Balloon-borne, ground-based and satellite observations of the Hunga Tonga Hunga Ha'apai volcanic plume during the BraVo campaigns

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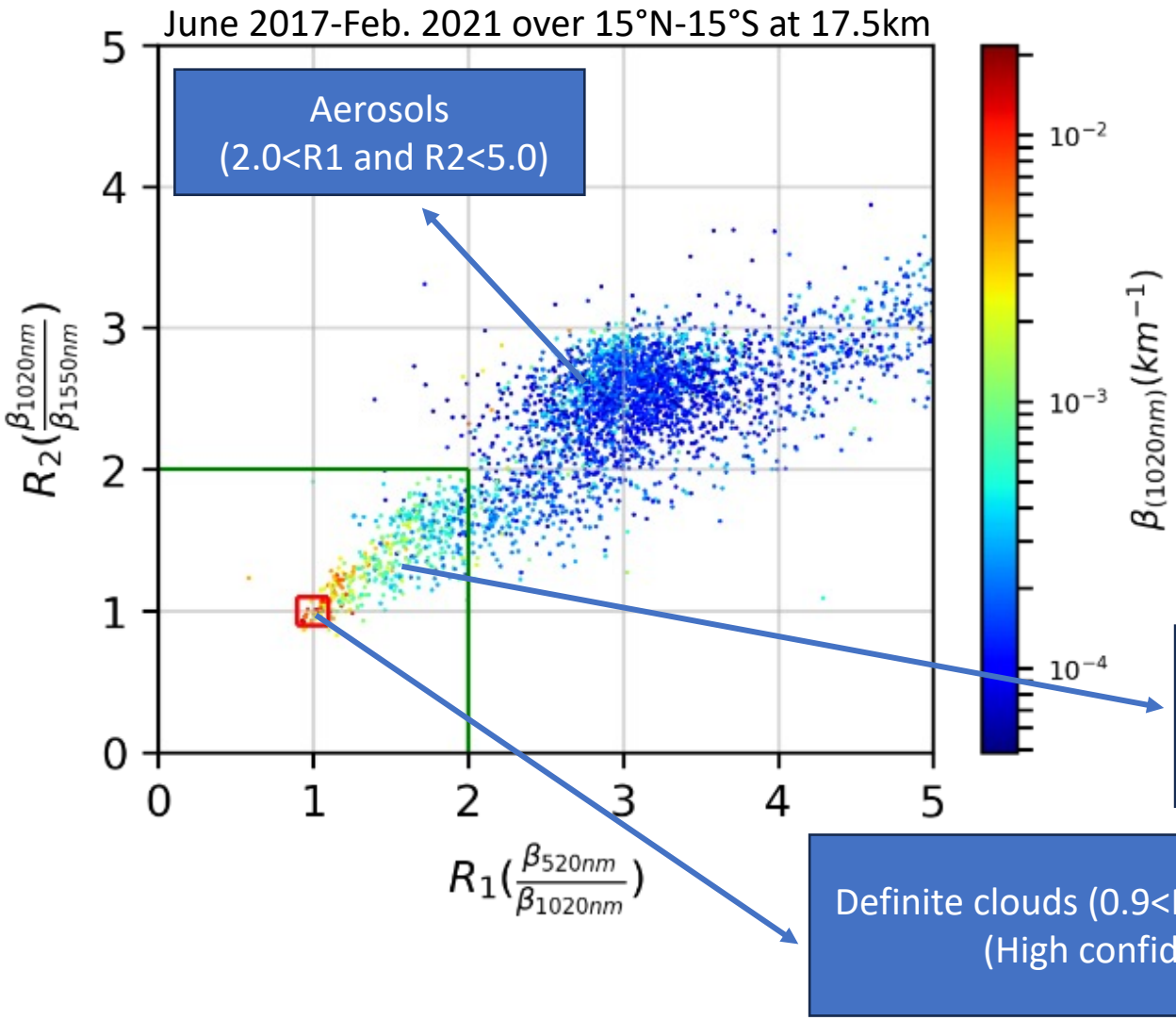
Outline

- Aerosol-cloud discrimination in SAGE III/ISS extinction data: A 3-λ approach
- SAGE III/ISS and CALIPSO observations of the HTHH aerosols
- Balloon measurements of the HTHH plume during the BraVo campaigns
- Co-located SAGE III/ISS and balloon measurements during and after one year of the BraVo campaigns
- Sedimentation of large particles from the HTHH plume & comparison with size retrieval
- Chemical composition of the HTHH plume
- Summary & Future directions

Aerosol-Cloud Discrimination in SAGE III/ISS Aerosol Extinction Data: The Extinction Color Ratio (ECR) Method

MOTIVATION: The **3**- λ method introduced by Kent et al. (1997) for SAGE III Meteor 3-M extinction data at 520, 1020 & 1550 nm could not be thoroughly tested on the SAGE data because:



- ✓ SAGE III Meteor-3M observations did not provide solar occultation data over the tropics (due to its orbit) and
- ✓ It did not observe any significant volcanic eruption during its operation period (Kent et al., 2007).

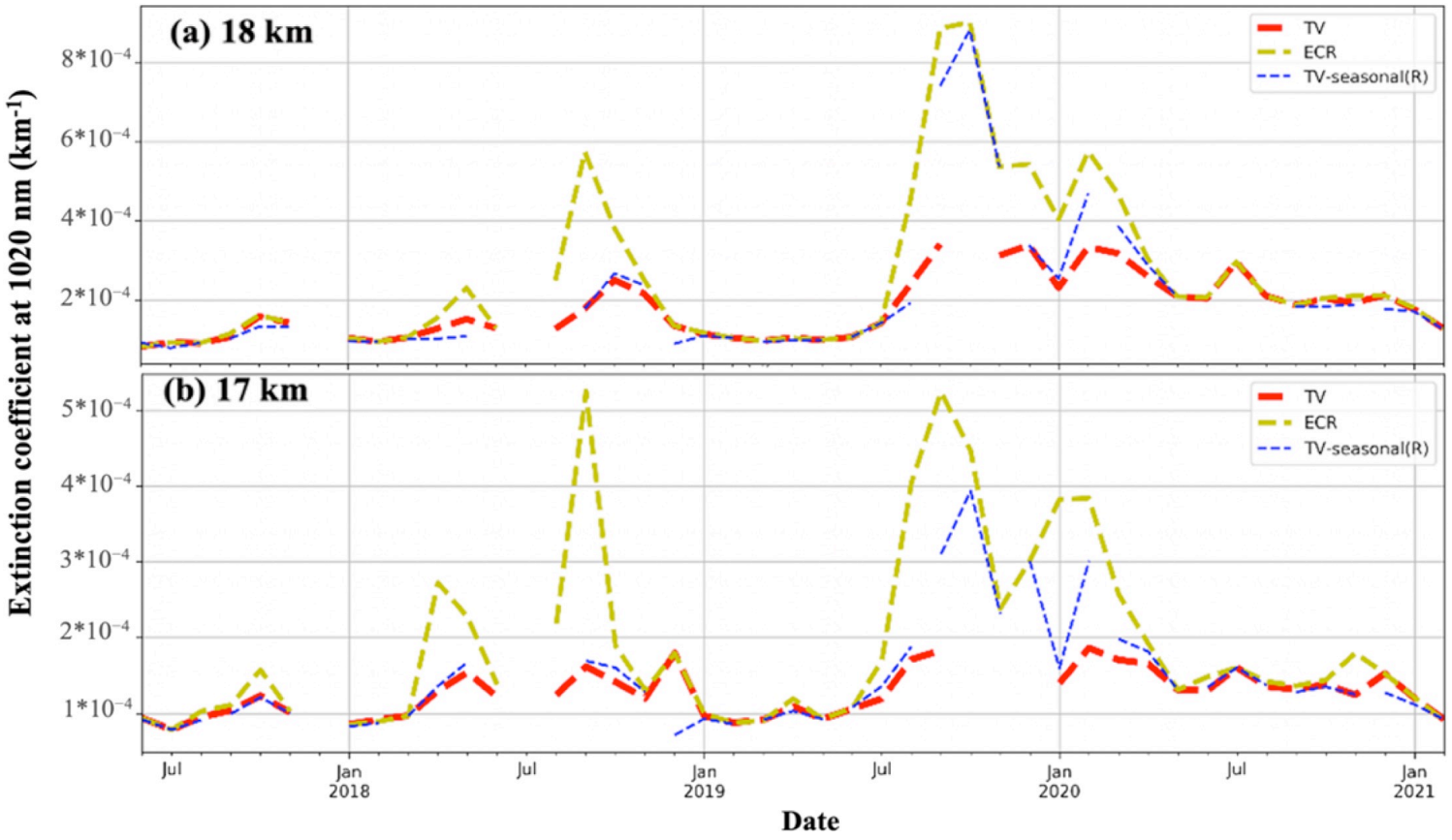
Extinction Color Ratios

$$R_1 = \frac{\beta_{520}}{\beta_{1020}} \quad \& \quad R_2 = \frac{\beta_{1020}}{\beta_{1550}}$$

Bhatta et al. (2023), Applied Optics

Usefulness of 3- λ vs 2- λ method for Climate studies

2- λ method : Thomason and Vernier (2013) - TV
3- λ method : Bhatta et al., (2023) - ECR

