INSENSITIVITY OF GLOBAL TEMPERATURE RESPONSE TO THE MAGNITUDE OF VOLCANIC ERUPTIONS

*In EGU session "**Understanding volcano-climate impacts and the stratospheric aerosol layer**"*

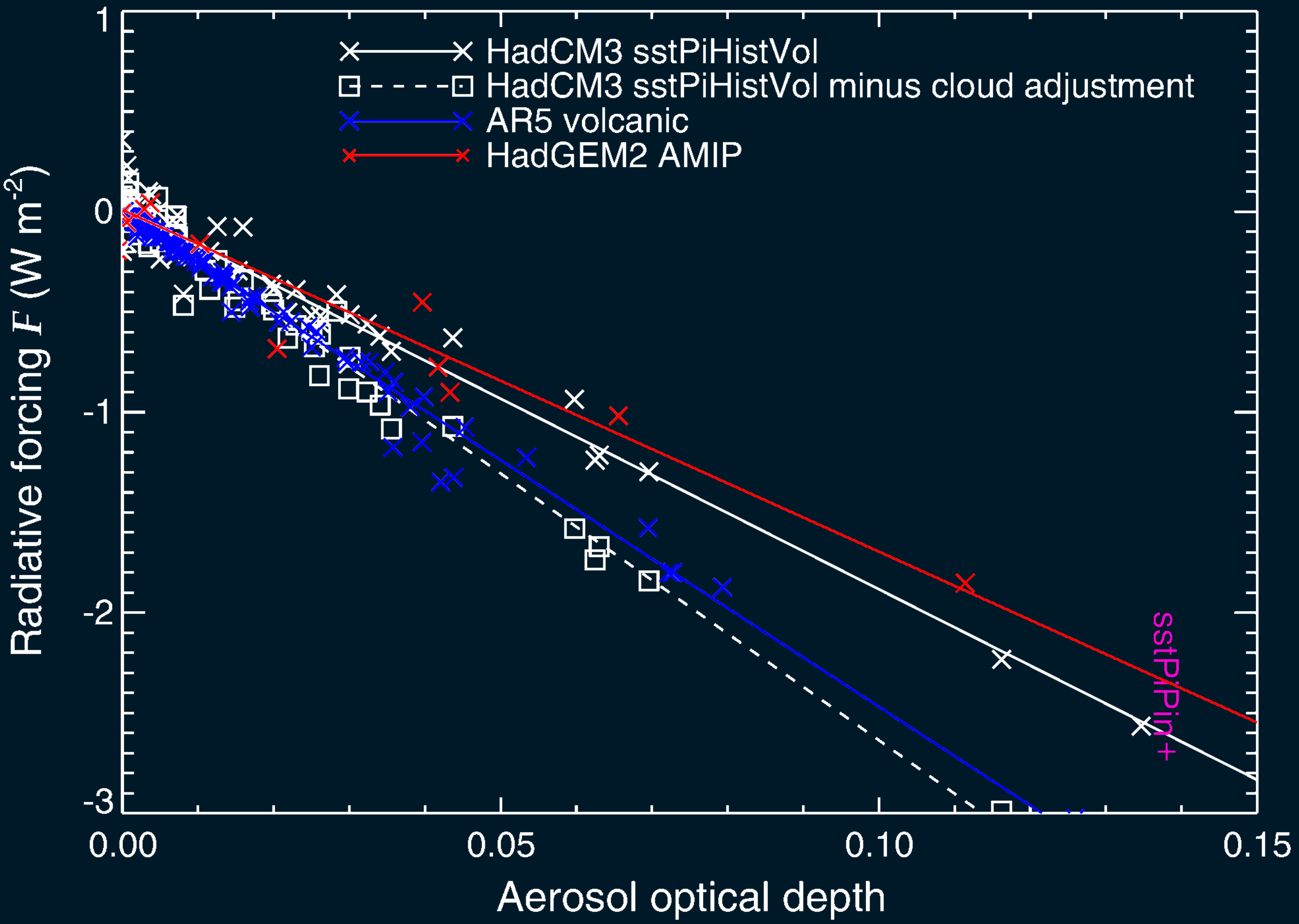
UiT The Arctic University of Norway

Sharing is encouraged

Speaker notes

My name is Eirik Enger, and I'm a PhD candidate at UiT the Arctic University of Norway. My work focus on how volcanoes affect climate, and today we will look at "Insensitivity of global temperature response to the magnitude of volcanic eruptions".

Figure from Gregory et al. (2016)



Speaker notes

This plot is from Gregory et al. (2016), and it's showing radiative forcing against aerosol optical depth. Two simulations were done by the authors using the HadCM3 climate model, one simulation by Andrews (2014) used the HadGEM2 climate model while the AR5 data points are from a time series from the Fifth Assessment report of the IPCC (intergovernmental panel on climate change).

This show a proportionality between annual mean values of AOD and radiative forcing, but only for AOD values up to 0.15, roughly equivalent to the peak of the 1991 Mt. Pinatubo eruption. Whether this property holds as one goes to much greater values, for example comparable to the Young Toba Tuff eruption 74ky ago, is of interest to us. Such a super volcano would have roughly one hundred times the AOD values as Mt. Pinatubo, but previous simulations indicate radiative forcing values that are only about twenty times that of Mt. Pinatubo. Is this because the linearity does not hold for this large values, or is it a shortcoming on the model's side?

Can we make a similar comparison of the peak values, for example in daily resolution (as opposed to averaging over the whole year before comparing)?

