



HAL
open science

A gap-filling method to reconstruct incomplete SAR displacement measurement time series

Alexandre Hippert-Ferrer, Yajing Yan, Philippe Bolon

► **To cite this version:**

Alexandre Hippert-Ferrer, Yajing Yan, Philippe Bolon. A gap-filling method to reconstruct incomplete SAR displacement measurement time series. Living Planet Symposium 2019, May 2019, Milan, Italy. 2019. hal-02125120

HAL Id: hal-02125120

<https://hal.science/hal-02125120>

Submitted on 12 Jul 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

A gap-filling method to reconstruct incomplete SAR displacement measurement time series

Alexandre Hippert-Ferrer, Yajing Yan, Philippe Bolon

Laboratoire d'Informatique, Systèmes, Traitement de l'Information et de la Connaissance, Annecy, France

Context

Synthetic Aperture Radar (SAR) displacement measurement time series can suffer from missing data in both space and time because of (1) raw data quality and/or (2) technical limitations of the displacement extraction methods (e.g. D-InSAR, offset tracking). A new method, namely Expectation Maximization-Empirical Orthogonal Functions (EM-EOF), is proposed to fill in missing data in SAR displacement time series. EM-EOF is based on an EOF analysis and uses the EM principle to estimate the missing values.

Interests of EM-EOF

- Deals with data complexity in terms of **displacement signal** and **noise behaviors**.
- Makes use of both **spatial** and **temporal information** in the reconstruction.

Background theory

Let $X(p, n)$ be a spatio-temporal field containing n displacement maps of size p . The **sample temporal covariance** is first estimated:

$$\hat{C} = \frac{1}{p-1} (X - \mathbf{1}_n \bar{X})^T (X - \mathbf{1}_n \bar{X})$$

EOF modes (U) are the solution to the eigenvalue problem:

$$\hat{C}U = U\Lambda$$

The **anomaly** field can be reconstructed using M leading EOF modes:

$$\hat{X}' = \sum_{i=1}^M a_i \mathbf{u}_i^t$$

where $a_i = X' \mathbf{u}_i$ are the **principal components**. Finally the spatial mean is added back:

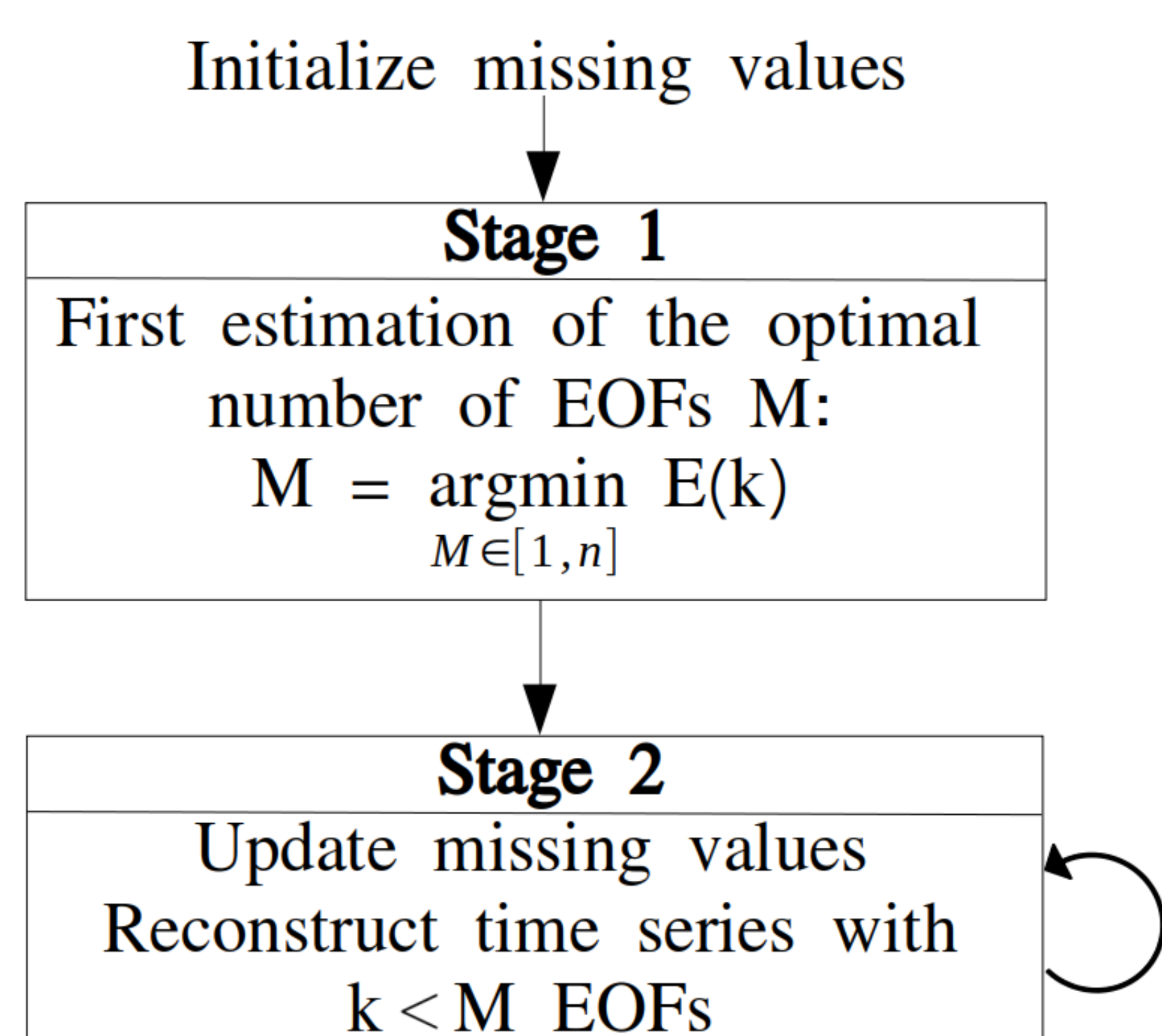
$$\hat{X} = \hat{X}' + \mathbf{1}_n \bar{X}$$

