The impact of Pyrocumulonimbus on atmospheric composition in UTLS

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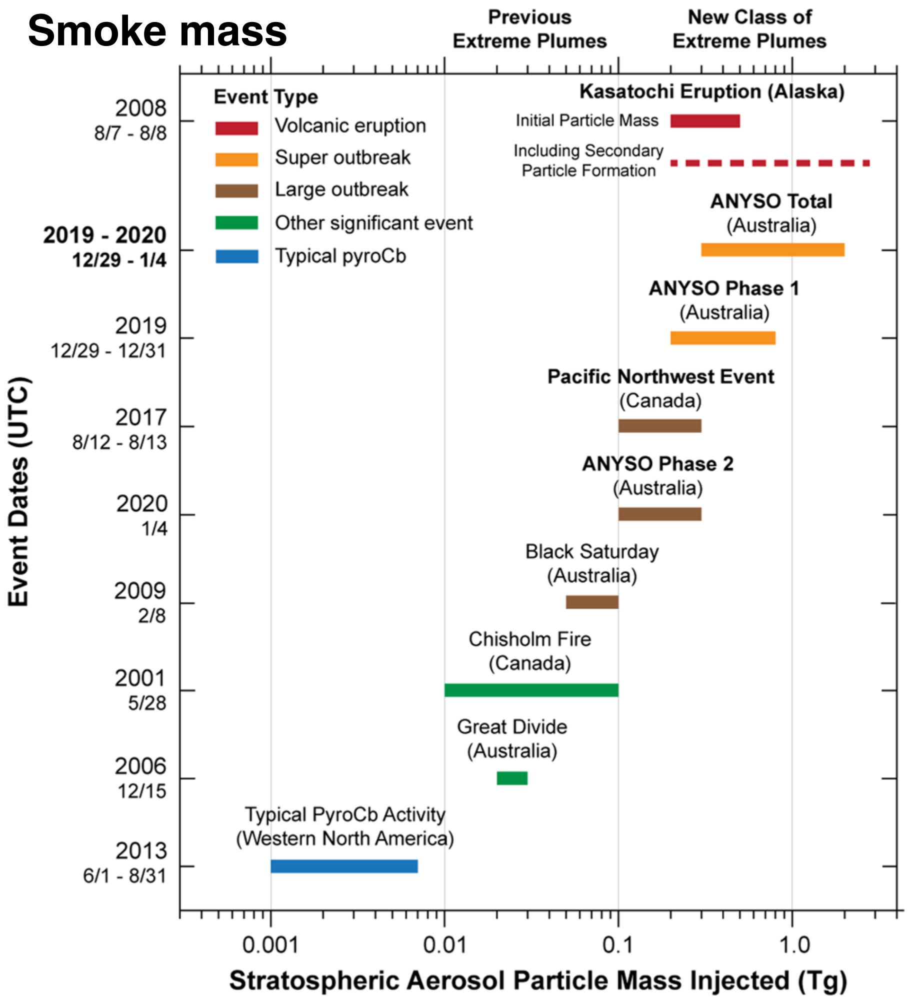
SAGE III/ISS Annual Science Meeting, 14 Oct. 2022

pyroCb can be equivalent to a moderate volcanic eruption

(amount and injection height)

Smoke mass



Wildfire-driven thunderstorms cause a volcano-like stratospheric injection of smoke **Peterson et al., 2018; 2021**

Volcanic SO_2

Table 1. Annual and Global Total Volcanic SO_2 Emissions (kt/yr)

	Year	Eruptive	Persistently Degassing
AeroCom[a]	2005–2009	8180	18,520 (Trop[b]: 2110)
OMI	2005–2009	1870	(Trop[b]: 1900)
OMI	2005–2012	1670	(Trop[b]: 1850)

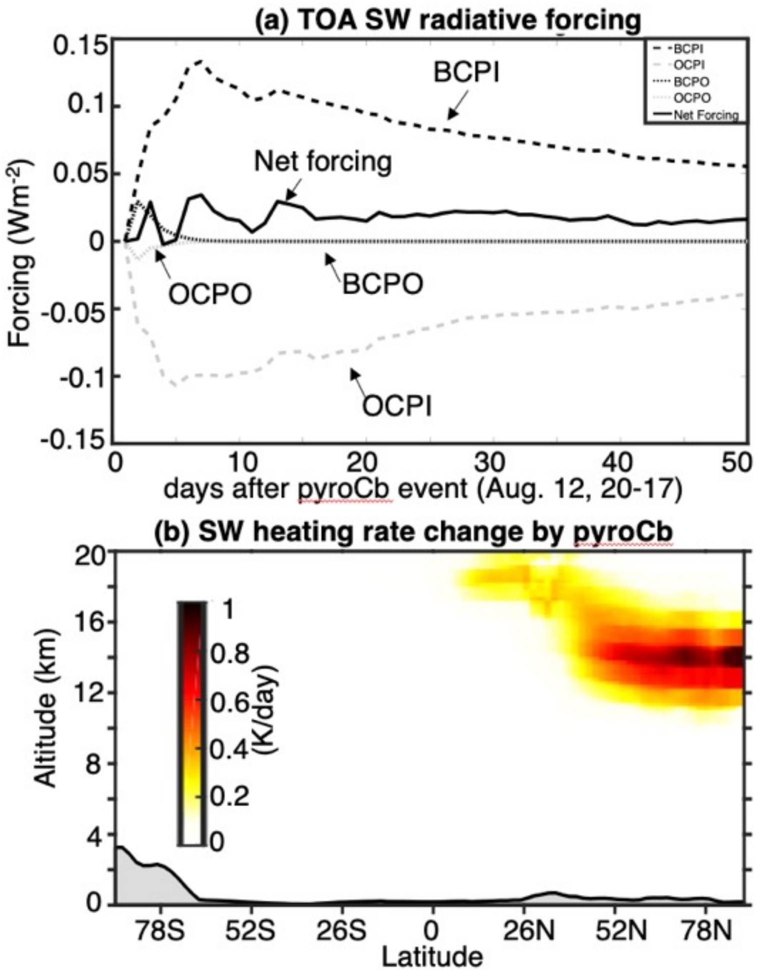
[a]1979–2009, http://aerocom.met.no/download/emissions/AEROCOM_HC/. And an updated version of the AeroCom database (including the year of 2010) can be accessed at http://aerocom.met.no/download/emissions/HTAP/.

[b]Trop: tropical. Subset of eight persistently degassing volcanoes over tropical area as presented in our OMI data.

Ge, Wang, et al., 2016

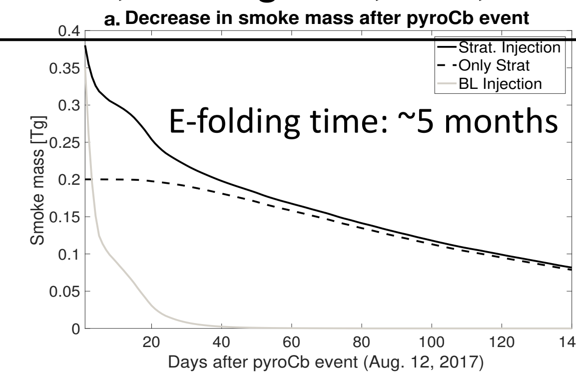
But, radiative effects and lifetime can be different …

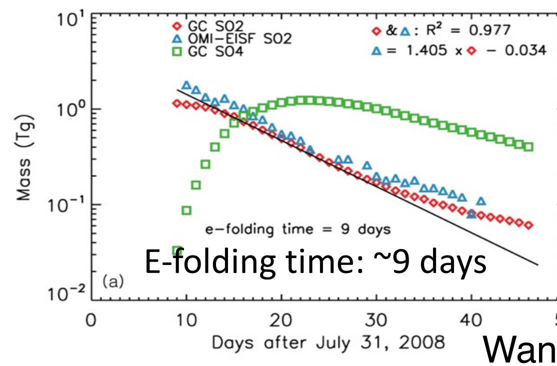
heating instead of cooling



Radiative forcing and stratospheric warming of Pyrocumulonimbus smoke aerosols: first modeling results with multisensory (EPIC, CALIPSO, and CATS) views from Space

