Assessment of boundary layer pollutants over the Indo-Gangetic Basin: implication to UTLS aerosol characteristics

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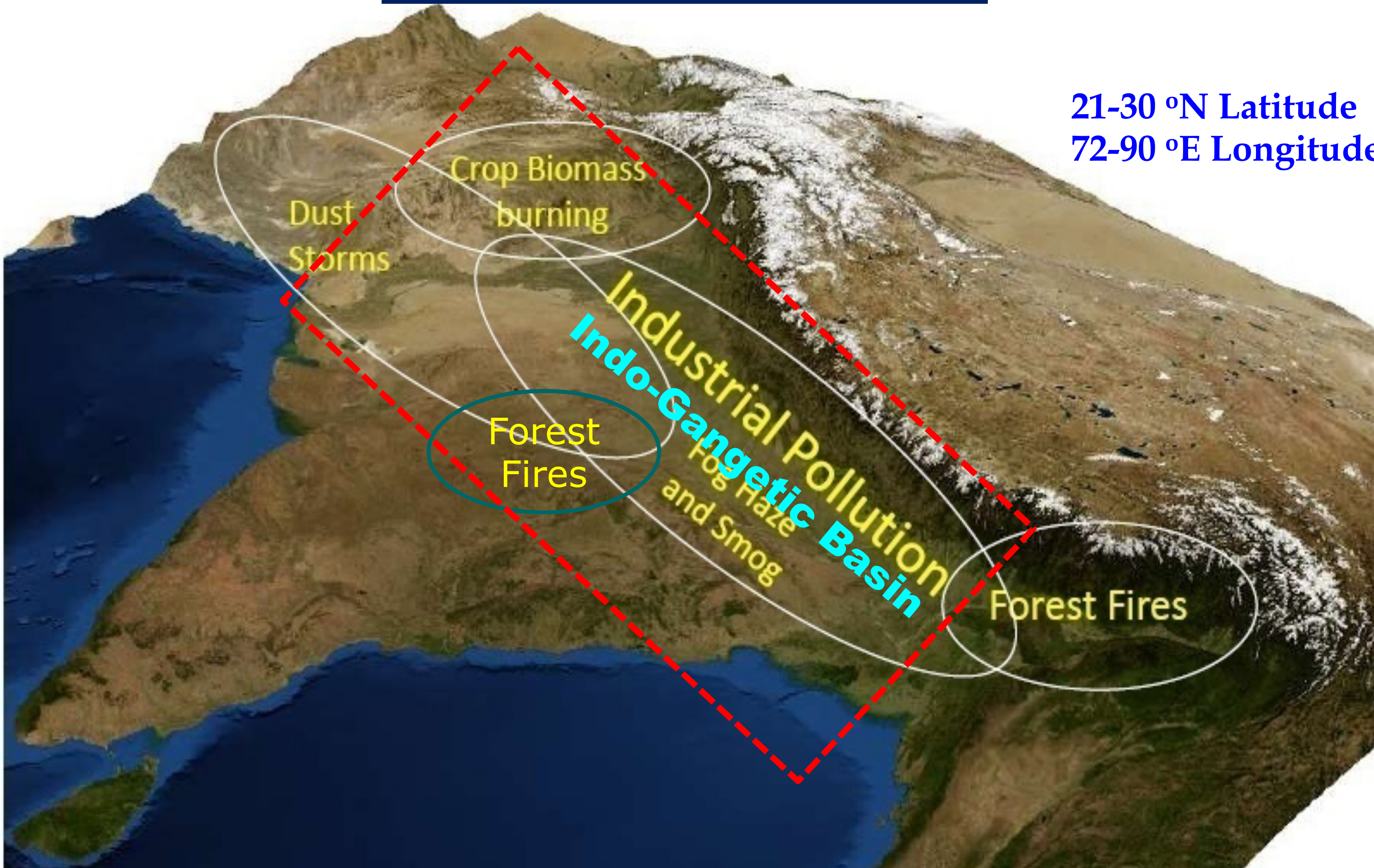
Motivation & Study region



21-30 ^{o}N Latitude
72-90 ^{o}E Longitude

Deep convection associated with monsoon trough (an elongated zone of low pressure region) occurs frequently over the region during summer monsoon period, which may play an important role in uplifting the background aerosols in the UTLS region.

Measurements and Data analysis

- **Long-term (2005-2012) near surface air pollution data, obtained from the Central Pollution Control Board (CPCB) at Delhi, an urban megacity in the western IGB region.**

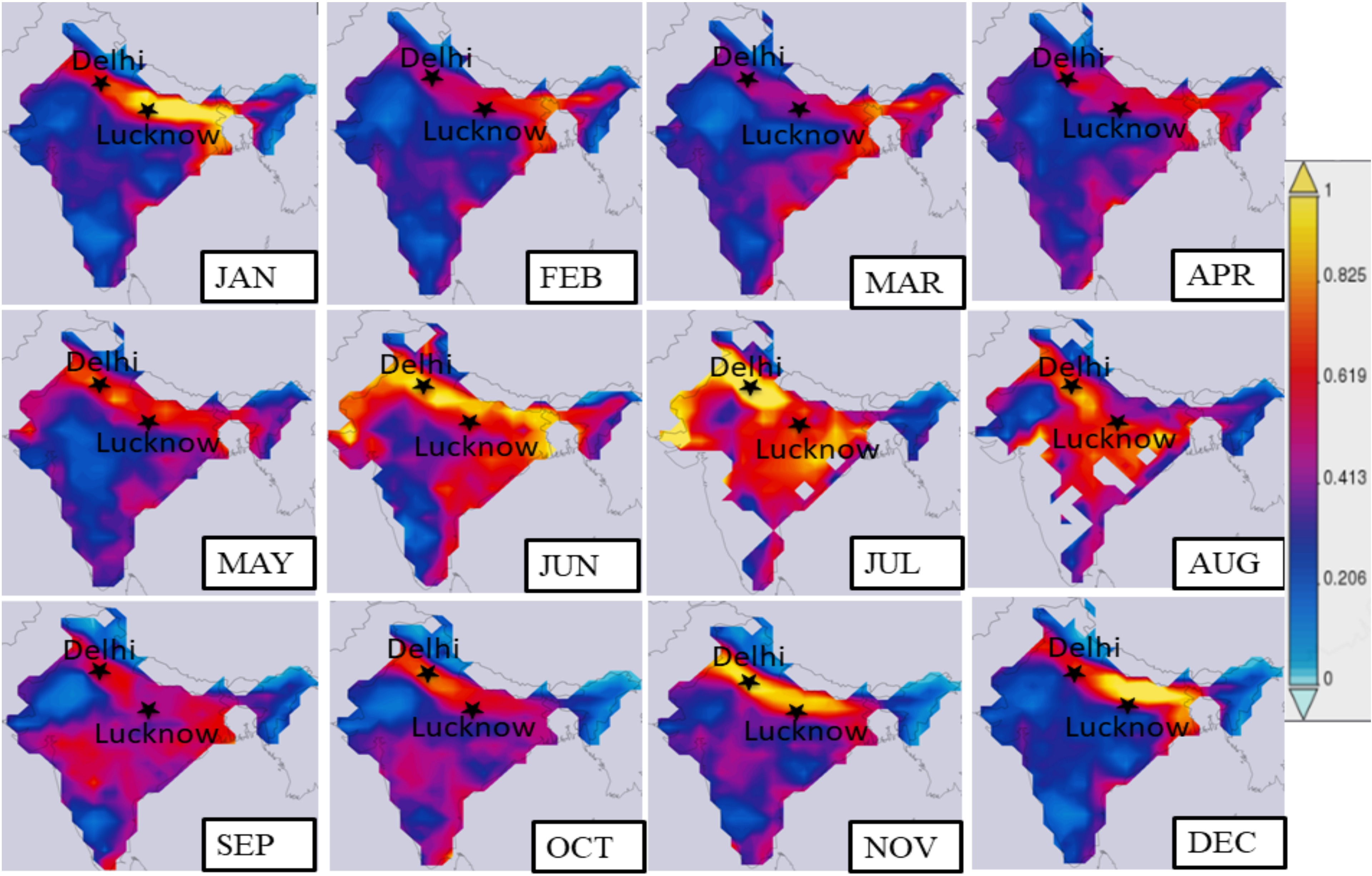
- **Vertical profile of aerosol optical parameters along with the tropopause height were obtained from CALIPSO satellite over the study region (extending from 21-30 ^{o}N lat. and 72-90 ^{o}E long.) during the two contrasting monsoon years (2008 & 09).**

- **Out-going Long-wave Radiation (OLR, a proxy for tropospheric convection) data was obtained from NOAA (National Oceanic and Atmospheric Administration).**

- **Vertical velocity data was obtained from NCEP (National Centers for Environmental Prediction).**

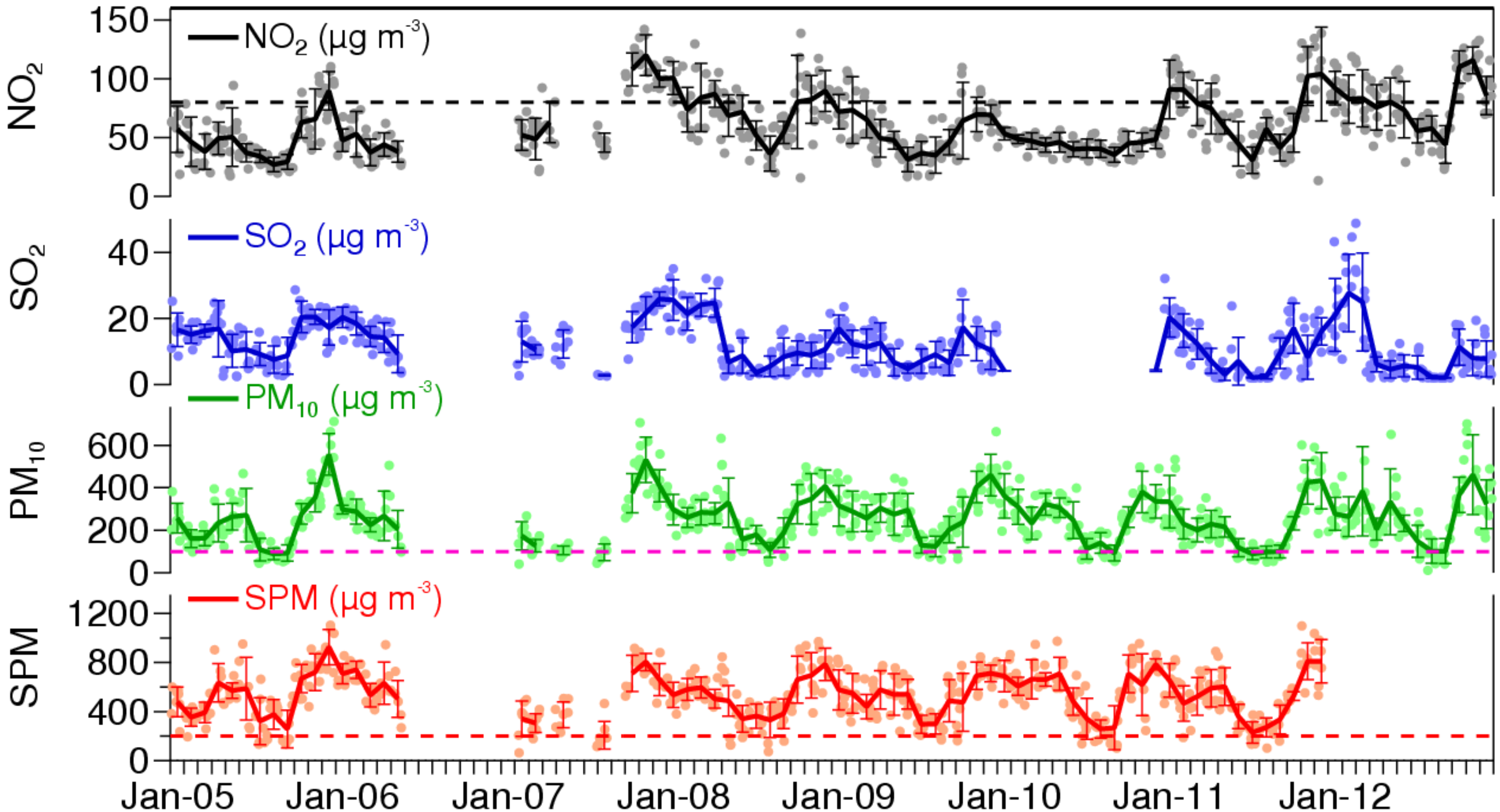
Results and Discussion

Climatological monthly mean variability of AOD over India during 2007-17



[*Kumar and Srivastava et al., 2019, In progress*]

