Impact of Asian pollution on the Asian Summer Monsoon (ASM) anticyclone

Suvarna Fadnavis[1], Martin G. Schultz[2], Kirill Semeniuk[3], Luca Pozzoli[4] and others

[1]Indian Institute of Tropical Meteorology, Pune, India

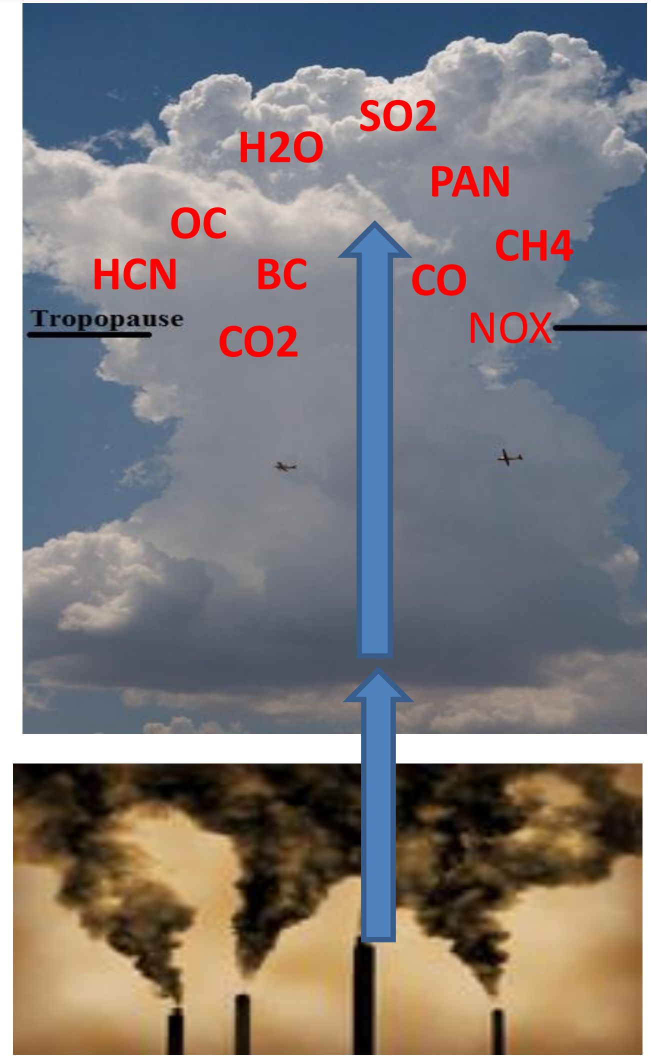
[2]Institute for Energy and Climate Research-Troposphere, Forschungszentrum Jülich, Germany

[3]Department of Earth and Space Sciences and Engineering, York University, Toronto, Canada

[4]Eurasia Institute of Earth Sciences, Istanbul Technical University, Turkey

Transport of boundary layer pollutants into the UTLS region via monsoon convection

- **ASM is one of the most powerful atmospheric circulation systems and its effects are seen over a polluted region in Asia.**
- **Deep monsoon circulation provides an entry of tropospheric polluted air into the anticyclone.**
- **Past studies have suggested that the impact of Asian pollutants on the UTLS may increase in coming decades because of the economical development.**

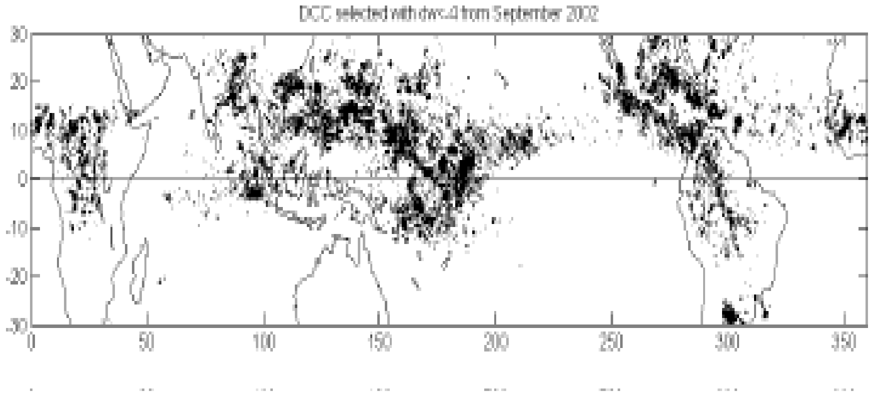


Emission: CO2, CO, VOCs, BC, SO2,NOX

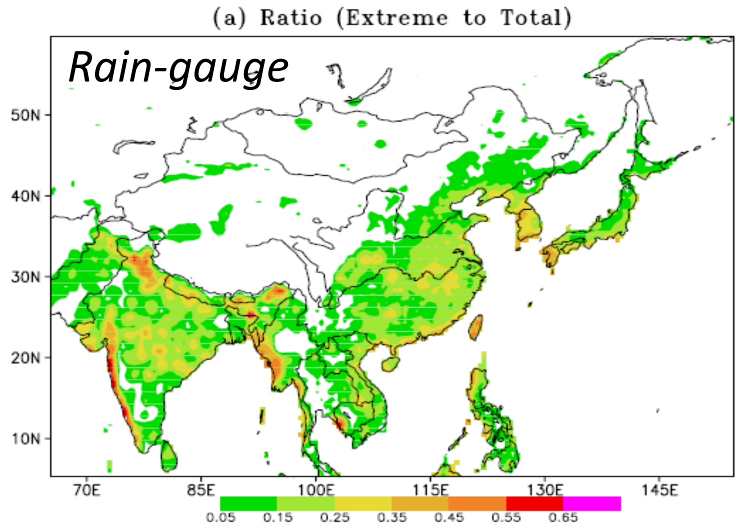
suvarna@tropmet.res.in

Deep convective clouds and extreme rain fall over the ASM

AIRS+MODIS

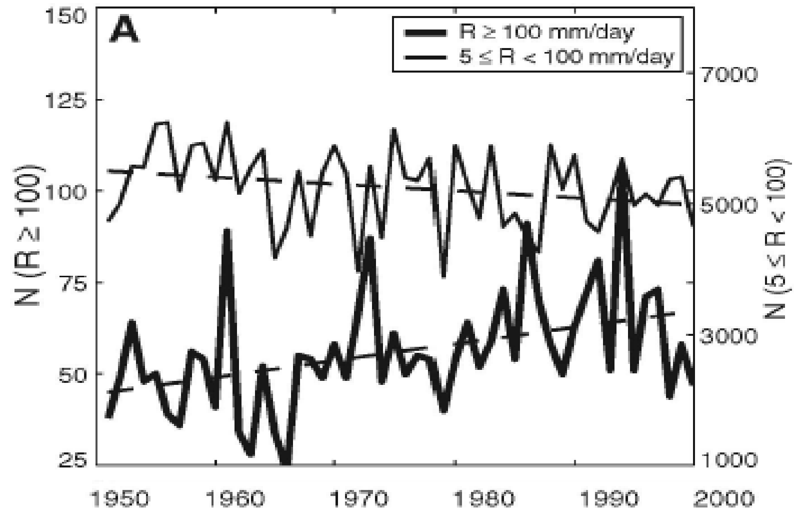


Aumann and Ruzmaikin, ACP, 2013



Yao et al., JGR, 2008

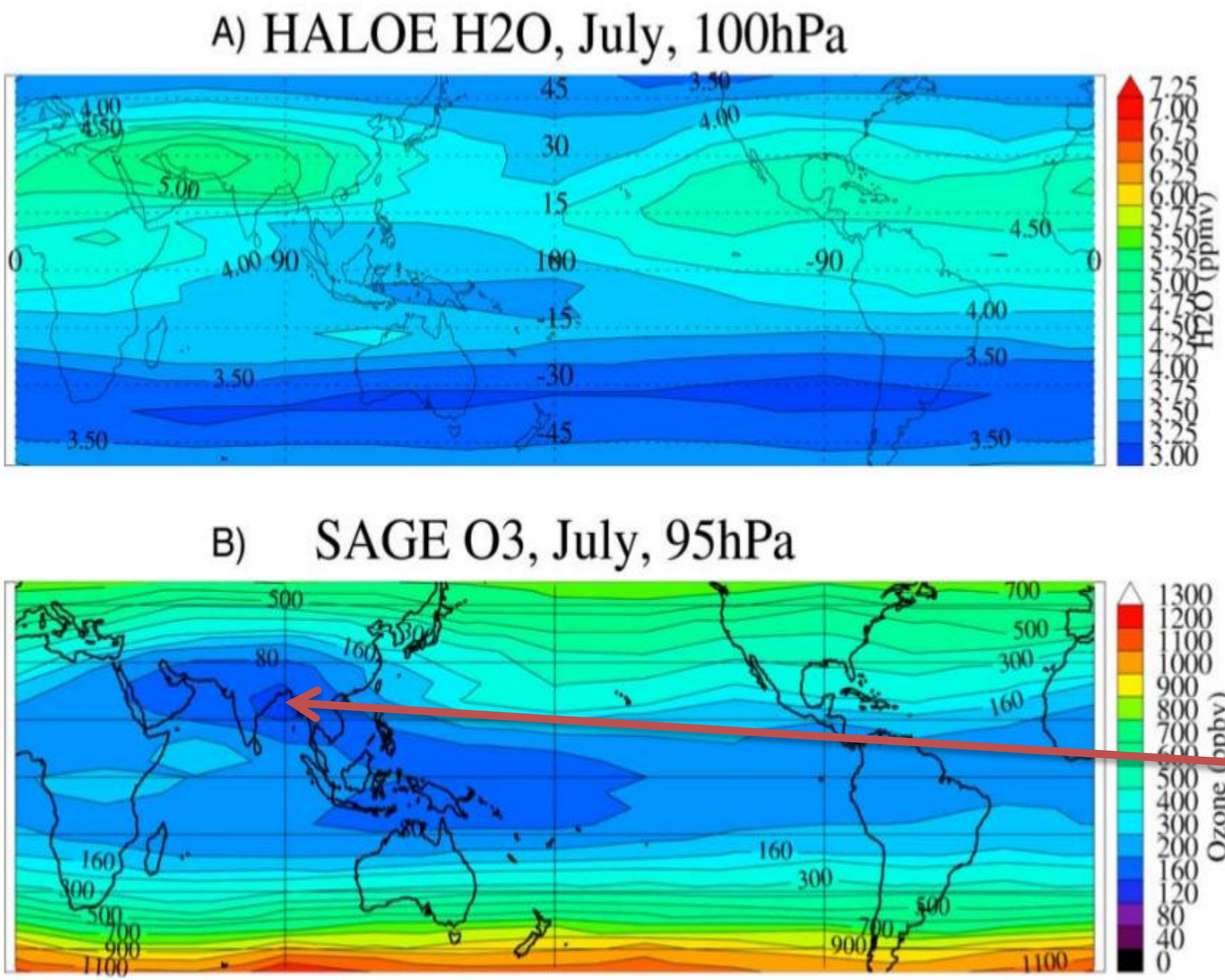
Goswami et al., Science, 2006



Temporal variation (1951 to 2000) in the number (N) of (A) heavy (R ≥ 100 mm/day, bold line) and moderate (5 ≤ R < 100 mm/day, thin line) daily rain events.

suvarna@tropmet.res.in

Water vapor in the ASM anticyclone



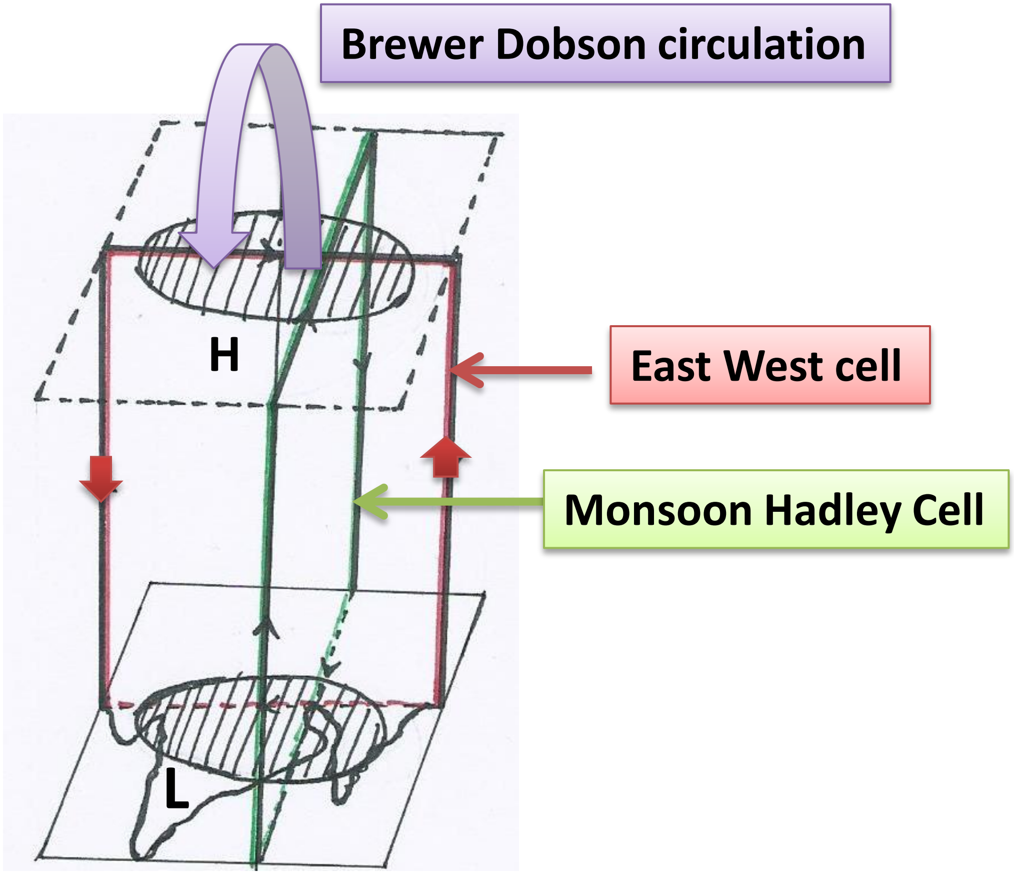
Maximum in CO, HCN, NO_2, PAN, aerosols ….. in the ASM anticyclone

Low ozone

Figure 1. Climatology of (a) water vapor from HALOE at 100 hPa and (b) ozone from SAGE at 95 hPa.

