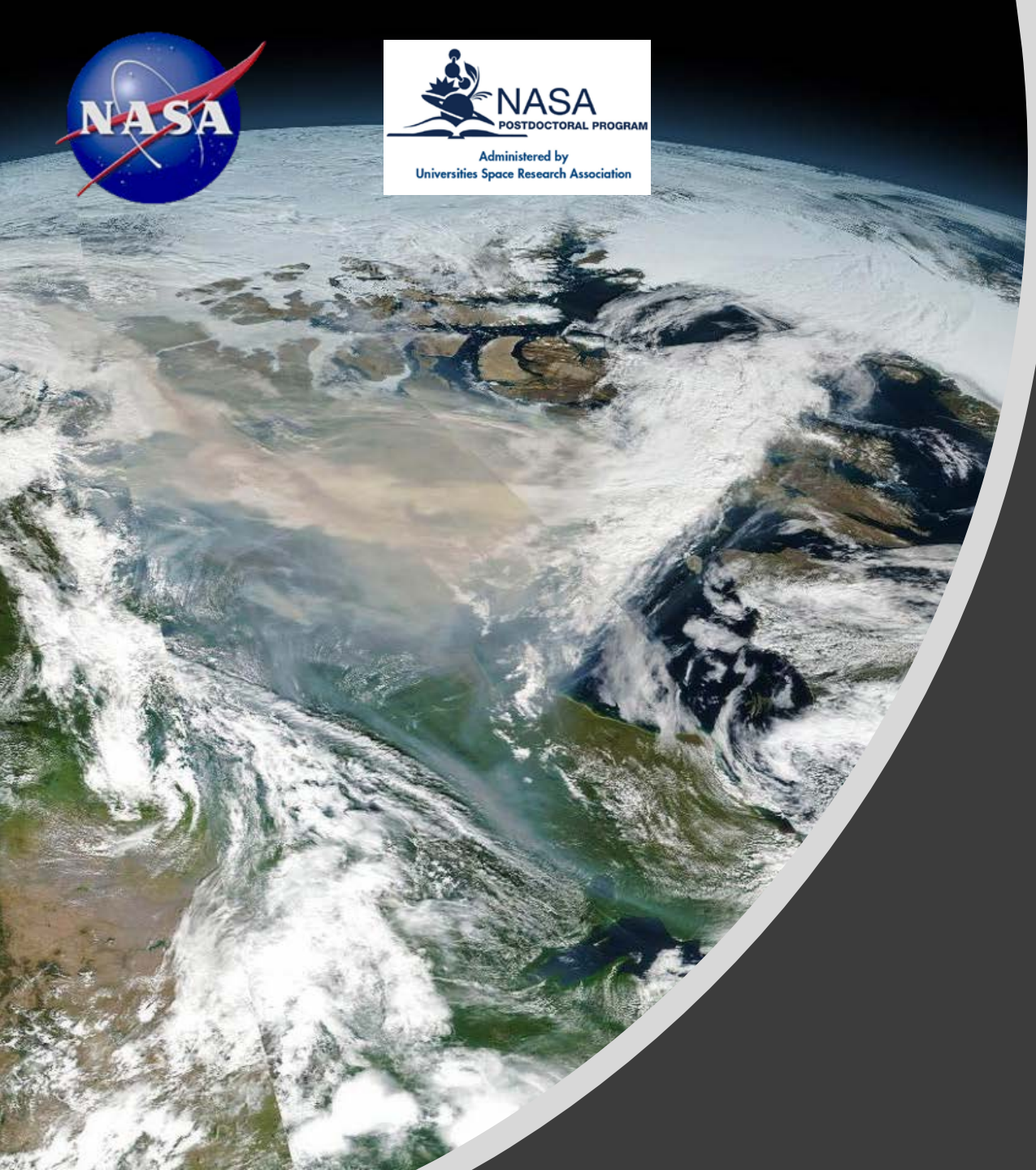
Title: Differences in the Vertical and Microphysical Evolution of Volcanic and Pyrocumulonimbus Stratospheric Aerosol Plumes as Observed by CALIOP and CATS Satellite Lidar

Abstract:
For some time, volcanic eruptions have been thought to be the only significant direct injectors of aerosols in the stratosphere. However, recent fire seasons have featured fire events resulting in large volcanic-sized pyrocumulonimbus plumes of smoke aerosols reaching many kilometers into the lower stratosphere. To understand and model the effects of these pyrocumulonimbus events on stratospheric composition and climate, a natural analogy lies with better studied volcanic events; however, differences in plume composition may limit this comparison. Using satellite lidar from both CATS and CALIOP, we show that the stratospheric aerosol plumes from the record-setting Pacific Northwest pyrocumulonimbus event of 2017 and the Calbuco volcanic eruption of 2015 evolve differently both vertically and microphysically. Specifically, depolarization ratios indicate that this pyrocumulonimbus event's aerosol particles became more irregularly shaped over time in contrast to volcanic aerosols which become more spherical over time. Accounting for these changes in aerosol properties may be significant in assessing the effects of pyrocumulonimbus events on the Earth's radiative balance and aid in refining stratospheric aerosol typing algorithms to differentiate volcanic from pyrocumulonimbus plumes.



Differences in the Vertical and Microphysical Evolution of Volcanic and Pyrocumulonimbus Stratospheric Aerosol Plumes as Observed by CALIOP and CATS Satellite Lidar

