# Interactive historical volcanic emissions, effects on chemistry and climate

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# Historical CMIP5 GISS Radiative Forcing

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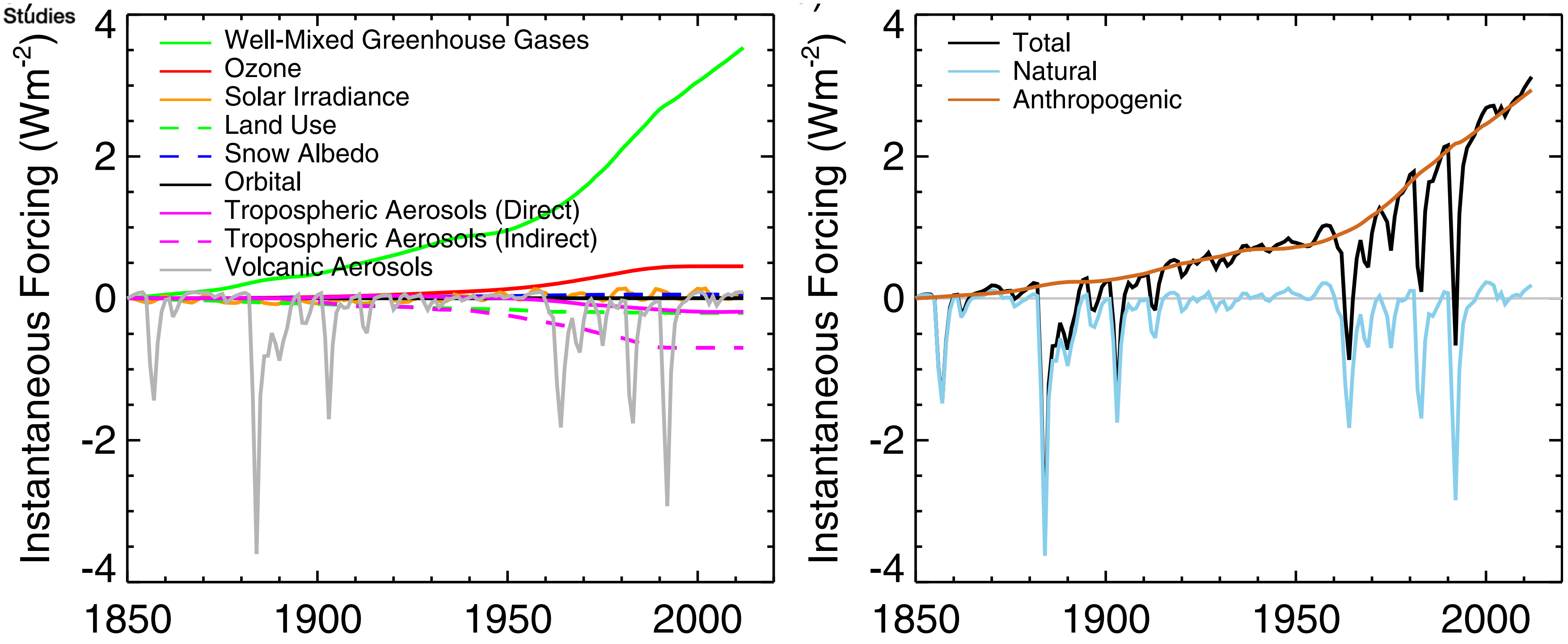


**Figure 2.** Instantaneous global radiative forcing at the tropopause ($Wm^{-2}$) in the E2-R NINT ensemble. (a) Individual forcings and (b) Total forcing, along with the separate sum of natural (solar plus volcanic aerosol plus orbital) and anthropogenic forcings.

Miller et al 2014

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# Motivation

How do we have to represent volcanic eruptions in climate simulations?

Can we prescribe forcings, aerosol optical thickness (eff. radius..)?

When simulated interactively (emission driven) how much do aerosol microphysical details matter?

What is the climate response to the different representations of volcanoes in a coupled climate model?

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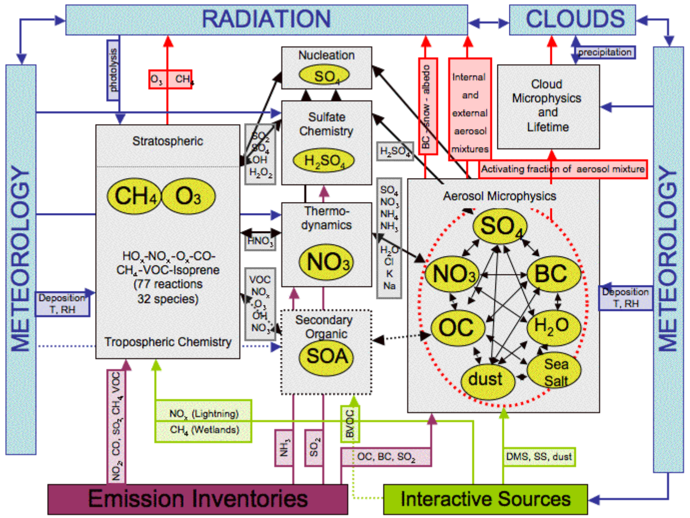
# Representation of Volcanic Forcings: CMIP5 to CMIP6

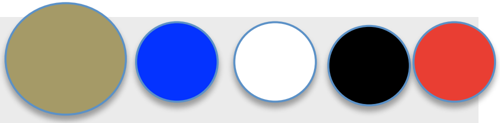
CMIP5: Prescribed Stratospheric Volcanic AOD, Sato et al 1993, and updates
CMIP6: Prescribed Stratospheric Volcanic AOD , Luo et al (CMIP6 protocol)
Emission driven: Historical VolcanEESM emissions (Neely, Schmidt, 2016)

## NASA GISS E2.1 Earth System Model



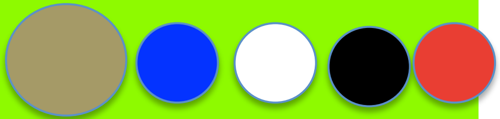

**NINT**

Offline Ozone and Aerosol fields are read in



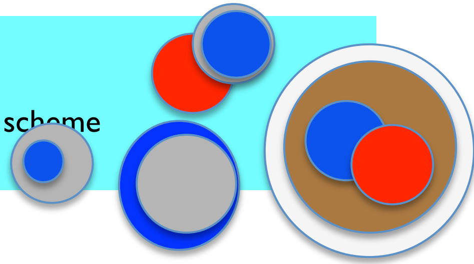
**OMA**

Interactive Chemistry and aerosol scheme [Mass]



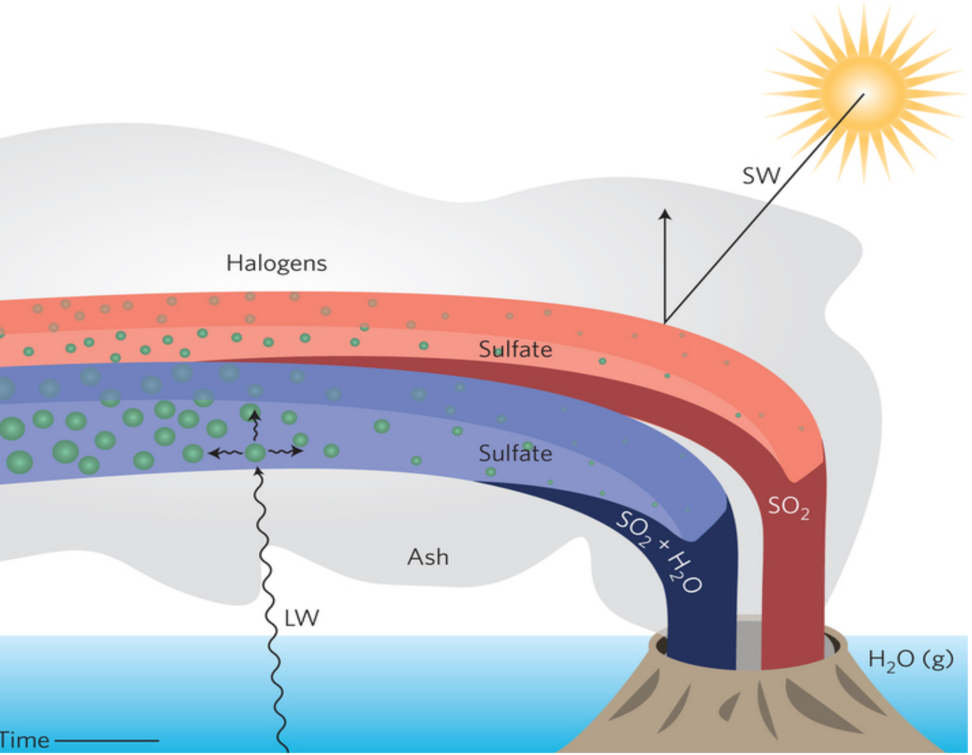
**MATRIX**

Interactive Chemistry and aerosol microphysical scheme [Mass, Number, Mixing State]

