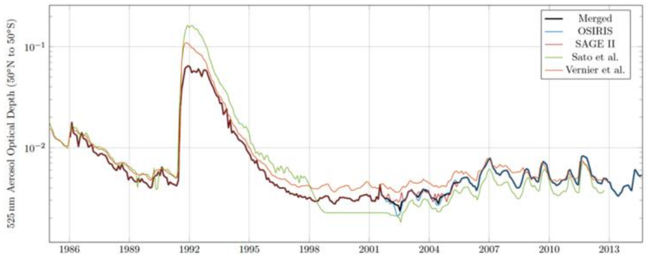

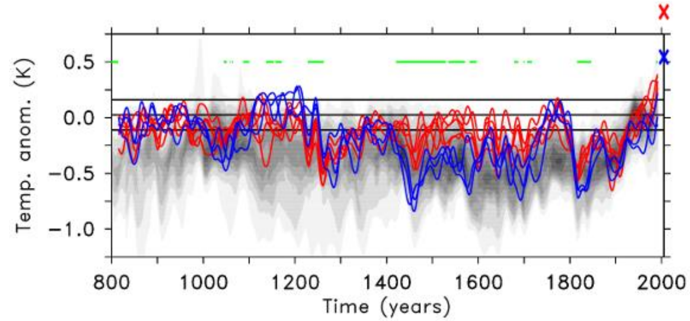

Towards a coordinated modeling assessment of the climate response to stratospheric aerosol

Claudia Timmreck[1], Davide Zanchettin[2], Myriam Khodri[3], Graham Mann[4]

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Università Ca'Foscari Venezia

Institut Pierre Simon Laplace

UNIVERSITY OF LEEDS

The IPCC-AR5 report states (WG1, Ch. 8):

"Volcanic eruptions […] are the dominant natural cause of externally forced climate change on the annual and multi-decadal time scales […]"

"The RF [radiative forcing] of volcanic aerosols is well understood"

	Evidence	Agreement	Confidence Level	Basis for Uncertainty Estimates (more certain / less certain)	Change in Under-standing Since AR4
Volcanic aerosol	Robust	Medium	*High*	Observations of recent volcanic eruptions/Reconstructions of past eruptions	Elevated owing to improved understanding

Table 8.5 from Myhre et al., 2013 | **Confidence levels for the forcing estimates**

"The volcanic RF has a **very irregular temporal pattern** and for certain years has a strongly negative RF"

"Although the effects of volcanic eruptions on climate are largest in the 2 years following a large stratospheric injection […] there is **new work indicating extended volcanic impacts** via long-term memory in the ocean heat content and sea level […]"

