UNIVERSITY OF CAMBRIDGE

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Volcanic forcing of climate since 1850 in an interactive aerosol-chemistry-climate model

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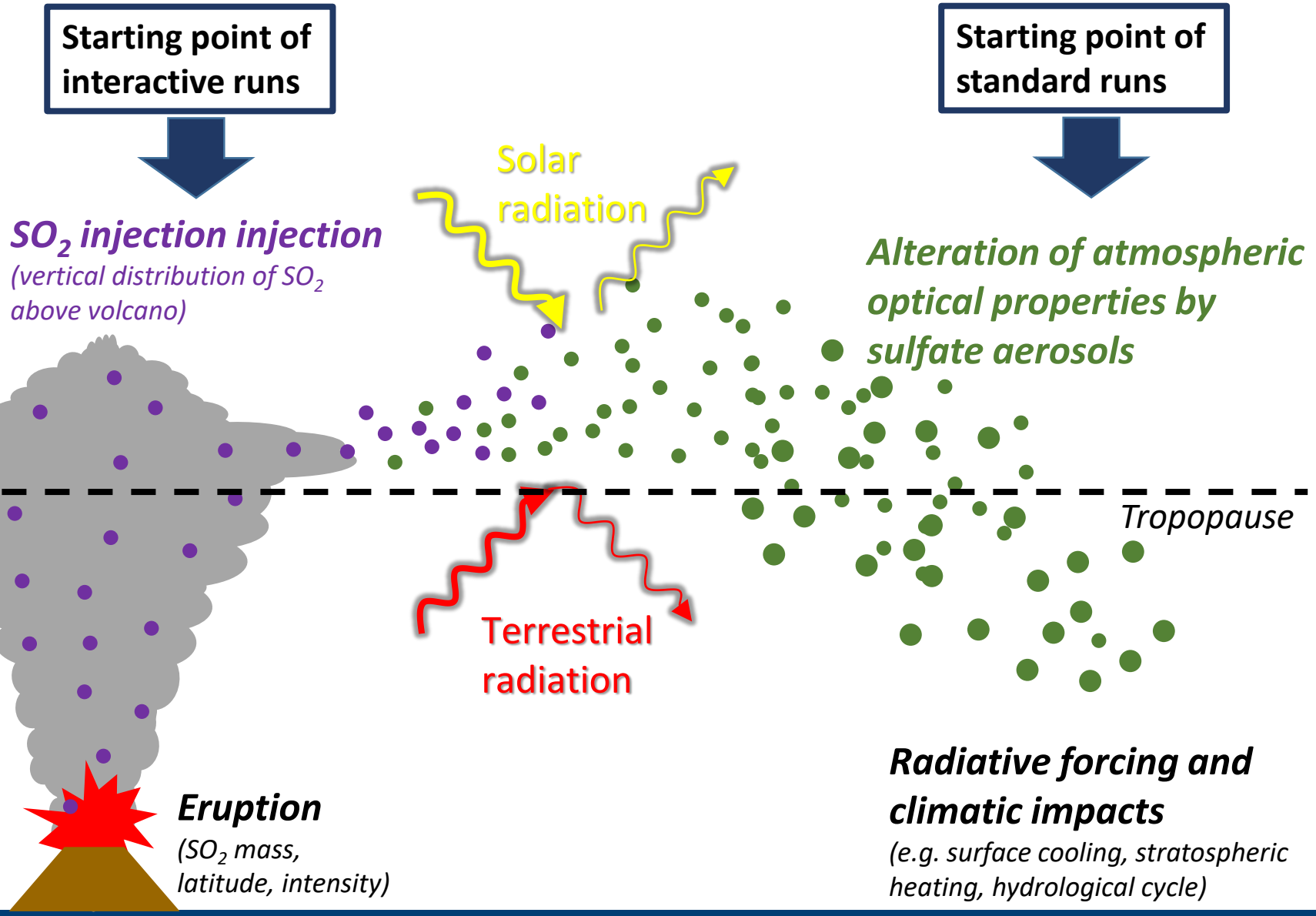
Session:
Understanding volcano-climate impacts and the stratospheric aerosol layer

Breakout text chat:
09.44h to 10.30h CET 27 April 2021

Motivation



The UK Earth System Model (UKESM, version 1.0) CMIP6 historical simulations were run with the prescribed stratospheric aerosol properties recommended for CMIP6 ("standard" runs). However, UKESM has the capability to interactively simulate volcanic stratospheric aerosol cycle from prescribed volcanic SO_2 emissions ("interactive" runs).

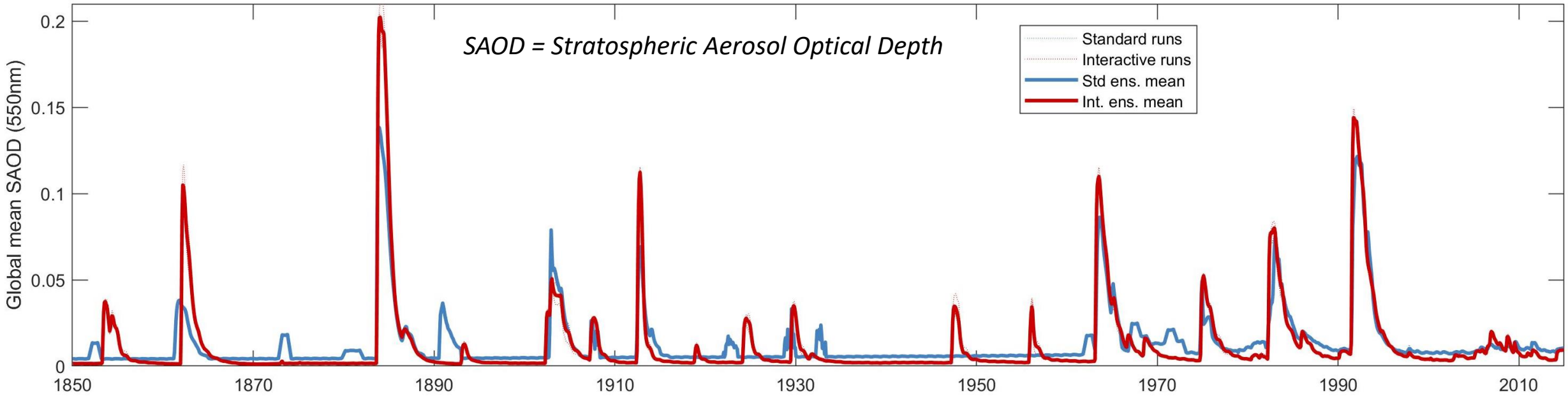
→ How do these two different forcing representations (standard vs interactive) affect the 1850-2015 climate simulated by UKESM?

