Vasco modelling volcanic risk

Initial thoughts

“[Lara] She’s interested in volcanoes that could cause 100m deaths. She thinks there’s a 1-in-5 chance of this in the next century.”

- This seems completely off.
- Lara said the probability this century of a volcanic eruption with VEI of 7 or 8 is 1/6, and VEI 8 is 1 or 2 OOMs less likely than VEI 7, so the above would require around 100 M deaths conditional on an eruption of VEI of 7.
- The 1815 eruption of Mount Tambora was VEI, but caused 3 OOMs less deaths than Lara’s 100 M. “The total figure of 71 000 makes the Tambora eruption the deadliest known in history. In the database of volcanic disasters compiled by Tanguy et al. (1998), which begins with Laki in 1783 and ends with Montserrat 1997, Tambora accounts for nearly 30% of the total number of deaths”.
- 71 k is probably an underestimate because it neglects global impacts. Maybe the total impact was 3 times the direct one, i.e. 213 k deaths, although it is hard to tell due to confounders (the Napoleonic Wars ended just before the eruption in 1815, so they could explain starvation in Europe).
- Population was 1.05 G in 1815, so I guess the death rate was roughly 0.02 % (= 213*10^3/(1.05*10^9)), which is similar to the current death rate from protein-energy malnutrition in the worst off countries (search for “Central African Republic” in this Doc).
- We have also had 200 years of economic growth since then, so we are now more resilient (agriculture is now a much smaller fraction of the economy), and the death rate for the same eruption would be lower.

Further work: Extinction risk from volcanic eruptions seems super small

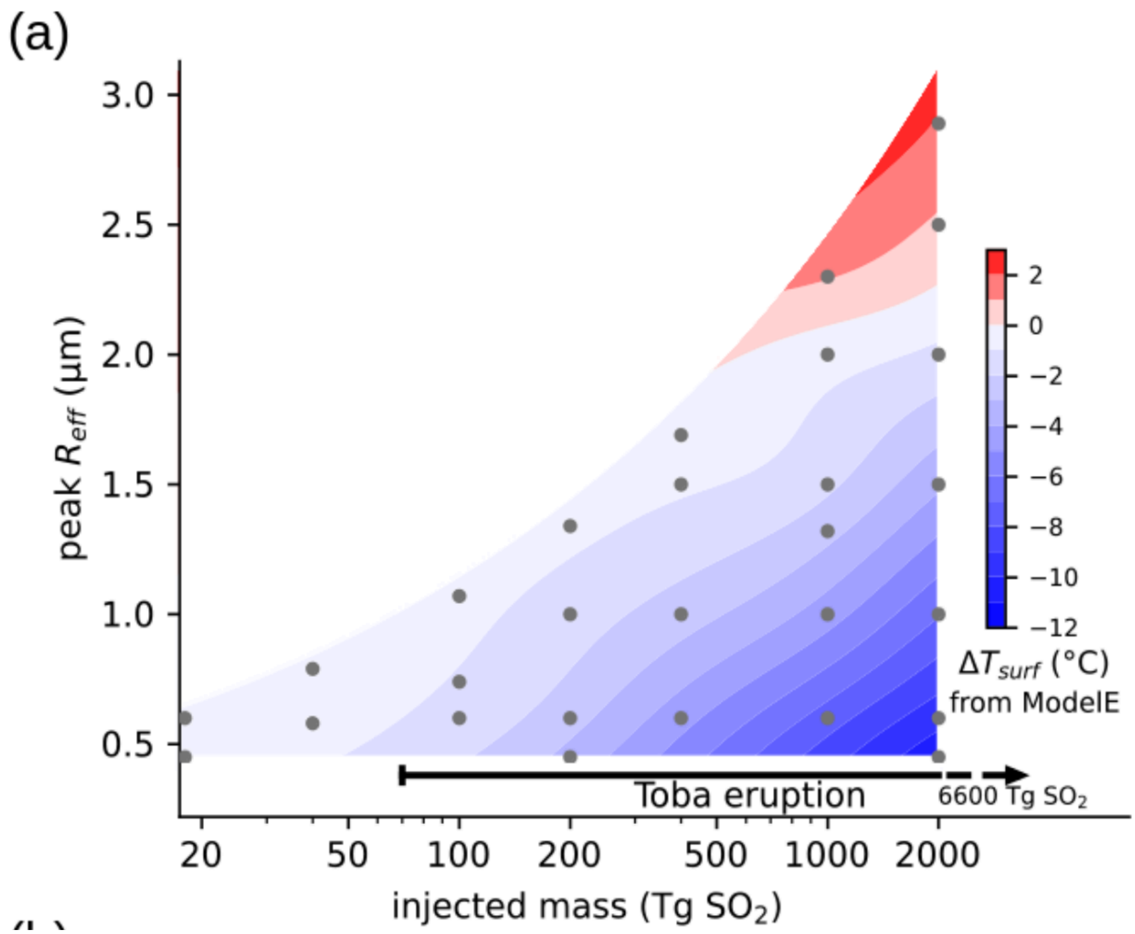
Cooling is limited: review of McGraw 2023

