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Corrigendum to
"Impacts of Mt Pinatubo volcanic aerosol on the tropical stratosphere in chemistry–climate model simulations using CCMI and CMIP6 stratospheric aerosol data" published in Atmos. Chem. Phys., 17, 13139–13150, 2017

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Abstract. An error in the model formulation and underlying CMIP6 stratospheric aerosol data set led to incorrect results reported for the post-Pinatubo eruption period in the original paper. These errors and the corrected results are described below.

Revell et al. (2017) performed chemistry–climate model (CCM) simulations with two stratospheric aerosol data sets: the SAGE-4λ data set compiled for the Chemistry-Climate Model Initiative (CCMI) and the newer SAGE-3λ data set compiled for the sixth phase of the Coupled Model Intercomparison Project (CMIP6). Unfortunately, the model simulations performed by Revell et al. (2017) using version 3 of the CMIP6 stratospheric aerosol data set (CMIP6 v3) are subject to two partly compensating errors: (i) the model simulation set-up and (ii) problems in the CMIP6 v3 data set. In the model, the longwave aerosol radiative properties were assigned to the wrong spectral intervals. The correction of this error leads to an increase in tropical mid-stratospheric temperature of approximately 7 K following the 1991 Mt Pinatubo eruption, compared to the 2 K reported by Revell et al. (2017) and the ERA-Interim and MERRA reanalyses. The unrealistic warming of 7 K is related to error (ii), which can be traced back to problems in the cloud-clearing scheme applied to the CLAES (Cryogenic Limb Array Etalon Spectrometer) measurements, used for gap-filling in the CMIP6 v3 stratospheric aerosol data set following the eruption. The correction of this second error has recently prompted the release of a revised version CMIP6 v4 of the aerosol data set. We performed CCM simulations with CMIP6 v4, resulting in a warming in the tropical mid-stratosphere of 4 K following the eruption, which is very similar to the warming simulated with the CCMI stratospheric aerosol data set. Simulations performed with the CCMI stratospheric aerosol data are unaffected by these problems. In the period following the Mt Pinatubo eruption, the revised CMIP6 v4 Pinatubo aerosols have radiative properties similar to those of the CCMI aerosol data, whereas the erroneous CMIP6 v3 data set should be avoided in new model simulations.

1 Introduction

Revell et al. (2017) explored simulated changes in the tropical stratosphere to aerosol resulting from the 1991 Mt Pinatubo eruption with the SOCOL v3 (Solar Climate Ozone Links version 3) chemistry–climate model (CCM). Two stratospheric aerosol data sets were used: version 2 of the SAGE-4λ data set compiled for the Chemistry-Climate

