Enhanced Aerosol Mass in the Tropical Tropopause Layer Linked to Ozone Abundance

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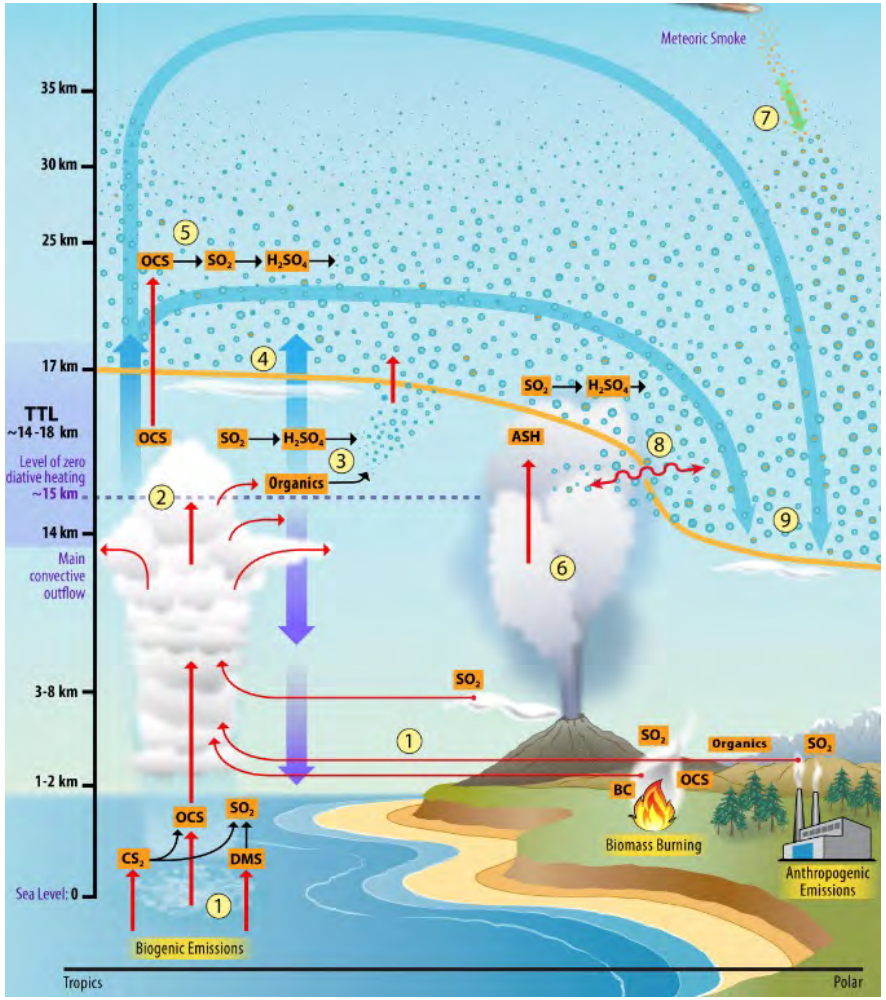
Background



- TTL is the main pathway for the transport of tropospheric air to the stratosphere
- Aerosols affect stratospheric water vapor budget through TTL dehydration processes by serving as nuclei for cirrus clouds
- Cirrus clouds have substantial impacts on the earth's radiative balance
- Aerosols facilitate condensation of low vapor pressure gasses such as sulfuric acid and promote heterogeneous chemistry that depletes ozone

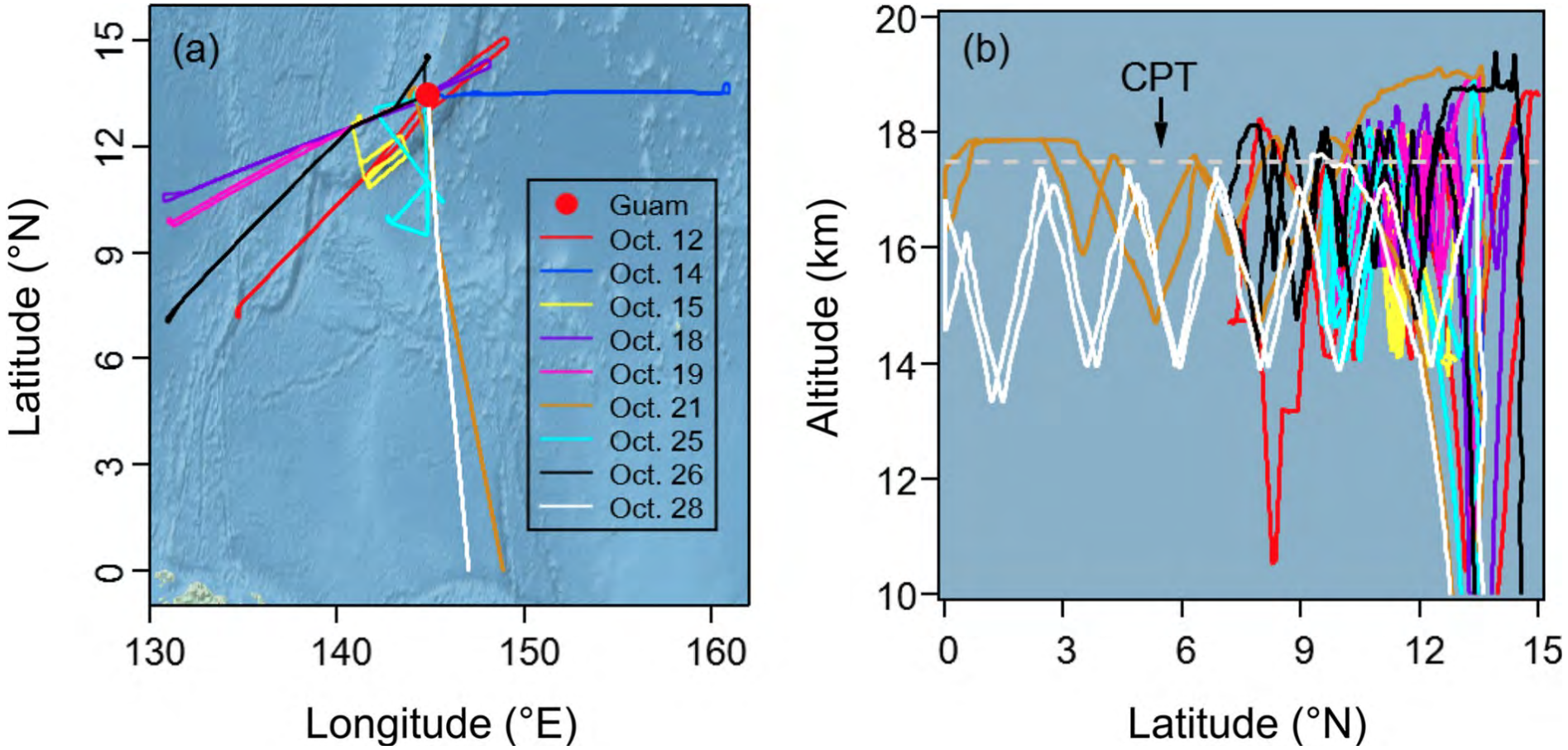
https://storymaps.arcgis.com/stories/d00ae4acebff48d08f8df953f101ef94

The POSIDON Campaign

Pacific Oxidants, Sulfur, Ice, Dehydration, and cONvection
Guam, October 2016

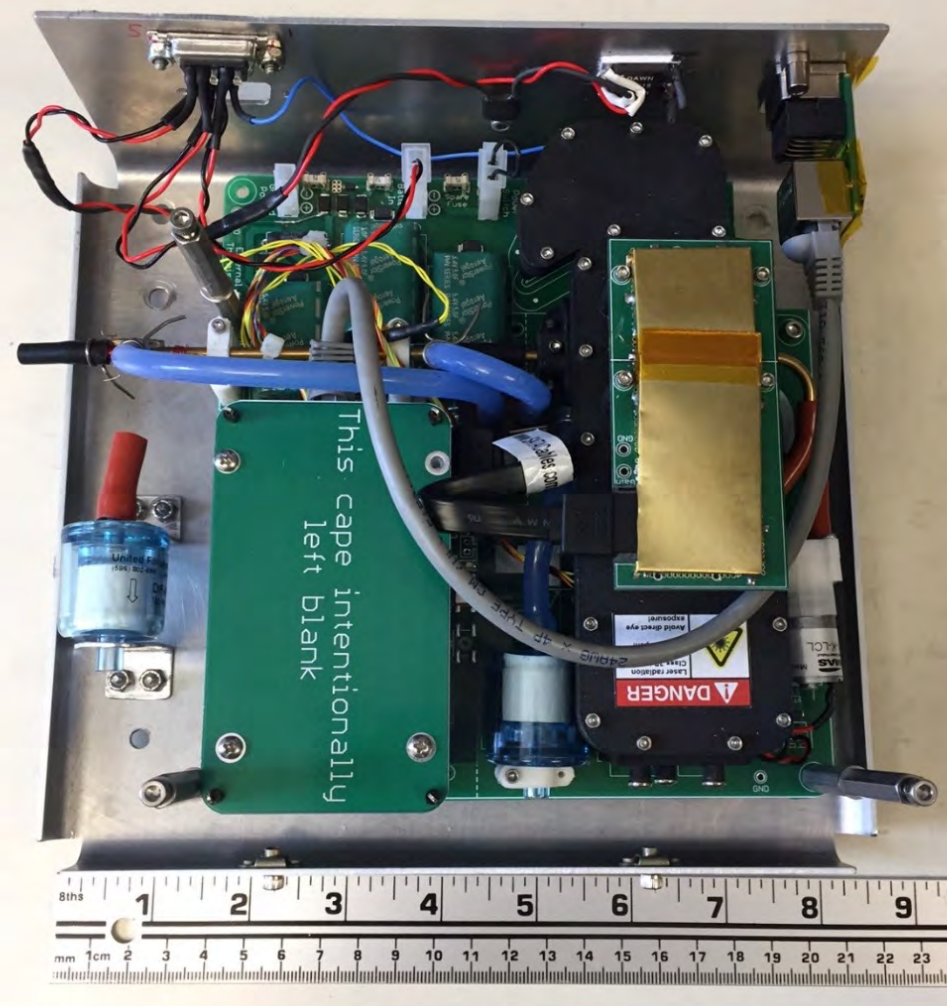
- Investigate low O_3 values in the western Pacific upper troposphere
- Investigate the transport and chemistry of sulfur and short-lived halogenated compounds
- Compare microphysical properties of convectively-generated anvil cirrus and in situ formed cirrus
- Assess the validity of chemical transport model predictions of sulfur species and aerosols

