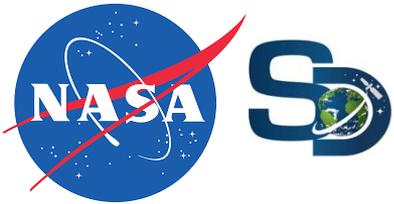


# The Asian Tropopause Aerosol Layer

through combined satellite and balloon-borne measurements

*J.-P. Vernier<sup>1</sup>, T.D. Fairlie<sup>2</sup>, T. Deshler<sup>3</sup>, M. Natarajan<sup>2</sup>, A. K. Pandit<sup>4</sup>, S.T. Akhil Raj<sup>4</sup>, A. Hemanth Kumar<sup>4</sup>, M. V. Ratnam<sup>4</sup>, H. Gadhavi<sup>4</sup>, T. Wegner<sup>2</sup>, N. Baker<sup>2</sup>, A. Jayaraman<sup>4</sup>, D. Vignelles<sup>7</sup>, S. Kumar<sup>5</sup>, A. Singh<sup>6</sup>, Sarvan Kumar<sup>6</sup>, Stenchikov<sup>8</sup>, F. Wienhold<sup>9</sup>, L. Ziemba<sup>2</sup>, J. Bian<sup>10</sup>, J. Crawford<sup>2</sup>, L. Thomason<sup>2</sup> and G. Berthet<sup>7</sup>*



1. Science Systems and Applications, USA
2. NASA Langley Research Center, USA
3. University of Wyoming, Laramie, USA



4. National Atmospheric Research Laboratory, Gadanki, India
5. National balloon facility, TIFR, Hyderabad, India
6. Banaras Hindu University, Varanasi, India



7. LPC2E, CNRS, Orléans, France



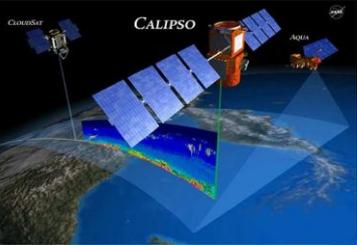
8. King Abdullah University of Science and Tech., Saudi Arabia



9. Swiss Federal Institute of Tech., Zurich, Switzerland

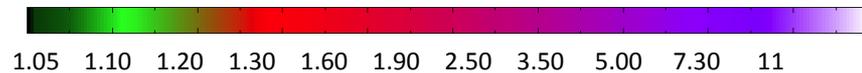
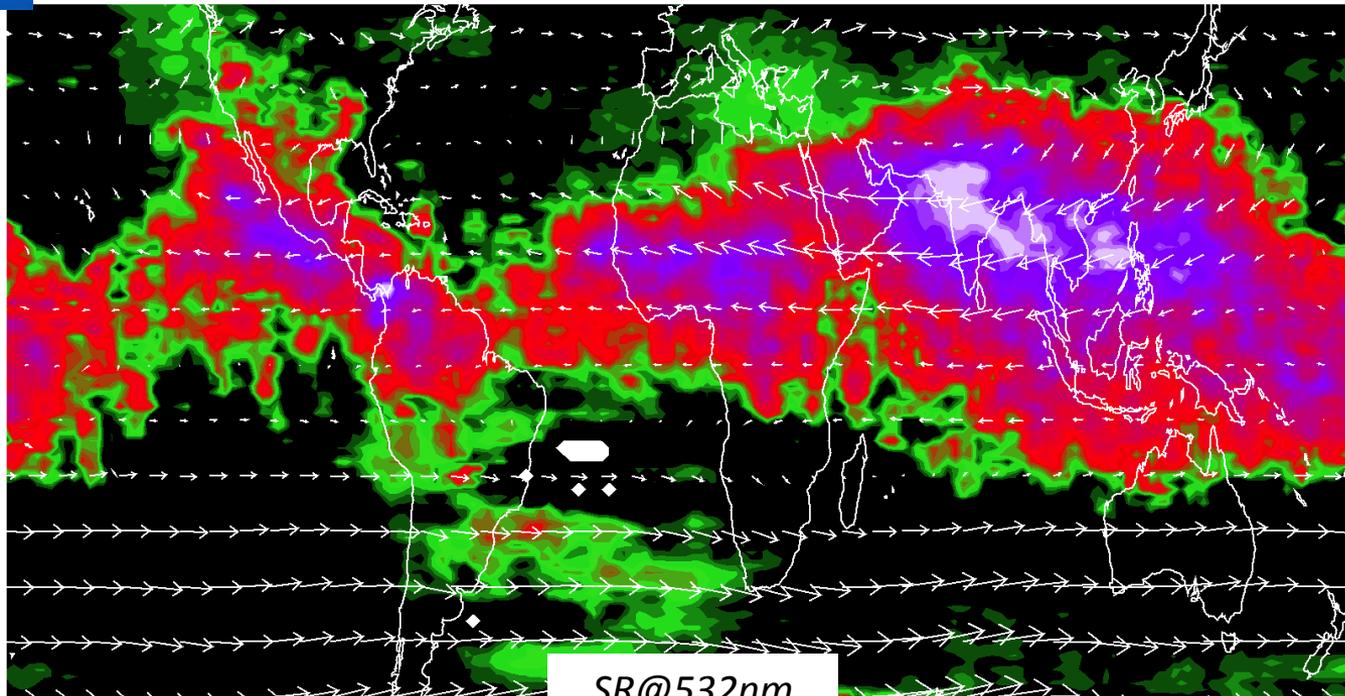
10. LAGEO, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China





# The Summer Upper Tropospheric Cloud Cover from CALIPSO

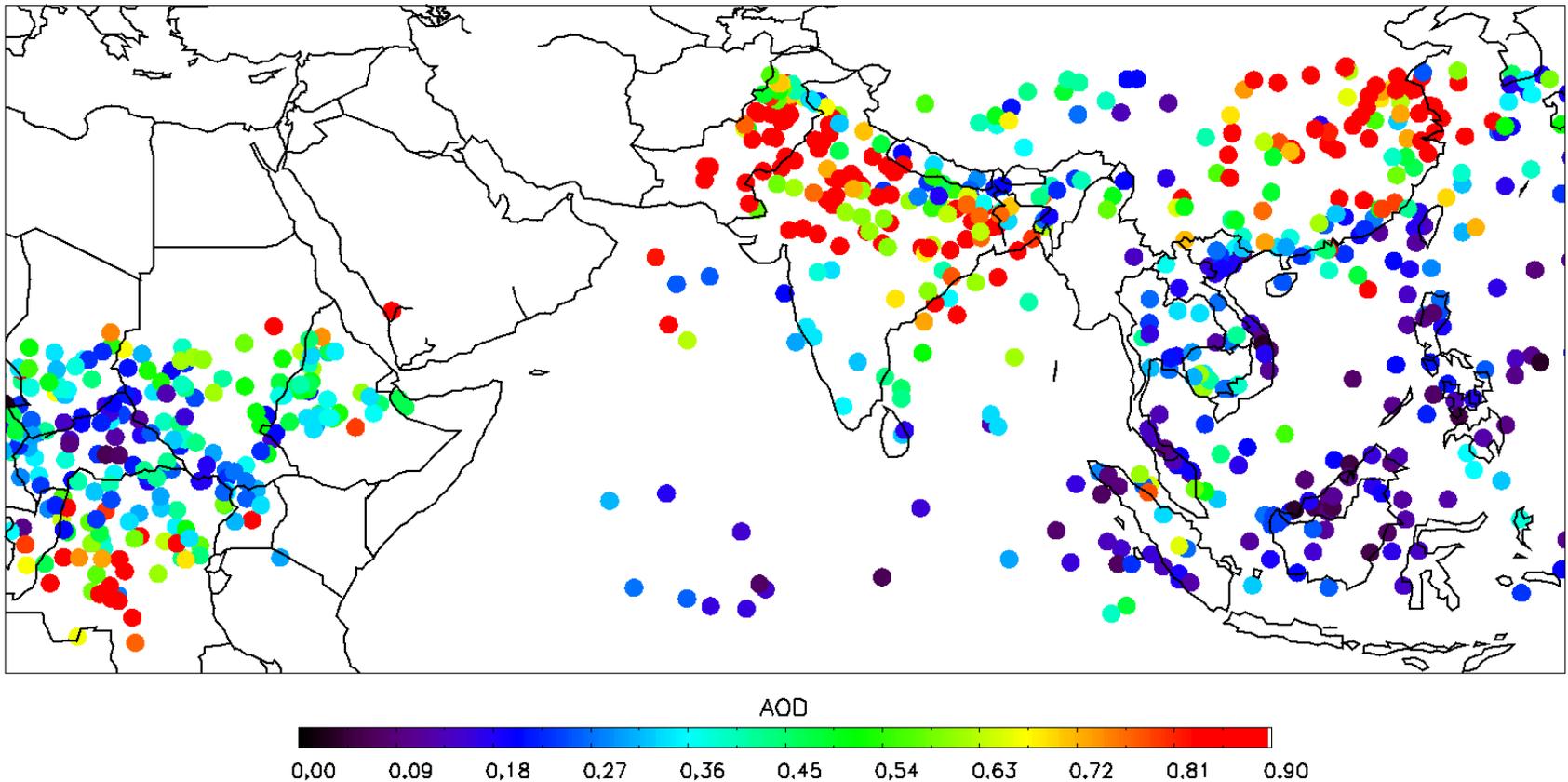
*15-17 km July-Aug 2006-2008*



- Climatology of ice cloud equivalent optical thickness in the UT from the CALIOP lidar onboard CALIPSO.
- Signature of the Mexican, African and S.E Asian Monsoons
- Highest values over India and Southeast Asia are from deep convective clouds.

# Polluted versus Pristine Convection

TRMM/MODIS June-July-August 2008

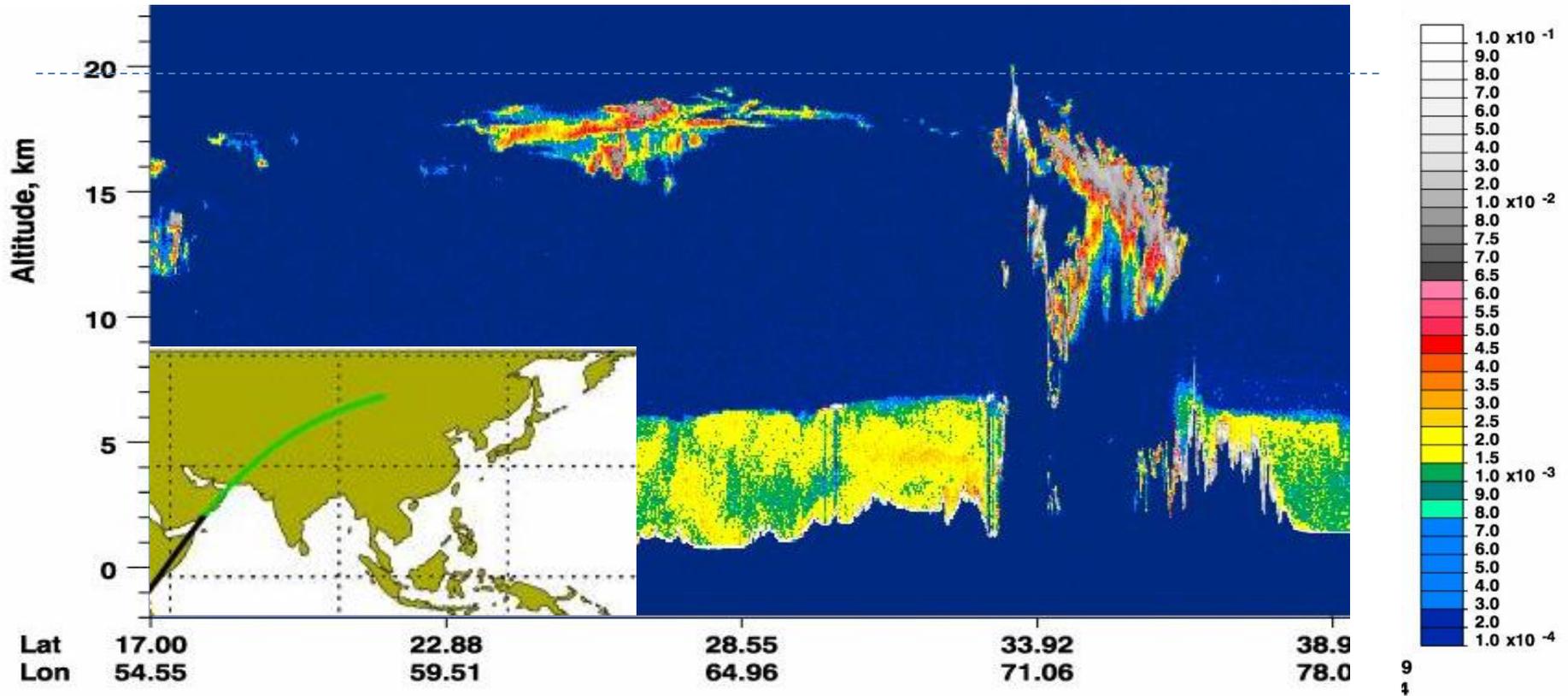


- Mesoscale Convective Systems (MCS) observed by the Tropical Rainfall Measuring Mission (TRMM) reaching 14 km and colored by the nearest AOD retrieved by MODerate Imaging Spectrometer (MODIS) (2days\*3 Lon\*3Lat)
- North India/Pakistan and Eastern China contrasts with Maritime continent convections

