Impact of August 2017 British Columbia Pyrocumulonimbus Injection Events on Lower Stratospheric Composition

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Model and Measurements

- We are using the Goddard Earth Observing System model in Replay mode run at C180 on the cubed sphere (~0.5°) with 72 vertical layers
- Replay is a constrained dynamics run using 3hrly ASM (U, V, T, H_2O, P) fields from MERRA-2 [*Orbe et al*. 2017]
- Water Vapor (H_2O) is handled differently in these simulations – replayed from surface to 1.3 * TPP and blended to the tropopause so that above the tropopause H_2O is based on the free model
- Coupled to the Global Modeling Initiative (GMI) stratospheric and tropospheric chemical mechanism
- Also including the GOCART aerosol module BRC, BC, OC, SU, DU, SS, NI and a full suite of transport diagnostic tracers

Aura Satellite measurements:
Microwave Limb Sounder (MLS) Level 2 data from Version 4.2
Constituents – CO, H_2O, CH_3OH, O_3, HNO_3
We used the standard quality and convergence criteria for each constituent recommended by Livesey et al. [2015]

Aerosol and Trace Gas Injections

We injected 230 Gg of Brown Carbon (BRC) and 9.2 Gg of Black Carbon (BC) (additional 4%) from 0z to 5z on Aug. 13, 2017 between 10-11 km

61% of total mass in PyroCb's 3 and 4
13% of total mass in PyroCb 2
26% of total mass in PyroCb 5

The 0z restart on 8/14 was used to initialize injections of CO, CH_3OH, H_2O
Scaling was based on the amount and distribution of BRC with factors based on [*Andreae and Merlet*, 2001 and *Parmar et al.* 2008]

CO - 10x mass of BRC = 2.3 Tg
CH_3OH - 0.2x mass of BRC = 46 Gg
H_2O - 300x mass of BRC = 69 Tg

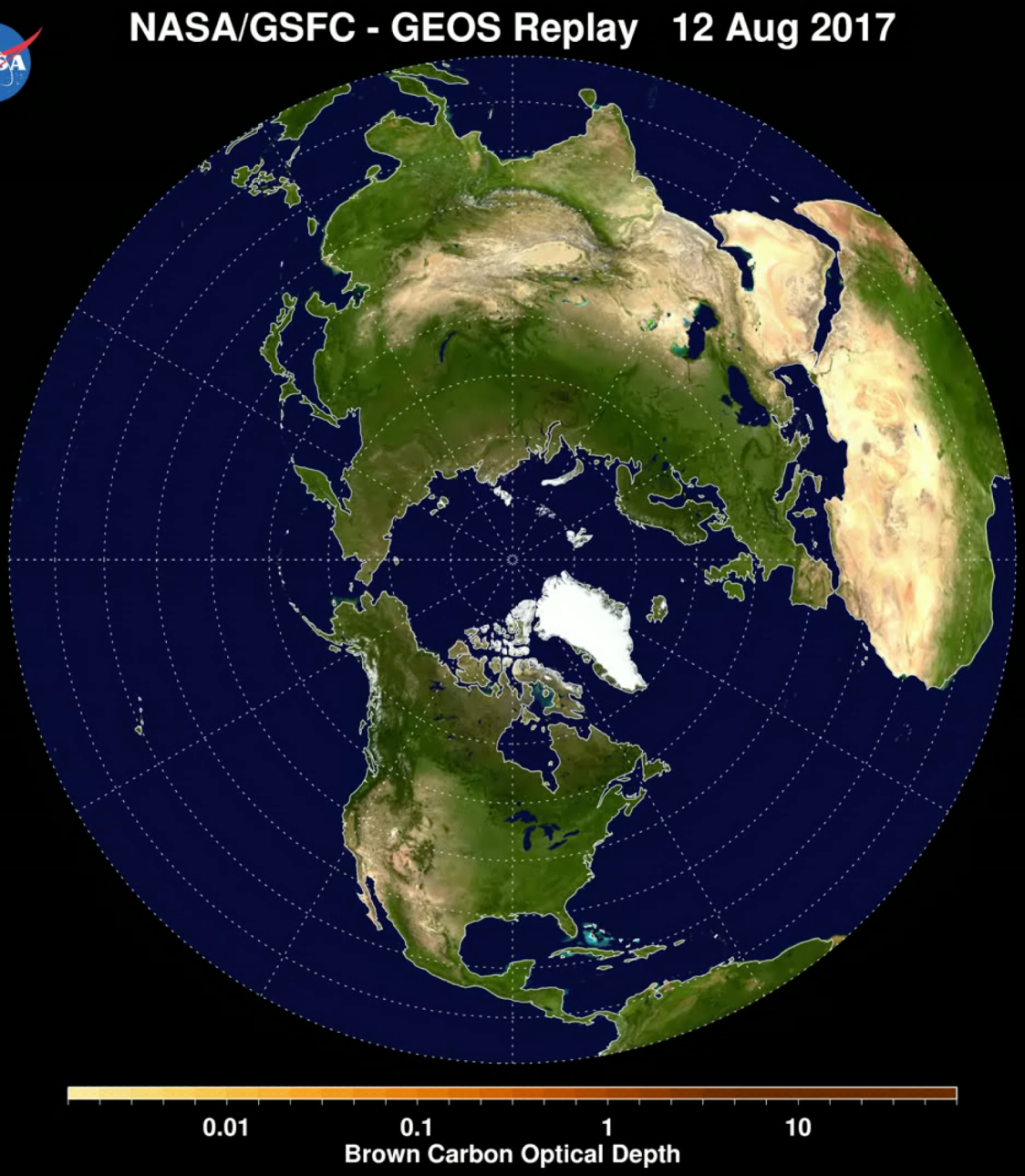
Modeled Evolution of Brown Carbon AOD for 1 month following the PyroCb's