K. Christian, J. Wang et al., 2019, GRL

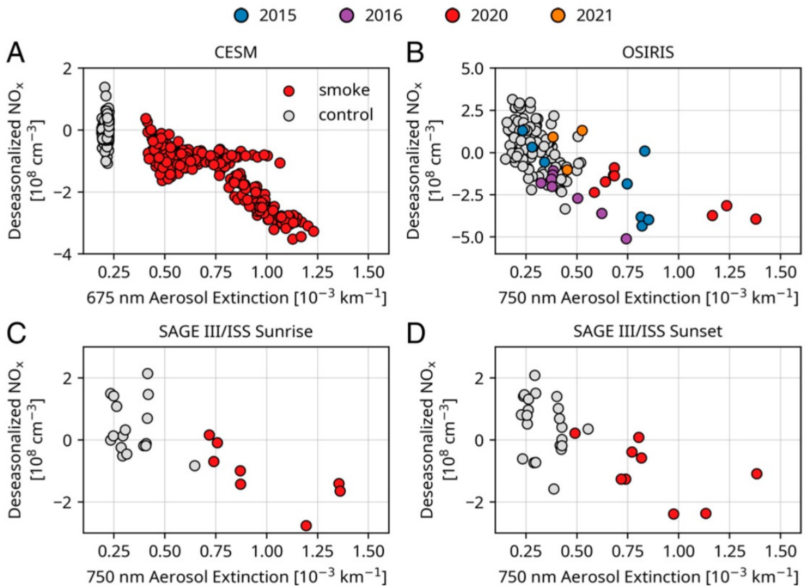




Wang et al., ACP, 2013

Heterogeneous chemistry deplete ozone
hydrated smoke

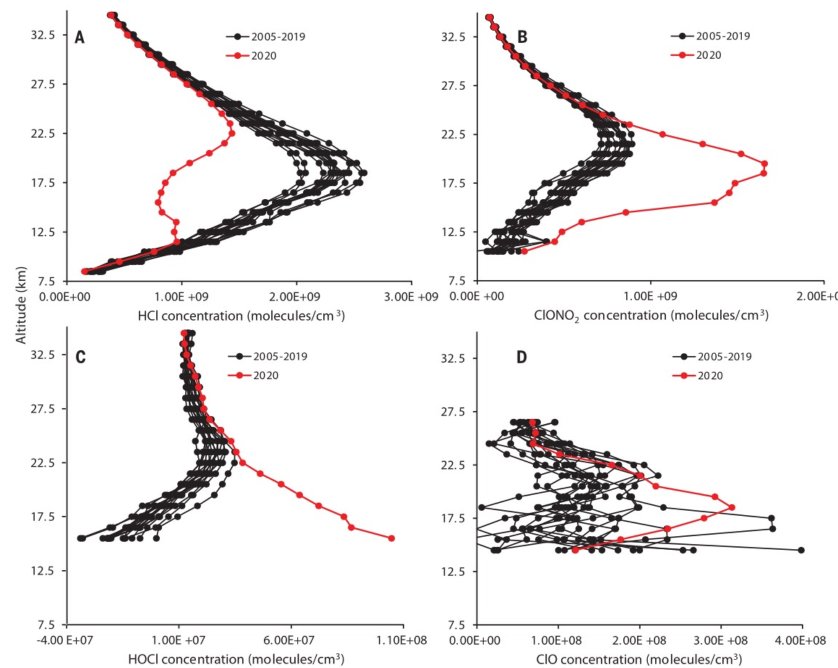
NOx decrease

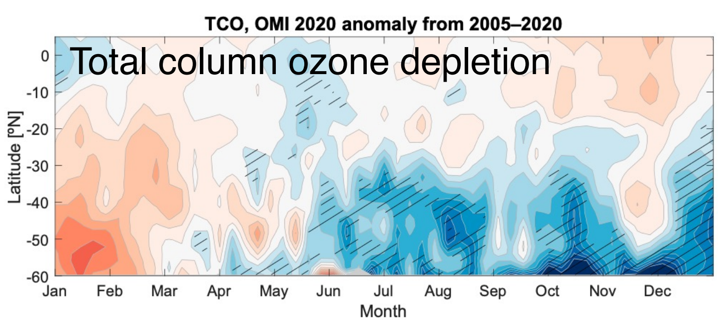


Wildfire smoke destroys stratospheric ozone through NOx, ClOx, HOx-catalyzed ozone loss

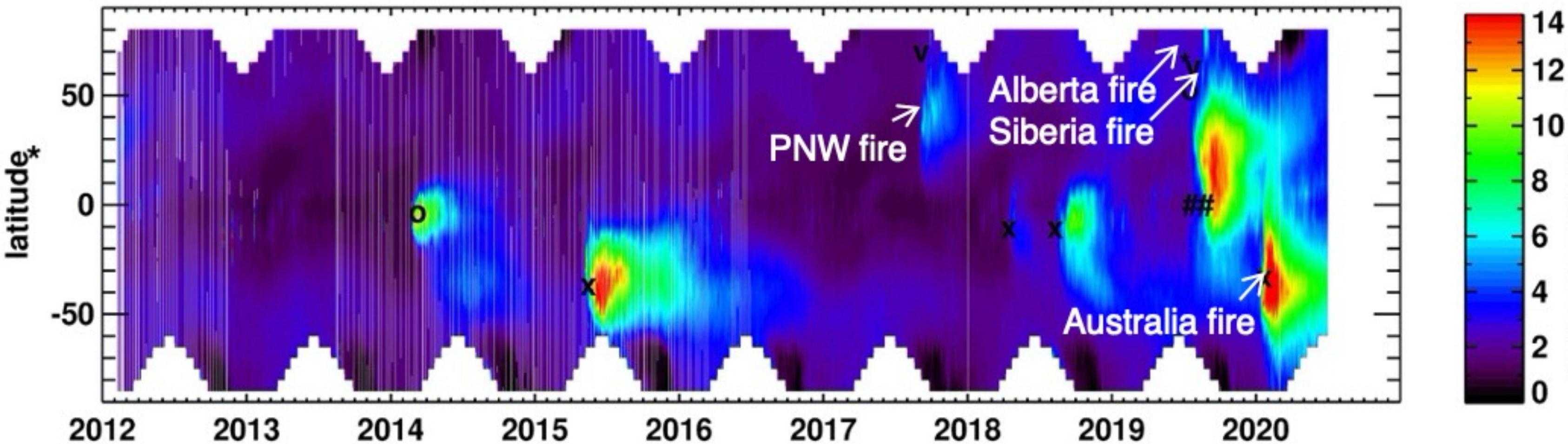
S. Solomon et al., PNAS, 2022

P. Bernath et al., Science, 2022





The goal of this project:



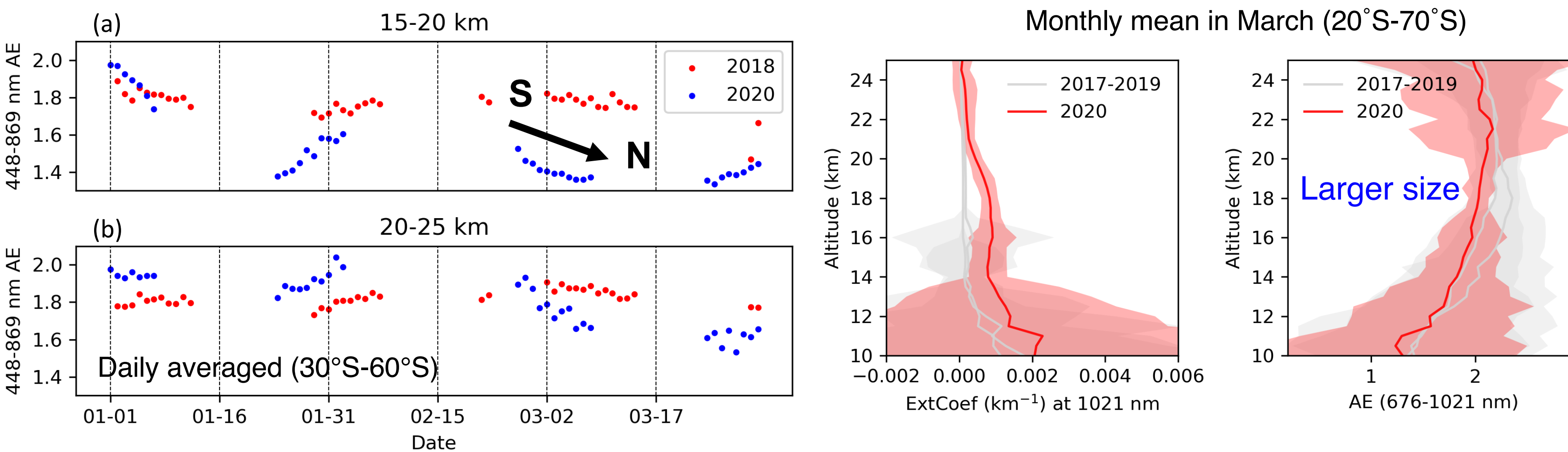
ANYSO: Australian New Year Super Outbreak (2019/2020)

Using SAGE comprehensive and long-term data record and other datasets together with models:

- Study pyroCb effects on aerosol loading at the regional-to-global scale with different temporal durations (e.g., monthly, seasonally, and longer)
- Modeling/process studies of UTLS background aerosol variability (such as due to the change of emissions)
- Stratospheric aerosol forcing and effect studies