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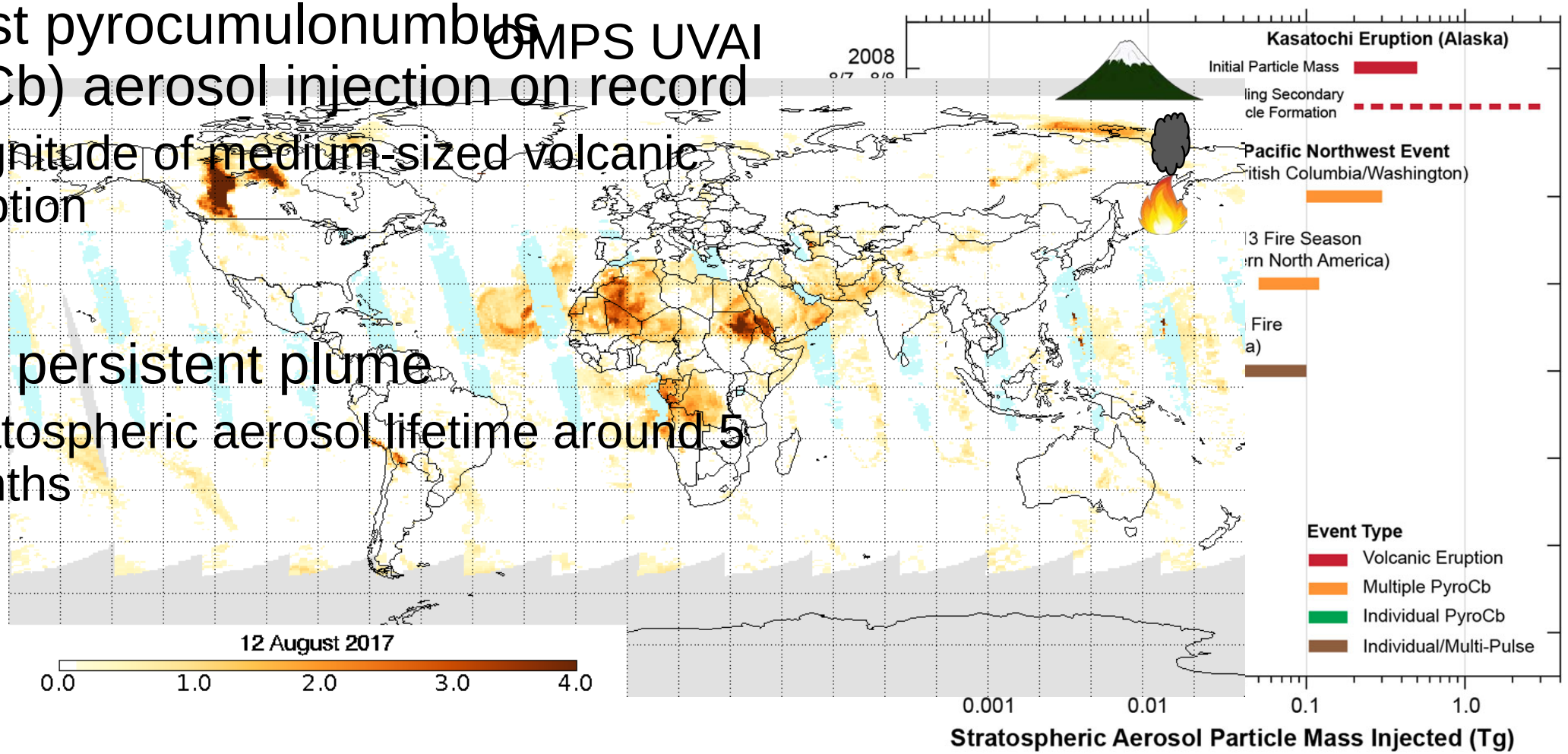
What's unique about the PNW PyroCb?

- Largest pyrocumulonumbus (PyroCb) aerosol injection on record
  - Magnitude of medium-sized volcanic eruption
- Large, persistent plume
  - Stratospheric aerosol lifetime around 5 months



Peterson et al., 2018

CATS & CALIOP Lidar

- Depolarization
  - Ratio of perpendicular and parallel components of the total attenuated backscatter
  - Particle shape proxy