Experimental design

Historical experiments (1850-2015)	Ensemble size	Volcanic forcing	1850-1978 key features	1979-2015 key features
Standard (ran by UK Met Office for CMIP6)	19	CMIP6-recommended stratospheric aerosol optical properties	Aerosol optical properties derived from SO_2 emissions from ice-core (Gao et al. 2008) + AER-2D model (Arfeuille et al. 2014)	Aerosol optical properties observed by satellite (GloSSAC, Thomason et al 2018)
Interactive (this study)	3	Explosive volcanic SO_2 emissions from Neely and Schmidt (2016)	SO_2 emissions derived from ice-core (Neely and Schmidt 2016)	SO_2 emissions observed by satellite (Neely and Schmidt 2016)
Control (this study)	3	zeroed	-	-

In the following slides, anomalies refer to the difference wrt control ensemble-mean values

1850-2015 global mean SAOD at 550 nm



1850-1960:

- Important differences in eruption inventory and timing
- Large differences in global mean SAOD simulated forfollowing key eruptions (e.g. Krakatoa 1883, Katmai 1912)

1960-2015:

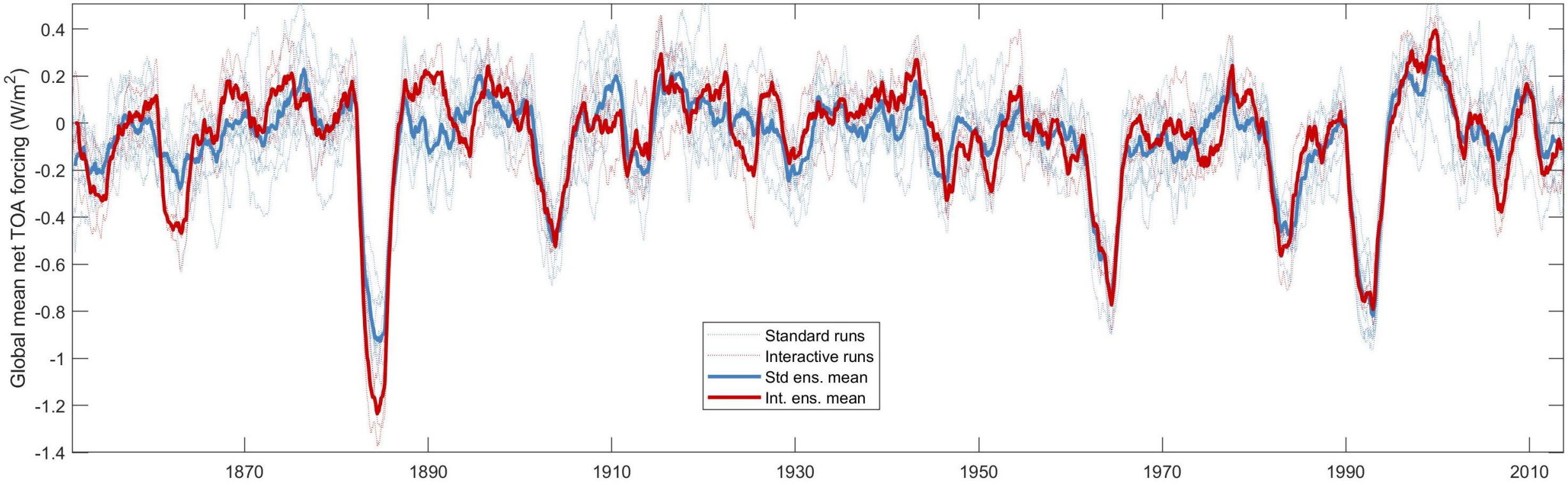
- General agreement for global mean SAOD

Throughout the whole period:

- Standard run background SAOD is very high because the non-volcanic background SAOD is “double-counted”: UKESM1-simulated from non-volcanic stratospheric aerosol + values imposed in prescribed CMIP6 dataset

1850-2015 global mean TOA radiative forcing

TOA= Top of the Atmosphere ; all time series smoothed over three years



- *1850-1930:* Large differences in global mean TOA forcing simulated following key eruptions (e.g. 1861 eruption, Krakatoa 1883)
- *1930-2015:* General agreement for global mean TOA forcing

A more detailed looks at key eruptions

In the following slides, for six of the most important eruptions of the 1850-2015 period, we show:

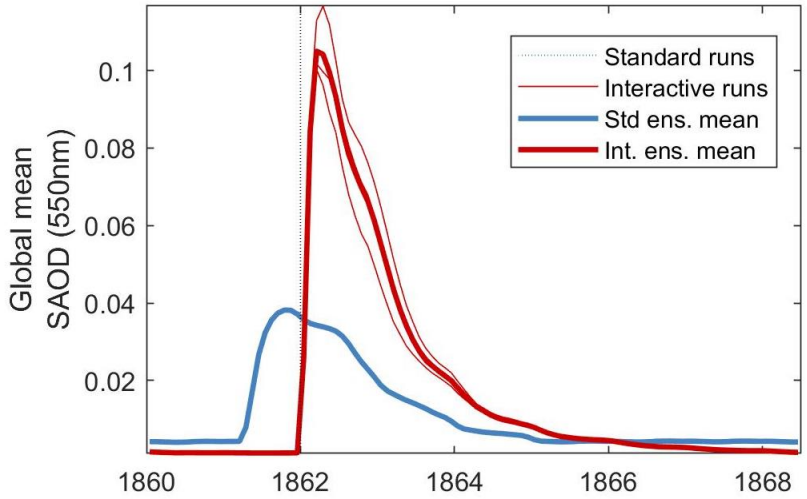
- The global mean SAOD at 550nm
- Global mean anomalies (smoothed over 6 months and relative to the 2-year pre-eruption mean) of:
  - TOA net radiative forcing
  - Surface air temperature
  - Precipitation
- Key features of the eruption SO_2 emission used in:
  - Interactive runs (Neely and Schmidt 2016)
  - Standard runs, i.e. what was used as input to the AER-2D aerosol model (Arfeuille et al. 2014) to generate aerosol optical properties used in the CMIP6 dataset
  - For comparison, the ice-core derived SO_2 mass from eVolv2k (Toohey and Sigl 2017), the recommended dataset for PMIP4