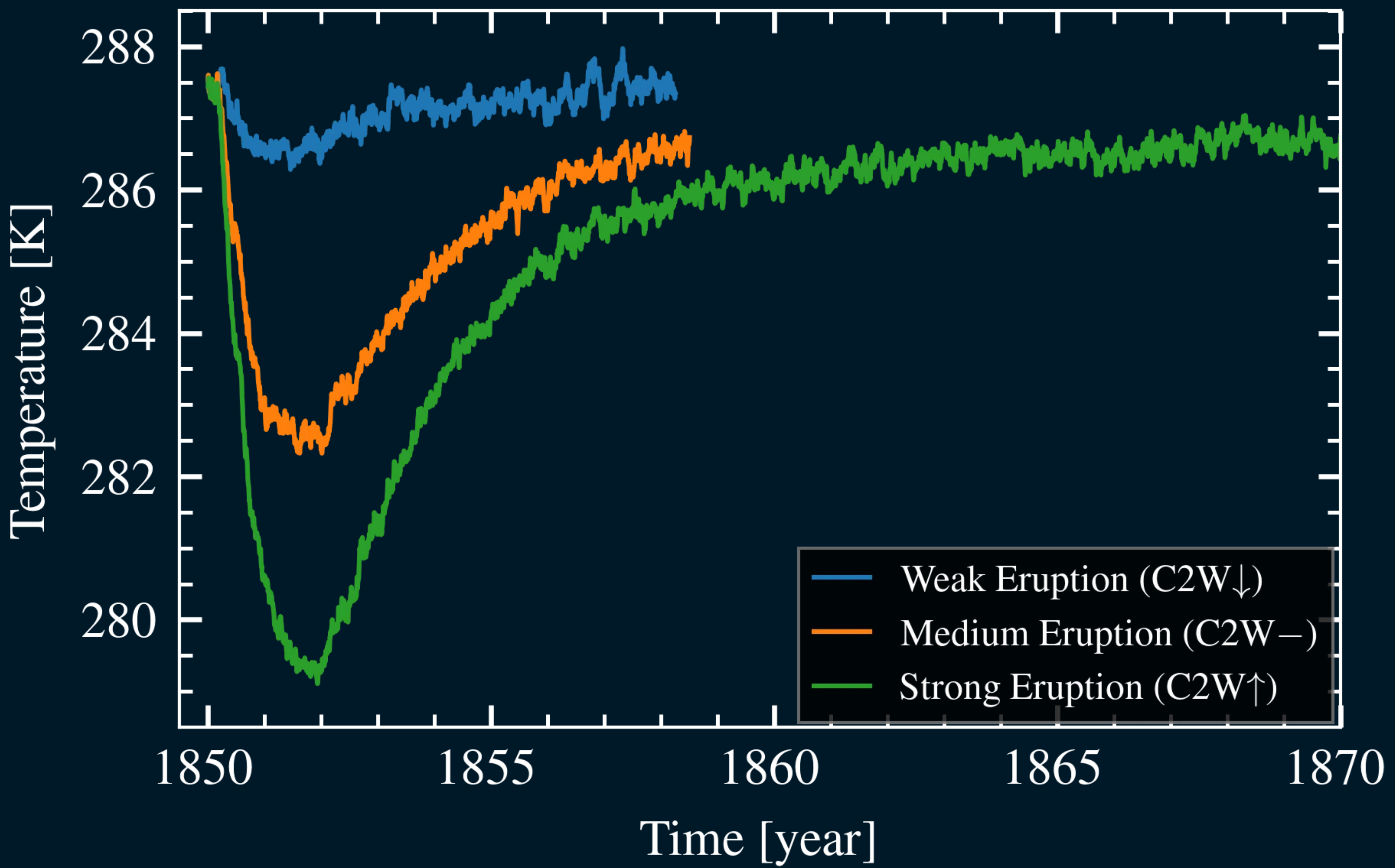
Plot from Gregory et al. (2016), figure 4.

SIMULATIONS

- CESM2 (Community Earth System Model, version 2.1.3)
- WACCM6 atmosphere
- Dynamic ocean and constant sea-surface conditions (AOGCM & AGCM)

Speaker notes

Simulations are carried out with the Community Earth System Model, version 2.1.3, and using the WACCM6 high-top atmosphere component, specifically in a nominal two degree resolution and the "middle atmosphere" component setting. Both simulations with a dynamic ocean (i.e., running the model as an AOGCM) and constant sea-surface conditions (i.e., a AGCM) have been done.


288
286
284
282
280
Temperature [K]
1850
1855
1860
1865
1870
Time [year]
Weak Eruption (C2W↓)
Medium Eruption (C2W−)
Strong Eruption (C2W↑)