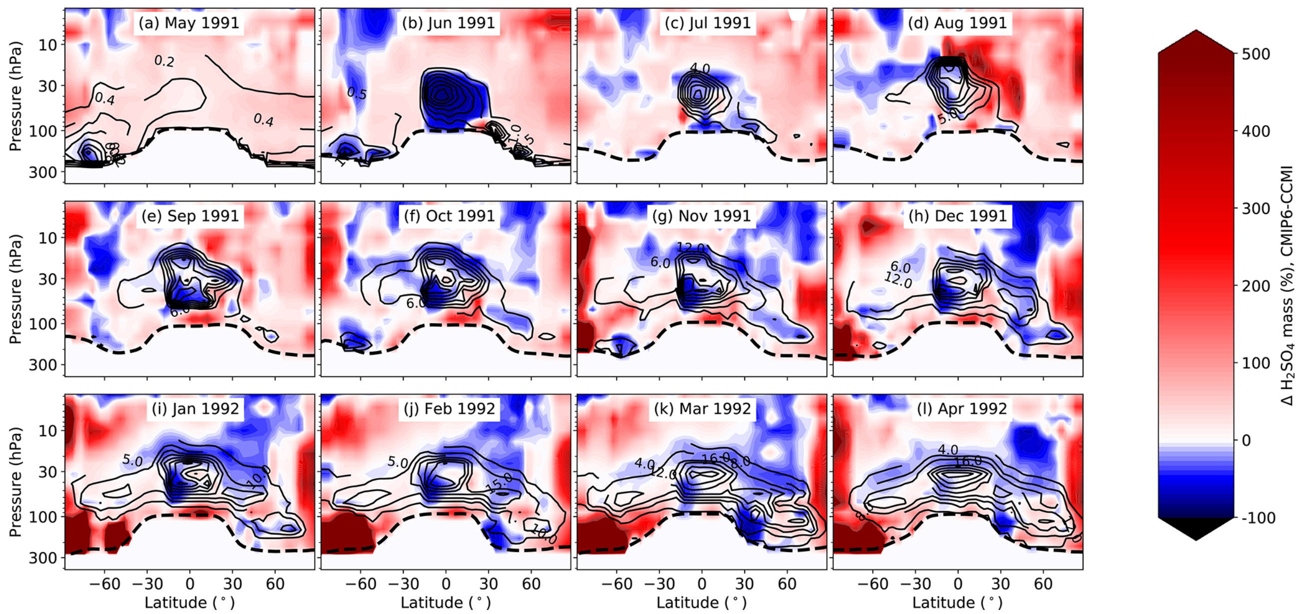

Figure 1. Percent difference in H_2SO_4 aerosol mass in the CCMI and the revised CMIP6 v4 stratospheric aerosol data sets for 12 months around the Mt Pinatubo eruption in June 1991; CMIP6 v4 minus CCMI. Black contours show the CCMI H_2SO_4 mass in 10^9 molecules cm^{-3}. The black dashed line shows the location of the WMO-defined tropopause. Note that aerosol data are supplied down to 5 km in altitude in the CCMI and CMIP6 v4 data sets, which are based on cloud-cleared SAGE II measurements, but these values are recommended for use only above the model tropopause.

Model Initiative (referred to as the CCMI data set) (Arfeuille et al., 2013), and the other was version 3 of the SAGE-3λ data set compiled for the Coupled Model Intercomparison Project Phase 6 – referred to as the CMIP6 v3 data set (Thomason et al., 2018). Unfortunately, errors have since been discovered relating to the description of stratospheric aerosols in the model's radiation code and to the formulation of the CMIP6 v3 data set. We describe these errors and these corrections in Sect. 2, the applied methodology in Sect. 3, and corrected results in Sect. 4.

2 Applied corrections

2.1 Spectral assignment of longwave aerosol radiative properties

SOCOL v3 uses the Rapid Radiative Transfer Model (RRTM) by Mlawer et al. (1997) for longwave radiative transfer calculations. The scheme resolves the spectral range from 10 to 3000 cm^{-3} within 16 intervals. To take radiative effects of volcanic eruptions into account, the model reads pre-calculated spectrally resolved aerosol extinction coefficients, single-scattering albedos, and asymmetry factors as functions of time, latitude, and altitude. Unfortunately, in the model simulations using the CMIP6 v3 data set published by Revell et al. (2017) the longwave aerosol radiative properties had been assigned to the wrong spectral intervals. The CCMI model simulations or other earlier simulations with SOCOL were not affected by this error.

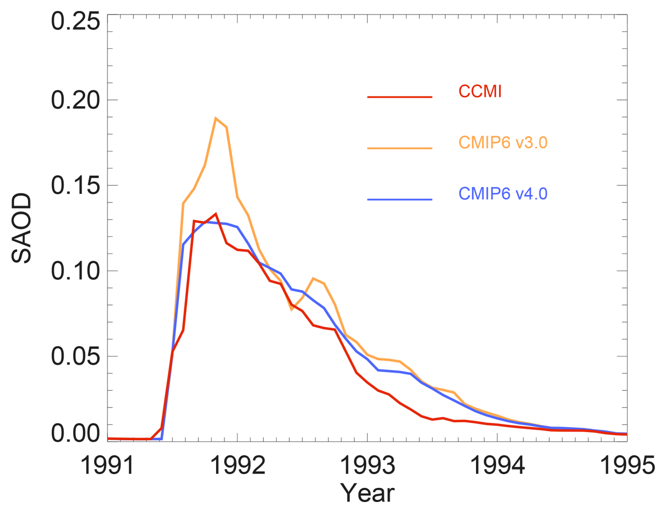

Figure 2. Stratospheric aerosol optical depth (SAOD) at 1020 nm for three stratospheric aerosol data sets between 5–10° N: CCMI, CMIP6 v3, and CMIP6 v4.

