Balloon Measurements of Cirrus Clouds over Hyderabad during BATAL Campaign

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[1]National Institute of Aerospace, Hampton, USA
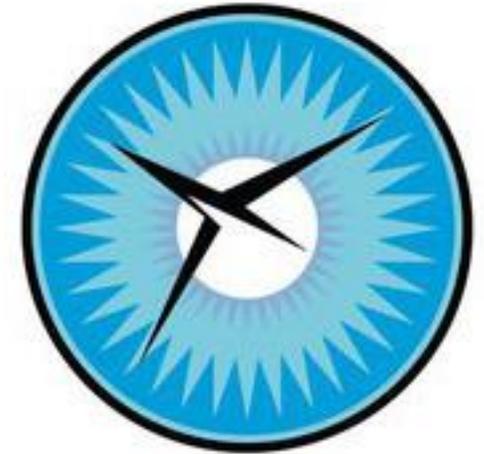
[2]NASA Langley Research Center, Hampton, USA

[3]SPEC Inc., Boulder, USA.

[4]Physical Research Laboratory, Ahmedabad, India

[5] National Atmospheric Research Laboratory, Gadanki, Ind

[6]TIFR Balloon Facility, Hyderabad, India.

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Balloon Measurement Campaigns of the Asian Tropopause Aerosol Layer (BATAL)

BATAL campaigns 2014-2019

Balloon Trajectories: Ascent/Descent (2015)
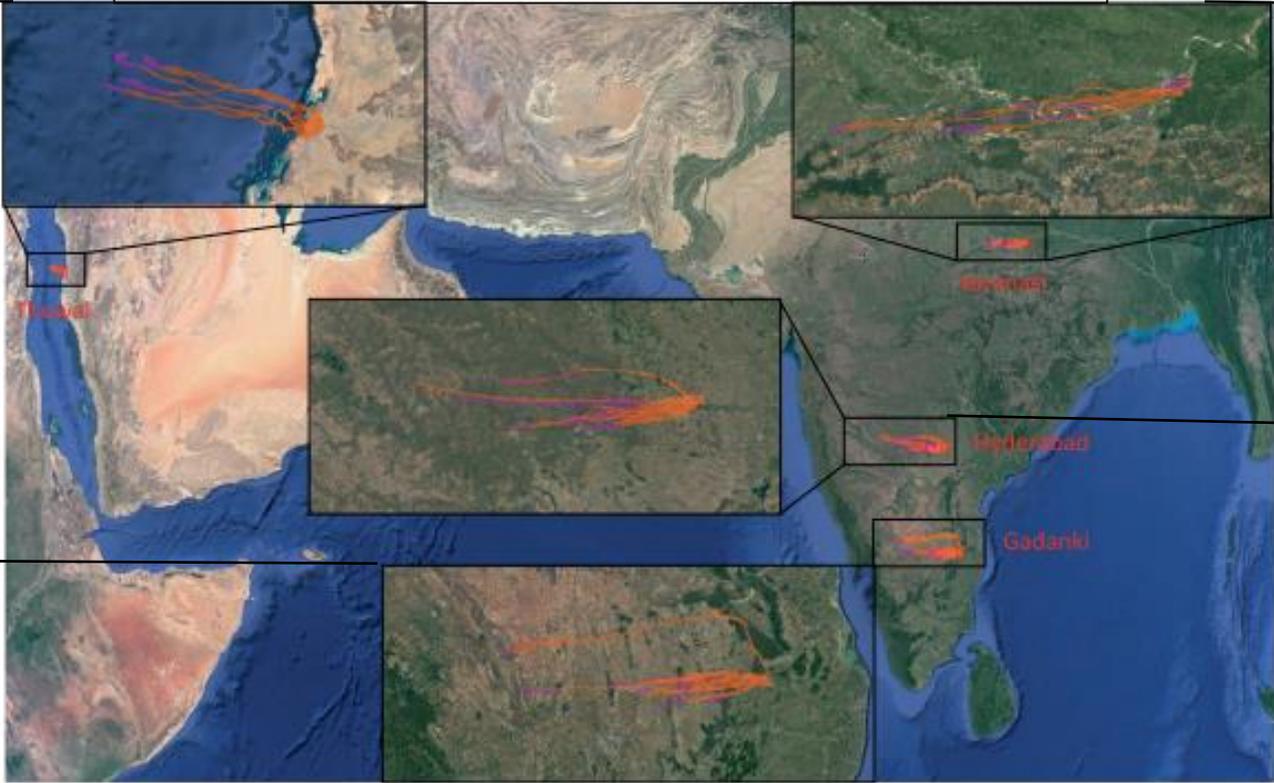
King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia

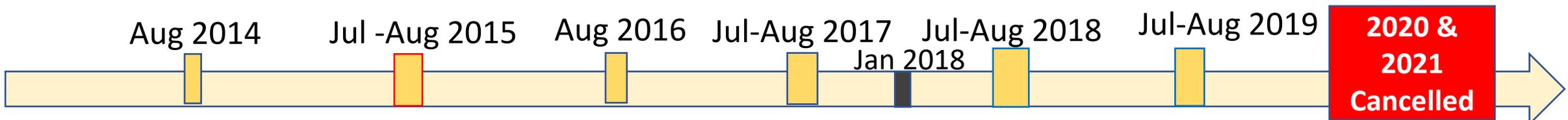Banaras Hindu University (BHU), Varanasi, India

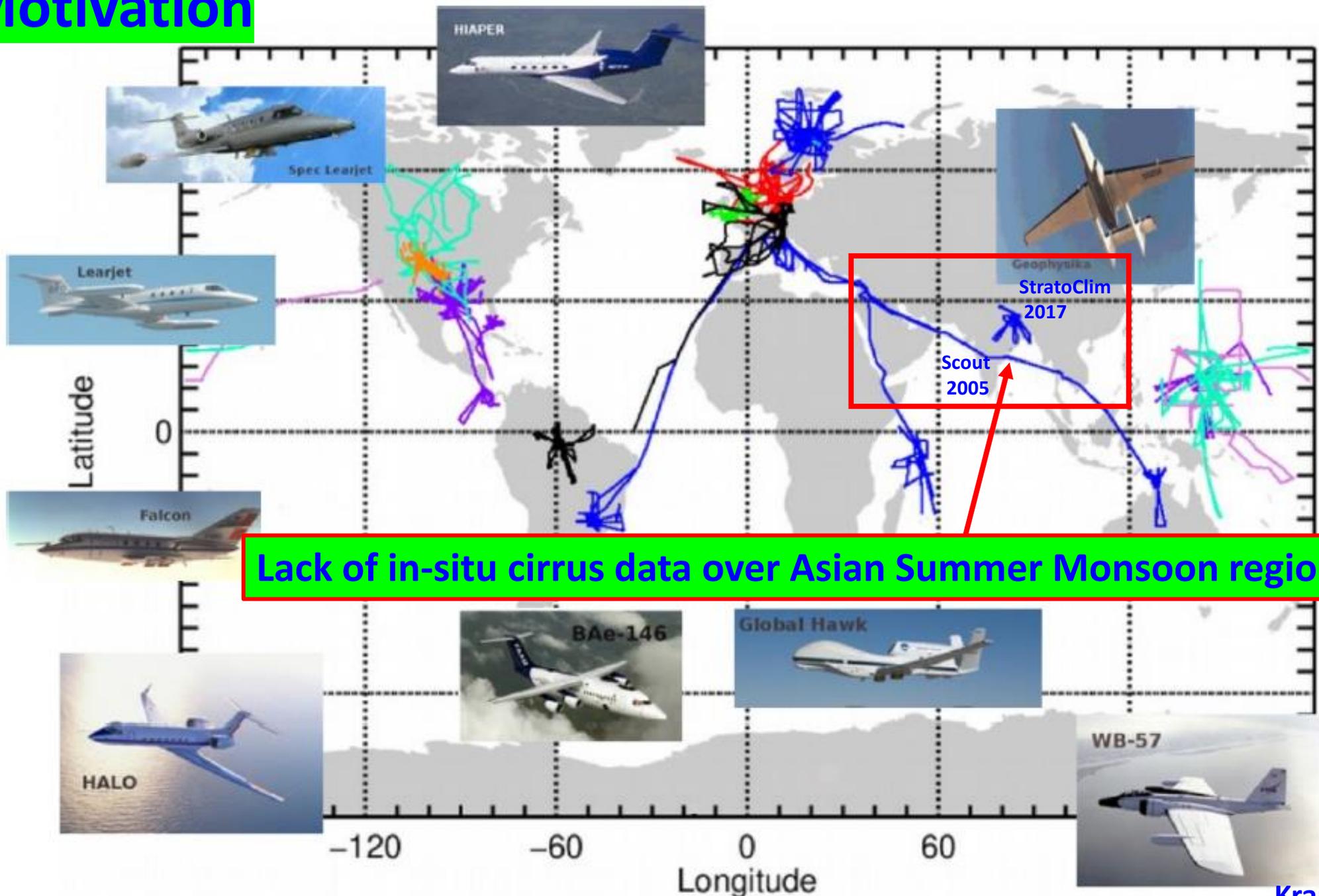National Atmospheric Research Laboratory (NARL), Gadanki, India

Tata Institute for Fundamental Research Balloon facility (TiFR)

Vernier et al., 2018, BAMS

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

Aug 2014   Jul -Aug 2015   Aug 2016   Jul-Aug 2017   Jul-Aug 2018   Jul-Aug 2019   **2020 & 2021 Cancelled**

Jan 2018

Motivation

StratoClim 2017

Scout 2005

Latitude

0

Longitude

-120   -60   0   60

Lack of in-situ cirrus data over Asian Summer Monsoon region

cirrus2003
cirrus2004
cirrus2006
airtoss2013_1
airtoss2013_2

coalesc2011

ape_theseo1999
envisat2002_2
euplex2003
envisat2003_1
troccinox2005

scout2005
stratoclim2017

crystal-face2002
midcix2004
tc4_2007
macpex2011
posidon2016

ml-cirrus2014
acridicon2014

attrex2014

start2008
contrast2014

LTU2012-18

sparticus2010

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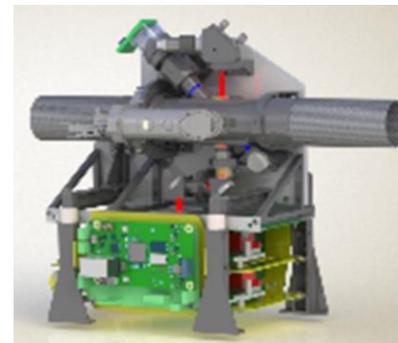
## Micro-COPP: Heritage from Global Hawk payload used during ATTREX

Micro-COPP

FSSP
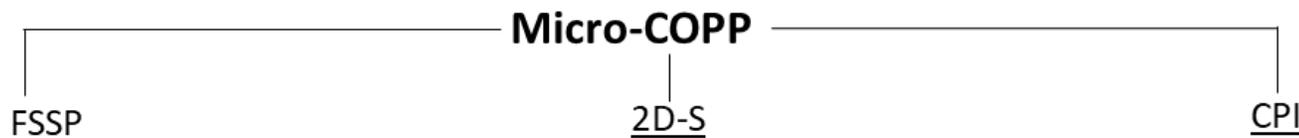
- Forward Scattering Spectrometer Probe
- Size distribution and concentration of cloud particles
- 1 to 50 µm over 20 bins

2D-S

- 2-Dimensional Optical Array Probe
- size distribution, concentration, and area/extinction of cloud droplets, precipitation and ice crystals
- Size range: 5µm-1mm
- 10 to 25 µm pixel resolution

