Gap-filling based on EOF analysis of spatio-temporal covariance of satellite image derived displacement time series.

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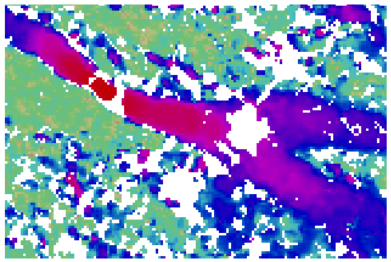
Motivation of the study

- Missing data hinder the full understanding of the physical phenomenon under observation.
- Causes : rapid surface changes, technical limitations, etc.



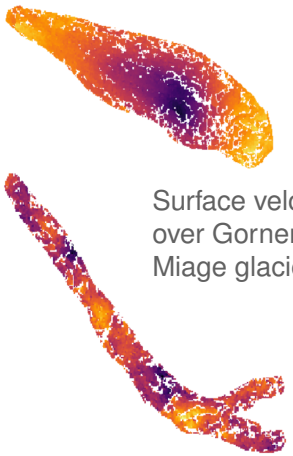
Surface velocity over Fox Glacier (Millan et al., 2019)

Previous approach : EM-EOF method

1. Uses temporal interpolation

Proposed : a statistical gap-filling method addressing

1. Randomness and space time correlation of noise and gaps
2. Mixed frequencies displacement patterns (complex signals)
3. Short time series



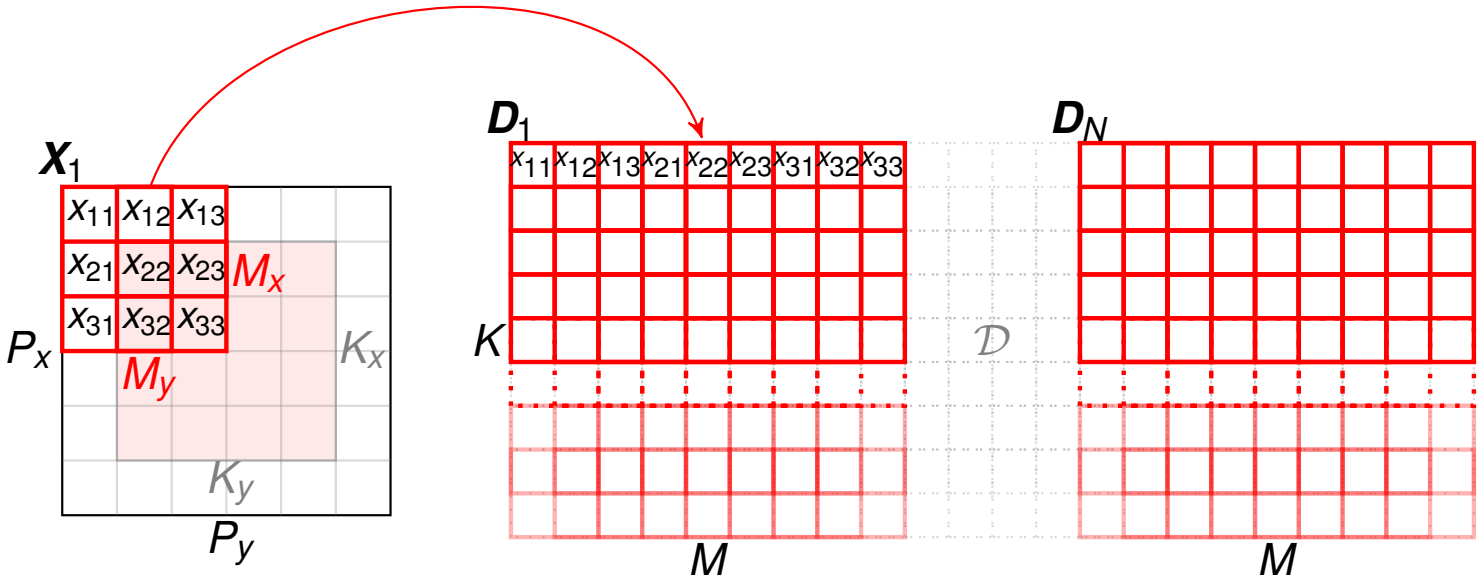
Surface velocity over Gorner and Miage glaciers.