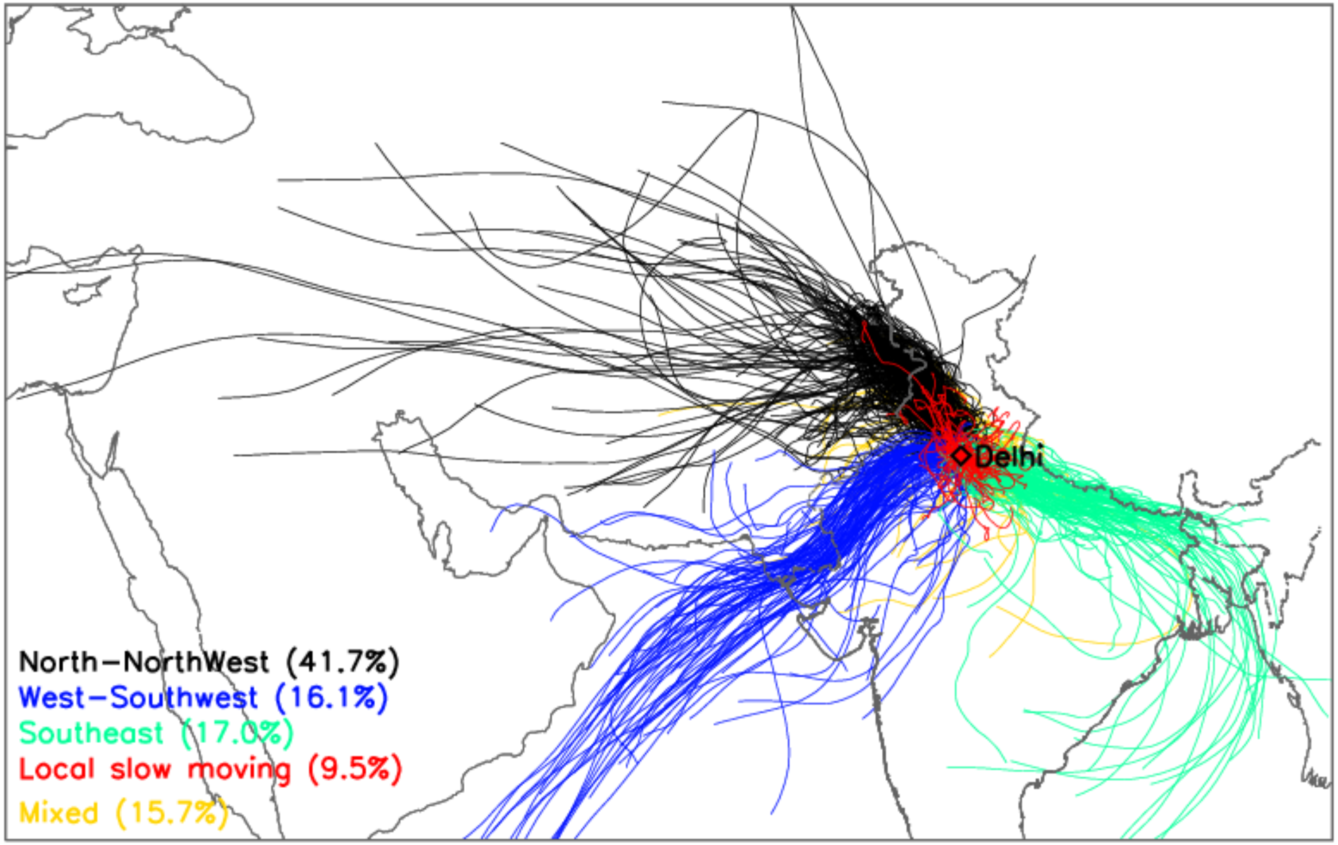
Time series analysis of near-surface pollutants [daily (dots) and monthly (solid line)]



- NO_2 varied from 14-142 μg m^{-3}, with a mean of 62±28 μg m^{-3} [NAAQS=80 μg m^{-3}].
- SO_2 varied from 2-50 μg m^{-3}, with a mean of 15±8 μg m^{-3} [NAAQS=80 μg m^{-3}].
- PM_{10} varied from 30 and 850 μg m^{-3}, with a mean of 254±134 μg m^{-3} [NAAQS=100 μg m^{-3}].
- SPM varied from 65- 1100 μg m^{-3}, with a mean of 530±213 μg m^{-3} [NAAQS=200 μg m^{-3}].

[Kishore and Srivastava et al., 2019, JESS]

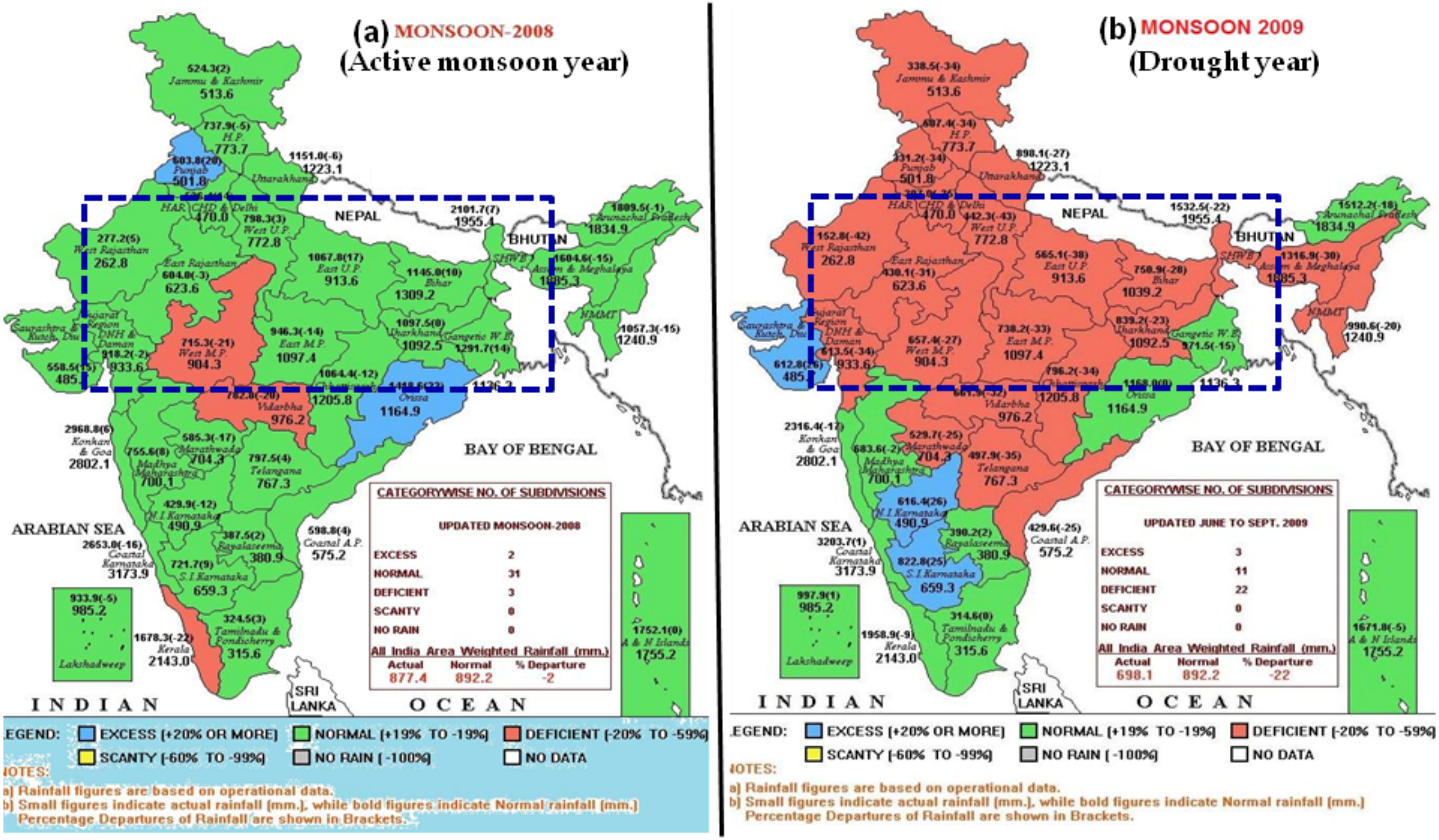
Identification of probable source sectors for air pollutants



	Trajectory occurrence (%)	NO_2 ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	SPM ($\mu g/m^3$)
N–NW	41.7	71.9±29.6	15.4±8.6	314.2±122	608.8±190.2
W–SW	16.1	25.1±27.5	3.6±5.5	102.4±130.8	209.2±257.3
SE	17.0	23.3±26.6	2.92±5.1	69.1±92.6	141.4±200.1
LSM	9.5	56.9±40.8	9.8±8.1	241.8±188.8	438.2±336.1
M	15.7	50.5±31.2	10.7±8.8	198.2±128.5	408.0±268.2