Nuclear winter scepticism déjà vu. It looks like past studies of volcanic eruptions have been overestimating risks. McGraw 2023, just published on December 13, found cooling is quite limited. Here is the abstract (emphasis mine). “Volcanic super-eruptions have been theorized to cause severe global cooling, with the 74 kya Toba eruption purported to have driven humanity to near-extinction. However, this eruption left little physical evidence of its severity and models diverge greatly on the magnitude of posteruption cooling. A key factor controlling the super-eruption climate response is the size of volcanic sulfate aerosol, a quantity that left no physical record and is poorly constrained by models. Here we show that this knowledge gap severely limits confidence in model-based estimates of supervolcanic cooling, and accounts for much of the disagreement among prior studies. By simulating super-eruptions over a range of aerosol sizes, we obtain global mean responses varying from extreme cooling all the way to the previously unexplored scenario of widespread warming. We also use an interactive aerosol model to evaluate the scaling between injected sulfur mass and aerosol size. Combining our model results with the available paleoclimate constraints applicable to large eruptions, **we estimate that global volcanic cooling is unlikely to exceed 1.5°C no matter how massive the stratospheric injection**. Super-eruptions, we conclude, may be incapable of altering global temperatures substantially more than the largest Common Era eruptions. This lack of exceptional cooling could explain why **no single supereruption event has resulted in firm evidence of widespread catastrophe for humans or ecosystems**".