Flight Measurements during POSIDON



- Nine research flights: 0 – 15 ºN, 130 – 160 ºE, 0 – 19 km
- Extensive sampling of the TTL

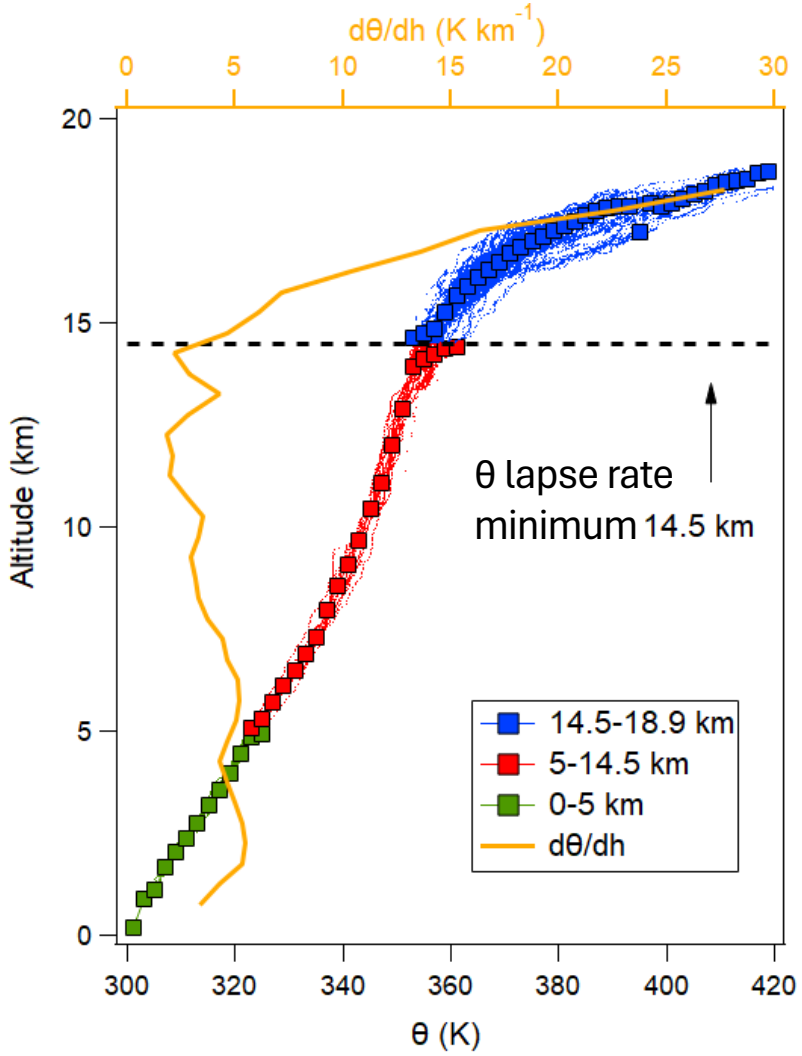
The NOAA POPS Instrument

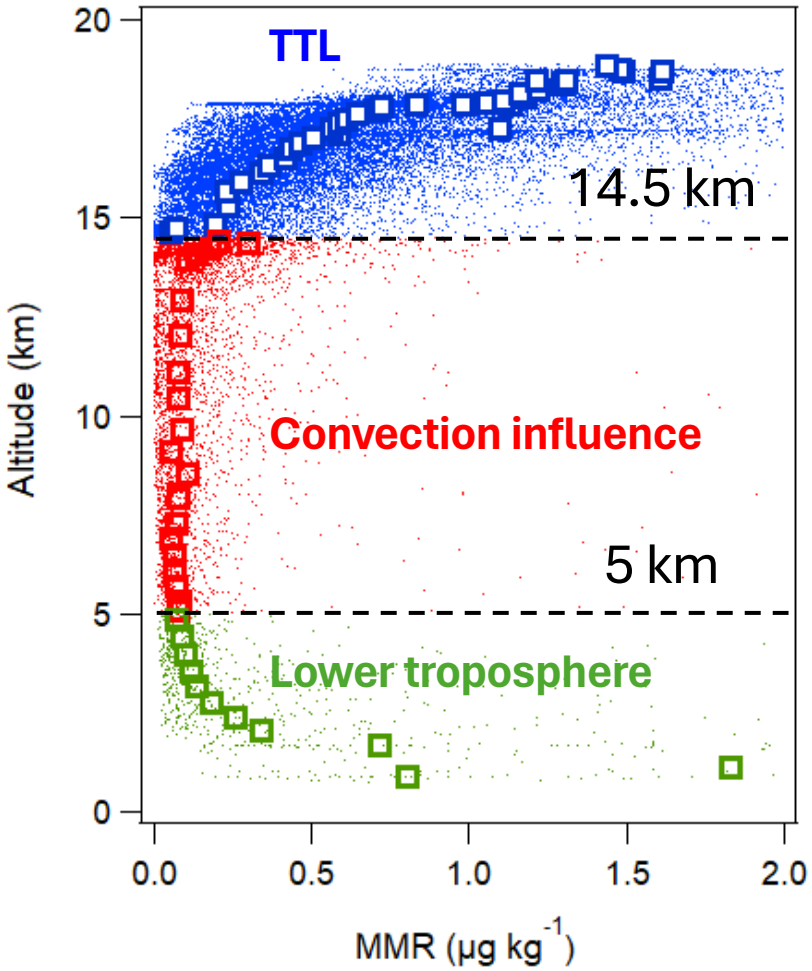


- **P**ortable **O**ptical **P**article **S**pectrometer
- Single-particle detection
- Size range: 140 – 3000 nm
- Weight: 550 g
- Voltage: 9 – 15 V
- Power: 5 Watts