0 → 1

spherical — irregular

- Color Ratio
  - Ratio of 532nm and 1064nm backscatter
  - Particle size proxy

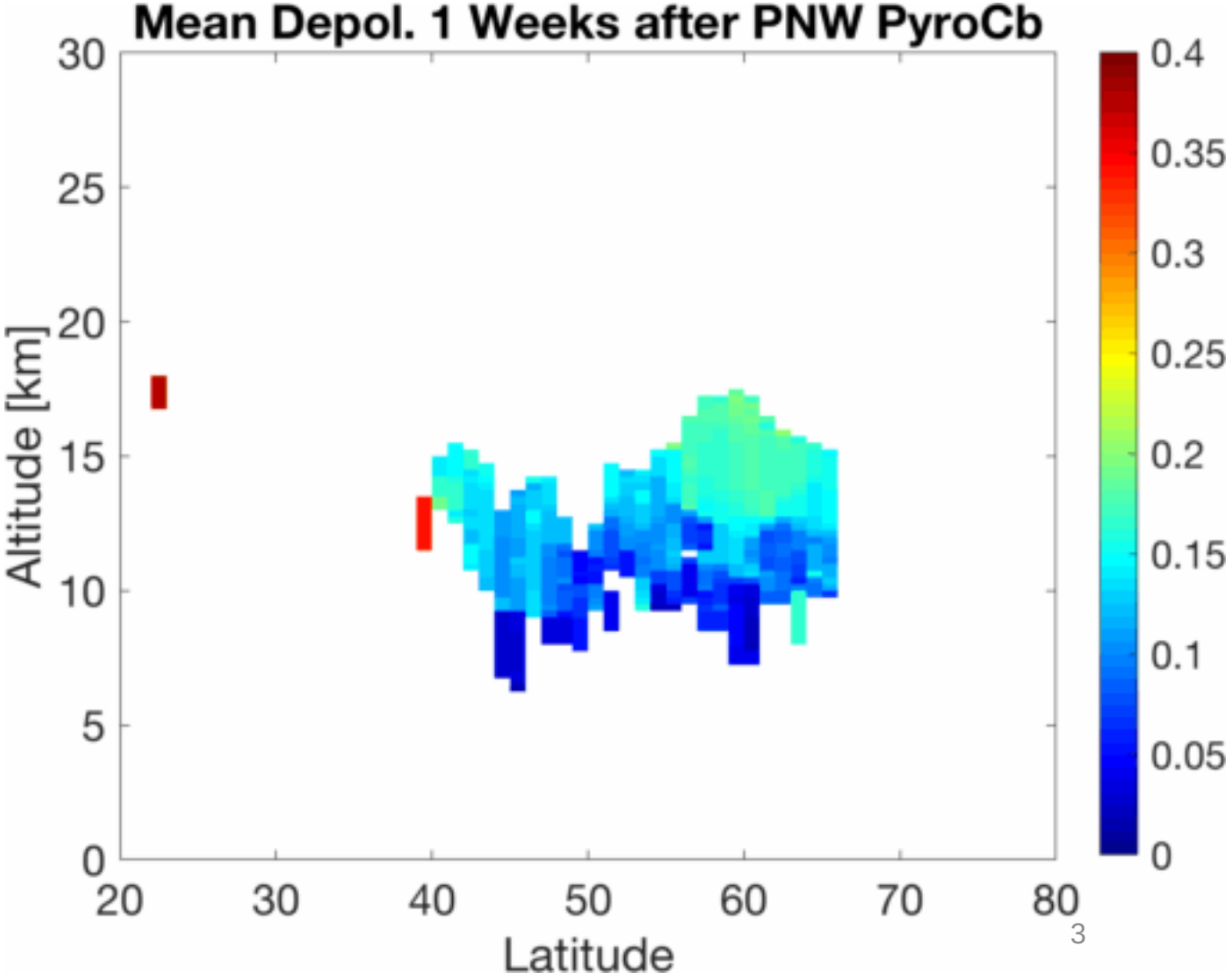
0 → 1+

small — large

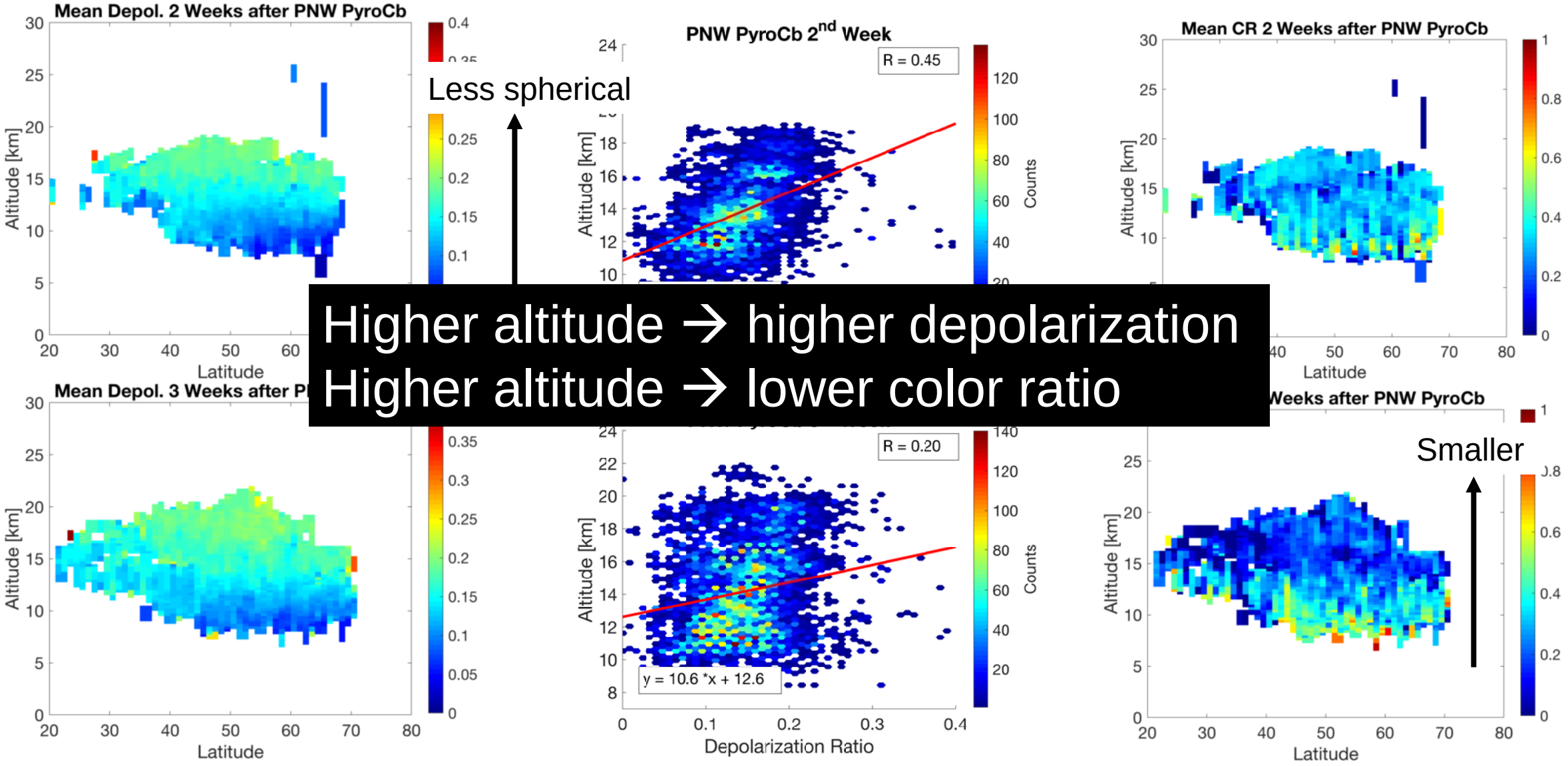
Use nighttime layer products for both CATS & CALIOP

PNW PyroCb Plume Evolution

- Plume rises over time
  - “self lifting” is common in pyroCb
- Vertical gradient in the depol ratios
  - More spherical particles lower in the plume
- >0.15 is a high depolarization for smoke