Evolution of ANYSO smoke particle size

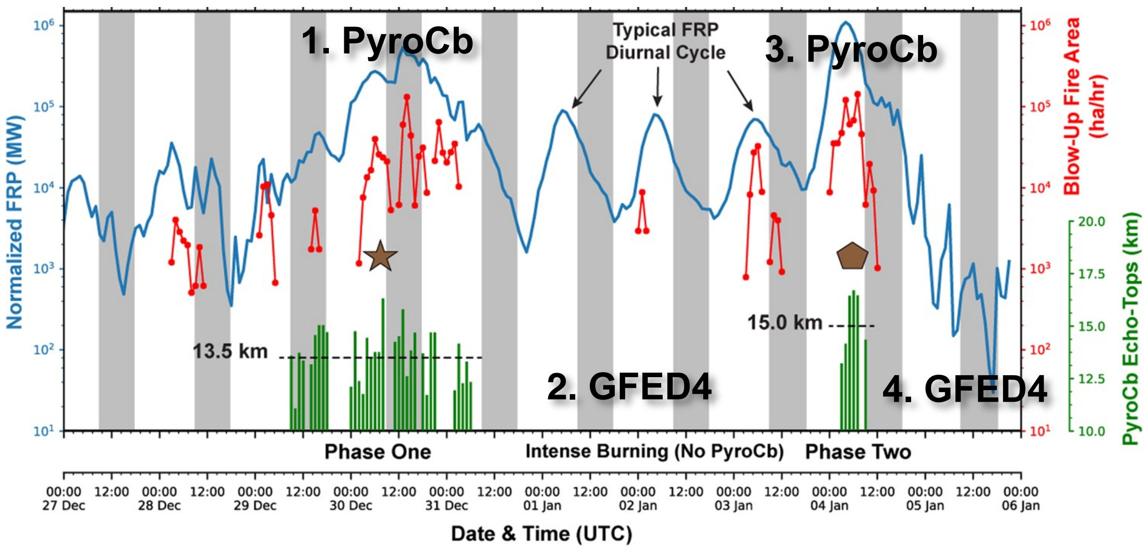
Insights from SAGE III/ISS



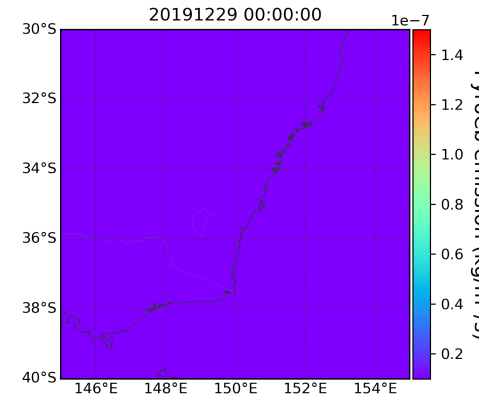
- ANYSO event leads to stronger aerosol extinction in 10-25 km in southern hemisphere midlatitude lasting ~1 year.
- Smaller AE values at 10-25 km are found in 2020 compared with previous years, indicating the particle size grows until late 2020.
- The particle size at lower altitude (15-20 km) increase since a few weeks after pyroCb injection, while the growth of particles at higher altitude (20-25 km) started ~2 months after injection through vertical transport.
- SAGEIII observations reflect the coupled effect of pyroCb evolution with time and zonal distribution in the UTLS.

ANYSO 3D emission inventory
apply in GEOS-Chem

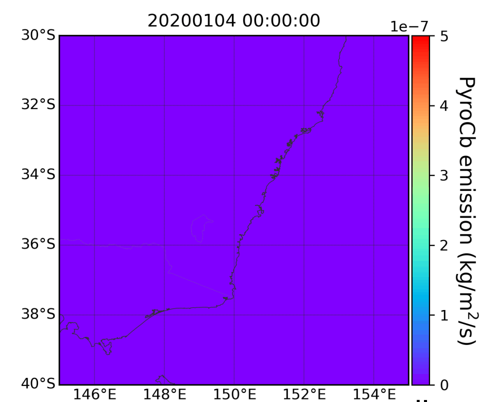
Peterson et al., npj Clim Atmos Sci, 2021



Phase 1: 0.8 Tg; ~45 hr



Phase 2: 0.3 Tg; ~6 hr



ilayer = 32

- With injection height observations (z), PyroCb emission flux vertical distribution is assumed. ***(K. Christian, J. Wang et al., 2019, GRL)***

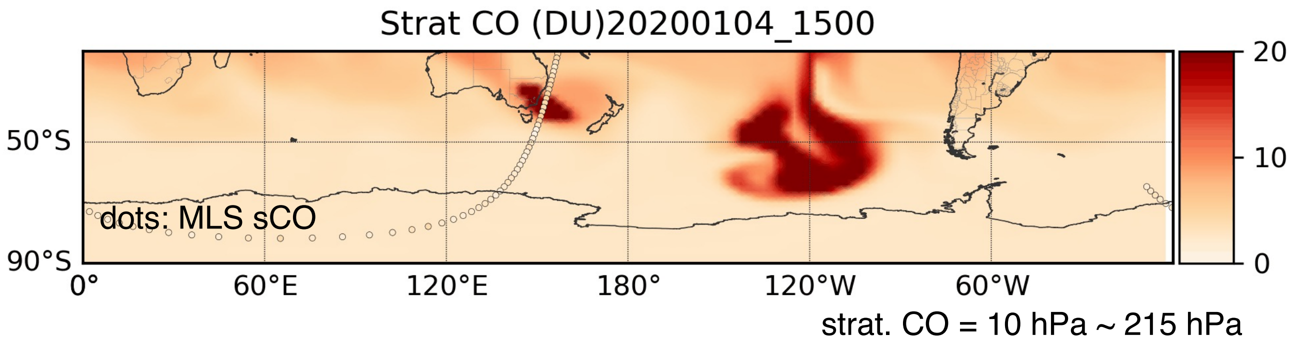
$$F_{(l<z)} = \frac{(0.5 * M_{\mathrm{PCB}})}{(N_{\mathrm{hours}} * A_{1x1} * z)}$$

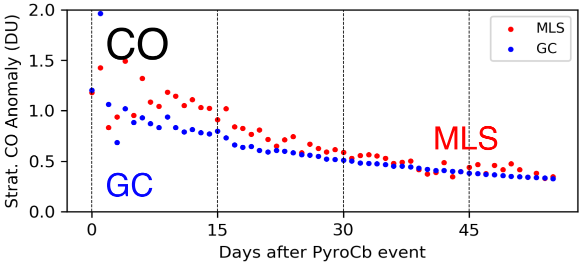
$$F_z = \frac{(0.5 * M_{\mathrm{PCB}})}{(N_{\mathrm{hours}} * A_{1x1})}.$$

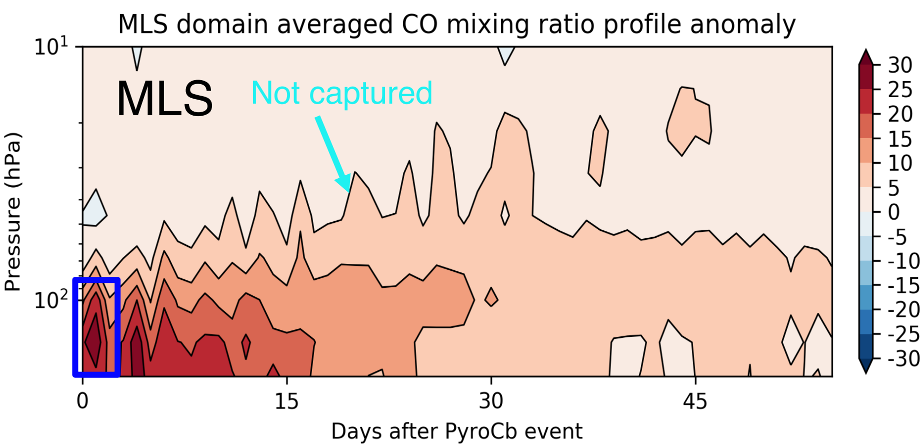
- Emission factors: BC (6%), OC (94%) (van der Werf et al., 2010), F_{CO}/F_{aer} = 9.87 (Andreae, 2019, ACP)

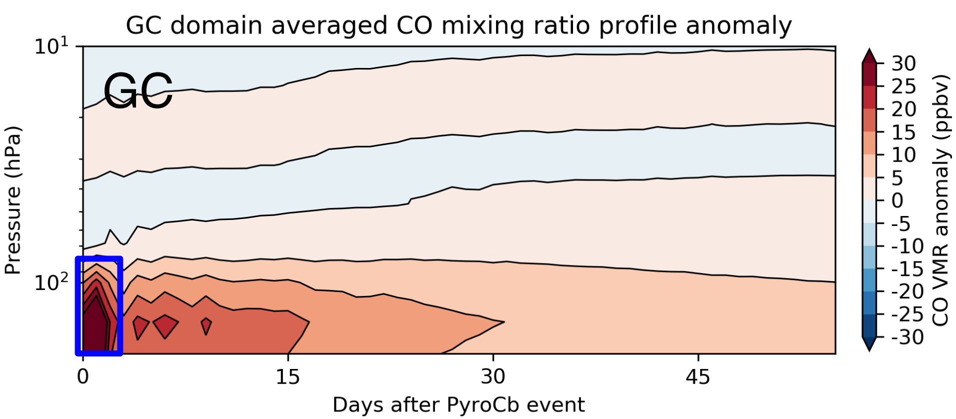
Simulation of stratospheric CO evolution

