

1 **At Least Nine CMIP6 Climate Models fail the Historical Experiment Test because they do**  
2 **not accurately reproduce the known occurrence of ENSO events and must be withdrawn**

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6 **Key Points:**

- 7 • Nine climate models do not accurately create the known occurrence of ENSO events in the  
8 Historical Experiment (HE) in CMIP6
- 9 • Additionally, these models do not incorporate aerosols at levels which are consistent with  
10 measurements and thus fail the HE test twice
- 11 • The IPCC Assessment Report 6 does not recognise that tropical, continental scale, aerosol plumes  
12 cause the global temperature to increase

## 13 Abstract

14 The Historical Experiment (HE) data in the Intergovernmental Panel on Climate Change (IPCC)  
 15 Climate Model Intercomparison Project six (CMIP6) should demonstrate that all submitted models  
 16 accurately simulate the climate of the recent past. I show: none of nine models analysed accurately  
 17 creates the known occurrence of ENSO events; no model agrees with any other; and average aerosol  
 18 levels of the South East Asian Plume (SEAP), the South American Plume (SAMP) and the West  
 19 African Plume (WAP) are too low. Additionally, the SEAP and the SAMP cause the global temperature  
 20 to rise in all nine models and the WAP in six models. Hence these models and all others which cannot  
 21 accurately portray the known occurrence of ENSO events should be withdrawn from CMIP6 until they  
 22 can and use of the IPCC Assessment Report six (AR6) should be paused until the effects of these  
 23 aerosol plumes on the global temperature is re-evaluated.

## 24 Plain Language Summary

25 The Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6 (AR6) is based on the  
 26 Climate Model Intercomparison Project six (CMIP6) which required all models to submit the Historical  
 27 Experiment (HE) data to demonstrate that each model accurately recreates the known climate from  
 28 1850 to 2014. This paper demonstrates that nine models from respected institutions fail this test as they  
 29 do not: reproduce the known sequence of El Nino Southern Oscillation (ENSO) events; nor incorporate  
 30 aerosol levels consistent with measurements. Additionally, three continental scale, aerosol plumes over  
 31 south east Asia, West Africa and Amazonia are shown to increase the global temperature by restricting  
 32 convection in the area of the plume, a fact not recognised by the IPCC. CMIP6 and AR6 should  
 33 therefore be withdrawn until the climate models are retuned using measured aerosol levels and the  
 34 effects of these three plumes on the global temperature reassessed after actual aerosol levels are  
 35 incorporated.

## 36 1. Introduction

### 37 1.1. Areas

38 The areas used in this analysis are shown in the Supporting Information and are: SEAP Area 10° S-10°  
 39 N and 90° E-160° E; SAMP Area 10°-15° S and 55°-65° W; WAP Area 0°-10° N 0°-10° E and the Nino  
 40 3.4 Area 5° S-5° N and 120°-170° W.

### 41 1.2. IPCC

42 The IPCC Assessment Report Six (AR6) (Core Writing Team, 2023) is based on CMIP6 which  
 43 included the HE (Eyring et al., 2016).

### 44 1.3. Models

45 Models from the UK Met Office (Ridley et al., 2019), NASA (Studies, 2019), NOAA (Krasting et al.,  
 46 2018), CESM2 (NCAR) (Danabasoglu, 2019), Canada (Swart et al., 2019), Japan (Shiogama et al.,  
 47 2019), France (Seferian, 2018), Norway (Seland et al., 2019) and CSIRO (Australia) (Ziehn et al., 2019)  
 48 are analysed.

### 49 1.4. ENSO

50 ENSO events are the greatest variation in the global climate (McPhaden et al., 2006), (Johnson, 2013)  
 51 and are characterised by a sea surface temperature (SST) 0.5°C above the long-term average SST in the  
 52 Nino 3.4 Area in the central Pacific Ocean and have global and regional effects on the climate (UK-  
 53 Met-Office, 2023) and on the global temperature (Geng et al., 2023; Privalsky & Jensen, 1995; Tsonis  
 54 et al., 2005).

## 55 2. Methods

The correct creation of ENSO events in climate models is crucial and the CMIP6 HE is designed to demonstrate that the models do precisely this. First using the above ENSO definition and the SST in the Nino 3.4 Area from the HadISST1 dataset (Rayner et al., 2003), at [https://psl.noaa.gov/gcos\\_wgsp/Timeseries/Nino34/](https://psl.noaa.gov/gcos_wgsp/Timeseries/Nino34/) (1870 – 2014) the HE years are classed as ENSO or non-ENSO years and then compared with the SST in the same area from each of the models. Second the power spectrum of the SST in the Nino 3.4 Area from HadISST1 is compared to the power spectra of the SST in the Nino 3.4 Area from each of the nine models individually.

