

Microphysical Properties of Tropopause Cirrus Clouds during BATAL Campaigns in India

Amit Kumar Pandit¹, Jean-Paul Vernier¹, T. Duncan Fairlie², Kristopher M. Bedka², Melody A. Avery², Harish Gadhavi³, M. Venkat Ratnam⁴, Akhil Raj S.T⁴, Frank G. Wienhold⁵, Chris Roden⁶, Hongyu Liu¹, Bo Zhang¹, and B. Suneel Kumar⁷

Abstract ID: 919298



¹National Institute of Aerospace, Hampton, USA

²NASA Langley Research Center, Hampton, USA.

³Physical Research Laboratory, Ahmedabad, India.

⁴National Atmospheric Research Laboratory, Gadanki, India.

⁵ETH Zurich, Zurich, Switzerland.

⁶University Cooperation for Atmospheric Research, Boulder Colorado, USA.

⁷TIFR Balloon Facility, Hyderabad, India.

Correspondence to: Amit Kumar Pandit (amit.pandit@nianet.org)



Acknowledgements

- NASA UARP/ACMAP, ISRO, NPP, and NIA for the funding support.
- Technical and logistical support from NASA LaRC, NIA, USRA, TIFR-BF, NARL and PRL.

BATAL campaigns 2014-2019

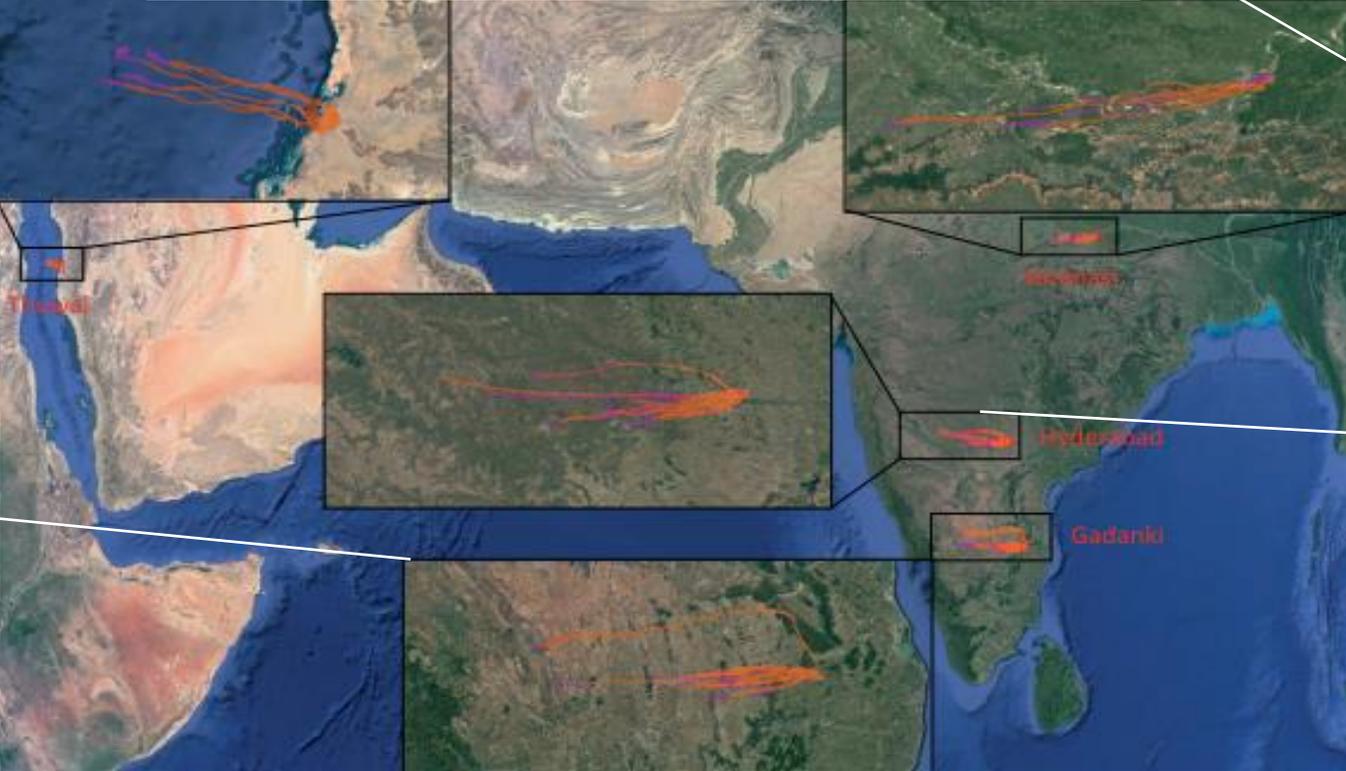
Balloon Trajectories: **Ascent**/**Descent** (2015)



King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia



National Atmospheric Research Laboratory (NARL), Gadanki, India



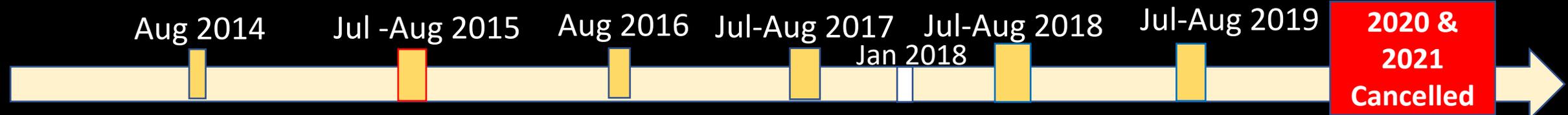
Banaras Hindu University (BHU), Varanasi, India



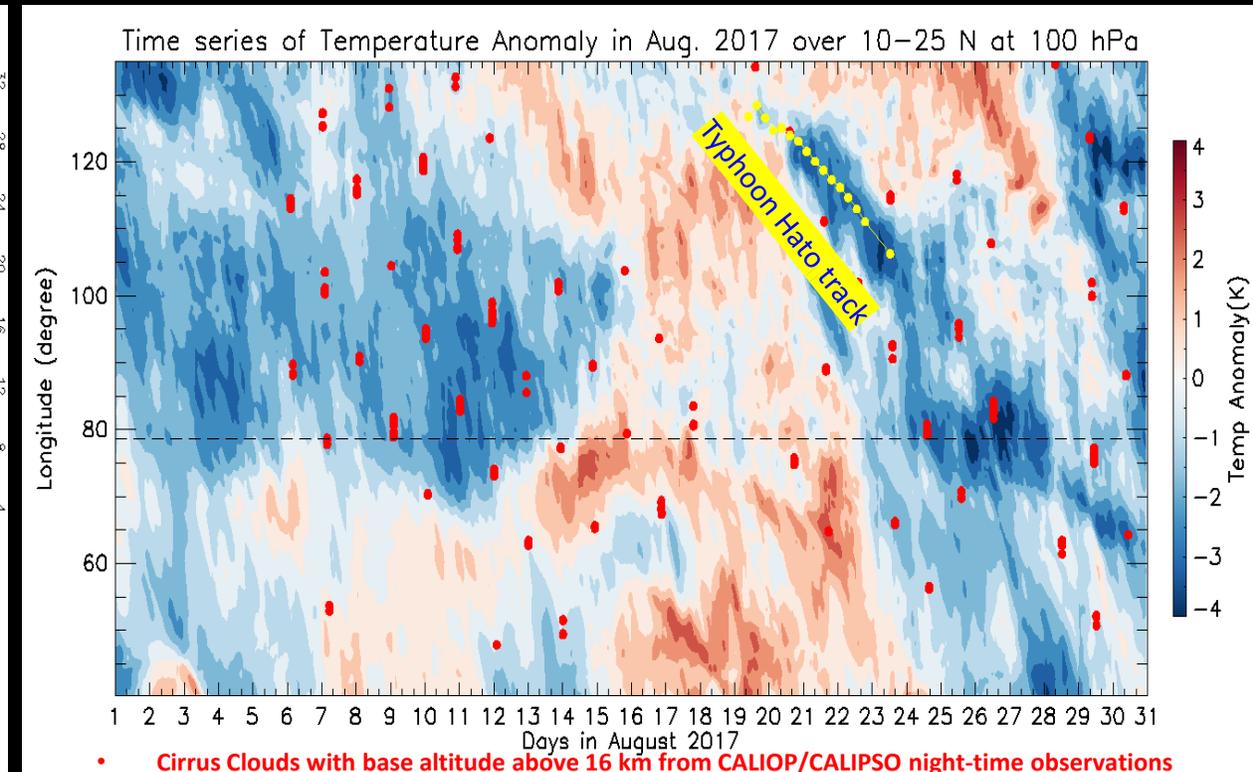
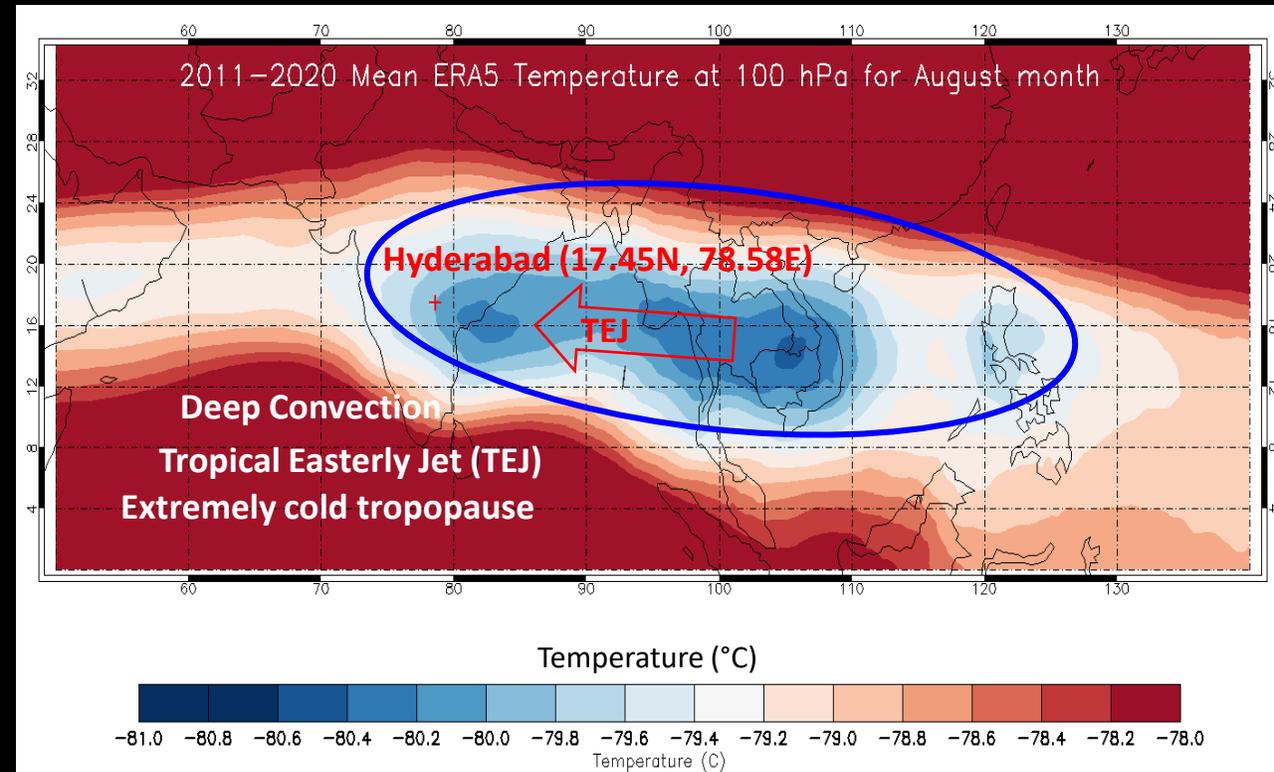
Tata Institute for Fundamental Research Balloon facility (TiFR)

- 6-year project 2014-2019
- 4 Launch locations (3 India, 1 Saudi Arabia)
- 12 Institutes Involved/ 6 Countries
- 101 Balloon Flights since 2014

Vernier et al., 2018, BAMS



Motivation and Objectives



- Number concentrations and shapes of ice-crystals smaller than 100 microns are uncertain (Heymsfield et al., 2017).
 - Past aircraft measurement results were influenced by shattering effects of ice-crystals.
 - Satellite derived (DARDAR) number concentrations are overestimated, and they do not represent thinnest cirrus clouds at cold temperatures (Krämer et al., 2020).
 - **Lack of in-situ measurements of optical and microphysical properties of cirrus clouds over the Asian Summer Monsoon region.**
- To obtain the in-situ measurements of cirrus cloud microphysical and optical properties over the Asian Summer Monsoon region using balloon borne sensors**

Balloon-borne Instruments for Measuring Ice Crystals in Cirrus Clouds

iMet Radiosonde + COBALD (A Backscattersonde)



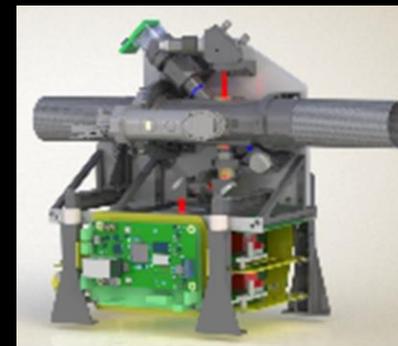
Meteorological parameters, GPS location, Backscatter ratio at 455 nm & 940 nm, and Color Ratio.