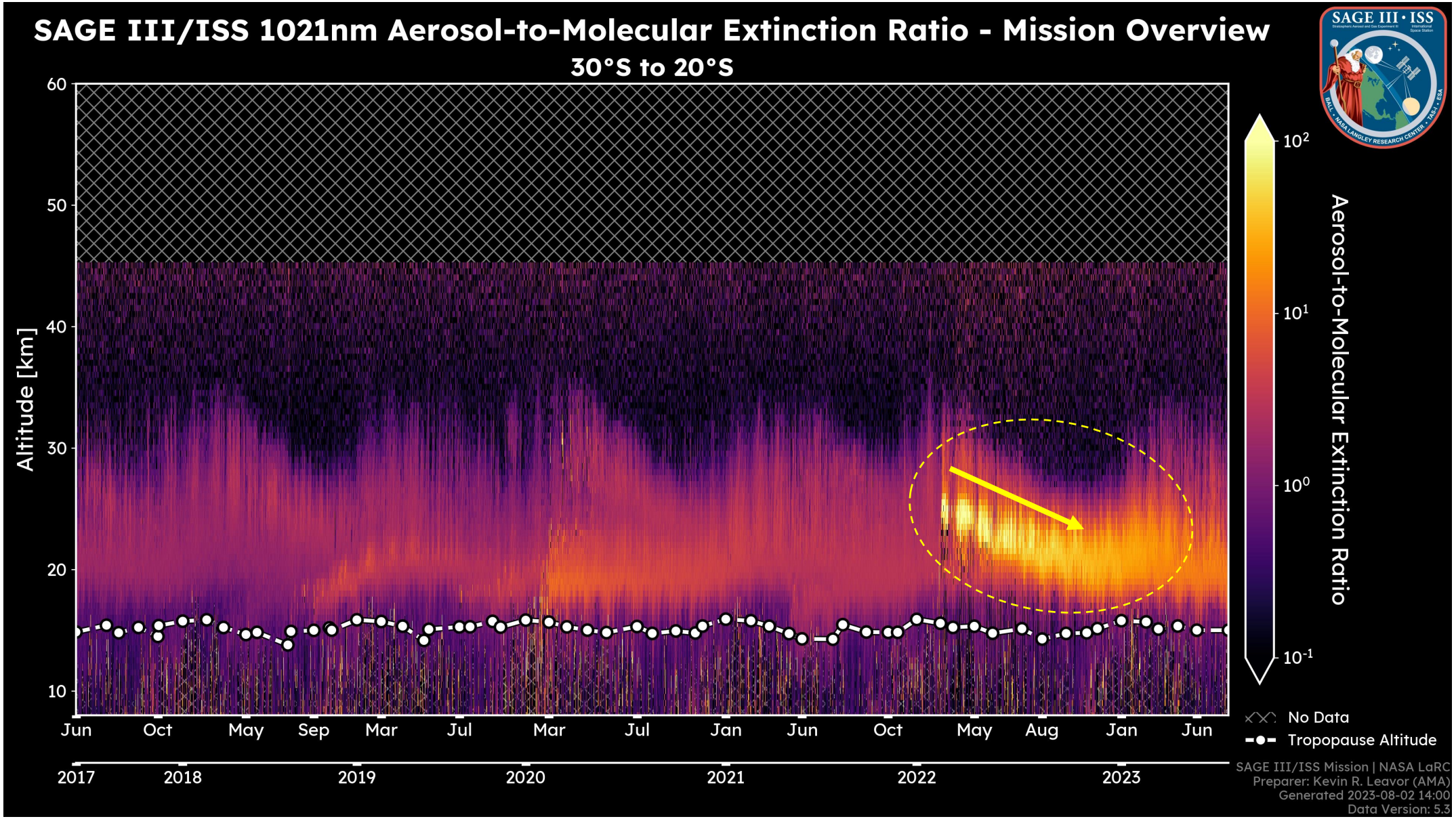


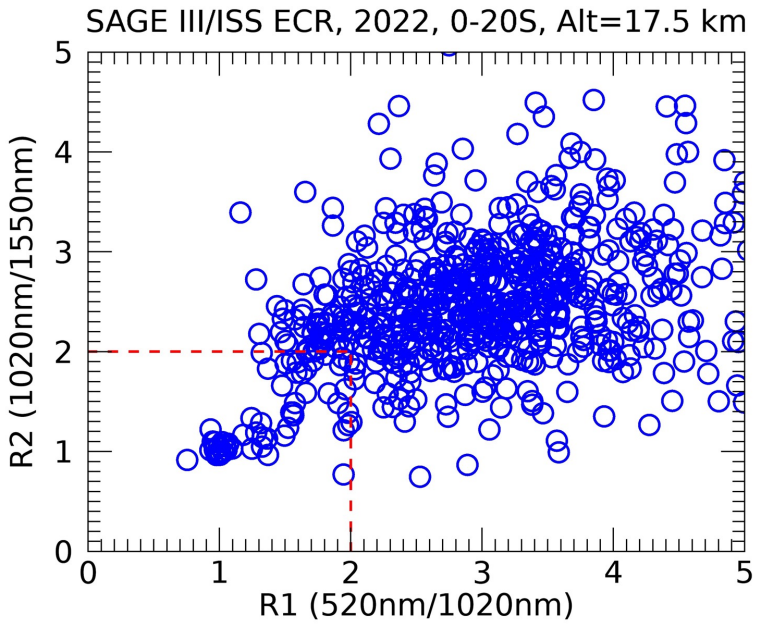
Bhatta et al. (2023), Applied Optics

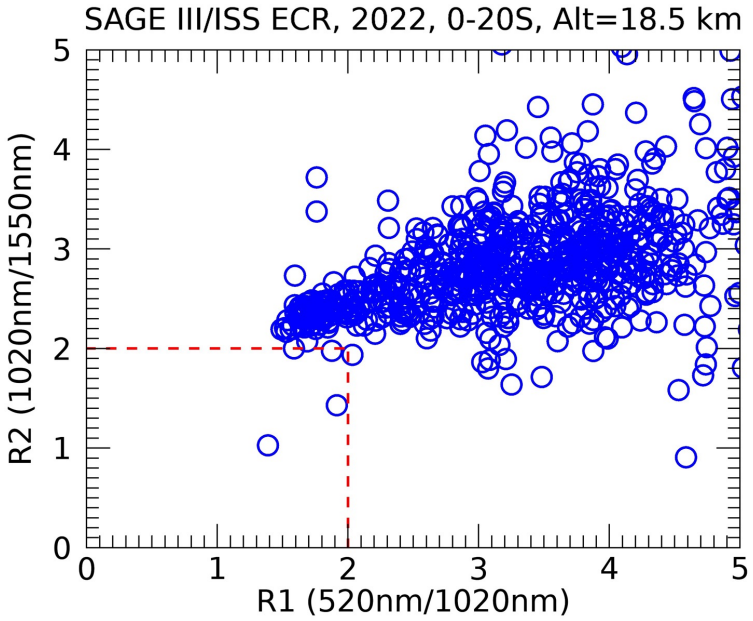
2-λ method	3-λ method
Uses one extinction ratio, R1 and one extinction coefficient at 1020nm	Uses two extinction ratios: R1 & R2.
Requires estimation of centroid & k_0	Not required
Centroid location shifts during different sampling periods: Dynamic thresholds	Fixed thresholds
Can be used for long-term climate studies using both SAGE II & SAGE III data.	Limited to short-term climate studies after 2017.

Altitude	Period	Centroid (R)	Corresponding Extinction (k_0)
18 km	2017/06/07-2021/02/28	3.11	-3.72
	2018/07/01-2018/12/31	4.37	-3.88
	2019/01/01-2019/05/31	3.38	-4.05
	2019/07/01-2019/12/31	2.99	-3.22
17 km	2017/06/07-2021/02/28	2.88	-3.96
	2018/07/01-2018/12/31	3.98	-3.90
	2019/01/01-2019/05/31	2.87	-4.03
	2019/07/01-2019/12/31	3.89	-3.66

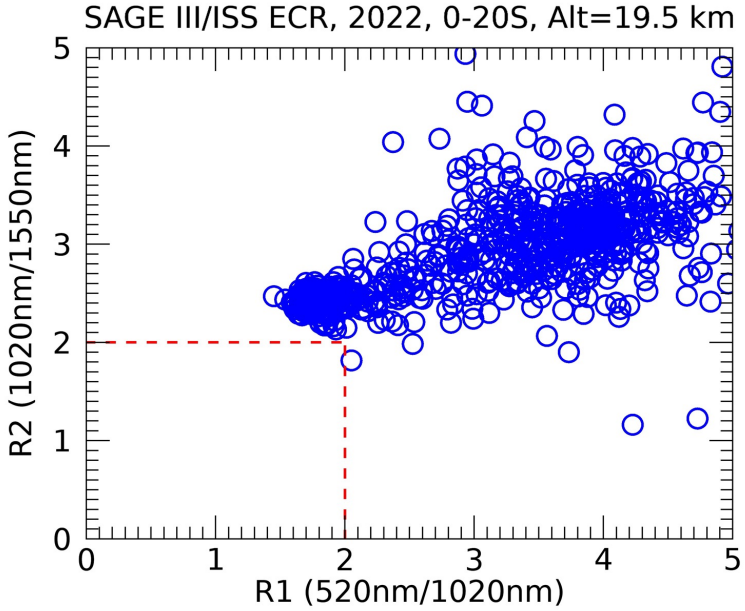
SAGE III/ISS Observations of the HTHH aerosols

