Influence of enhanced Asian NO_x emissions on ozone in the Upper Troposphere and Lower Stratosphere (UTLS) in chemistry climate model simulations

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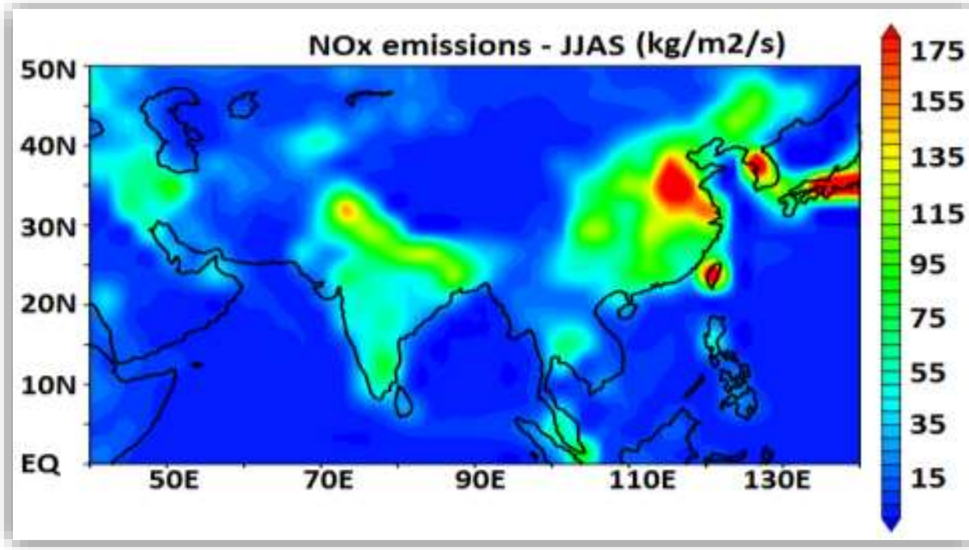
Introduction

• Rapid economic development and urbanization in Asia has resulted in an unprecedented growth in anthropogenic emissions of NO_x, CO, CO_2, CH_4

Distribution of NO_x emission mass flux (kg m^{-2} s^{-1}) from RETRO, averaged for JJAS



• Positive trends in Asian tropospheric column NO_x have been reported

• Increase in anthropogenic NO_x over India — 3.8% yr^{-1} from SCIAMACHY (2003-2011)

• Increase in anthropogenic NO_x over China — 7.3% yr^{-1} from OMI (2002-2011)

• Tropospheric ozone, which is both an important polluting agent and a greenhouse gas, gets affected

• ASM convection transports Asian pollutants from the boundary layer into the UTLS

• Rise in anthropogenic emissions over the ASM region alters the chemical composition of the UTLS

Scientific Objective

How do increasing Asian NO_x emissions and the associated ozone production affect ozone radiative forcing and monsoon circulation???