CPI

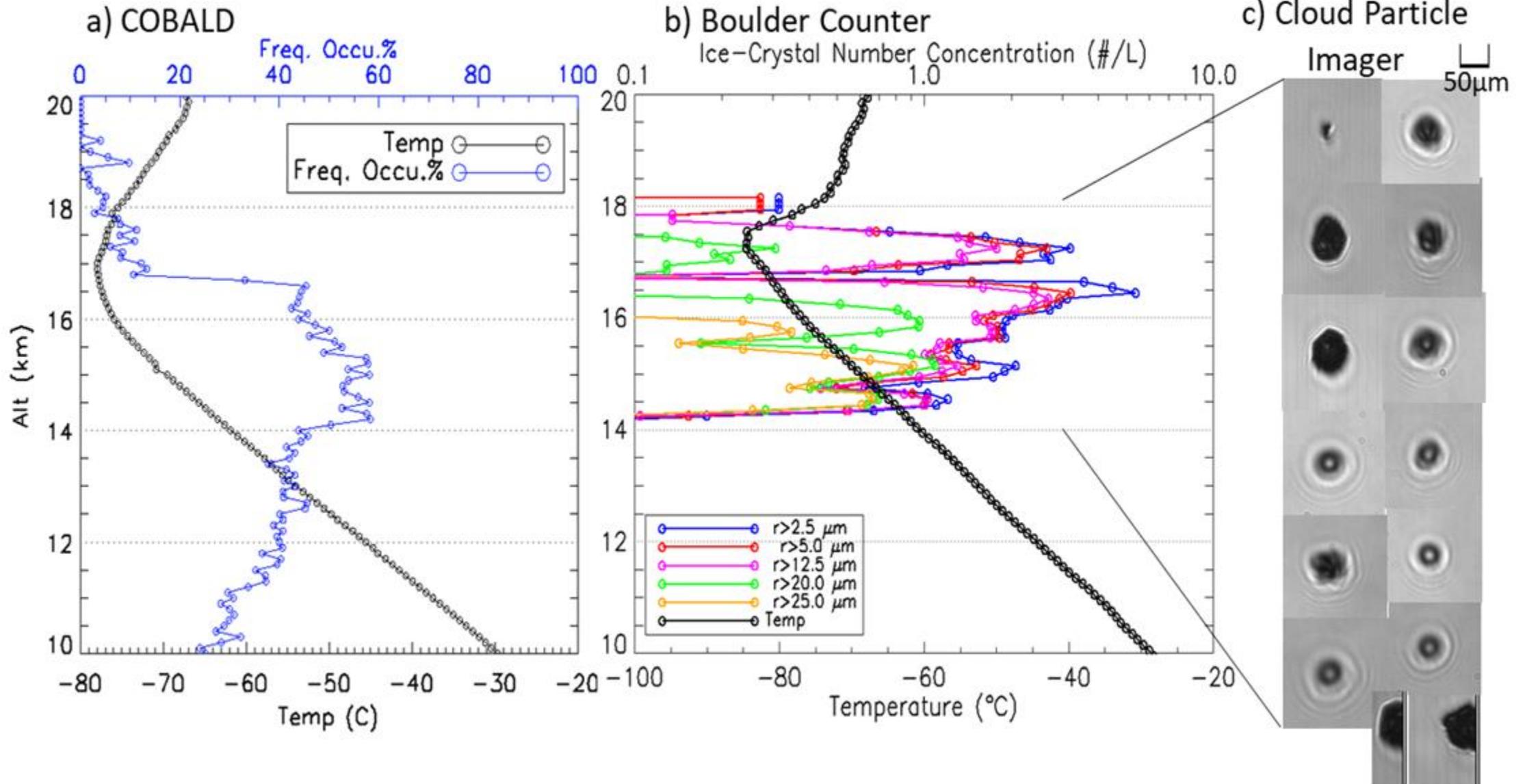- Cloud Particle Imager
- Digital camera
- Up to 400 frames per second
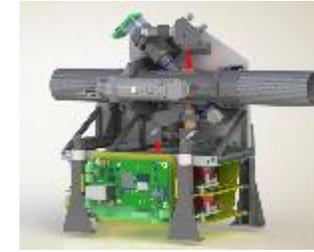- Size range: 5µm-1mm
- Resolution 1 µm
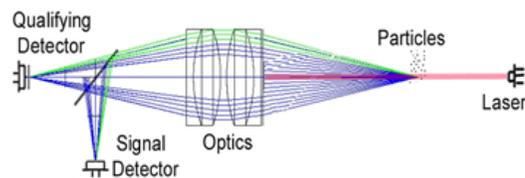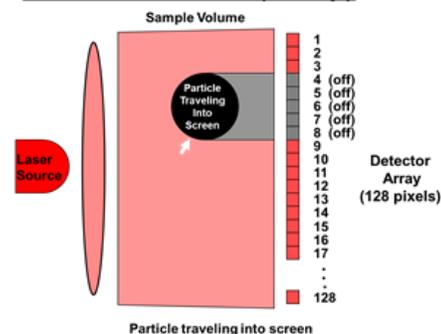
Altitude Distribution of Occurrence Frequency, Size and Shape of Ice crystals over Hyderabad
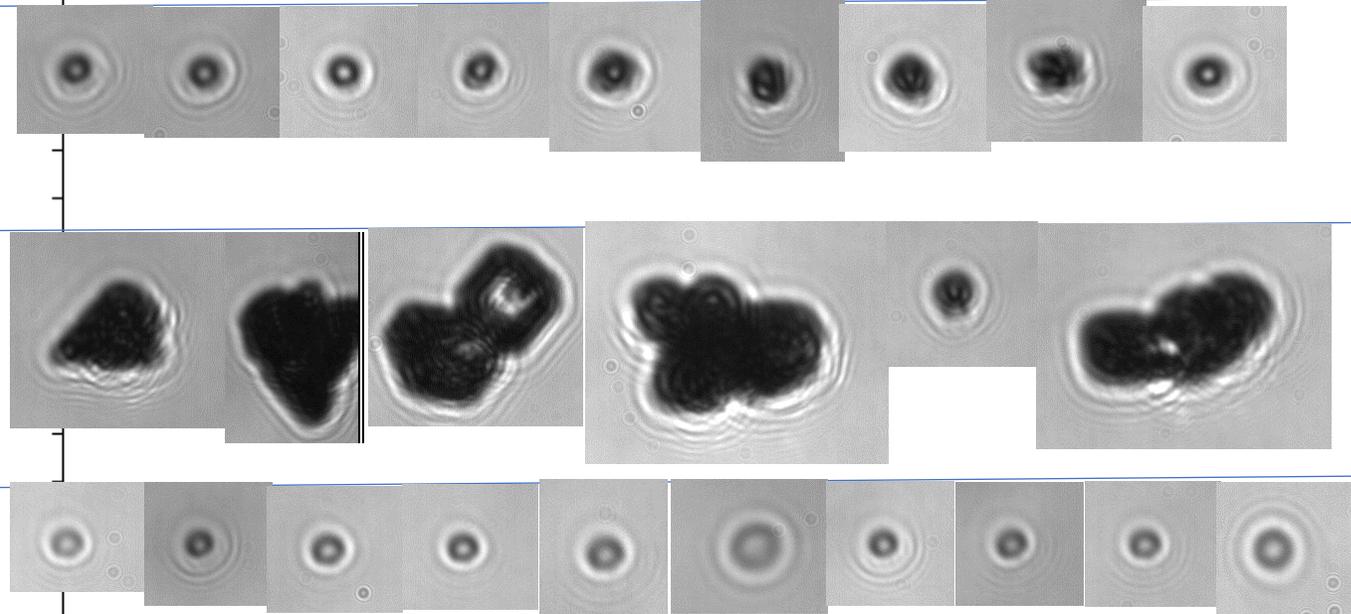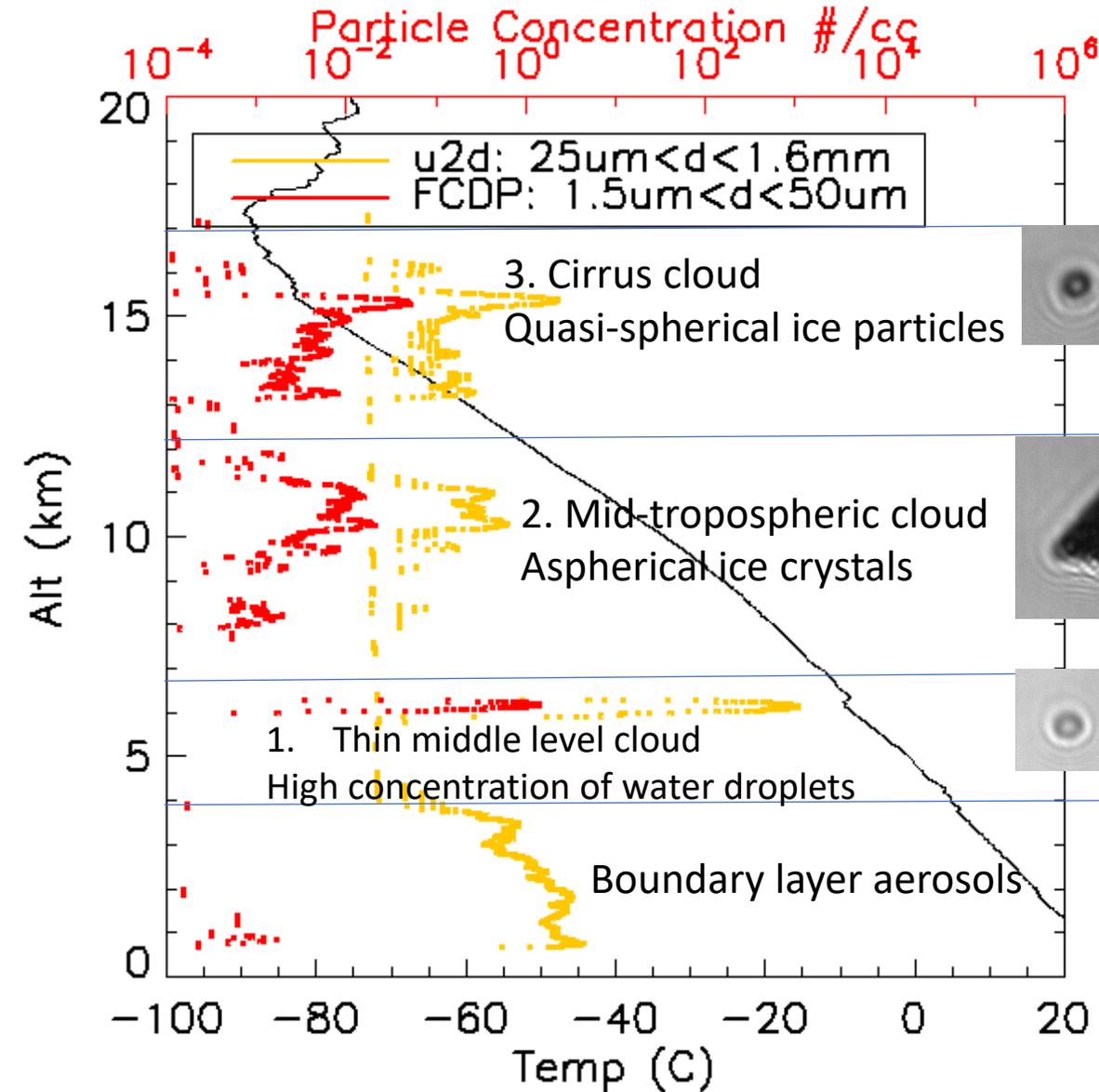
First balloon-borne characterization of ice particles during Asian Summer Monsoon
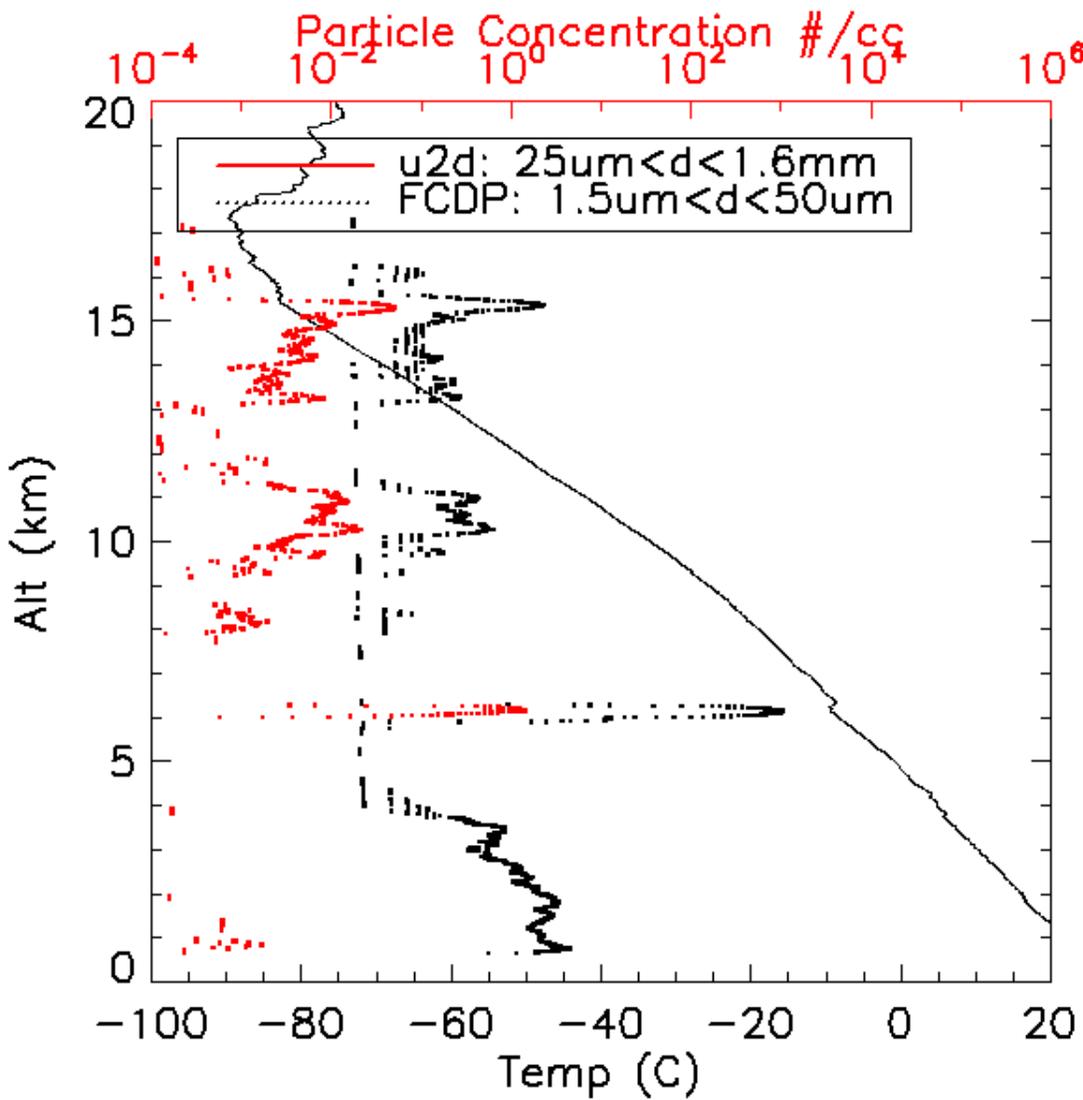