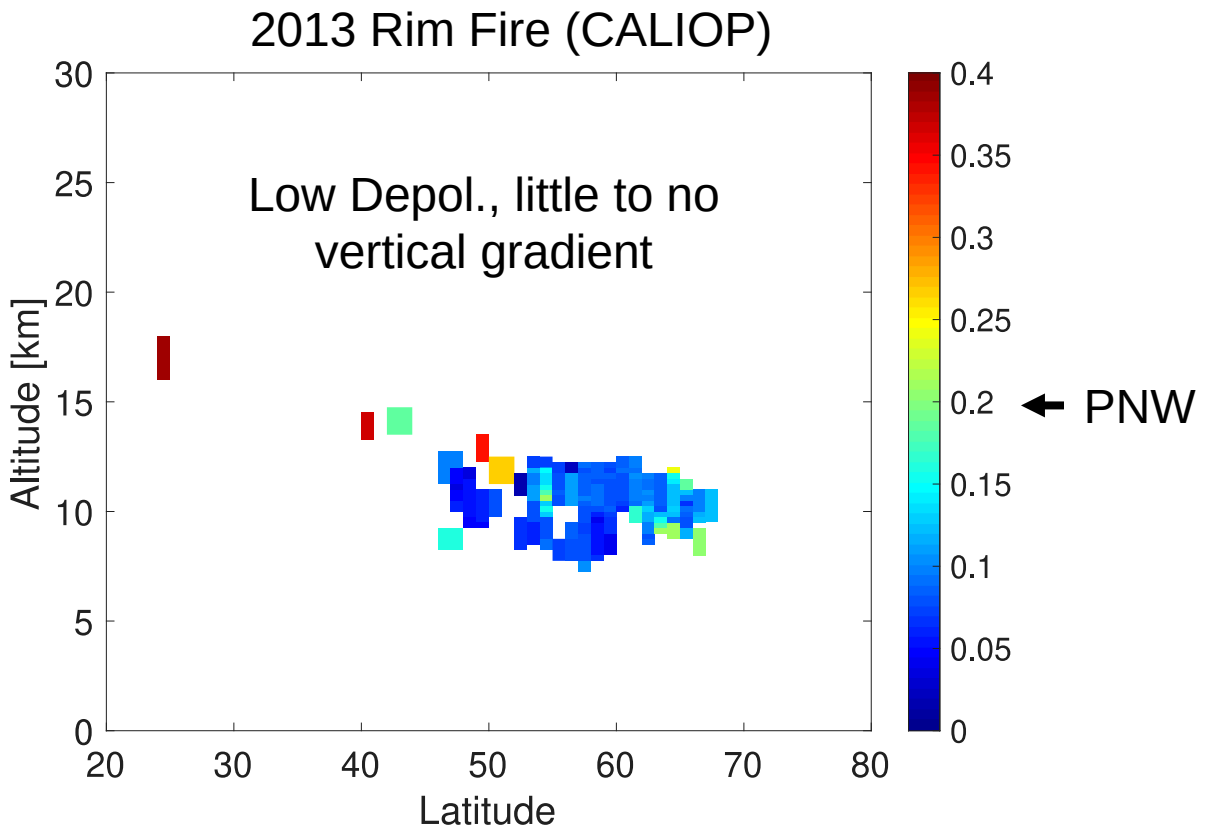


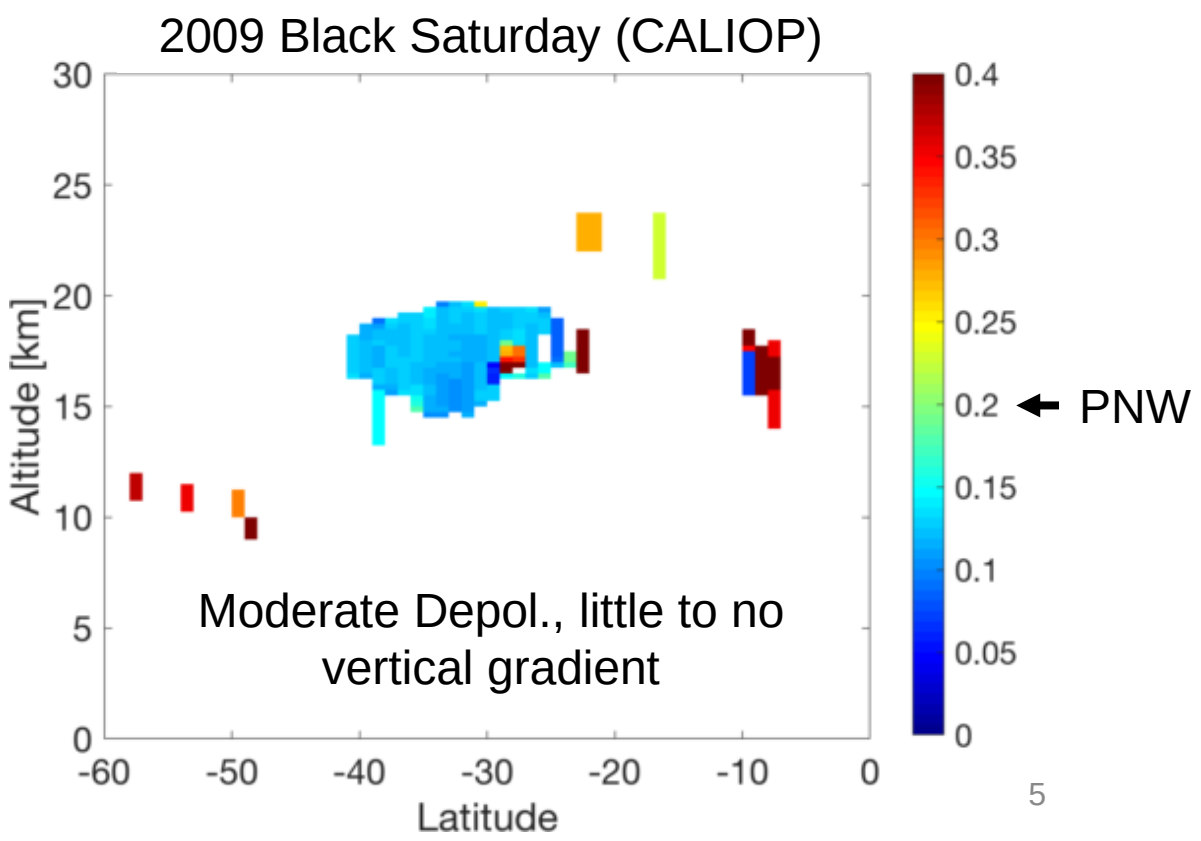
Altitude vs Depolarization & Color Ratio



How does this compare to other pyroCbs?

- PNW PyroCb has higher depolarization ratios
- No vertical gradient in depolarization





