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Spatio-temporal missing data reconstruction in satellite displacement measurement time series

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Time series analysis constitutes a thriving subject in satellite image derived displacement measurement, especially since the launching of Sentinel satellites which provide free and systematic satellite image acquisitions with extended spatial coverage and reduced revisiting time. Large volumes of satellite images are available for monitoring numerous targets at the Earth's surface, which allows for significant improvements of the displacement measurement precision by means of advanced multi-temporal methods. However, satellite image derived displacement time series can suffer from missing data, which is mainly due to technical limitations of the ground displacement computation methods (e.g. offset tracking) and surface property changes from one acquisition to another. Missing data can hinder the full exploitation of the displacement time series, which can potentially weaken both knowledge and interpretation of the physical phenomenon under observation. Therefore, an efficient missing data imputation approach seems of particular importance for data completeness. In this work, an iterative method, namely extended Expectation Maximization - Empirical Orthogonal Functions (EM-EOF) is proposed to retrieve missing values in satellite image derived displacement time series. The method uses both spatial and temporal correlations in the displacement time series for reconstruction. For this purpose, the spatio-temporal covariance of the time series is iteratively estimated and decomposed into different EOF modes by solving the eigenvalue problem in an EM-like scheme. To determine the optimal number of EOFs modes, two robust metrics, the cross validation error and a confidence index obtained from eigenvalue uncertainty, are defined. The former metric is also used as a convergence criterion of the iterative update of the missing values. Synthetic simulations are first performed in order to demonstrate the ability of missing data imputation of the extended EM-EOF method in cases of complex displacement, gaps and noise behaviors. Then, the method is applied to time series of offset tracking displacement measurement of Sentinel-2 images acquired between January 2017 and September 2019 over Fox Glacier in the Southern Alps of New Zealand. Promising results confirm the efficiency of the extended EM-EOF method in missing data imputation of satellite image derived displacement time series.