Some notable highlights:

Well follows the observed track north through BC over NW Terr. and south towards Hudson Bay then streaming out over the Atlantic over Nova Scotia

Upper portions of the rising aerosol stay concentrated due to the low wave activity this time of year above 16-18 km but portions below are fairly quickly spread over much of the NH – seen in OMPS aerosol extinction measurements

Easterly QBO transporting BRC in the tropics



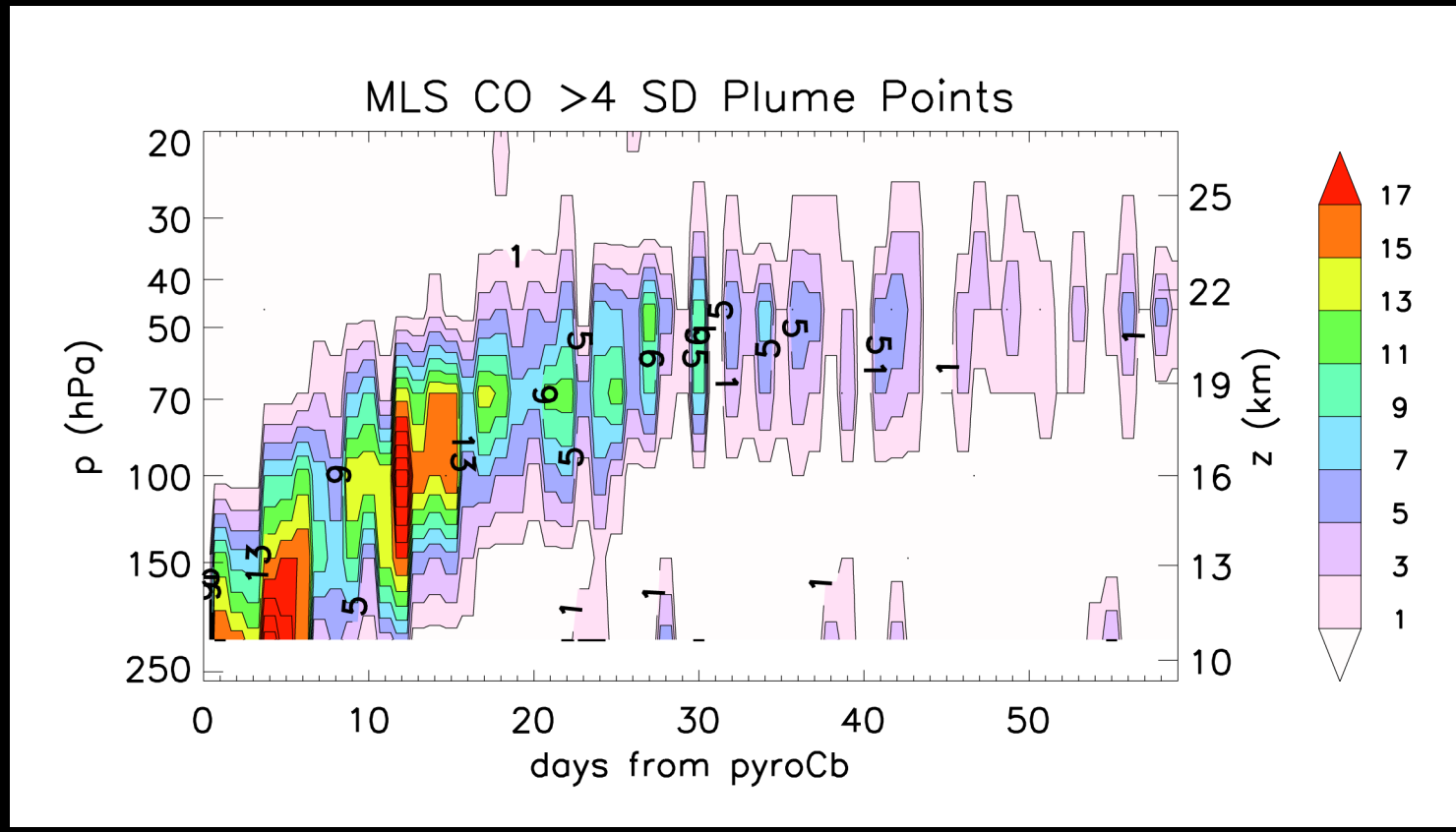
Using CO to Track the Plume