Model simulation and experimental set-up

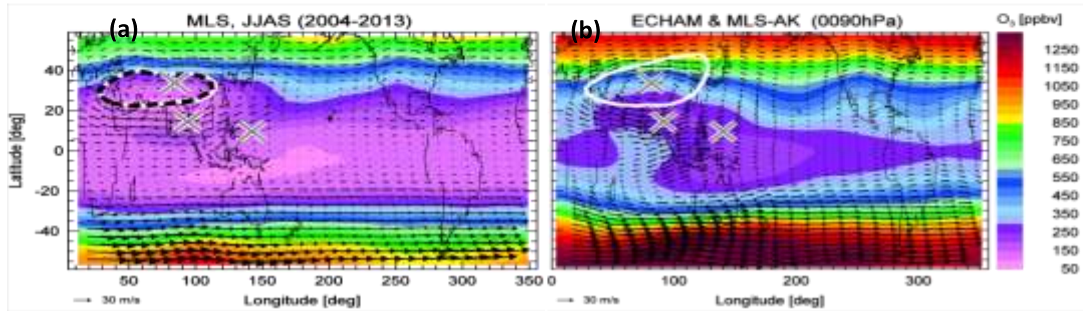
Model used

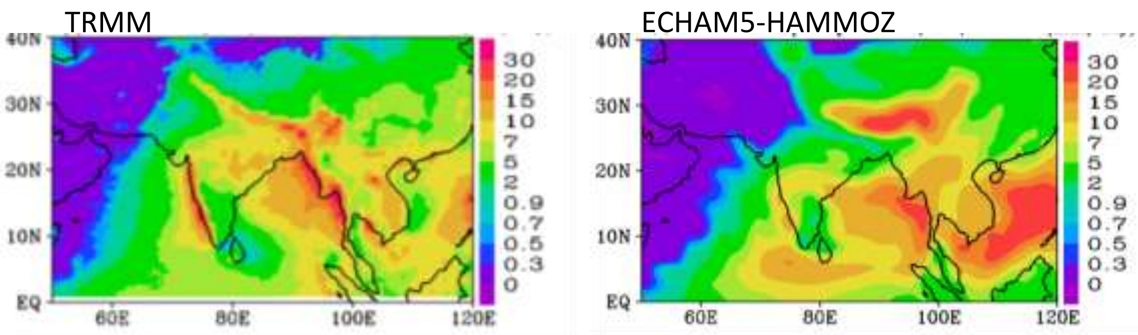
ECHAM5-HAMMOZ

General circulation model, ECHAM5

Tropospheric chemistry module, MOZART2

Aerosol module, HAM





Model ozone shows good agreement with the MLS satellite

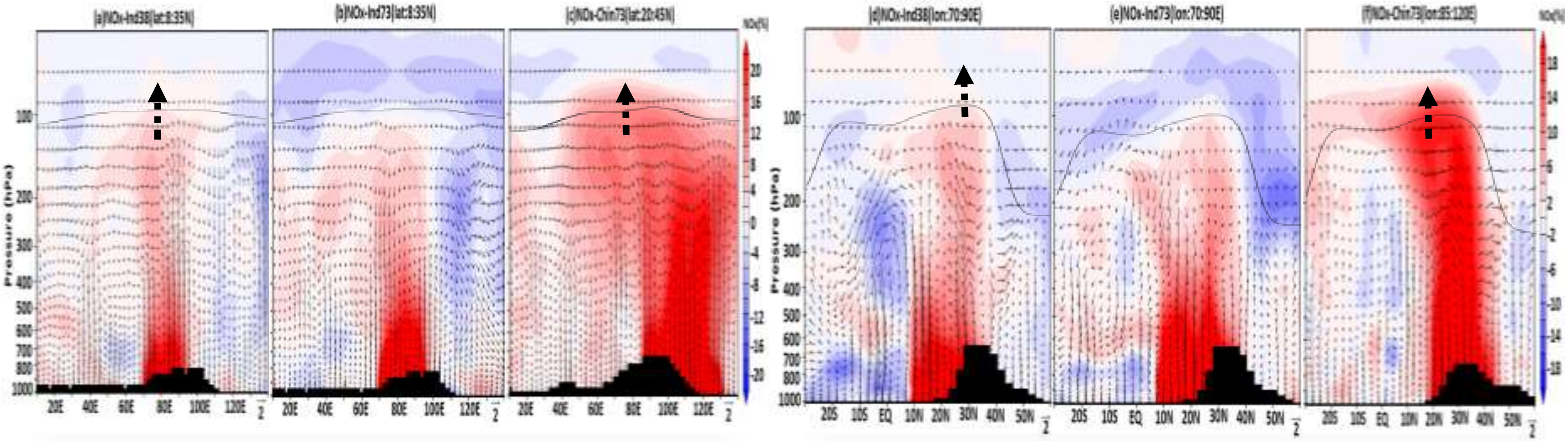
Precipitation pattern is reasonably well captured in the model

Sensitivity simulations carried out (for the years 2000 - 2010)

1. Control (CTRL)
2. Anthropogenic NO_X emissions increase over India by 38% (Ind38)
3. Anthropogenic NO_X emissions increase over China by 73% (Chin73)
4. Anthropogenic NO_X emissions increase over India by 73% (Ind73)

RESULTS

Results [1/6]



Longitude pressure cross-sections of percentage NO_x anomalies with respect to CTRL for JJAS

(a) Ind38

(b) Ind73

(c) Chin73

Latitude pressure cross-sections of percentage NO_x anomalies with respect to CTRL for JJAS

(d) Ind38

(e) Ind73

(f) Chin73

- Convective winds over the Bay of Bengal (80-90°E), southern flank of the Himalayas, south China sea seen in Ind38 and Chin73
- Enhanced NO_x emissions are lifted to the upper troposphere.
- Transport across the tropopause is not present in the Ind73 simulation, where it is inhibited by the wind anomalies that show a descending branch over central India.