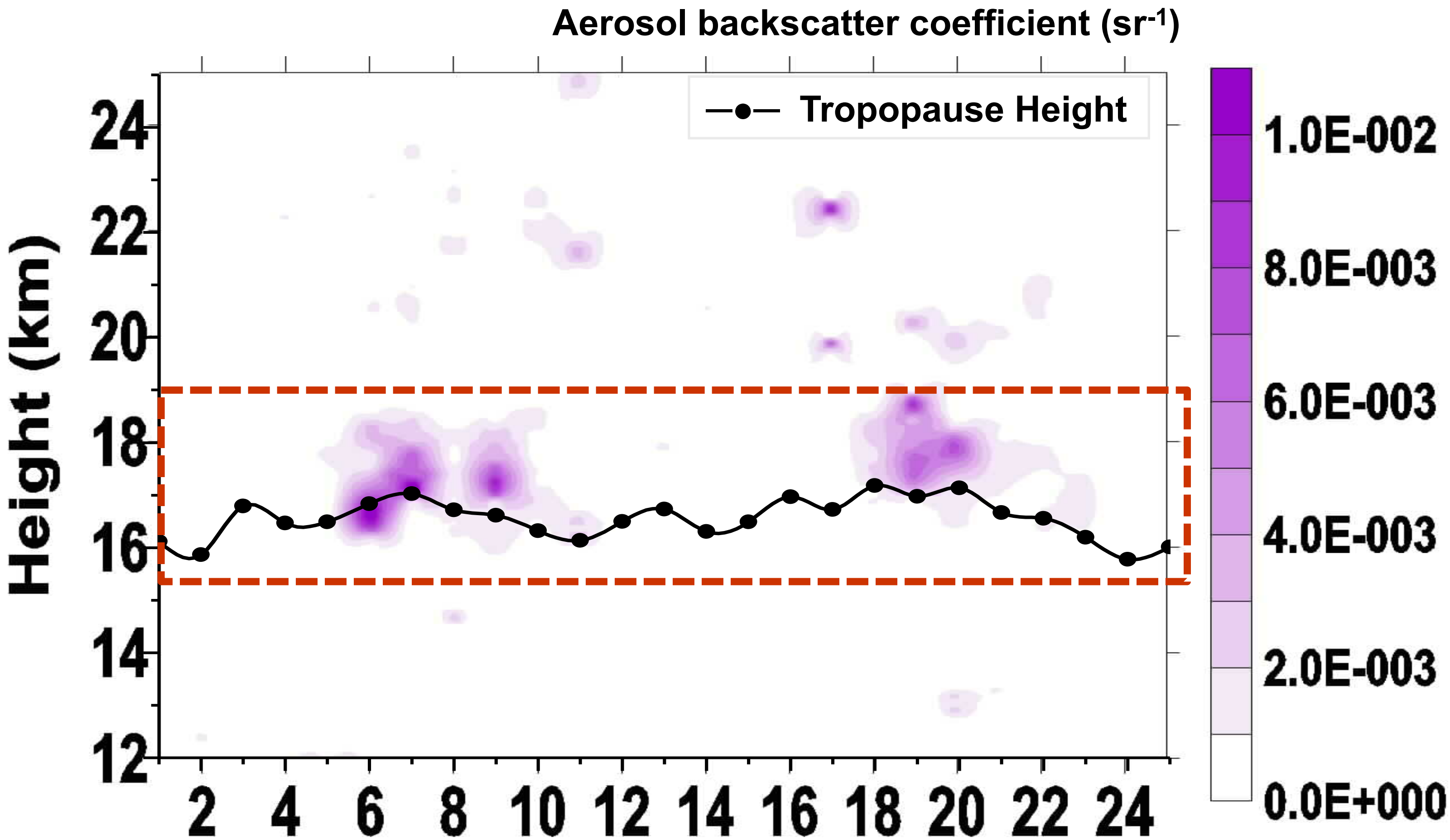
N–NW: north–northwest; W–SW: west–southwest; SE: southeast; LSM: local slow moving; M: mixed.

All India mean rainfall distribution during Indian summer monsoon period (June to September)



Blue : **Excess rainfall**
Green : **Normal rainfall**
Red : **Deficient rainfall**

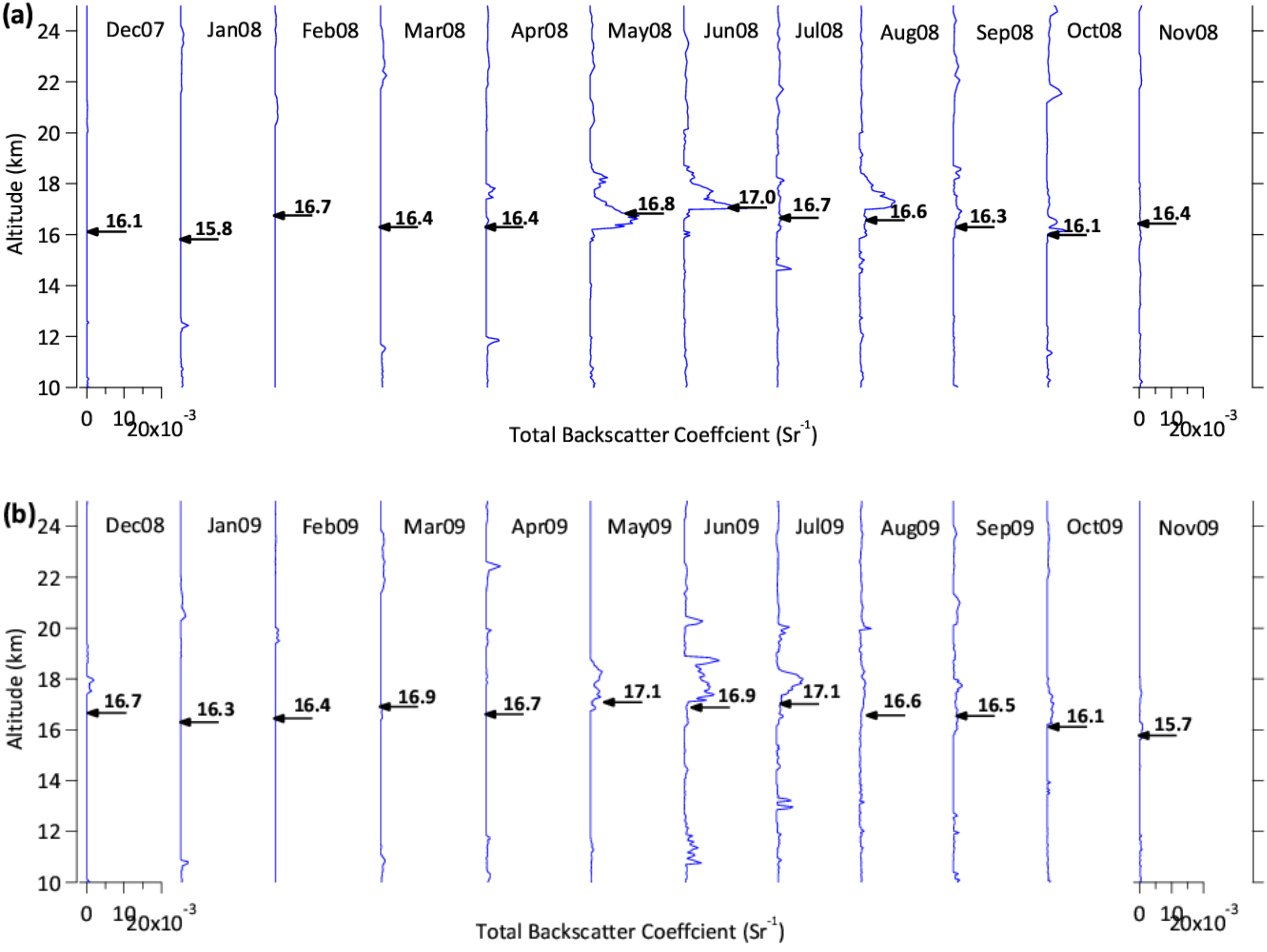
[*Source:* *http://www.imd.gov.in*]



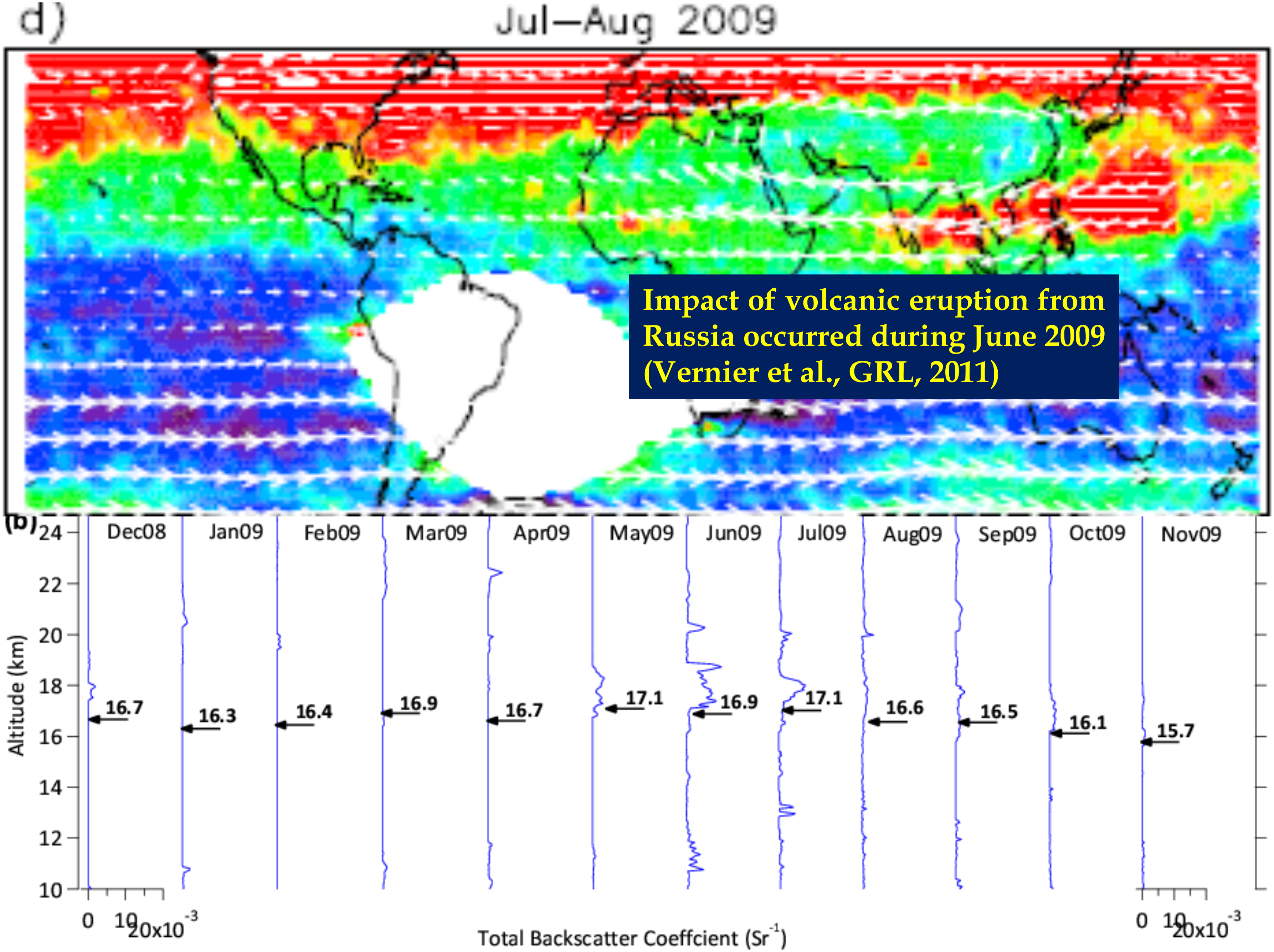
Months (Dec 2007-Dec 2009)

[*Srivastava et al., 2019, AE*]