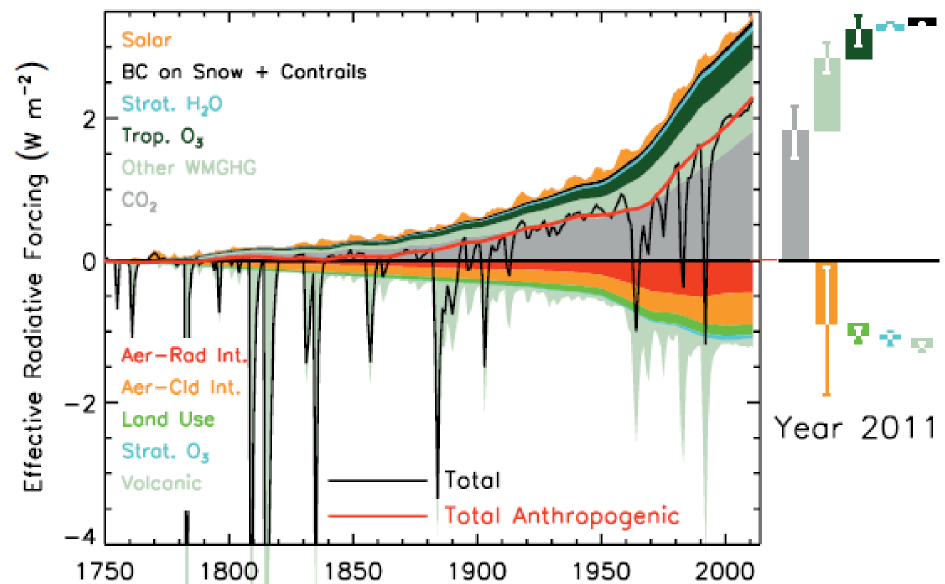


Figure 8.18 from Myhre et al., 2013 | **Time evolution for anthropogenic and natural forcing mechanisms**

Volcanoes and the climate: uncertainties /1

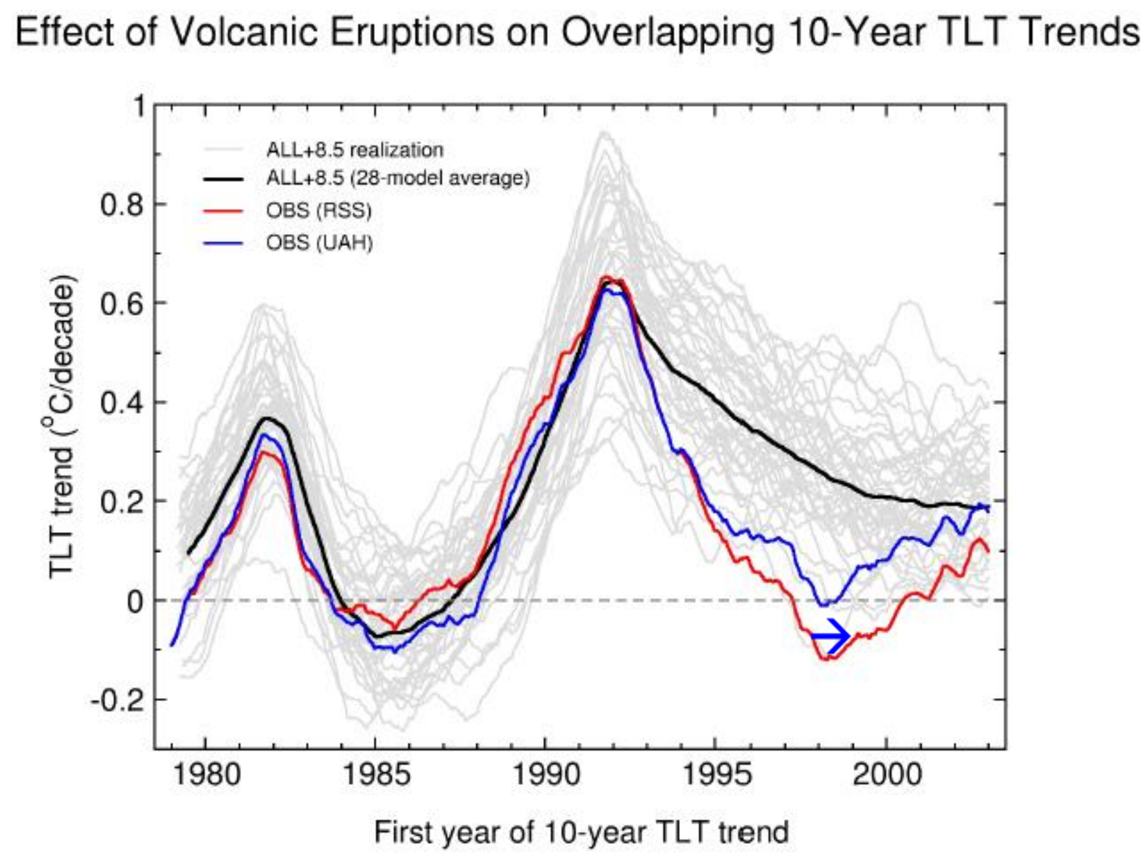


Figure 4 from Santer et al. 2014 Behavior of overlapping 10-year trends in the 'ENSO removed' near-global (82.5 N–70 S) TLT data. Least-squares linear trends were calculated over 120 months ,.