Cross-validation

A **cross-validation** root-mean-square error (cross-RMSE) is computed to estimate the optimal number of EOF modes:

$$E(k) = \left[\frac{1}{N} \sum_{i=1}^N |\hat{\mathcal{X}}_k - \mathcal{X}|^2 \right]^{1/2}$$

EM-EOF work flow



Stage 1 finds the optimal number of EOF modes which minimizes the cross-RMSE $E(k)$. Stage 2 is an iterative update of the missing values until the convergence is reached.

Numerical simulations

The EM-EOF method is tested on simulated displacement time series composed of a linear basis and oscillatory components of various frequencies with superimposed noise and data gaps.

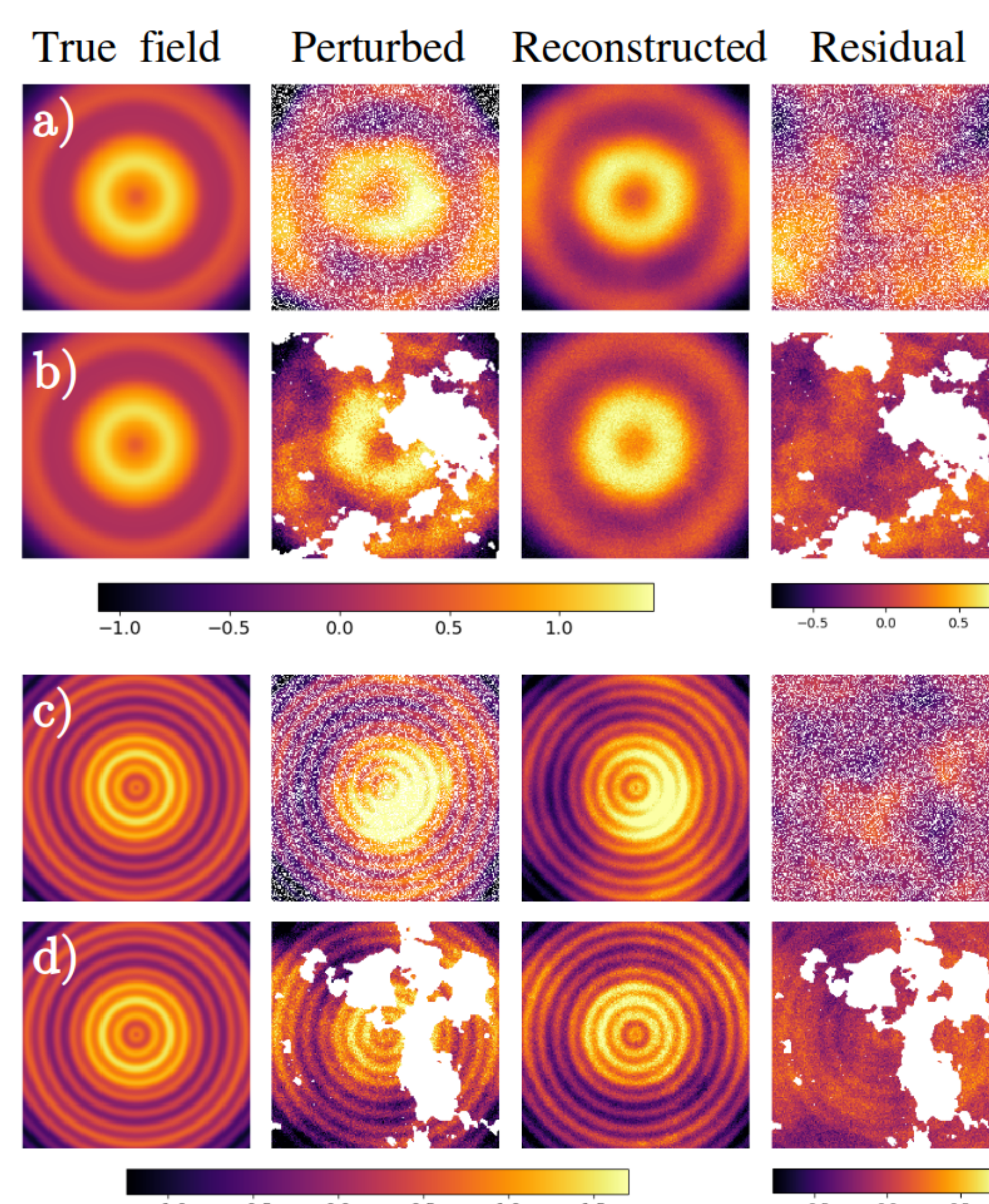
Examples of **1st** and **4th** order displacement models:

$$f(r, t) = (1 - 2r)t$$

$$g(r, t) = (1 - 2r)t + \sin\left(\frac{\pi}{2}t\right) \cos\left(\frac{\pi}{2}r\right) + 0.5 \cos\left(\frac{3\pi}{2}t\right) \cos(5\pi r) + 0.3 \sin\left(\frac{7\pi}{2}t\right) \sin(15\pi r)$$