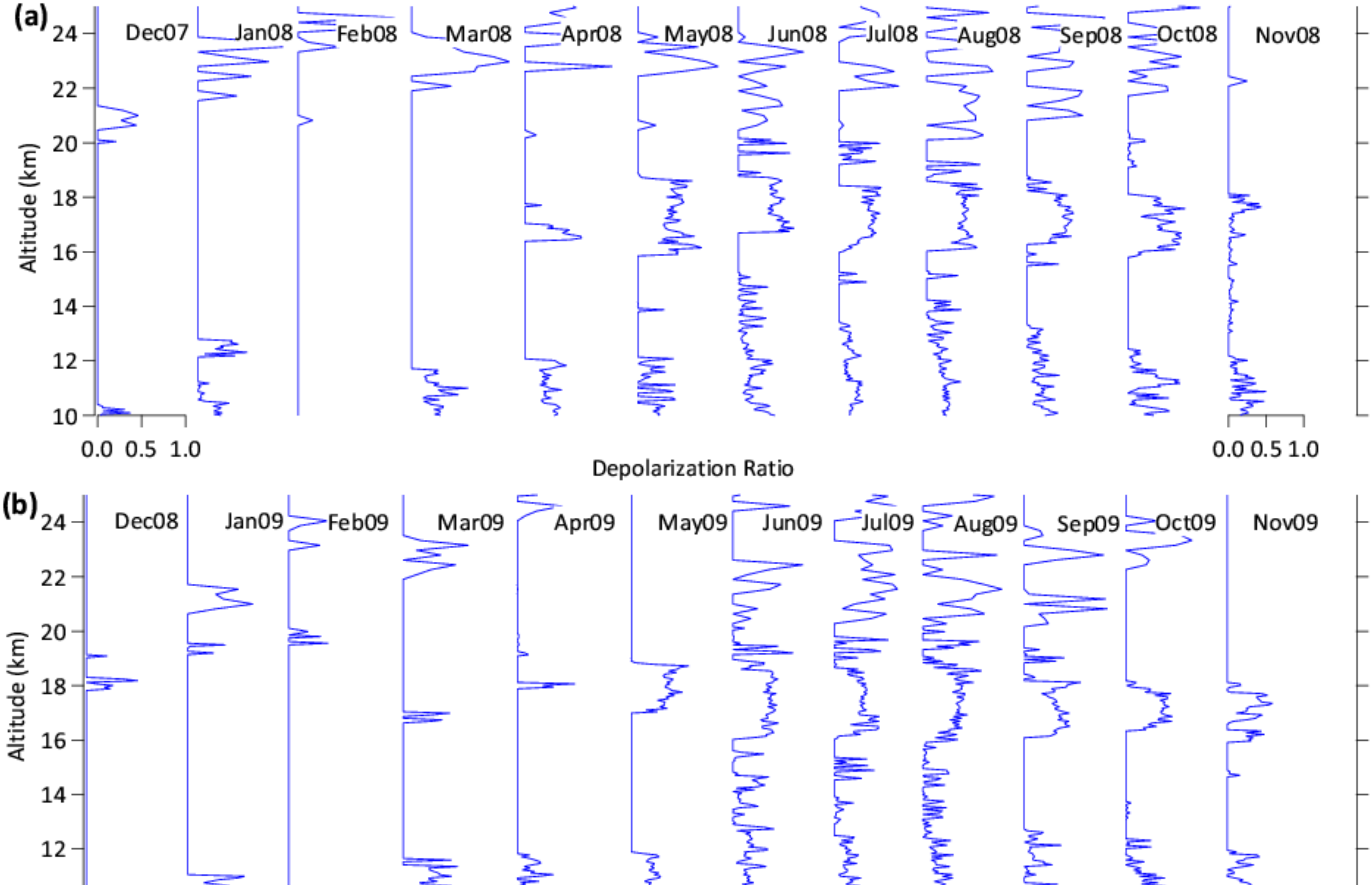
Monthly variations in aerosol backscatter profiles



Mean scattering ratio between 15-17 km in July-Aug 2009

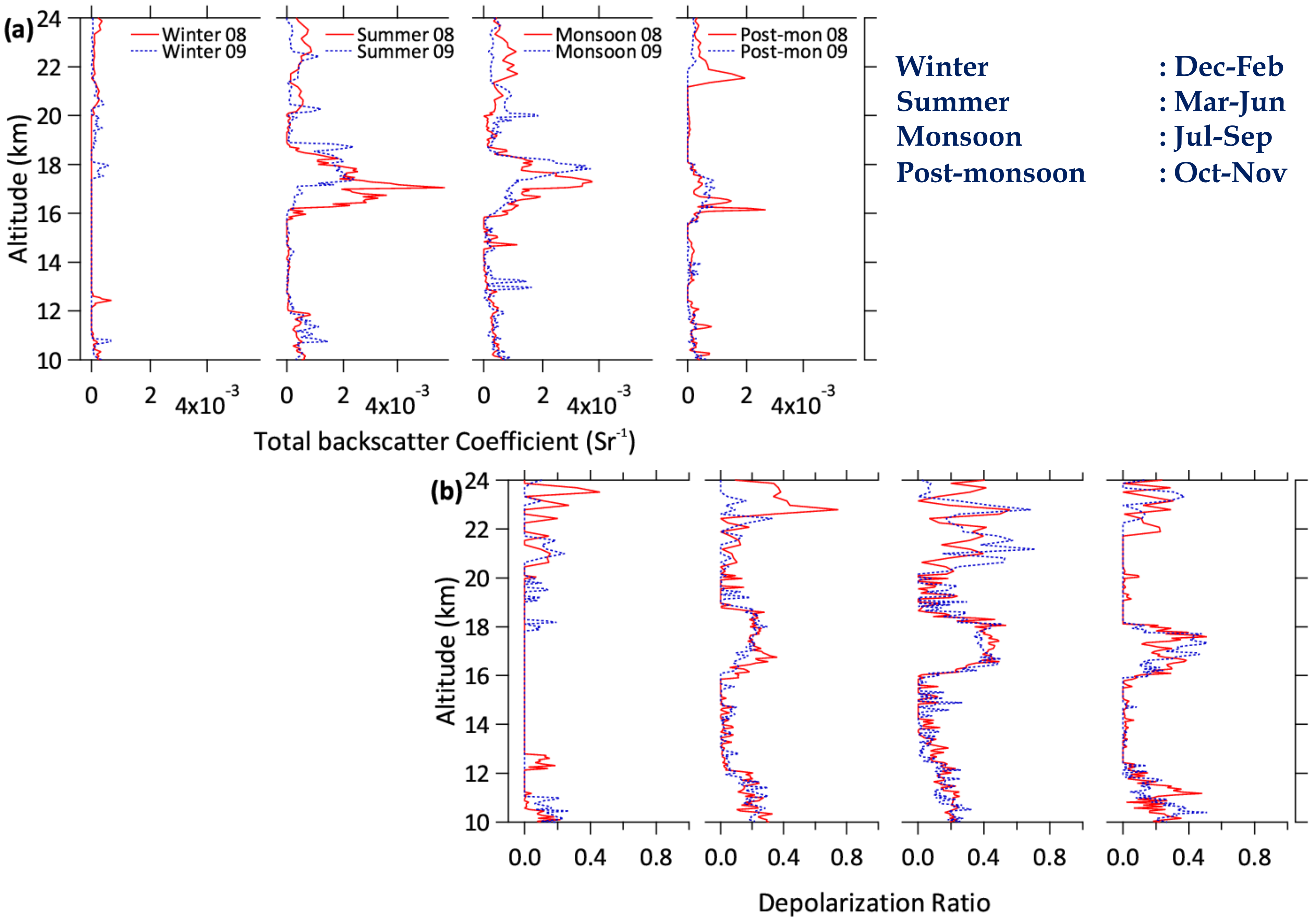


Monthly variations in depolarization ratio



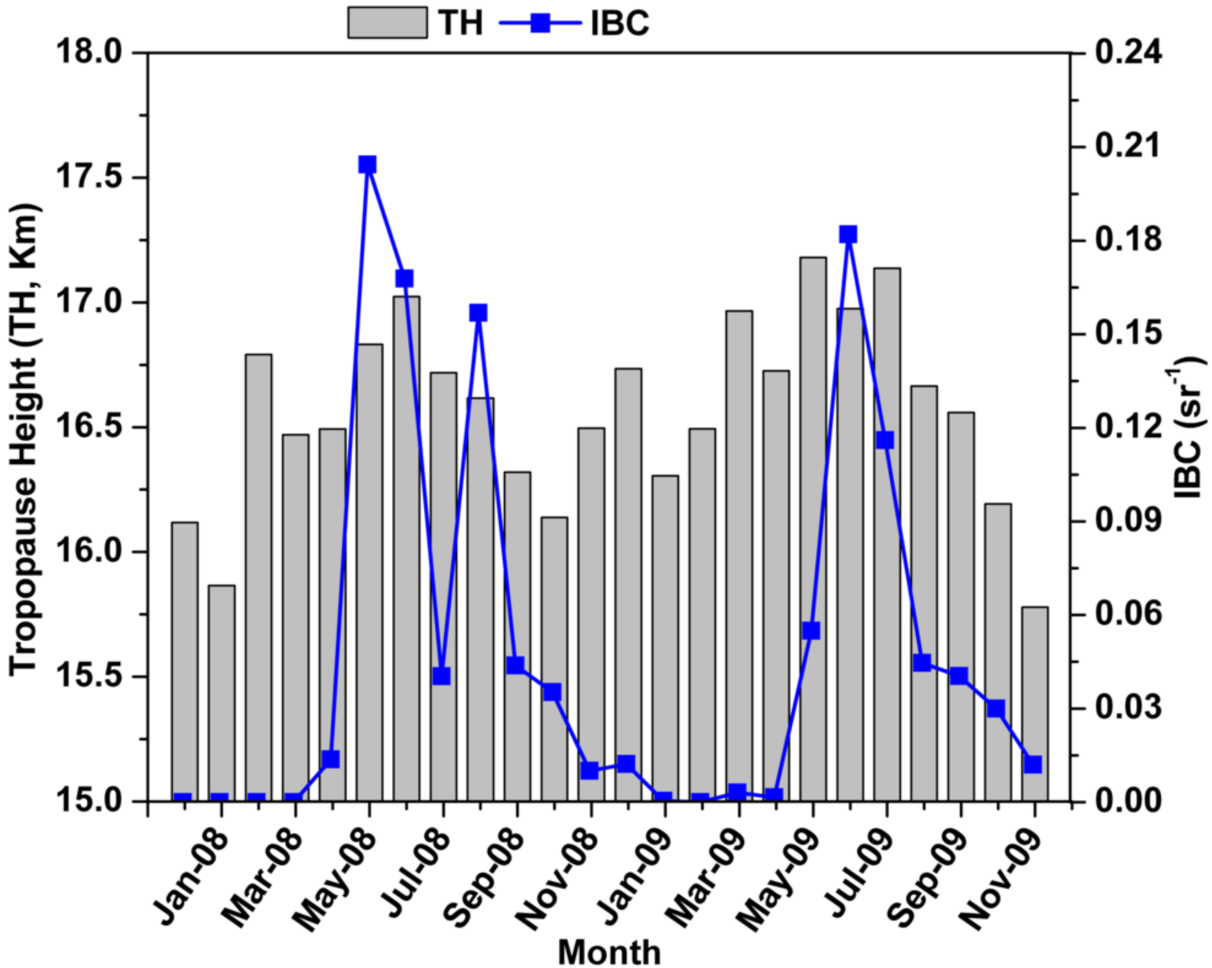
Depolarization ratio exceed from 0.2 suggests anisotropic/non-spherical nature of the particles (Shin et al., 2013; Govardhan et al., 2017).

