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Intercomparison of the stratospheric ozone data assimilation among three CTMs based on observation system experiments

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The impact of the model performance on the stratospheric ozone analysis is investigated using three different models with a common chemistry-meteorology coupling data assimilation framework. To develop a system for assimilation of meteorological field variables with ozone, we used a local ensemble transform Kalman filter (LETKF) with the CCSRNIES chemistry-climate model (CCM), the MRI CCM, and the CHASER chemical transport model (CTM). For the assimilation, we used ozone profiles provided by Aura/Microwave Limb Sounder (MLS) and total ozone provided by the Ozone Monitoring Instrument-Total Ozone Mapping Spectrometer (TOMS). We also used meteorological field variables of reanalysis data (JMA Climate Data Assimilation System), assimilated by LETKF or nudged, to drive the models. As a result, we found the effects of model bias in ozone on their assimilation performance as follows:

1. MLS assimilation

- The model-bias deteriorated the assimilation performance through the amplifying the growth of errors and preventing that of the ensemble spread. Both of these caused an underestimation of the forecast error covariance.

- An ozone bias causes a temperature bias through the radiation process. Therefore, in the stratosphere, reduction of the ozone bias by the assimilation of MLS ozone profiles greatly led to a reduction of temperature bias.

- In contrast, in the upper stratosphere and mesosphere, where the ozone concentration is mainly controlled chemically, the MLS assimilation did not work effectively. In this altitude range, the ozone spread rapidly converges to a photochemical equilibrium value. As a result, LETKF underestimated the forecast error of ozone because of the small ensemble spread relative to the observation error. In order to avoid the underestimation of forecast error, including some other chemical species into the assimilation will be needed to perturb the chemical equilibrium.

- In the troposphere, MLS ozone assimilation did not improve tropospheric ozone profiles because of the lack of data in the middle and lower troposphere and the large uncertainties of the data in the upper troposphere. The error in total ozone was not sufficiently reduced by the MLS data assimilation because of the uncorrected bias in tropospheric ozone. This is evident in the CCSRNIES model, which showed a large bias in ozone in the troposphere. Further, the MLS ozone assimilation for total ozone in CHASER was less effective than that in CCSRNIES and MRI, because in CHASER the ozone concentration above 70 hPa was fixed to the climatology.

2. OMI-TOMS assimilation

- Assimilation of OMI-TOMS total ozone data modified the ozone concentration profiles thorough the forecast error covariance, with the result that the modeled total ozone was close to the observation. In this study, we used a simplified method for vertical localization in which the localization distances were set to zero. It might be necessary to choose the localization distance more carefully to improve the assimilation performance. For example, applying a vertical localization using averaging kernel may be effective.

3. MLS and OMI-TOMS assimilation

- Assimilation of both MLS and OMI-TOMS data greatly reduced biases in the ozone profiles in both the stratosphere and the troposphere, resulting in a good assimilation performance for total ozone. Biases in total ozone were nearly zero, and the RMSE was smaller than the SCIAMACHY observation error in the NH and tropics. The biases between the CCSRNIES and MRI models showed little difference, although bias of CCSRNIES without assimilation was larger than that of MRI.

Keywords: stratospheric ozone, chemistry transport model, a local ensemble transform Kalman filter, data assimilation