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Learning nonlinear feature representations from spatio-temporal Earth observation data

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Remote sensing observations, products and simulations are fundamental sources of information to monitor our planet. Uncovering the main modes of spatial and temporal variability in Earth data is essential to analyze and understand the underlying physical dynamics and processes driving the Earth System. Dimensionality reduction methods can work with spatio-temporal datasets and decompose the information efficiently. Principal Component Analysis (PCA), also known as Empirical Orthogonal Functions (EOF) in geophysics, has been traditionally used to analyze climatic data. However, when nonlinear feature relations are present, PCA/EOF fails. We propose a nonlinear PCA method to deal with spatio-temporal Earth data. The proposed method, called Rotated Complex Kernel PCA (ROCK-PCA for short), works in reproducing kernel Hilbert spaces to account for nonlinear processes, operates in the complex kernel domain to account for both space and time features, and adds an extra rotation for improved flexibility. The result is a spatially-explicit and temporally-resolved decomposition of the Earth data cube. The method is unsupervised and computationally very efficient. We illustrate its ability to uncover spatio-temporal patterns using synthetic experiments and real data. Results of the decomposition of three essential climate variables are shown: satellite-based global Gross Primary Productivity (GPP) and Soil Moisture (SM), and reanalysis Sea Surface Temperature (SST) data. The ROCK-PCA method allows identifying their annual and seasonal oscillations, as well as their non-seasonal trends and spatial variability patterns. The main modes of GPP and SM match expected distributions of land-cover and eco-hydrological zones, respectively; the inter-annual component of SM is shown to be highly correlated with El Niño Southern Oscillation (ENSO) phenomenon; and the SST annual oscillation is perfectly uncoupled in magnitude and phase from the global warming trend and ENSO anomalies, as well as from their mutual interactions.