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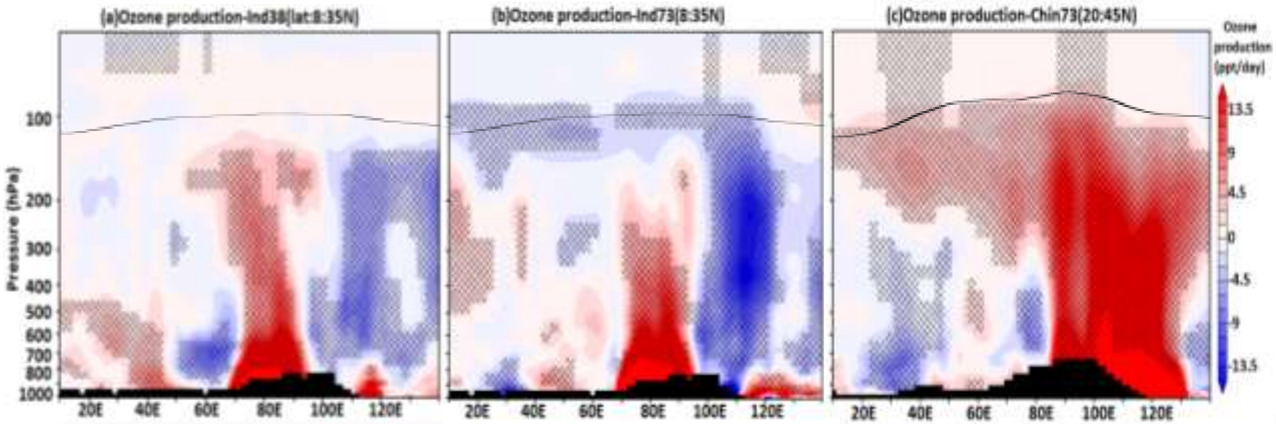
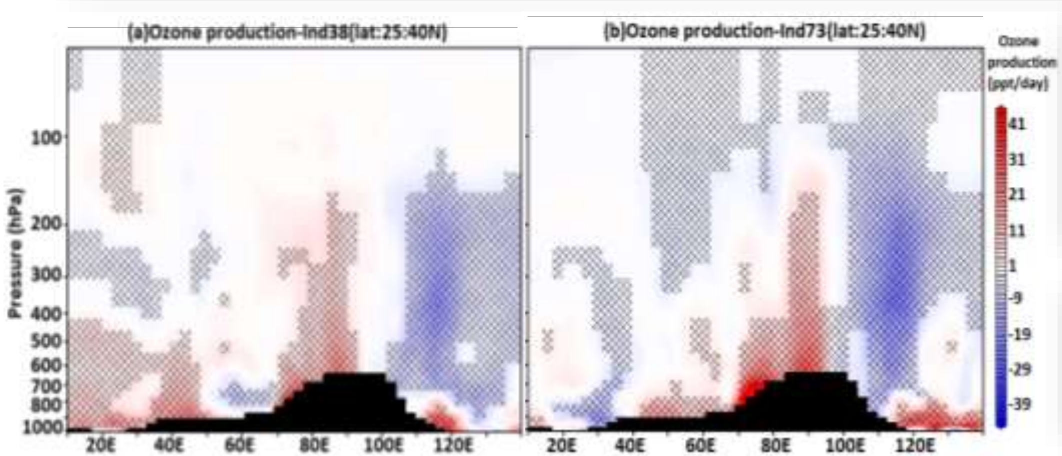
Results [2/6]



Longitude pressure cross-sections of ozone production with respect to CTRL for JJAS
(a) Ind38
(b) Ind73
(c) Chin73