# Polluted convective environment

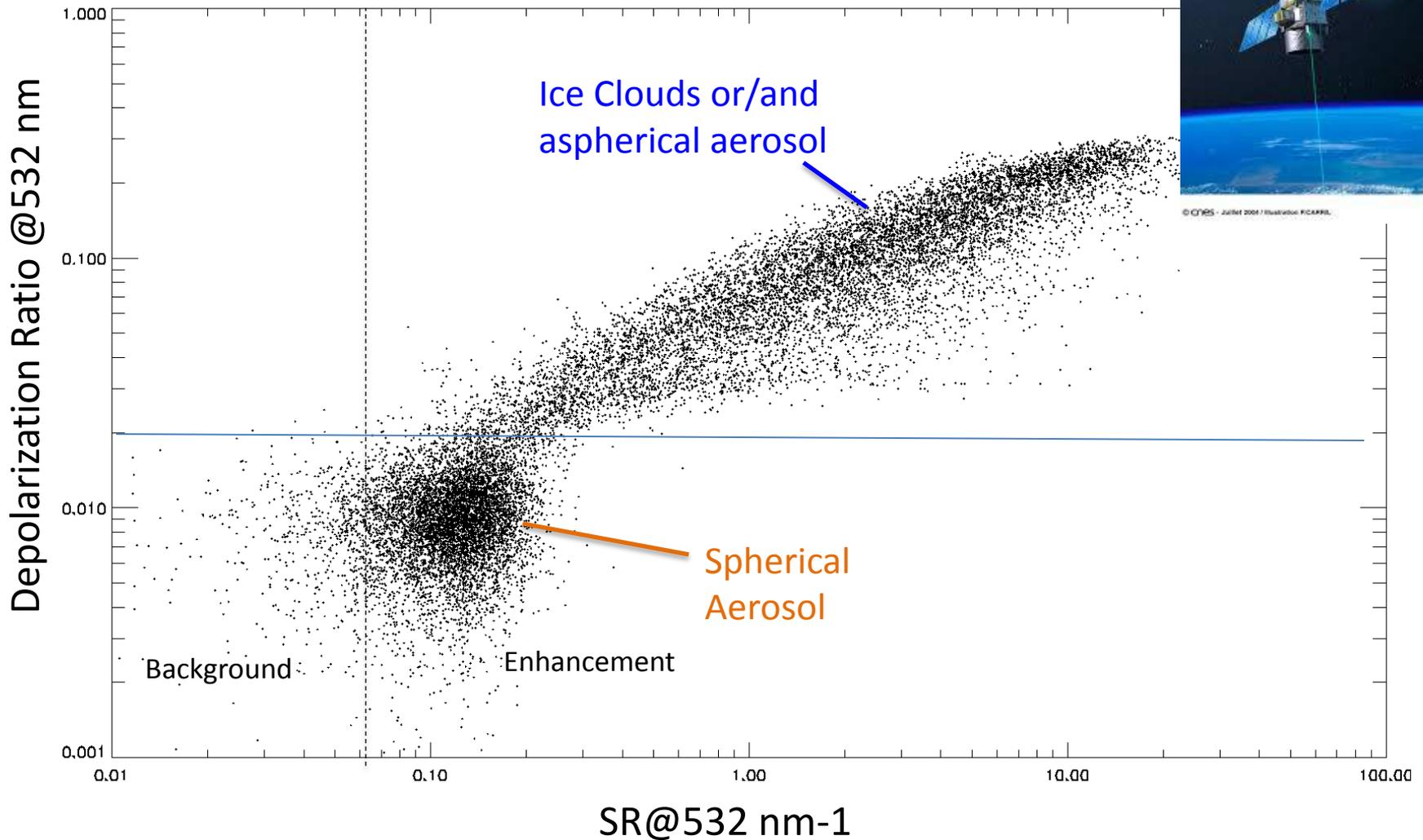


1064 nm total backscatter CATS/ISS lidar 07/16/2015 21 UTC



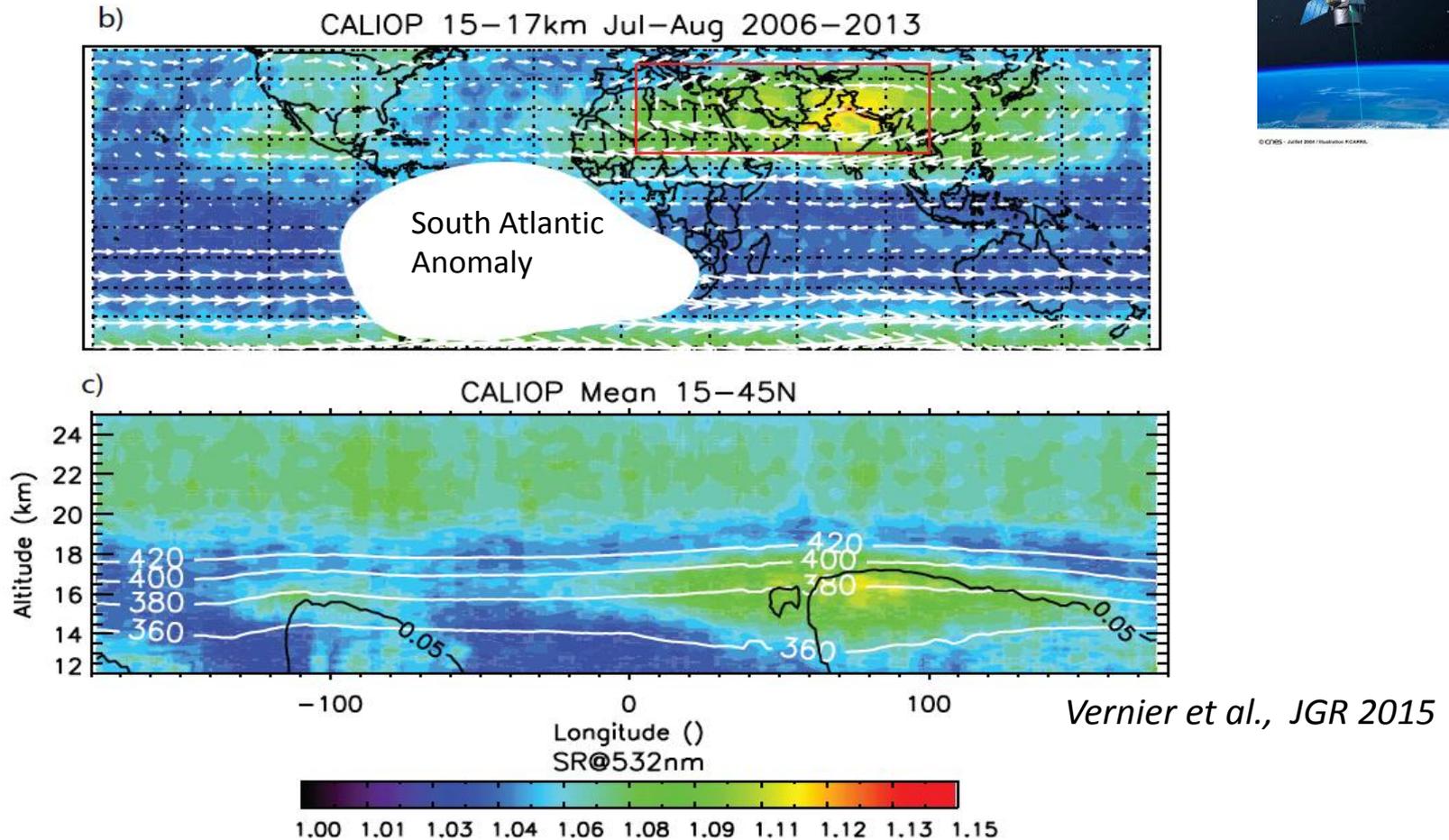
- Lidar curtain shows Evidence for strong convection reaching the lower stratosphere in very polluted environment over Pakistan
- How efficient is convection to transport primary aerosol and/or their gas precursors in the UTLS ?

# ATAL's detection



- Diagram of depolarization from CALIPSO observations in South East Asia Jul-August 2008 : 15-17 km
- Signature of Ice Clouds and Low depolarizing spherical particles

# The Asian Tropopause Aerosol Layer



- The Existence of the ATAL was recognized through CALIOP lidar observations
- Confined area of enhanced aerosol associated with Asian Summer Monsoon spanning from the E. Med Sea to W. China
- Extends from top of convective outflow over much of SE Asia

# ATAL's Validation

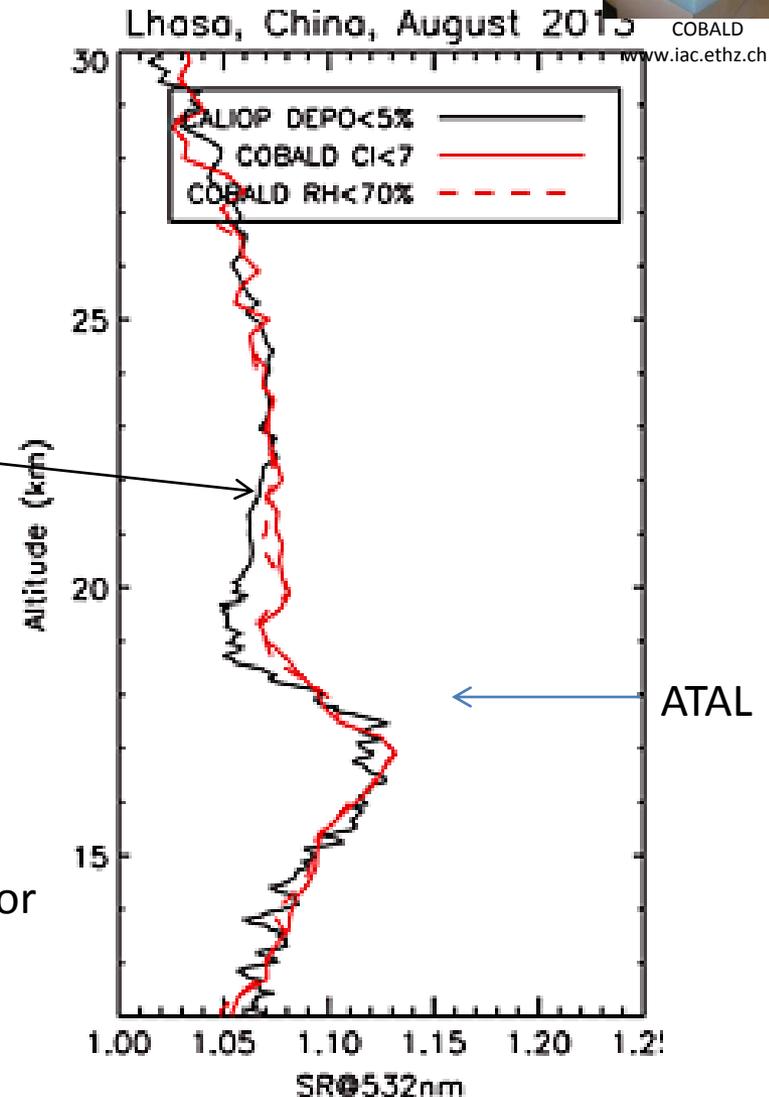
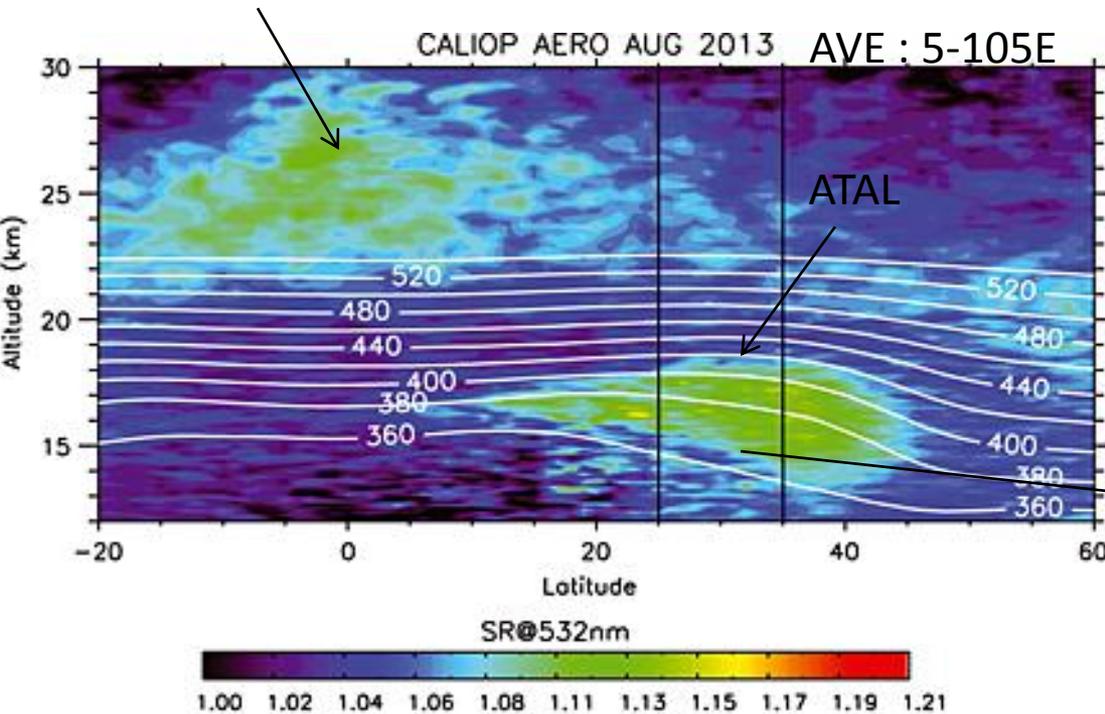
balloon-borne backscatter measurements