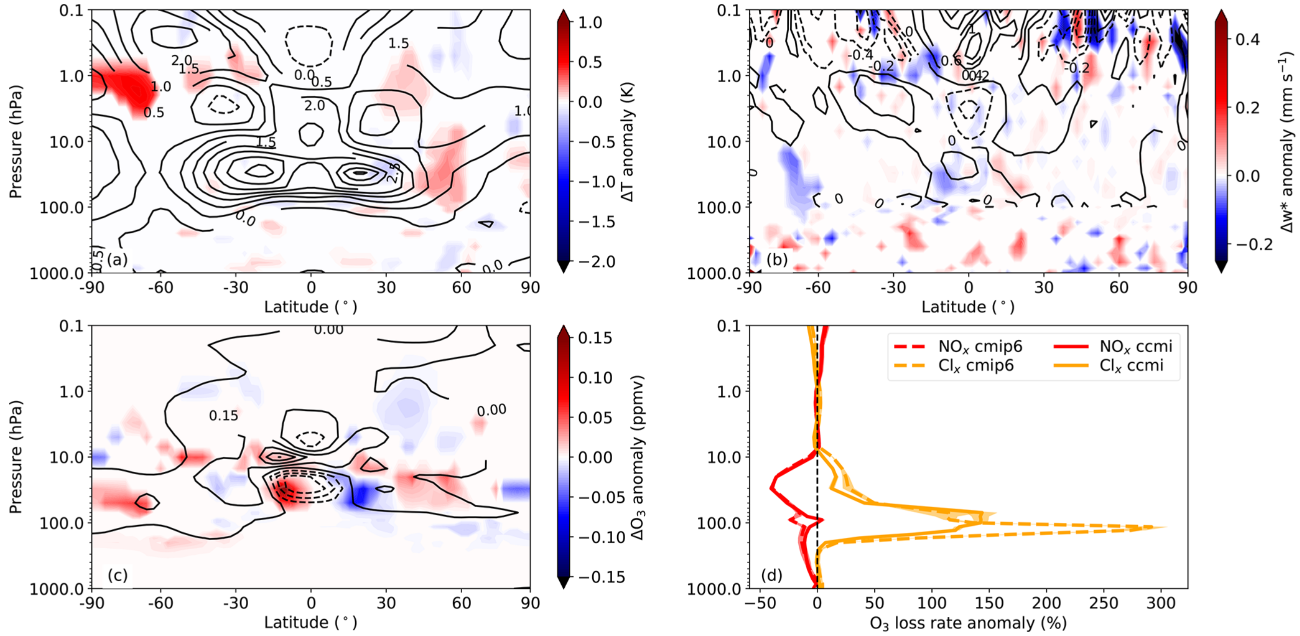

Figure 3. Differences in ensemble-mean, zonal-mean anomalies averaged over the 6 months following the Mt Pinatubo eruption between the ensembles using CMIP6 v4 and CCMI aerosol (i.e., CMIP6 v4 minus CCMI). For the contour plots **(a–c)**, regions that are not statistically significant at the 95 % level of confidence (as calculated with a Student's t test, $p < 0.05$) are set to zero. **(a)** Difference in temperature anomalies (red and blue shading). For reference, the black contours represent the CCMI anomalies over the same period. **(b)** As for **(a)**, but showing anomalies in the vertical residual circulation. **(c)** As for **(a)**, but showing ozone anomalies. **(d)** Anomalies in tropical (15° N–15° S) ozone destruction rates by the NO_x and Cl_x ozone destruction cycles in the CCMI and CMIP6 v4 ensembles. Negative anomalies indicate slower ozone destruction. Shading indicates the ensemble standard deviation.

2.2 Corrected CMIP6 stratospheric aerosol data set, CMIP6 v4

Following the 1991 Mt Pinatubo eruption, while the SAGE (Stratospheric Aerosol and Gas Experiment) II instrument was optically blind, the CMIP6 v3 data set used measurements from CLAES (Cryogenic Limb Array Etalon Spectrometer on the UARS satellite) for data gap-filling. Conversely, the CCMI data set used exclusively ground-based lidar data for gap-filling. Recently, an error was identified in the cloud clearing for the CLAES data used in CMIP6 v3, which unfortunately corrupted the CLAES gap-filling process to varying degrees; particularly at lower altitudes. The error leaves the vertical shape of the aerosol distributions largely unchanged, but the peak extinctions may drop by more than a factor of 2, with corresponding ramifications for radiative forcing.

