Toba volcano super eruption destroyed the ozone layer and caused a human population bottleneck

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Few notes...

You can click links, for example, references.

Paper is under review, drop me an email, if you would like a copy.

The original presentation is here (Google Slides, not PDF).

Introduction

History and evolution of the Toba catastrophe theory:

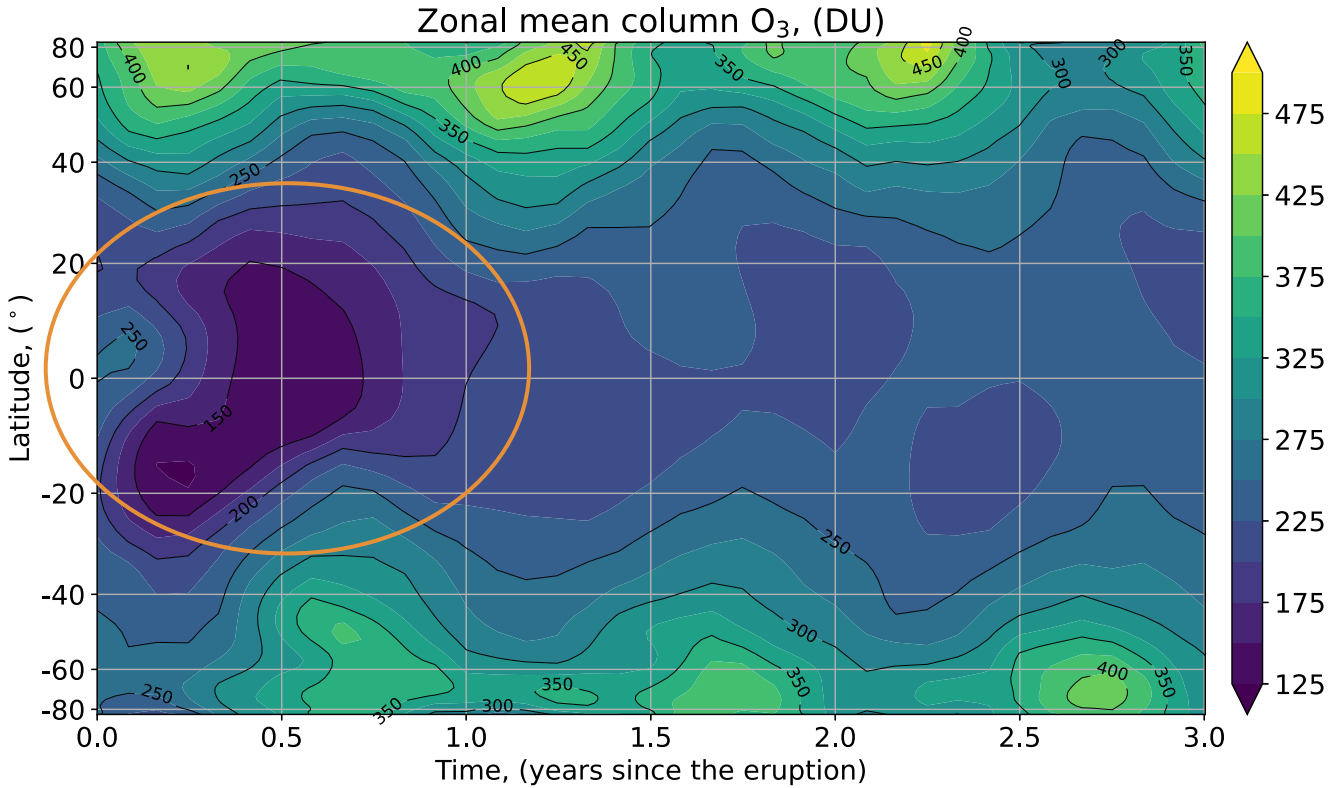
- According to DNA analysis, 74 ka humanity experienced a population genetic bottleneck, coincident with the Toba supervolcano eruption [1, 2].
- Toba catastrophe theory was put forward to explain the sharp population decrease as well as the onset of the glacial period.
- Modeling of the volcanic winter effects (cooling and drying) improved,and the estimate of the pick temperature anomaly dropped from 15 to 3.5 ℃ [3, 4, 5].
- The only observations (African lake Malawi sediments) substantiate the reduced precipitation and consequent vegetation perturbation after the Toba eruption but do not confirm a cooling event that could have been catastrophic for humans [5, 6].
- Toba catastrophe hypothesis became disputed.