Seasonal mean variations in aerosol vertical features



Winter : Dec-Feb
Summer : Mar-Jun
Monsoon : Jul-Sep
Post-monsoon : Oct-Nov

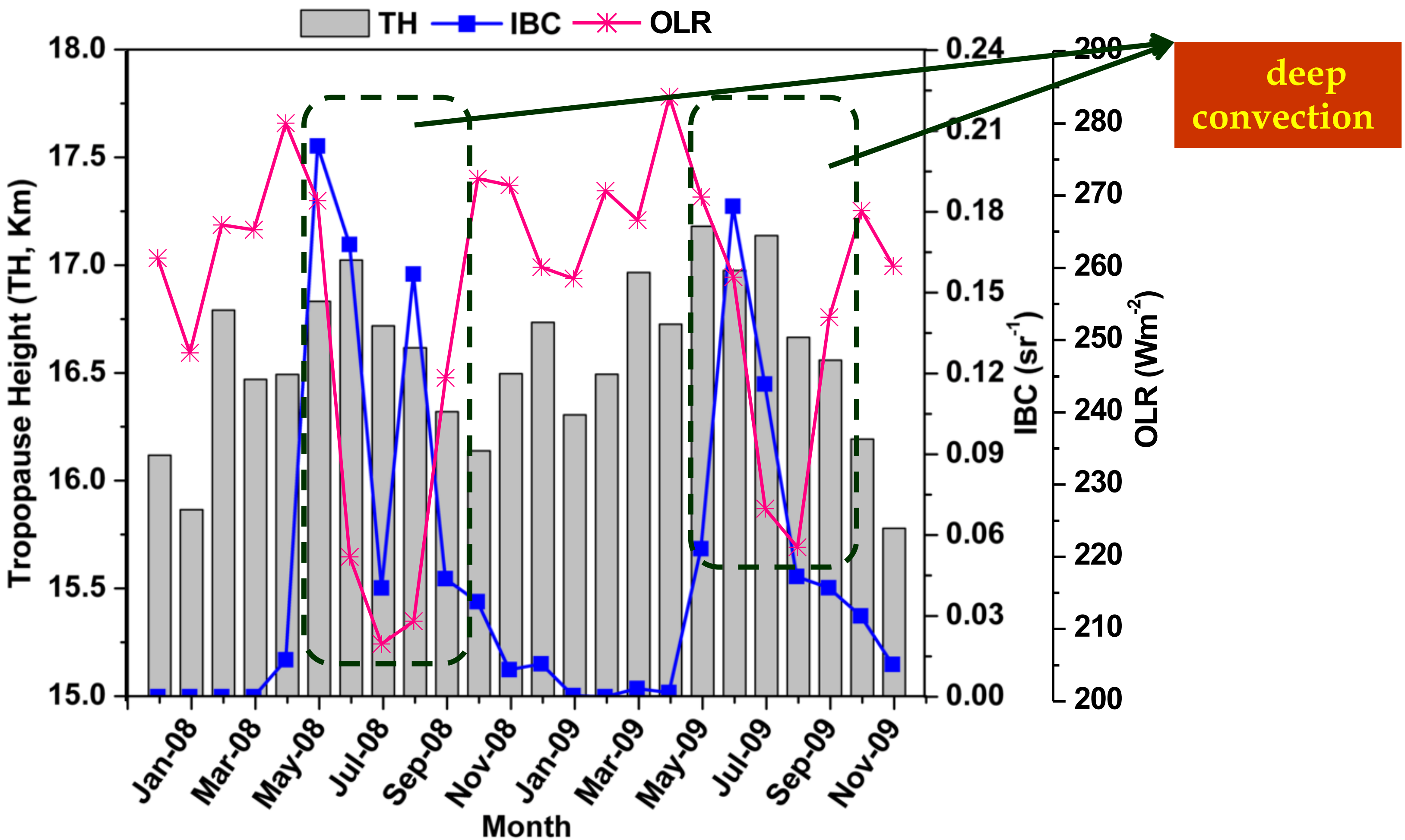
Association between tropopause and backscatter coefficient in UTLS region



IBC: Integrated Backscatter Coefficient (15-19 km)

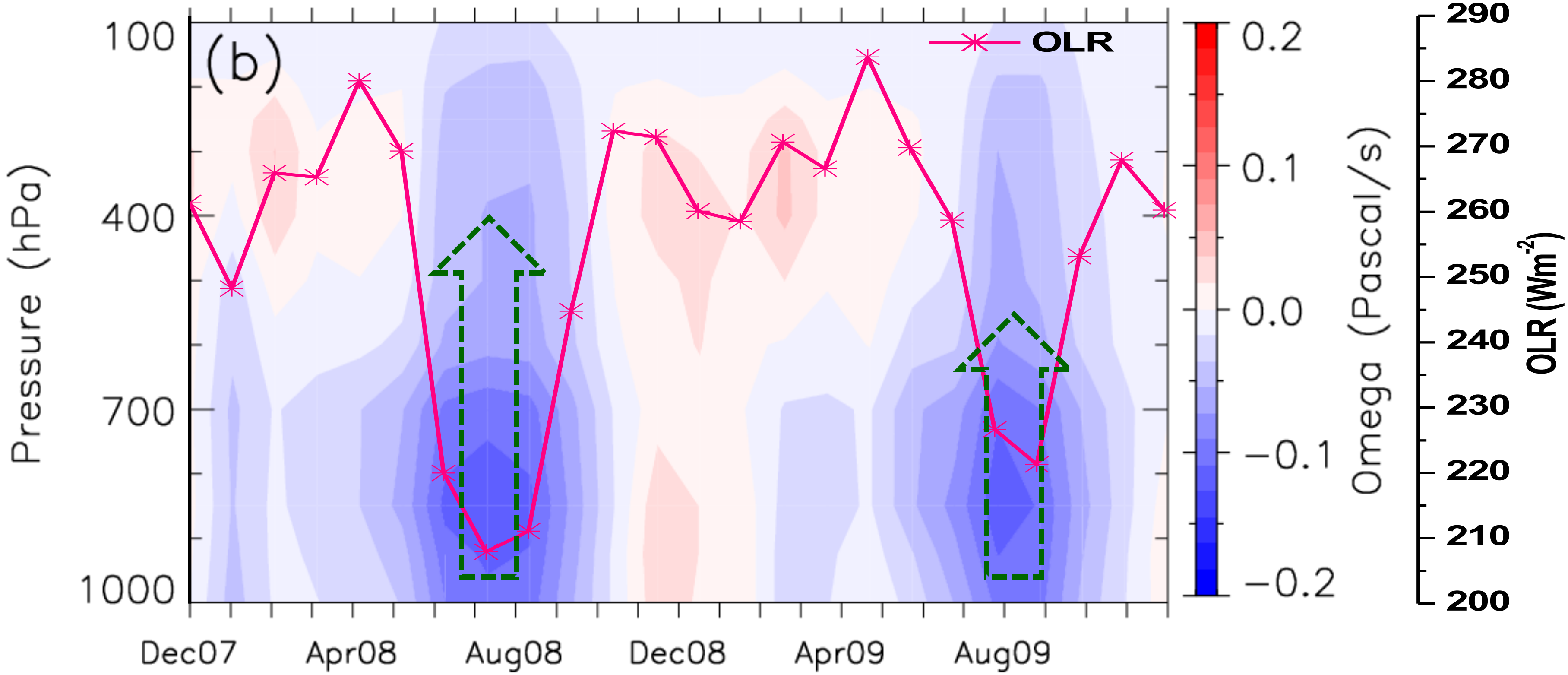
Tropopause height was highest during the summer-monsoon months in both the years, with corresponding enhancement in IBC, which is more pronounced during the active monsoon year as compared to the drought year. IBC is ~30% higher during summer-monsoon periods of 2008 as compared to 2009.

Role of deep convection on tropopause and IBC



The lowest OLR (occurrence of deep convection), corresponding to an enhancement in tropopause height and IBC during the summer-monsoon months in both the years, suggests vertical uplifting of boundary layer aerosols into the UTLS over the study region. This association is relatively more pronounced during active monsoon year as compared to drought when OLR value was ~7% lower and suggests more intense deep convection during the active monsoon period.

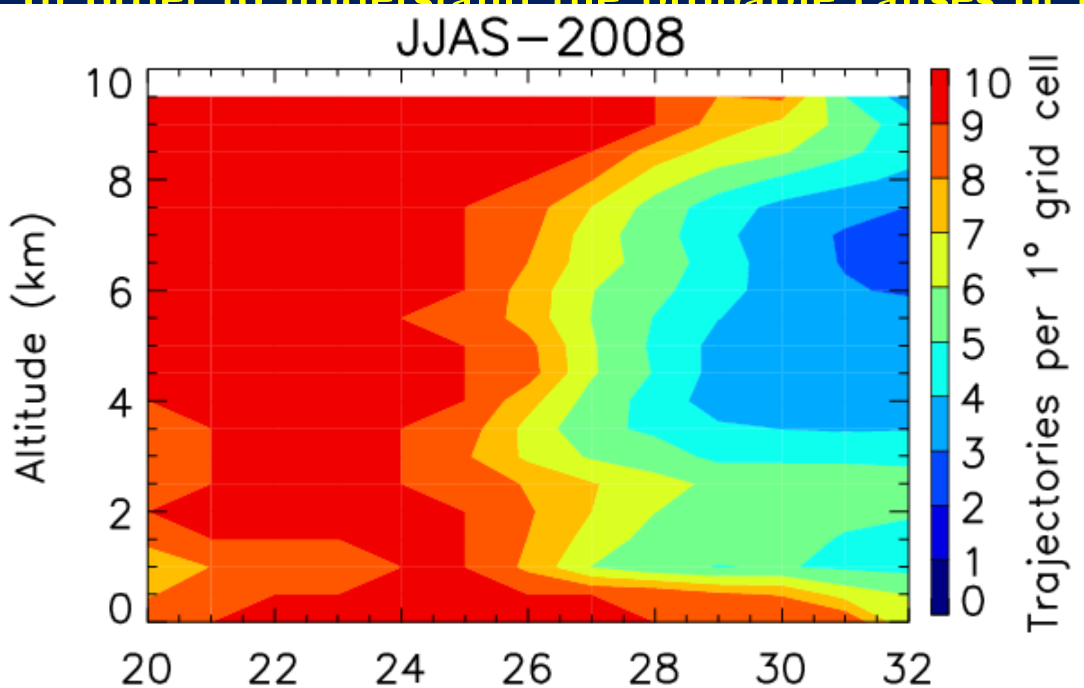
Vertical profile of omega (vertical velocity)



Probability of vertical transport of boundary layer aerosols over the region during summer-monsoon period is more pronounced during the active monsoon period (2008) as compared to drought period (2009).