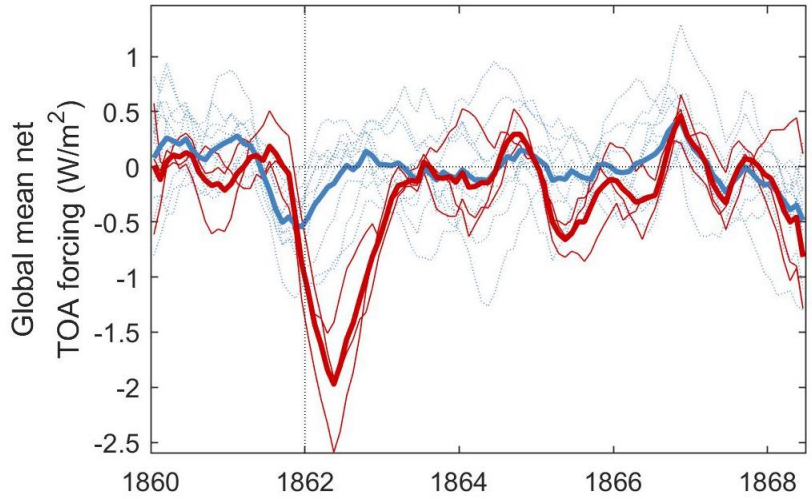
Disclaimer: Characteristic of SO_2 emissions used in AER-2D to generate the CMIP6 dataset are not fully documented and are based on our best understanding of the CMIP6 documentation and Arfeuille et al. (2014)

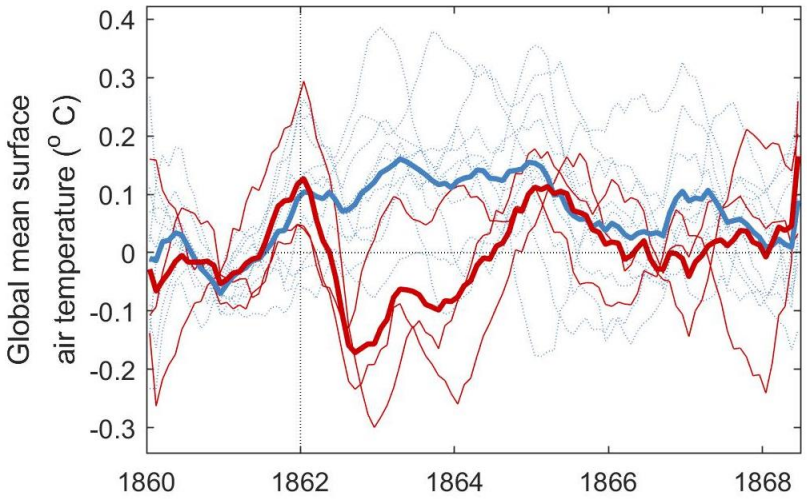
Makian (?) 1861

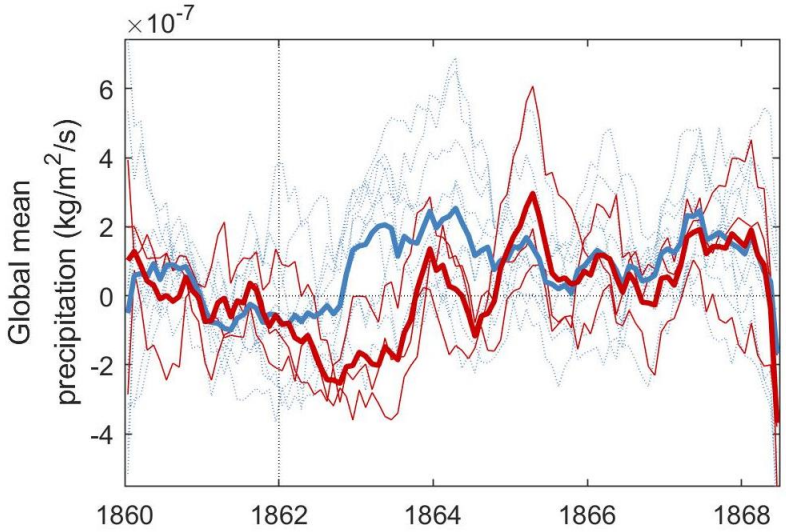
Characteristic of SO_2 emissions	Interactive runs	CMIP6-AER2D	eVolv2k (Toohey and Sigl 2017)
Date	Dec 28 1861	Apr 1st 1861	
SO_2 Mass (Tg SO_2)	9.8	2.06	9±2.6
Latitude (°N)	0.31	-40	
Altitude (km a.s.l.)	15-19.6	24-25	

Completely different SAOD, forcing and temperature/precipitation response with a clear volcanic footprint in interactive runs.