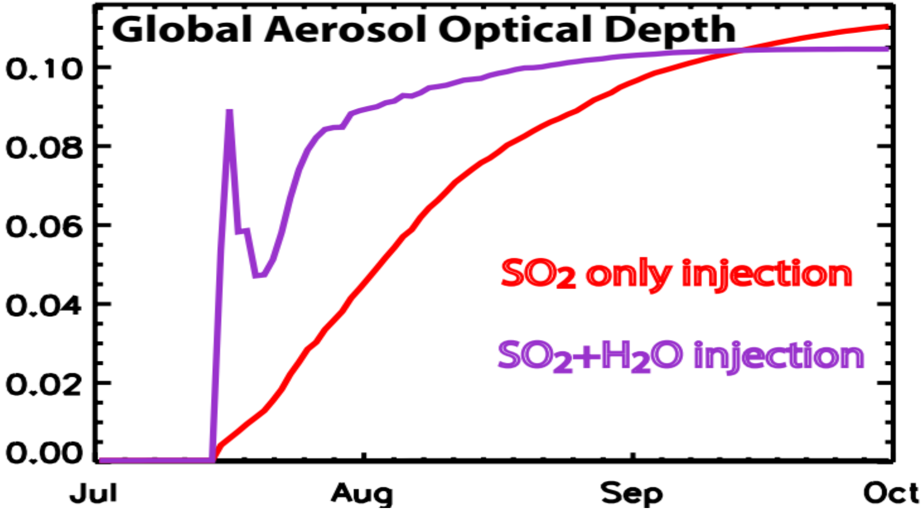


*Bauer et al 2008, Schmidt et al 2013, Miller et al 2014, Shindell et al 2012*

# MATRIX: Injection of H2O with SO2




- Shown here the very fast formation of sulfate, triggered by the enhanced OH radical concentrations when $H_2O$ is co-injected, the loss of ultrafine aerosols due to coagulation, and the subsequent (slower) formation of accumulation mode aerosols.




LeGrande, Tsigaridis, and Bauer, Nature Geosci, 2016

# Model setup

- ❑ AMIP simulation: prescribed sea ice and sea surface temperature
- ❑ Model run can be analyzed for 80 years 1850 - 1930
- ❑ Microphysics vs Bulk vs SAOD
- ❑ Feedbacks can only be studies for chemistry and aerosols

1. OMA with emission driven volcanoes
2. OMA with no volcanoes
3. OMA with prescribed AOD for volcanoes (Sato)
4. MATRIX with emission driven volcanoes
5. MATIX with no volcanoes
6. MATRIX with prescribed AOD for volcanoes (Sato)

# TOA Forcing changes without volcanoes

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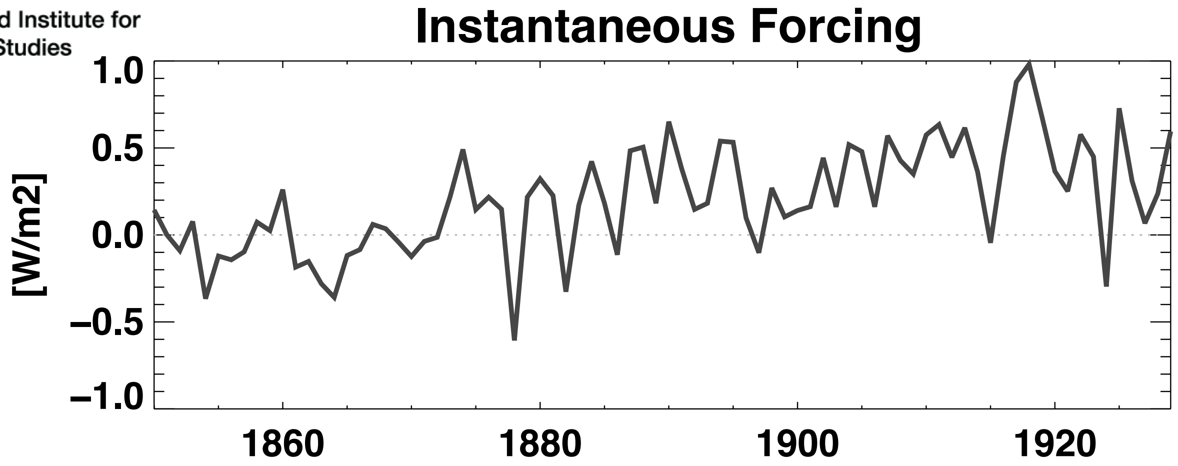

# TOA Forcing changes without volcanoes

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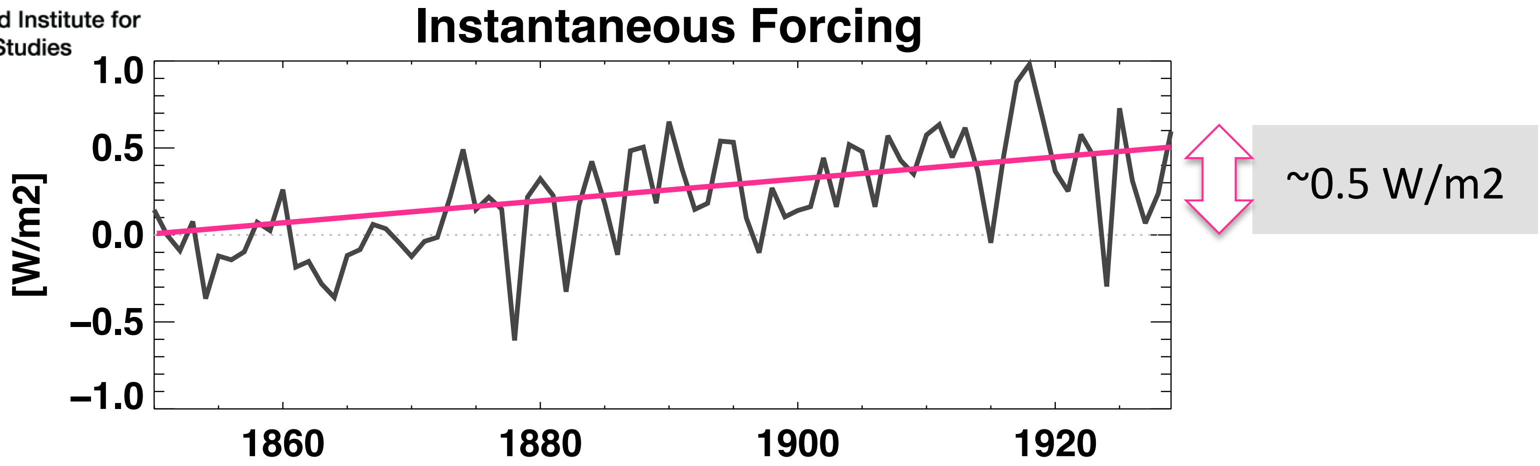
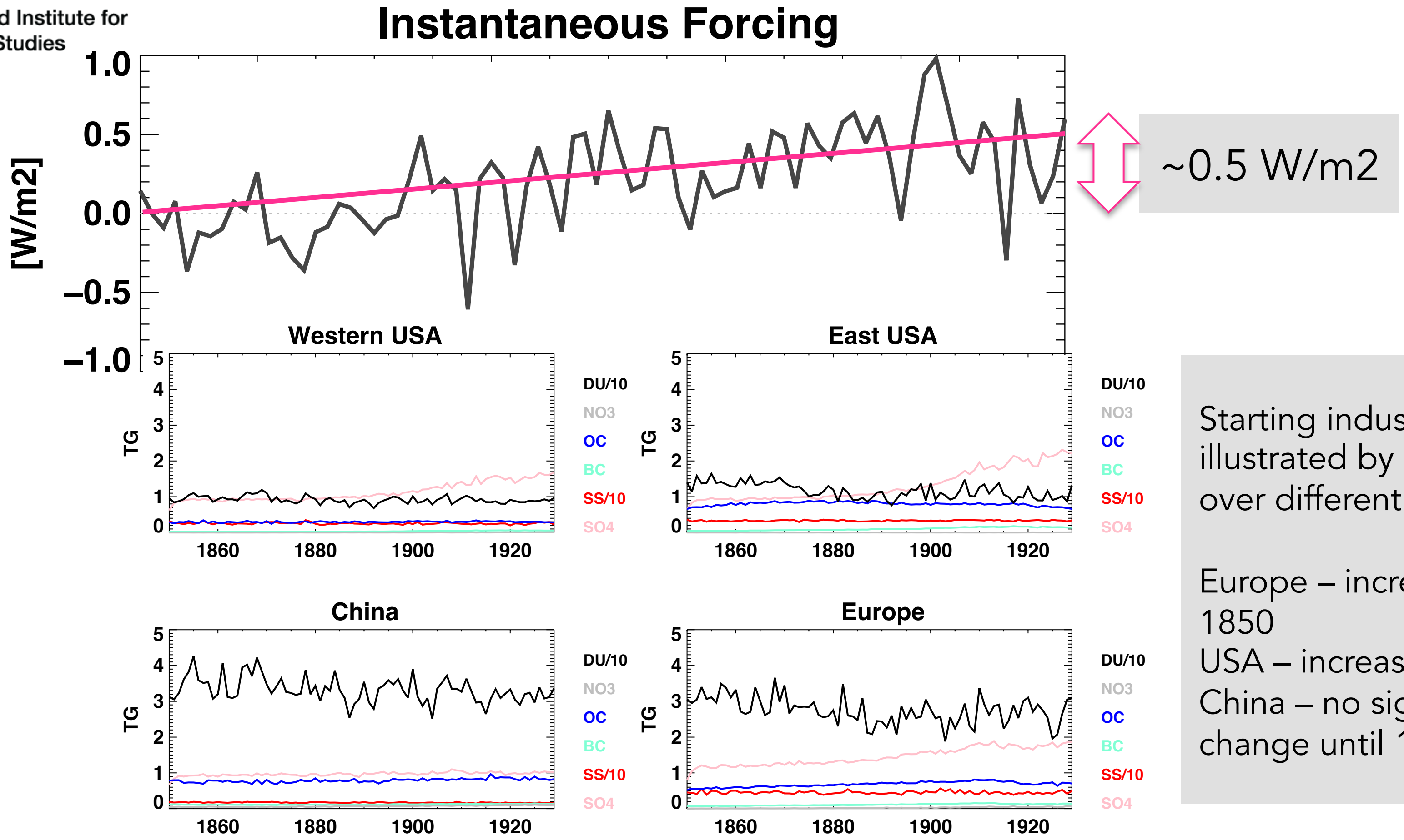