→ The largest uncertainties in the estimates of radiative forcing from historical climate simulations occur during periods of strong volcanic activity [*e.g.Santer et al., 2014*]

Uncertainties of the emission strength , global aerosol simulations suggest an aerosol load much smaller than known from satellite observations -> see posters by Graham Mann et al. and Lindsay Lee et. al

Volcanoes and the climate: uncertainties /2

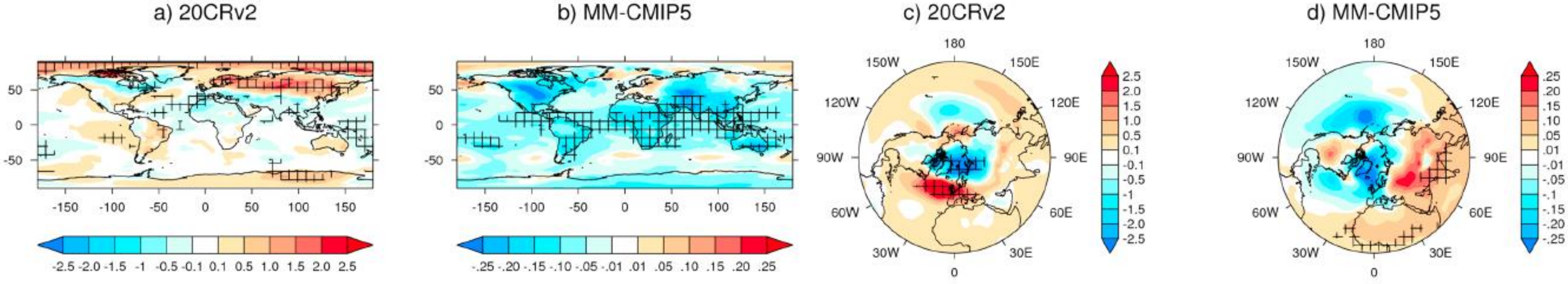


Figure 4 from Driscoll et al., 2012 | **Comparison between reanalyses and CMIP5 multi-model mean. Composite anomalies averaged after 2 post-volcanic winters for near-surface temperatures (a,b) and sea-level pressure (c,d)**

"The **models generally fail to capture the NH dynamical response following eruptions**. They do not sufficiently simulate the observed post-volcanic strengthened NH polar vortex, positive NAO, or NH Eur-asian warming pattern, and they tend to overestimate the cooling in the tropical troposphere." [*Driscoll et al., 2012*]