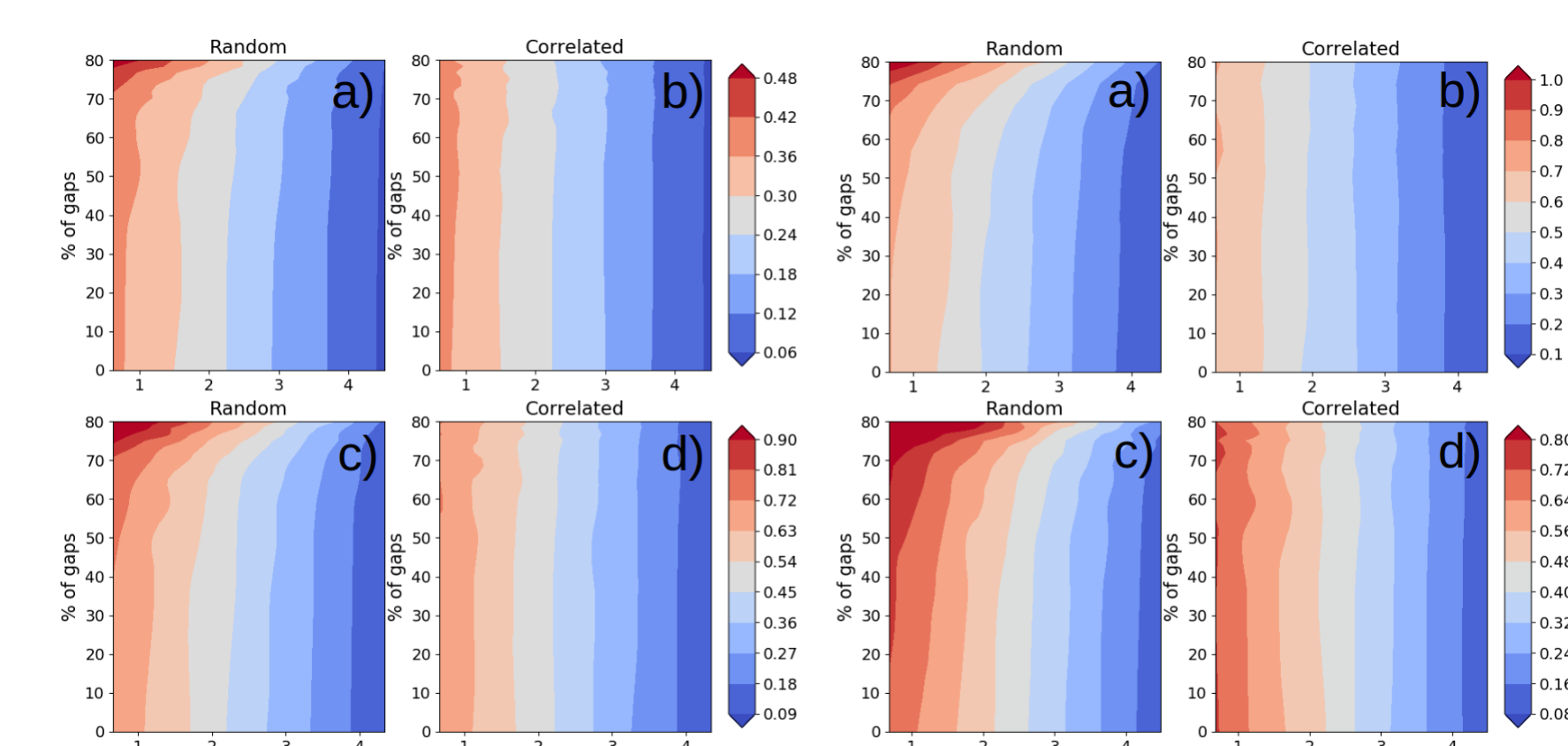
We investigate the impact of different **key parameters** on the reconstruction efficiency:

1. **Type of gaps**: random, seasonal
2. **Type of noise**: random, spatially & spatio-temporally correlated
3. **Initialization value**: spatial mean, spatial mean + random noise, spatial mean + spatially correlated noise
4. **Signal-to-noise ratio (SNR)**: [0.5, 4.5]
5. **Quantity of gaps**: [0, 80%]



Reconstructed displacement fields with 30% of gaps and $1.24 < \text{SNR} < 1.61$. (a)(b): 3rd order. (c)(d): 4th order. (a)(c): Random gaps + spatially correlated noise. (b)(d): Seasonal gaps + spatio-temporally correlated noise.

