

# The Asian Tropopause Aerosol Layer

balloon-borne measurements, satellite observations and modeling approaches

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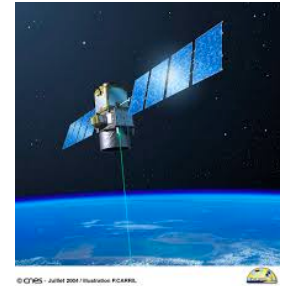


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6. National balloon facility, TIFR, Hyderabad, India
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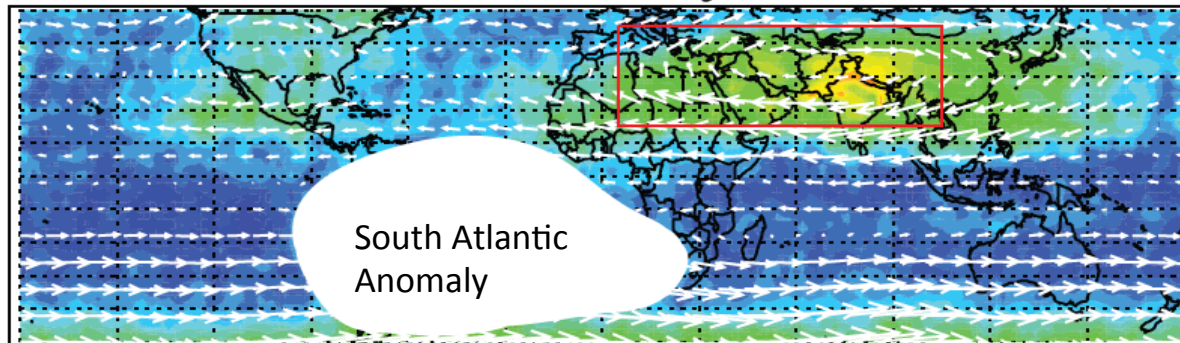


8. LPC2E, CNRS, Orlean, France
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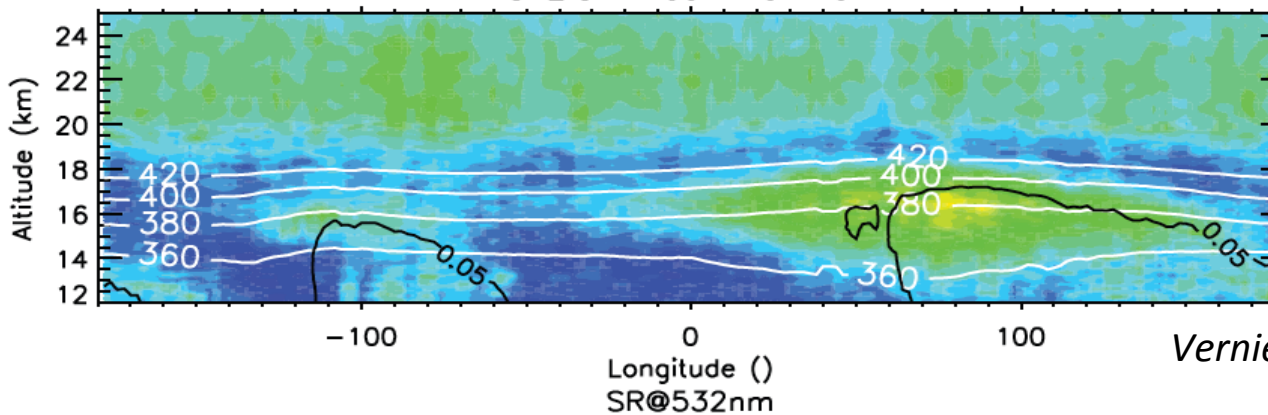
# The Asian Tropopause Aerosol Layer



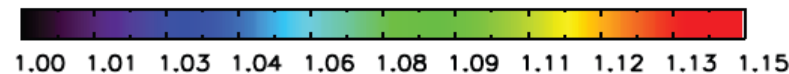
b) CALIOP 15–17km Jul–Aug 2006–2013



c) CALIOP Mean 15–45N



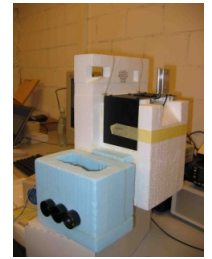
Vernier et al., JGR 2015



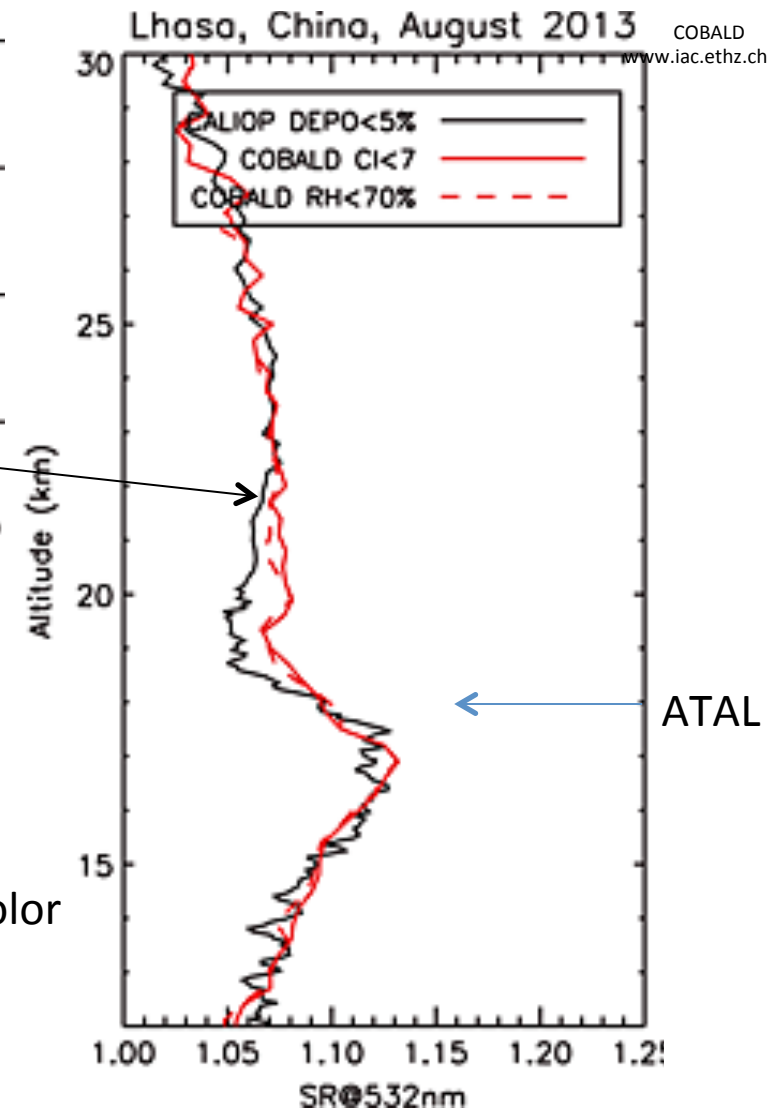
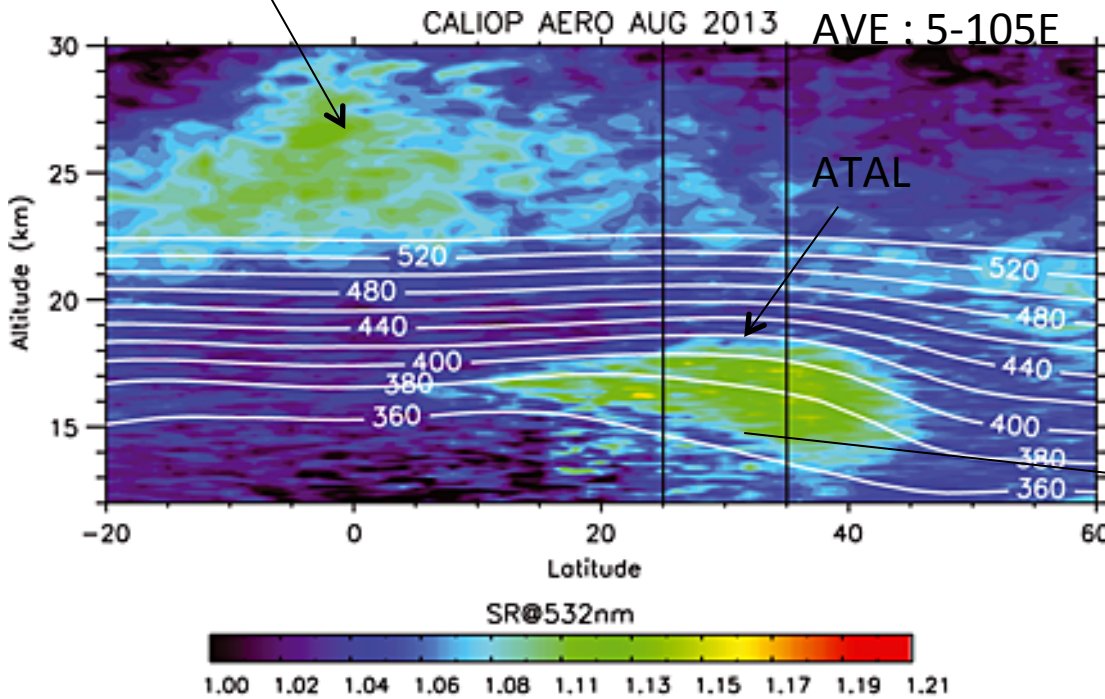
- The Existence of the ATAL was recognized through CALIOP lidar observations
- Buildup of enhanced aerosol associated with Asian Summer Monsoon anticyclone, extending from the E. Med Sea to W. China
- Extends from top of convective outflow over much of SE Asia

