University of Saskatchewan

Stratospheric residence time and the lifetime of volcanic aerosol

Matthew Toohey
Yue Jia, Susann Tegtmeier

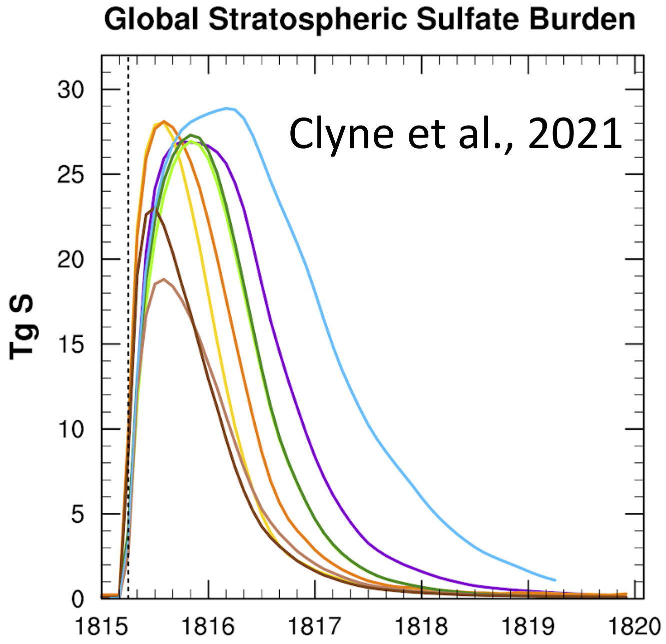
Institute for Space and Atmospheric Studies
University of Saskatchewan, Canada

vEGU21: Gather Online, April 2021

BE WHAT THE WORLD NEEDS

Background

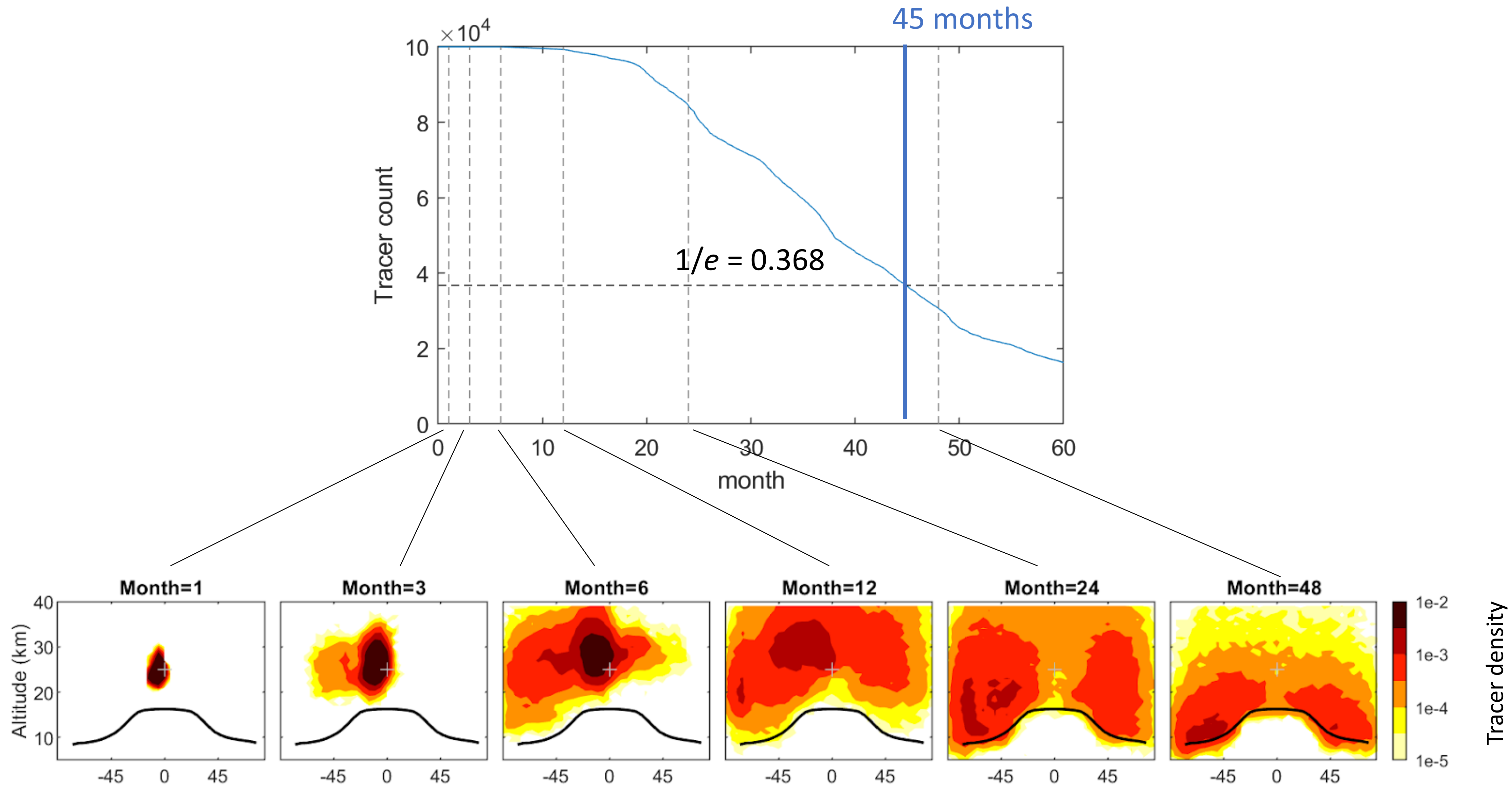
- Stratospheric aerosols have an efficient climate impact due in large part to their long atmospheric lifetime.
- Based on recent observed eruptions, it is usually said that the lifetime of volcanic aerosols is about 1 year for tropical eruptions, and some months for high latitude eruptions (e.g., IPCC 2013).
- In the VolMIP Tambora aerosol model experiment, model simulate strongly varying aerosol lifetimes (Clyne et al., 2021).
- Can we assess model performance, and accurately predict the lifetime of aerosol from past or future eruptions?
- How does stratospheric aerosol lifetime depend on eruption latitude, plume height or other factors?
- What is the role of atmospheric transport vs. gravitational settling?