29 August 2018

Cloud Particle Imager (CPI)

200µm

- u2d: 25um<d<1.6mm
- FCDP: 1.5um<d<50um

3. Cirrus cloud
Quasi-spherical ice particles

2. Mid-tropospheric cloud
Aspherical ice crystals

1. Thin middle level cloud
High concentration of water droplets

Boundary layer aerosols

- Balloon measurements unaffected by shattering

Particle Concentration #/cc

Alt (km)

Temp (C)

Micro-COPP Vs COBALD
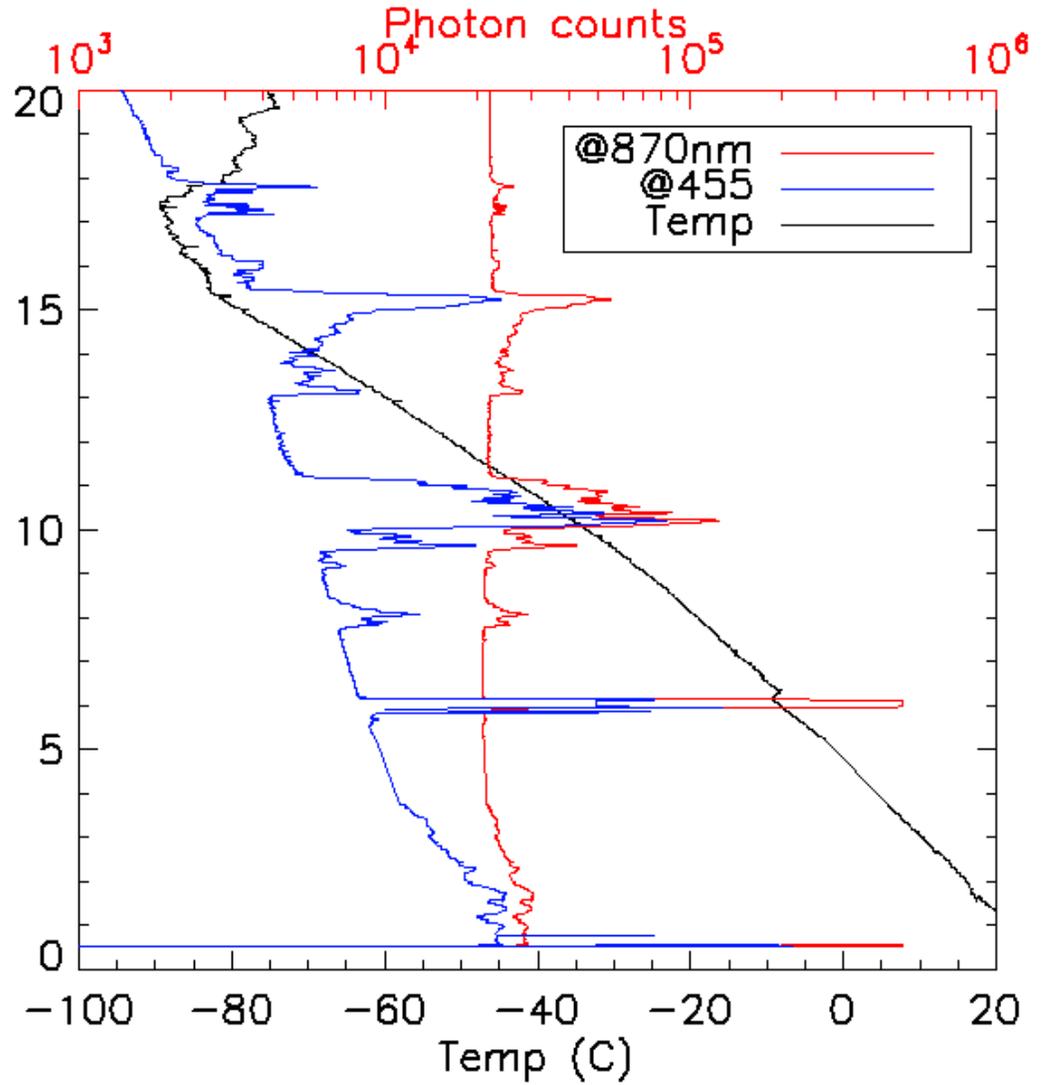
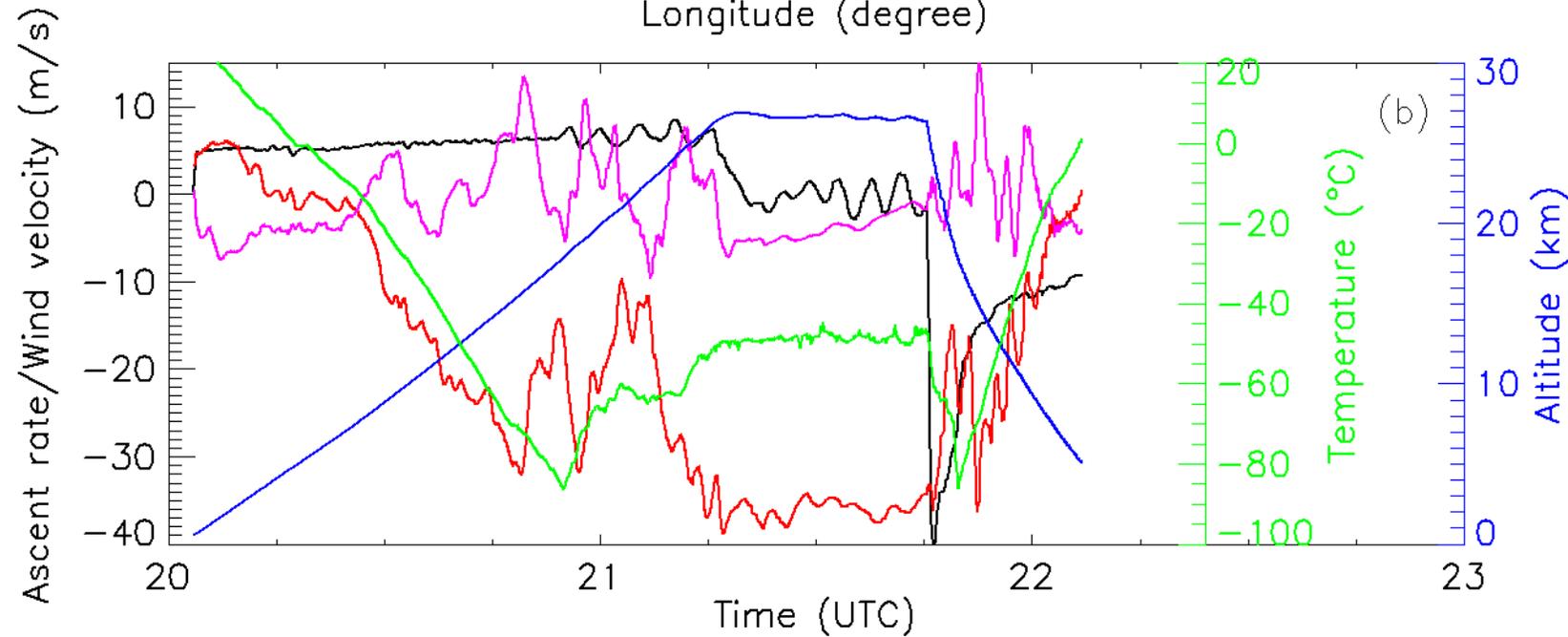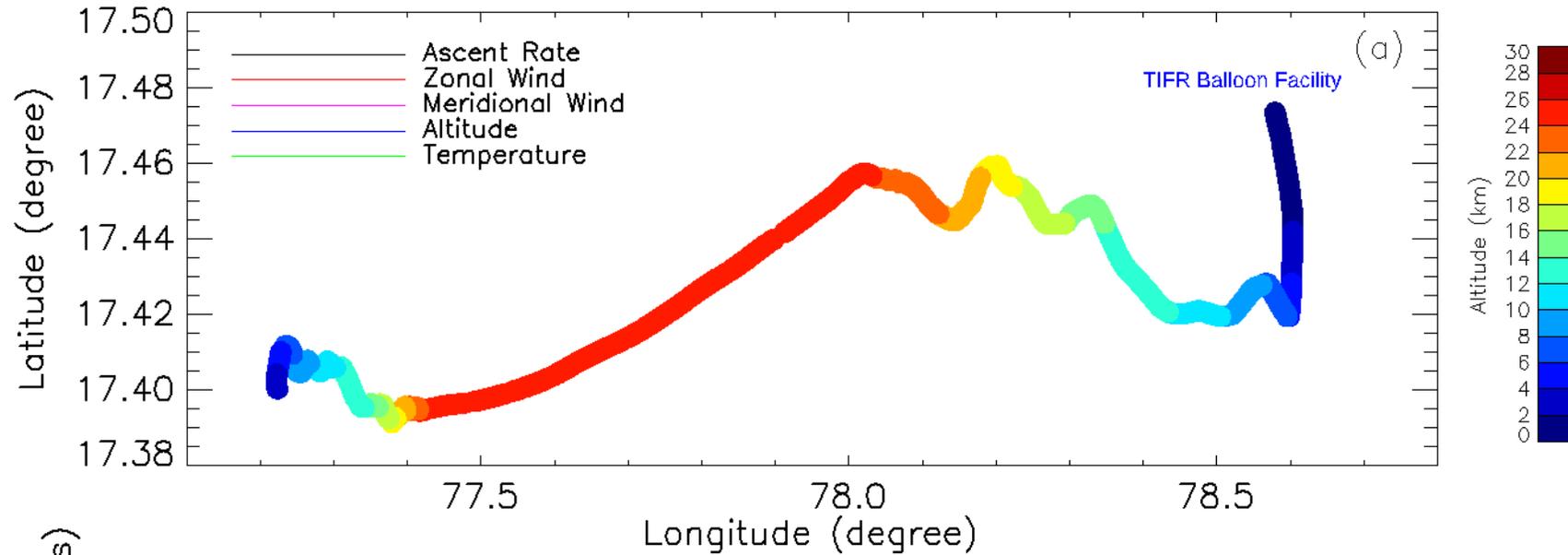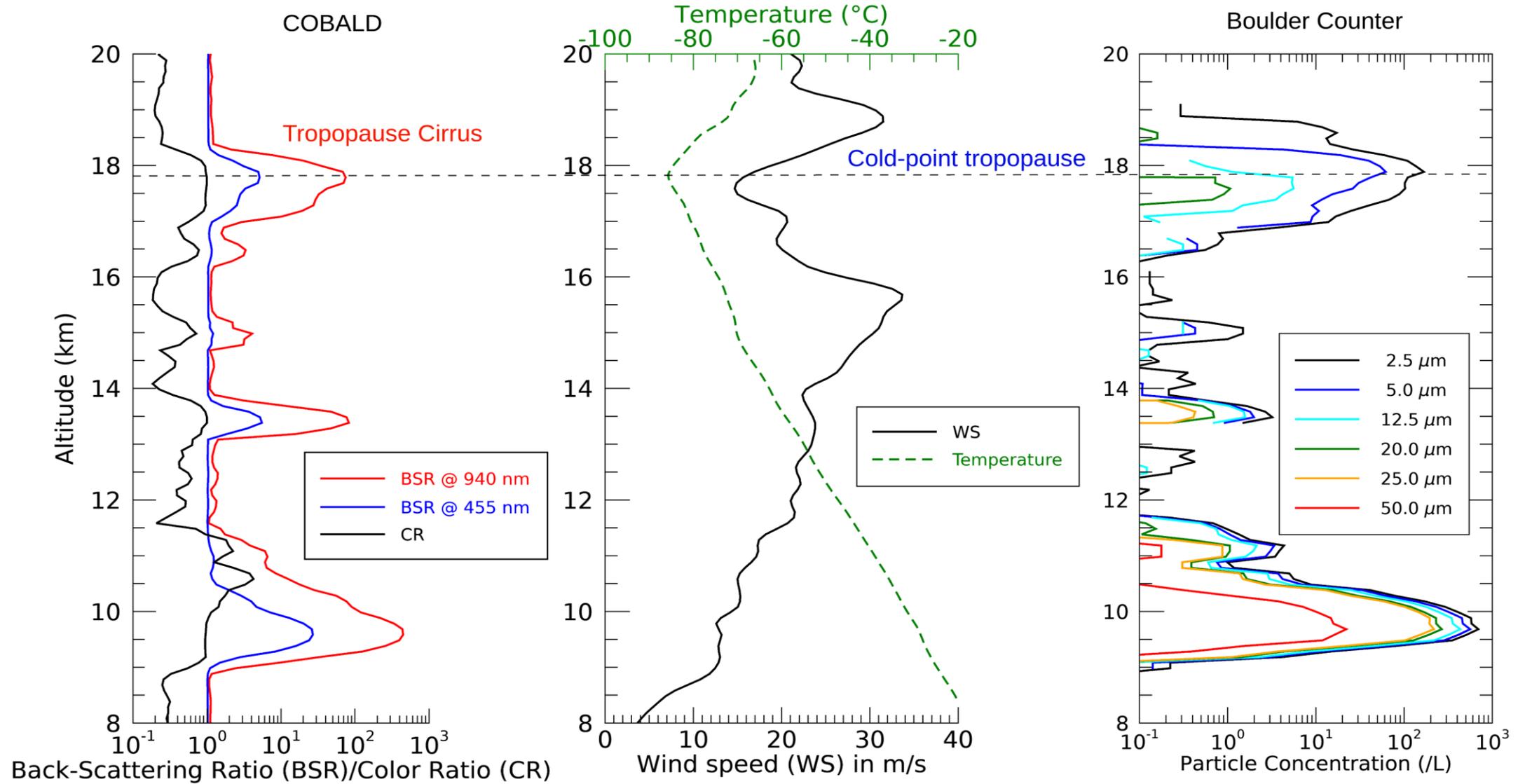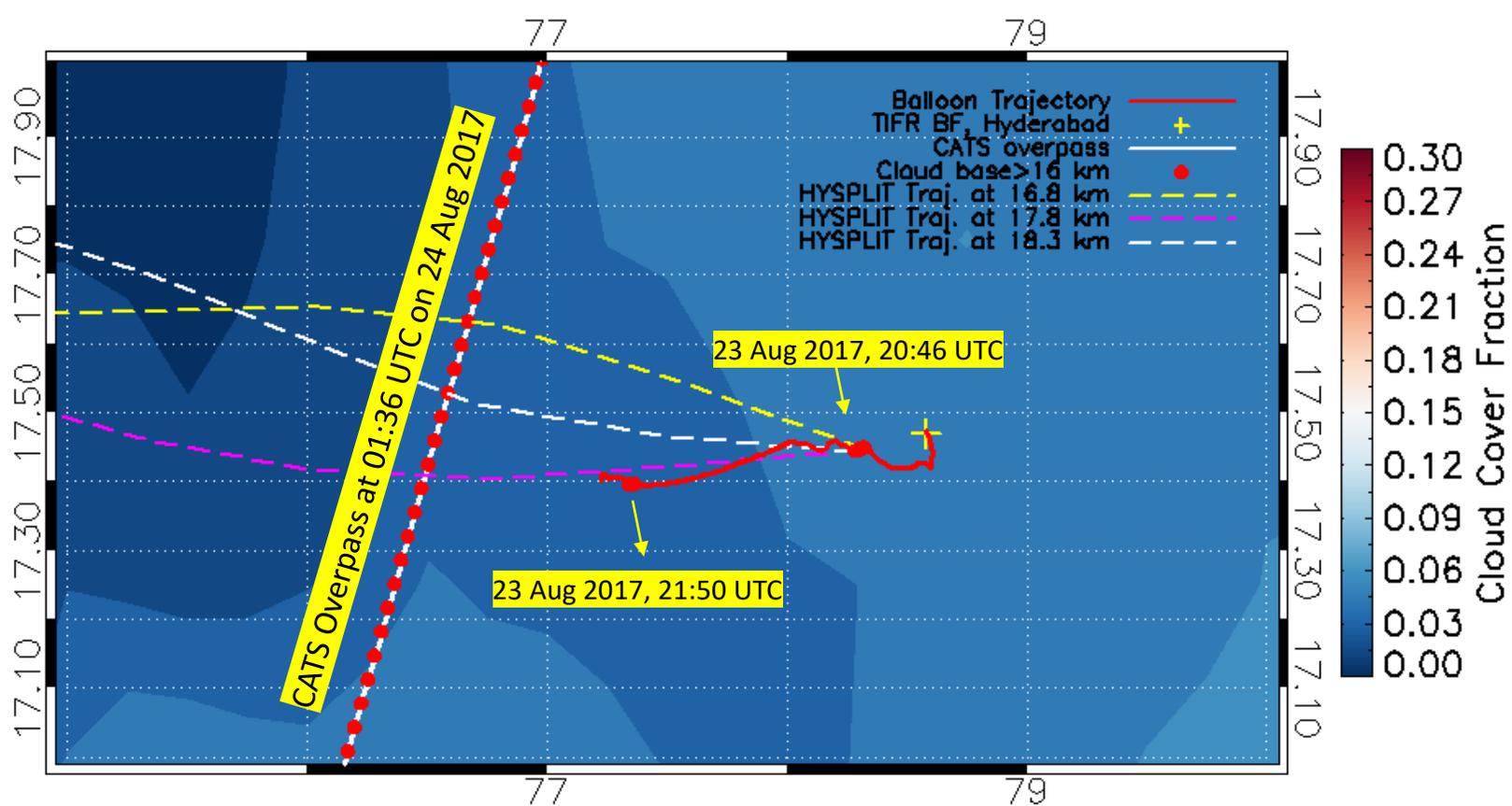# Balloon flight Trajectory on 23 August 2017 from TIFR Balloon Facility Hyderabad, India