# Validation of CALIPSO observations

with balloon-borne backscatter measurements



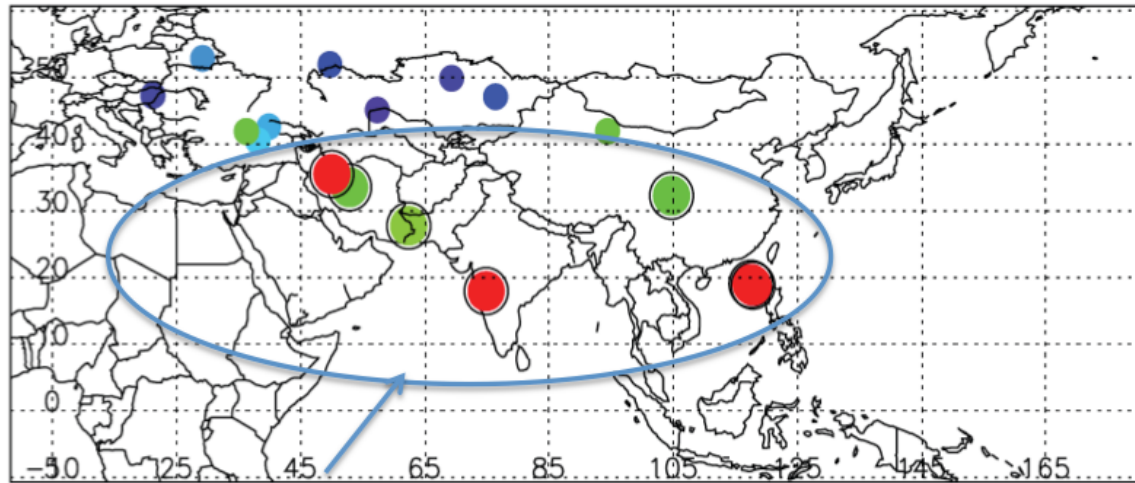
Stratospheric aerosol layer



- 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 not the result of unfiltered cirrus clouds

# Limited in situ observations indicate aerosol composition 10-12 km in lower ATAL mainly Sulfate + Carbonaceous

CARIBIC AUG 2006–2008 elemental composition C/S (10–12 km)



C to S mass ratio

mc/ms

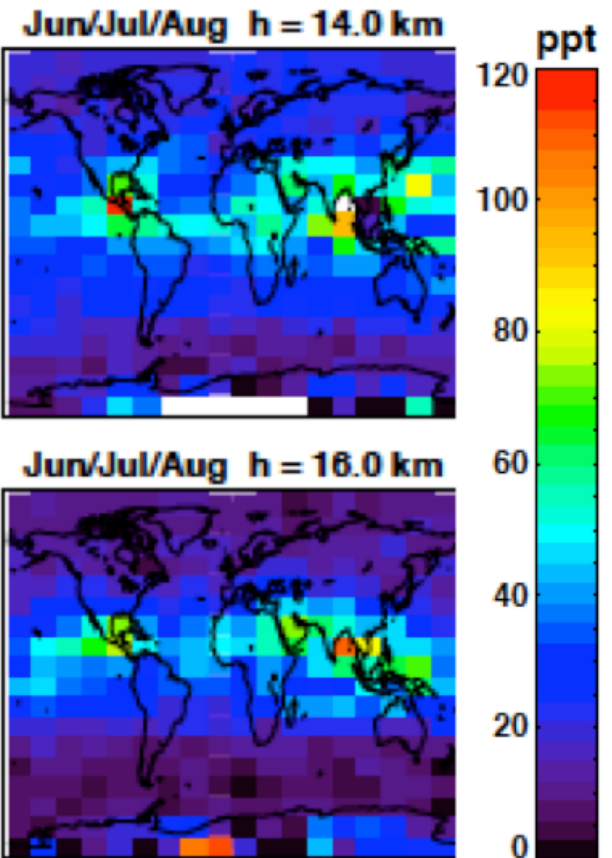
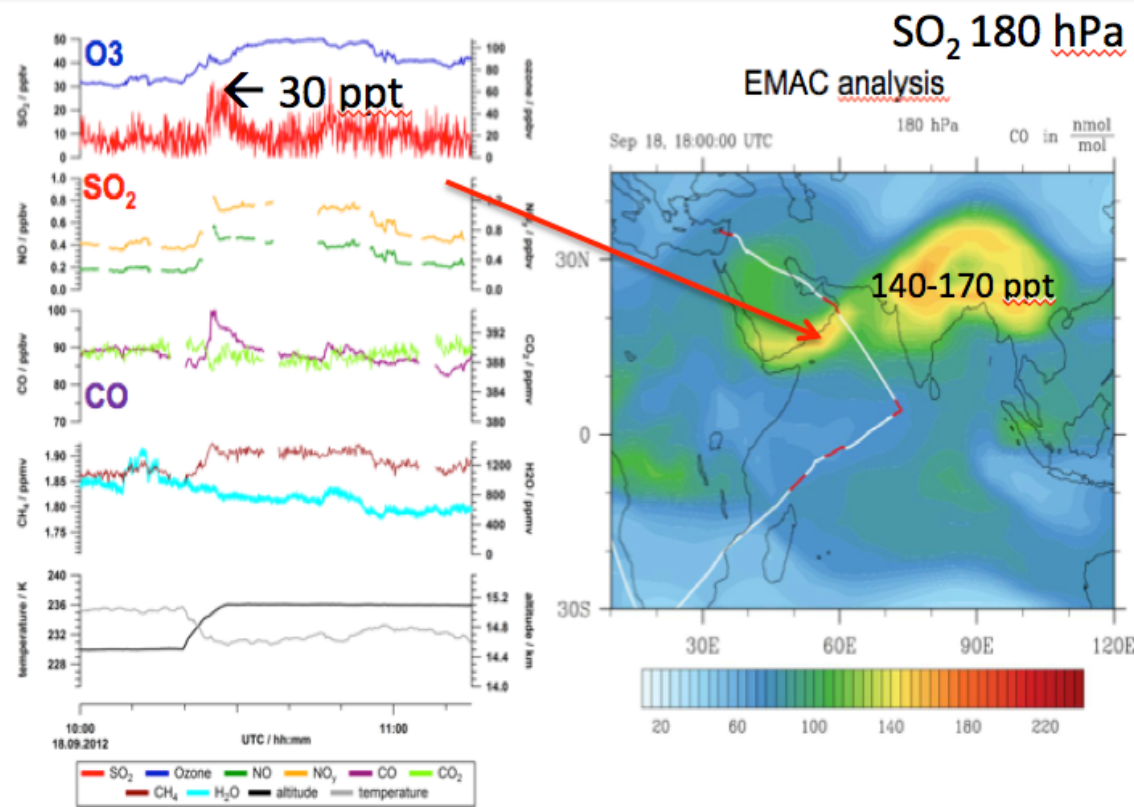


0.00 0.38 0.75 1.12 1.50 1.88 2.25 2.62 3.00

CARIBIC impactor data  
 Martinsson et al., 2014

	<u>ng S m<sup>-3</sup> (STP)</u>	<u>ng C m<sup>-3</sup> (STP)</u>	<b>C/S</b>	PV < 1 PVU; 0° < <u>lat</u> < 45°N; P < 300 <u>hPa</u> ; 20° < <u>lon</u> < 130°E
median	12	25	1.8	
mean	21	29	2.8	
<u>Std</u>	23	15	2.6	From <u>Vernier et al. (JGR, 2015)</u>