Key features of the extended EM-EOF method

- Data is spatially augmented
- Signal learned as "modes" (extended empirical orthogonal functions)
- Low rank structure of the sample spatio-temporal covariance matrix.
- Expectation-Maximization (EM)-type algorithm for resolution.

Expectation Maximization-Empirical Orthogonal Functions

- Let $\boldsymbol{X}_t = \{x_{ij}(t)\}$ be a spatial grid observed at time $t = 1, \ldots, N$.



- Sample spatio-temporal covariance :

$$\hat{\mathbf{C}} = \frac{1}{K}\boldsymbol{\mathcal{D}}^T\boldsymbol{\mathcal{D}} = \boldsymbol{U}\Lambda\boldsymbol{U}^T \tag{1}$$

- Reconstruction with an optimal number of EOF modes $R \ll NM$:

$$\hat{\boldsymbol{\mathcal{D}}} = \boldsymbol{\mathcal{D}}\boldsymbol{U}_R\boldsymbol{U}_R^T \tag{2}$$

Problem : find the optimal R

Diagram of the method

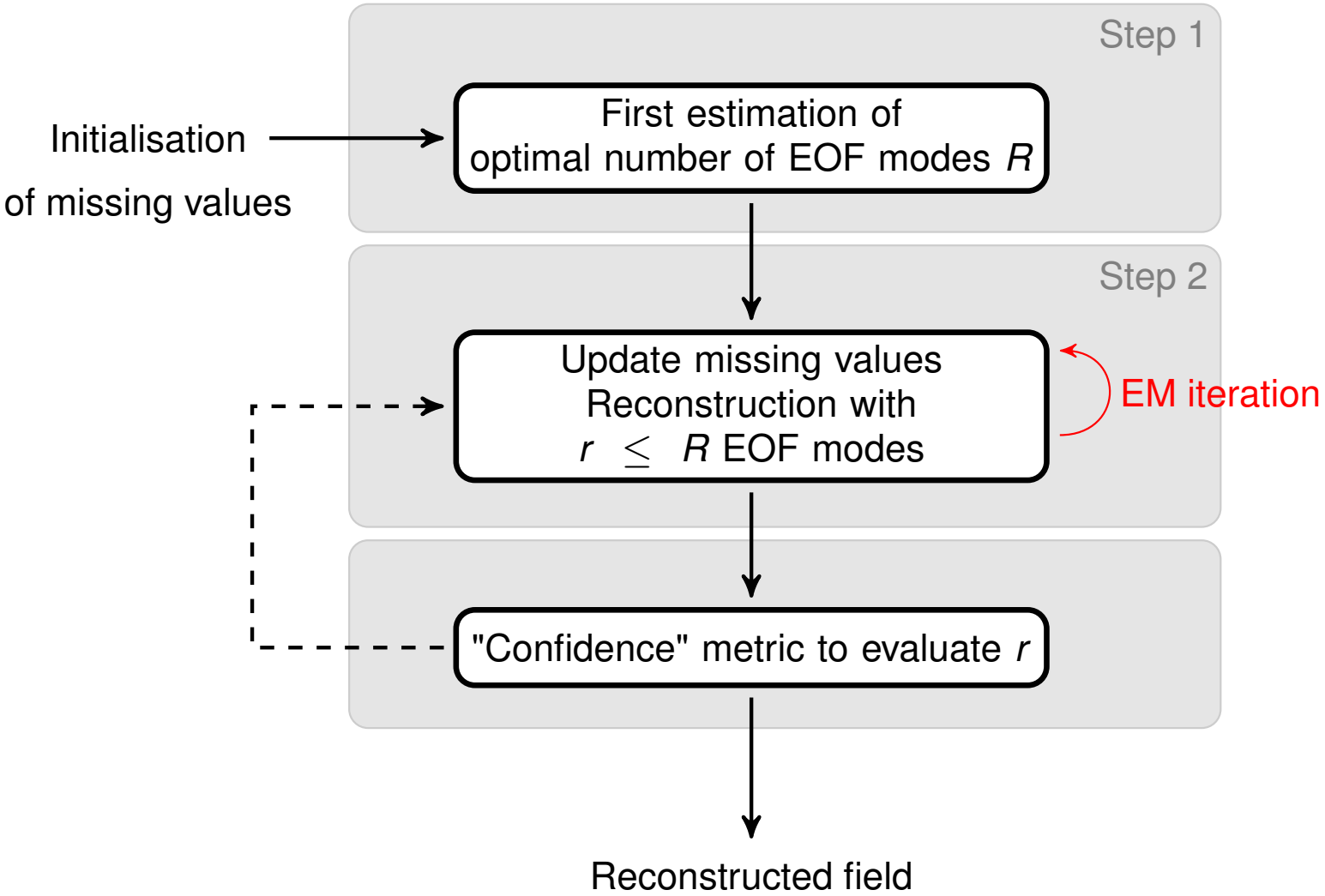
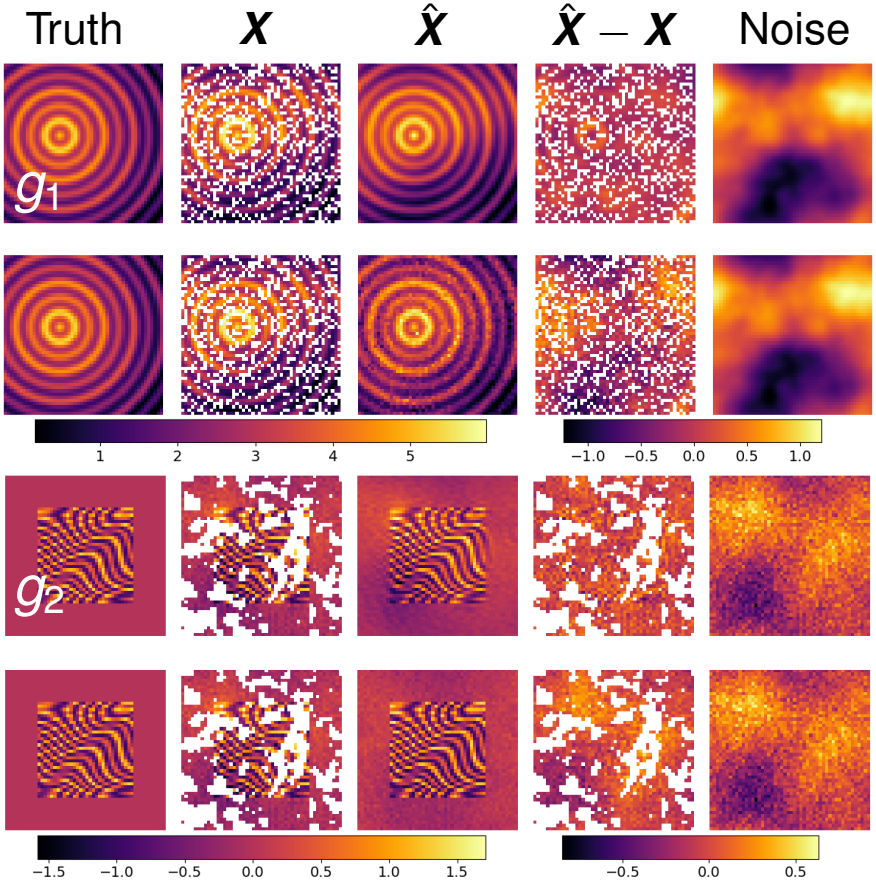


