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Spatially resolved evaluation of Earth system models with satellite column-averaged CO_2

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Earth system models (ESMs) participating in the Coupled Model Intercomparison Project Phase 5 (CMIP5) showed large uncertainties in simulating atmospheric CO_2 concentrations. We utilize the Earth System Model Evaluation Tool (ESMValTool) to evaluate emission-driven CMIP5 and CMIP6 simulations with satellite data of column-average CO_2 mole fractions (XCO_2). XCO_2 time series show a large spread among the model ensembles both in CMIP5 and CMIP6. Using the satellite observations as reference, the CMIP6 models have a lower bias in the the multi-model mean than CMIP5, but the spread remains large. The satellite data are a combined data product covering the period 2003–2014 based on the Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY)/Envisat (2003–2012) and Thermal And Near infrared Sensor for carbon Observation Fourier transform spectrometer/Greenhouse Gases Observing Satellite (TANSO-FTS/GOSAT) (2009–2014) instruments. While the combined satellite product shows a strong negative trend of decreasing seasonal cycle amplitude (SCA) with increasing XCO_2 in the northern midlatitudes, both CMIP ensembles instead show a non-significant positive trend in the multi-model mean. The negative trend is reproduced by the models when sampling them as the observations, attributing it to sampling characteristics. Applying a mask of the mean data coverage of each satellite to the models, the SCA is higher for the SCIAMACHY/Envisat mask than when using the TANSO-FTS/GOSAT mask. This induces an artificial negative trend when using observational sampling over the full period, as SCIAMACHY/Envisat covers the early period until 2012, with TANSO-FTS/GOSAT measurements starting in 2009. Overall, the CMIP6 ensemble shows better agreement with the satellite data than the CMIP5 ensemble in all considered quantities (mean XCO_2, growth rate, SCA and trend in SCA). This study shows that the availability of column-integral CO_2 from satellite provides a promising new way to evaluate the performance of Earth system models on a global scale, complementing existing studies that are based on in situ measurements from single ground-based stations.