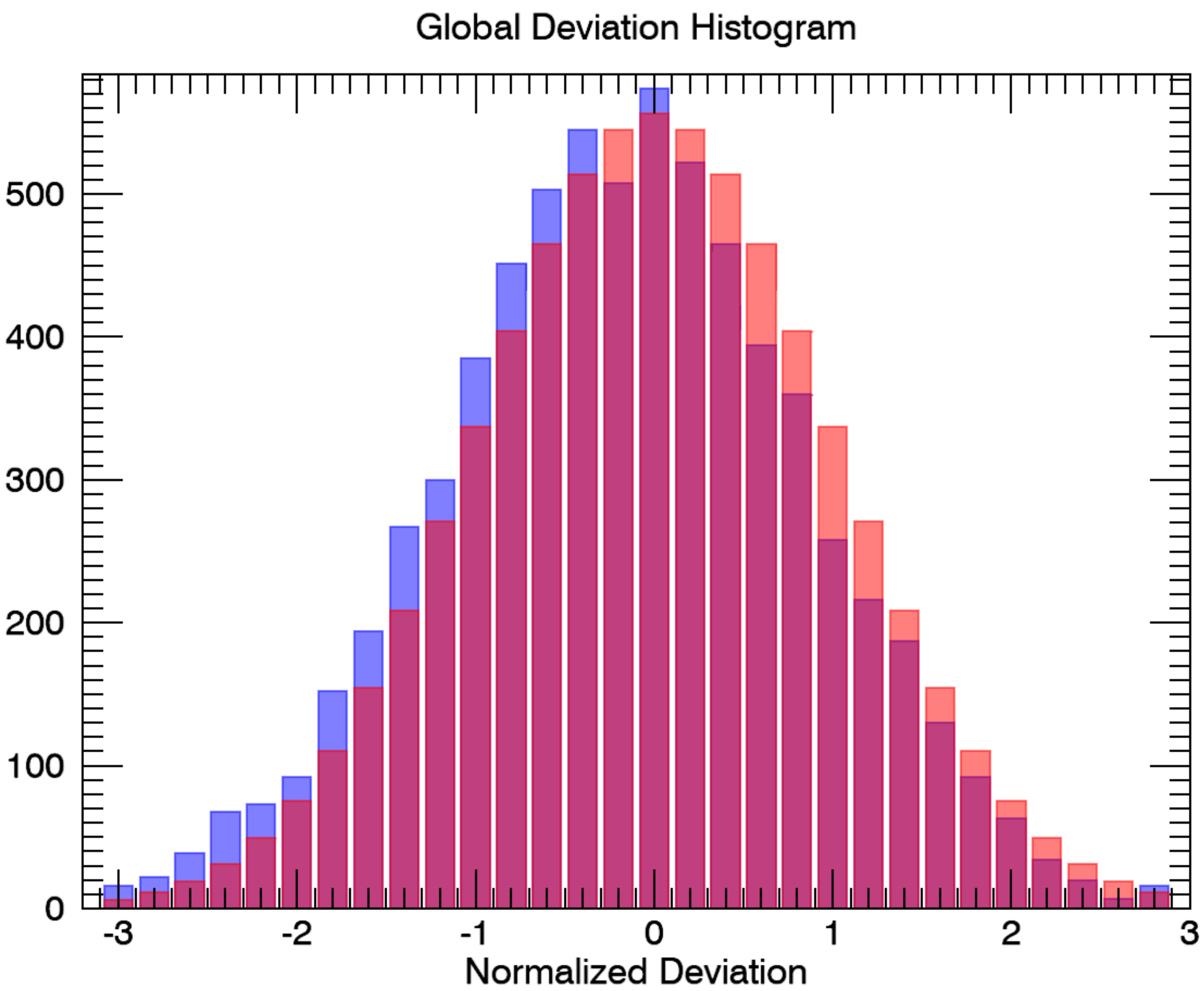
…and some bad


Variogram Fitting SPHERICAL
Variance [mm²/y²]
Distance [km]
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
50
100
150
200


Deviation Histogram
0
10
20
30
40
50
-3
-2
-1
0
1
2
3
Normalized Deviation


Variogram Validation
Variance [mm²/y²]
100.0
10.0
1.0
0.1
10
100
Distance [km]

Overall Histogram of the Standardized Offsets



- Red = $N(0,1)$ re-scaled to histogram
- Blue = Histogram of standardized offsets
- $$\begin{aligned} \mu &= -0.06 \\ \sigma &= 1.02 \\ Skew &= -0.02 \\ Kurtosis &= -0.01 \end{aligned}$$

- Dataset used:
  - 41 stacks Ascending/Descending
  - > 100 Acquisitions per stack
  - Coverage: whole Germany
  - Variable GNSS stations density

Conclusions

- ❑ Error analysis of the InSAR results
- ❑ Optimal merging/calibration based on the knowledge of the spatial spectrum of InSAR errors
- ❑ Error traceability up to the merged/calibrated results
- ❑ Validation of the InSAR Covariance using GNSS over 41 stacks gave an assessment of the error analysis