

# **Eruption plume height and its impact on volcanic forcing: Towards more realistic volcanic forcing reconstructions and scenarios for future climate projections**

***Thomas J. Aubry, Matthew Toohey, A.Mark Jellinek & Anja Schmidt***



THE UNIVERSITY  
OF BRITISH COLUMBIA

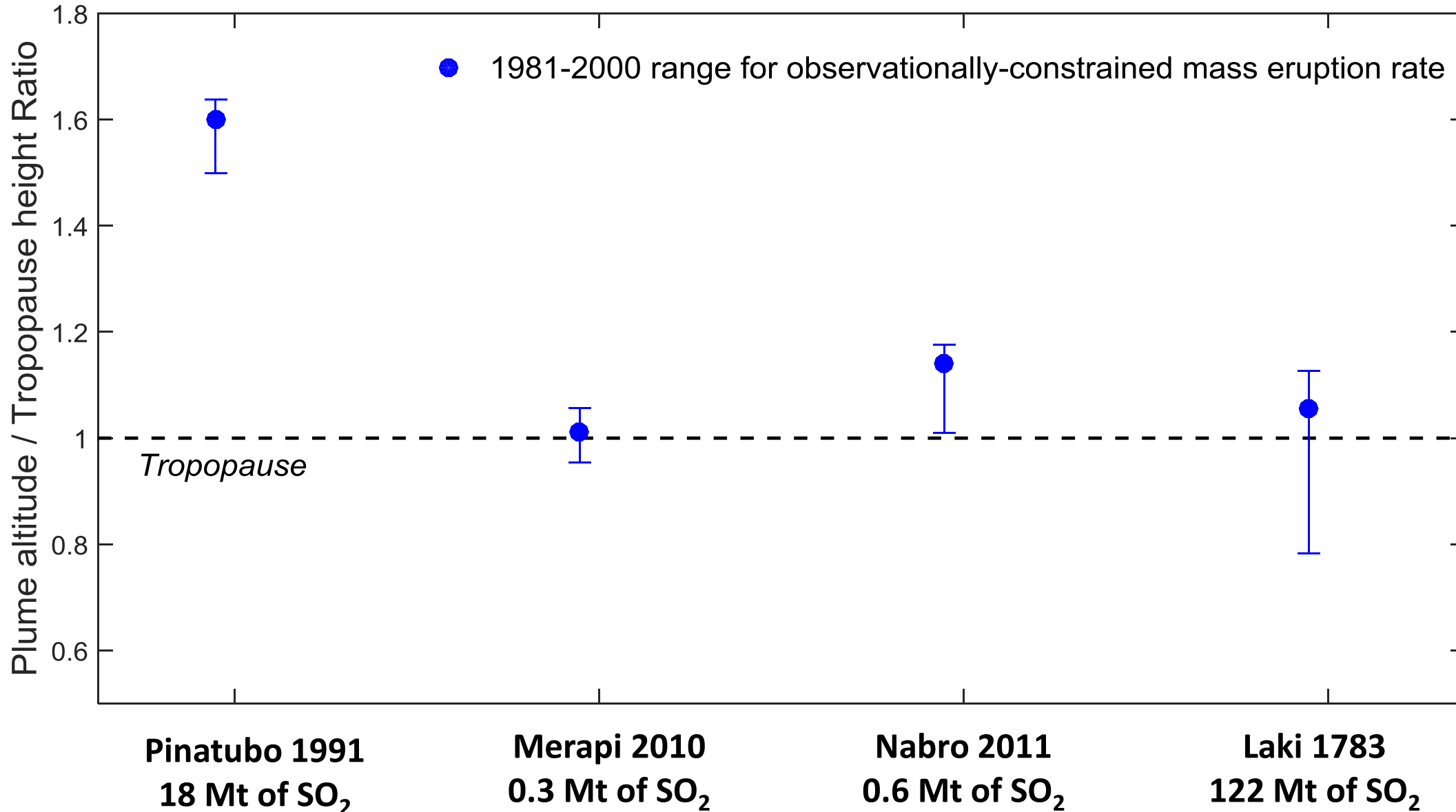


Helmholtz Centre for Ocean Research Kiel



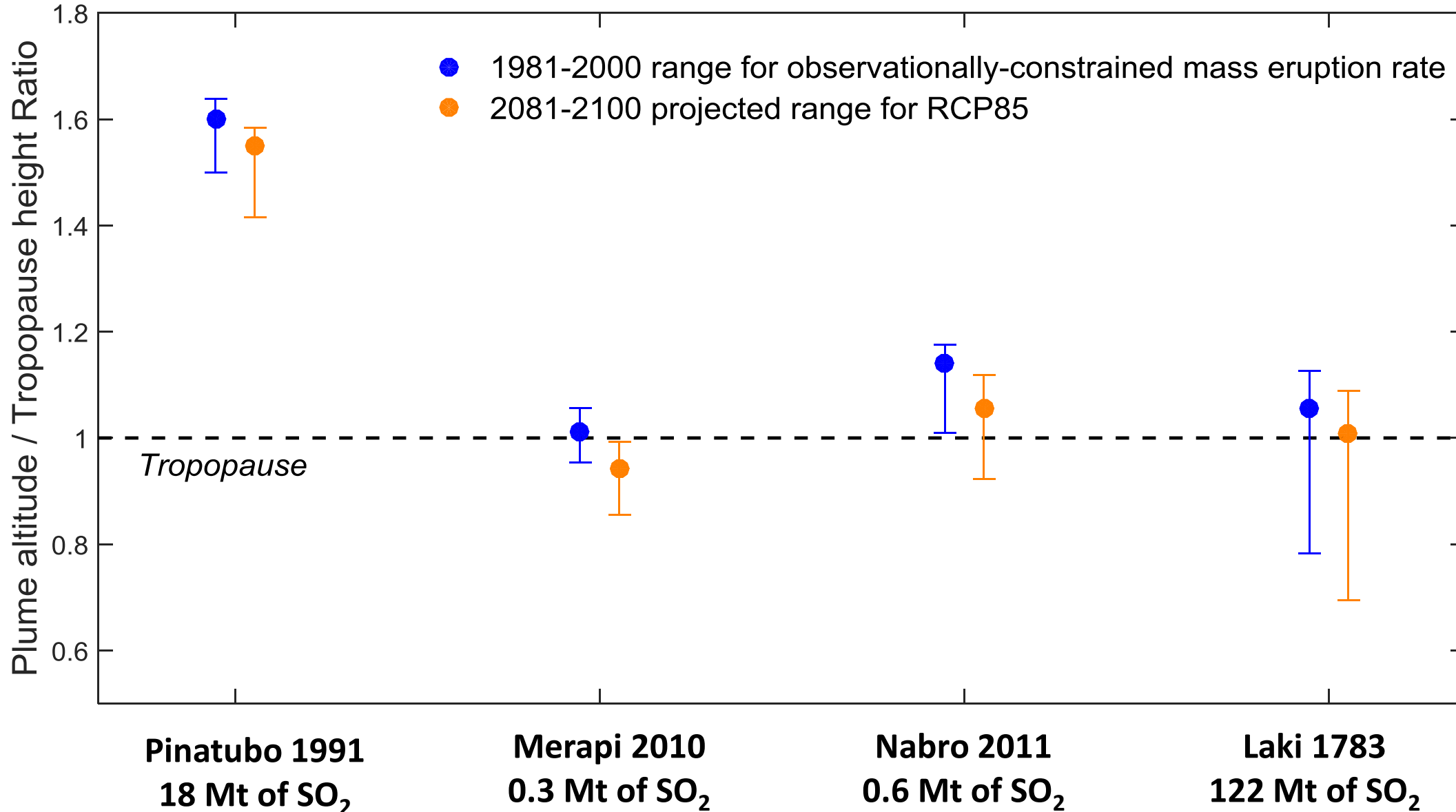
UNIVERSITY OF  
CAMBRIDGE

# Motivation: To what extent will projected changes in volcanic plume height impact volcanic forcing?



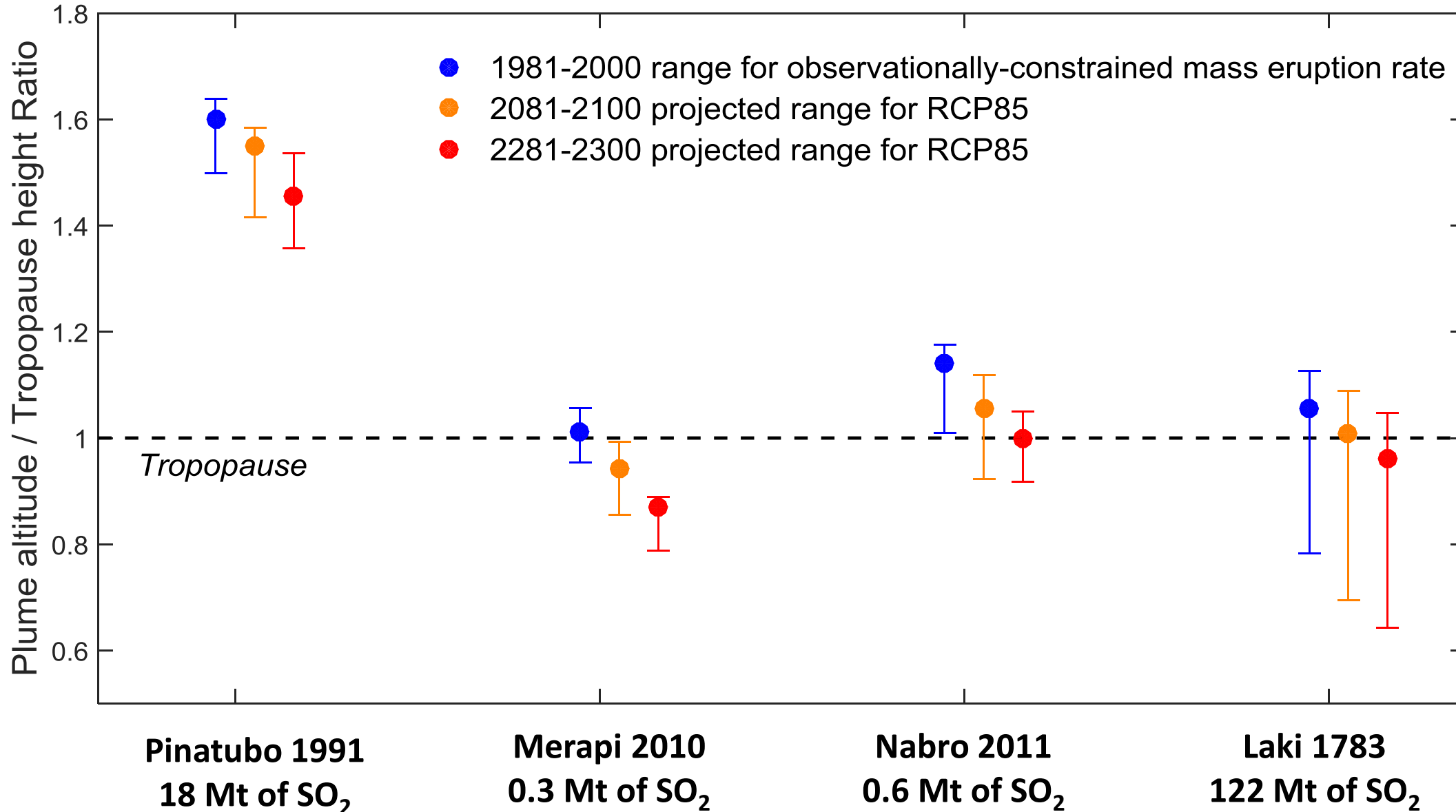
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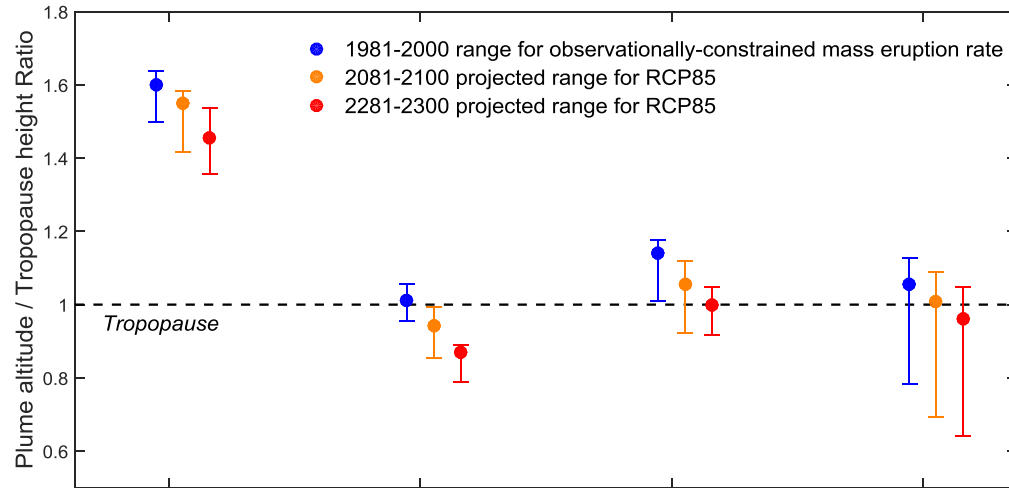
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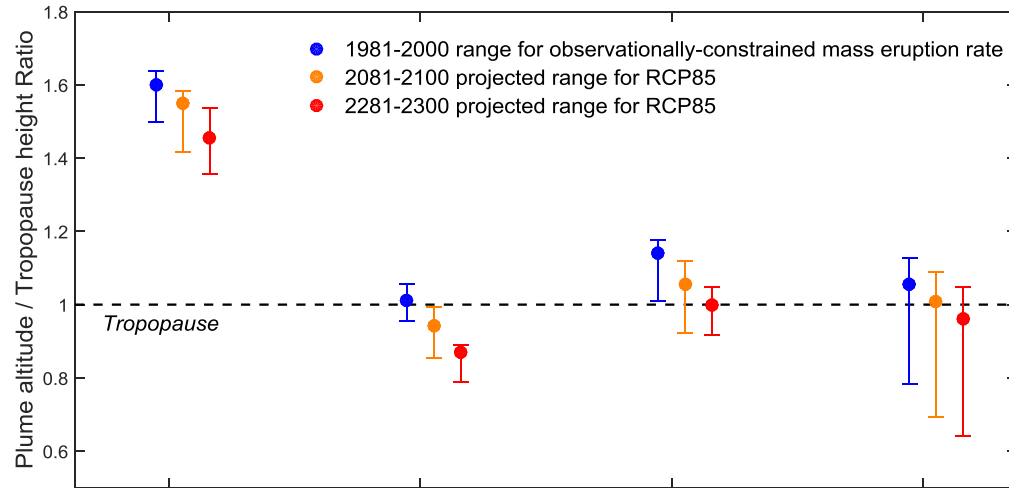
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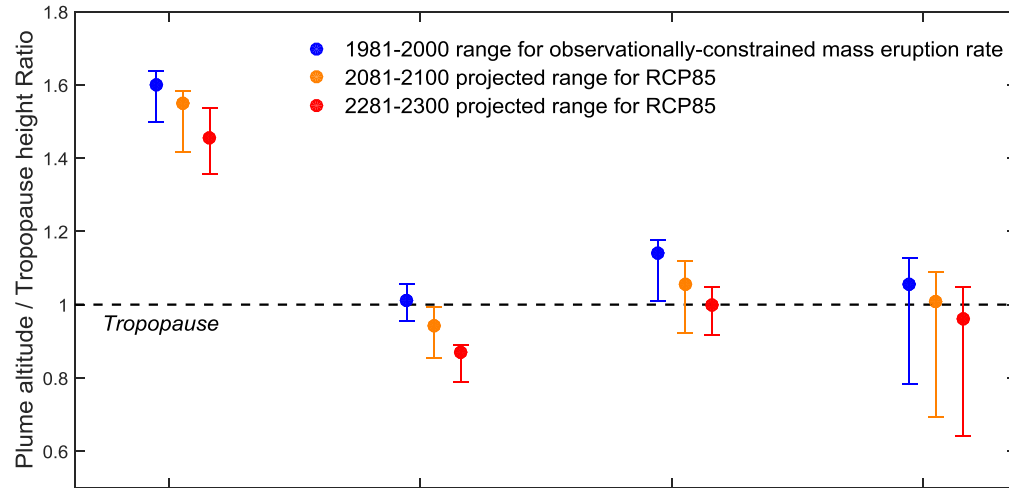
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→ **We design a new idealized model overcoming these limitations**