Boulder Counter- An Optical Particle Counter

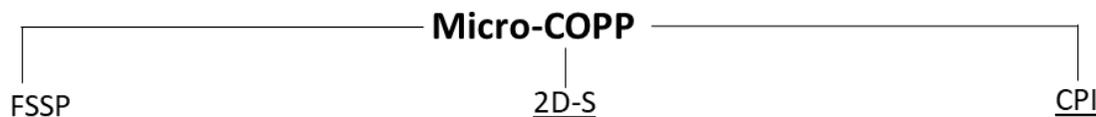


Particle counts @ 5, 10, 25, 40, 50 and 100 μm .
Flow at 28.3 LPM (1 CFM)
Sampling time: 5s

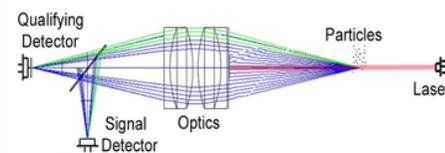
Micro-COPP



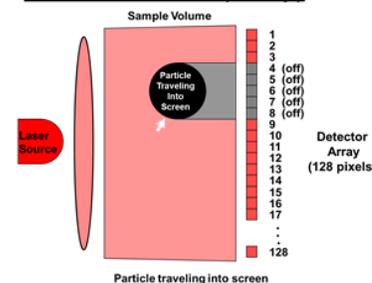
Micro-COPP: Heritage from Global Hawk payload used during ATTREX



- FSSP**
 - Forward Scattering Spectrometer Probe
 - Size distribution and concentration of cloud particles
 - 1 to 50 μm over 20 bins
- 2D-S**
 - 2-Dimensional Optical Array Probe
 - size distribution, concentration, and area/extinction of cloud droplets, precipitation and ice crystals
 - Size range: 5 μm -1mm
 - 10 to 25 μm pixel resolution
- CPI**
 - Cloud Particle Imager
 - Digital camera
 - Up to 400 frames per second
 - Size range: 5 μm -1mm
 - Resolution 1 μm



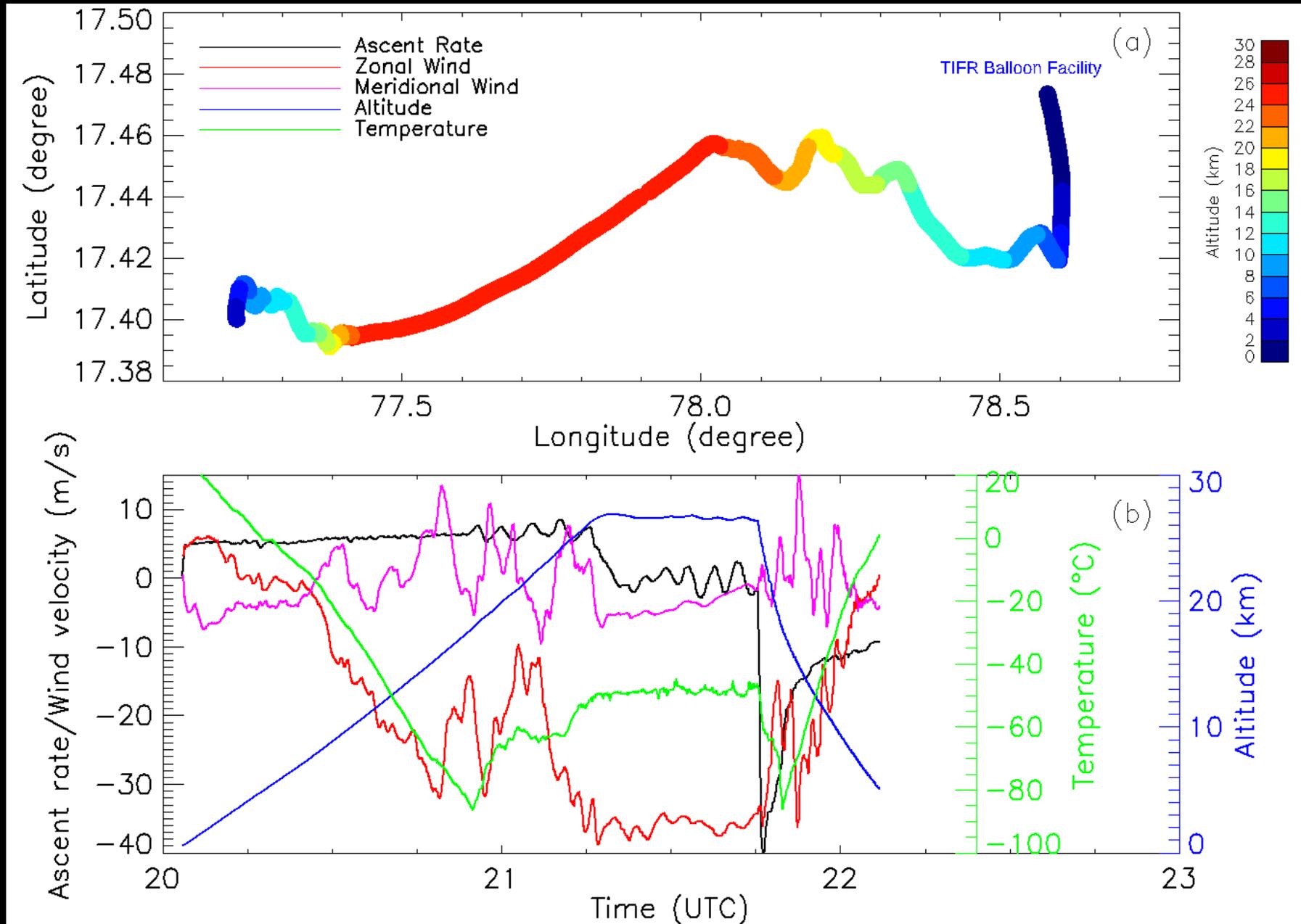
128 - Detectors (Array)



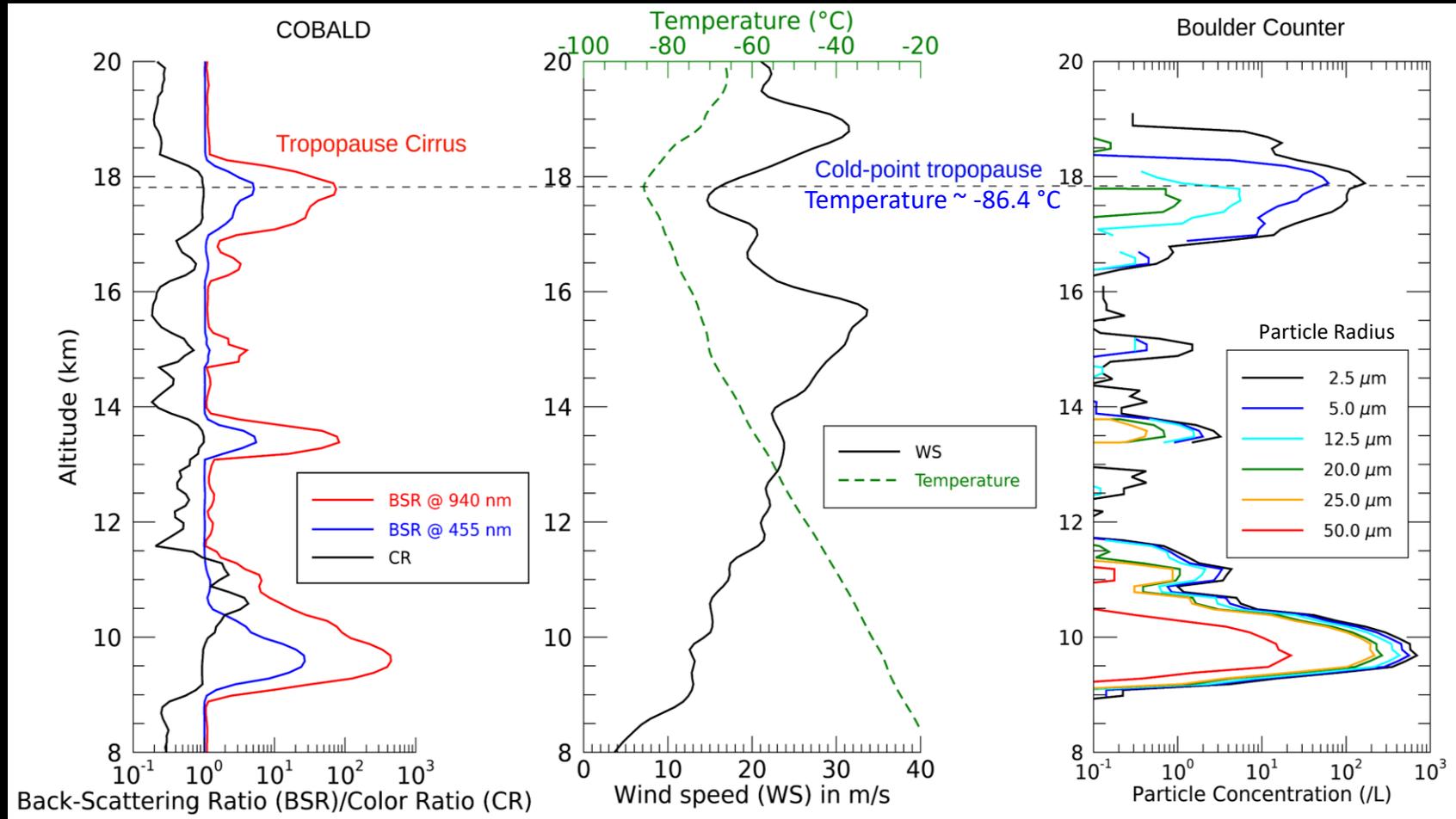
Satellite Observations, Lagrangian Back-trajectories and Reanalysis

Satellite/Model	Resolution	Output Parameters
CALIOP/CALIPSO (L2 5km V4.2 Clay & Cpro products)	Vertical:60 m, Horizontal: 5km along the orbit track	532 nm backscatter ratio, cloud base and top heights
CATS/ISS (5km M7.2 Level 2, Version 3.0 Operational Layer (OL) and Profile (OP) products)	Vertical resolution: 60 m, Horizontal: 5km along the orbit track	1064 backscatter ratio, cloud base and top heights
Himawari-8	Horizontal: ~2 km for IR bands, Temporal: 10 min	10.4 μm cloud top brightness temperature
MLS/Aura (L2 V5.1)	Vertical: ~ 3km in UTLS, Horizontal:~200 x 7 km	Water vapor mixing ratio
GNSS-RO (L2 atmPrf) obtained from COSMIC-1, Metop A/B, GRACE, KOMPSAT-5, TSX, TDX	Vertical: 100 m	Temperature profiles, cold-point tropopause height
Daily 0 UTC radiosonde data (IMD stations near Hyderabad)	Not fixed	T, RH, u, v, wind speed and wind direction profiles.
ERA 5 Reanalysis (at 70 &100 hPa levels)	Horizontal:0.25° x 0.25°, Temporal: 1h	Temperature, relative humidity and cloud fraction
Langley Trajectory Model (LaTM)	Vertical: 100m,Temporal: 1 hour	3D back-trajectories using winds from NASA GMAO V5 GEOS-5 FP

Balloon flight on 23 August 2017 from TIFR Balloon Facility in Hyderabad



Balloon flight on 23 August 2017 from TIFR Balloon Facility in Hyderabad



- **Backscatter Ratio (BSR):** Ratio of total backscattering coefficient ($\beta = \beta_p + \beta_m$) to the molecular backscattering coefficient (β_m).

- **Color Index (CI) and Particulate Color Ratio (CR):** $CI = (BSR_{940} - 1) / (BSR_{455} - 1) = 18 \cdot \left(\frac{\beta_{p940}}{\beta_{p455}} \right) = 18 \cdot CR$

CR < 0.7 - Aerosol

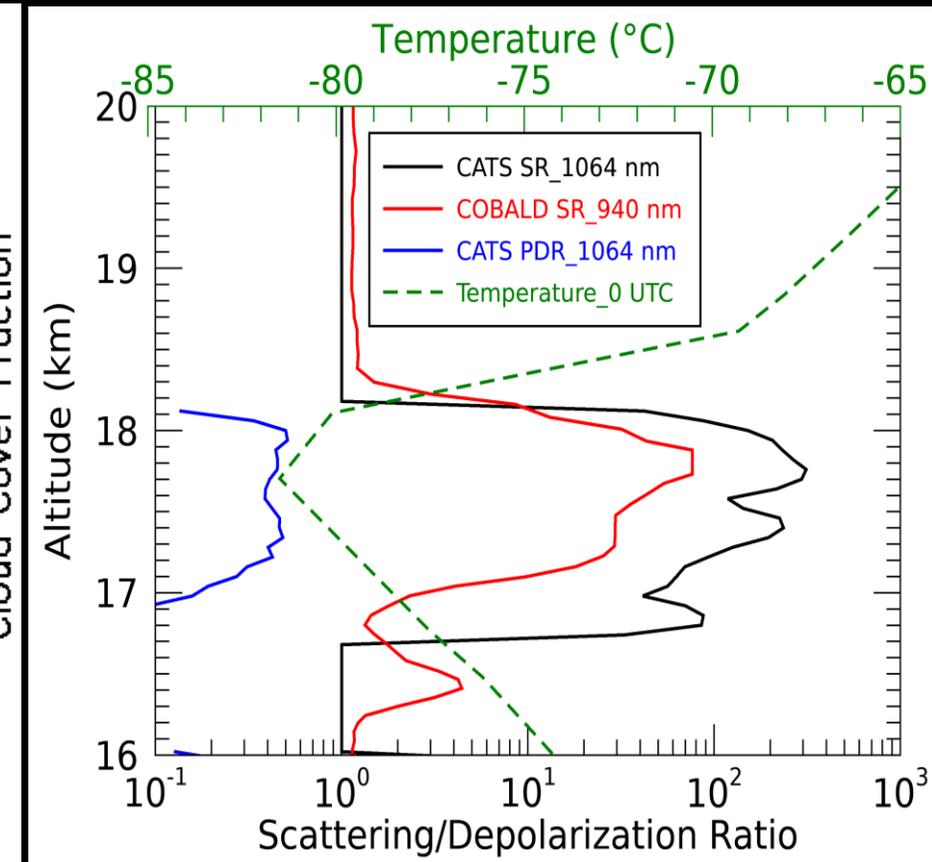
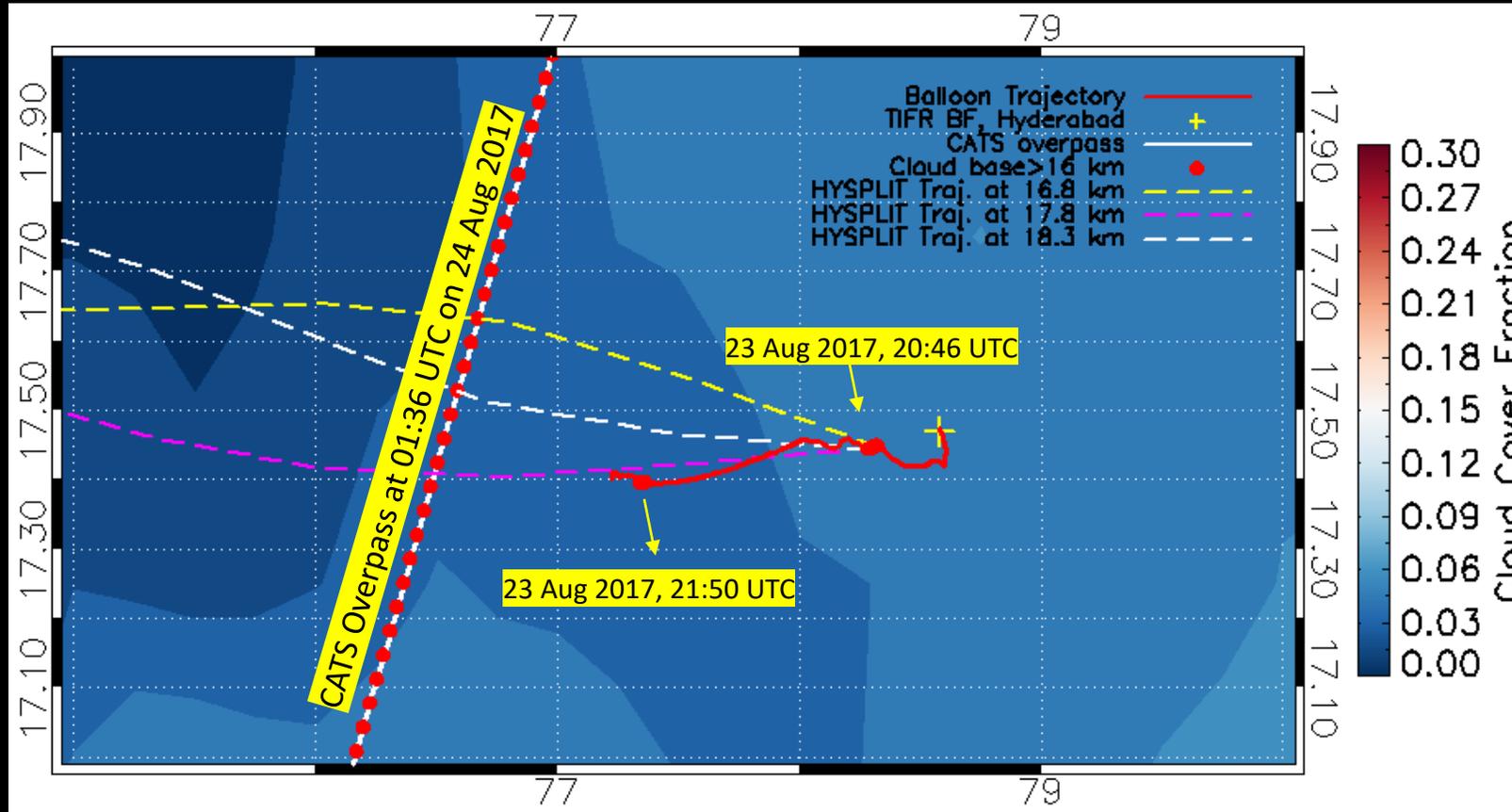
CR > 0.7 - Cloud

