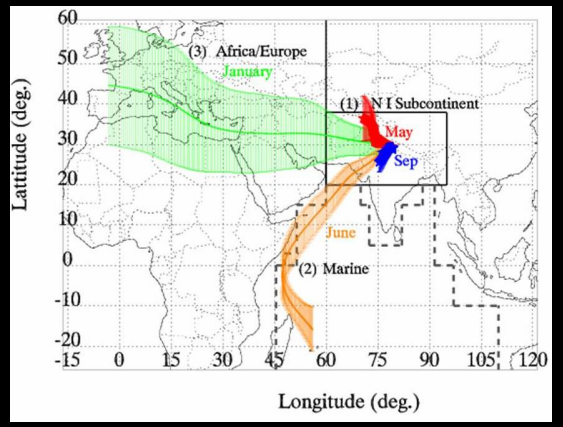
Variability in the tropospheric ozone in Asian Summer Monsoon region: Ozonesonde observations (2011-2023) from ARIES, Nainital

Manish Naja

Aryabhatta Research Institute of Observational Sciences, Nainital

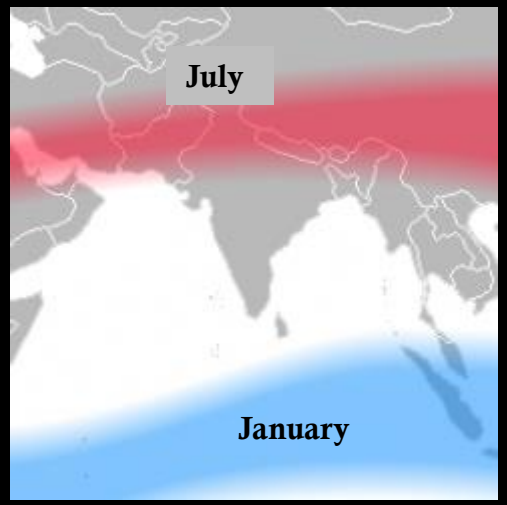
* Mukesh Kumar * Prajjwal Rawat * Vikrant Tomar *
* Piyush Bhardwaj * Mahendar Rajwar * Rajesh Kumar *



STIPMEX, IITM Pune [2-7 June 2024]