**I - Design and performance of a new idealized model of volcanic forcing**

**II – Scenarios for future volcanic forcing and estimation of a climate volcano feedback**

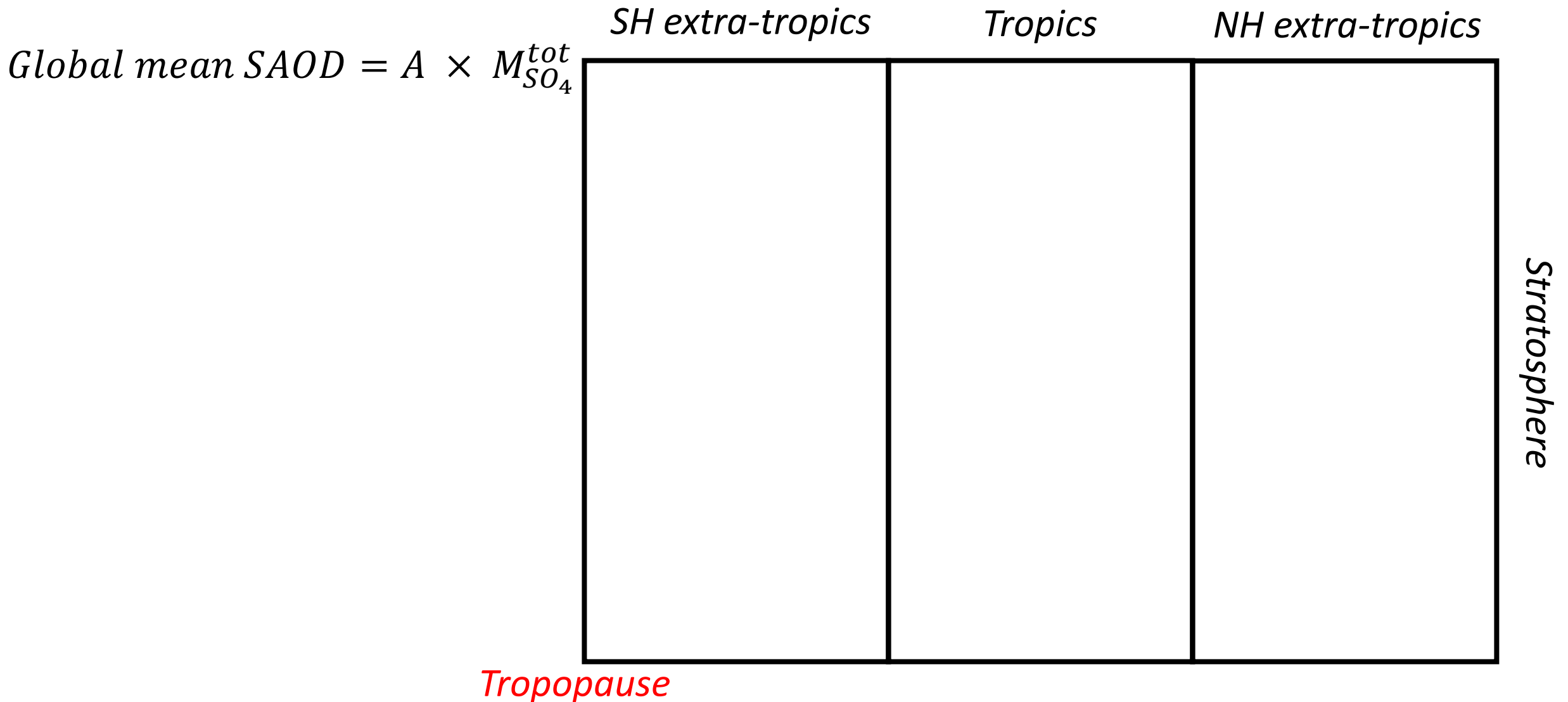




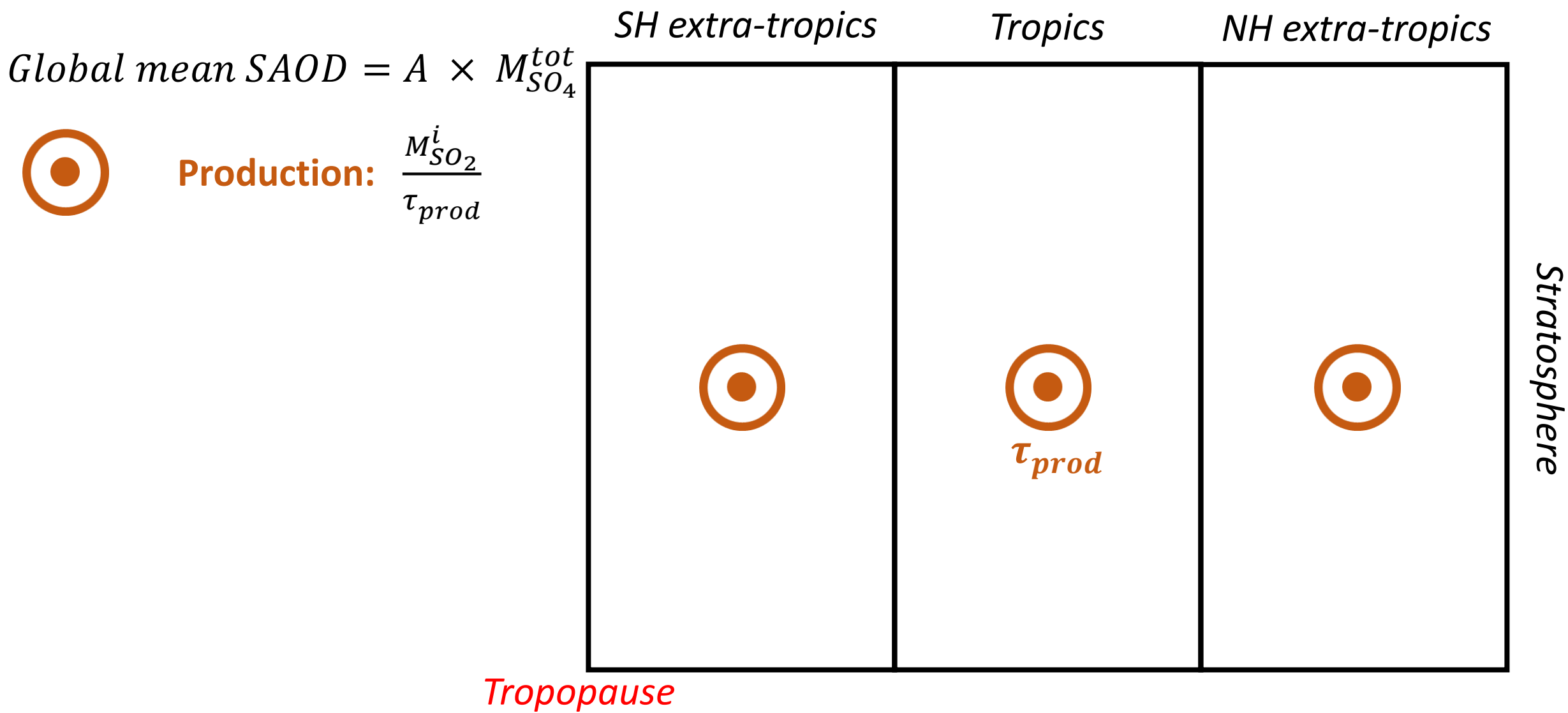
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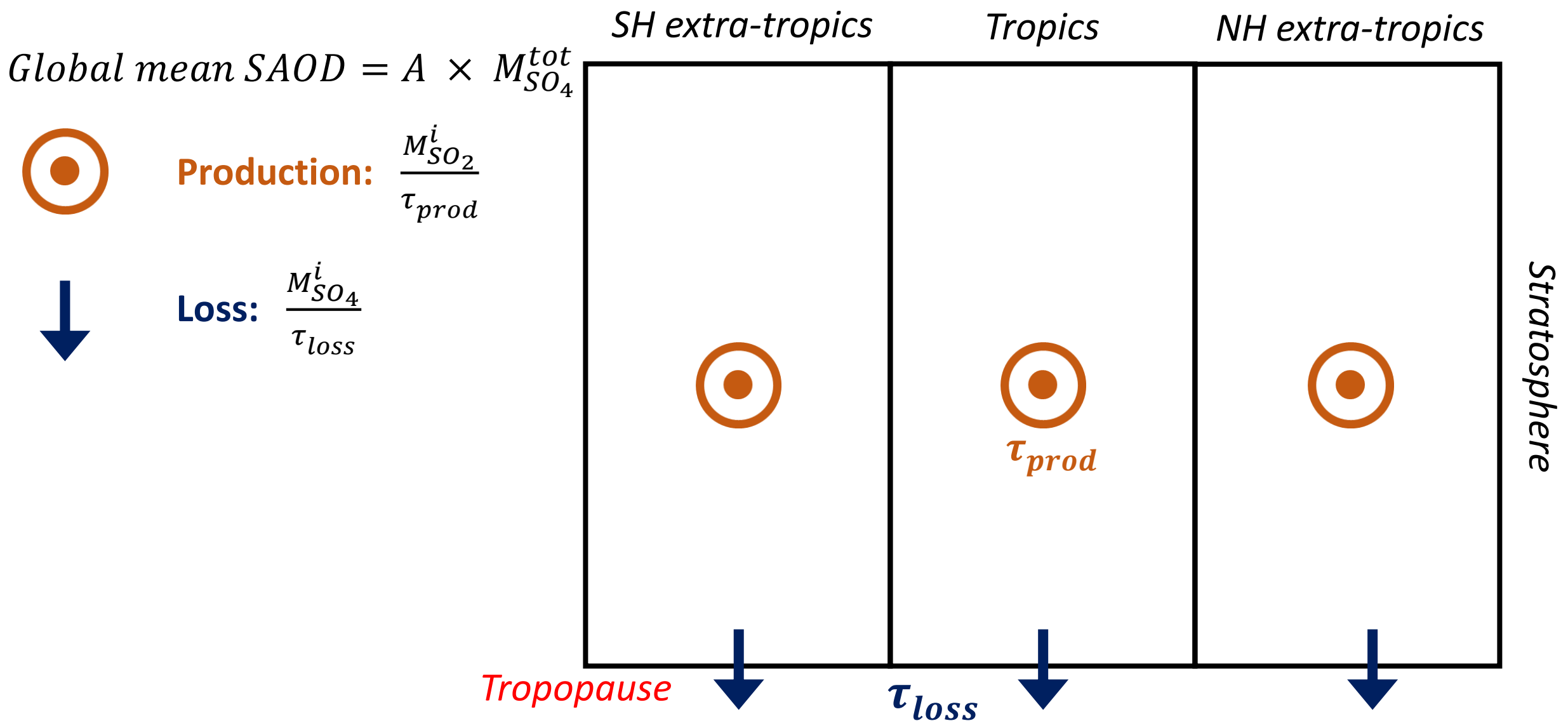
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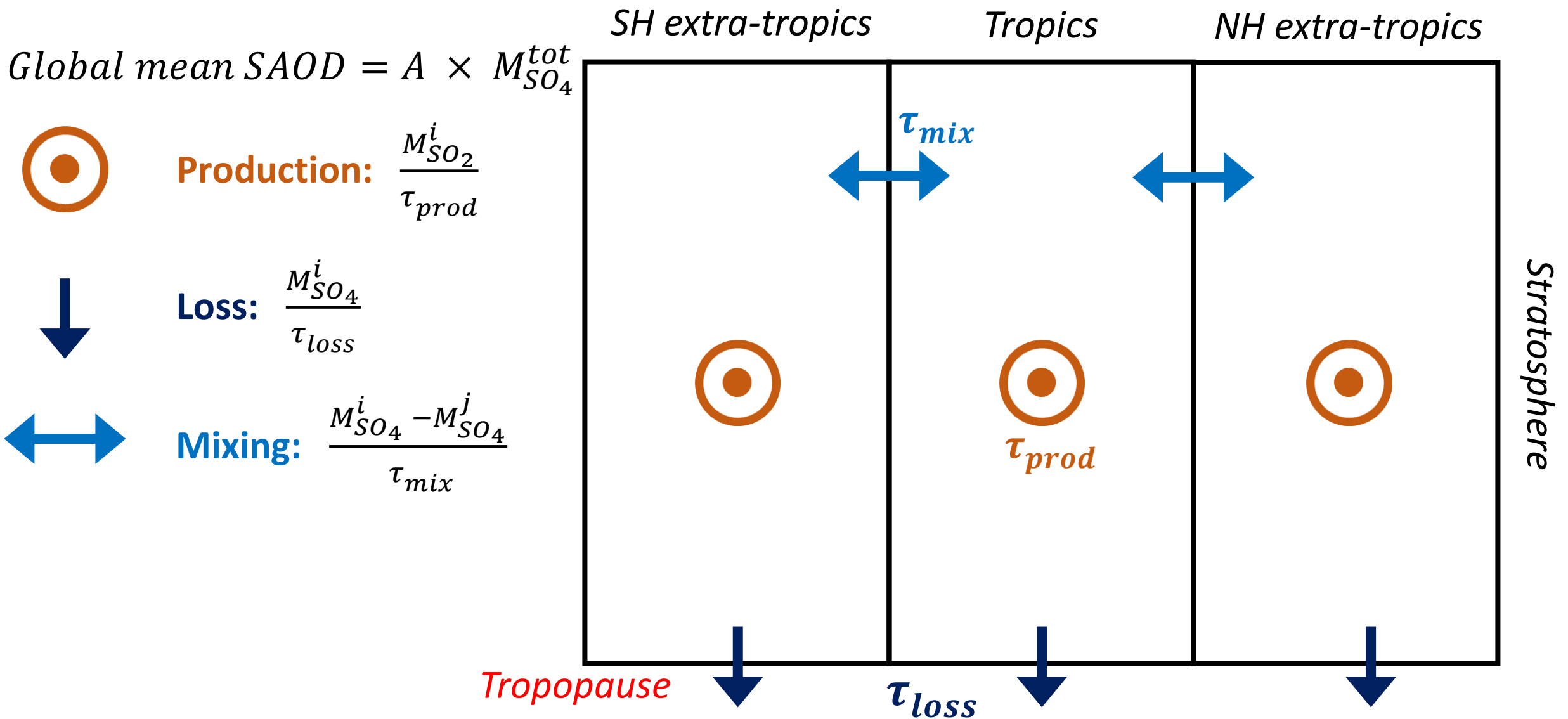
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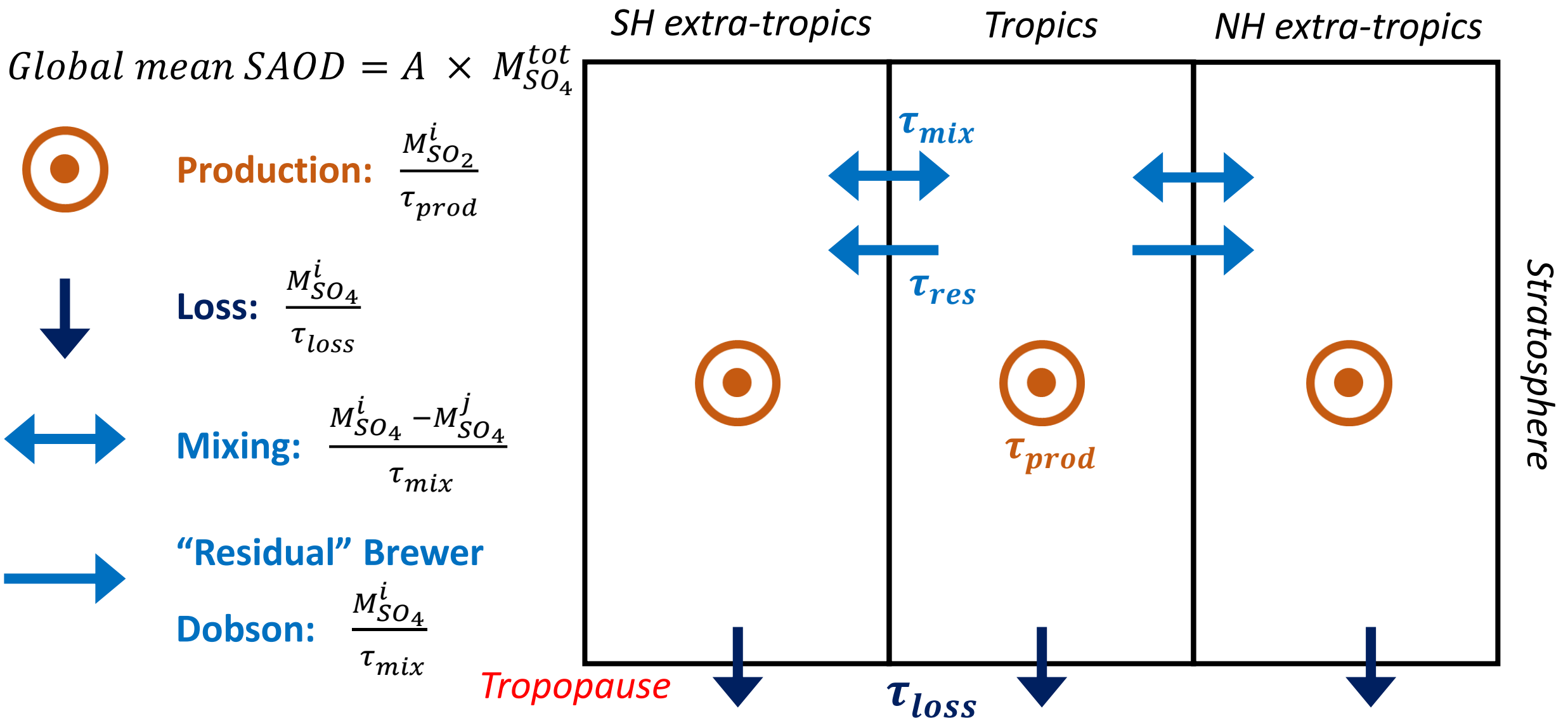
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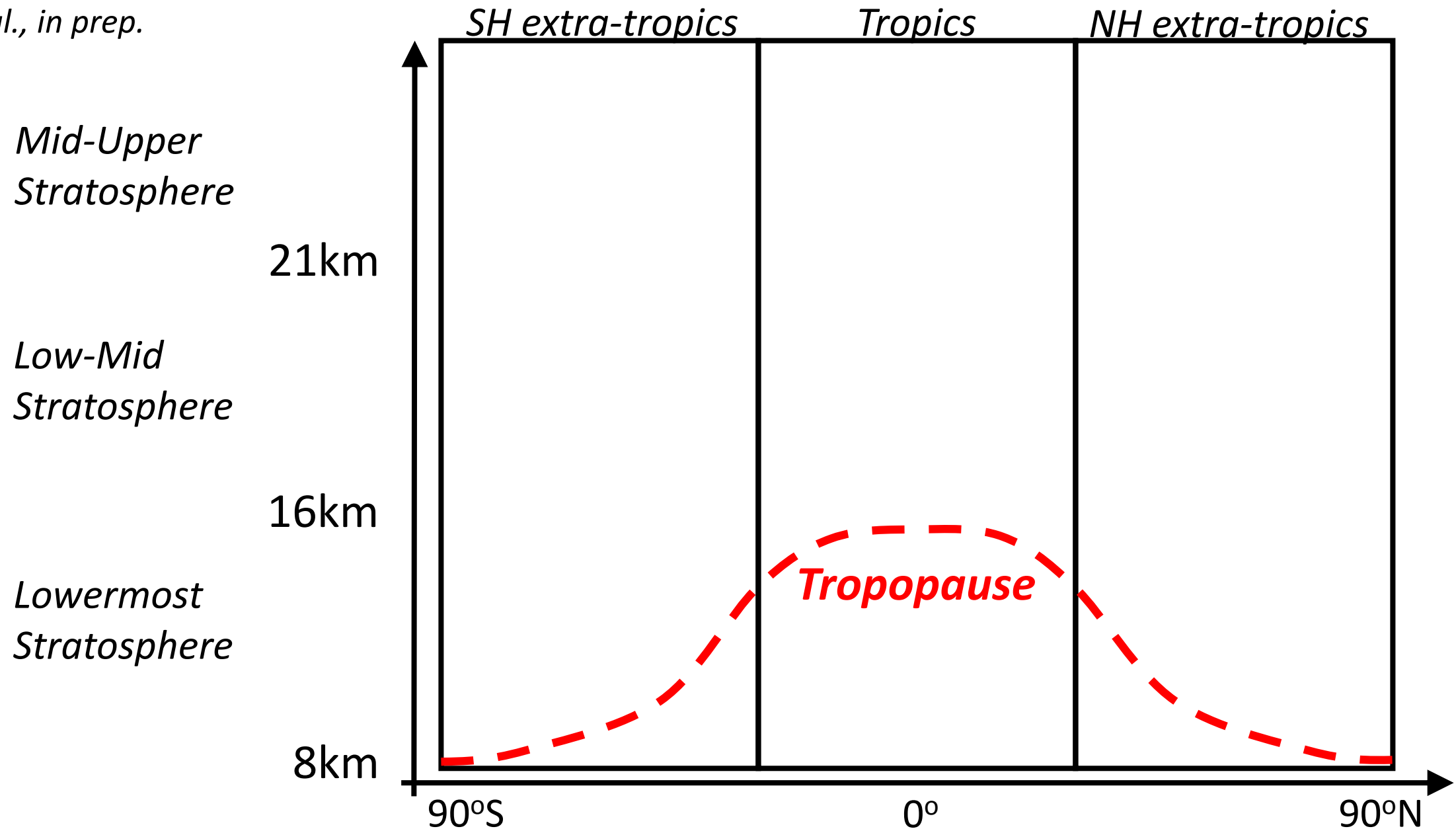


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# Design of our new idealized model

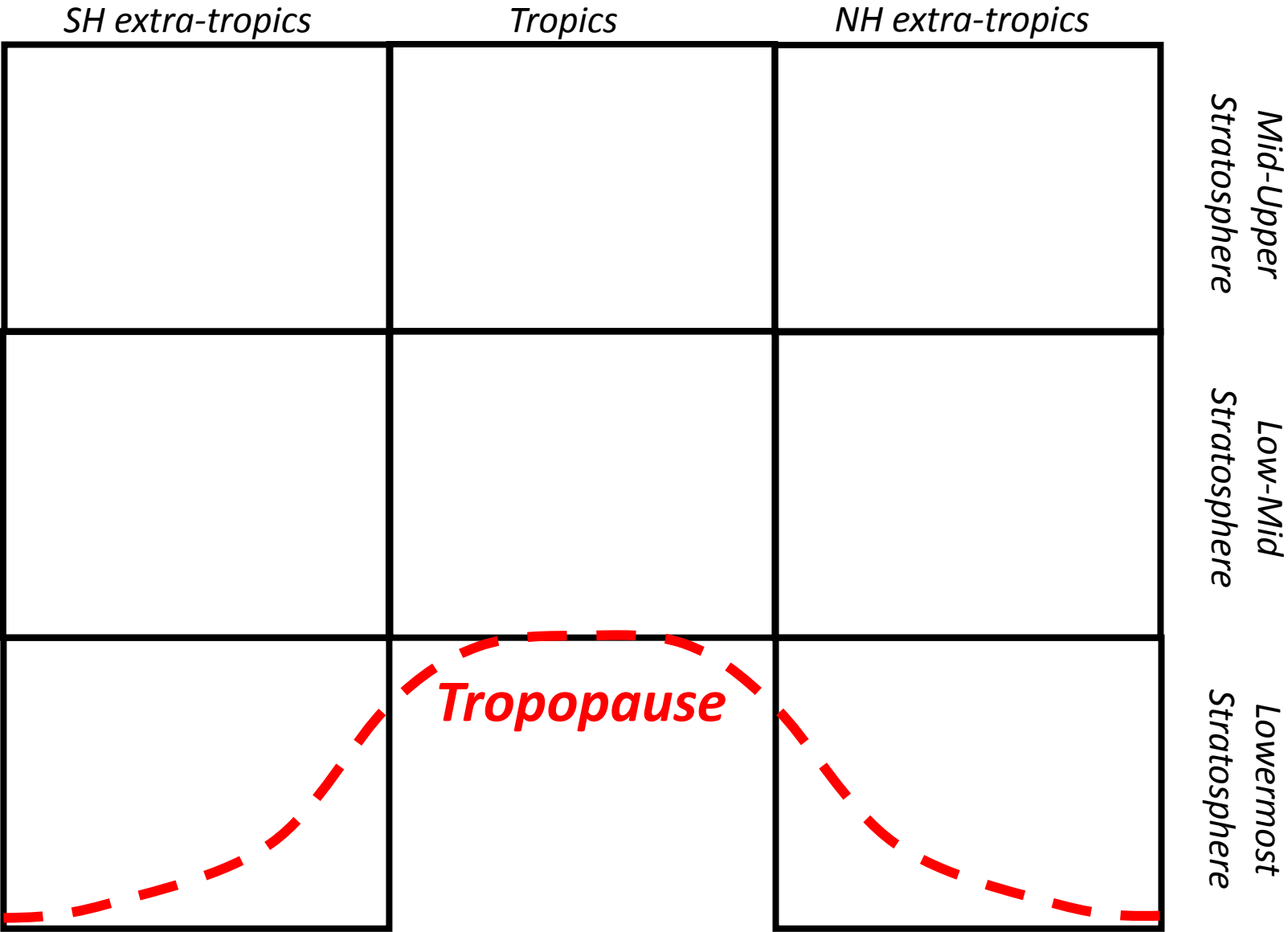
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# Design of our new idealized model

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*Global mean SAOD = A × M<sup>tot</sup><sub>SO<sub>4</sub></sub>*













# Design of our new idealized model

Aubry et al., in prep.

Global mean SAOD =  $A \times M_{SO_4}^{tot}$

 **Production:**  $\frac{M_{SO_2}^i}{\tau_{prod}}$

	SH extra-tropics	Tropics	NH extra-tropics	
				Mid-Upper Stratosphere
		 $\tau_{prod}$		Low-Mid Stratosphere
				Lowermost Stratosphere

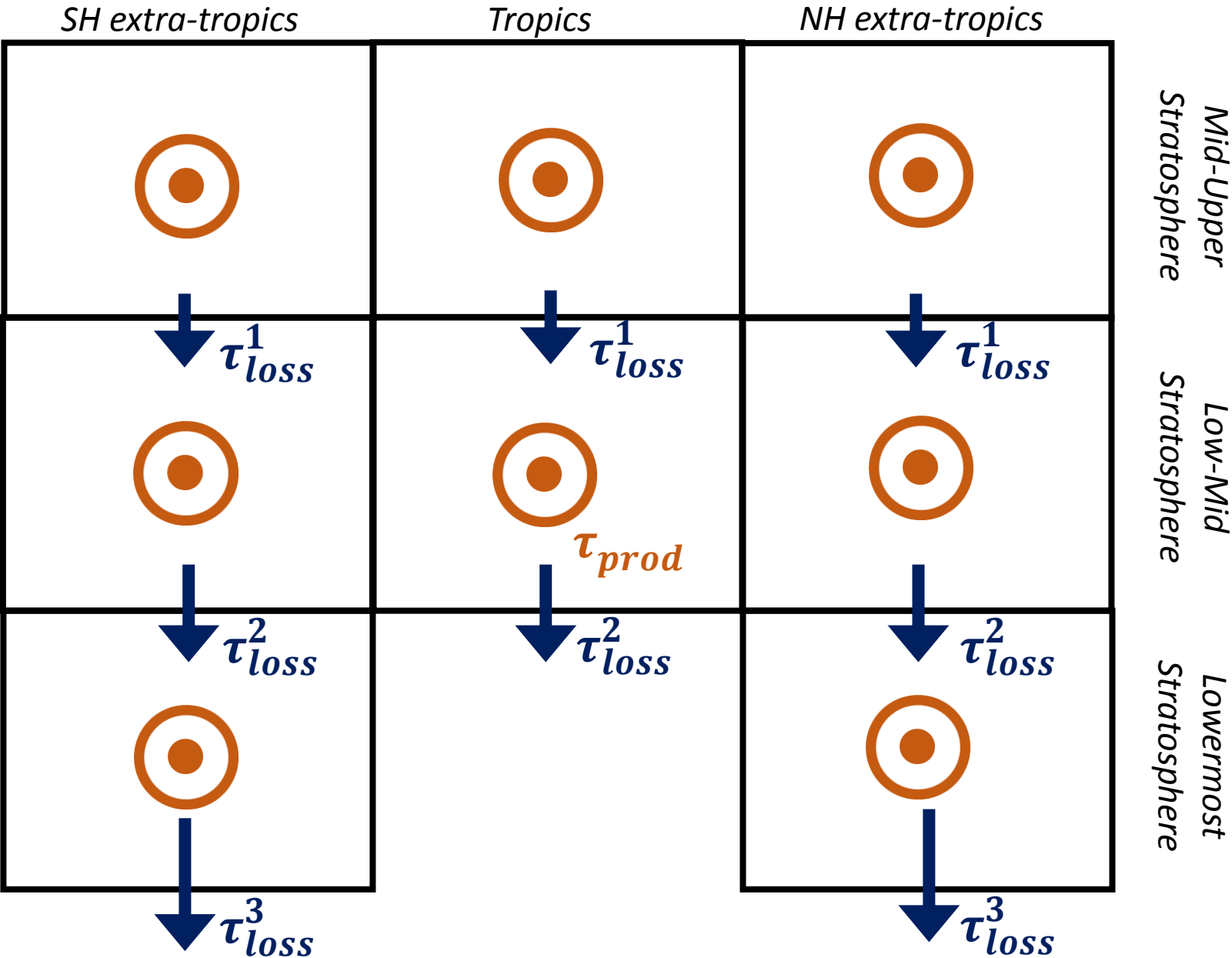
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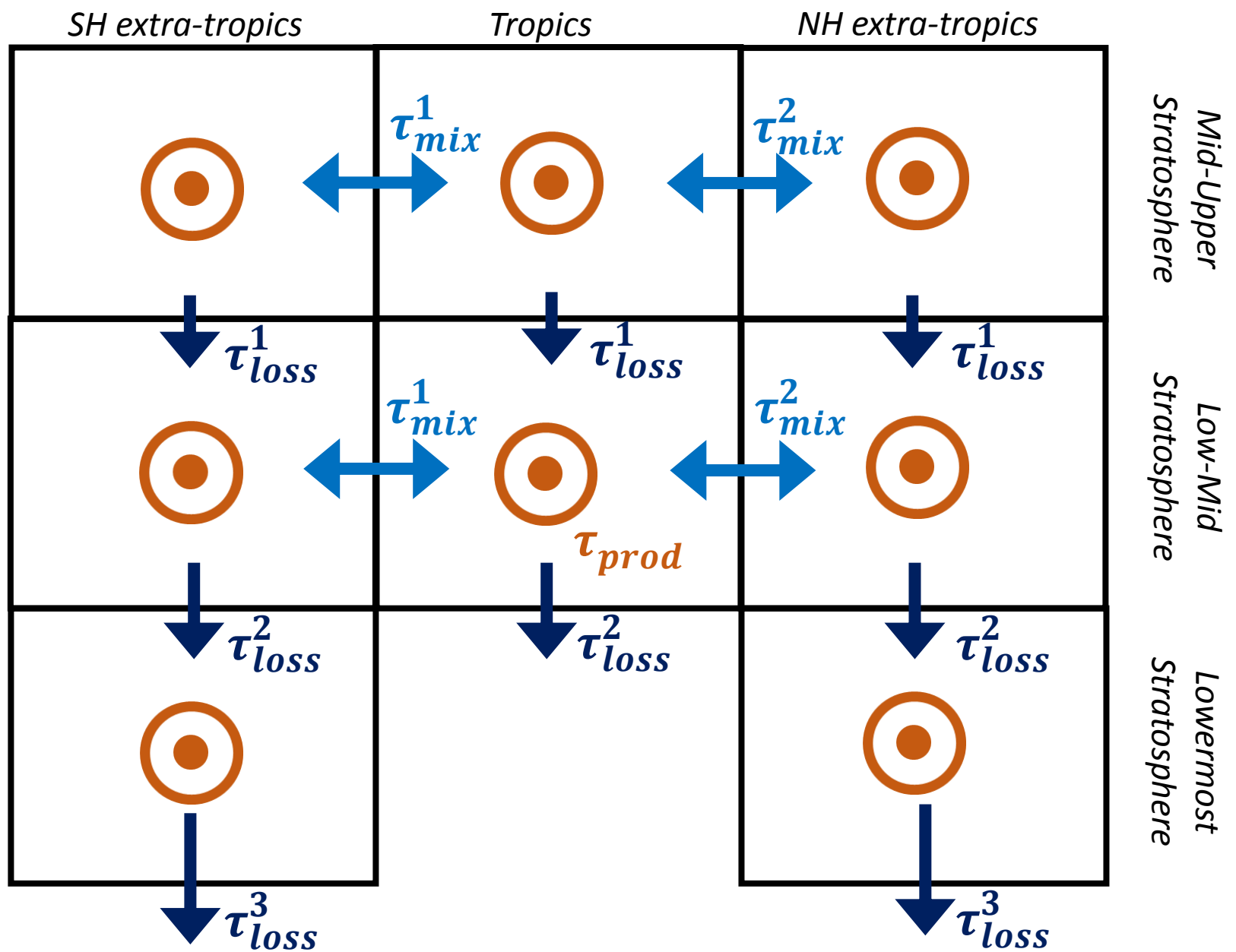
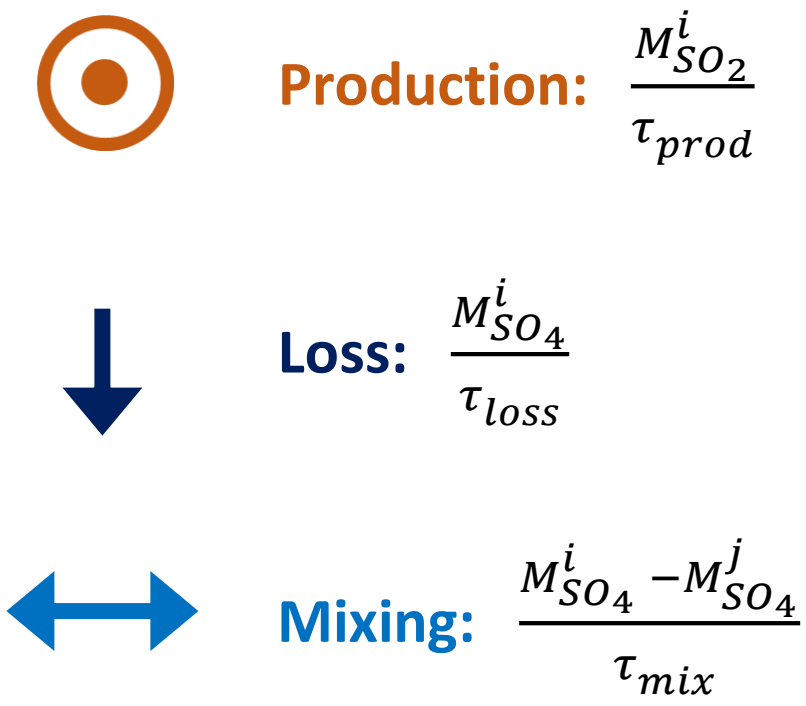
 **Loss:**  $\frac{M_{SO_4}^i}{\tau_{loss}}$