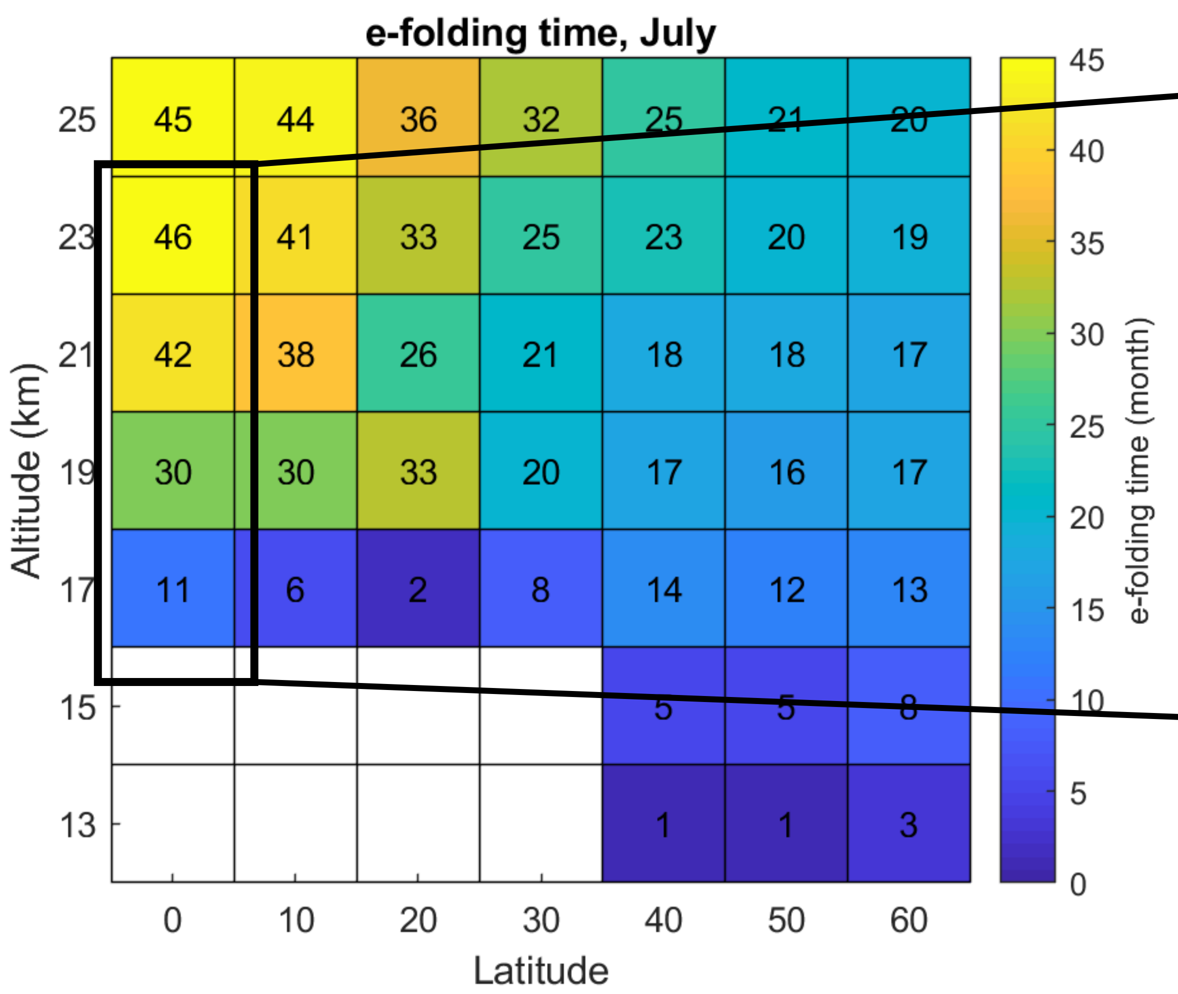
Method

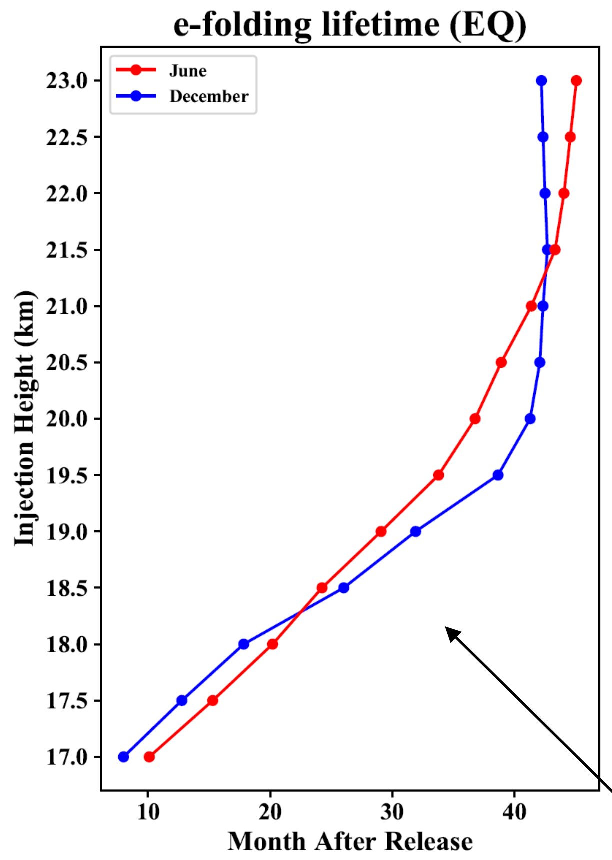
- Definitions:
  - *Stratospheric residence time* is the average time an **air parcel** spends in the stratosphere
  - *Stratospheric aerosol lifetime* is the average time an **aerosol particle** spends in the stratosphere: may differ from stratospheric residence time due to gravitational settling (sedimentation) of larger particles
  - *e-folding timescale* is the time required for a quantity to decrease to a factor of $1/e$ of its initial amount. If (but only if) decay is exponential, then e-folding timescale is equal to lifetime or residence time.
- Passive tracer injection experiment
  - FLEXPART Lagrangian particle dispersion model
  - Release 100,000 tracers at specific latitude and height
  - Tracer trajectory calculated using winds from atmospheric reanalysis (ERA-Interim)
  - Keep track of fraction of tracers which remain in the stratosphere
  - Idealized "passive tracer" means particles do not experience gravitational settling: we're estimating residence time, not aerosol lifetime