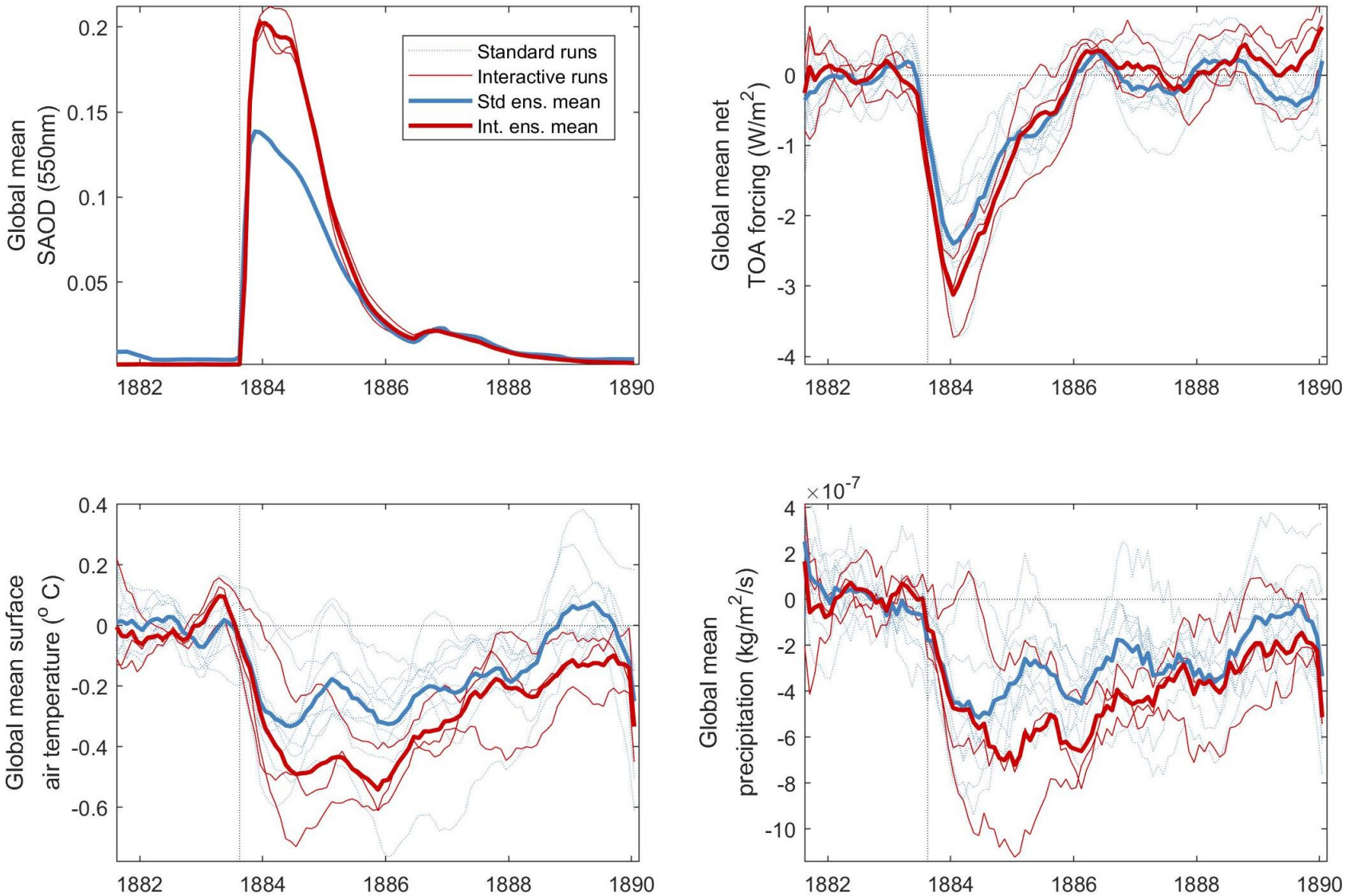




Krakatoa 1883

Characteristic of SO_2 emissions	Interactive runs	CMIP6-AER2D	eVolv2k (Toohey and Sigl 2017)
Date	Aug 27 1883	Aug 27 1883	
SO_2 Mass (Tg SO_2)	16.9	10.72	18.6 ±3.8
Latitude (°N)	-6.1	0	
Altitude (km a.s.l.)	22.5-25.5	24-25	

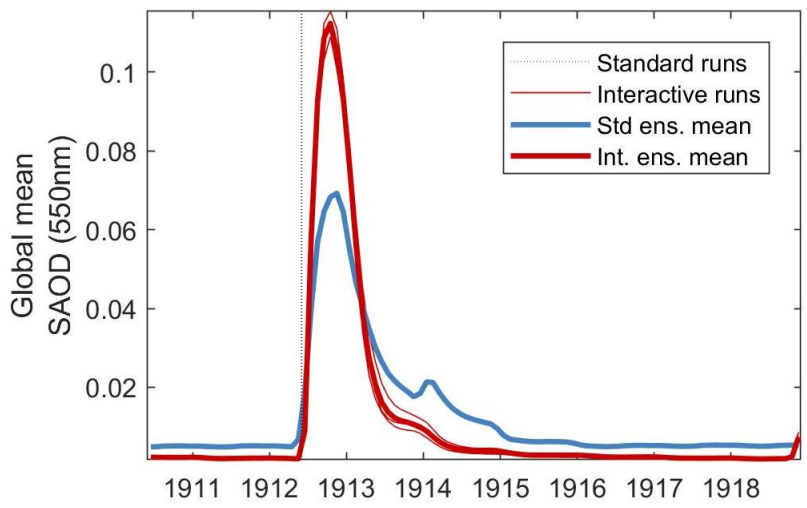
Strongly amplified SAOD, forcing and temperature/precipitation response in interactive runs.