I also show that:

1. The AOD levels of the SEAP, SAMP and WAP do not match historical measurements in the HE which they should;
2. The SEAP has a statistically significant connection to ENSO whilst the SAMP and WAP do not.
3. The SEAP, SAMP and WAP have strong connections to the global temperature.

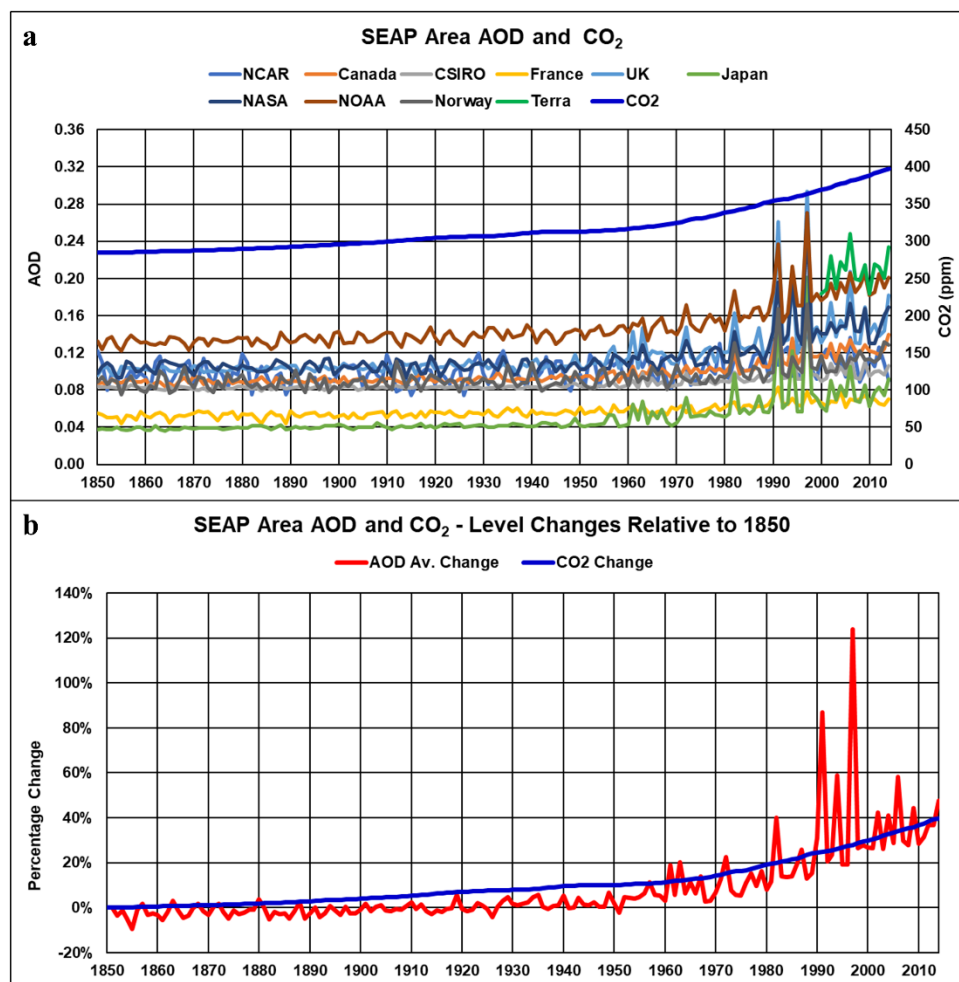
### 3. Data and Results

Data is derived from CMIP 6, the Terra satellite (Kaufman et al., 2000) and the NCEP reanalysis (Kalnay et al., 1996).

#### 3.1 Aerosols

Aerosols are solid or liquid particles suspended in the atmosphere (Farmer et al., 2021) and are the greatest source of uncertainty in climate modelling (Kahn et al., 2023). Eight continental scale aerosol plumes now exist each year and are described in the Supporting Information. The Aerosol Optical Depth (AOD) of the SEAP Area from the nine models and Terra (2000-2022) is shown in Fig.2(a) with the carbon dioxide (CO<sub>2</sub>) levels (Meinshausen et al., 2017). It is clear from Fig. 2(a) that the AOD levels in the SEAP Area are significantly underrepresented in the nine models compared with the Terra data. Only the NOAA data is close. Across the nine models only 1.95% (29 of 1,485 months) of the AOD levels fall within the Terra data range when about 20% should be expected to fall in this range from 1980 to 2014. Hence the models are underrepresenting the occurrence of SEAP Area AOD in this period by an order of magnitude and the average AOD from the nine models is only 46% of the average Terra AOD.

