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Climate Model Biases and the Climate Change Signal

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Climate change impact research and risk assessment require accurate estimates of the climate change signal (CCS, future climate minus current climate). Generally, climate model biases do not cancel out in the calculation of the CCS so the CCS is also biased. Recent research suggests that model biases are well approximated as being dependent only on the magnitude of the simulated/observed values: a feature named *intensity dependence*. For example, higher precipitation amounts tend to have larger biases. Therefore, bias-correction methods that apply individual corrections to different model intensities have been shown to improve climate statistics. However, whether or not the resulting modification of the CCS is a beneficial effect, is debatable. The mechanisms of that modification are analytically understood only for the distribution mean of variables that have no zero values (also known as *interval variables*) such as temperature. Current knowledge is not directly transferable to variables that have a natural zero limit (*ratio variables*), such as (sub)daily precipitation and wind speed that are of primary importance for assessment of the future severe flooding and wind energy potential. This is because zeros are treated differently than positive values.

Here, we present a novel linearised analytical theory of the effect of climate model biases on the CCS of the distribution mean and quantiles. The bias-free CCS is expressed as sum of a scaled component that describes the removal of intensity-dependent biases and a level component that adjusts the CCS level in accordance with the biases and CCS of the positive-event probability. Adjusting the positive-event probability affects the CCS of the distribution mean and is quantified by an additional ϵ component. The theoretical approach can be extended in a straightforward manner for non-linear biases and other climate statistics.

The theory reveals that misrepresented model intensities and probability of non-zero (positive) events have the potential to distort raw model CCS estimates. We test the analytical description in a challenging application of bias-correction and downscaling to daily precipitation over alpine terrain, where the output of 15 regional climate models (RCMs) is reduced to local weather stations. The theoretically predicted CCS modification well approximates the modification by the bias correction method, even for RCMs and locations for which the effect is close to or exceeds 100 %. These results strongly suggest that the CCS modification by bias correction is a direct consequence of removing model biases and, hence, a desirable effect. The analytical theory can be used as a tool to 1) recognize model biases, for which the simulated CCS should be considered with particular caution and 2) efficiently generate novel, improved CCS datasets. The latter will form the base for supporting climate change adaptation, mitigation, and resilience strategies for end users, stakeholders, and policymakers. Future research needs to focus on developing physically based bias corrections that depend on simulated intensities rather than preserving the raw model CCS.