A new version of the CMIP6 stratospheric aerosol data set (CMIP6 v4) has been released, which corrects the error in the gap-filling algorithms between 1991 and 1994. Figure 2 shows the stratospheric aerosol optical depth (SAOD) of the CCMI, CMIP6 v3, and CMIP6 v4 data sets. The overestimation of SAOD is constrained to the period following the 1991 Mt Pinatubo eruption, while the corrected CMIP6 v4 data set is in close agreement with the CCMI SAOD. Figure 1 shows the percent difference in sulfate aerosol mass between the CCMI and CMIP6 v4 data sets and corrects Fig. 1 of Revell et al. (2017). The lower sulfate mass in the tropical lower stratosphere in CMIP6 v4 compared to CMIP6 v3 is noticeable.

3 Methods

An ensemble consisting of five SOCOL v3 CCM simulations using the CMIP6 v4 stratospheric aerosol data set was performed. All ensemble members ran from 1986 to 2005 and were otherwise identical in their boundary condition set-up to the simulations analysed by Revell et al. (2017). Corrected versions of Figs. 3 and 4 in Revell et al. (2017) are shown in Sect. 4. Figure 2 from Revell et al. (2017) remains unchanged as it shows results only from simulations using CCMI stratospheric aerosol, and these simulations are unaffected by the errors discussed here.

4 Corrected results

Figure 3 shows differences between the SOCOL v3 simulations using CCMI and CMIP6 v4 stratospheric aerosol, averaged over the 6 months following the Mt Pinatubo eruption. Differences in temperature and the rate of the vertical residual circulation are minimal (Fig. 3a, b). Ozone differences of