South American Volcanic Events

Calbuco

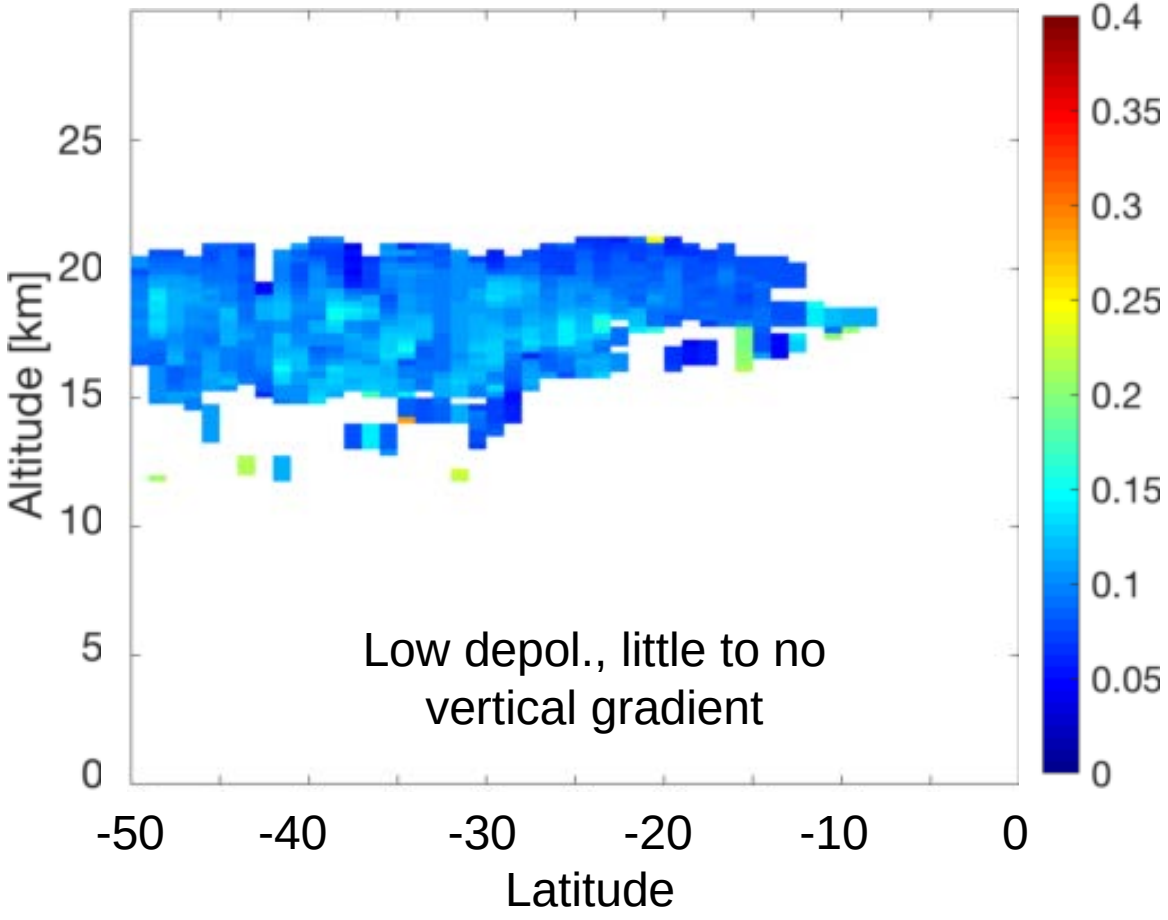
- April 2015
- Sulfate aerosol dominated plume
- Observed by CATS & CALIOP

Puyehue

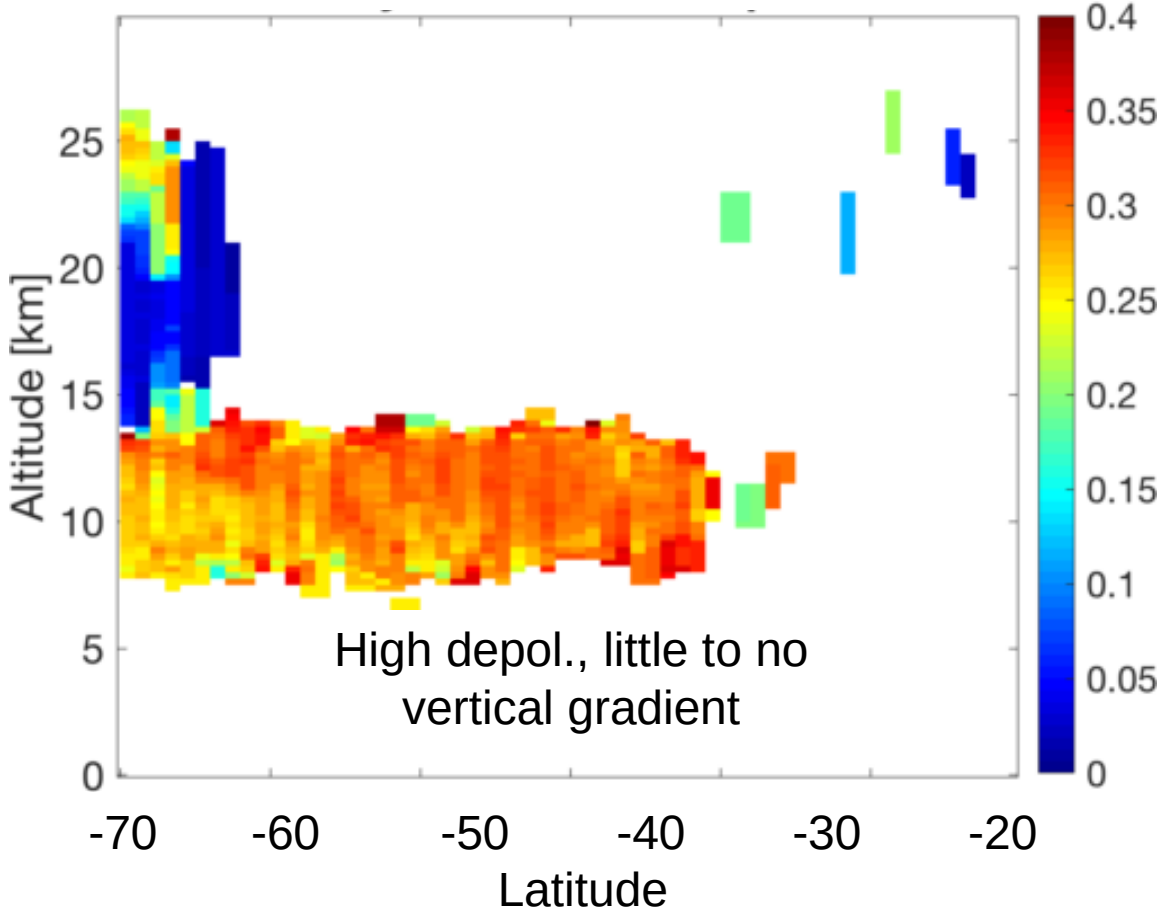
- June 2011
- Ash aerosol dominated plume (unusual)
- Observed by CALIOP

How does PNW PyroCb compare to volcanic plumes?