Cross-RMSE analysis

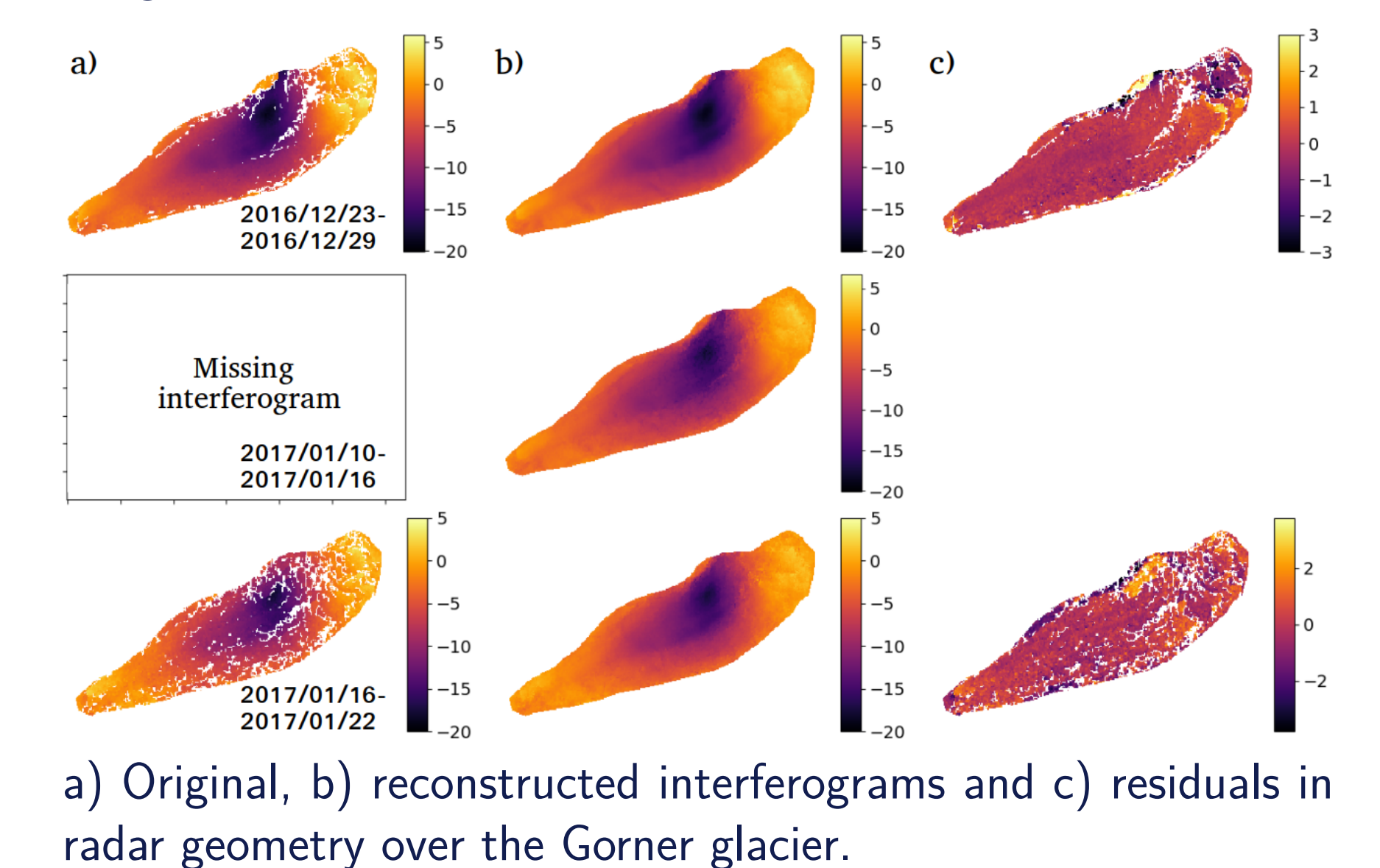


Cross-RMSE in function of SNR and % of gaps of 1st-2nd order (left) and 3rd-4th (right) displacement fields with random (a)(c) and correlated (b)(d) gaps.

