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A State Space Representation of a Two-Component Energy Balance Model

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Energy Balance models (EBMs) condense the complicated processes underlying temperature change into a single equation that describes the disequilibrium between absorbed radiation and emitted radiation, where the relation between temperature change and radiative forcing is established. The two-component EBM divides the climate into a mixed shallow ocean/atmosphere layer and a deep ocean layer, thereby accommodating the heat exchange between these two layers. However, the predominant nature of non-stationarity in the observations of climate variables poses challenges for standard statistical inference.

This study maps the two-component EBM into a versatile linear state space system (named EBM-SS model) of temperatures in the mixed layer and in the deep ocean layer with radiative forcing. This EBM-SS model allows for the modeling of non-stationarity and time-varying behaviors, the incorporation of multiple alternative variables for one object of interest, and the handling of missing observations. It opens up the possibility to couple with other frameworks to identify the drivers underlying the temperature evolution while maintaining consistency with physical theory. We decompose the latent state of radiative forcing, which is exogenous in this system, into a smooth component and a rough component. The smooth component is modeled as a random walk process with drift to represent the deterministic and stochastic trends of radiative forcing, while the rough component captures the transitory episodes in forcing following major volcanic eruptions.

We conduct an empirical analysis on data series at the global level from the period 1955 -- 2019, where the maximum likelihood estimates of the physical parameters are obtained via outputs from the Kalman Filter. We employ proxy variable for the temperature in the deep ocean layer, which is an integral quantity of the ocean temperature and represents the heat storage in the ocean.