Time evolution of meteorological parameters measured by an onboard radiosonde

HF2 Balloon Flight Hyderabad, 23 August 2017

Define color ratio & Backscatter ratio

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

CATS profiles averaged between 17.40N and 17.65N
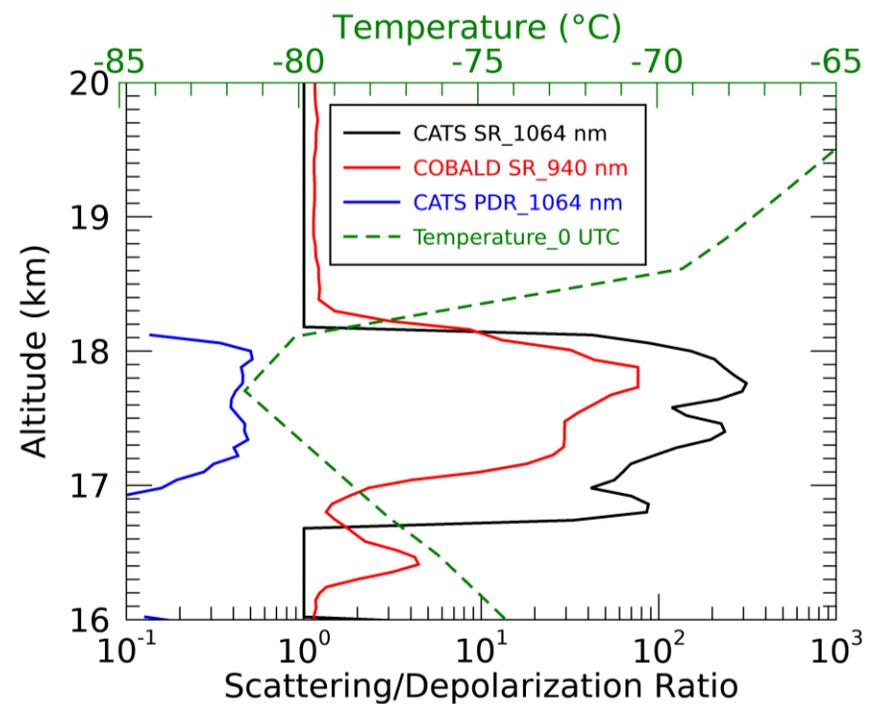
Log-Normal Size Distribution for Tropopause Cirrus ice-crystals using Boulder Counter Measurements

Number & Volume Concentration for 17-18 cloud layer

Sigma=2.50, No=0.25, Rm = 1.66 microns

Legend:
- O O O N_data
- Cumul. No. concn.
- No. concn.
- Vol. concn.

X-axis: Radius (μm)

Y-axis: N, dN/dlog(r) (#/cm^-3), dV/dlog(r) (μm^3 /cm^-3)
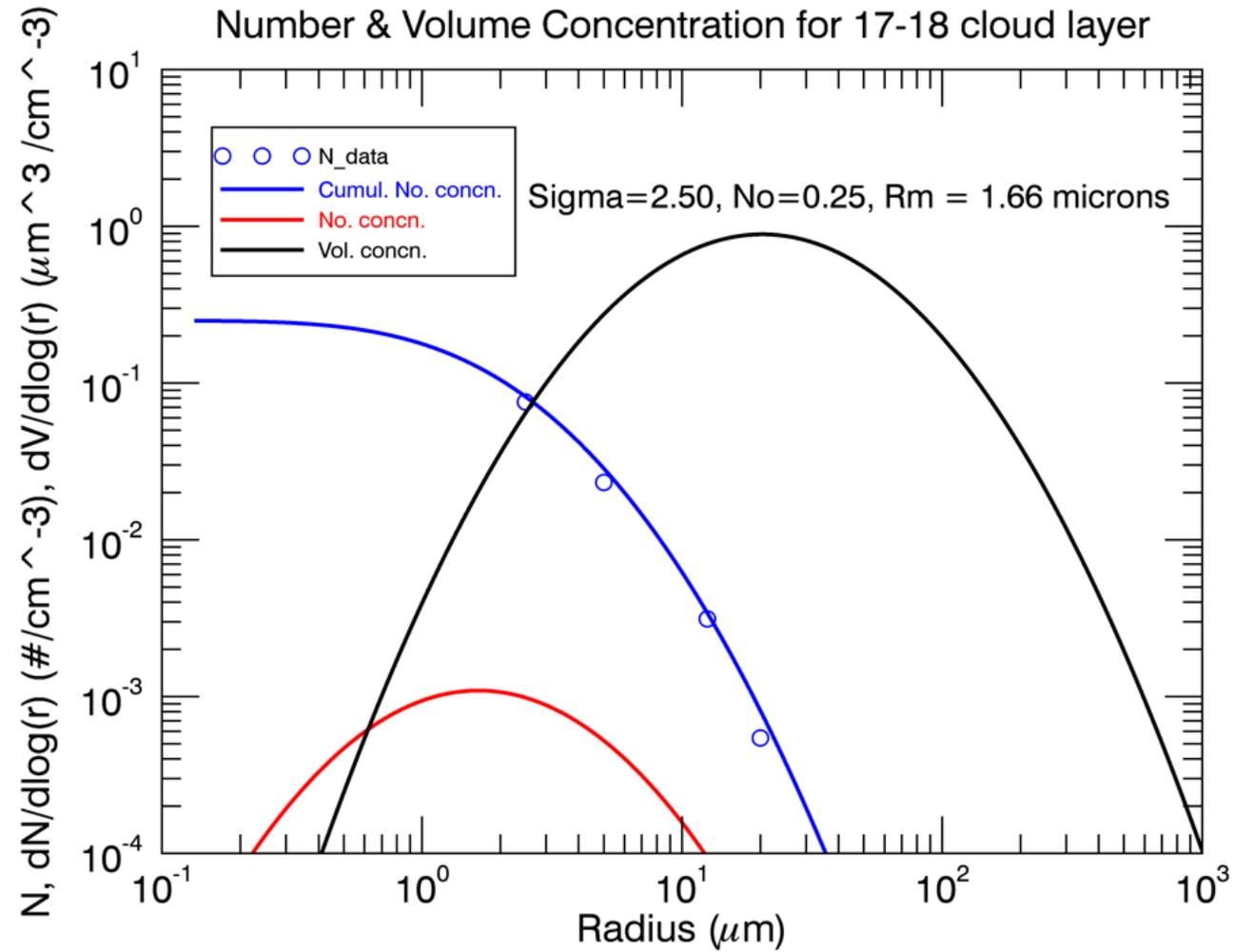
Table1. Optical and Microphysical Properties of Tropopause cirrus cloud

Altitude (km)	Temperature (°C)	Number concentration (#cm-3)	Effective Diameter (microns)	Extinction coefficient (km-1)	Ice-Water Content (mg/m3)	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	-83.93±1.35	0.0953±0.0181	19.45±5.61	0.027±0.009	0.173±0.109	30.9±11.6