## SO<sub>2</sub> in-situ observations in Asian Monsoon outflow

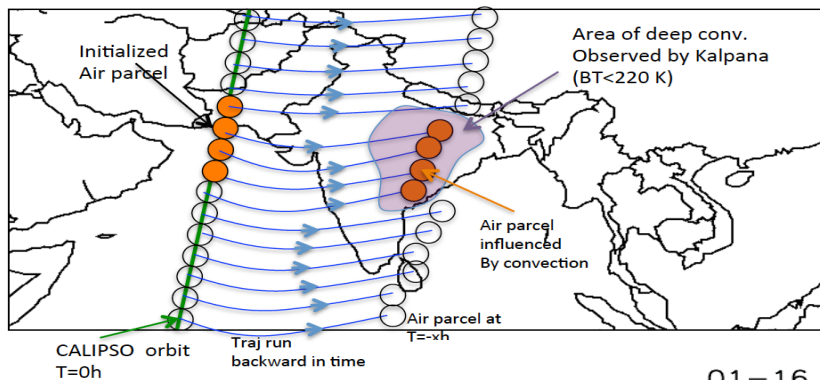


HALO ESMVal flight of 18 Sept. 2012, shows up to **30 ppt SO<sub>2</sub> at ~15km** in UT Asian outflow.

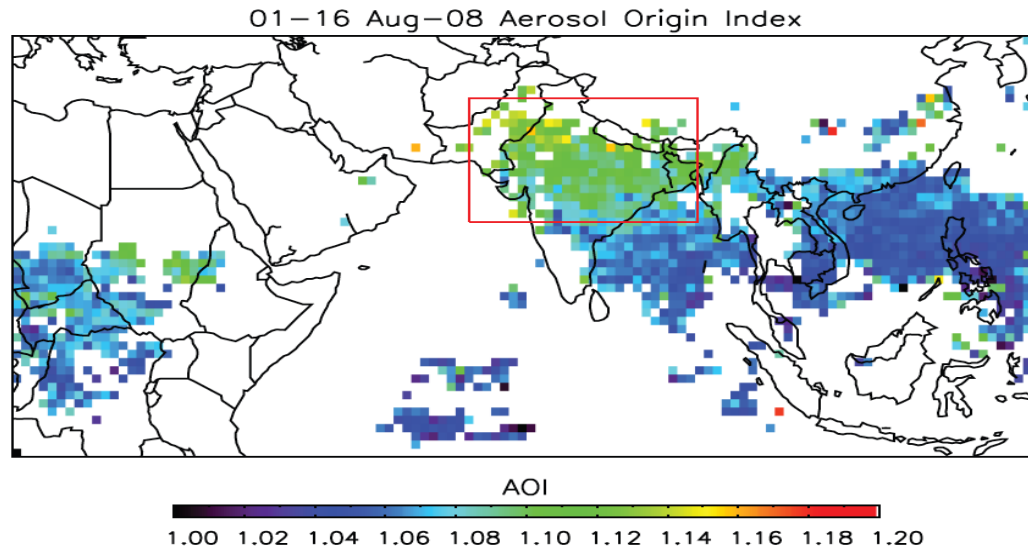
from A. Roiger et al. presentation to SPARC SIRC workshop, Atlanta, GA, October, 28-30, 2013.

MIPAS shows SO<sub>2</sub> of 50-100 ppt at 14-16 km in seasonal mean maps (2002-2012), filtered for volcanic episodes. from M. Hoepfner et al., MIPAS SO<sub>2</sub> in the UTLS, ACPD, 2015.

# Origin of ATAL



Trajectory mapping of CALIPSO observations to regions of deep convection (BT<220K from Kalpana);



Trajectory-mapped CALIPSO SR (AOI) to locations of deep convection, 1-16 Aug., 2008, indicates Northern India as key deep convective source for elevated aerosol in the ATAL.

# BATAL 2015 : Balloon-borne measurements of the ATAL

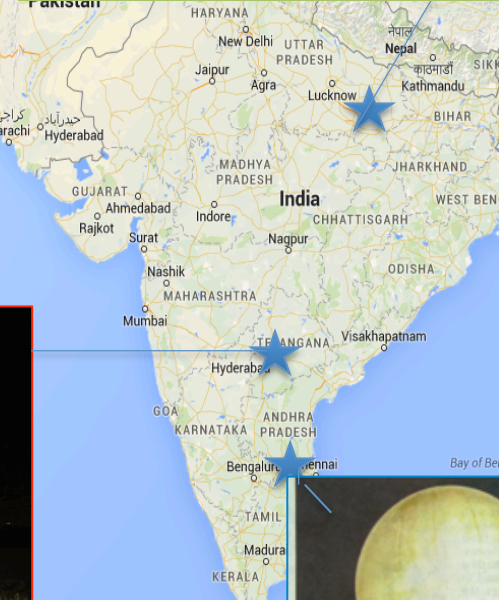
5 weeks : July-August 2015 : 30 Launches/ 4 locations/9 Institutes involved



- , 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

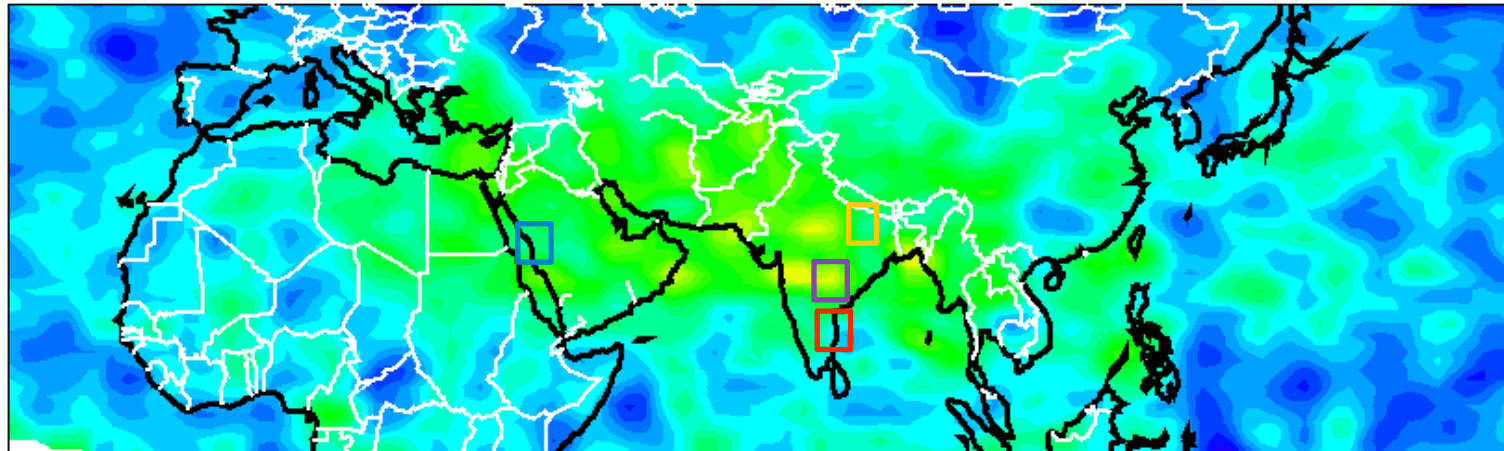
- 17-25 July 15: National Atmospheric Research Laboratory, Gadanki, India,  
- 6 launches of aerosol and chemical sensors