comparison with MLS





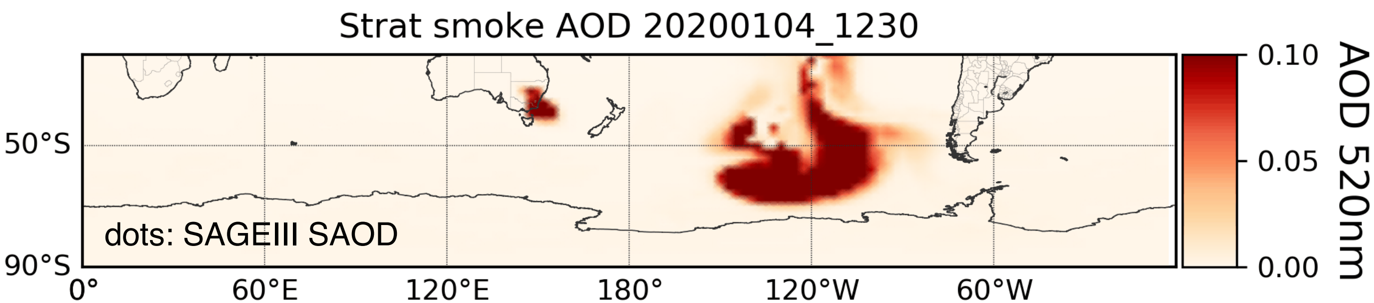




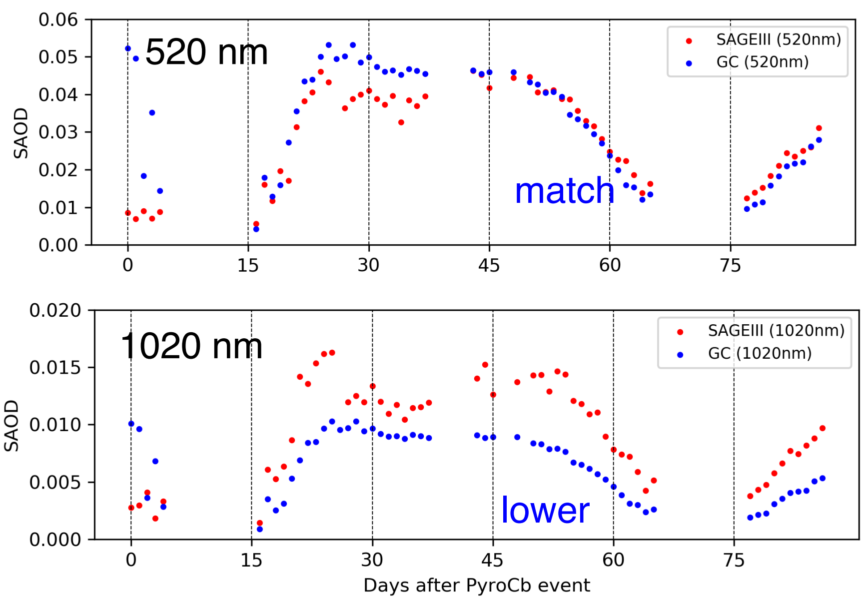
- GEOS-Chem CO cannot capture the anomaly at higher altitude (30-70 hPa), but still show similar evolution in lower stratosphere during long-term period.

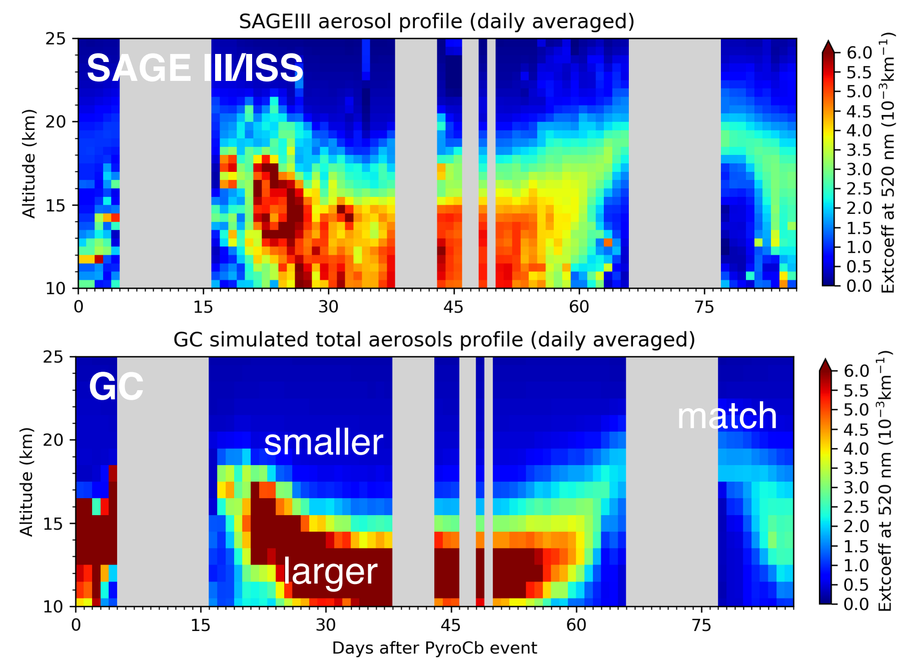
Simulation of stratospheric smoke evolution