Passive tracer experiment: injection at 0°N, 25 km



Passive tracer experiment: *e*-folding times, July eruption

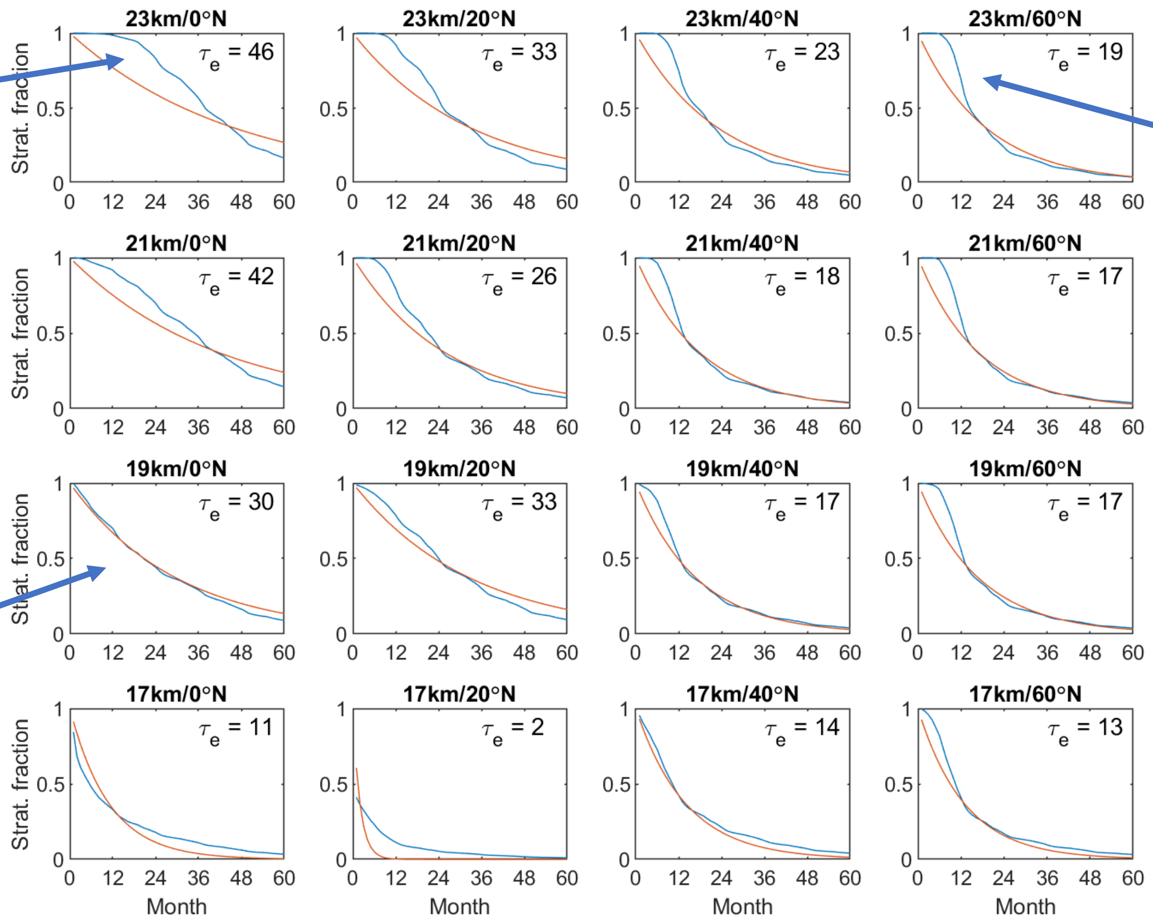




Factor 4 difference in *e*-folding