Gettelman et al., JGR, 2004

Transport into the UTLS linkages with Ocean-Atmosphere interaction



Atmospheric circulation

- Monsoon Hadley circulation
- East-west circulation
- Brewer Dobson circulation

Ocean response to ASM

- El-Nino/La-Nina
- Indian Ocean dipole

suvarna@tropmet.res.in

Impact of Asian pollution on the Asian monsoon anticyclone

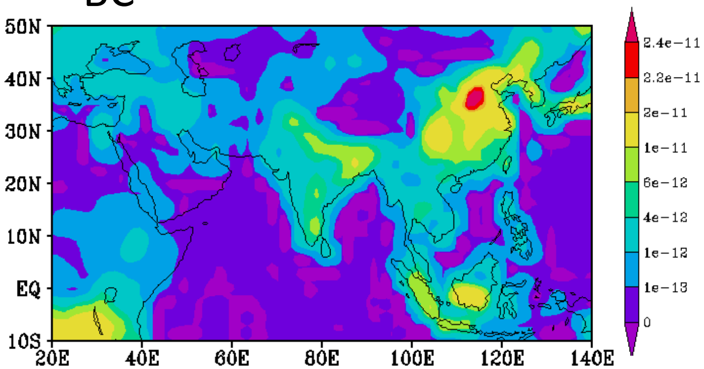
Key elements :

❖ASM: NOx limited region, sensitive to ozone radiative forcing.

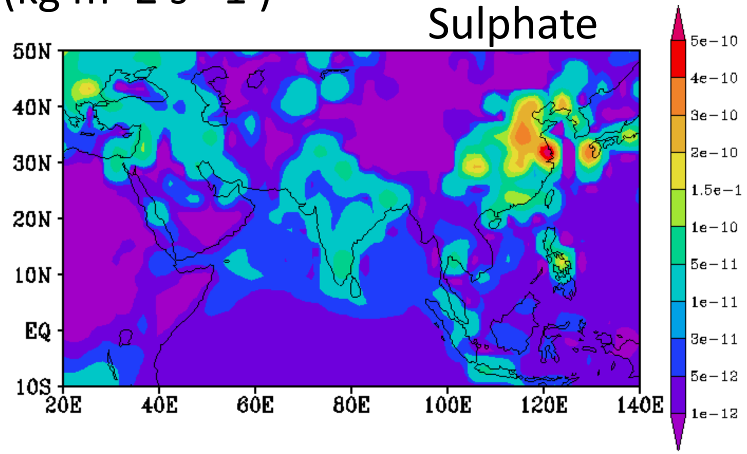
❖Aerosols: High BC and dust aerosols affecting , temperature, cloud micro physics and monsoon precipitation through direct and indirect effects.

emission mass flux (kg m−2 s −1)

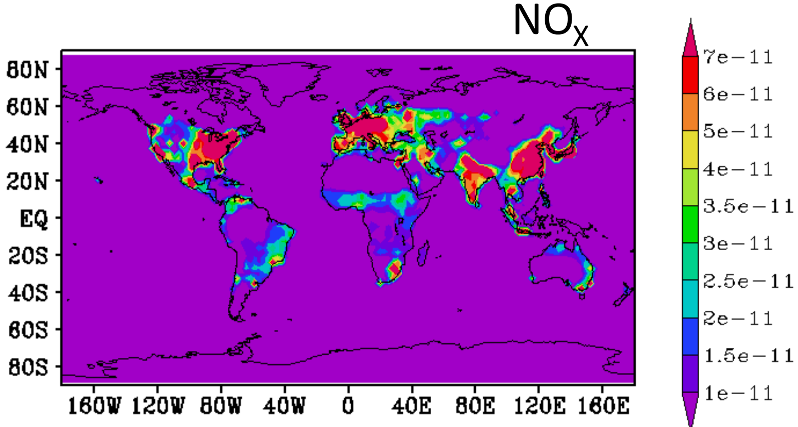
BC



Sulphate



NO_X



➢**Impact of aerosols on the UTLS**

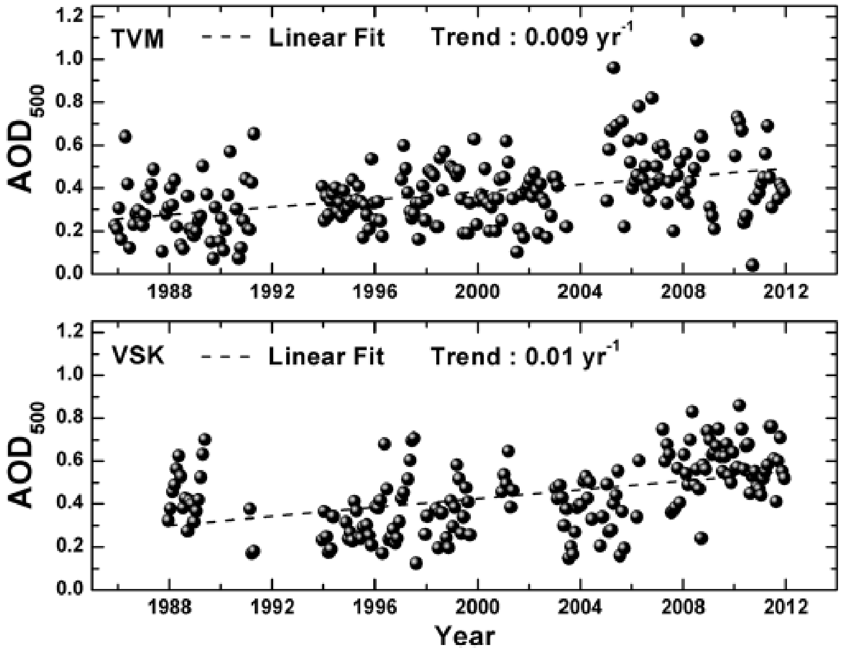
➢**Impact of Asian NOx emission on PAN, HNO_3, ozone in the UTLS**

➢**Transport from other monsoon systems to the ASM and vice-a-versa**

suvarna@tropmet.res.in

Trend in NOx and AOD over India and China

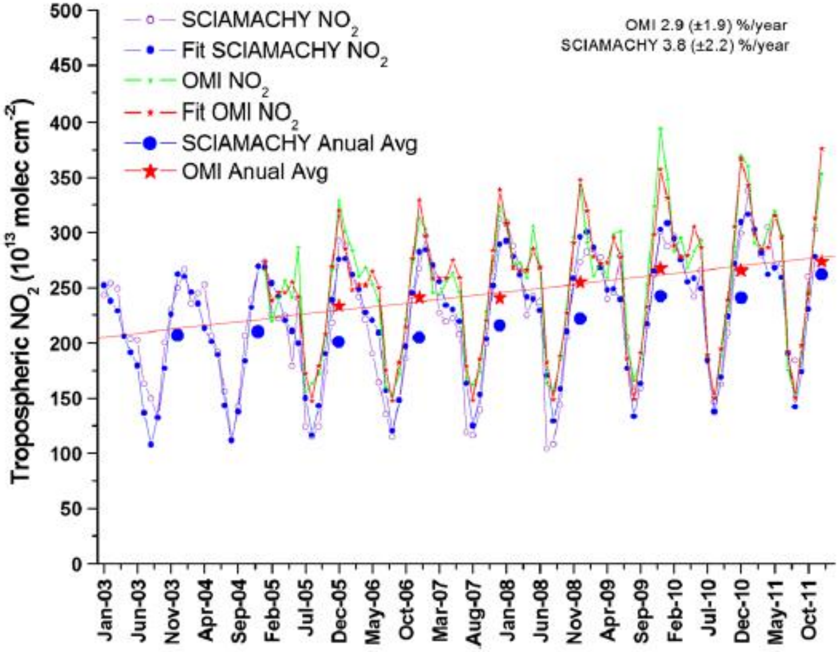
AOD



AOD at 550 mn at Trivandrun and Visakhapatnam

Babu et al., JGR, 2013

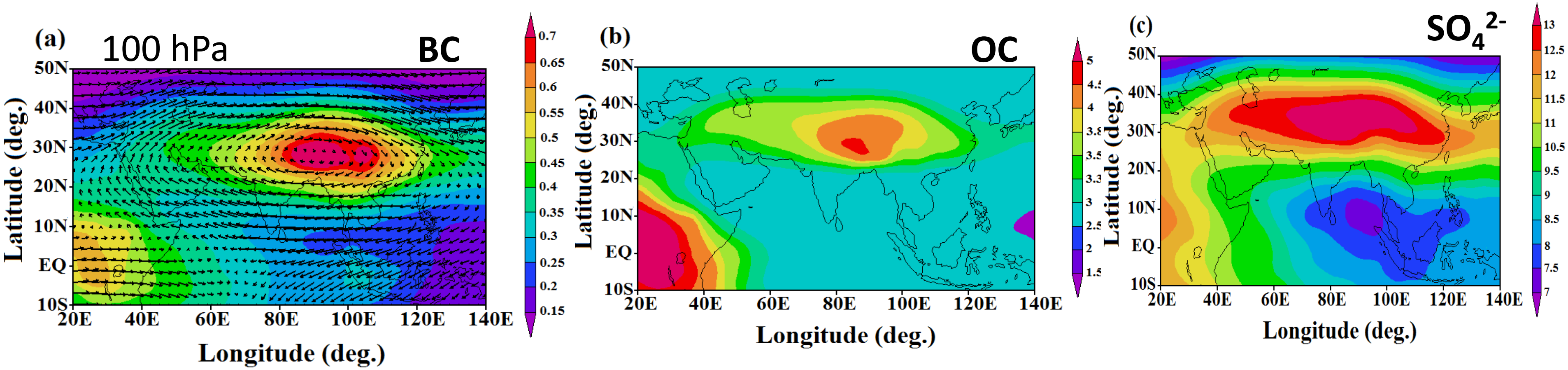
NOx



Trend in Tropospheric NO_2 column over
India = 3.8%/year (Ghude et al., 2013)
China= 7.3 %/year (Schneider and van der A, 2012)

suvarna@tropmet.res.in

Transport of aerosols into monsoon anticyclone: Model simulations



ECHAM5-HAMMOZ : Aerosol-chemistry-climate model, 10 member ensemble mean, 2003

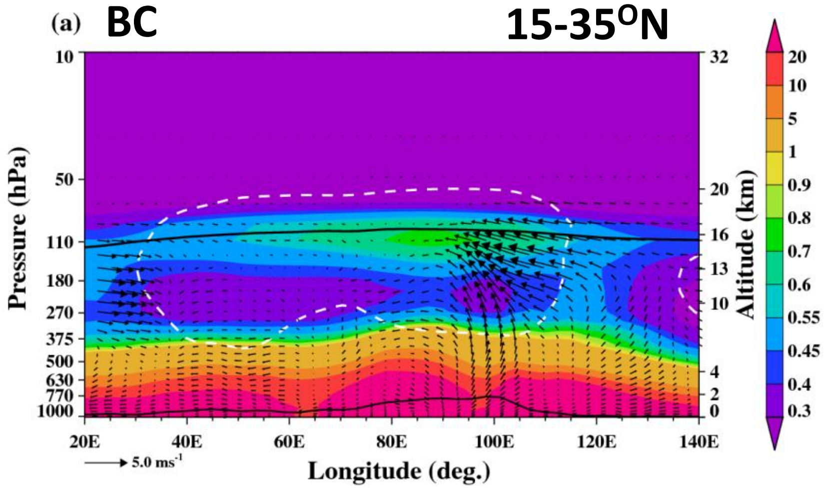
The simulations show persistent maxima in black carbon, organic carbon, sulfate, and mineral dust aerosols within the anticyclone in the UTLS throughout the ASM (period from July to September).