comparison with SAGE III/ISS



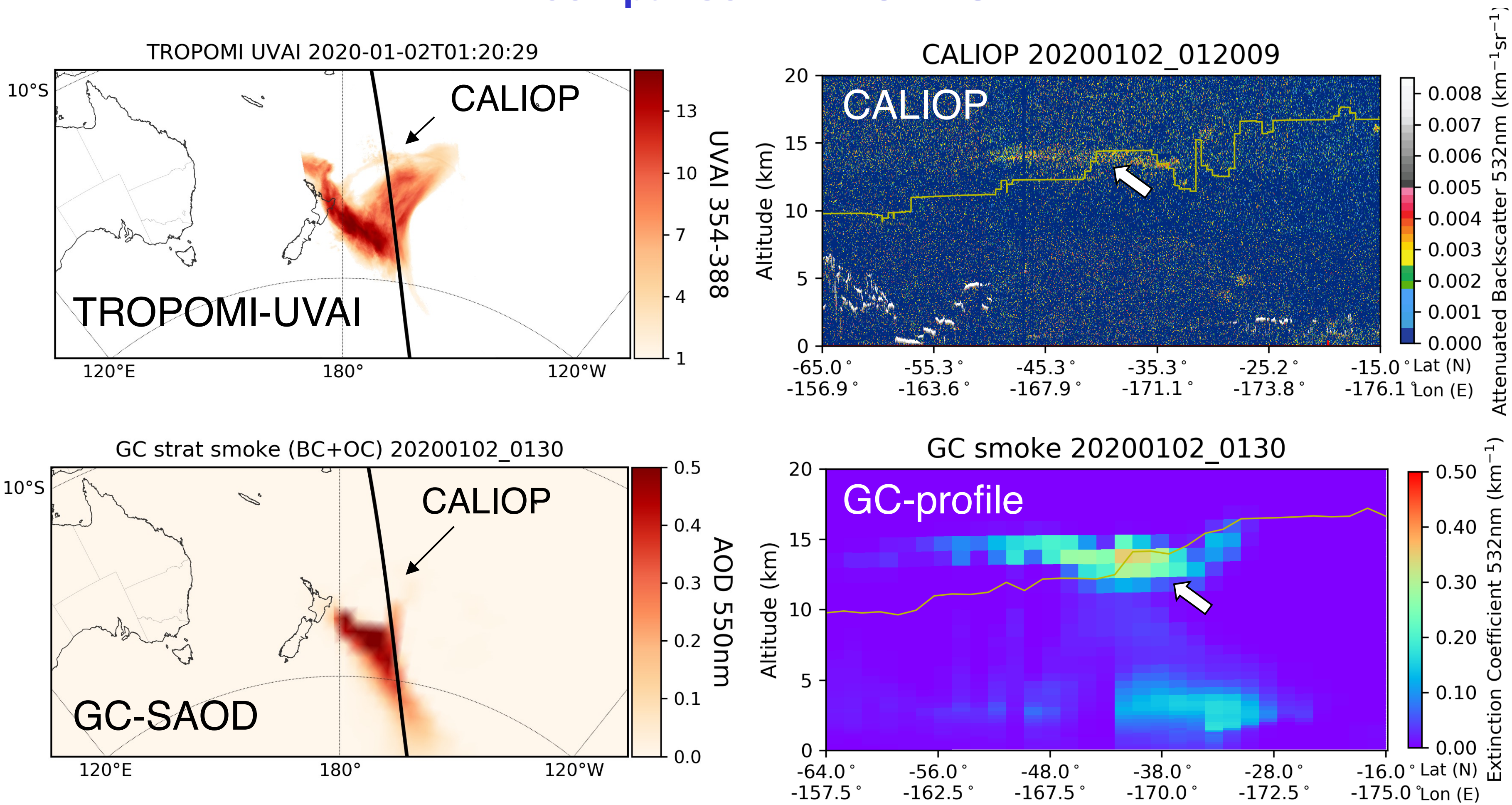
smoke AOD = OC + BC



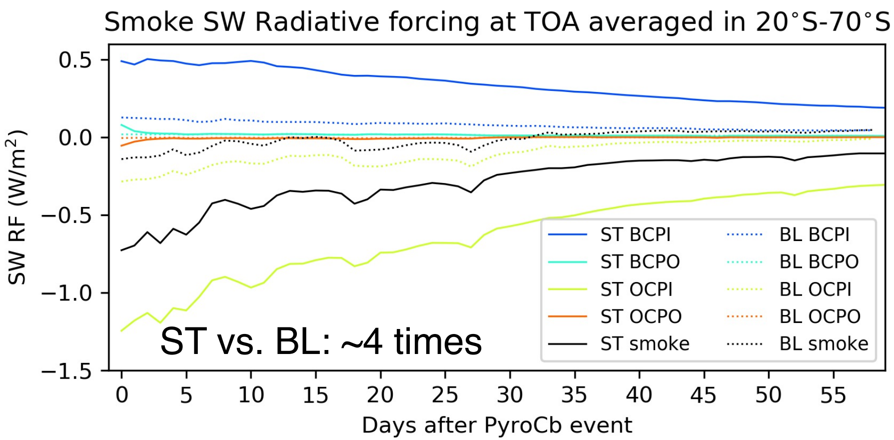


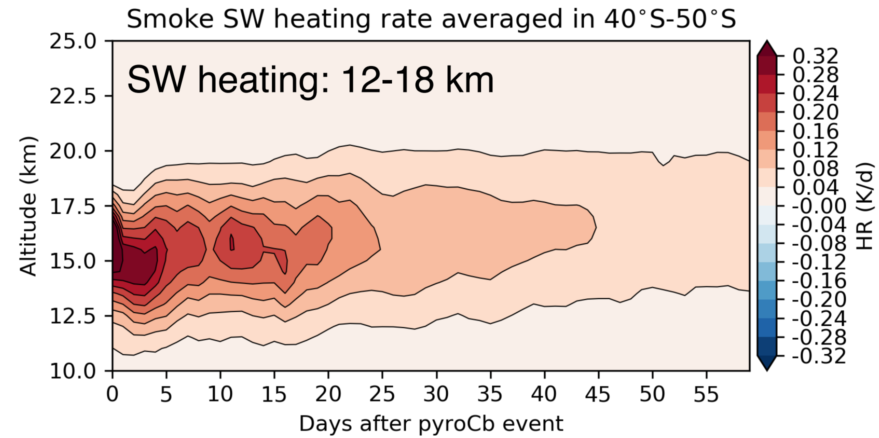
Simulation of stratospheric smoke vertical transport

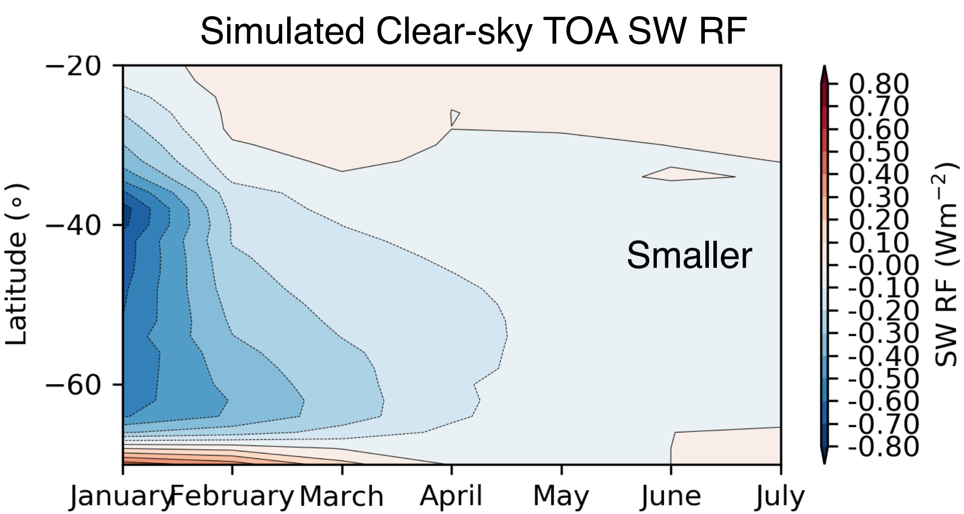
comparison with CALIOP

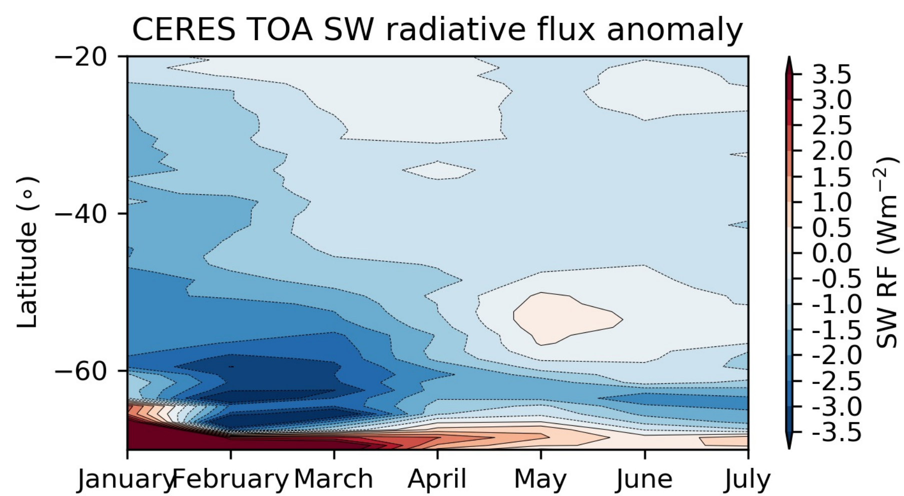


Radiative forcing and stratospheric warming of smoke





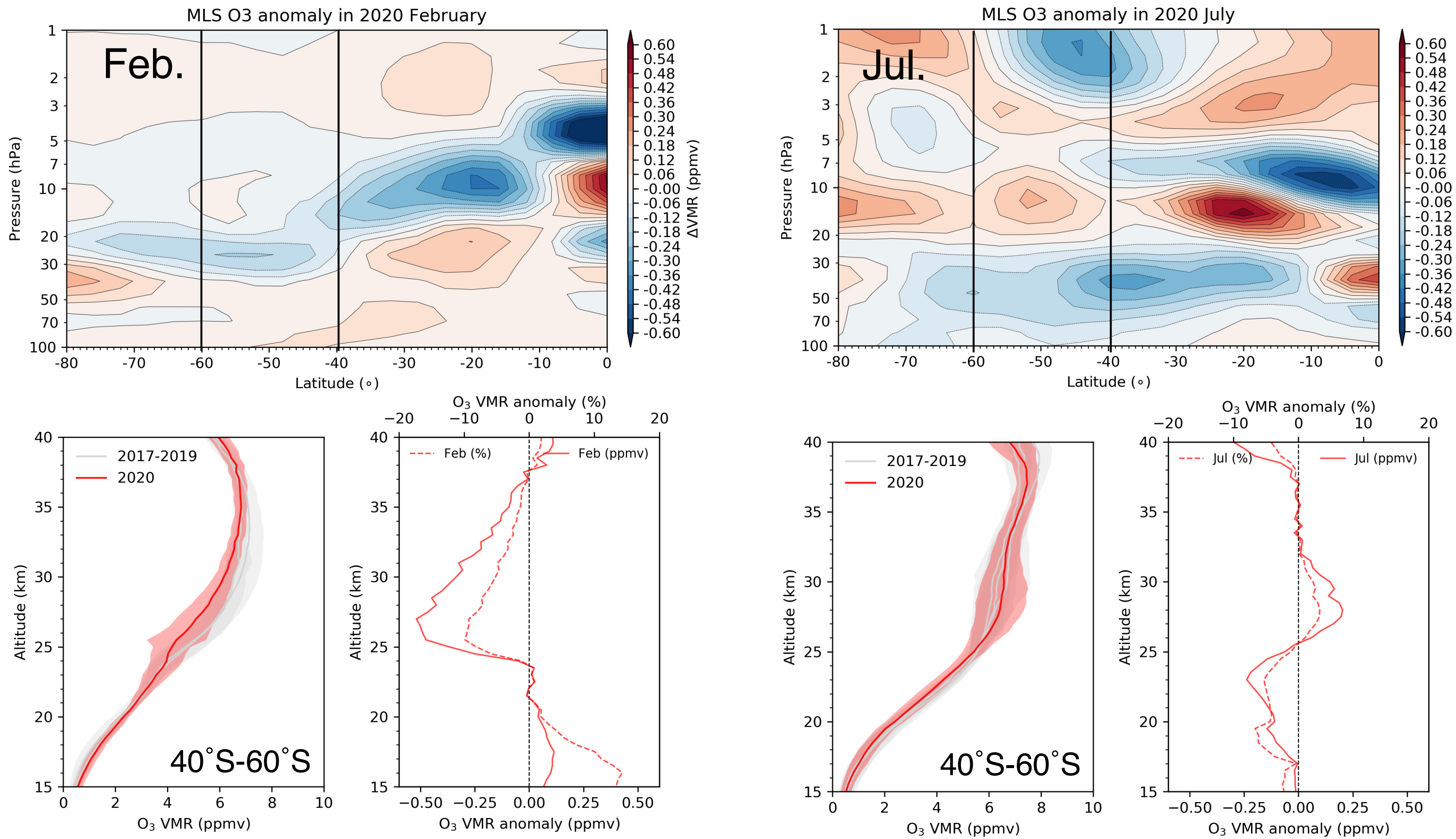




Stratospheric ozone profile evolution

MLS

SAGE III/ISS



- The stratospheric ozone depletion started at upper layer (> 25 km) and then shown up at lower stratosphere (15-25 km).