We use the methodology in *Pumphrey et al.* [2011] to locate the unusual points

This was done for plume tracking of MLS CO perturbed by the Black Saturday fire in Feb. 2009

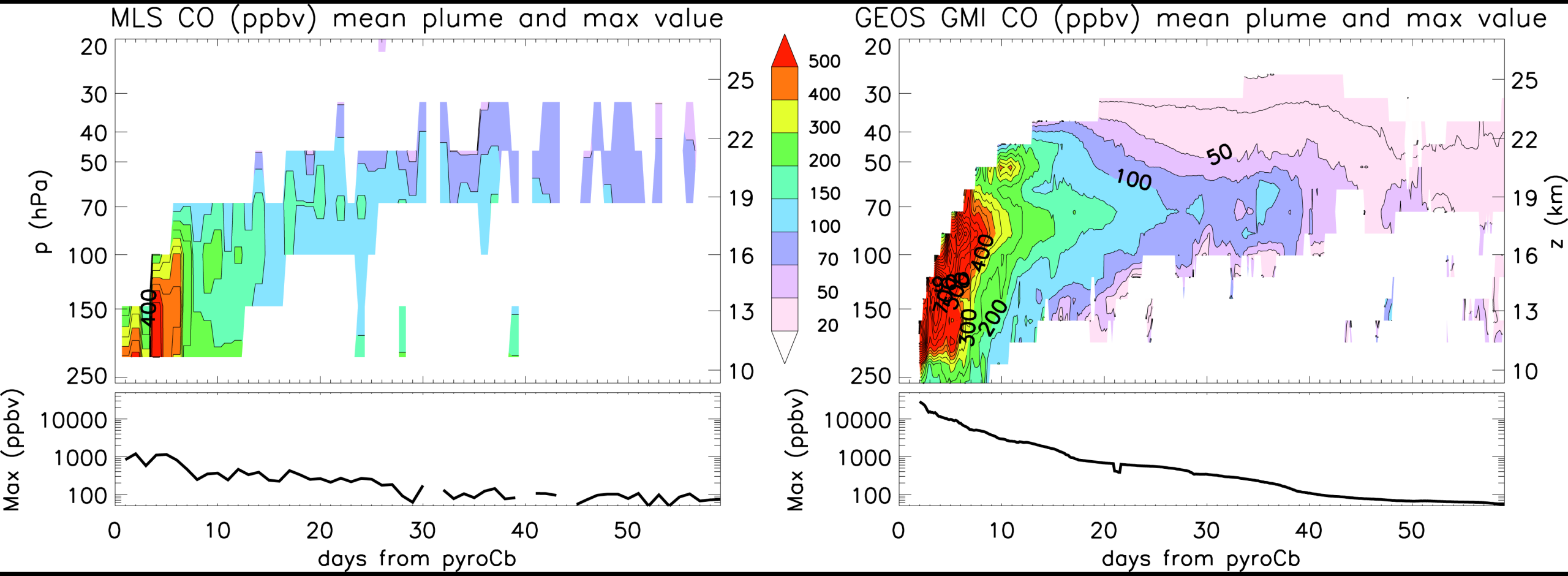
- Calculate the mean and SD over latitude bands and levels
- Looking for unusual points (excess of 4 SD)
- Exclude unusual points and iterate a couple times to converge on a mean and SD that doesn't include extreme values
- Anything that exceeds this threshold is considered a plume polluted point.