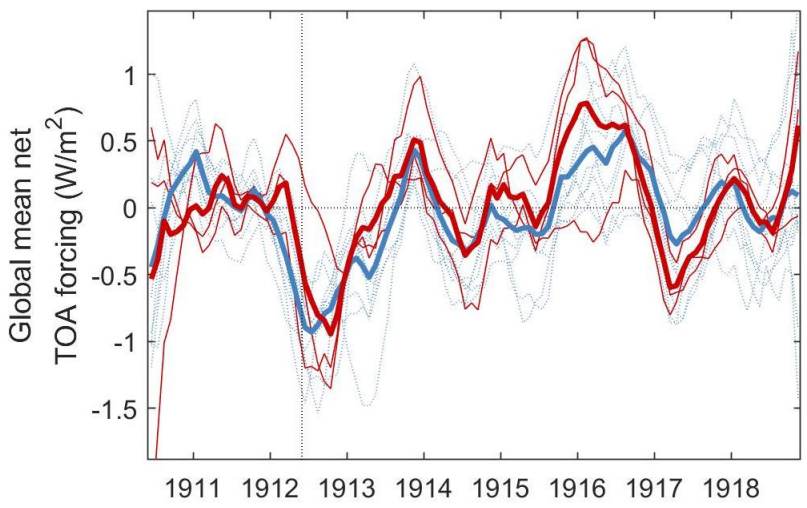


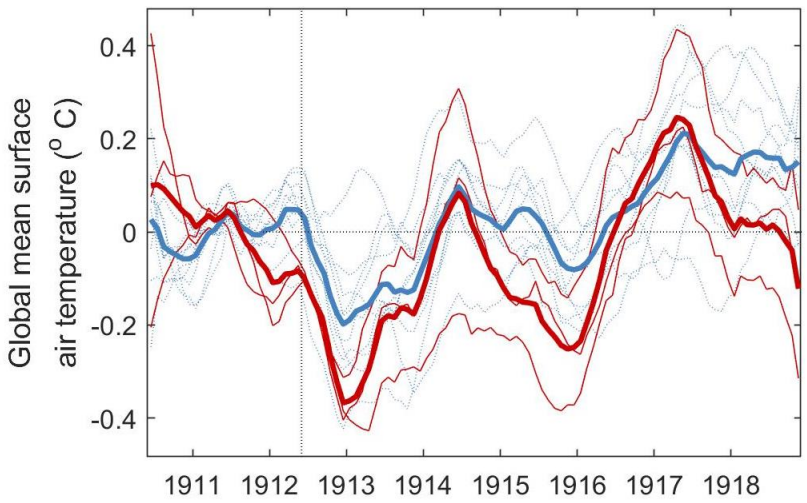
Katmai 1912

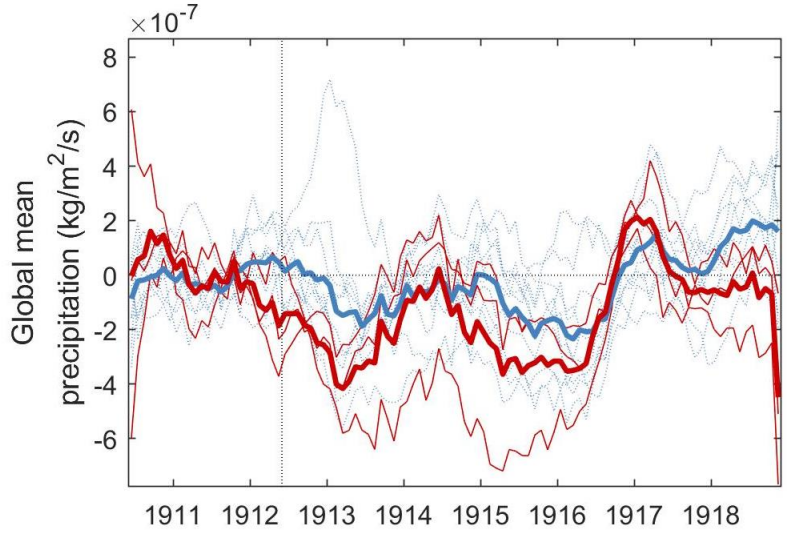
Characteristic of SO_2 emissions	Interactive runs	CMIP6-AER2D	eVolv2k (Toohey and Sigl 2017)
Date	Jun 6 1912	6 June 1912	
SO_2 Mass (Tg SO_2)	7.2	5.39	NA
Latitude (°N)	58.3	58.3	
Altitude (km a.s.l.)	15.5-18.5	15.5-18.5	

Larger SAOD peak and temperature response in interactive runs, despite consistent forcing.