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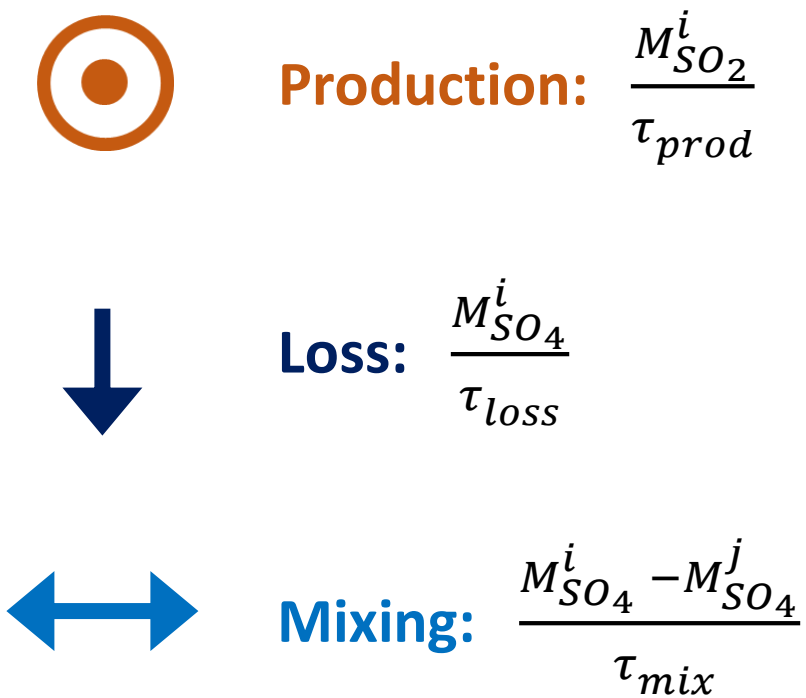
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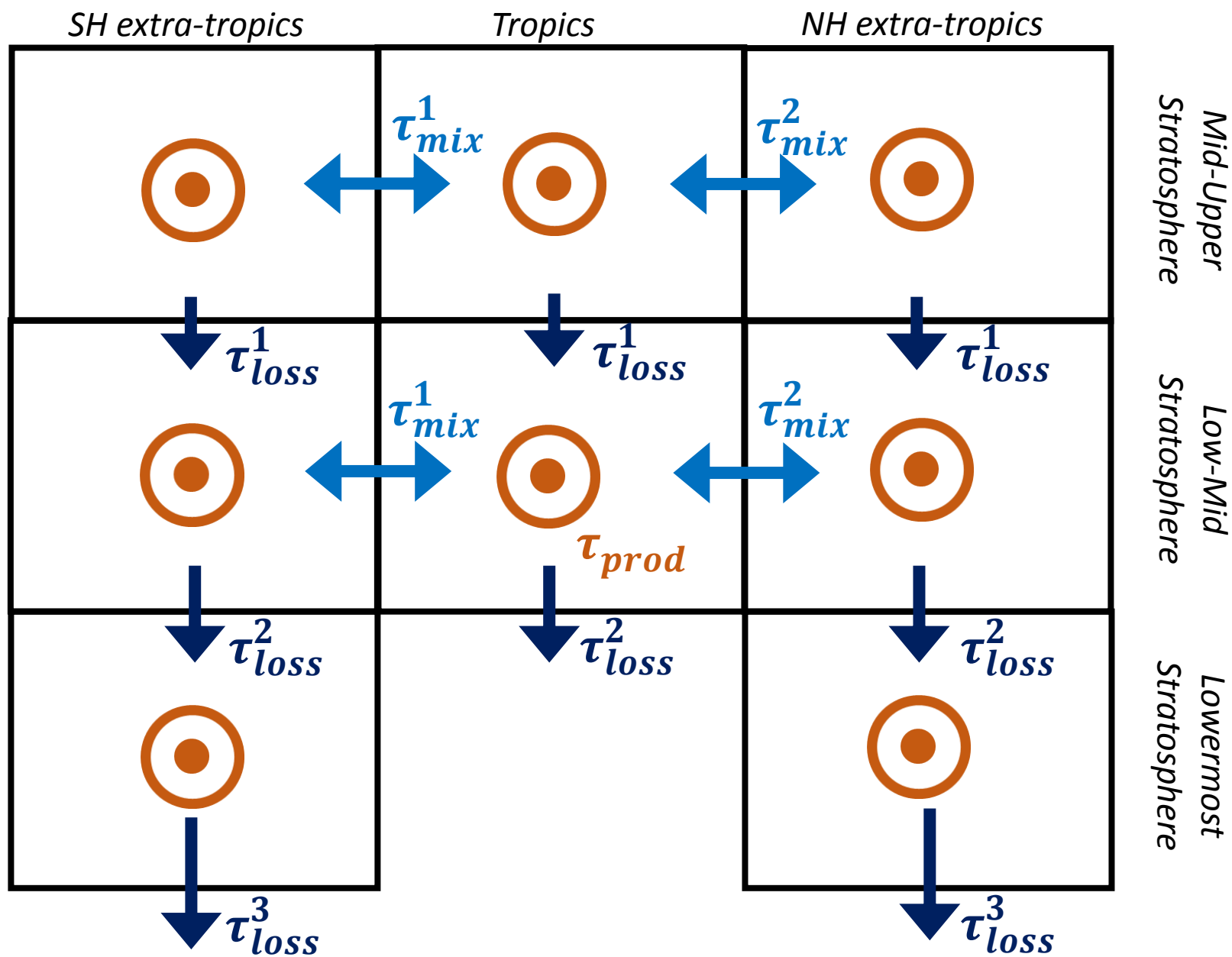
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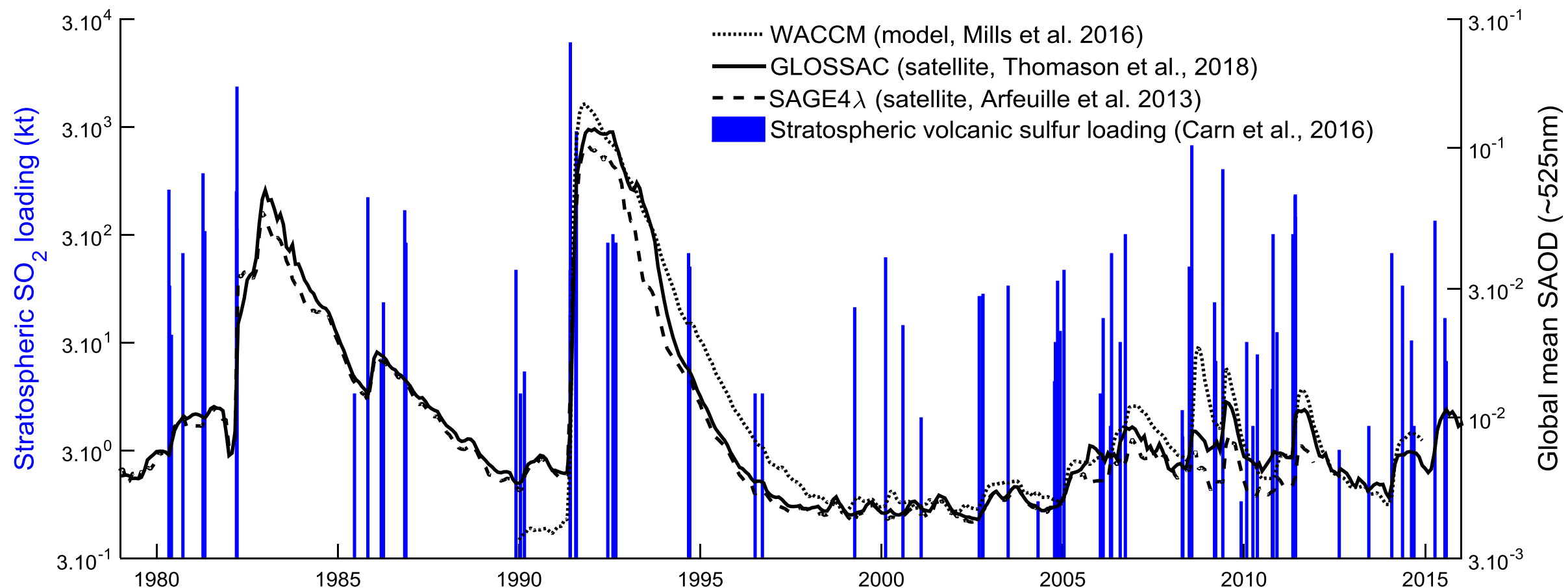


Additional fluxes/parameter dependence currently being explored!



# Datasets used to calibrate our model

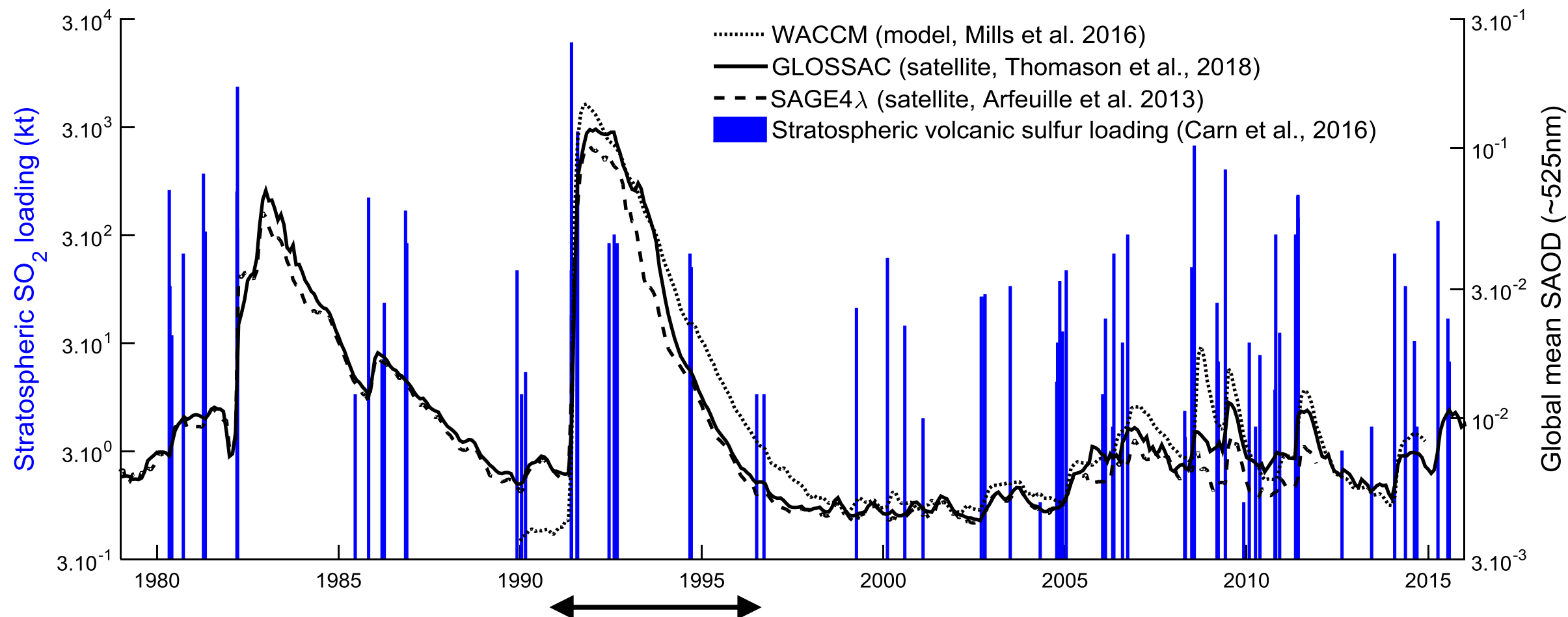
Main strategy (so far) = Tune model parameters to best reproduce GLOSSAC SAOD from the *Carn et al. (2016)* SO<sub>2</sub> injection inventory



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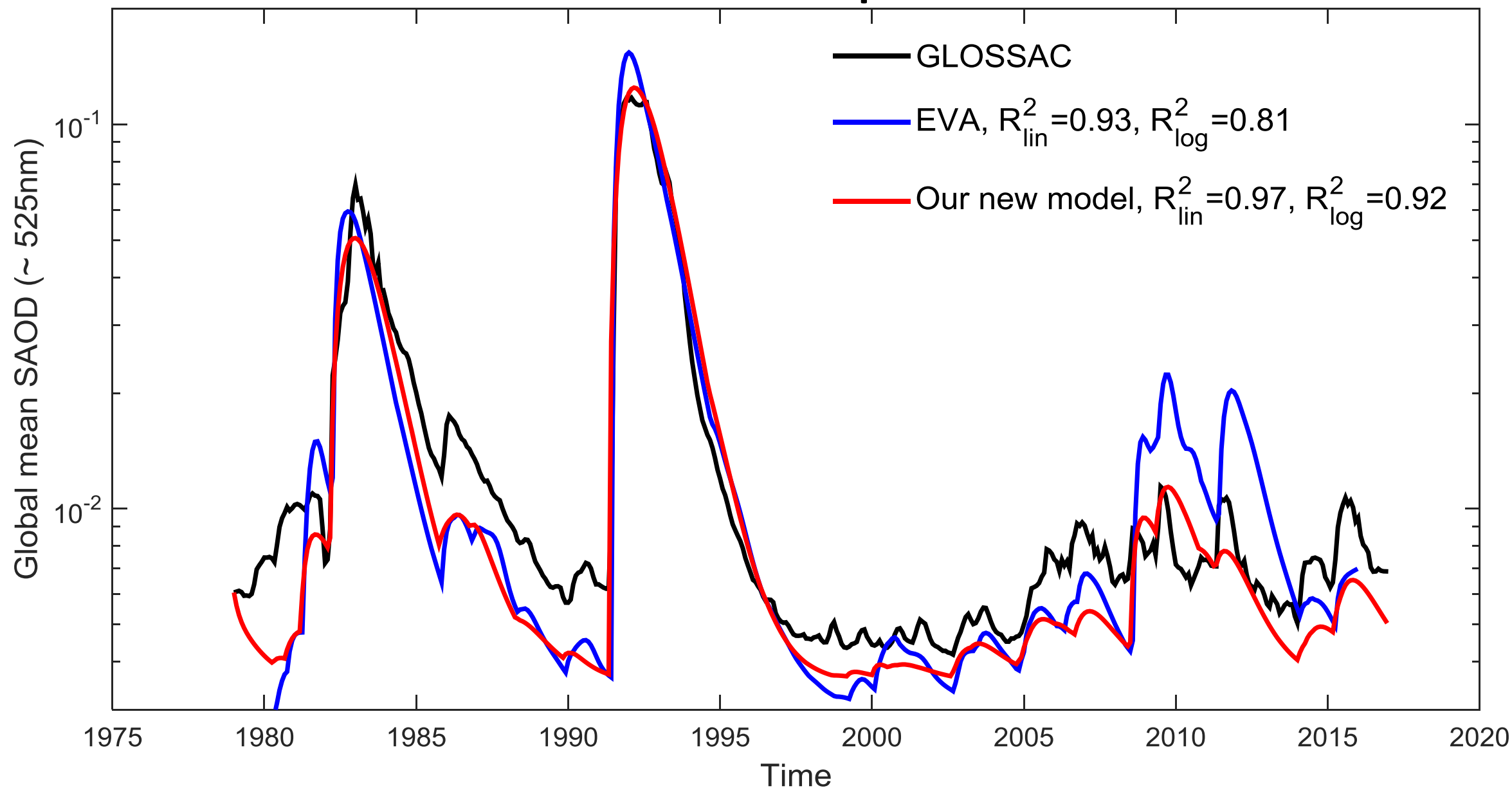
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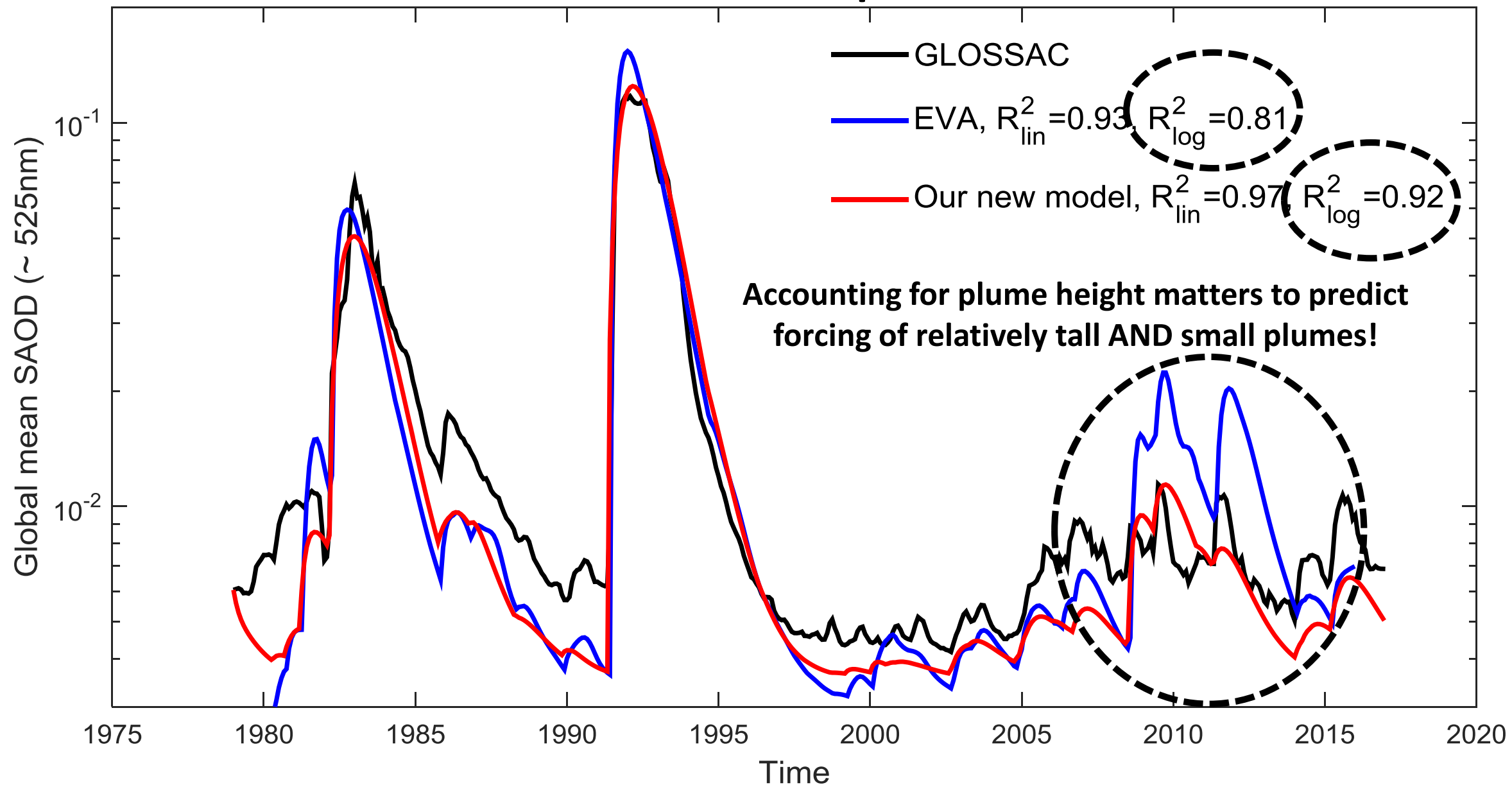
We use  $\approx 35$  years of data with a large span of eruption magnitude/height/latitude instead of Pinatubo 1991 only!