COBALD

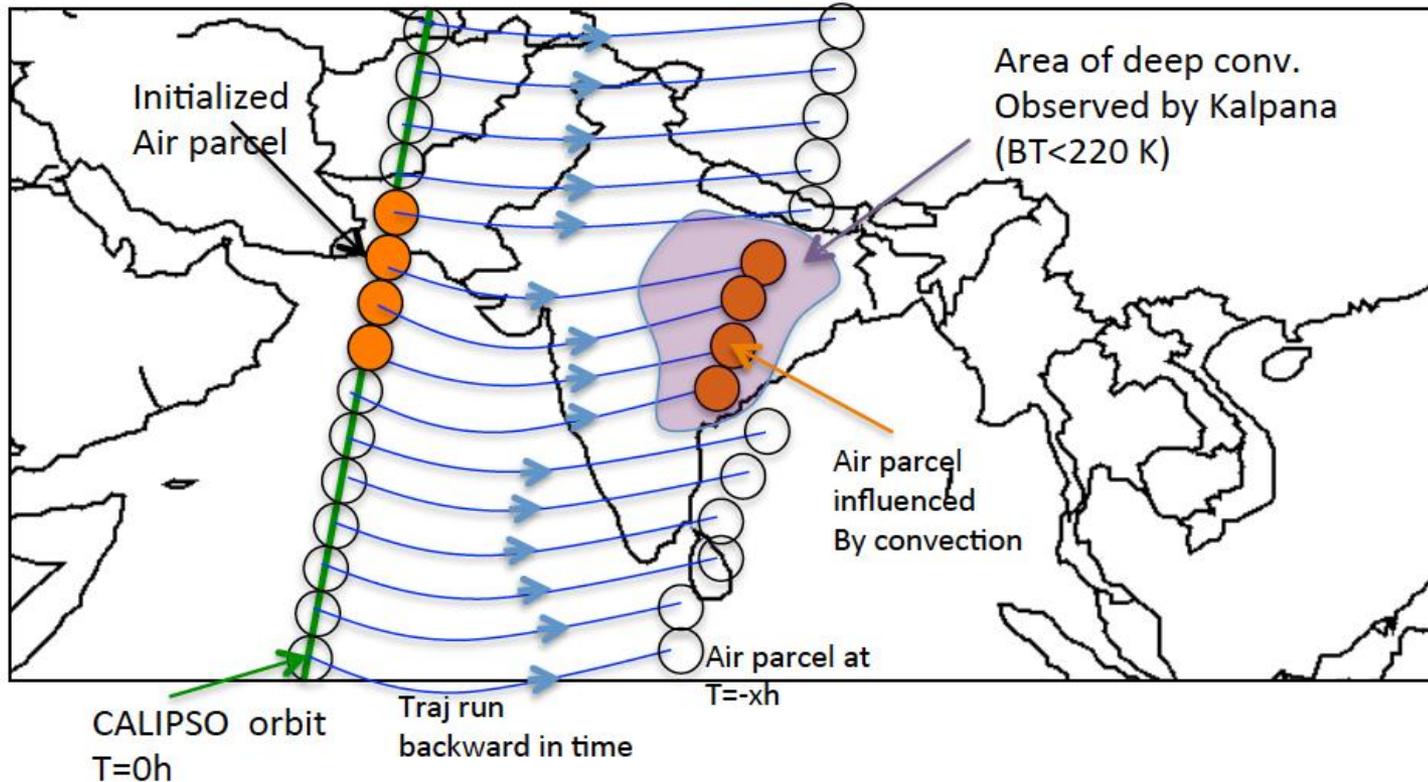
www.iac.ethz.ch

Stratospheric aerosol layer



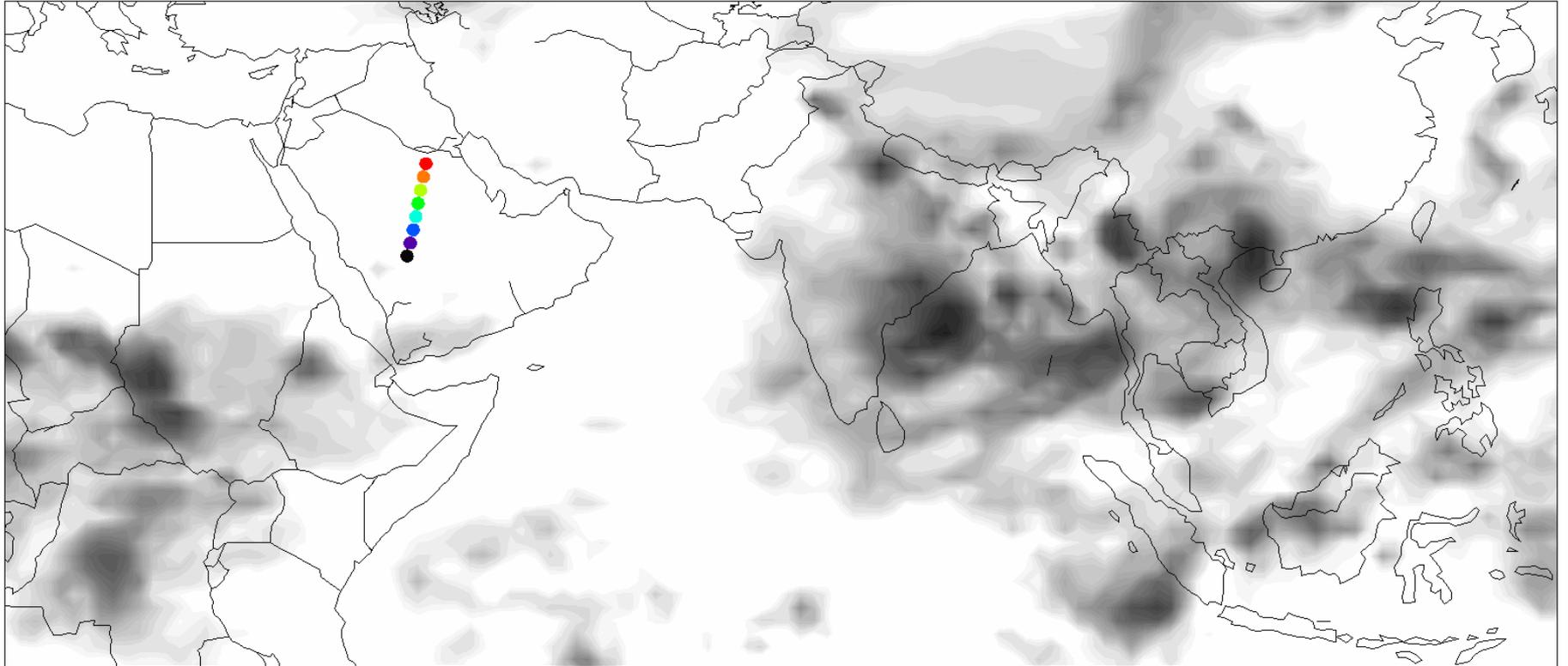
- COBALD backscatter data from Lhasa in August 2013 (SWOP campaign Courtesy J. Bian and F. Wienhold)
- Multiple cloud-clearing methods (using  $RH < 70\%$ , Color Index  $< 7$ , Depolarization  $< 5\%$ )
- Good agreement between COBALD and CALIOP
- ATAL does not result from unfiltered cirrus clouds

# Source region of the ATAL

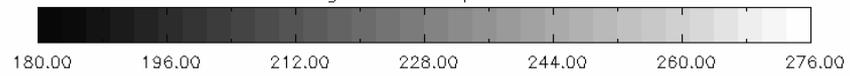


- CALIOP observations in the UTLS (14-18 km) used to initialize a trajectory model
- Trajectory model run backward in time
- Search for intersection with deep convection (Brightness Temperature < 200K).

2008080720

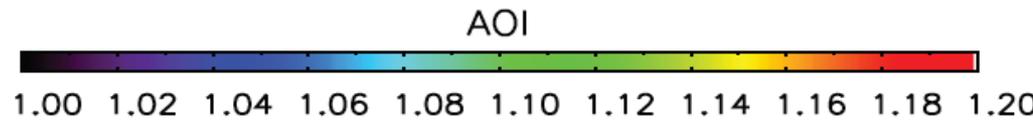
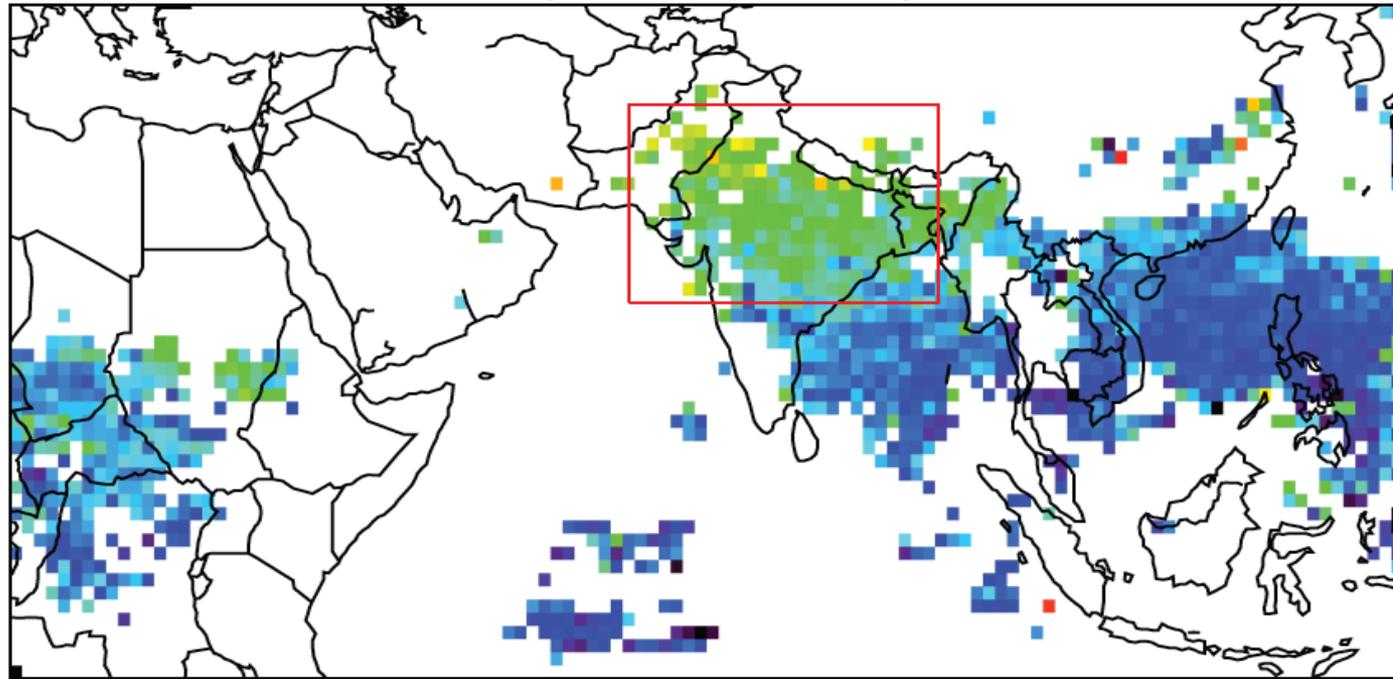


Brightness Temperature



# ATAL's origin

01–16 Aug–08 Aerosol Origin Index



$$AOI(i, j) = \frac{\sum_{t=0}^n SR_t}{n}$$

- Pixels shows the position of deep convection subsequently sampled by CALIOP and colored by their measured Scattering Ratio :
- Aerosol Origin Index for 1-16 Aug., 2008.
- Indian sub-continent identified as key deep convective source for elevated aerosol in the ATAL.