Summary

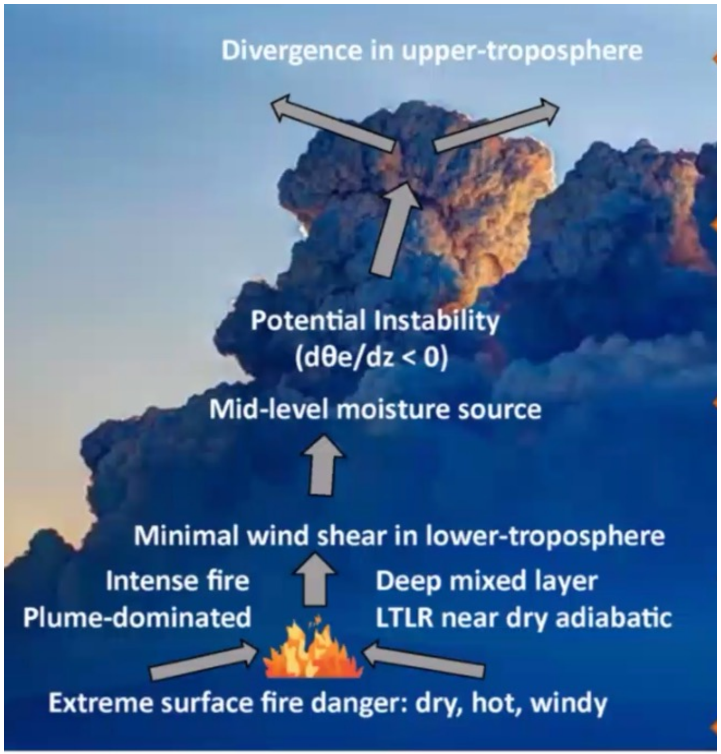
- Implementing pyroCb emission in UTLS, GEOS-Chem aerosols and CO evolution overall agree with satellite observations, but show slightly lower values at higher altitudes. The wavelength dependence of pyroCb smoke extinction is different with that used in model.
- Consideration of the injection height of pyroCb emission in UTLS can lead to ~4 times larger radiative forcing from smoke particles and result in significant warming in UTLS.
- Radiative forcing from smoke particles is smaller than satellite observations, indicating the abnormal optical properties of pyroCb aerosol particles as well as other possible factors affecting the radiative forcing, especially in higher latitudes.
- The evolution of ozone profile anomaly may be related to aerosols from pyroCb event and deserves more study.

Acknowledgment

BACKUP

pyroCb inject smoke particles into UTLS

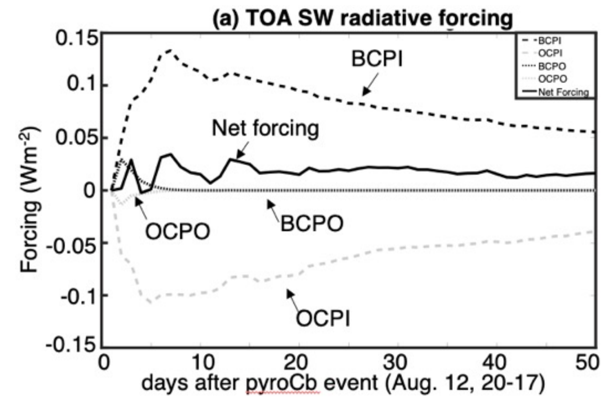
PyroCb: smoke plumes from intense wildfires could spawn towering thunderstorms and cause a volcano-like stratospheric injection

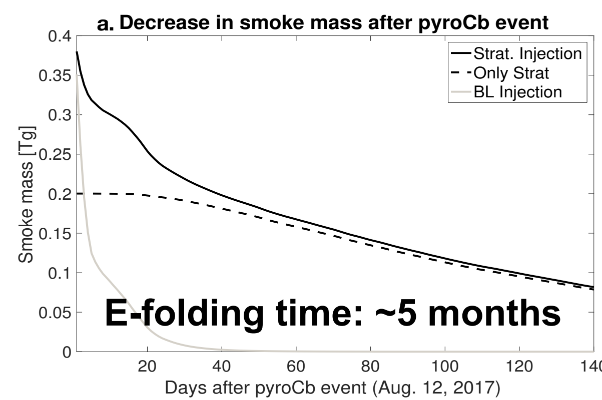


Peterson et al., 2017 (Mon. Wea. Rev)

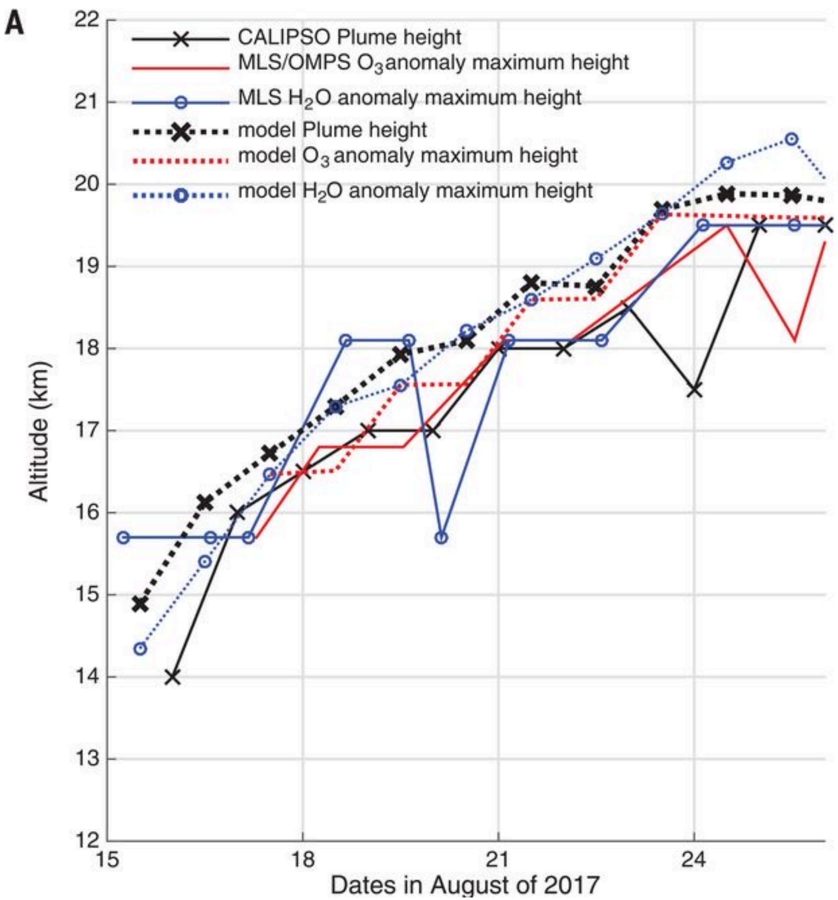
Radiative effects can be **heating**

K. Christian, J. Wang et al., 2019, GRL



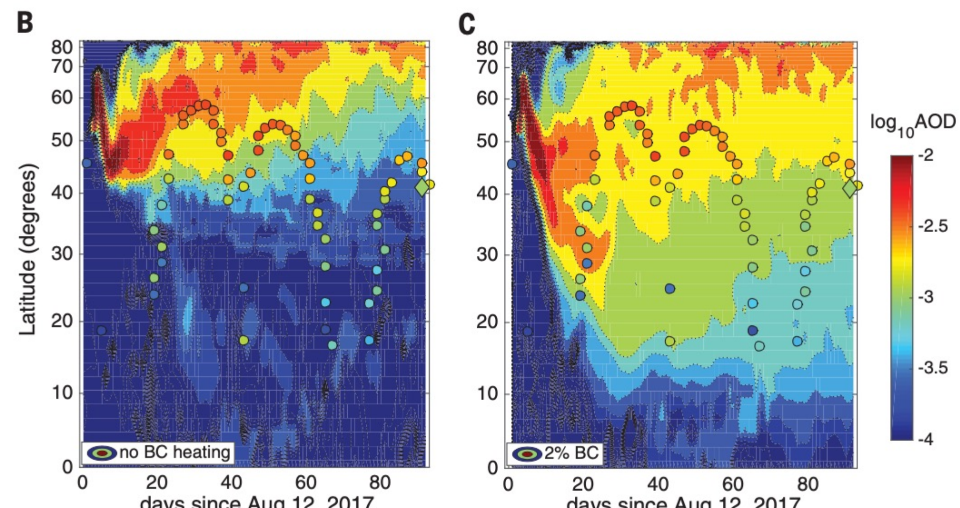


The radiative feedback on dynamics …
self-lofting, self-sustain, water vapor, etc.

