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Evaluation of a novel non-parametric approach to identify Time of Emergence (ToE) of climate signals

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The time when a climate signal permanently exceeds its natural variability is called time of emergence (ToE). ToE shall serve policy makers as an indication of when to expect the climate and the environment to undergo significant changes. Identifying ToE, however, is challenging, primarily because of the lack of a standard to quantify exceedance, which, in turn, requires a definition of a natural background variability. Existing approaches often rely on a high level of arbitrary parameter values, e.g. selecting a specific number of times the standard deviation of a reference period as natural variability, selecting specific moving window widths to smooth a signal, or the arbitrary choice of a significance level for a statistical test. Such choices of course have a large influence on the final results and would in theory require exhaustive sensitivity analyses and discussion.

In order to minimize the level of parameterization for ToE estimates, we have developed a novel approach. It assesses exceedance of a climate signal by measuring distances between probability density functions (PDF) of the signal at different times (reference vs. target periods), using the Hellinger distance (HD) metric. The HD metric can be understood as the geometrical overlap of the respective PDFs and we adjusted it to describe the emergence as dissimilarity (0%-100%). In order to derive the PDFs, we use a kernel density estimator (KDE). This, however, introduces the KDE-bandwidth hyperparameter, which determines how smoothly the PDF is generated. Together with the choices for the length of the target and reference periods, and the end of the reference period, a set of less numerous but unavoidable hyperparameters are present that affect the outcome of ToE estimates. We present an extensive sensitivity analysis and highlight strengths and shortcomings of our approach with respect to the frequently used Kolmogorov–Smirnov (KS) test, and the used distance metric within it. We consider a set of synthetic datasets that show similar features as climate model temperature time series. In these datasets, we control the onset of change, variability levels, or trends in the data. Results show that our approach can more precisely identify the changes as compared to the KS-based approach. In particular when the changes in the signal are of low amplitude and sample sizes are small, our approach performs superior. The sensitivity of our approach in the considered tests to varying KDE-bandwidths is less than 5%. The approach has so far been applied on time-series of annual temperature and precipitation. Changes in the distribution of various other climate variables are potential fields of application. Associated challenges with non normally-distributed data, for example high temporal resolution

precipitation data, are discussed.