time from 17 to 20 km injection height

Passive tracer experiment vs. ideal exponential decay

Not exponential!



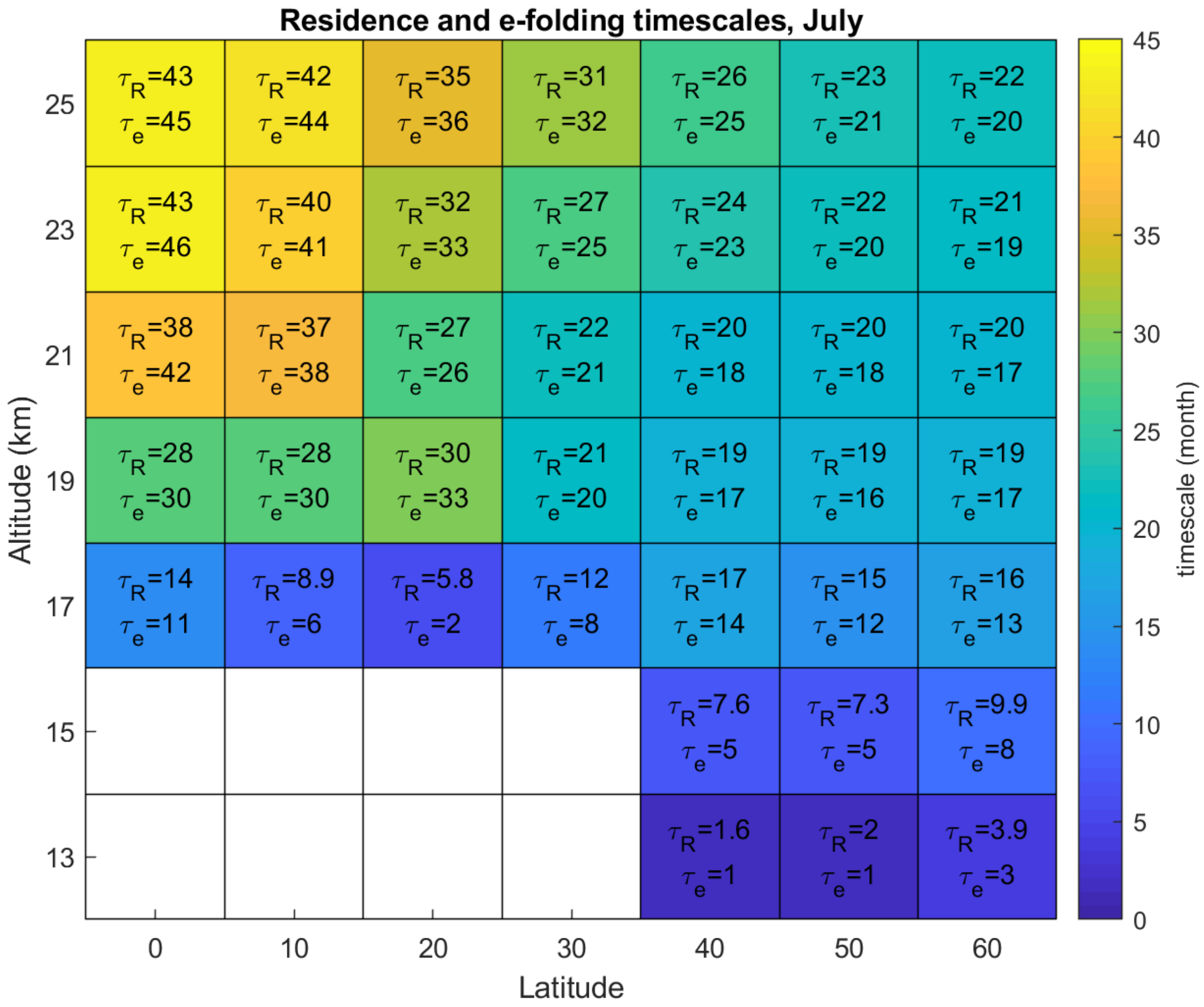
Not exponential!

Exponential!