Gao et al. 2016 AST
Cui et al. 2018 AE
Yu et al. 2017 PNAS
Liu et al. 2021 PNAS

Aerosol Vertical Profile over Guam

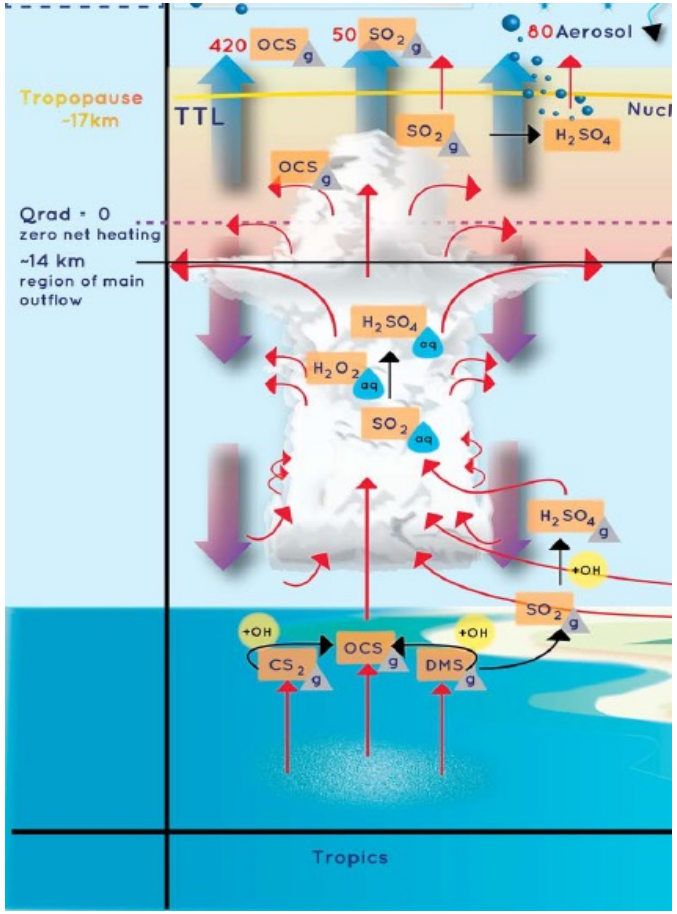


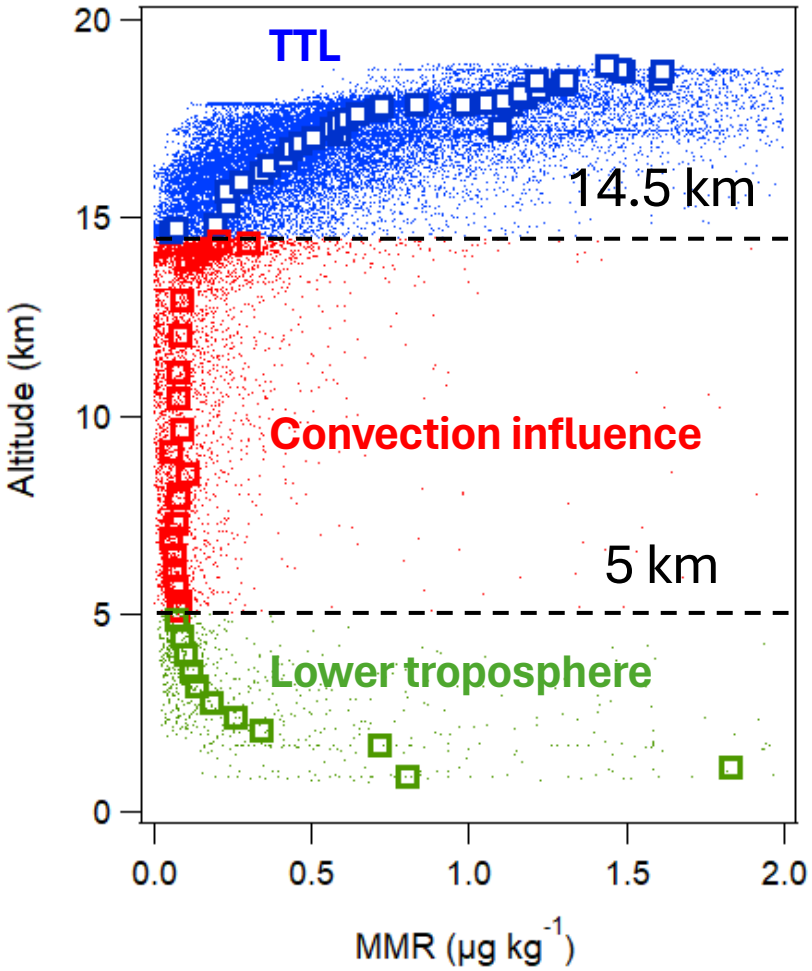


Aerosol vertical profile shows three layers with distinct characteristics.

Aerosol Vertical Profile over Guam

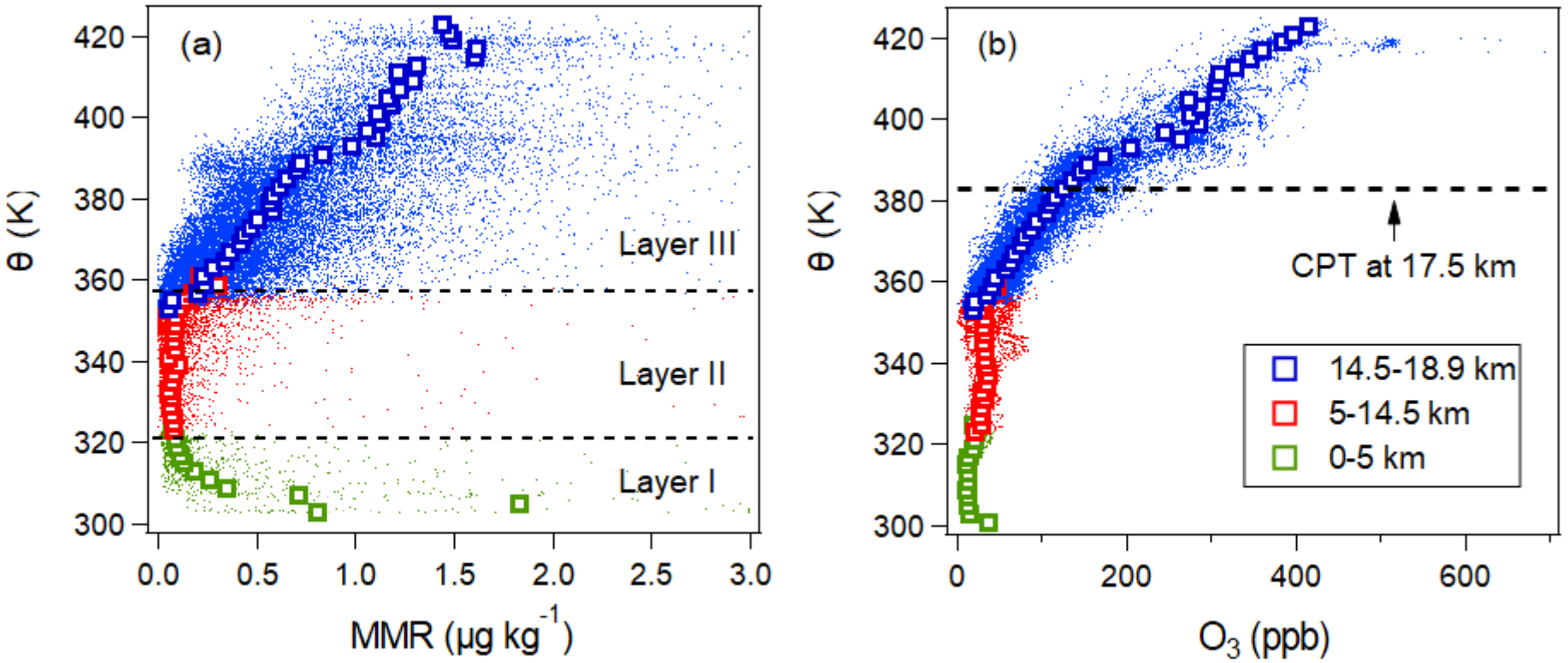
Region of main outflow at ~14 km (Kremser et al. 2016)





Aerosol vertical profile shows three layers with distinct characteristics.

