The Balloon measurement campaigns of The Asian Tropopause Aerosol Layer (BATAL)

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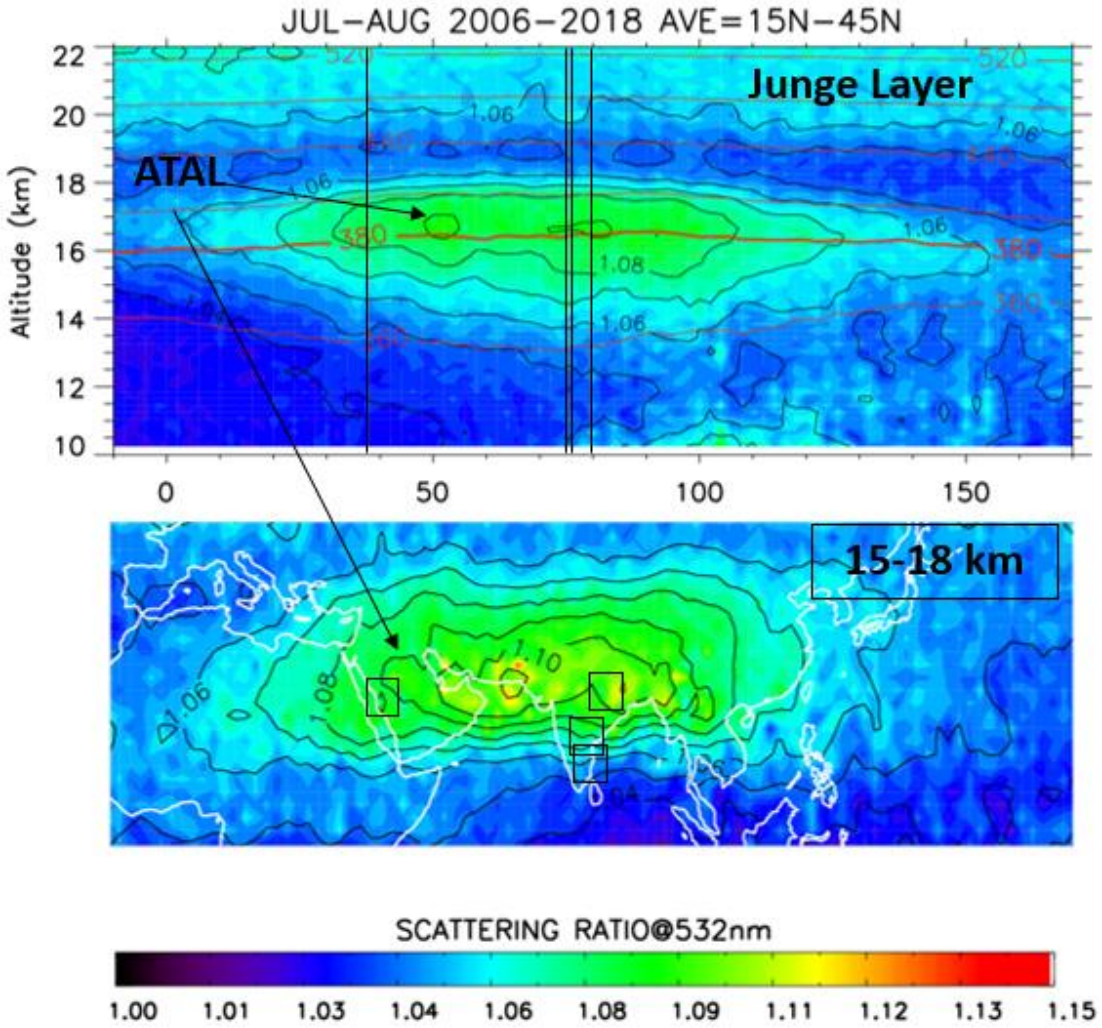
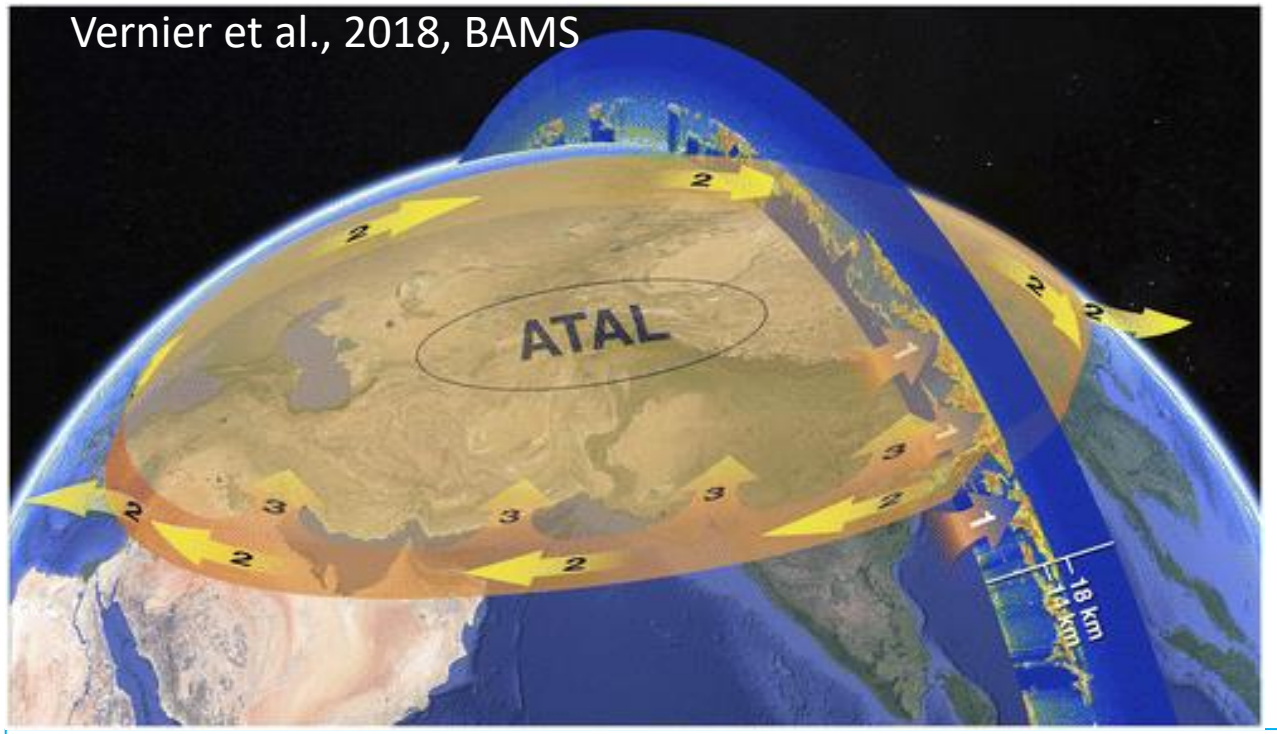
* In the memory of Duncan who left us too early

BATAL is built on International Partnerships

The Asian Tropopause Aerosol Layer (ATAL)