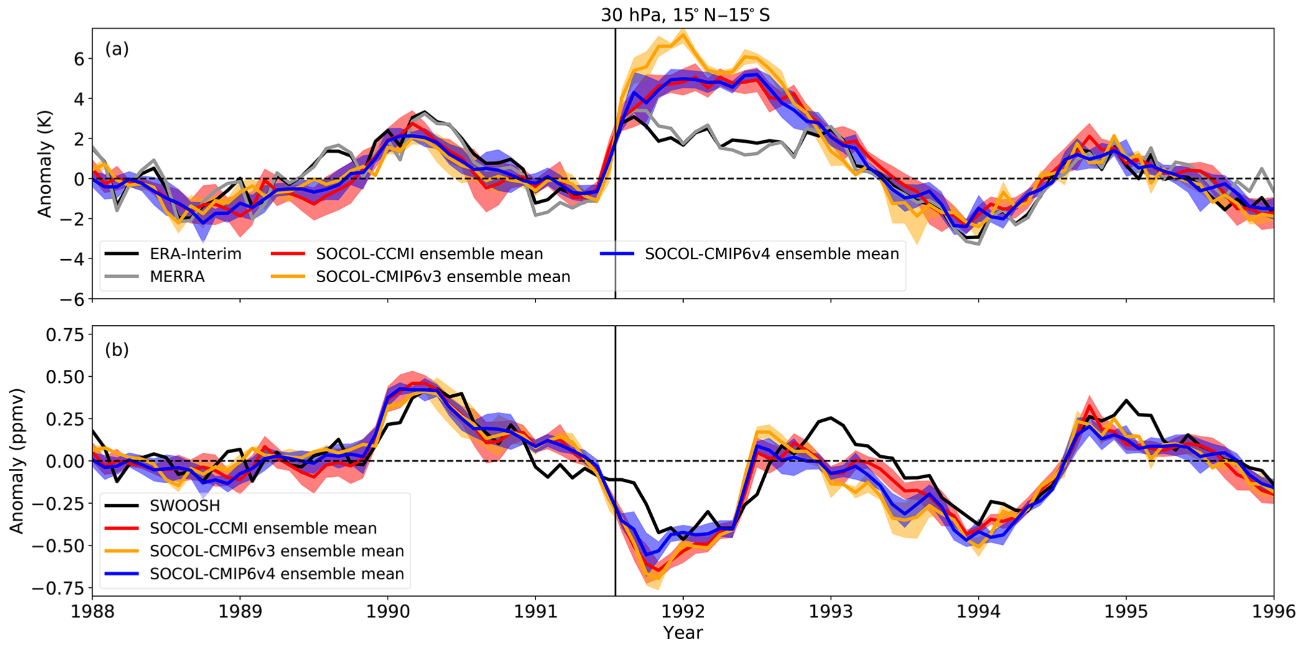

Figure 4. Time series of **(a)** temperature and **(b)** ozone anomalies at 30 hPa, 15° N–15° S. The red, orange, and blue lines denote the SOCOL v3 ensemble mean of the simulations using CCMI, CMIP6 v3, and CMIP6 v4 stratospheric aerosol, respectively. Black and grey lines are based on observational data as indicated in the figure legends. The shaded areas denote the ensemble mean plus or minus 1 standard deviation of simulated anomalies, and the vertical lines show the timing of the Mt Pinatubo eruption on 15 June 1991.

up to 0.14 ppmv are simulated (Fig. 3c); however these are not widespread across the tropics as in Fig. 3 of Revell et al. (2017).

In the simulations with the CMIP6 v4 stratospheric aerosol data set, differing rates of ozone-depleting chemical reactions in the tropical lower stratosphere (∼ 100 hPa) are seen (Fig. 3d) compared with the corresponding Fig. 3d of Revell et al. (2017). When going from CCMI to CMIP6 v4, the rate of NO_x ozone loss slows by approximately 20 %, while gas-phase chlorine-induced ozone loss accelerates by up to 300 %. These changes are likely related to the redistribution of aerosol mass in the updated CMIP6 v4 stratospheric aerosol data set (Fig. 1). However, relatively little ozone is present in this region of the atmosphere, and the overall impact on ozone of a 300 % increase in chlorine-induced ozone loss at 100 hPa is minimal.

Finally, Fig. 4 shows time series of temperature and ozone anomalies in the tropical middle stratosphere. Revell et al. (2017) showed that CCM simulations using the CMIP6 v3 stratospheric aerosol data set led to a good agreement between the model and reanalyses and observations, in terms of the temperature and ozone changes simulated. However, when we analyse simulations using the CMIP6 v3 data set with the spectral assignment of longwave aerosol radiative properties corrected (Section 2.1), the simulated warming in the tropical mid-stratosphere following the Mt Pinatubo eruption reaches 7 K (orange line in Fig. 4a). This far exceeds the 2 K warming shown by the ERA-Interim and MERRA reanalyses. The simulated ozone decrease following the eruption is similar to that simulated using the CCMI data set (Fig. 4b).

Using the CMIP6 v4 data set, the simulated warming following the Mt Pinatubo eruption is approximately 4 K, which is practically identical to that simulated by SOCOL v3 using the CCMI data set (red and blue lines in Fig. 4a). Simulated ozone decreases do not vary much with the different data sets and are in reasonably good agreement with observations from the merged SWOOSH (Stratospheric Water and Ozone Satellite Homogenized) data set.

5 Conclusions

Errors in the cloud-clearing procedures applied to CLAES data, which were used for gap-filling in the CMIP6 v3 stratospheric aerosol data set following the 1991 Mt Pinatubo eruption, lead to erroneously large stratospheric aerosol optical depths. Therefore, when stratospheric aerosol properties were prescribed in the SOCOL v3 chemistry-climate model using the CMIP6 v3 data set, the model simulates an erroneously large warming following the eruption. Unfortunately, Revell et al. (2017) did not see these errors because they were disguised by an incorrect spectral assignment of longwave aerosol radiative properties. With these compensating errors resolved, we see that model simulations with the new CMIP6 v4 stratospheric aerosol data set show a response of the tropical stratosphere to the 1991 Mt

Pinatubo eruption similar to that of simulations using the older CCMI stratospheric aerosol data set. In conclusion, the original CMIP6 v3 data set, which is used as input by many CMIP6 models, provides an erroneously high tropical lower-stratospheric heating following the eruption of Mt Pinatubo (4–5 K above reanalysis values in our CCM), while the revised CMIP6 v4 data set is very similar to the CCMI data set, but still produces too much warming in our CCM by 2–3 K.

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