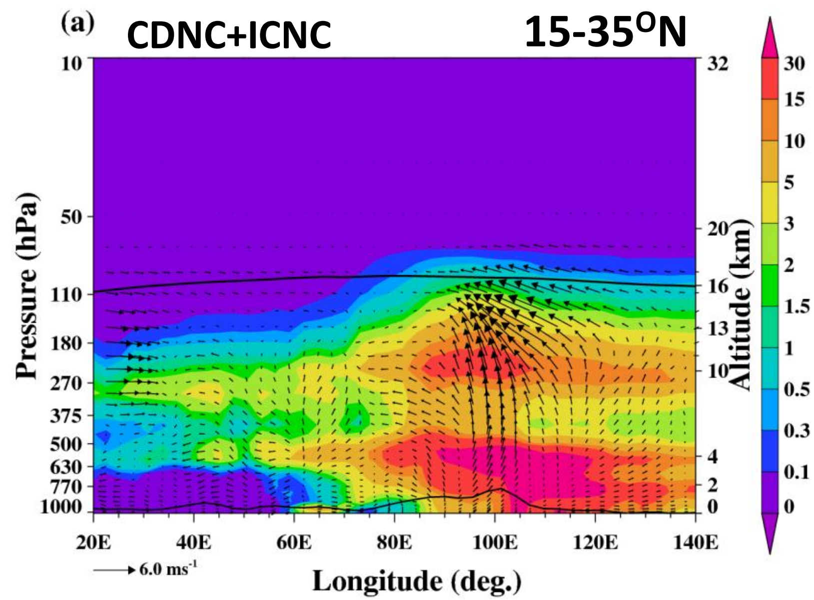
They indicate boundary layer aerosol pollution as the source of this UTLS aerosol layer and identify ASM convection as the dominant transport process.

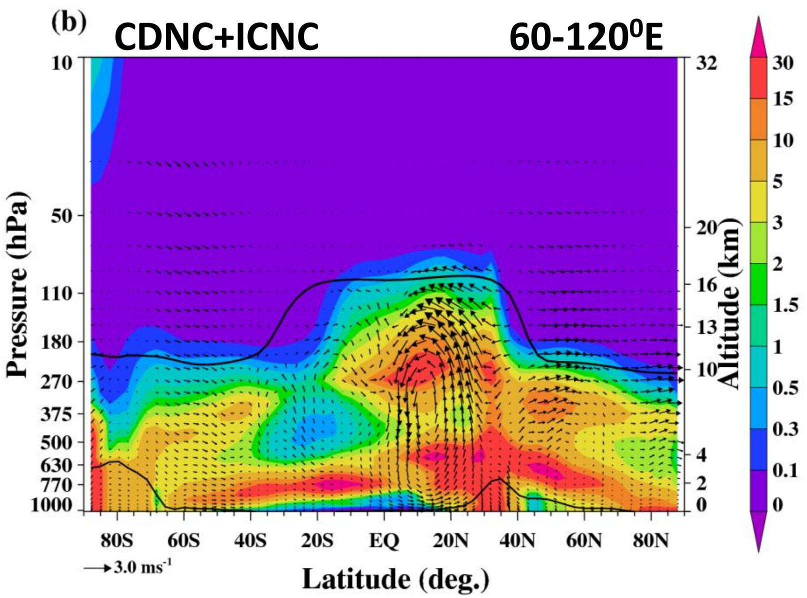
Fadnavis et al., ACP, 2013

suvarna@tropmet.res.in

Convective Transport of Boundary layer aerosols







Convective transport from

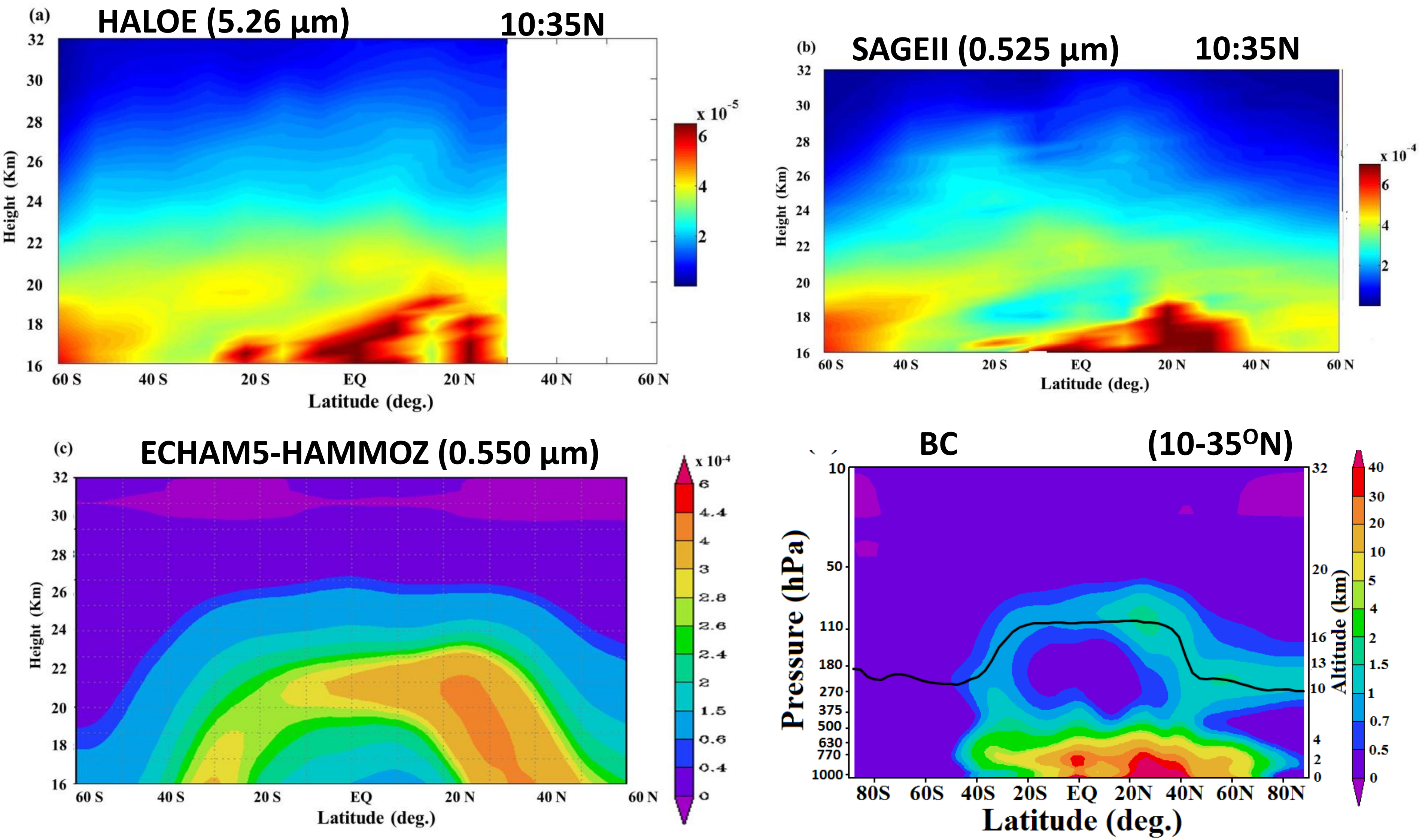
Southern Slopes of Himalayas

Region extending BOB to South China Sea

Fadnavis et al., ACP, 2013

suvarna@tropmet.res.in

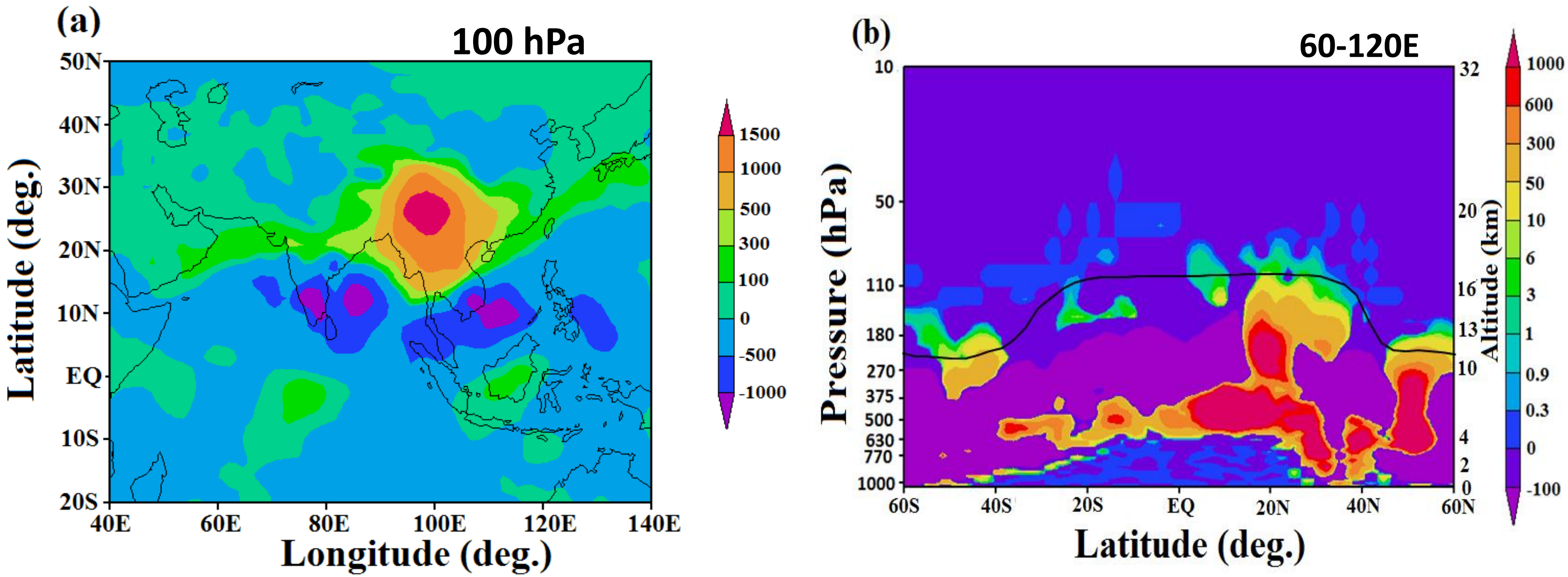
Aerosol distribution in the lower stratosphere



Fadnavis et al., ACP, 2013

suvarna@tropmet.res.in

Aerosol induced cloud ice

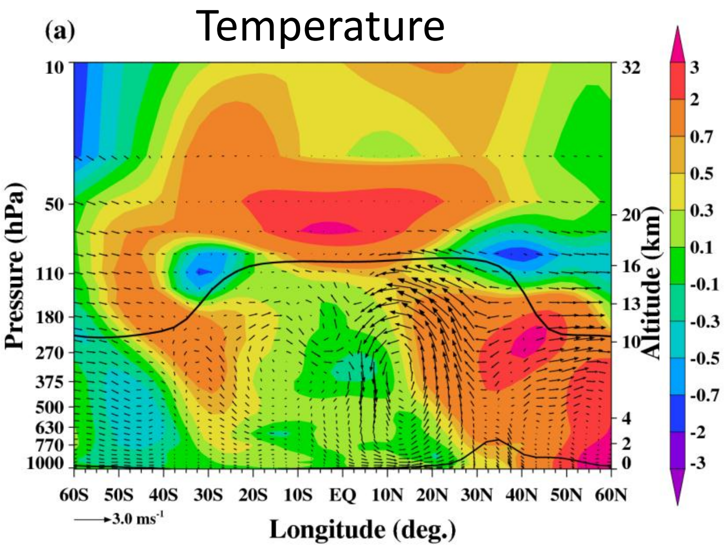


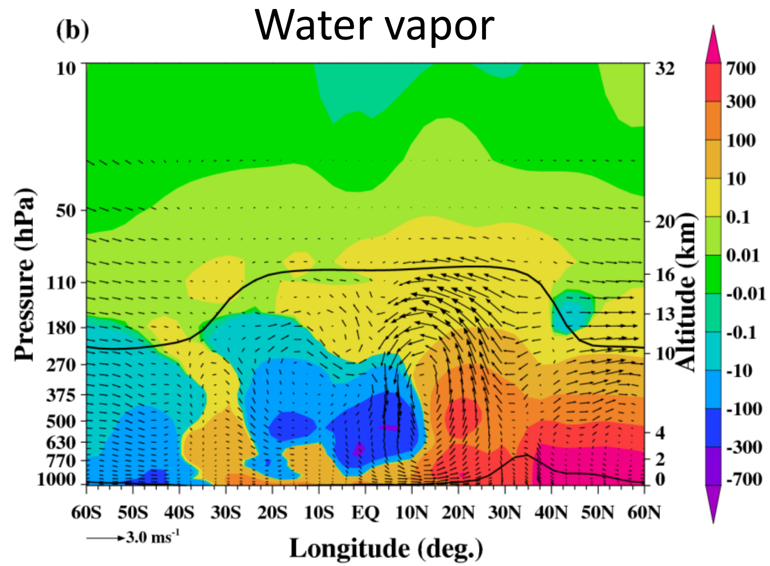
➢**Figure (a) --> A prominent feature at the eastern end of the anticyclone region, where the cloud ice anomaly has a maximum (15 mgm−3).**