# BATAL 2015 : Balloon-borne measurements of the ATAL

5 weeks : July-August 2015 : 30 Launches/ 4 locations/9 Institutes involved



- , 15-24 Aug 15 : Banaras Hindu University, Varanasi, India  
- 7 launches of aerosol and chemical sensors

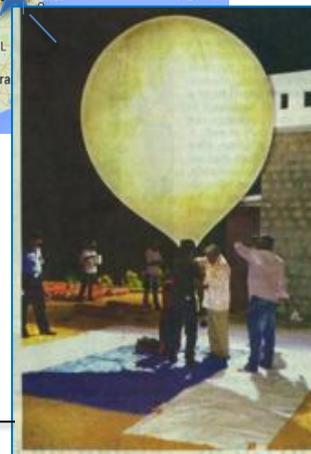


- King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia, Aug 15  
- 6 launches of COBALD backscatter and meteorological sondes



- 29 July-13 Aug 15 : Tata Institute for Fundamental Research Balloon facility, Hyderabad, India, 11 Launches of large and small aerosol, and chemical sensors

- 17-25 July 15: National Atmospheric Research Laboratory, Gadanki, India,  
- 6 launches of aerosol and chemical sensors



# BATAL-India 2015



*Vanarasi, India, August 2015*



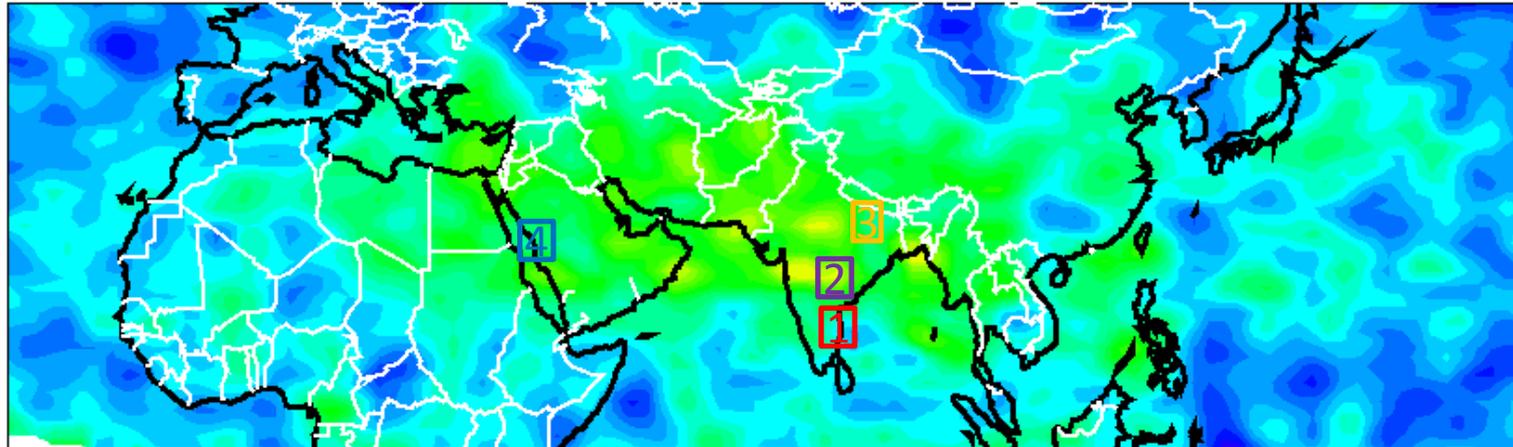
*Gadanki, India, July 2015*



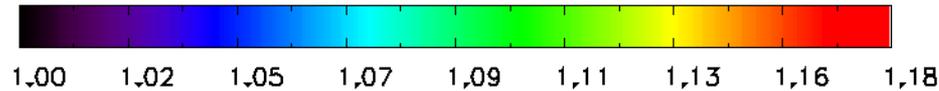
*Hyderabad, India, August 15*

# CALIOP/BATAL-2015

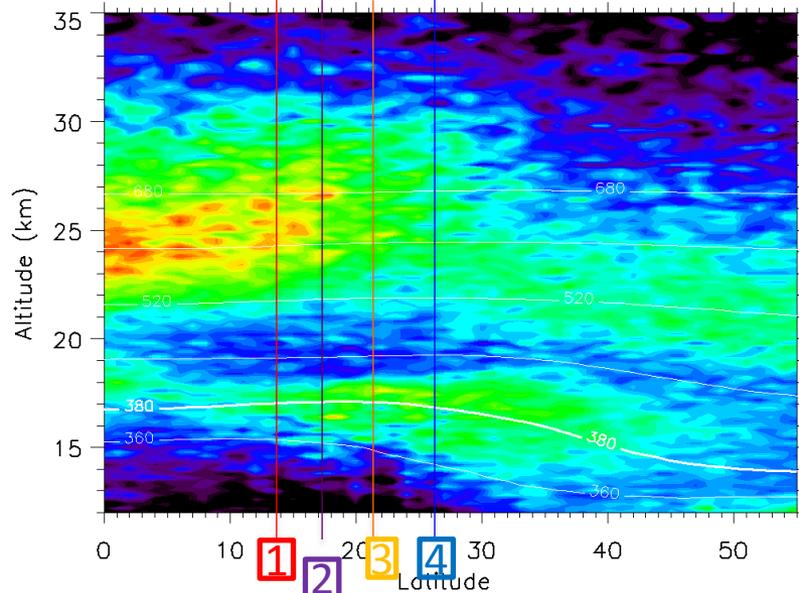
CALIPSO JULY/AUGUST 2015



SCATTERING RATIO@532nm

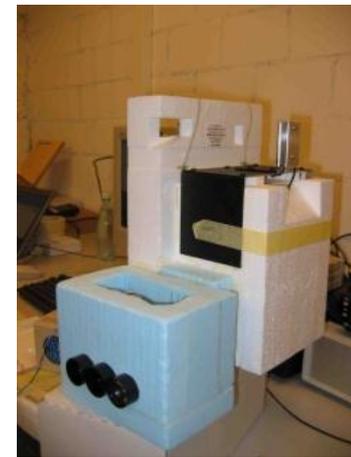
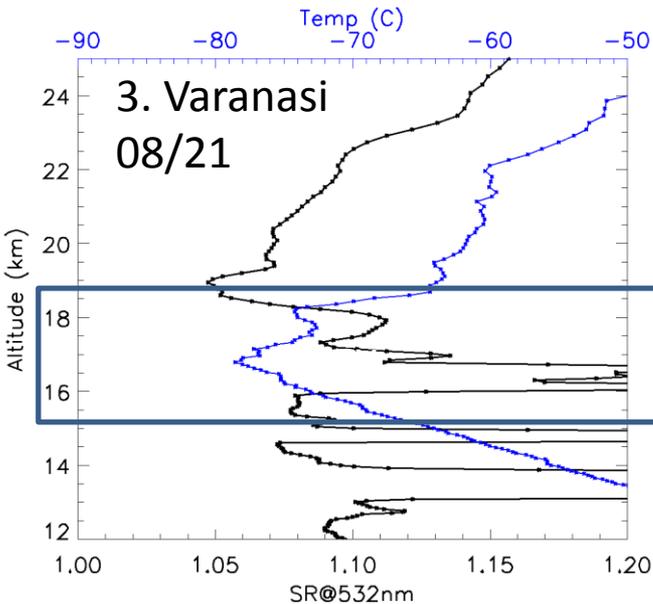
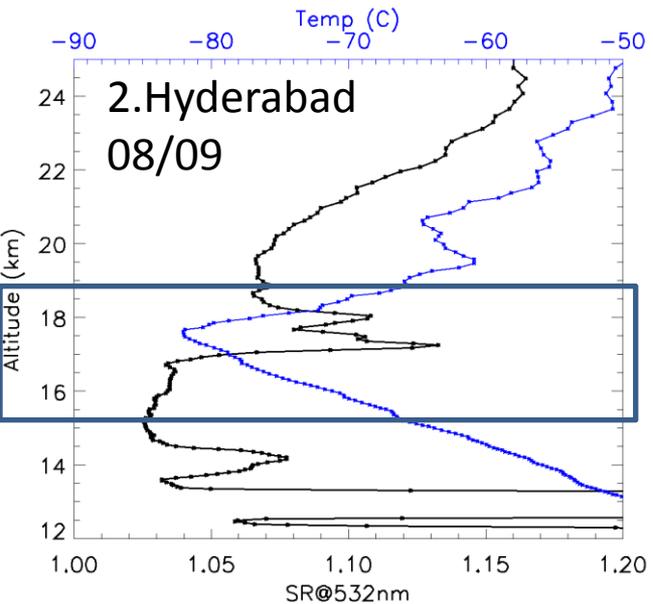
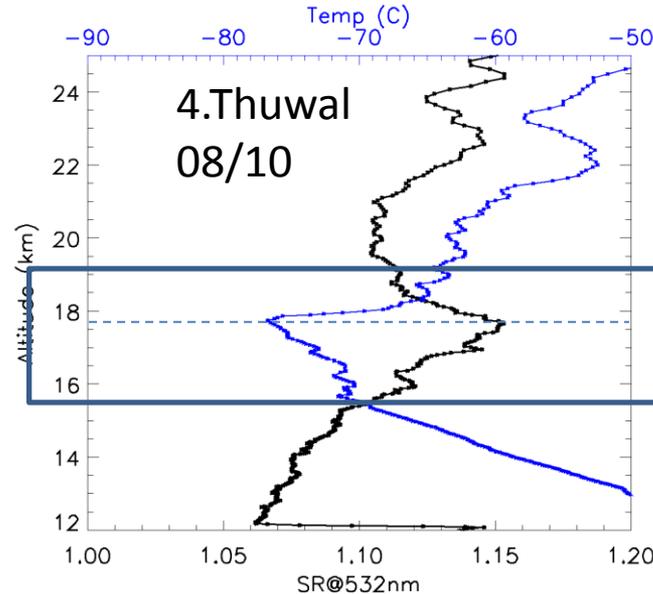
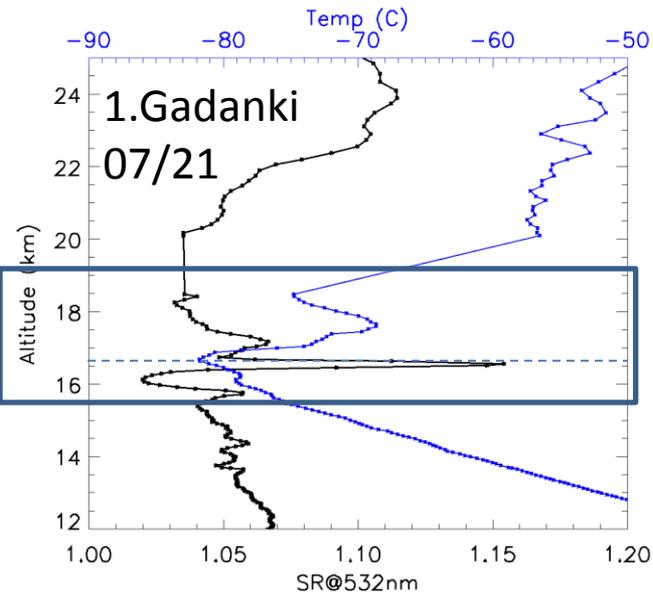


JULY–AUGUST 2015



- Significant enhancement of aerosol SR observed during the summer 2015
- BATAL launching locations covered a large area from the southern to the northern edge of the ATAL and the convective outflow region (Arabic Peninsula)
- Lower and middle stratosphere still influence by an old volcanic plume from Kelud eruption in Feb 2014.

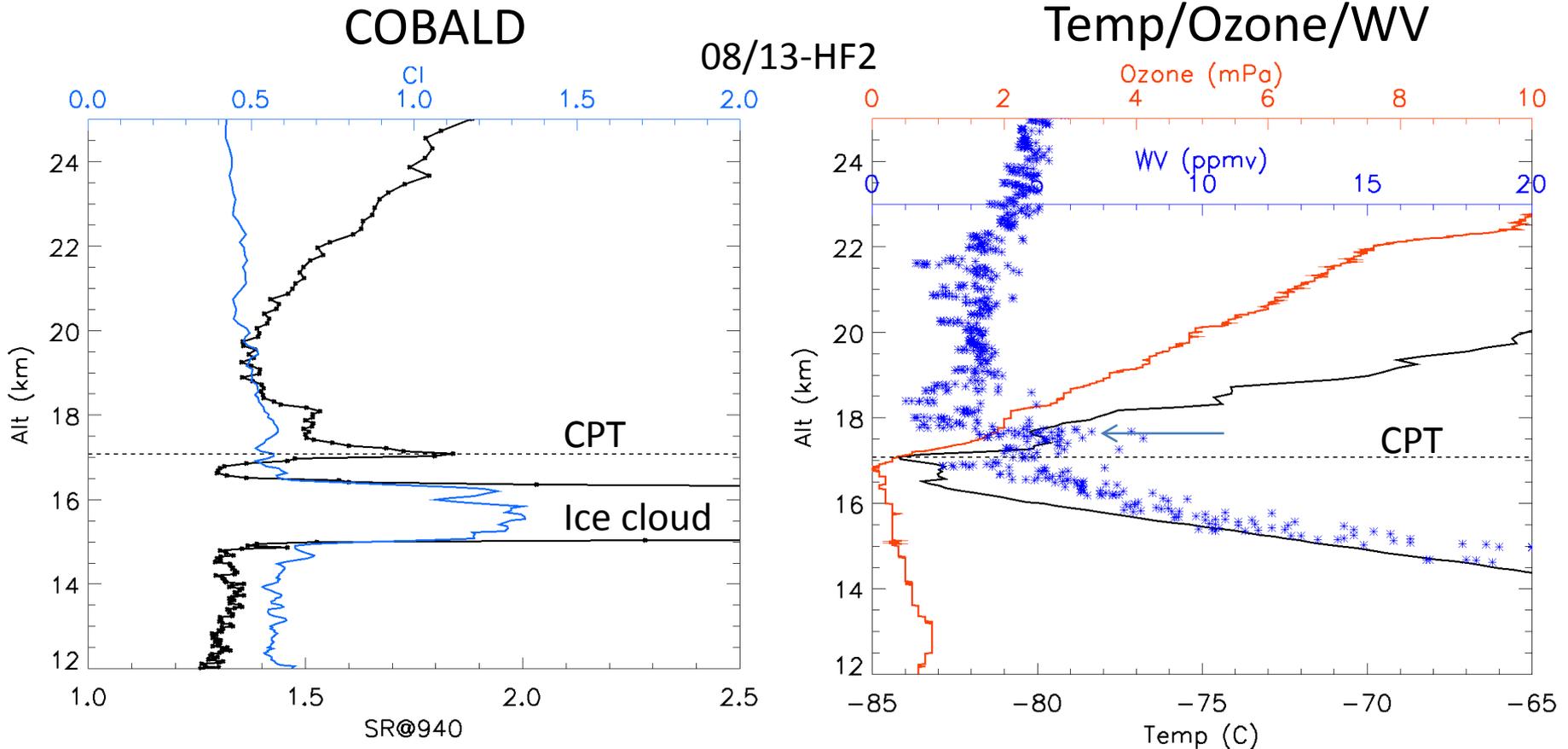
# BATAL 2015/COBALD flights



COBALD  
[www.iac.ethz.ch](http://www.iac.ethz.ch)