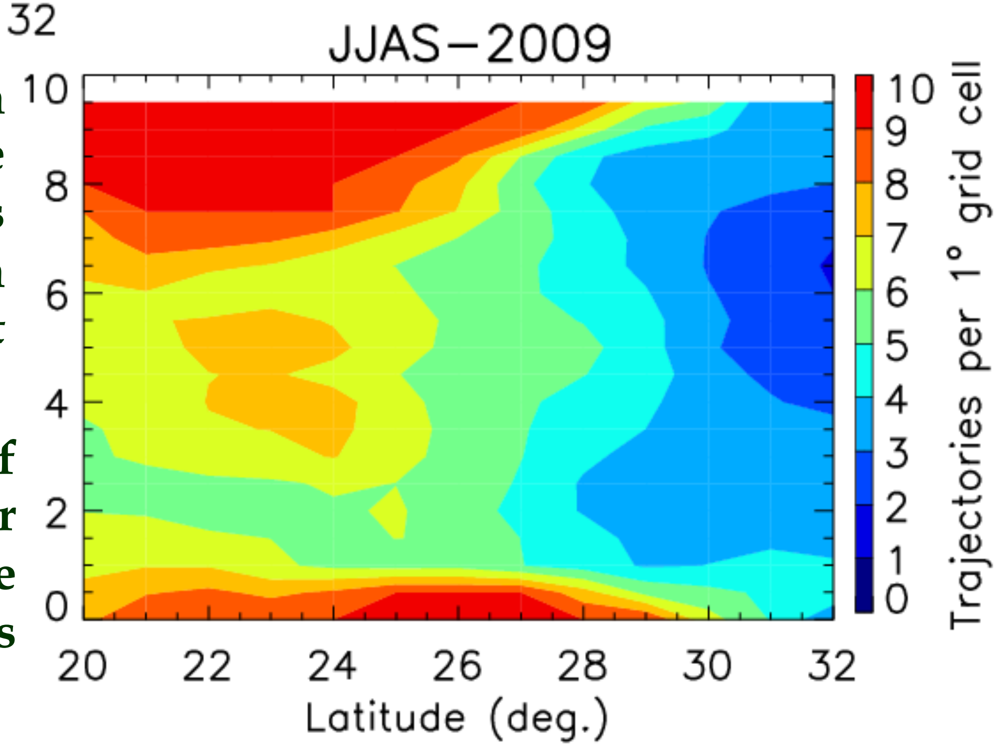
In order to understand the probable causes of observed aerosol layers in the UTLS
…ry were analyzed using PC-version
…ajectory (HYSPLIT) model.

…for a fixed longitude of 80 ºE and
…of 10 km above ground level.



Air mass trajectories starting at 10 km reaching to the surface and the frequency of such trajectories is higher during the active monsoon period (2008) as compared to drought period (2009).

This further confirms our findings of convection-driven boundary layer aerosol transport into the UTLS (more pronounced during active monsoon as compared to drought year).



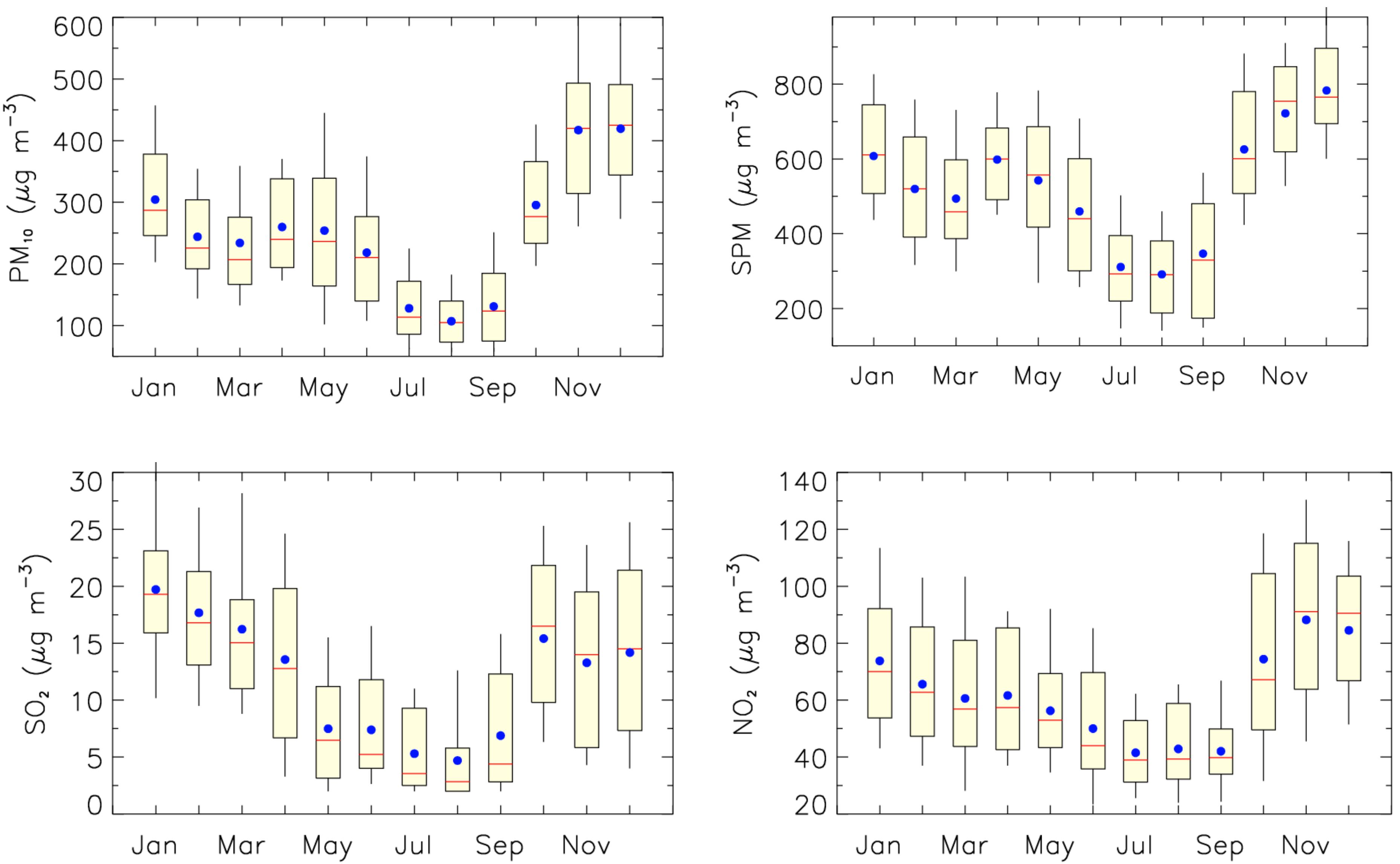
Summary

- Enhancement in boundary layer aerosol loading was observed over the entire study region, including the IGB, associated with high anthropogenic as well as natural emission sources.
- An enhanced aerosol layer of anisotropic nature was identified in the UTLS between 15 and 19 km over the study region during the summer-monsoon period of two contrasting monsoons.
- The aerosol backscatter coefficient was relatively more intensified with a sharp peak during the active monsoon period whereas it has relatively broader peak with low magnitude during drought period.
- The enhanced aerosol layer was found to be closely associated with tropopause height and surface deep convection, which is found to be more pronounced during the active monsoon period as compared to drought period.
- Results are found to be associated with the vertical velocity and air mass back-trajectories, which further confirms updraft during the summer-monsoon period and suggests the probability of vertical transport of boundary layer aerosols up to the UTLS, which was more pronounced during the active monsoon period as compared to drought period.

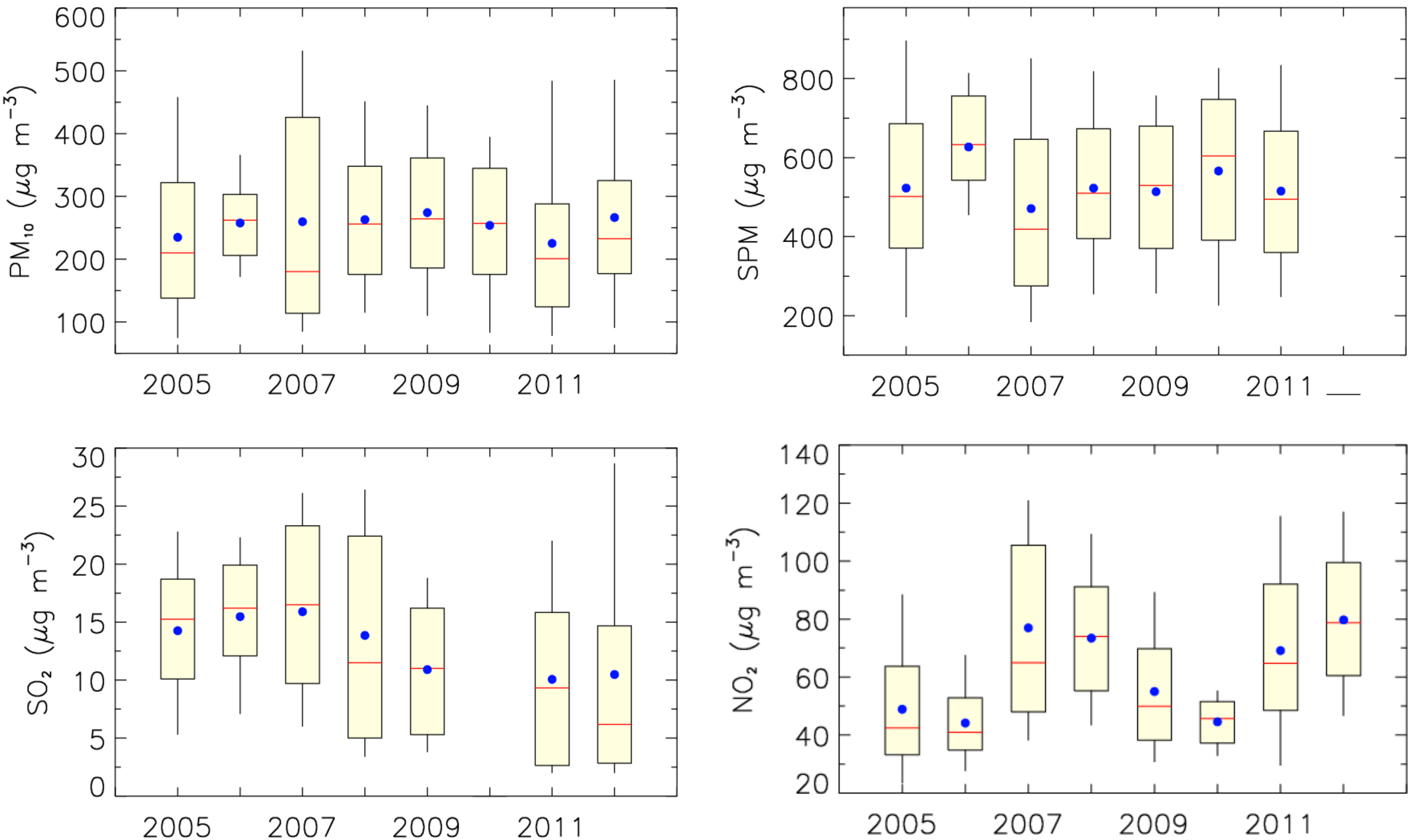
Thank You…

- **Asia is one of the largest source regions for various aerosol/gaseous pollutants from high anthropogenic as well as natural emissions (Park et al., 2009, 2010).**
- **The Asian monsoon circulation, mostly characterized by deep convection, may provide a possible pathway for vertical transport of various atmospheric species from boundary layer up to the UTLS through convective overshooting (Randel et al., 2010; Bian et al., 2011; Bourgeois et al., 2012; Fadnavis et al., 2013; Vernier et al., 2015).**
- **Several studies have been carried out to investigate stratospheric aerosol characteristics on global scale after the major volcanic eruptions (Haywood et al., 2010; Vernier et al., 2011; He et al., 2014); however, such studies are limited on regional scales and during the non-volcanic period.**