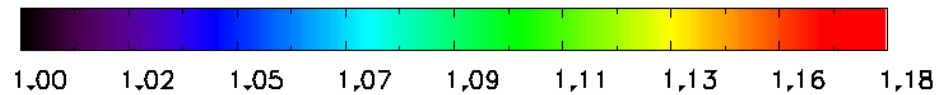
# CALIOP/BATAL-2015

15 - 18 km

CALIPSO JULY/AUGUST 2015

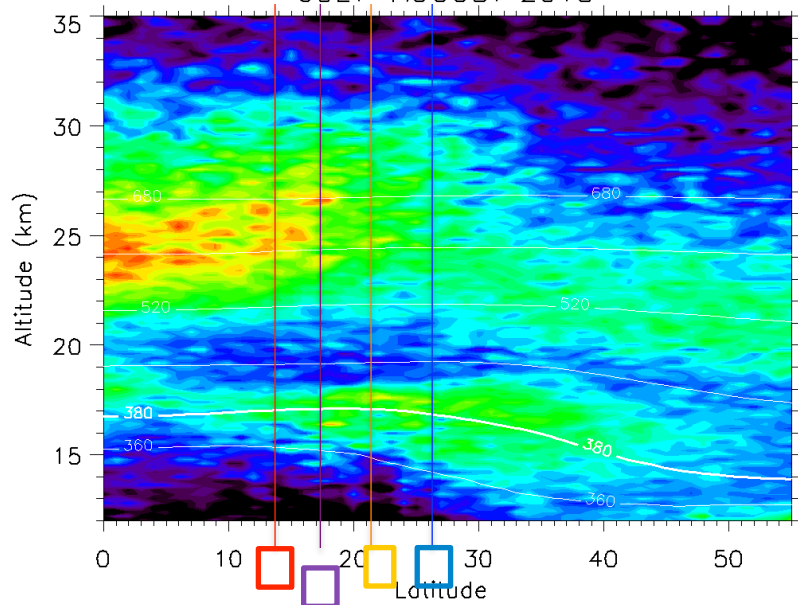


SCATTERING RATIO@532nm



5 - 105E

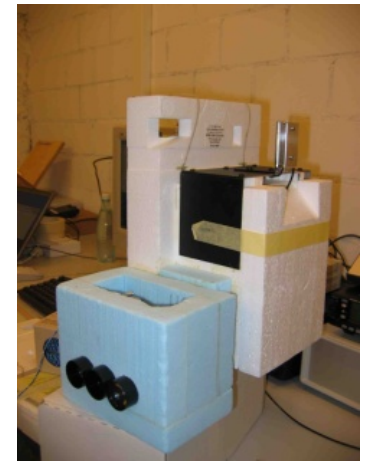
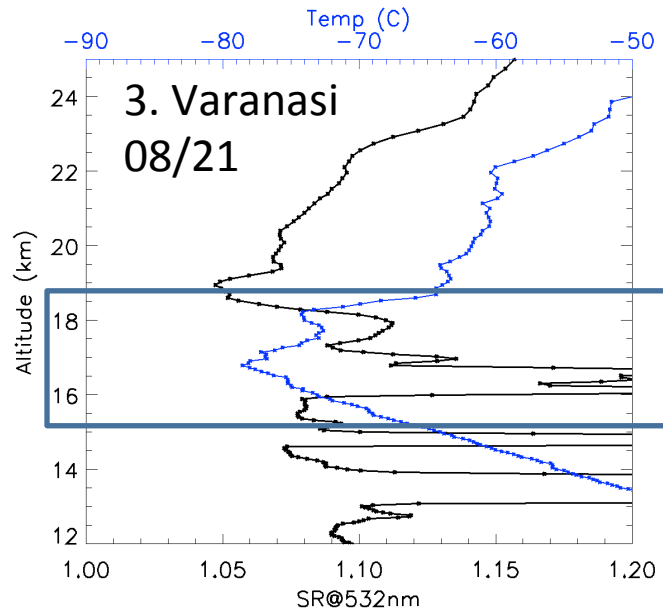
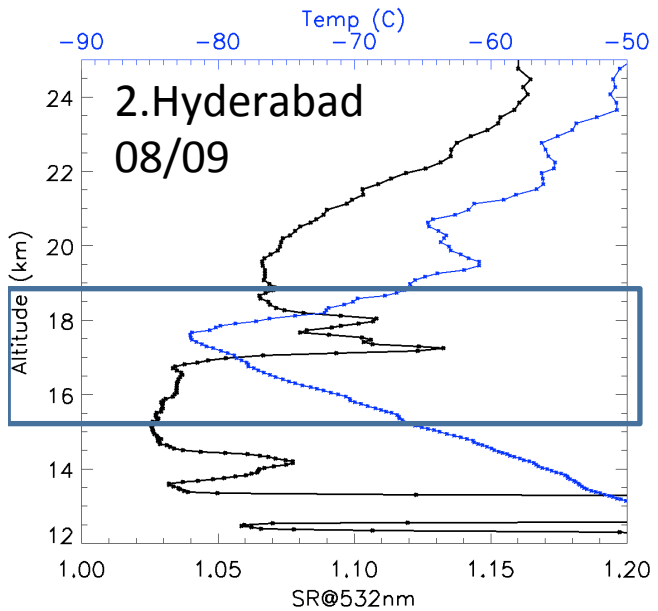
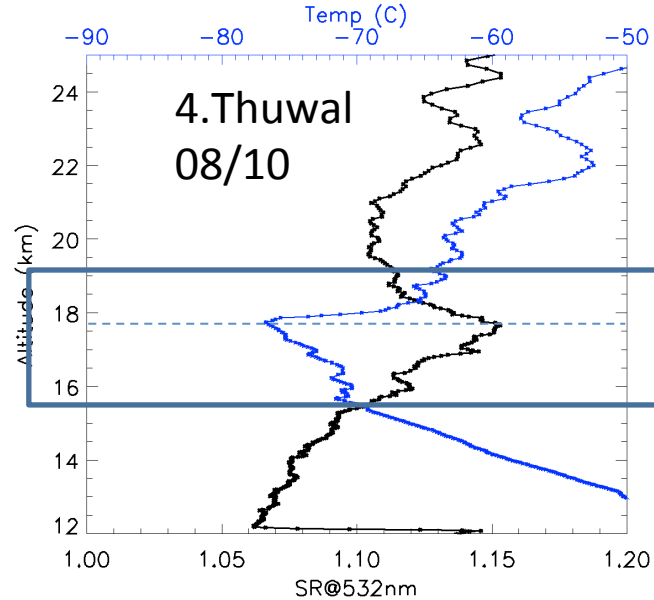
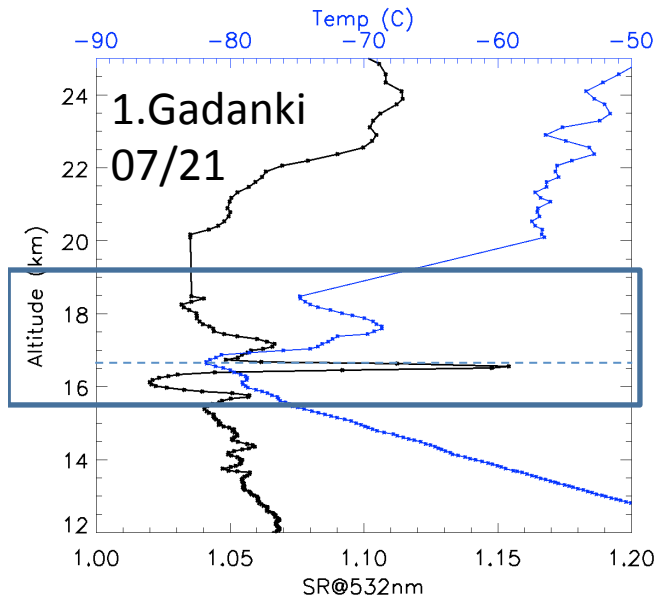
JULY-AUGUST 2015



- 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.