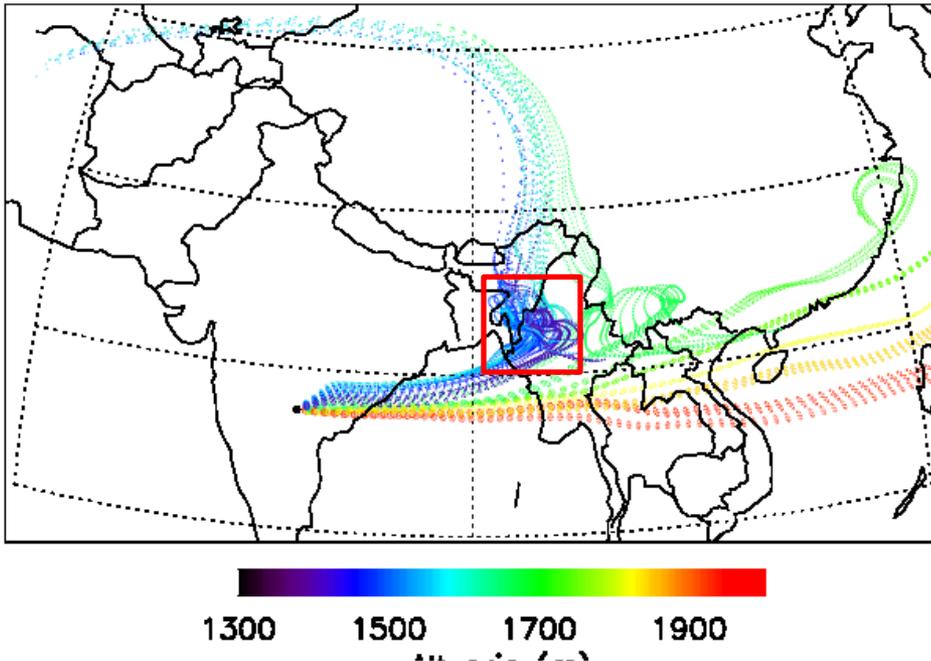
- COBALD backscatter and Temp Profiles
- Thin aerosol layers near the tropopause
- Contrast with broader layer observed from the Arabic Peninsula
- Ice clouds near the tropopause over Varanasi

# Moisture transport in the UTLS



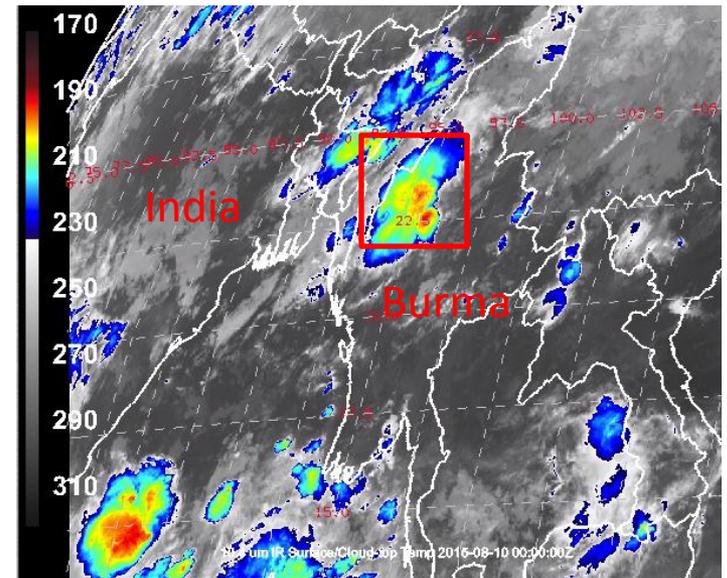
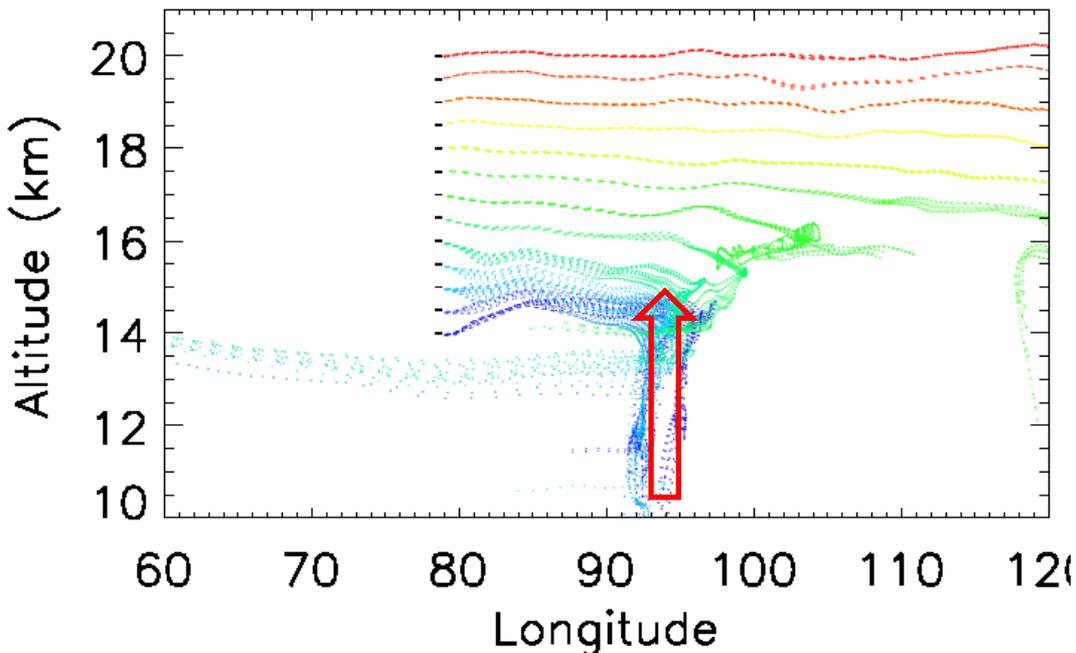
- Maximum of aerosol from COBALD at the cold point tropopause
- Low Color Index (CI) values measured by COBALD in contrast with ice clouds showing CI near unity (15-16.5km).
- Enhanced water vapor (up to 8-9ppmv) near 18 km likely resulting from the recent convective transport of moisture

GEOS5 BWD Traj @ 17.47N 78.58E, 20150813 120hr

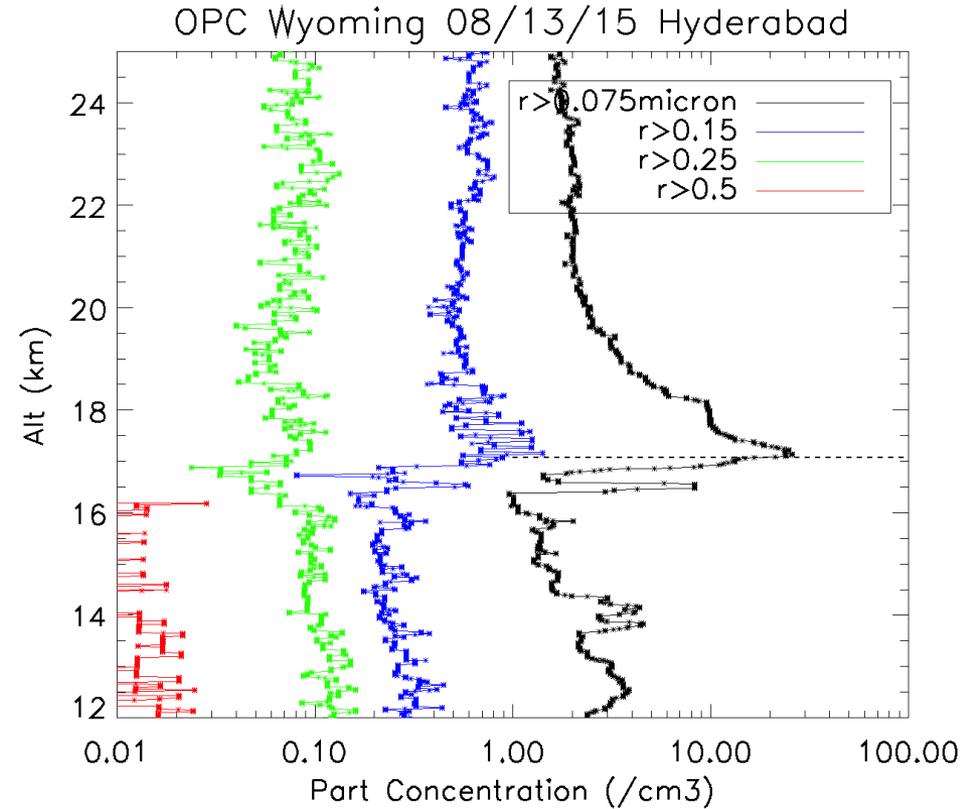
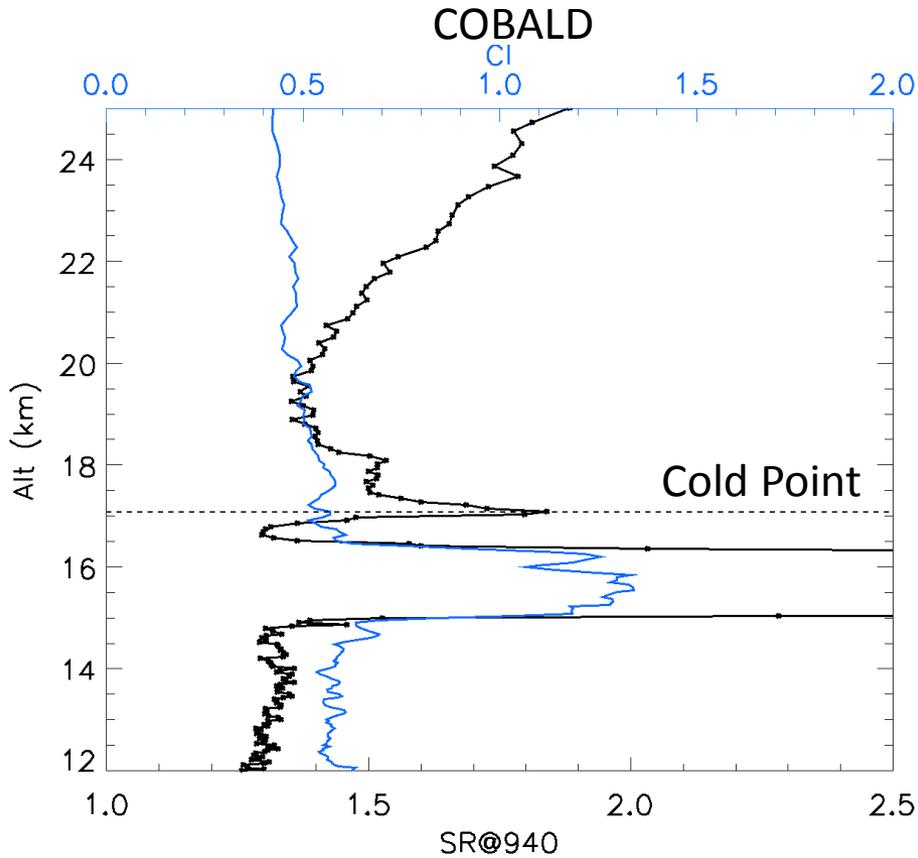


# Air masses origin

- Back-trajectories from air masses sampled by the 08/13 balloon flight from Hyderabad
- Influenced by deep convection over Western Burma and Eastern India previous 48-72 h.

