

In our response, referee comments are marked in bold, our responses and original text in plain text, and altered text in the paper in bold italic.

## Response to reviewer 3 (Anonymous reviewer)

We thank the reviewer for their interesting and useful comments on our manuscript. Our responses to these comments are given below.

**Main comment: One comment I have, is that it should be made more clear in abstract and conclusion, and also some figures and tables, that they use synthetic observations and not real observations. And define synthetic observations the first time it is mentioned.**

We have adapted the text in the abstract and conclusions, and in the captions of Table 2 and Figures 3 and 7 to make this clearer throughout the manuscript.

- In the abstract, we have revised the following sentence on page 1 line 18:  
“The model uncertainty is calculated by using a perturbed parameter ensemble that samples twenty-seven uncertainties in both the aerosol model and the physical climate model, **and we use synthetic observations generated from the model itself to determine the potential of each observational type to constrain this uncertainty.**”
- The caption of Table 2 has been adjusted to:  
“**Table 2.** Observed quantities and corresponding uncertainty ranges used for the constraints applied over Europe. Values are a European July mean, **synthetically generated from the model output of a selected PPE member.**”
- The caption of Figure 3 has been adjusted to:  
“**Figure 3.** Calculated uncertainty in the aerosol quantities and aerosol ERF terms from the 4 million member sample. Results are for July-mean over Europe. The red bar shows the assumed range of each **synthetic** observation used to constrain the uncertain parameter space and the aerosol forcing uncertainty from Table 2.”
- The caption of Figure 7 has been adjusted to:  
“**Figure 1.** The relative constraint achieved for aerosol ERF,  $ERF_{ACI}$ ,  $ERF_{ARI}$  and  $ERF_{ARIClr}$  over Europe given the individual **synthetic** constraints applied (colours) and the simultaneous constraint (ALL). The relative constraint is evaluated as the ratio of the standard deviation of the forcing in the constrained sample ( $\sigma_{constrained}$ ) to the standard deviation of the forcing in the original, unconstrained sample ( $\sigma_{full}$ ).”
- In the conclusions section we have added the following sentence to page 28 line 17 of the original manuscript (page 30, line 16 in the revised manuscript).  
“**Using synthetic observations (taken from the output of one of our simulations) we determine the extent of the potential constraint that these nine aerosol and cloud-related properties can generate.**”

Finally, we have defined the term “synthetic observations” at the point it is first mentioned in the body of the manuscript, in the introduction section on page 5 line 6 of the original manuscript (page 5 line 8 in the revised manuscript). The revised text is as follows:

“Although large observational datasets of aerosol in-situ microphysical and chemical properties are available (Reddington et al., 2017), we use synthetic observations here – *i.e.*, **observations that are**

**generated from a model simulation** – to postpone addressing some of the challenges faced when comparing model output and in-situ observations (Schutgens et al., 2016a, 2016b).”

**Minor Comment 1: Page 7 line 10. Specify that it is biomass burning emissions.**

Page 7, line 10 of the original manuscript is an empty line break between paragraphs. However, we think this is referring to page 7 lines 19-20 (page 7 line 23 of the revised manuscript), and have updated the text here as follows:

“Carbonaceous **biomass burning** aerosol emissions for recent decades were prescribed using a ten year average of 2002 to 2011 monthly mean data”

**Minor Comment 2: Table 2: Indicate that this is not real observations. Useful to define Europe also. In addition to the synthetic observations, real observations are used for ToA flux, am I right?**

We have adjusted the caption for Table 2 to be clear that the observations are not real observations. (See bullet point 3 in our reply to the Main Comment above.)

We have updated the text at the end of the introduction section (page 5, line 9 of the original manuscript; page 5 line 11 of the revised manuscript) to more clearly define the Europe region that we have used. Revised text:

“The analysis is restricted to **the region of Europe (defined in this study by the longitude range: 12°W to 41°E, and latitude range: 37.5°N to 71.5°N)** for the month of July.”