(Vernier et al., 2015; Brunamonti et al., 2018)

Validation of Balloon Measurements using CATS Lidar observations onboard ISS

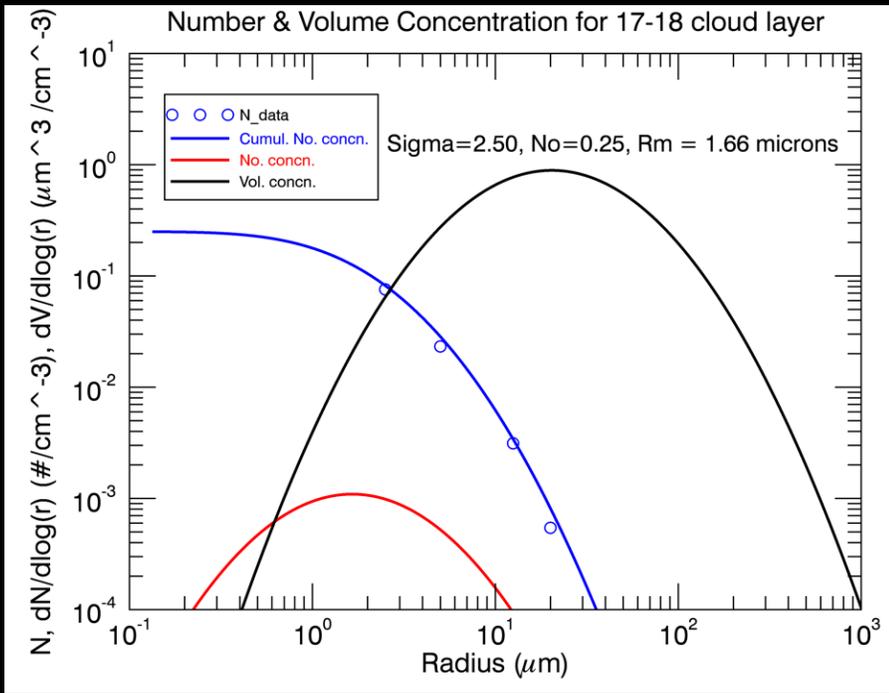
ERA5 Cloud cover Fraction at 100 hPa on 24 Aug 2017 between 1 & 2 UTC

CATS profiles averaged between 17.40 -17.65°N



Horizontal extent of tropopause cirrus is > 500 km along the CATS orbit track

Optical & Microphysical Properties of a Tropopause Cirrus on 23rd August 2017



Using the log-normal size distribution,

$$\frac{dN(r)}{d(r)} = N_0 \frac{\exp\left[-\frac{1}{2} \left\{ \frac{\ln^2\left(\frac{r}{r_m}\right)}{\ln^2\sigma} \right\}\right]}{r \ln\sigma \sqrt{2\pi}}$$

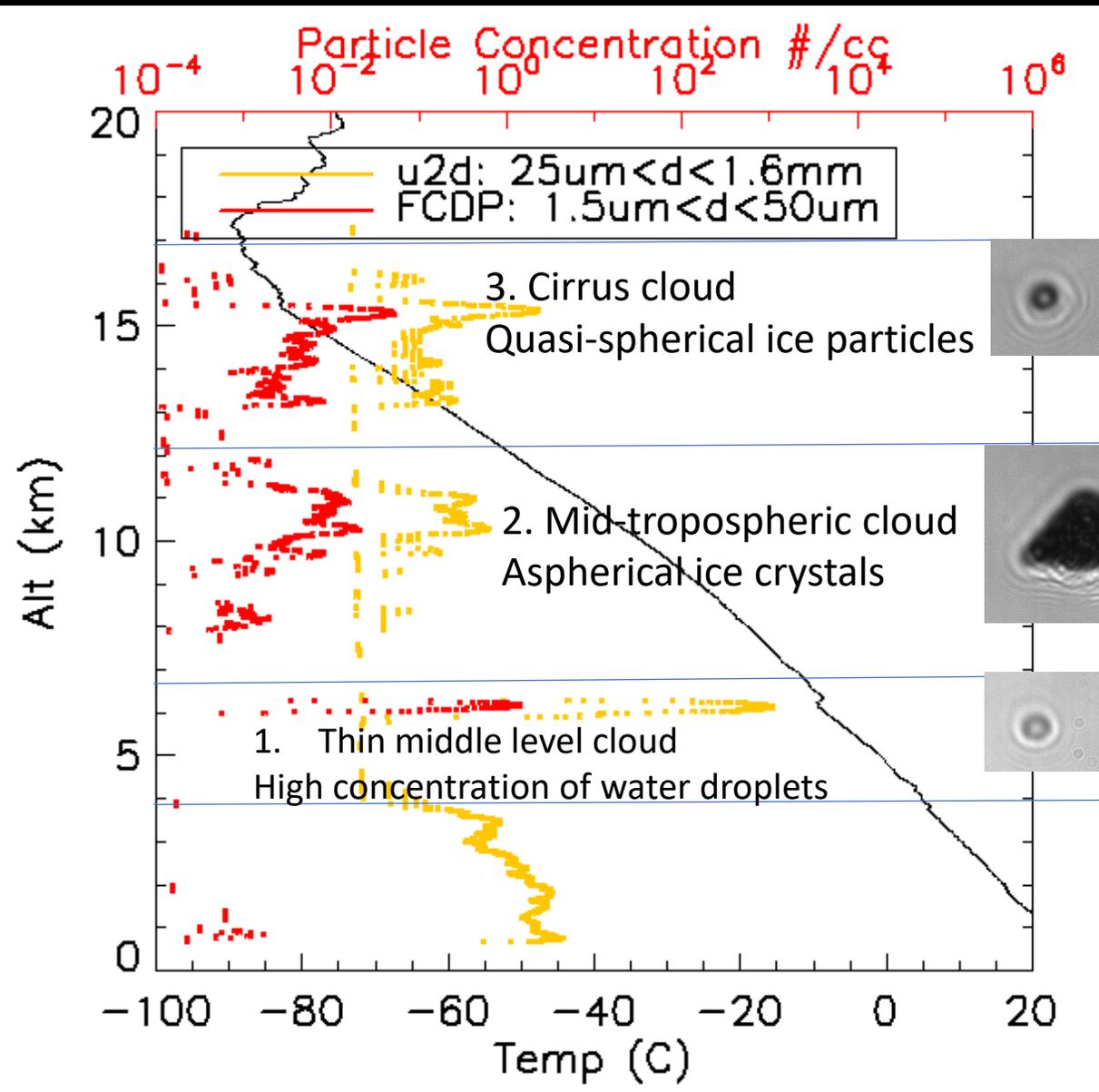
we can derive:

- Effective diameter (D_e), $D_e = 2 \cdot \frac{\int_0^r r^3 N(r) dr}{\int_0^r r^2 N(r) dr}$
- Extinction coefficient (σ_{ext}), $\sigma_{ext} = 2 \cdot \sum_j N_j \pi r_j^2$ (Geometric approximation)
- Ice-Water Content (IWC): IWC = Total volume x Ice Density (917 kg/m^3)

Altitude (km)	Temperature (°C)	Number concentration (#cm ⁻³)	Effective Diameter (μm)	Extinction coefficient (km ⁻¹)	Ice-Water Content (mgm ⁻³)	Lidar ratio (sr)
17.38	-82.19	0.06727	13.49	0.0144	0.06	23.47
17.48	-83.10	0.09337	17.22	0.0257	0.135	41.81
17.58	-83.95	0.09341	18.94	0.0284	0.164	35.08
17.68	-84.80	0.11418	28.67	0.0405	0.355	39.65
17.78	-85.61	0.10809	18.93	0.0261	0.151	14.54
Mean ± Std. Dev (COBALD)	-83.93 ± 1.35	0.0953 ± 0.0181	19.45 ± 5.61 (17.71 ± 0.38)	0.027 ± 0.009 (0.026 ± 0.010)	0.173 ± 0.109 (0.112)	30.9 ± 11.6 (CATS Ir: 28)

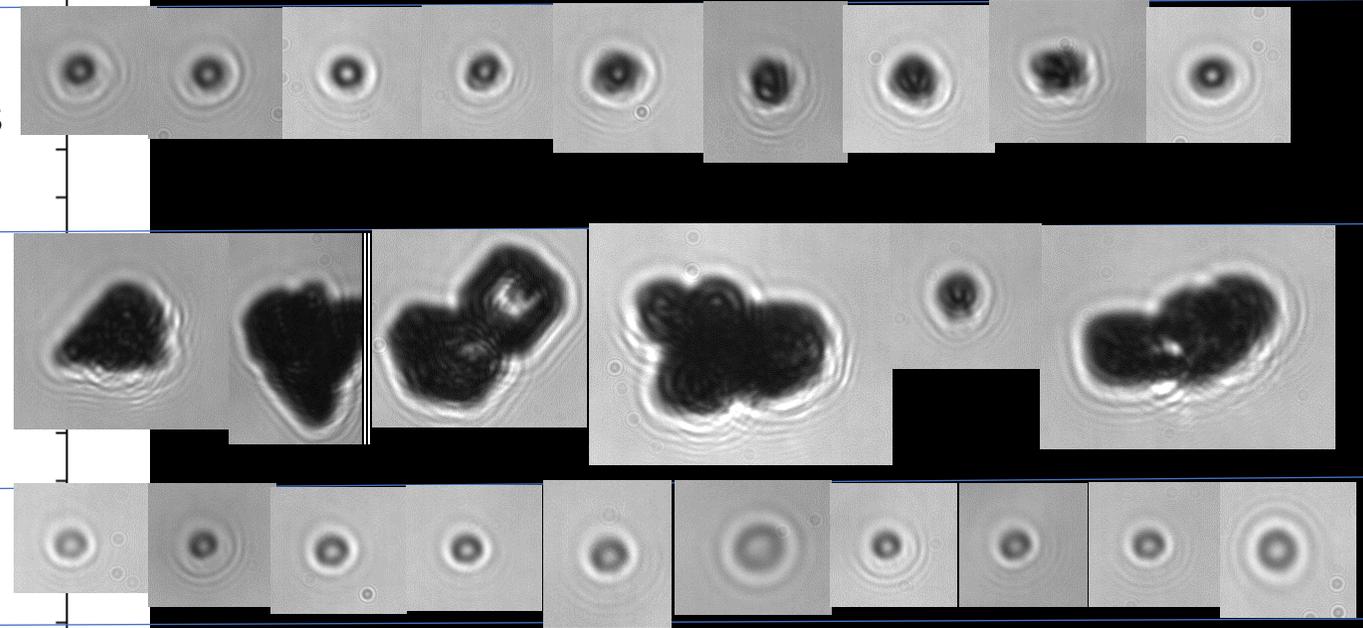
Micro-COPP Measurements on 29th August 2018

29th August 2018



Cloud Particle Imager (CPI)