but Toba also caused the tropical ozone hole

… in addition to cooling and drying.

Ozone dropped to 125 DU in tropics, which is half of the climatological 250 DU.

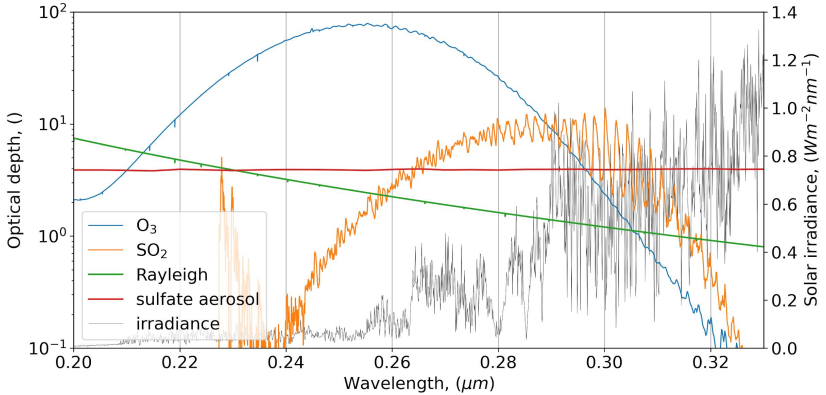
The ozone hole definition is 220 DU or less.

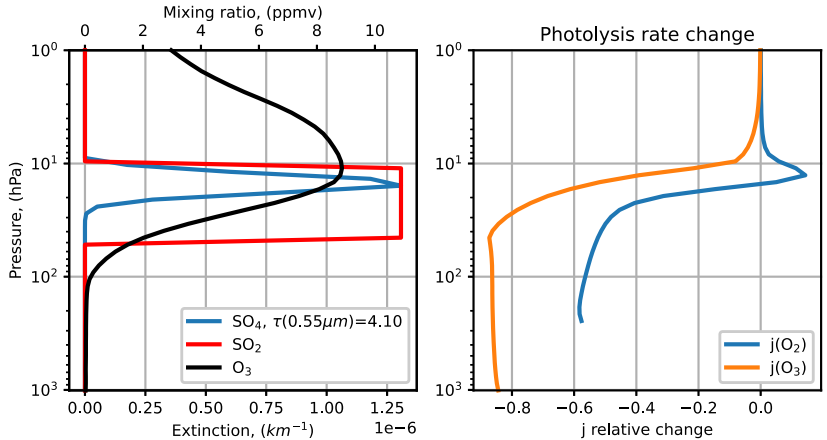


The radiative mechanism of ozone depletion

The primary source of stratospheric ozone is O_2 photolysis (λ<242 nm) in the tropics (transported poleward afterward by Brewer-Dobson circulation).

O_3 and molecular Rayleigh scattering control radiative transfer at these wavelengths, but Toba adds sulfate aerosols, which reduce $j(O_2)$ and cause ozone depletion.