All models show similar trajectories for the SEAP Area AOD levels from 1850 to 2014 – steady to 1950 then increasing to 2014 even though the absolute values are significantly different. Fig. 2(b) shows the average SEAP Area AOD and CO<sub>2</sub> percentage changes since 1850 which are nearly identical although the SEAP AOD shows much greater variability in recent years which is relevant in the context of the recent global temperature trajectory.



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90 Figure 1: SEAP Area AOD from the nine models and Terra and CO<sub>2</sub> (a). percentage changes (b).

### 91 3.2 ENSO

92 The Supporting Information lists the ENSO/Non-ENSO years with the correlations of the HE models  
 93 and HadISST1 data (Table S1) and the cross-correlation matrix (Table S2). No model creates a  
 94 sequence of ENSO events which correctly matches the historical record and, more surprisingly, no  
 95 model sequence of ENSO events matches any other model.

96 The power spectra, using PAST3 (Hammer et al., 2001), of each model Nino 3.4 Area SST from the HE  
 97 and the HadISST1 Nino 3.4 SST data is shown in Fig.1. No model accurately matches the HadISST1  
 98 power spectrum which shows major peaks at 3.5 to 3.8 years and at 5.7 years. Only one model, CSIRO,  
 99 shows a major peak which coincides with the 5.7 year peak whilst the MIROC6 graph (Fig. 2d)  
 100 uniquely shows only one major peak which is double the power of the next largest, a clear indicator that  
 101 the model is oscillating at the frequency of the peak.