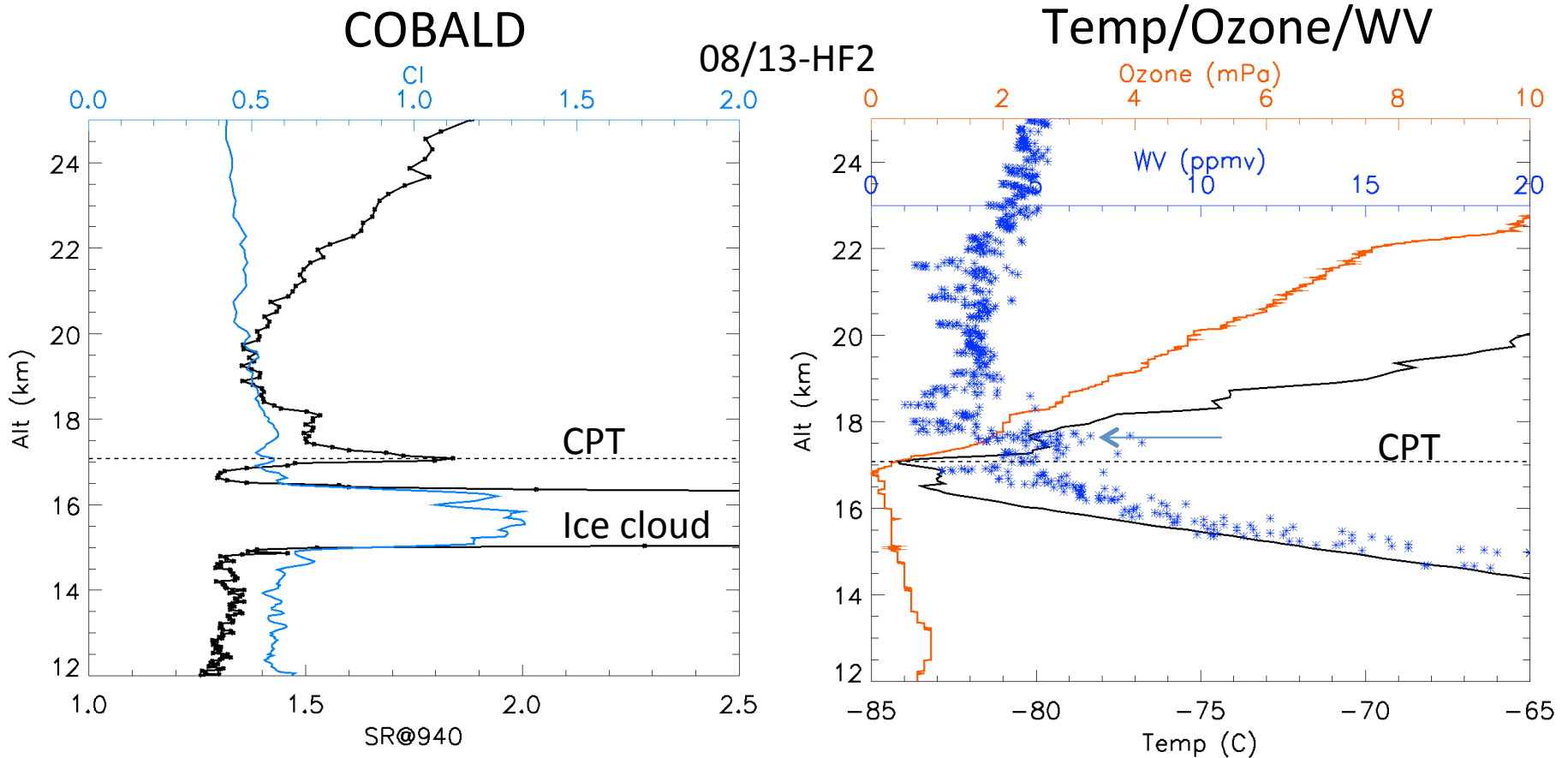
# BATAL 2015/COBALD flights



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

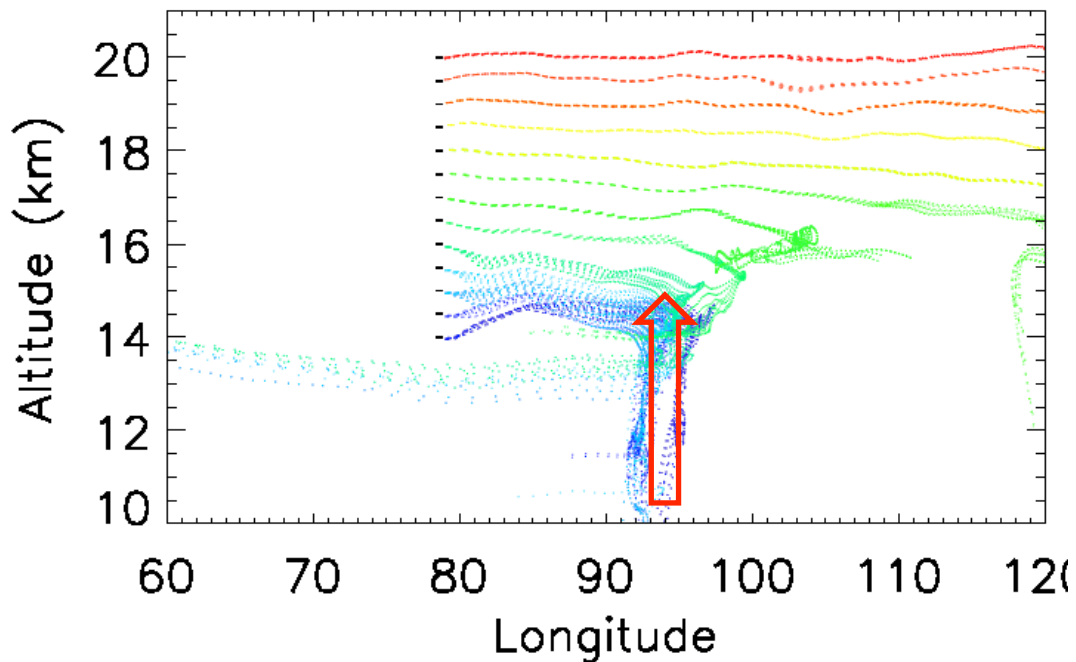
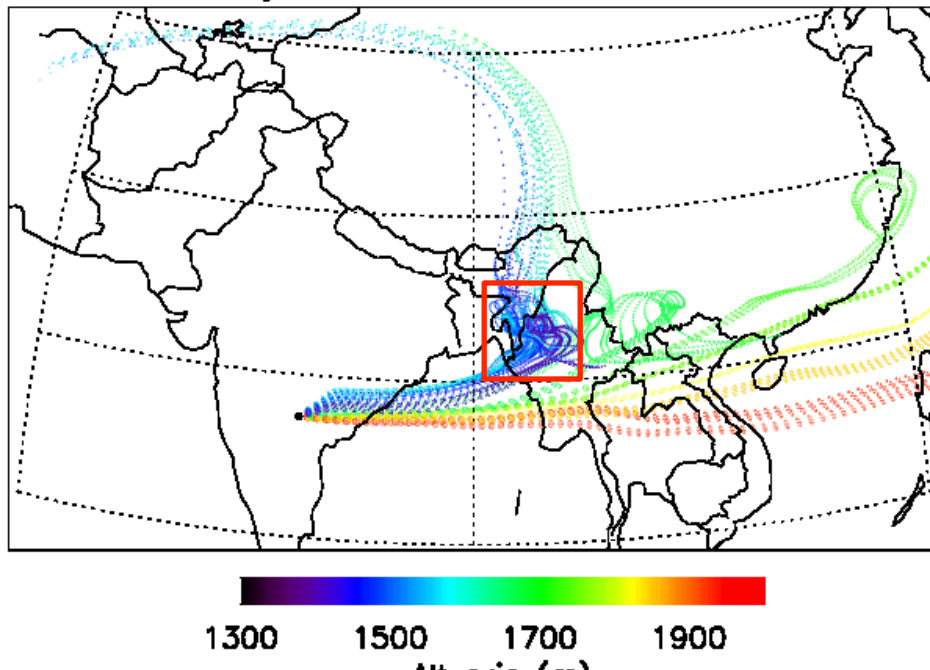
- COBALD backscatter and Temp Profiles
- Thin aerosol layers near the tropopause
- Contrast with broader layer observed from the Arabic Peninsula
- Ice clouds near the tropopause over Varanasi

# Moisture transport in the UTLS, HF flight of 8/13



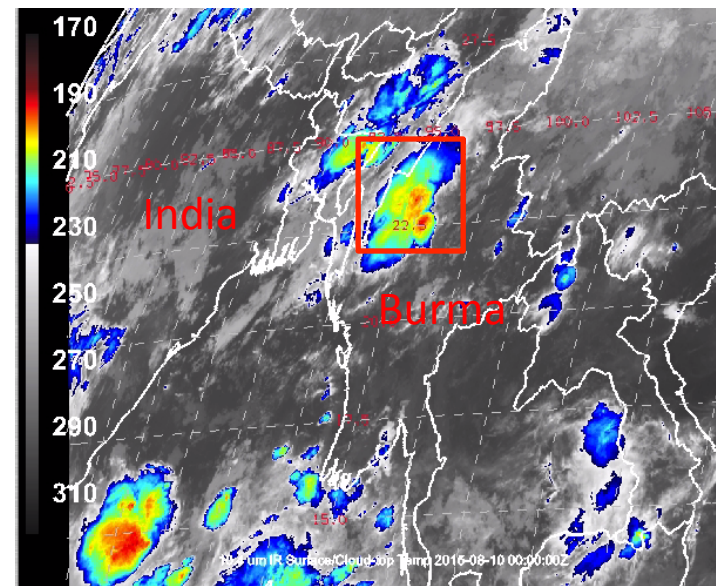
- Maximum of aerosol measured by COBALD found at the cold point tropopause
- Low Color Index (CI, blue line) for aerosol measured by COBALD contrasts with CI for ice clouds which is near unity (15-16.5km).
- Enhanced water vapor (up to 8-9ppmv) near 18 km likely resulting from the recent convective transport of moisture