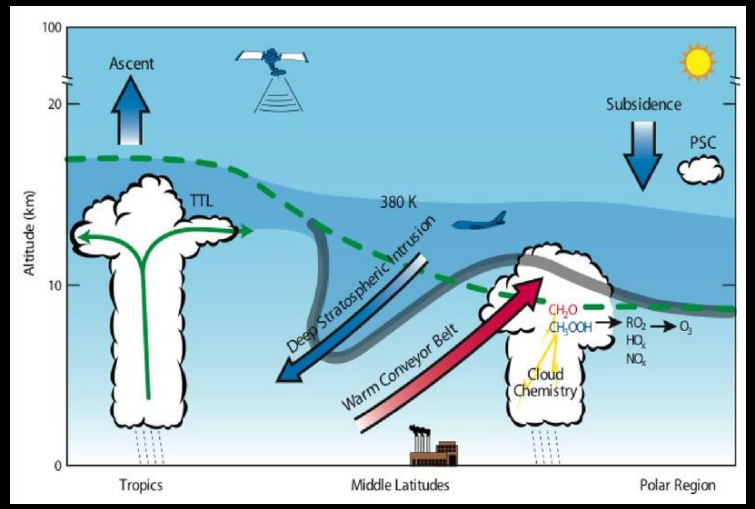
Importance of the Himalayan region

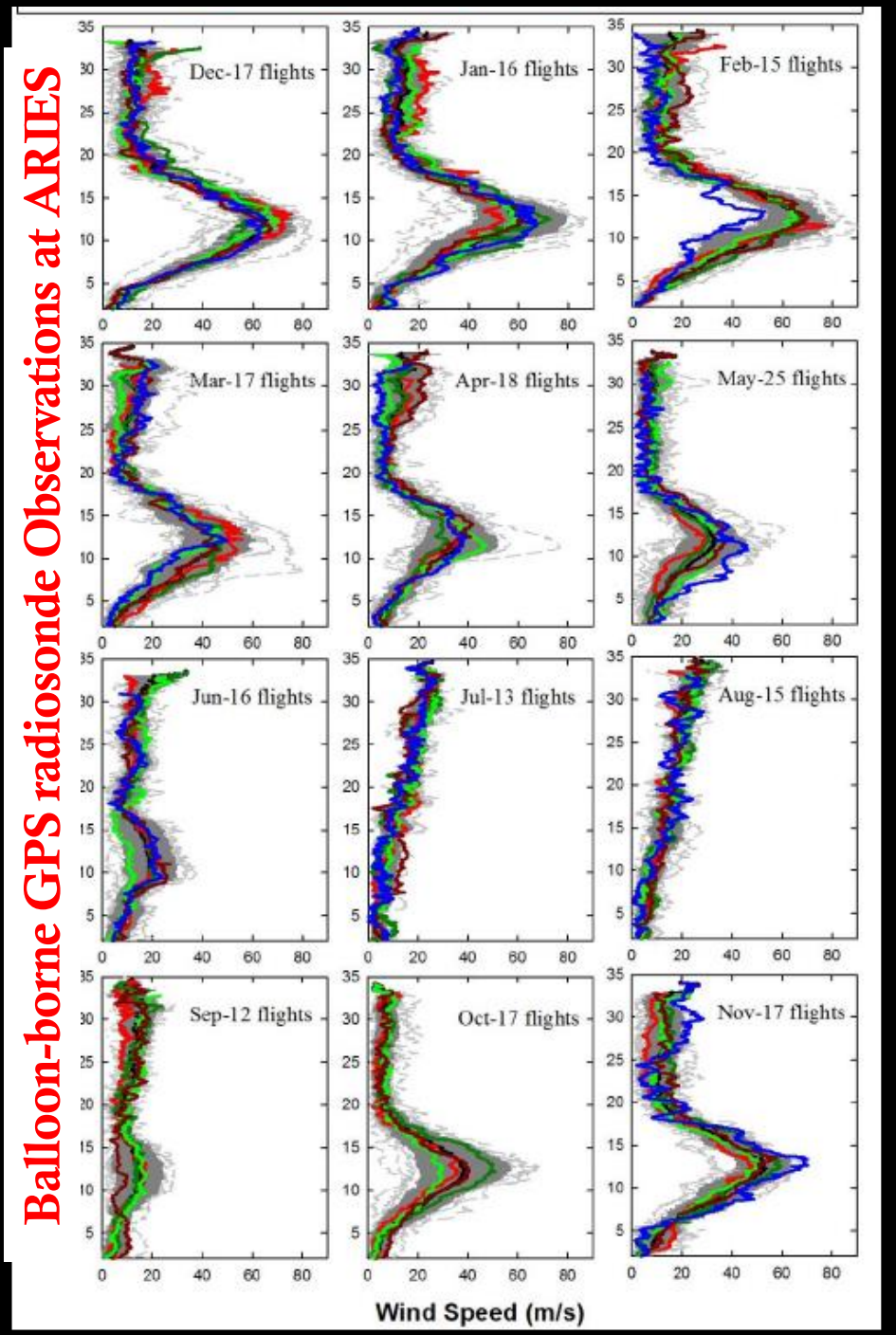
- Nainital, being close to the foothills of the Himalayas, happens to be north of the monsoon trough and is under the low level southeasterly winds.
- ITCZ also reaches to this region.



- This region is also dominated by western disturbances during winter and spring.
- This is also region of deep convection and ASM anticyclone, leading to efficient transport of air-mass and redistributing to wider regions at higher height.

- This region is also in the proximity of the Tropopause breaks latitude.