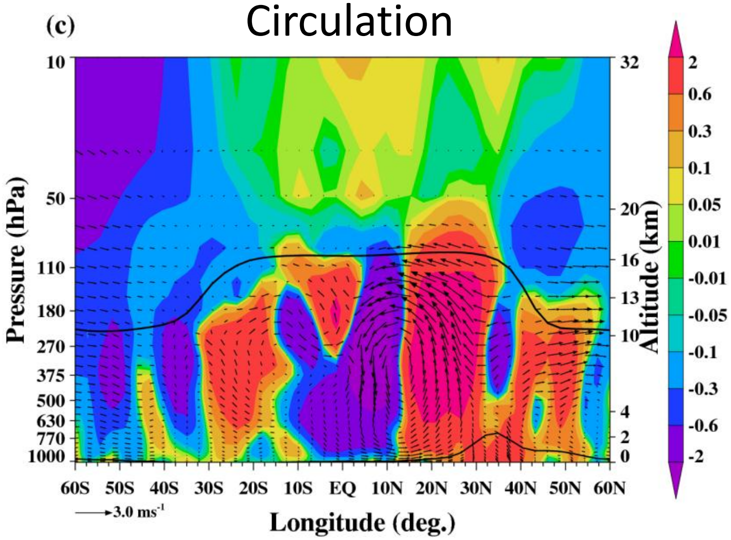
➢**Figure (b) --> Increase in cloud ice up to 10 µgm−3 near the tropical tropopause due to aerosol loading.**

Fadnavis et al., ACP, 2013

Impact of aerosols on temperature, water vapour, and circulation



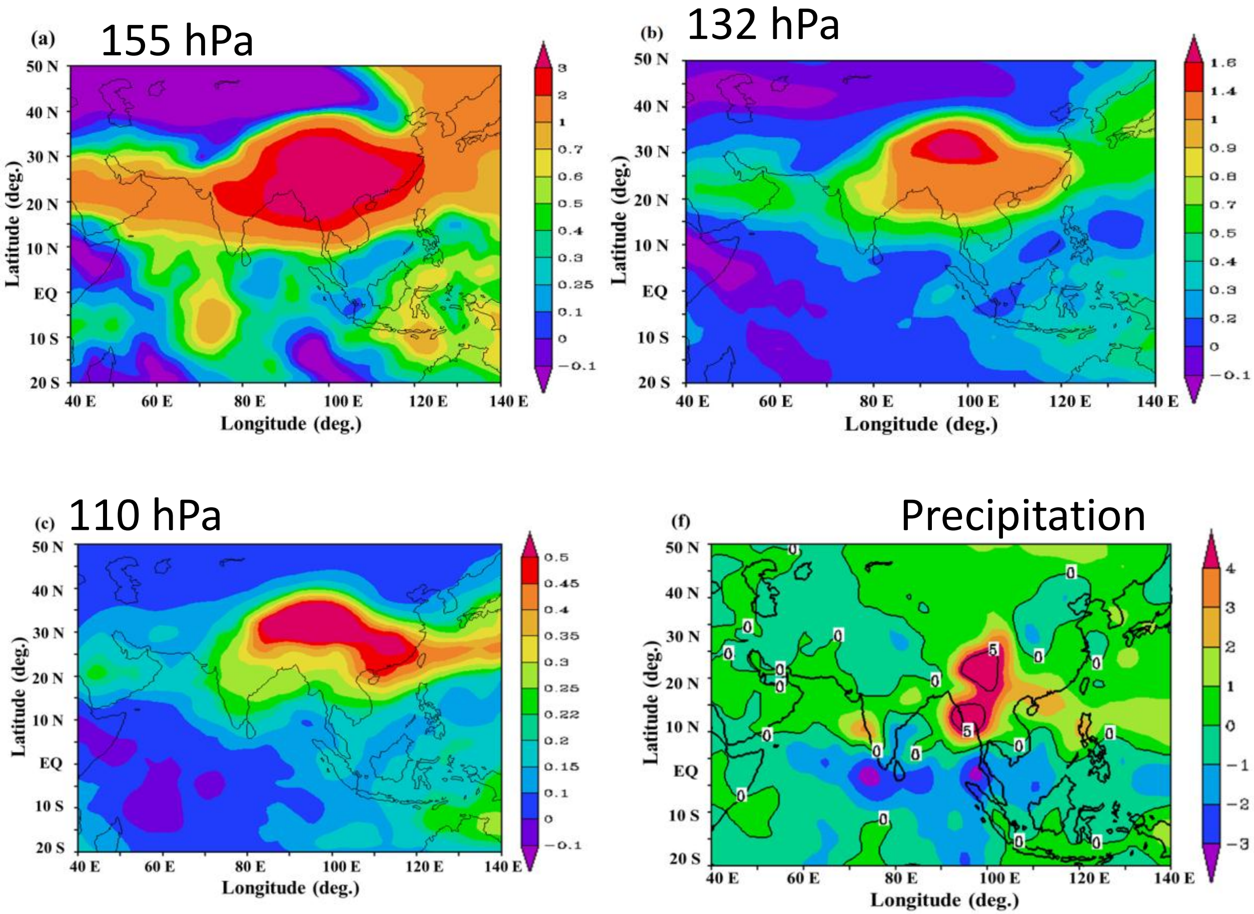




- ❖**Temperature increases by 1–5K near the tropical tropopause. Tibetan Plateau experiences a significant warming.**
- ❖**Increase in vertical transport of H_2O over the southern flanks of the Himalayas.**
- ❖**A weakening of the monsoon Hadley circulation due to aerosol forcing.**

suvarna@tropmet.res.in

Aerosol induced changes in water vapor and precipitation



• Positive water vapour anomalies (0.2 – 3 ppmv) in the ASM anticyclone

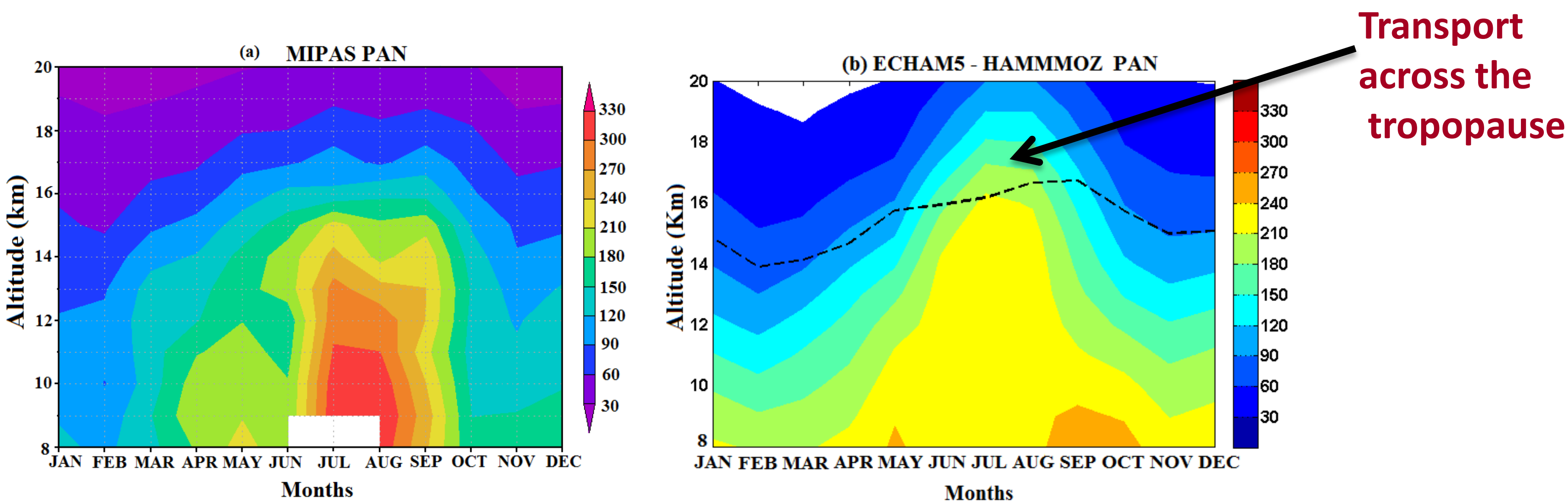
• Decrease in precipitation ~-1 to -3mm/day over southern India .

• At the eastern end of anticyclone there is significant increase in precipitation ~5–7 mm/day.

Fadnavis et al., ACP, 2013

suvarna@tropmet.res.in

Distribution of Peroxyacetyl Nitrate (PAN) over ASM region



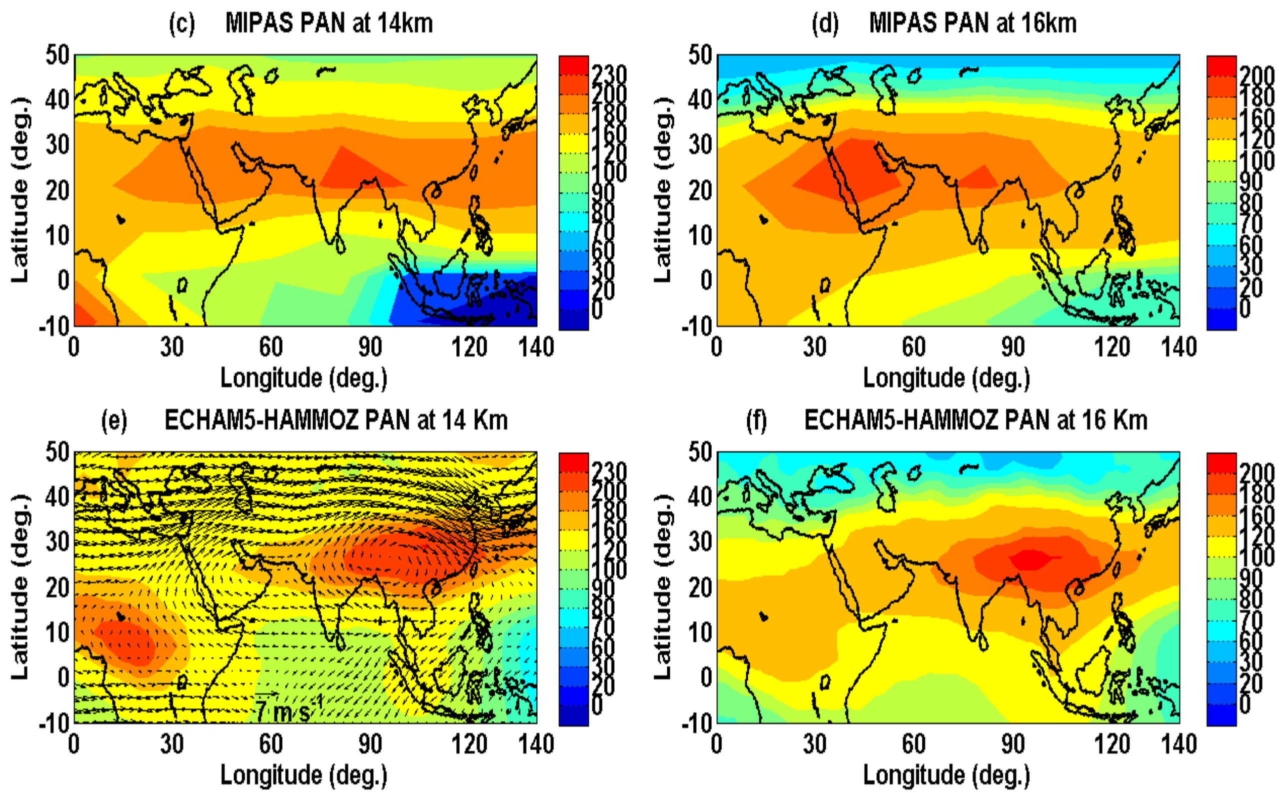
PAN averaged over the ASM region (10-35^{O}N; 60-120^{O}E). Simulated PAN mole fractions are smoothed with the averaging kernel of MIPAS.

MIPAS satellite and Model simulations show significant vertical transport by deep convection and diabatic heating induced upwelling.

