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Understanding climate impacts on vegetation using a spatiotemporal non-linear Granger causality framework

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Satellite data provide an abundance of information about crucial climatic and environmental variables. These data – consisting of global records, spanning up to 35 years and having the form of multivariate time series with different spatial and temporal resolutions – enable the study of key climate–vegetation interactions. Although methods which are based on correlations and linear models are typically used for this purpose, their assumptions for linearity about the climate-vegetation relationships are too simplistic. Therefore, we adopt a recently proposed non-linear Granger causality analysis [1], in which we incorporate spatial information, concatenating data from neighboring pixels and training a joint model on the combined data. Experimental results based on global data sets show that considering non-linear relationships leads to a higher explained variance of past vegetation dynamics, compared to simple linear models.

Our approach consists of several steps. First, we compile an extensive database [1], which includes multiple data sets for land surface temperature, near-surface air temperature, surface radiation, precipitation, snow water equivalents and surface soil moisture. Based on this database, high-level features are constructed and considered as predictors in our machine-learning framework. These high-level features include (de-trended) seasonal anomalies, lagged variables, past cumulative variables, and extreme indices, all calculated based on the raw climatic data. Second, we apply a spatiotemporal non-linear Granger causality framework – in which the linear predictive model is substituted for a non-linear machine learning algorithm – in order to assess which of these predictor variables Granger-cause vegetation dynamics at each 1° pixel. We use the de-trended anomalies of Normalized Difference Vegetation Index (NDVI) to characterize vegetation, being the target variable of our framework.

Experimental results indicate that climate strongly (Granger-)causes vegetation dynamics in most regions globally. More specifically, water availability is the most dominant vegetation driver, being the dominant vegetation driver in 54% of the vegetated surface. Furthermore, our results show that precipitation and soil moisture have prolonged impacts on vegetation in semiarid regions, with up to 10% of additional explained variance on the vegetation dynamics occurring three months later. Finally, hydro-climatic extremes seem to have a remarkable impact on vegetation, since they also explain up to 10% of additional variance of vegetation in certain regions despite their infrequent occurrence.

References

[1] Papagiannopoulou, C., Miralles, D. G., Verhoest, N. E. C., Dorigo, W. A., and Waegeman, W.: A non-linear Granger causality framework to investigate climate–vegetation dynamics, Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-266, in review, 2016.