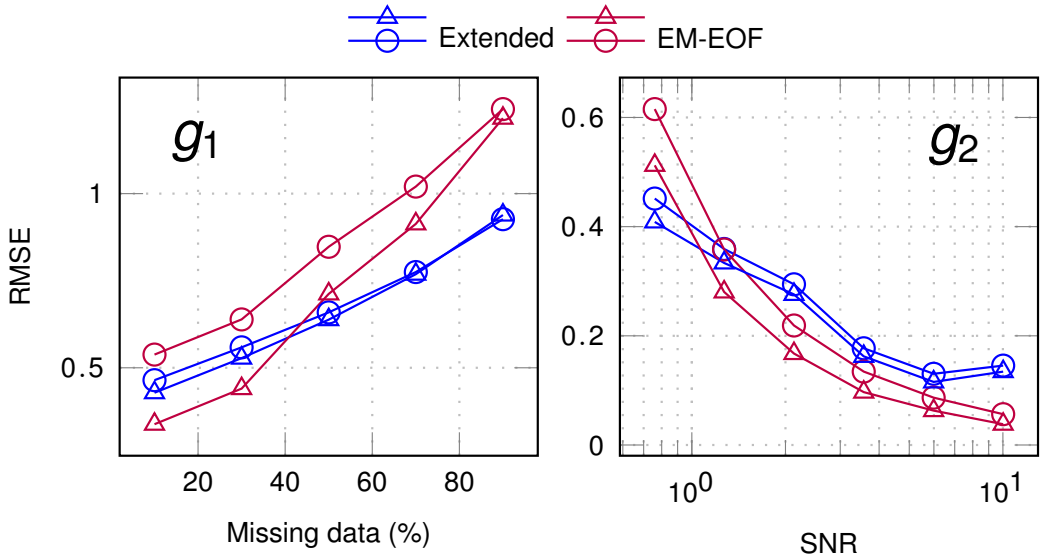
FIGURE – Simplified diagram of the extended EM-EOF method.