# TOA Forcing changes without volcanoes




Starting industrialization, illustrated by aerosol loads over different regions:

Europe – increases since 1850
USA – increases since 1890
China – no significant change until 1930

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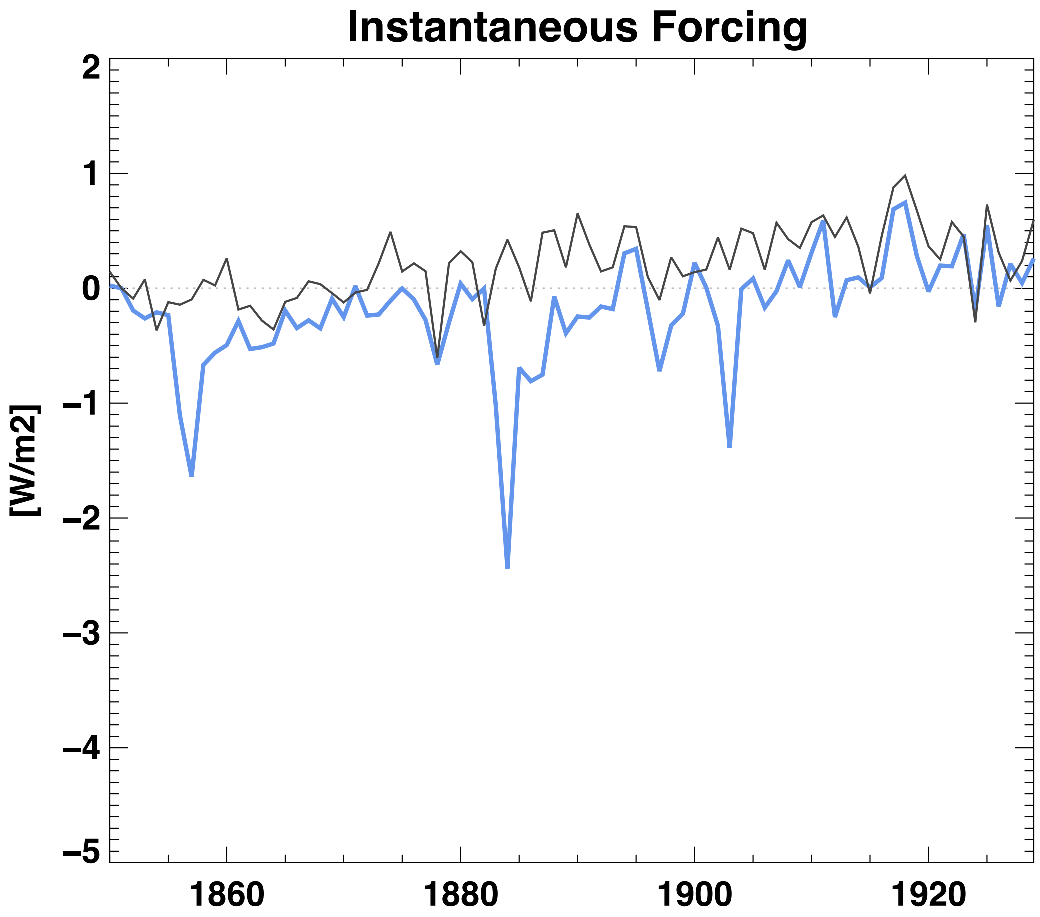
# TOA Forcing changes with and without volcanoes




- no volc
- AOD volc

# TOA Forcing changes with and without volcanoes

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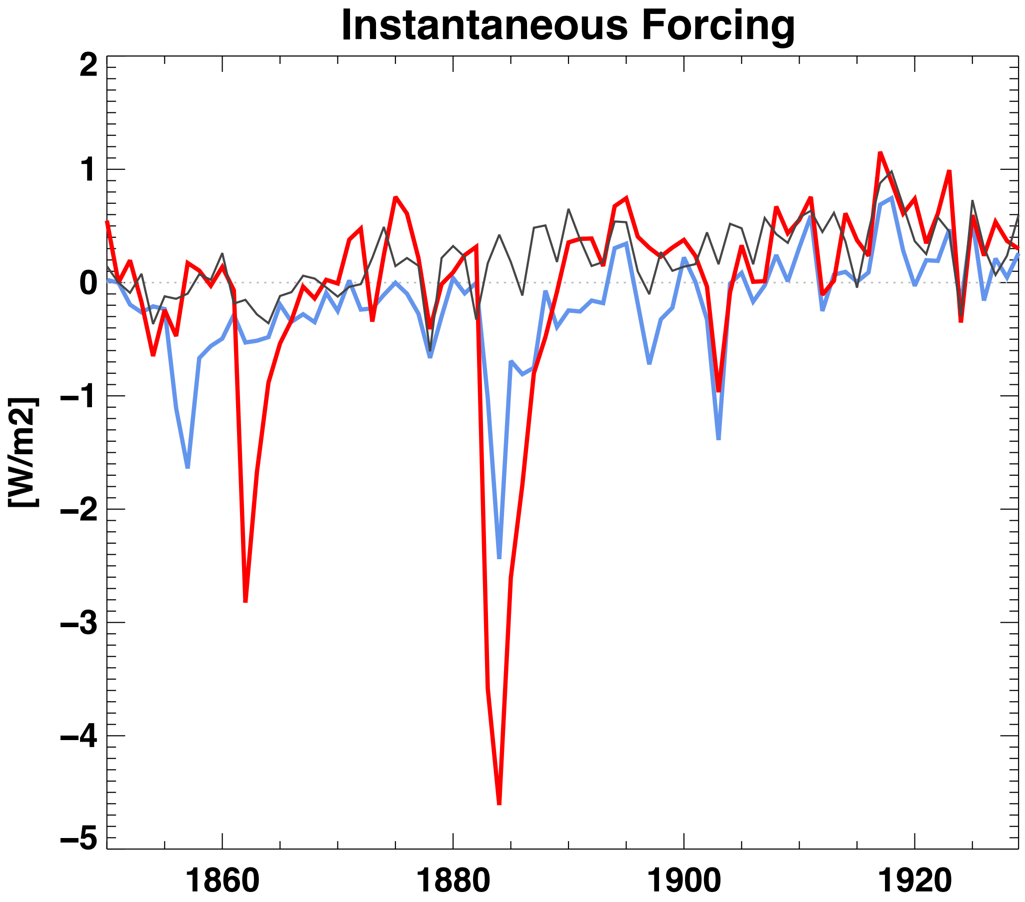