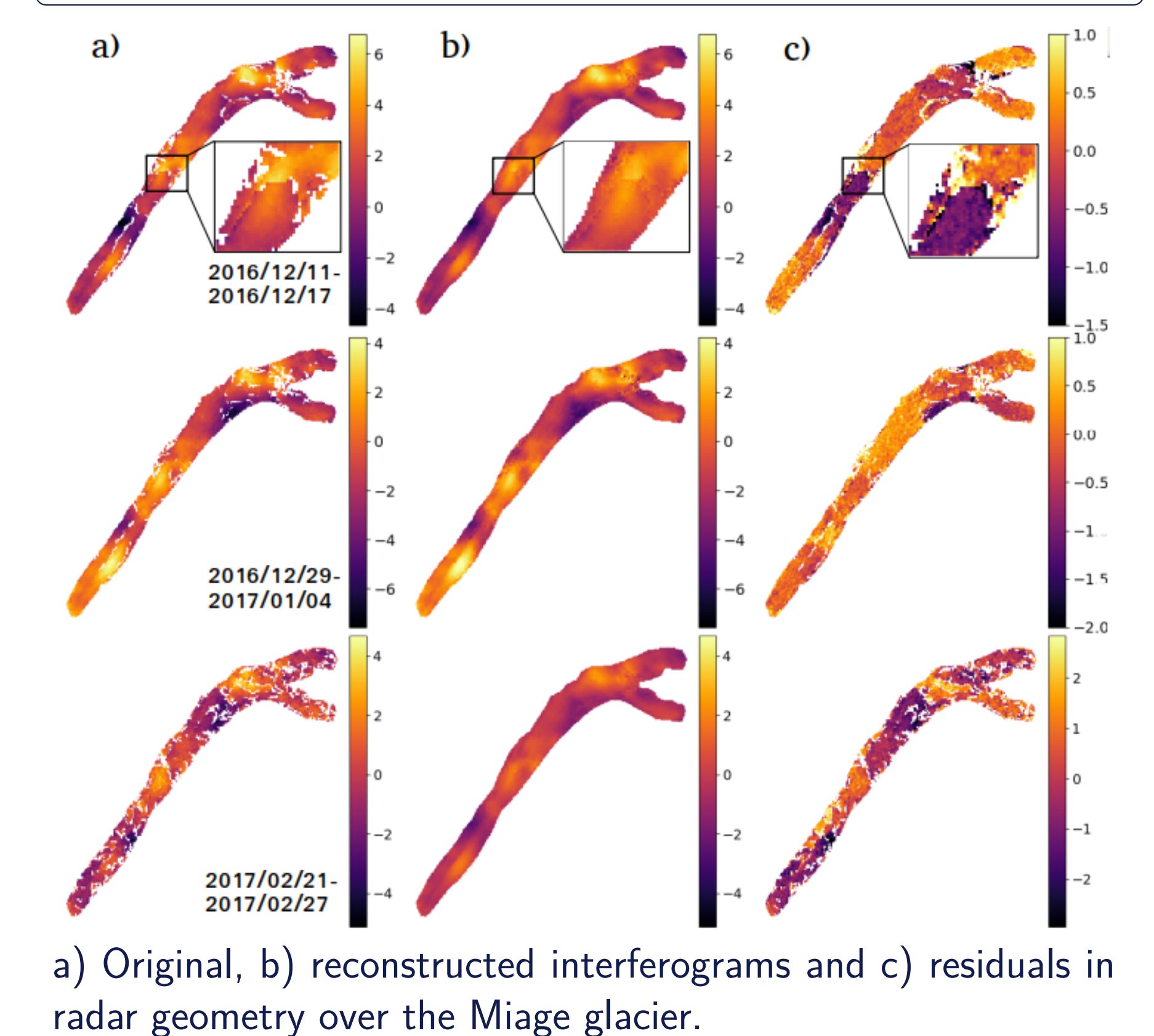
- Reconstruction performance is more affected by SNR than by % of gaps.
- Initializing data gaps by the **spatial mean** gives the best results.
- Random gaps affect more the reconstruction than seasonal gaps.

Application to SAR data over alpine glaciers

The EM-EOF method is applied to two time series of 6-days interferograms over Gorner and Miage glaciers obtained from a time series of Sentinel-1 A/B SAR images acquired in winter 2016-2017.



- Reconstructed displacement patterns are consistent
- Missing interferograms can be reconstructed.
- Phase jumps can be corrected in the reconstruction.



Conclusions

1. Cross-RMSE analysis shows the efficiency at retrieving missing values in case of complex signals with different types of noise and gaps.
2. Application to real data confirms its capacity to handle challenging issues as missing interferograms, phase jumps, and correlated data gaps.
3. EM-EOF can help increasing the effective size of the time series and to better characterize the physical phenomenon under observation.

Perspectives

- Estimation of a spatio-temporal covariance matrix.
- Apply EM-EOF to wrapped interferograms time series.

Acknowledgements

This work is supported by the Programme National de Télédétection Spatiale (PNTS), grant n° PNTS-2019-11.

References

- [1] R. Prébet, Y. Yan, M. Jauvin, and E. Trouvé. A data-adaptive EOF based method for displacement signal retrieval from InSAR displacement measurement time series for decorrelating targets. *IEEE Trans. Geosci. Remote Sens.*, 2019.