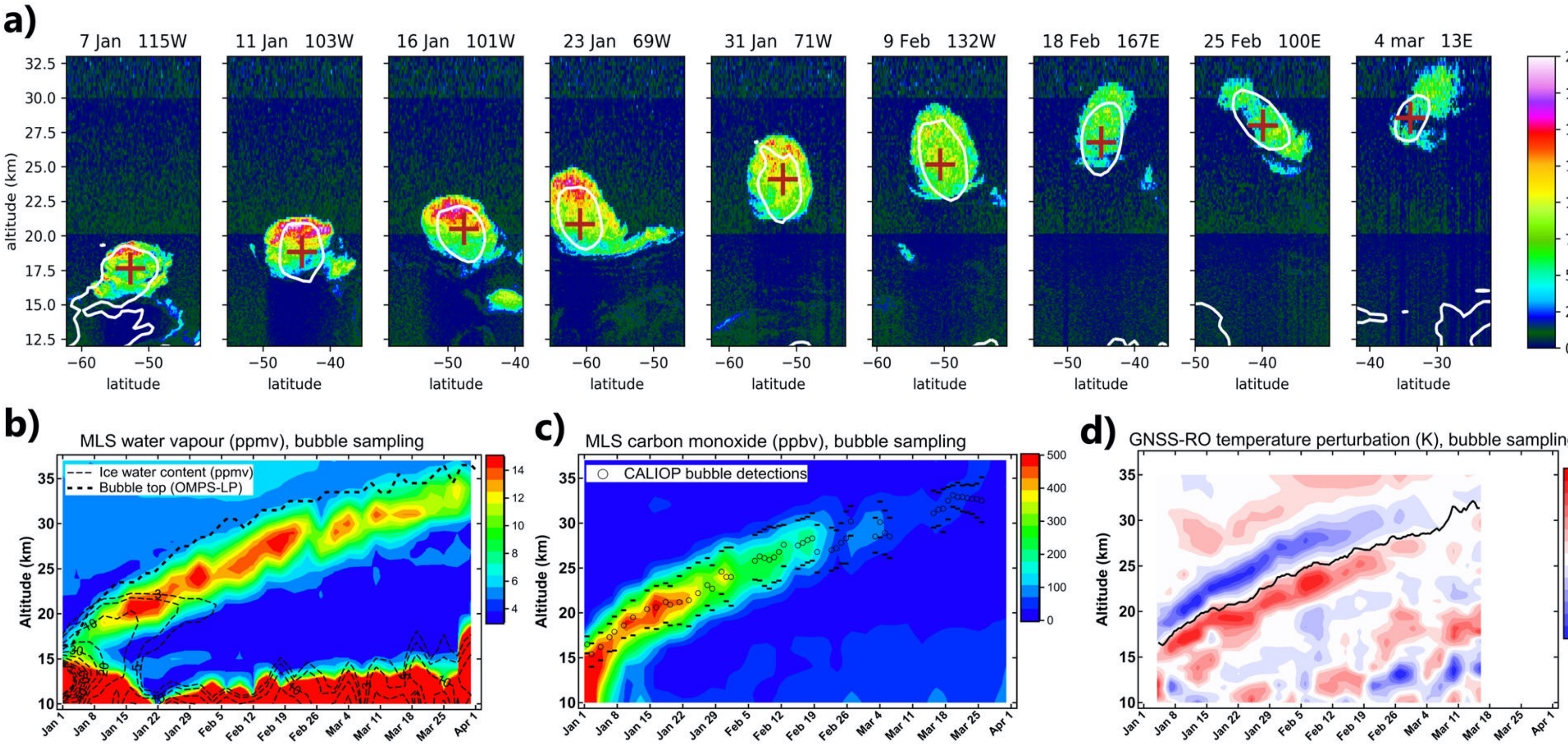


Black carbon lofts wildfire smoke high into the stratosphere to form a persistent plume

Yu et al., Science, 2019.

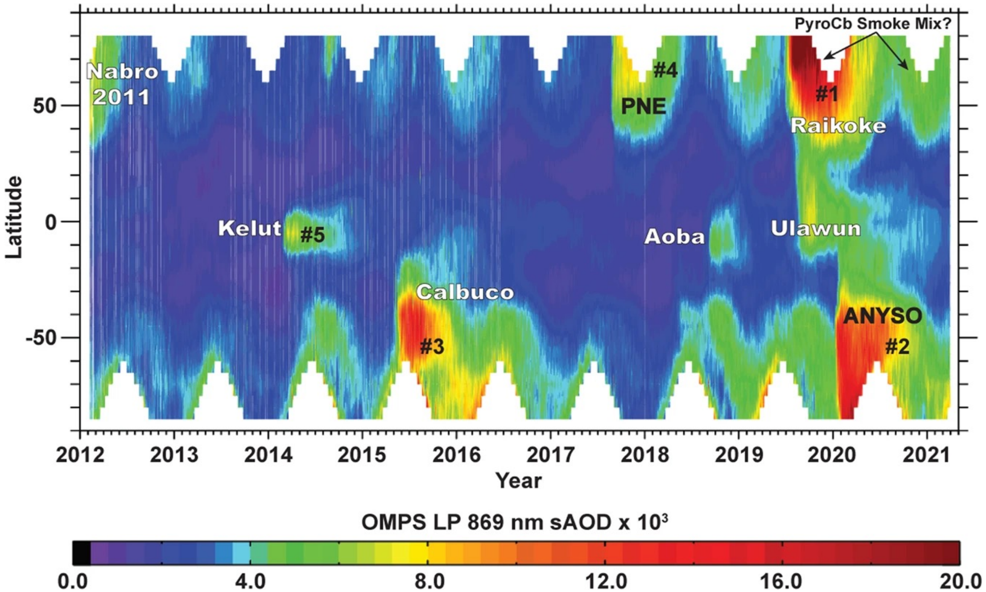


ANYSO Fire case shows the similar observations
ANYSO: Australian New Year Super Outbreak (2019/2020)

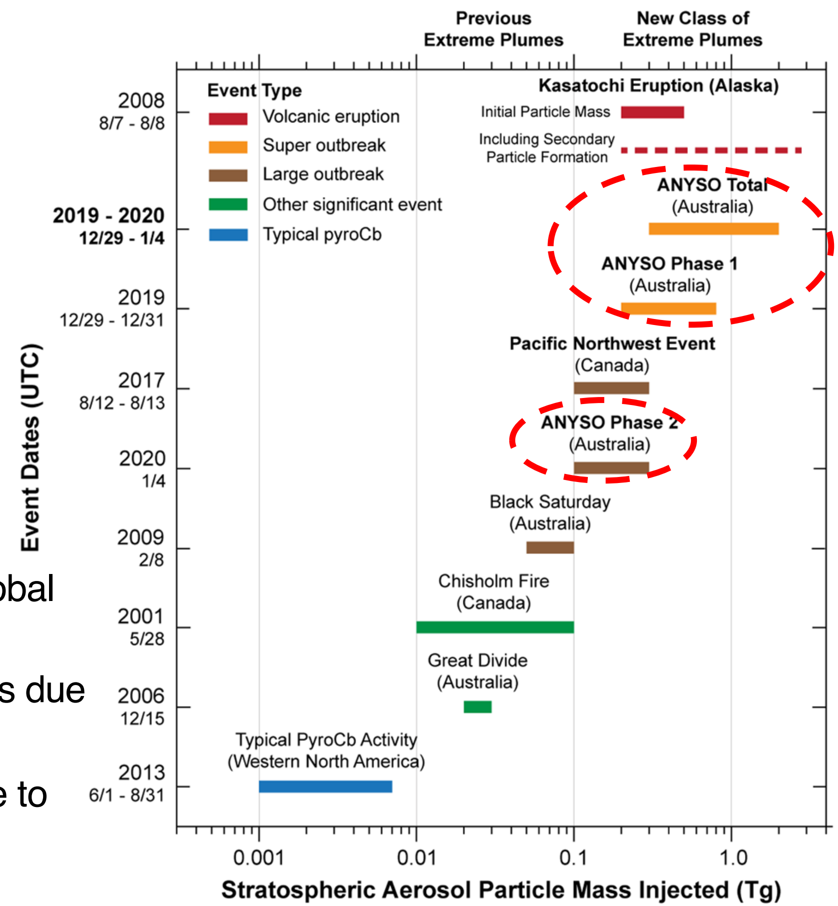


Khaykin et al., 2020, Commsenv.

The goal of this project



(Peterson, D.A. et al., 2021)