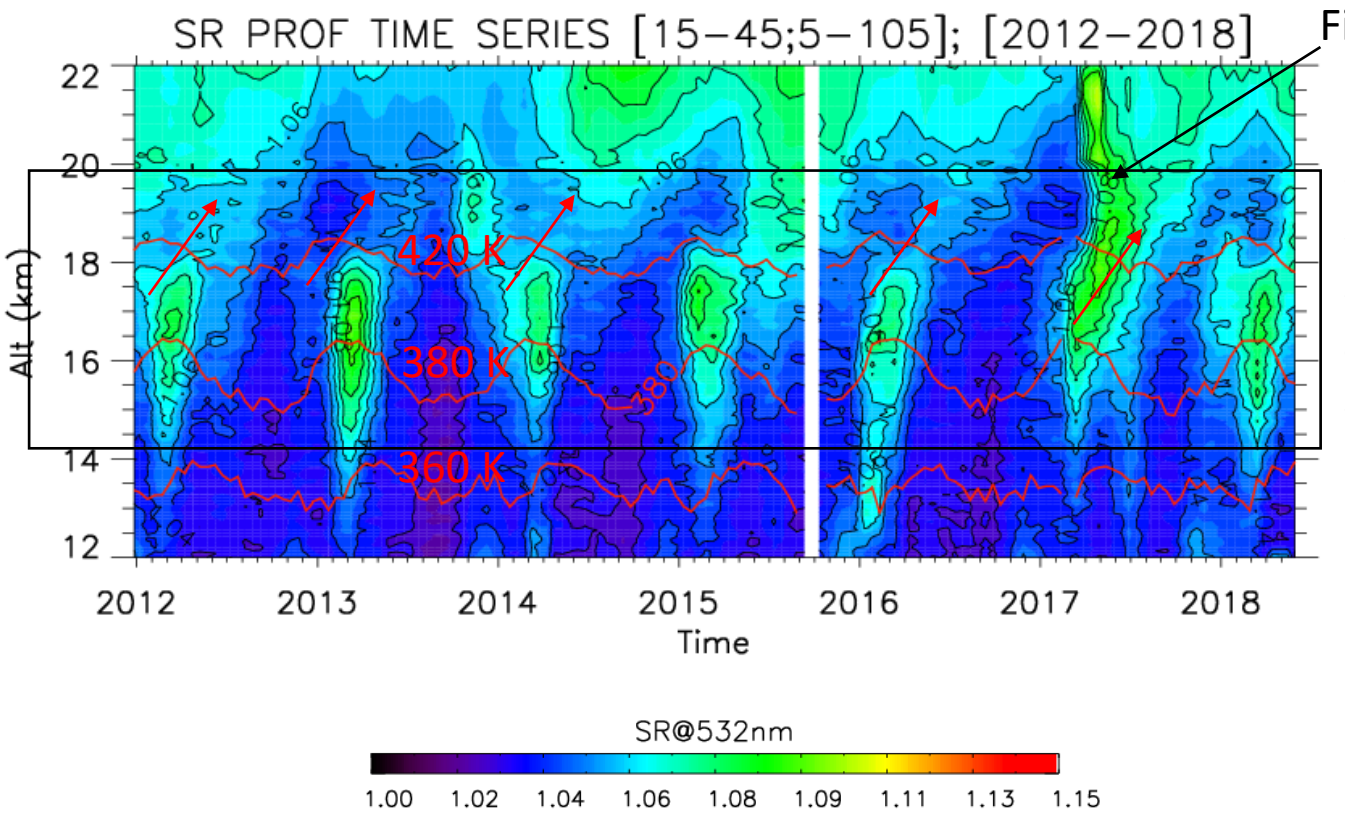
Scattering Ratio : SR
optically equivalent to an aerosol mixing ratio

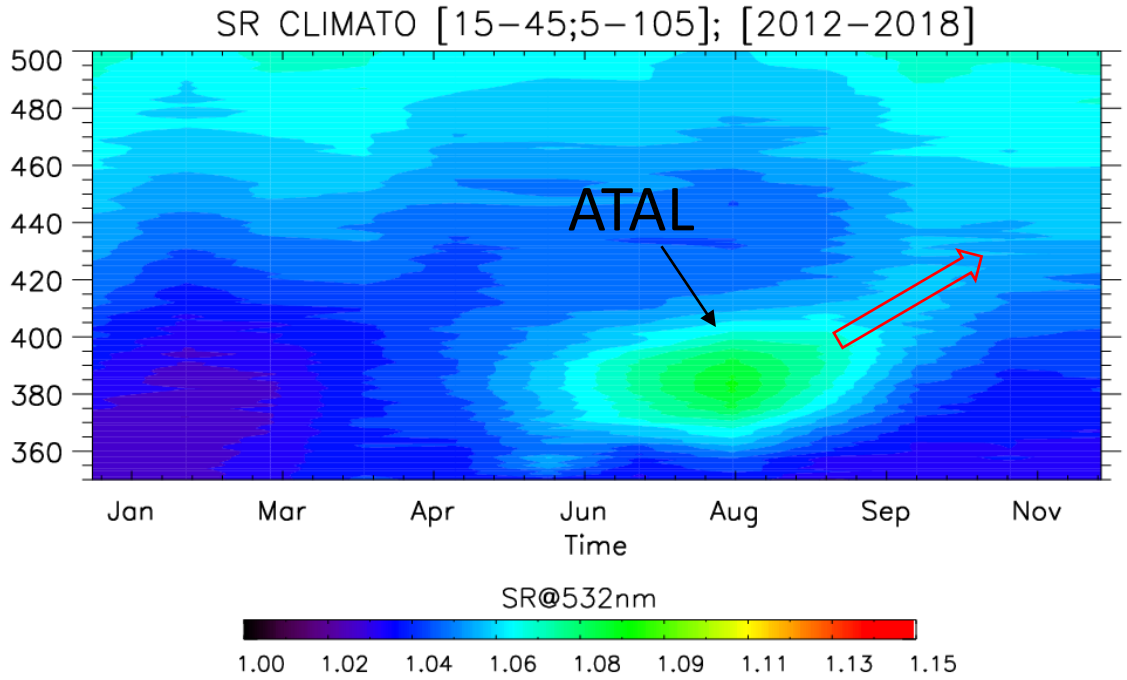


<u>Transport pathways and the ATAL</u>:

1. Deep convection from ASM connects boundary layer pollution to UTLS (Park et al., 2009, Randel et al., 2010)
2. The monsoonal outflow transport through tropical easterlies southern branch of the Asian anticyclone
3. Air in the tropical upper troposphere/southern edge of the Asian anticyclone can be uplifted into the lower stratosphere via diabatic ascent (Garny and Randel 2016)