- no volc
- AOD volc
- MATRIX e.d.°

°e.d. emission driven

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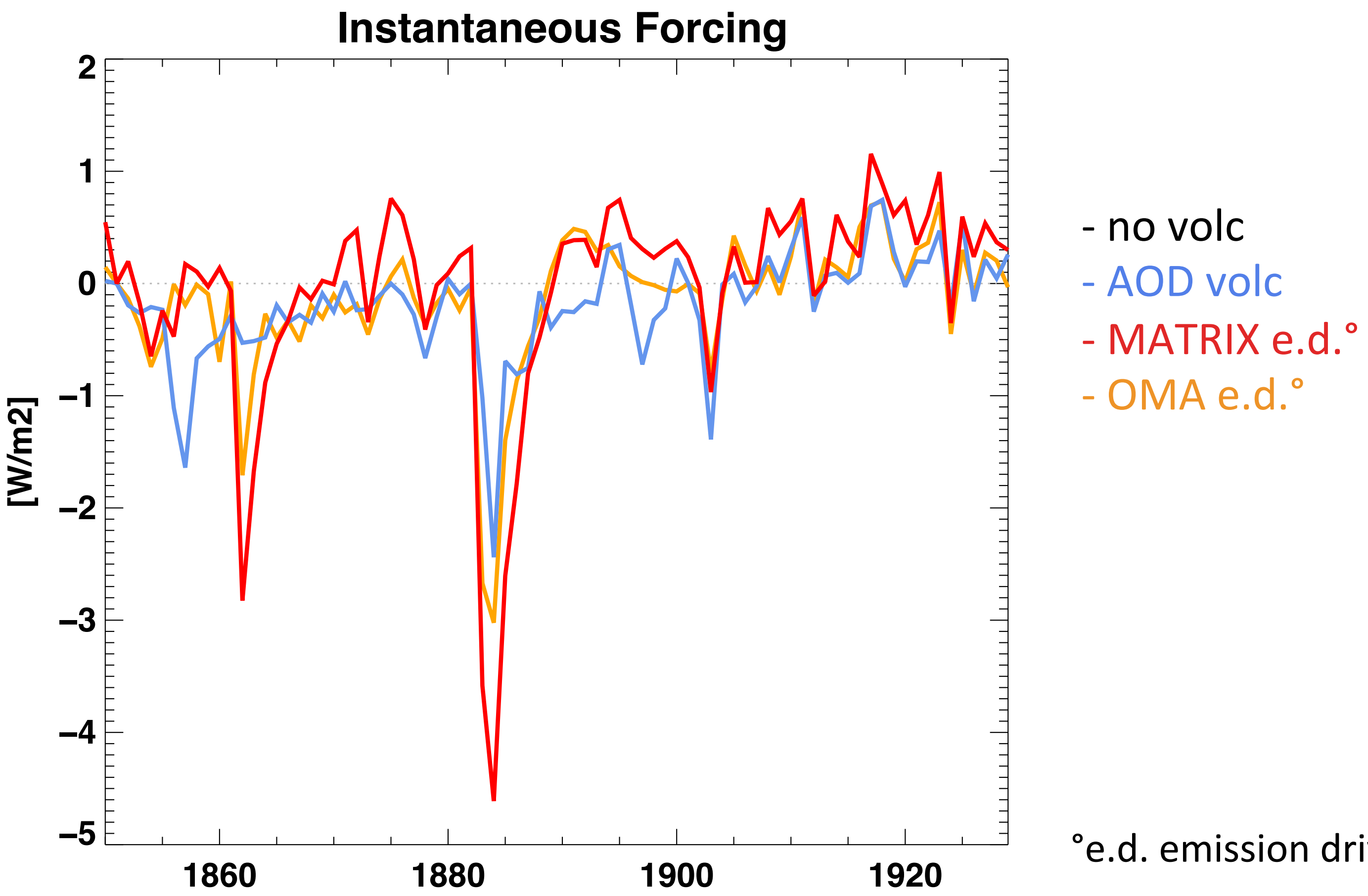
# TOA Forcing changes with different representations of volcanoes




°e.d. emission driven

# Forcing changes from different components

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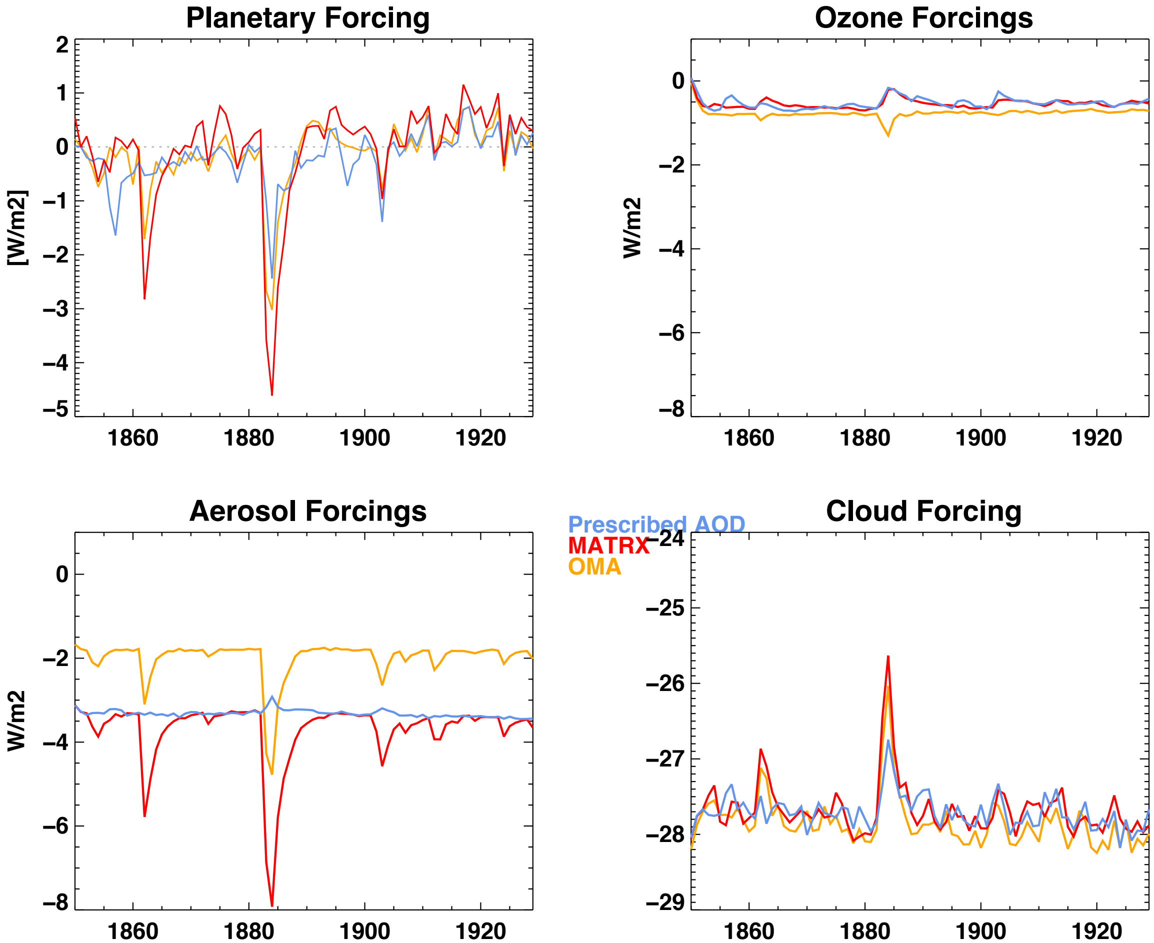