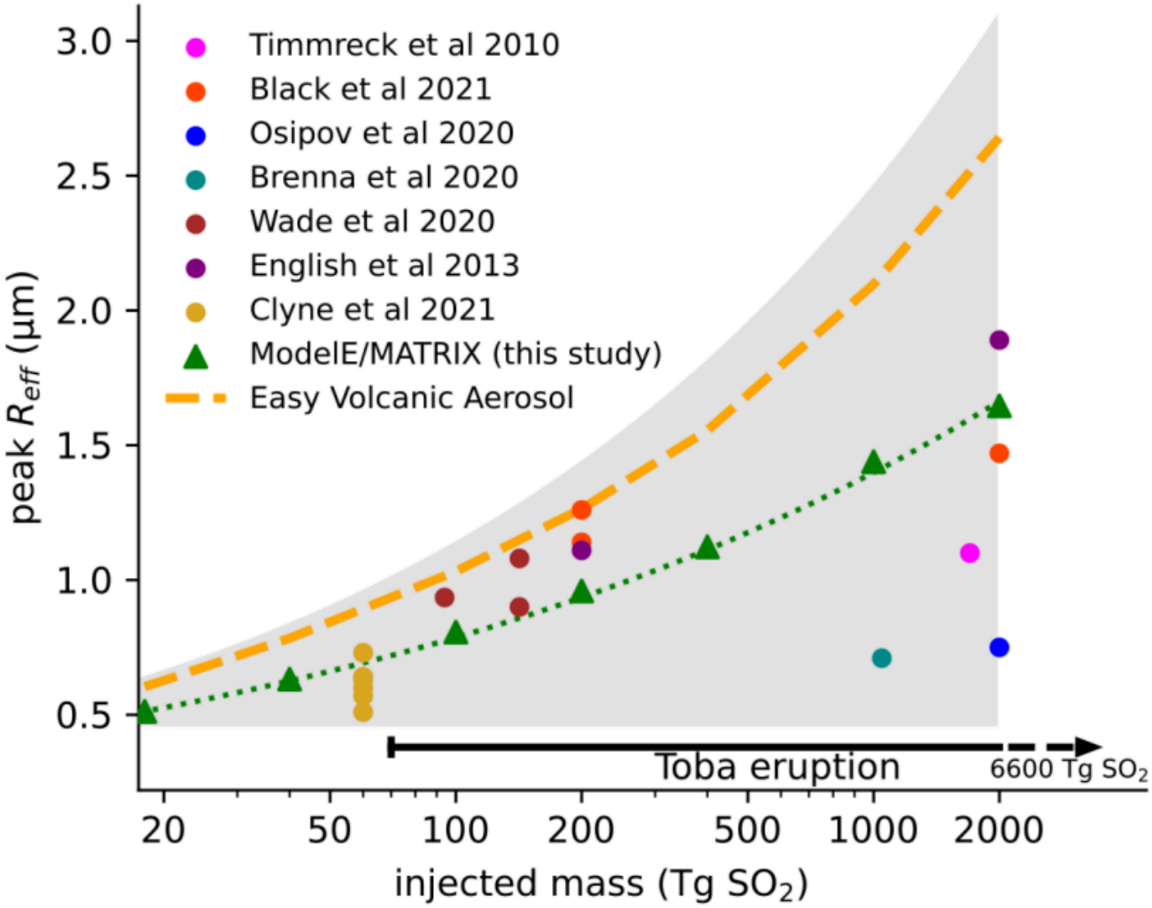
I would be curious to know Lara's thoughts on this study. I have no expertise in volcanology, but I found it quite rigorous. In particular, they are able to use their model to replicate the more pessimistic results of past studies tweeking just 2 input parameters (highlighted by me below):

- "We next evaluate if the assessed aerosol size spread is the likely cause of disagreement among past studies with interactive aerosol models. For this task, we interpolated the peak surface temperature responses from our ModelE simulations to the **injected mass and peak global mean aerosol size** from several recent interactive aerosol model simulations of large eruptions (Fig. 7, left panel). Accounting for these two values alone (left panel), our model experiments are able to reproduce remarkably similar peak temperature responses as the original studies found". By remarkably well, they mean R^2 = 0.87 (see Fig. 7).
- "By comparison, if only the injected masses of the prior studies are used, the peak surface temperature responses cannot be reproduced". The R^2 ranges from -1.82 to -0.04 (see Fig. 7; R^2 can be arbitrarily negative because one can make arbitrarily bad predictions).

They agree with past studies on the injected mass, but not on the [aerosol](#) size (aerosol is just a fancy term for cloud, except that it has to contain both solids and liquids, as opposed to just one of these). Figure 3a, which is below, illustrates the importance of the peak mean aerosol size. The greater the size, the weaker the cooling. I assume because aerosols fall down faster if they are bigger (in a vacuum, falling time does not depend on mass, but with drag bigger particles, which have more mass per area, fall faster).