Numerical simulations : synthetic displacement fields

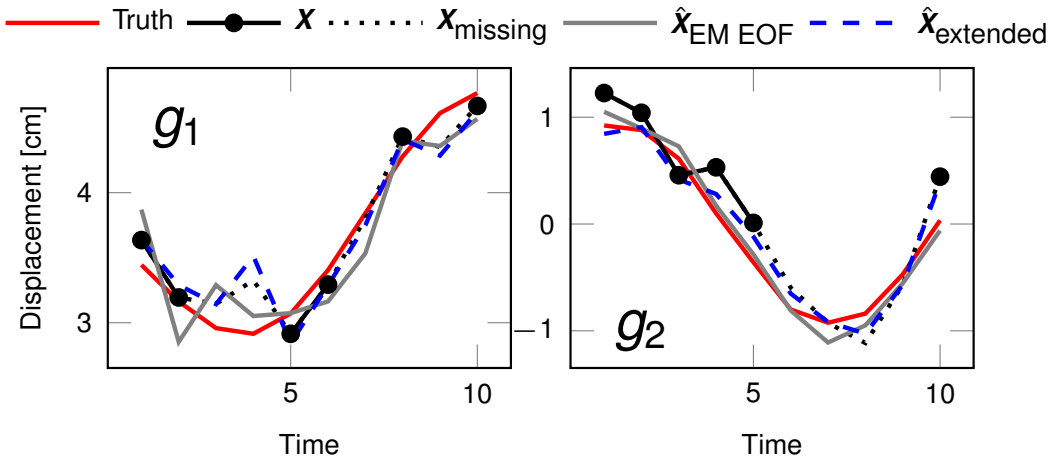


- Extended EM-EOF gives generally better results with low SNR and high % of gaps.