Aerosol and Ozone Vertical Profile over Guam



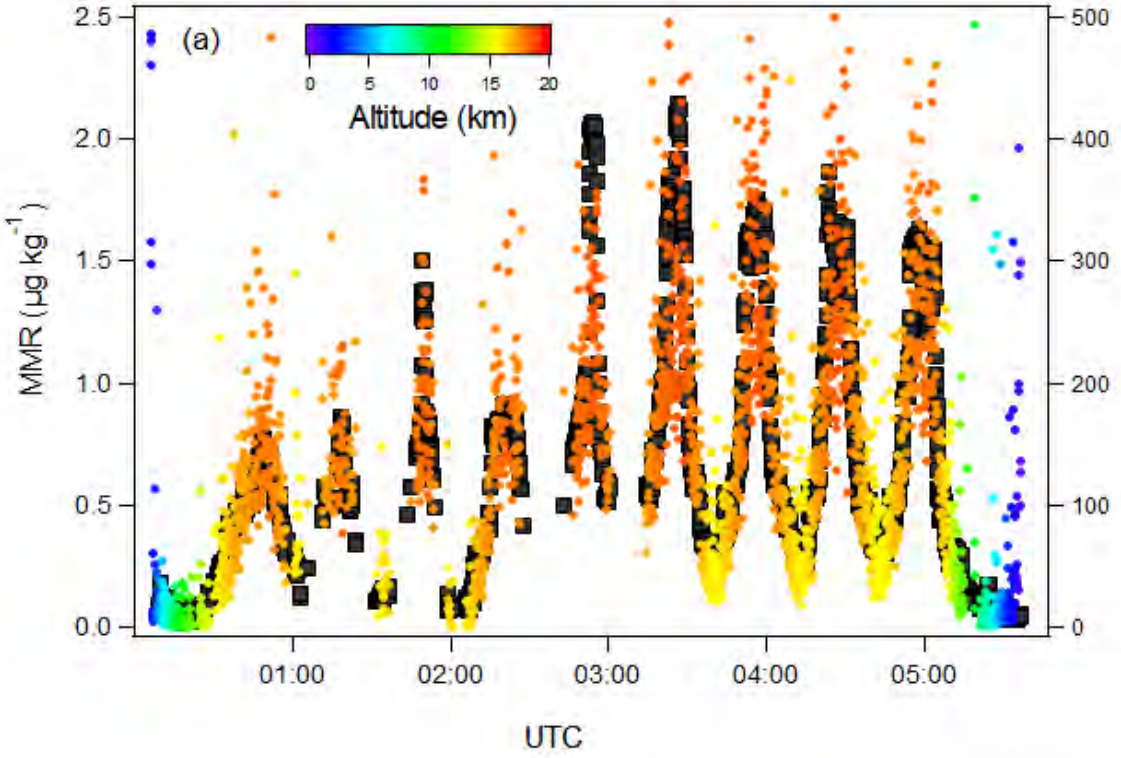
Layer I: 0 – 5 km
Lower troposphere

Layer II: 5 – 14.5 km
Convection influence

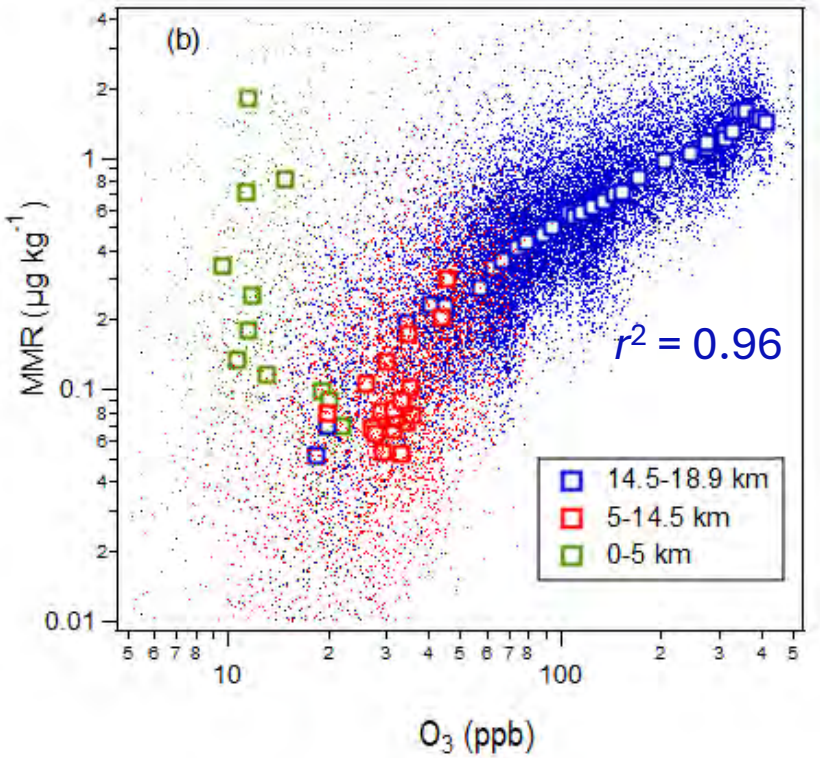
Layer III: 14.5 – 19 km
Tropical tropopause layer

Aerosol Tightly Correlates with O_3 in the TTL

Example of the Oct 18 flight



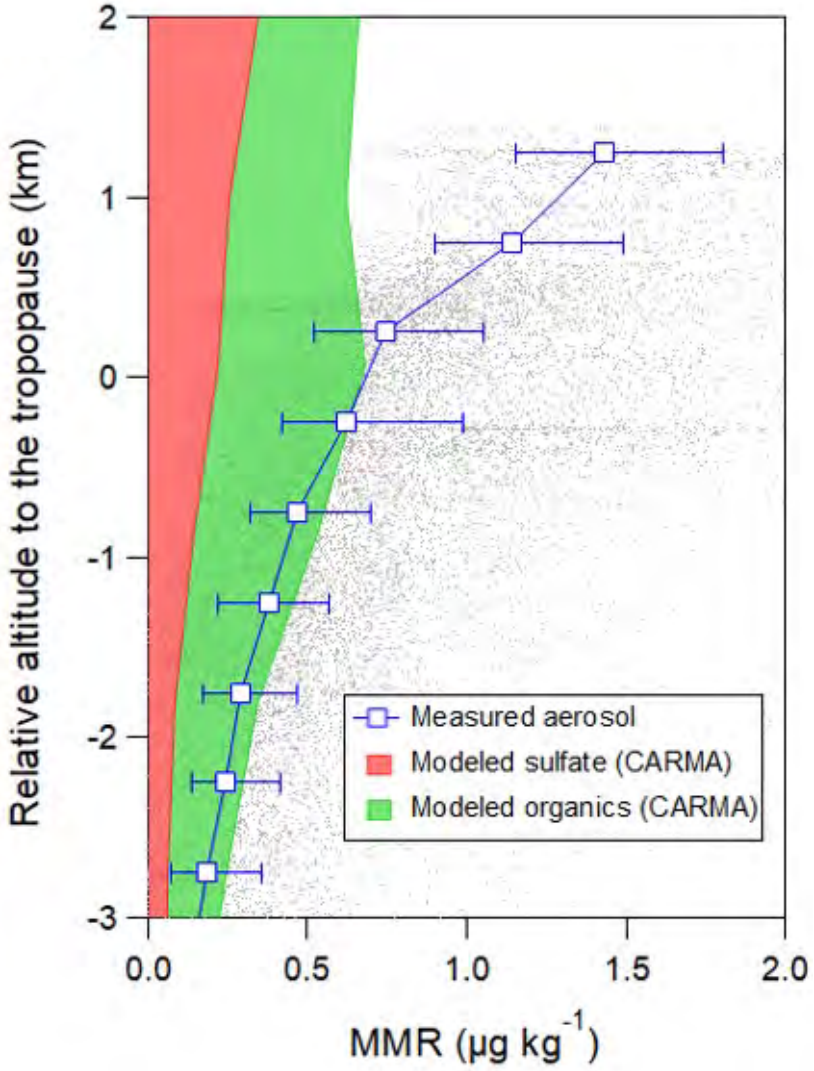
All flights

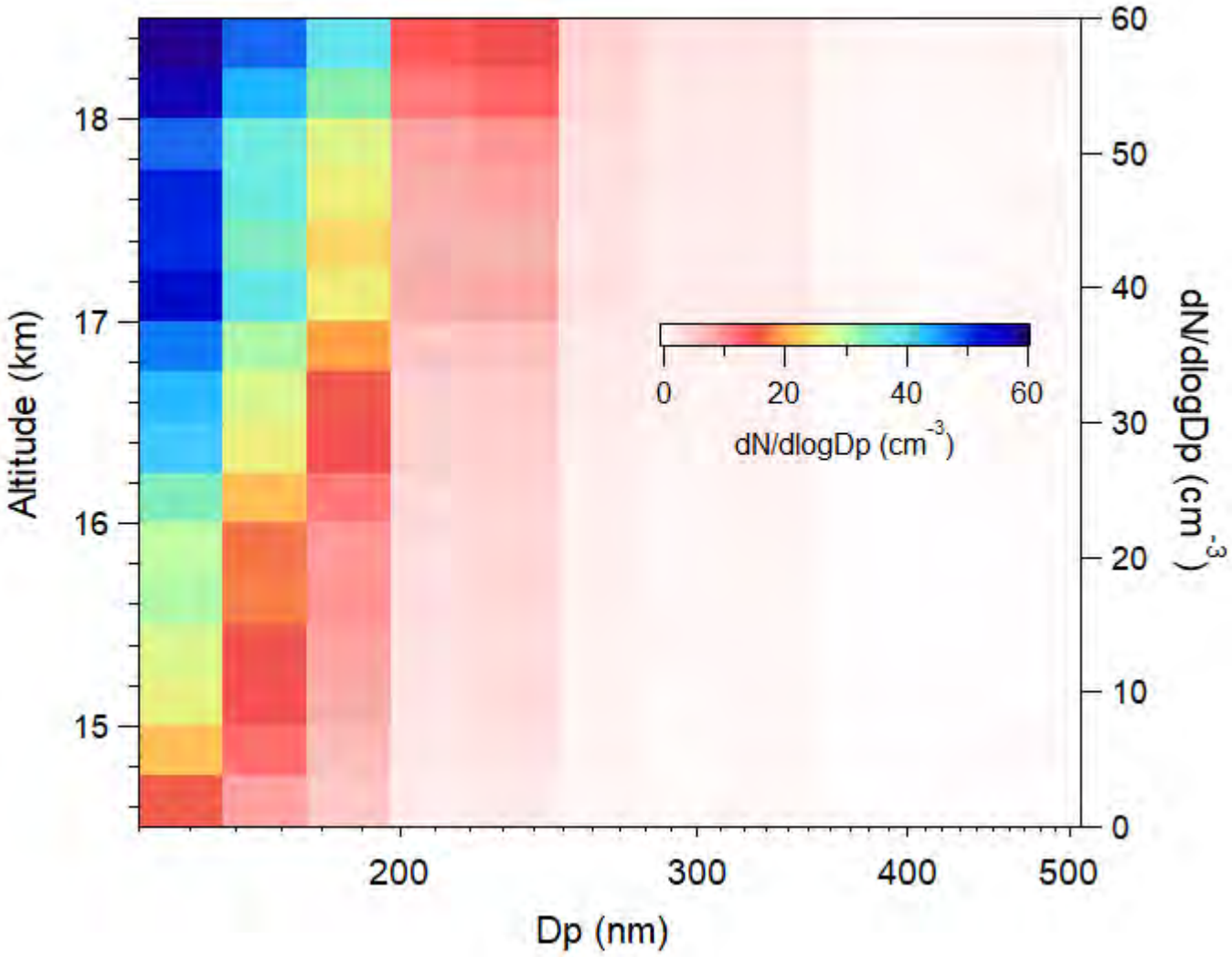


Possible mechanisms for aerosol enhancement in the TTL:

1. Photochemical production
2. Isentropic mixing from extratropics

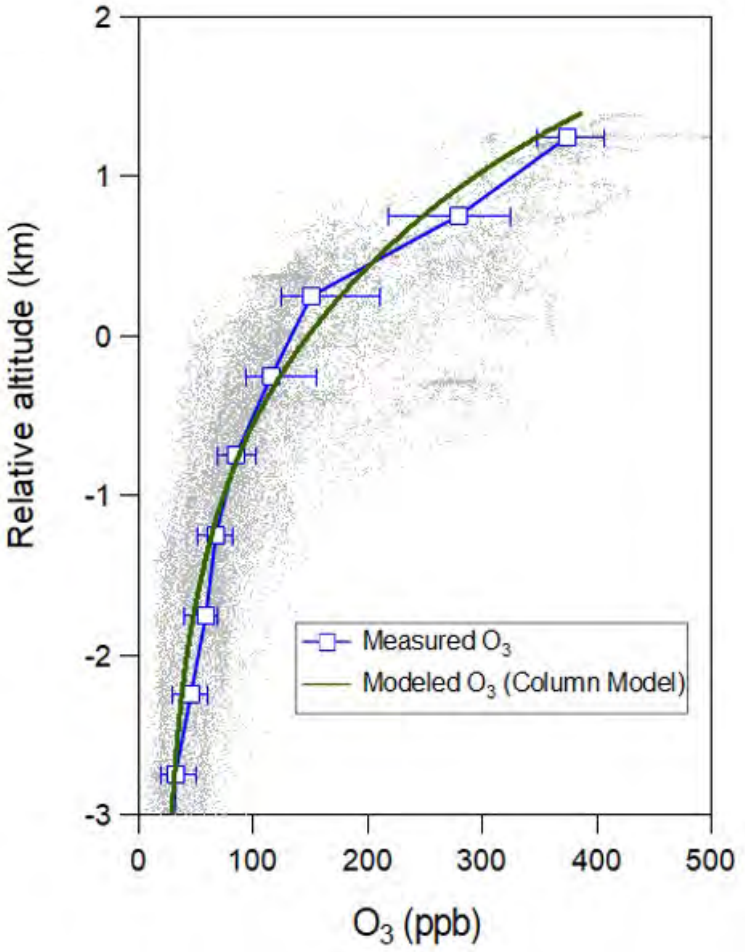
Mechanistic Insights from Models and Size Distribution

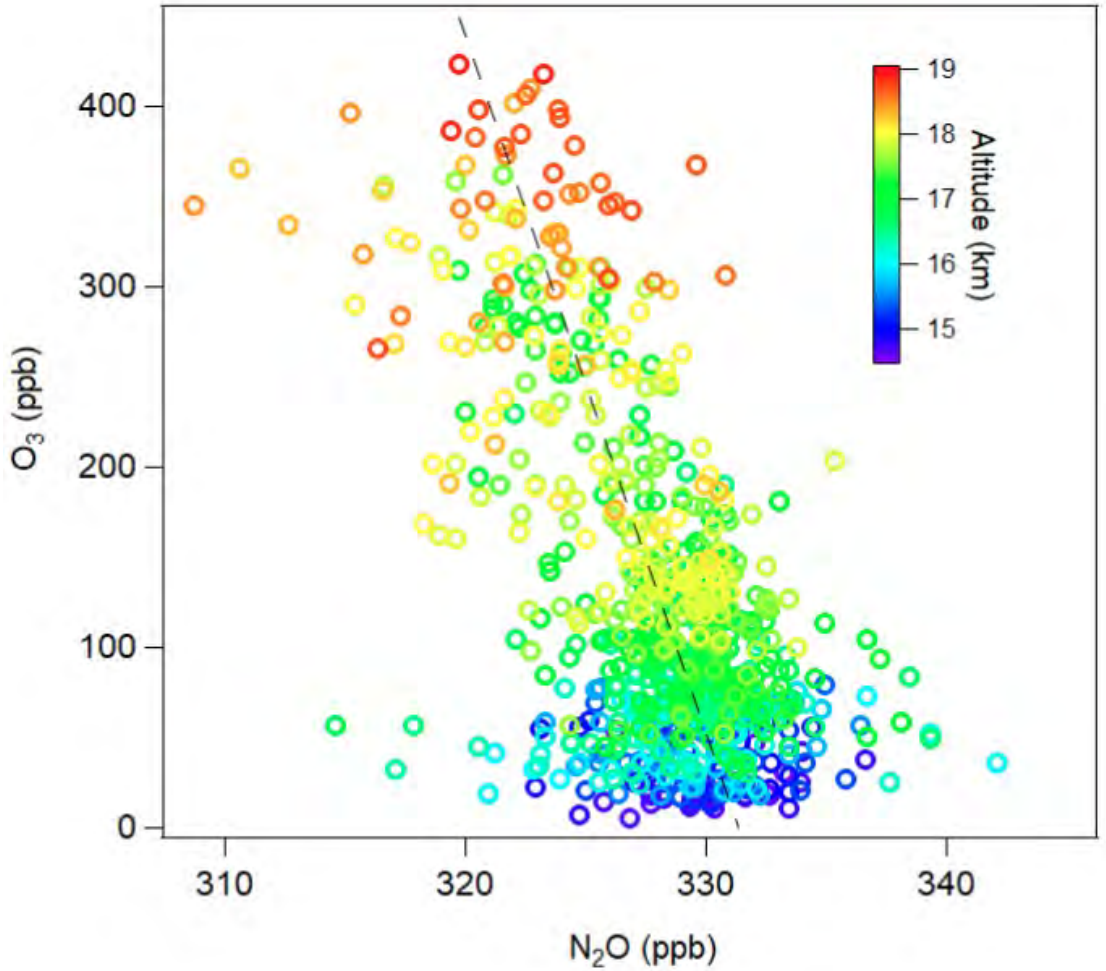




Aerosols are likely generated through the process of NPF and growth.