According to Fig. 2 (see below), aerosol size increases with injected mass, which makes intuitive sense. So we are lucky big eruptions have less cooling potential per injected mass. For context, the 1815 eruption of Mount Tambora (VEI 7) had an injected mass of SO2 of 56 Tg (Table 1 of Wolff 2023).



However, past studies have used small aerosol mass for large eruptions, so they estimated much greater cooling. On the relationship between injected mass and aerosol mass:

- "While a power law scaling (Eqn. 1) is a common assumption, we are aware of only one study that tested this relationship with interactive aerosol models (Aubry et al. 2020), and no study that specifically compared different eruption realizations (rather than different months within simulations) or included injection masses >100 Tg SO2".
- "Therefore, to test the validity of the power law functional form we ran GISS ModelE with the MATRIX interactive aerosol model (Bauer et al. 2008, 2020) over a wide range of SO2 injection masses".
- "Our results confirm that a power law emerges, with peak global mean effective radius values (green triangles in Fig. 2) closely following a k=1/4 power law fitting to injected mass (dashed green line in Fig. 2)".

Figure 10 is pretty crucial to their conclusion of 1.5 ºC maximum cooling. In Fig. 10a, they define 4 potential scalings based on the aerosol size of the eruptions of Pinatubo and Samalas:

- (a) is defined by their upper bounds, so it is optimistic (overestimates the constant of proportionality, and therefore overestimates aerosol size, and underestimates cooling).

- (b) is defined by the means of their aerosol size (their best guess). “As scaling (b) traverses the mean of both our Pinatubo and Samalas Reff bounds, we treat this as our best estimate for how aerosol size scales with injection mass”.
- (a) is defined by their lower bounds, so it is pessimistic (underestimates the constant of proportionality, and therefore underestimates aerosol size, and overestimates cooling).
- (d) is the defined by the upper bound of Pinatubo (smaller eruption), and and lower bound of Samalas (larger eruption), so it is very pessimistic (underestimates the exponent, and therefore greatly underestimates aerosol size, and greatly overestimates cooling).