*Aubry et al., in prep.*

# Global mean SAOD predictions



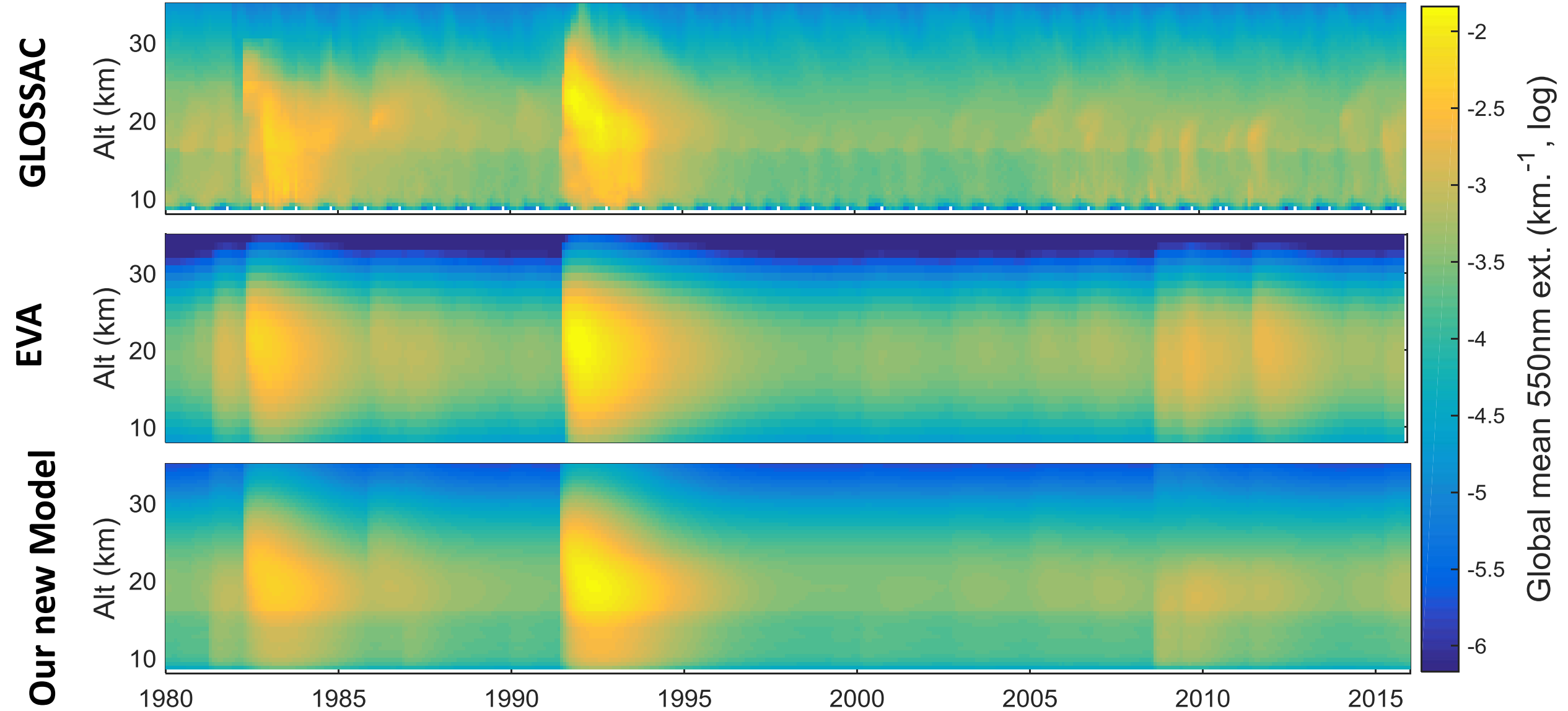
# Global mean SAOD predictions





# Predictions of the vertical structure of extinction

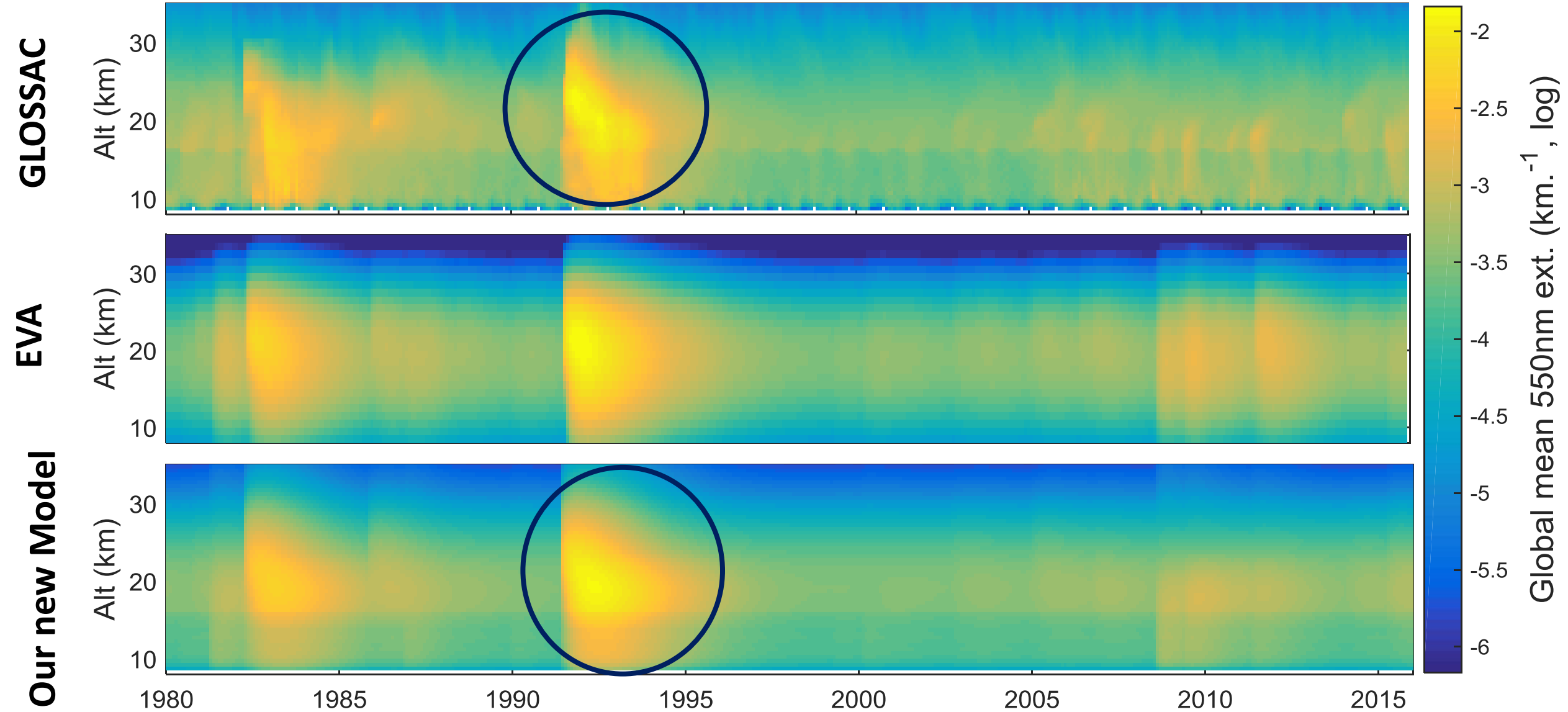
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# Predictions of the vertical structure of extinction

Clear time evolution of the vertical structure, in contrast with  
EVA structure = Gaussian centered on Pinatubo height

*Aubry et al., in prep.*

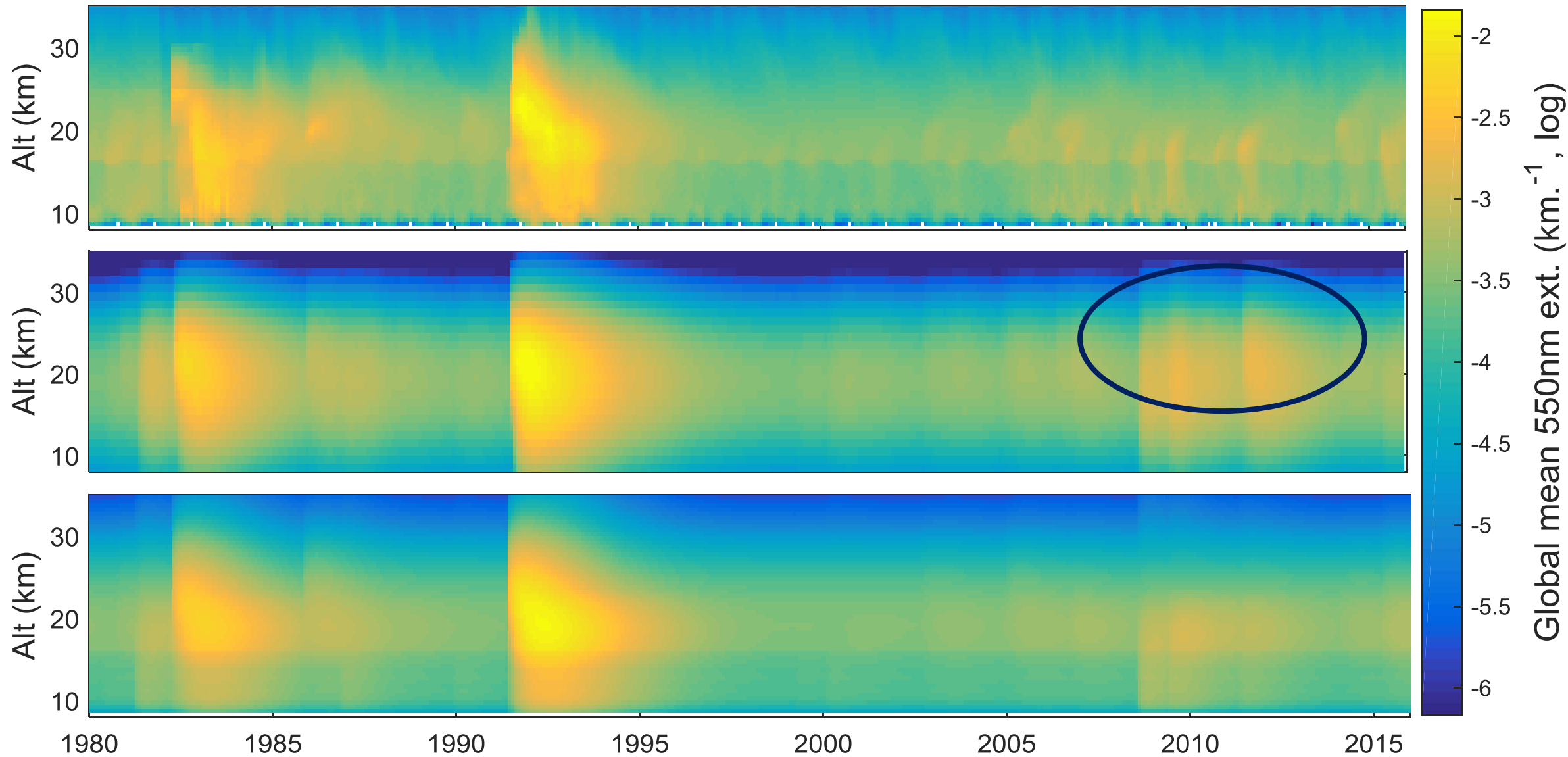


# Predictions of the vertical structure of extinction

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Height of extinction increase largely overestimated

**GLOSSAC**

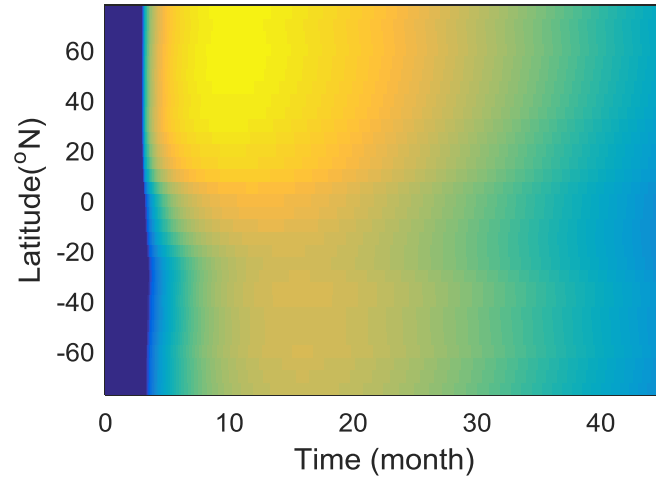


# High-latitude eruptions forcing sensitivity to plume height

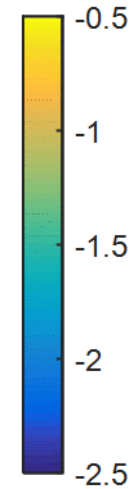
SAOD time-latitude evolution for an injection of 8.5 TgS at 56°N and:

## Our new idealized model

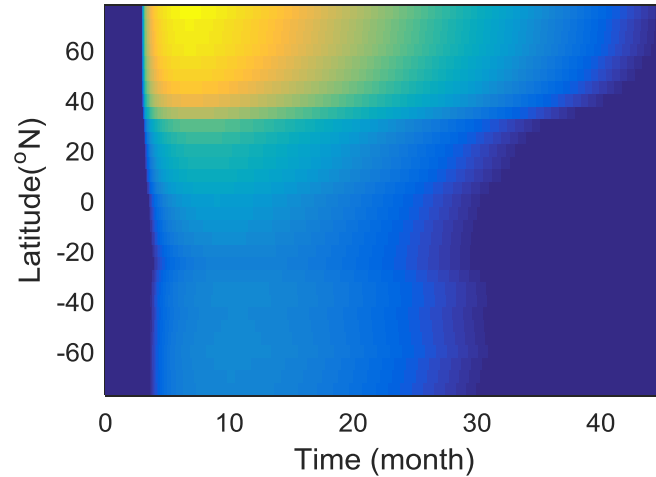
23.5 km a.s.l



SAOD  
(log)



13.5 km a.s.l



*Aubry et al., in prep.*

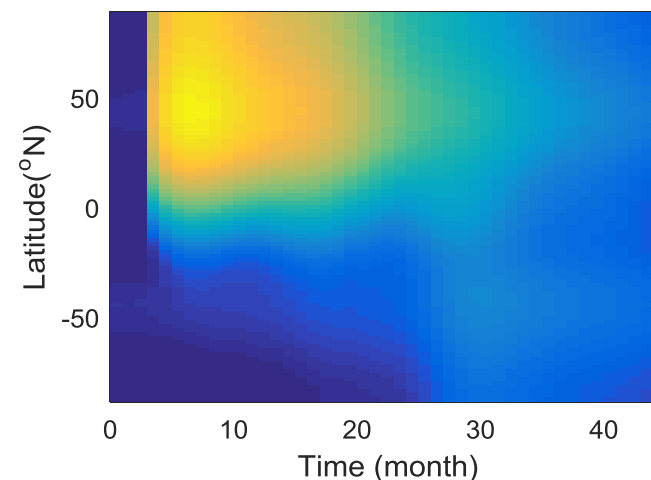
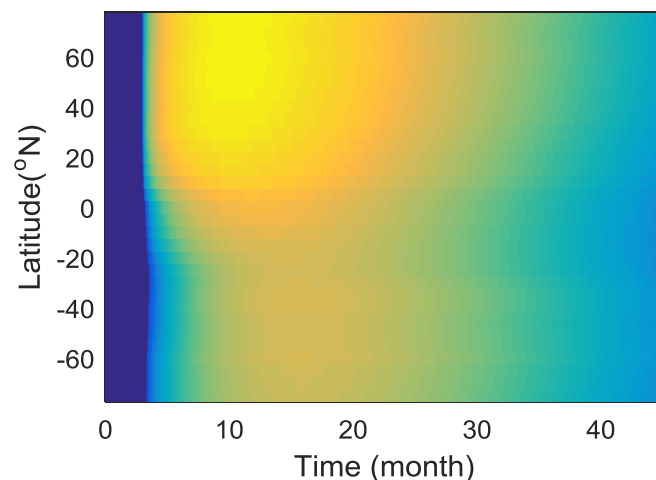
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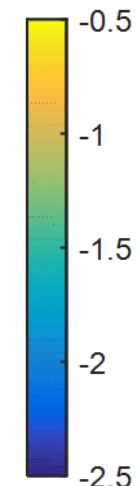
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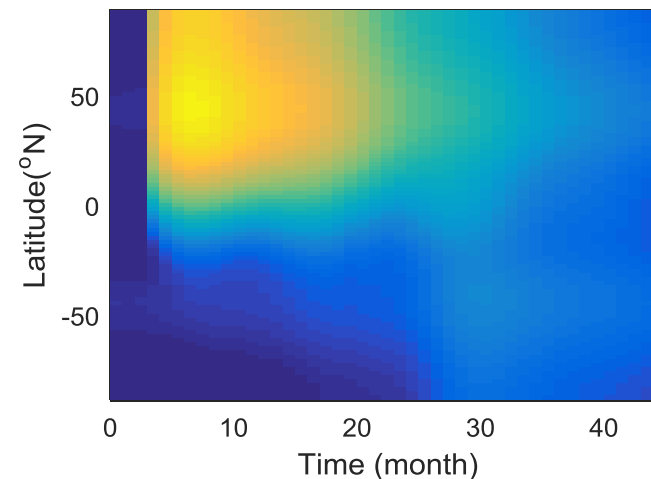
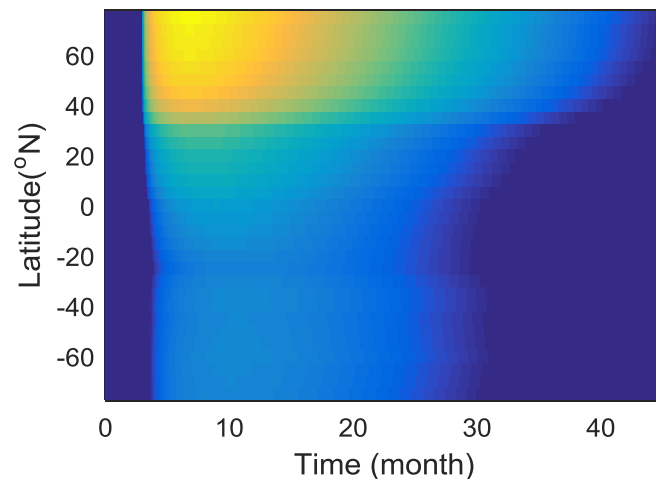
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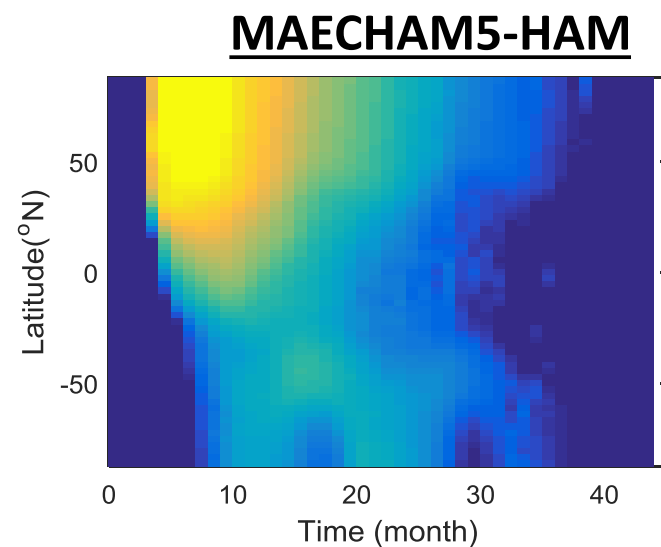
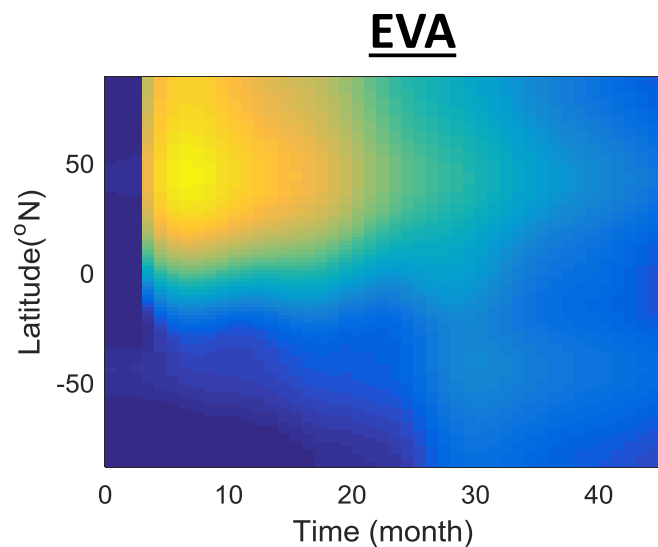
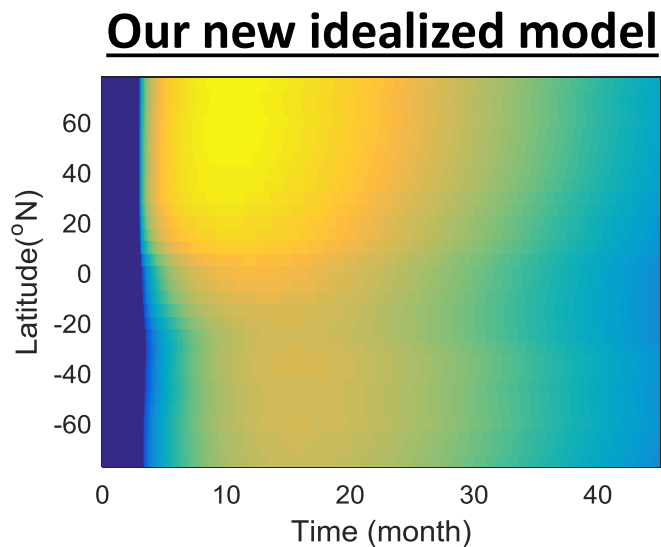


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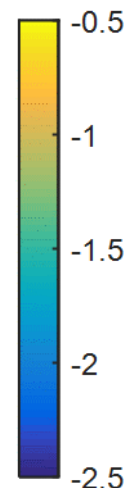
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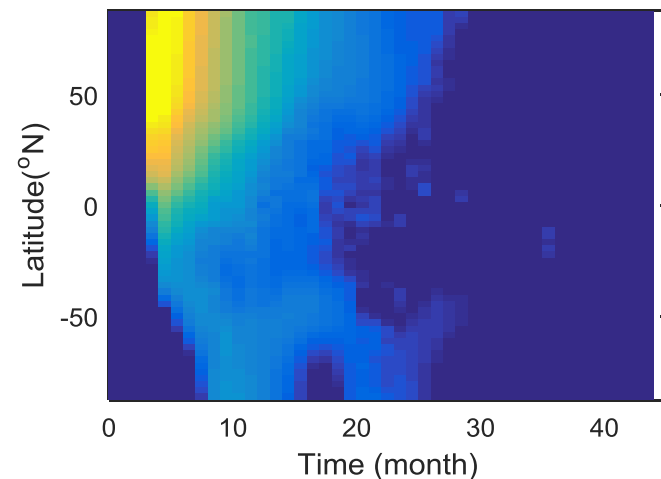
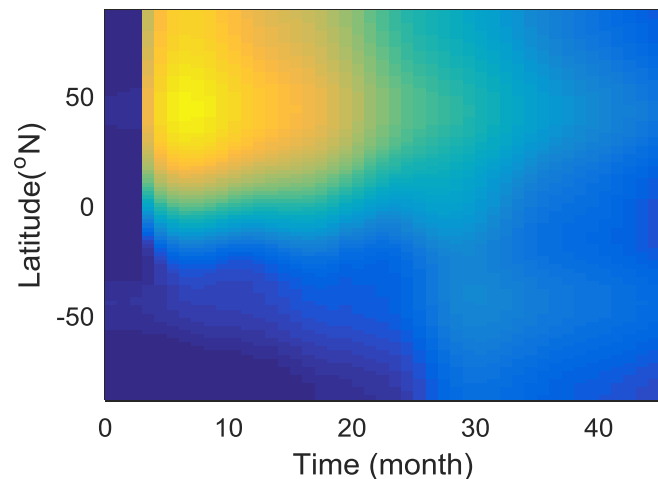
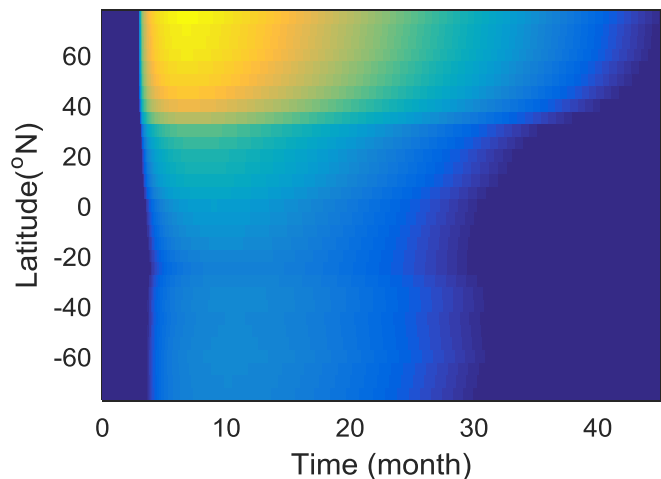
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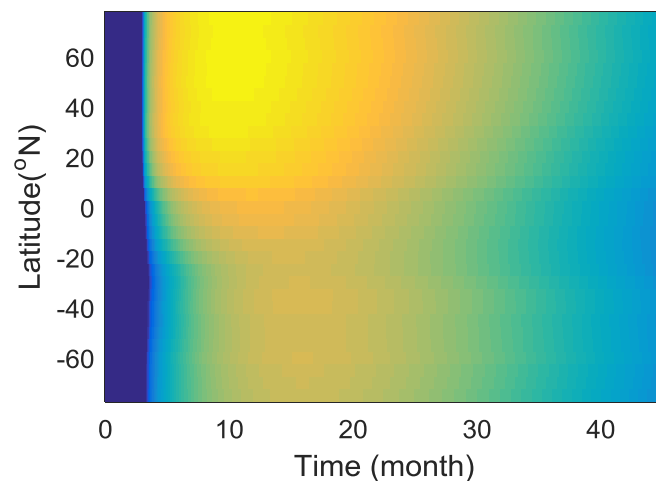
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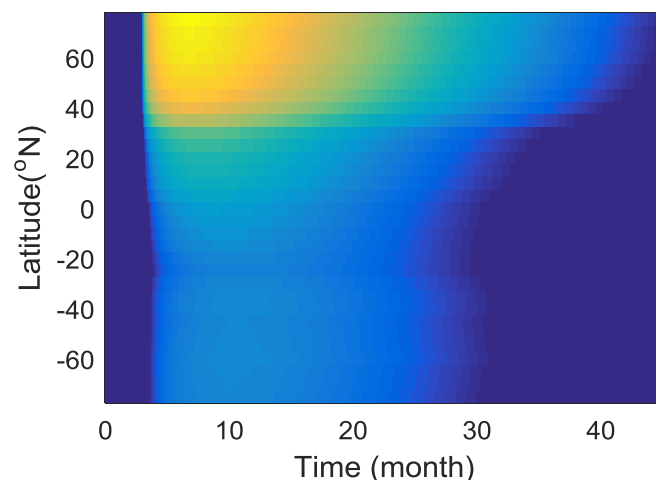
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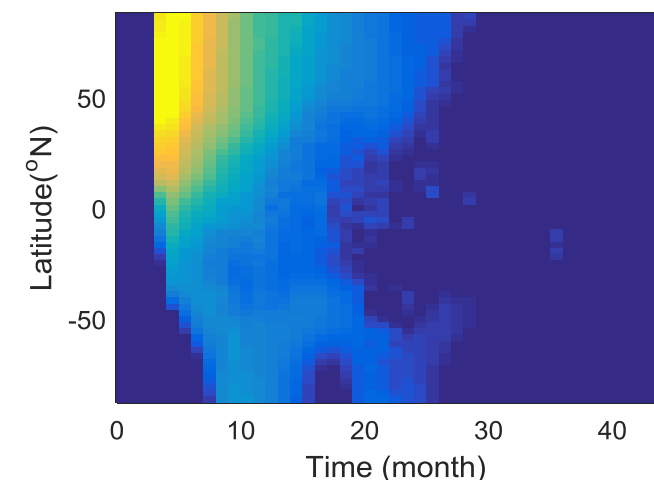
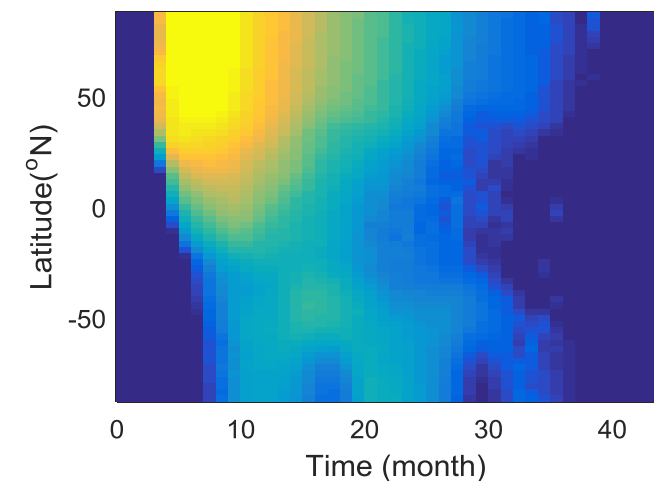
Similarities between fully coupled model and new idealized model:

For NH eruption above tropical tropopause:

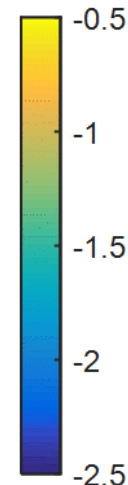
- Much longer forcing timescale
- Tropical and even some SH spread of the cloud

The idealized model overestimates these trends because we still have to improve latitudinal mixing calibration!