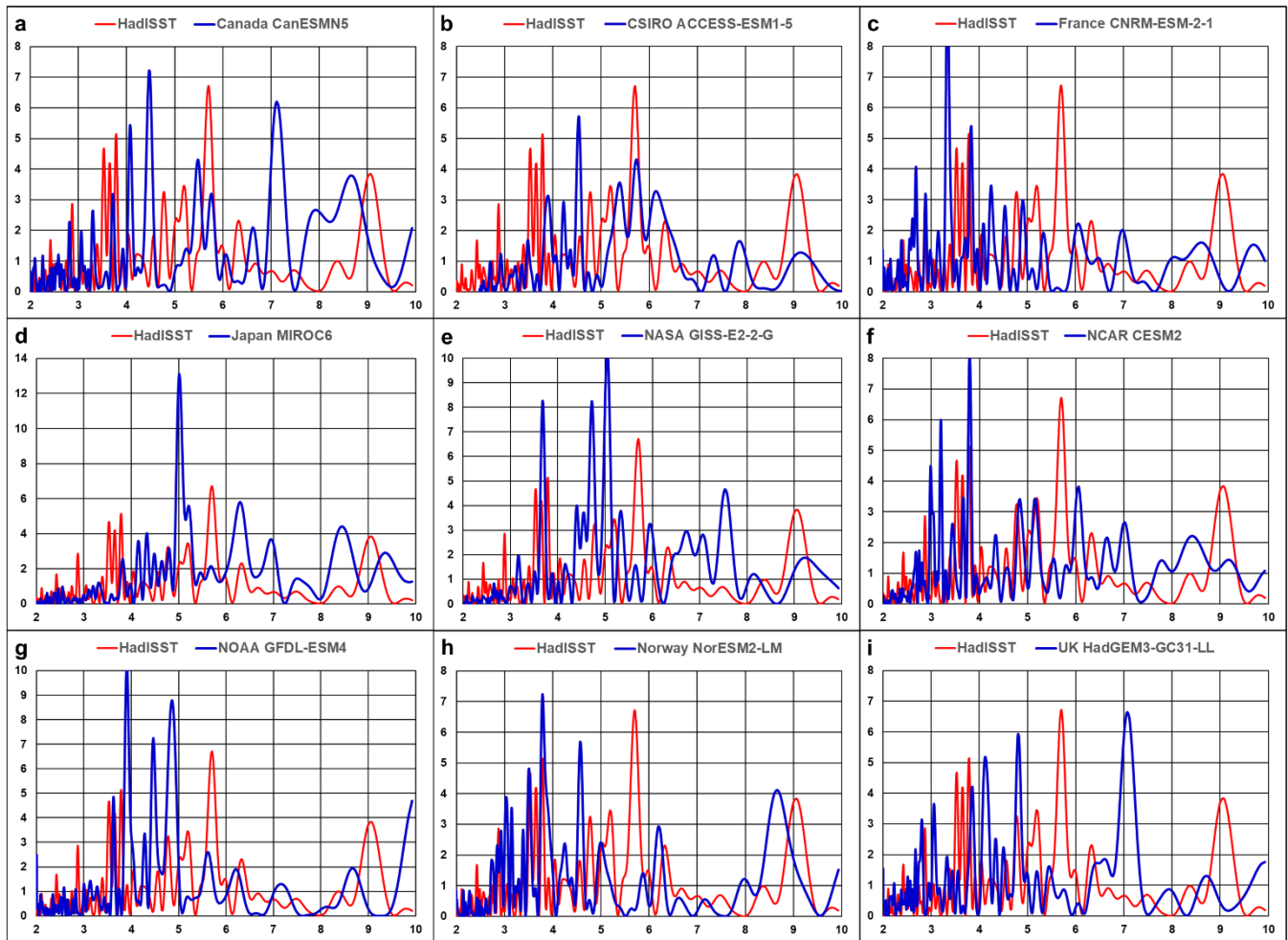


Figure 2: PAST3 Lomb periodogram power spectra (1870-2014) of the Nino 3.4 SST from the HadISST1 dataset and the nine models. The source country/model designation is in the title. The x axis is years and y axis power.

### 3.3. Climate Models and ENSO

Two theories exist to explain the occurrence of ENSO events: (1) a stable mode interacting with High Frequency Forcing (HFF); and (2) a Self-Sustaining Oscillation (SSO) (Wang, 2018) and all climate models are “tuned” and “retuned” to produce, inter alia, the required ENSO return frequency (Hourdin et al., 2017; Mauritsen & Roeckner, 2020; Mignot et al., 2021; Schmidt et al., 2017; Senior et al., 2020). One paper suggests tuning is the most time-consuming process confronted in the development of a climate model, taking up to 3 years. Since the nine models analysed display different occurrences of ENSO events in the HE they must individually incorporate the SSO theory as all the forcing scenarios in the HE are specified (Eyring et al., 2016) and if the HFF theory was being used the models would show at least a modicum of similarity.

Note:

CMIP6 models are assessed for “ENSO Performance” using Planton et al. (2021) and no metric assesses the accurate reproduction of the sequence of known ENSO events in the HE.

The comments re the MIROC6 model oscillation above.