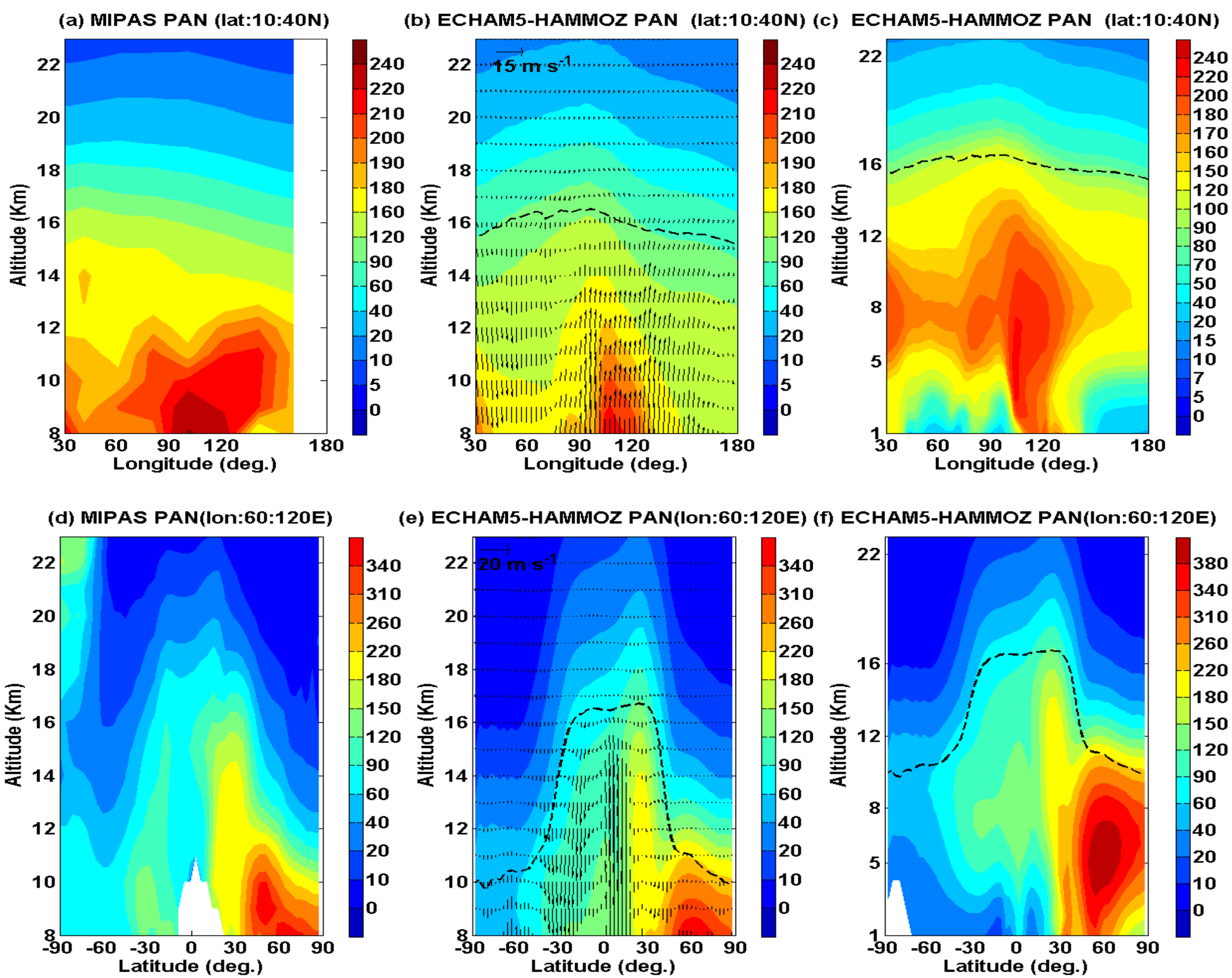
PAN distribution in the monsoon anticyclone

➢MIPAS Climatology (JJAS) and control simulations show
➢PAN maximum in the monsoon anticyclone.

➢MIPAS-E PAN is higher than model by ~30-60 ppt. These differences may be due to uncertainties in VOC, NO_x emissions, chemistry represented in the model, transport errors and model coarse resolution.



Transport of PAN into the UTLS

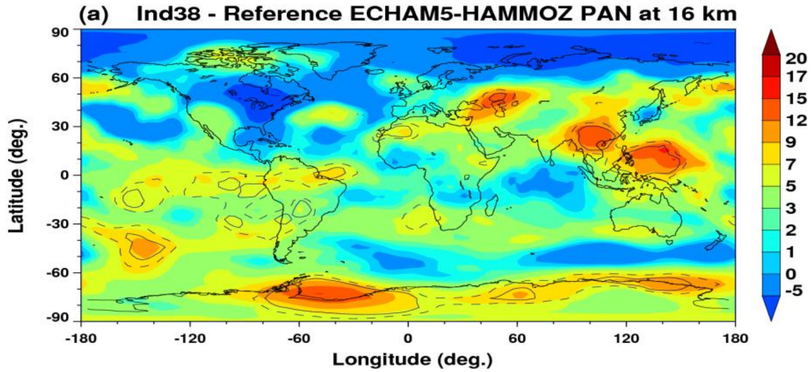


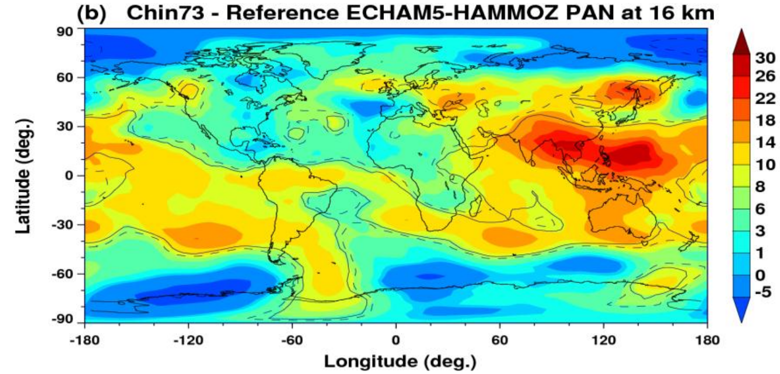
✓Transport of boundary layer PAN to UTLS mainly from strong convection region of the South China Sea (~100-120E) and Southern Flank of Himalaya (~80-90E).

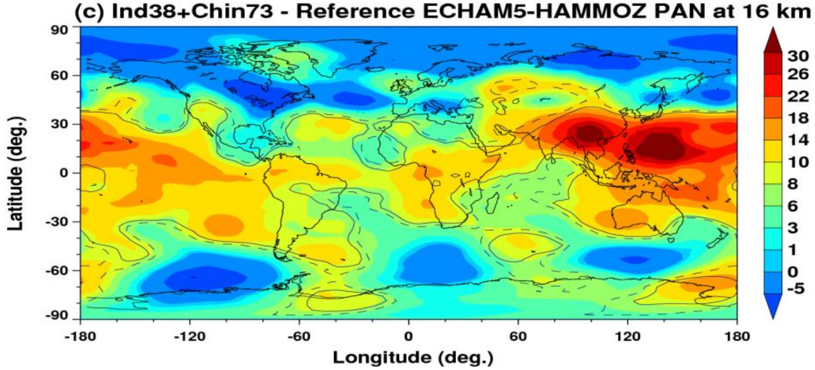
✓High levels of PAN over the northern subtropics (20-40^{O}N).

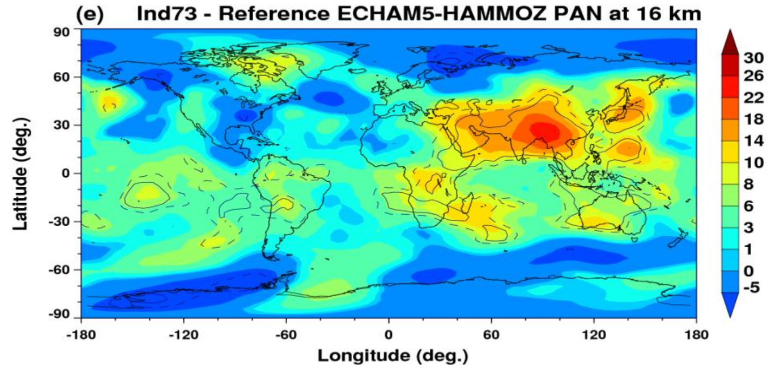
✓The PAN is also transported from 40-60^{O}N reaching up to 16 km.

Impact on PAN









NOx Sensitivity experiments

(a) India 38% (ind38)

(b) China 73% (chin73)

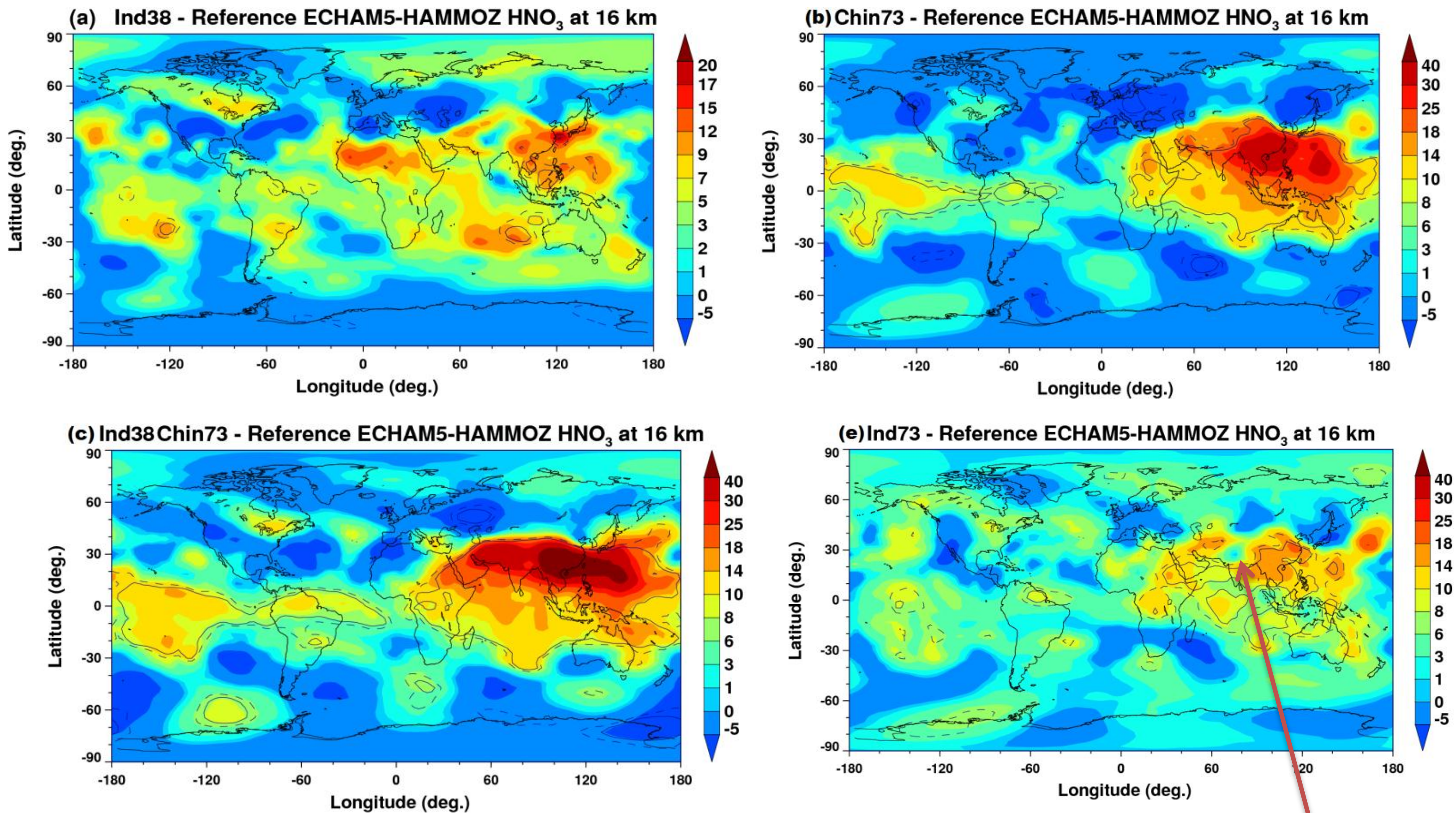
(c) India 38% +China 73% (ind38+chin73)

(d) India 73% (Ind73)