- no volc
- AOD volc
- MATRIX e.d.°
- OMA e.d.°

°e.d. emission driven

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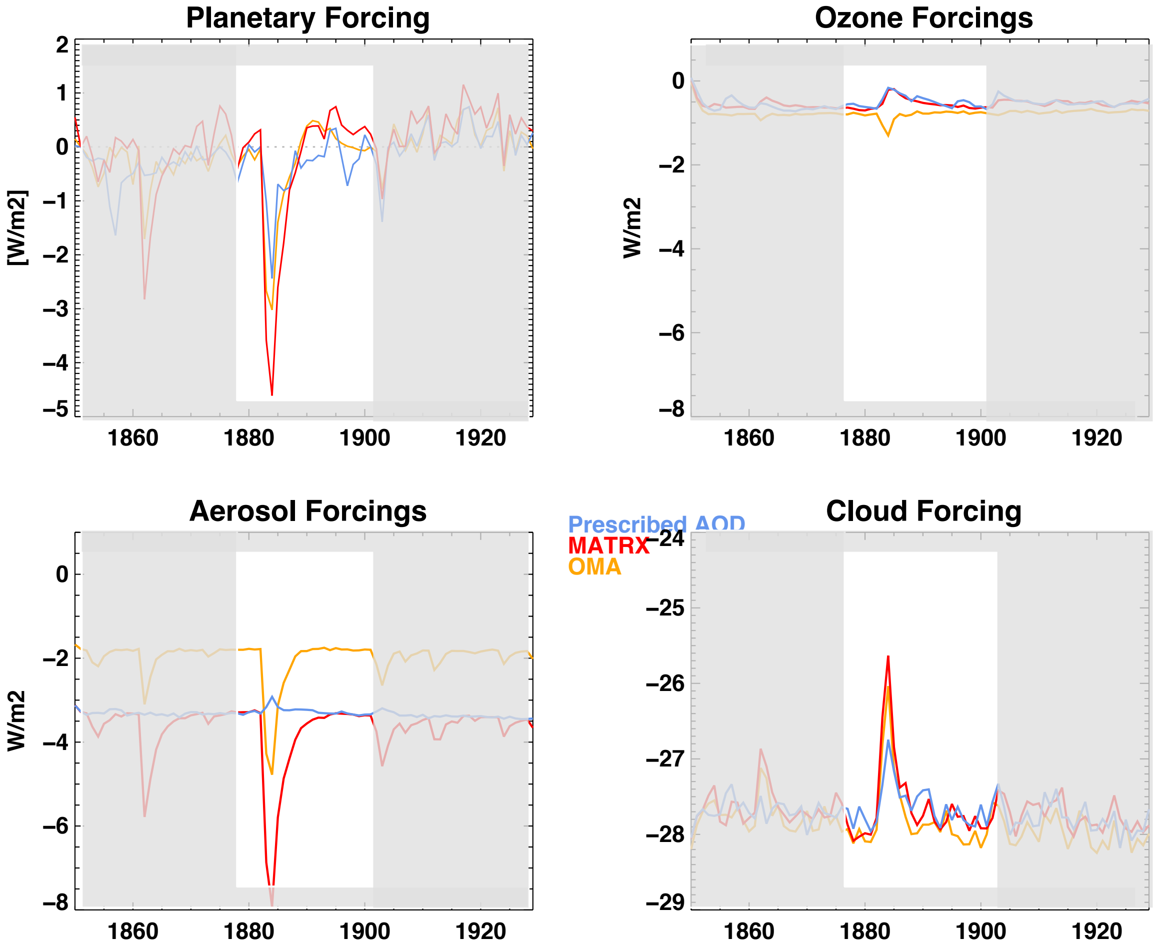
# Forcing changes from different components

1880 – 1900:

1883 Krakatoa

1886 Mount Tarawera




- no volc
- AOD volc
- MATRIX e.d.°
- OMA e.d.°

°e.d. emission driven

# Ozone Response

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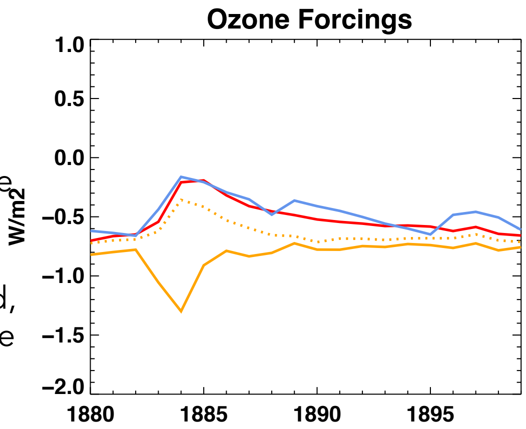
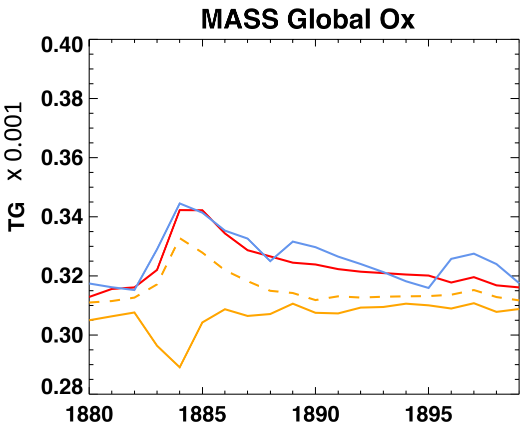
Expected:
Volc -> Nox, ClOx, BrOx, HOx chem. Leads to more O3 column load:

Depends on chlorine load, diff pre and post 1980 (Tie and Brasseur 1995)

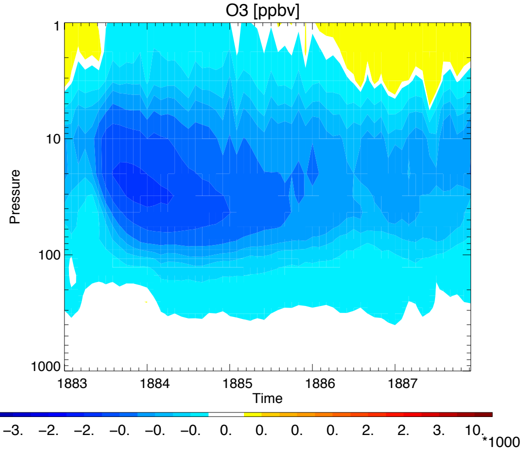


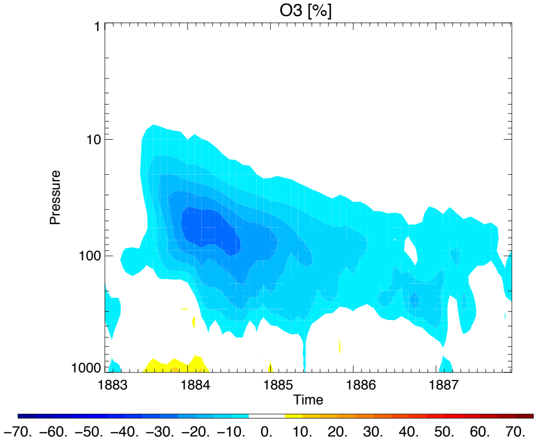




- no volc
- AOD volc
- MATRIX e.d.
- OMA e.d.

- - - OMA without aerosol
– photolysis coupling

OMA (no photolysis) - OMA




Reduction up to 30% of total Stratospheric Ozone around 100 – 50 hPa due to aerosol -photolysis effect.

# Forcing changes from different components

OMA - MATRIX

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- no volc
- AOD volc
- MATRIX e.d.
- OMA e.d.