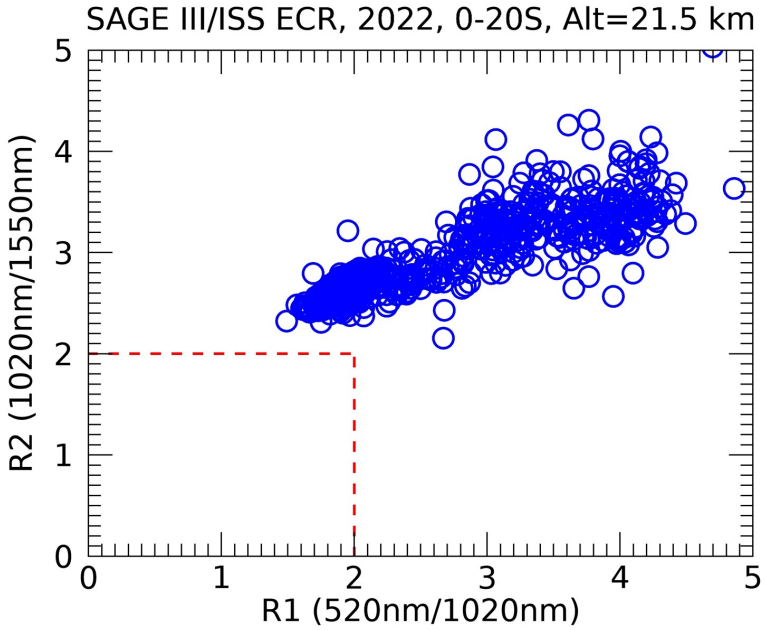




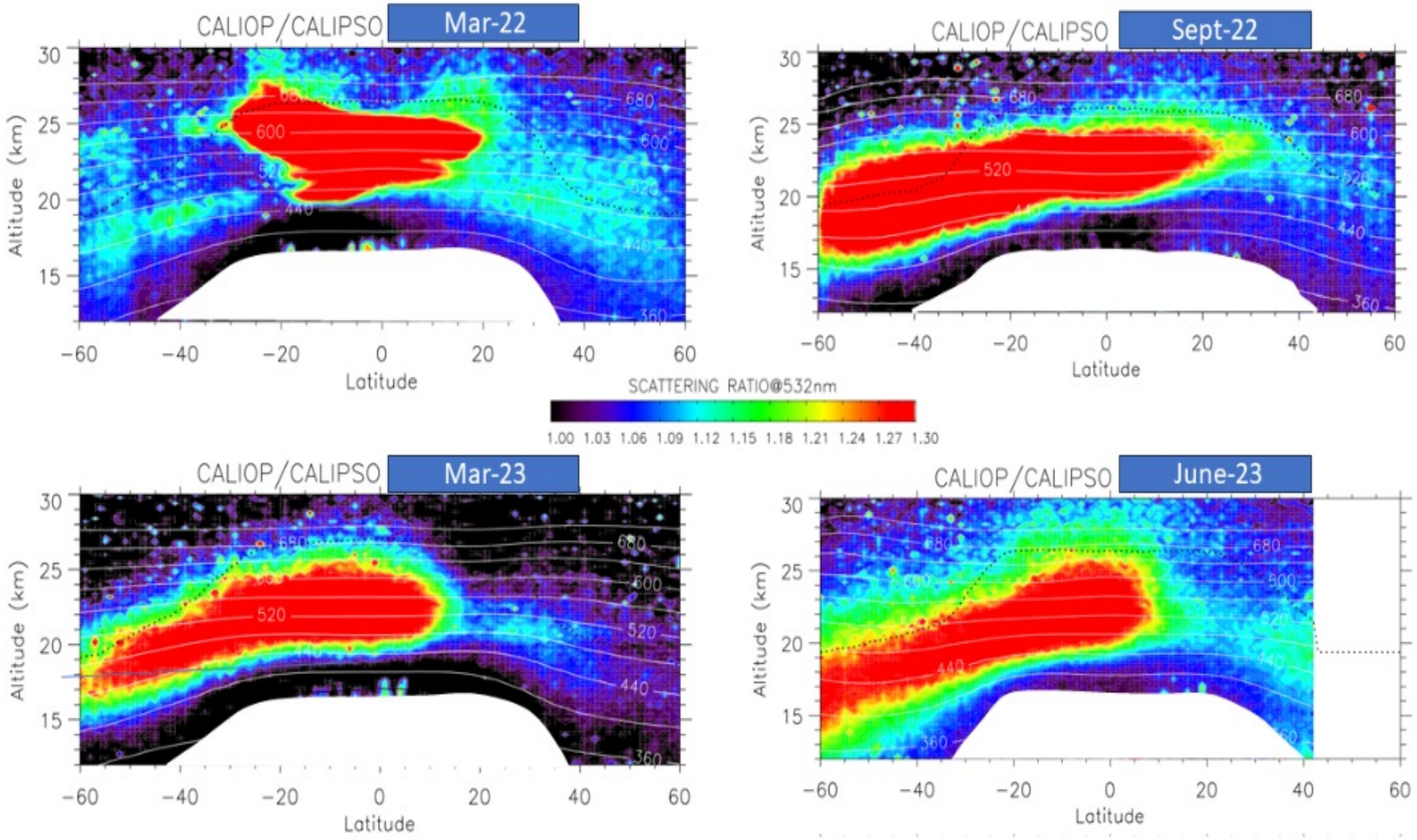


Extinction Color Ratios (R_1 & R_2) for the HTHH period





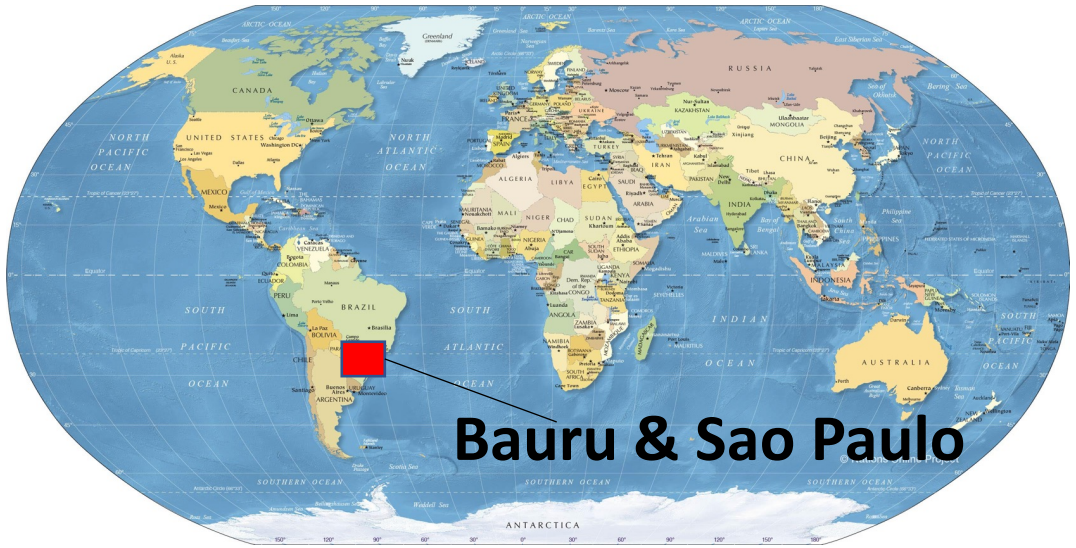
CALIPSO Observations of the HTHH Plume



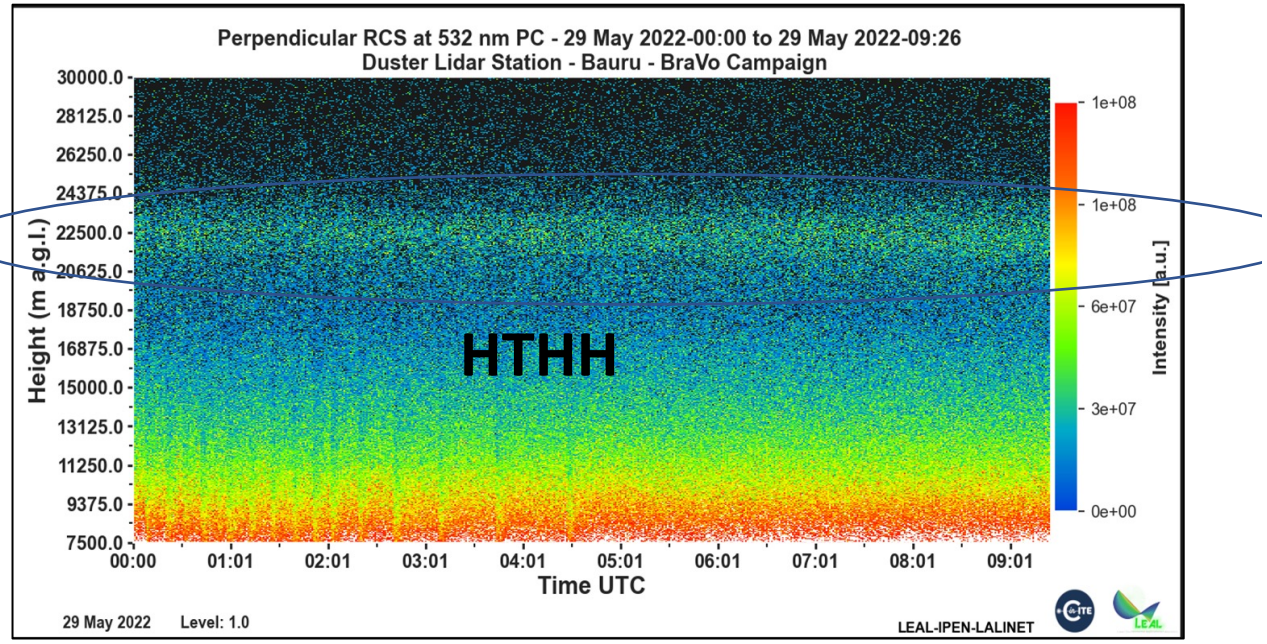
Scattering ratio derived using method given by Vernier et al. (2009)

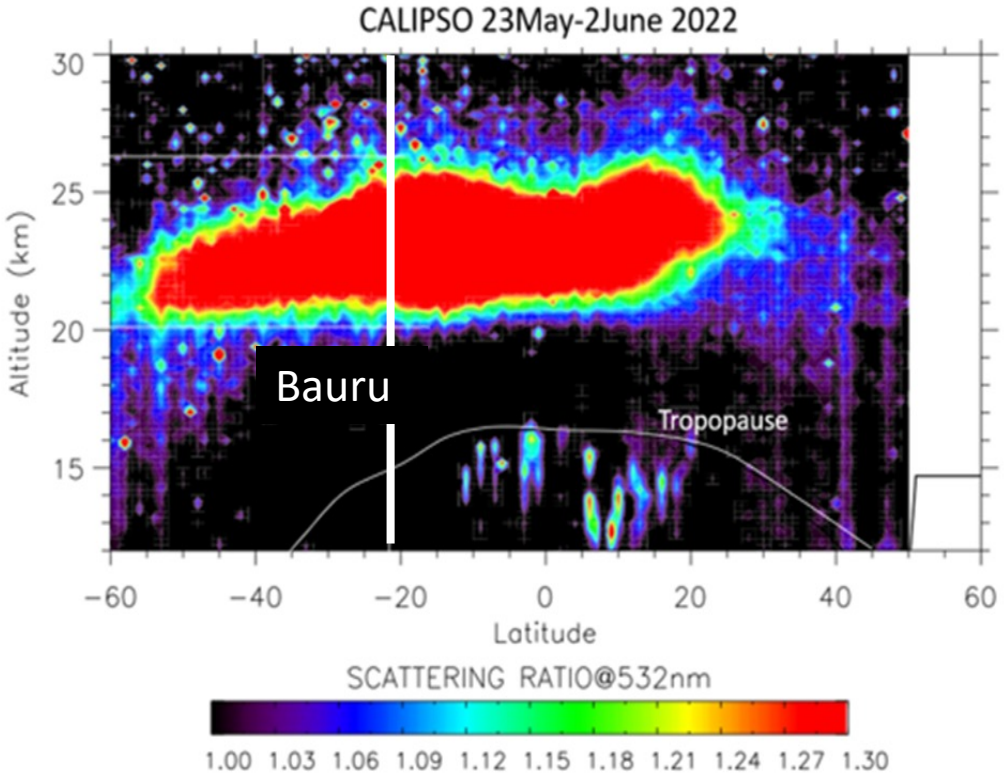
Downwelling of the HTHH plume over the Southern Hemisphere

The Brazil Volcano: BraVo Project



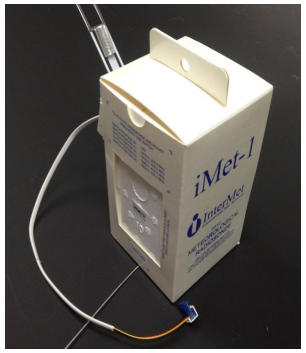
- Ground based lidar observations from Bauru and Sao Paulo
- Balloon observations between May and November 2022 (extensive campaign in May and August 2022)





Balloon-borne Instruments used during the BraVo Campaigns

iMet-1 Radiosonde



- T, P, RH, u, & v
- GPS location

Compact Optical Backscatter AerosoL Detector (COBALD)

- A two-wavelength backscatter sonde
- Backscatter ratio (BSR) at 455 nm (blue) & 940 nm (IR) wavelengths.
- Color Ratio = BSR_{940}/BSR_{455}

En-Sci ECC Ozone sonde (NOAA GML)

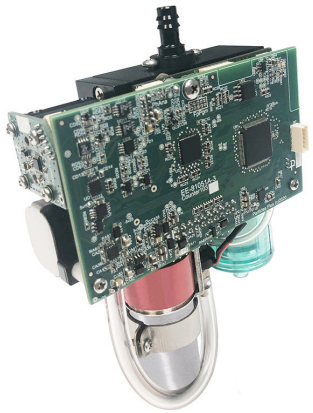
- Potassium iodide based ECC.
- Ozone mixing ratio profile.