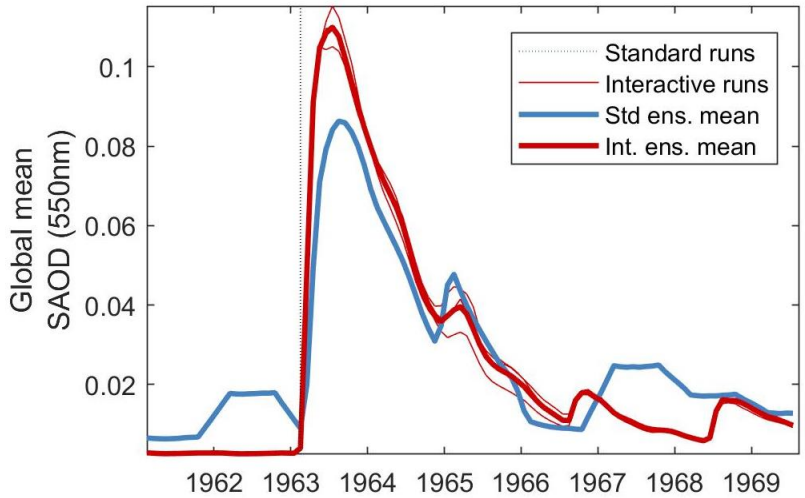


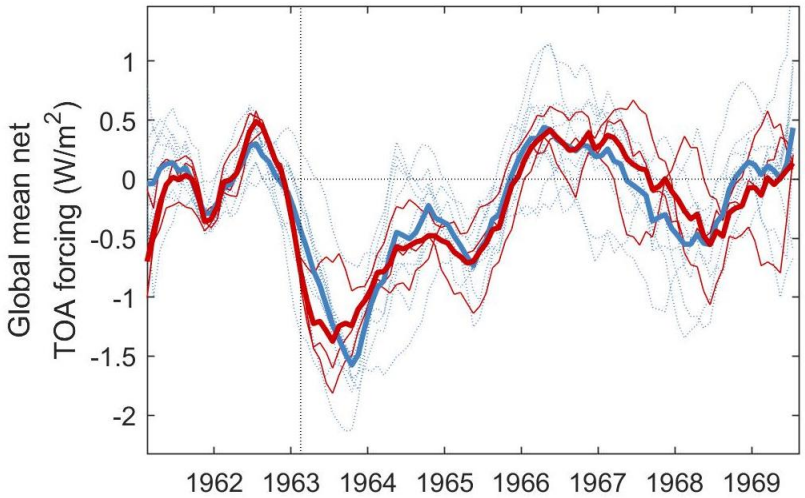


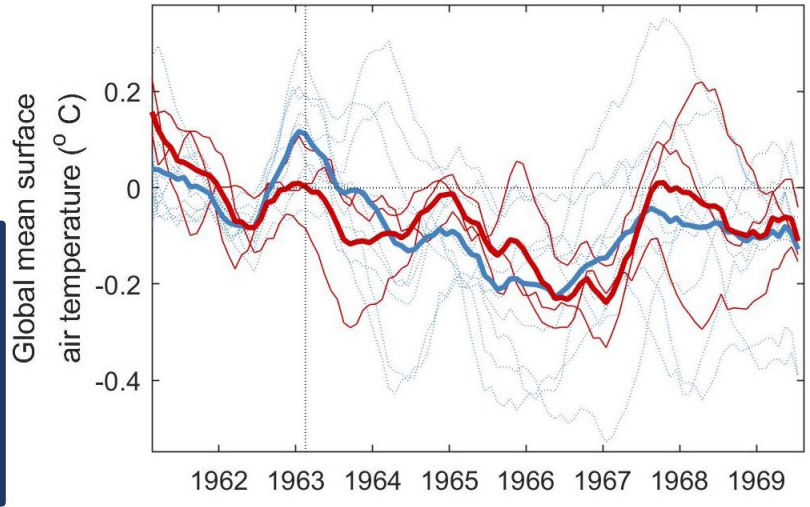
Agung 1963

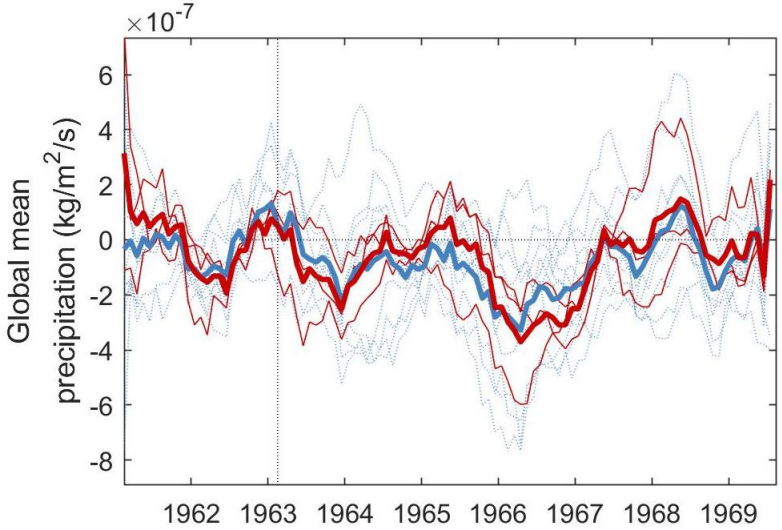
Characteristic of SO_2 emissions	Interactive runs	CMIP6-AER2D	eVolv2k (Toohey and Sigl 2017)
Date	Feb 18 1963	Mar 17 1963	
SO_2 Mass (Tg SO_2)	7.5	10.23	NA
Latitude (°N)	-8.3	-15 - 0	
Altitude (km a.s.l.)	20-23	21-22	

Larger SAOD peak in interactive runs but surprisingly good agreement for forcing and temperature/precipitation response.