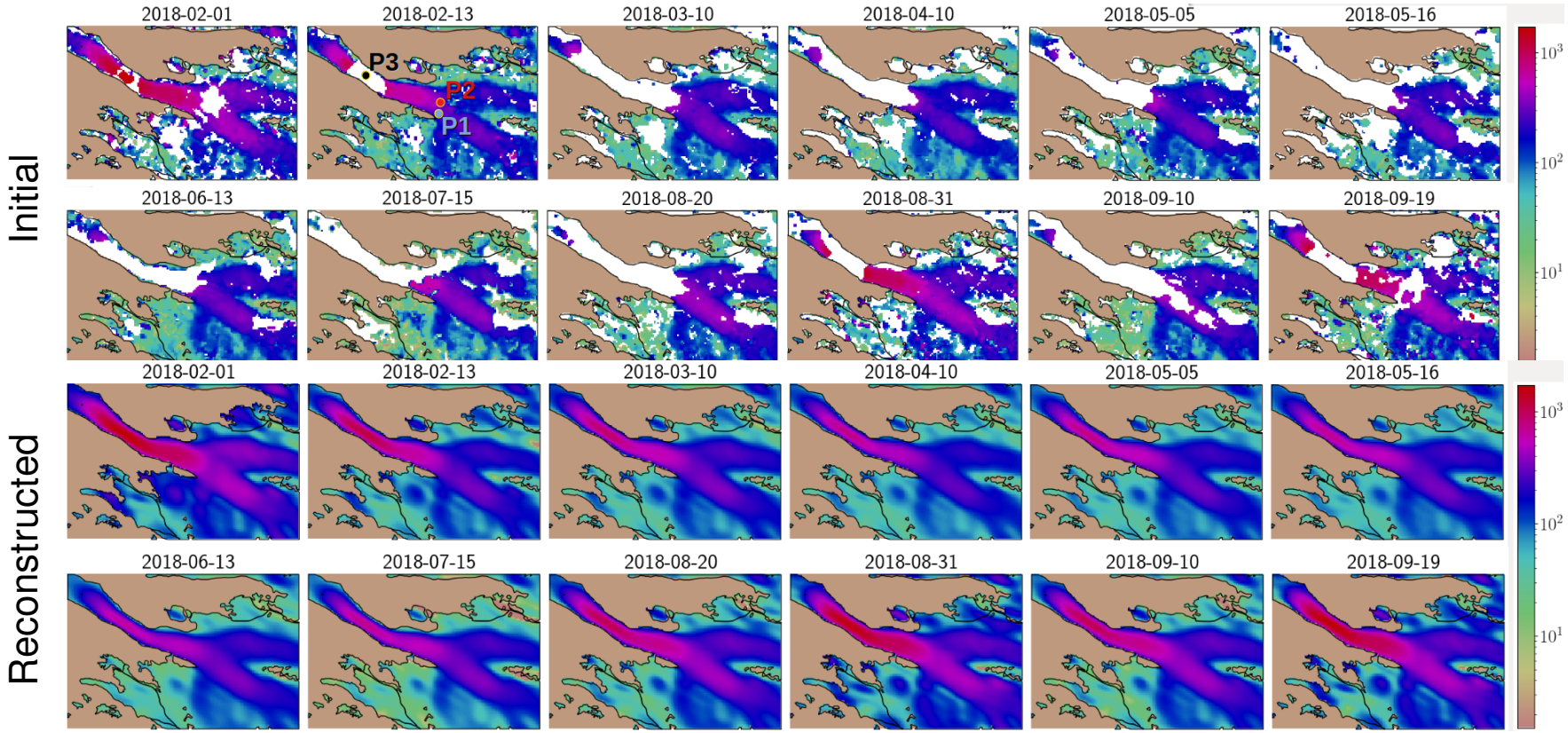
Errors versus % of gaps and SNR :

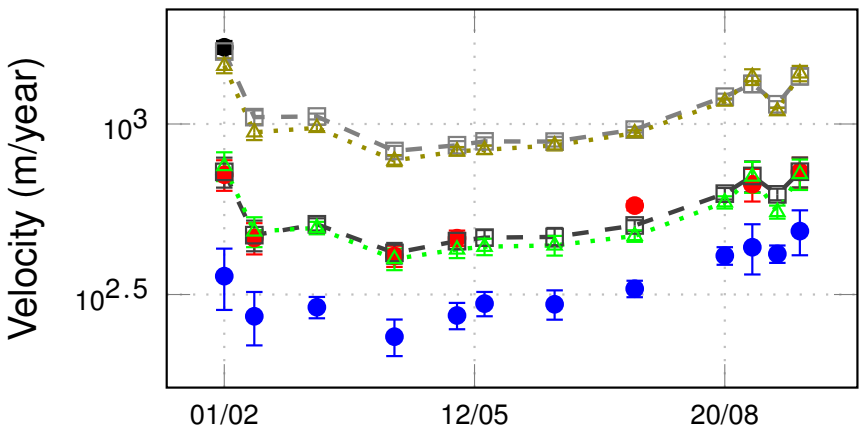


Reconstructed time series :



Result on Fox Glacier, New Zealand





- Seasonal variation is retrieved
- Heterogeneous features as noise are removed
- Values up to 1500m/year at the main icefall of Fox Glacier [2]

References

Thank you for your attention.

[1] A. Hippert-Ferrer, Y. Yan, and P. Bolon. Gap-filling based on iterative EOF analysis of temporal covariance : application to InSAR displacement time series. In **IGARSS**, pages 262–265, 2019. doi : 10.1109/IGARSS.2019.8898952.

[2] A. Kääb, S. H. Winsvold, B. Altena, C. Nuth, T. Nagler, and J. Wuite. Glacier remote sensing using sentinel-2. part i : Radiometric and geometric performance, and application to ice velocity. **Remote Sensing**, 8(7), 2016. doi : 10.3390/rs8070598.

[3] R. Millan, J. Mouginot, A. Rabatel, S. Jeong, D. Cusicanqui, A. Derkacheva, and M. Chekki. Mapping surface flow velocity of glaciers at regional scale using a multiple sensors approach. **Remote Sensing**, 11(21), 2019. doi : 10.3390/rs11212498.

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