### 3.4. SEAP, SAMP and WAP AOD and ENSO

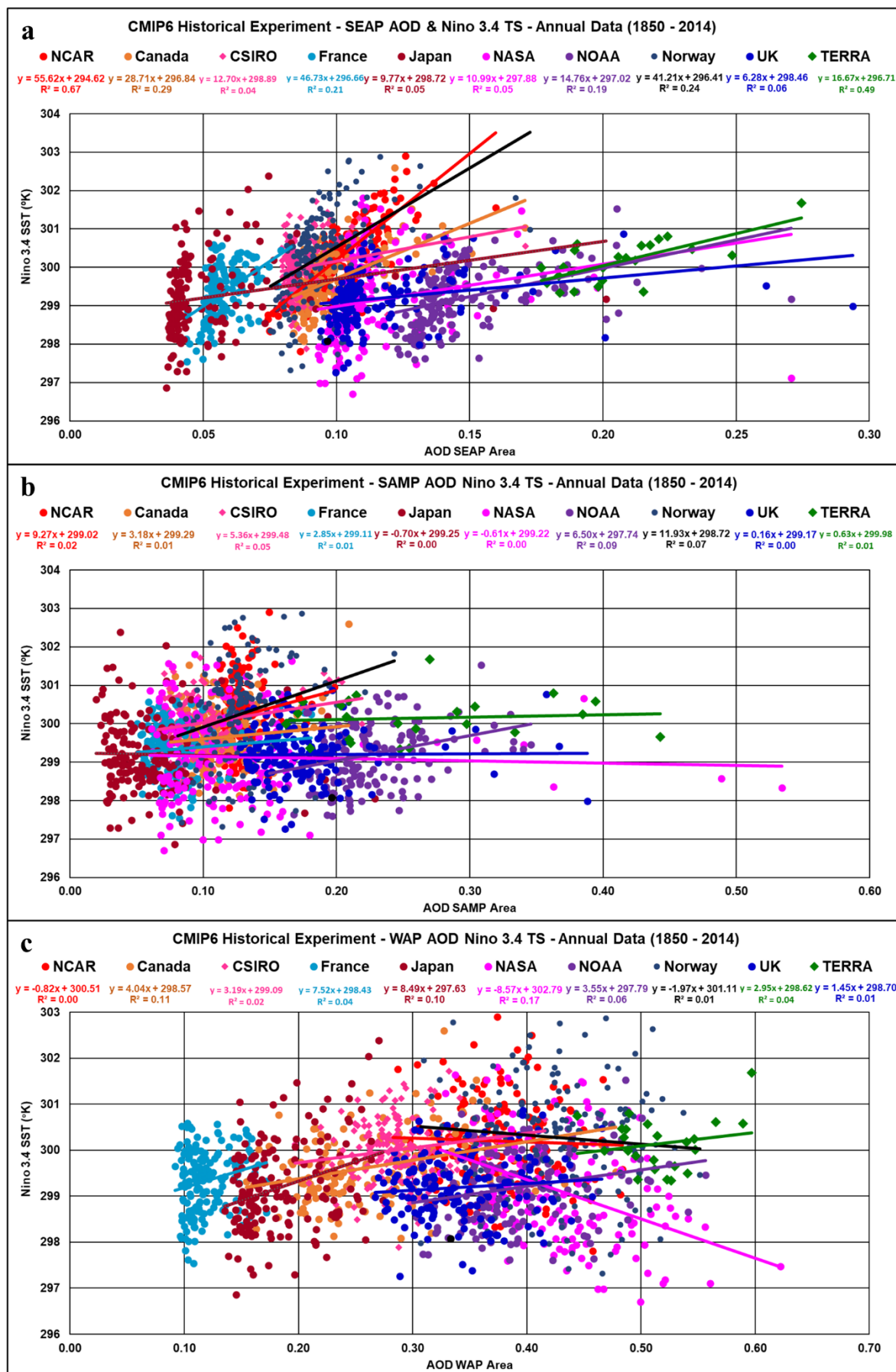
Fig. 3a, b and c show the SEAP, SAMP and WAP AOD with the SST of the Nino 3.4 Area and Table 1 shows the correlation magnitudes of the AOD of the three plumes and the Nino 3.4 SST.

123 **SEAP:** It is clear that the SEAP Area AOD levels in the models are much lower than in the Terra  
 124 measured data. All models show increasing SST in the Nino 3.4 area as the SEAP Area AOD rises.  
 125 Noting that the AOD levels are too low and that the trend in, for example, the NCAR model is  
 126  $56^{\circ}\text{K}/\text{unit AOD}$ . If the average NCAR AOD (0.1) was corrected to the average Terra AOD levels (0.21)  
 127 along this trend the average Nino 3.4 SST would increase from  $300.2^{\circ}\text{K}$  to  $306.4^{\circ}\text{K}$  – an obvious  
 128 impossibility as the highest Nino 3.4 SST in the NOAA Nino 3.4 long data at  
 129 [https://psl.noaa.gov/gcos\\_wgsp/Timeseries/Data/nino34.long.data](https://psl.noaa.gov/gcos_wgsp/Timeseries/Data/nino34.long.data) is  $301.7^{\circ}\text{K}$ . In eight models the  
 130 statistical significance of the correlation between the SEAP AOD and the Nino 3.4 SST is  $<0.01$  and in  
 131 one  $< 0.05$ . The Terra data shows a very strong correlation much greater than the average of the nine  
 132 models. Hence in all modelled and measured data there is a statistically strong connection between the  
 133 SEAP AOD and the Nino 3.4 SST.

134 **SAMP:** Three models show a positive correlation with the Nino 3.4 SST, four show small positive  
 135 correlations and two small negative. The average correlation across the nine models is 0.12 which is not  
 136 significant statistically in the 165-year dataset and the Terra data shows no significant correlation.

137 **WAP:** Four models show significant positive correlation, three show negative correlations, one  
 138 statistically significant, and two show no significant correlation. The average is 0.09 which is not  
 139 significant. The Terra data shows no significant correlation.

140 Hence the SEAP is unique as it alone shows significantly positive correlations with the Nino 3.4 SST in  
 141 both the model and Terra data and the Terra data shows correlation magnitudes greater than all but one  
 142 of the models.