Cryogenic Frost-point Hygrometer

- Based on chilled mirror principle
- Frost-point temperature
- Water vapor mixing ratio & RH_{ice}

iMet-4 Radiosonde

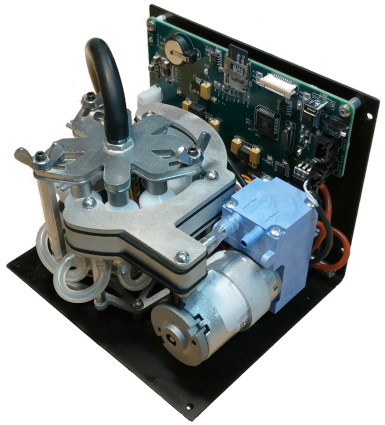
+



Particle Plus 9301 OEM Series Particle Counter (NPOPC)

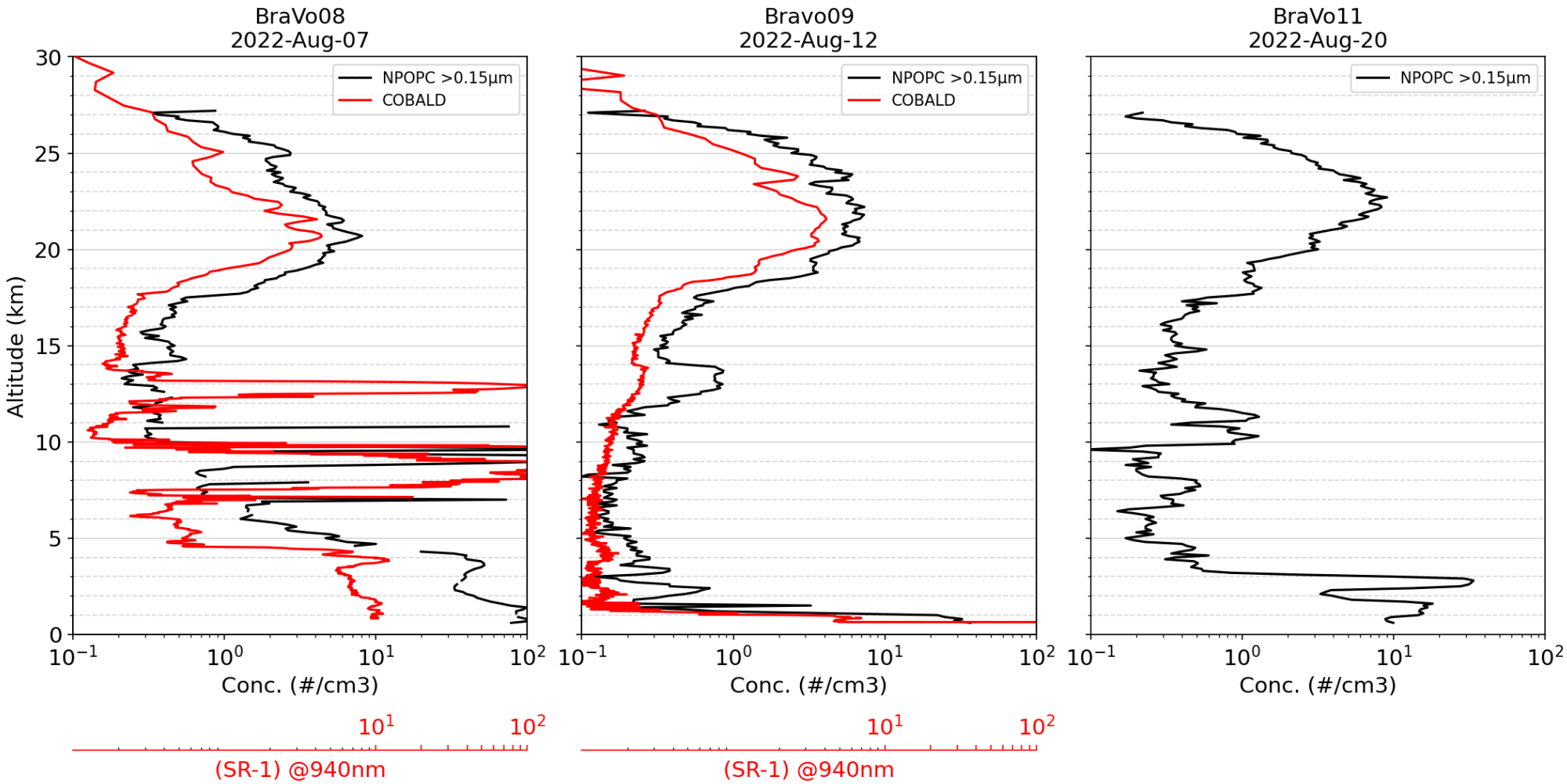
- Laser diode based optical particle counter
- Particle counts at 30 size channels every 2 seconds
- Size range: 0.3 -10 µm (diameter)
- Flow: 2.83 LPM (0.1 CFM)

Brechtel Filter Sampler

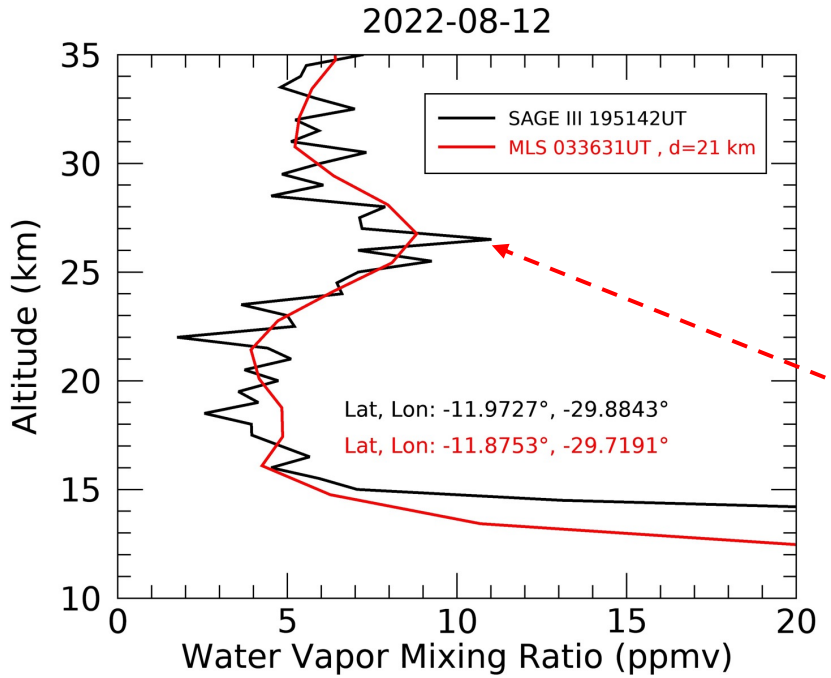


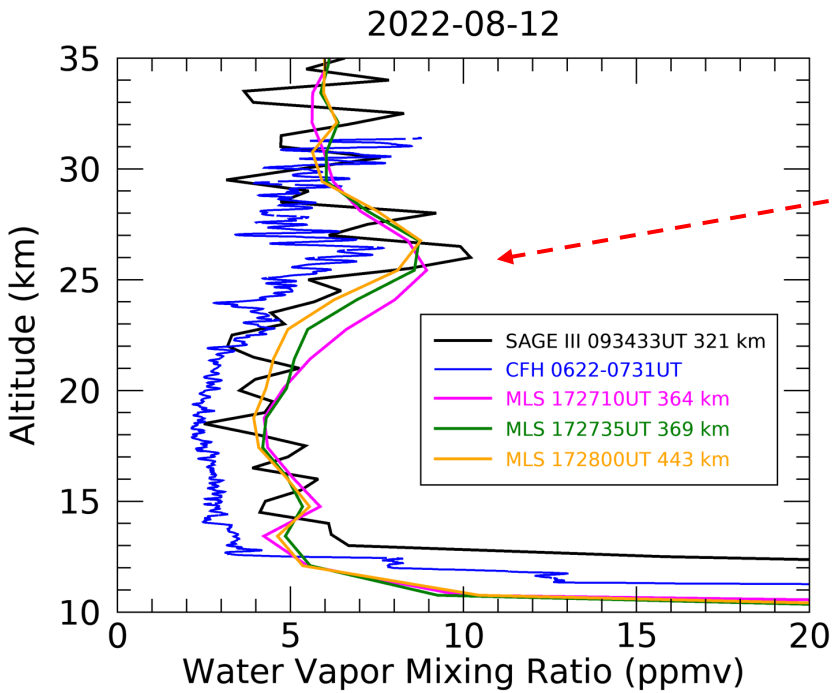
- Eight filters or TEM grids with software actuated sampling.
- Samples collected on filters used for ion-chromatography

