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Bias and robustness of uncertainty components estimates in transient climate projections

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A critical issue in climate change studies is the estimation of uncertainties in projections along with the contribution of the different uncertainty sources, including scenario uncertainty, the different components of model uncertainty and internal variability. Quantifying the different uncertainty sources faces actually different problems. For instance and for the sake of simplicity, an estimate of model uncertainty is classically obtained from the empirical variance of the climate responses obtained for the different modeling chains. These estimates are however biased. Another difficulty arises from the limited number of members that are classically available for most modeling chains. In this case, the climate response of one given chain and the effect of its internal variability may be actually difficult if not impossible to separate. The estimate of scenario uncertainty, model uncertainty and internal variability components are thus likely to be not really robust.

We explore the importance of the bias and the robustness of the estimates for two classical Analysis of Variance (ANOVA) approaches: a Single Time approach (STANOVA), based on the only data available for the considered projection lead time and a time series based approach (QEANOVA), which assumes quasi-ergodicity of climate outputs over the whole available climate simulation period (Hingray and Saïd, 2014). We explore both issues for a simple but classical configuration where uncertainties in projections are composed of two single sources: model uncertainty and internal climate variability. The bias in model uncertainty estimates is explored from theoretical expressions of unbiased estimators developed for both ANOVA approaches. The robustness of uncertainty estimates is explored for multiple synthetic ensembles of time series projections generated with MonteCarlo simulations.

For both ANOVA approaches, when the empirical variance of climate responses is used to estimate model uncertainty, the bias is always positive. It can be especially high with STANOVA. In the most critical configurations, when the number of members available for each modeling chain is small (< 3) and when internal variability explains most of total uncertainty variance (75% or more), the overestimation is higher than 100% of the true model uncertainty variance. The bias can be considerably reduced with a time series ANOVA approach, owing to the multiple time steps accounted for. The longer the transient time period used for the analysis, the larger the reduction. When a quasi-ergodic ANOVA approach is applied to decadal data for the whole 1980-2100 period, the bias is reduced by a factor 2.5 to 20 depending on the projection lead time. In all cases, the bias is likely to be not negligible for a large number of climate impact studies resulting in a likely large overestimation of the contribution of model uncertainty to total variance.

For both approaches, the robustness of all uncertainty estimates is higher when more members are available, when internal variability is smaller and/or the response-to-uncertainty ratio is higher. QEANOVA estimates are much more robust than STANOVA ones: QEANOVA simulated confidence intervals are roughly 3 to 5 times smaller than STANOVA ones. Excepted for STANOVA when less than 3 members is available, the robustness is rather high for total uncertainty and moderate for internal variability estimates. For model uncertainty or response-to-uncertainty ratio estimates, the robustness is conversely low for QEANOVA to very low for STANOVA. In the most critical configurations (small number of member, large internal variability), large over- or underestimation of uncertainty components is very thus likely.

To propose relevant uncertainty analyses and avoid misleading interpretations, estimates of uncertainty components should be therefore bias corrected and ideally come with estimates of their robustness.

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