Mechanistic Insights from Tracers

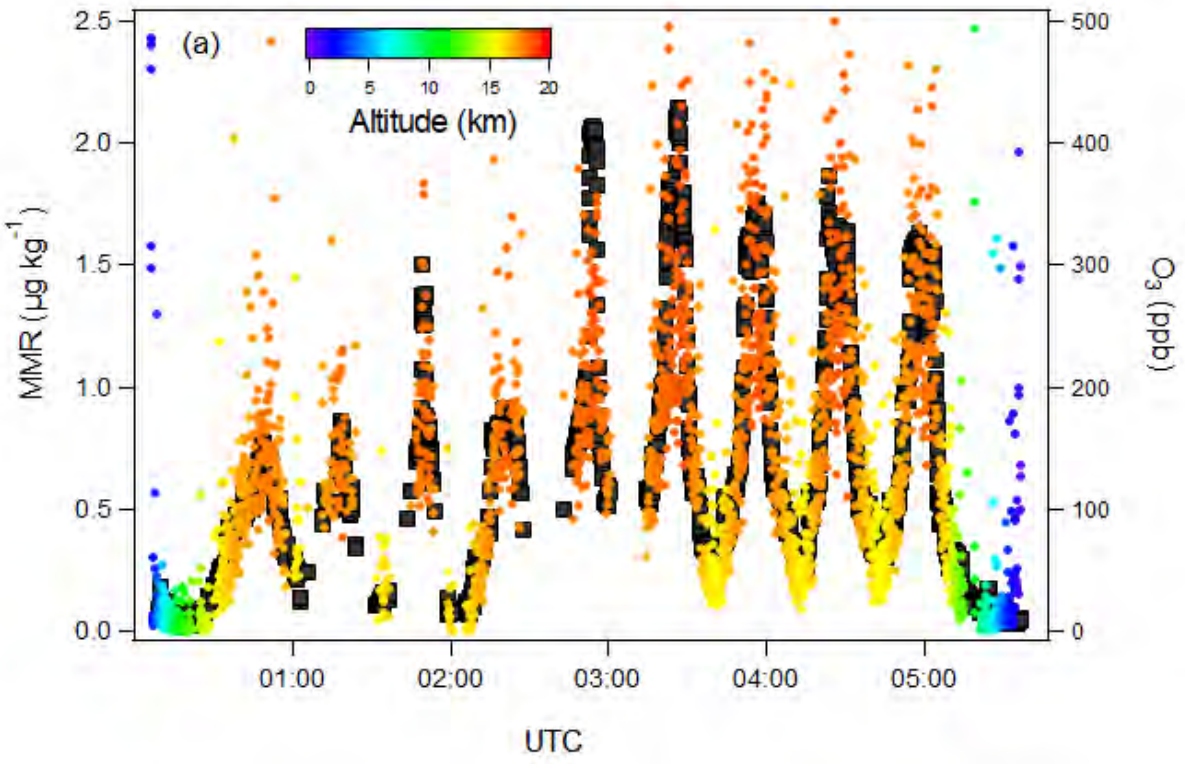




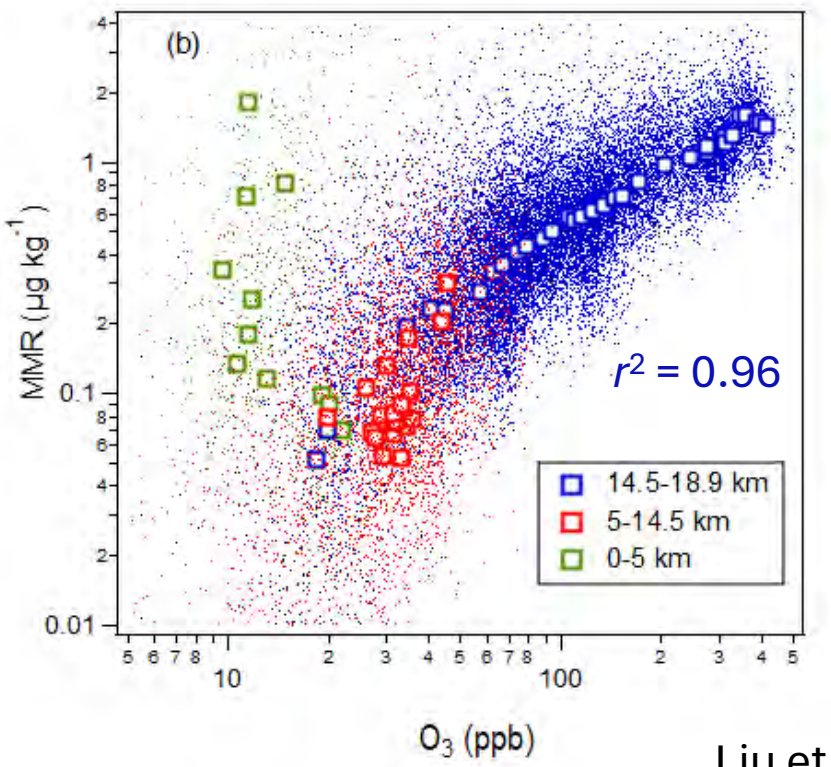
- Contributions from both chemical production and stratospheric in-mixing to TTL O_3.
- TTL aerosols might also be influenced by these chemical and physical processes.

Parameterization of TTL Aerosol MMR using O_3

Example of the 10/18 flight



All flights



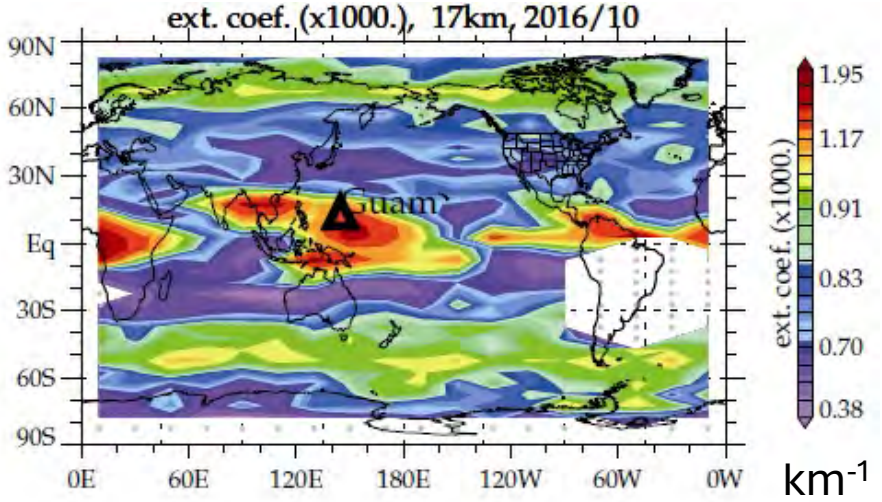
Liu et al. 2024 GRL

Aerosol MMR (μg kg^{-1}) = 0.0074($\pm 2.2 \times 10^{-4}$) x [O_3] (ppb) + 0.23 ($\pm$0.049)

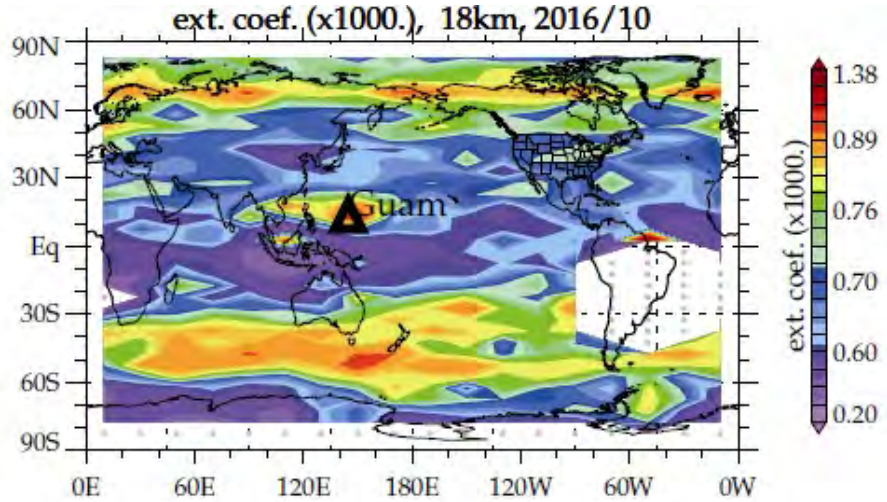
Limited to the observation region and time.