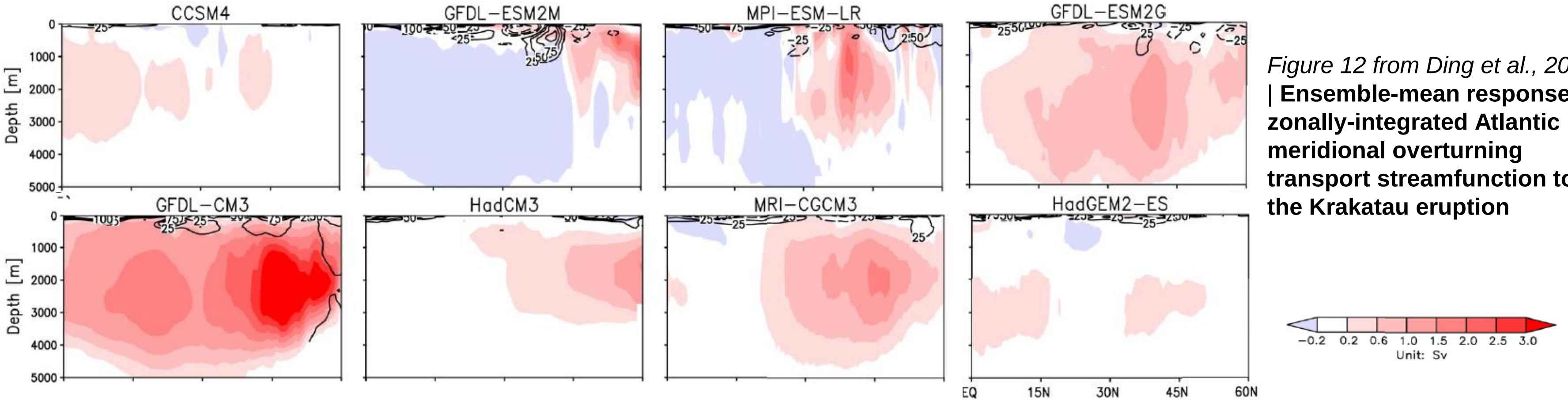


Figure 12 from Ding et al., 2014 | **Ensemble-mean response of zonally-integrated Atlantic meridional overturning transport streamfunction to the Krakatau eruption**

"The **strength of this overturning increase varies considerably from model to model** and is correlated with the background variability of overturning in each model. Any cause/effect relationship between erruptions and the phase of El Niño is **weak**." [*Ding et al., 2014*]

→ non robust simulated dynamical responses to volcanic eruptions

Volcanoes and the climate: uncertainties /3

“ **Uncertainties grow considerably for events that occurred in the more remote past** […] which contribute substantially to our understanding.” [*Zanchettin et al., 2015*]

