CLDERA

Sandia National Laboratories

Dynamically Identifying Circulation Changes by Volcanic SAIs with the E90 Passive Tracer

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All-hands: October 16th – 19th 2023

U.S. DEPARTMENT OF ENERGY | NNSA

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Orientation

Goal: Identify volcanic perturbations to the global circulation through the E90 tracer

Challenge

E90 is typically used in analysis of long-term climatology; we'll need to employ nonstandard metrics on this field to identify the signatures of volcanic forcing events.

Approach

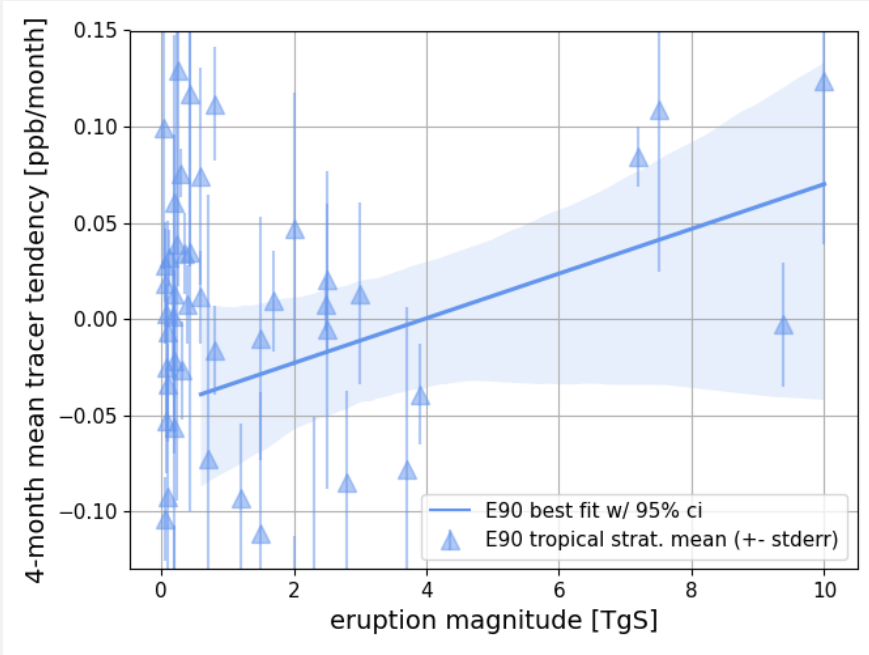
As a function of eruption magnitude, we will investigate three quantities:

- The anomalous position of the tropical tropopause
- The anomalous position of the tropical E90 90ppb contour
- The anomalous concentration of E90 in the tropical lower-middle stratosphere

Result

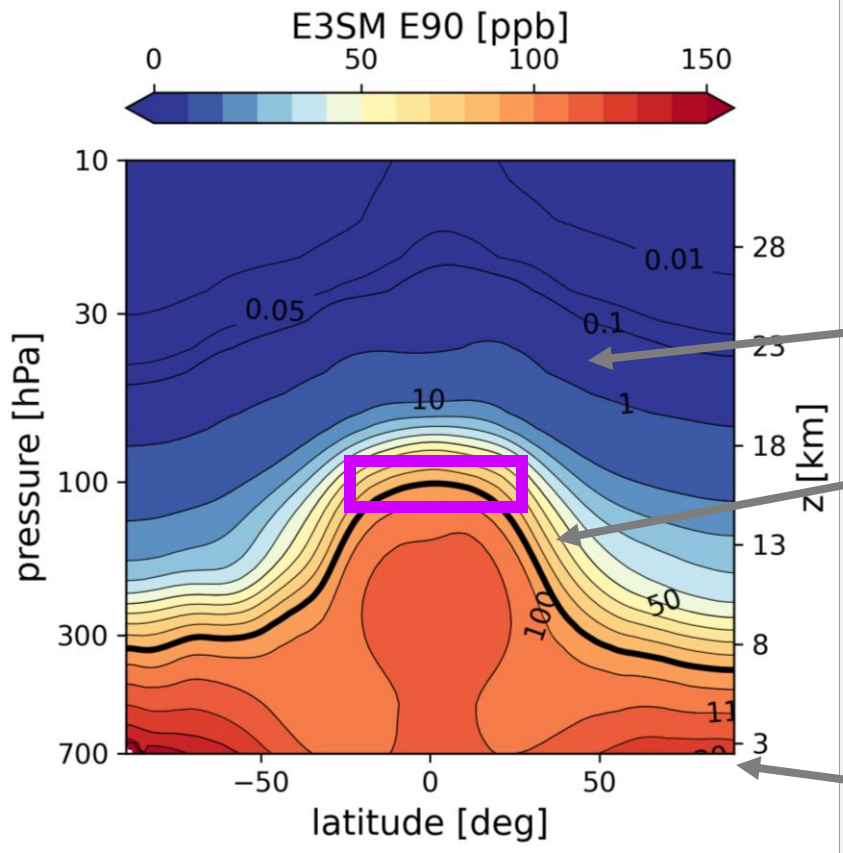
Our preliminary results suggest that volcanic sulfate forcing of the stratosphere causes both a *sinking of the tropical tropopause*, as well as *enhanced exchange across the tropical tropopause,* from troposphere to stratosphere.

Both of these effects scale with eruption magnitude in TgS.



Summary Figure: the 4-month time tendency in anomalous E90 tropical stratospheric mean concentration, as a function of eruption magnitude. Takeaway: Volcanic sulfate forcing of the lower-mid stratosphere causes enhances exchange across the tropical tropopause, from troposphere to stratosphere.

Brief E90 Overview



E90 is an arbitrary name for a passive tracer which:

Where E90 is steep, it is sensitive to perturbations; vertical movement of the 90ppb contour indicates tropopause movement, exchange across the tropopause, or both

… and persists at very low values in the stratosphere

… accumulates at the tropopause

… dissipates everywhere with e-folding timescale of 90 days

… is emitted uniformly at the surface

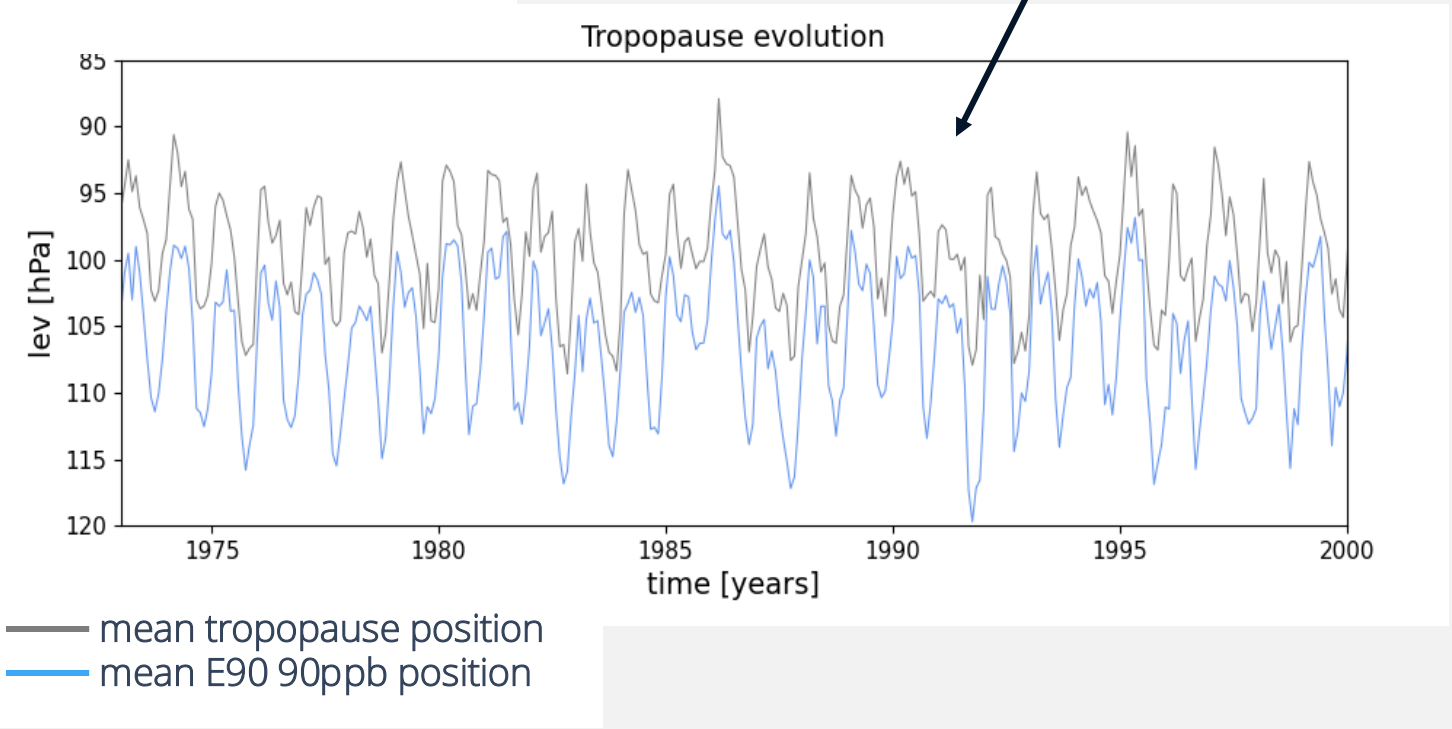
Tropopause Anomalies Scale with Injection Magnitude

Steps:

1) Find tropical mean position of **tropopause** (lapse rate), and **E90 90ppb**

seasonal variations

Weighted average on lat = [-20, 20]