143

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Figure 3: SEAP (a), SAMP (b) and WAP (c) AOD and Nino 3.4 SST from the nine models and the Terra satellite.

|             | Canada | NCAR  | CSIRO | France | UK   | Japan | NASA  | NOAA | Norway | Average | Terra |
|-------------|--------|-------|-------|--------|------|-------|-------|------|--------|---------|-------|
| <b>SEAP</b> | 0.54   | 0.82  | 0.19  | 0.46   | 0.24 | 0.21  | 0.22  | 0.43 | 0.48   | 0.40    | 0.70  |
| <b>SAMP</b> | 0.10   | 0.13  | 0.22  | 0.09   | 0.01 | -0.03 | -0.04 | 0.30 | 0.27   | 0.12    | 0.09  |
| <b>WAP</b>  | 0.33   | -0.04 | 0.14  | 0.21   | 0.09 | 0.32  | -0.41 | 0.24 | -0.09  | 0.09    | 0.19  |

Table 1

Table 1 Correlation magnitudes of SEAP, SAMP and WAP AOD and Nino 3.4 SST annual data. Colours show significance: Yellow <0.01, brown <0.02, negative (not significant) light purple negative and significant dark purple.

### 3.5. SEAP, SAMP and WAP AOD and the Annual Global Temperature

Fig. 4a, b and c show the SEAP, SAMP and WAP AOD with the global temperature. All models show the global temperature increasing as the level of aerosols increases in the SEAP Area. The models correlate at an average 0.59 significance <0.01 in all cases and the Terra/NCEP data (2000-2014), with a one-year delay in the temperature data, at 0.52 significance < 0.02. Interestingly all the models except MIROC6 show a much lower global temperature than the NCEP data.

The high correlation between the Terra data and the global temperature the following year is probably because the high levels of SEAP AOD occur late in the year, from September to November (Potts, 2022), which intensifies ENSO events late in the year and with the time the ocean takes to relax from an ENSO event to a neutral state the higher global average temperatures extend into the following year