Calbuco Depol. Ratio (CATS)

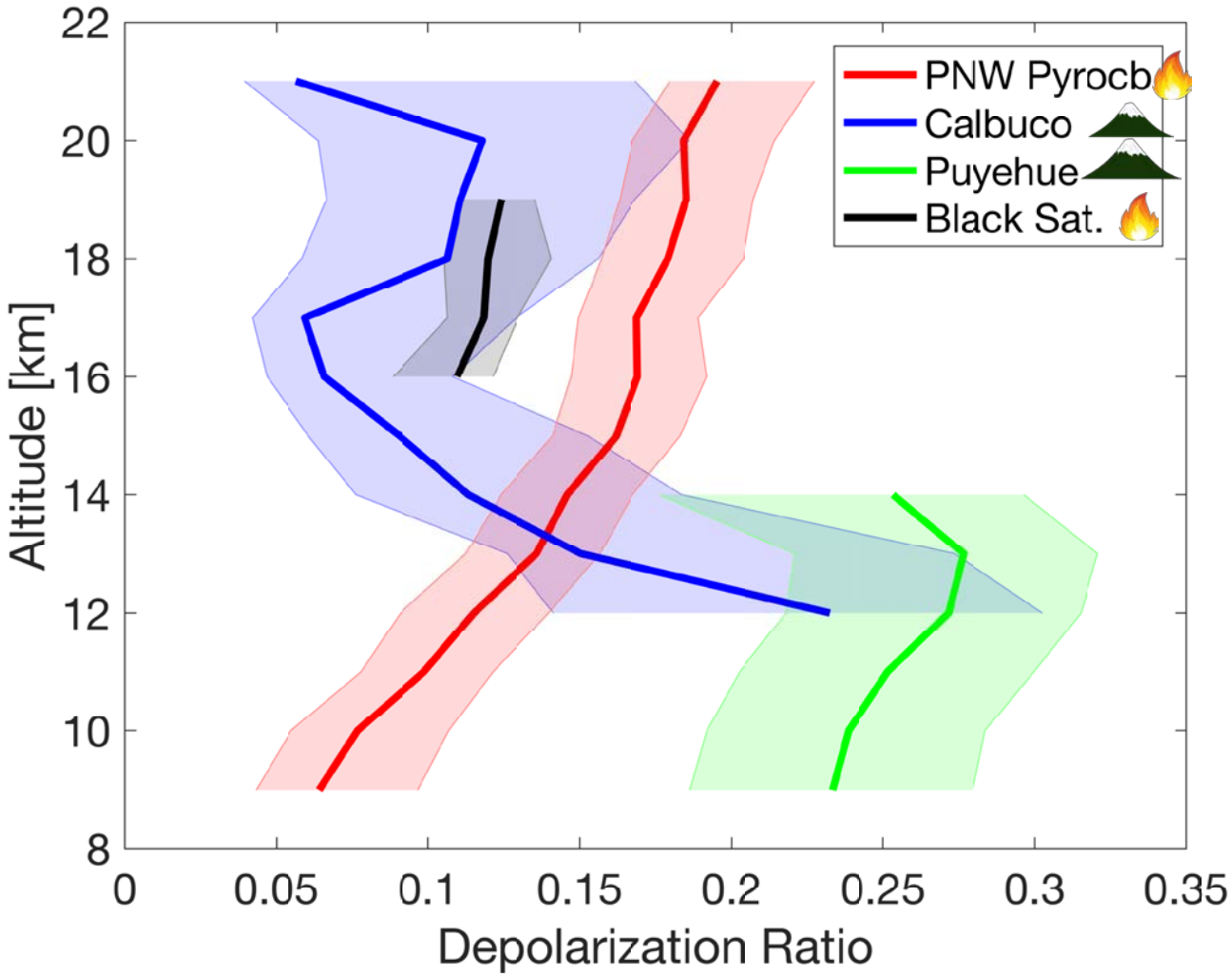


Puyehue Depol. Ratio (CALIOP)