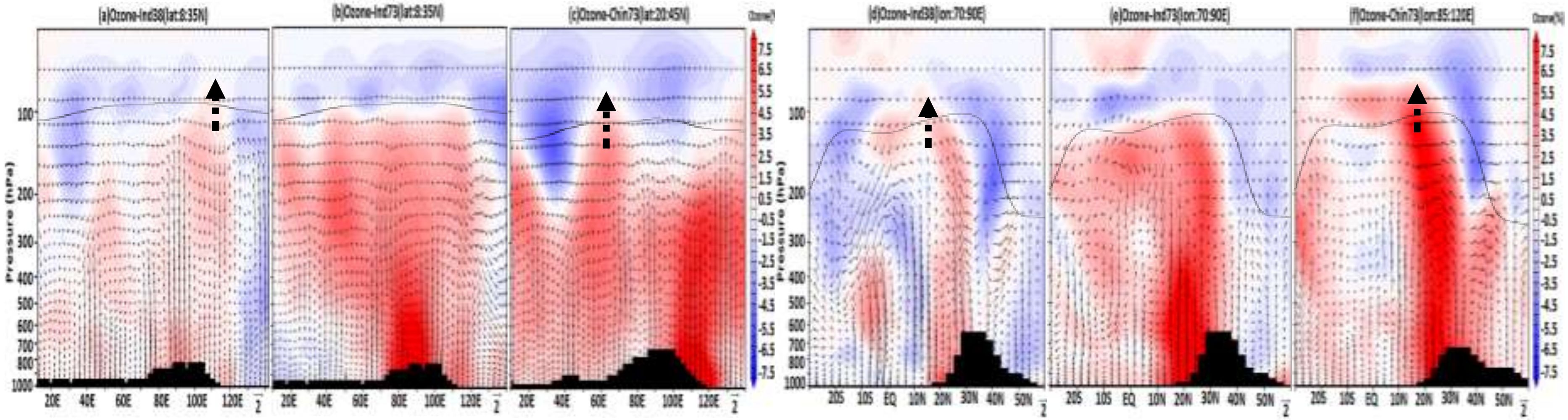
- Anomalous ozone production occurs in the lower troposphere
- At altitudes below 300 hPa, the ozone production ~15 ppt day^{-1}
- In the upper troposphere (300-150 hPa), additional net ozone production in Ind38 and Ind73 is ~3 to 7 ppt day^{-1}
- In Chin73 additional net ozone production ~3 to 13 ppt day^{-1}



- Higher anomalous ozone production in Ind73 in comparison to Ind38 over IGP
- Hatched lines show the significance at 95% confidence level

Longitude pressure cross-sections of ozone production with respect to CTRL for JJAS (averaged over IGP) (a) Ind38 (b) Ind73

Results [3/6]



Longitude pressure cross-sections of percentage ozone anomalies with respect to CTRL for JJAS

(a) Ind38

(b) Ind73

(c) Chin73

Latitude pressure cross-sections of percentage ozone anomalies with respect to CTRL for JJAS