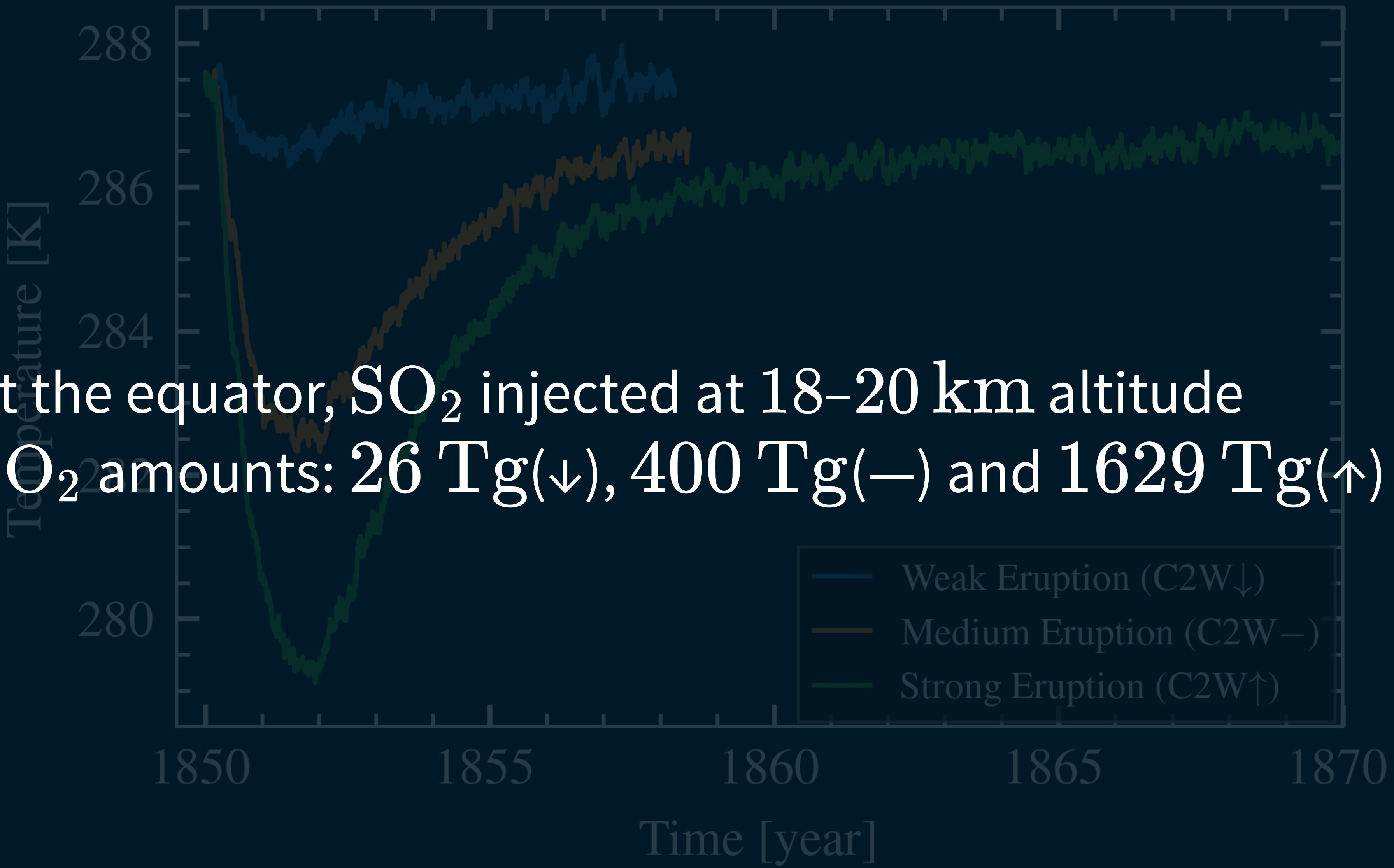
Speaker notes

We here see the three main simulations that have been run, of individual volcanic eruptions at the equator with three different magnitudes defined by inputting different amounts of SO2 into the atmosphere.

We are specifically looking at the temperature response from the three different eruption magnitudes, where the notation of a downward arrow, horizontal line and upward arrow will be used to indicate the different magnitudes of a weak, medium and strong eruption, respectively.

> *For similar plots of aerosol optical depth and radiative forcing, see the supplementary.*

