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Stochastic Mode Reduction – a Parameterization Based on First Principles?

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In climate models many subgrid-scale (SGS) parameterizations contain empirical parameters. Consequently, the models are dependent on the data used to tune the closures. In particular, if the system is perturbed the tuning parameters might become erroneous and the SGS parameterization may no longer be helpful in simulating the correct dynamics of the perturbed atmosphere. Parameterizations based on first principles circumvent this issue since they contain (nearly) no tuning parameters. Instead, they are dependent on the model equations. Thus, closures based on first principles are able to respond to external forcings. Recently, the stochastic mode reduction (SMR; Majda et al. 2001) gained interest in geoscience. For systems with an intrinsic scale separation, the SMR allows the derivation of a reduced stochastic model (RSM) based on first principles. While there is still some tuning involved, we expect the RSM to be more robust than low-order models with traditional data-driven SGS closures.
To test the ability of the RSM to respond to external forcings we apply the SMR to a three-layer quasigeostrophic model (QG3LM). Furthermore, we place a local anomalous heat source in the extratropics. In addition, we consider a semi-empirical low-order model (SEM) that is constructed based on a reduced number of QG3LM variance patterns and has an empirical linear closure as SGS parameterization.
We show that for the unperturbed case the RSM is able to produce quantitatively similar results compared to the SEM. Furthermore, we discuss experiments with a perturbed model climate and study the response of the RSM in comparison to the response of the SEM. Additionally, we investigate the possibility to treat the remaining empirics by the fluctuation-dissipation theorem as described in Pieroth et al. (2018), to improve the response of the RSM even further.

References:

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