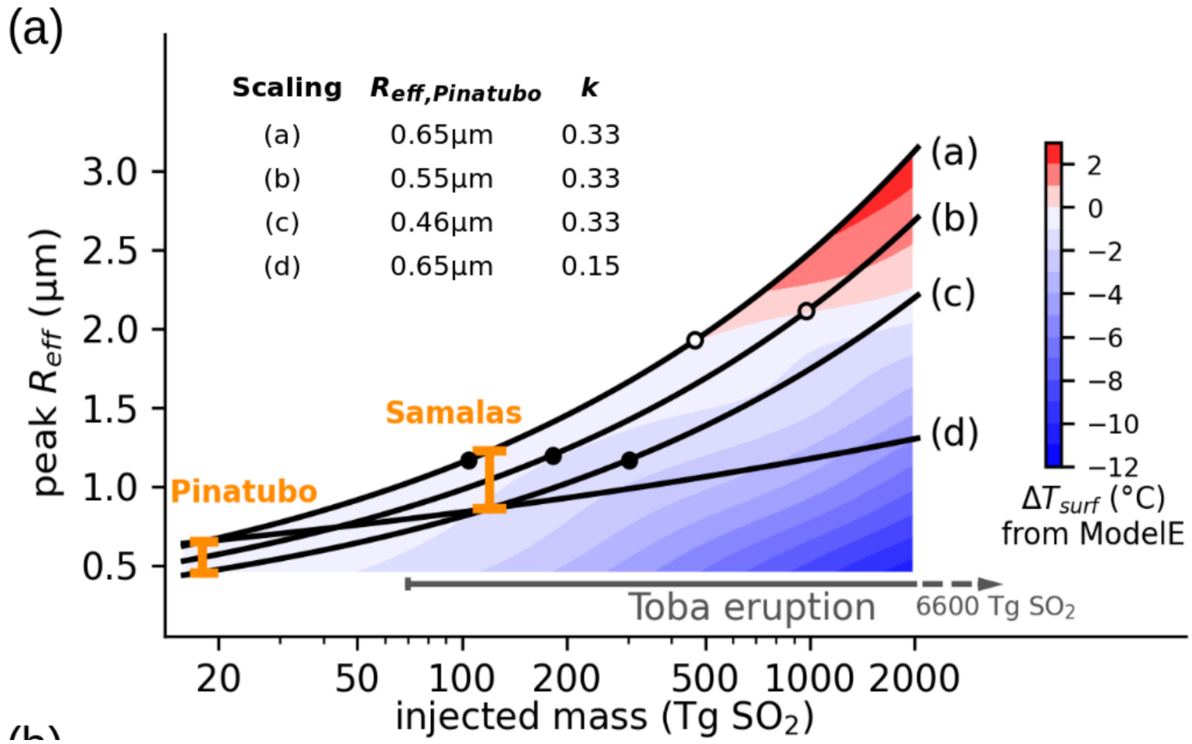
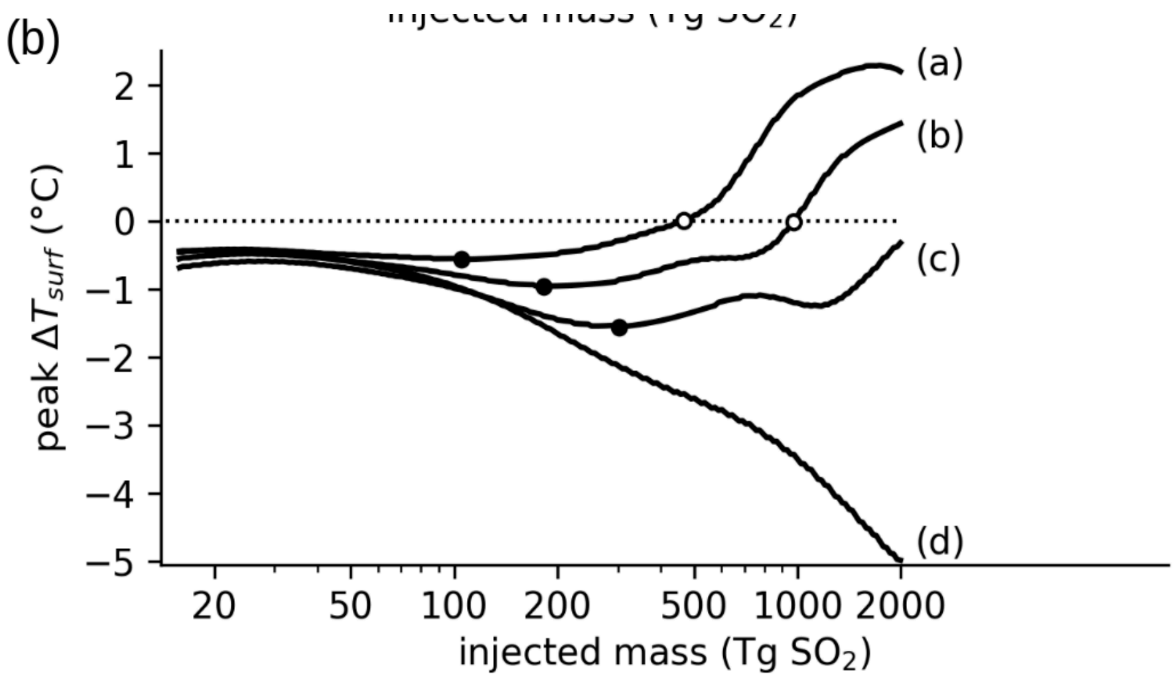


Figure 10b shows the cooling for the various levels of scaling. The maximum cooling is:

- 0.5 ºC for their optimistic aerosol size (a).
- 1 ºC for their best guess aerosol size (b).
- 1.5 ºC for their pessimistic aerosol size (c). This is the number they mention in the abstract.
- 5 ºC for 2 k Tg of SO2 and their very pessimistic aerosol size (d). 2 k Tg is the mass injected in the [Toba eruption](#) (see Table 1), which some argue almost caused human extinction.