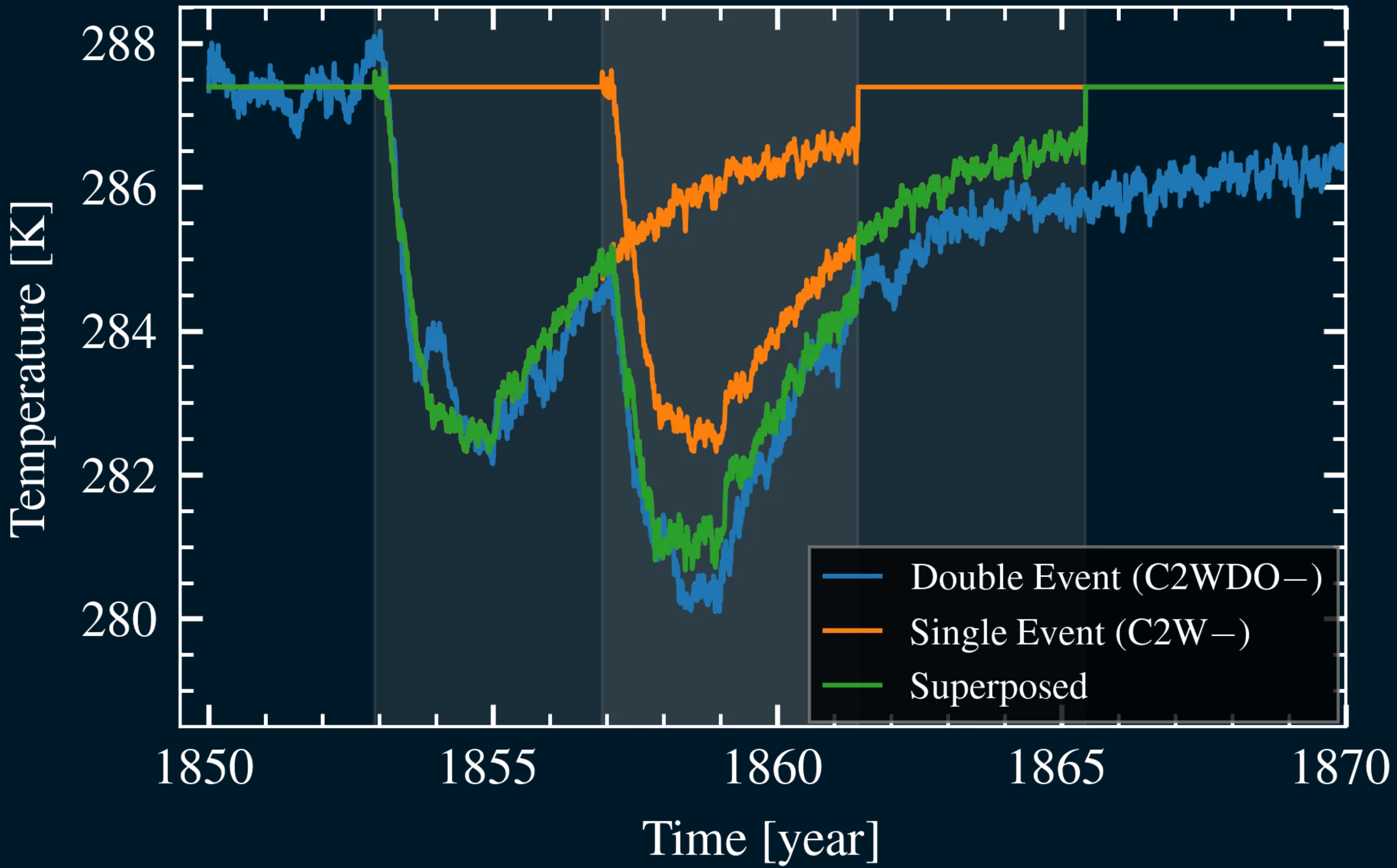
- At the equator, SO_2 injected at $18–20\ \mathrm{km}$ altitude
- SO_2 amounts: $26\ \mathrm{Tg}$(↓), $400\ \mathrm{Tg}$(—) and $1629\ \mathrm{Tg}$(↑)



Speaker notes

The volcanoes were created from an equatorial eruption, with the SO_2 injected between 18 and 20 km altitude. The amounts of injected SO_2 were 26 Tg (similar to Mt. Pinatubo), 400 Tg and 1629 Tg (same order of magnitude as young Toba Tuff ~74 ky ago) of SO_2 into the atmosphere between 18 and 20 km height.

Tg = tera gram = Mt = mega tons = 1e12 grams



288
286
284
282
280
Temperature [K]
1850
1855
1860
1865
1870
Time [year]
Double Event (C2WDO−)
Single Event (C2W−)
Superposed

Speaker notes

Let us say we take the medium-sized volcano and let it erupt twice with four years apart. This is what we see here in blue, with two copies of the medium-sized volcano shown in orange, aligned so that the eruption occurs at the same time (the shadings mark the two regions of the single events). Superposing the two orange individual eruption time series gives the green time series.

The volcano erupted first on 15. February 1853 and then on the same day in 1857.

From this initial simulation of overlapping pulses, the superposing of temperature response is relatively good, motivating further analysis of the linearity (or lack thereof) of the temperature response. From this alone one might expect that temperature does indeed respond linearly to *some representation* of the radiative forcing.

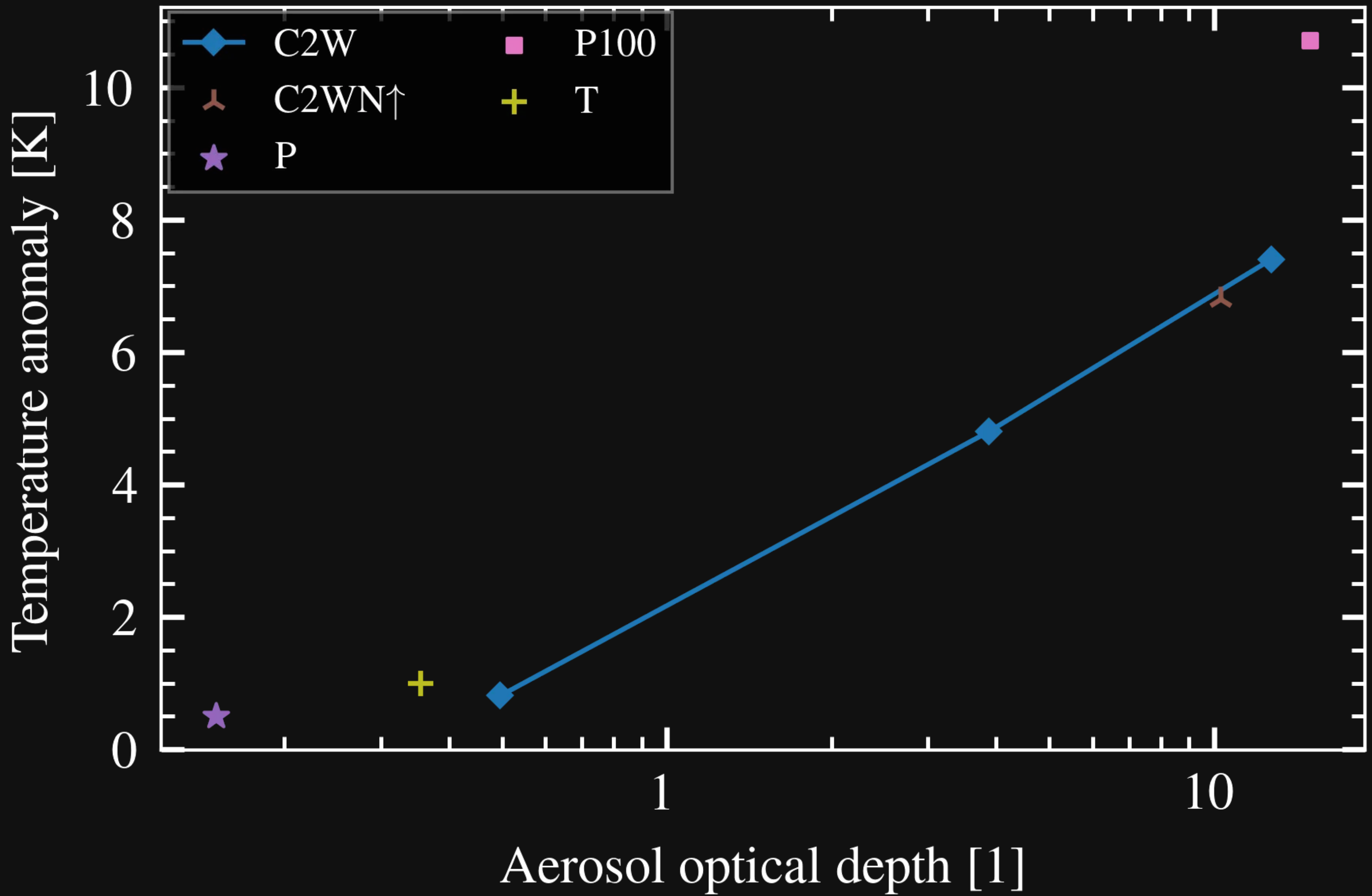
Legend description for the forthcoming figures.