## MAECHAM5-HAM



SAOD  
(log)



*Toohey et al., submitted to Nat. Geos.*



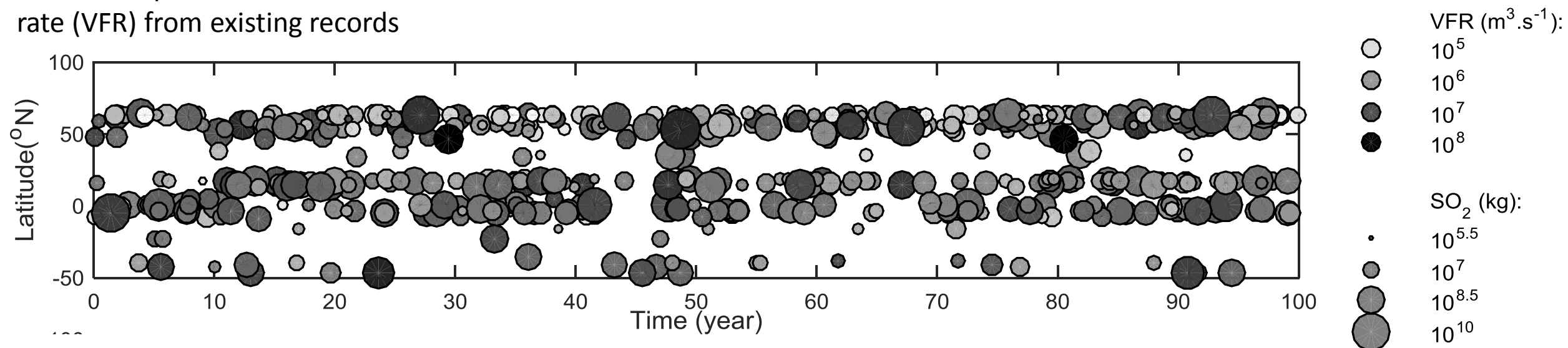
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# Designing scenarios for future volcanic forcing

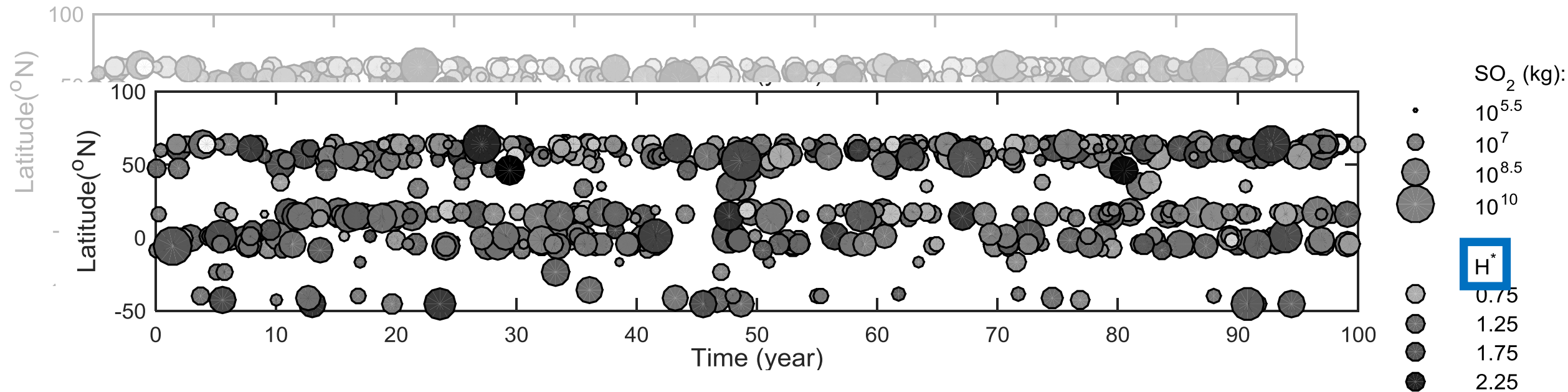
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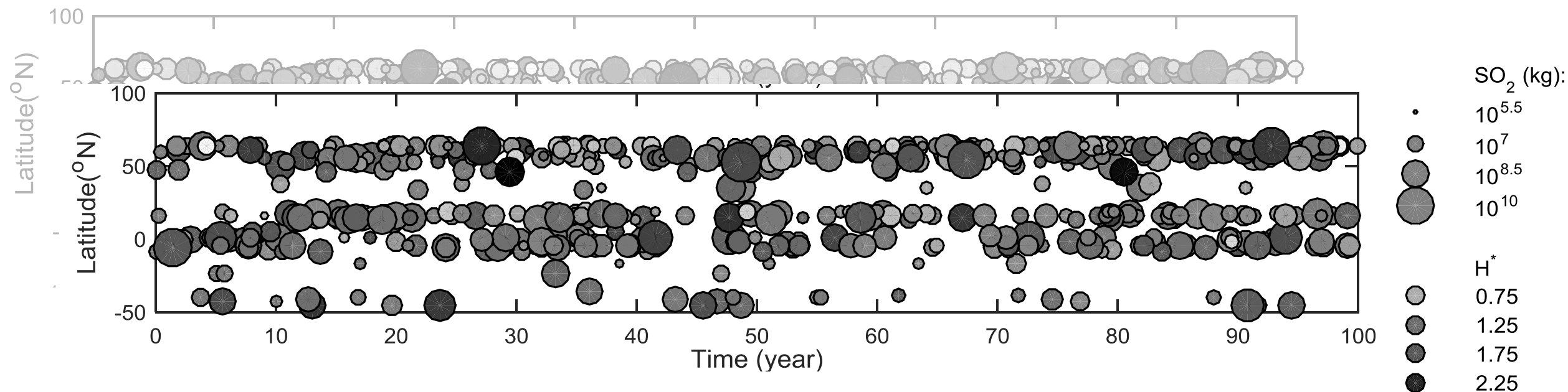
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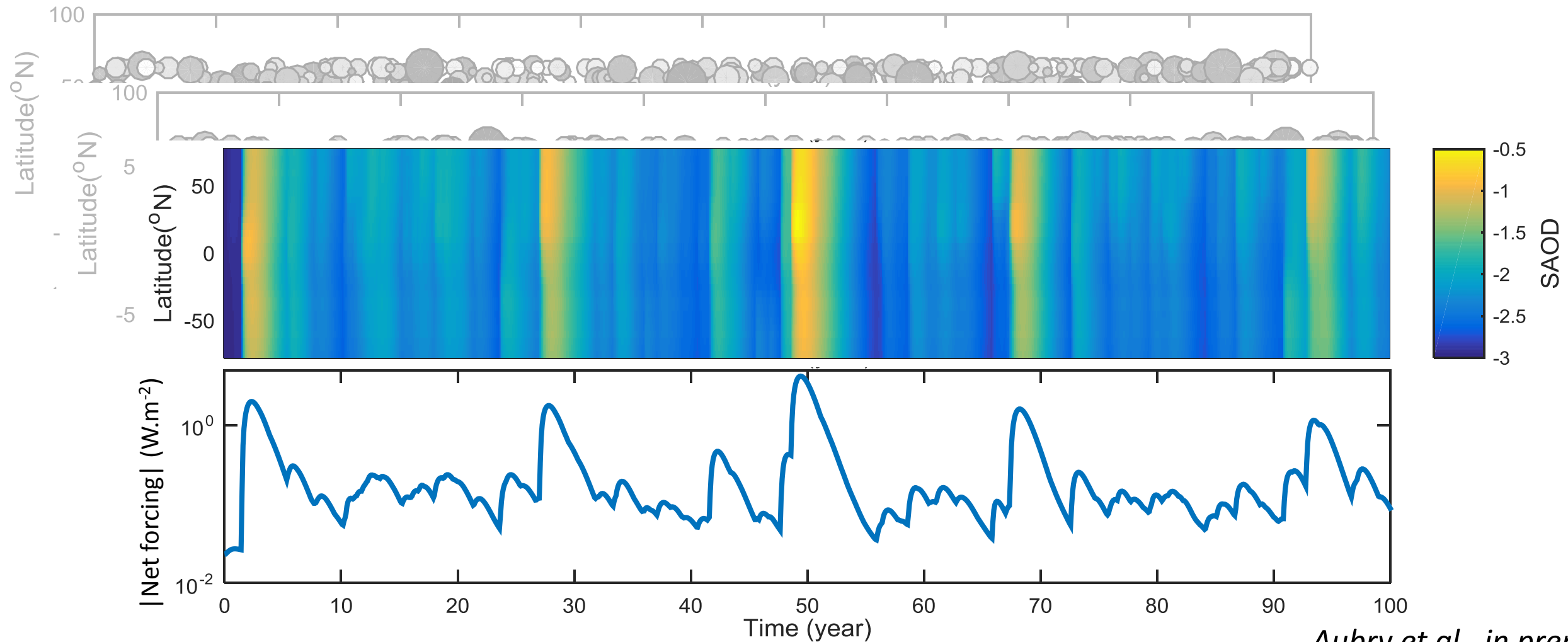
*At this step, using different climate conditions enables to investigate feedbacks between climate and the rise of volcanic plumes*

# Designing scenarios for future volcanic forcing

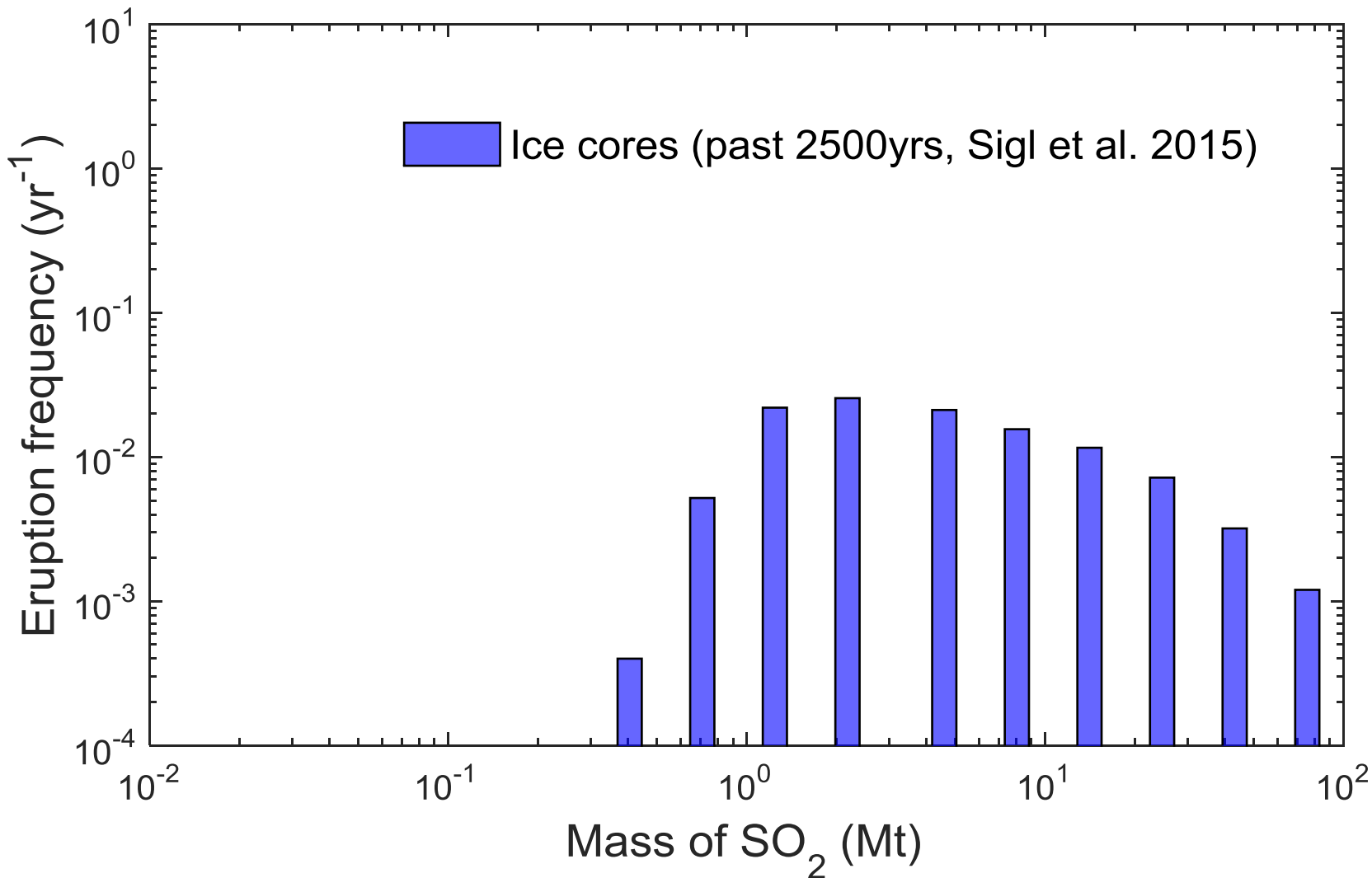
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3) Use our new idealized forcing model to get zonal mean optical properties and forcing



## Resampling strategy

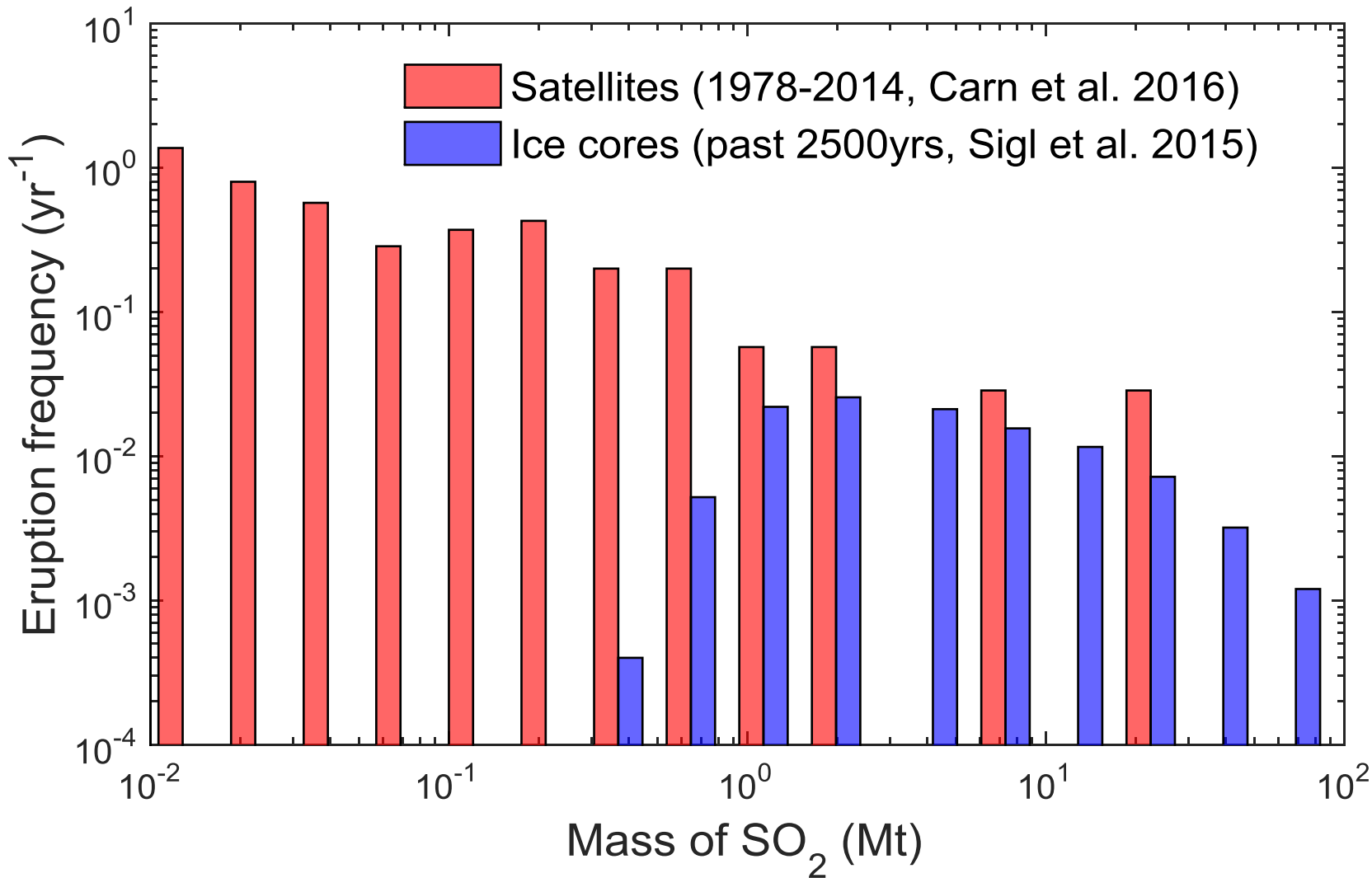


Option #1 (Bethke et al., Nature 2017):

Resample from ice-cores “only” → first implementation of volcanic forcing statistically consistent with ice-cores in climate projections

*Modified from Aubry et al. (JGR 2016)*

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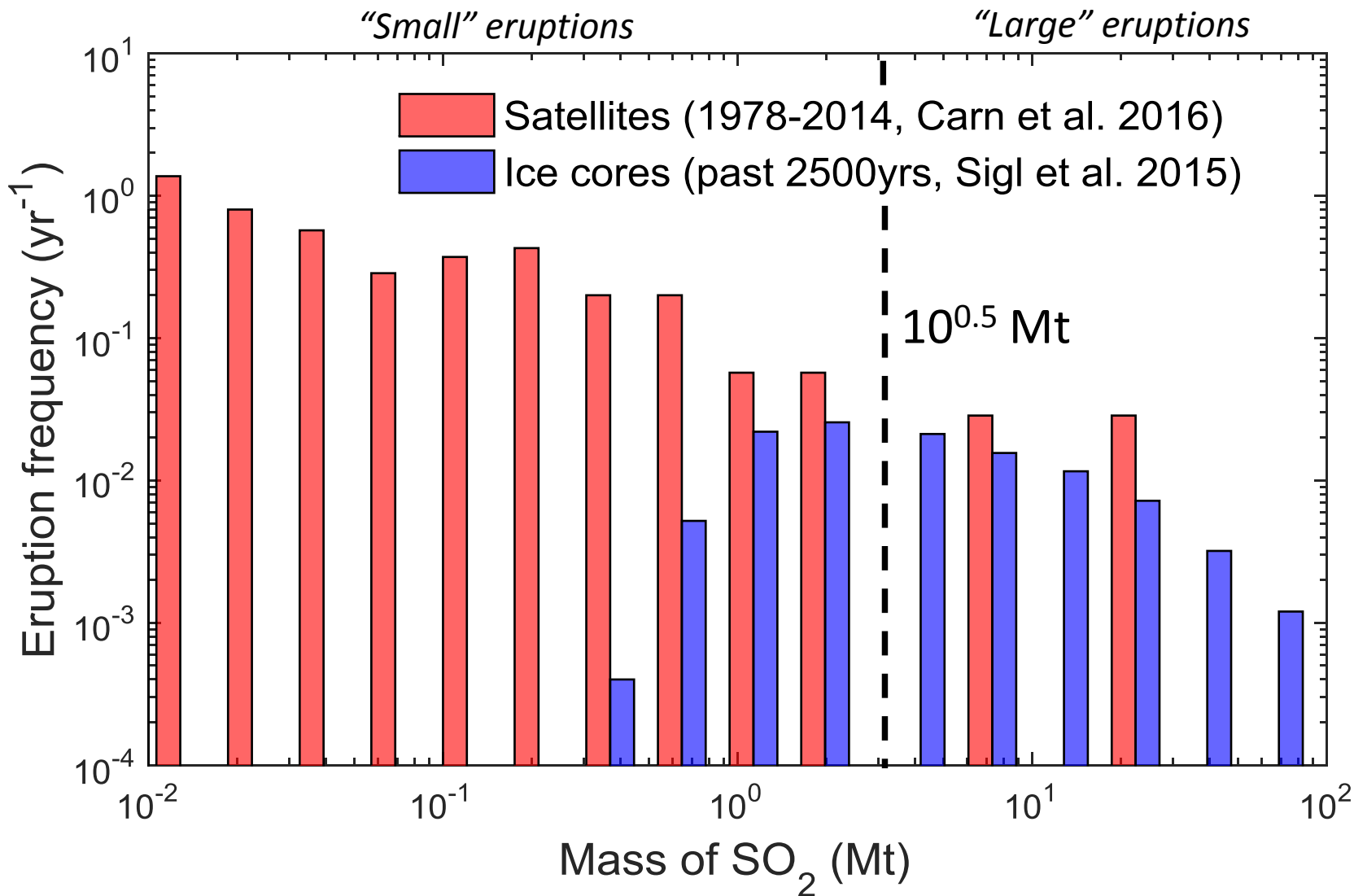