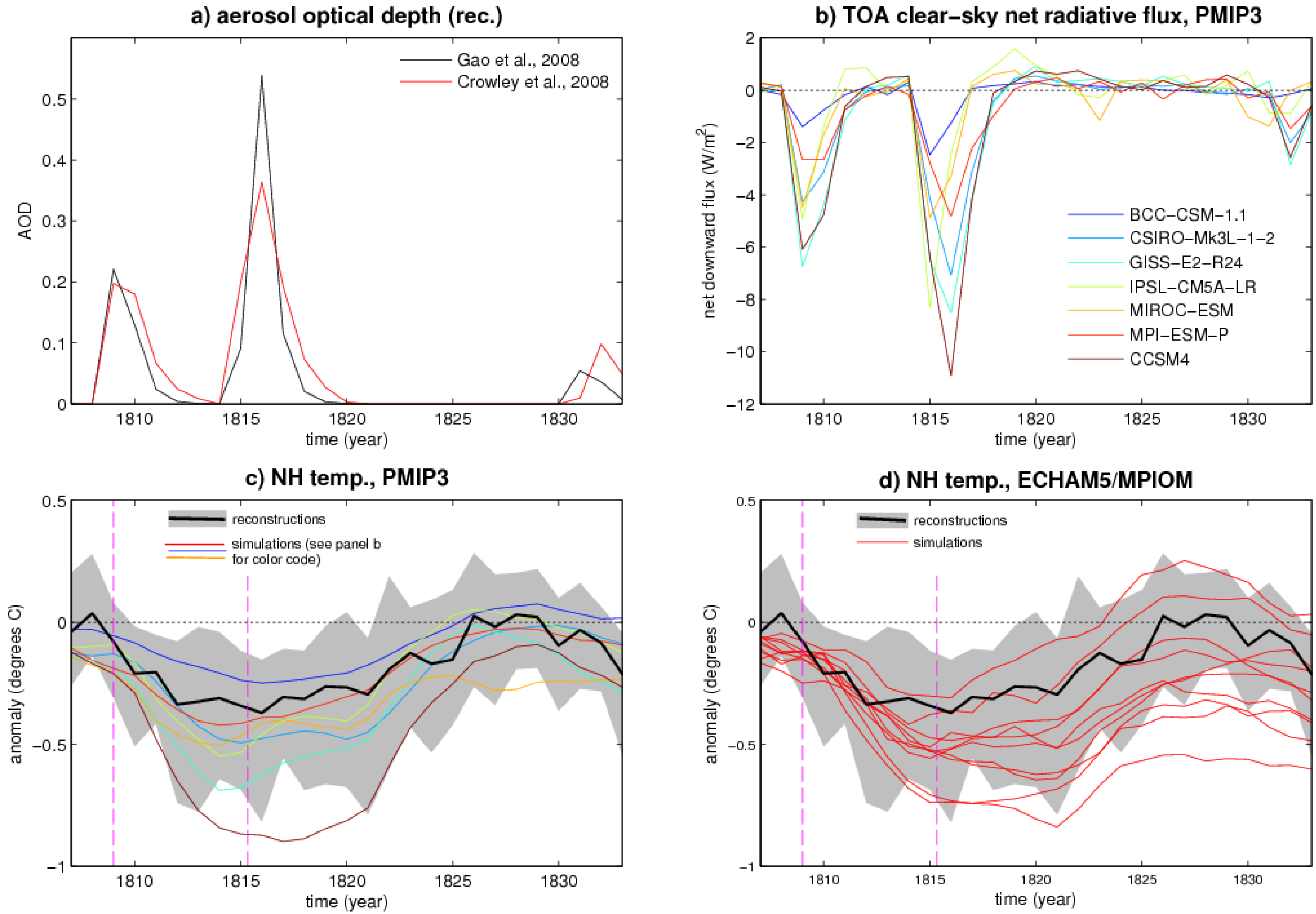
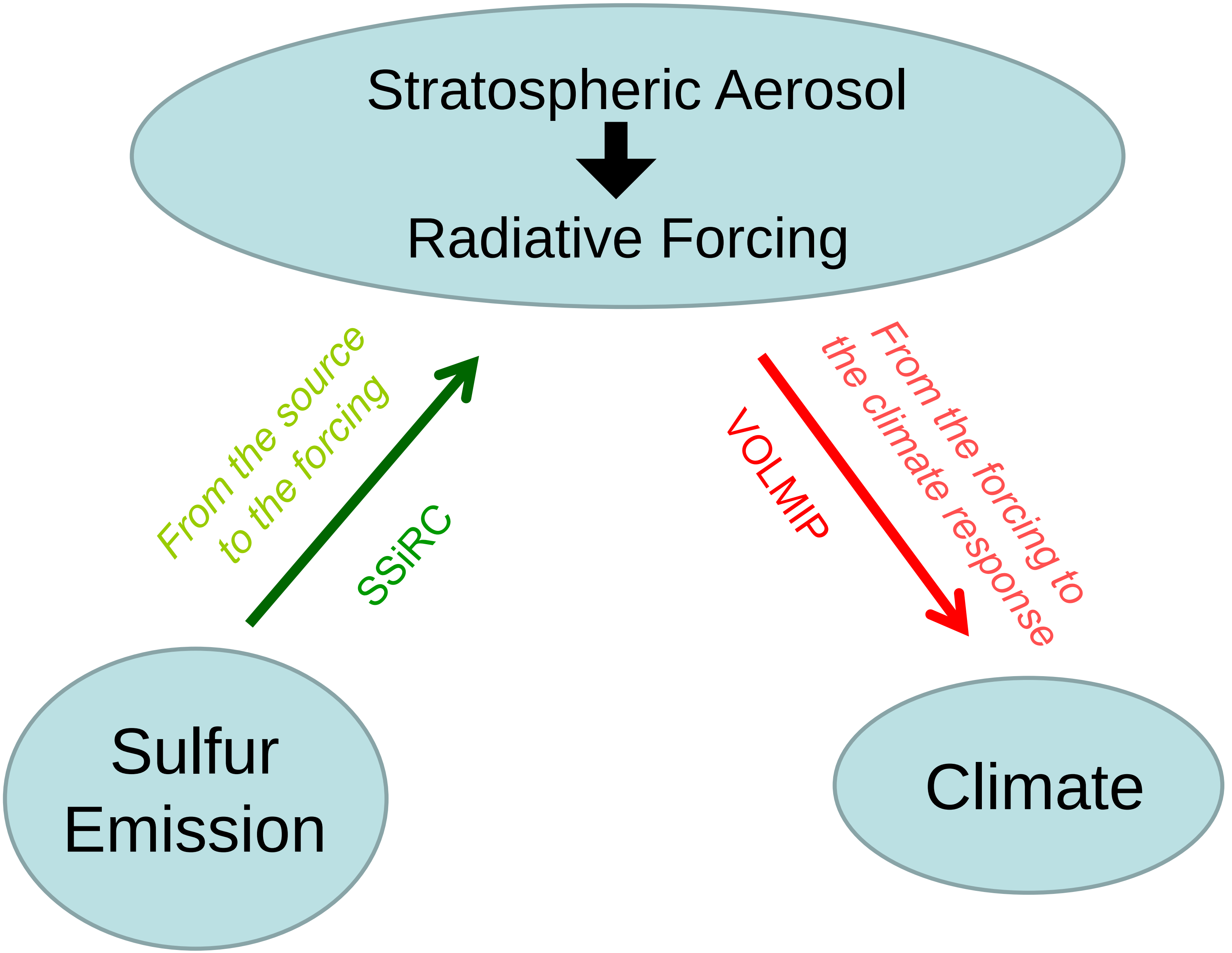