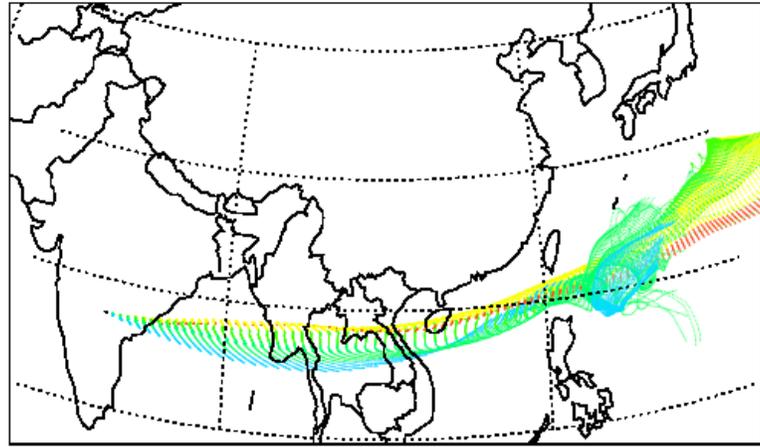Extinction coefficient = $2 \times \Sigma_j\, n_j\, \pi r^2$

Lidar ratio = Extinction coefficient/Backscattering coefficient

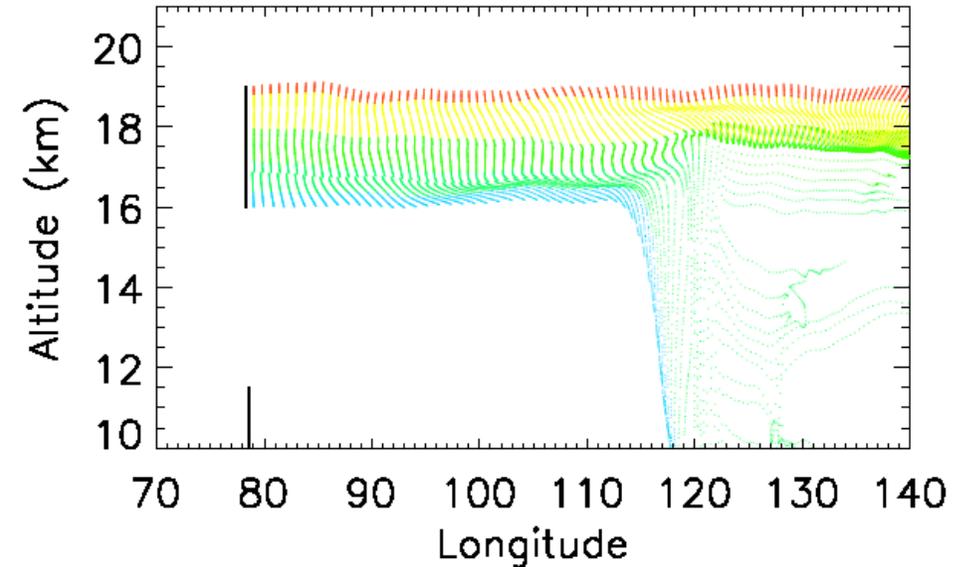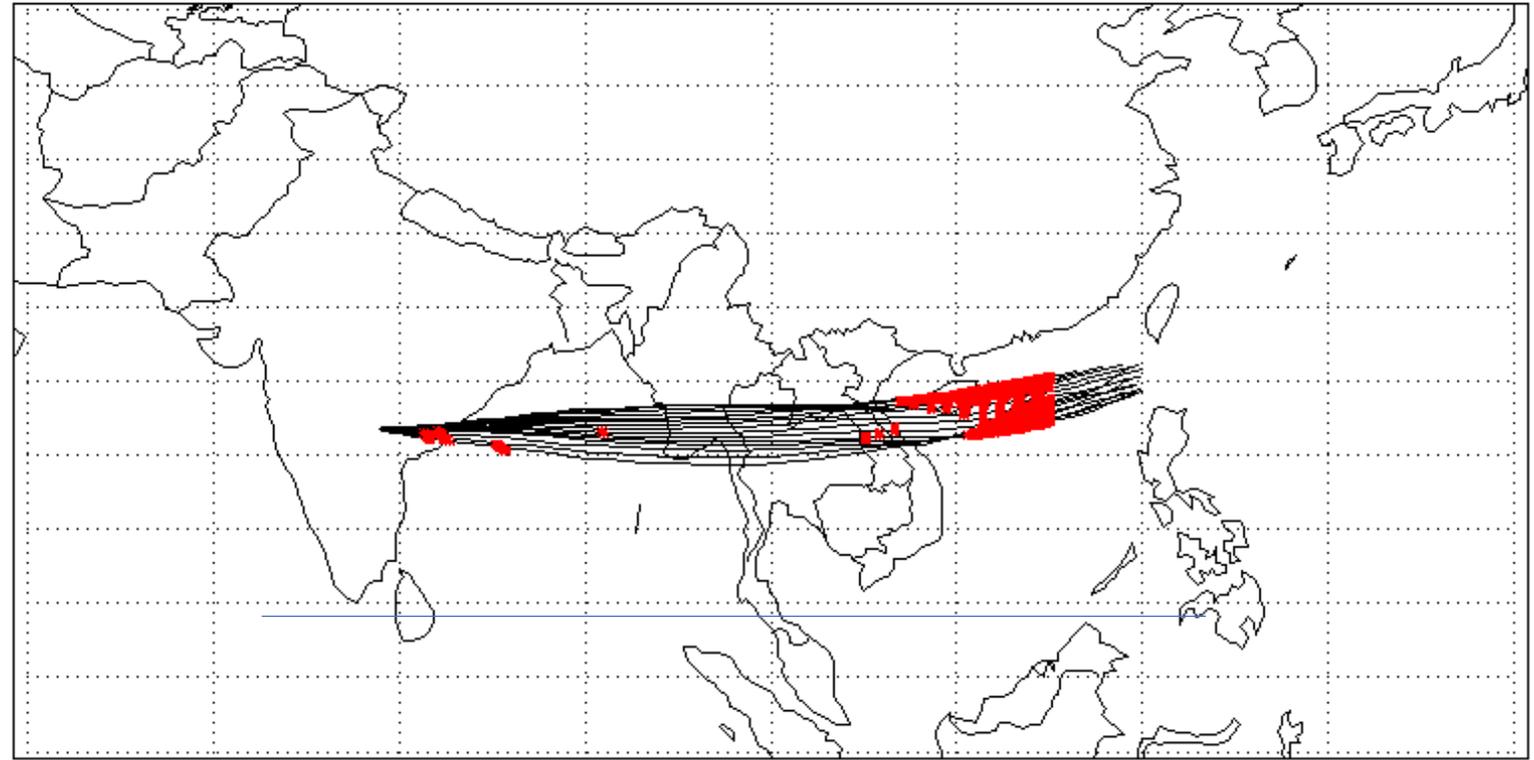LR from CATS = 28 sr, Mean LR from balloon measurement = 30.9 ± 11.6sr

Back-trajectories initialized from the tropopause cirrus location using Langley Trajectory Model (LaTM) and Convective influence from Himawari-8 Cloud top BT images
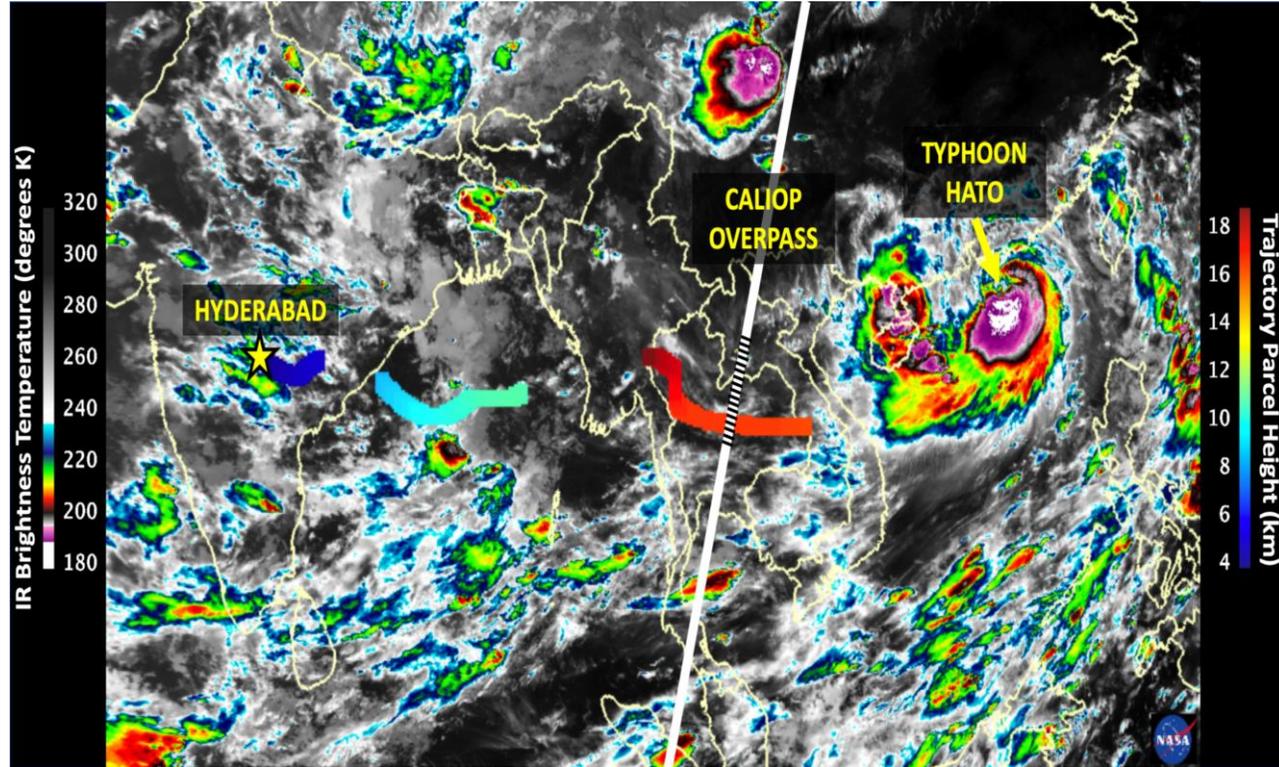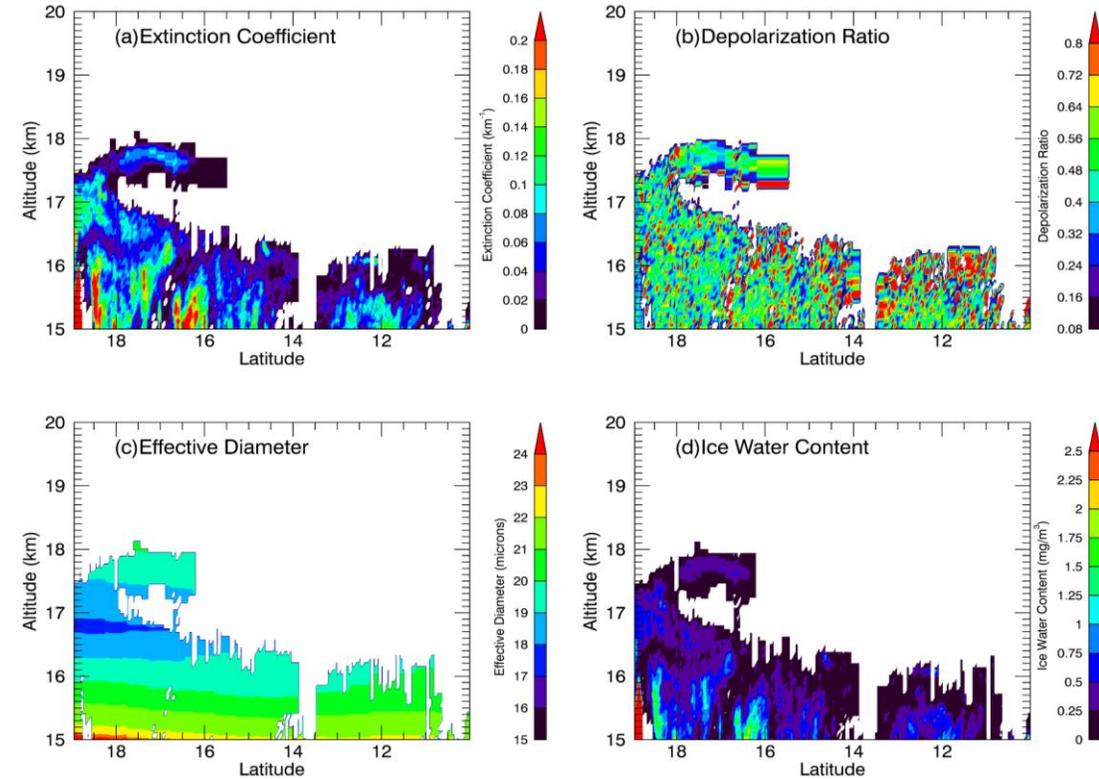
Cloud-top Brightness Temperature from Himawari-8 on 22 Aug 2017 19 UTC & Near-coincident optical & microphysical properties of tropopause cirrus clouds in the outflow of Typhoon *Hato* from CALIOP data
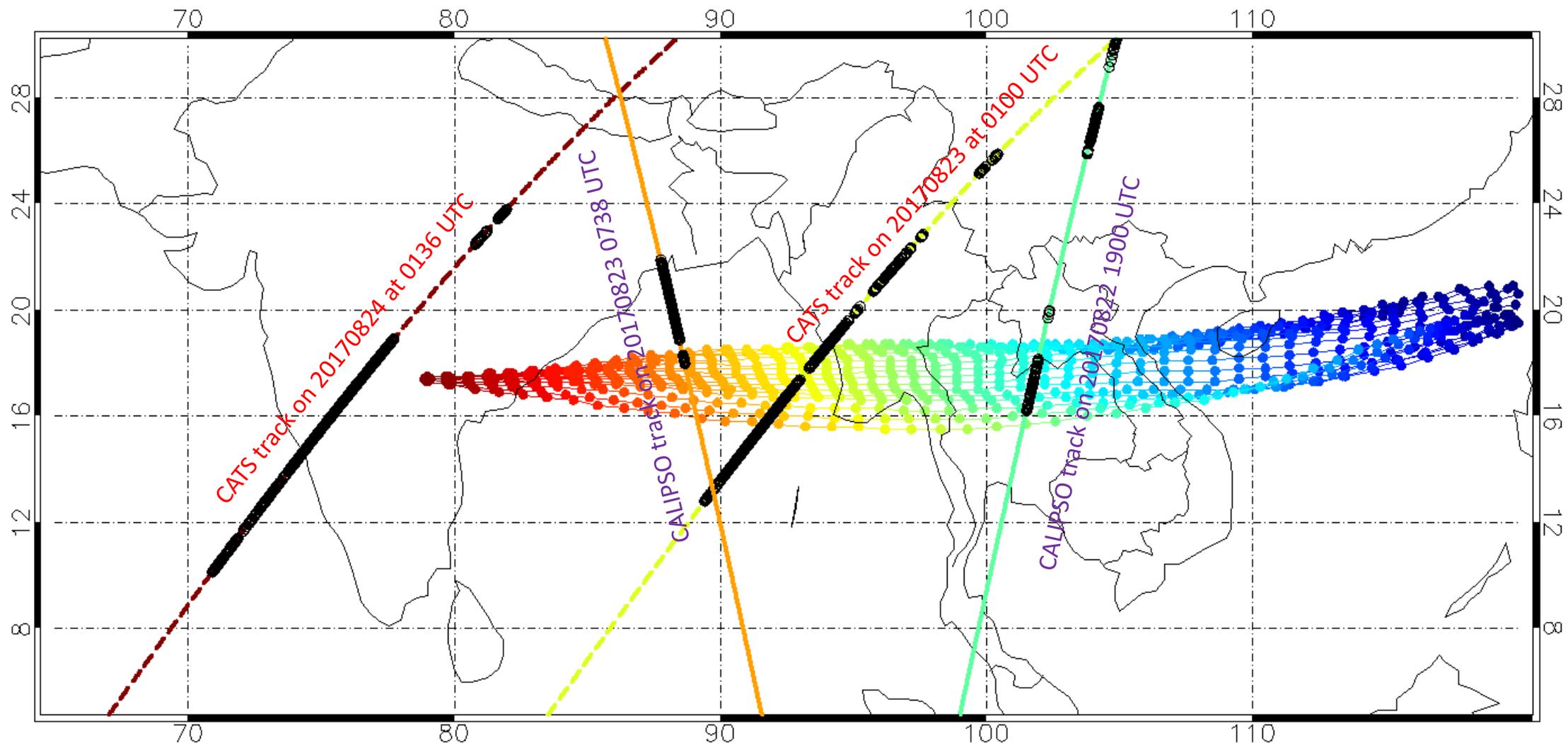