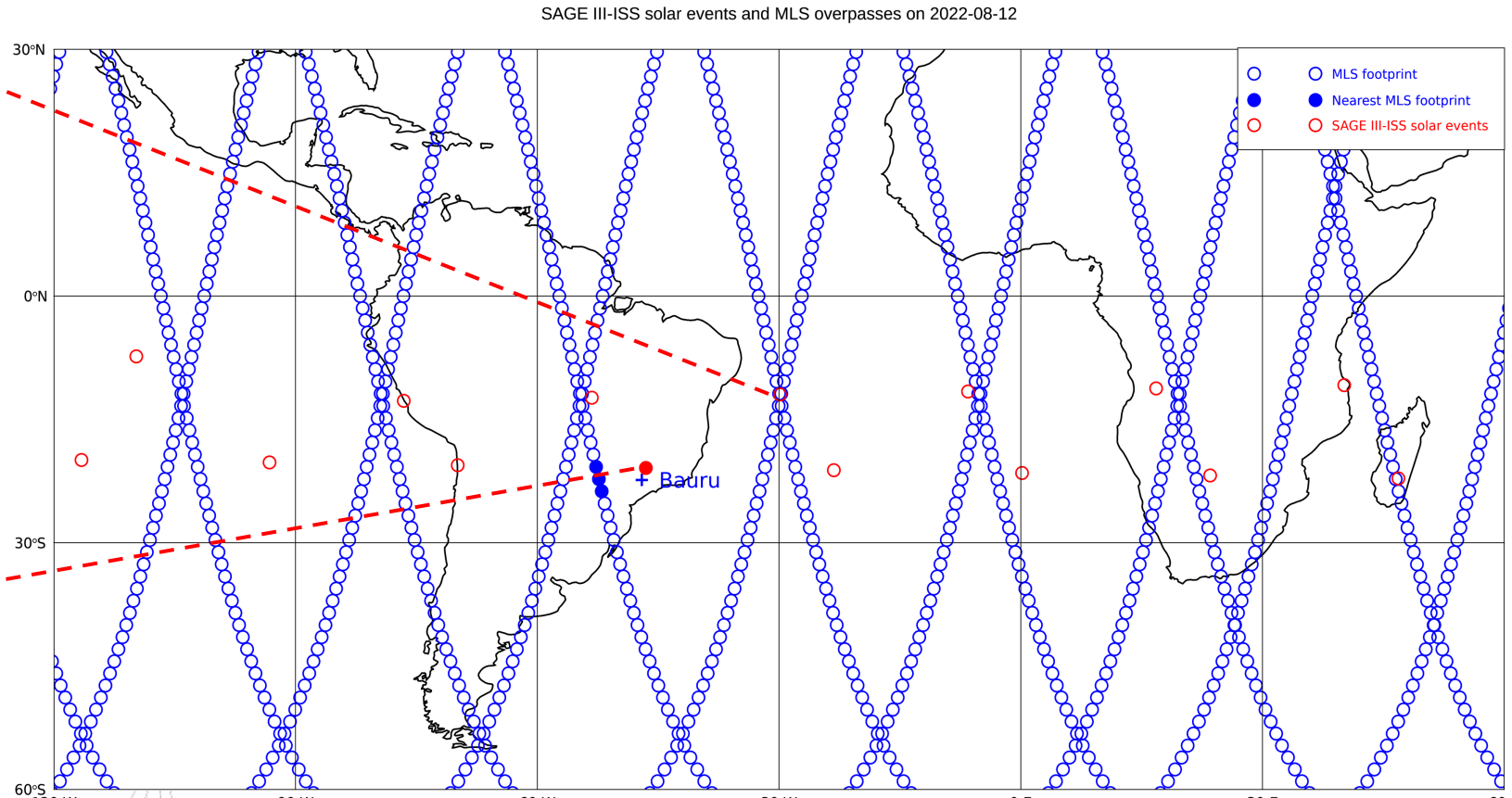
Qualitative Comparison between POPC and COBALD during the BraVo 2022 campaign

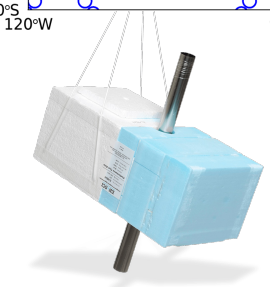


Co-located SAGE III/ISS and Balloon measurements of Water Vapor during the BraVo 2022 campaign