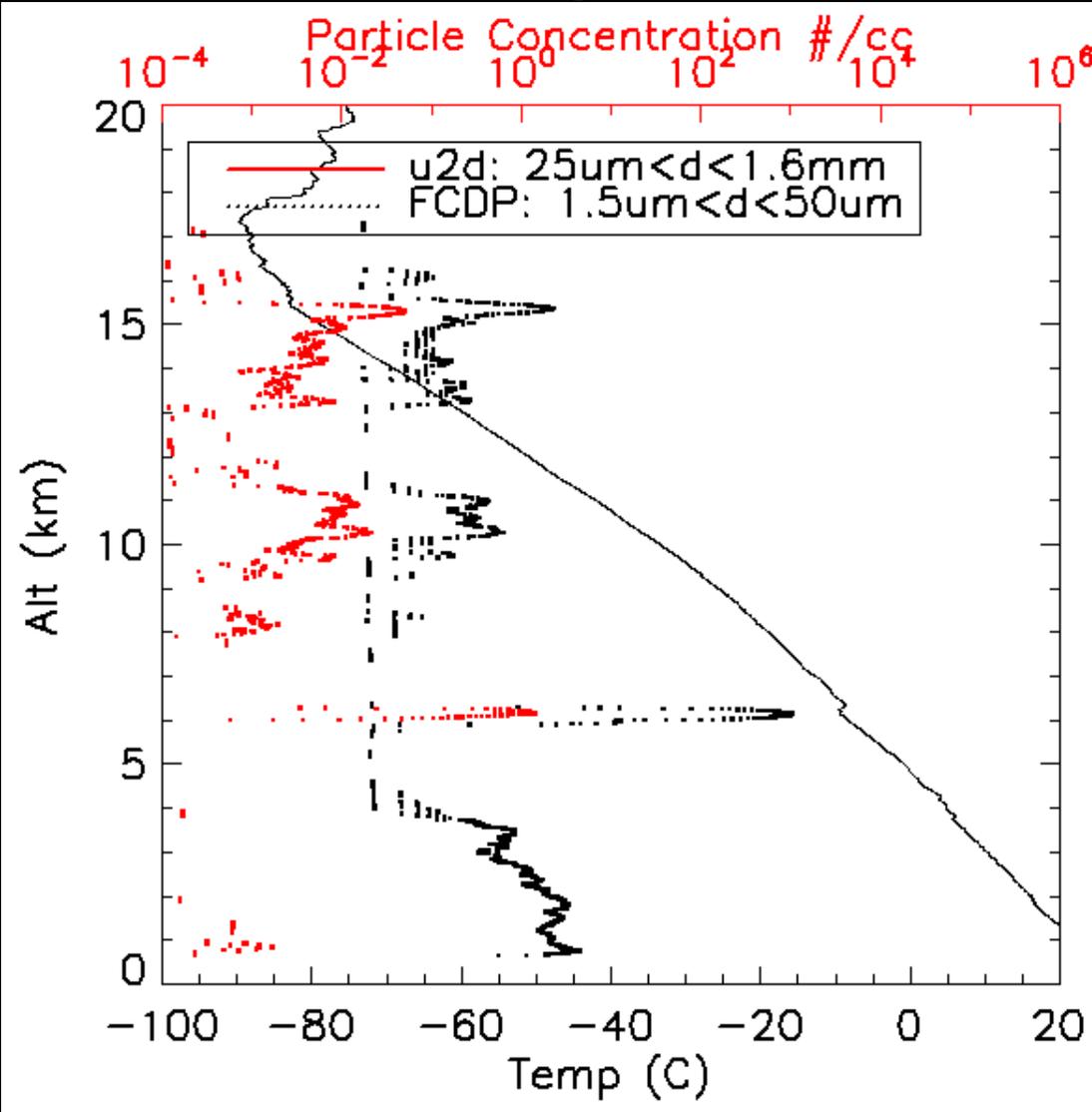
200 μm



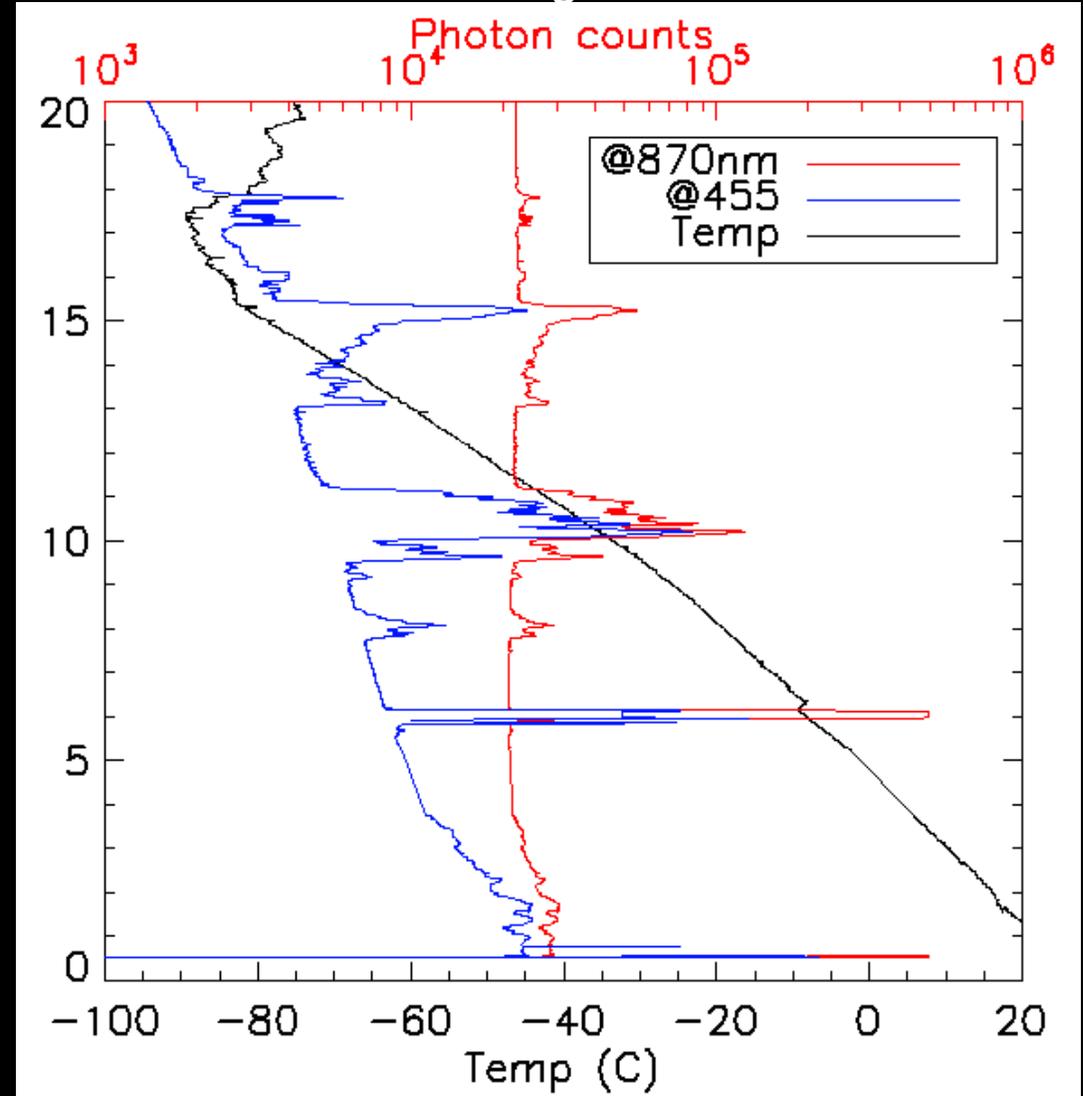
Balloon measurements unaffected by shattering

Micro-COPP Vs COBALD

29 August 2018

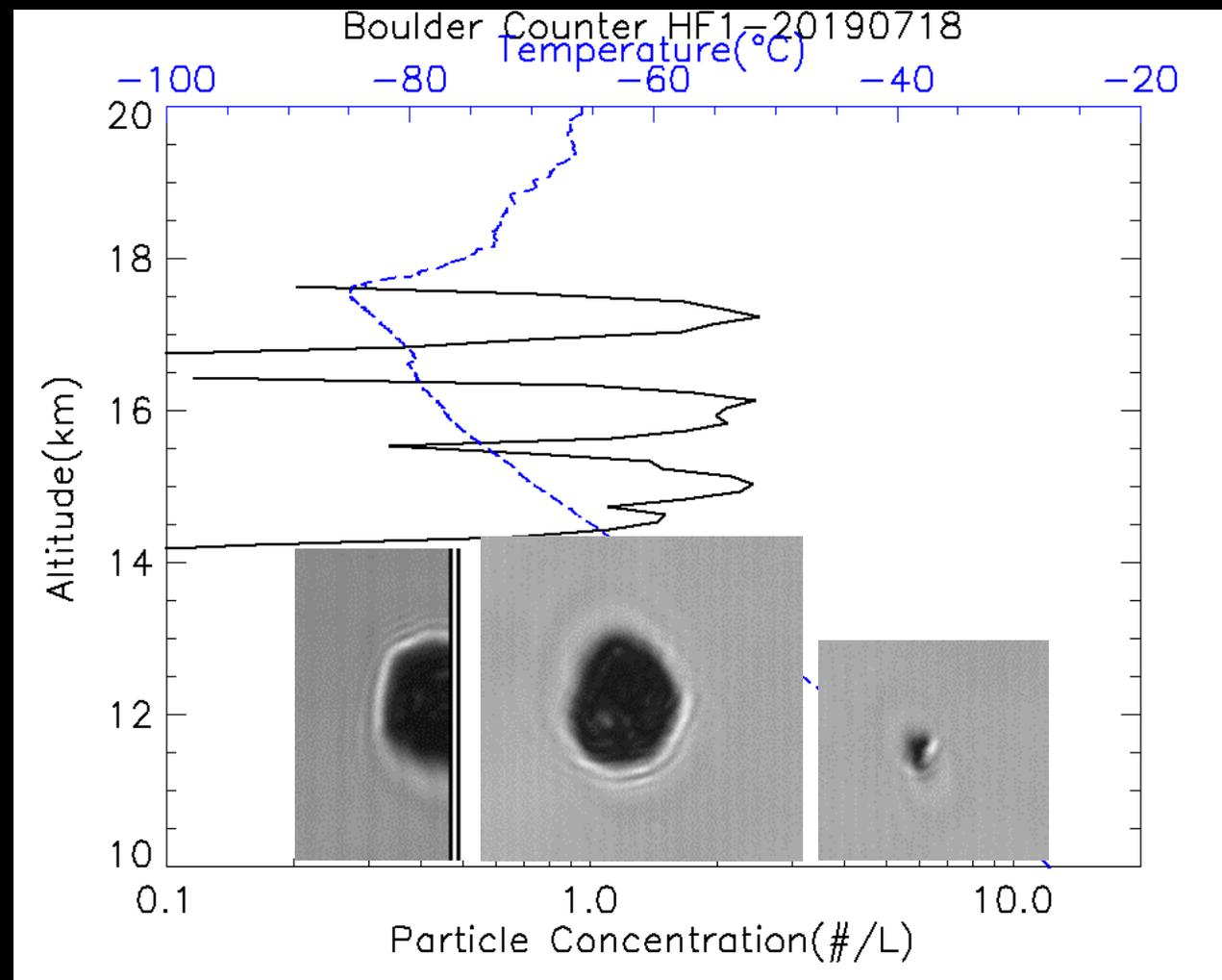
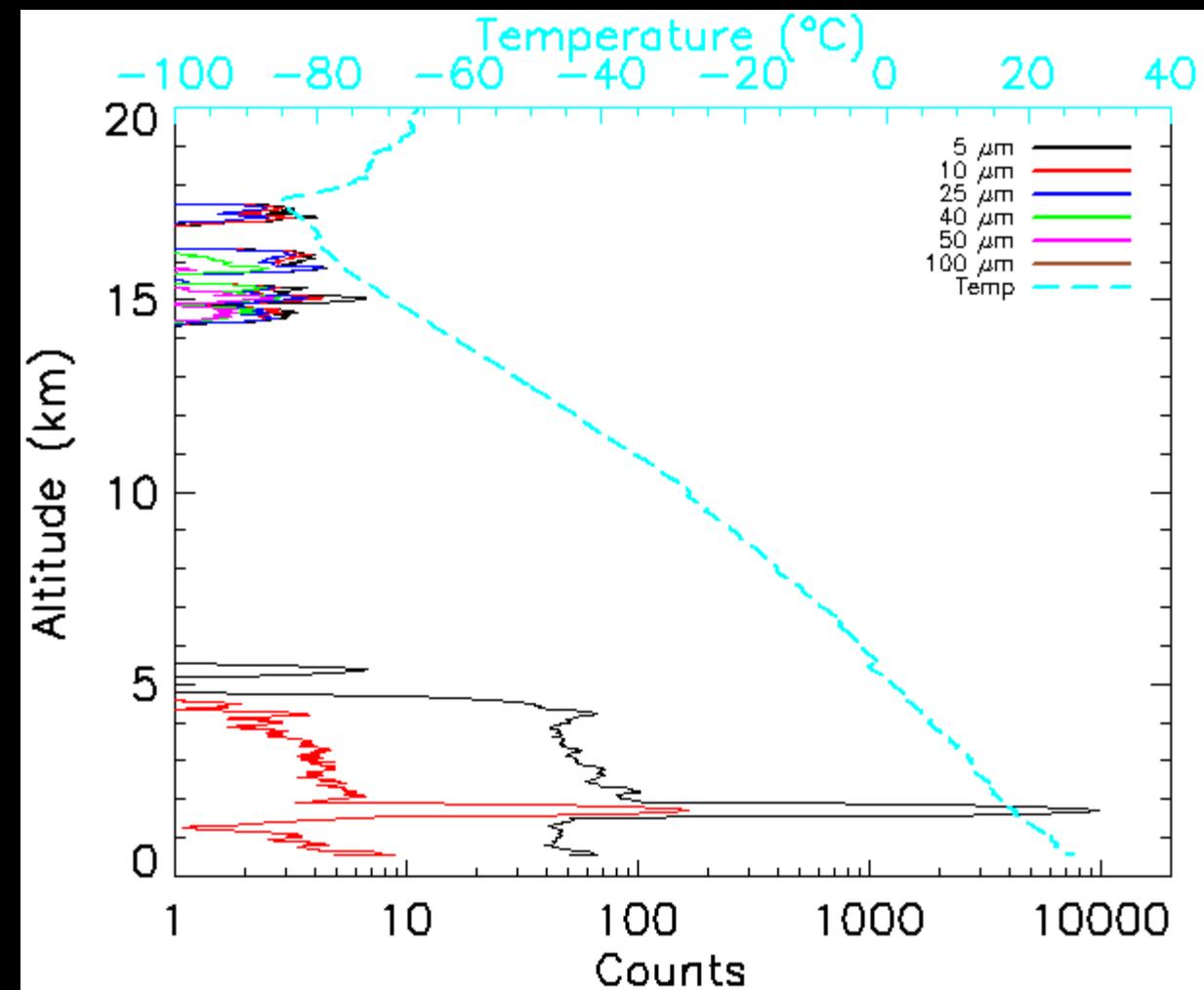