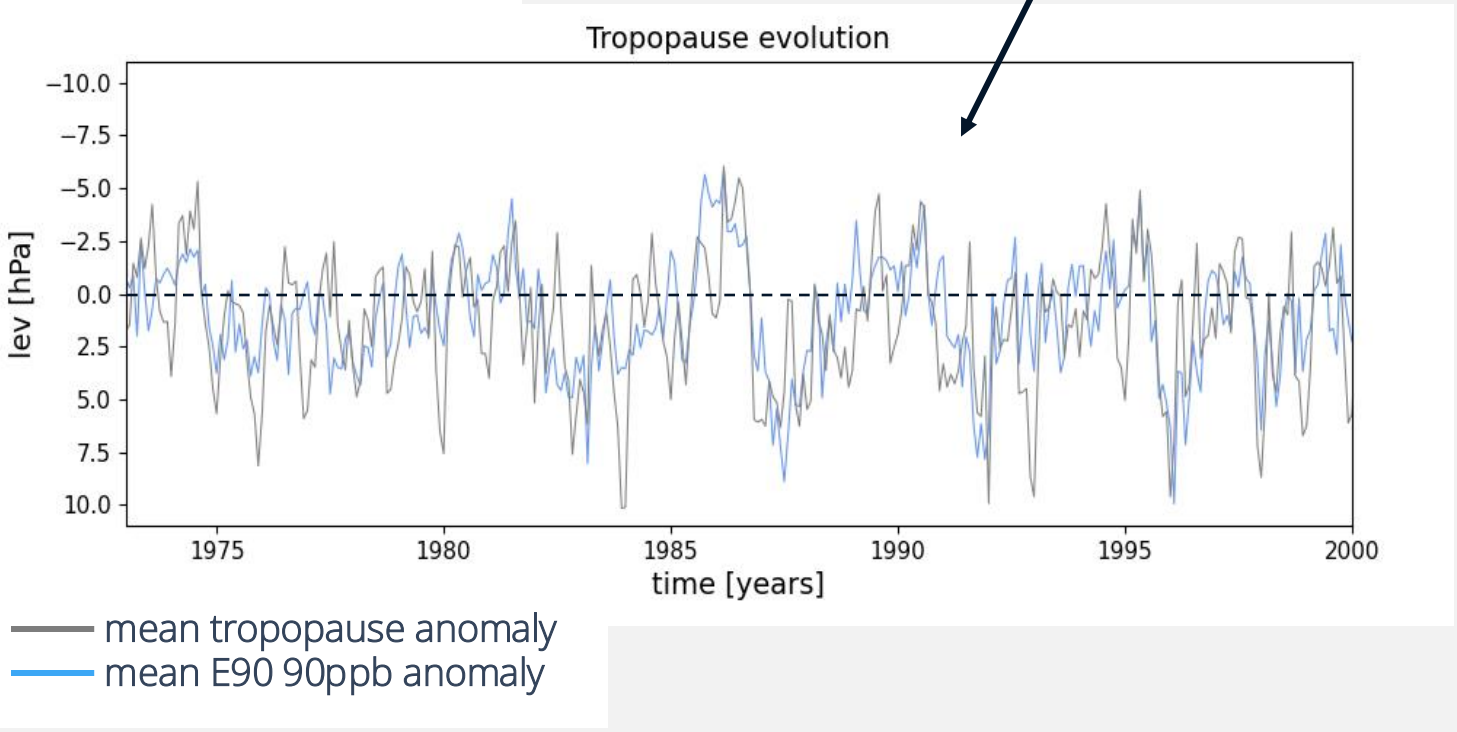


Tropopause Anomalies Scale with Injection Magnitude

Steps:
1) Find tropical mean position of **tropopause** (lapse rate), and **E90 90ppb**
2) Compute tropopause position **anomaly**

average seasonal variation subtracted

Weighted average on lat = [-20, 20]



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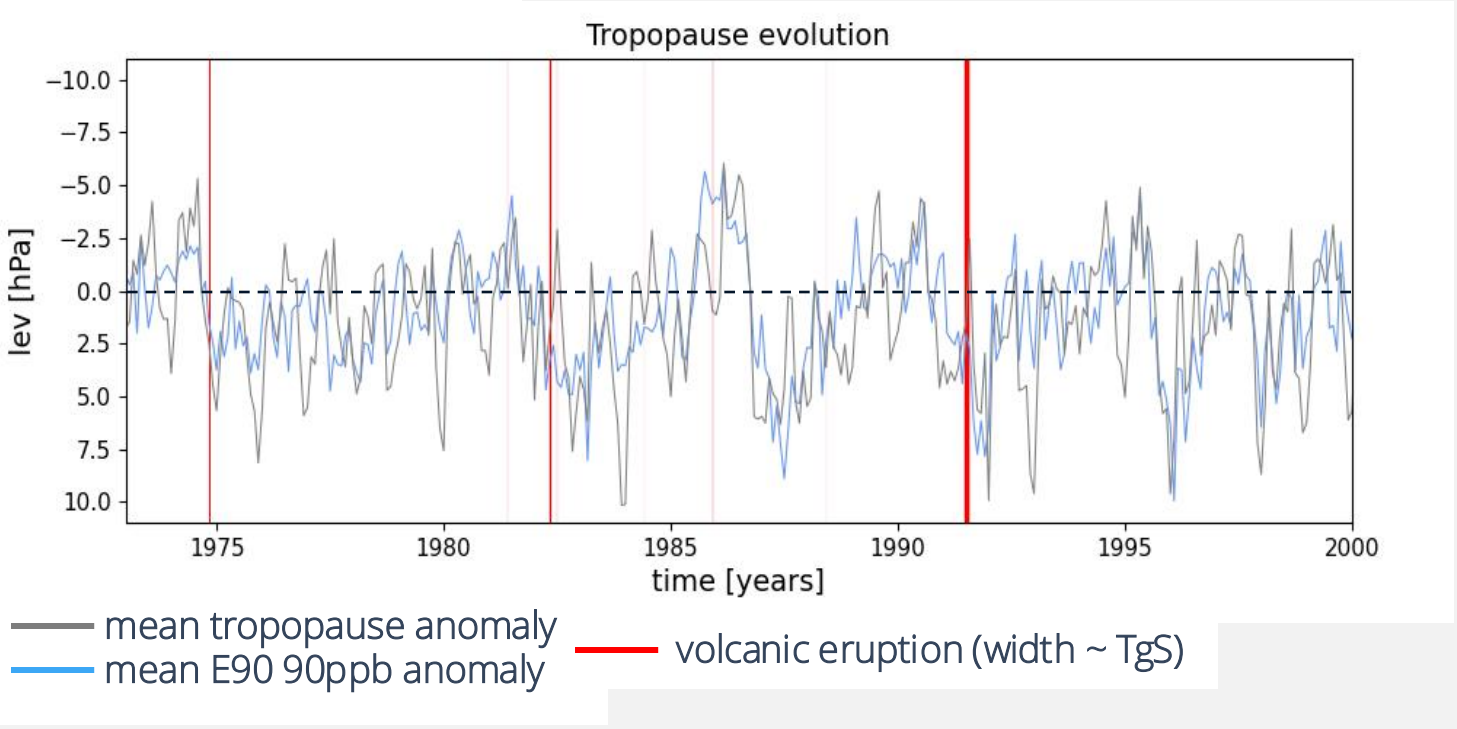
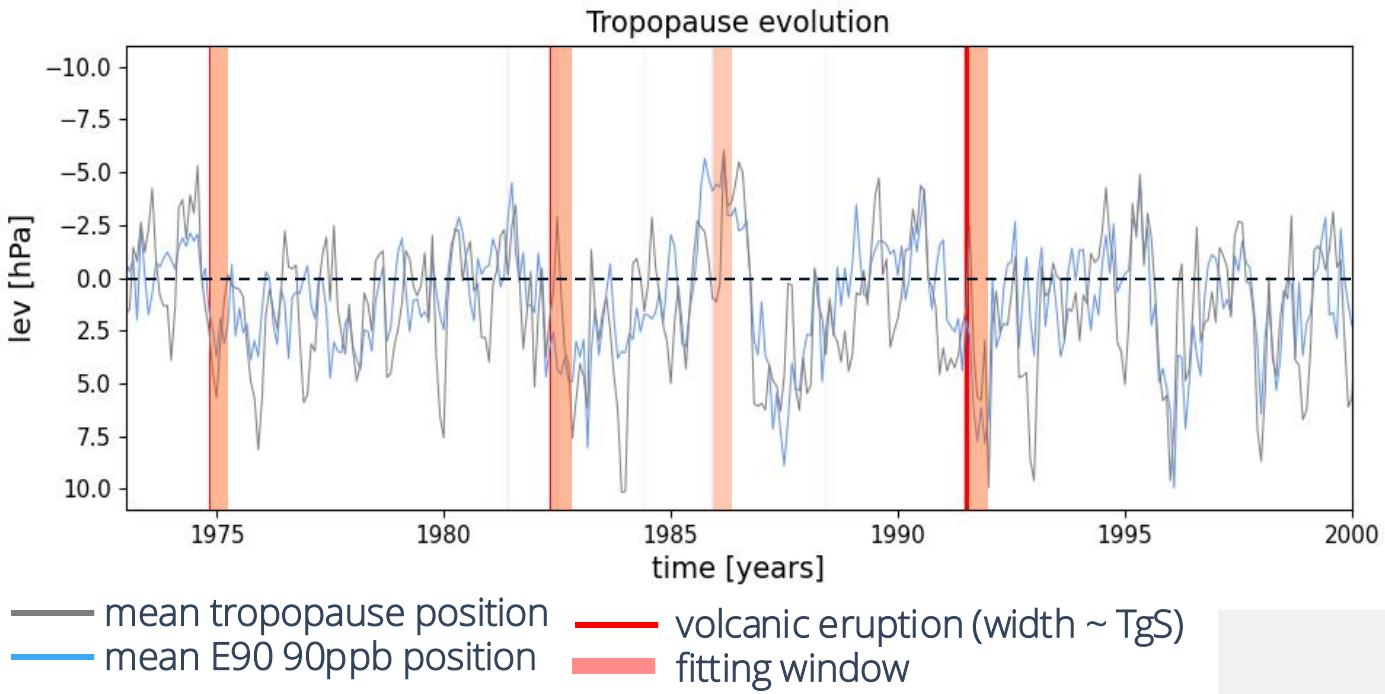


Tropopause Anomalies Scale with Injection Magnitude

Steps:

1) Find tropical mean position of **tropopause** (lapse rate), and **E90 90ppb**
2) Compute tropopause position **anomaly**
3) Do linear fit in 4-month post-eruption windows

Weighted average on lat = [-20, 20]



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Steps:

1) Find tropical mean position of **tropopause** (lapse rate), and **E90 90ppb**
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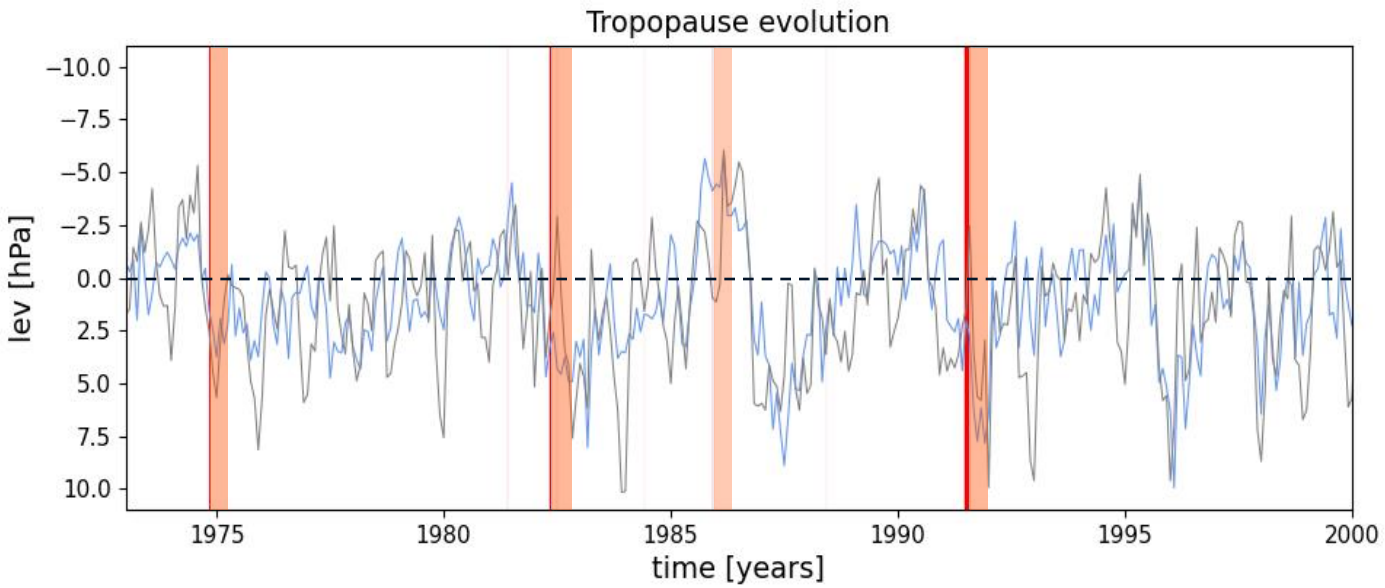
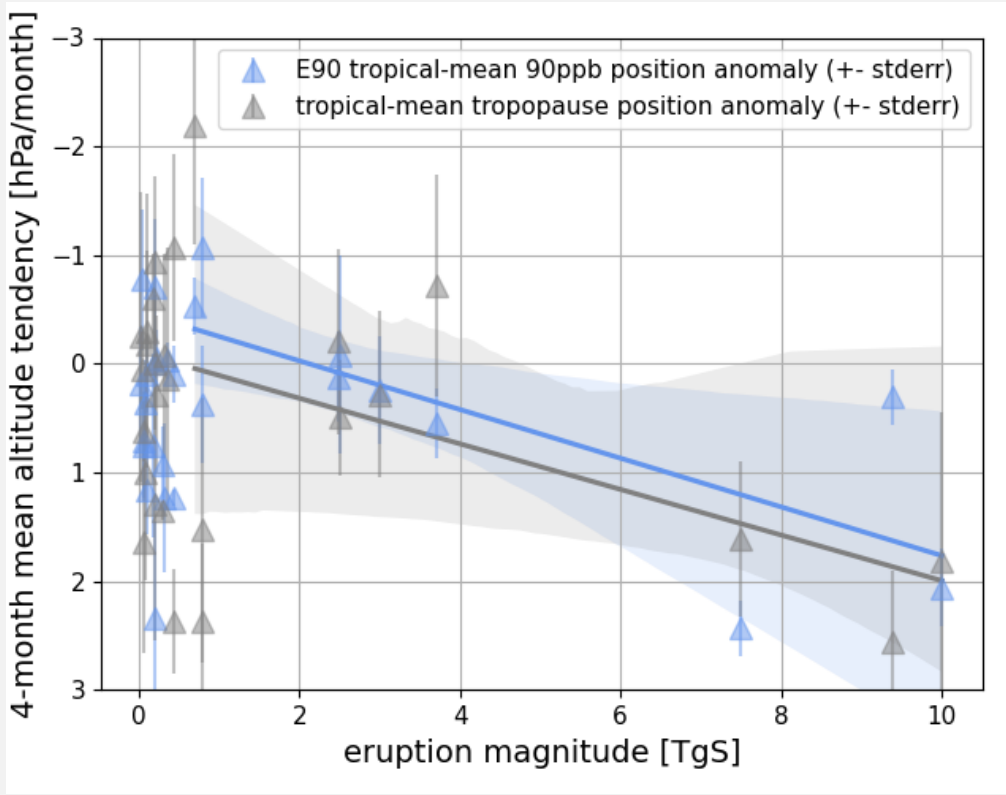
4) Plot the result as a function of eruption magnitude

Weighted average on lat = [-20, 20]





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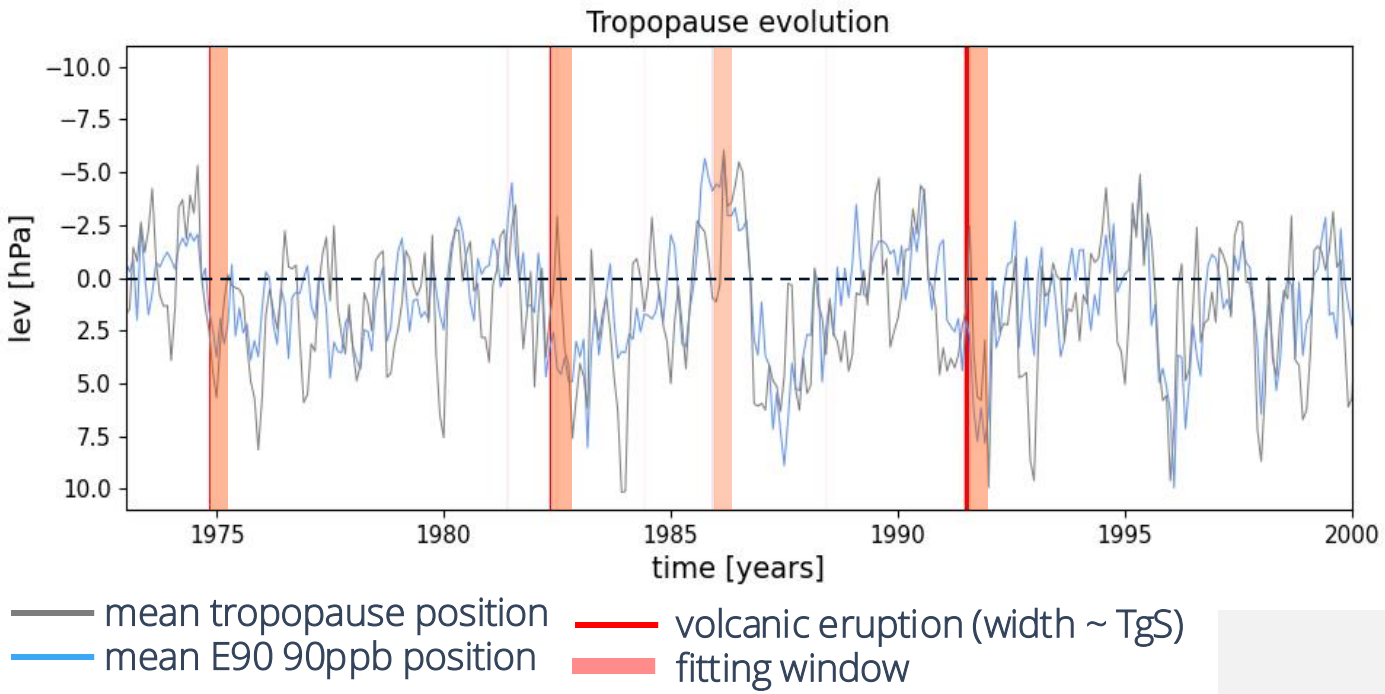
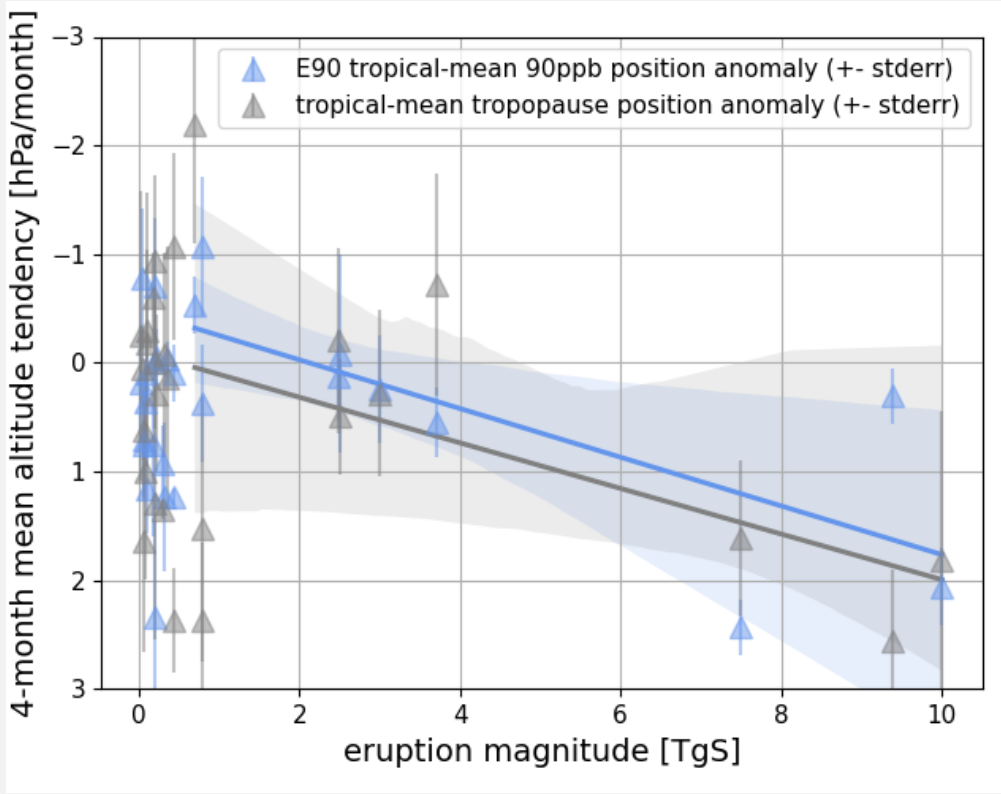
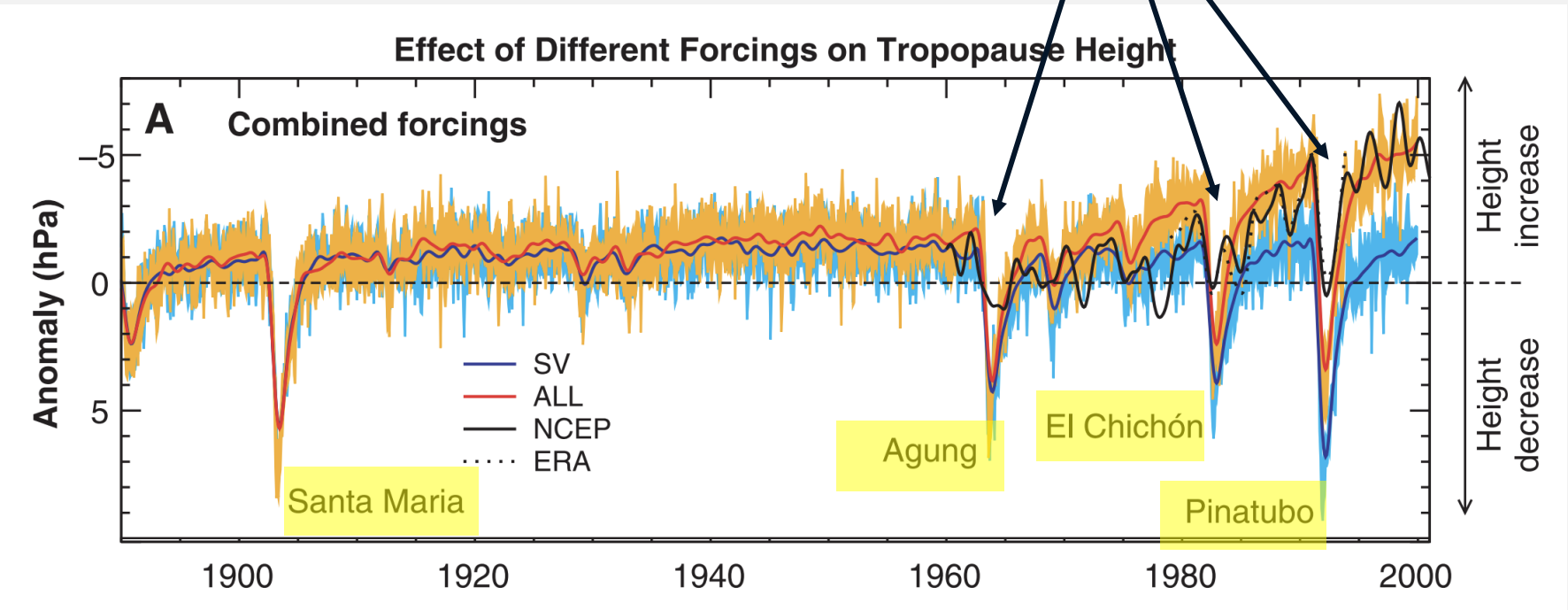