Evidence for the transport of the ATAL into the stratosphere

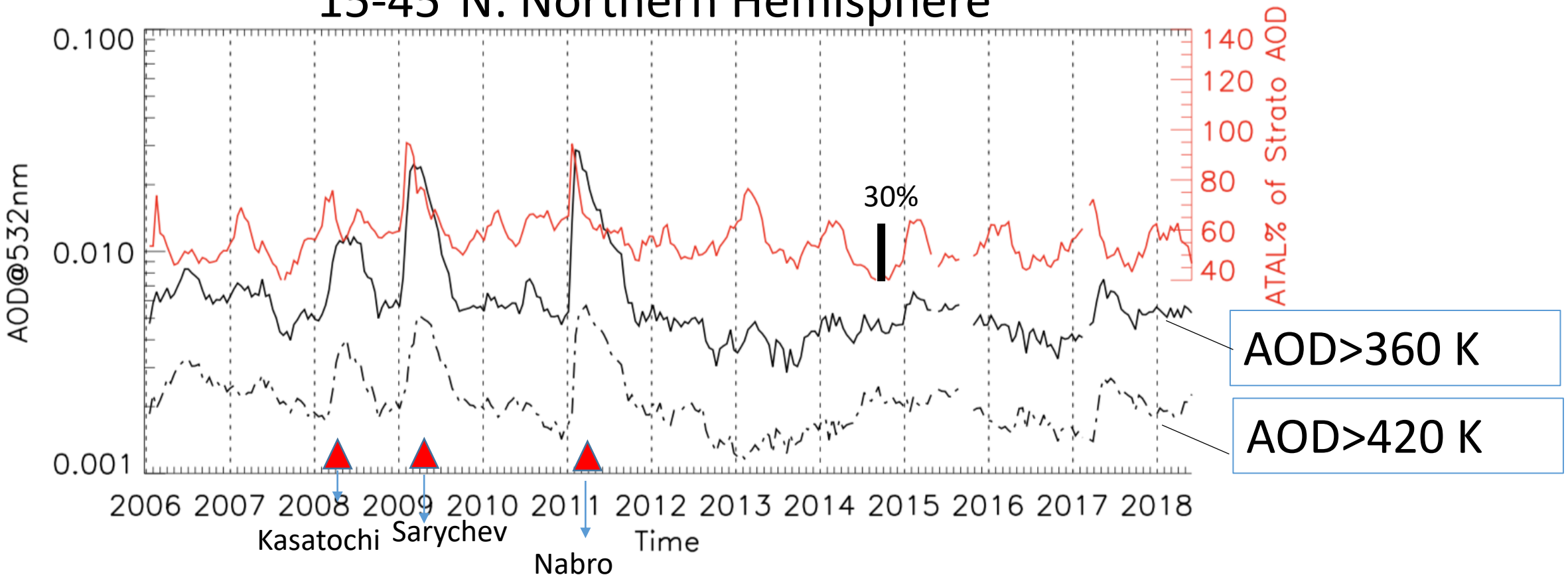




- ATAL's extends between 360 and 420 K (14-18 km) during Summer Asian Monsoon
- Maximum SR in August
- Export above 420 K is evident but limited after September

Global Influence of the ATAL on NH Stratospheric AOD

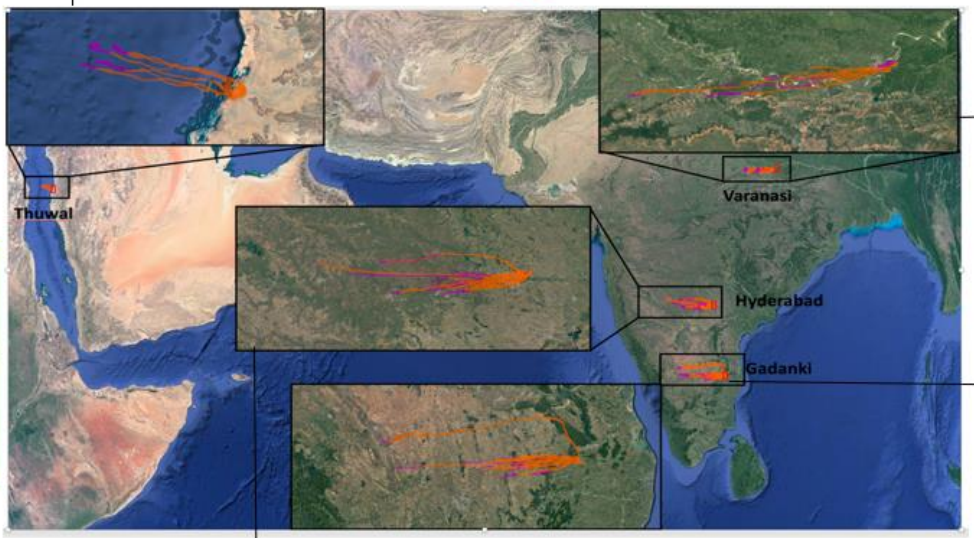
ATAL% of Strato AOD=
100* ($AOD_{>360K}$-$AOD_{>420K}$)/$AOD_{>380K}$



- Footprint of the ATAL observed across the Northern Hemisphere

BATAL deployments 2014-2020
93 flights

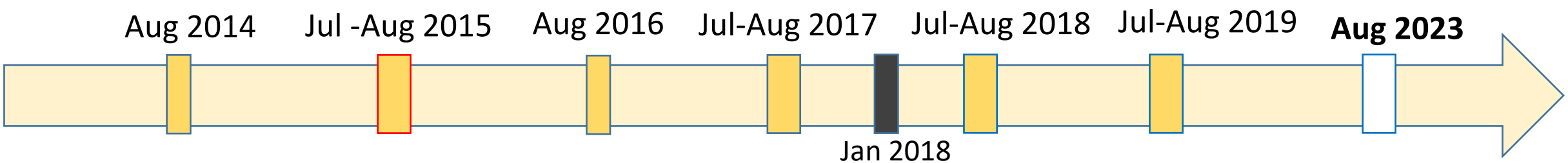
- King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia
- August 15/16
- 11 balloon flights



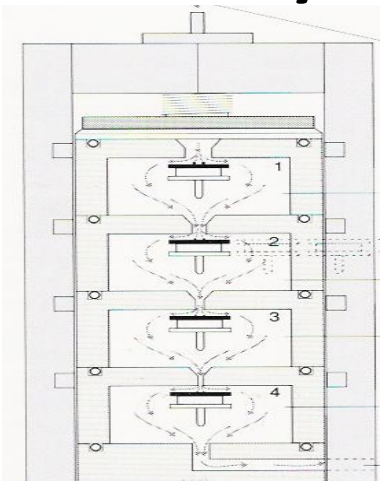
- Banaras Hindu University, Varanasi, India
- August 15/16
- 13 balloon flights

- Tata Institute for Fundamental Research Balloon facility, Hyderabad, India
- Aug 15/17/18/19/20
- 51 balloon flights

- National Atmospheric Research Laboratory, Gadanki, India,
- Jul/Aug 15/16/17
- 18 balloon flights

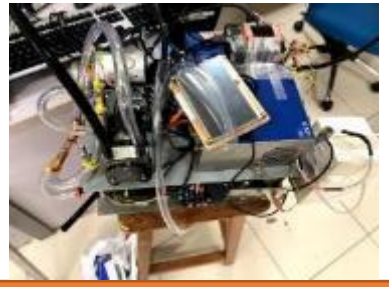


Payloads to cover all aerosol and ice sizes



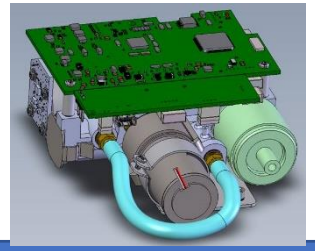
Aerosol Impactor (7lpm), 4 stages

COBALD: Bulk aerosol/cloud measurements



Lighthouse 1104

r>0.05-0.5 µm 8 channels



POPC

r>0.15-5 µm
6 channels

Micro-COPP

Forward Scattering Measurement
r=0.5-25 µm
20 bins

CCD Camera
2.5µm-0.5mm
0.5 µm- Resolution

128 Element Photodiode Array
12.5 µm-1.6 mm
12.5 µm resolution

Mixing Condensation Nuclei Counter
r>7nm

ICE CLOUDS

AEROSOL

0.01 0.10 1.00 10.00 100.00

Particle Radius (µm)