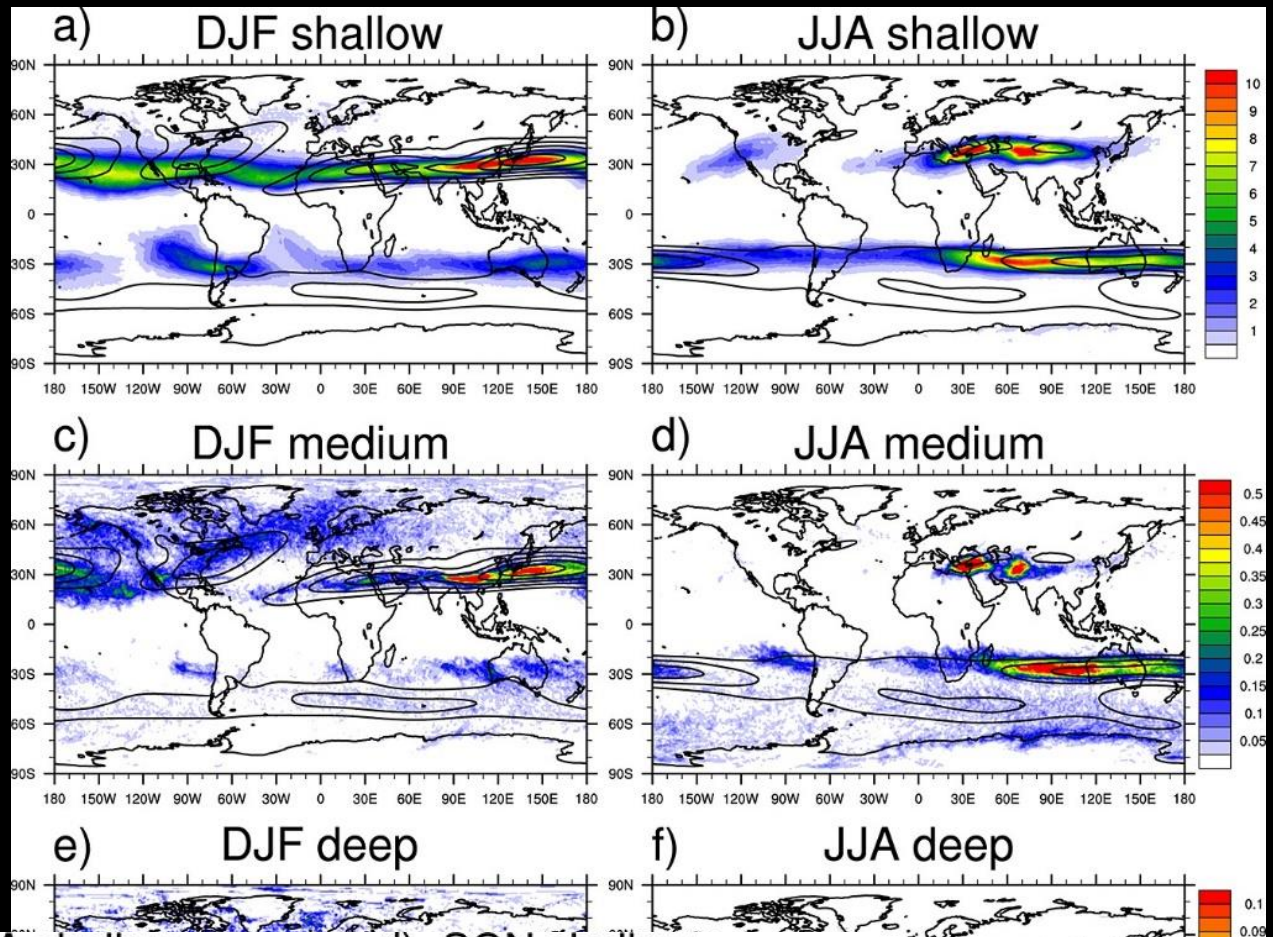


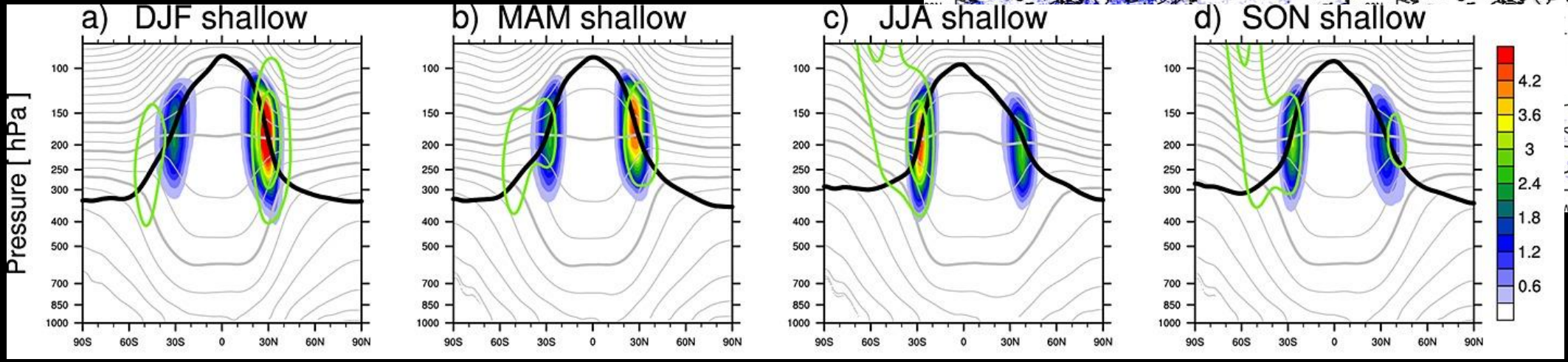
ERA-Interim reanalysis data from 1979 to 2012