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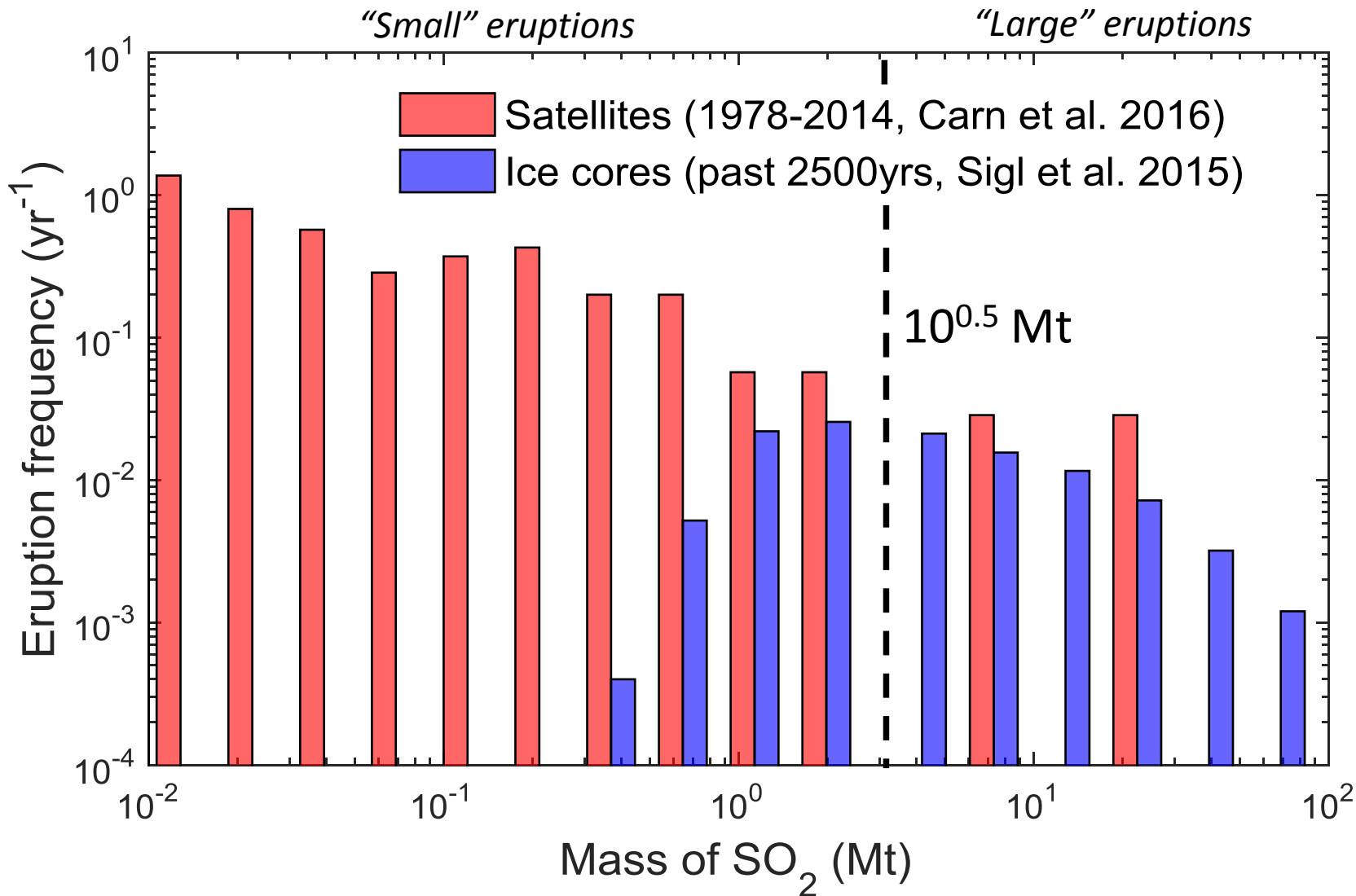
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Option #2 (Aubry et al., JGR 2016):

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**Is it important to resample small eruptions?**

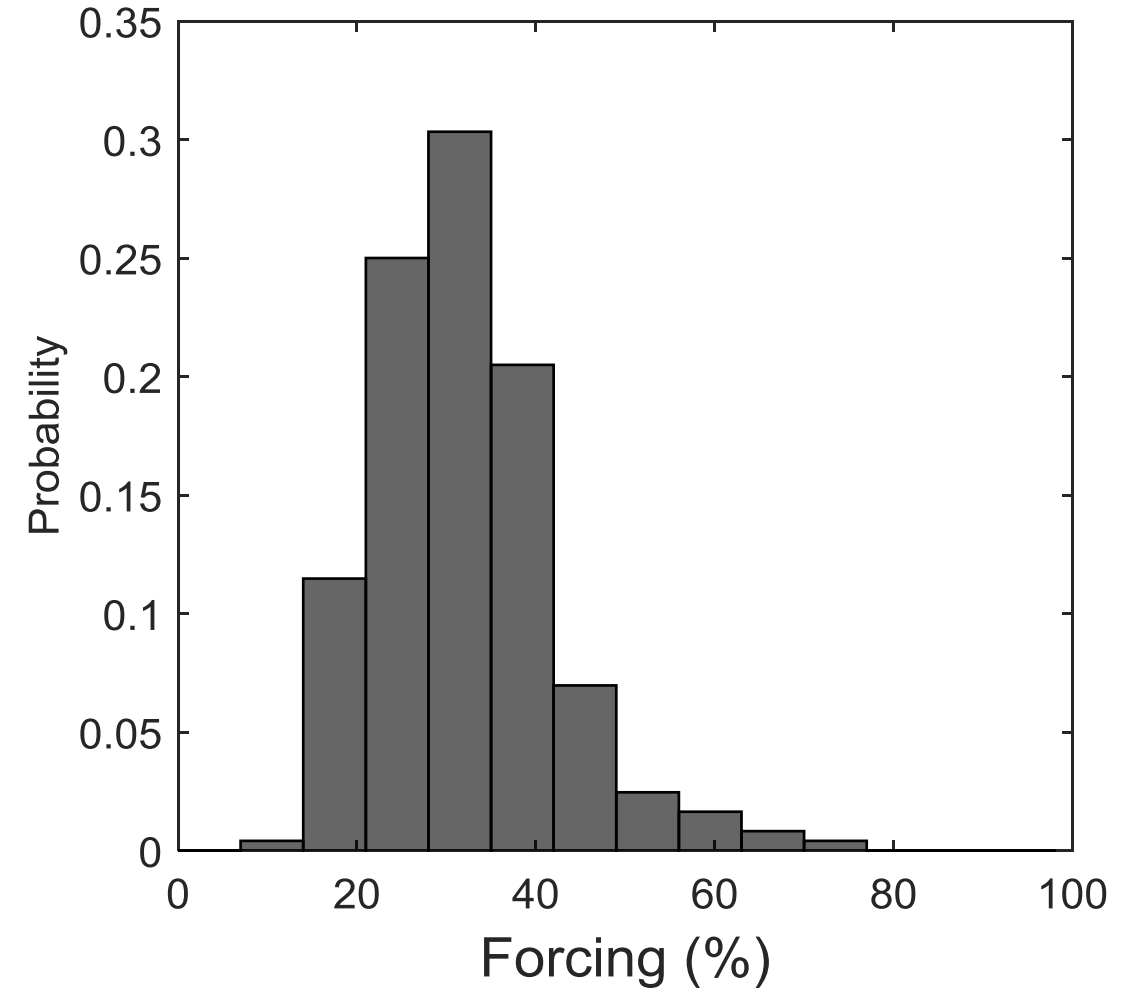
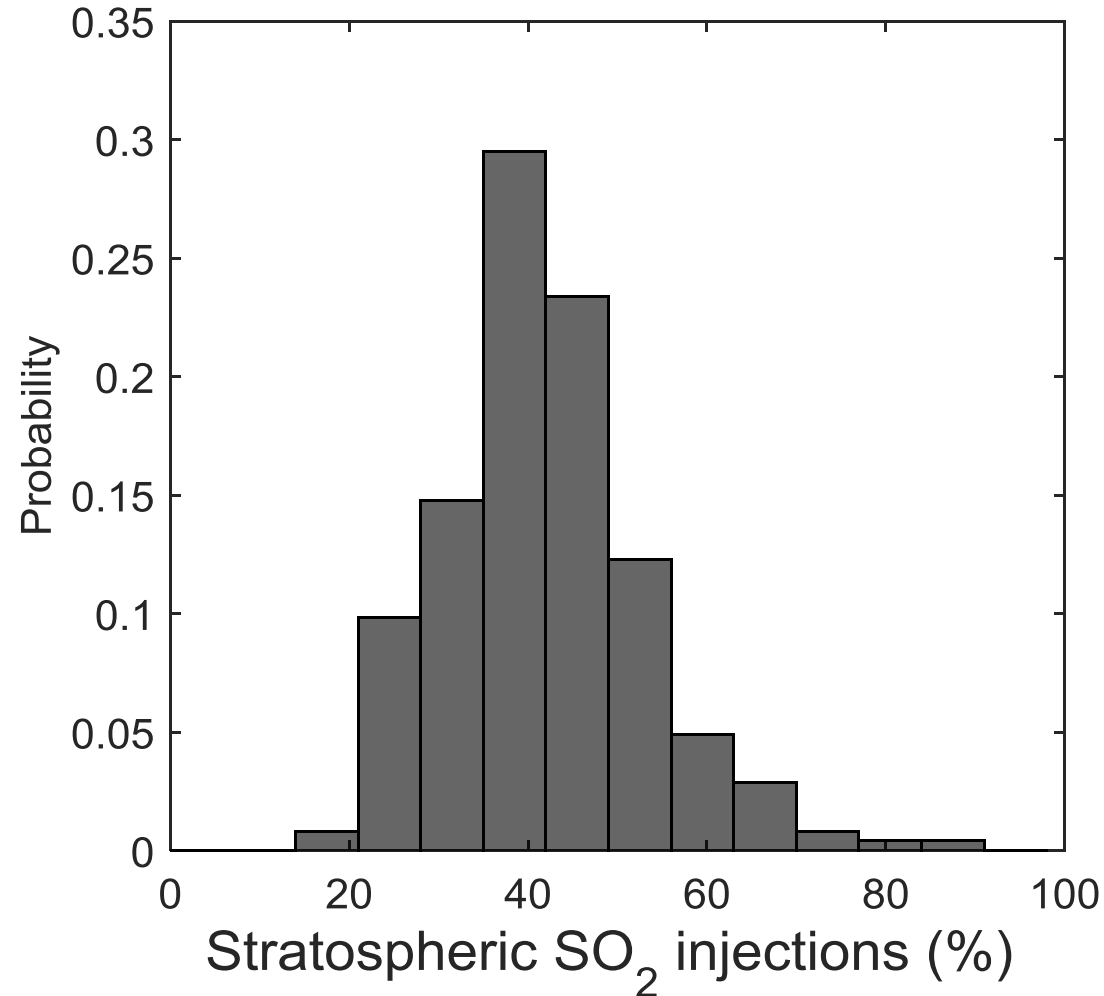
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# Do “small” SO<sub>2</sub> injections matter for volcanic forcing scenarios?

Probability distribution for the percentage of...

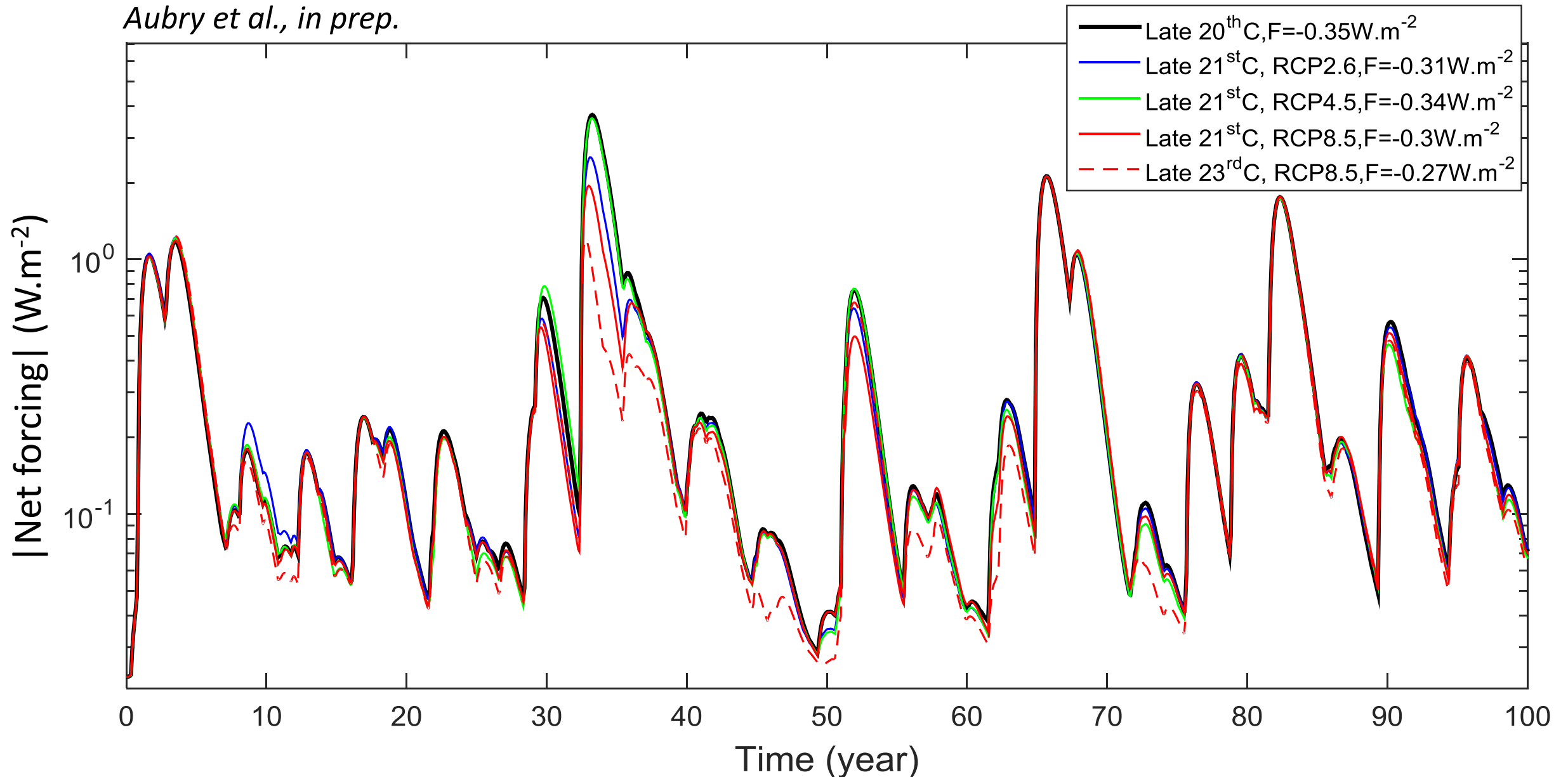
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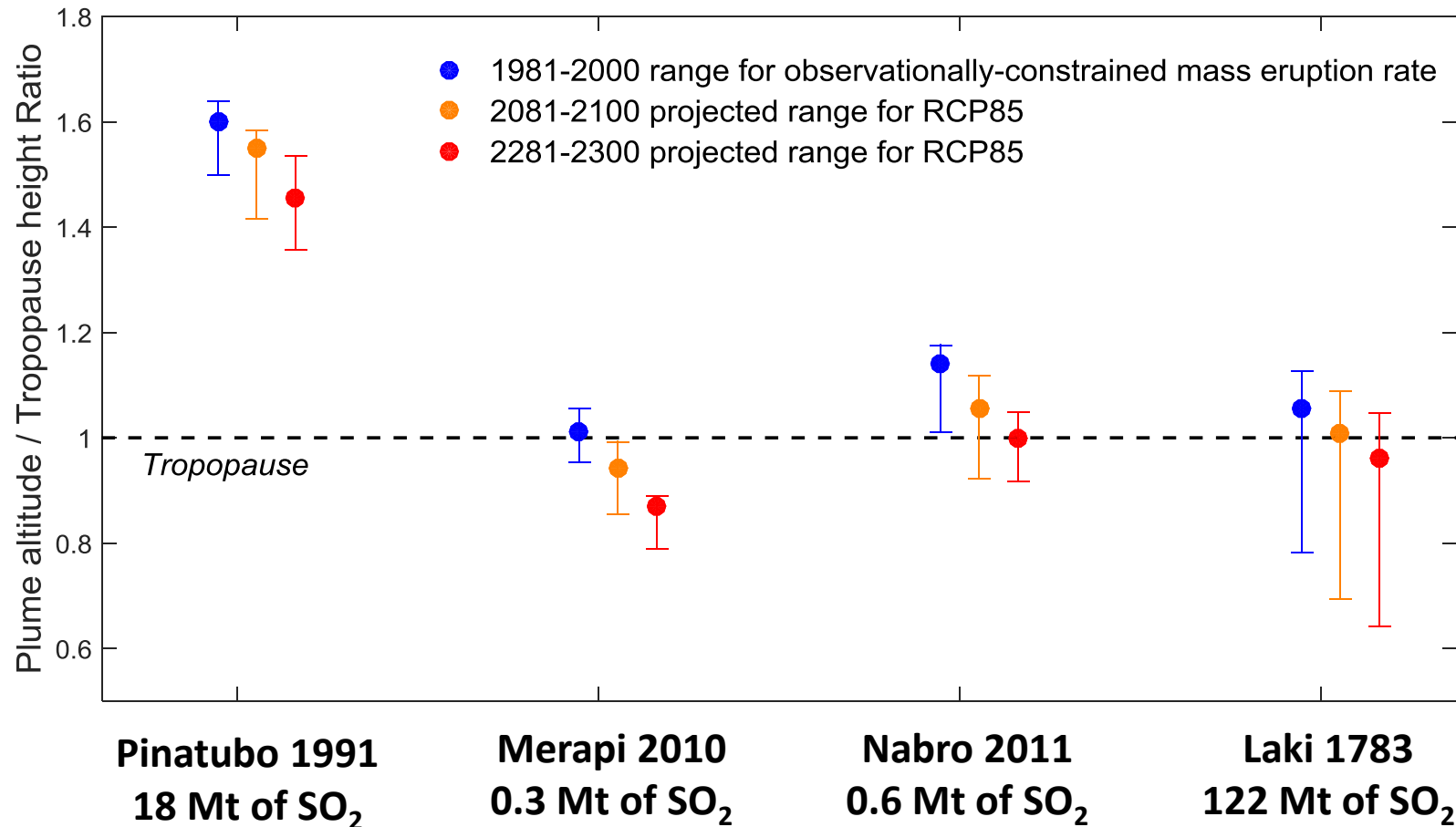
...neglected when resampling large eruptions only for 100-year scenarios

# Sensitivity of forcing to climate conditions

*Aubry et al., in prep.*

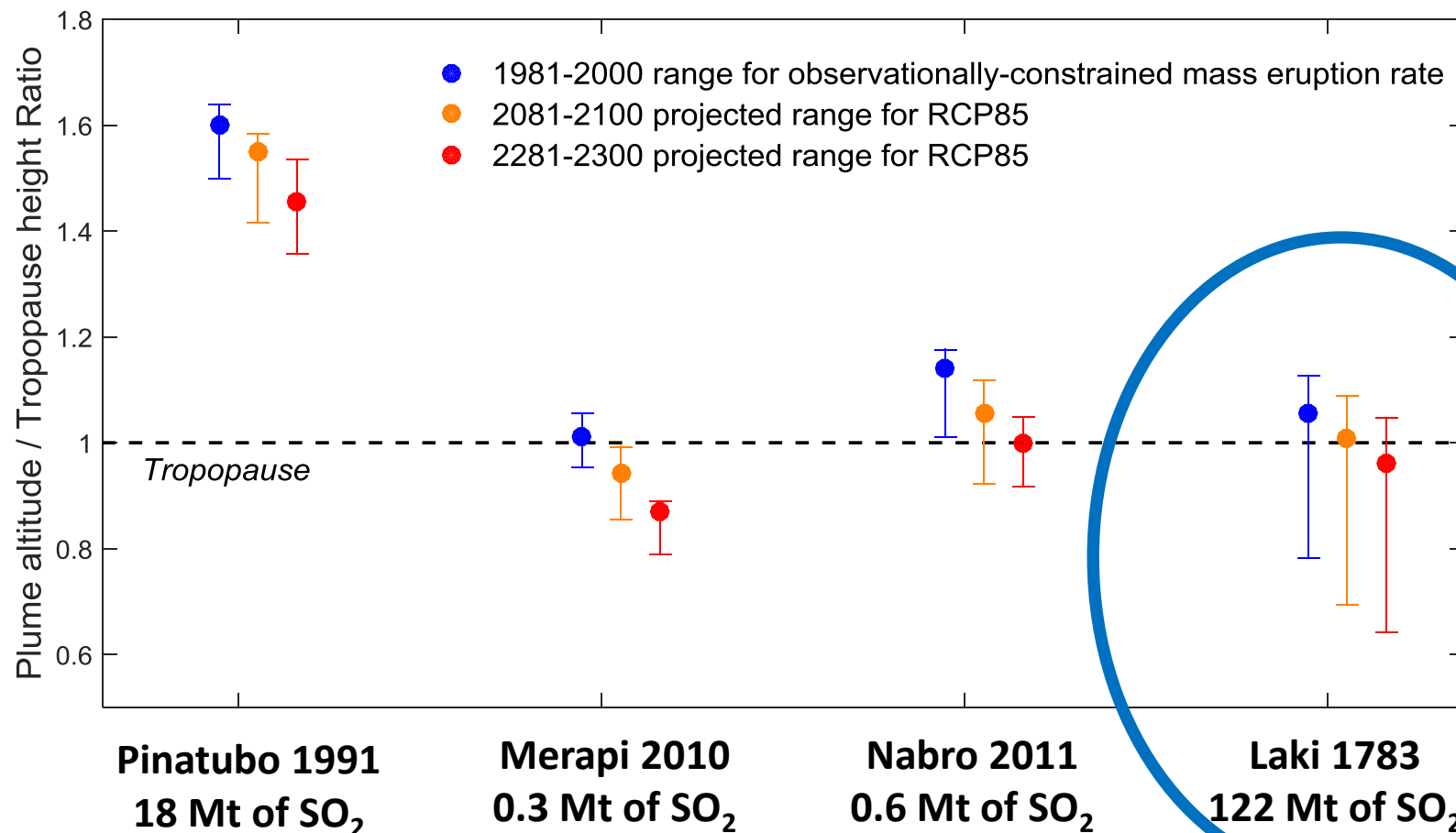


# Sensitivity of forcing to climate conditions and potential climate-volcano feedback



Our current estimate of the climate-plume rise feedback for silicic eruptions:  
 $10^{-3}$ - $10^{-2}$  W.m<sup>-2</sup>/W.m<sup>-2</sup>  
 (to be refined once we are done improving the idealized model)

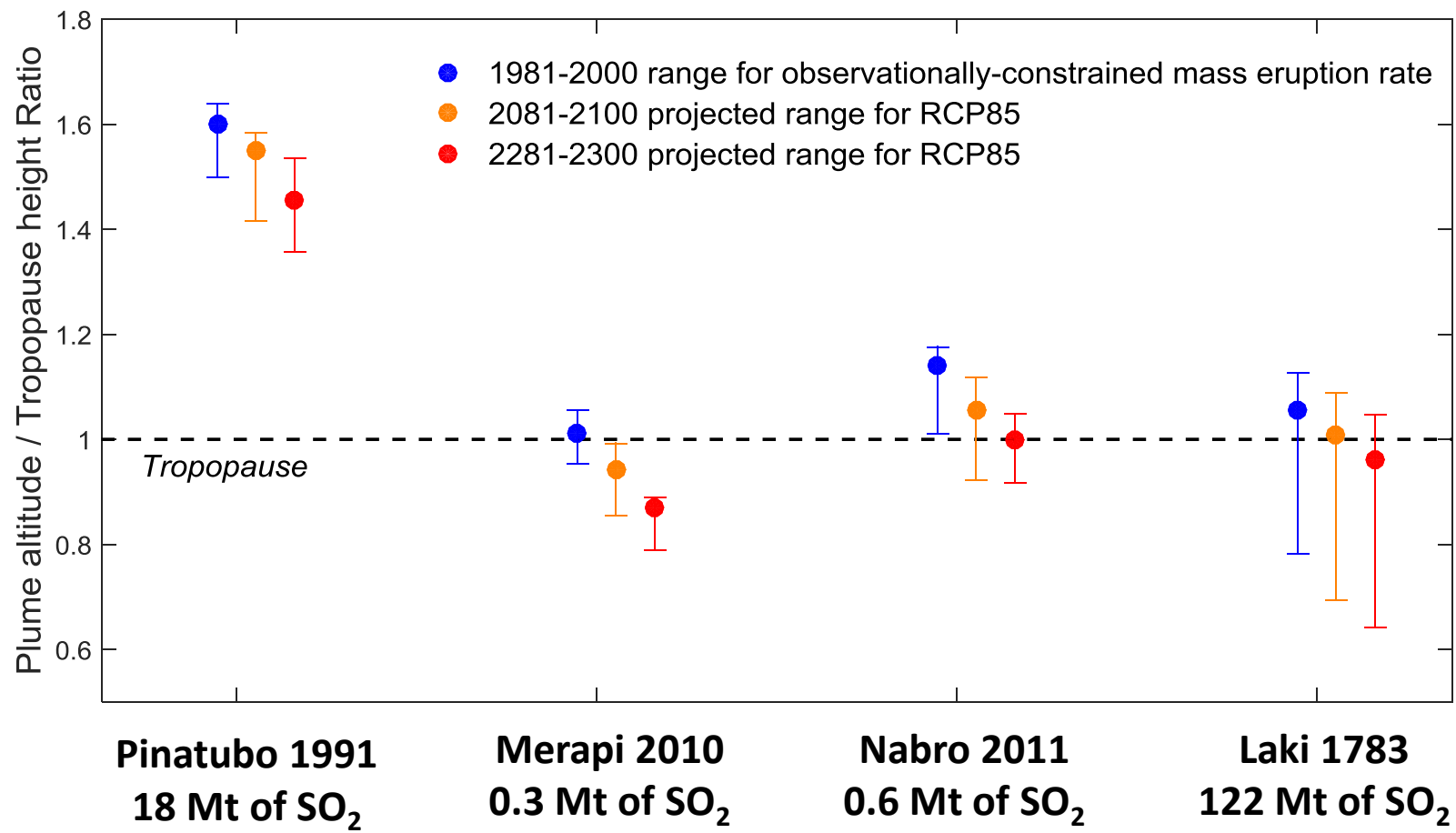
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Implications of the feedback for basaltic eruptions?