29 August 2018

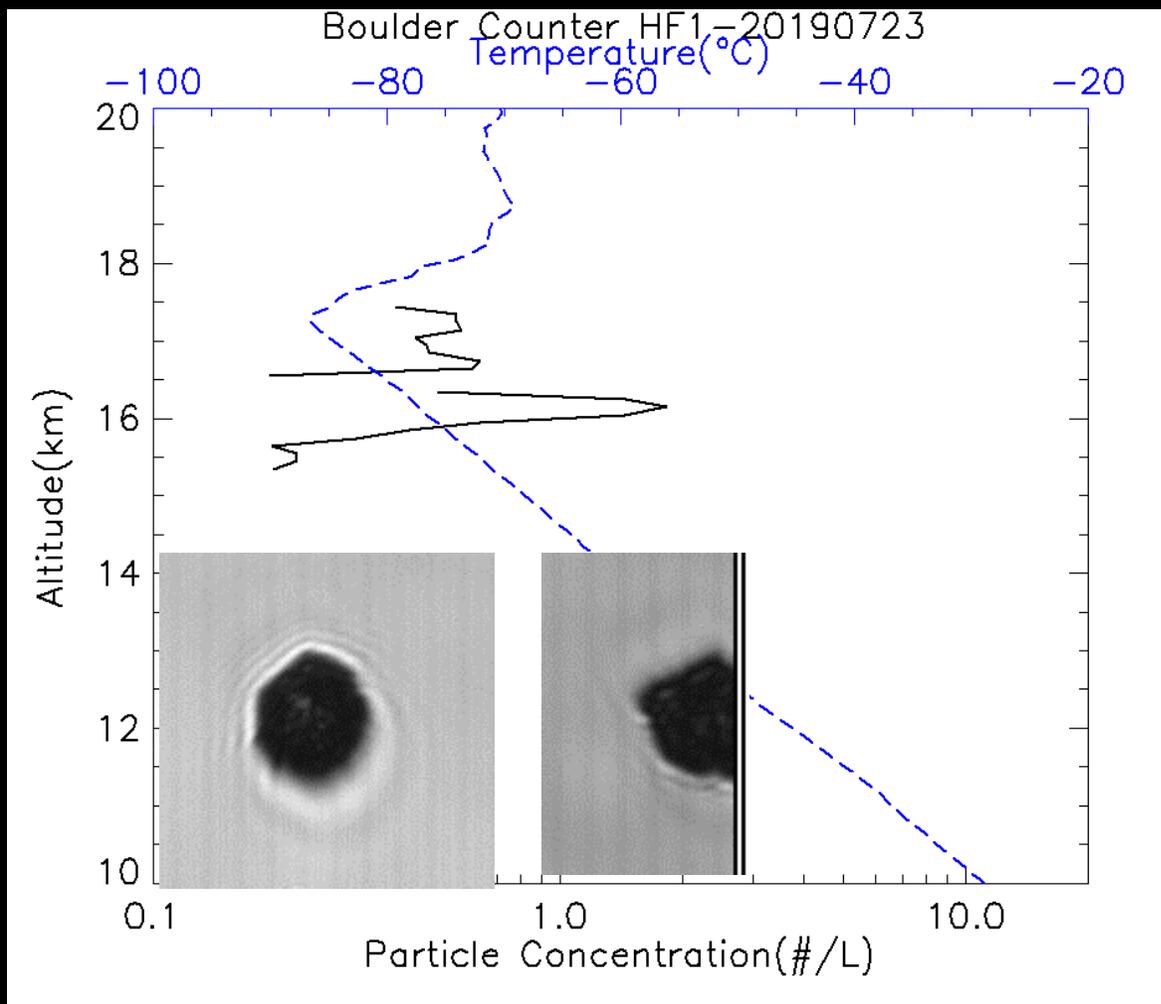
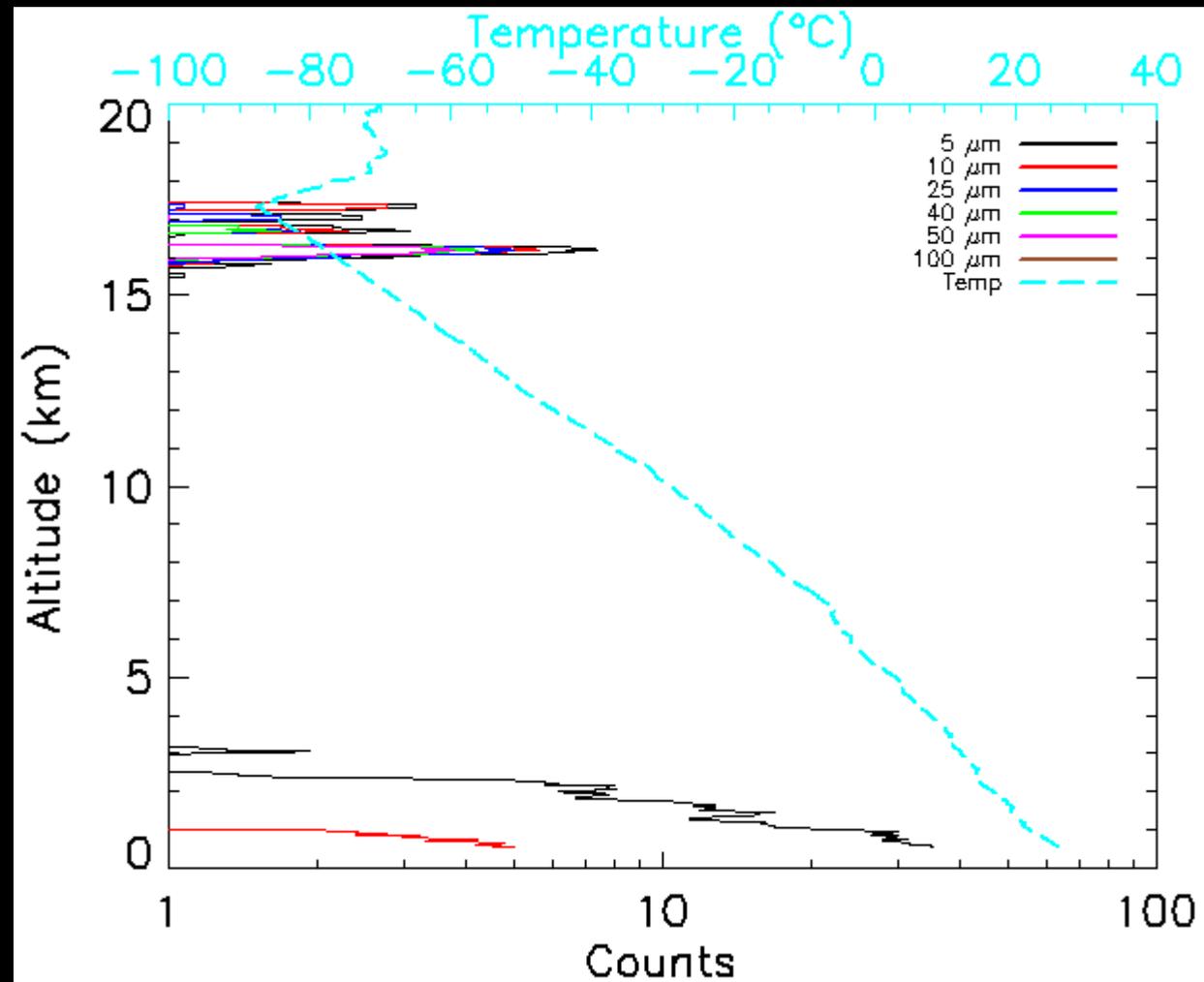


Boulder Counter and CPI Measurements during BATAL-2019

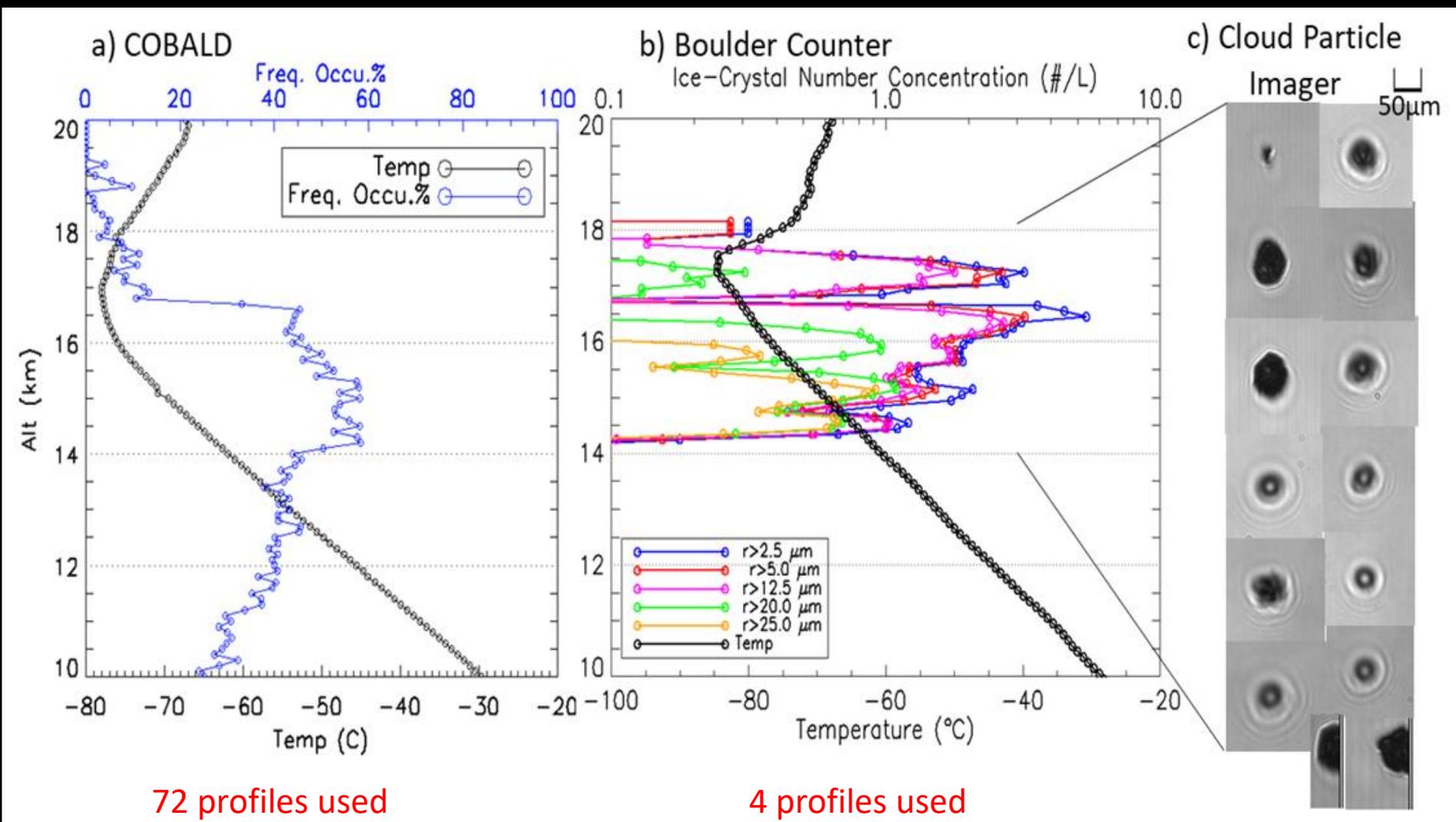
HF1-20190718, Boulder Counter



Boulder Counter and CPI Measurements during BATAL-2019

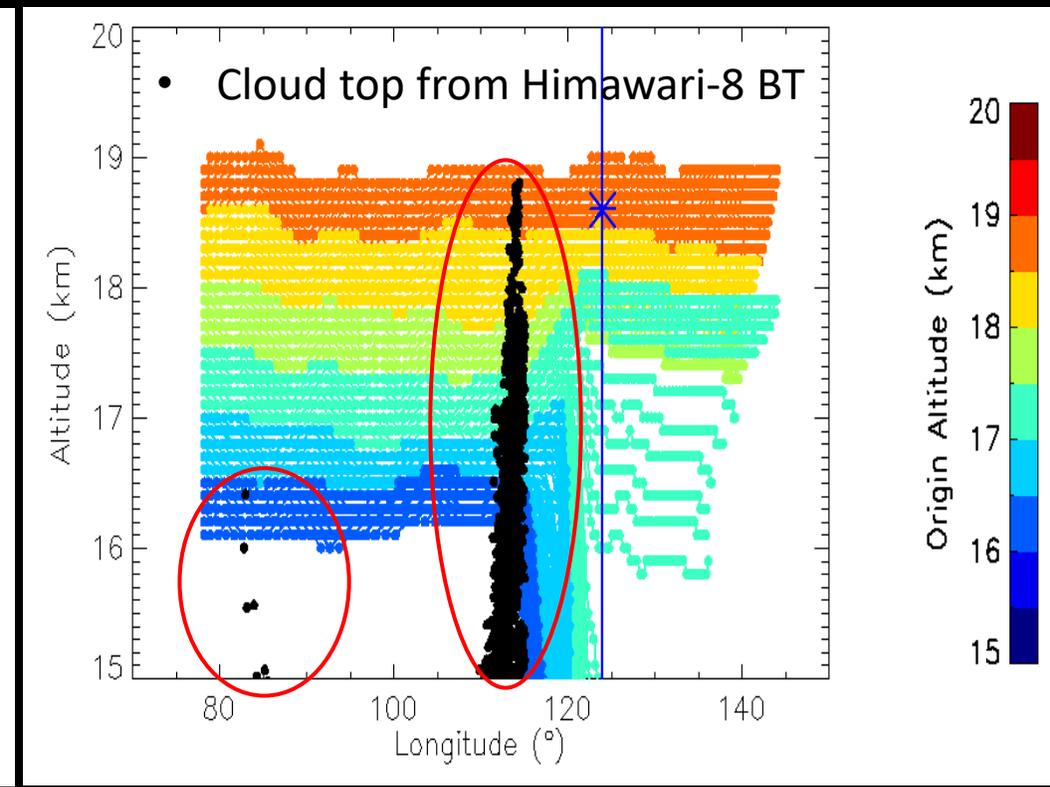
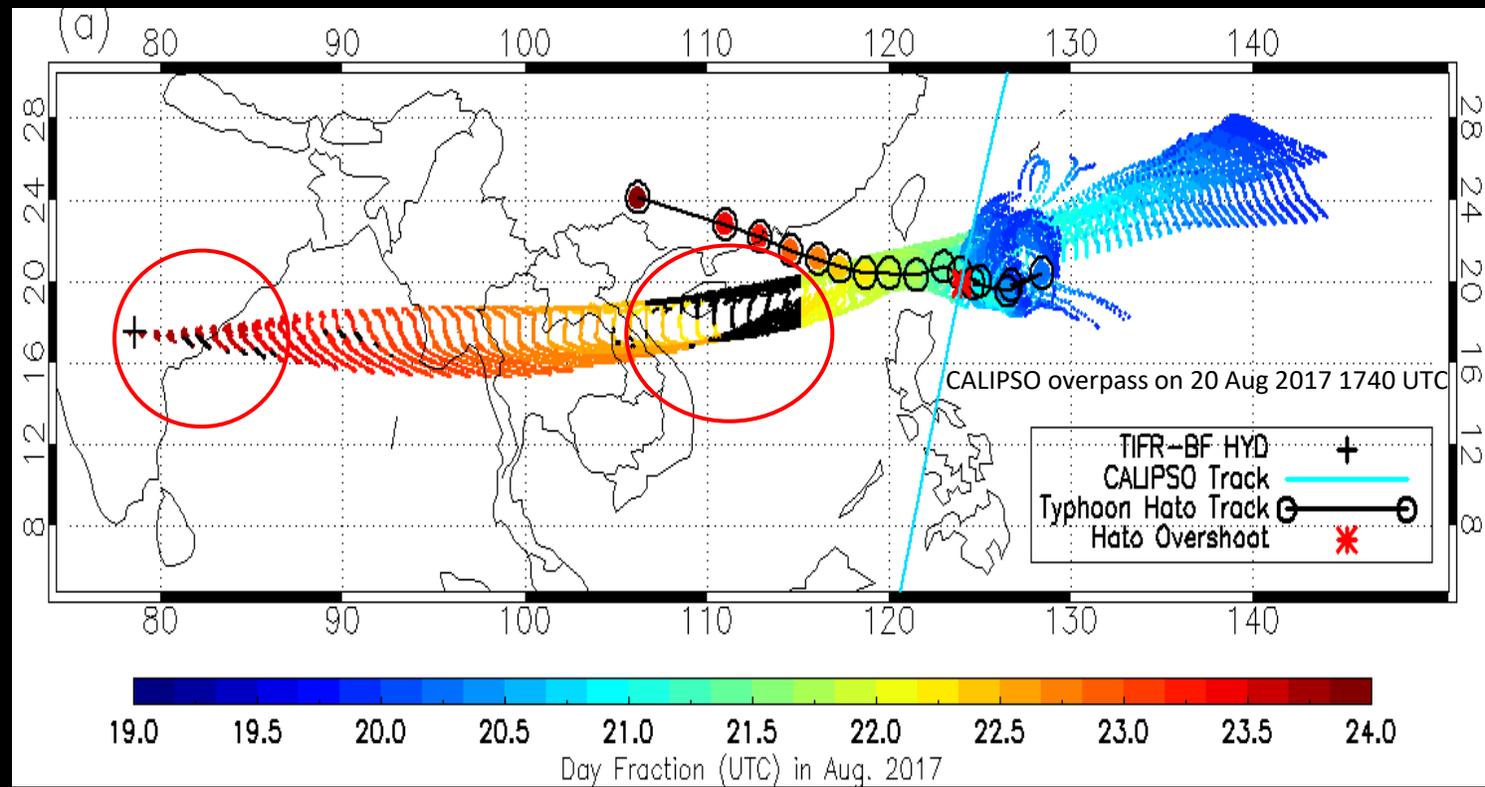