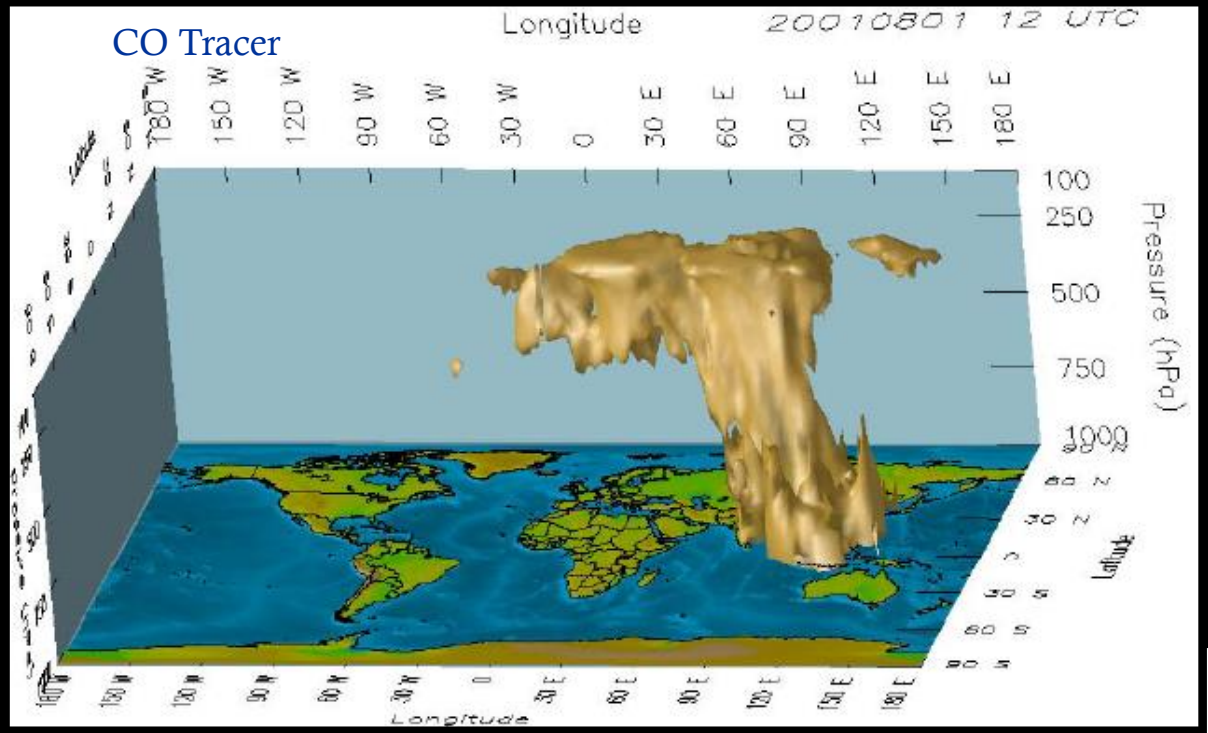
Shallow	$50\text{hPa} \leq \Delta p < 200\text{hPa}$
Medium	$200\text{hPa} \leq \Delta p < 350\text{hPa}$
Deep	$\Delta p \geq 350\text{hPa}$

Most shallow tropopause folds occurs along the subtropical jet stream

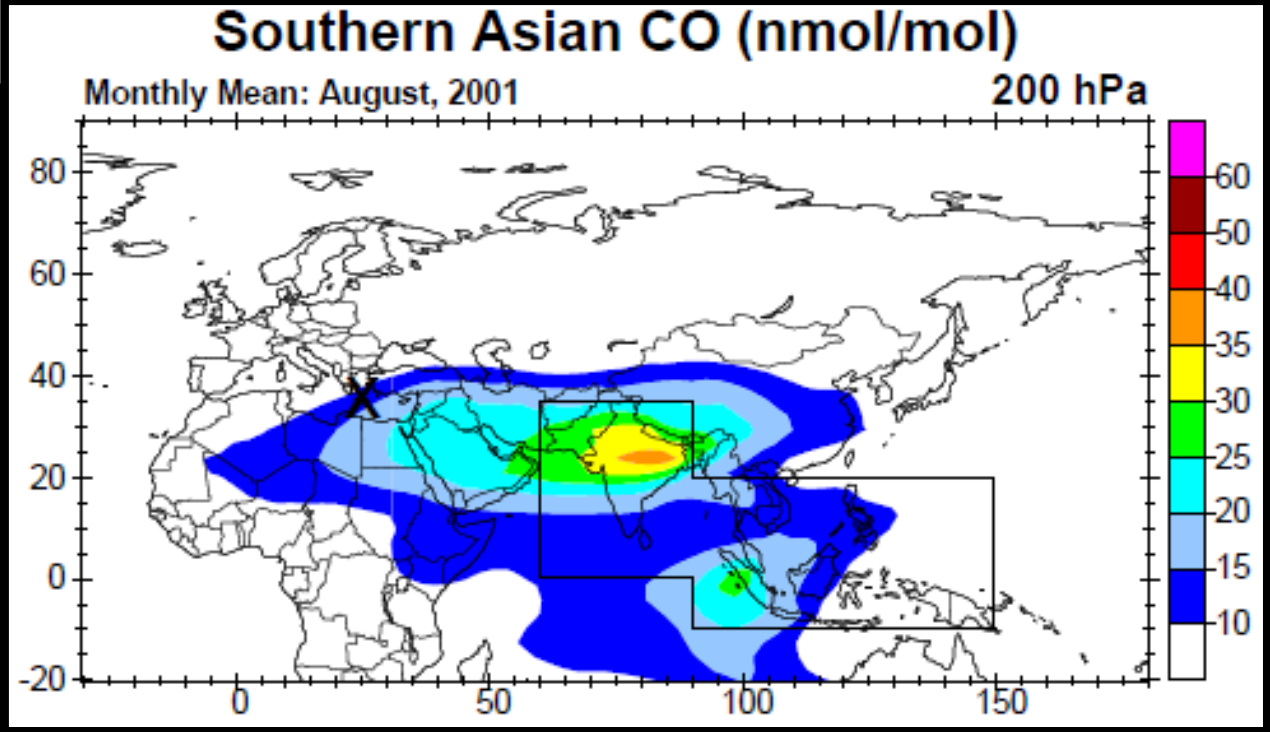
(Škerlak et al., 2015)