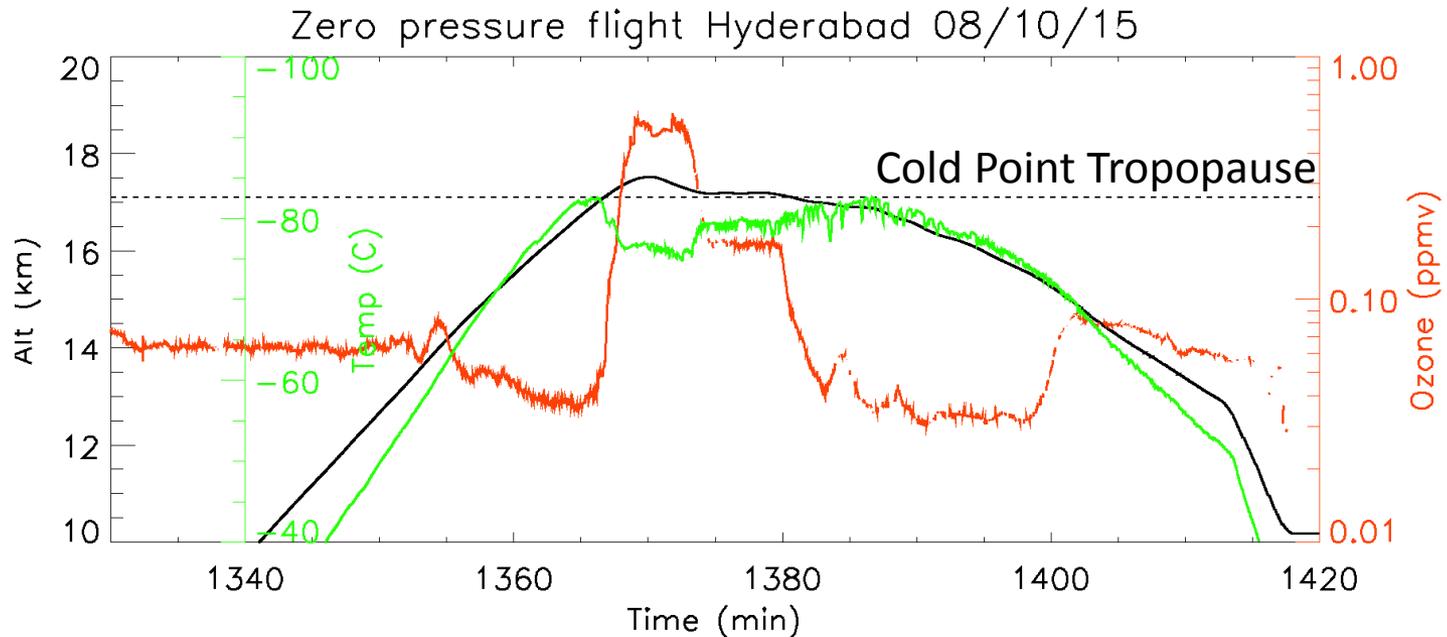


# First size distribution obtained from the ATAL



- Maximum of SR and concentration for  $r > 75\text{nm}$  at the cold point tropopause
- ~97 % of the total number of particles counted lie in the size range  $0.075\ \mu\text{m} < r < 0.15\ \mu\text{m}$ .
- ATAL made of very small/liquid particles peaks at the cold point tropopause (New Particle formation) -> Terry's talk

# Floating balloon near the tropopause

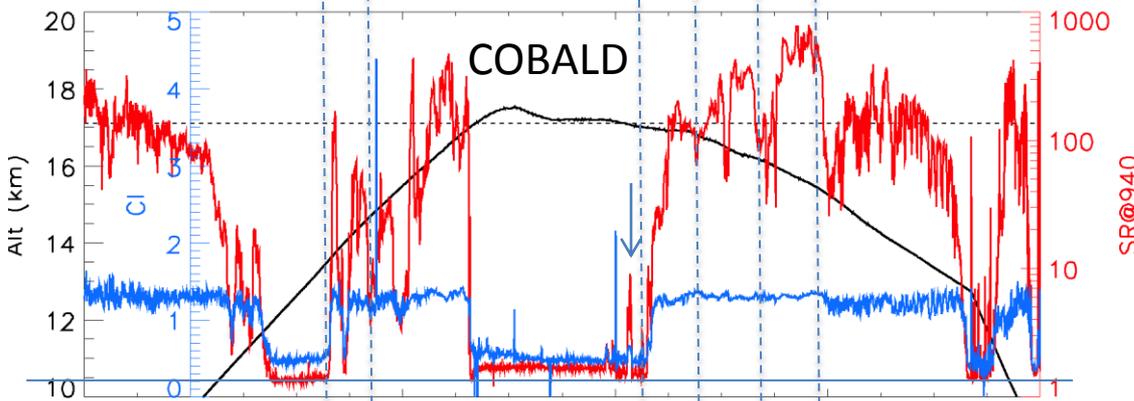
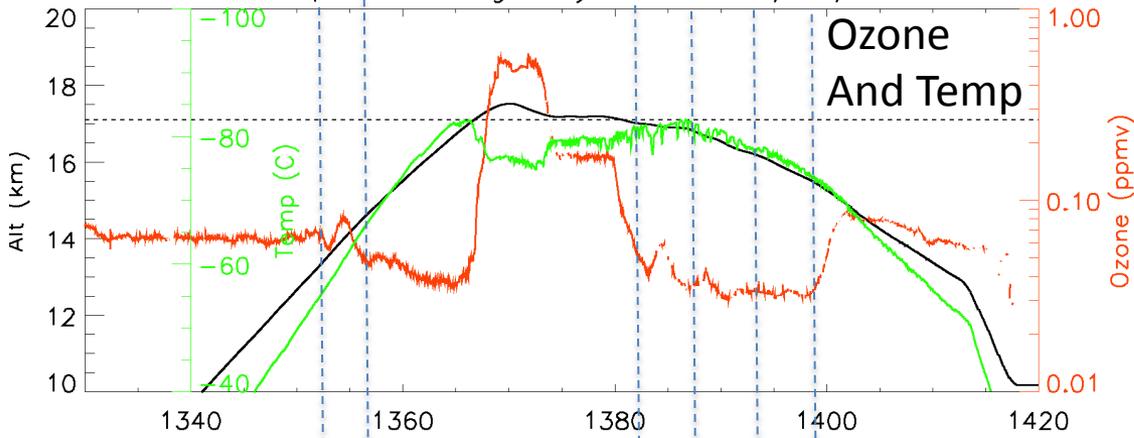


- Experimental floating balloon flight near the tropopause : 1h within 14-18 km
- Reach the lower stratosphere (sharp increase in ozone) and slowly came down in the TTL.

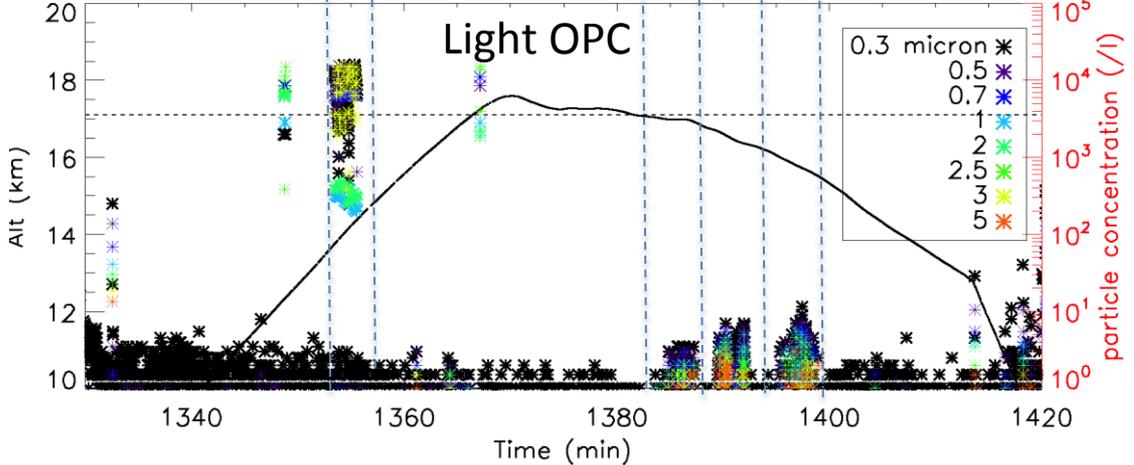
# Floating balloon near the tropopause

- Combined ozone, COBALD and light OPC measurements
- Sharp particle conc. increase of all particle sizes near 14 km within a cloud (bump in ozone)
- Enhanced particle concentration near the tropopause within a cloud.

Zero pressure flight Hyderabad 08/10/15



Zero pressure flight Hyderabad 08/10/15

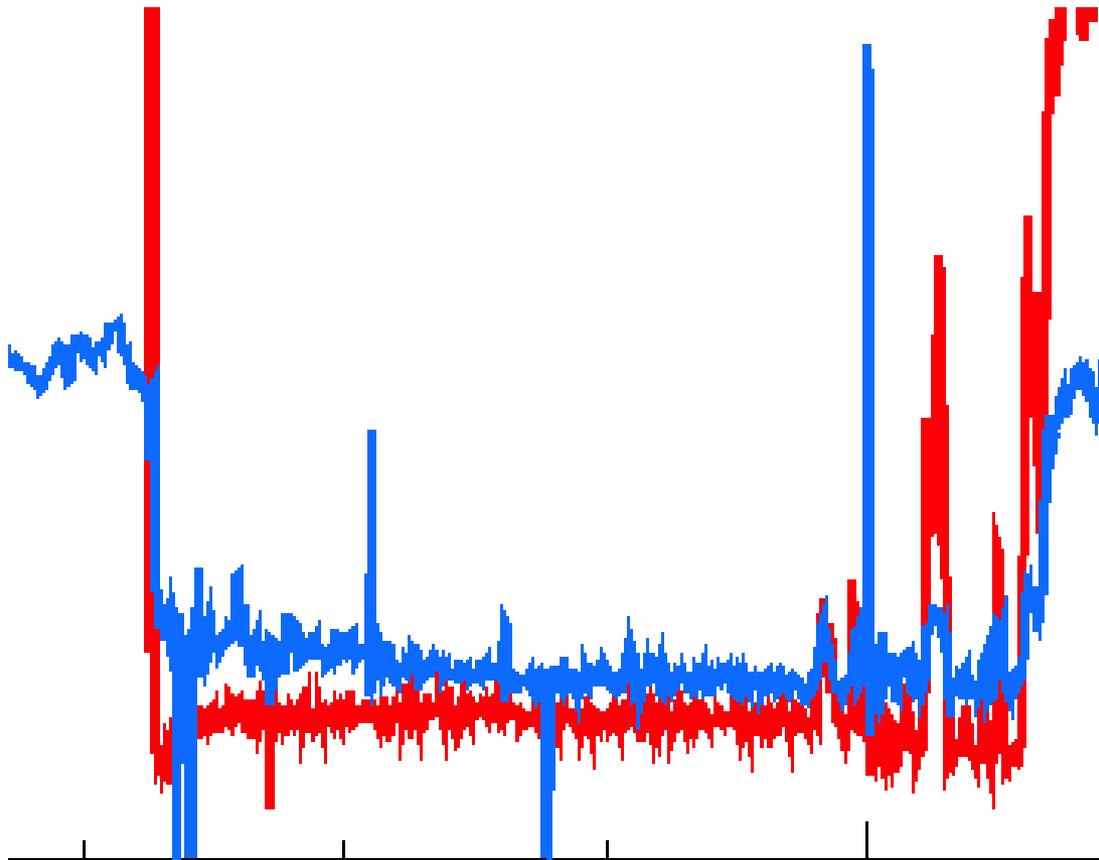


# Conclusions

- Indian Sub-continent key place to understand ATAL's origin
- Key results of the BATAL campaign includes :
  - ❑ First size distribution of the ATAL : Made of very small/volatile particles of less than 0.2 micron.
  - ❑ Strongly correlated with Cold Point Temperature
  - ❑ Influenced by convective moisture.
  - ❑ Likely resulting from New Particle Formation (sulfate or SOA ?)
- Experimental floating balloon flight near the tropopause show interesting features (cloud or aerosol layers ?)
- Next : BATAL 2016 ?