Short Name	**Long Name**
C2W	CESM2(WACCM6)
C2WN↑	CESM2(WACCM6), high latitude, north
C2WDO—	CESM2(WACCM6), double and overlapping
P	Pinatubo
P100	Pinatubo times 100
T	Tambora

Speaker notes

We have run the CESM2 as an AOGCM and AGCM with constant SST conditions with made up volcanic eruptions of three different sizes:

- the smallest volcano is comparable to the Mt. Pinatubo eruption
- the largest volcano is comparable to the Young Toba Tuff eruption (i.e., roughly 100 times Mt. Pinatubo)
- the third sits in the middle between the two extremes.


C2W
P100
C2WN↑
T
P
10
8
6
4
2
0
1
10
Temperature anomaly [K]
Aerosol optical depth [1]

Speaker notes

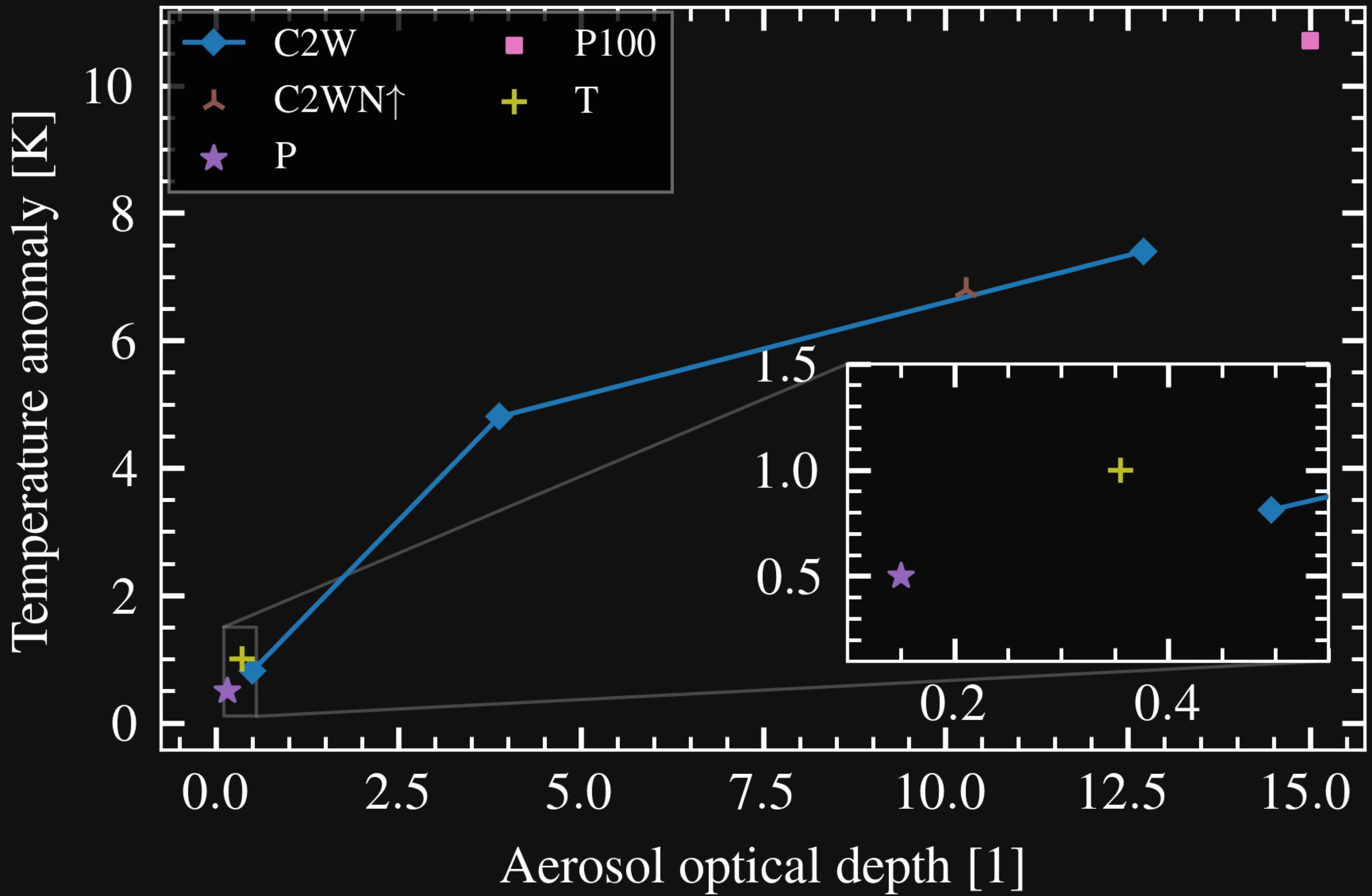
Aerosol optical depth versus temperature on semilog-x axis.