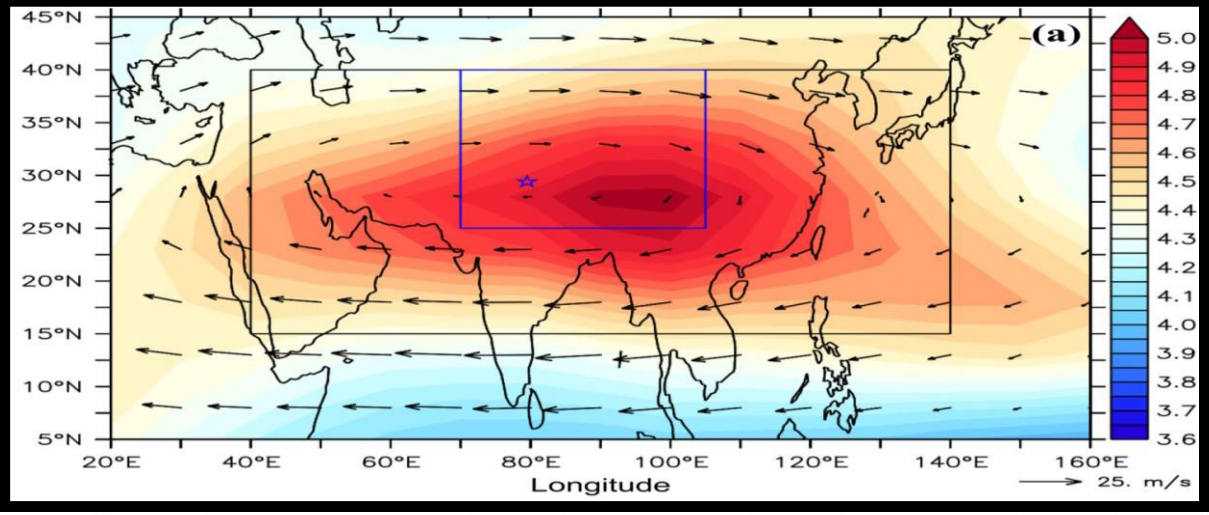
Model simulation showed uplifting and accumulation of pollutants at higher heights and their redistribution in wider region.