Each panel shows the time evolution of the fraction of tracers remaining in stratosphere after release at given height/latitude

Passive tracer experiment: *e*-folding time vs. residence time

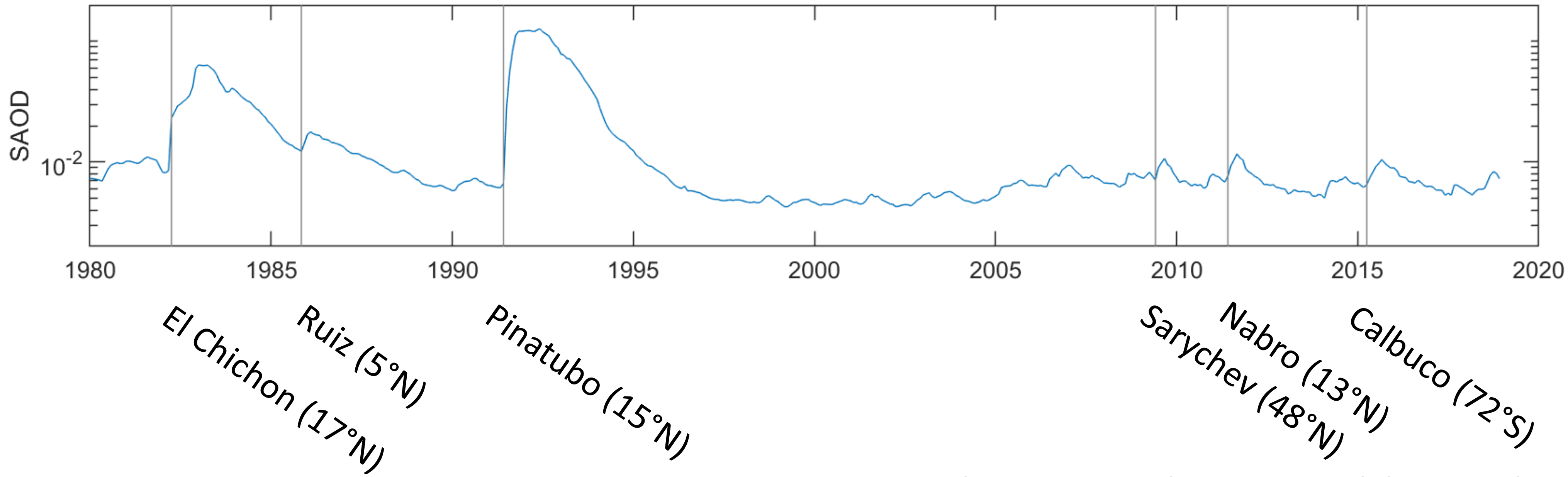
- From passive tracer simulations, we can compare *e*-folding time to actual residence time
- *e*-folding time generally underestimates residence time, but effect is small except for in lower stratosphere
- This occurs because a small portion of every injection remains in the stratosphere for a very long time



OK, but these residence times—over 40 months for some tropical stratosphere injections!—are way longer than the typically quoted 12 months “residence time” for aerosol from the 1991 Mt. Pinatubo eruption, and so not very useful, right?

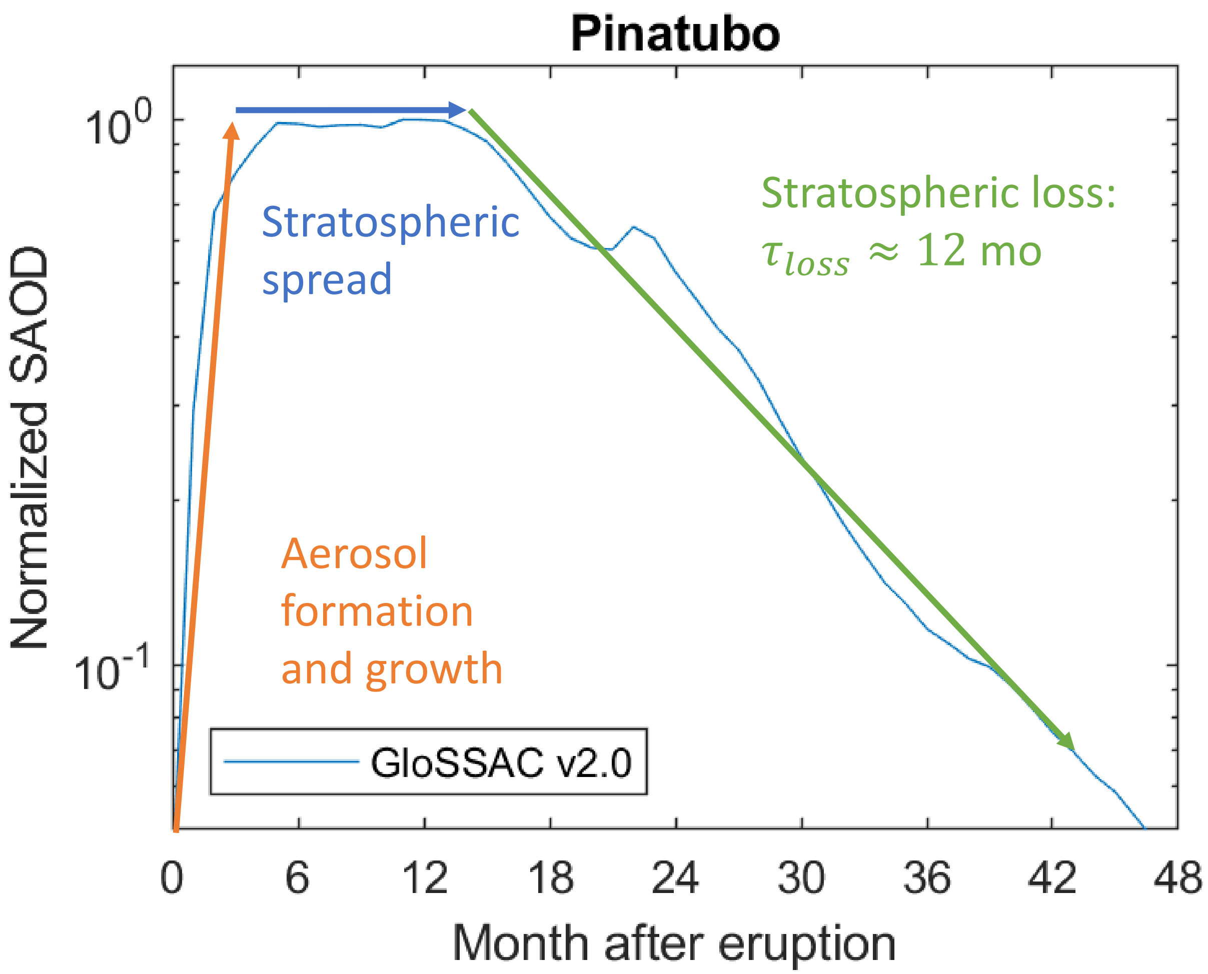
GloSSAC v2.0 global mean stratospheric aerosol optical depth (SAOD)