- Apply same methodology to model



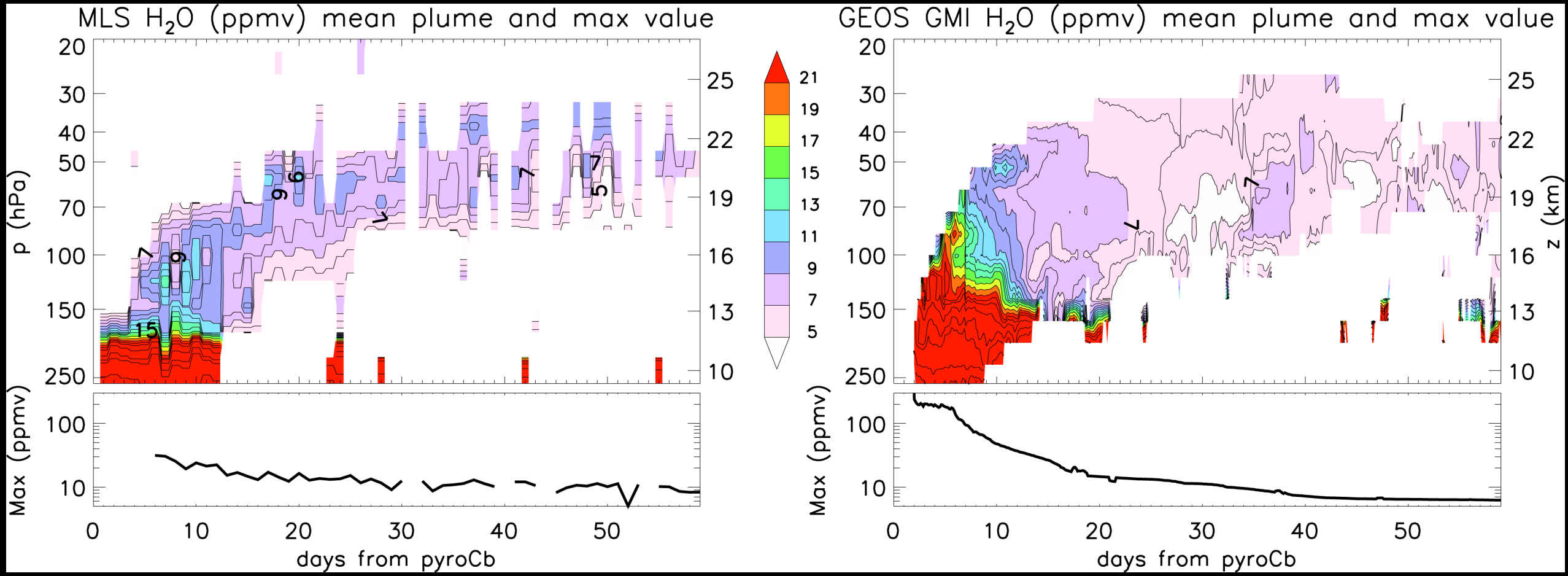
Carbon Monoxide (CO) in the polluted plume from MLS and GEOS GMI