CALIPSO Validation with COBALD

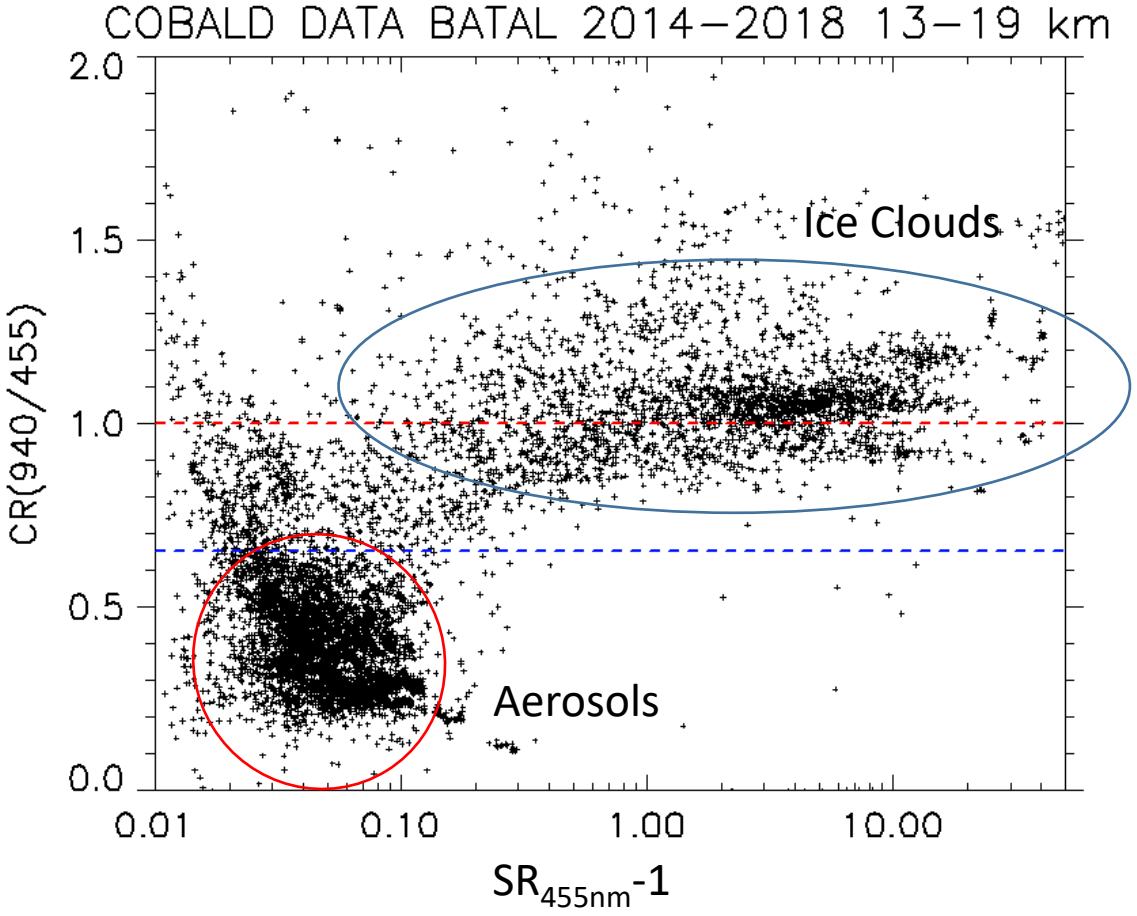
- COBALD backscatter sonde (ETH)
- In situ backscatter at two wavelengths (455nm & 940nm)
- 72 flights with COBALD [2014-2018]

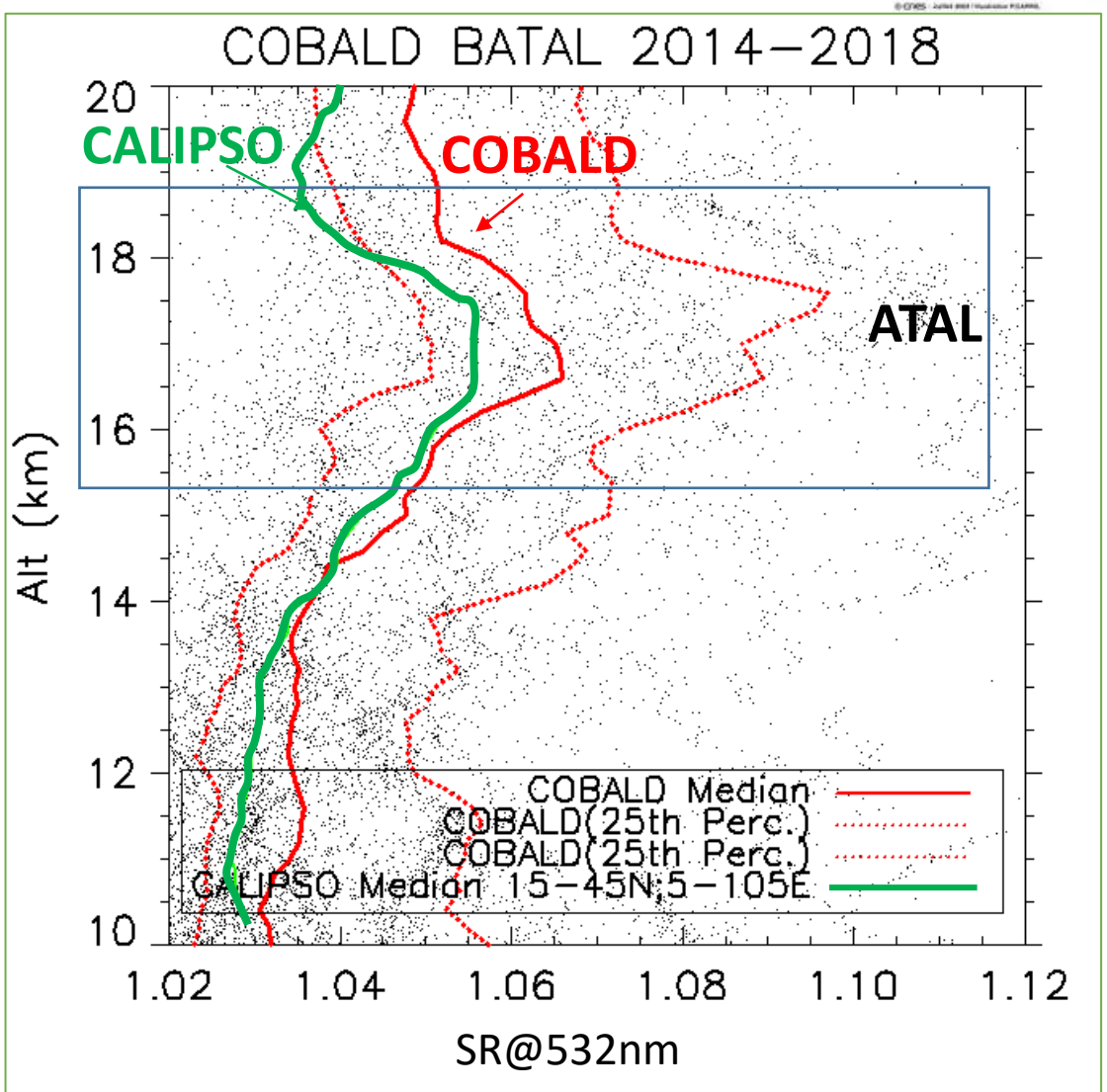
$$SR_{455nm} = 1 + \frac{\beta_{part,455nm}}{\beta_{mol,455nm}}$$