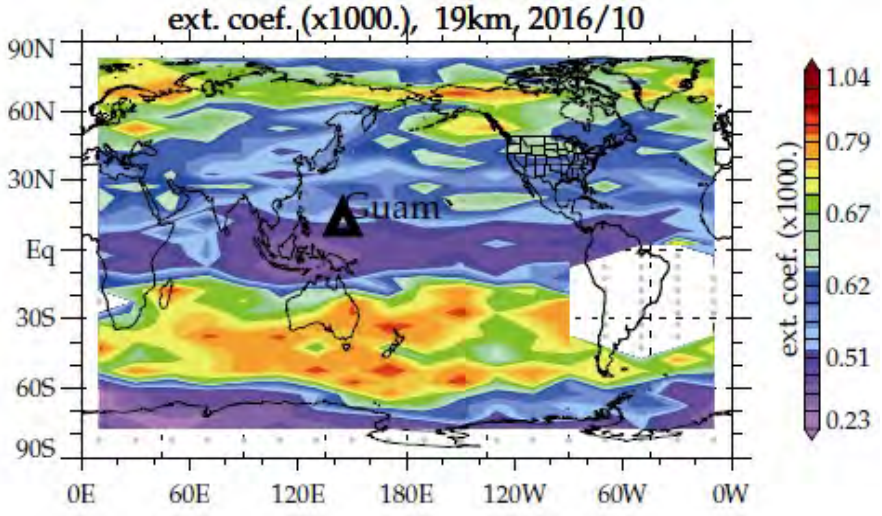
Satellite TTL Aerosol Data

Monthly Average CALIPSO Level 3 Stratospheric Aerosol Profiles Product



km^{-1}





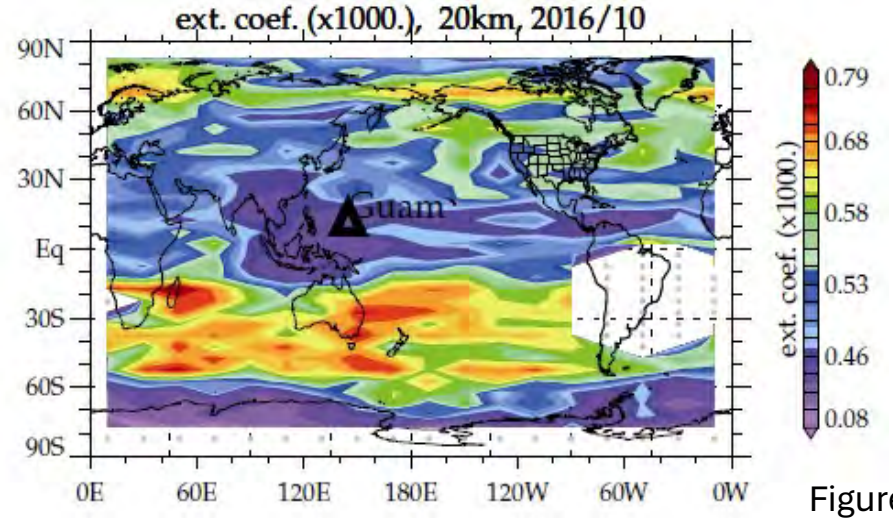
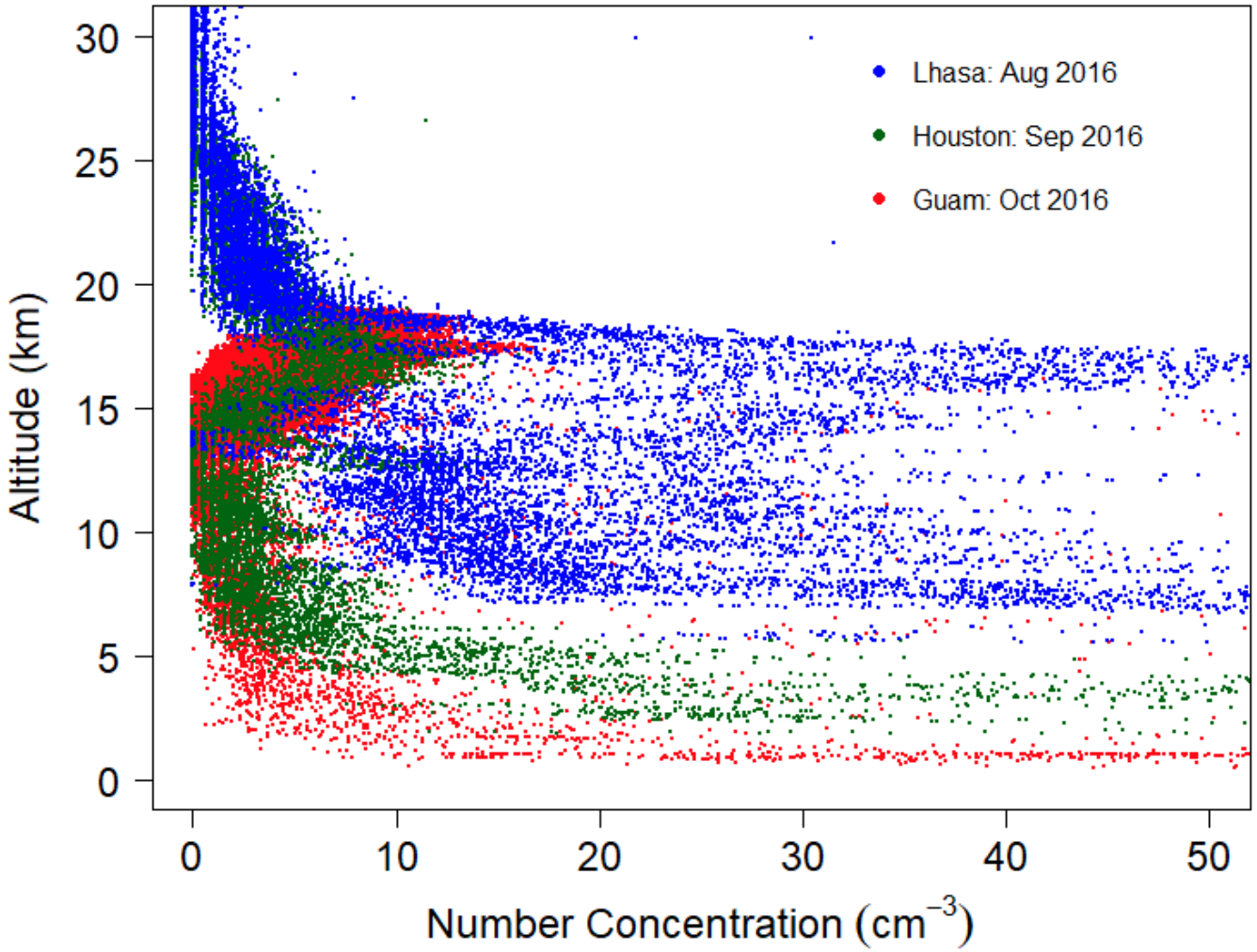


Figure Credit: Tao Wang

Aerosol in the TTL, ATAL, and NATAL

TTL: Tropical Tropopause Layer; **ATAL**: Asian tropopause aerosol layer
NATAL: North American Tropospheric Aerosol Layer