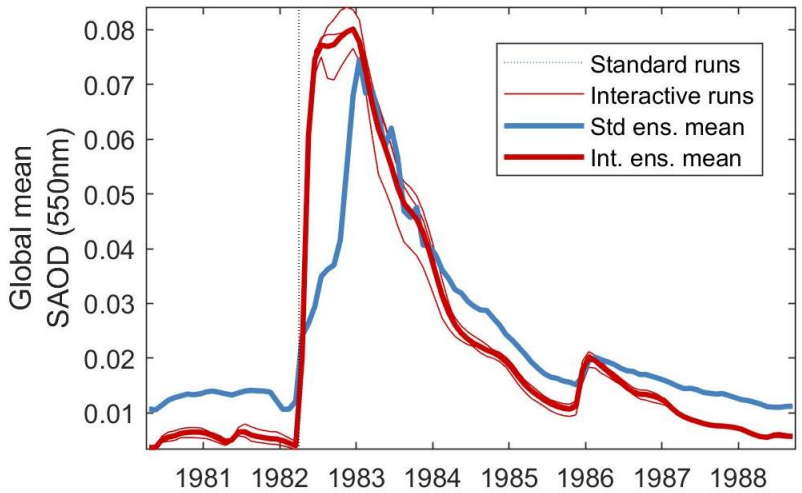


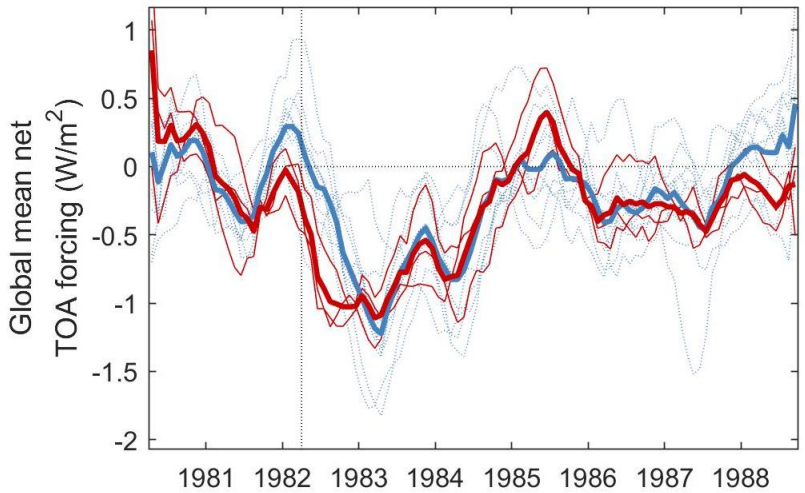


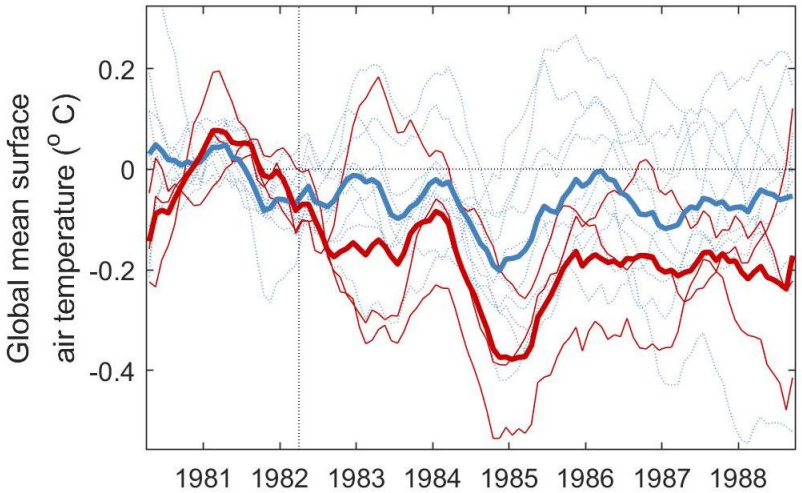
El Chichon 1983

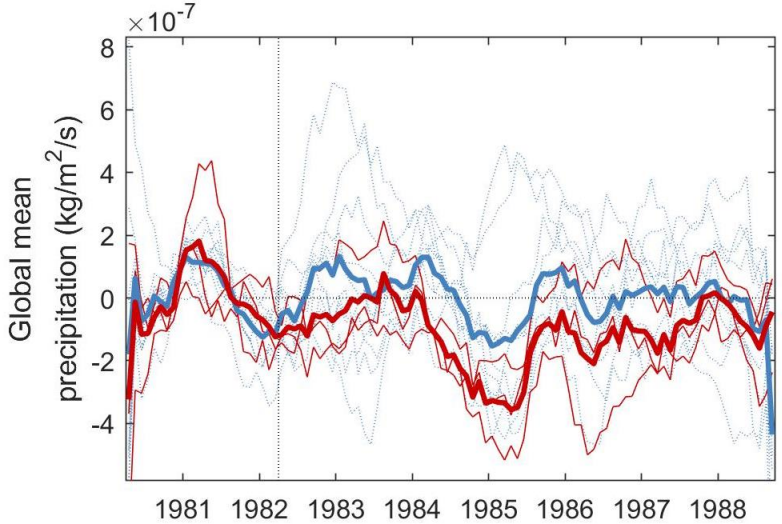
Characteristic of SO_2 emissions	Interactive runs	CMIP6-AER2D	eVolv2k (Toohey and Sigl 2017)
Date	28 Apr – May 4 1982	NA – GloSSAC used instead of SO_2 + AER2D	
SO_2 Mass (Tg SO_2)	5.6		NA
Latitude (°N)	17.36		
Altitude (km a.s.l.)	22-26		

Good agreement for SAOD/forcing and temperature/precipitation response.





