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Studying Climate Response to Forcing by the Nonlinear Dynamical Mode Decomposition

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An analysis of global climate response to external forcing, both anthropogenic (mainly, CO_2 and aerosol) and natural (solar and volcanic), is needed for adequate predictions of global climate change. Being complex dynamical system, the climate reacts to external perturbations exciting feedbacks (both positive and negative) making the response non-trivial and poorly predictable. Thus an extraction of internal modes of climate system, investigation of their interaction with external forcings and further modeling and forecast of their dynamics, are all the problems providing the success of climate modeling.
In the report the new method for principal mode extraction from climate data is presented. The method is based on the Nonlinear Dynamical Mode (NDM) expansion [1,2], but takes into account a number of external forcings applied to the system. Each NDM is represented by hidden time series governing the observed variability, which, together with external forcing time series, are mapped onto data space. While forcing time series are considered to be known, the hidden unknown signals underlying the internal climate dynamics are extracted from observed data by the suggested method. In particular, it gives us an opportunity to study the evolution of principal system's mode structure in changing external conditions and separate the internal climate variability from trends forced by external perturbations. Furthermore, the modes so obtained can be extrapolated beyond the observational time series, and long-term prognosis of modes' structure including characteristics of interconnections and responses to external perturbations, can be carried out.
In this work the method is used for reconstructing and studying the principal modes of climate variability on inter-annual and decadal time scales accounting the external forcings such as anthropogenic emissions, variations of the solar activity and volcanic activity. The structure of the obtained modes as well as their response to external factors, e.g. forecast their change in 21 century under different CO_2 emission scenarios, are discussed.

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[2] Gavrilov, A., Mukhin, D., Loskutov, E., Volodin, E., Feigin, A., & Kurths, J. (2016). Method for reconstructing nonlinear modes with adaptive structure from multidimensional data. Chaos: An Interdisciplinary Journal of Nonlinear Science, 26(12), 123101. http://doi.org/10.1063/1.4968852