Aerosol Scattering Ratio

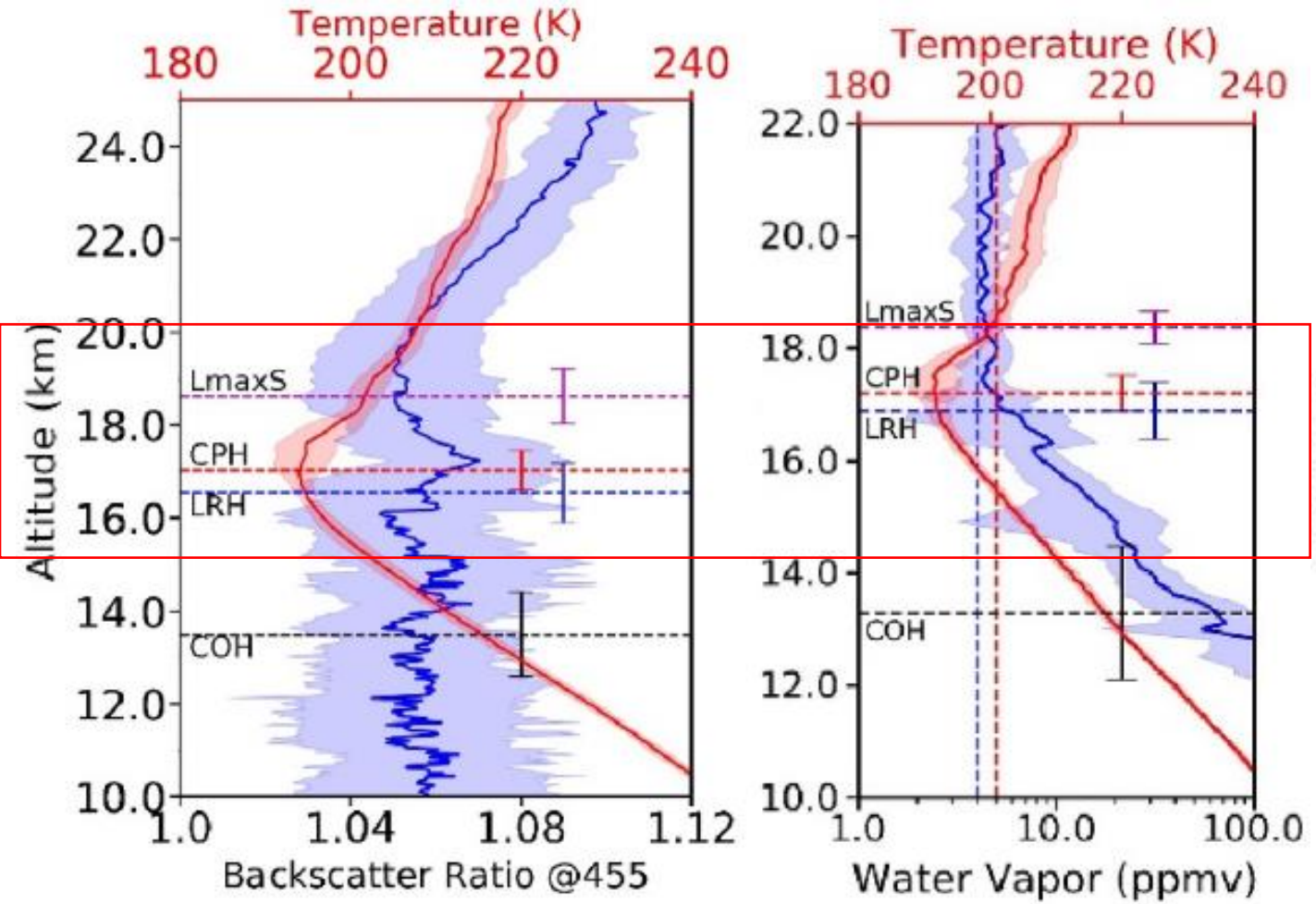
$$CR = \left(\frac{SR_{940nm}-1}{SR_{455nm}-1}\right)/(940/455)^2$$

