

## Dichotomy between process-level constraint on warm rain and energy-based requirement on aerosol indirect effect in AGCM

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Global climate models (GCMs) are commonly formulated to reach a required energy balance for the historical period at the top of atmosphere (TOA) before they are used to predict future climate changes due to changes in atmospheric agents (e.g. aerosols and greenhouse gases). However, increasing studies showed that models suffer from substantial biases at the process-level of physics, even though they well reproduce the historical climate. The biases in the manner of physical processes may cause mis-prediction of the climate response to variations in atmospheric agents in the future.

The representation of warm precipitation process is one key source of bias that contribute largely to the uncertainty in predicted energy budget. Many studies have corroborated one common bias in warm precipitation process among state-of-the-art GCMs: precipitation is triggered much too easily and too frequently relative to observations. However, the peculiar study with the GFDL CM3 model demonstrated that the delaying of warm precipitation process (more realistic) caused a failure in reproducing the warming trend in the last century, due to overestimation of aerosol indirect effect. This ‘dichotomy’ between precipitation process and energy balance requirement should not peculiarly a case for the GFDL CM3 model, considering the common ‘too-easy, too-frequent’ precipitation problem among models.

This study explores the ‘dichotomy’ with the MIROC5.2 model and its cause at a fundamental process level focusing on interplay among key processes relevant to aerosol-cloud interactions, i.e. precipitation formation and aerosol wet deposition. Results show that the MIROC5.2 model also, like GFDL CM3, produces unrealistically large negative forcing due to the aerosol indirect effect when constrained with satellite observations for the warm precipitation process. This would result in a cooling that could cancel much of the greenhouse warming in the last century. In an attempt to isolate the relative roles between the precipitation and scavenging, a set of sensitivity tests with fixed cloud number concentrations for the wet-deposition of aerosols are conducted to turn off the feedback from aerosol-induced precipitation change on wet scavenging. The results show that the indirect forcing is less pronounced when fixed droplet number concentration is used for wet scavenging, suggesting that the aerosol indirect forcing is significantly amplified through coupling between the precipitation formation and the wet deposition. Namely, the following positive feedback is likely to operate: Aerosol-induced inhibition of rain formation causes less efficient wet deposition of aerosols, which induces larger increase in cloud droplet number concentration that further inhibits rain and causes pronounced increase in cloud water amount. This means that the “dichotomy” between the rain process constraint and the energy-balance requirement is amplified through mutual coupling among aerosols, clouds and precipitation, which might contain compensating biases between the precipitation process and other processes. Given the common bias of the precipitation process among major GCMs, this finding with MIROC5.2, together with the previous result with GFDL CM3, has a broad implication for other GCMs as well, underscoring the requirement of better constraint on key aerosol and cloud processes against observations in the near future.

Keywords: precipitation, aerosol indirect effect, energy balance, cloud, climate model, dichotomy