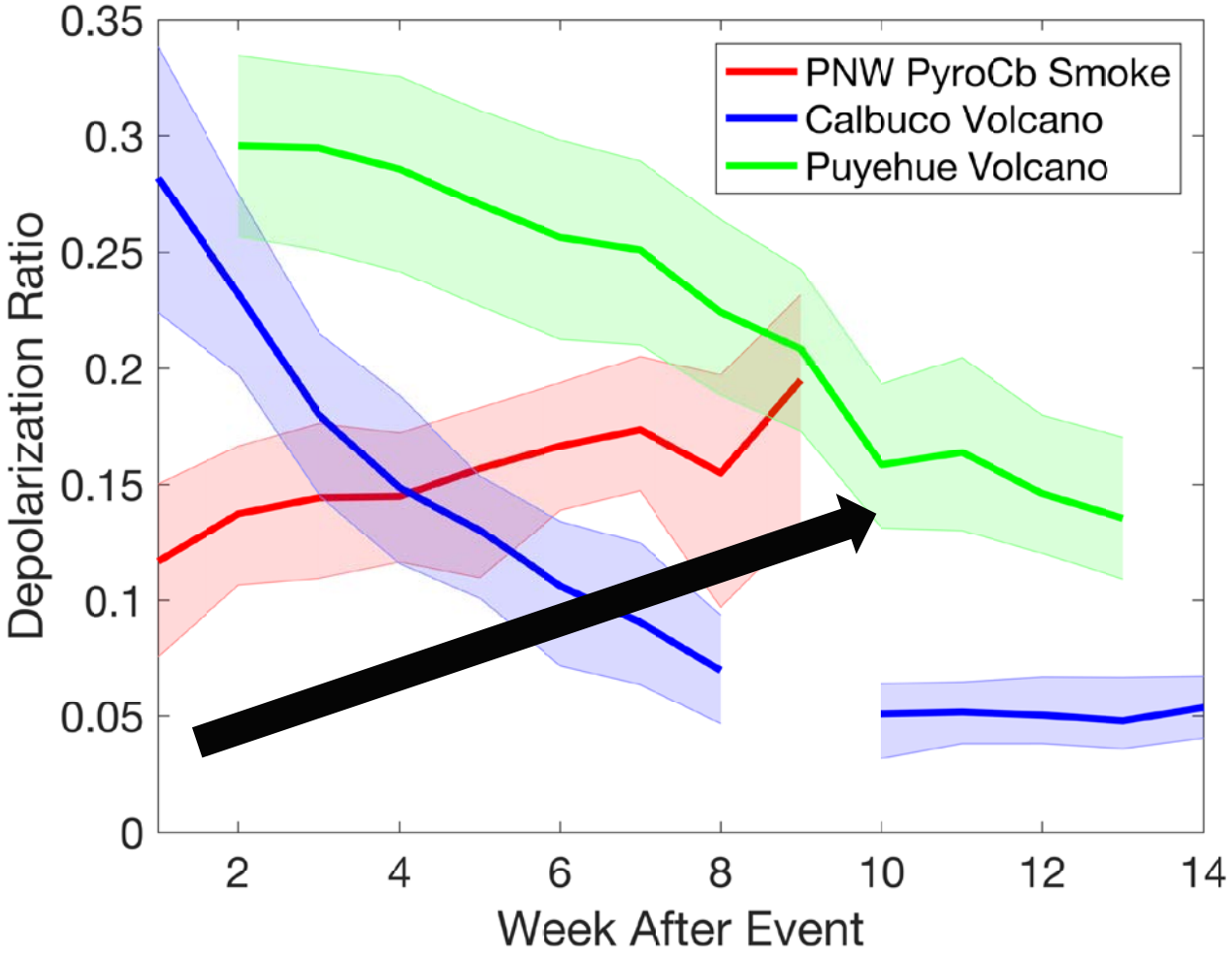


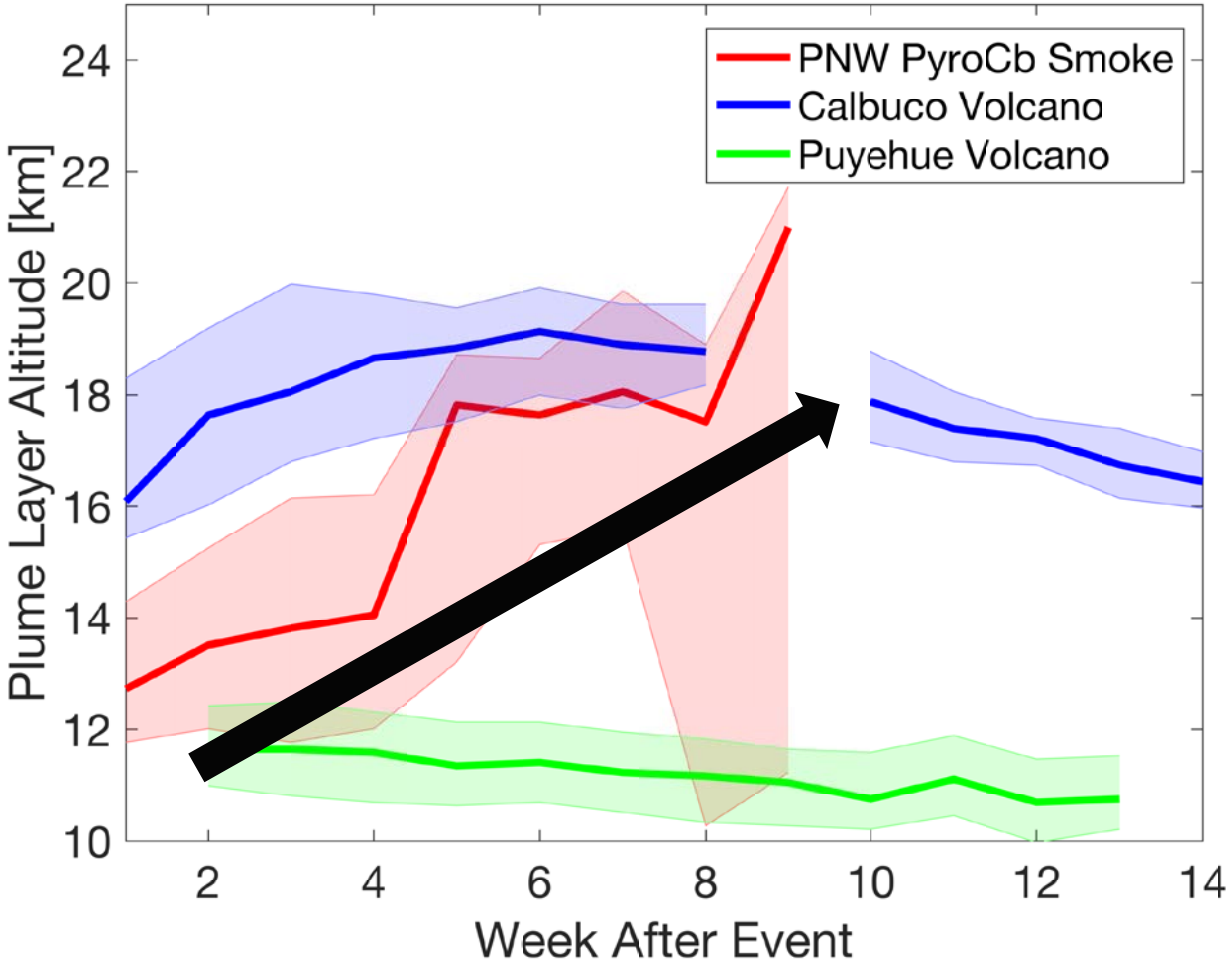
Event depolarization vs. altitude

- PNW PyroCb depol. increases with altitude
- Calbuco's plume depol. decreases with altitude
- Puyehue's plume depol. fairly constant with altitude



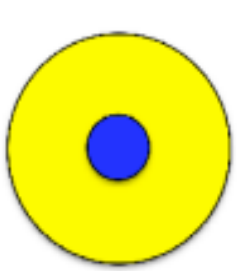
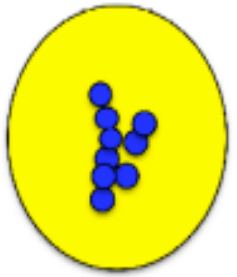
PNW PyroCb evolves differently





Why the high depolarization?

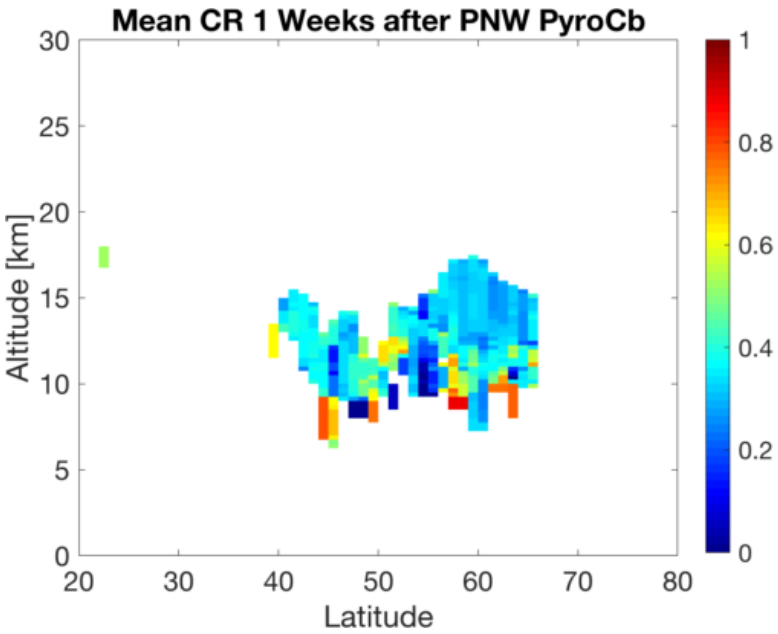
- *Don't know yet…*
- Yu et al. (2019) proposed that the particles may be coated fractals
  - Explains the higher depolarization
  - Doesn't explain the inhomogeneity within the plume
- Hopefully modeling work will give us a hypothesis