Occurrence Frequency, Number Concentration & Shape of Ice crystals



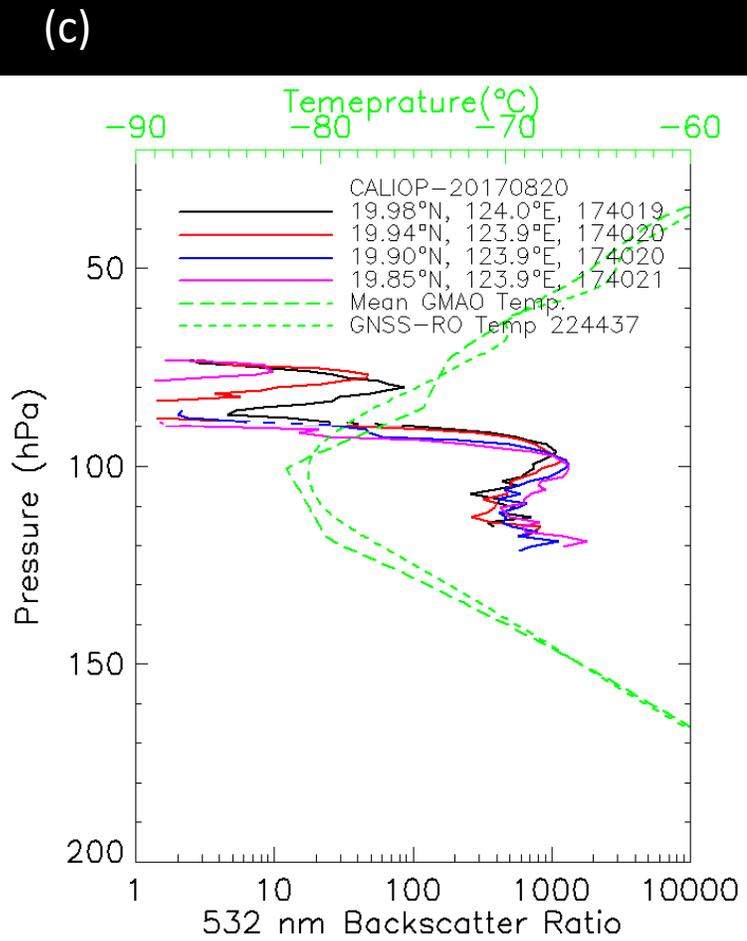
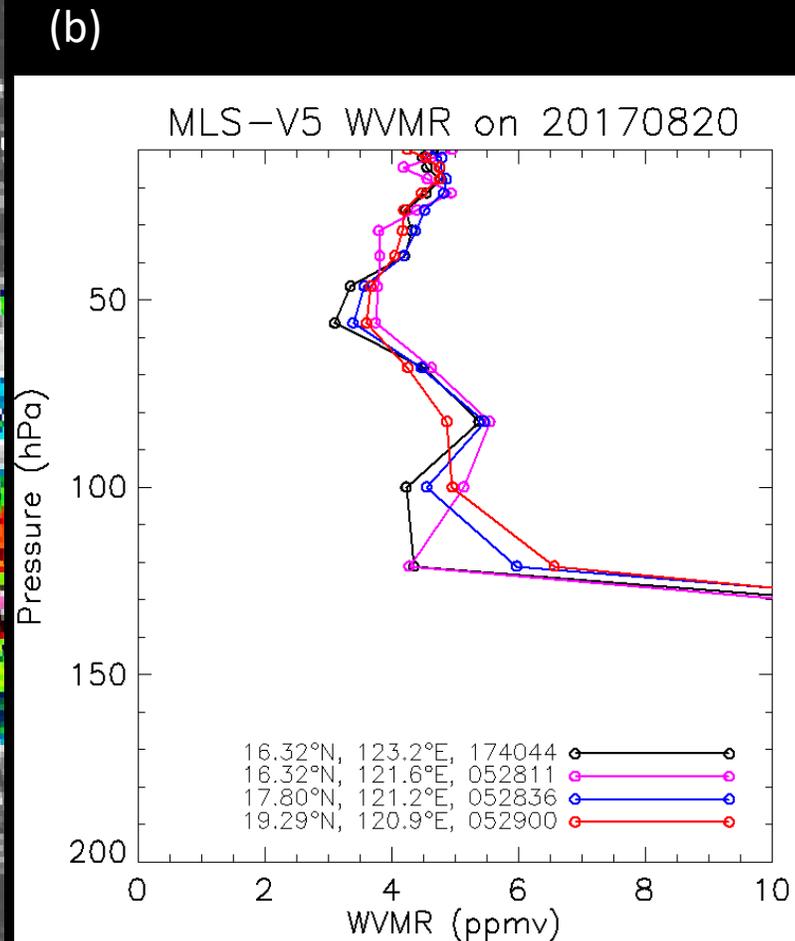
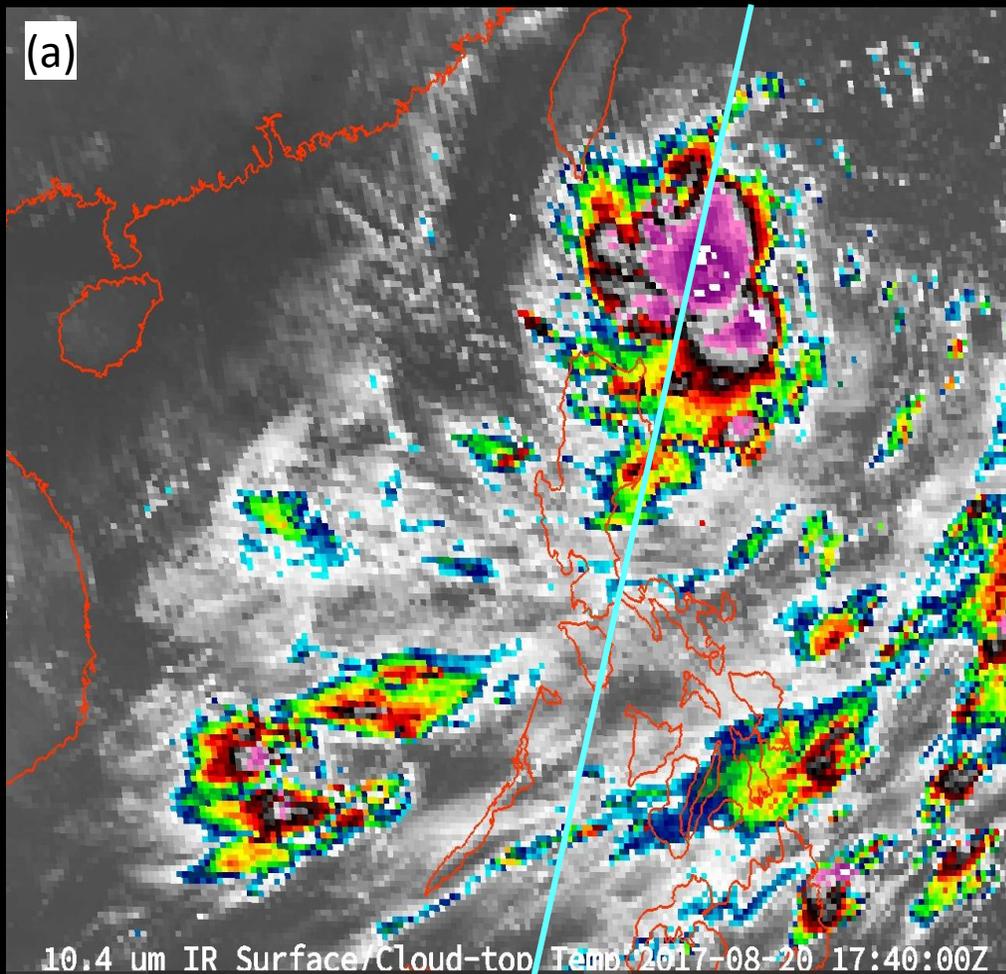
High occurrence of cirrus clouds near the cold-point tropopause (16-18 km) at extremely cold temperatures with quasi-spheroid ice-crystals smaller than 50 μm diameter.

Formation Mechanism: Back-trajectories and Convective Influence



- Back-trajectories initialized from the tropopause cirrus site between 16-18 km are influenced by local and distant convection.
- Local convection: Late afternoon convection near the East coast India.
- Distant Convection: Typhoon Hato – a category-3 tropical cyclone.

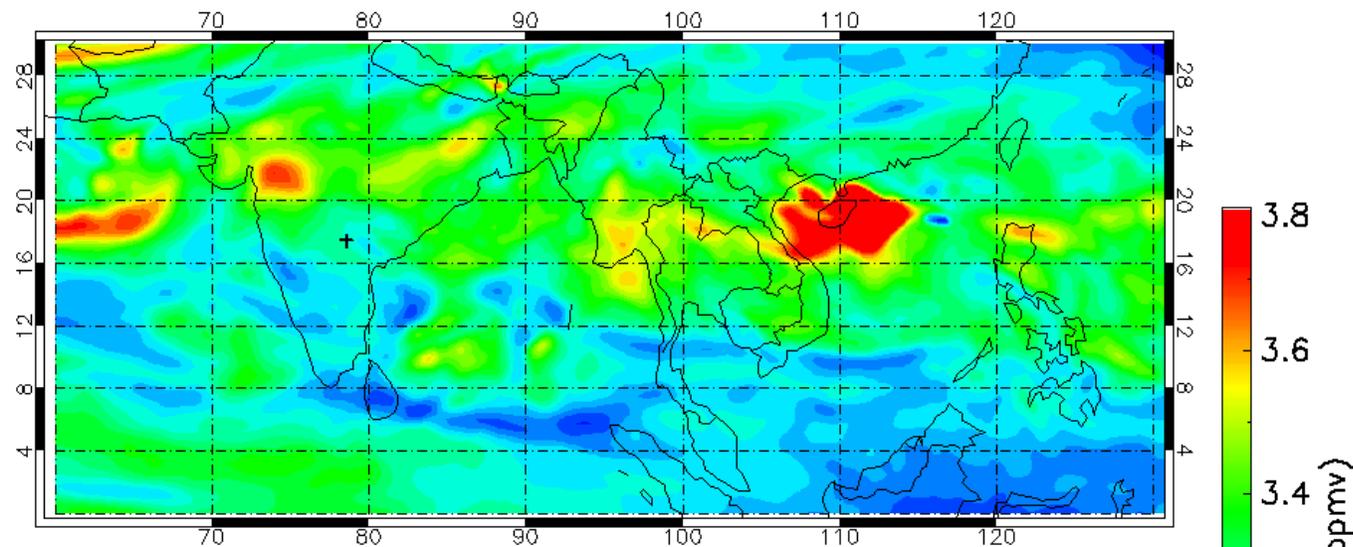
Lower Stratospheric Hydration due to Overshooting Convection on 20 Aug 2017



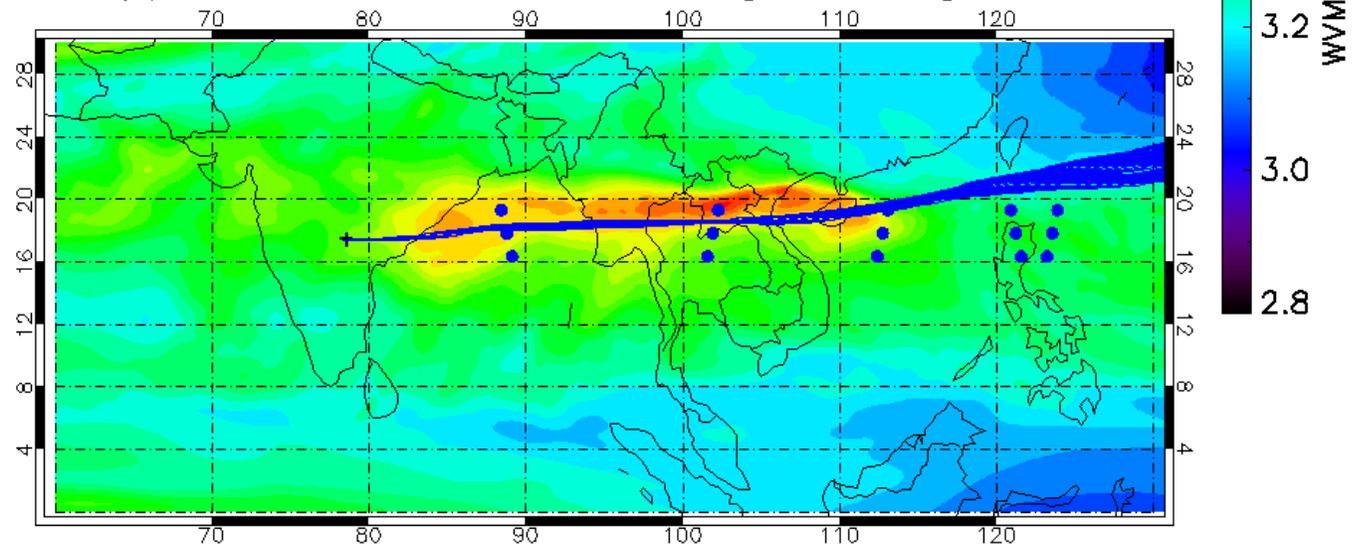
This hydration patch could have advected along the trajectories towards Hyderabad

Advection of Hydration Patch by the ASM Anticyclone towards Hyderabad

(a) ERA5 WVMR at 70 hPa on 22 August 2017 at 09 UTC

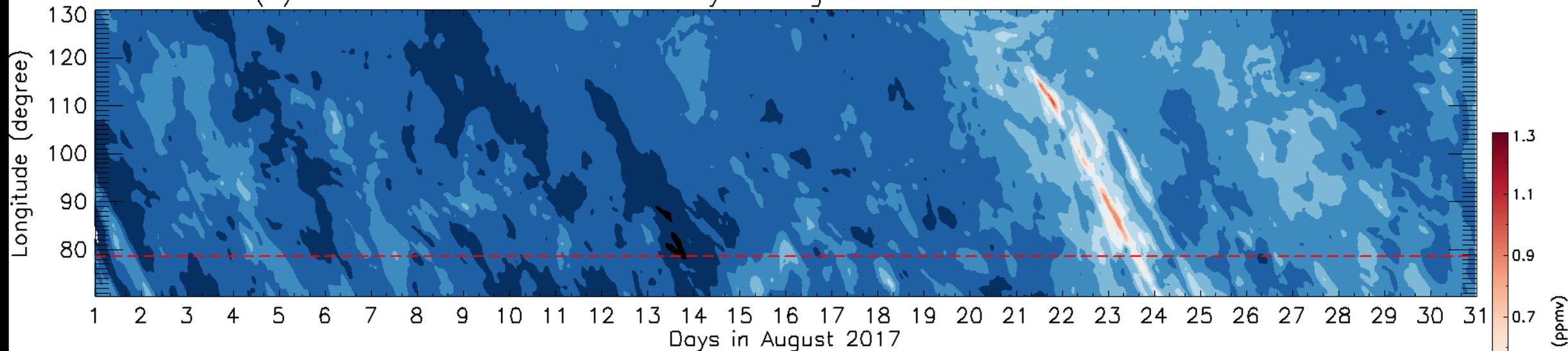


(b) Mean ERA5 WVMR at 70 hPa during 22–23 August 2017

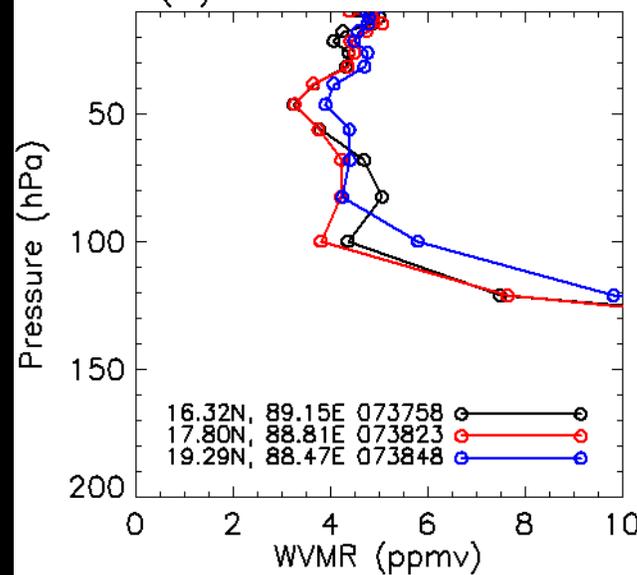


Advection of Hydration Patch by the ASM Anticyclone towards Hyderabad

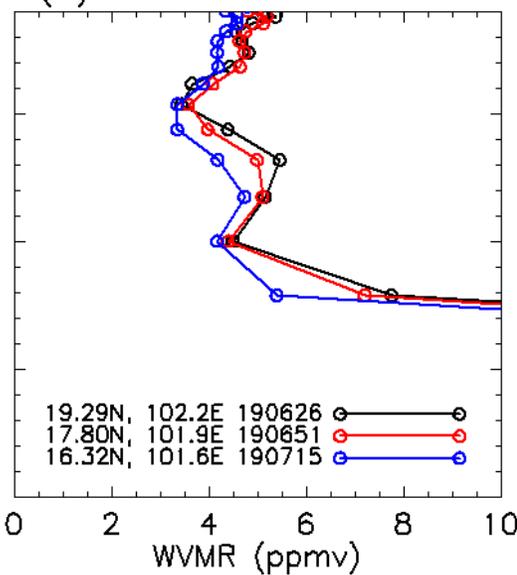
(a) Time series of WVMR Anomaly in August 2017 over 15–20 N at 70 hPa