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

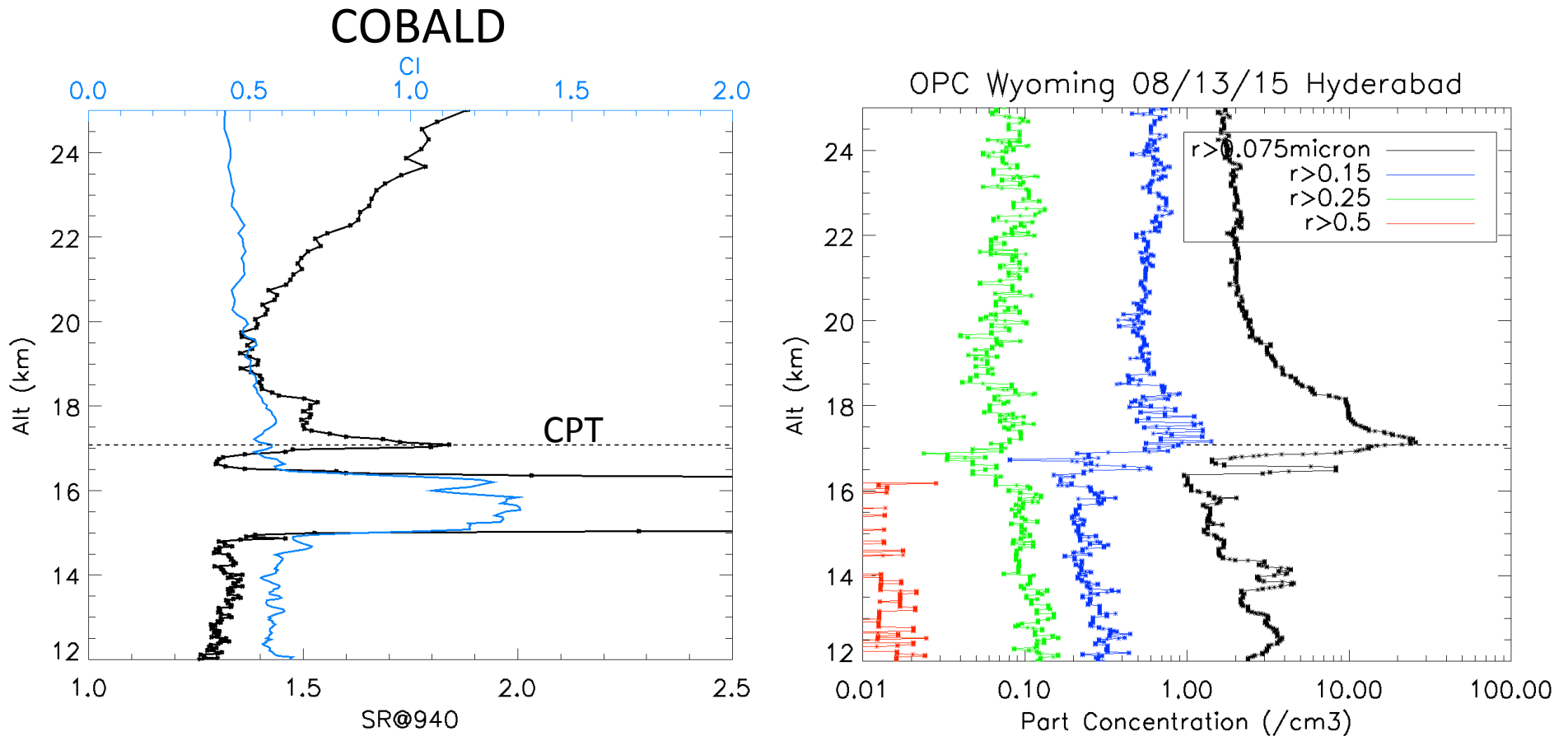


## Air masses origin

- Back-trajectories from air masses sampled by the 08/13 HF 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 COBALD SR coincides with peak in OPC number concentration for  $r > 75$  nm at the cold point tropopause (data for unheated inlet shown)
- ~97% of particles counted lie in the size range  $0.075 < r < 0.15 \mu\text{m}$
- Heated/unheated inlets on OPC instruments indicate ATAL composed primarily of very small/liquid particles

# GEOS-Chem simulations

3-D CTM for gas-phase and aerosols transport and photochemistry in the troposphere, driven by GEOS-5 meteorology ([www.geos-chem.org](http://www.geos-chem.org)), V9.02, 2x2.5 deg. 72 levels.

## Emissions:

**Fossil fuel:** EDGAR, with regional options, e.g. Streets (S.E. Asia);

**Carbonaceous aerosol:** Bond (2007)

**Biofuel:** Logan and Yevich (2003), with regional options

**Biogenic:** MEGAN

**Biomass Burning:** GFED3 (daily)

**Volcanic:** (SO<sub>2</sub> from AeroCom project)

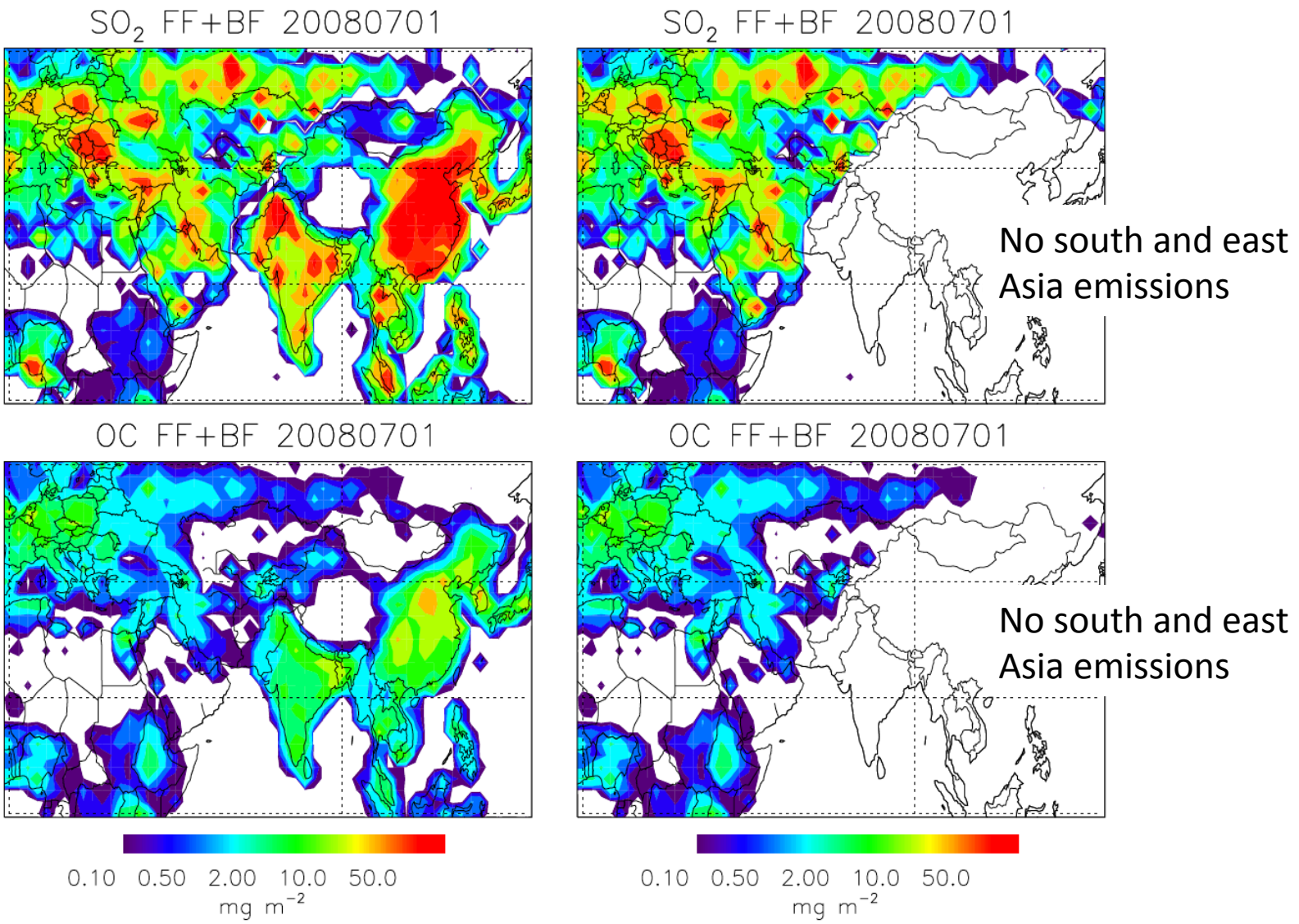
**Aerosol Components:** OC, BC, SO<sub>4</sub>, dust, NO<sub>3</sub>, limited SOA in current run.