- Compiled mostly from satellite measurements
- Some gaps filled with ground-based and airplane measurements.
- Various types of calculations used to fill spatial gaps, merge datasets into a consistent timeseries of SAOD at 525 nm.
- Assume SAOD is approximately proportional to aerosol mass

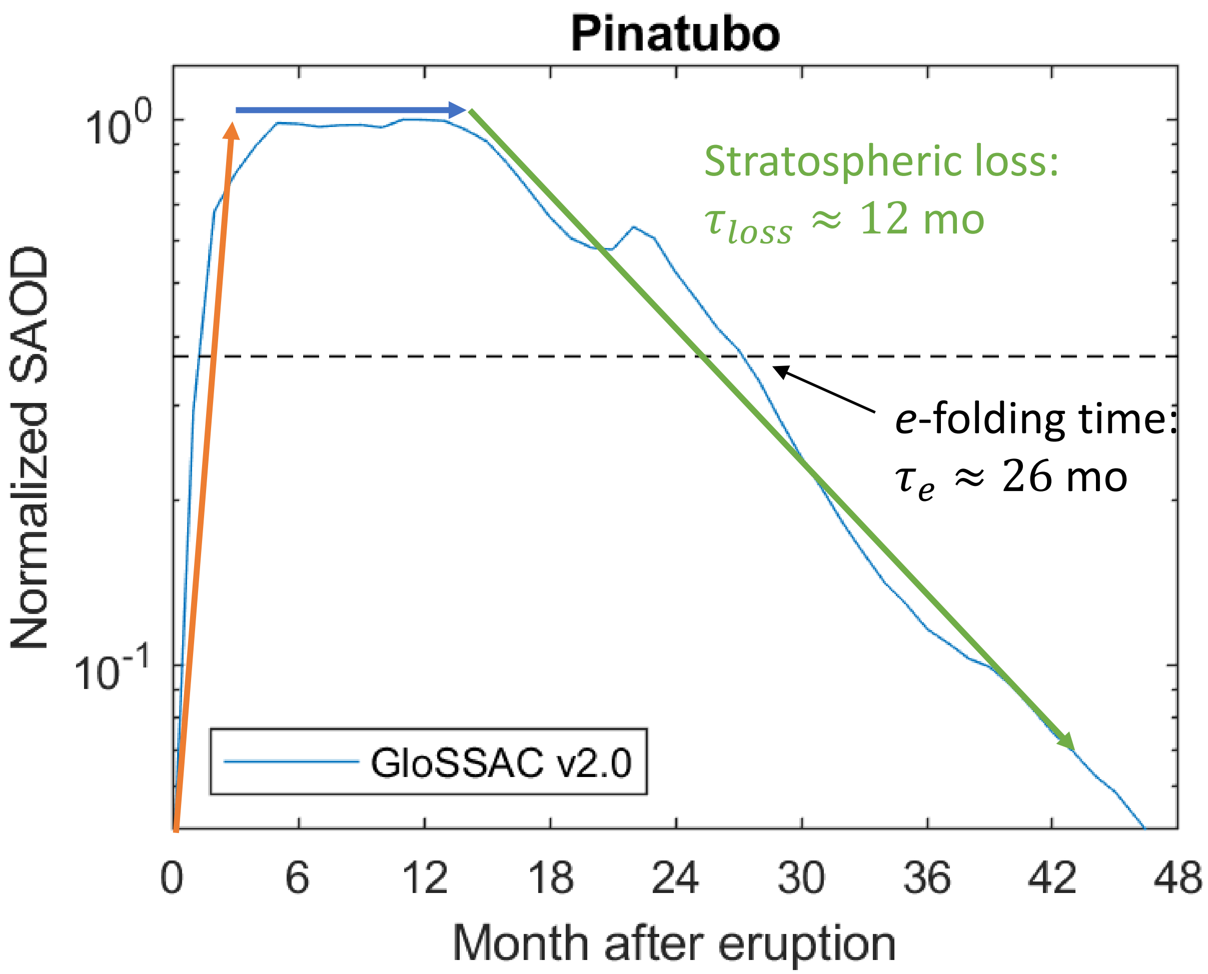


Thomason et al., 2018, Kovilakam et al., 2020

Pinatubo global aerosol optical depth

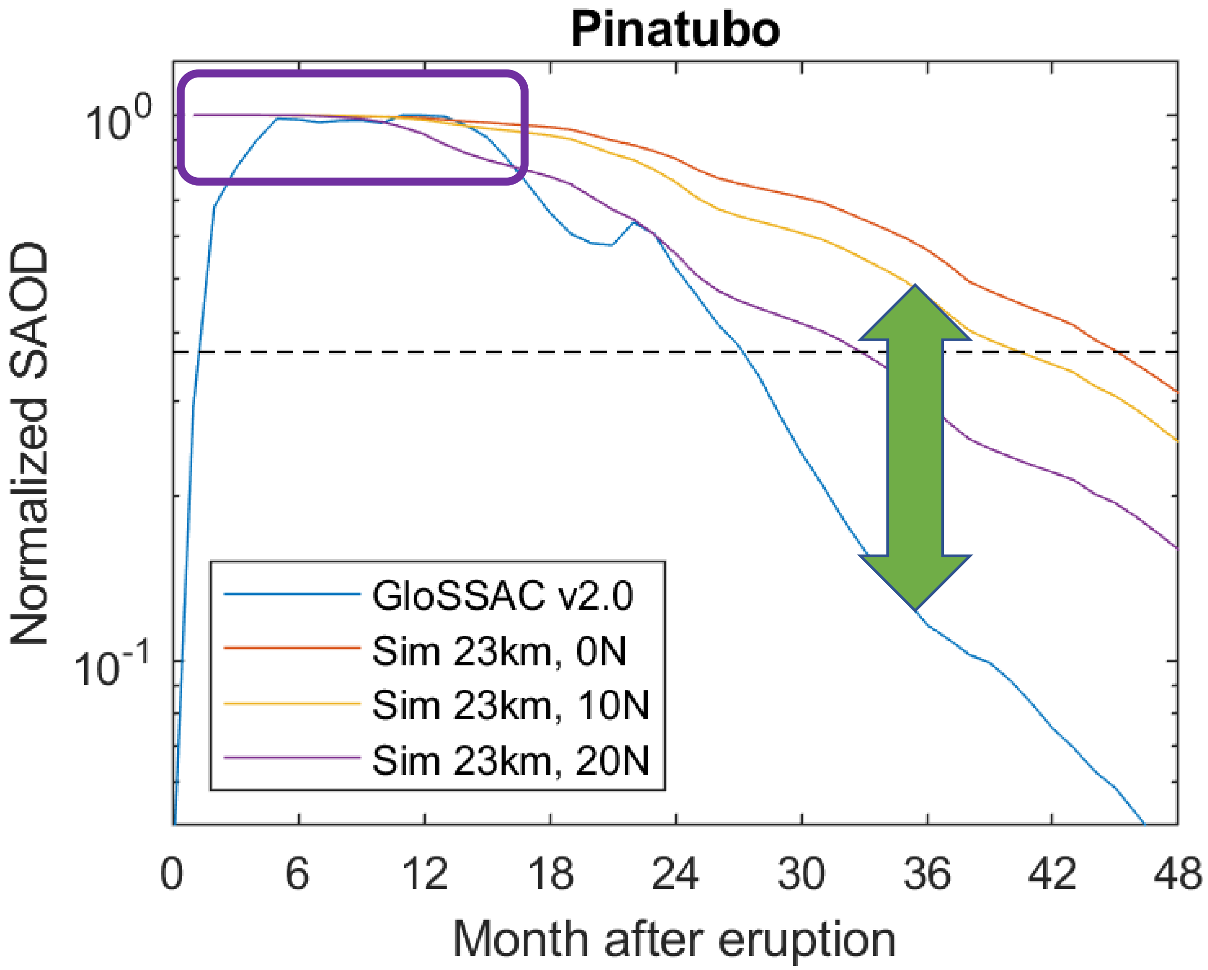


Pinatubo global aerosol optical depth

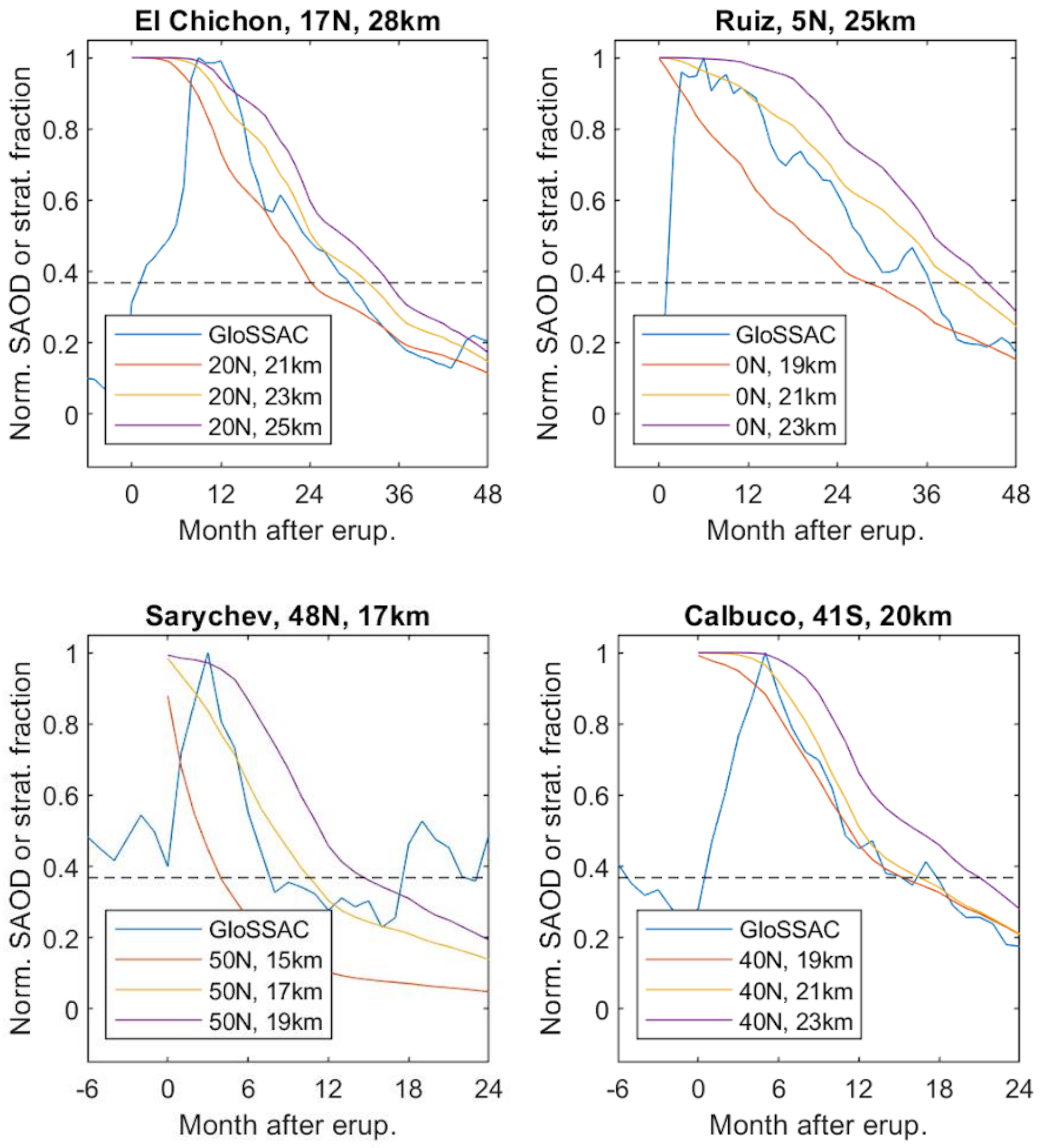


1. The *e*-folding time *from time of stratospheric injection* is ~26 months, and strongly related to the ~16 month delay between injection and the start of loss
2. Assuming *e*-folding time is good estimate of residence time, residence time for tropical eruption like Pinatubo is ~26 months, not ~12 months!