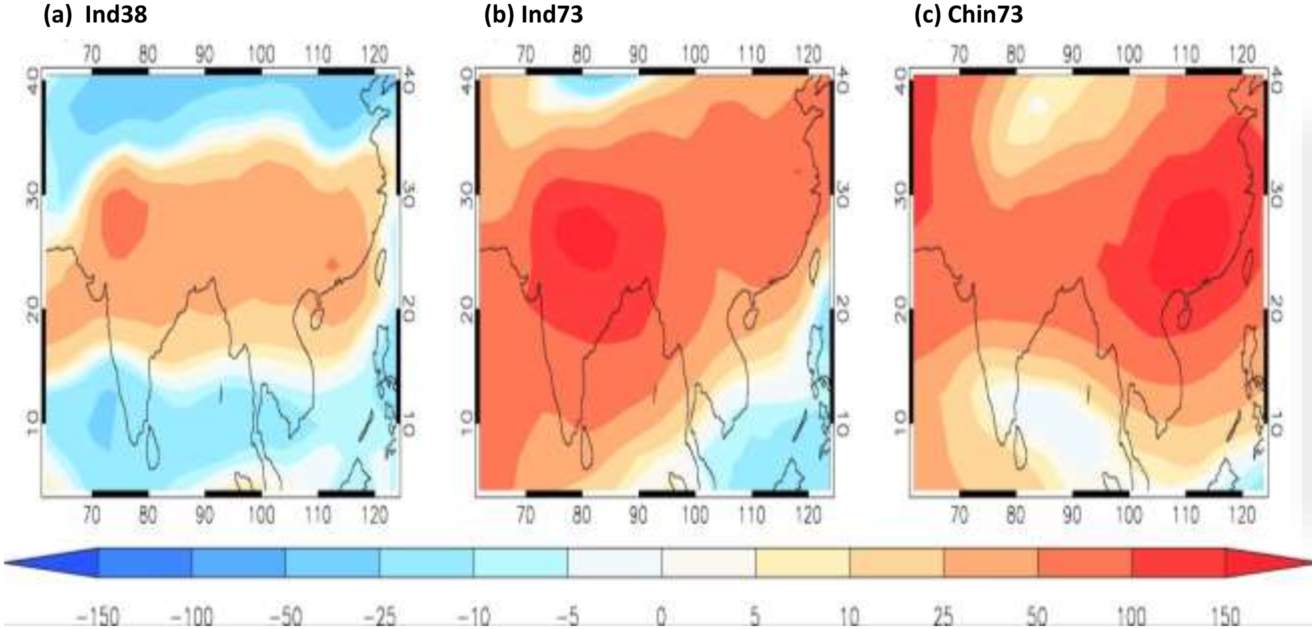
(d) Ind38

(e) Ind73

(f) Chin73

- Elevated amounts of ozone anomalies in response to enhanced anthropogenic NO_x emissions.
- Convection over the BOB, the southern slopes of the Himalayas and the South China Sea lifts the enhanced ozone anomalies from India and China into the upper troposphere, further across the tropopause and into the lower stratosphere.
- In the Ind73 simulation, the descending branch of circulation over central India suppresses the vertical transport of ozone anomalies across the tropopause

Results [4/6]



Latitude-longitude distribution changes in ozone radiative forcing (mW m^{-2}) with respect to CTRL for JJAS

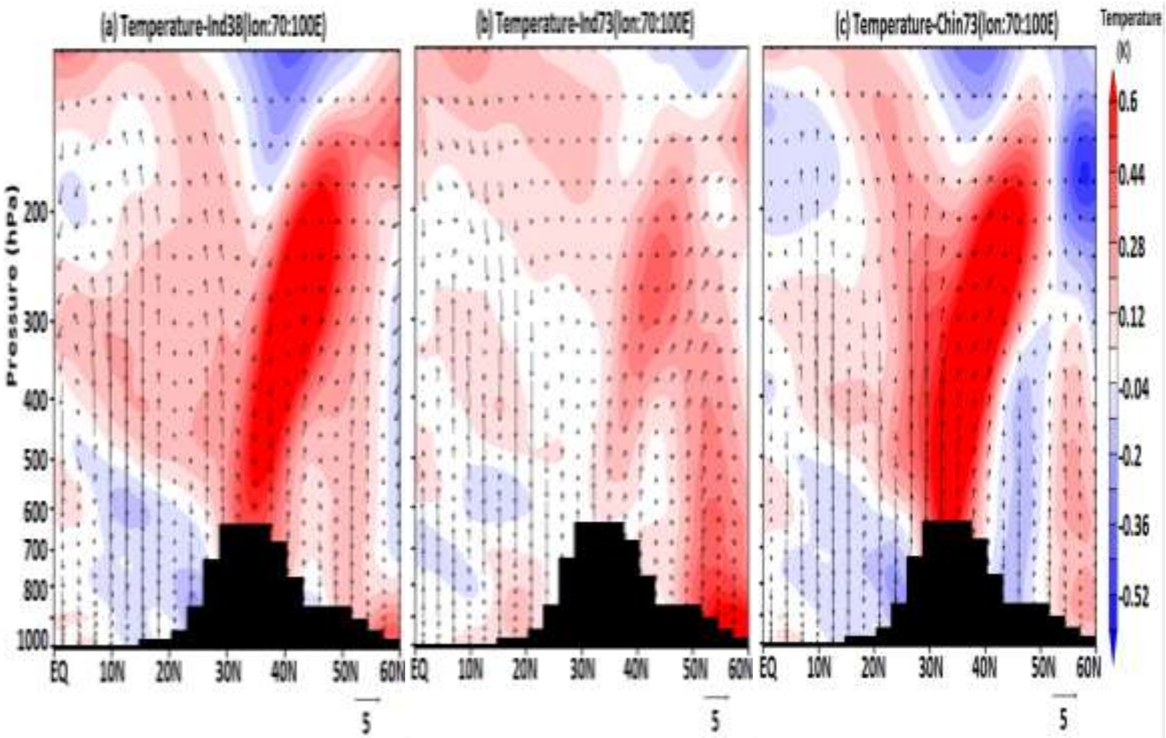
(a) Ind38

(b) Ind73

(c) Chin73

- Average radiative forcing in the monsoon anticyclone (15ºN-40ºN, 60-120ºE) in the Ind38, Ind73 and Chin73 simulations is estimated to be 16.3, 69.9, 78.5 mW m^{-2} respectively
- The overall increase in tropospheric ozone has a warming effect on climate

Results [5/6]



Latitude pressure cross-sections of temperature anomalies over TP with respect to CTRL for JJAS