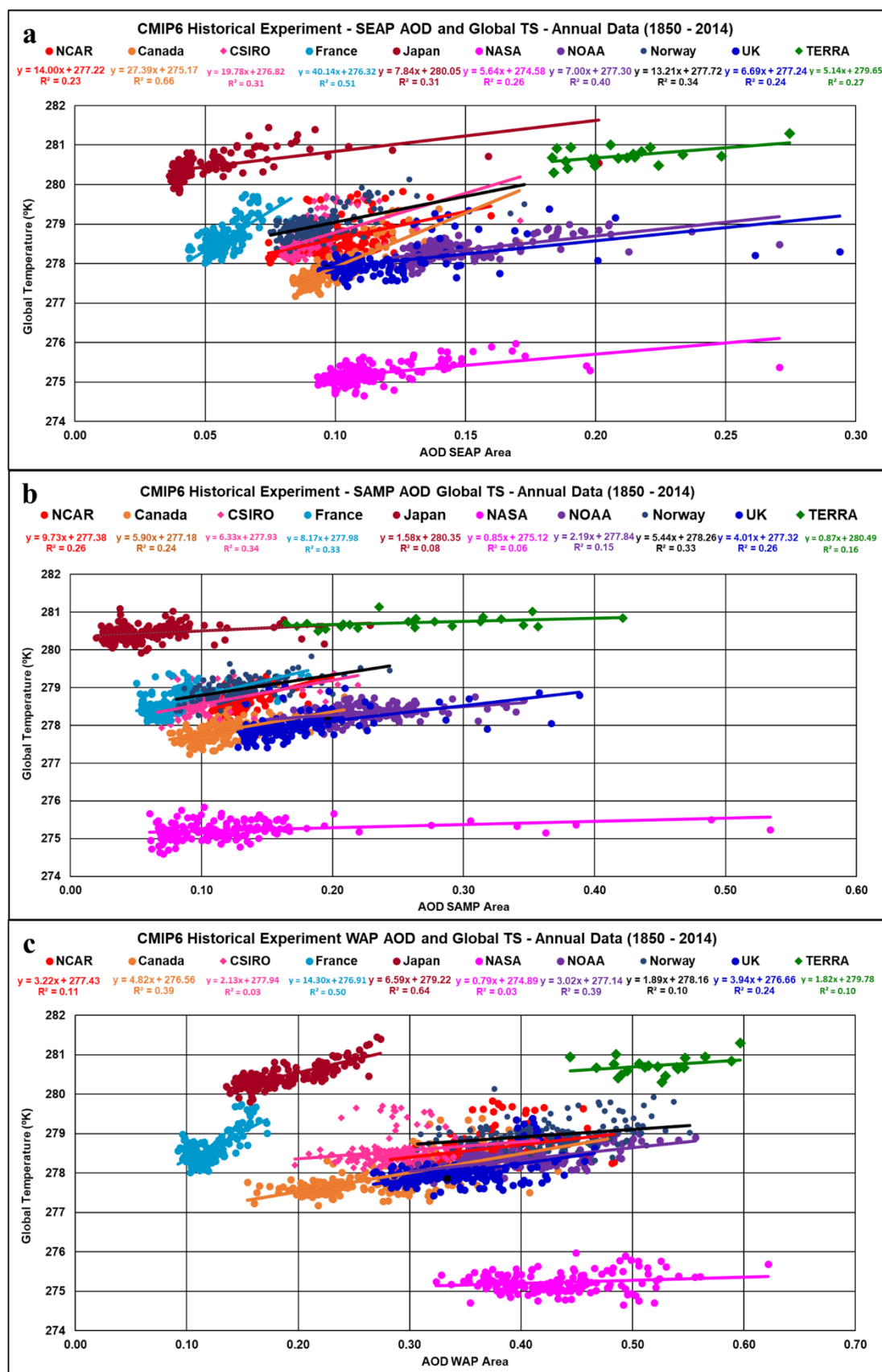


Figure 4: SEAP (a), SAMP (b) and WAP (c) AOD and the global temperature from the nine models and the Terra satellite.

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|      | Canada | NCAR | CSIRO | France | UK   | Japan | NASA | NOAA | Norway | Average | Terra |
|------|--------|------|-------|--------|------|-------|------|------|--------|---------|-------|
| SEAP | 0.81   | 0.48 | 0.55  | 0.71   | 0.49 | 0.56  | 0.51 | 0.64 | 0.58   | 0.59    | 0.52  |
| SAMP | 0.49   | 0.51 | 0.58  | 0.57   | 0.51 | 0.28  | 0.25 | 0.38 | 0.57   | 0.46    | 0.40  |
| WAP  | 0.62   | 0.33 | 0.17  | 0.70   | 0.49 | 0.80  | 0.17 | 0.63 | 0.31   | 0.47    | 0.52  |

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169 Table 2: Correlation magnitudes SEAP, SAMP and WAP AOD and global temperature for the nine  
 170 models, the average and Terra data. Colours show significance: Yellow <0.01, brown <0.02, green  
 171 <0.05, blue <0.10.

### 172 3.6. Aerosols, Convection and The Global Temperature

173 Heat can be moved between two points by conduction, convection and radiation. Conduction is  
 174 impossible in the atmosphere leaving convection and radiation to remove the heat the Earth absorbs  
 175 daily from the sun. The SEAP Area covers an area 4,842 by 1,383 Km or  $6.7 \times 10^{12} \text{ m}^2$  and convection  
 176 reduces significantly in times of high AOD. The nine models show average omega at 700 hPa in the  
 177 SEAP Area at -0.034 Pa/s with an average increase of 0.042 Pa/s per unit increase in AOD which with  
 178 an AOD average range of 0.12 implies a reduction in convection of 0.005 Pa/s or 14% from minimum to  
 179 maximum AOD. The Last Millennium Ensemble (LME) (Otto-Bliesner et al., 2016), Terra/NCEP and  
 180 MERRA2 (Gelaro et al., 2017) also show a reduction in convection in the SEAP Area as the SEAP  
 181 AOD rises (Potts, 2022) and in the WAP Area as the WAP AOD rises in (Potts, 2021). This reduction  
 182 of convection over such immense areas will result in a significant reduction in the heat removed from  
 183 the Earth's surface by convection and therefore cause in an increase in the global temperature.

184 It is also worth noting that removing heat from the Earth's surface by convection in the tropics rather  
 185 than by radiation negates the effects of most of the greenhouse gases in the atmosphere as convection  
 186 raises the warm air to the top of the troposphere, about 17 Km altitude (110 hPa pressure), which is then  
 187 above about 90% of the atmosphere.