CO is an important biomass burning component and typical background stratospheric values are 20-50 ppbv
We use it as a key species for tracking the polluted plume in observations and model
MLS shows significant enhancement in the mean plume that can be tracked for at least 60 days
Model also shows significant enhancements over the same general altitudes – peak values higher and decrease faster



Significant Increases in Water Vapor within the Plume Observed with MLS

Water Vapor is a known biomass burning emission constituent + intense convection can inject H_2O through the Tropp.
MLS observed strong enhancements of H_2O in the plume at least for 2 mo. avg. up to 10 ppmv (2x background) - day 50
Much of plume values are flagged in the first few days - max values looking at values at p < 150 hPa
GEOS GMI simulates peak values of 200 ppmv with 20-30 ppmv in the plume average – does not maintain the values



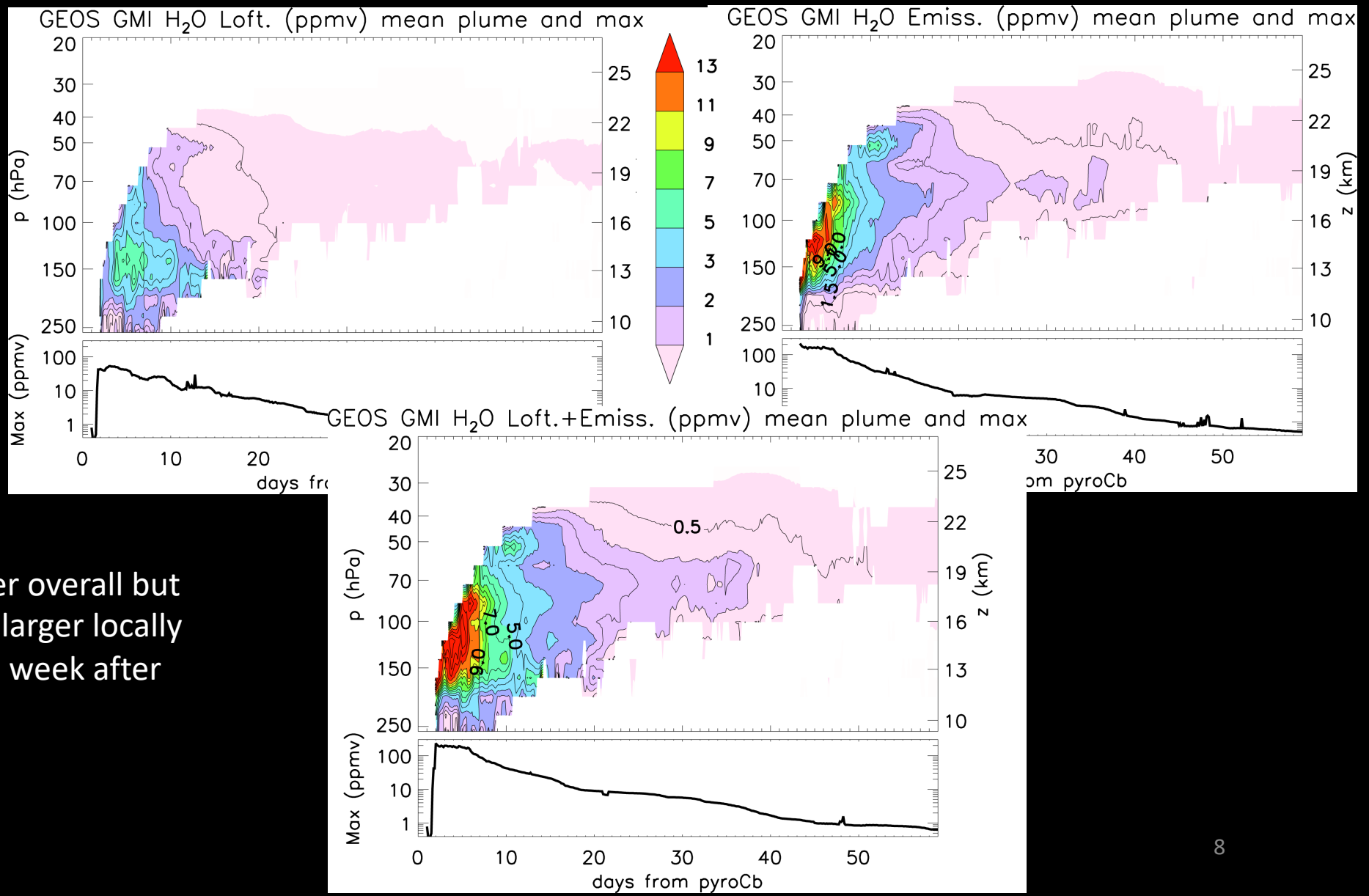
GEOS GMI simulations indicate H_2O is injected into the stratosphere just from including Carbonaceous aerosols