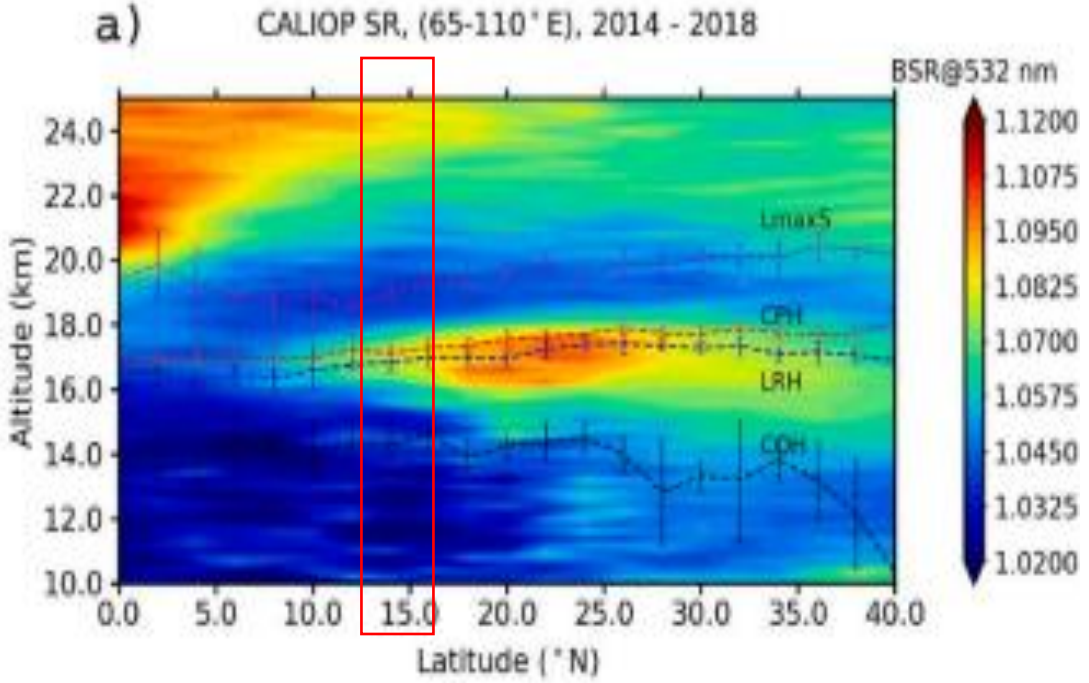
Cloud-cleared SR profiles





Defining upper boundary of ATAL

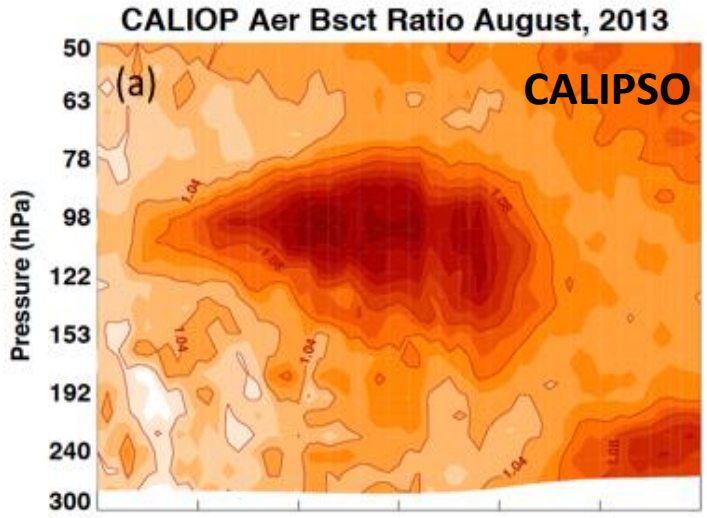




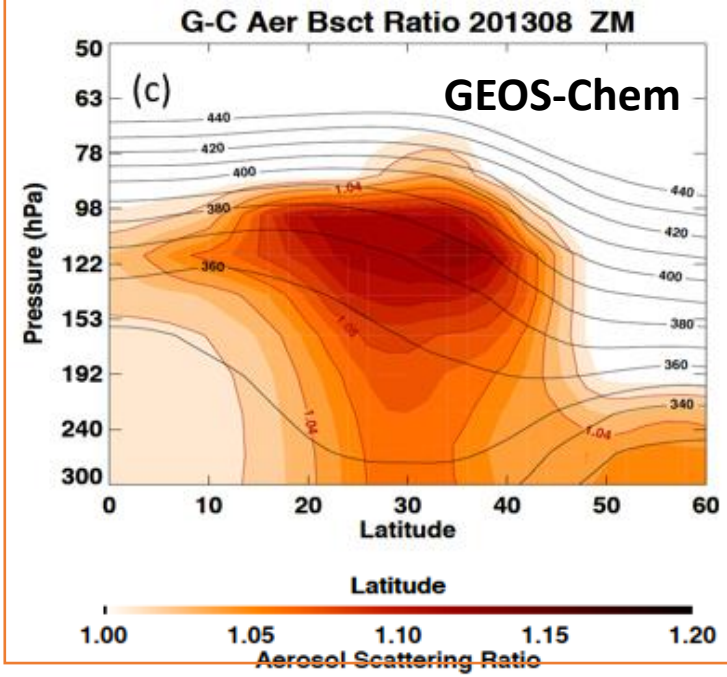
Raj et al., 2022 Atmospheric Pollution Research, 2022

- BATAL observations suggest that the layer of maximum stability (LmaxS) can separates the ATAL from the well-known stratospheric 'Junge layer'.
- The top of the enhanced water vapor layer in the LS also coincides with the LmaxS.

Nitrate contributions from India and China

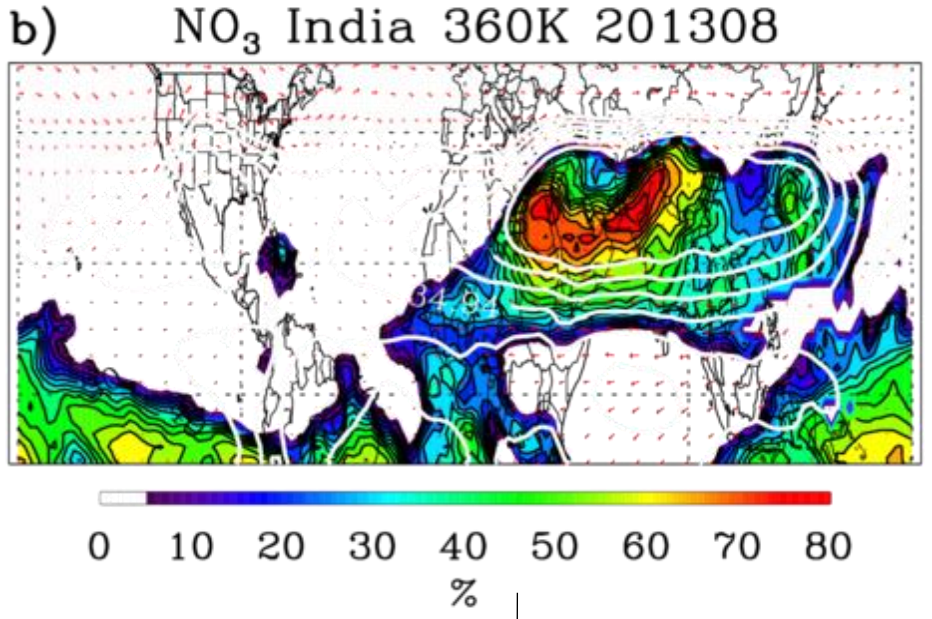


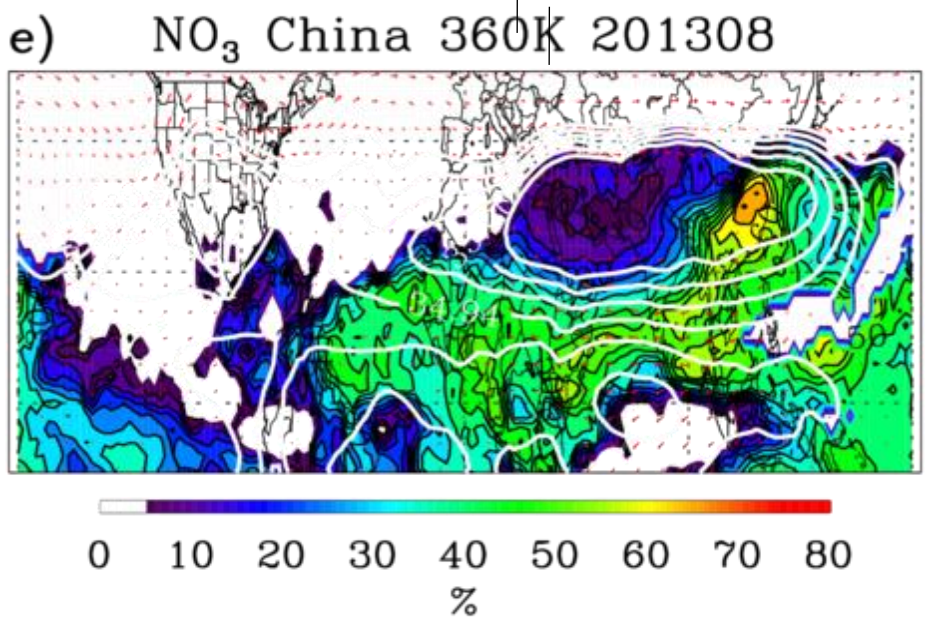
- GEOS-Chem (CTM) Aug 2013
- Aerosols: SO_4, NO_3, NH_4, BC, OC, SS, Dust
- Treatment of SO_2 in Aqua phase improved using Henry's law
- Shape and Magnitude of ATAL agree well with CALIPSO



- <u>Source attribution study</u>:

Nitrate is a dominant component of aerosol composition on the southern flank of the ASM anticyclone. Lightning sources of NO_x are found to make a significant (10-15%) contribution to nitrate in the ATAL for the case studied