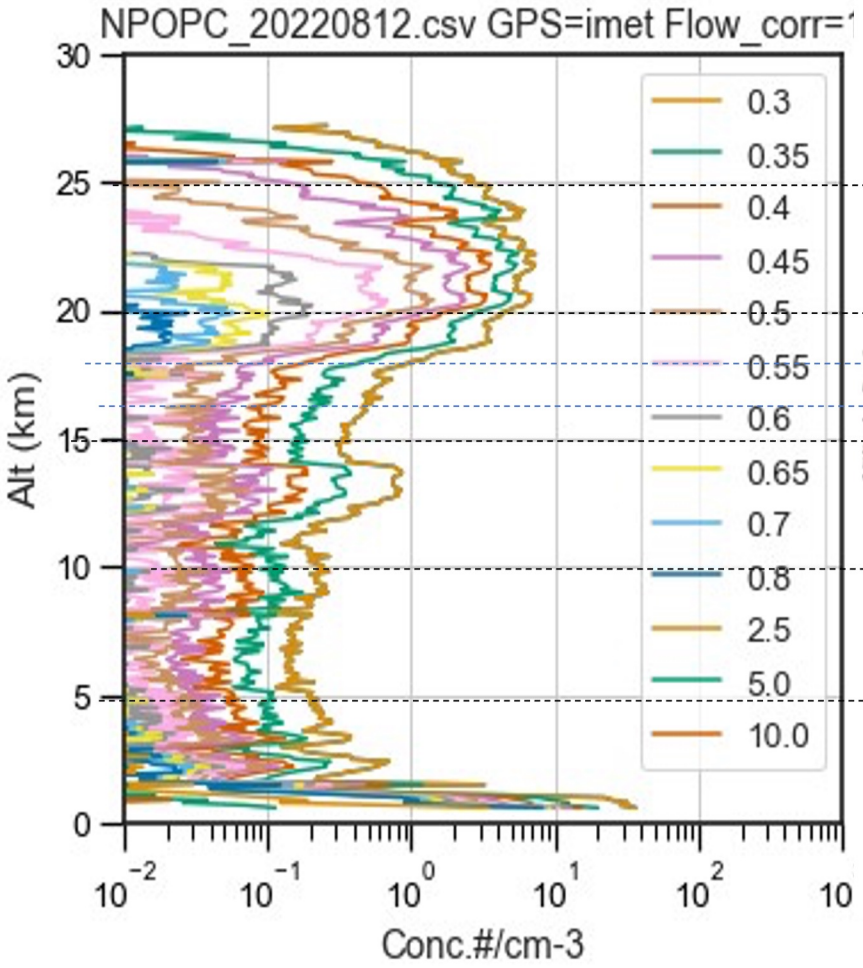




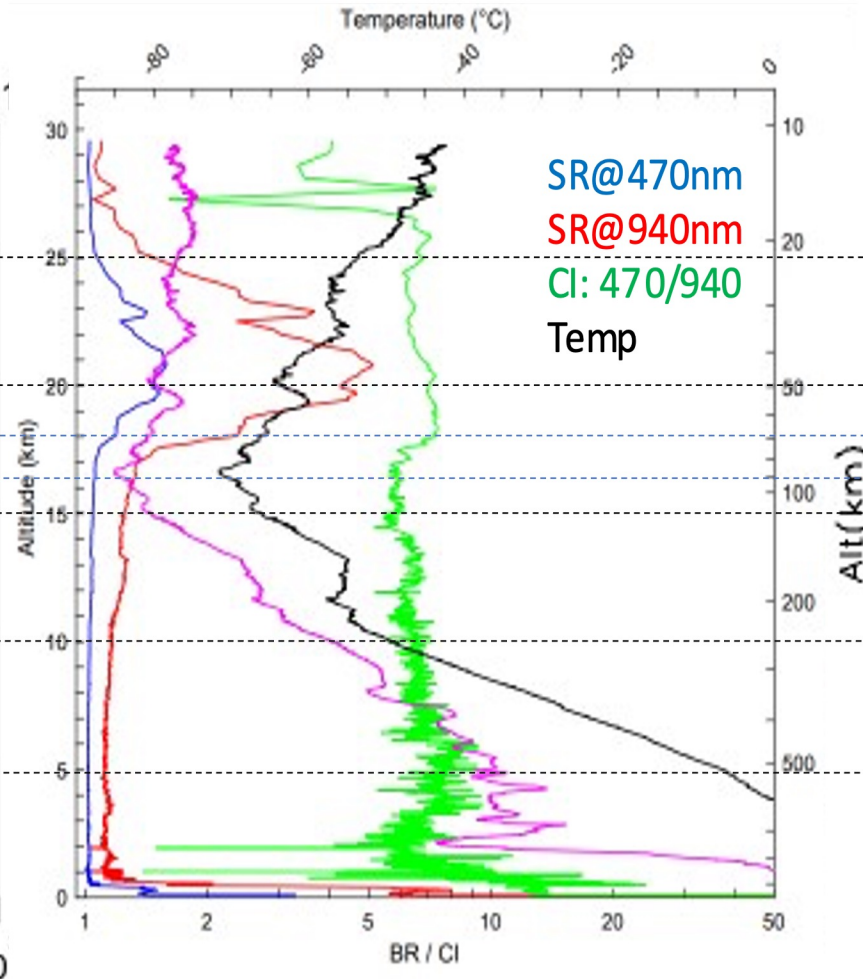


Co-located SAGE III/ISS and Balloon measurements of Aerosols during BraVo

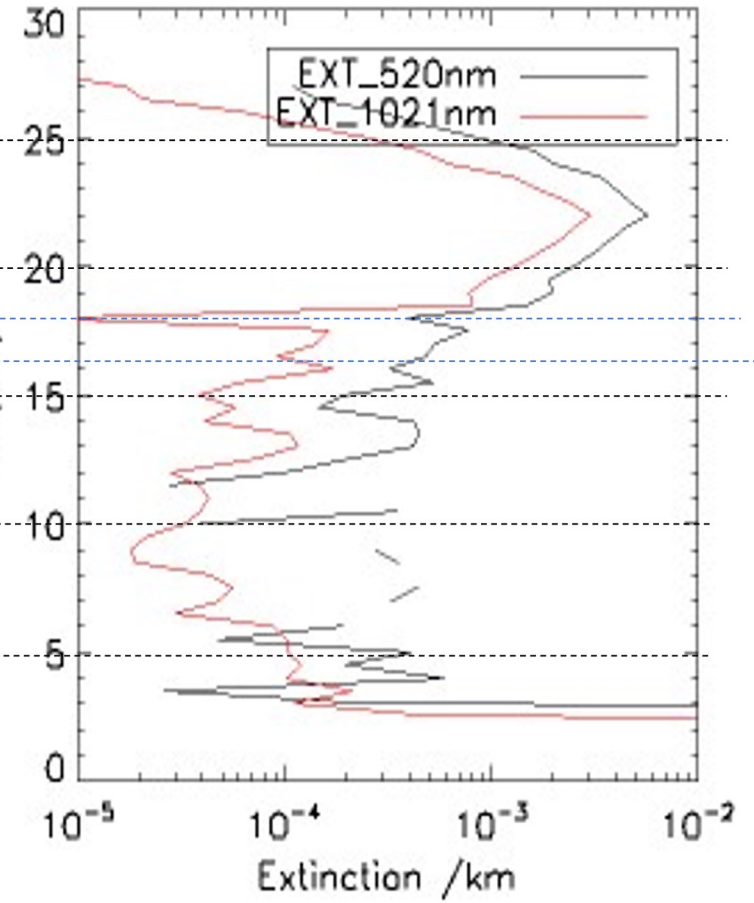
(a) POPC 08122022



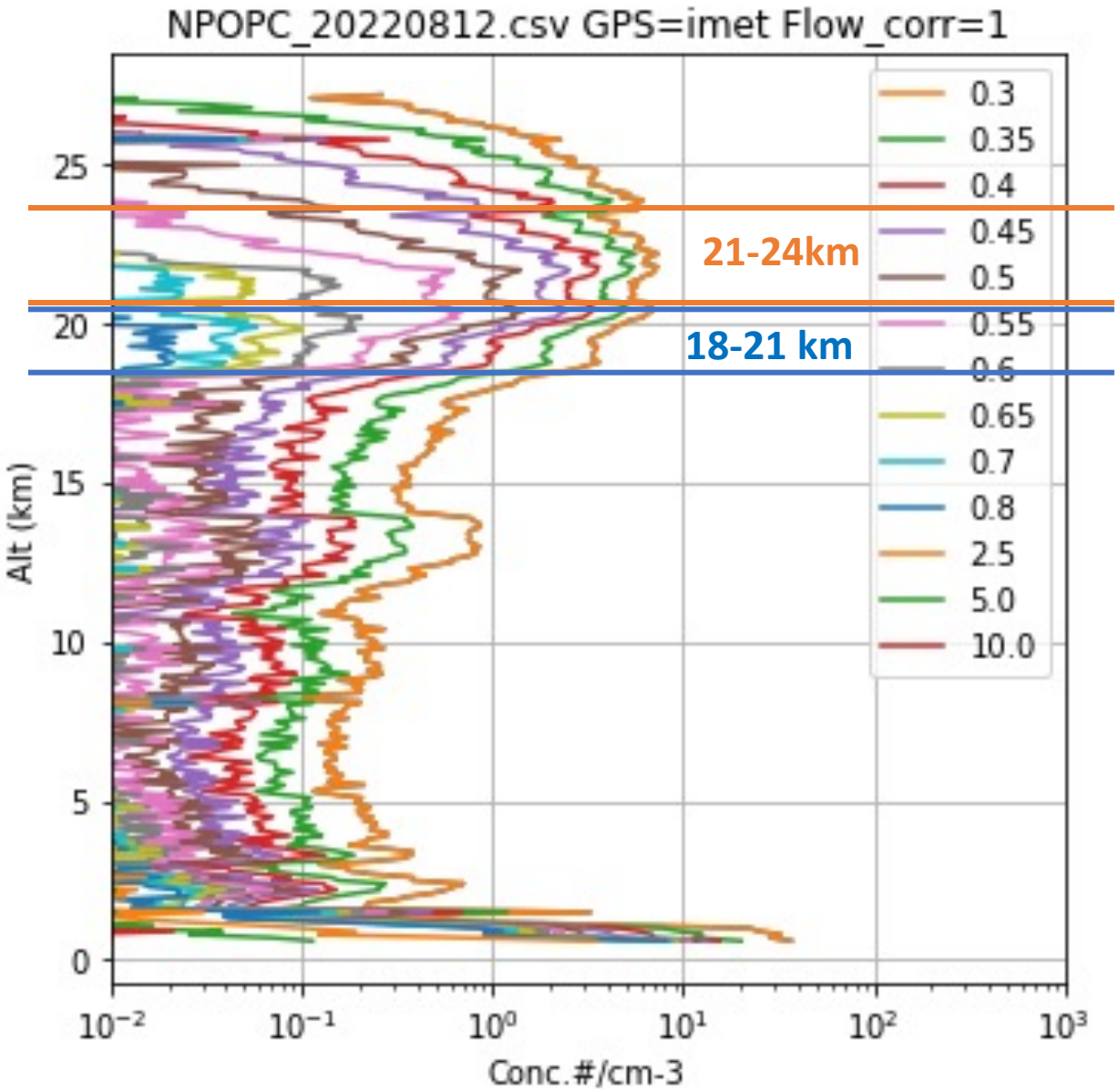
(b) COBALD 08122022

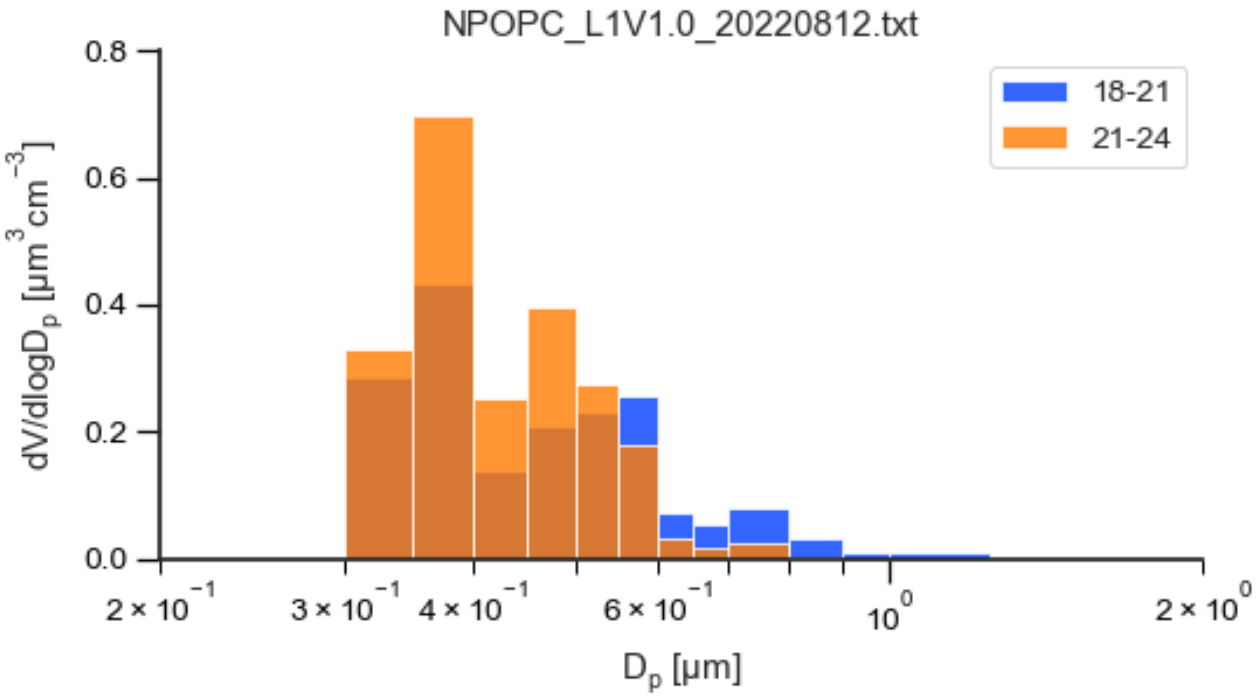


(c) SAGE III/ISS 08122022



Size distribution Altitude-dependence

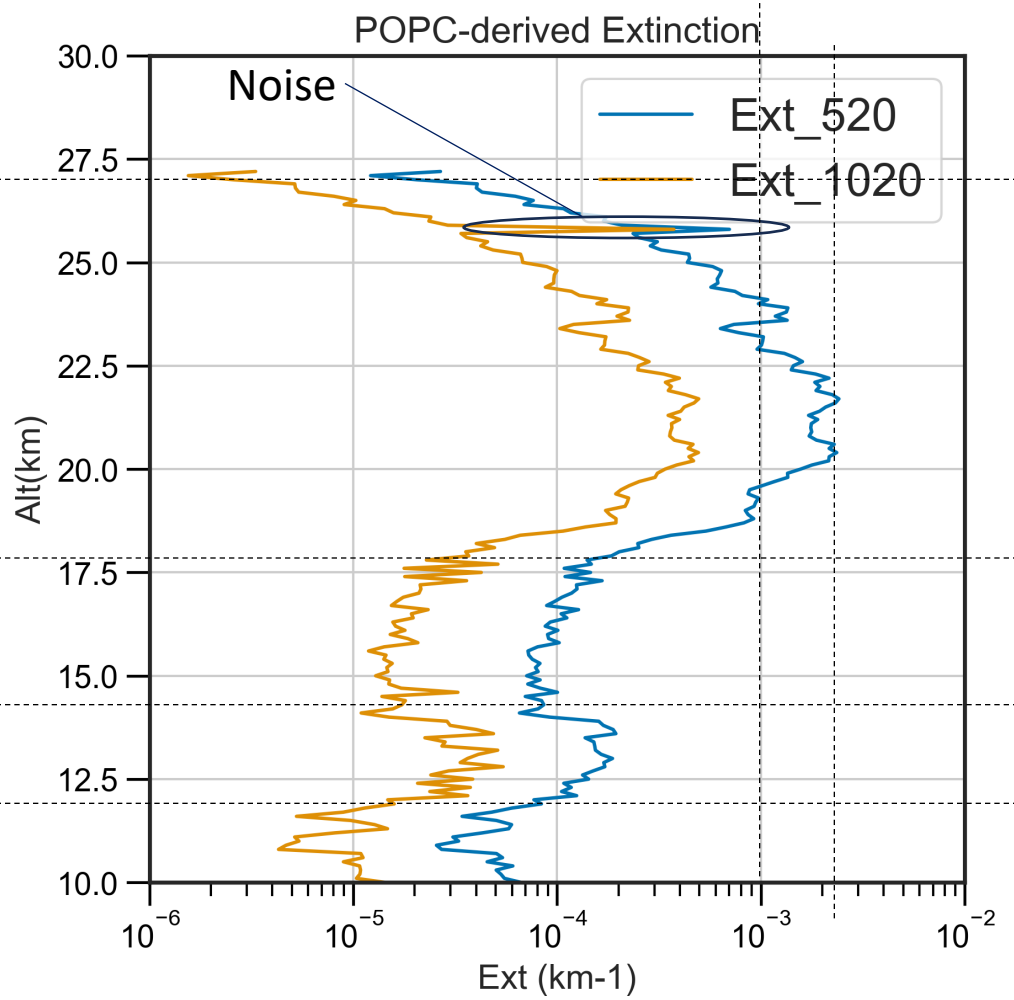


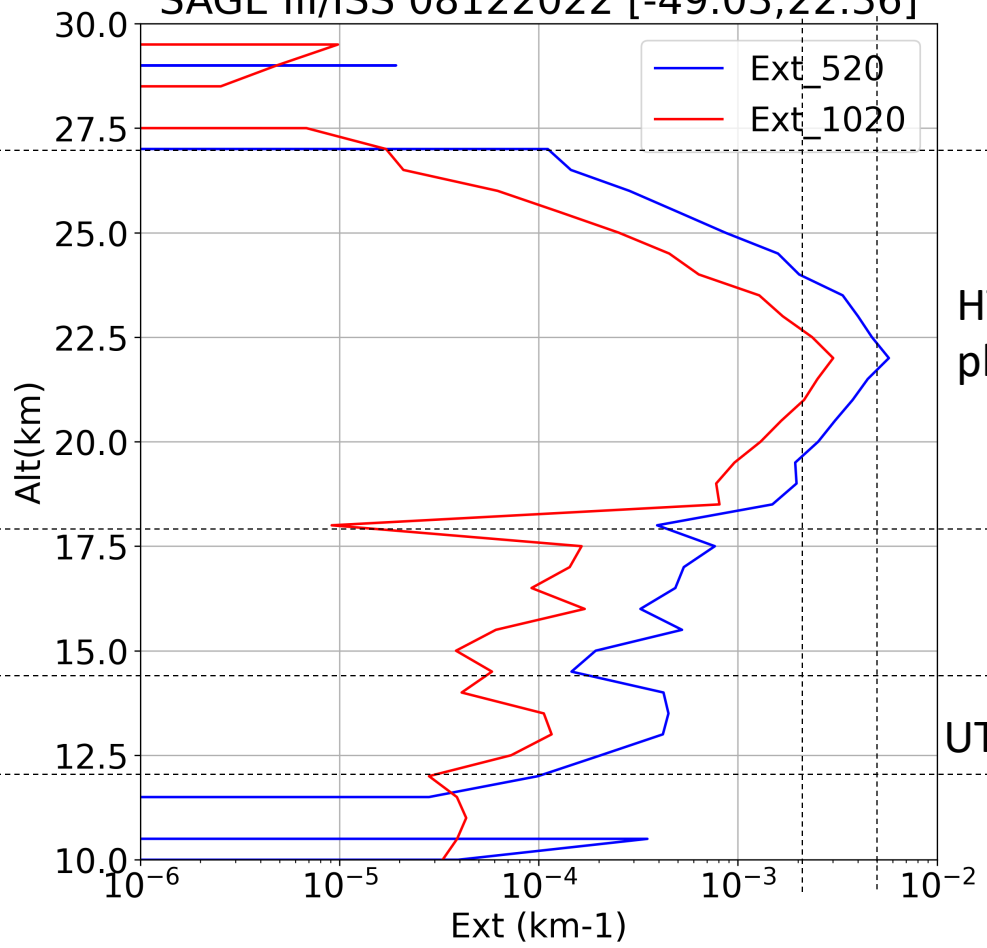


- Volume distribution show a mode of larger particles at the bottom of the HTHH plume
- 3 different modes for the bottom plume near 0.35-0.4µm; 0.5-0.6µm and 0.7-0.8 µm
- Differ from simplistic view of a unimodal distribution
- Could indicate the presence of different types of aerosol