Monthly mean variability of near-surface air pollutants



Inter-annual variability of near-surface air pollutants



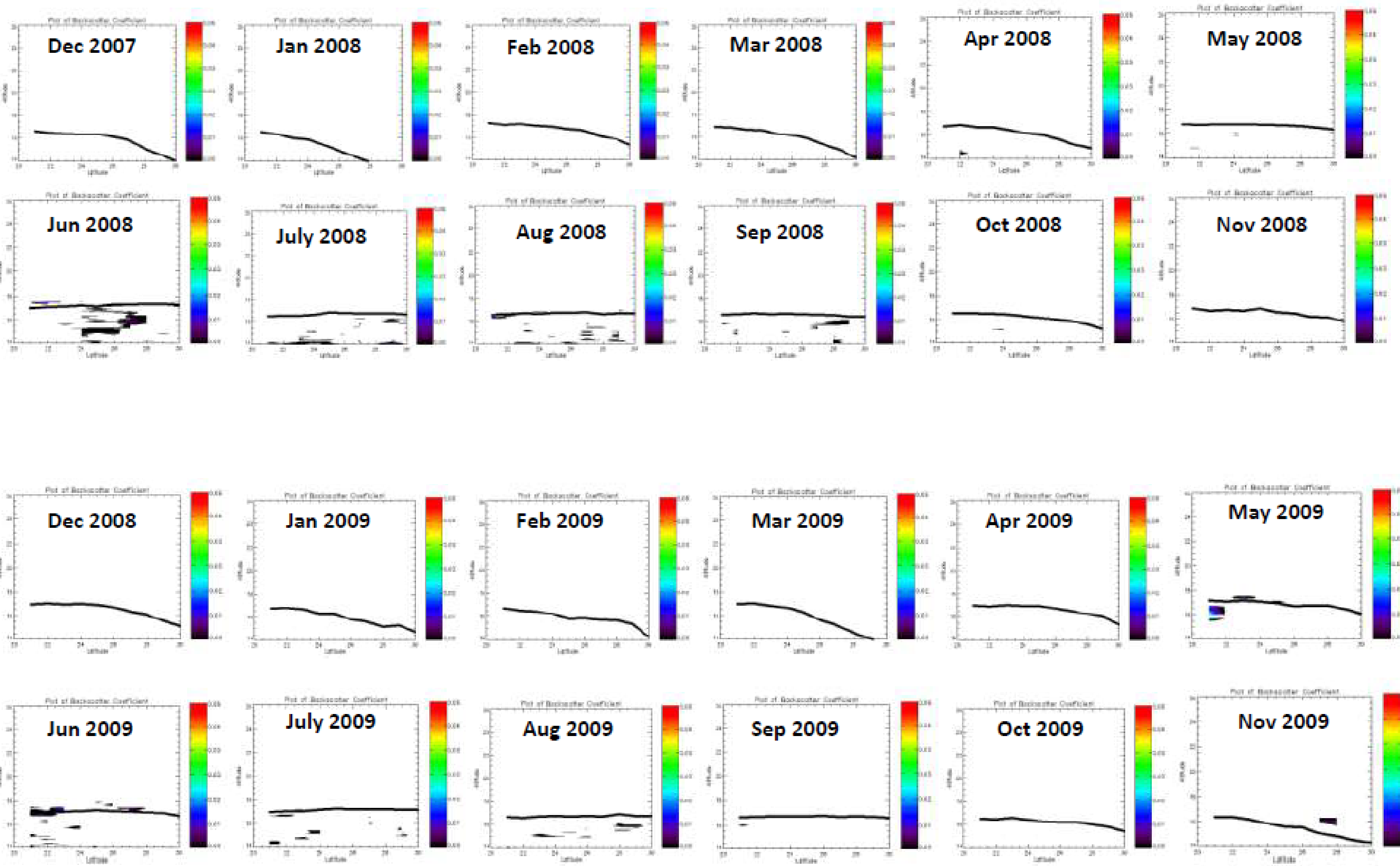
Measurements and Data analysis

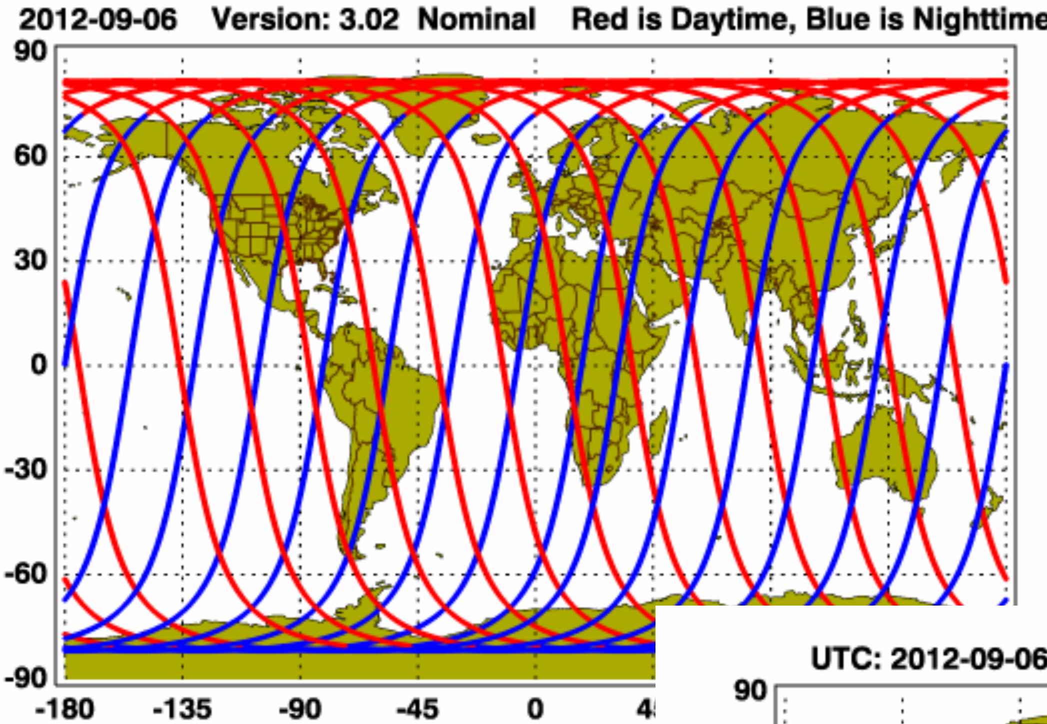
- Aerosol vertical profile & tropopause height : CALIPSO Satellite
- Out-going Long-wave Radiation (OLR) (proxy for tropospheric convection) : NOAA (National Oceanic and Atmospheric Administration)
- Vertical velocity : NCEP (National Centers for Environmental Prediction)

- CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation) is a first kind of satellite, having vertically down-looking lidar system, known as CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization).
- Provides high-resolution vertical distribution of aerosols and clouds as well as their optical properties globally.
- It measures laser backscatter at 1064 nm and the parallel and cross-polarized components at 532 nm, from which the depolarization ratio (a crucial parameter to identify sphericity of particles) is derived.

We analyzed two-years (2008-2009) CALIOP level 2 (version 3.1) aerosol profile products, mainly backscattering coefficient and depolarization ratio over the Indian Summer Monsoon (ISM) region, extending from 21-30 ^{o}N lat. and 72-90 ^{o}E long. During the entire period, a total of 940 days data was obtained over the study region.

Spatial variability of Aerosol Backscatter Coefficient




2012-09-06 Version: 3.02 Nominal Red is Daytime, Blue is Nighttime
90
60
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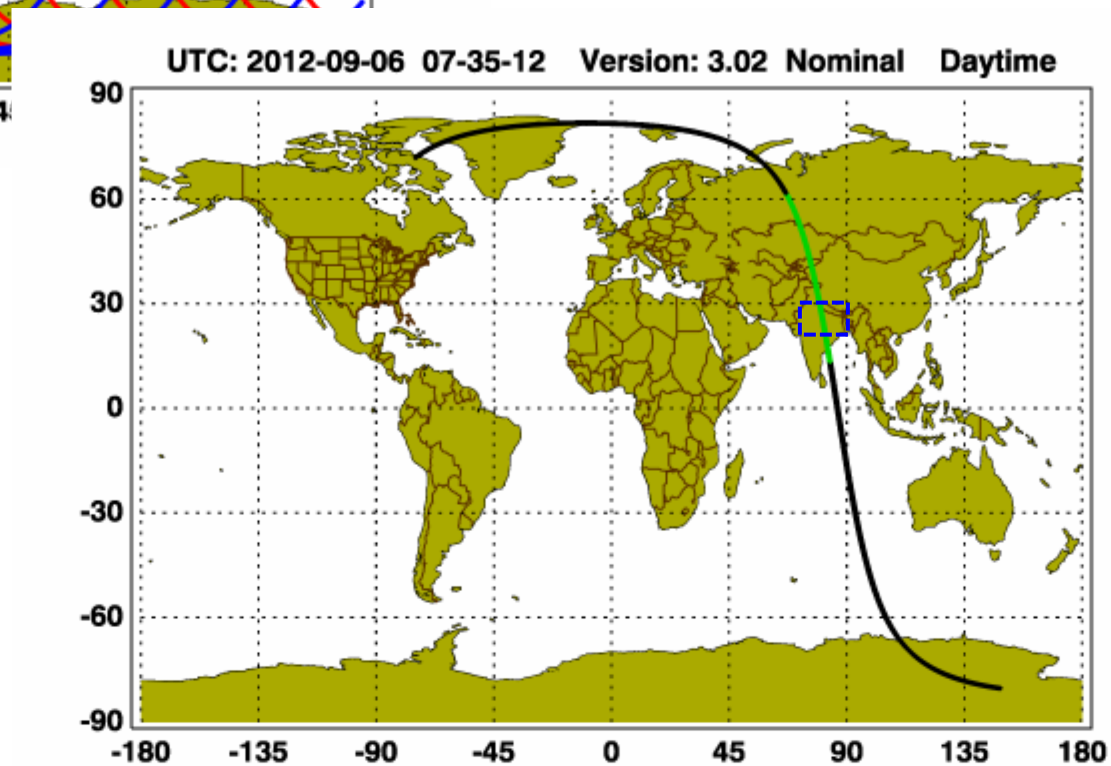
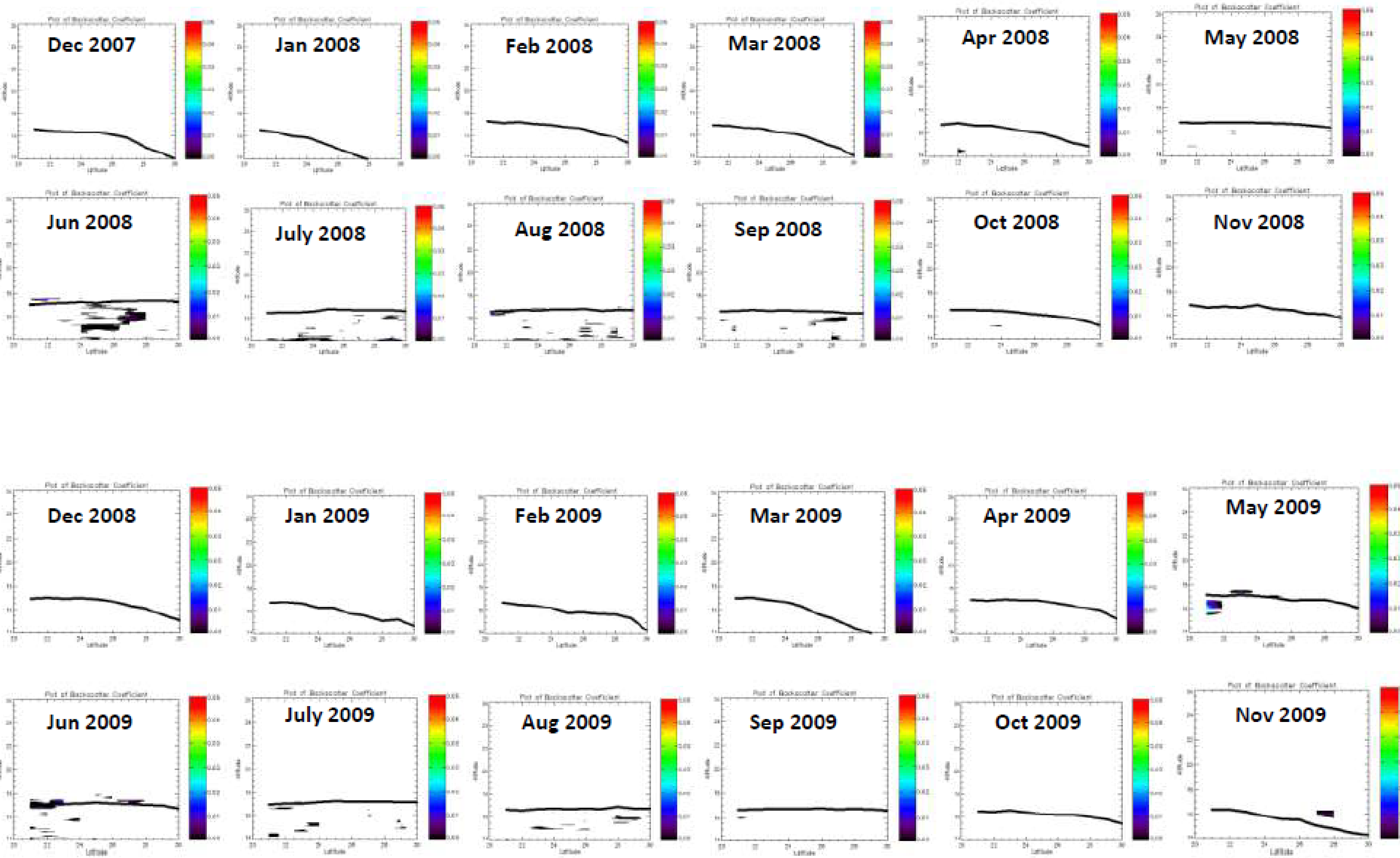