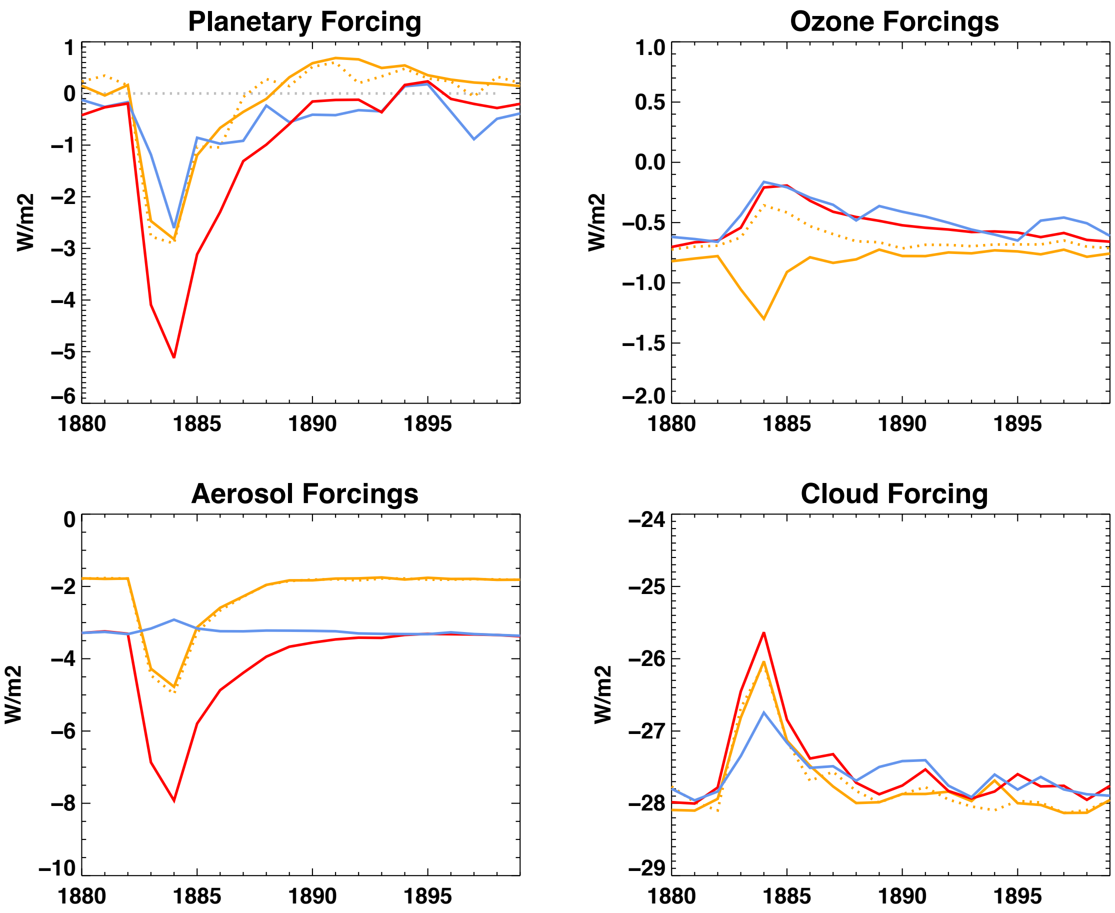
-2.3 W/m²

+1.1 W/m²

-1.5 W/m²

-1.6 W/m²

+0.35 W/m²



# $SO_2$ and $SO_4$ Response

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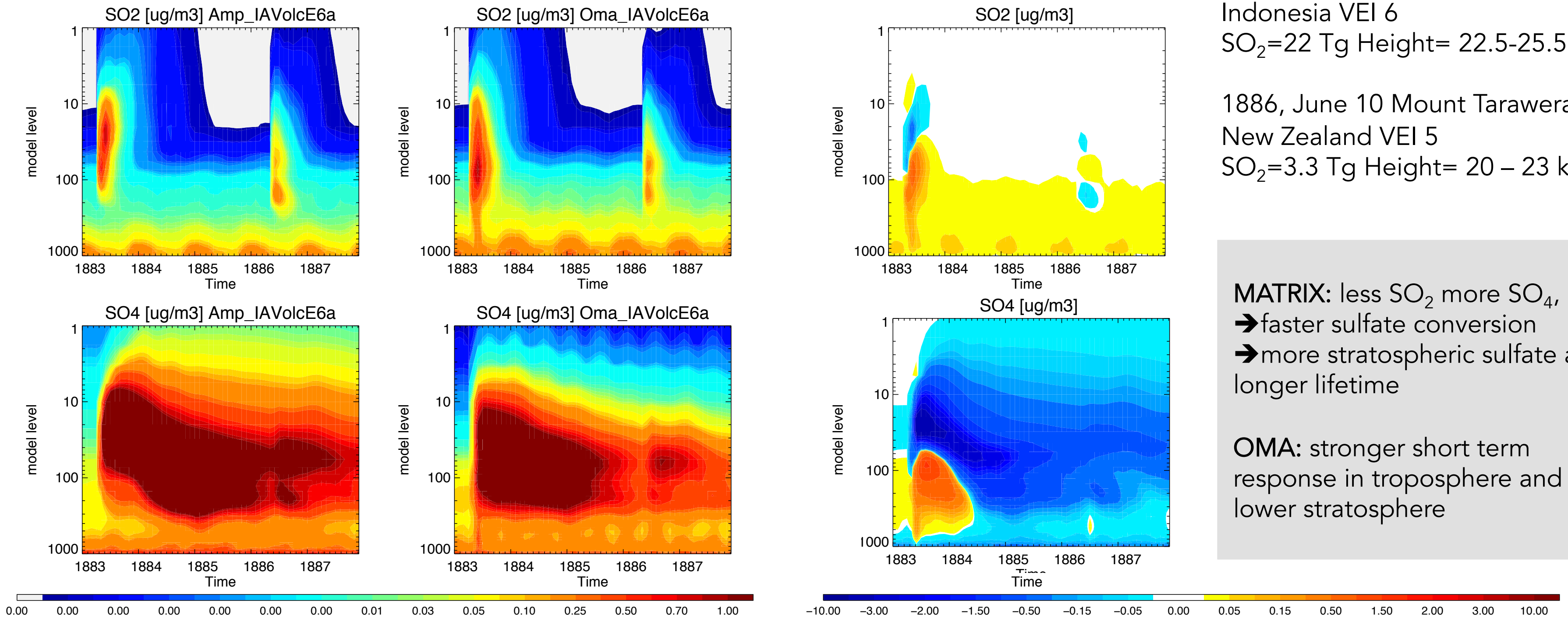
MATRIX | OMA | OMA - MATRIX