Takeaway:
Volcanic forcing of the tropical stratosphere causes a *sinking of the tropical tropopause,* proportional to the strength of the forcing



Result is Qualitatively Consistent with Literature

Ensemble-mean experiment results from **Santer et al. (2003)** shows positive anomalies in tropopause pressure (height decrease), scaling with eruption magnitude



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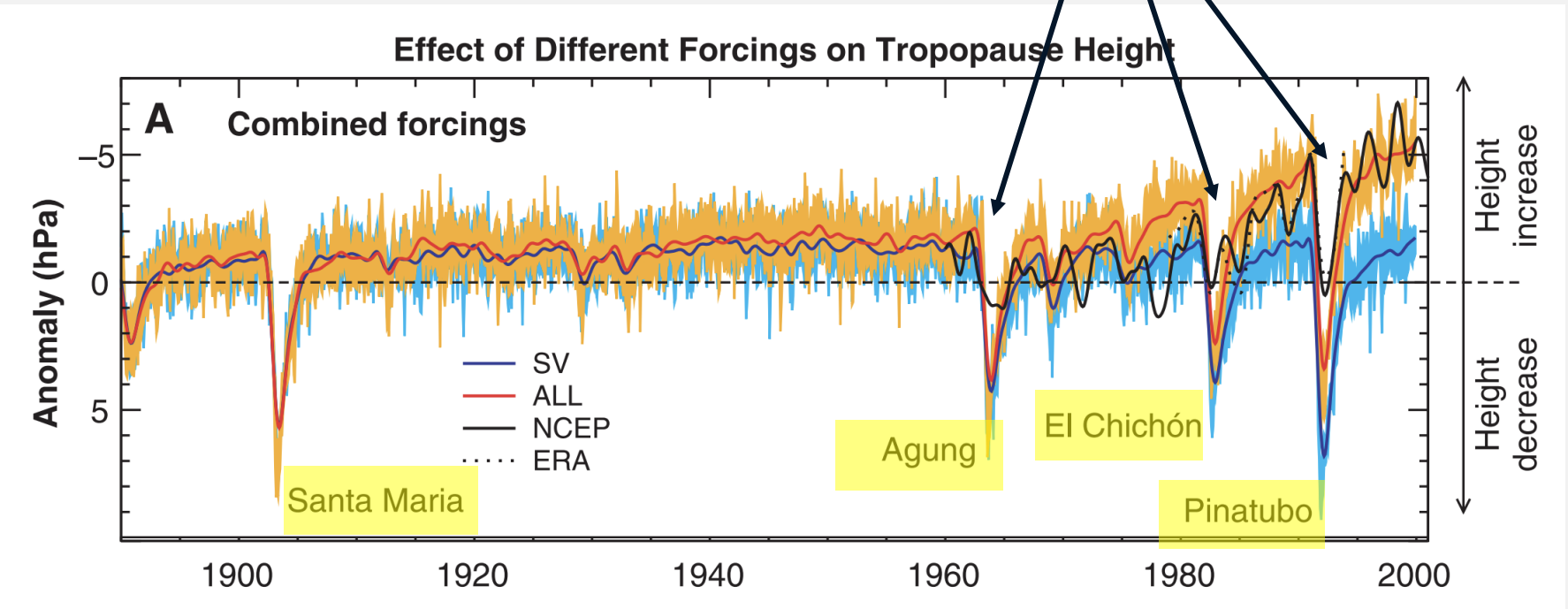


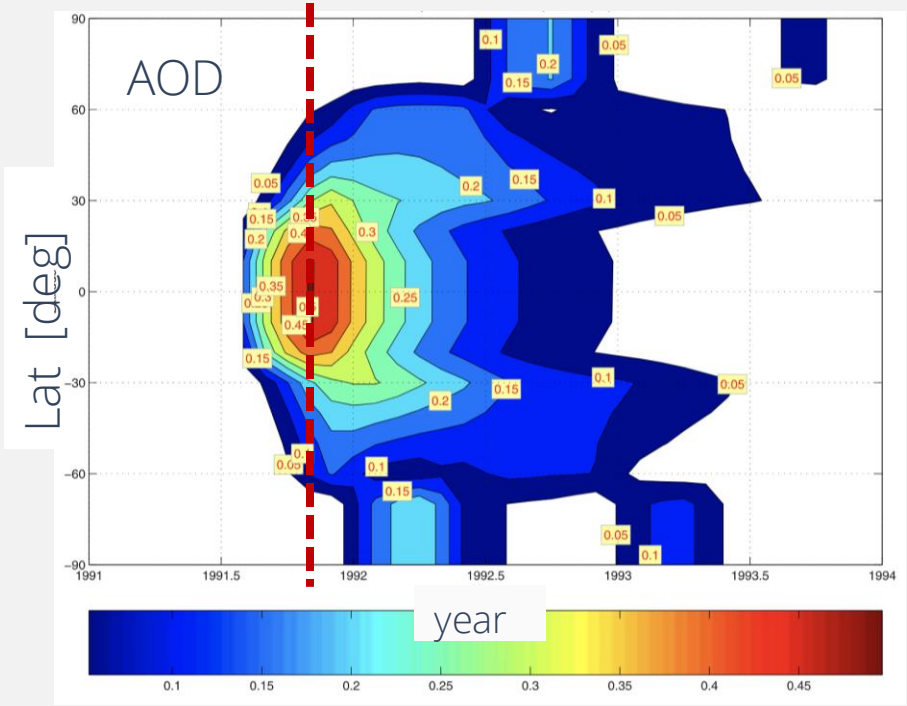
New advantage over this previous work: our calculation is derived from a full 3D field (E90); we thus have much more flexibility in searching related similar dynamic impacts

Result is Qualitatively Consistent with Literature

Q: Why do we choose a 4-month window for recovering the post-eruption tendencies?
A: Because that's where the signal is strongest. This is also consistent with various other studies, e.g.:

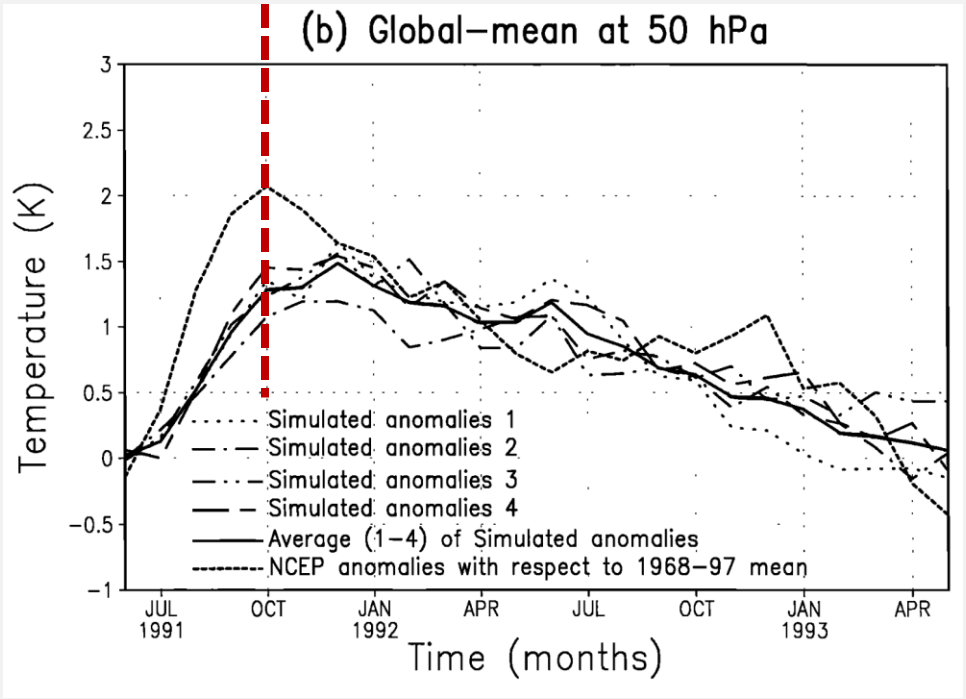
~4 months

Gao et al. (2008)