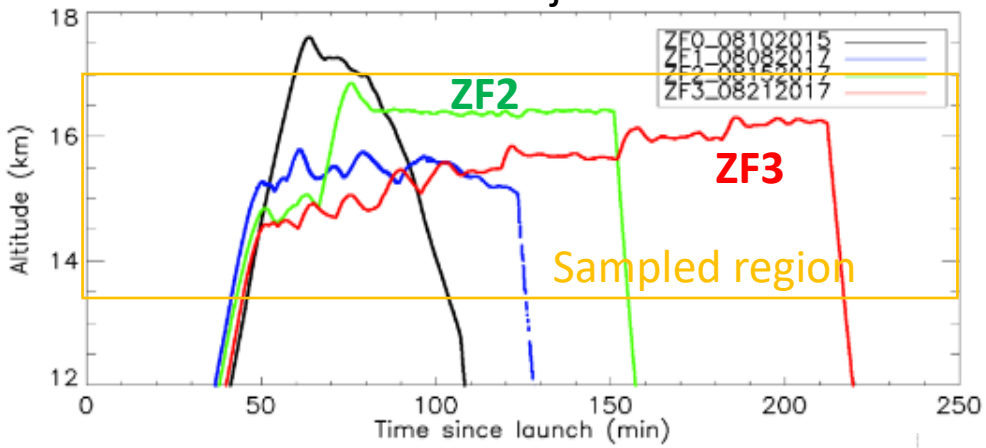




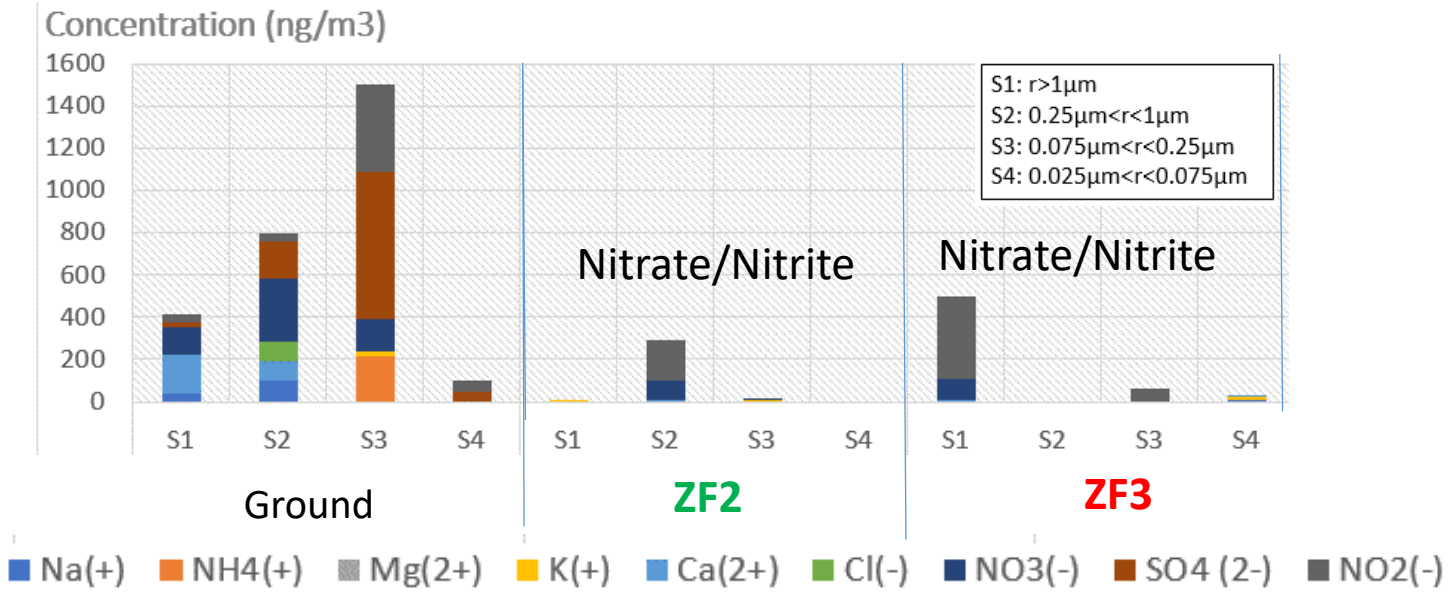
Fairlie et al., 2020, JGR

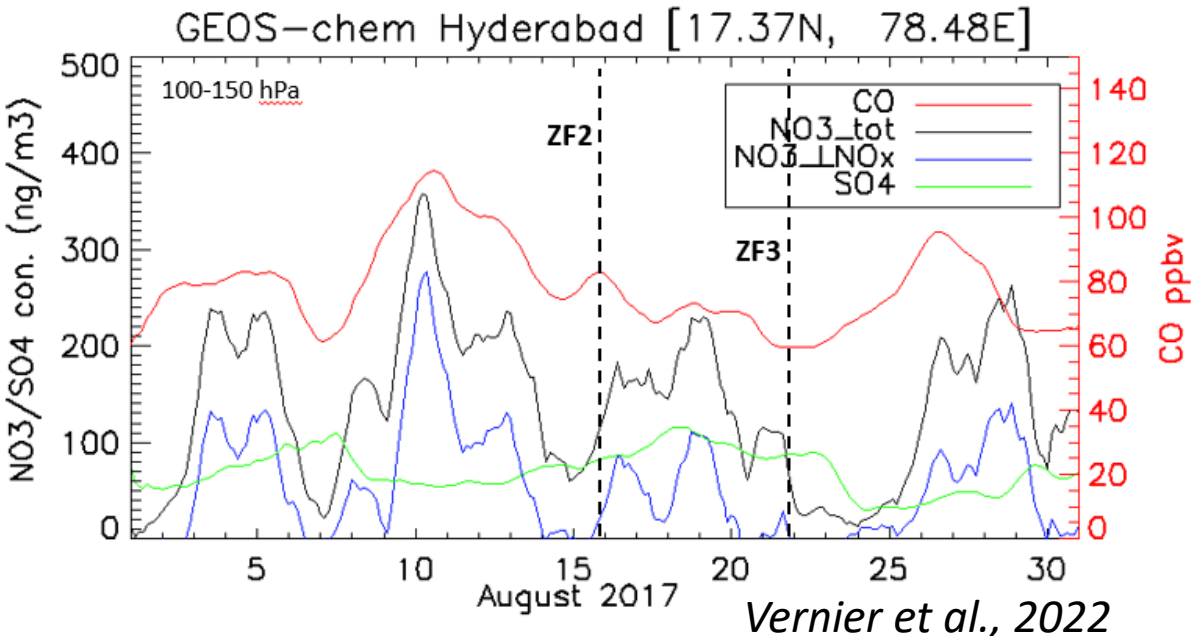
Nitrate domination within the ATAL

Balloon trajectories



BATAL 2017

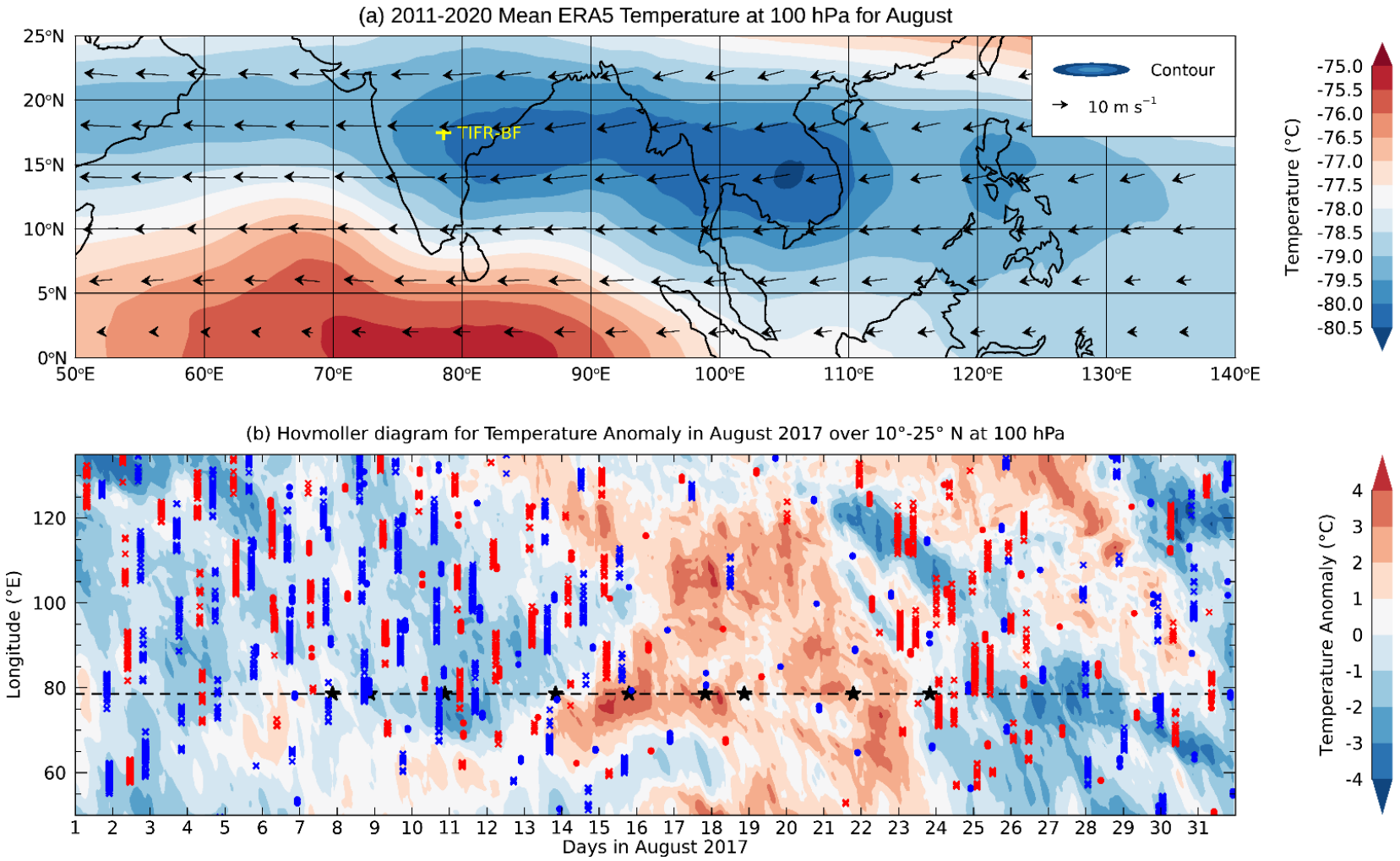




Vernier et al., 2022

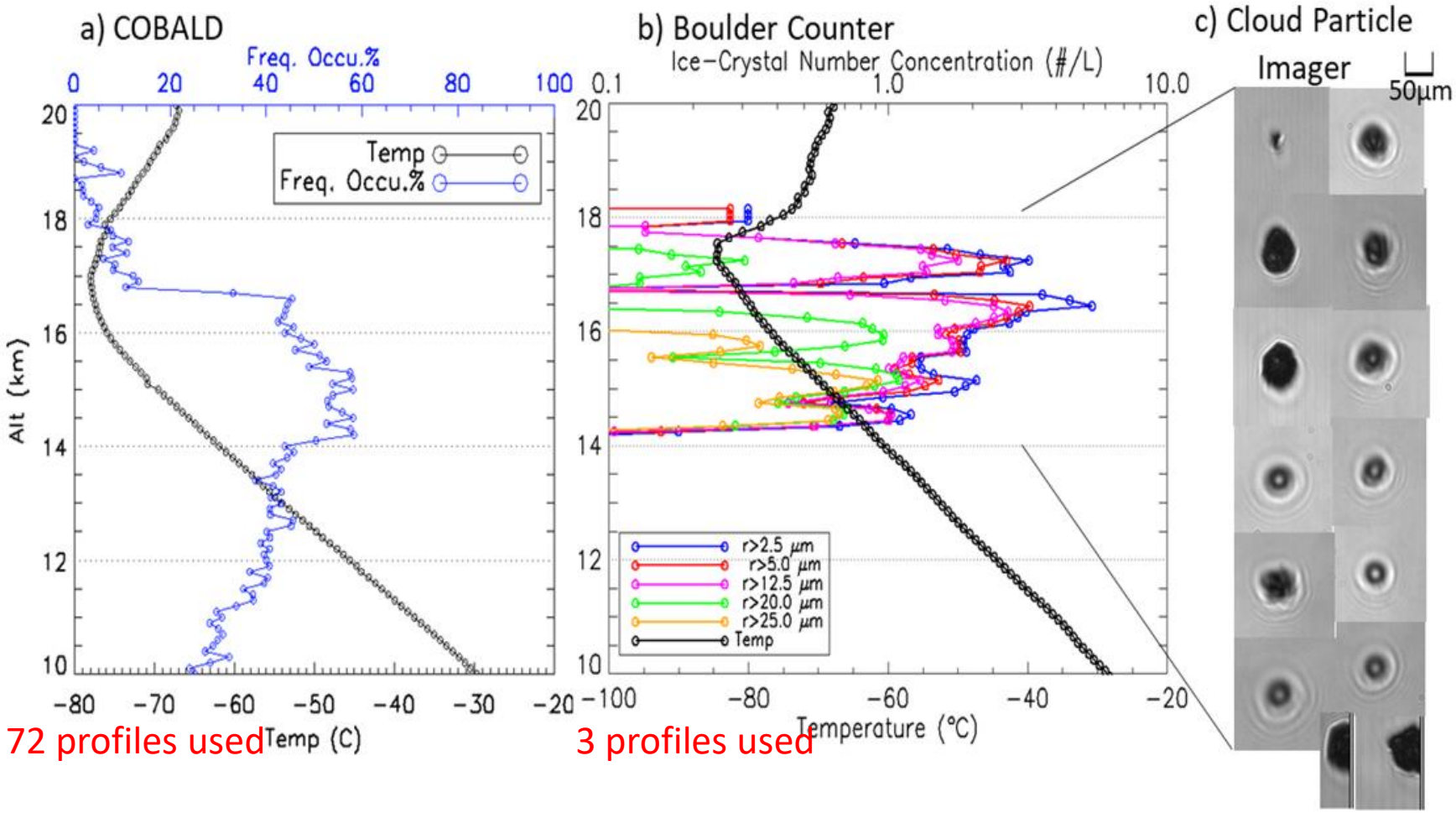
- Extended balloon flights for aerosol sampling near the tropopause reveal the presence of nitrate/nitrate aerosols.
- GEO-Chem simulation shows that a fraction (<20%) of nitrate is produced through Lightning-induced NOx.

ATAL & Cirrus cloud formation



- Southern Part of the ASM anticyclone coincide with a cold temp anomaly
- Favorable conditions to study the ATAL and cirrus cloud interaction

Occurrence Frequency, Number Concentration & Shape of Ice crystals



72 profiles used

3 profiles used

High occurrence of cirrus clouds near the cold-point tropopause (16-18 km) at extremely cold temperatures with quasi-spheroid ice-crystals smaller than 50 μm diameter.

Next Steps for the BATAL project

- NASA-ISRO IA expired in 2022, Agreement Extension 2023-2027, for next deployment during the summer 2023.
- Technical intercomparison of OPC (NOAA POPS, University of Wyoming OPC, LaRC OPC, LPC2E LOAC)
- Development of payloads and flight systems for measurements across the Bay of Bengal to study aerosol-cloud interaction.
- Measurements near Deep convective system around polluted areas to better understand the role of the monsoon in transporting pollution in the stratosphere.
- Engage with more groups in Asia to coordinate balloon flights

Thank you !