In the prior slide we looked at mean plume H_2O concentrations

Here we break it down – part due to the H_2O lofting (top left) with absorbing aerosol – riding the escalator into the stratosphere

The part due to H_2O emissions only (top right) and the combined impact (bottom)

The emissions component is larger overall but the lofting component can cause larger locally effects in the 150-100 hPa layer 1 week after



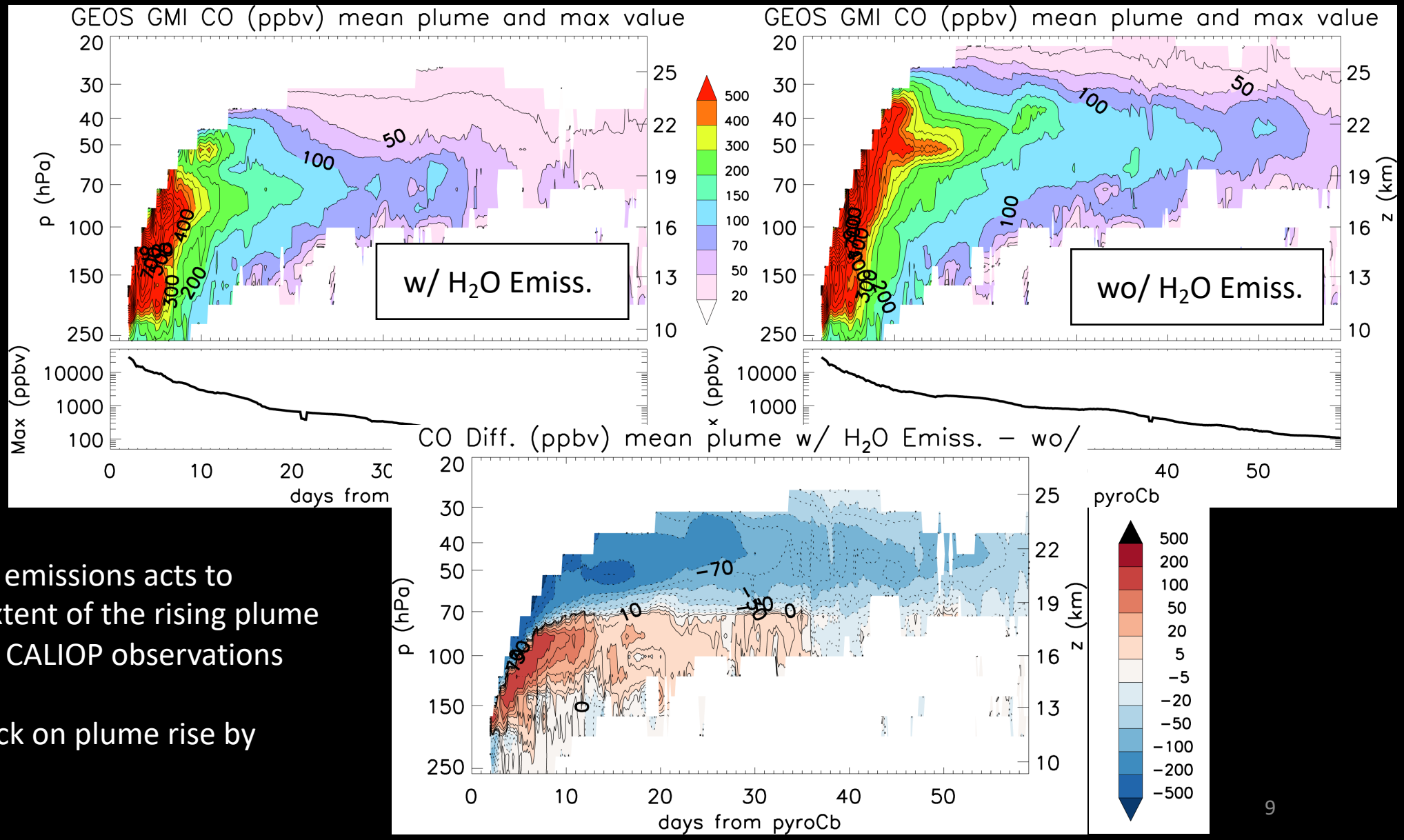
CO Plume Evolution Differences with and without H_2O Emissions