~4 months

Stenchikov et al. (1998)



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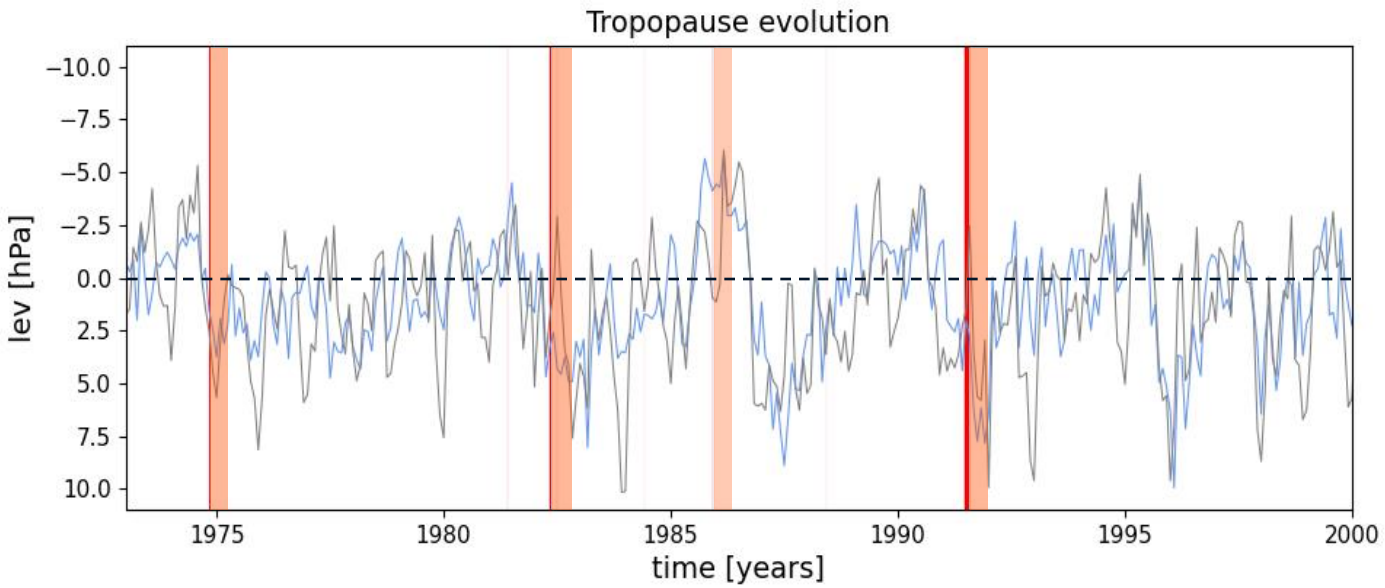
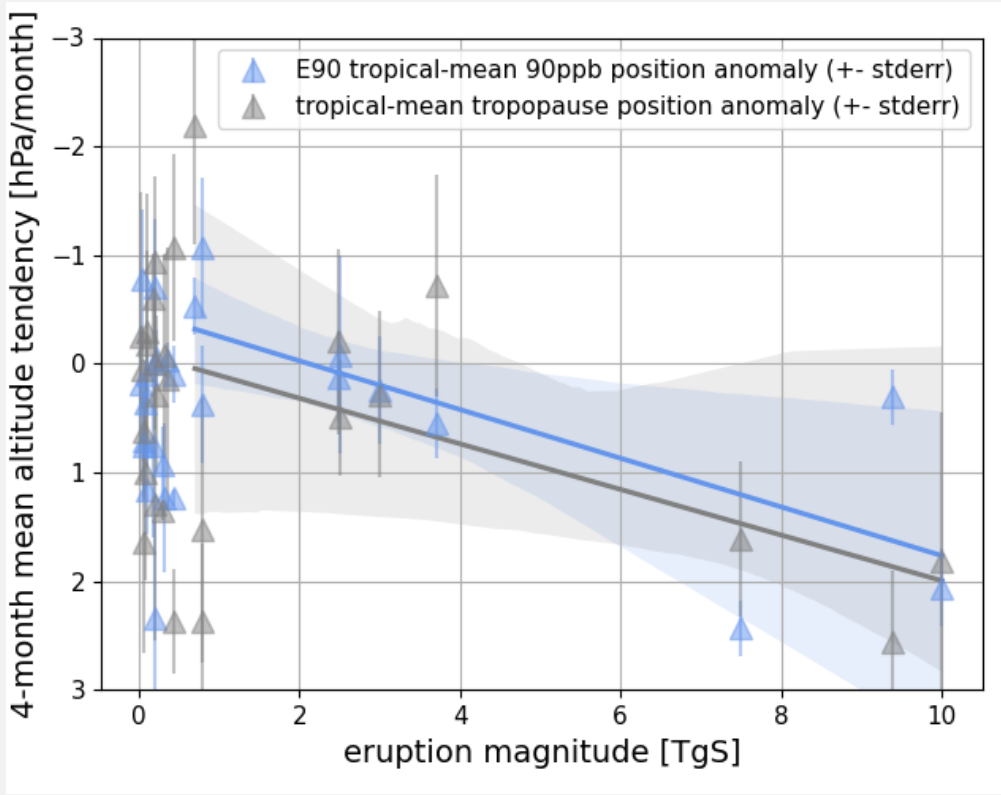
Weghted average on lat = [-20, 20]



4-month fitting window post-eruption



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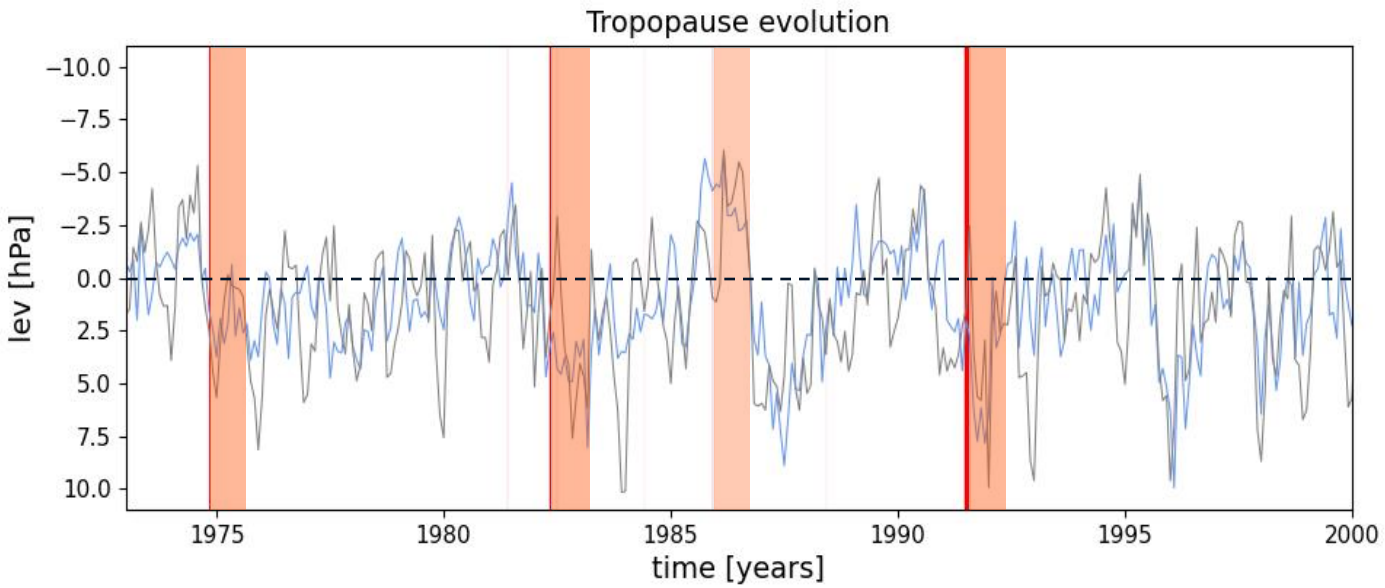
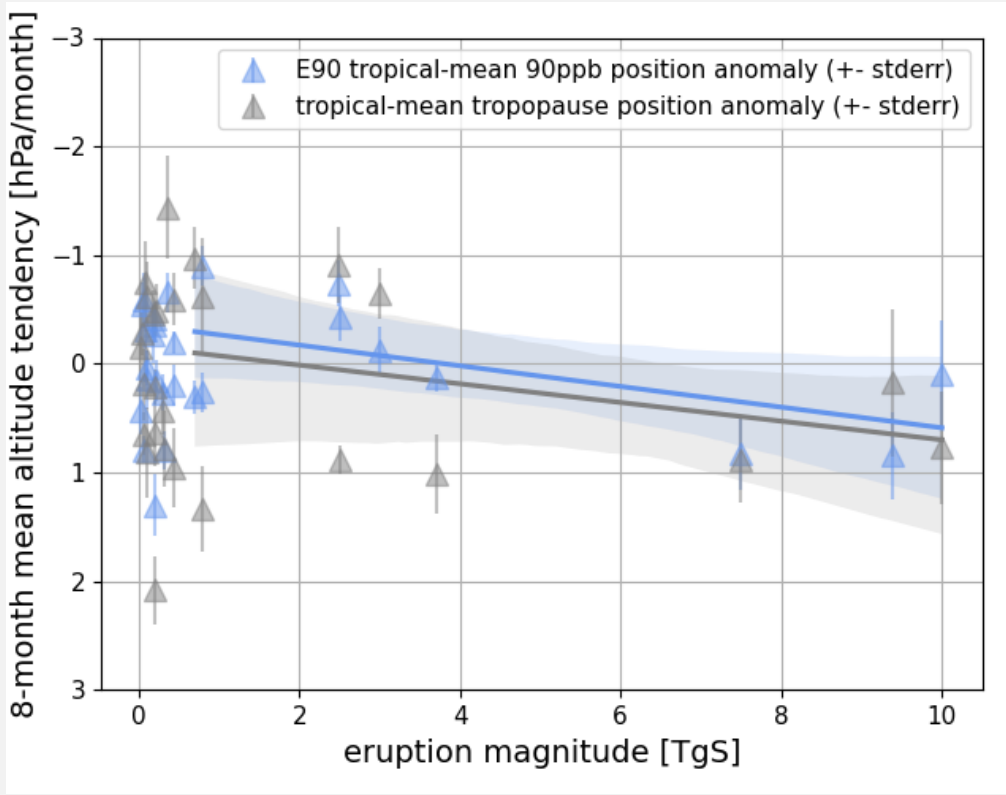


