Climate sensitivity estimates from volcanoes in the CESM2

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Introduction

In order to estimate the global temperature response and climate sensitivity to radiative forcing, volcanic activity is an important testbed. Estimates are to be made using a non-parametric approach, contrary to most previous attempts (e.g. [1, 2]). For this, datasets with high resolution and eruptions of well known physical properties and frequency are needed, and we therefore run simulations with custom made synthetic volcanic data in the Community Earth System model, version 2 (CESM2).

Creating Volcanoes

We are running CESM2.1.3 with the WACCM6 atmosphere model with middle atmosphere chemistry. Evolution of stratospheric aerosols are calculated from SO2 emissions obtained from emissions files, show in Figure 1. Figure 2 show a simple diagram of how new forcing files are created and run in CESM2. The process of generating working forcing files is carried out fully by the python project volcano-cooking, which can be found on GitHub using the QR code in the heading.

Figure 1: Emissions file used in historical runs of CESM2 to simulate volcanic eruptions between 1850 and 2016. Each bar represent the total emission for a given day, with emissions lasting six hours per day.

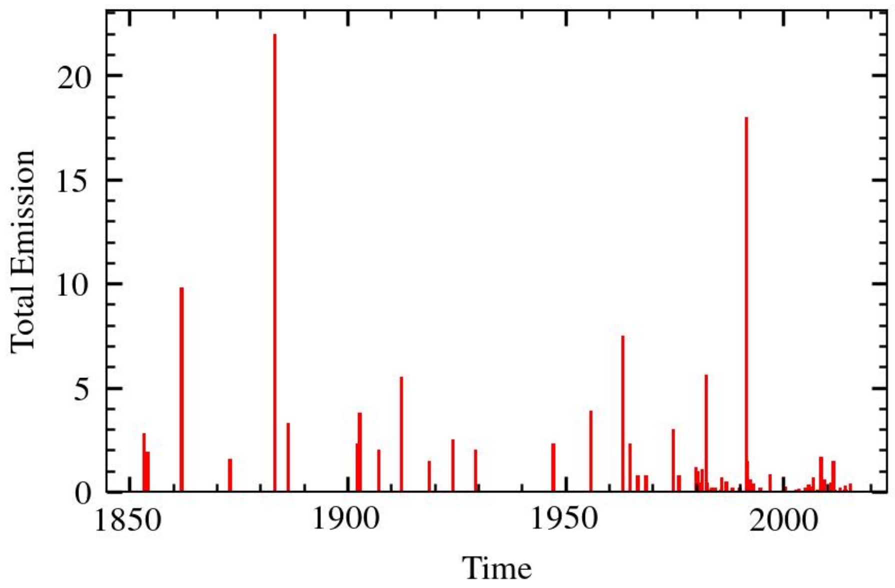
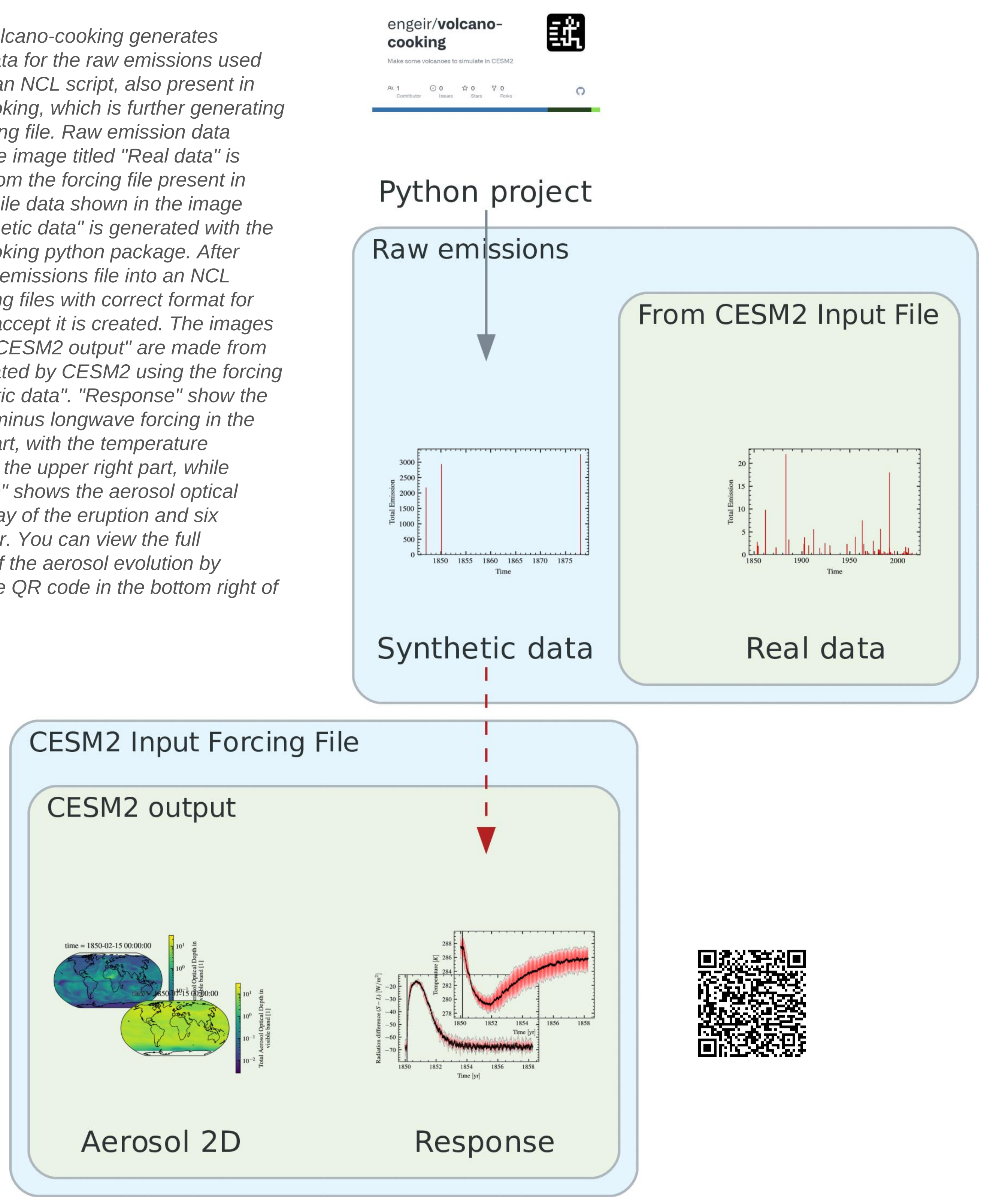