Himawari-8 10.4 μm Cloud Top Brightness Temperature on 22 Aug 2017 19 UTC

CALIOP 22 Aug 2017 19 UTC

Time history of the Back-trajectories and Tropopause Cirrus cloud Information from CATS & CALIOP data

CATS track on 20170824 at 0136 UTC

CALIPSO track on 20170823 0738 UTC

CATS track on 20170823 at 0100 UTC

CALIPSO track on 20170822 1900 UTC

• Clouds with base altitude >16km (Laminar cirrus). Trajectories are between 16 and 19 km

Day Fraction (UTC) in Aug. 2017
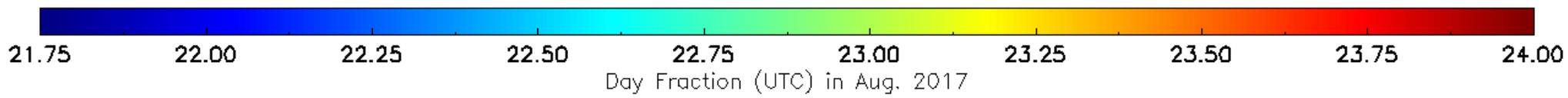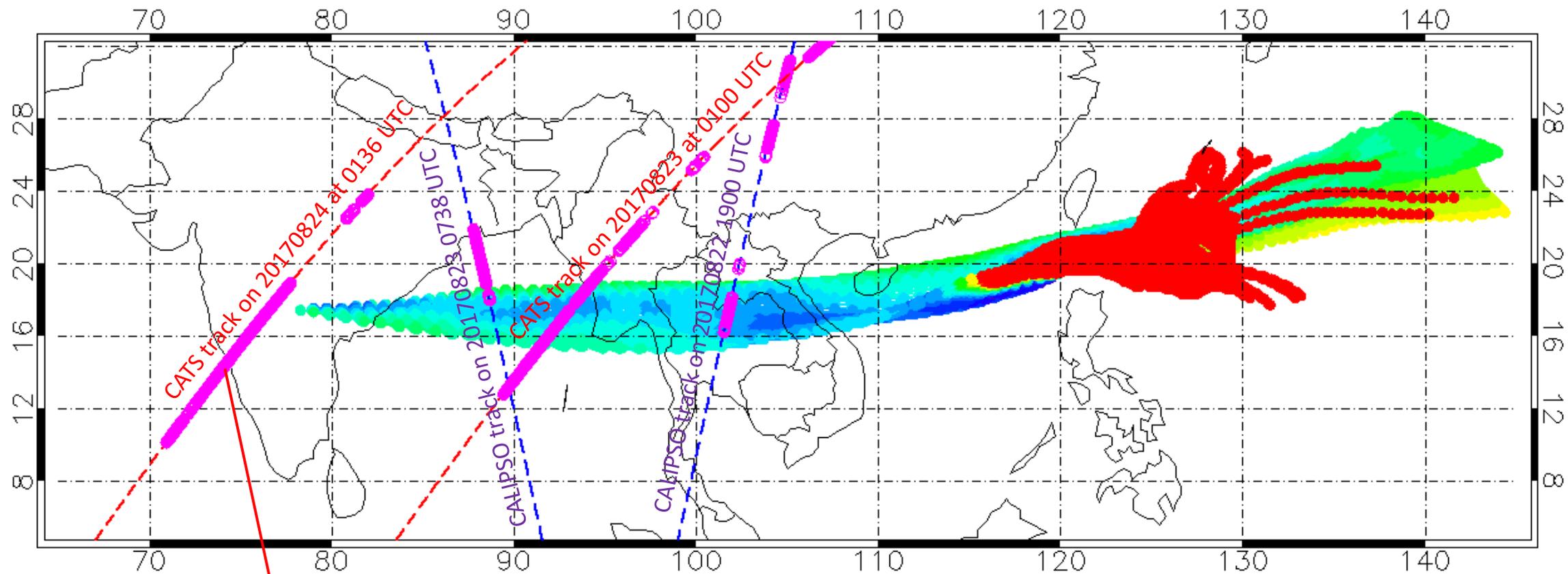
Temperature history of the Back-trajectories and Tropopause Cirrus cloud Information from CATS & CALIOP data

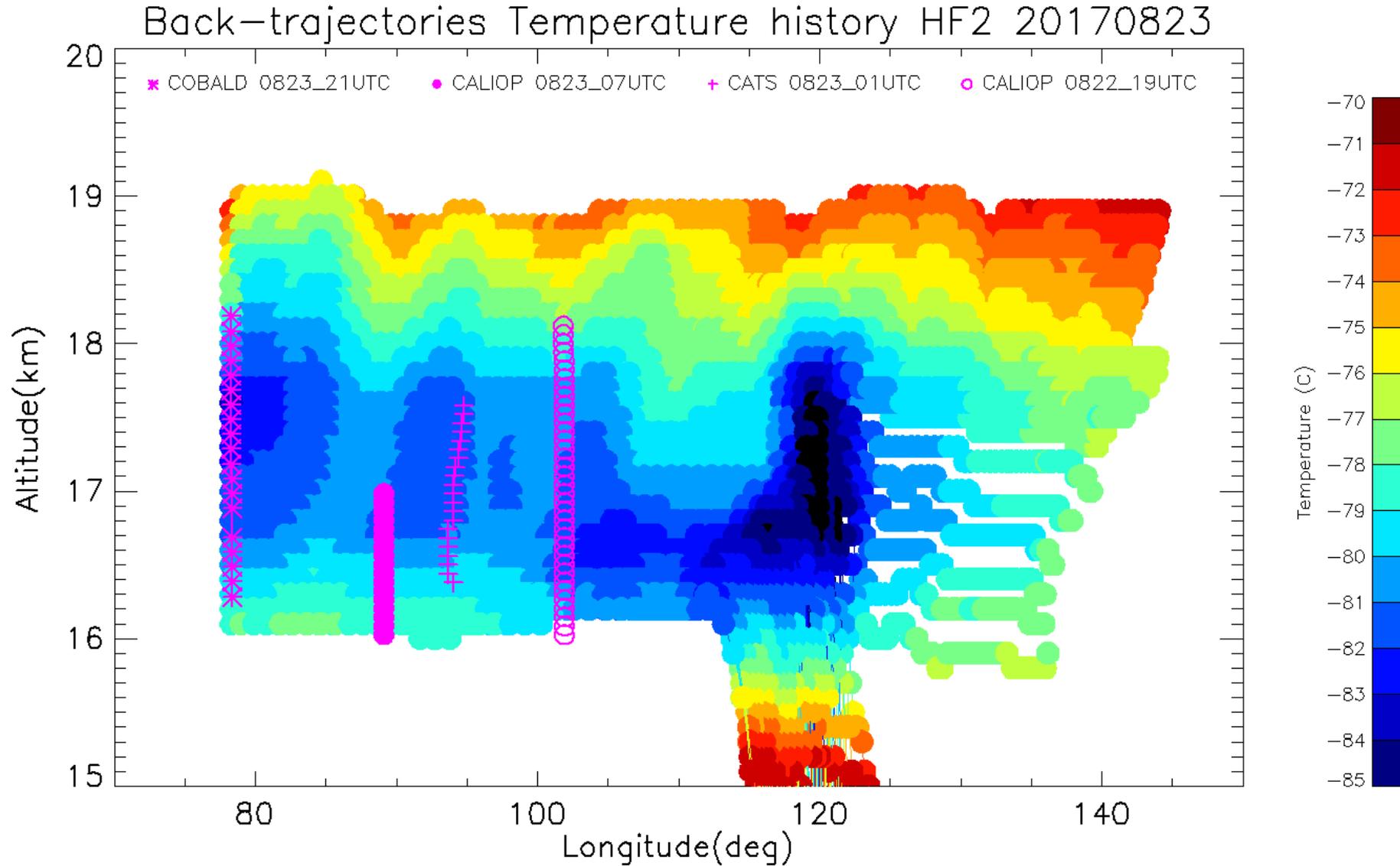Clouds with base altitude >16km (Laminar cirrus). Trajectories are between 16 and 19 km
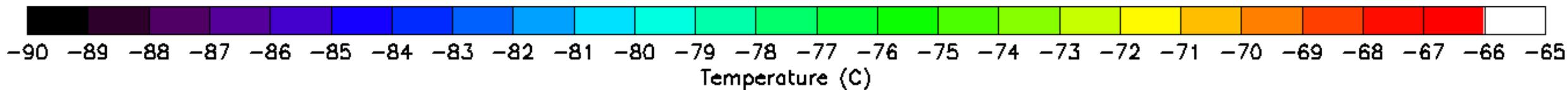
Temperature (C)

Cirrus clouds are found in the colder regions along the back-trajectories

Presence of cirrus clouds in wave-like cold-temperature anomalies along the back-trajectories from COBALD, CATS and CALIOP Measurements

Locations of cirrus clouds in colder regions are shown in Magenta colored symbols