Pinatubo global aerosol optical depth



1. Tracer simulations of injections to 23 km have spreading times of 8-20 months before loss starts, consistent with observations.
2. Difference in loss rate between observations and trajectory simulations clear indication of the role of gravitational settling.



Tropical eruptions El Chichon (1982) and Ruiz (1985):

- Observed SAOD *e*-folding time of 24-36 months agrees closely with passive tracer simulations, albeit for injection heights lower than the estimated plume heights from observations (Carn et al., 2016)

Extratropical eruptions Sarychev (2009) and Calbuco (2015):

- Observed SAOD evolution with *e*-folding time of 6-18 months agrees closely with passive tracer simulations for similar latitude and height
    - For these smaller eruptions, aerosol lifetime appears to be equal to residence time (i.e., gravitational settling not important)

Conclusions

1. Stratospheric residence time depends on the latitude of eruption, and on the eruption plume height
   - Factor of 4 sensitivity within the lower few km of the stratosphere!
   - This is likely to be a major source of uncertainty in forcing reconstructions.
2. Stratospheric lifetime of aerosol from strong tropical eruptions like Pinatubo and El Chichón is ~2 years, not 1 year
   - Aerosol loading decays pseudo-exponentially with timescale 1 year, but only after a ~1 year stratospheric "spreading" time
3. Stratospheric lifetime for smaller recent eruptions consistent with residence time calculated from passive tracer experiments
   - Residence time may provide reasonable estimate for aerosol lifetime for many past and future eruptions.