### 188 3.7. Recommendations for Future Work

189 Future work to develop models which can replicate the known occurrence of ENSO events should  
 190 incorporate the HFF theory. This theory is outlined in detail in (Potts, 2022) which shows that the SEAP  
 191 Area hosted over 26% of the global volcanic eruptions (Venzke, 2013) since 1800 and confirms the  
 192 close association between the AOD in the SEAP Area and the Nino 3.4 SST using the LME, MERRA-2  
 193 and Terra/NCEP datasets. This paper also shows: the power spectra of the Nino 3.4 SST (HadISST\_1)  
 194 and volcanic tephra in Fig. 3 which are much closer in form than any of the nine models analysed here;  
 195 and outlines the sources of the SEAP Area volcanic and anthropogenic aerosols in the Supporting  
 196 Information. Therefore, given the failure of the SSO theory of ENSO to create the known sequence of  
 197 ENSO events in the CMIP6 HE and the close association of the SEAP Area AOD and the Nino 3.4 SST  
 198 in many datasets it is surely time to use HFF by SEAP Area aerosols combined with emissions which  
 199 create the known levels of aerosols in the areas of all eight continental scale aerosol plumes. This will  
 200 automatically create ENSO events at the time of high SEAP Area AOD and will force all nine models  
 201 to replicate the known sequence of ENSO events as they all show a statistically significant connection  
 202 between the SEAP Area AOD and the Nino 3.4 SST.

203 It is also worth noting that the global CO<sub>2</sub> levels and the AOD of the SEAP Area show the same  
 204 percentage increases over the HE period in Fig. 2b and both show a connection to the global  
 205 temperature. It is therefore crucial to disentangle the individual effects of CO<sub>2</sub> and these aerosol plumes  
 206 on the global temperature to enable mitigation of each to be undertaken.

Therefore, the nine climate models and all others with similar flawed characteristics should be retuned using AOD levels which match the Terra AOD data and not the very low preindustrial AOD levels. This will force the incorporation of the effects of the SEAP, SAMP and WAP on the global temperature into the models and this will undoubtedly require a reassessment of the effects of greenhouse gases within the models and the sensitivity of the models to greenhouse gas levels may well have to be reduced, possibly substantially.

#### 4. Conclusions

The nine models analysed fail to:

1. Create the known sequence of ENSO events in the CMIP6 HE;
  2. Agree on the sequence of ENSO events between themselves;
  3. Accurately incorporate the AOD of the SEAP, the SAMP and the WAP in the models; and
- the IPCC fails to acknowledge that the SEAP, the SAMP and the WAP force the global temperature higher stating only in AR6 that “Observed warming is driven by emissions from human activities, with greenhouse gas warming partly masked by aerosol cooling”.

For these reasons:

1. All the nine climate models are obviously fatally flawed and should be withdrawn from CMIP6;
2. All other models with the same flawed characteristics should also be withdrawn; and
3. Use of the IPCC AR6 should be paused until the effects of the SEAP, SAMP and WAP aerosol plumes on the global temperature are fully understood as we may be only addressing one issue when, in fact, there may be nine (greenhouse gases plus eight plumes) requiring attention and we have no understanding of their relative importance at present!

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#### Conflict Of Interest

The author declares no conflicts of interest relevant to this study

#### Open Research

##### Data and Software Availability Statement

No new data was created in this research project. Original data and software is cited in the references and is available at:

**CMIP6 data:** <https://esgf-index1.ceda.ac.uk/search/cmip6-ceda/>

**Last Millennium Ensemble data:** <https://www.earthsystemgrid.org/>

**NASA Terra and MERRA2 data:** <https://giovanni.gsfc.nasa.gov/giovanni/>

**NCEP Reanalysis data:** <https://psl.noaa.gov/cgi-bin/data/timeseries/timeseries1.pl>

- 243 **Volcanic Eruption data:** <https://volcano.si.edu/>
- 244 **HadISST1 Nino 3.4 SST:** [https://psl.noaa.gov/gcos\\_wgsp/Timeseries/Nino34/](https://psl.noaa.gov/gcos_wgsp/Timeseries/Nino34/)
- 245 **Greenhouse gas concentrations:** <https://www.climatecollege.unimelb.edu.au/cmip6>
- 246 **NOAA gas flare data:** [https://www.ngdc.noaa.gov/eog/viirs/download\\_global\\_flare.html](https://www.ngdc.noaa.gov/eog/viirs/download_global_flare.html)
- 247 **NOAA Images:** <https://psl.noaa.gov/data/gridded/reanalysis/>
- 248 **Dr Robert Schmunk - Panoply:** <https://www.giss.nasa.gov/tools/panoply/> (**netcdf data viewer**)

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