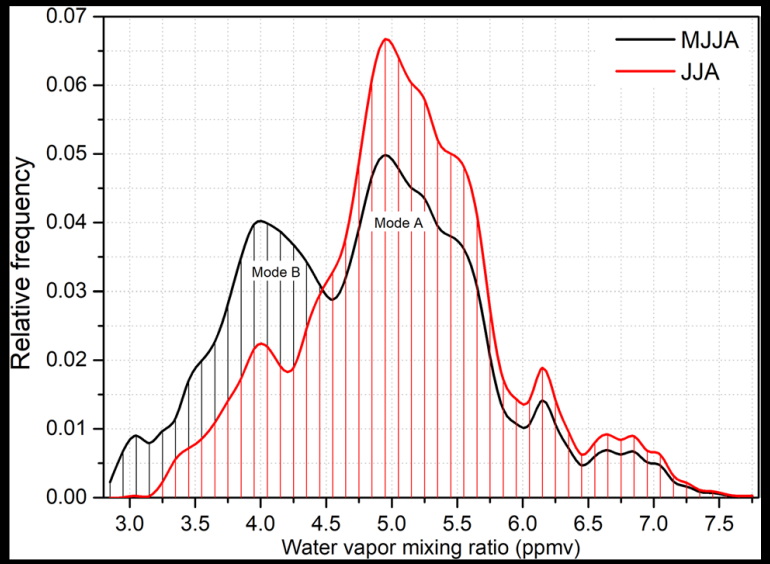


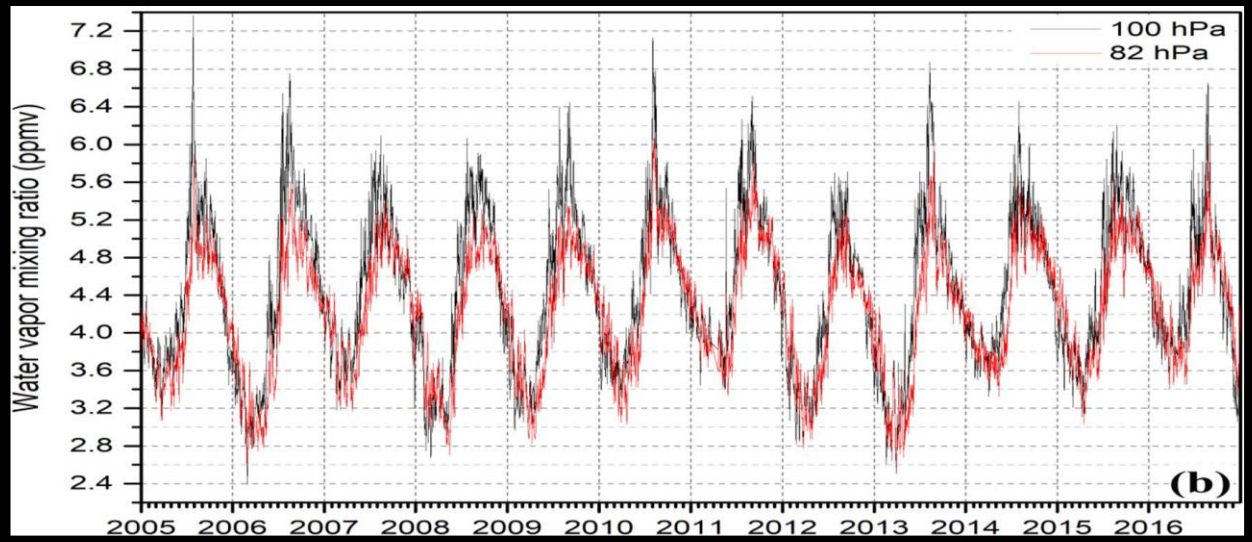
Lawrence et al., 2003

- Debate on the role of monsoon convective intensities on the UT/LS water vapor accumulations.
- Water vapor show a clear enhancement in UT/LS region, with two modes during MJJA.
- GLORIA observations (July) shows NH_3 layer at around 10-15 km.