6 month simulations (1 Apr. 2008 – 1 Oct. 2008)

***Update to wet scavenging of SO<sub>2</sub> in convective updrafts:***

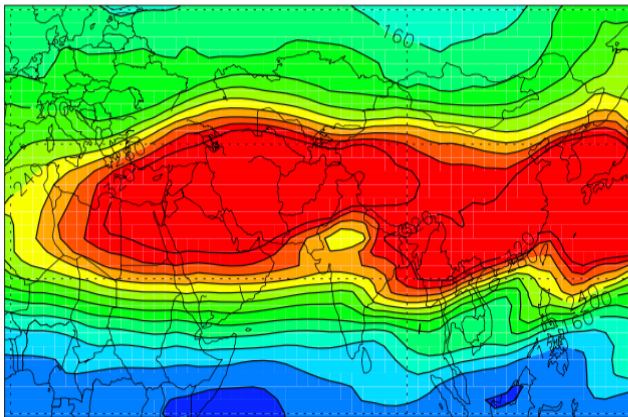
*fraction of SO<sub>2</sub> subject to scavenging limited by Effective Henry's Law equilibrium and aqueous oxidation by H<sub>2</sub>O<sub>2</sub>*

# FF, BF emissions of SO<sub>2</sub>, OC, July 2008 with (left) without (right) those of south, east Asia



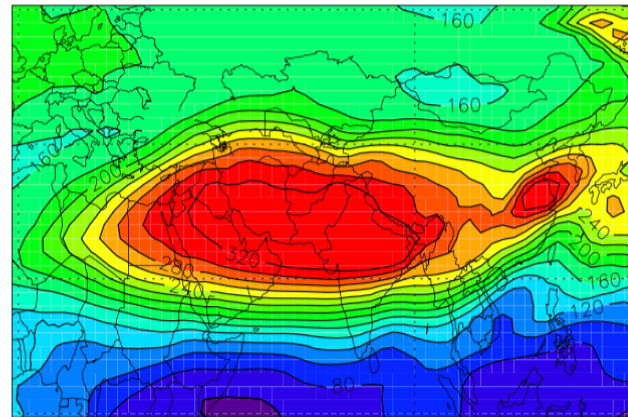
# G-C columns of SO<sub>4</sub>, OC, SO<sub>2</sub> S/C mass ratio July 2008, CARIBIC observations

SO<sub>4</sub> colm 100–230mb 20080701



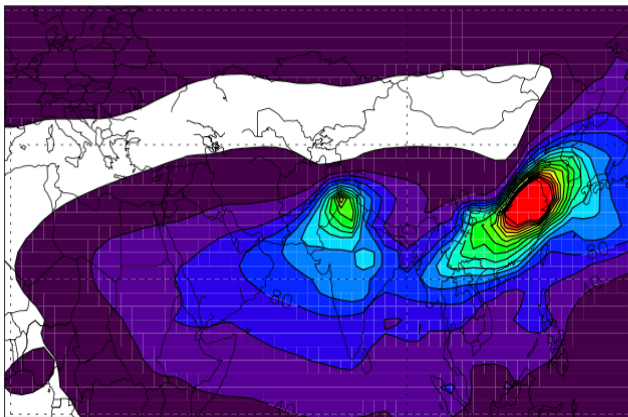
0.00 40.0 80.0 120. 160. 200. 240. 280. 320.  
ug S m<sup>-2</sup>

OC colm 100–230mb 20080701



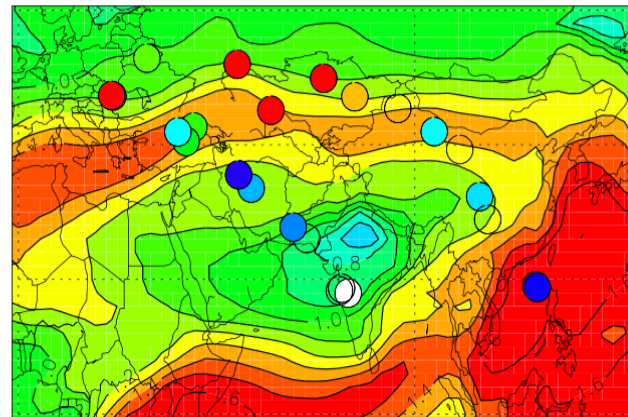
0.00 40.0 80.0 120. 160. 200. 240. 280. 320.  
ug C m<sup>-2</sup>

SO<sub>2</sub> colm 100–230mb 20080701



0.00 40.0 80.0 120. 160. 200. 240. 280. 320.  
ug S m<sup>-2</sup>

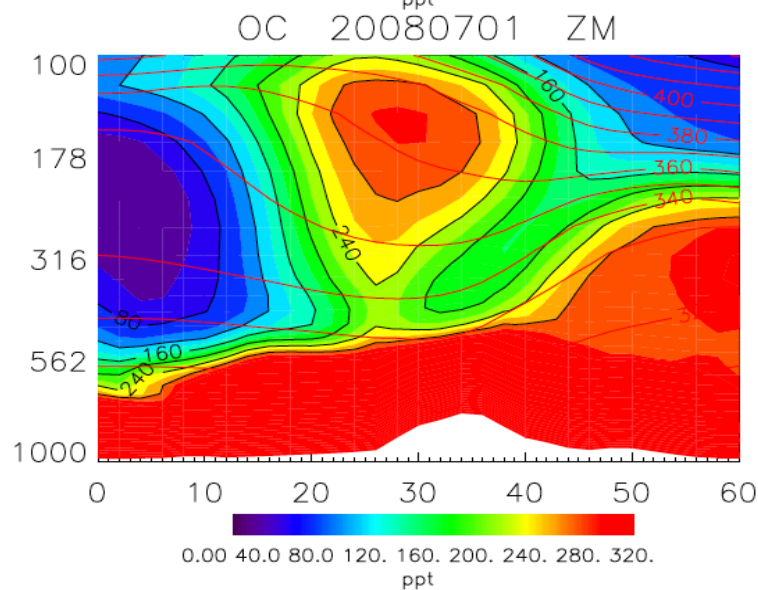
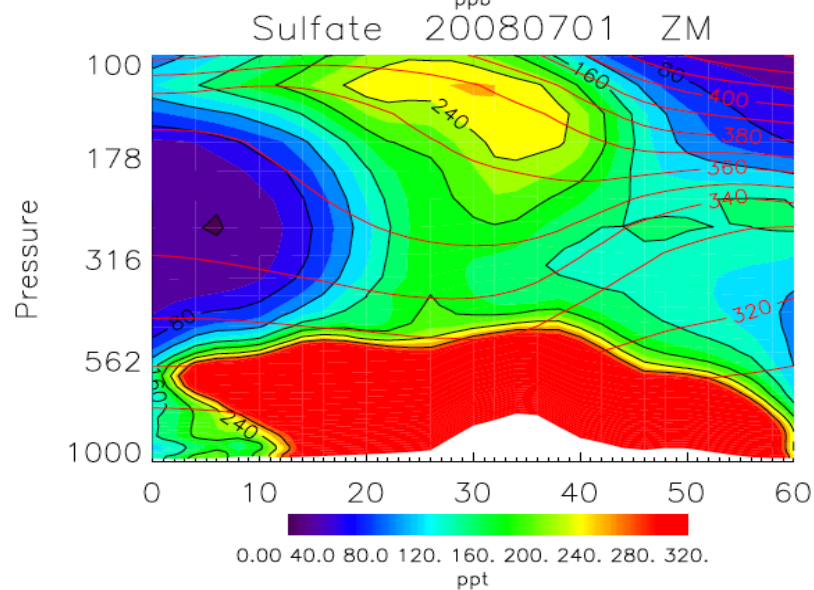
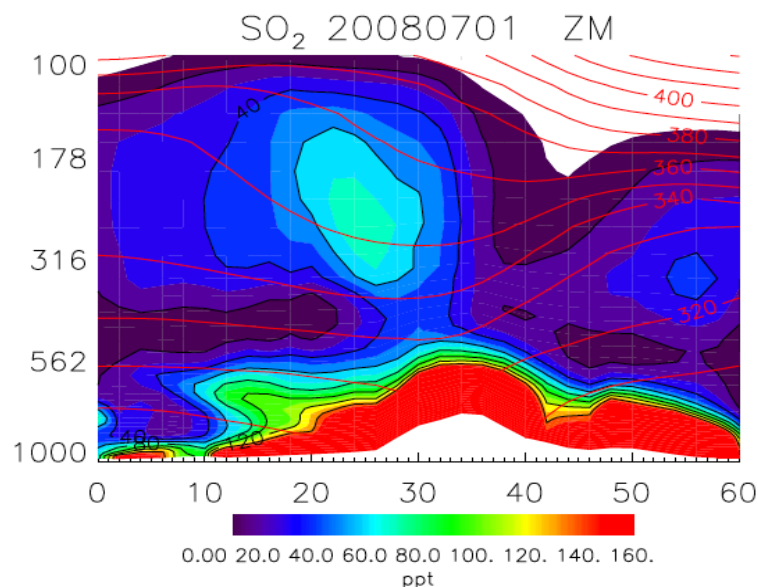
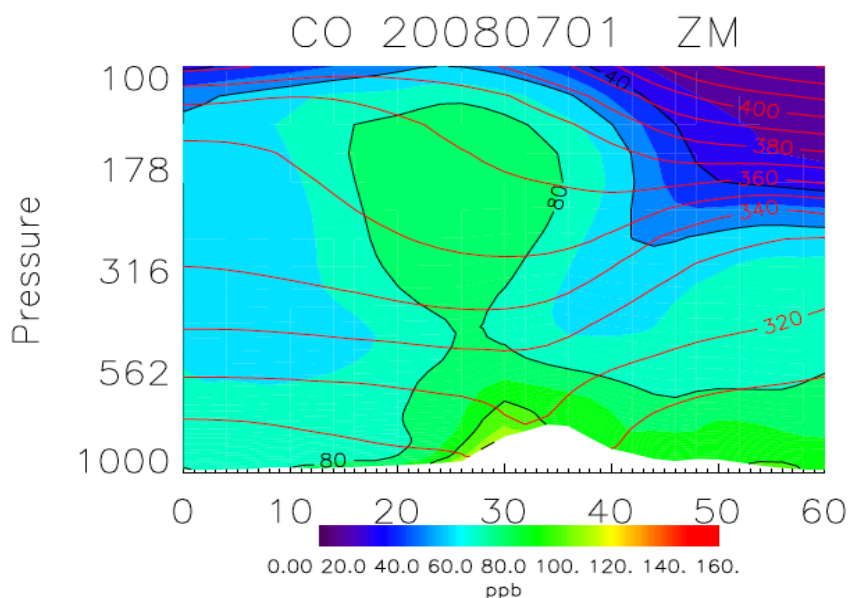
S/C 100–230mb 20080701