8-month fitting window post-eruption



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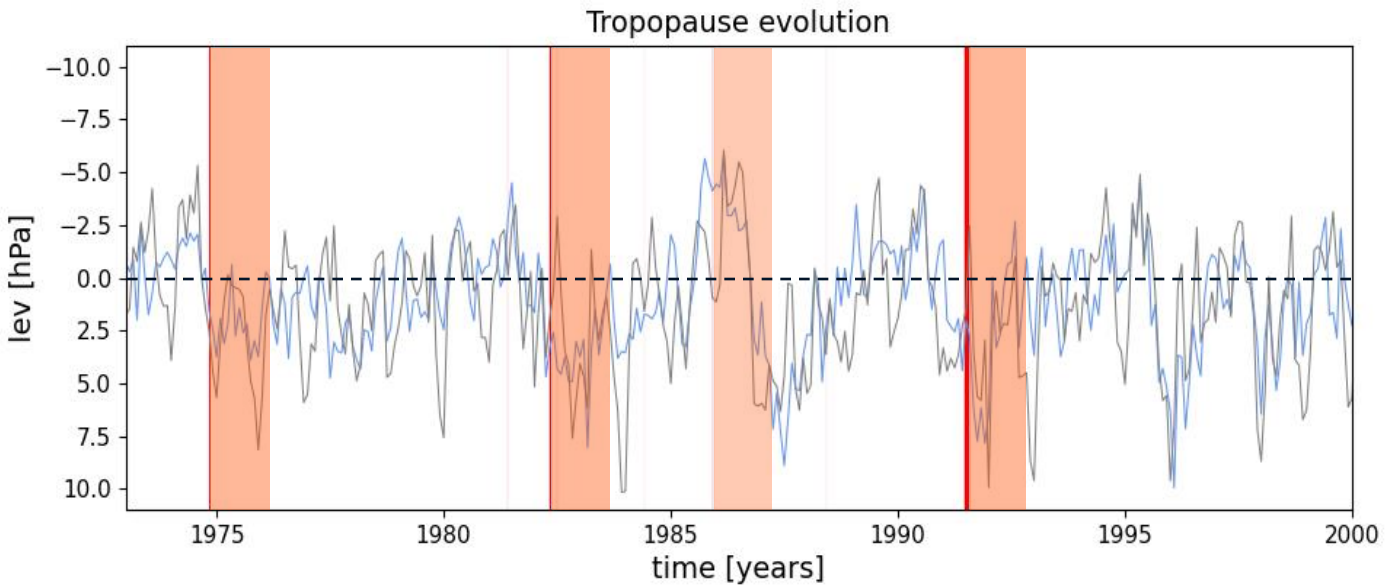
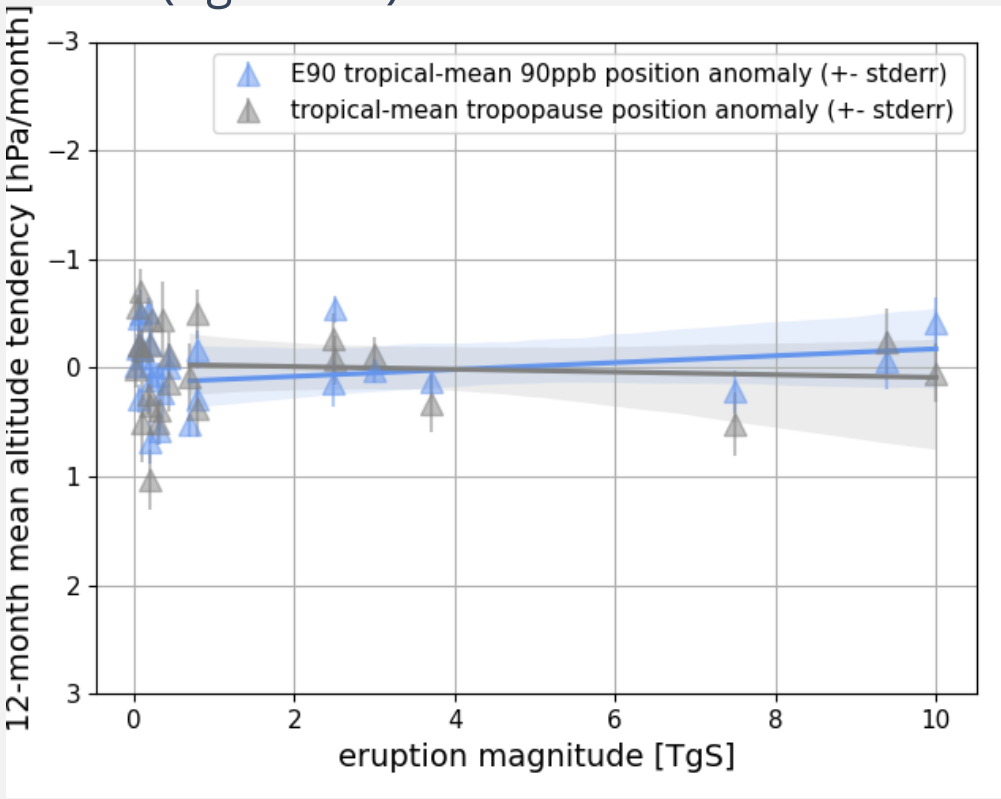
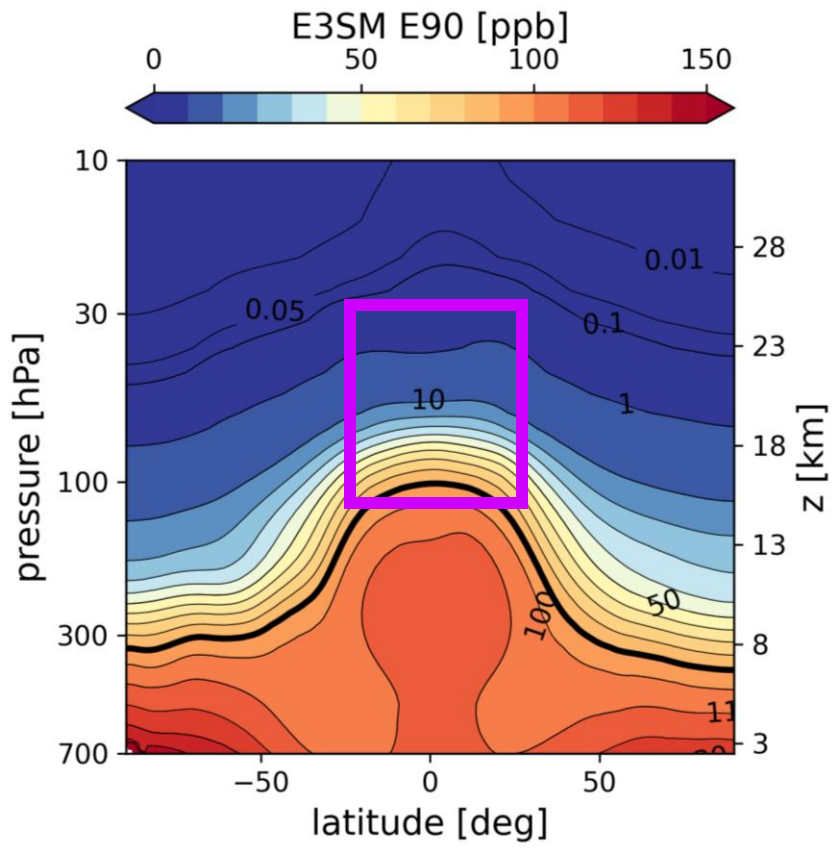


12-month fitting window post-eruption (signal lost)