Figure 1 from Zanchettin et al., 2015 | **Uncertainty in radiative forcing and climate response for the early-19th-century eruptions. Different models and forcing inputs (c) and internal climate variability (d) similarly contribute to simulation-ensemble spread**

Tackling the uncertainties: a modeling approach



SSiRC

Stratospheric Sulfur and its Role in Climate

SPARC

SSiRC aims at better understanding and hence modelling of the stratospheric aerosol layers and its controls, particularly precursor gaseous sulfur species that are a direct input of major volcanic eruptions.

Components of SSIRC

- Understanding aerosol measurements
  - Making data accessible
  - Preserving historical data sets
  - Improving the aerosol climatology for 1850 to 2015
  - Planning a community response to the next big eruption
- Understanding how stratospheric aerosols impacts climate
  - The role of small eruptions in modulating stratospheric aerosol levels and climate change
  - Understanding cataclysmic eruptions impact on climate
- Facilitating the development of an interactive sulfur-aerosol model for climate models

http://www.sparc-ssirc.org/

SSiRC aerosol model intercomparisons

with interactive stratospheric aerosol modules

(co-chairs: *Claudia Timmreck, Graham Mann*)

Coordinated experiments to intercompare simulated stratospheric aerosol properties, assess volcanic SO_2 emissions & quantify uncertainty in predicted volcanic forcings:

Background Stratospheric Aerosol	*D. Weisenstein; J. English, v. Aquila*	10 year climatology to understand sources and sinks of stratospheric background aerosol
Transient Strat Aerosol [MITAR]	*R. Hommel; M. Chin; R. Neely; C. Brühl*	Evaluate models over the period 1998-2012
Historic Eruption SO_2 Emission Assessment [HErSEA] **Poster-> Graham**	*G. Mann, S. Dhomse, M. Mills, J. Sheng*	Intercompare mini-ensembles of Agung, El Chichon and Pinatubo eruptions among interactive strat-aerosol CCMs Assess appropriate SO2 to emit.
Pinatubo Emulation in Multiple Models [PoEMS] **Poster-> Lindsay**	*L. Lee G. Mann; V. Aquila; M. Toohey*	Intercompare Pinatubo perturbation to strat-aerosol properties with full uncertainty analysis over PPE run by each model.

2nd Workshop on Stratospheric Sulfur and its Role in Climate
Potsdam, Germany, 25-28 April 2016

VolMIP – Model Intercomparison Project on the climatic response to Volcanic forcing

<u>in a nutshell:</u>

VolMIP is a CMIP-endorsed activity (co-chairs: *Davide Zanchettin, Claudia Timmreck, Myriam Khodri*) which defines a common protocol focused on **multi-model assessment of climate models‘ performance under strong volcanic forcing conditions**.