UTC: 2012-09-06 07-35-12 Version: 3.02 Nominal Daytime
90
60
30
0
-30
-60
-90
-180
-135
-90
-45
0
45
90
135
180

Major Specifications of CALIOP-Lidar

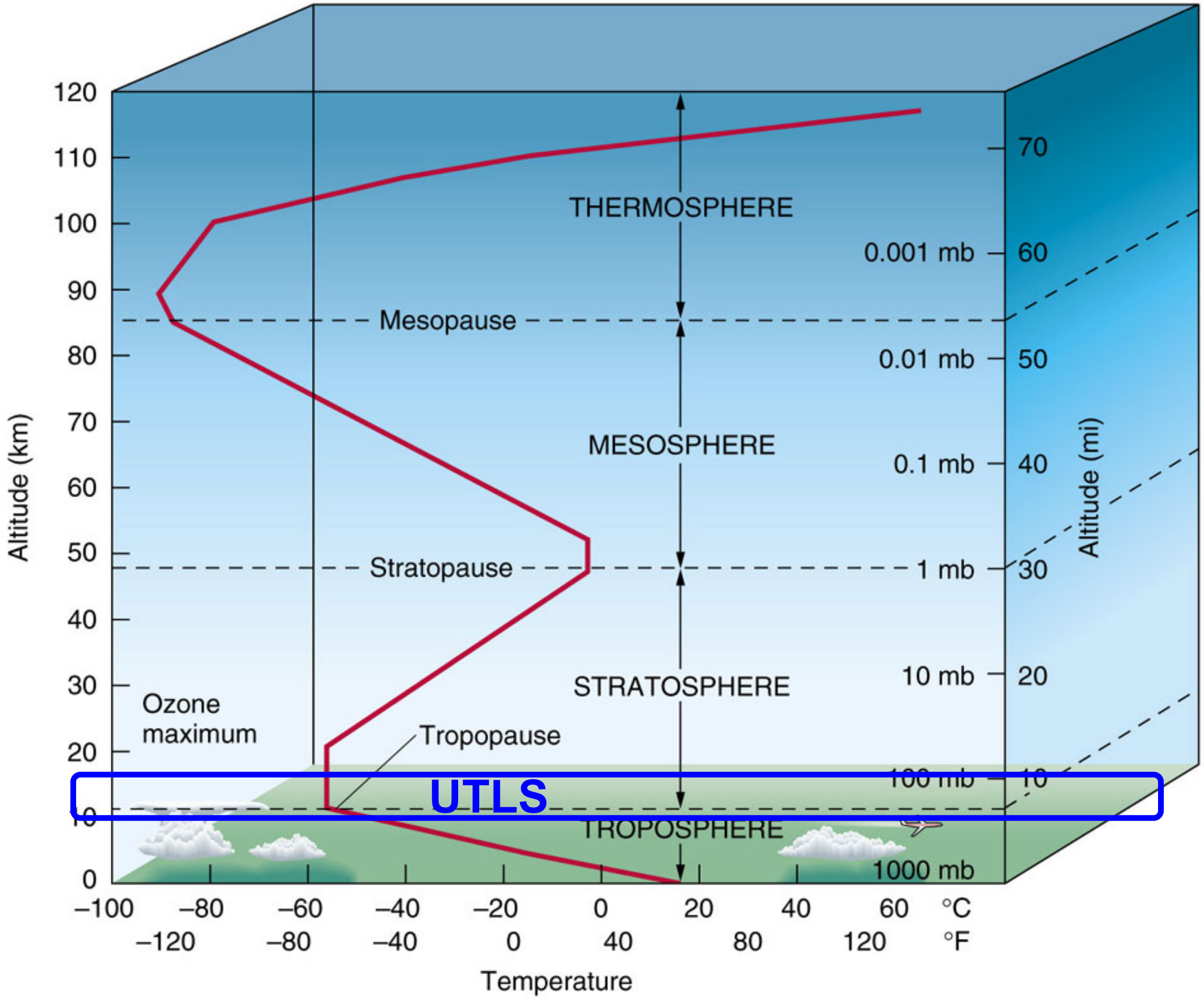
Laser	Nd:YAG, diode-pumped
Wavelength	532 and 1064 nm
Pulse Energy	110 mJ each wavelength
Repetition rate	20 Hz
Pulse length	20 nsec
Beam divergence	100 µrad (after beam expander)
Telescope aperture	1 m diameter
FOV	130 µrad
Horizontal / vertical resolution	330 m/30-60 m

Spatial variability of Aerosol Backscatter Coefficient



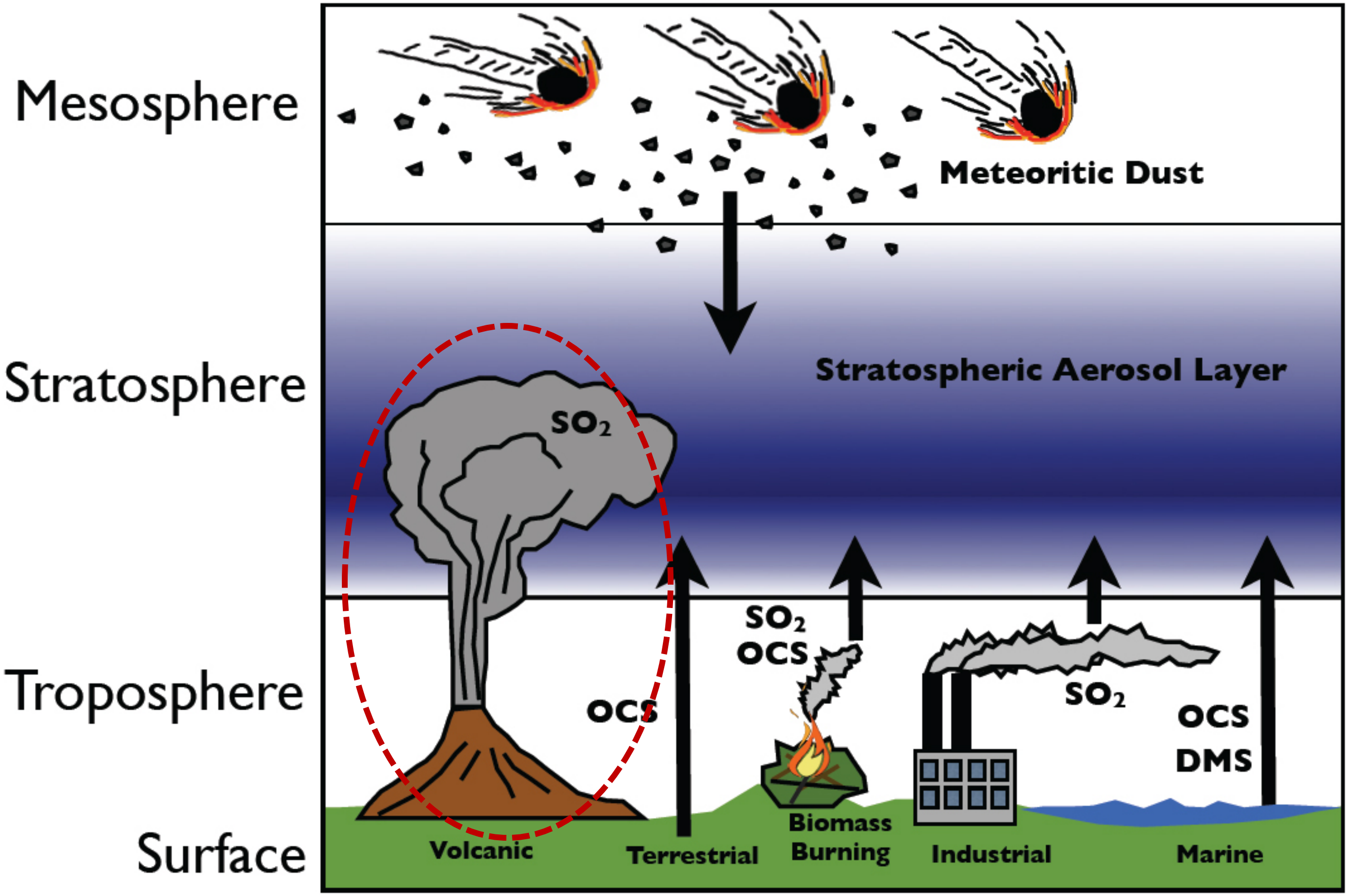
Background & Motivation

Structure of Earth's Atmosphere



The upper troposphere lower stratosphere (UTLS) region is situated between 12–18 km above sea level. It is the unique region encompassing the tropopause, and transition between the troposphere and the stratosphere.

Sources of Aerosols in Troposphere and Stratosphere



- Aerosols in the troposphere have large spatio-temporal variability because of large heterogeneity in the distribution of their sources (natural/anthropogenic) with short residence time, which can produce regional/seasonal climatic impacts.
- Stratospheric aerosols are quite different from the tropospheric aerosols because stratospheric aerosols can produce long-term global impacts due to their long residence time in the stratosphere.

During volcanically calm period, non-volcanic background aerosols may also come from the lower troposphere through vertical transport from deep convection.