1883, May 20 Krakatoa
Indonesia VEI 6
$SO_2$=22 Tg Height= 22.5-25.5 km

1886, June 10 Mount Tarawera
New Zealand VEI 5
$SO_2$=3.3 Tg Height= 20 – 23 km

**MATRIX:** less $SO_2$ more $SO_4$,
➔faster sulfate conversion
➔more stratospheric sulfate and longer lifetime

**OMA:** stronger short term response in troposphere and lower stratosphere

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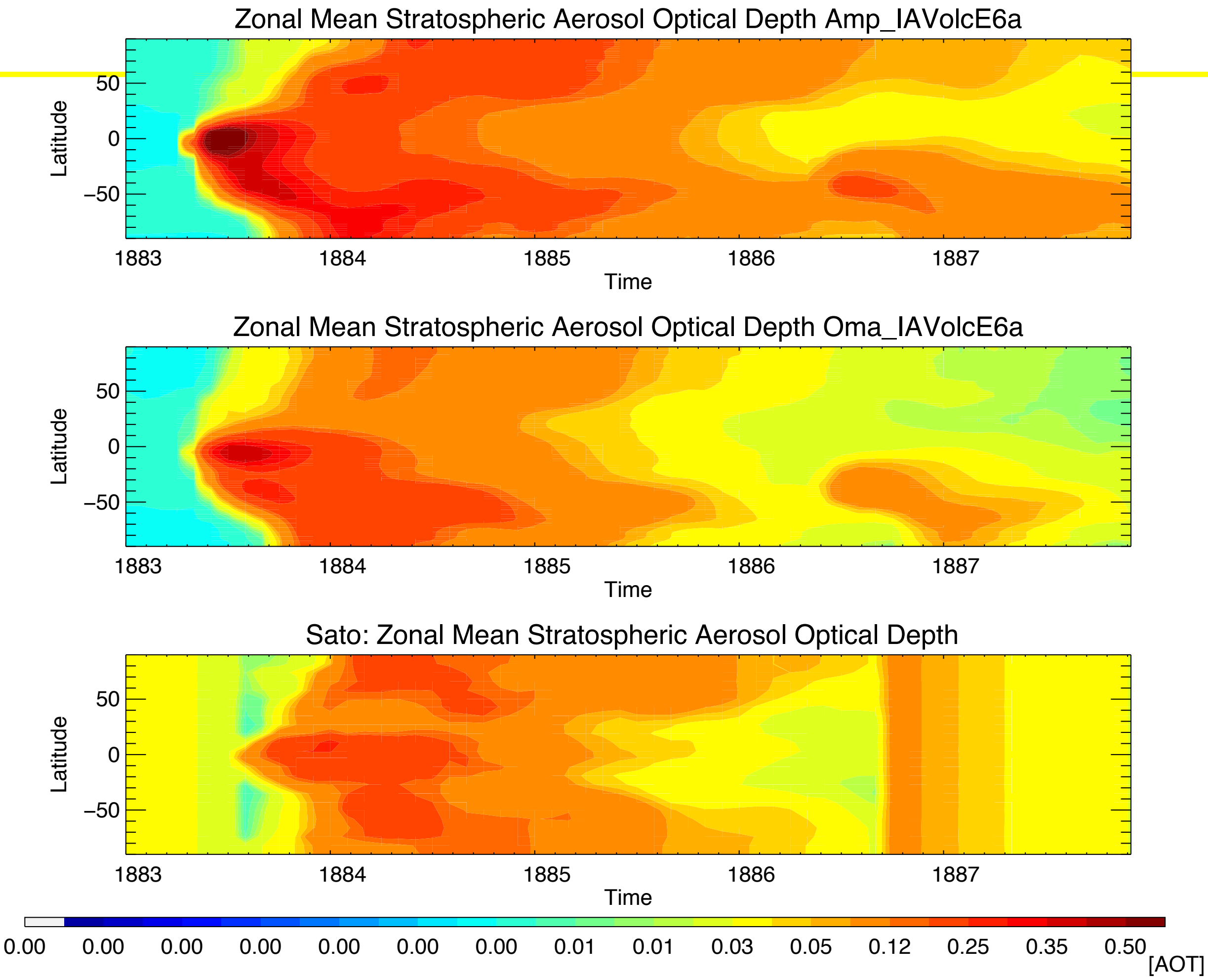


MATRIX

OMA

Sato AOD

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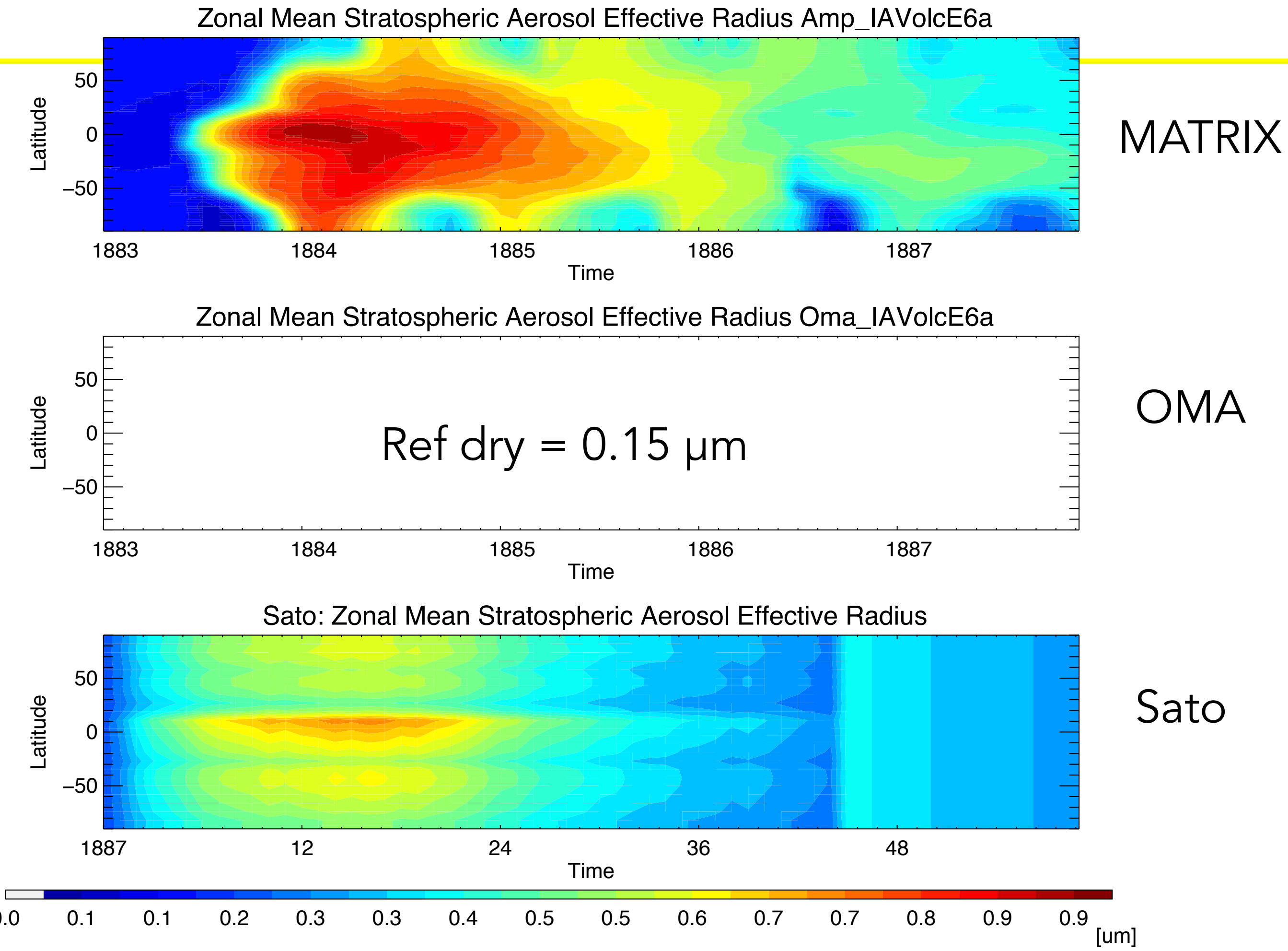

# Forcing changes from different components

OMA - MATRIX

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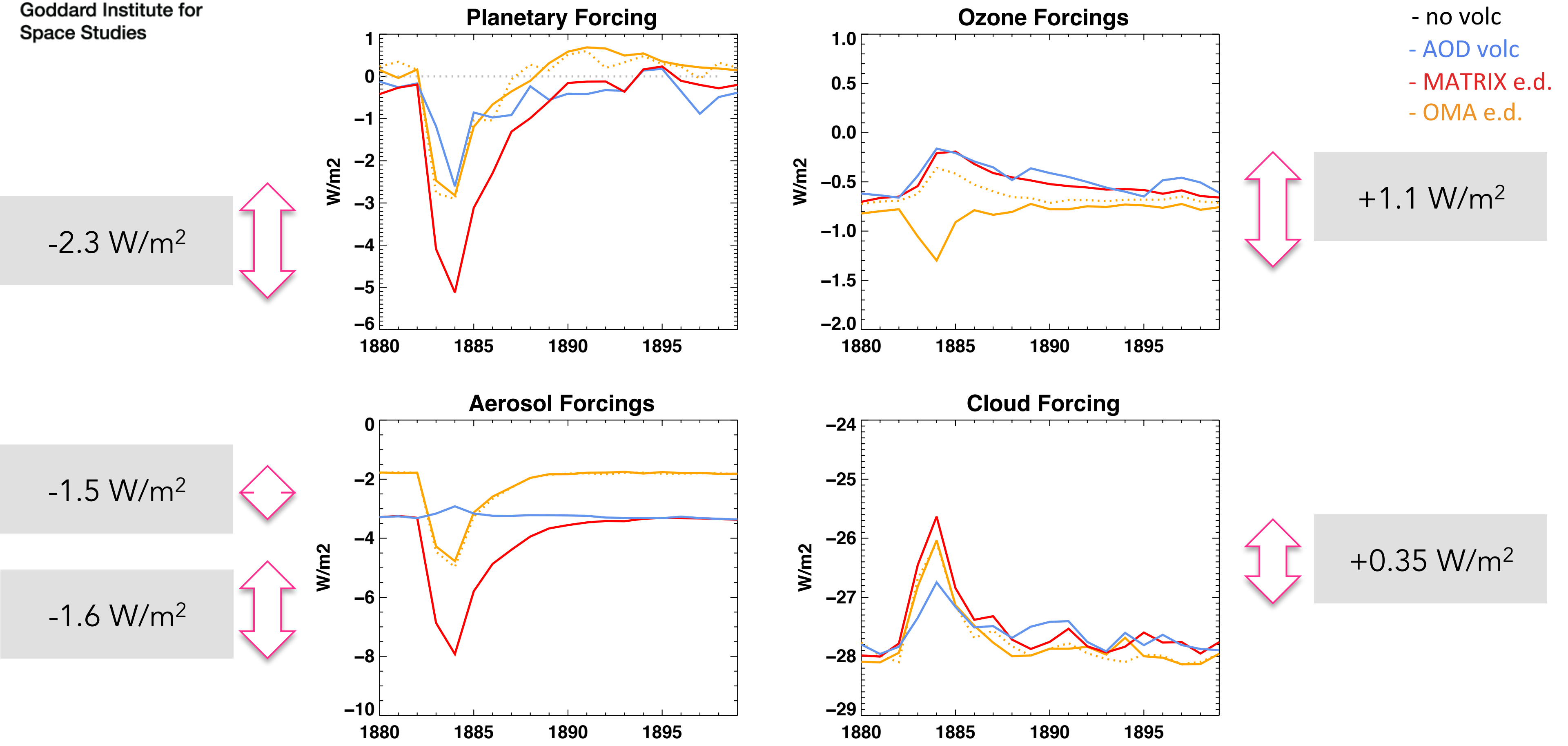