Stratospheric E90 Anomalies Scale with Injection Magnitude



Stratospheric E90 Anomalies Scale with Injection Magnitude

Steps:
1) Find tropical mean tropical **stratospheric concentration of E90**
2) Compute concentration **anomaly**
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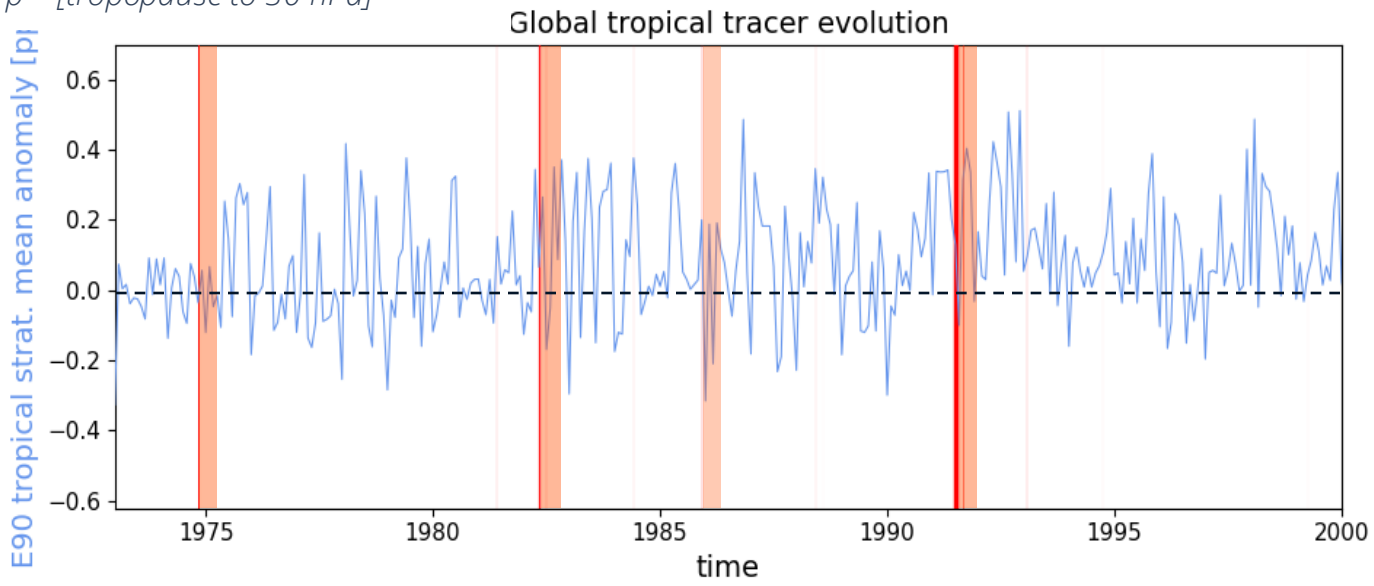
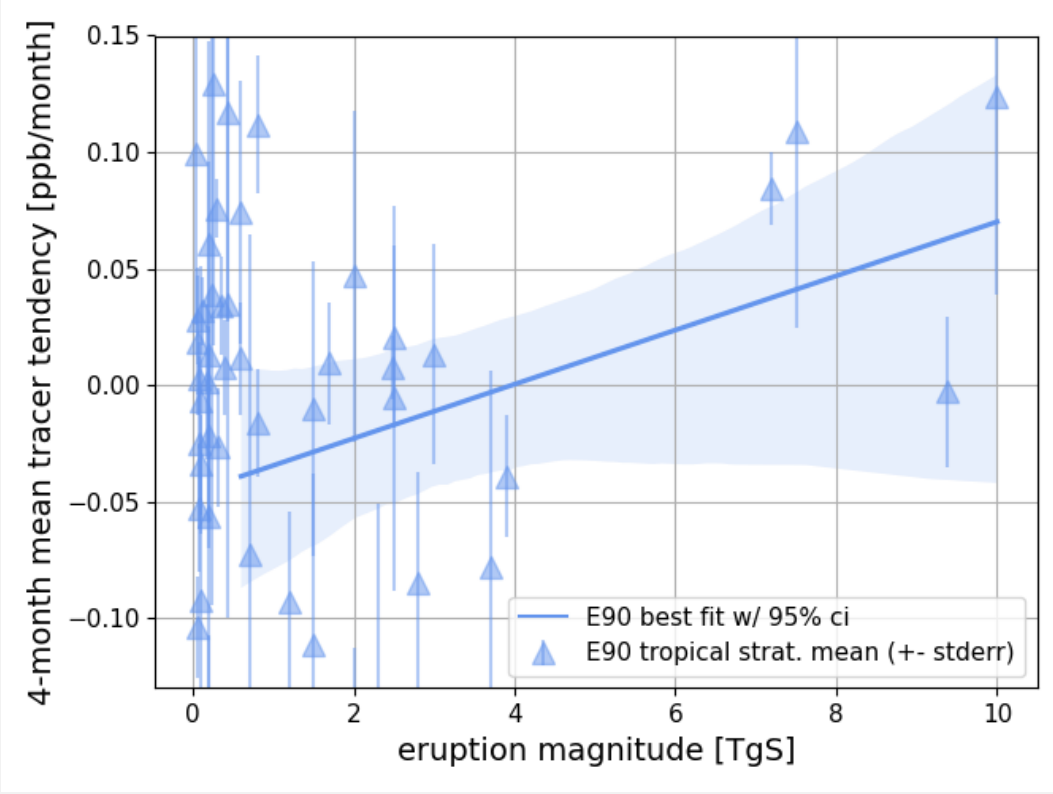
4) Plot the result as a function of eruption magnitude

Weighted average on lat = [-20, 20],
p = [tropopause to 30 hPa]





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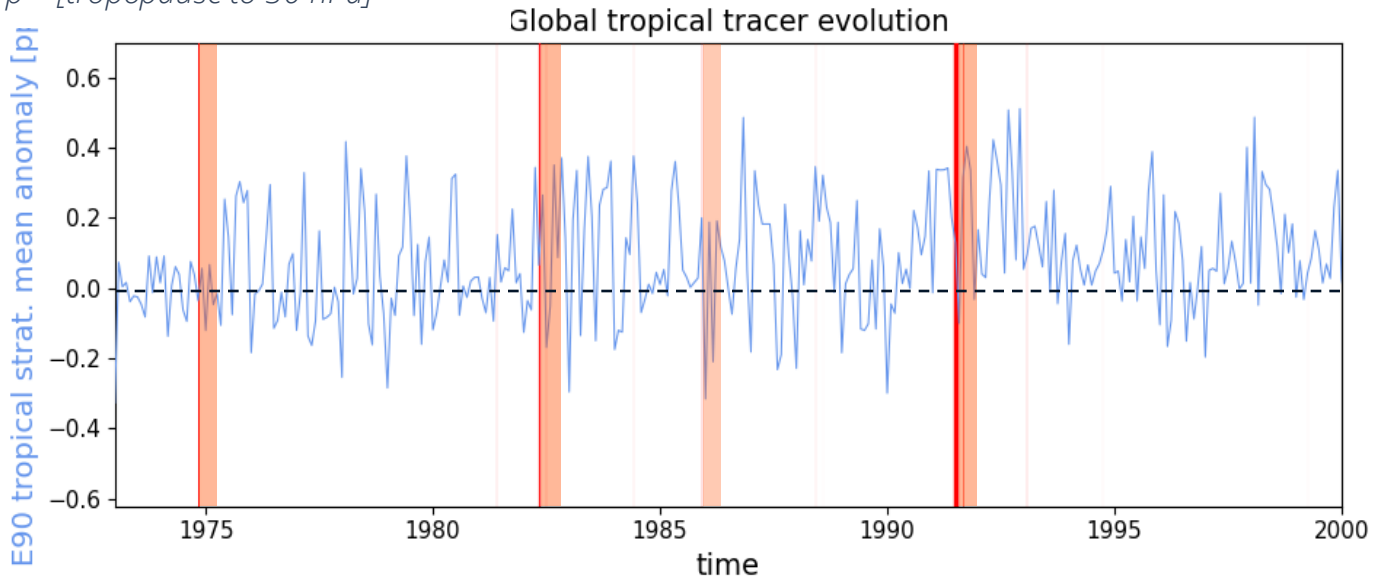
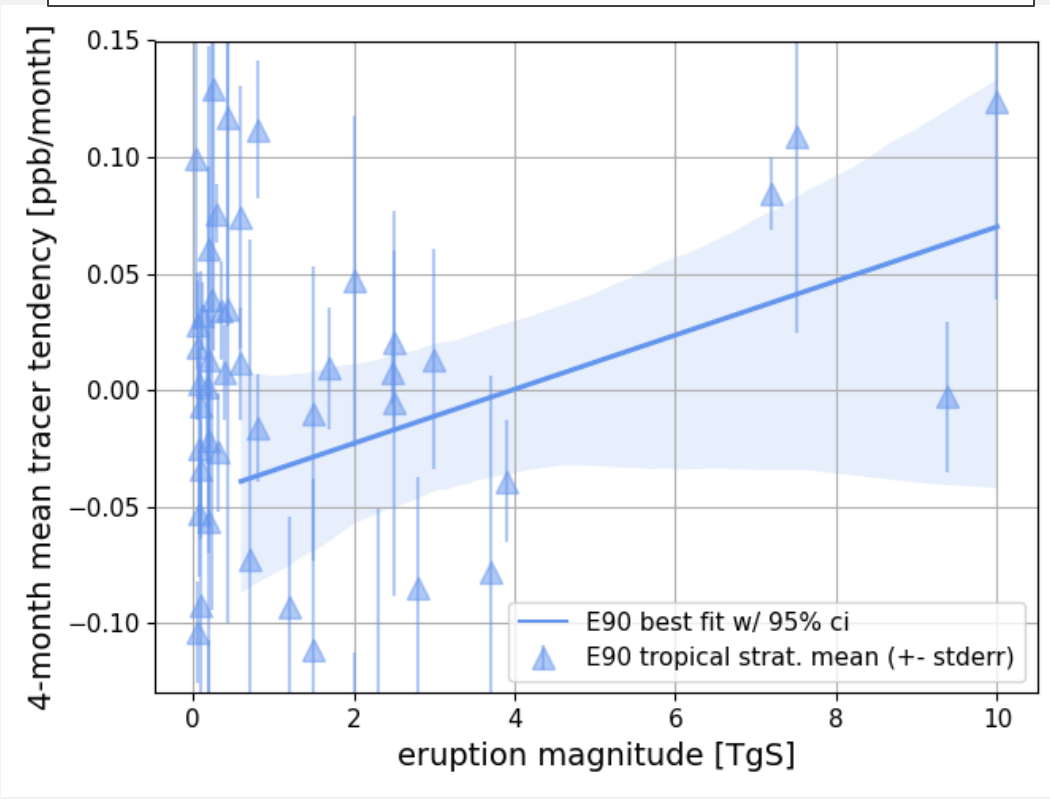
Volcanic forcing of the tropical stratosphere causes an *enhanced exchange across the tropical tropopause*, from troposphere to stratosphere, proportional to the strength of the forcing

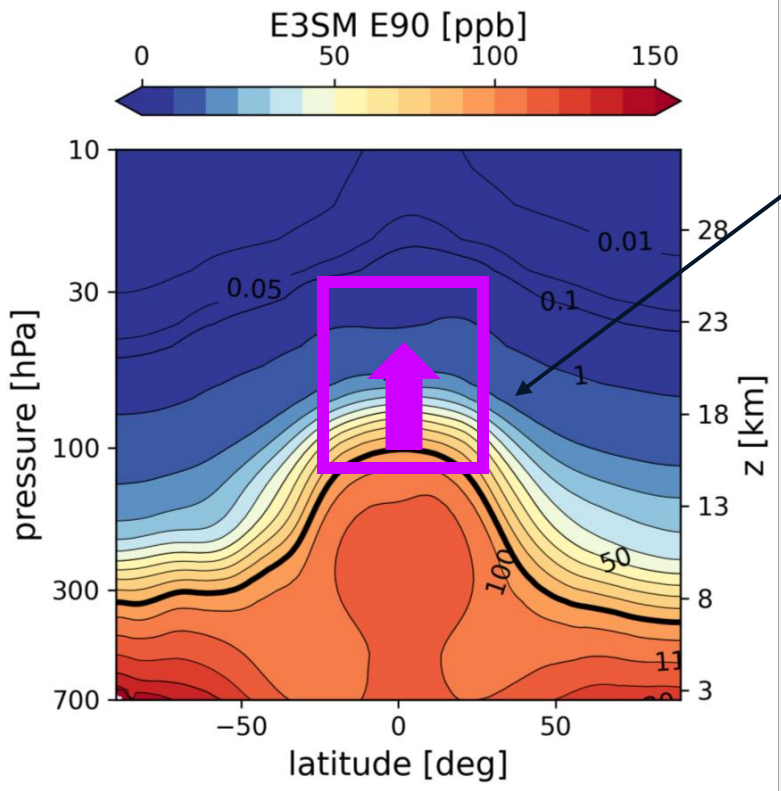
Weighted average on lat = [-20, 20], p = [tropopause to 30 hPa]