Fadnavis et al., ACP, 2014

suvarna@tropmet.res.in

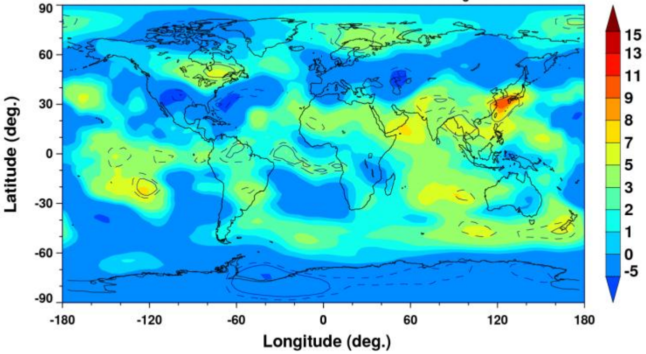
Impact on HNO_3



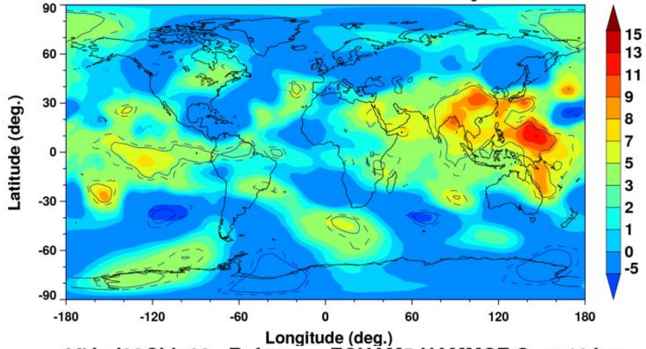
Low HNO_3 at the slopes of Himalayas

Impact on ozone

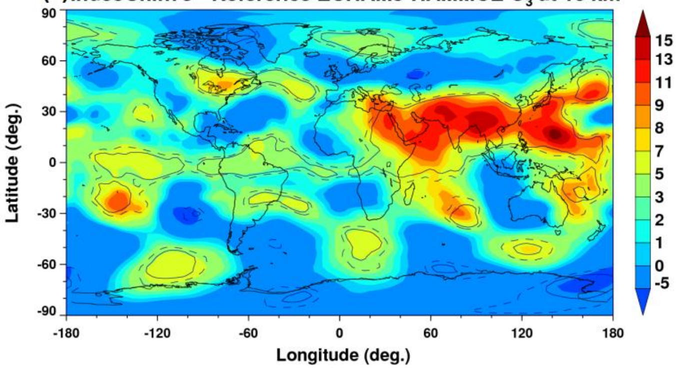
(a) Ind38 - Reference ECHAM5-HAMMOZ O_3 at 16 km



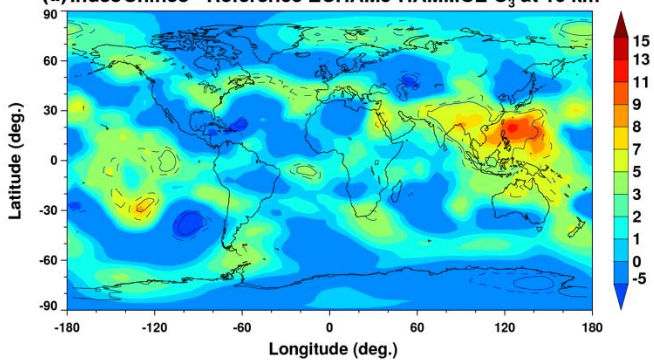
(b) Chin73 - Reference ECHAM5-HAMMOZ O_3 at 16 km



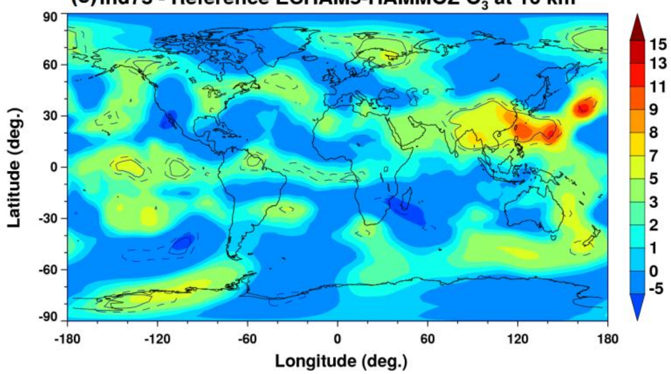
(c) Ind38Chin73 - Reference ECHAM5-HAMMOZ O_3 at 16 km



(d) Ind38Chin38 - Reference ECHAM5-HAMMOZ O_3 at 16 km



(e) Ind73 - Reference ECHAM5-HAMMOZ O_3 at 16 km



I. **Increases in ozone (3-7% or 20-60 ppt) over the Indian Ocean and South China Sea.**

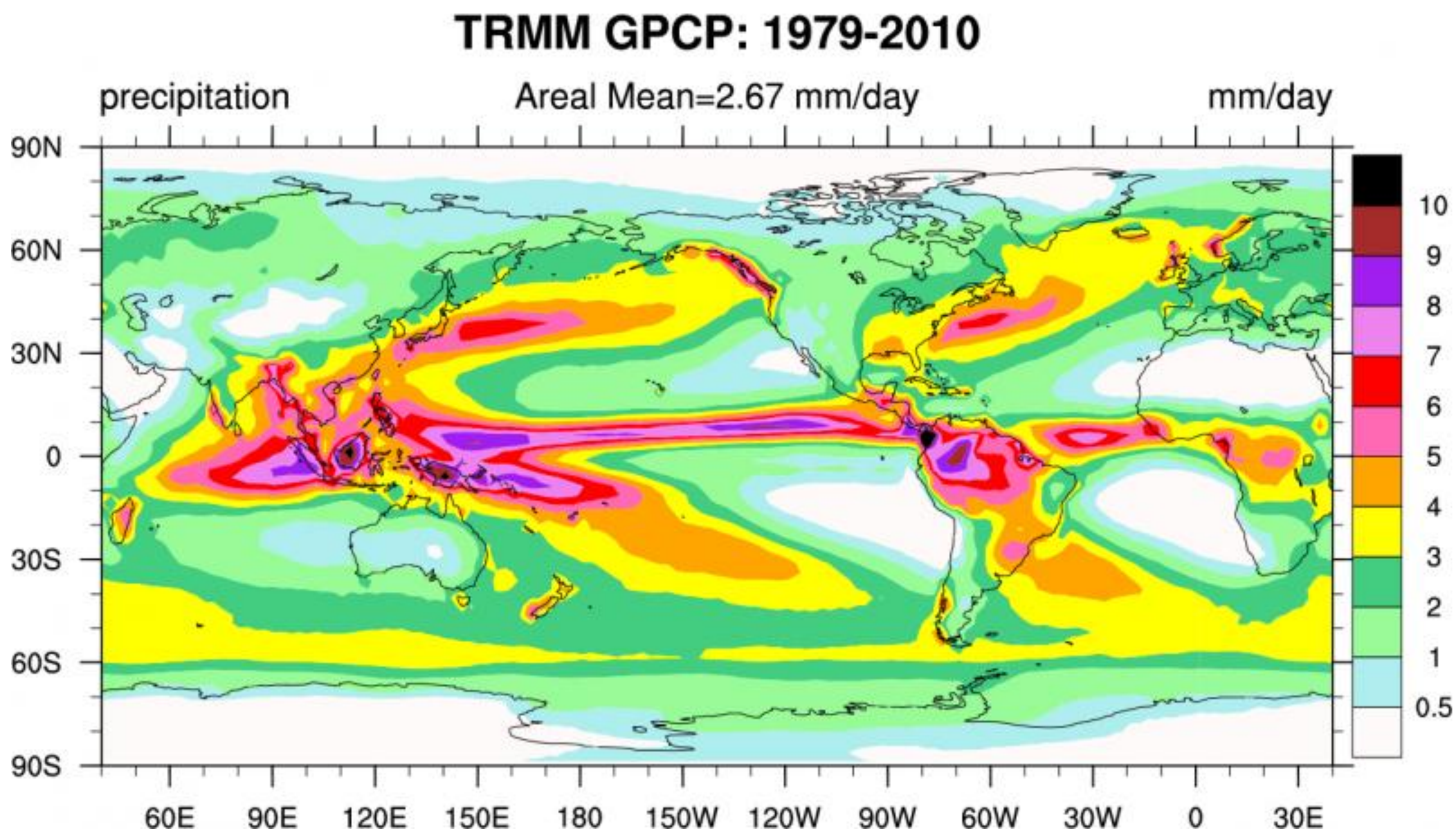
II. **Transport of ozone to Indian Ocean, South East Asia, the South China Sea and the Pacific Ocean, by westerly winds.**

III. **More increase in ozone in the monsoon anticyclone in the case of Chinese emissions compared to emissions from India.**

Fadnavis et al., ACP, 2014

suvarna@tropmet.res.in

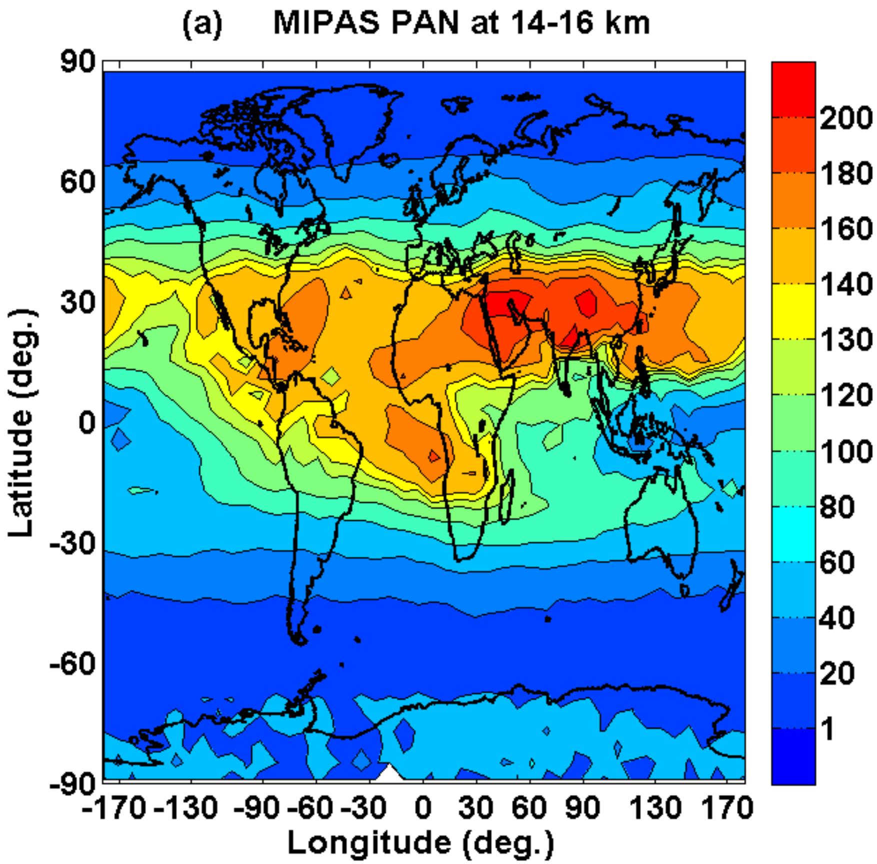
Influence from other monsoon systems on the ASM UTLS

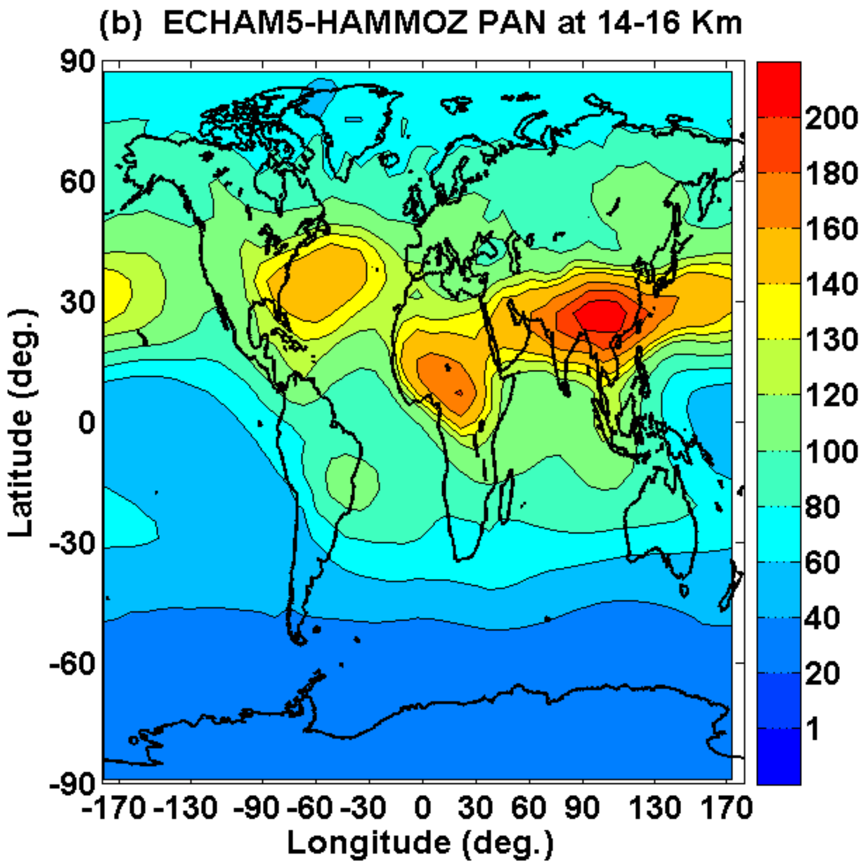


Ref: The Climate Data Guide: GPCP (Monthly): Global Precipitation Climatology Project.