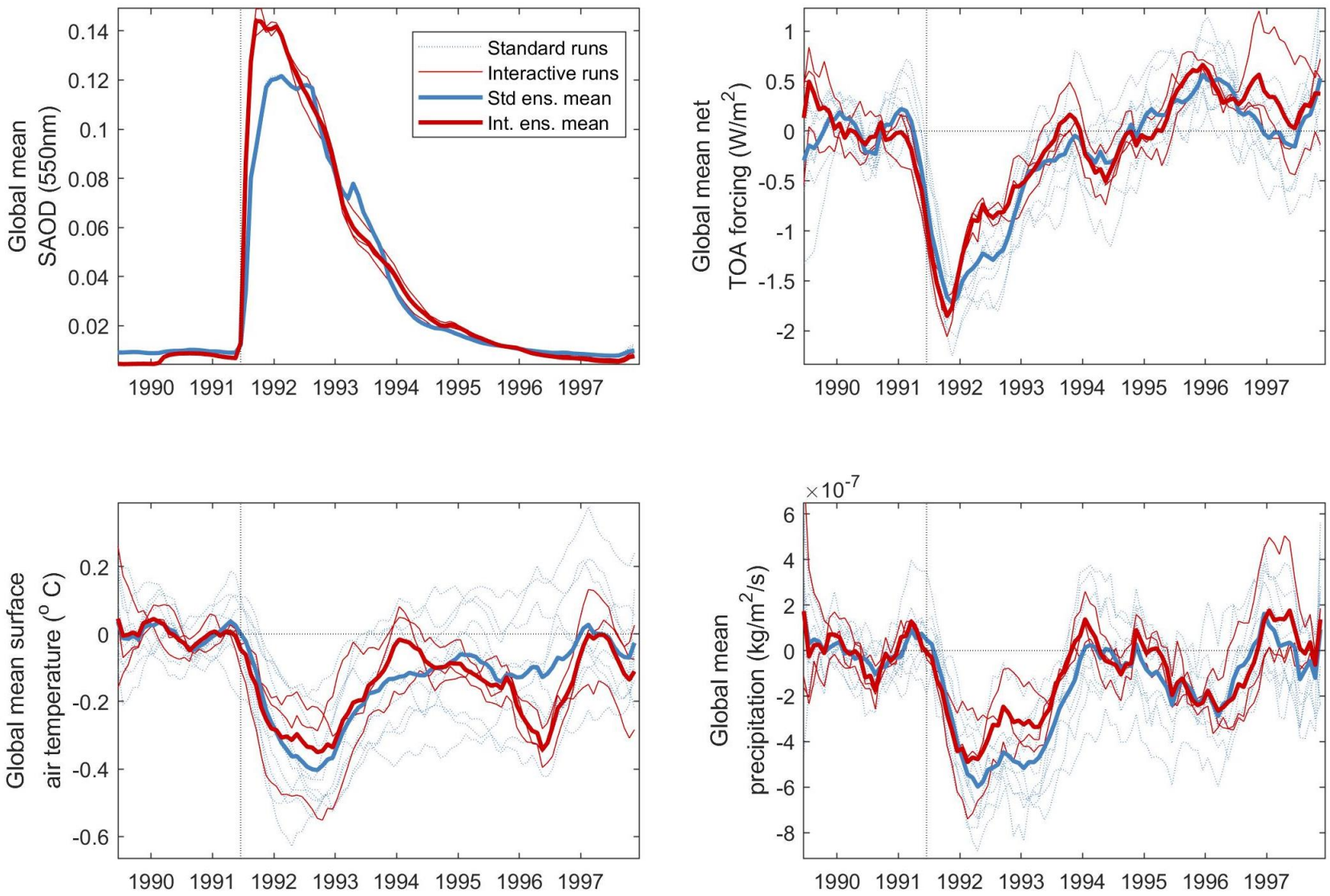




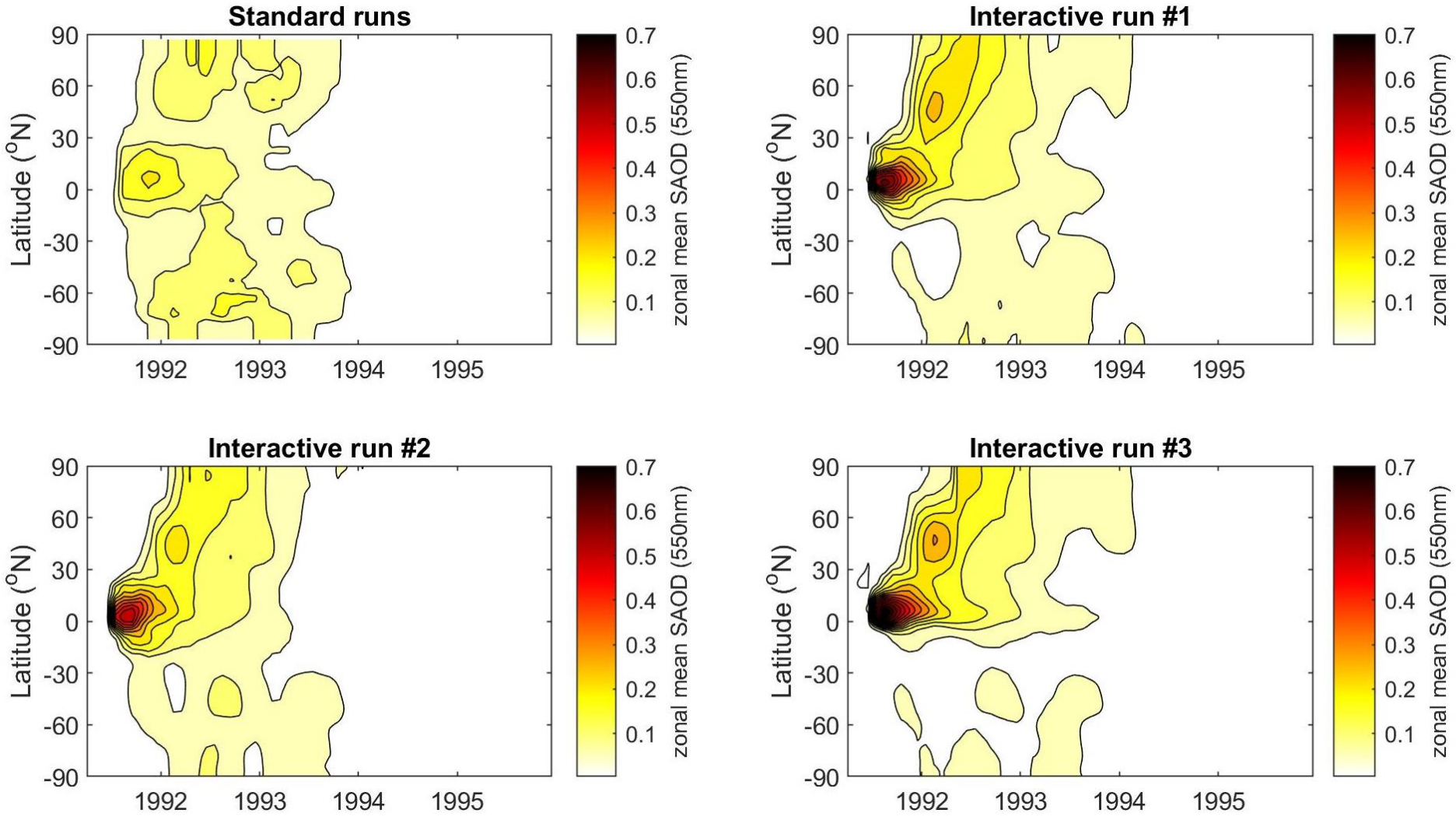
Pinatubo 1991

Characteristic of SO_2 emissions	Interactive runs	CMIP6-AER2D	eVolv2k (Toohey and Sigl 2017)
Date	Jun 15 1991	NA – GloSSAC used instead of SO_2 + AER2D	
SO_2 Mass (Tg SO_2)	10		NA
Latitude (°N)	0-15		
Altitude (km a.s.l.)	22-25		

Slightly larger SAOD peak in interactive runs but good agreement for forcing and temperature/precipitation response.



Pinatubo 1991: aerosol dispersal



Despite good agreement in simulated global mean SAOD, forcing and climate response, there are important differences between standard and interactive runs in the spatial structure of the forcing which may have important implications for the dynamical response to the eruption.

Preliminary conclusions and future work

We ran new historical simulations with UKESM1 using the interactive stratospheric aerosol capability to represent volcanic forcing. Compared to standard CMIP6 run with prescribed aerosol optical properties, we find:

- Strong differences in global mean SAOD and forcing for the 1850-1950, for which volcanic forcing is derived from ice-core estimates of SO_2 emissions and aerosol modeling
- A general agreement in global mean forcing and climate response for the satellite (1979-2015) era
- Interactive runs exhibit strong variability in aerosol dispersal which may result in challenges for simulating the dynamical response to well-observed eruptions (e.g. Pinatubo 1991)
- A much larger (and overestimated) background non-volcanic SAOD in standard runs compared to interactive runs

In the future, we will:

- Investigate in details the ocean and dynamical (e.g. ENSO, NAO) response to eruptions in the standard and interactive ensemble
- Rigorously assess the significance of differences between standard and interactive runs
- Compare our results with reconstructions and observations of climate, as well as with other model runs from the VolMIP (Zanchettin et al. 2016) and ISA-MIP (Timmreck et al. 2018) model intercomparison projects