0.00 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60  
ug/ug

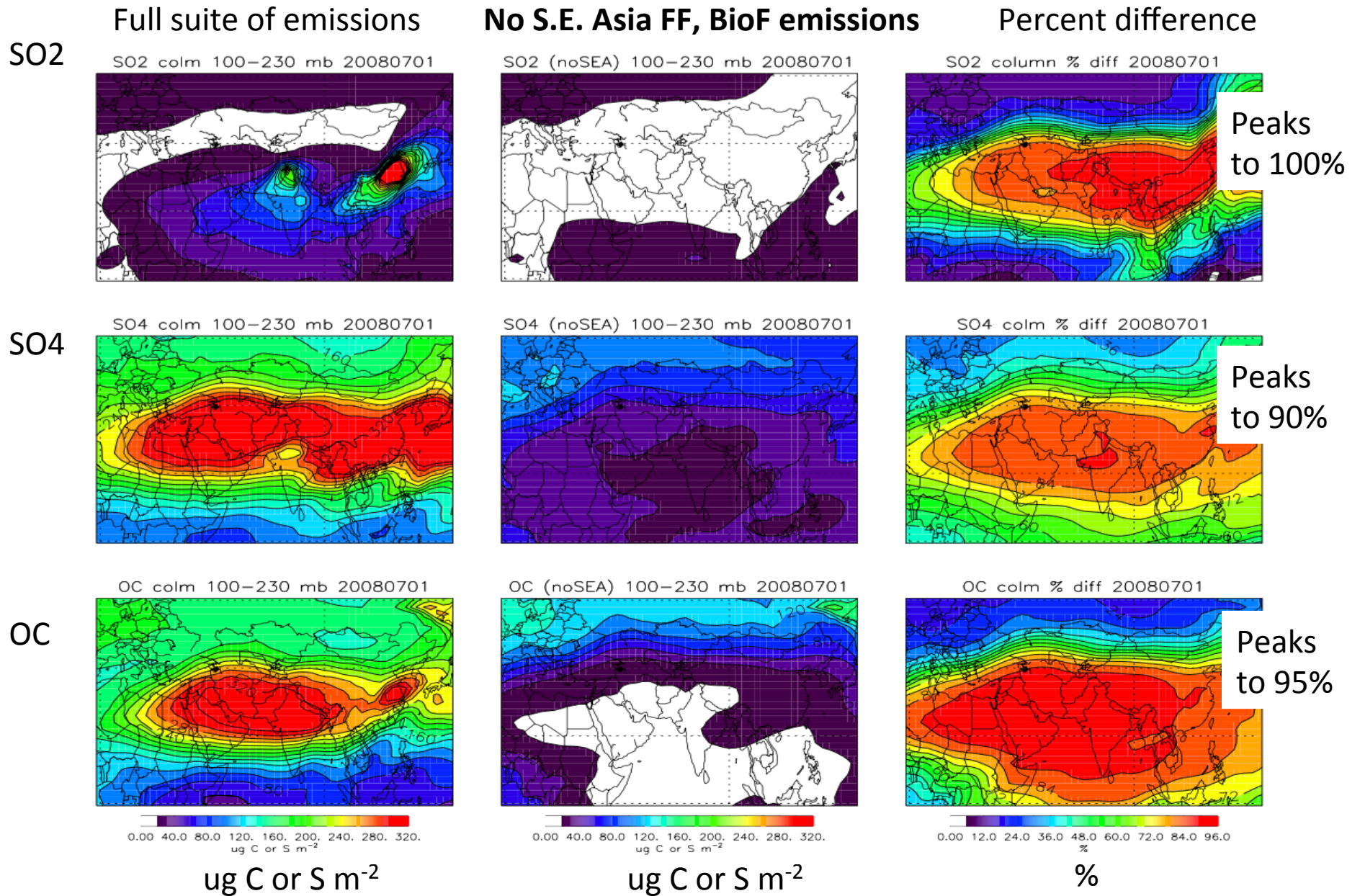
# G-C Latitude X-sections

## 45-105°E average, July, 2008





# G-C columns (100-230 mb), July 2008 mean Contribution of S.E. Asian emissions



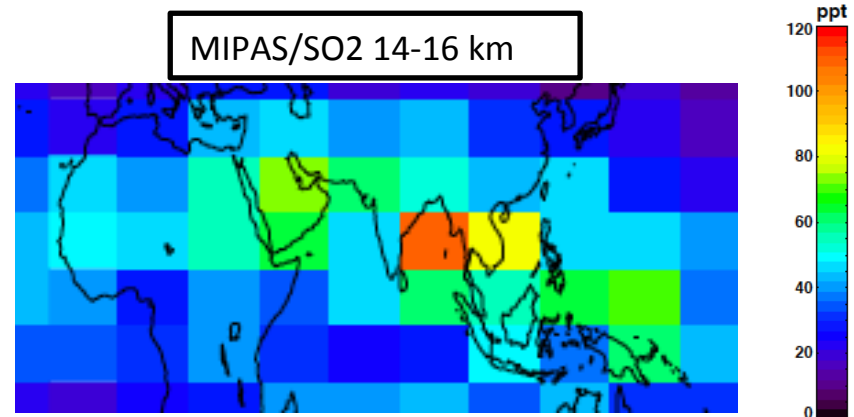
# Conclusions

- 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 ?)
- Modeling studies indicate:
  - ❑ ATAL composition a combination of sulfate and organic carbon
  - ❑ South and East Asian sources dominant
  - ❑ Contributions of regional emissions sensitive to parameterized wet scavenging efficiency

# 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

# Improved representation wet scavenging in convective updrafts for SO<sub>2</sub> in GEOS-Chem CTM



- MIPAS shows SO<sub>2</sub> of 50-100 ppt at 14-16 km in seasonal mean maps (2002-2012), filtered for volcanic episodes. from M. Hoepfner et al., ACP, 2015.
- SO<sub>2</sub> in new scheme, allowed to survive convective storm and be converted into aerosol in the Upper Troposphere (consistent with satellite and a few in situ measurements)