suvarna@tropmet.res.in

PAN in the Global UTLS



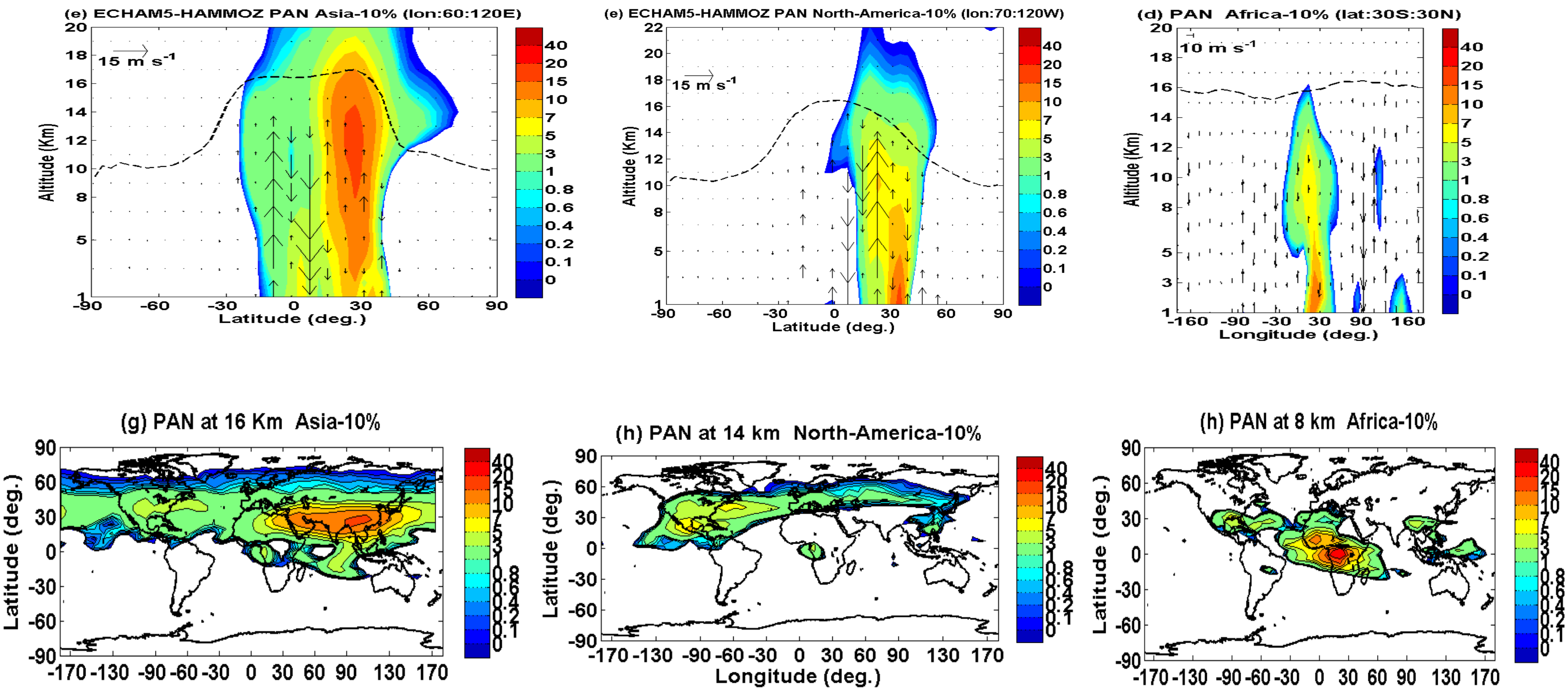


- **Signature of High PAN over global monsoon regimes – ASM, Africa and America**

Fadnavis et al., ACP, 2015

suvarna@tropmet.res.in

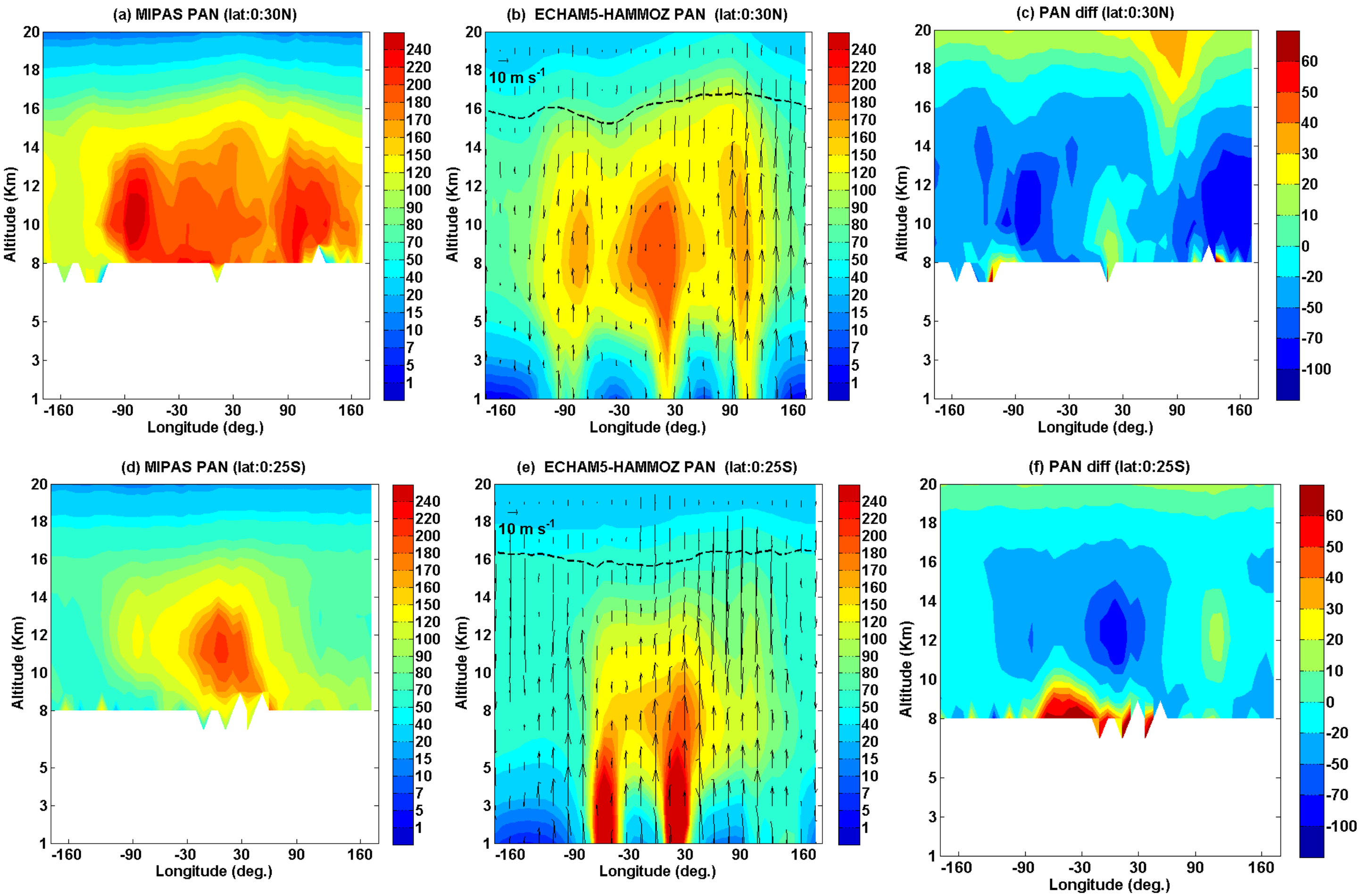
Emission sensitivity experiments



❖Comparison of emission change over Asia, North America and Africa shows highest transport of PAN, HNO_3 and ozone occurs in the UT over Asia and least over Africa.

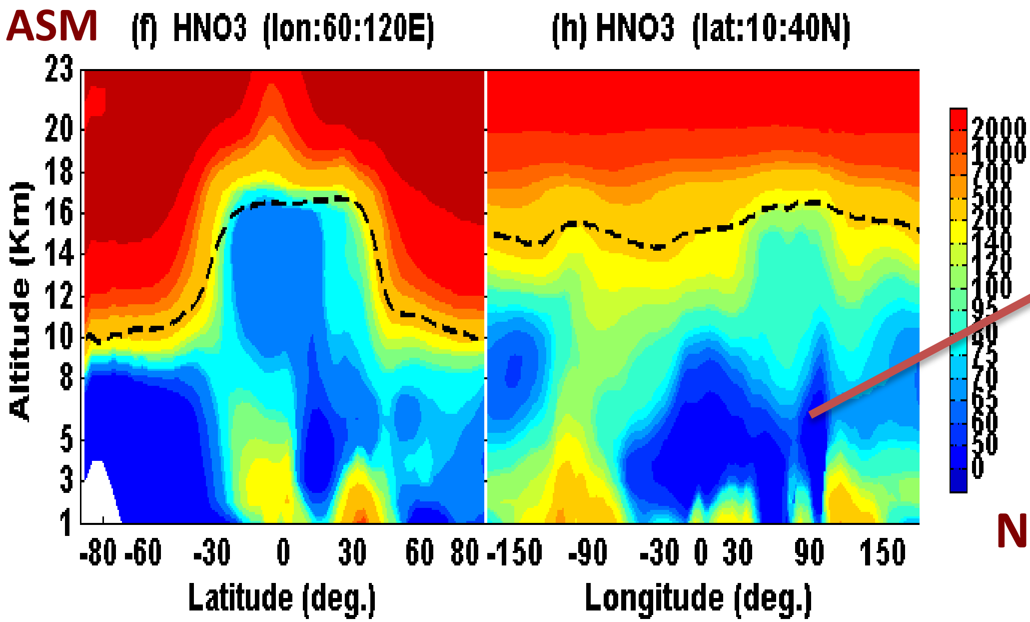
suvarna@tropmet.res.in

Emission sensitivity experiments



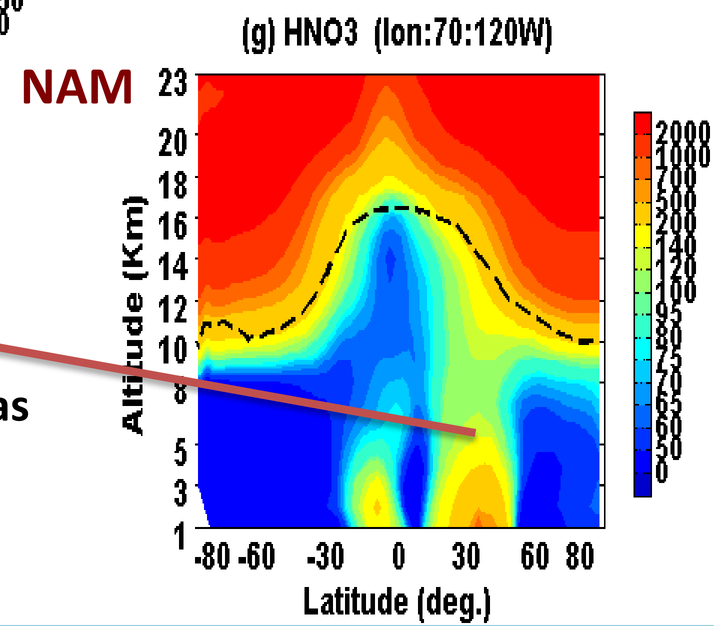
10% change in Asian emissions, transport ~5-30 ppt of PAN in the UTLS over Asia, ~1-10 ppt of PAN in the UTLS of Northern subtropics and mid latitudes, ~7-10 ppt of HNO_3 and ~1-2 ppb of ozone in UT over Asia.

Distribution of HNO_3



- Depletion of HNO_3 in the region of intense convection near the Himalayas.

- Efficient removal of NOx by wet scavenging



Transport from North America.

NAM is not as intense and not as deep as ASM.

Summary

❖Asian Aerosol and NO_X emissions show significant impact on the UTLS.

❖ Simulations show significant change in NO_X chemistry at the foot hills of Himalayas. Should be confirmed from observations.

❖Aerosol induced changes in circulation, H_2O and temperature causes reduction in Precipitation over India.