# Balloon Sunrise during BATAL





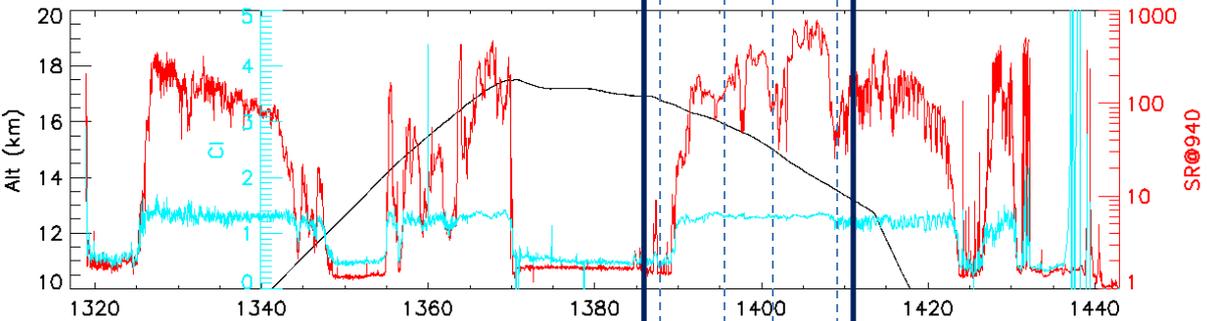
More slides

# What is the origin of ATAL?

- Modeling by Neely using WACCM suggests that the aerosol is primarily sulfate with about 30% originating in south Asia
- Similarly, work by Fairlie suggests that it is primarily sulfate but that up to 90% of the sulfur originates in India
- Composition and source remains a matter of debate at this time

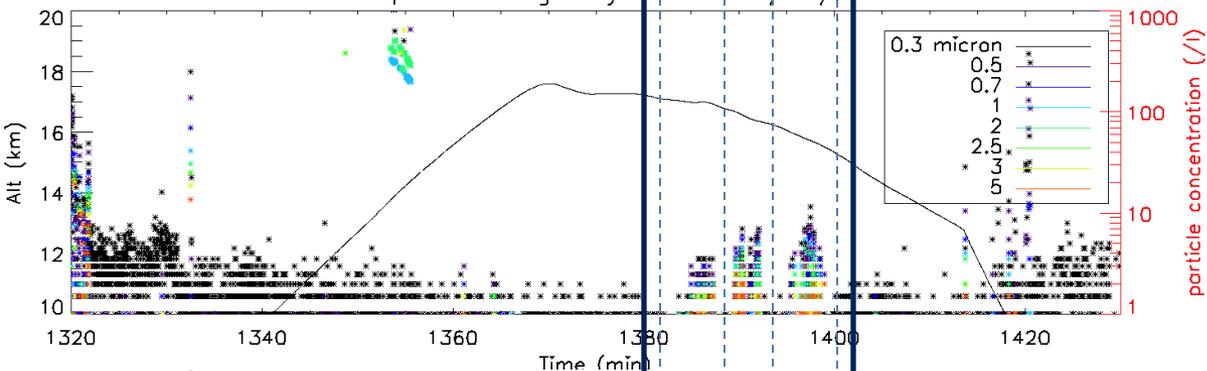
# Floating balloon near the tropopause

COBALD

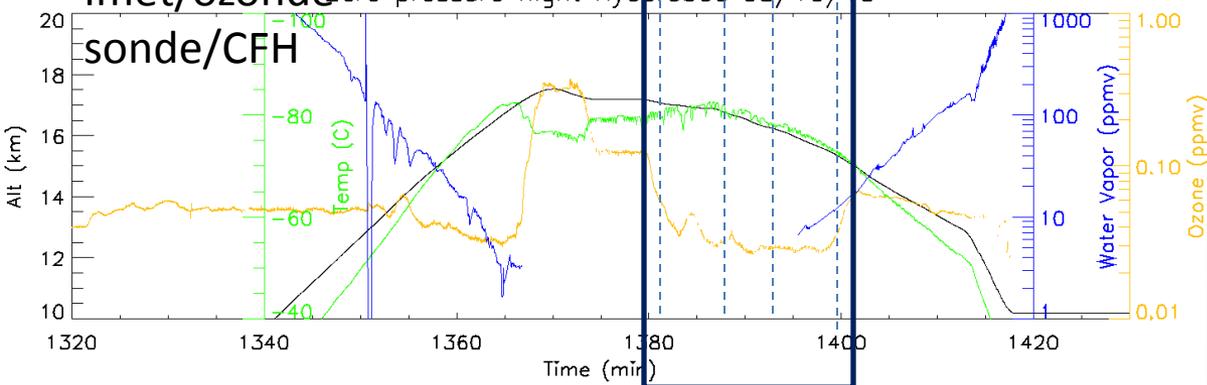


ZF1  
In the TTL

OPC Zero pressure flight Hyderabad 08/10/15

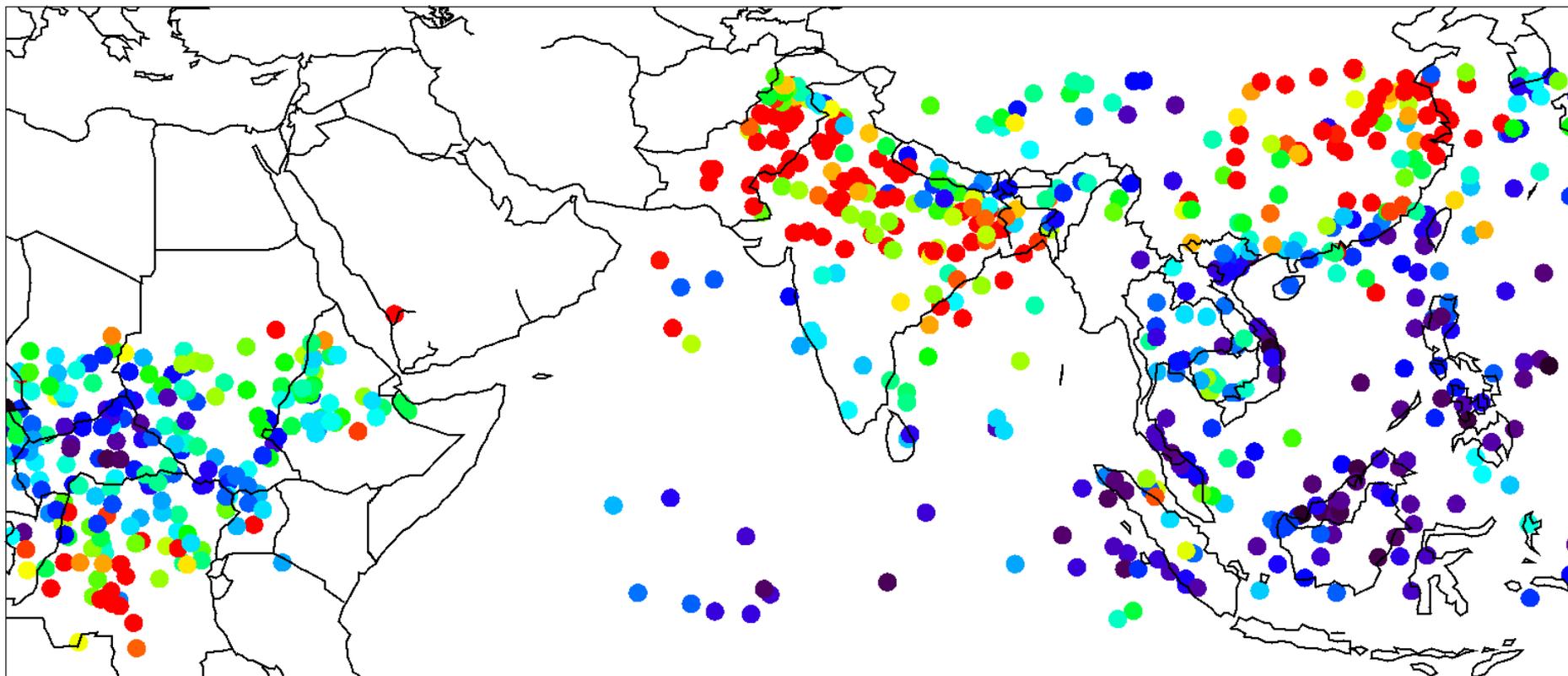


Imet/ozonde sonde/CFH Zero pressure flight Hyderabad 08/10/15

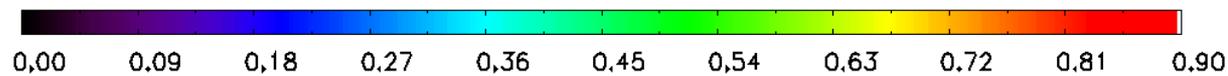


Within 2 days and  
Grid map [3lon\*3Lat]

TRMM convective storms and MODIS aerosol  
June-July-August 2008

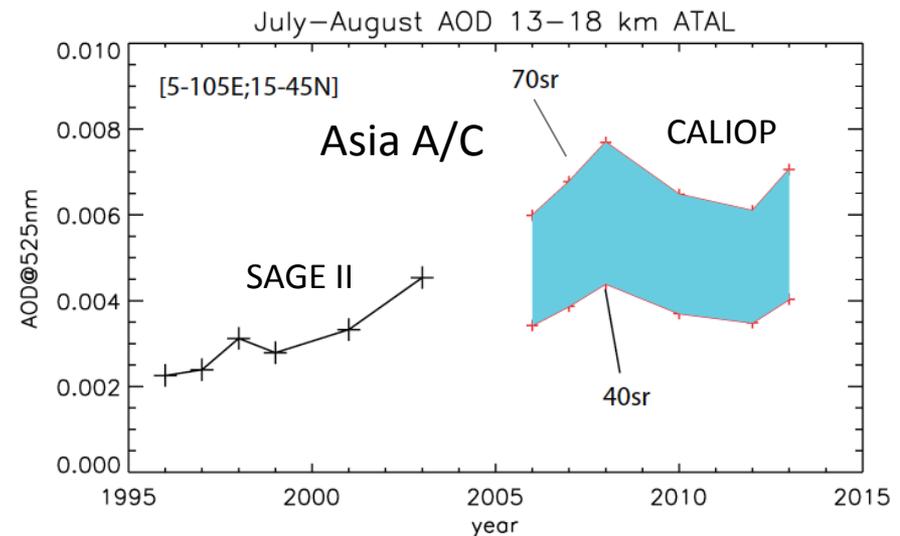
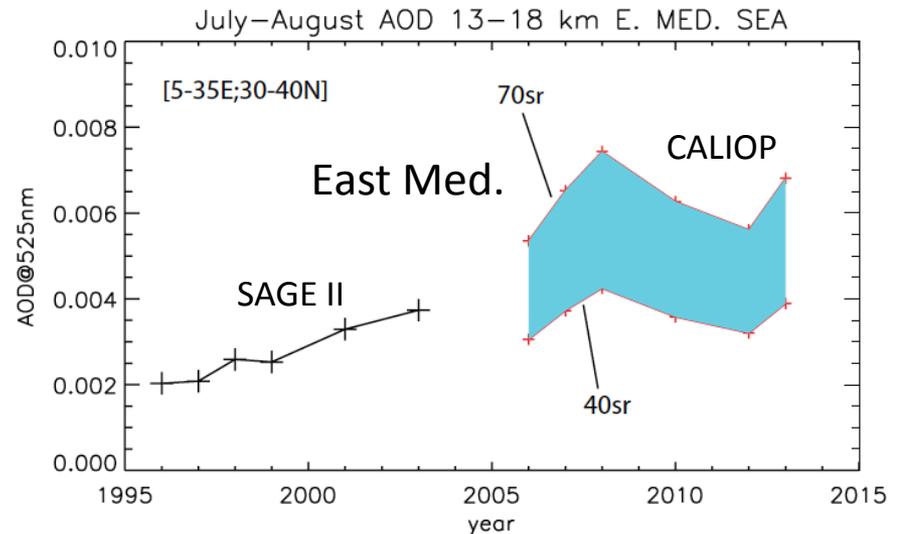