Association of Cold-Anomalies with Updrafts

Back-trajectories Vertical Wind history HF2 20170823

Balloon Ascent Rate on 20170823_20UTC

20170823, 20 UTC

Cloudy region

Increase in Ascent rate
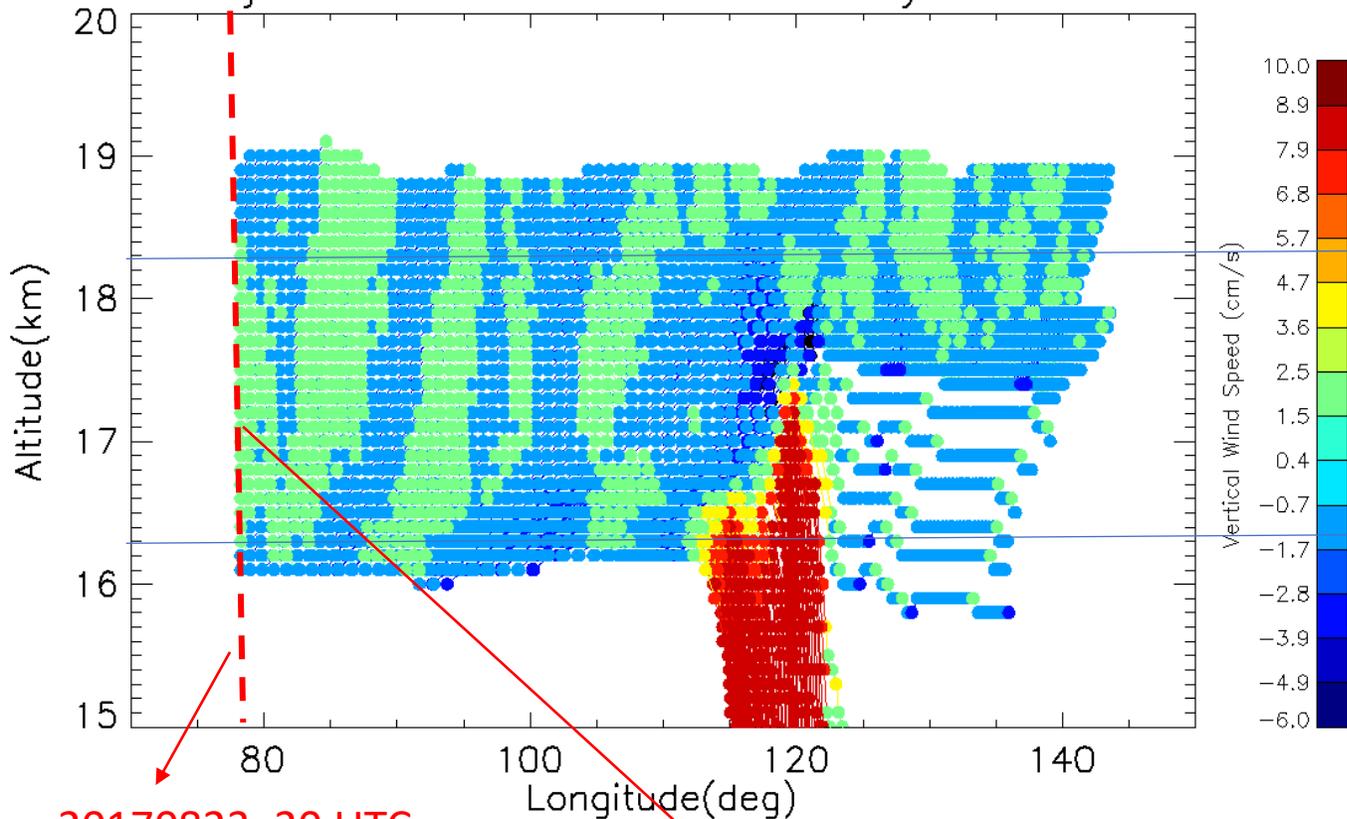
Updraft shown by MERRA-2 vertical wind can cause cooling necessary for cirrus cloud formation

19

COBALD
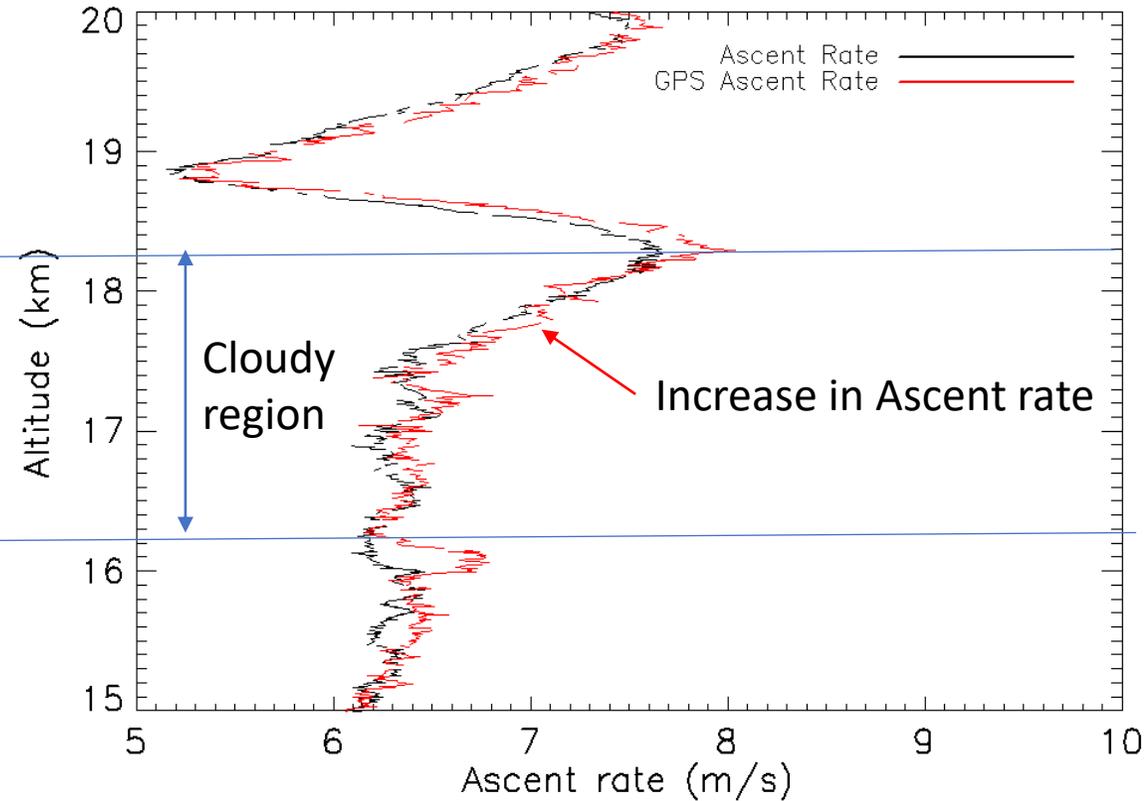20170823_2040 UTC,
17.45N, 78.31E
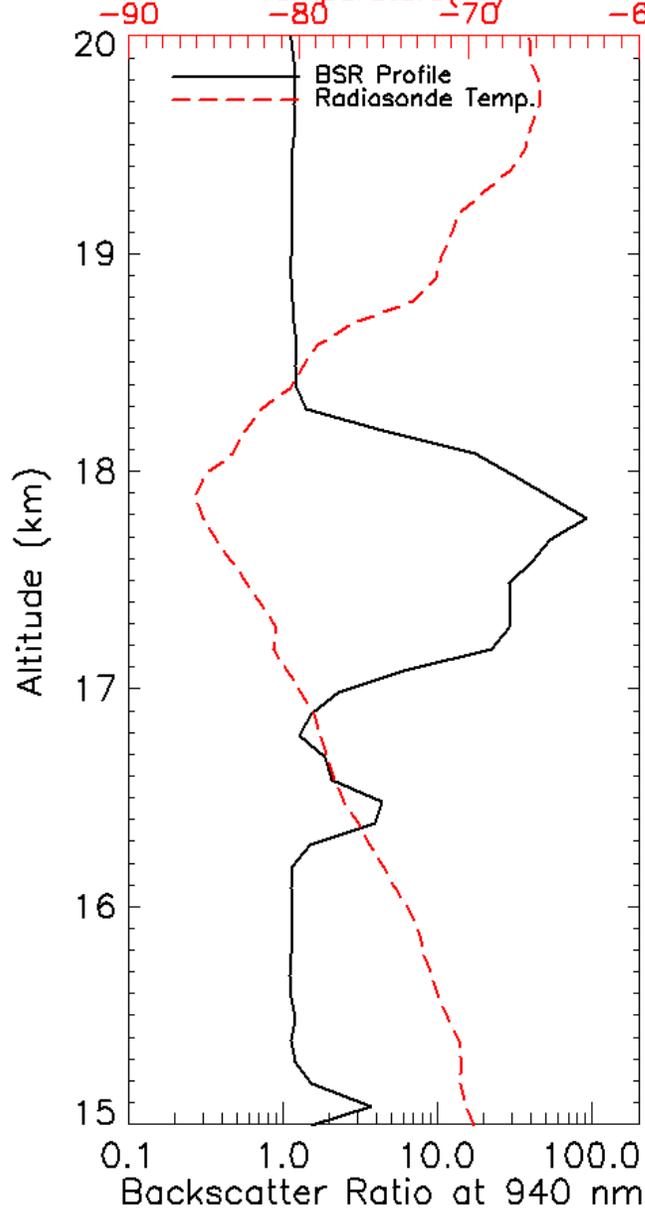
CALIOP
20170823_0738 UTC,
16.99N, 88.88E
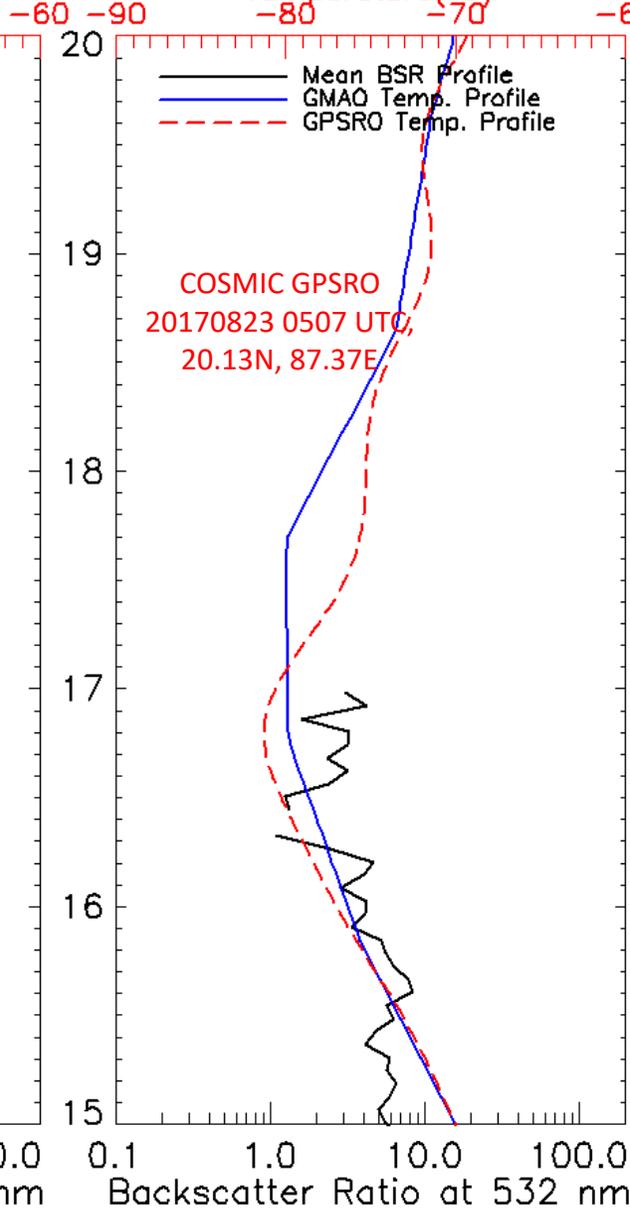
CATS
20170823_0059UTC,
17.01N, 92.68 E
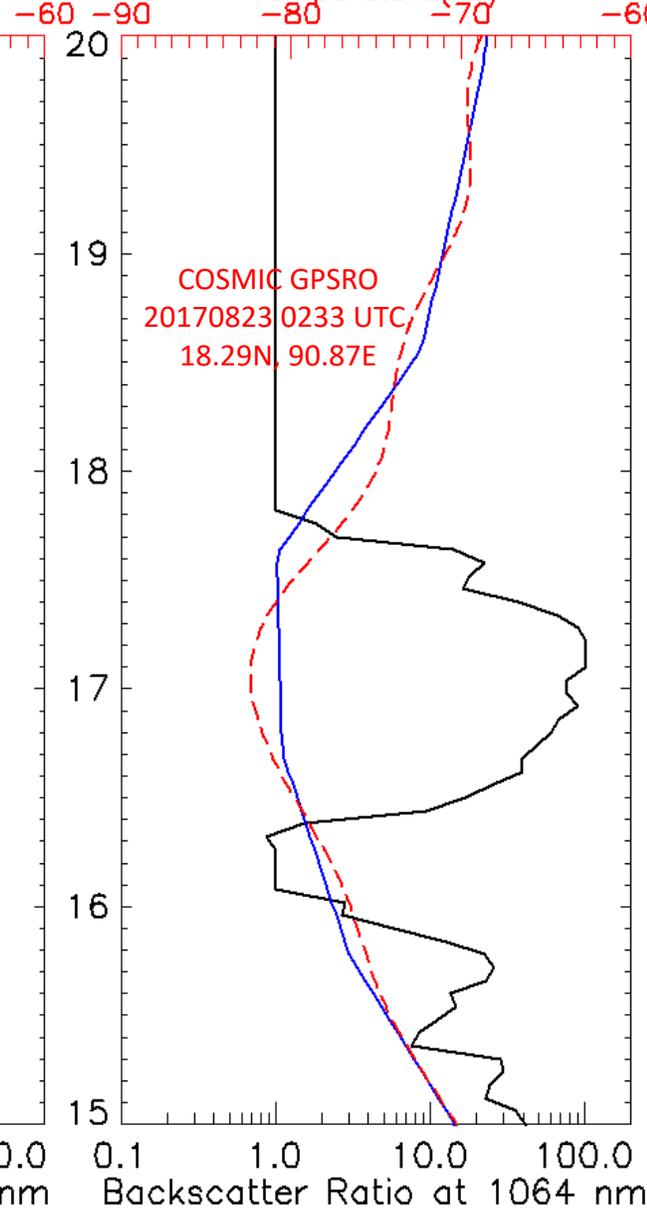
CALIOP
20170822_1907 UTC,
16.99N, 101.68E

Temperature(°C)

BSR Profile
Radiasonde Temp.