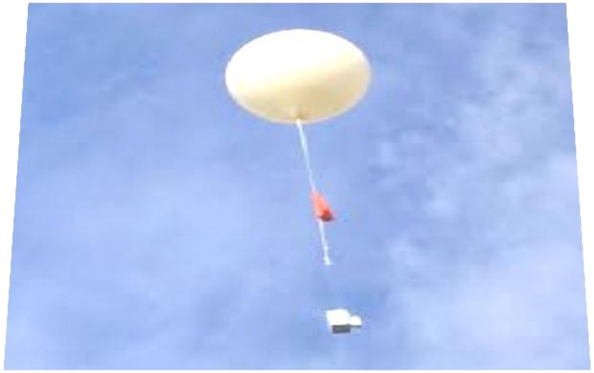
❖ Ozone radiative forcing due to enhanced NO_X emission may feedback the Asian summer monsoon circulation. Needs detail analysis.

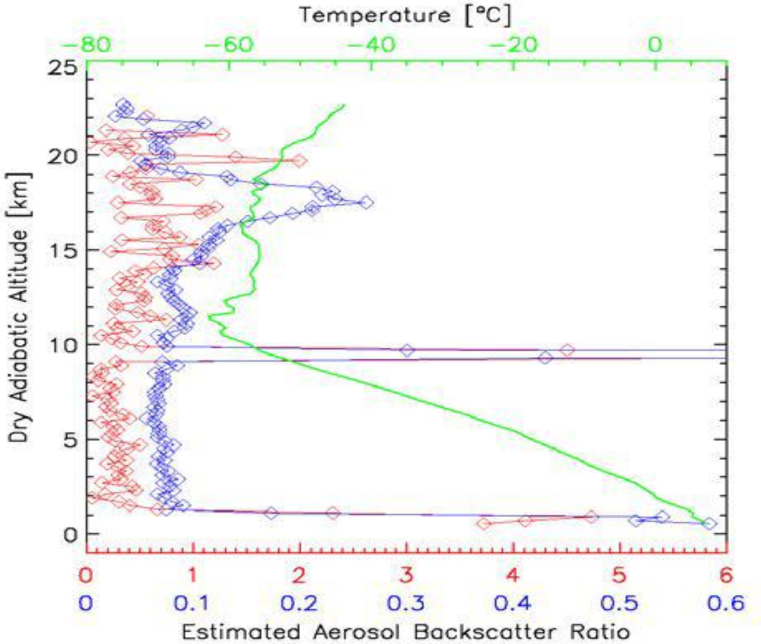
suvarna@tropmet.res.in

Balloonsonde measurements in India

Locations: Nainital and Nagpur

1. **Radiosonde : 25Nos**
2. **Ozonesonde: 25 Nos**
3. **Aerosol back scatter (COBALD): 25 Nos**
4. **Water vapor: Cryogenic Frostpoint Hygrometer) (CHF) : 25 Nos**





➢**Tentative Flying strategy: can be discussed and modified.**

➢**Coordinated with Aircraft for comparison when aircraft measurements taken over Northern India – 3 balloonsonde flights.**

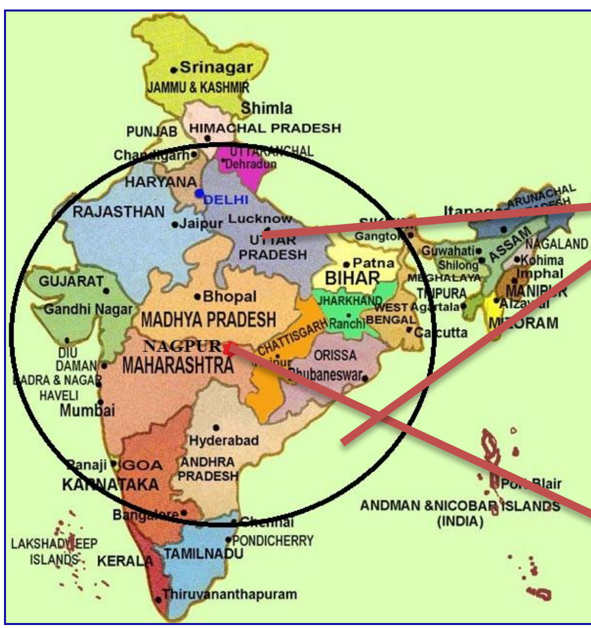
➢**Balloon sonde flights at Nainital- Night time– 15**
➢**Balloon sonde flights at Nainital- day time– 5**
➢**Balloon sonde flights at Nagpur- Night time - 5**
➢**Balloon sonde flights at Nagpur- day time - 5**

Indo-German Project: Influence of Asian Summer Monsoon (ASM) on the upper troposphere-lower stratosphere (UTLS): Feedback on monsoon circulation

Geophysica Aircraft Payload

- **Gas phase: H_2O, CO, O_3, NO, NOy, CH_4, SF_6, Clo, Bro, SO_4, H_2SO_4 , CO_2 etc**
- **Particles: Cloud image probe, particle back scatter, size distribution, condensation nuclei etc.**
- **Temperature , pressure, winds etc.**

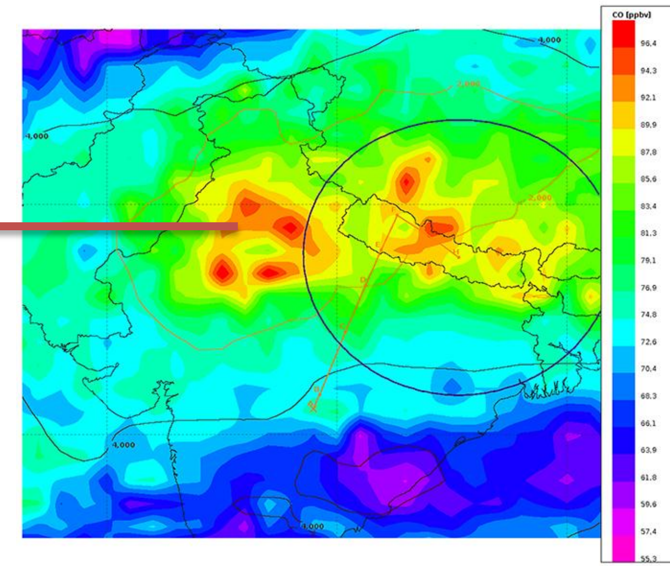
July – August 2016, No of Days: 25, Flight Hours: ~60



Probing into convective zones cross the tropopause.

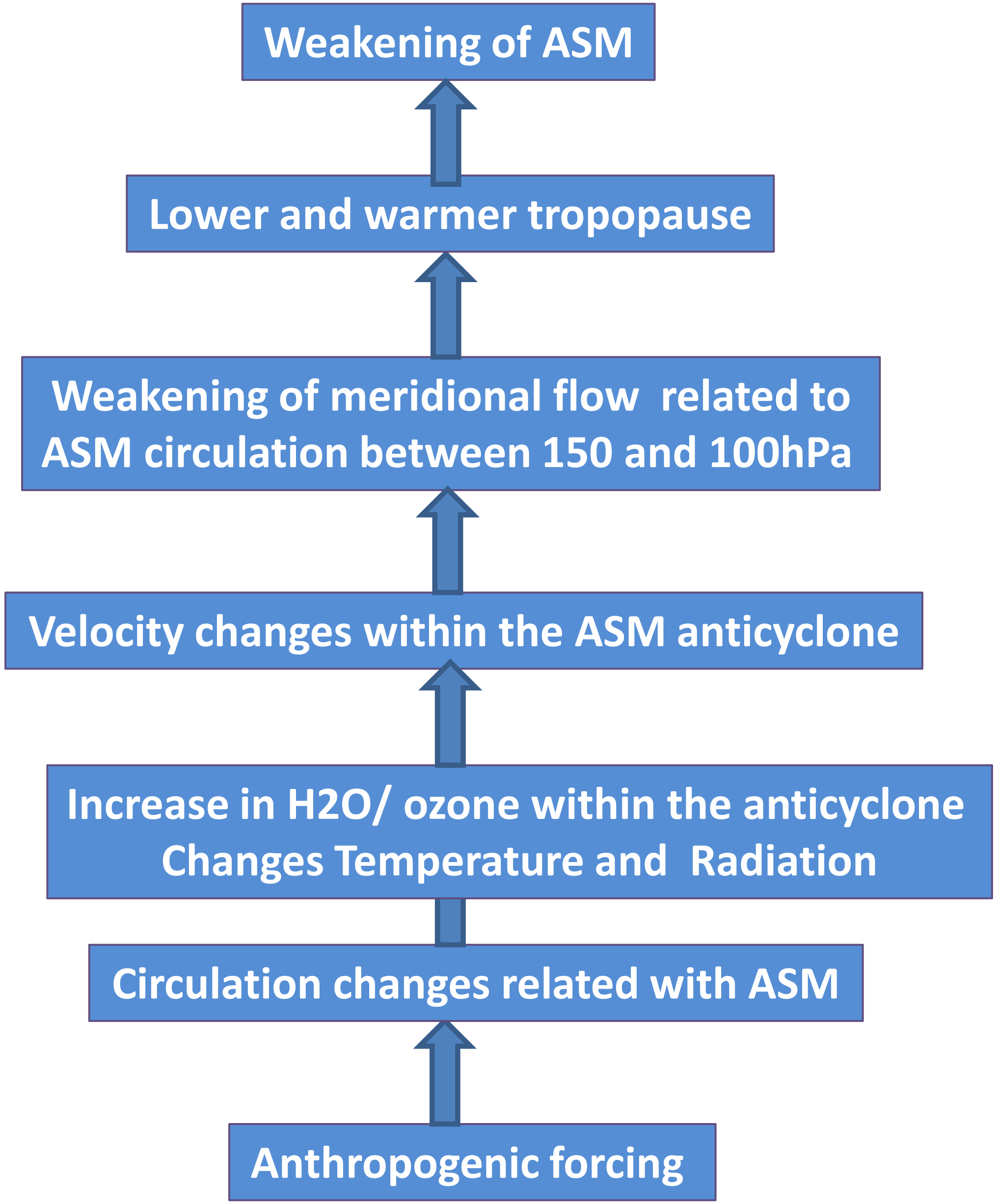
Base camp at Nagpur

CO at 100 hPa

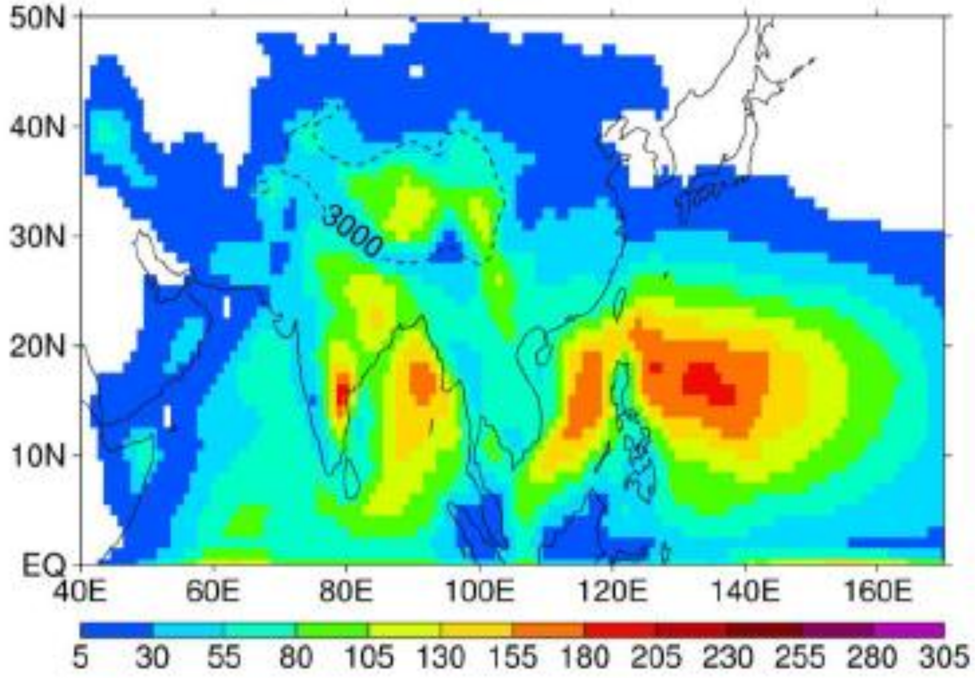



Thank You !
suvarna@tropmet.res.in

Increased water vapour / decreased ozone in the anticyclone: Linkages with ASM



Trajectory Analysis: Transport pathways



Density field of numbers of all TST trajectories in 1x1 grid, during June-July 2001-2009

1. **38 % from the region between tropical Western Pacific region and South China Seas (WP)**
2. **21 % from Bay of Bengal and South Asian subcontinent (BOB)**
3. **12 % from the South Slope of the Himalayas.**

Chen et al., ACP, 2012

suvarna@tropmet.res.in