There is a clear difference in the CO evolution whether or not we include H_2O biomass burning emissions

The additional water vapor radiatively cools above and heats below

To some extent the H_2O emissions acts to compress the vertical extent of the rising plume which is consistent with CALIOP observations

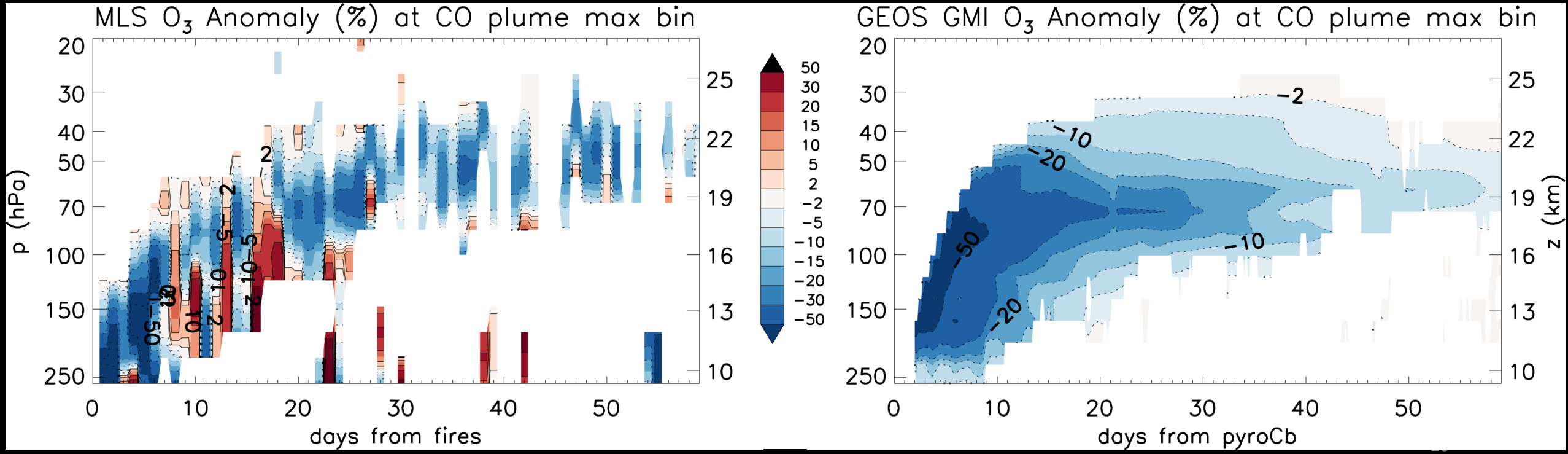
Overall negative feedback on plume rise by including H_2O emissions



Large Decreases in Ozone over the peak CO plume in MLS and GEOS GMI

For O_3 the concentrations vary so much over different areas of the LS we need to analyze with a different method because we are interested in the anomaly. We bin MLS daily ozone into 5x5° bins, we use the location of the peak plume CO to define our O_3 bin and find the diff. with the mean of the surrounding O_3 points that are not CO polluted.