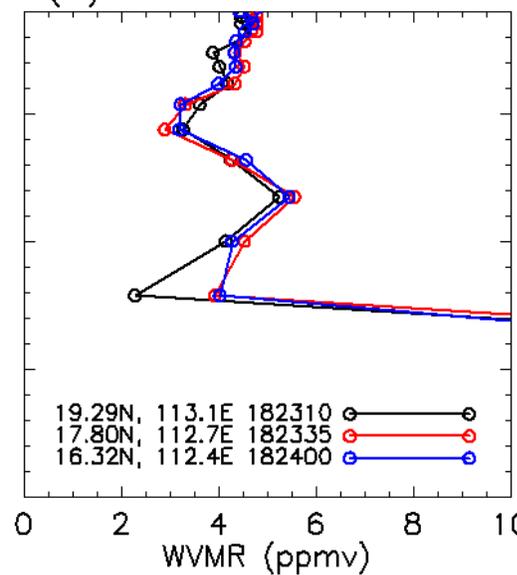
(b) MLS-V5 20170823



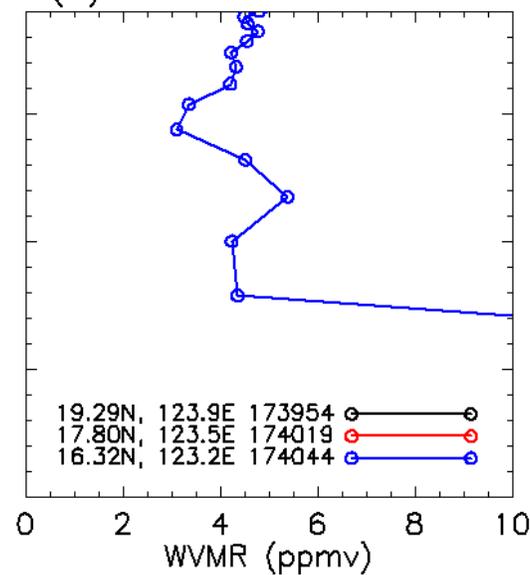
(c) MLS-V5 20170822



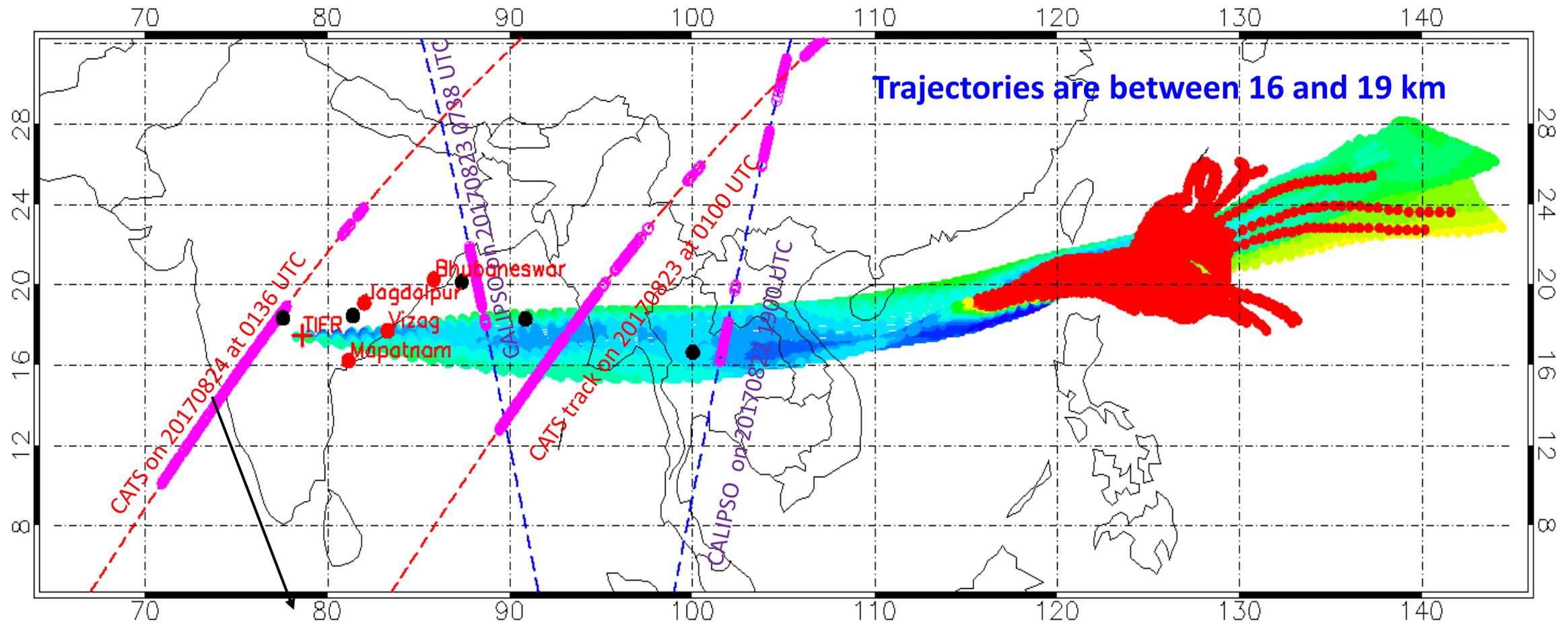
(d) MLS-V5 20170821



(e) MLS-V5 20170820

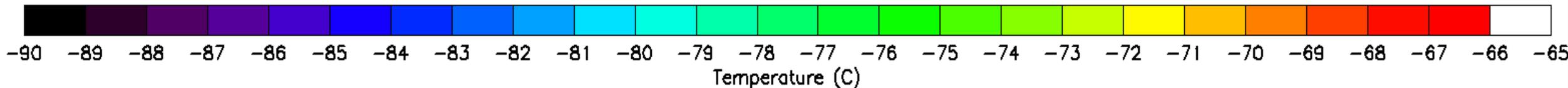


Temperature history of Air Parcels & CALIOP/CATS clouds



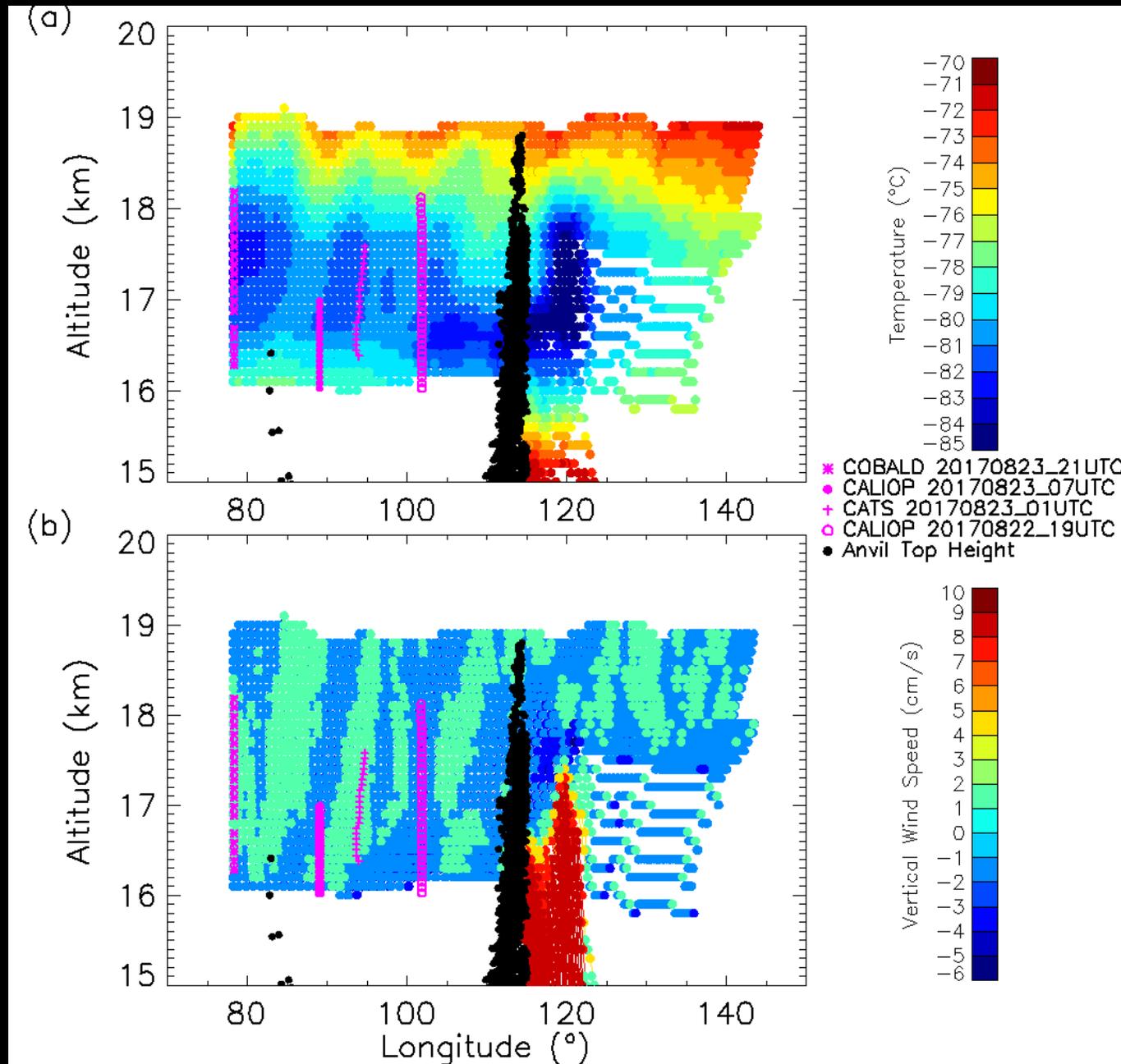
Trajectories are between 16 and 19 km

- Clouds with base altitude >16km (Laminar cirrus)
- 0 UTC IMD Radiosonde
- GPSRO Temperature profile



Tropopause cirrus clouds are found in the colder regions along the back-trajectories

Temperature, Vertical Velocity of Air Parcels, & CALIOP/CATS Clouds Vs Altitude



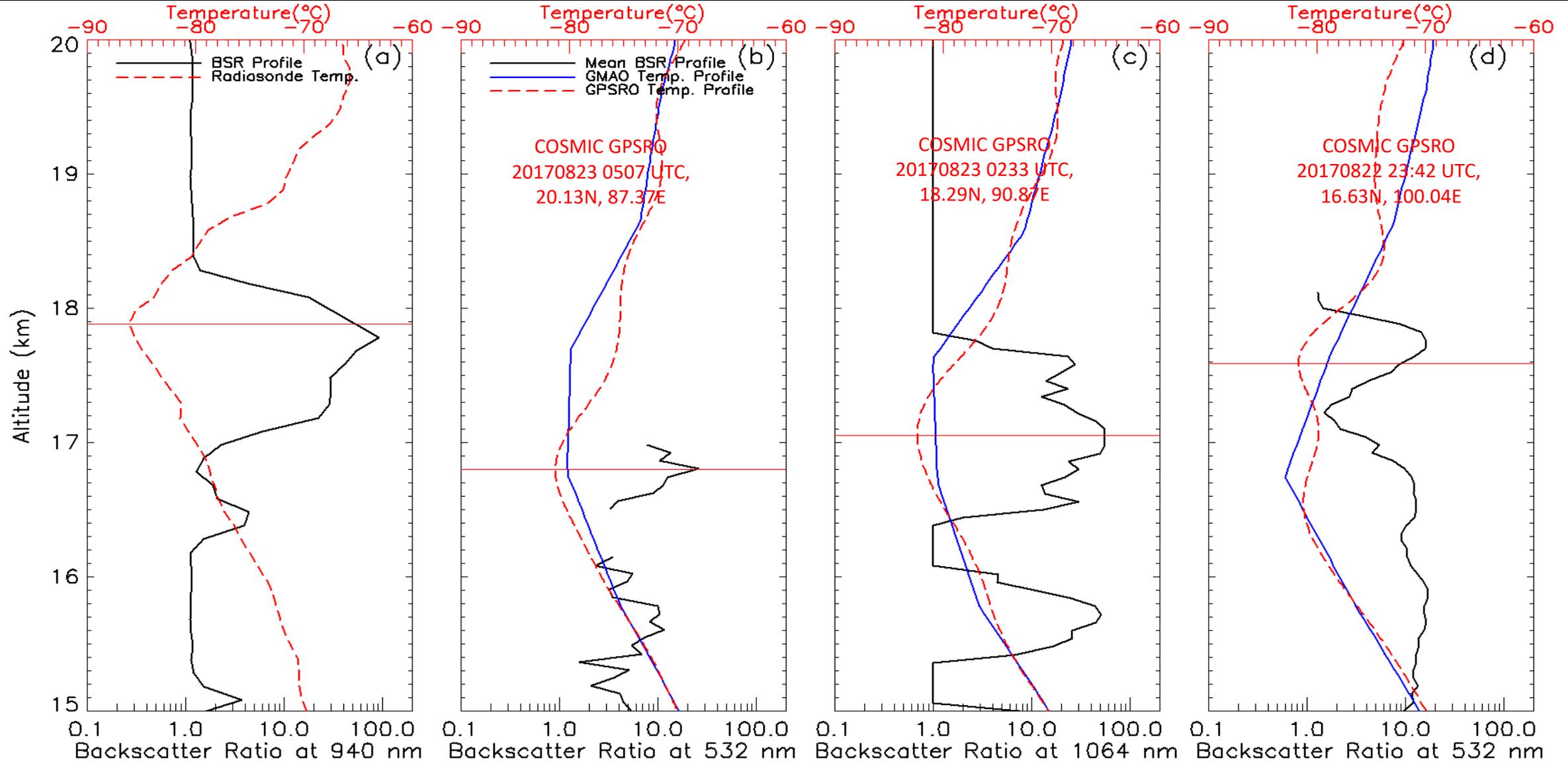
GPSRO Temperature Profiles & CALIOP/CATS Scattering Ratio