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# Pinatubo

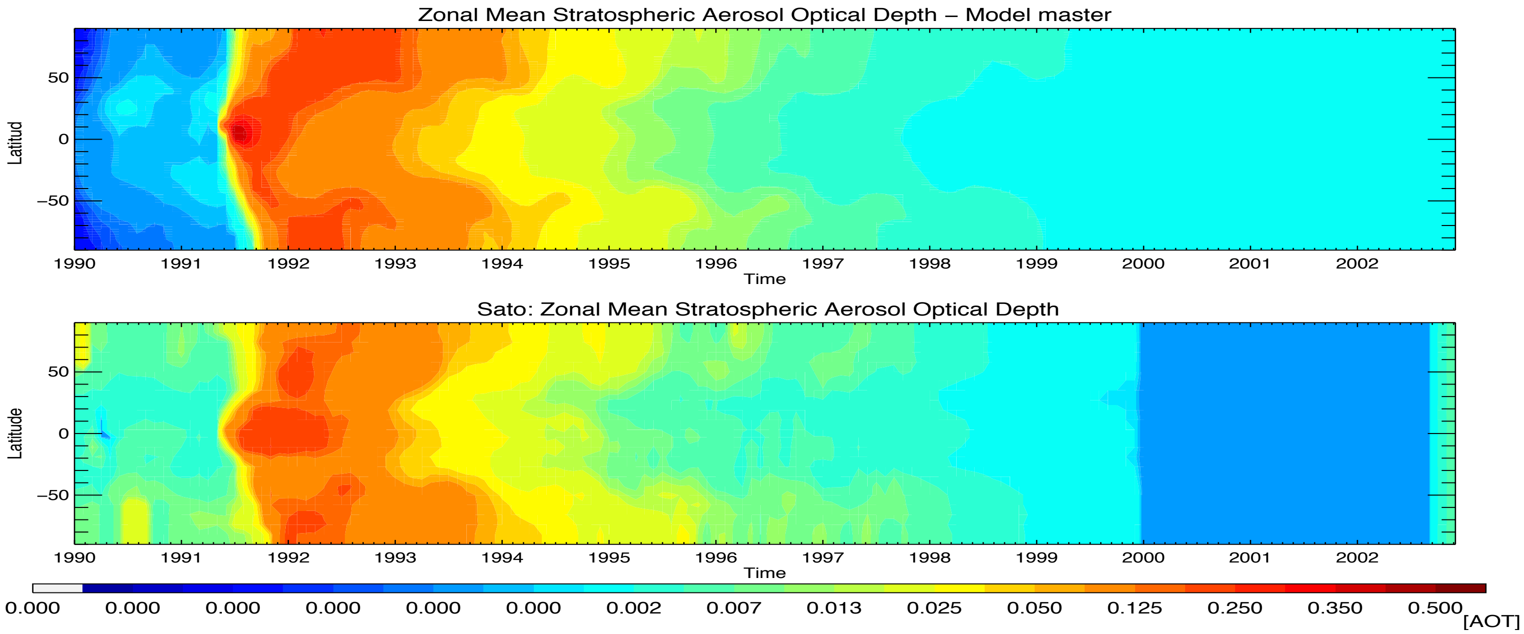
# Transient volcanic aerosol simulation

The formation and evolution of stratospheric volcanic aerosols, including their aerosol microphysical properties, can be interactively simulated

**Pinatubo AOD via GISS E2.1 + MATRIX**

MATRIX

Sato – Satellite based AOD



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# Summary and Outlook:

- Aerosol - photolysis feedbacks important for Ozone
- Aerosol microphysics lead to doubling of aerosol forcing in response to Krakatoa compared to CMIP5 AOD, and bulk model.

- Redo runs with updated CMIP6 AOD forcing, Luo et al.
- Evaluate model against Pinatubo and Post-Pinatubo conditions
- Run models with coupled ocean and study volcanic forcing climate feedbacks
- Run everything in high atmosphere version of the GISS model – 102 layers
- Participate in multi model studies

- All runs are immediately available to the community. Extra runs of interest can be setup.

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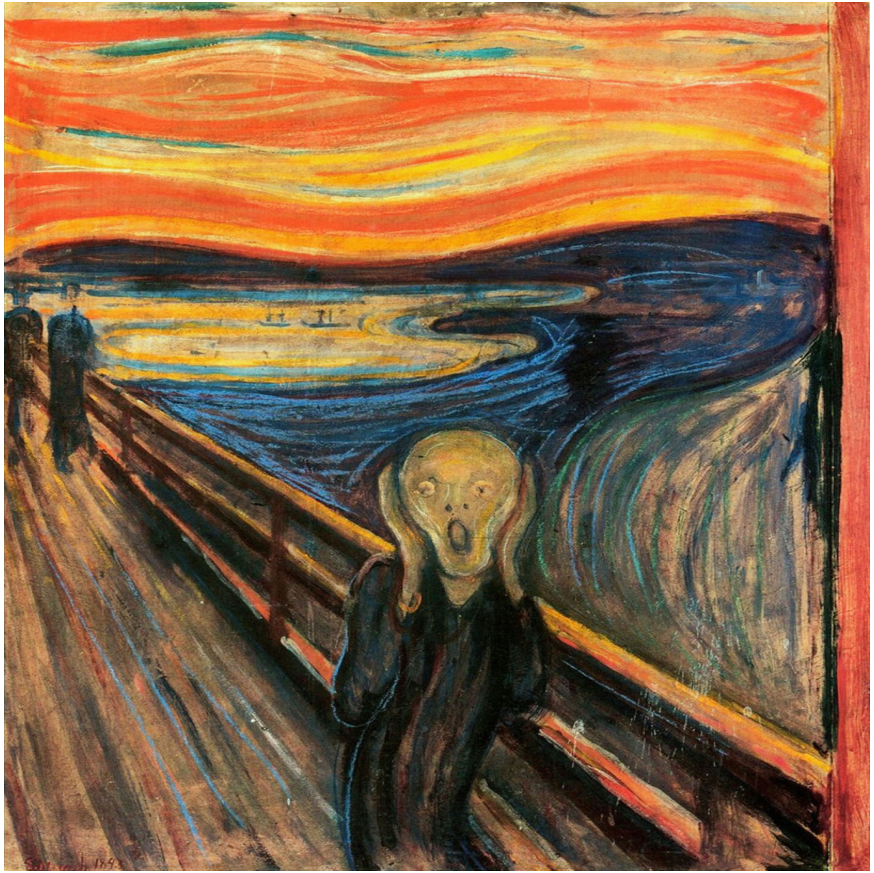
# Still lots of work to do



*"I was walking along the road with two friends – then the sun set – all at once the sky became blood red – and I felt overcome with melancholy. I stood still and leaned against the railing, dead tired – clouds like blood and tongues of fire hung above the blue-black fjord and the city. My friends went on, and I stood alone, trembling with anxiety. I felt a great, unending scream piercing through nature."*

Edvard Munch, “The Scream” (1883)