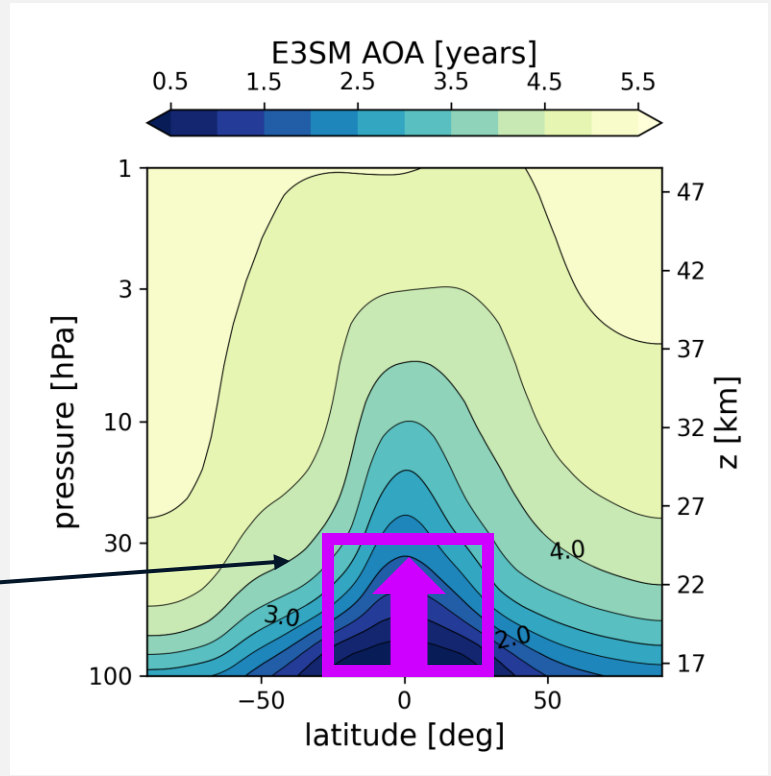
Stratospheric E90 Anomalies Scale with Injection Magnitude

Enhanced E90 concentrations above the tropopause imply **enhanced vertical residual velocity**



mean E90 concentration increases by lofting of isolines

age-of-air (AOA) isolines will be lofted simultaneously; mean AOA *decreases* (air becomes younger)



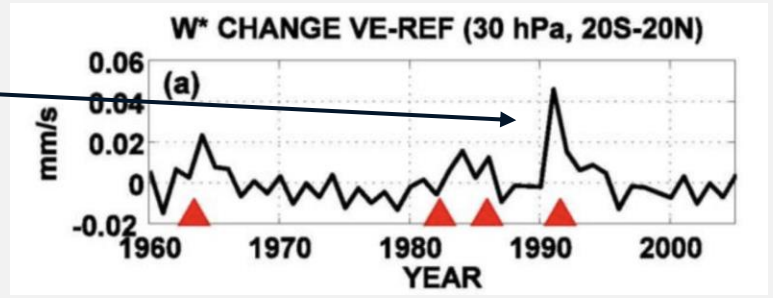
Result is Qualitatively Consistent with Literature

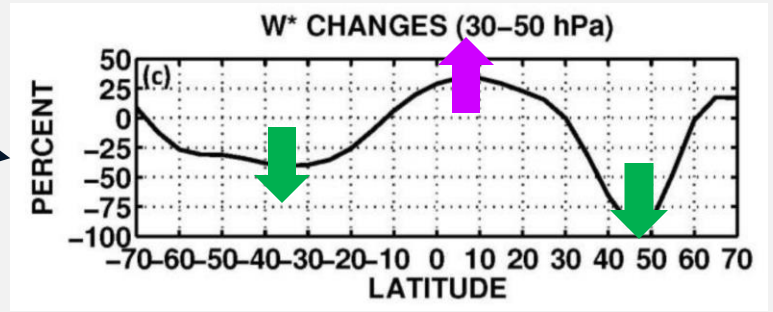
ULAQ-CCM results from Pitari et al. (2016)
"VE - REF" is analogous to CLDERA "forced - counterfactual"

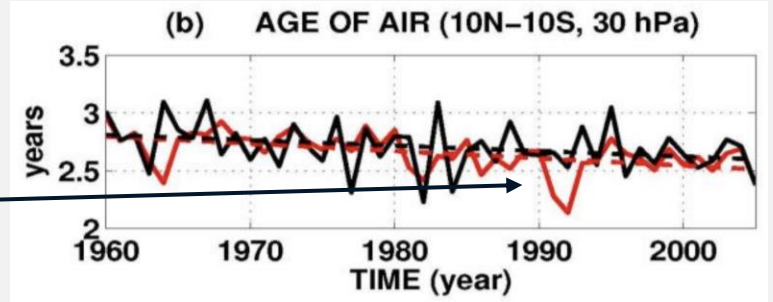
Volcanic eruptions (red triangles) enhance vertical residual velocity in the tropical stratosphere

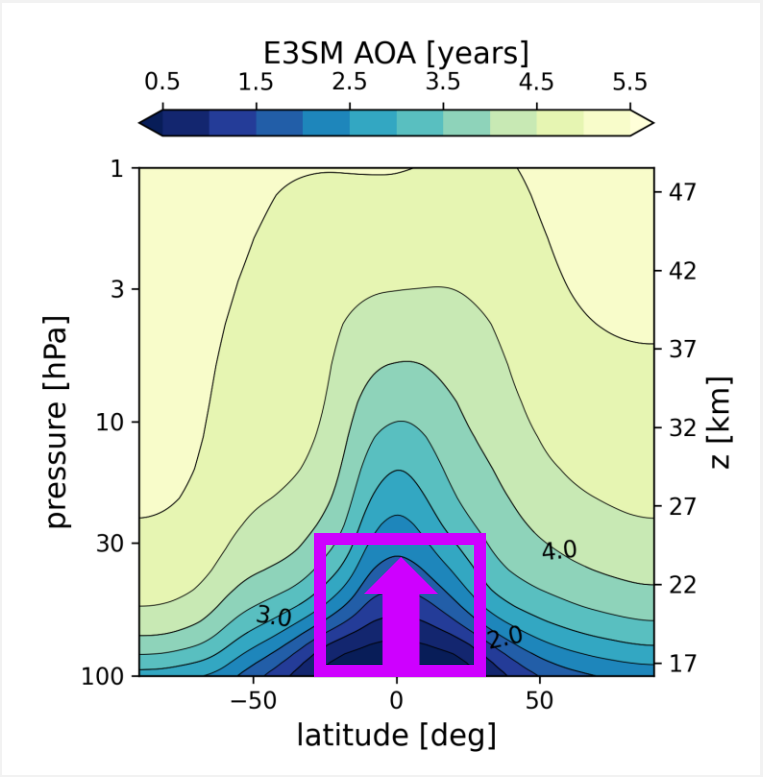
Full story outside of the tropics is more complicated; enhanced **updrafts** in the tropics, enhanced **downdrafts** in the midlatitudes (accelerated Brewer Dobson Circulation)

Younger air is advected into the region; mean AOA drops

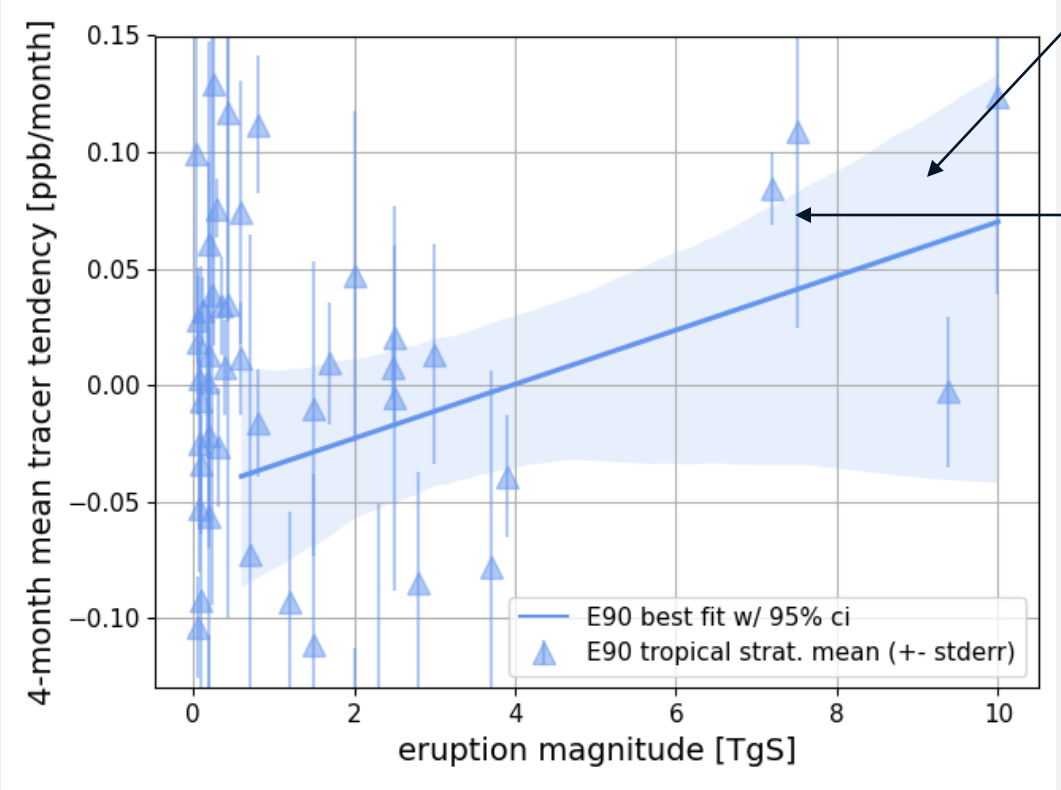








Sources of Uncertainty: Limited Data, Variable Background



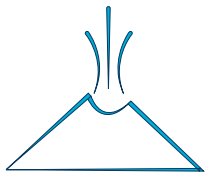
- Far too few high-mass eruptions for a robust result (confidence band on fit)
- Likely too much variation in the background conditions of each eruption for a clean signal
- Monthly tracer data is provided too coarsely (vertical error bars on single points)

Next Steps:

Make use of varying source magnitude low-variability P1 runs once available. These will allow:

- Fill in the high-mass end (figure on right)
- Extend analysis to include the complementary tracer ST80 (implementation was recently updated)

Also planned: shorter (~6 month) runs coincident with P1 ensemble members for extracting dynamical variables at higher resolution



Questions?