This plot is showing the peak values of the three individual CESM2(WACCM6) runs, the CESM2(WACCM6) run that is the same as the largest individual, but placed at 56 degree north, as well as data from the Mount Pinatubo eruption, Pinatubo times 100 simulation and Mount Tambora Eruption.

The C2W temperature data show close to logarithmic dependence on AOD, while data from other sources than CESM2 fall slightly off this, with especially the Pinatubo times 100 simulation having a large temperature response.

Short Name	Long Name
C2W	CESM2(WACCM6)
C2WN↑	CESM2(WACCM6), high latitude, north
P	Pinatubo
P100	Pinatubo times 100
T	Tambora

Pinatubo *AOD data from Sukhodolov et al. (2018), temperature from Hansen et al. (1999).* ***Pinatubo times 100*** *AOD and temperature data from Jones et al. (2005).* ***Tambora*** *AOD data from Toohey, M. and Sigl, M. (2017), temperature from Raible et al. (2016).*


C2W
P100
C2WN↑
T
P
10
8
6
4
2
0
Temperature anomaly [K]
1.5
1.0
0.5
0.2
0.4
0.0
2.5
5.0
7.5
10.0
12.5
15.0
Aerosol optical depth [1]

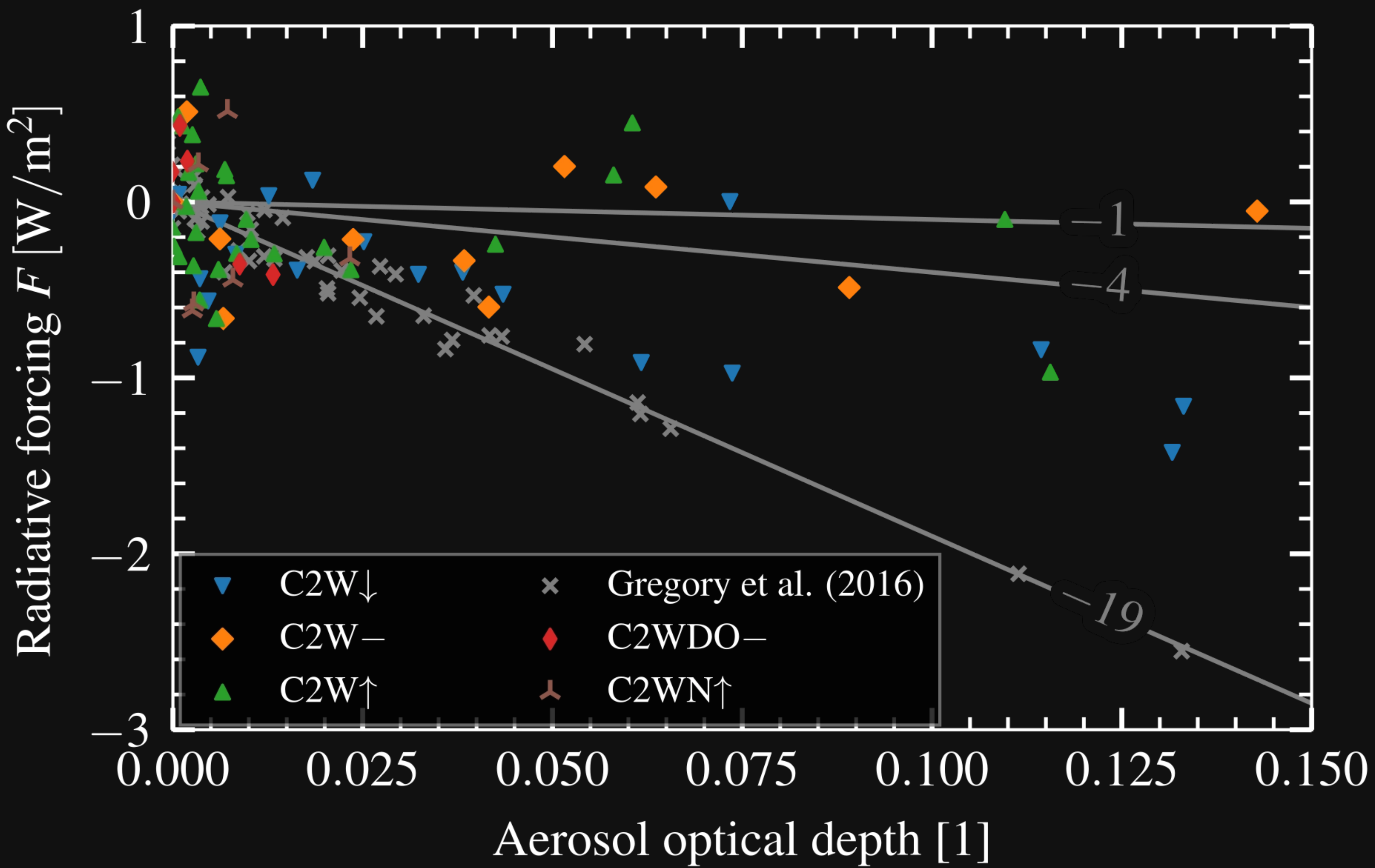
Speaker notes

