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The gravity wave parameterization calibration problem: A 1D QBO model testbed

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An essential step in implementing any new parameterization is calibration, where the parameterization is adjusted to work with an existing model and yield some desired improvement. In the context of gravity wave (GW) momentum transport, calibration is necessitated by the facts that: (i) Some GWs are always at least partially resolved by the model, and hence a parameterization should only account for the missing waves. Worse, the parameterization may need to correct for the misrepresentation of under-resolved GWs, i.e., coarse vertical resolution can bias GW breaking level, leading to erroneous momentum forcing. (ii) The parameterized waves depend on the resolved solution for both their sources and dissipation, making them susceptible to model biases. Even a "perfect" parameterization could then yield an undesirable result, e.g., an unrealistic Quasi-Biennial Oscillation (QBO). While model-specific calibration is required, one would like a general "recipe" suitable for most models. From a practical point of view, the adoption of a new parameterization will be hindered by a too-demanding calibration process. This issue is of particular concern in the context of data-driven methods, where the number of tunable degrees of freedom is large (possibly in the millions). Thus, more judicious ways for addressing the calibration step are required.

To address the above issues, we develop a 1D QBO model, where the "true" gravity wave momentum deposition is determined from a source distribution and critical level breaking, akin to a traditional physics-based GW parameterization. The control parameters associated with the source consist of the total wave flux (related to the total precipitation for convectively generated waves) and the spectrum width (related to the depth of convection). These parameters can be varied to mimic the variability in GW sources between different models, i.e., biases in precipitation variability. In addition, the model's explicit diffusivity and vertical advection can be varied to mimic biases in model numerics and circulation, respectively. The model thus allows us to assess the ability of a data-driven parameterization to (i) extrapolate, capturing the response of GW momentum transport to a change in the model parameters and (ii) be calibrated, adjusted to maintain the desired simulation of the QBO in response to a change in the model parameters. The first property is essential for a parameterization to be used for climate prediction, the second, for a parameterization to be used at all. We focus in particular on emulators of the GW momentum transport based on neural network and regression trees, contrasting their ability to satisfy both of these goals.