COBALD 20170823_2040 UTC,
17.45N, 78.31E

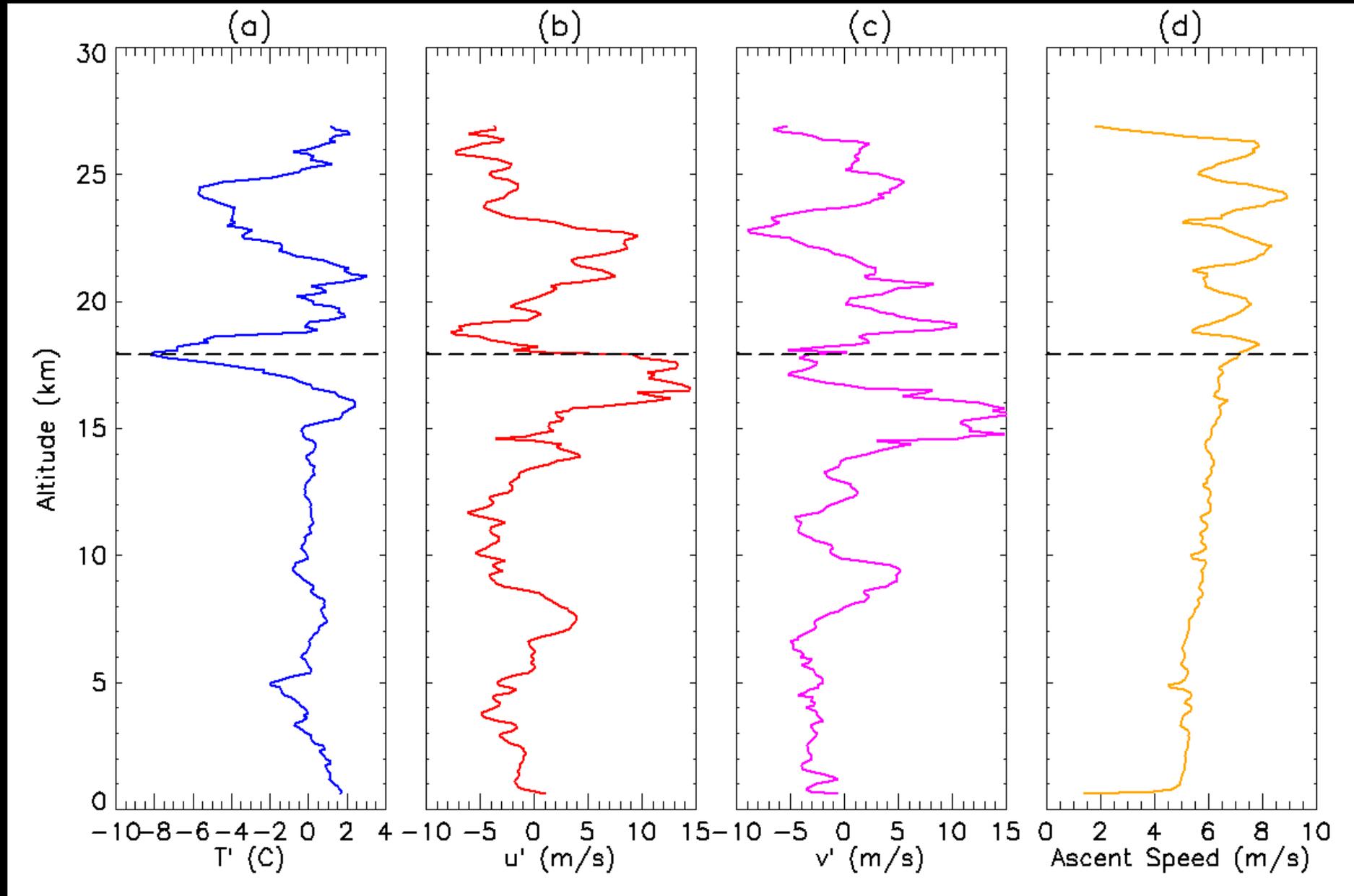
CALIOP 20170823_0738 UTC,
16.99N, 88.88E

CATS 20170823_0059UTC,
17.01N, 92.68 E

CALIOP 20170822_1907 UTC,
16.99N, 101.68E



Anomalies in Temperature (T'), Zonal (u') and Meridional Wind Speed (v')



Concluding Remarks

- First balloon-borne measurements of ice-crystal characteristics over the Asian Summer Monsoon region are conducted during the BATAL campaign in Hyderabad, India.
- Cirrus clouds form frequently in the cold-temperature anomalies near the cold-point tropopause (16-18 km) during the Asian Summer Monsoon.
- Boulder Counter & COBALD measurements were used to derive optical and microphysical properties of a tropopause cirrus.
- The ice-water content for this layer estimated from our measurements is 0.17 mg/m^3 .
- Layer mean lidar ratio (30.9 sr) is also estimated using independent measurements of backscatter and extinction coefficients from COBALD and Boulder Counter measurements, respectively.
- Ice-crystals in tropopause cirrus cloud layer are smaller than $50 \text{ }\mu\text{m}$ and they are mostly spheroids in shape
- The formation mechanism responsible for this tropopause cirrus is investigated using three-dimensional back trajectories, observations from space-borne lidars (CALIOP/CALIPSO and CATS/ISS) along with cloud-top brightness temperature images from Himawari-8 satellite and temperature from GPS radio occultation temperature measurements.
- These combined data suggest that the formation of the tropopause cirrus is likely influenced by a Category-3 Typhoon, *Hato* which hit Macau and Hong Kong on 23 August 2017.

Thank you!

Back-up Slides

Microphysical Properties of Tropopause Cirrus Clouds during BATAL Campaigns in India



BATAL: Balloon measurement campaigns of the Asian Tropopause Aerosol Layer



(July-August
2014-2019)

Gadanki, India

Hyderabad, India

Varanasi, India

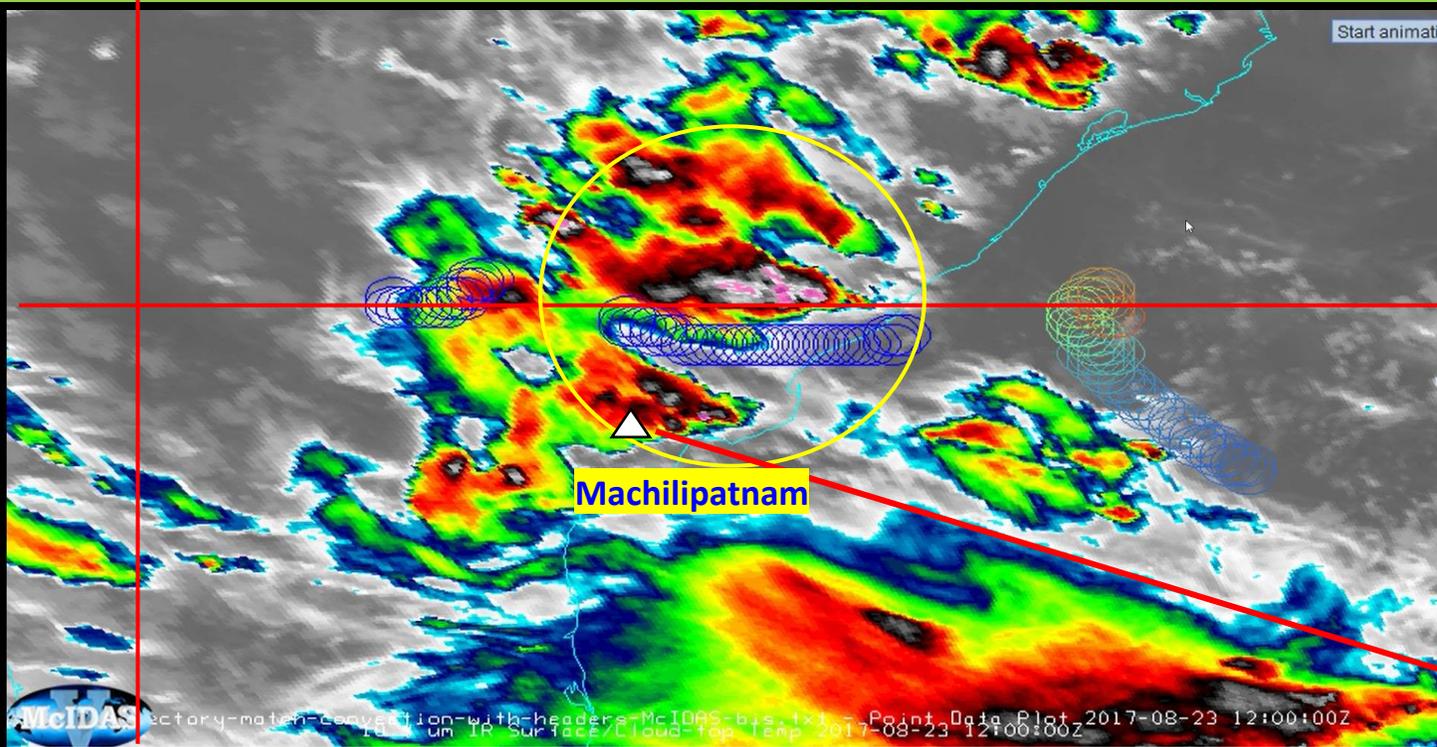
Thuwal, Saudi Arabia



Acknowledgements

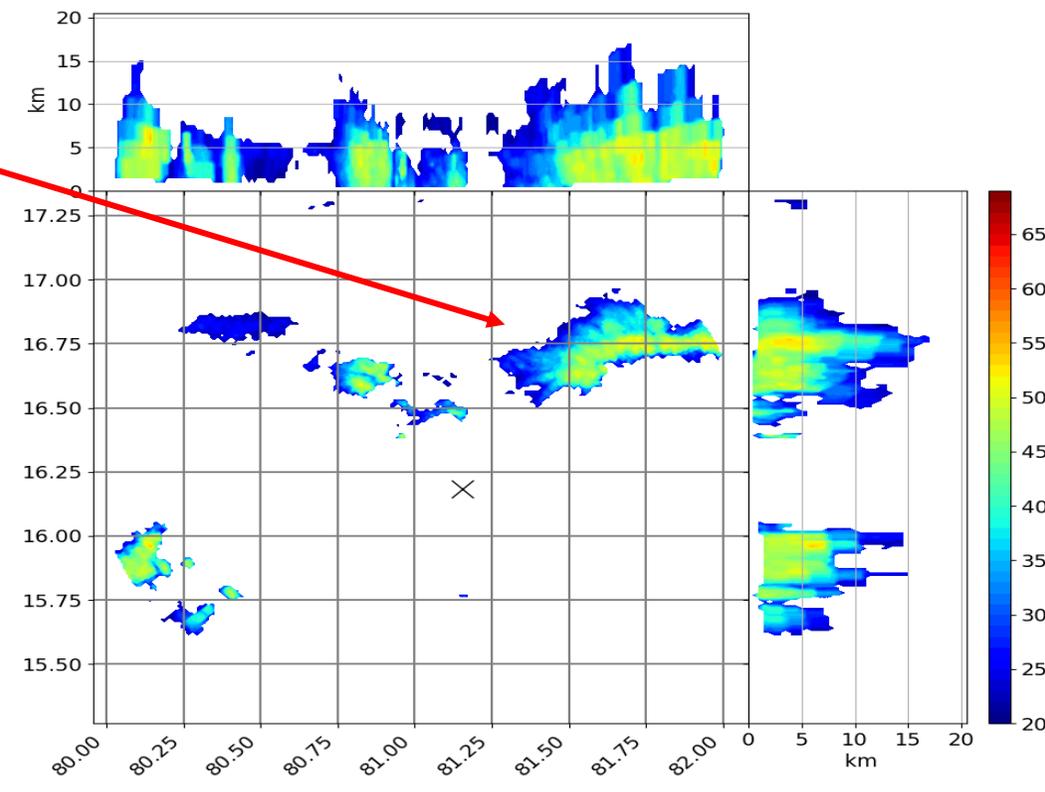
- NASA UARP/ACMAP, ISRO, NPP, and NIA for the funding support.
- Technical and logistical support from NASA LaRC, NIA, USRA, TIFR-BF, NARL and PRL.

Formation Mechanism: Local Convection

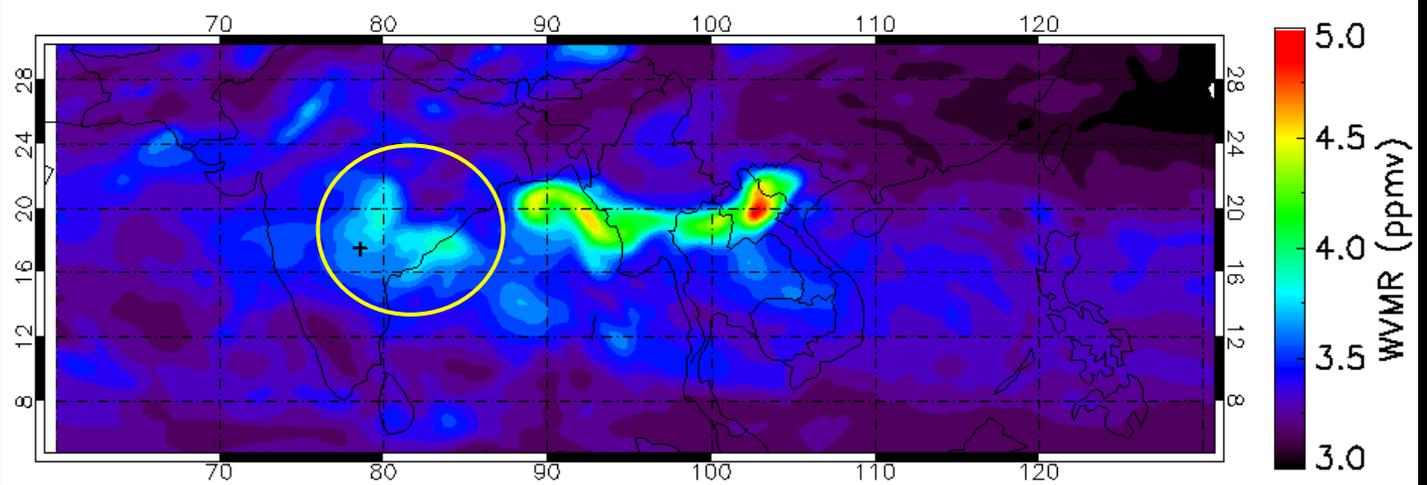


- No nearby CATS and CALIOP overpasses
- No MLS WVMR profiles

Machilipatnam Doppler Radar, 20170823, 1201 UTC



ERA5 WVMR at 70 hPa 2017-08-23 1200



Tropopause Temperature Variations on 23 August 2017 in and around Hyderabad

Date/Time	23 Aug 2017, 0UTC	23 Aug 2017, 14 UTC	23 Aug 2017, 2046 UTC	23 Aug 2017, 2150 UTC	24 Aug 2017, 0 UTC
Lat/Lon	~ 17.40, 78.46, 0UTC	18.449, 81.40, 14UTC	17.445N, 78.297, 20:54:59 UTC	17.396, 77.359, 21:49:46 UTC	~ 17.40, 78.46, 0UTC
Displacement from TIFR-BF (km)	~100	332	38.9	135.5	~100
CPT Altitude (km)	17.20	17.30	17.9	17.75	17.7
CPT Temp (°C)	-77.2	-82.5	-86.4	-86.1	-81.5

- Convection peaks in the late afternoon and early evening hours
- Convectively influenced tropopause cooling could have formed the tropopause cirrus cloud