Mean BSR Profile
GMAO Temp. Profile
GPSRO Temp. Profile

COSMIC GPSRO
20170823 0507 UTC,
20.13N, 87.37E

COSMIC GPSRO
20170823 0233 UTC,
18.29N, 90.87E

COSMIC GPSRO
20170822 23:42 UTC,
16.63N, 100.04E

Altitude (km)

Backscatter Ratio at 940 nm

Backscatter Ratio at 532 nm

Backscatter Ratio at 1064 nm

Backscatter Ratio at 532 nm
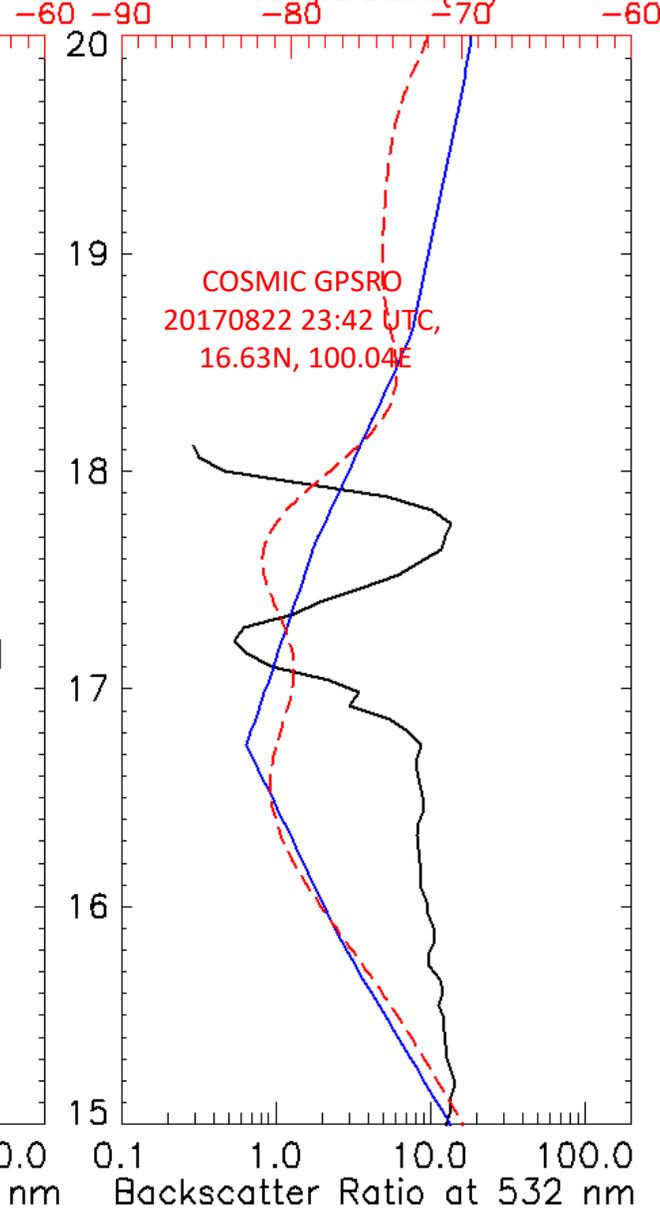
Anomalies in Temperature, Zonal and Meridional winds for 23 August 2017 case
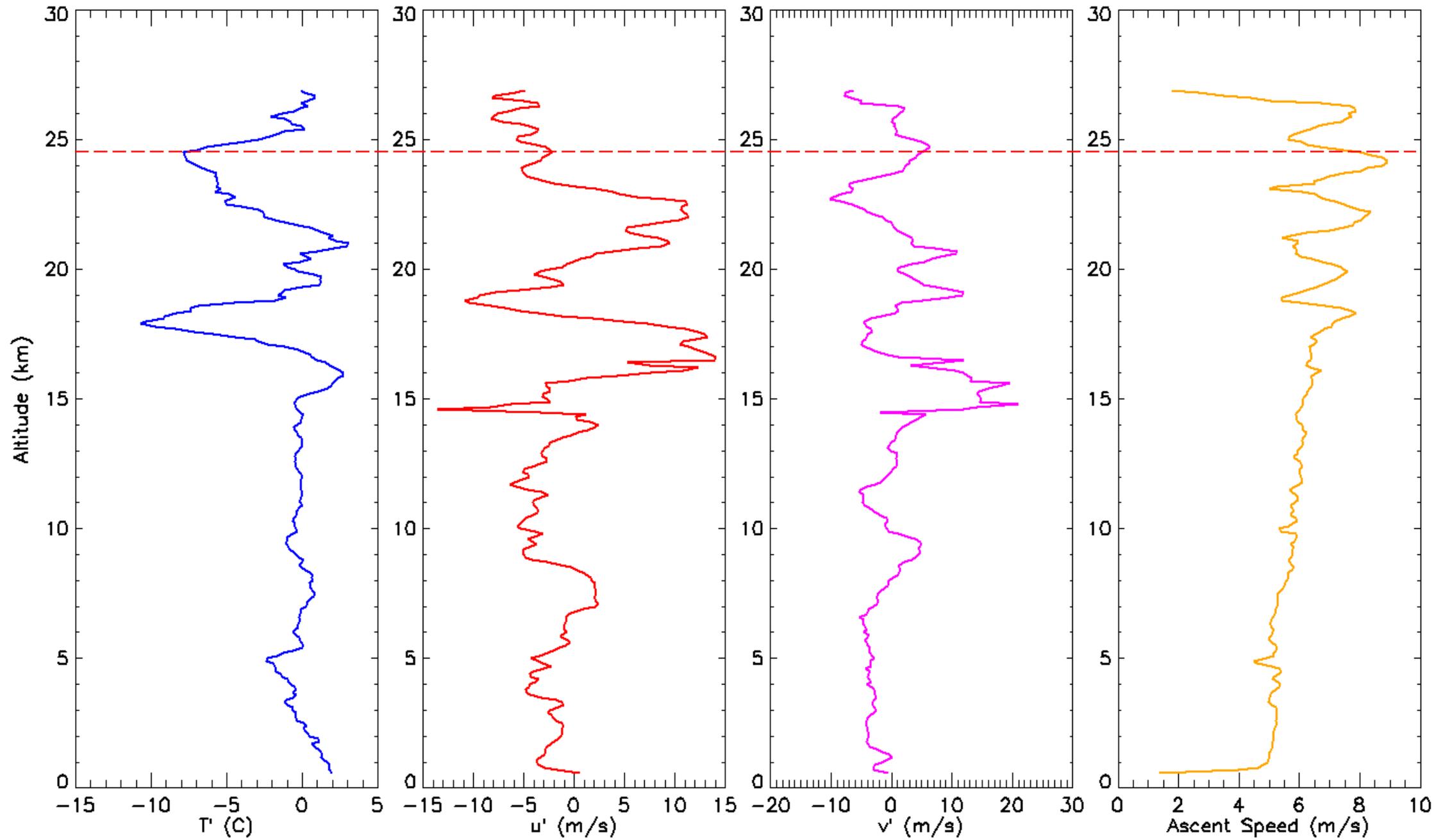
Temperature Anomaly from ERA5 & Cirrus cloud Occurrence from CALIOP data (red dots)

Time series of Temperature Anomaly in Aug. 2017 over 10−25 N at 100 hPa

Typhoon Hato track

Concluding Remarks

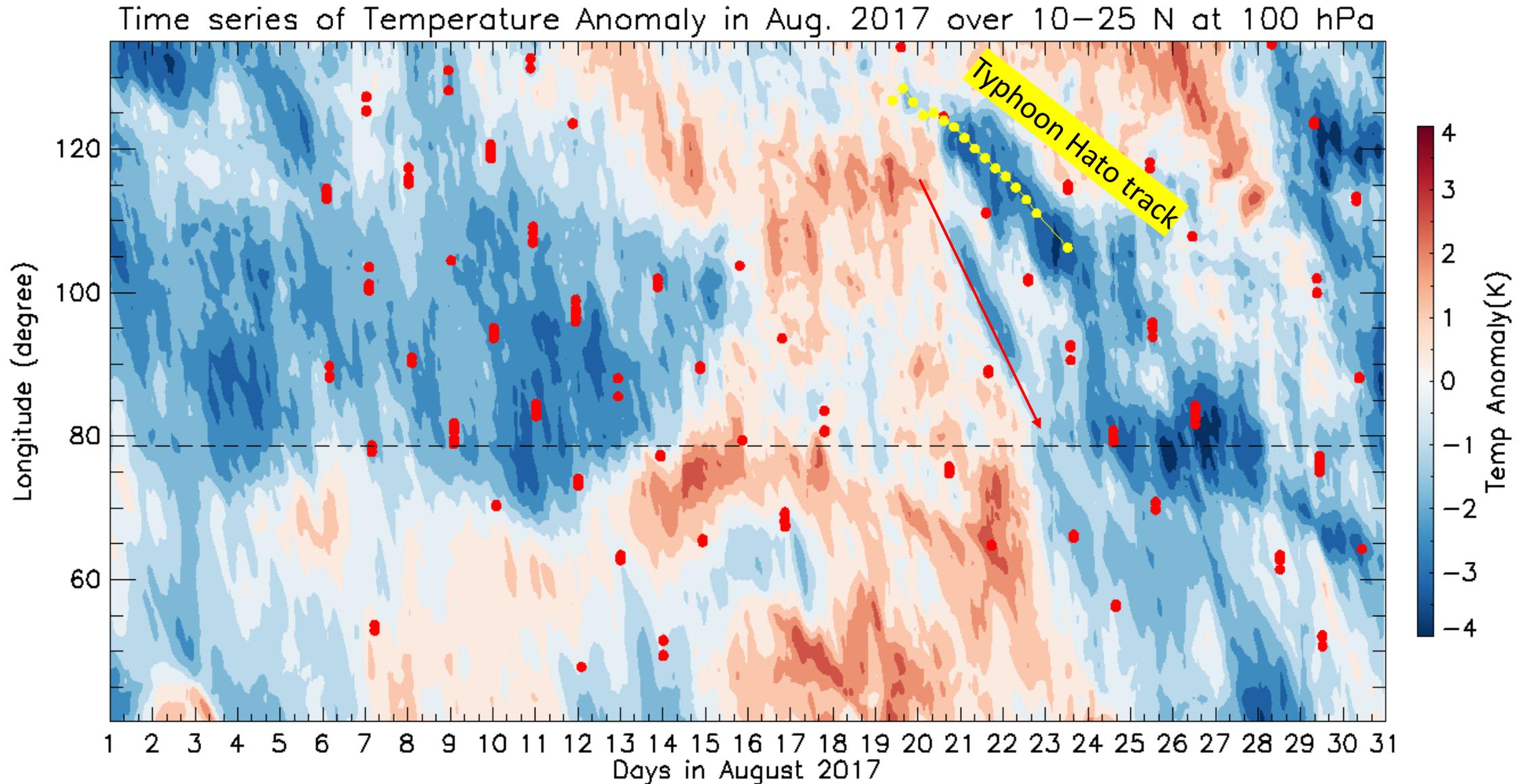- First balloon-borne measurements of ice-crystal characteristics over the Asian Summer Monsoon region is conducted during the BATAL campaign in Hyderabad, India.

- Cirrus clouds form frequently in the cold-temperature anomalies near the cold-point tropopause during Asian Summer Monsoon.

- Good agreement between the COBALD, Boulder-Counter and Micro-COPP measurements of ice-clouds.

- Boulder Counter & COBALD measurements were used to derive optical and microphysical properties of a tropopause cirrus.

- Ice-crystals in tropopause cirrus cloud layer are smaller than 50 μm with a mean concentration of about 47.5 L^{-1}.

- 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.

- 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!