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Confronting chemistry transport models with UV/Vis satellite retrievals: avoiding and quantifying representativeness errors

K. Folkert Boersma (1,2), Geert C.M. Vinken (3), and Henk J. Eskes (2)

(1) Wageningen University, Meteorology and Air Quality Group, Wageningen, The Netherlands (folkert.boersma@wur.nl), (2) Royal Netherlands Meteorological Institute, Climate Observations Department, De Bilt, The Netherlands (boersma@knmi.nl), (3) Eindhoven University of Technology, Fluid Dynamics Department, Eindhoven, The Netherlands

UV/Vis satellite retrievals of trace gas columns of nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and formaldehyde (HCHO) are useful to evaluate, test, and improve models of atmospheric composition. However, because models and satellite measurements do not represent the exact same geophysical quantities, a comparison of model fields and satellite measurements leads to additional representativeness errors, which degrade the quality of the comparison beyond contributions from model and measurement errors alone. Here we discuss three types of representativeness errors that arise from the act of carrying out a model-to-satellite measurement comparison: (1) horizontal representativeness errors due to imperfect collocation of the model grid cell and an ensemble of satellite pixels, (2) temporal representativeness errors originating mostly from differences in cloud cover between the modelled and observed state, and (3) vertical representativeness errors because of reduced satellite sensitivity towards the surface, accompanied with necessary retrieval assumptions on the state of the atmosphere. To minimize the extent to which representativeness errors compromise model-to-satellite comparisons, we require that models and retrievals are sampled as consistent as possible. A practical confrontation of TM5 and GEOS-Chem NO_2 simulations with OMI NO_2 retrievals suggests that horizontal representativeness errors, while unavoidable, are limited to well within 5-10% in most cases (depending on the exact model resolution) and of random nature. Temporal representativeness errors from mismatches in cloud cover, and, consequently, in photolysis rates, are more severe –on the order of 10%– and systematic, but largely avoidable. A recommendation following from this work is that models need to be sampled on the same mostly cloud-free days as the satellite retrievals. The most relevant representativeness error is associated with the vertical sensitivity of the satellite retrievals. Simple vertical integration of the modelled profiles leads to systematically different model columns compared to applying the appropriate averaging kernels. In the case of comparing OMI NO_2 to GEOS-Chem simulations of NO_2, these systematic differences are as large as 15-20% in Summer, but, again, avoidable. For future evaluations of chemistry transport models with UV/Vis satellite retrievals (of NO_2, HCHO, or SO_2), we strongly recommend to follow the recommendations laid out in this paper, especially with respect to the required clear-sky sampling and appropriate vertical smoothing, which eliminates temporal and vertical sampling errors and limits the overall representativeness error to not more than 5-10% from imperfect horizontal sampling.