Aerosol Extinction from Co-located SAGE III/ISS and Balloon measurements for HTHH plume

Preliminary results





HTHH plume

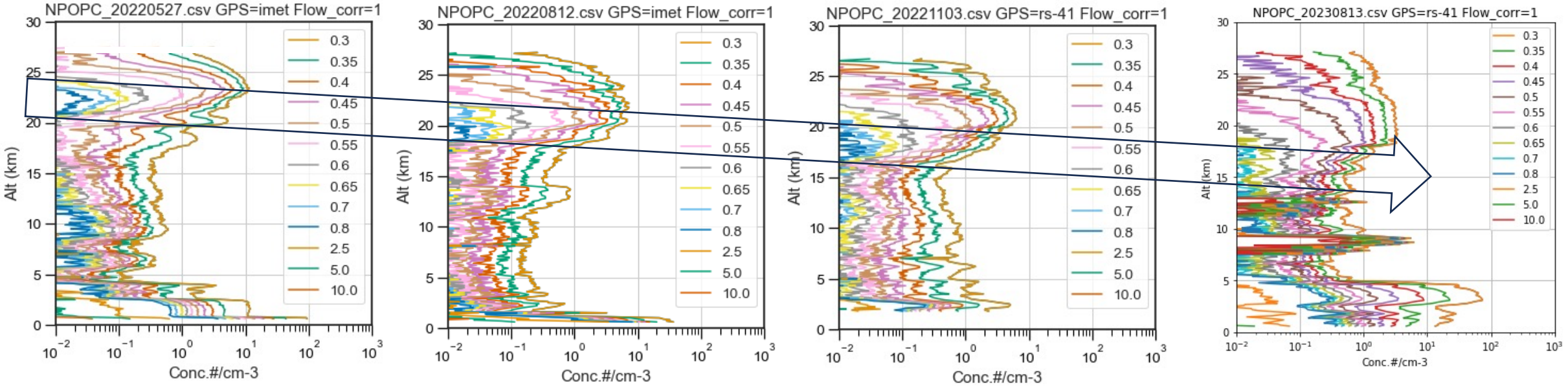
UT aerosol layer

- POPC and SAGE III see qualitatively the same atmospheric layers (HTHH, UT aerosol layer)
- POPC derived extinction using refractive Index of sulfate aerosol (Knepp et al., 2022)
- SAGE III/ISS extinction larger by a factor 2 [Mie coefficient calculated using size distribution rather than fit]

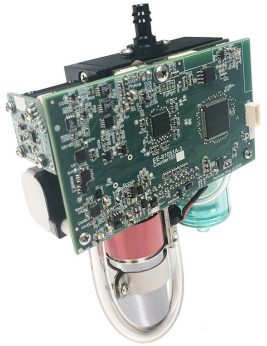
Sedimentation of Large particles from the HTHH plume

+ 4 months (after eruption) **+ 7 months** **+ 10 months** **+ 19 months**

#1042 #1042 #1042 #1042



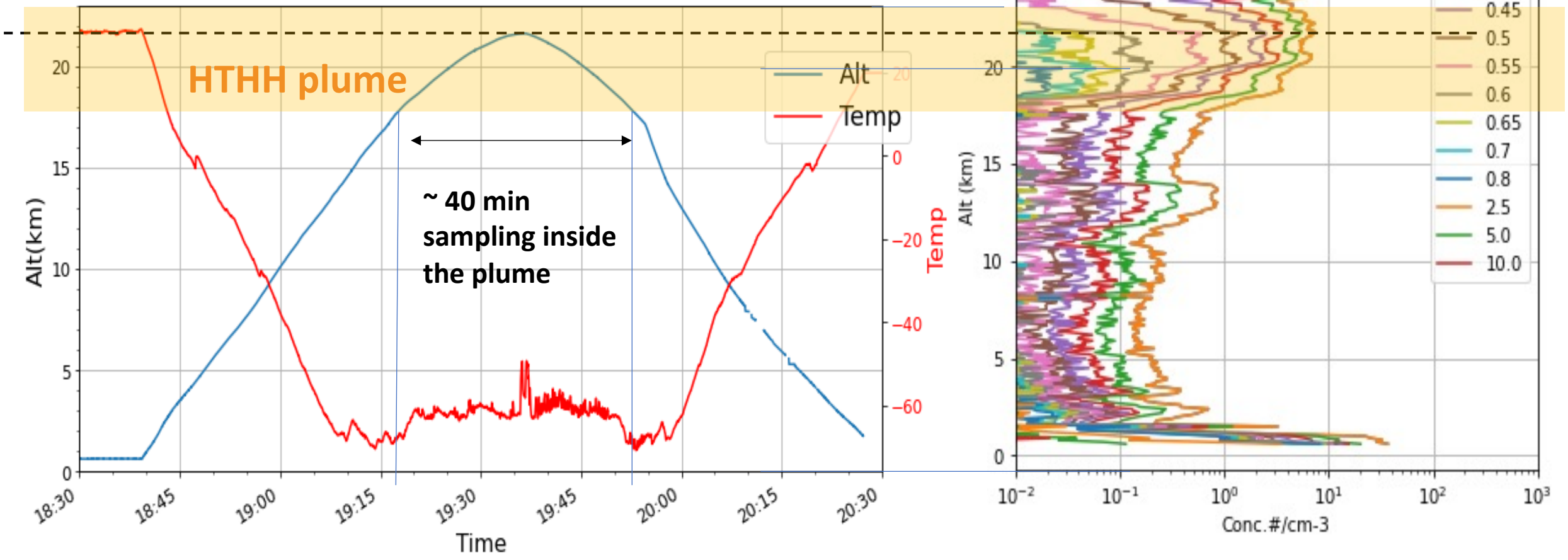
- HTHH aerosol size information derived from POPC during the first 19 months after the eruption from Brazil
- Large particles [d>0.7-0.8 µm] settling due to sedimentation
- Could the larger particle be made of something else than sulfate ?



The balloon-controlled system allowed reaching 40 min of sampling inside the HTHH plume

Chemical Composition of the HTHH plume

Balloon flight on 08/16 with the Aerosol Sampler



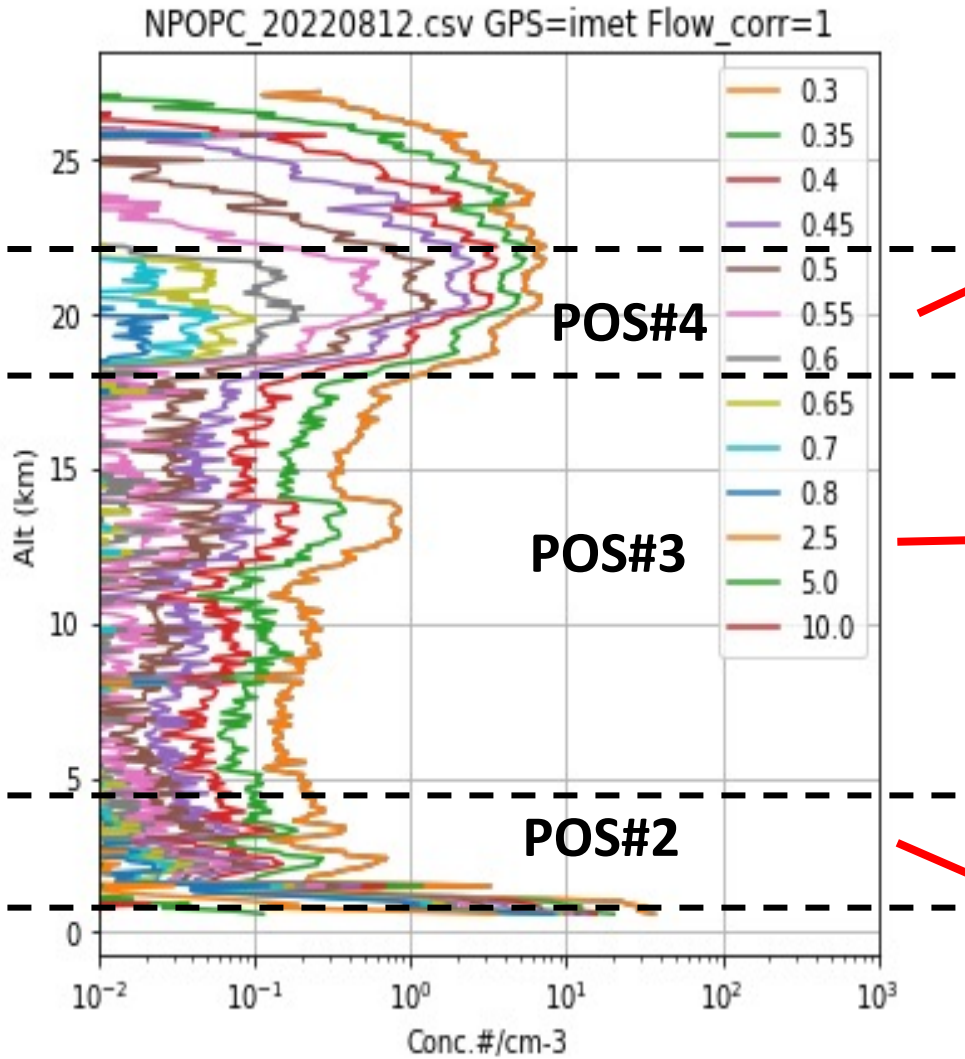
Sample Extraction and Ion Chromatography Analysis

