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Inter-model variability and biases of the global water cycle in CMIP3 coupled climate models

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Observed changes such as increasing global temperatures and the intensification of the global water cycle in the 20th century are robust results of coupled general circulation models (CGCMs). In spite of these successes, model-to-model variability and biases that are small in first order climate responses, however, have considerable implications for climate predictability especially when multi-model means are used. We show that most climate simulations of the 20th and 21st century A2 scenario performed with CMIP3 (Coupled Model Inter-comparison Project Phase 3) models have deficiencies in simulating the global atmospheric moisture balance. Large biases of only a few models (some biases reach the simulated global precipitation changes in the 20th and 21st centuries) affect the multi-model mean global moisture budget. An imbalanced flux of −0.14 Sv exists while the multi-model median imbalance is only −0.02 Sv. Moreover, for most models the detected imbalance changes over time. As a consequence, in 13 of the 18 CMIP3 models examined, global annual mean precipitation exceeds global evaporation, indicating that there should be a 'leaking' of moisture from the atmosphere whereas for the remaining five models a 'flooding' is implied. Nonetheless, in all models, the actual atmospheric moisture content and its variability correctly increases during the course of the 20th and 21st centuries. These discrepancies therefore imply an unphysical and hence 'ghost' sink/source of atmospheric moisture in the models whose atmospheres flood/leak. The ghost source/sink of moisture can also be regarded as atmospheric latent heating/cooling and hence as positive/negative perturbation of the atmospheric energy budget or non-radiative forcing in the range of $^{-1}$ to +6 W m−2 (median +0.1 W m−2). The inter-model variability of the global atmospheric moisture transport from oceans to land areas, which impacts the terrestrial water cycle, is also quite high and ranges from 0.26 to 1.78 Sv. In the 21st century this transport to land increases by about 5% per century with a model-to-model range from 1 to 13%. We suggest that this variability is weakly correlated to the land–sea contrast in air temperature change of these models. Spatially heterogeneous forcings such as aerosols contribute to the variability in moisture transport, at least in one model. The polewards shifts of dry zones in climate simulations of the 21st century are also assessed. It is shown that the multi-model means of the two subsets of models with negative and positive imbalances in the atmospheric moisture budget produce spatial variability in the dry zone positions similar in size to the spatial shifts expected from 21st century global warming. Thus, the selection of models also affects the multi-model mean dry zone extension. In general, we caution the use of multi-model means of E − P fields and suggest self-consistency tests for climate models.