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Validation of the Arctic water and energy cycles in CMIP6 with consistent observation-based estimates

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This contribution focuses on the Arctic water budget, including its atmospheric, terrestrial, and oceanic components. Oceanic volume fluxes through the main Arctic gateways are calculated, using data from the CMEMS Global Reanalysis Ensemble Product (GREP), and compared to water input to the ocean from atmosphere and land. For this purpose, we use various state-of-the-art reanalyses, including the European Centre for Medium Range Weather Forecast's (ECMWF) latest products ERA5 and ERA5-Land and evaluate them against available satellite (e.g., GRACE) and in-situ river discharge observations.

To obtain a consistent estimate of all physical terms, we combine the most credible estimates of the individual budget terms and perform a variational optimization to obtain closed water budgets on annual and seasonal scales. This up-to-date estimate of the Arctic water cycle is subsequently used to validate historical runs from the Coupled Model Intercomparison Project Phase 6 (CMIP6). Modelled water budget components are analyzed concerning their annual means, seasonal cycles and trends and compared to our observationally constrained data. Results suggest that there remain large uncertainties in the simulation of the Arctic water cycle of the recent decades.

Furthermore, we choose a similar approach to validate the coupled energy budget in CMIP6 models, including oceanic heat transports through the Arctic gateways (where mooring-derived oceanic heat transports are available), atmospheric energy transports and vertical energy fluxes at the surface and top-of-the-atmosphere, as well as Arctic Ocean heat storage.

This assessment helps to understand model biases in typically analyzed quantities such as sea ice extent or volume. It also provides physically based metrics for detecting outliers from the model ensemble which can help to reduce spread in future projections of Arctic change.