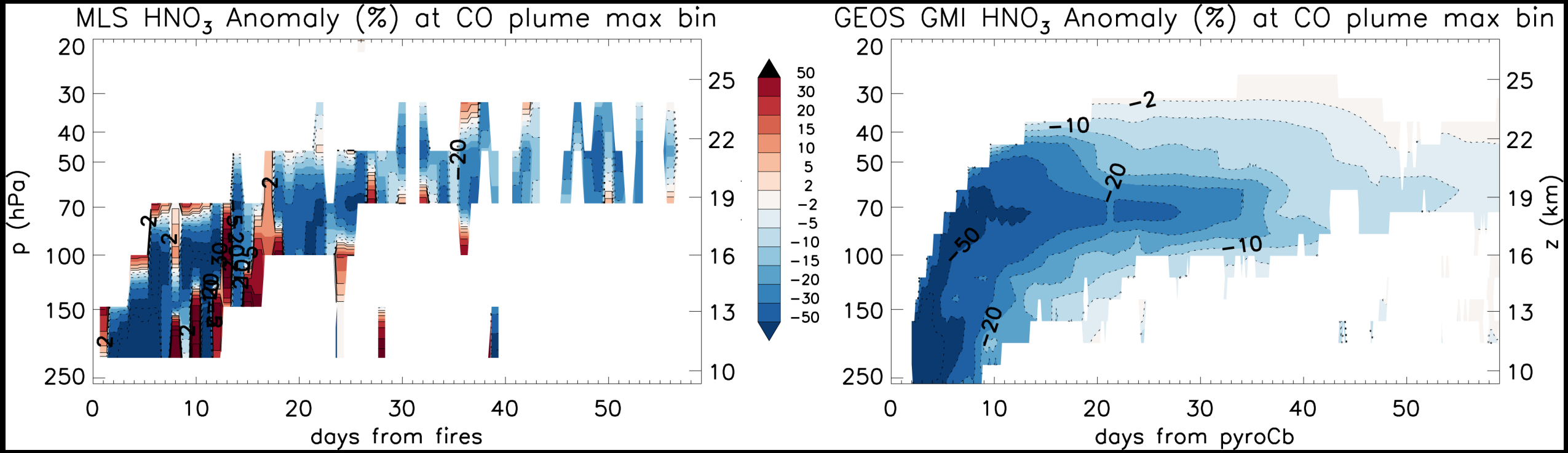
MLS measurements indicate decreases of 50-70% in the first few days and 20-30% around 19-22 km 30-60 days later
For GEOS GMI we are averaging over the top 100 CO plume points for each time and level



Similarly Large Decreases in HNO_3 in MLS and GEOS GMI

Generally similar pattern seen in HNO_3 but slightly larger anomalies than we see in Ozone

This is consistent with dynamical response to the diabatic heating of the carbonaceous aerosols bringing up younger air with lower concentrations of O_3 and HNO_3 air into the lower stratosphere



Conclusions

- We were able to track the rising aerosol and trace gas injection for at least 60 days - diabatic heating causes the aerosol and trace gases to rising from 10-11 km to over 22 km

- Water vapor is injected into the stratosphere through BB emissions as well as lofting along with the absorbing aerosols
- Including water vapor emissions clearly impacts the evolution of the aerosol and other trace gases – initially compressing and overall reduces the rise

- A dynamical response acting to decrease ozone (O_3) and nitric acid (HNO_3) is clearly detectable in the MLS observations and can be demonstrated in model simulations that include the carbonaceous aerosol emissions