All observations used in this study, including the ToA Flux observation, are synthetic and come from a model run with all parameters set to their median value from the parameter’s distribution that was obtained through our expert elicitation exercise. However, information from real observations (where available) was used to determine appropriate uncertainty ranges on the synthetic observations. For ToA flux, the uncertainty range was estimated to be in line with information from the Clouds and the Earth’s Radiant Energy System (CERES) and IPCC uncertainty estimates (Hartmann et al., 2013). The information on the origin of the ToA flux observation used in this study in paragraph 2 of Section 2.6 was incorrect in our original manuscript, and we have amended paragraphs 2 and 3 of Section 2.6 to address this. The revised paragraphs are as follows:

“We use synthetic observations (Table 2) of European July-mean cloud condensation nuclei (CCN) concentration at 0.2% supersaturation at approximate cloud-base height, surface concentrations of PM2.5, mass concentrations of sulphate, OC and BC at the surface, **the outgoing shortwave radiative flux at the top of the atmosphere (ToA flux)**, AOD at a wavelength of 550 nm, and the change in AOD ( $\Delta$ AOD) and surface solar radiation ( $\Delta$ SSR) between 1978 and 2008. The period 1978 to 2008 was originally chosen because it is an interesting period for global and regional forcing changes. Although AOD measurements are not available back to 1978, this is not vital to the present study which aims to assess potential constraint over a period with substantial aerosol changes.

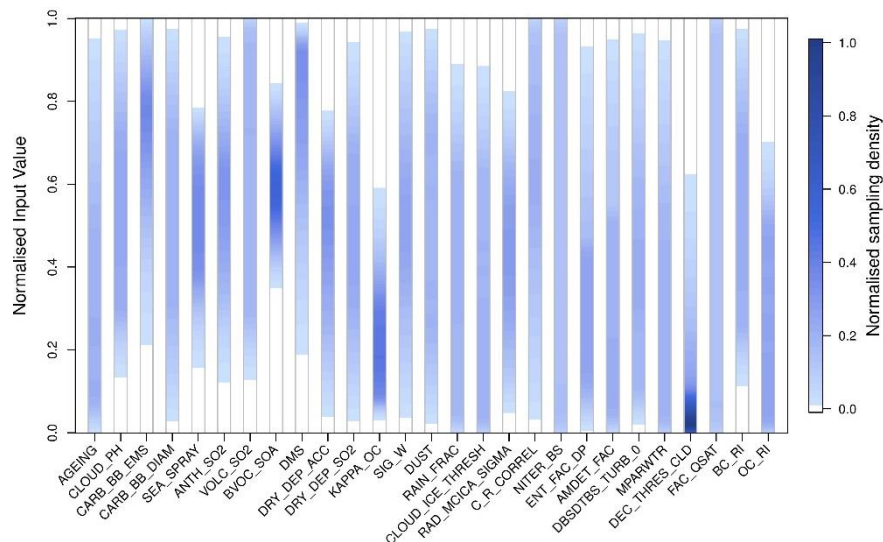
The observation uncertainties are based on our judgement about the combined effect of instrument uncertainties and the uncertainty associated with measurement representativeness (colocation of high-frequency point measurements within low-spatial-resolution, monthly-mean model output subject to meteorological variability (Reddington et al., 2017; Schutgens et al., 2016a, 2016b). **Where**

available, we have used sets of real observations to inform these judgements and estimates. For example, we selected our uncertainty range on the ToA Flux such that it is in line with information from the Clouds and the Earth's Radiant Energy System (CERES) and IPCC uncertainty estimates (Hartmann et al., 2013). In the constraint process we also account for the emulator error (i.e., the estimated uncertainty in each of the 4 million points associated with using the emulator instead of the model itself).”

**Minor Comment 3: Figure 9: Does the color shading mean anything? Include a colorbar or remove the shading.**

The colour represents the marginal normalised sampling density (normalised across parameters) of each input parameter over its range. The parts of the marginal parameter space that are effectively ruled out by the constraint are shown in white (normalised sampling density <0.02).

The plot has been updated and a colour bar has been added. We have also updated the caption of the figure to clearly state the meaning of the colour-scale. The new figure is below.



**Figure 2.** One-dimensional projection of the remaining parameter space after simultaneous constraint of all atmospheric quantities and decadal trends. *The colour-scale shows the marginal normalised sampling density (normalised across parameters) of each input parameter over its range. Parts of the marginal parameter space that are effectively ruled out are shown in white (normalised sampling density <0.02).*

We have also updated a sentence on page 24 line 28 of the original manuscript (page 26 line 28 of the revised manuscript) for clarity. This sentence now reads:

“Figure 9 identifies parts of the *marginal* parameter space that are *effectively* ruled out *in white*.”