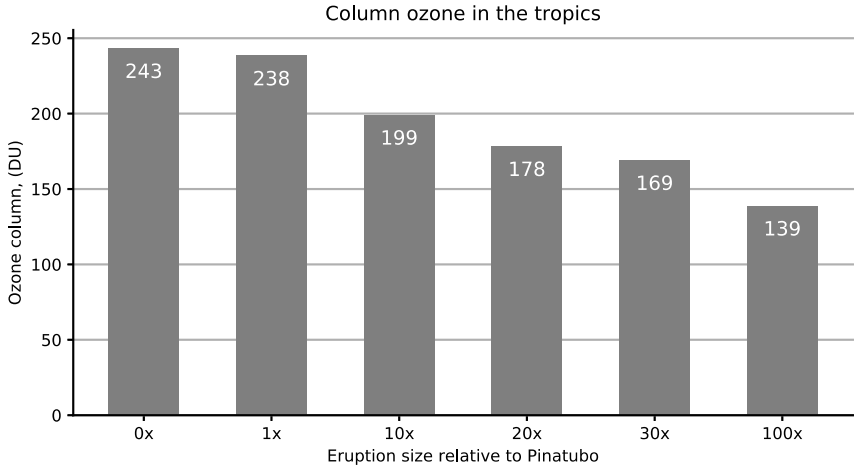




Discussion

- Our results represent a lower limit of the UV increase, because we did not include halogens (no info on emissions). Toba eruption likely was not halogen-rich, yet fraction of these compounds will have been co-emitted and will have aggravated ozone loss [Brenna et a., 2019].

- The depth of the tropical ozone hole does not strongly depend on assumptions about the eruption magnitude. Even 10x Pinatubo produces ozone hole (<220 DU).



Conclusions 1/2

We presented the overlooked radiative mechanism of stratospheric ozone depletion by volcanic aerosols.

This mechanism extends the spectrum of the volcanic effects and adds UV exposure as the new environmental stress in addition to well known cooling and drying climate impacts.

For the Toba case, the mechanism reconciles the seemingly conflicting data about volcanic winter conditions (the magnitudes of the simulated and observed cooling and drying).

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Conclusions 2/2

We updated the “Toba UV catastrophe theory”:

- Tropics: limited cooling and drying & severe biological UV damage.
- Extra-tropics: harsh volcanic winter conditions.

Finally, we recommend that the impact of sunlight extinction by thick stratospheric aerosol plumes on ozone formation are accounted for in future studies of the environmental consequences of explosive volcanoes, nuclear conflicts, and solar radiation management (geoengineering).

Supplementary >

UV-induced health-hazardous effects

- Environmental, ecological, health-hazardous and societal consequences [UNEP].
- short term: eye damage (photokeratitis and photoconjunctivitis) and erythema.
- longer term: the increased carcinogenesis (cataract and skin cancer), immune system suppression, and general DNA damage.

- several times larger than during the aftermath of a massive nuclear conflict [Mills2008, Mills2014].