Filters were unloaded in a Laminar Air Flow & preserved in dry ice until analysis using Pre-sterilized instruments

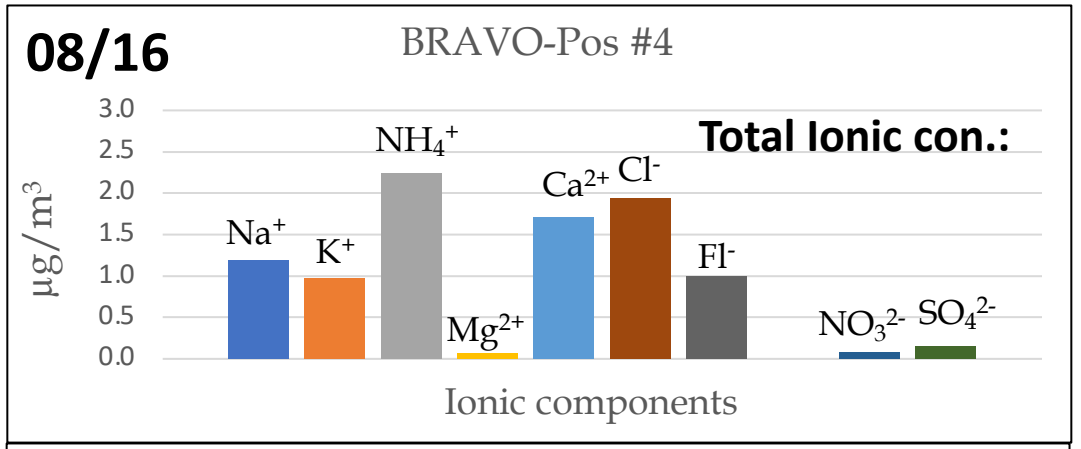
Aerosol extraction & Calibration of the IC Unit using ultra-pure Water in preparation for analysis.

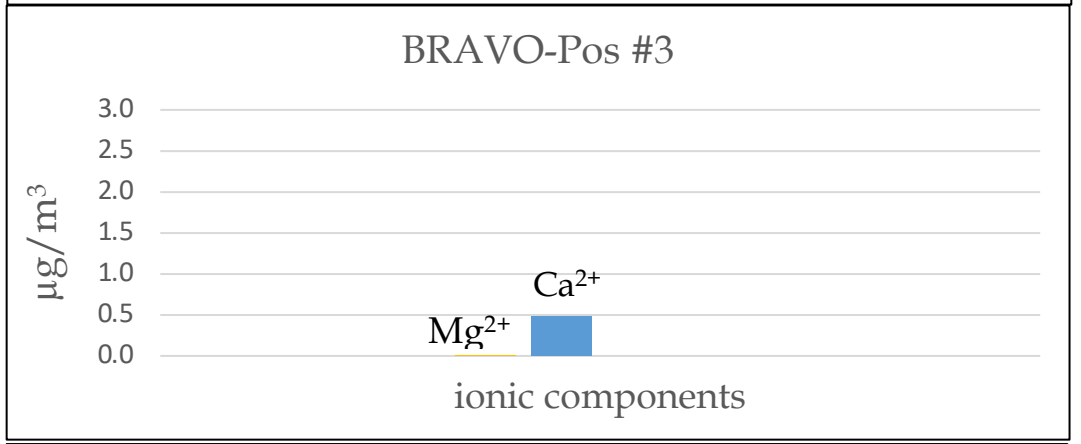
Reagent-free IC System (Detection limit-0.01 µg/L)

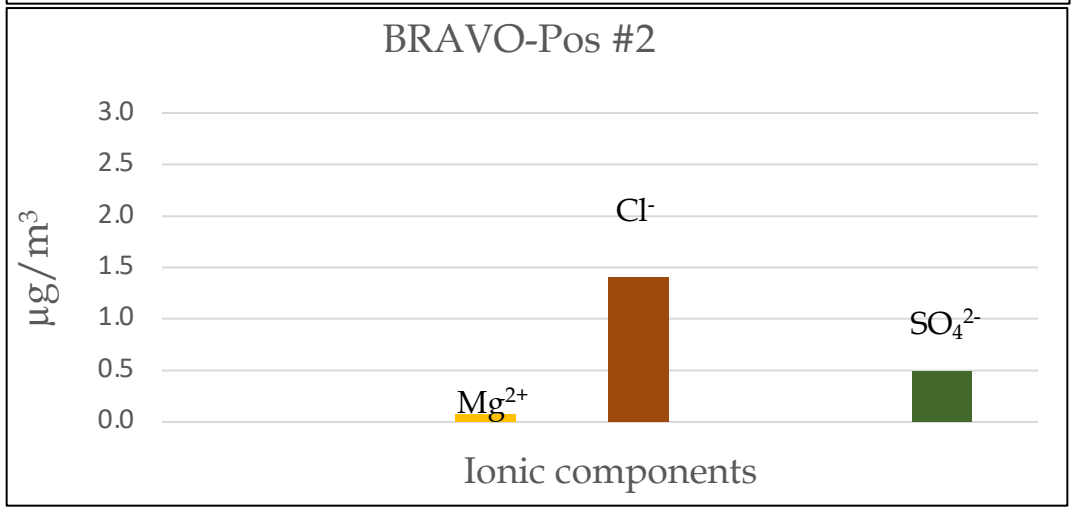
Results from POPC and Ion Chromatography



Assuming aerosol concentration profile obtained on 08/12 for sampler flight 08/16 and mass density of sea salt : **Expected aerosol collected : 3.4 μg/m³**







Summary and Future Directions

Summary:

- Extinction Color Ratio (ECR) or 3-λ method was tested for the SAGE III/ISS observations under perturbed stratospheric conditions.
- 3-λ method was used for separating aerosols from aerosol-cloud mixture for the HTHH volcanic plume.
- Both SAGE III/ISS and CALIOP/CALIPSO observations show downward transport of the HTHH plume over the Southern hemisphere.
- Balloon-borne measurements of the HTHH plume were conducted during the Brazil Volcano (BraVo) field campaign after four months of the HTHH eruption.
- BraVo campaign provided physical and chemical characteristics of the HTHH plume.
- Both aerosols and water vapor measurements inside the HTHH plume were obtained and validated with co-located SAGE III/ISS observations.
- Larger particles in the HTHH plume were seen to sediment with time
- Controlled balloon flight allowed to sample the HTHH plume for ~40 minutes.
- Ion chromatography of the collected HTHH sample confirmed presence of sea salts confirming the submarine source of the HTHH plume.

Future Directions:

- Plan to continue balloon measurements of the HTHH plume from Brazil with co-located SAGE III/ISS measurements.
- Impact of downwelling HTHH plume on cirrus cloud properties.

Acknowledgements

- SAGE III/ISS Science Team for funding support.
- Brazilian scientists and engineers for their support during the BraVo campaigns.
- LPC2E, National Institute of Aerospace & Physical Research Laboratory.

Thank you!

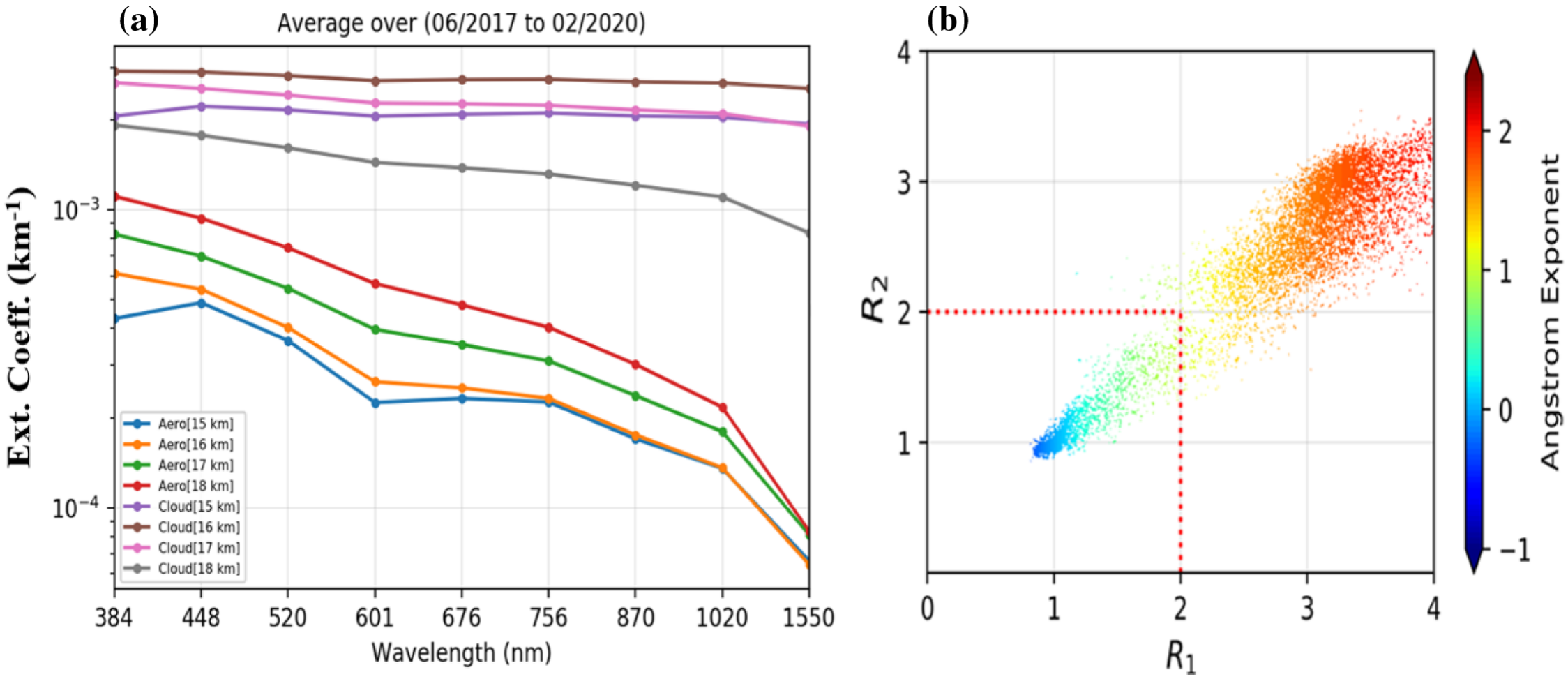


Fig. 2. (a) Variation of mean extinction coefficient as a function of different wavelength channels for discriminated possible cloud-like events (PCLE) and aerosols found from June 2017 to February 2020 based on the proposed ECR method D for altitude levels from 15 km to 18 km with an interval of 1 km. (b) Relation between both ECR (R_1 and R_2) with the aerosol Angstrom exponent. The red dotted lines represent the separation between the possible cloud-like events (PCLE) and aerosols.