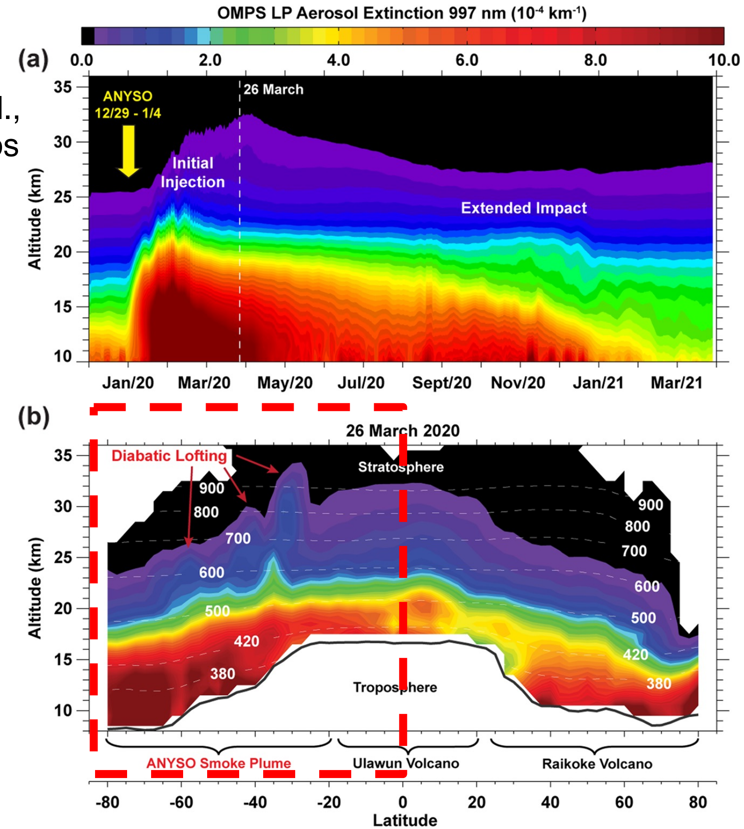


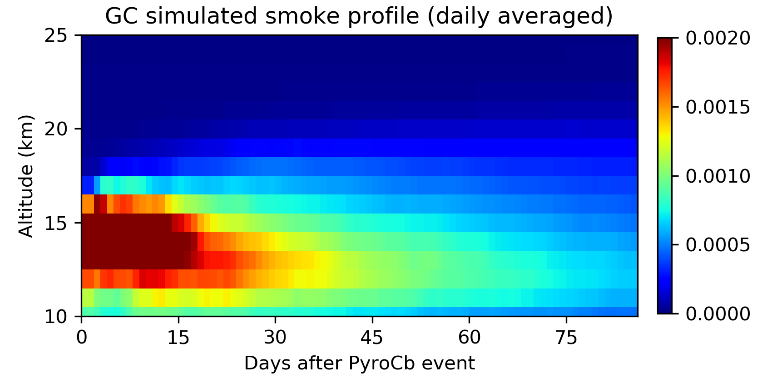
- Study pyroCb effects on aerosol loading at the regional-to-global scale with different temporal durations
- Modeling/process studies of UTLS species variability (such as due to the change of emissions)
- Study the change of radiative forcing and photochemistry due to these stratospheric anomaly.

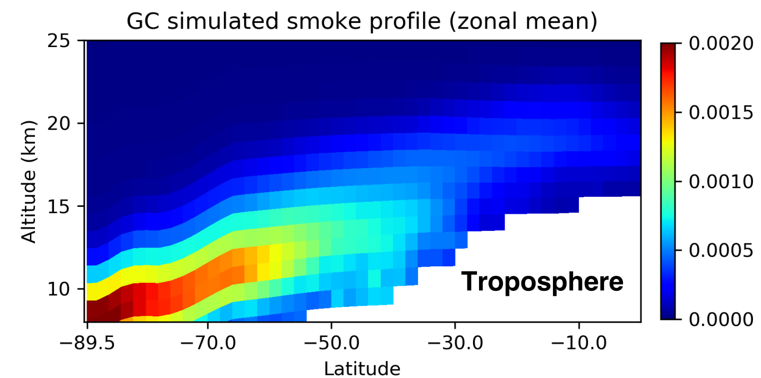
ANYSO evolution and persistence in the stratosphere

comparison with OMPS LP

Peterson et al., npj Clim Atmos Sci, 2021

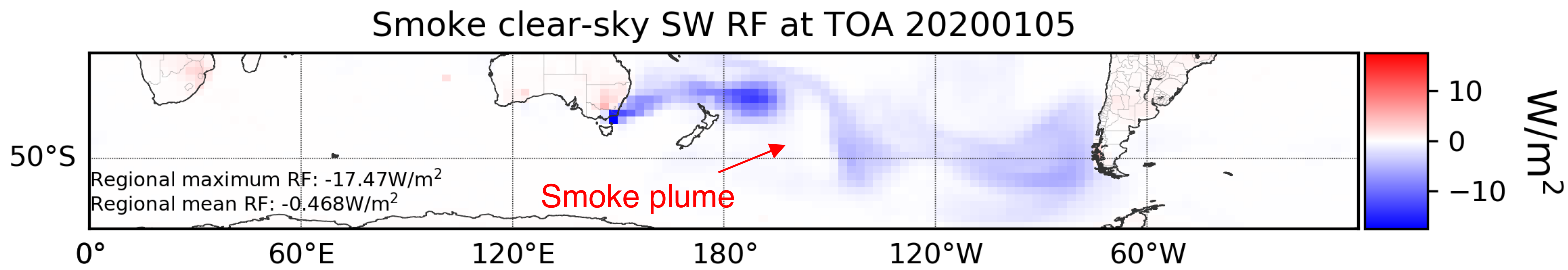


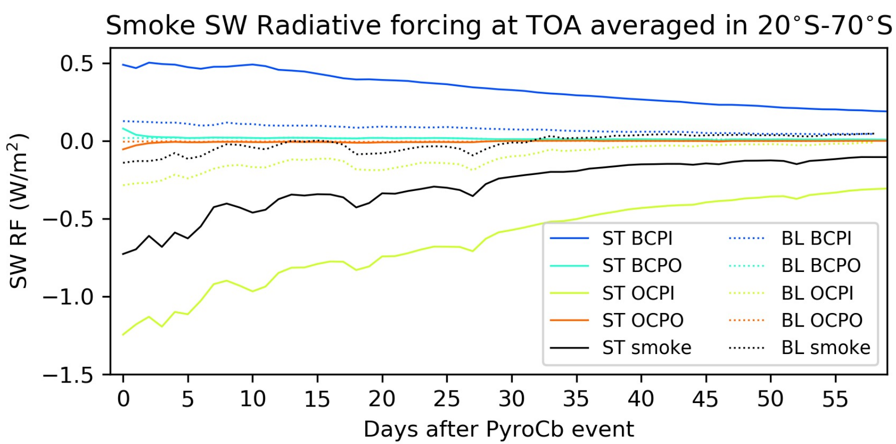


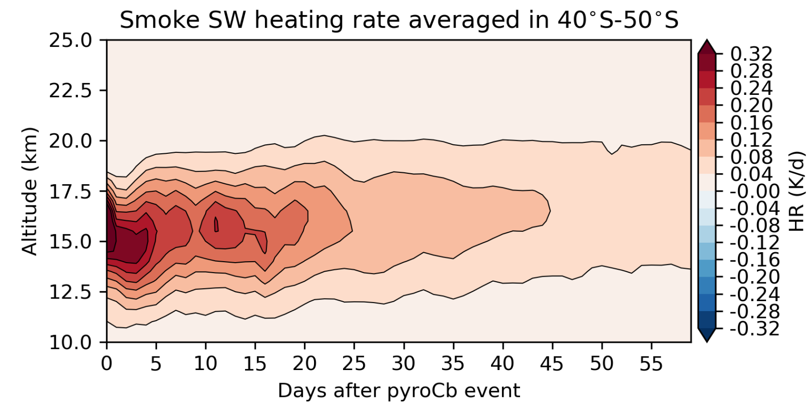


- OMPS LP observations indicate the increase of smoke extinction locates at 15 ~ 20 km, while model simulation shows increase at lower altitude (12 ~ 18 km).
- Both satellite and model present longer e-folding time for plume at higher altitudes (>18km).

Radiative forcing and stratospheric warming of smoke

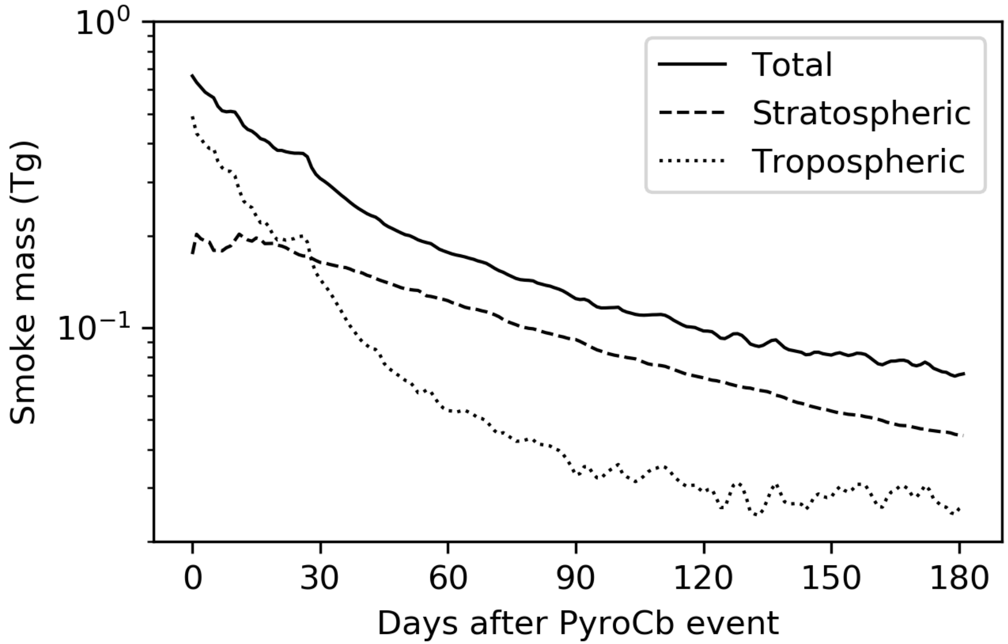






- Stratospheric smoke emissions can cause ~ 4 times RF compared with only boundary layer emissions of biomass burning.
- The stratospheric smoke caused SW heating focuses on 12~18 km in mid-latitude and lasts for longer than 2 months, indicating the stratospheric warming from pyroCb event.

ANYSO e-folding time



E-folding time: ~ 4 months