May–August (2005-2016) climatology of 100 hPa MLS water vapor mixing





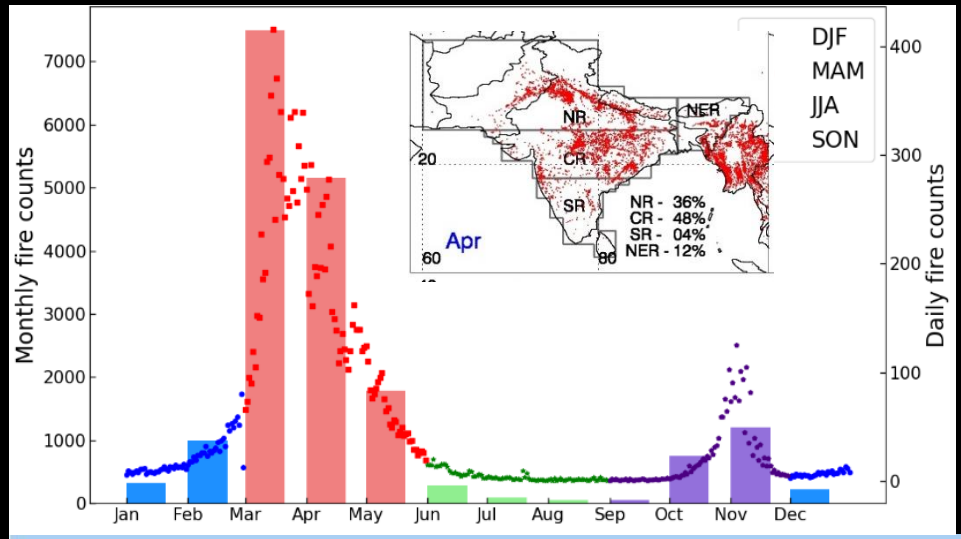


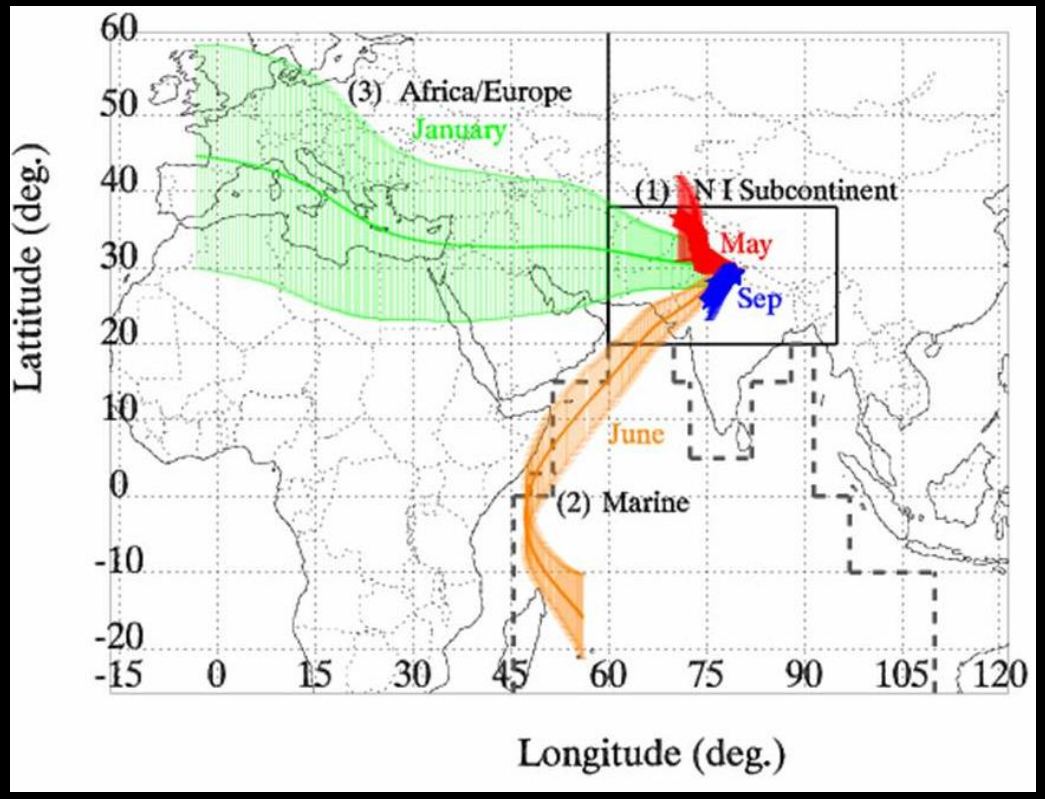
Singh et al., 2021

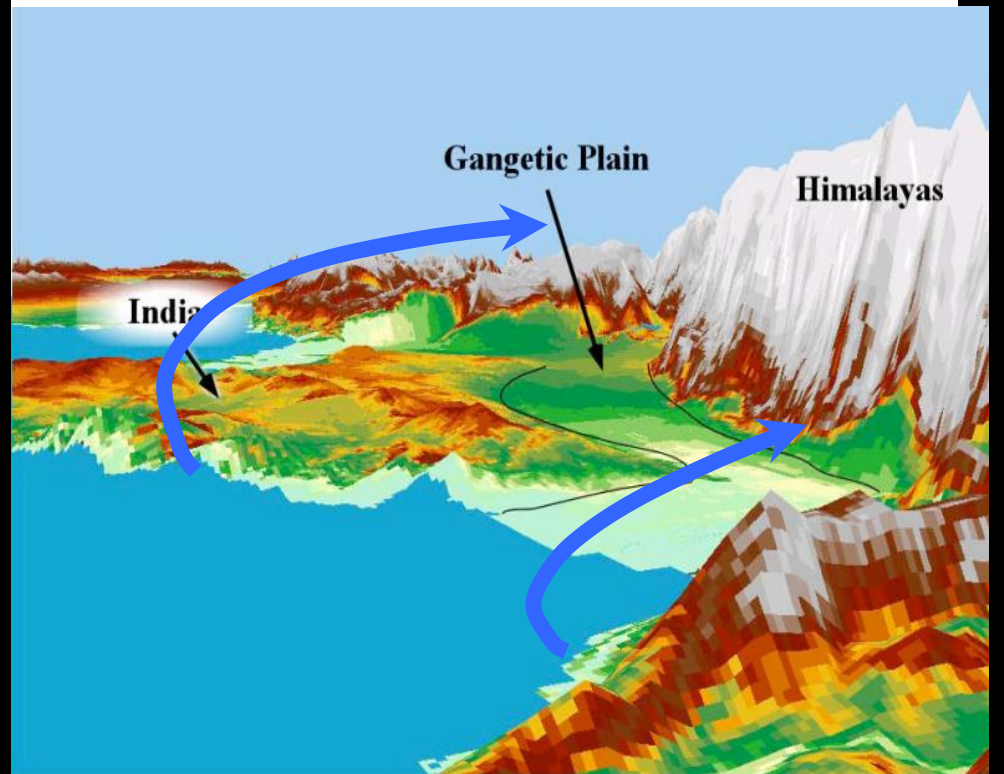
Factors controlling variabilities over the central Himalayas

- Regional Emissions
- Biomass Burning and Forest Fires
- Long-range transport
- Dynamics/Convection
- Background levels