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# Sensitivity of forcing to climate conditions and potential climate-volcano feedback



*How does this feedback between plume rise and climate (Aubry et al. 2016) combines with recently suggested feedbacks related to changes in background climate conditions that will affect volcanic forcing and climate response (Fasullo et al. 2017, Hopcroft et al. 2017)?!*

# Concluding remarks

## A new idealized model of volcanic forcing...

- Accounting for plume height and predicting vertical structure
- Calibrated against state-of-the-art datasets
- Still under improvement but already promising performance
- With exciting preliminary results to reconstruct past volcanic forcing/design statistically realistic future volcanic forcing scenarios

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**Thank you!**  
**Questions?**

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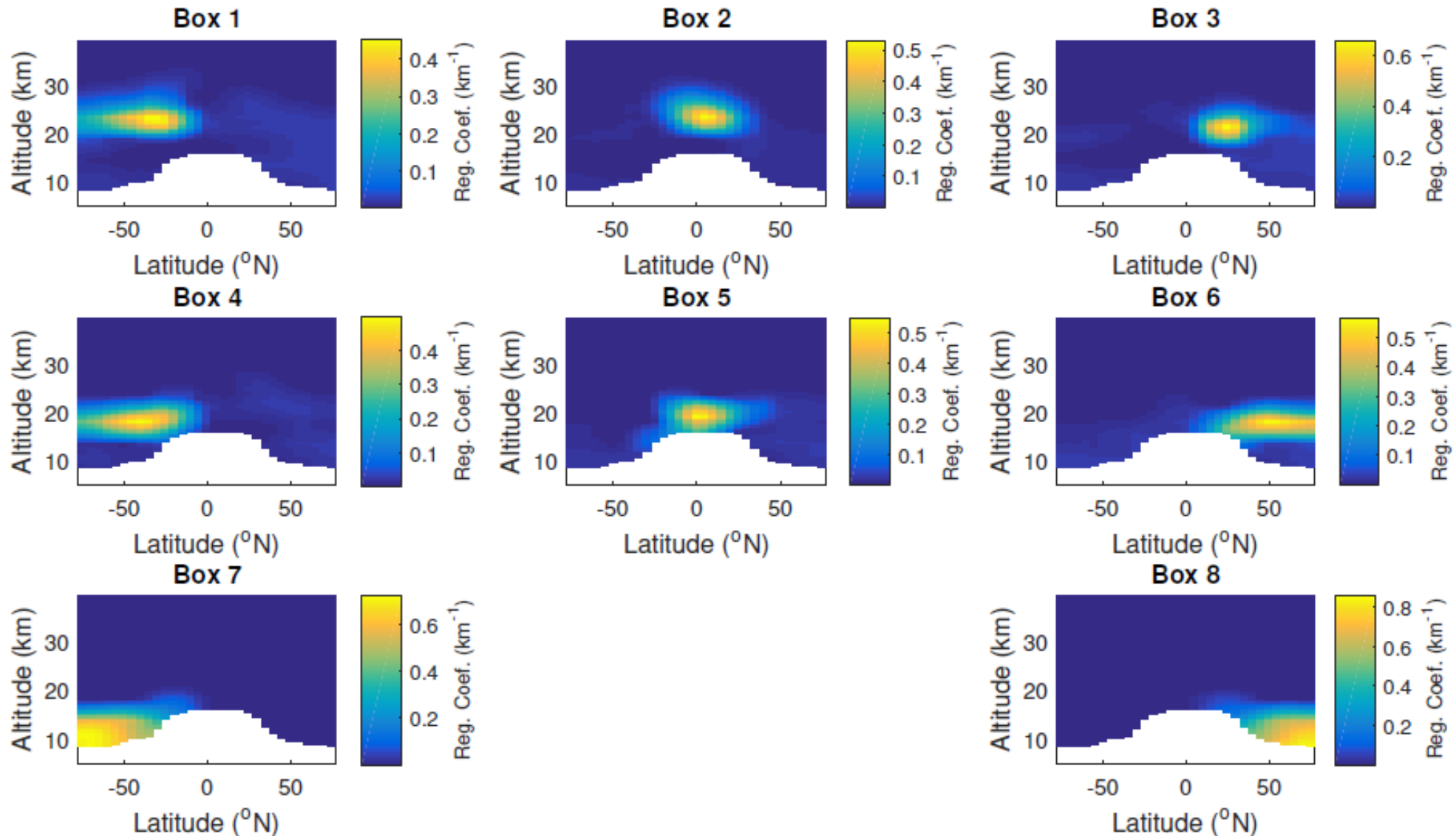
[thom.aubry@gmail.com](mailto:thom.aubry@gmail.com)

<https://sites.google.com/site/thomasjaubry/>



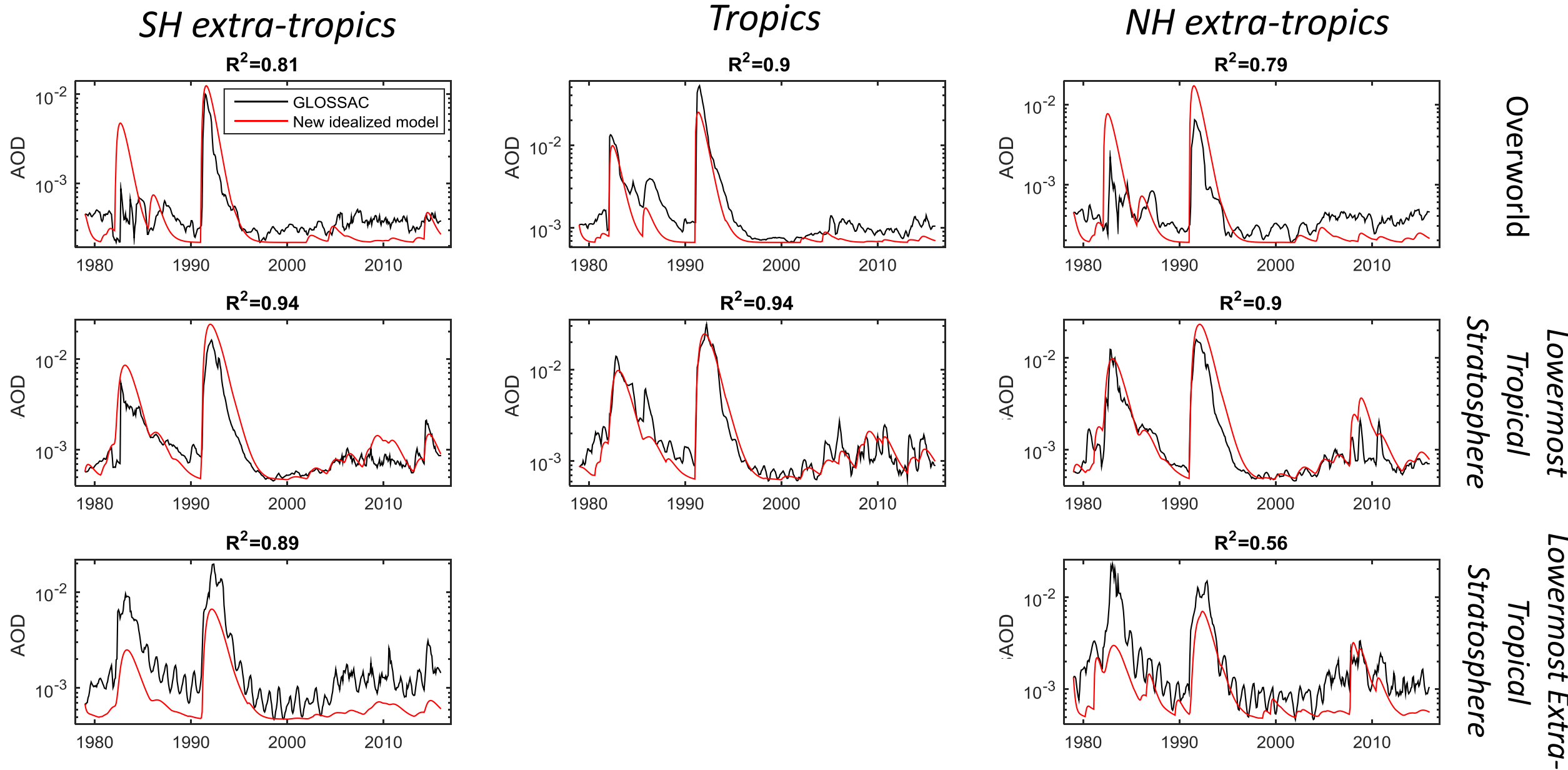
# Shape functions of the model

$$EXT_{525}(\lambda, z, t) = \sum_{i=1}^8 c_i(\lambda, z) \times SAOD_i(t) + \epsilon(\lambda, z, t)$$

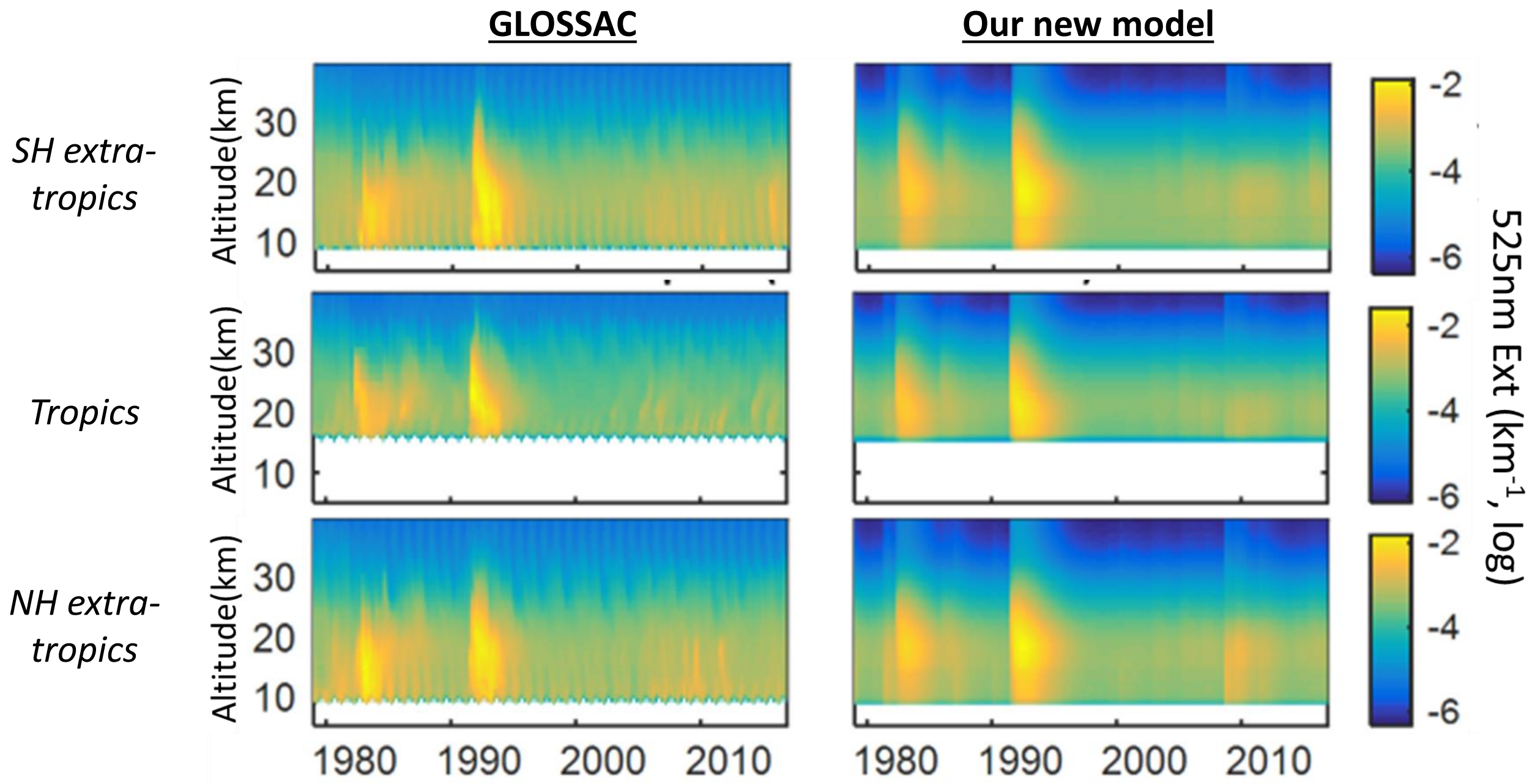




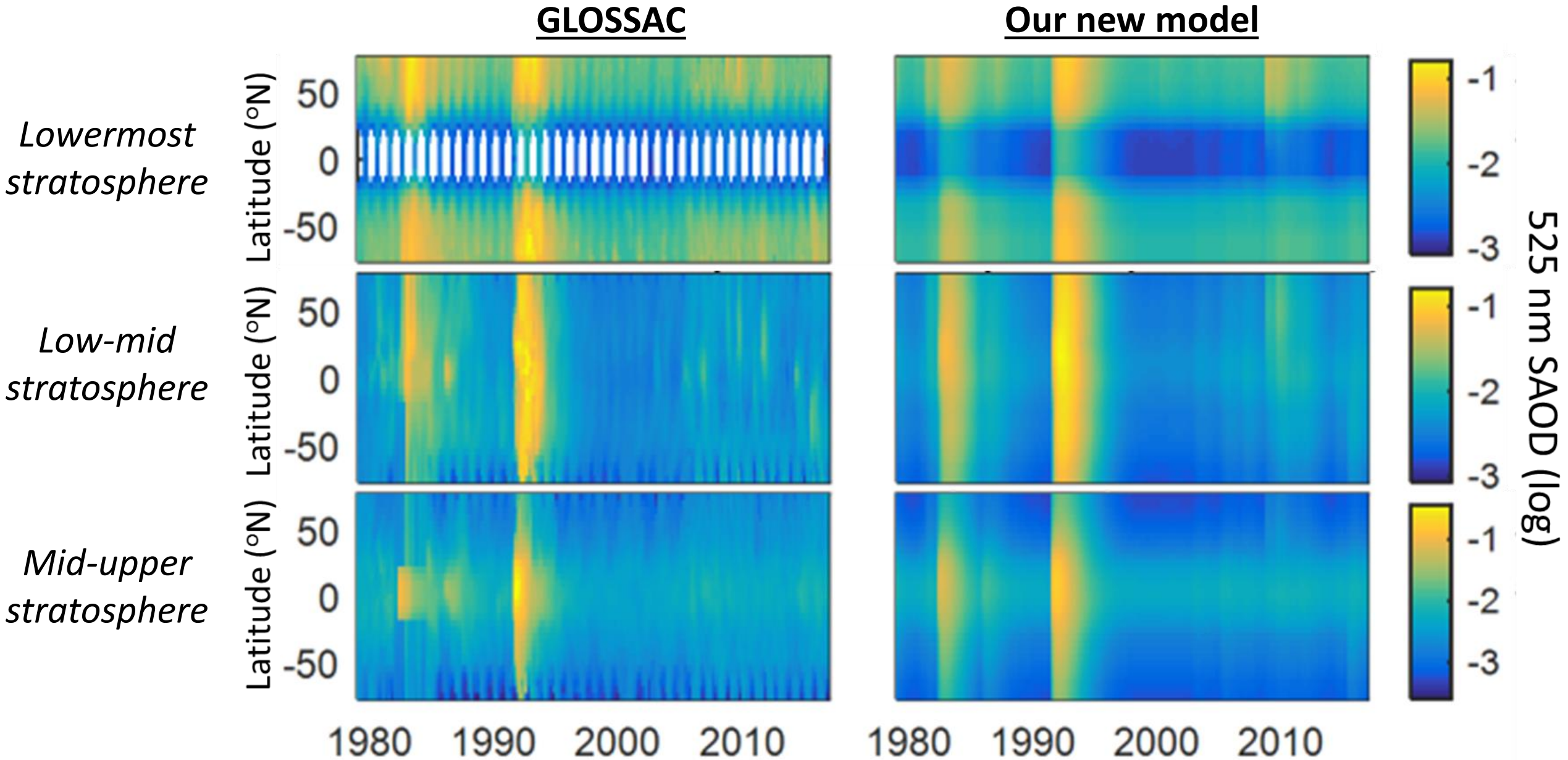
# SAOD predictions in each box



# Vertical distribution of extinction: observations vs new model



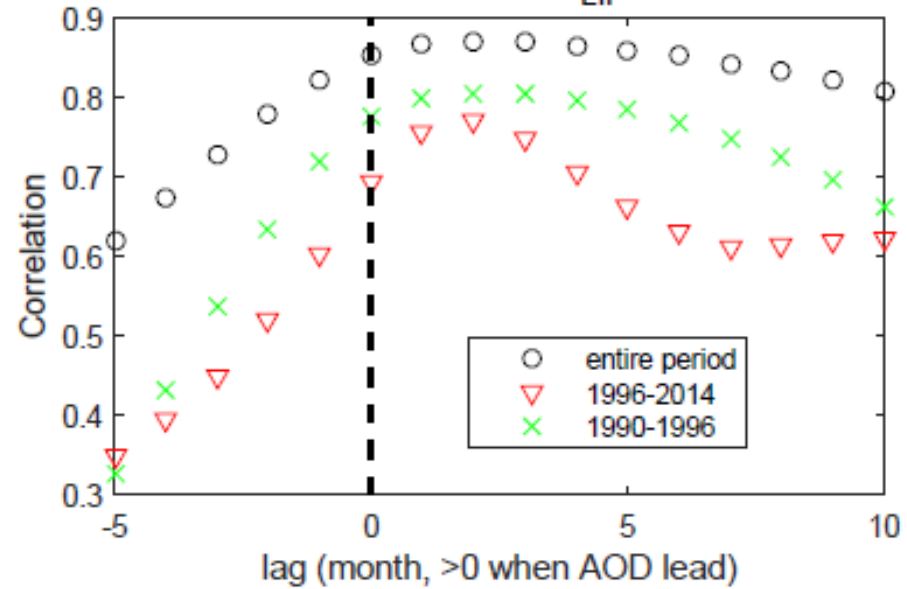
# Meridional distribution of SAOD: observations vs new model



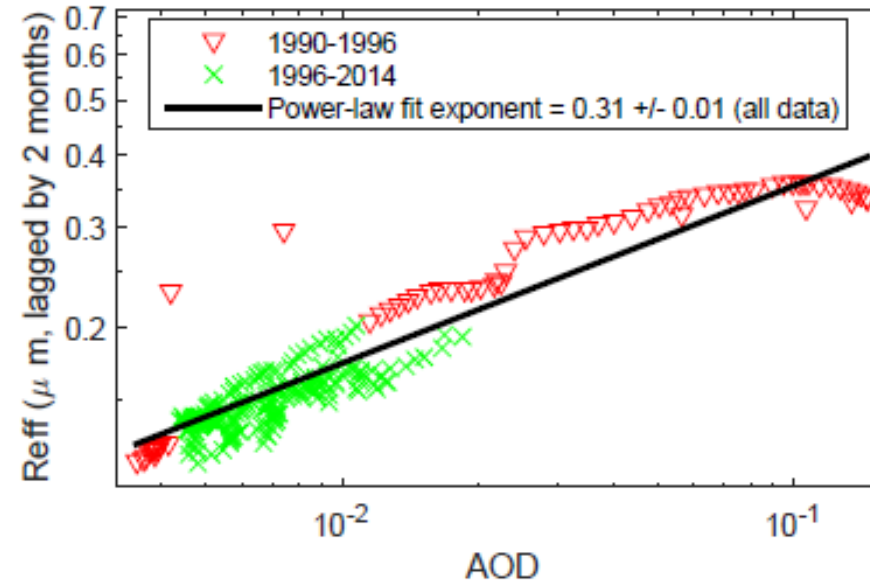


# Grounds for the scaling for effective radius

WACCM AOD- $R_{\text{Eff}}$  lag



WACCM AOD- $R_{\text{Eff}}$  scaling

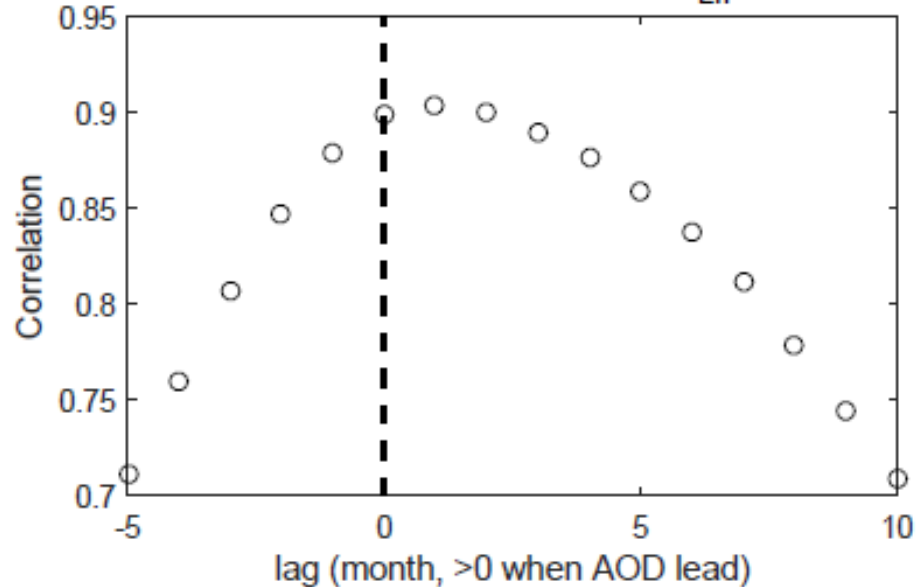


Scaling used in our new idealized model:

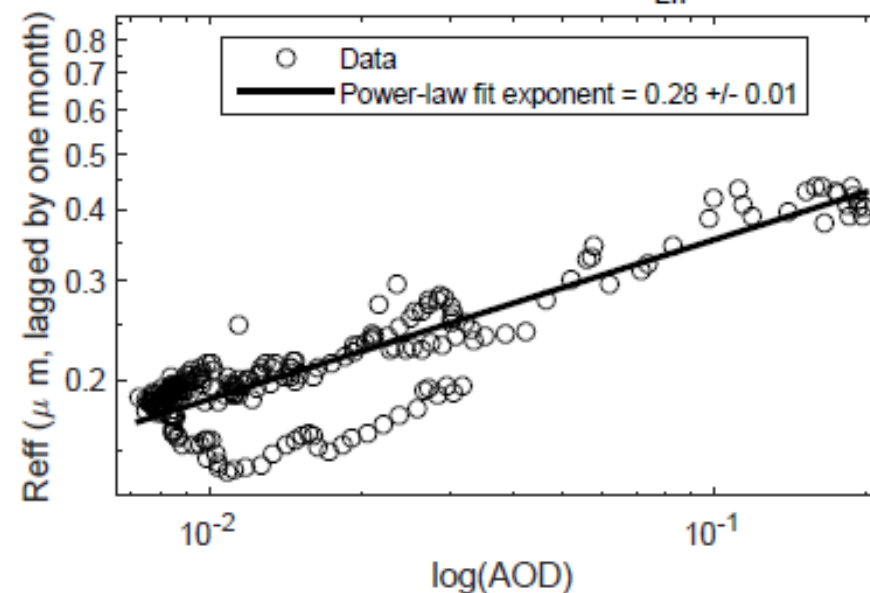
$$R_{\text{eff}} = \text{SAOD}(t - \tau_{\text{lag}})^{1/3}$$

$$\tau_{\text{lag}} = 2 \text{ months}$$

SAGE4  $\lambda$  (1985-2005) AOD- $R_{\text{Eff}}$  lag

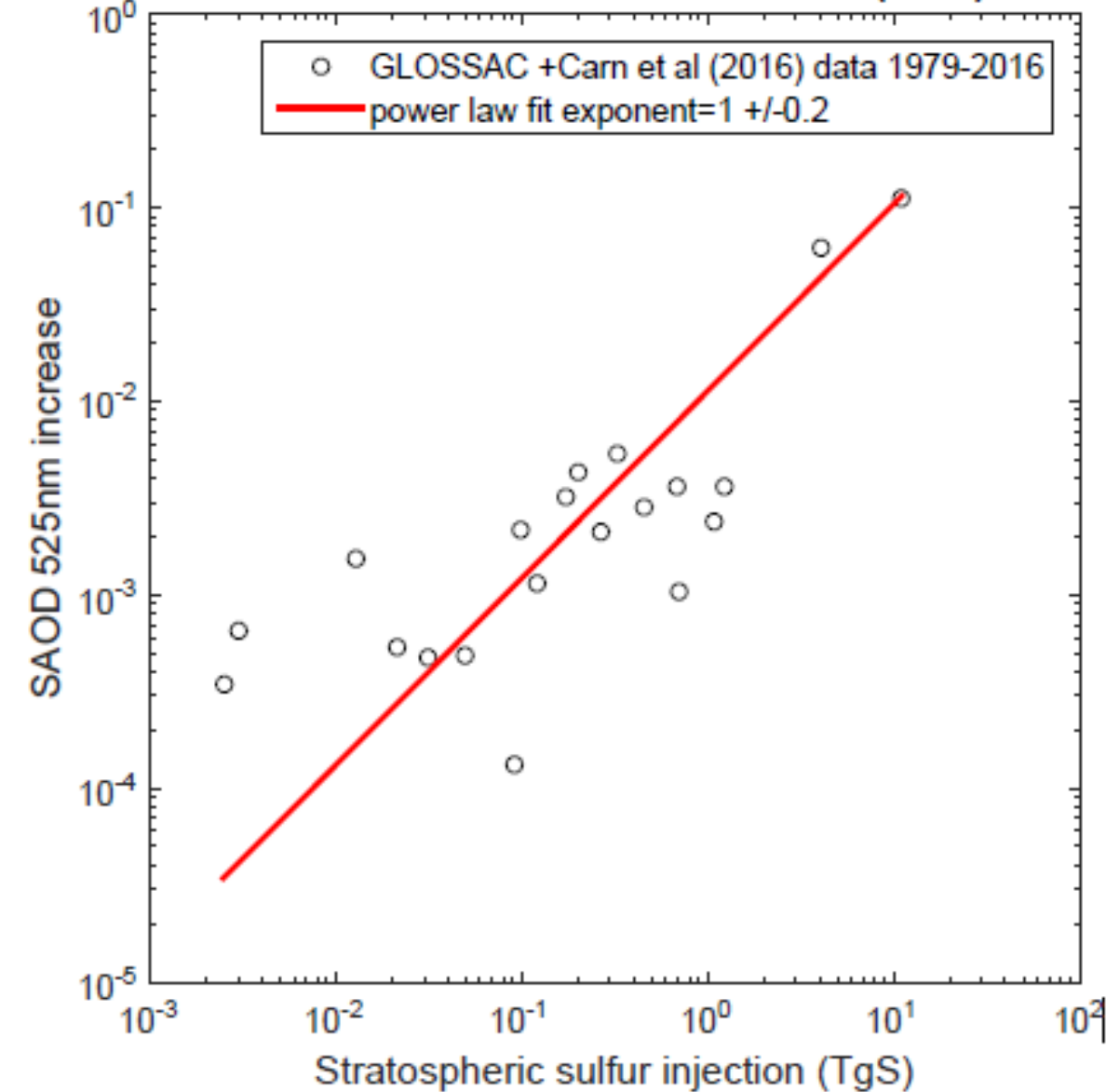


SAGE4  $\lambda$  (1984-2005) AOD- $R_{\text{Eff}}$  scaling

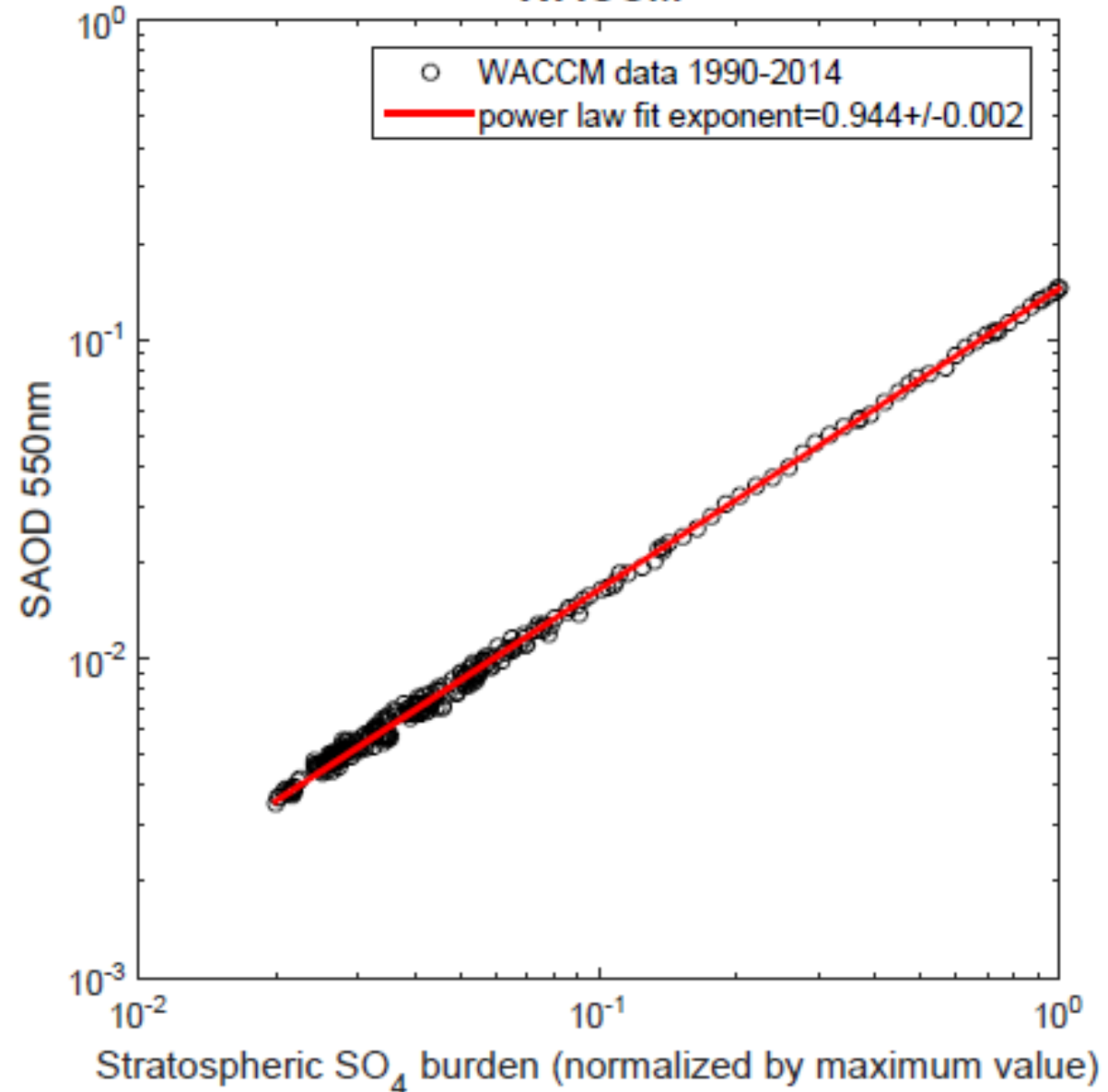


# Grounds for a linear SAOD-sulfate mass scaling

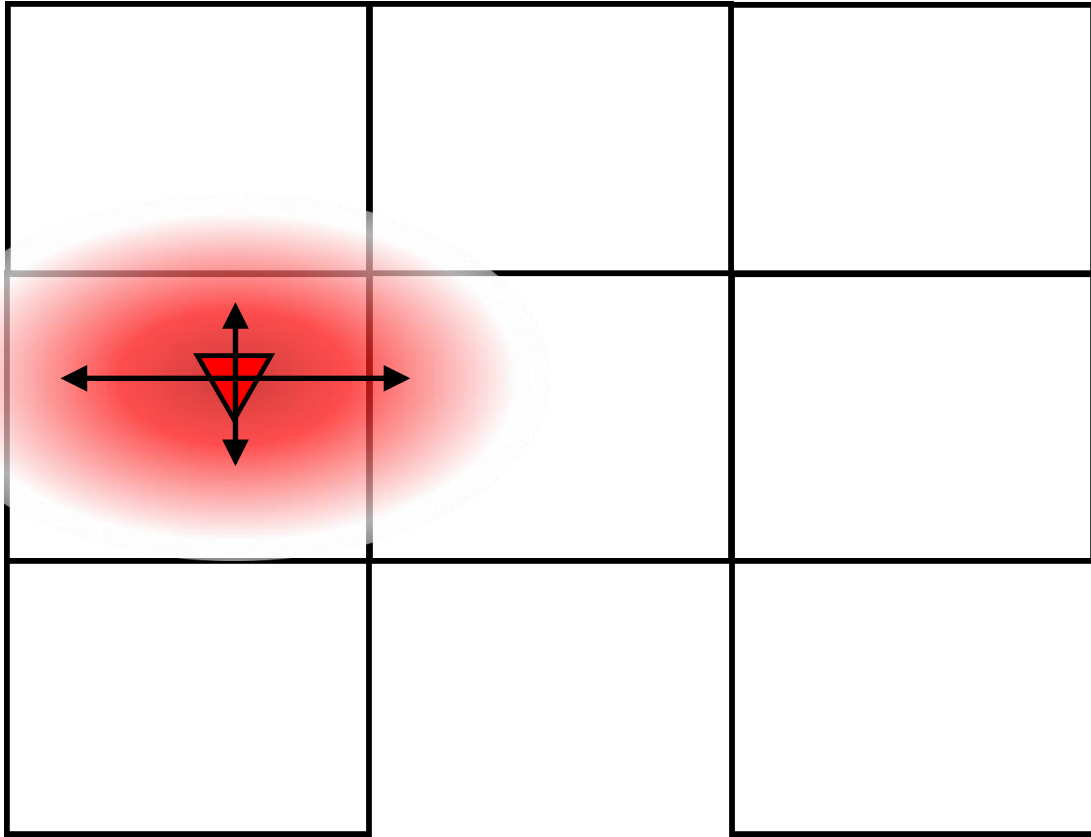
GLOSSAC and Carn et al 2016 (SO<sub>2</sub>)



WACCM

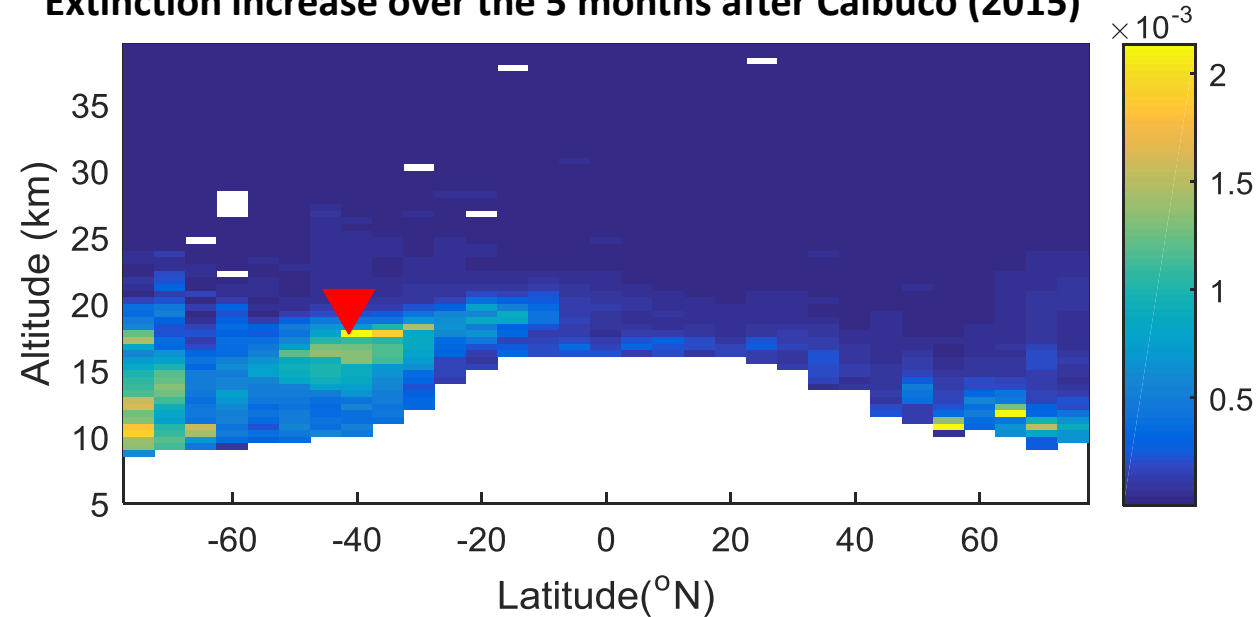


# SO<sub>2</sub> injections in the new idealized model

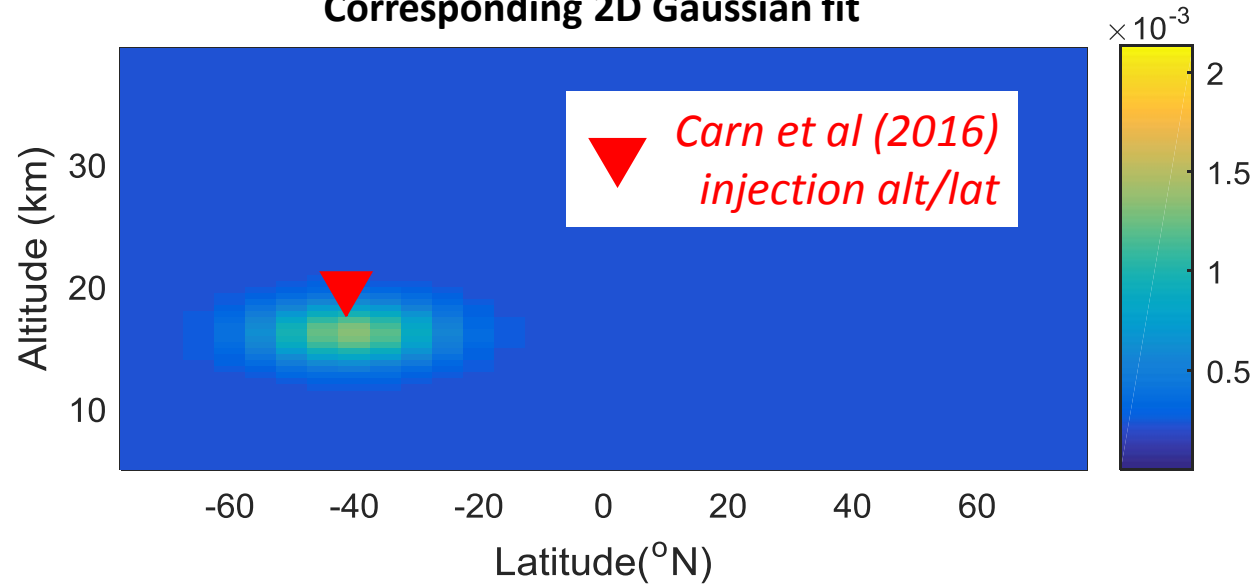


- SO<sub>2</sub> distributed among boxes using a 2D Gaussian function centered on injection altitude/latitude estimates from *Carn et al. (2016)*
- Gaussian widths determined from fit of extinction increase in GLOSSAC in the 5 months following each eruption

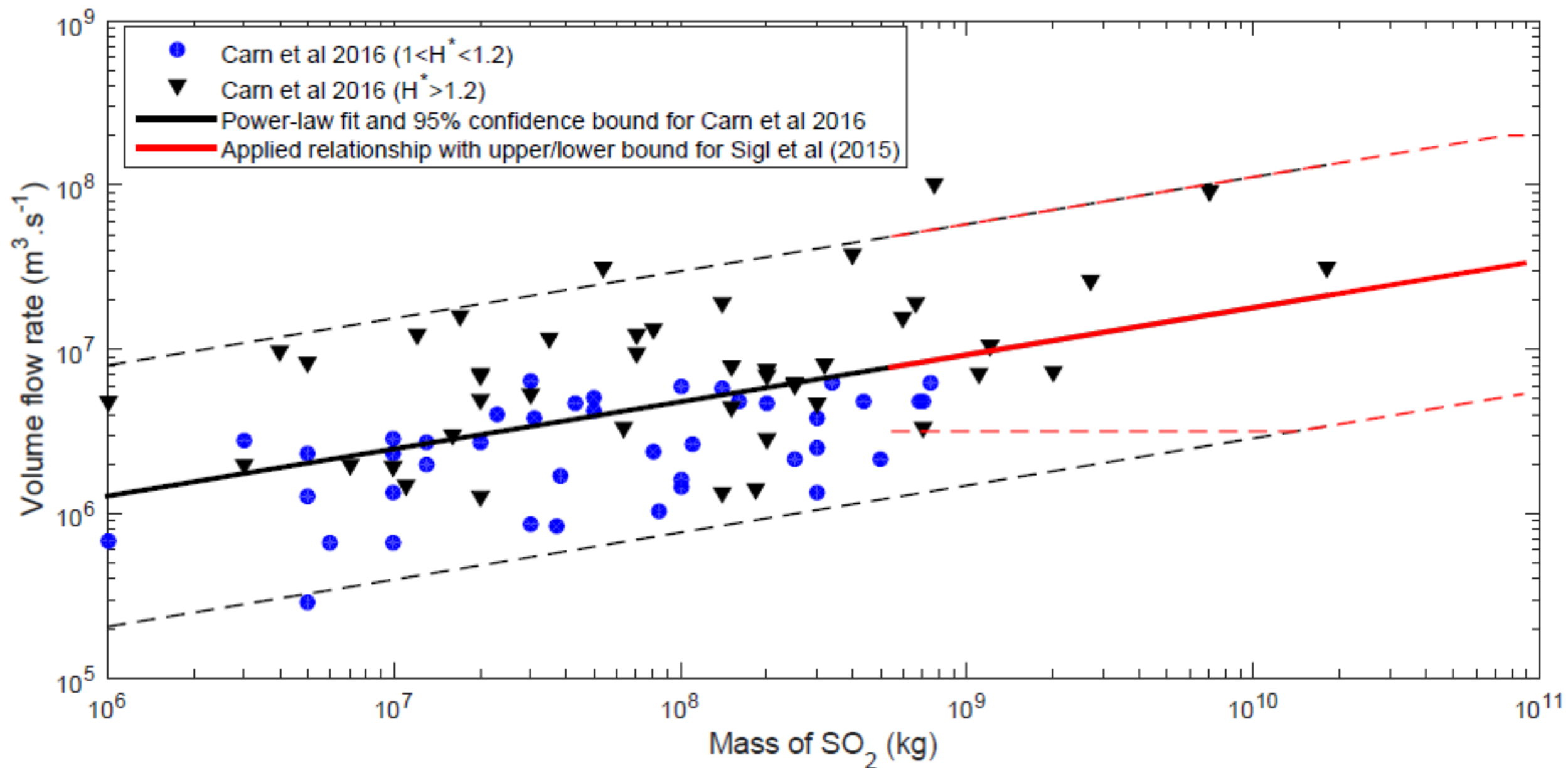
Extinction increase over the 5 months after Calbuco (2015)



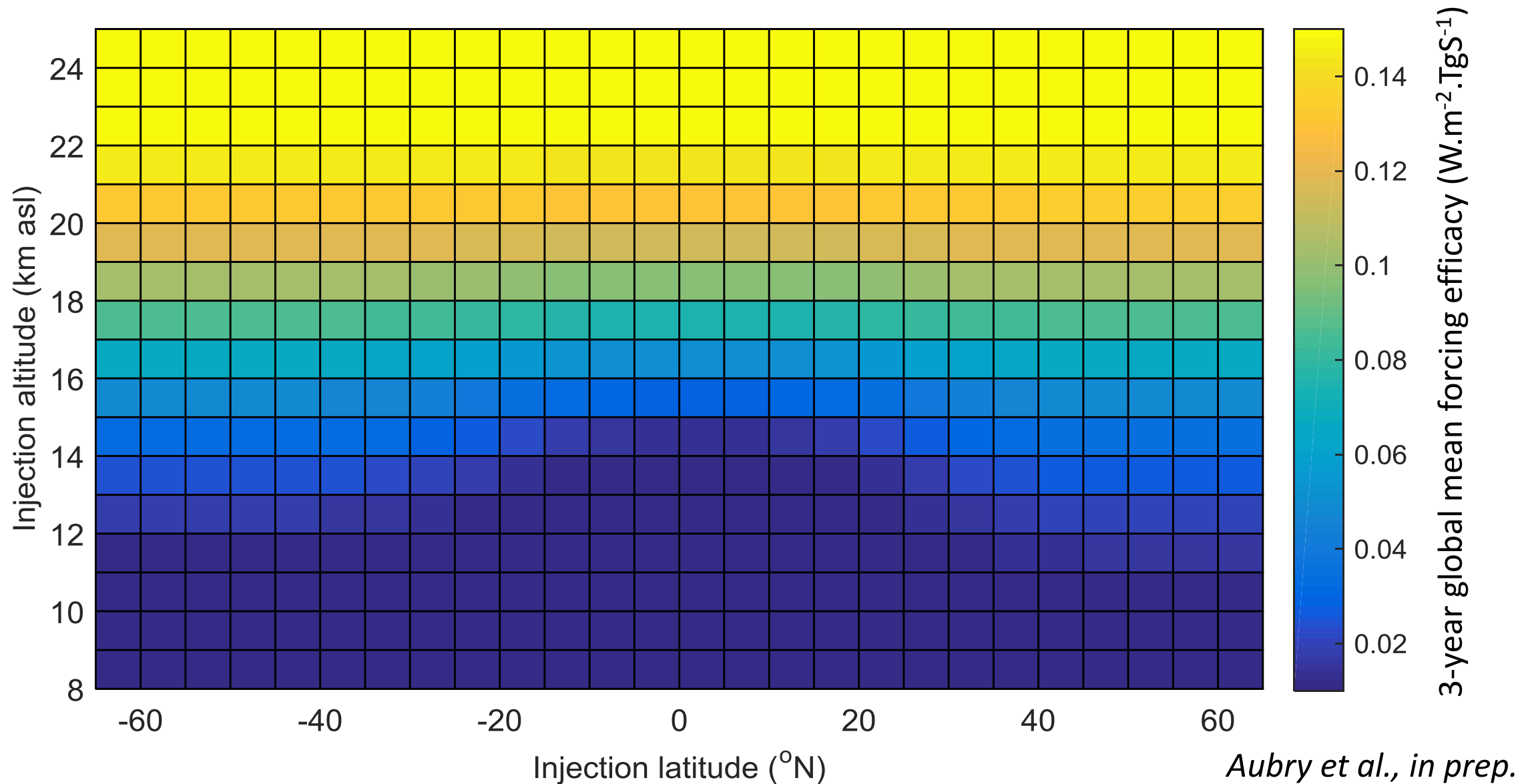
Corresponding 2D Gaussian fit



# Attributing a volume flow rate to eruptions recorded in ice-cores



# Sensitivity of forcing to injection height and latitude in our new model





# What was the climate impact of the Katmai (1912) eruption?

5-8 Mt of SO<sub>2</sub> at 58.3°N and 22-26 km a.s.l. (*Bonadonna and Costa, 2013*)

SAOD prediction from *Amman et al. (2003)* used implemented in a climate model in *Oman et al. (2005)* to test the climate impact of high-latitude eruptions

SAOD (log) prediction of our new model (*Aubry et al., in prep*)