Plotting this on linear axis makes it more clear that the biggest outlier is the Pinatubo times 100 simulation, while the Pinatubo and Tambora data lie close to the weakest CESM2 simulation.

A similar plot can be made with temperature anomaly against injected SO_2 (input field to the CESM2 simulations), but this is not shown here since it is close to a simple scaling of the x-axis.

Short Name	Long Name
C2W	CESM2(WACCM6)
C2WN↑	CESM2(WACCM6), high latitude, north
P	Pinatubo
P100	Pinatubo times 100
T	Tambora

***Pinatubo** AOD data from Sukhodolov et al. (2018), temperature from Hansen et al. (1999). **Pinatubo times 100** AOD and temperature data from Jones et al. (2005). **Tambora** AOD data from Toohey, M. and Sigl, M. (2017), temperature from Raible et al. (2016).*



Radiative forcing F [W/m^2]
Aerosol optical depth [1]
1
0
−1
−2
−3
0.000
0.025
0.050
0.075
0.100
0.125
0.150
−1
−4
−19
C2W↓
C2W−
C2W↑
Gregory et al. (2016)
C2WDO−
C2WN↑

Speaker notes

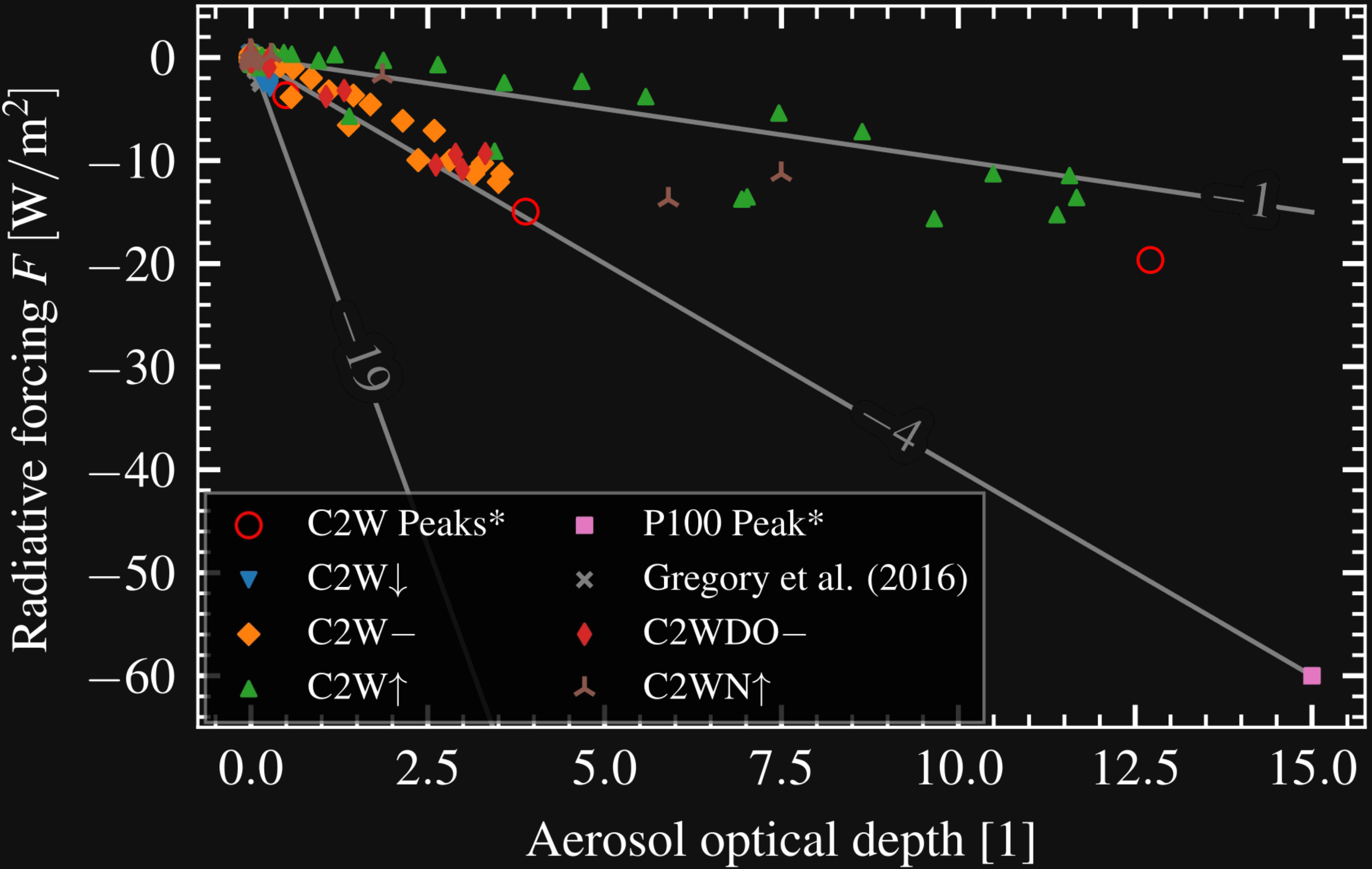
Similar plot to the one shown from Gregory et al. (2016), of annual mean radiative forcing against aerosol optical depth.