They "deem cooling beyond 5°C highly unlikely". I guess around 3.38*10^-6 per century (= 2.5*10^-3*1.35*10^-3), multiplying:

- 0.25 % (= 0.05^2) chance of a more pessimistic relationship between injected mass and aerosol size than the suggested by (d), assuming a probability of 5 % of the power law being defined by:
    - Greater aerosol mass than the upper bound of Pinatubo.
    - Smaller aerosol mass than the lower bound of Samalas.
- 0.135 % (= 1/(74*10^(3 - 2))) chance of an eruption worse than Toba's per century, since the Toba eruption was 74 k years ago. This is very rough, and there is probably a paper estimating the frequency as a function of injected mass.

Extinction risk for maximum cooling is limited

5 ºC of peak cooling would hardly cause human extinction:

- We would have ice age temperatures. From NOAA, "the latest ice age peaked about 20,000 years ago, when global temperatures were likely about 10°F (5°C) colder than today".
- I seem to recall the peak cooling would happen in around 1 year, roughly like in a nuclear winter.
- Eyeballing Figure 3 of Toon 2014, a peak cooling of 5 ºC corresponds to a nuclear winter involving 63.1 Tg (= 10^1.8) of soot injected into the stratosphere.
- Interpolating and eyeballing data from Fig. 5a of Xia 2022, 63.1 Tg leads to a calorie consumption of 1,780 kcal/person/d (= 2000 - (2000 - 600)/(150 - 47)*(63.1 - 47)) with the following adaptations:
    - i) Directing animal crops to humans.
    - ii) Eliminating household food waste.
    - iii) Equitable food distribution.
- 1,780 kcal/person/d would not cause a significant fraction of the population to starve.

    - The country with the lowest calorie supply to households (which I guess is similar to the lowest calorie consumption given low waste when people are at risk of starving) in 2020 was the Central African Republic, with 1,640 kcal/person/d.
    - Deaths from protein-energy malnutrition there in 2020 were 1,211, i.e. just 0.0227 % (= 1.21*10^3/(5.34*10^6)) of the total population.
- I think i), ii) and iii) above would be a no-brainer nationally, because a state would rather do some rationing than have people starving. There would also be other adaptations which could increase calorie production. Stopping biofuels, expanding crop area, and changing to cold tolerant crops would also be simple measures.
- Food distribution would not be equitable globally, but this actually decreases the chance of extinction.
    - For example, with 1000 kcal/person/d and equitable distribution, everyone would starve because it is not possible to survive on that.
    - However, if 1000 kcal/person/d is just an average, there will be places with enough calories to survive (Luisa Rodriguez often made this point in the context of collapse).
    - Major food crops and marine fish production for Australia in a 47 Tg and 150 Tg nuclear winter would be 36.0 % and 24.2 % higher than under normal conditions (see Table S2 of Supplementary Information). I also seem to remember Australia produces like 20 times as many calories counting those going to animals and biofuels than they consume, so a 95 % reduction or so in calories would be needed for significant starvation there.
- Given all of the above, I guess extinction conditional on 5 ºC of peak cooling in 1 year or so would be smaller than 0.01 %. This is in agreement with Luke Oman, one of the 3 authors of Robock 2007, having guessed a risk of extinction of 0.001 % to 0.01 % conditional on a nuclear winter of 150 Tg (more than my upper bound of 63.1 Tg for volcanic eruptions).

Based on the above, and a probability of 3.38*10^-6 per century of having a volcanic eruption causing more than 5 ºC (see previous section), I get a probability smaller than 3.38*10^-10 (= 3.38*10^-6*10^-4) of extinction from a volcanic eruption per century.