VolMIP defines a set of *idealized* volcanic perturbations based on historical eruptions

Volcanic forcing is implemented through prescribed aerosols optical parameters **derived from radiation parameters of documented eruptions**.

The experiments are designed as ensemble simulations, with sets of **initial climate states sampled from an unperturbed preindustrial simulation (piControl)**.

Several models have already committed to perform VolMIP core experiments, including CanESM, CESM, EC-Earth, FGOALS, GISS, IPSL, MIROC-ESM, MPI-ESM, MRI-ESM1.x, NorESM and UKESM.

http://www.volmip.org/

Experimental design

VolMIP experiments are designed based on a twofold strategy

	VolShort	VolLong
FOCUS	the seasonal-to-interannual atmospheric response to a 1991 Pinatubo-like volcanic eruption disentangling the role of surface cooling and stratospheric warming for the short-term atmospheric dynamical response impact of volcanic forcing on seasonal-to-interannual climate predictability (with DCPP)	long-term (up to the decadal time scale) climate response to very strong volcanic eruptions (like Tambora, Laki) signal propagation pathways of volcanic perturbations within the coupled atmosphere-ocean system
INITIAL CONDITIONS	ENSO, QBO, AMOC, NAO, polar vortex	ENSO, AMOC

Identification of consensus forcing input data for both types of experiments is an integral part of VolMIP

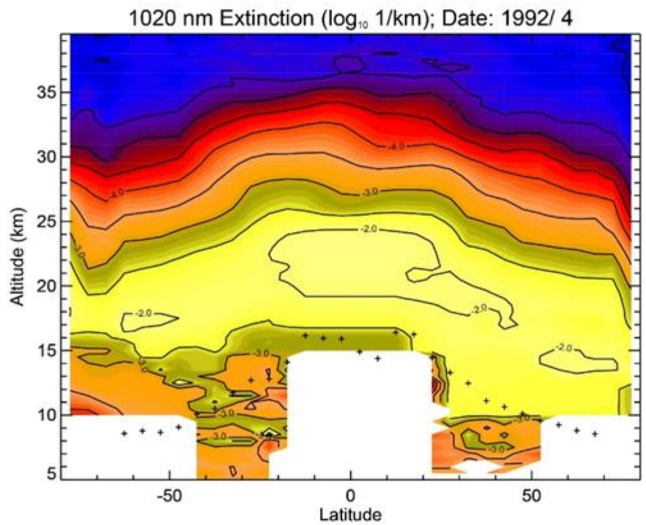
VolMIP core (Tier 1) experiments

Name	Aim	Ens. Size	Length	Forcing
VolShort20EQFull	accurately estimate **uncertainty in simulated responses** to volcanic forcing comparable to the amplitude of internal interannual variability	25	3	CMIP6 stratospheric aerosol data set (Thomason et al., 2015) for the volcanic forcing of the 1991 Pinatubo eruption which is set up for the CMIP6 *historical* simulation
VolShort20EQstrat	**isolate the impact of stratospheric warming** by volcanic aerosols	25	3	Prescribed perturbation to the total (LW+SW) radiative heating rates seeking to mimic the local impact of aerosol
VolShort20EQsurf	**isolate the cooling of the surface** by mimicking the attenuation of solar radiation by volcanic aerosols	25	3	Either via prescribed TOA clear sky SW flux or via restoring of the surface albedo
VolLongS60EQ	designed to realistically reproduce the radiative forcing resulting from the 1815 Tambora eruption	9	20	consensus forcing under identification