Figure 2: volcano-cooking generates synthetic data for the raw emissions used as input to an NCL script, also present in volcano-cooking, which is further generating the full forcing file. Raw emission data shown in the image titled "Real data" is extracted from the forcing file present in CESM2, while data shown in the image titled "Synthetic data" is generated with the volcano-cooking python package. After feeding the emissions file into an NCL script, forcing files with correct format for CESM2 to accept it is created. The images in the box "CESM2 output" are made from data generated by CESM2 using the forcing file "Synthetic data". "Response" show the shortwave minus longwave forcing in the lower left part, with the temperature response in the upper right part, while "Aerosol 2D" shows the aerosol optical depth the day of the eruption and six months after. You can view the full animation of the aerosol evolution by following the QR code in the bottom right of the figure!



Results

The shape of the temperature response to eruptions of different magnitude is not the same. Temperature peaks later when the climate system is forced with a larger eruption compared to the case of forcing with a smaller eruption.

In both cases, the temperature has its strongest response after one to two years. Also, even after eight years the temperature has not yet fully recovered back to equilibrium.

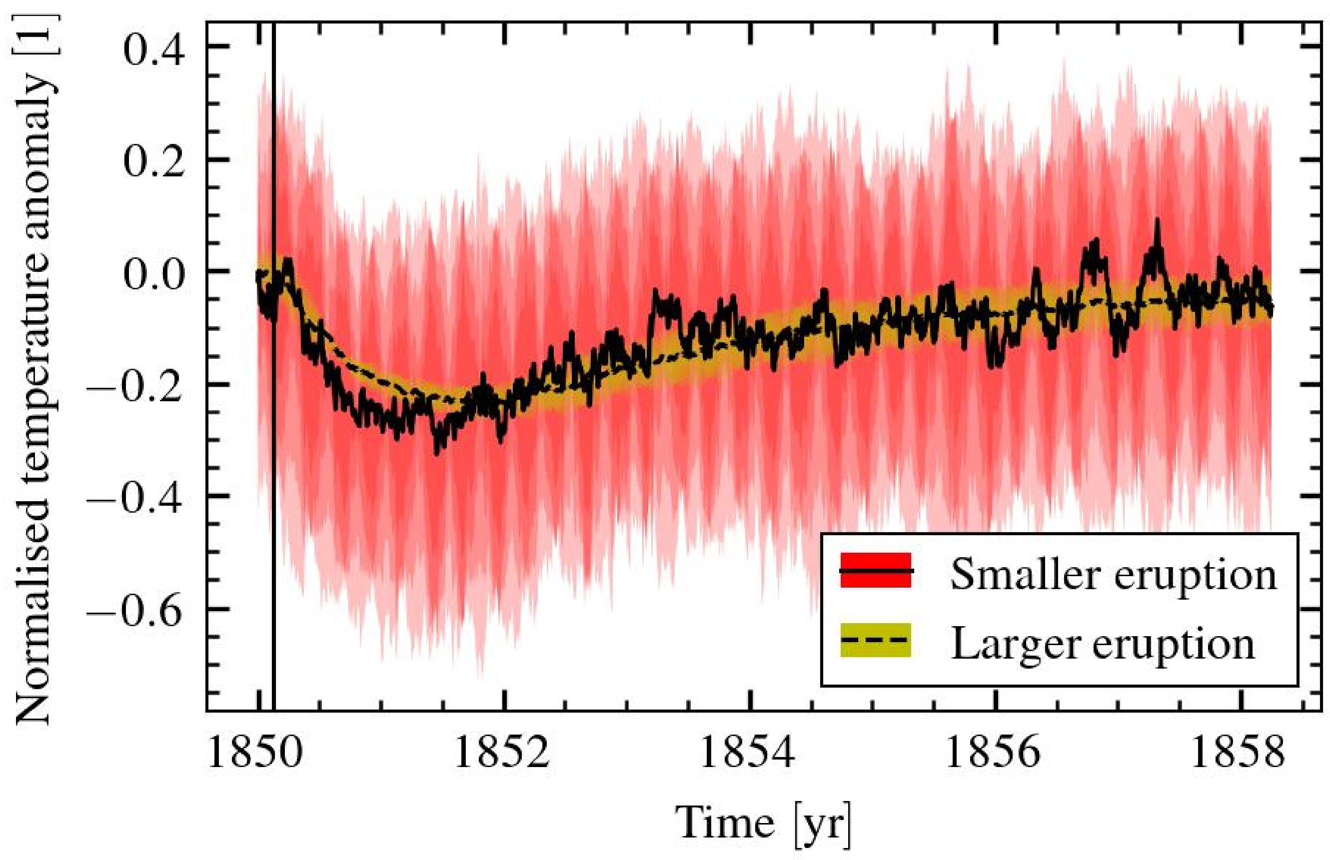


Figure 3: Comparison between the waveform of the temperature response from the smaller and the larger volcanic eruption. The black lines are medians from ensembles of four simulations, while the shading cover the 5th to the 95th percentile. All four simulations in the ensembles are identical, except from a three month delay of the eruption, placing the eruptions in the ensemble in all four seasons. This seasonal variability is also what cases the wide percentiles. The vertical line indicate the timing of the eruption.

Mathematical framework

The filtered Poisson process (FPP) is the phenomenological model used for the temperature response to volcanoes, shown below. It is a convolution equation, where forcing is convolved with a general shape representing a response function.

$$T_K(t) = [\phi * f_K]\left(\frac{t}{\tau_\mathrm{d}}\right)$$

Knowing the forcing and temperature signals, we get to the response by deconvolving, provided we feed the algorithm with an initial guess of the response function [3, 4].

$$\phi^{(n+1)} = \phi^{(n)} \frac{(T_K - \langle T_K \rangle) * \hat{f}_K + b}{\phi^{(n)} * f_K * \hat{f}_K + b}$$

Future work and use cases

The deconvolution algorithm introduces the non-parametric approach to estimating the temperature response. This does not need volcanic eruptions that are isolated in time, although linearity is assumed. Thus, volcanoes that overlap and cluster together in time are no problem, allowing us to gain insight into whether they simply superpose or not.

Studies argue that regional patterns may be important in relation to the outward radiation [5], with some studies looking more closely at the surface temperature patterns [6]. A different take to this may be to rather place volcanic eruptions in some key locations and compare the temperature responses obtained.

References

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