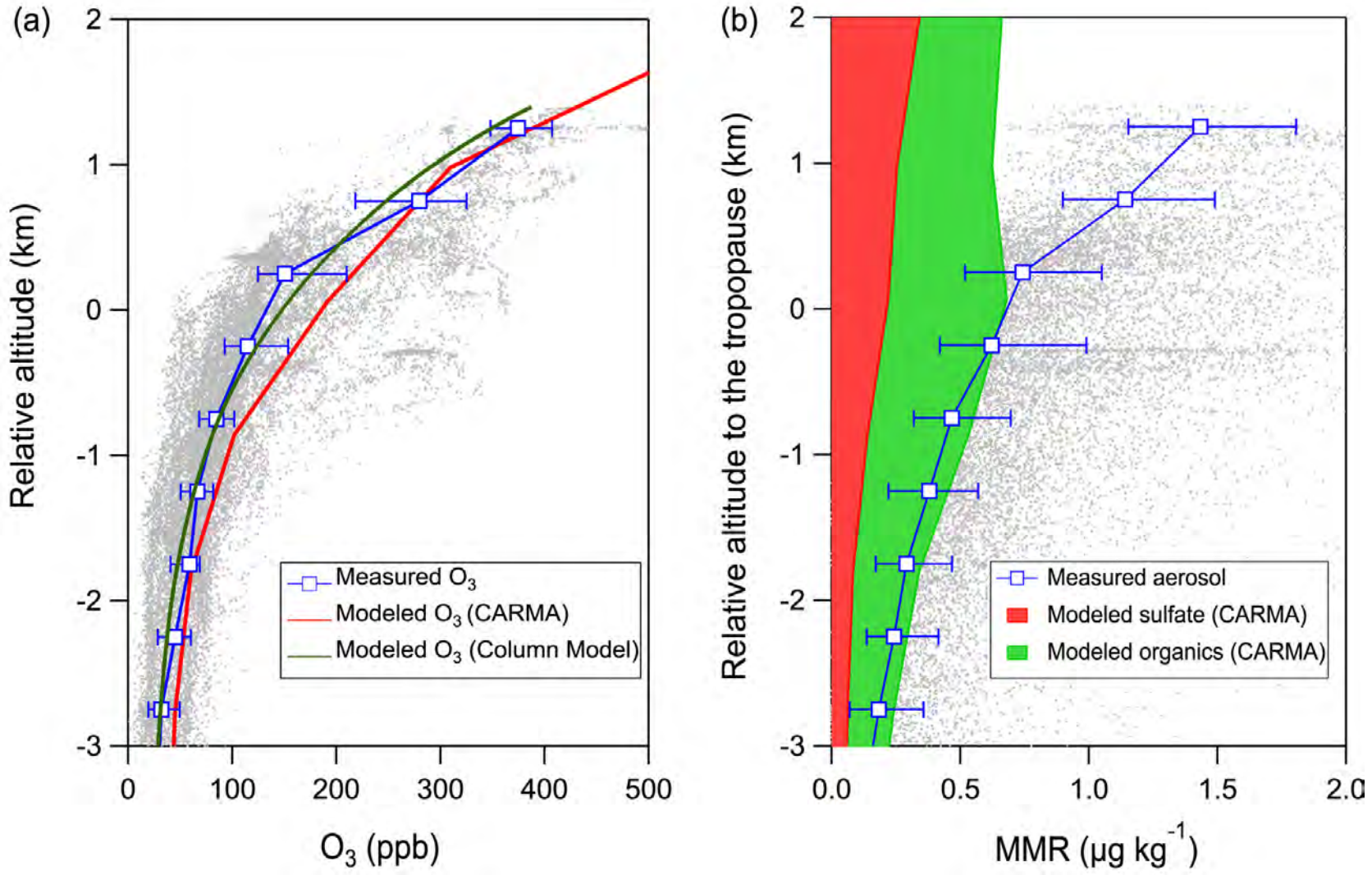


Conclusions

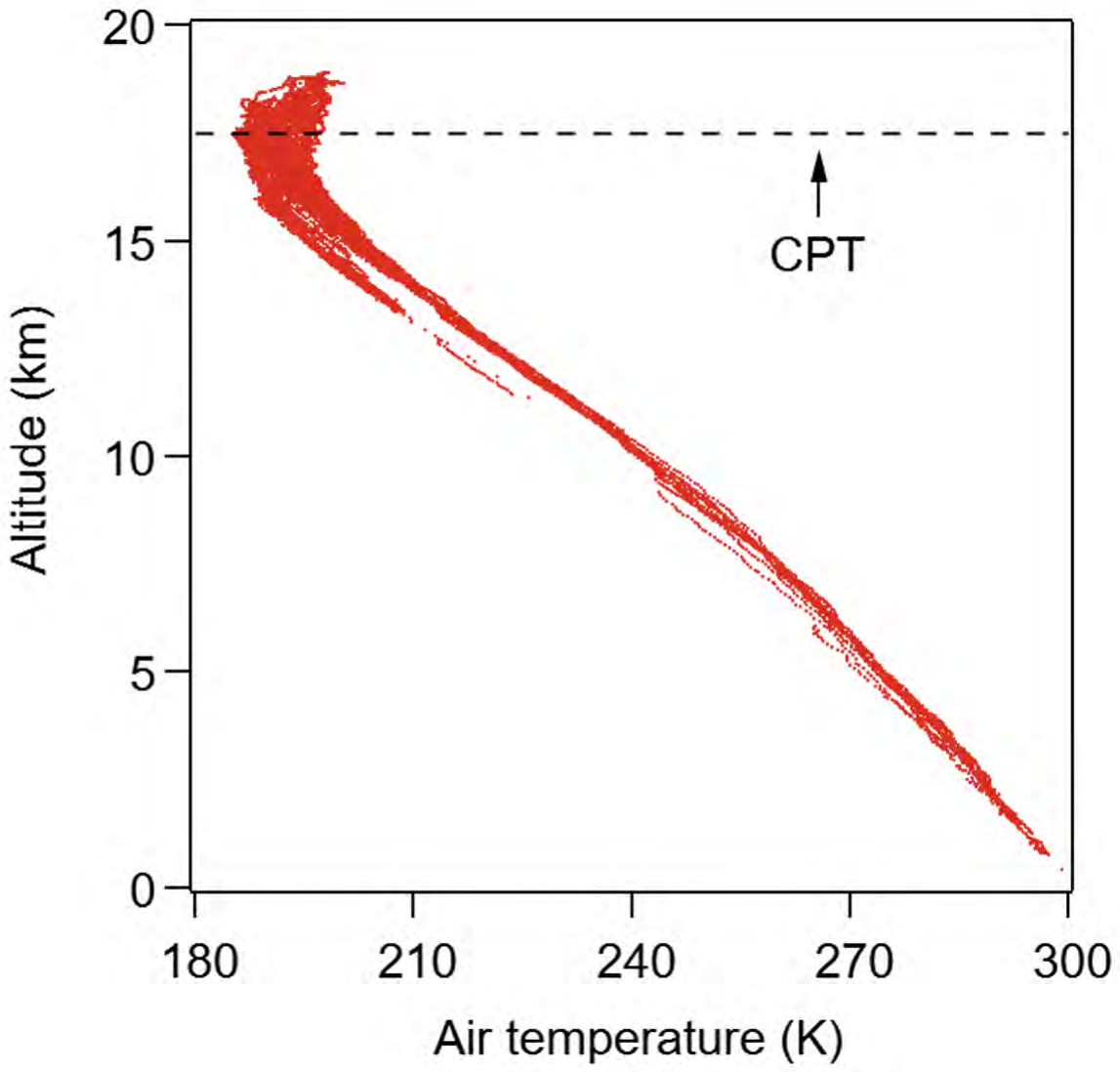
- Aerosol MMR is characterized by three distinct layers over Guam
- The modeling and tracer analysis suggest that TTL aerosols likely originate from a combination of chemical production and stratospheric in-mixing processes
- Derived an empirical parameterization that may allow for the estimation of aerosol MMR as a function of O_3 within the observation region and during the observation months.
- Limitations:
  - POPS has limited size coverage
  - Lack of chemical composition measurements
  - Limited spatial coverage, temporal coverage
  - Aerosol formation: Chemical production vs mixing

Backup Slides

Modeling Results



Vertical Temperature Profile



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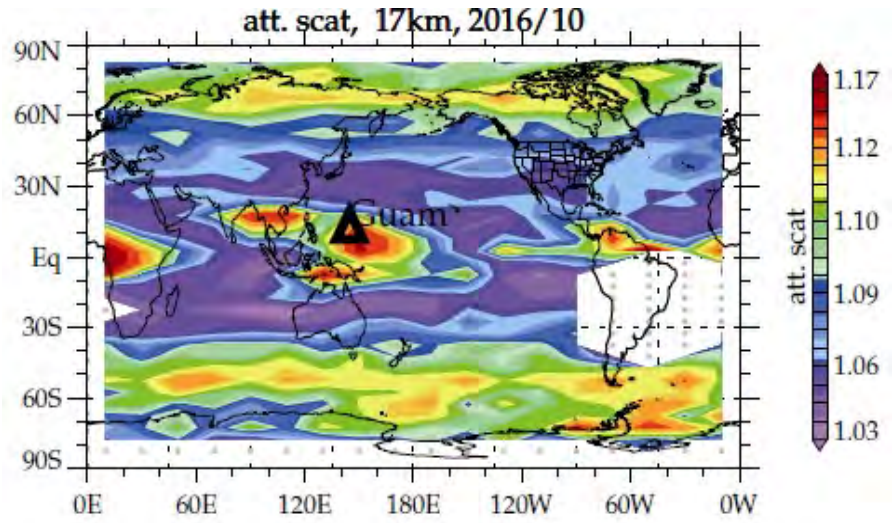

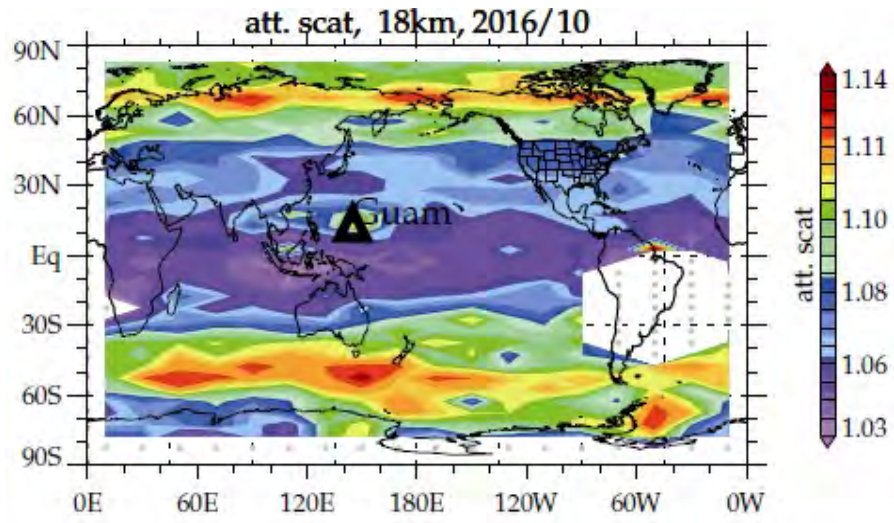

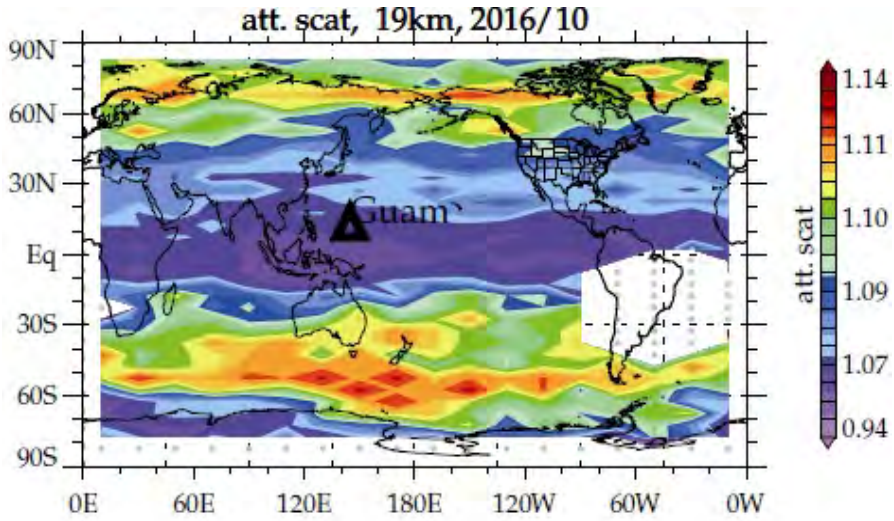

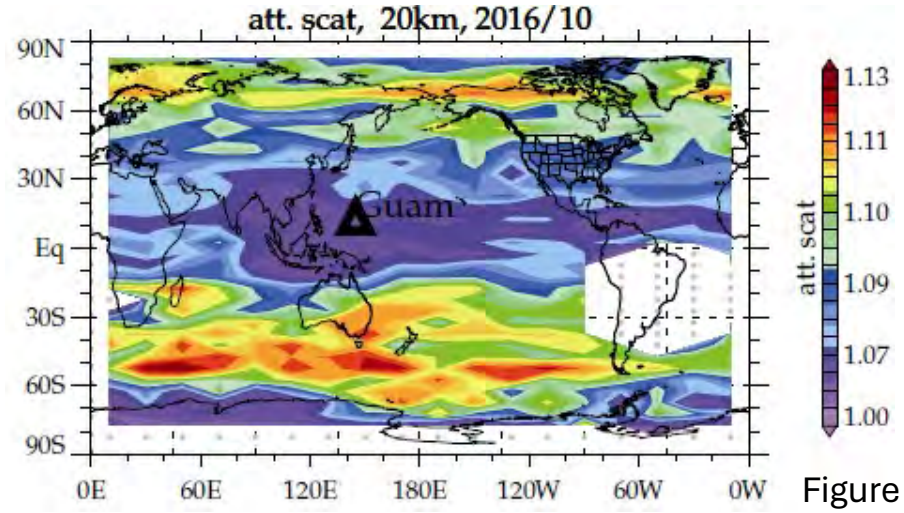

Figure Credit: Tao Wang