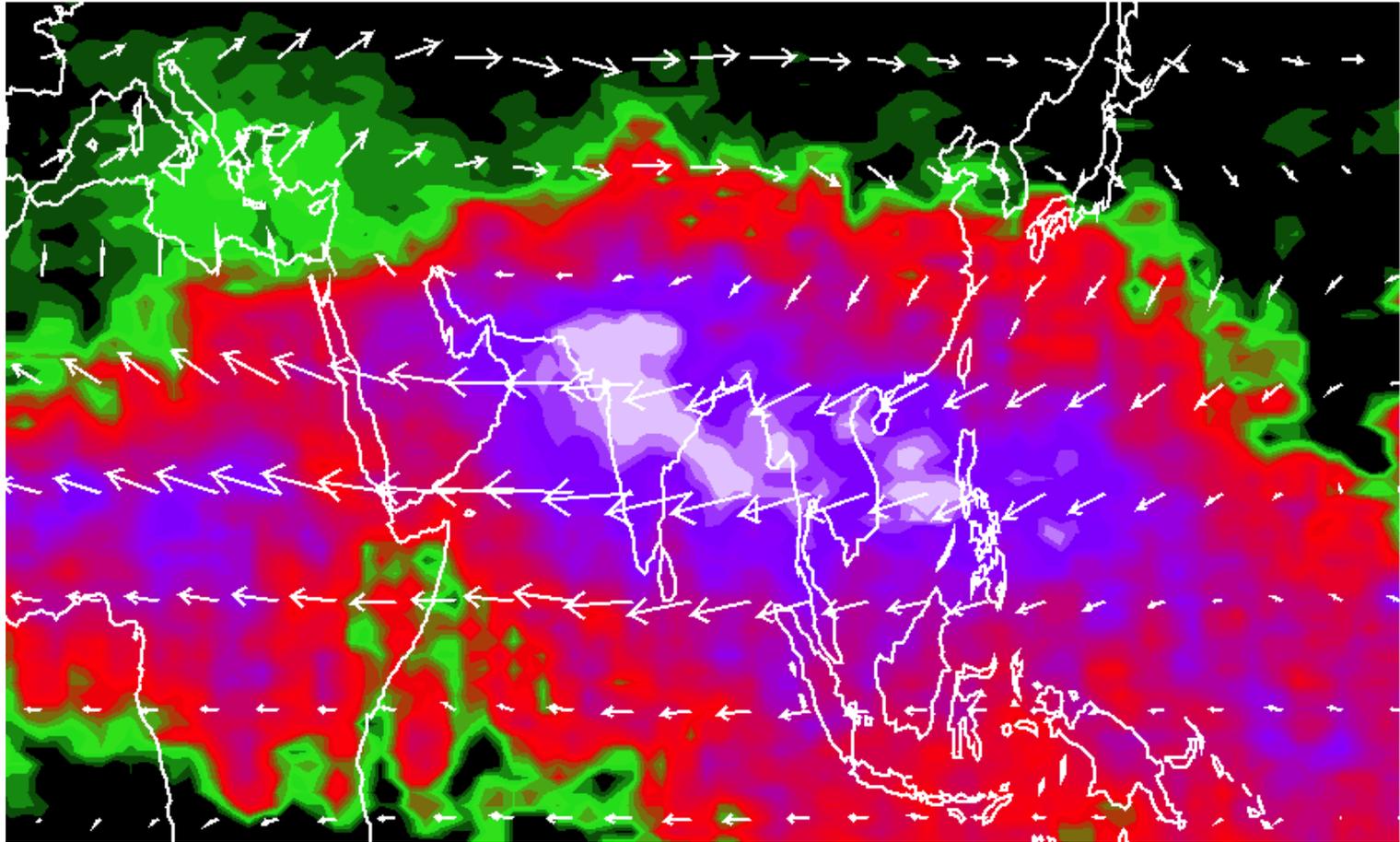
AOD



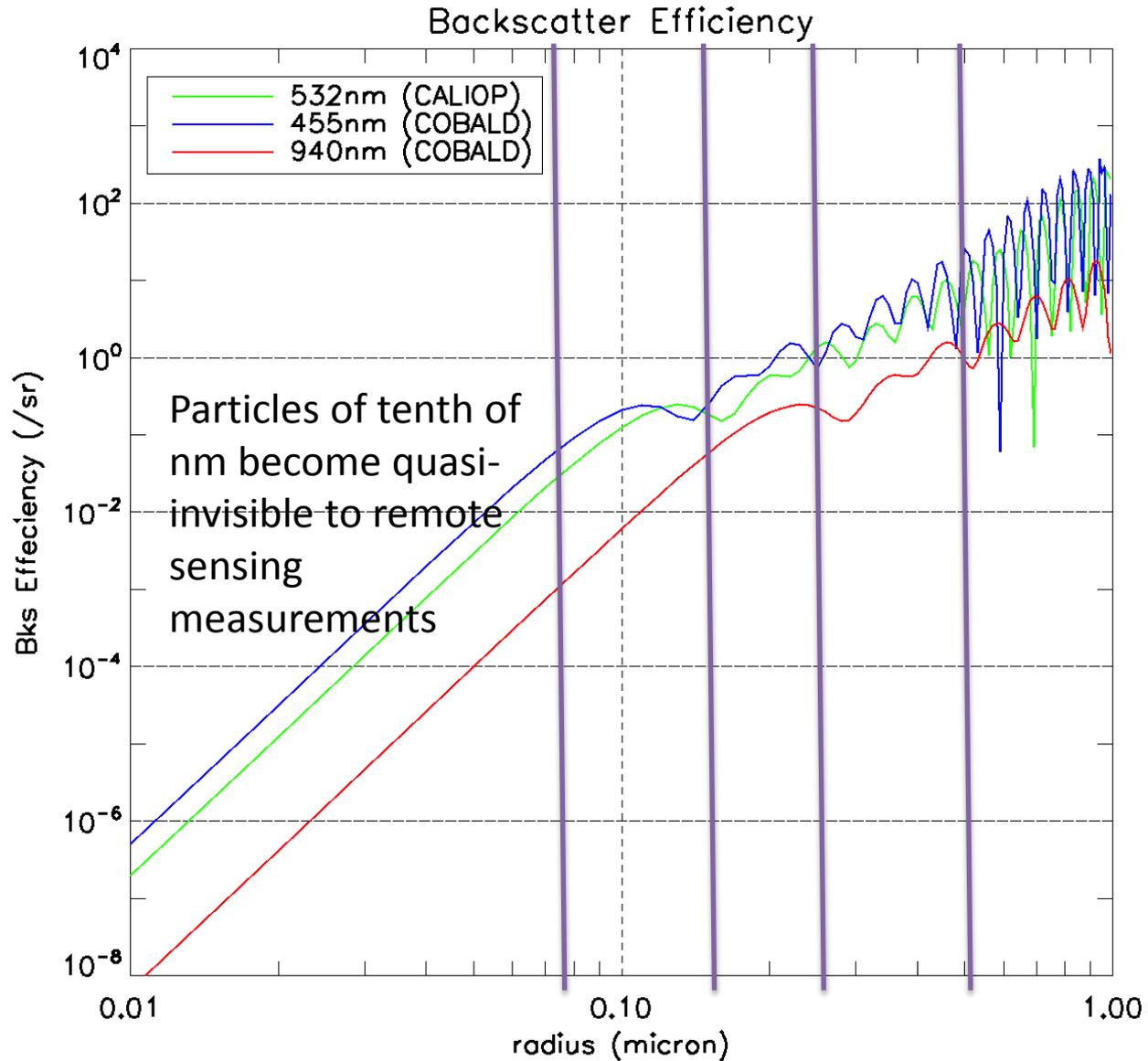
# ATAL: Intensifies during the 2000s

- SAGE II also observed ATAL after 1999 (Thomason and Vernier., 2013)
- Fig : Times series of summertime AOD between 13 and 18 km over Eastern Med and Asia
- Combined CALIPSO/SAGE II record suggests the **intensification of ATAL particularly between 2000 and 2010**





Mie Calculations :  
Sulfuric acid  
M=1.45

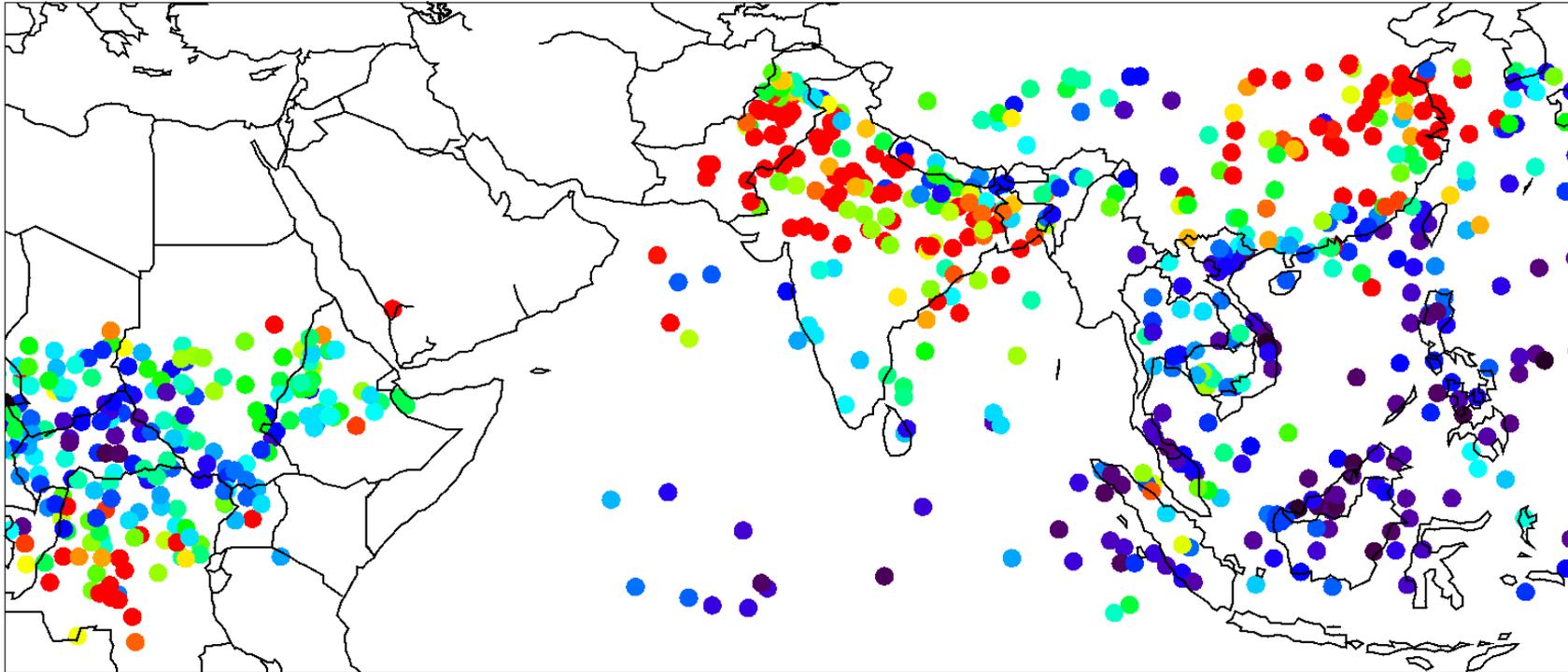


532 nm : particle of 0.15 micron is 6 times more efficient to backscatter light than at 0.075 micron  
940 nm : particle of 0.15 micron is 50 times more efficient to backscatter light than at 0.075 micron

# Polluted versus Pristine Convection

TRMM/MODIS June-July-August 2008

MODIS AOD



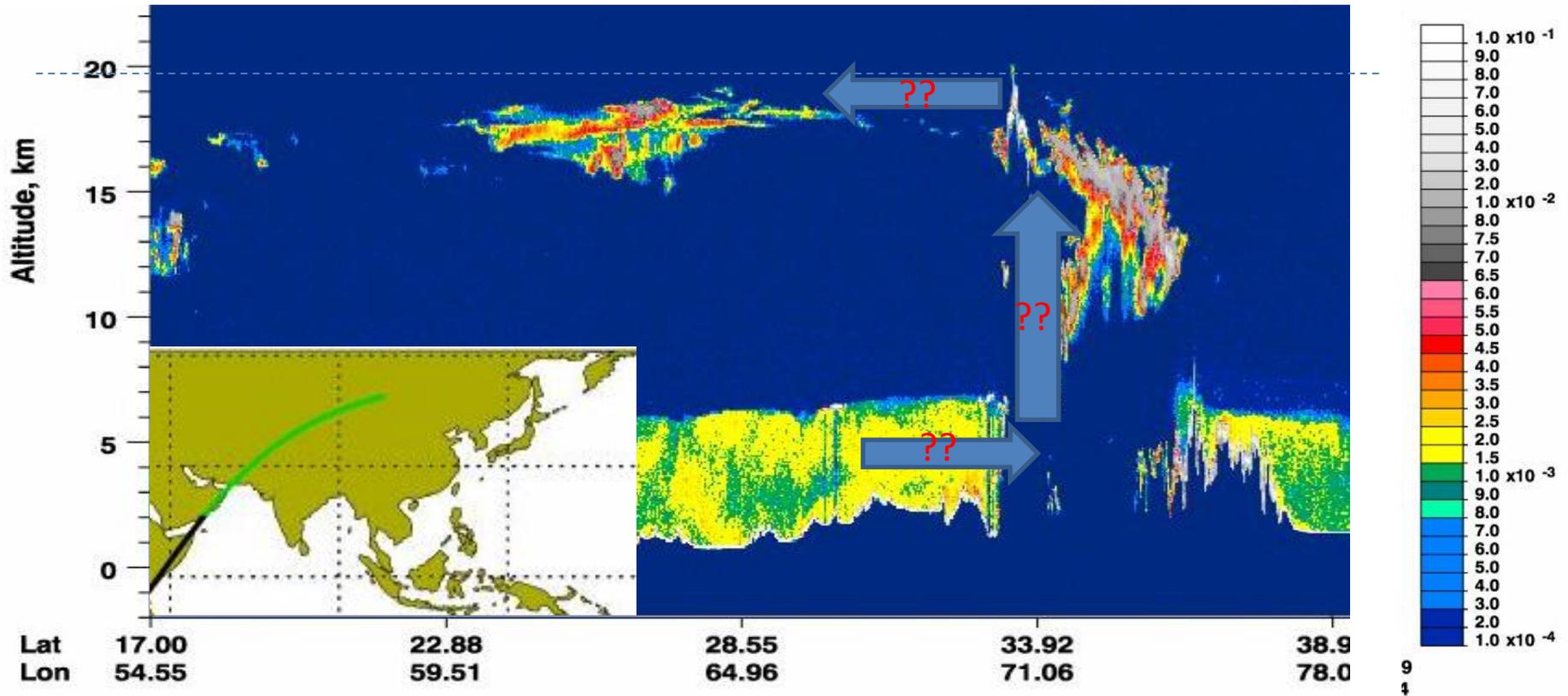
AOD

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- North India/Pakistan and Eastern China contrasts with Maritime content convections

# Polluted convective environment



1064 nm total backscatter CATS/ISS lidar 07/16/2015 21 UTC



- Evidence for strong convection reaching the lower stratosphere in very polluted environment over Pakistan
- How efficient is convection to transport primary aerosol and/or their gas precursors in the UTLS

# BATAL 2015



*Vanarasi, India, August 2015*



*Gadanki, India, July 2015*



*Hyderabad, India, August 15*



*Thuwal, Saudi-Arabia, August 2015*

OPC Wyoming 08/13/15 Hyderabad