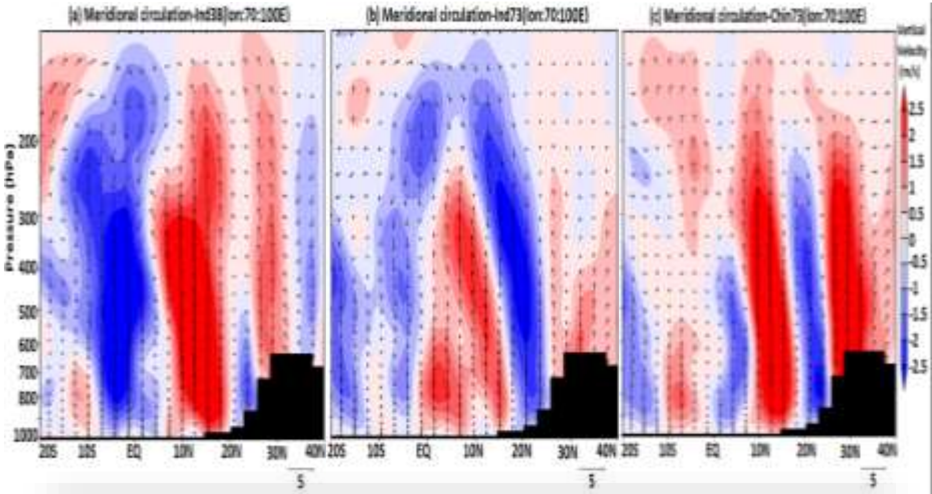
(a) Ind38

(b) Ind73

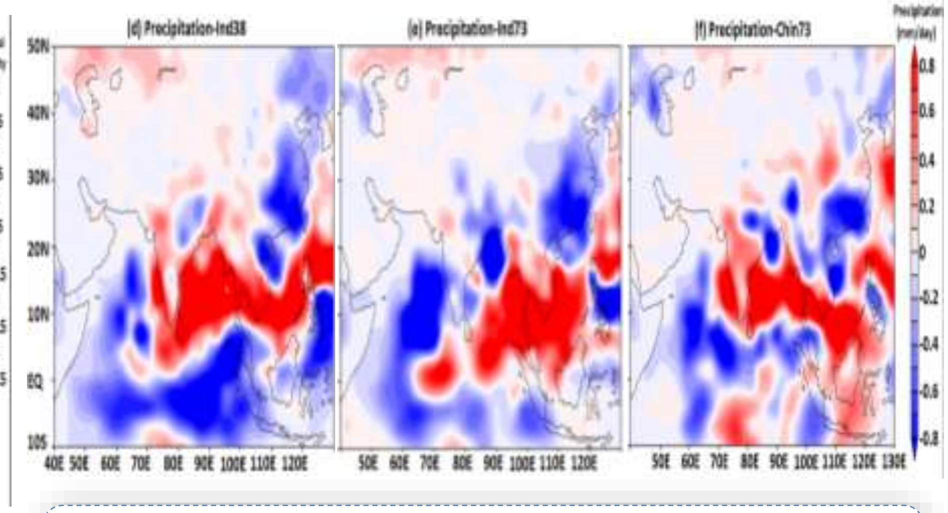
(c) Chin73

- Upper tropospheric warming over the TP is one of the key factors responsible for the ASM circulation
- Ind38 and Chin73 show anomalous warming in the upper troposphere over the TP
- It is subdued in the Ind73

Results [6/6]



Difference in the meridional circulation due to enhanced NO_X emissions for JJAS obtained from
(a) Ind38
(b) Ind73
(c) Chin73



Precipitation anomalies (mm/day) for JJAS obtained from
(d) Ind38
(e) Ind73
(f) Chin73

- Ind38 and Chin 73 show a strengthening of the monsoon Hadley circulation ; a strong ascending branch around 10°-20°N
- Tilted descending branch of Hadley cell is seen over 20°N in the Ind73
- Positive precipitation anomalies over the Indian region in Ind38 and Chin73. Reduced precipitation anomalies in the Ind73
- Upper tropospheric subsidence in Ind73 might have contributed to the weak precipitation anomalies over the North India
- Chin73 shows ascending motion near 12°N rising up to 110 hPa, which leads to positive precipitation anomalies over the Indian peninsula

Conclusion

- Increased Indian (Ind38) and Chinese (Chin73) NO_x emissions enhance precipitation over India via a strengthening of the monsoon Hadley circulation
- A further increase of NO_x emissions over India (Ind73) leads to high amounts of ozone in the lower troposphere over the Indo Gangetic plain and Tibetan Plateau
- Related ozone heating induces weakening of monsoon Hadley circulation in Ind73 simulation, thereby resulting in negative precipitation anomalies

Thank You!