All C2W-labels are simulations with the CESM2 climate model and WACCM6 in the middle atmosphere configuration. Blue, downward pointing triangles indicate annual means from the simulation with the weakest eruption (similar to Mt. Pinatubo); orange diamonds indicate the medium-sized eruption simulation and green upward pointing triangles indicate means from the strongest eruption simulation.

For comparison, the HadCM3 data points from the figure by Gregory et al. (2016) is also shown in grey "x"-es, as well as annual means from the double and overlapping simulation and one simulation with the strongest volcano placed in the Northern Hemisphere (228.7 E, 56.7 N; Canadian west coast).

There is still substantial noise in the C2W data, but no years across the whole ensemble fall below the "-19" gradient line for AOD values of only 0.02 and higher.

Short Name	**Long Name**
C2W↓	CESM2(WACCM6), weak eruption
C2W—	CESM2(WACCM6), medium eruption
C2W↑	CESM2(WACCM6), strong eruption
Gregory et al. (2016)	Values from HadCM3 sstPiHistvol by Gregory et al. (2016)
C2WDO—	CESM2(WACCM6), double and overlapping, medium eruption
C2WN↑	CESM2(WACCM6), high latitude, north, strong eruption


Radiative forcing F [W/m^2]
0
−10
−20
−30
−40
−50
−60
0.0
2.5
5.0
7.5
10.0
12.5
15.0
Aerosol optical depth [1]
−1
−4
−19
C2W Peaks*
C2W↓
C2W−
C2W↑
P100 Peak*
Gregory et al. (2016)
C2WDO−
C2WN↑

Speaker notes

If we then zoom out to include all data points, it is evident that the two largest eruption simulations make up a way less steep gradient than the HadCM3 data does.

The two largest (green and orange) line up quite well, but on different slopes; the medium with a steeper gradient than the strong, but where the strong have some points among the medium eruption (along the -4 gradient line) stemming from the initial rise of the eruption. The decaying part last longer, thus more points come from the decay, and they line up close to on a gradient of -1.

The points from double and overlapping simulation, shown by the red thin diamonds, places themselves among the points coming from the medium-sized individual simulation, as expected. The brown triplet shows an individual eruption simulation using the strongest eruption, but placed at 56 degrees north. The response is not as strong as for the equatorial eruption, but still the annual means fall in line with the path draw by the green triangles.

The peak values from the three main equatorial simulations are shown as the red circles. The peak values from the Pinatubo times 100 simulation is shown with a pink square. This simulation incidently falls on the same gradient line as the medium-sized eruption. The Pinatubo times 100 is from Jones et al. (2005). While the magnitude of the radiative forcing obtained from this simulation of a super-eruption seems to be too small when compared to the "-19" gradient line, compared to the simulations done here with CESM2, its radiative forcing magnitude seems too big.

Filling out this radiative forcing-AOD space may give a clearer answer to whether there is a linear relation to be found, and possibly its range of validity. And even if there is no linear relationship, the loop that is drawn out by the strongest eruption may hint to there being different dynamical processes at play during the initial rise and the slow decay to equilibrium when comparing radiative forcing and aerosol optical depth.

Short Name	**Long Name**
C2W Peaks*	CESM2(WACCM6), peak values
C2W↓	CESM2(WACCM6), weak eruption

Short Name	Long Name
C2W—	CESM2(WACCM6), medium eruption
C2W↑	CESM2(WACCM6), strong eruption
P100 Peak*	Pinatubo times 100, peak value
Gregory et al. (2016)	Values from HadCM3 sstPiHistvol by Gregory et al. (2016)
C2WDO—	CESM2(WACCM6), double and overlapping, medium eruption
C2WN↑	CESM2(WACCM6), high latitude, north, strong eruption

Pinatubo times 100 *AOD and temperature data from Jones et al. (2005).*

LINKS

FIXME: for now, I'm using an old slide as an example. Update the links!

The slides can be viewed both with (html, pdf) and without (html, pdf) speaker notes.

Link and QR code to the conference abstract information:

REFERENCES

- Gregory, J. M., T. Andrews, P. Good, T. Mauritsen, and P. M. Forster. 2016. “Small Global-Mean Cooling Due to Volcanic Radiative Forcing.” *Climate Dynamics* 47 (12): 3979–91. https://doi.org/10.1007/s00382-016-3055-1.
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- Sukhodolov, T., J.-X. Sheng, A. Feinberg, B.-P. Luo, T. Peter, L. Revell, A. Stenke, D. K. Weisenstein, and E. Rozanov. 2018. “Stratospheric Aerosol Evolution After Pinatubo Simulated with a Coupled Size-Resolved Aerosol–Chemistry–Climate Model, SOCOL-AERv1.0.” *Geoscientific Model Development* 11 (7): 2633–47. https://doi.org/10.5194/gmd-11-2633-2018.
- Toohey, M., and M. Sigl. 2017. “Volcanic Stratospheric Sulfur Injections and Aerosol Optical Depth from 500 BCE to 1900 CE.” *Earth System Science Data* 9 (2): 809–31. https://doi.org/10.5194/essd-9-809-2017.