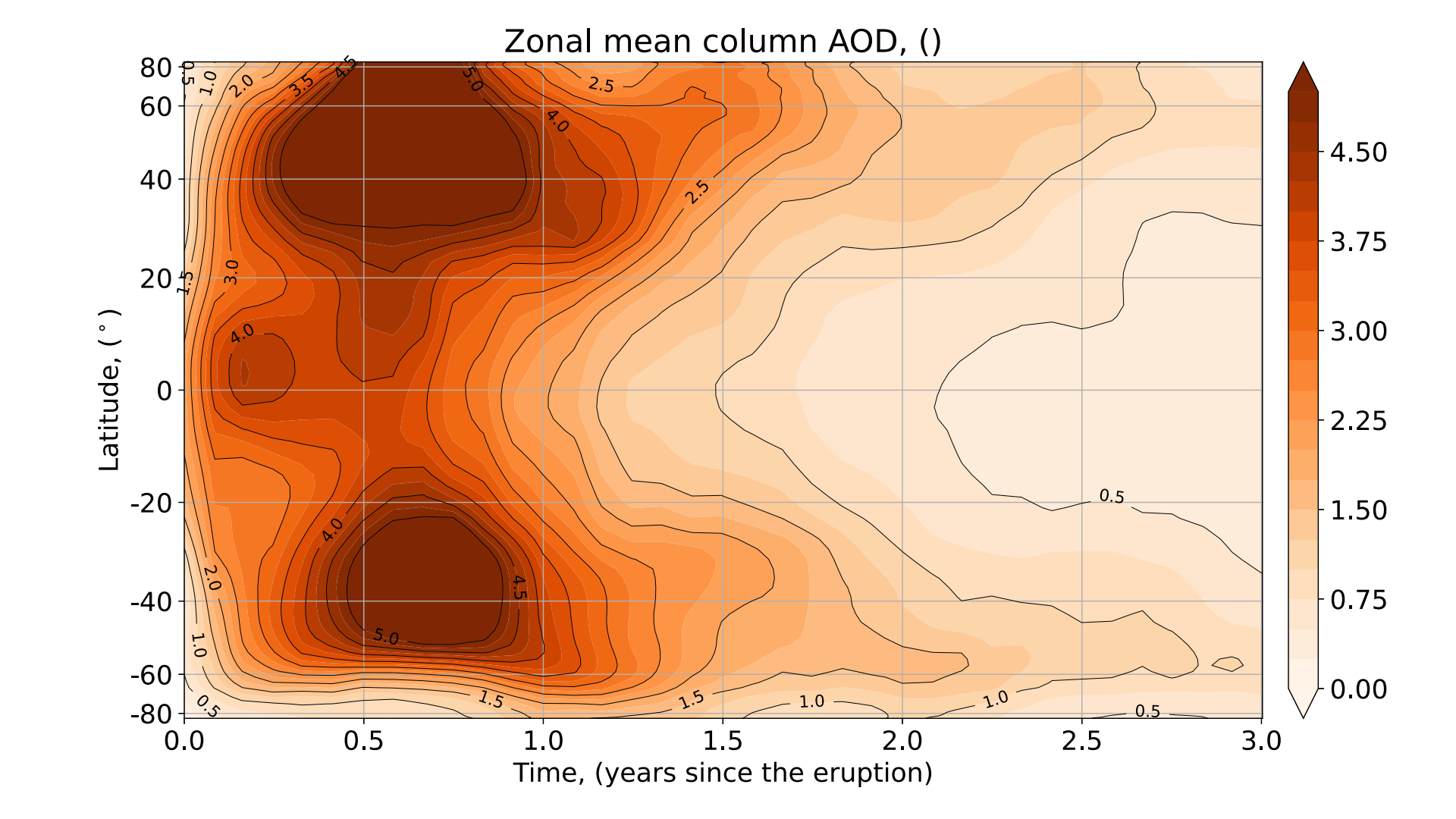
Model

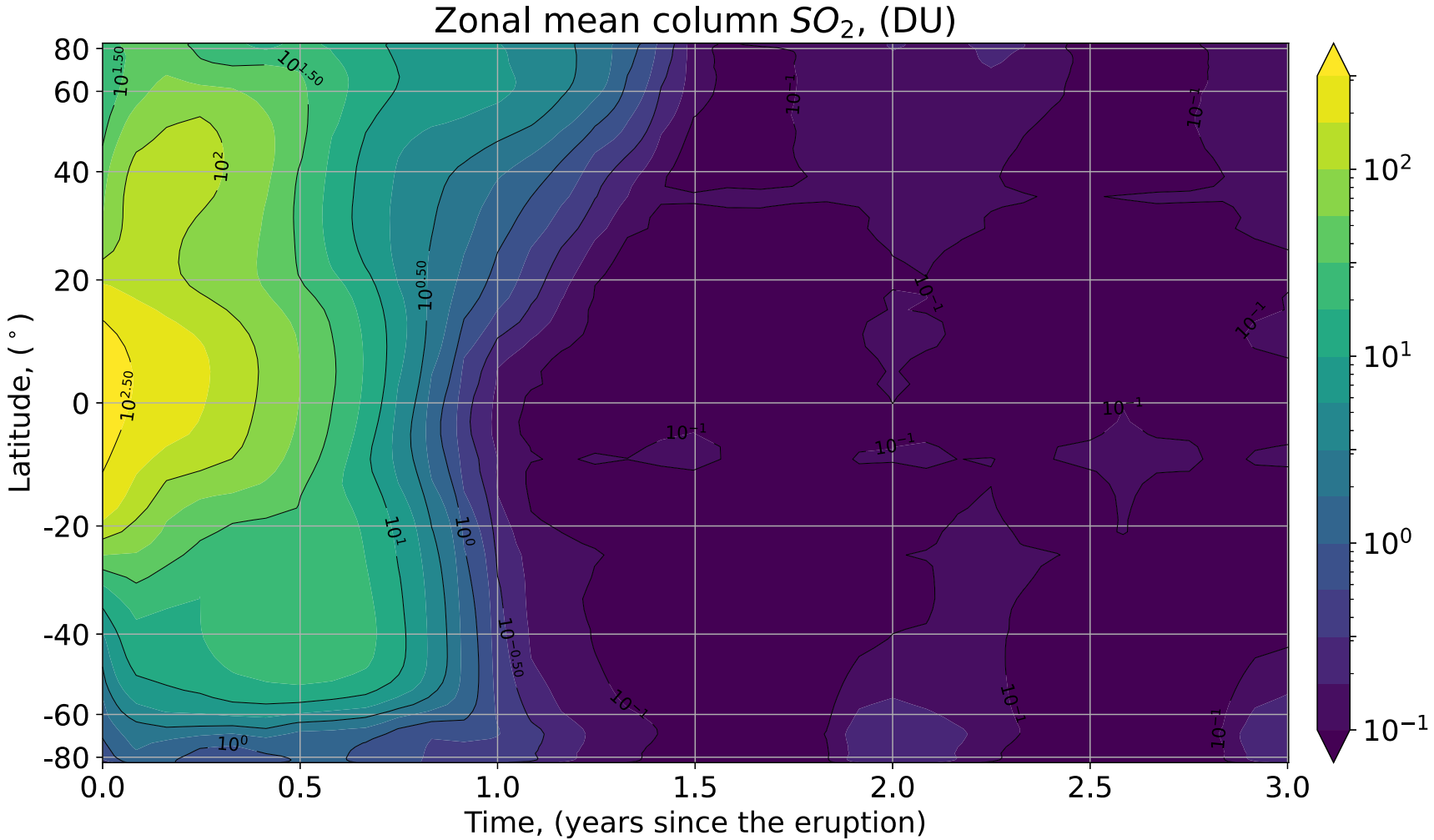
We applied the NASA-GISS ModelE.

- global interactive atmospheric chemistry–climate model.
- includes fully interactive chemistry related to ozone and sulfate.

The eruption of Toba is modelled by the instantaneous injection of 2000 Mt of SO_2 (about 100x Pinatubo, 20S-20N, 10-50 hPa).

Fast-J2 scheme was updated! Full multiple-scattering code is used for ƛ > 200 nm (previously 291 nm, important for O_2 photolysis), and replaced the default pseudo-absorption simplification. The original Fast-J2 version was not designed to capture the effects of volcanic plumes on stratospheric ozone chemistry and strongly overestimates ozone depletion.


Zonal mean column AOD, ()
Latitude, (°)
Time, (years since the eruption)
80
60
40
20
0
-20
-40
-60
-80
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
4.50
3.75
3.00
2.25
1.50
0.75
0.00


Zonal mean column SO_2, (DU)
Latitude, (°)
Time, (years since the eruption)
80
60
40
20
0
-20
-40
-60
-80
0.0
0.5
1.0
1.5
2.0
2.5
3.0
10^{2}
10^{1}
10^{0}
10^{-1}

Climate impacts of Toba and the role of the SO_2 radiative effects has been published separately in the Osipov et al., 2020. It also contains details on the experimental setup.