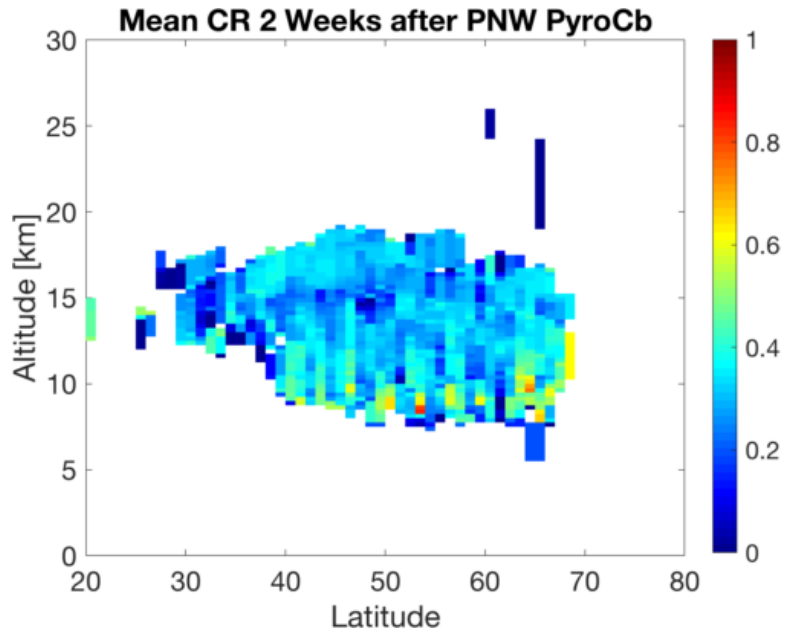
CASES	Observations	Coated Sphere	Coated Fractal
Morphology	N/A		
BC/OC	N/A	3%	2%
OC, Tg	0.1-0.3	0.3	0.3
SSA @532	0.8	0.92	0.82
LDR, % @535	15-25%	close to 0	10-20%
Aspect Ratio	N/A	1	0.8

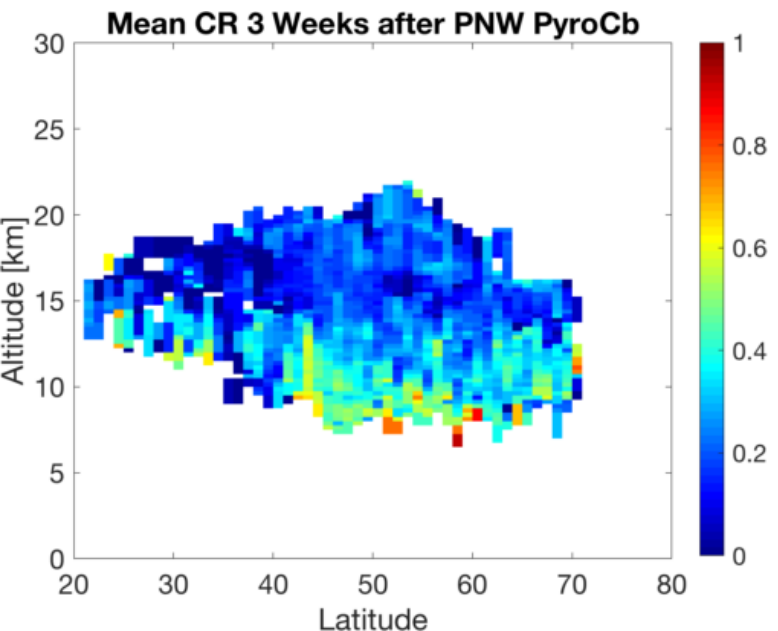
Yu et al., 2019

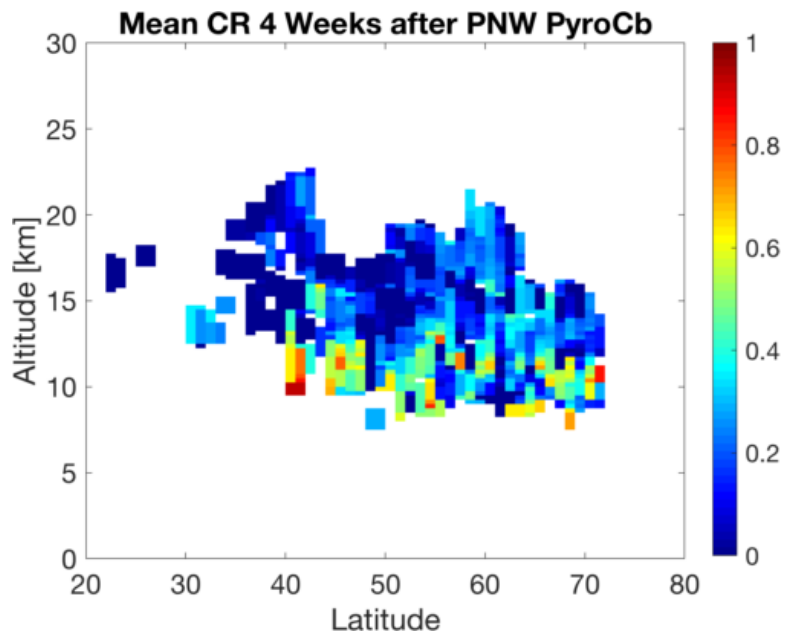
Conclusions

- PyroCb stratospheric plumes evolve differently compared to volcanic plumes
  - PyroCb plumes go up, volcanic plumes do not
  - PNW PyroCb depolarization increases, volcanic depolarization decreases
- PNW PyroCb plume had abnormally high depolarization
  - Higher than assumed in aerosol typing algorithms
  - Could affect radiative forcing calculations
- Still working to understand the reason for the variations in depol. and color ratios within the plume


Mean CR 1 Weeks after PNW PyroCb
Altitude [km]
Latitude


Mean CR 2 Weeks after PNW PyroCb
Altitude [km]
Latitude


Mean CR 3 Weeks after PNW PyroCb
Altitude [km]
Latitude


Mean CR 4 Weeks after PNW PyroCb
Altitude [km]
Latitude