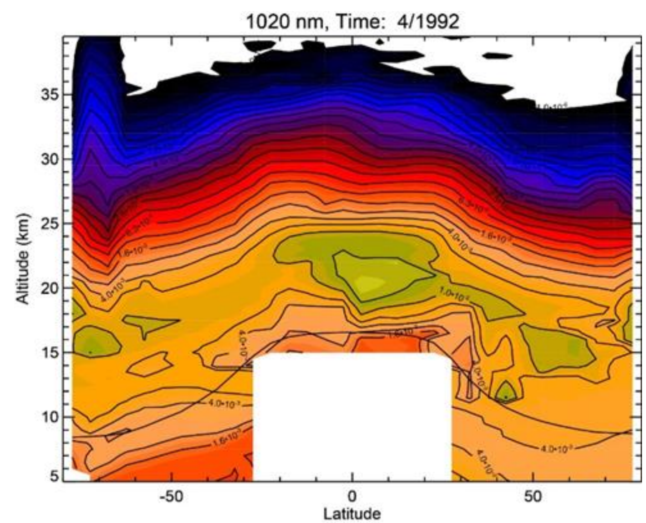
Well-defined volcanic forcing for VolLSHORT (Pinatubo)

Pinatubo forcing data from the improved CMIP/CCMI long-term stratospheric aerosol database Larry Thomason et al. in prep for CMIP6

- Pinatubo
  - SAGE II profiles terminated as high as 25 km in the immediate aftermath of the eruption
  - Development a methodology for using IR measurements by CLAES to fill
  - Generally increases low latitude optical depth
- High latitudes
  - Past 'gap-free' aerosol climatologies used unrealistic extrapolations/-interpolations to fill the winter high latitudes
  - A new method using equivalent latitudes and Equivalent latitude pdfs as a function of latitude has been implemented to provide a superior high latitude analysis



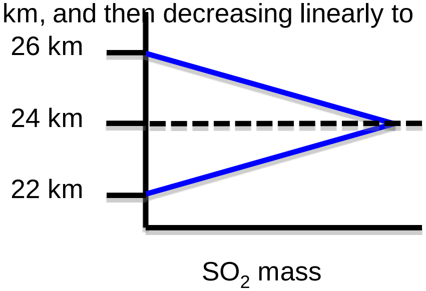
CMIP 5 Analysis for April 1992 Filled using subtropical lidar data



CMIP 6 Analysis for April 1992 Filled using tropical CLAES data (note change in contour levels and coloring)

Well-defined volcanic forcing for VolLongS60EQ

Coordinated assessment of radiative forcing uncertainties for VolLongS60EQ using aerosol climate models (activity leader: *Myriam Khodri, IPSL*)

Parameters	Values for Tambora
Eruption date	April 1, 1815
SO_2 emission	60 Tg SO_2
Erupt. length	24 hours
Latitude	Centered at the equator
QBO phase at time of erupt.	Easterly phase (as for Pinatubo and El Chichón)
SO_2 height injection	Same as Pinatubo, 100% of the mass between 22 and 26 km, increasing linearly with height from zero at 22 to max at 24 km, and then decreasing linearly to zero at 26 km. 
SST	Climatological from preindustrial control run
Other radiative forcing	Preindustrial CO_2, other greenhouse gases, tropospheric aerosols (and O_3 if specified)
Duration	5-years long to get the tail of the distribution
Ens. size	5 members

Output Parameters *Monthly, zonal average* *At model resolution in latitude and vertically*
Total stratospheric AOD at λ = 525 nm and 1020 nm (at each latitude)
effective radius, extinction, single scatter albedo, and asymmetry factor (at each grid-point)

- Global aerosol model outputs deliverable: Deadline October 2015

Participants:

UM-UKCA, **ECHAM5-HAM**, **UPMC-2D WACCM-CARMA**, **AER-2-D**, **GISS ModelE2**

Potential linkages /1

- AEROCOM:
  - Contributions in SSIRC experiments
  - e.g. UTLS proposal by Mian Chin
- CCMI:
  - Sensitivity experiments of chemistry climate with VolMIP Forcing
- AERCHEMIP
  - Comparison of volcanically perturbed periods
    - Pinatubo, El Chichon etc
    - early 21st century

Potential linkages /2

To be continued

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