MODIS Fire

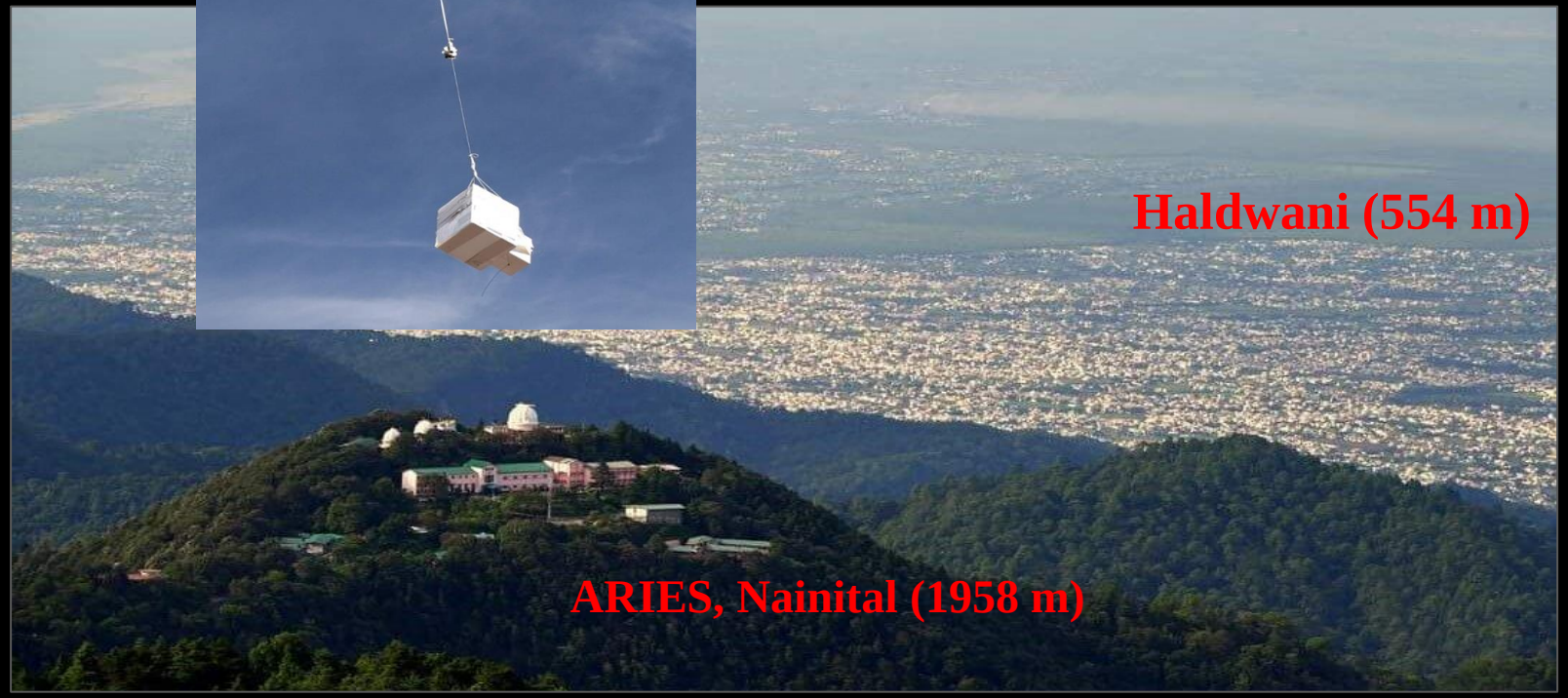




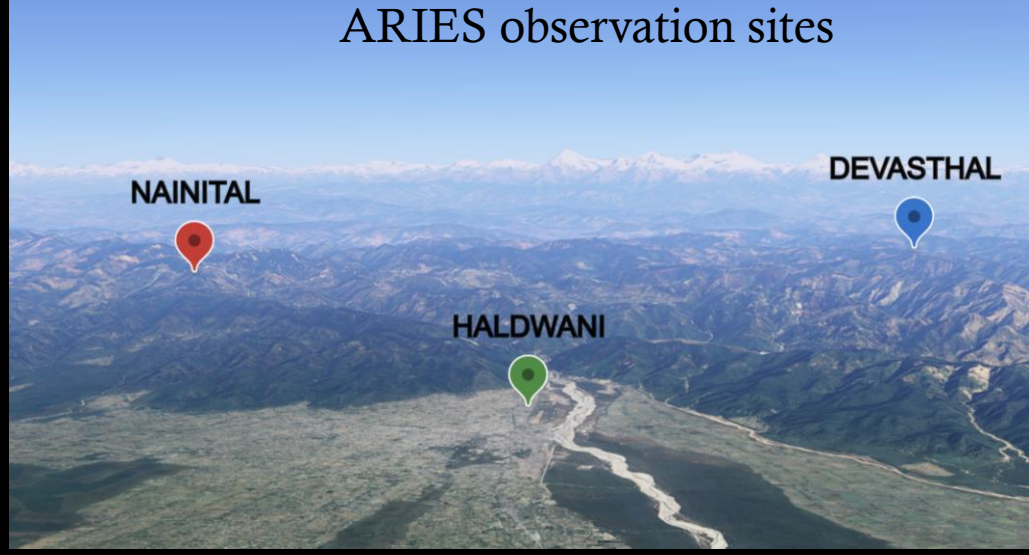


Ozone soundings and GPS Radiosonde since late 2010

ECC Ozonesonde
GPS Radiosonde

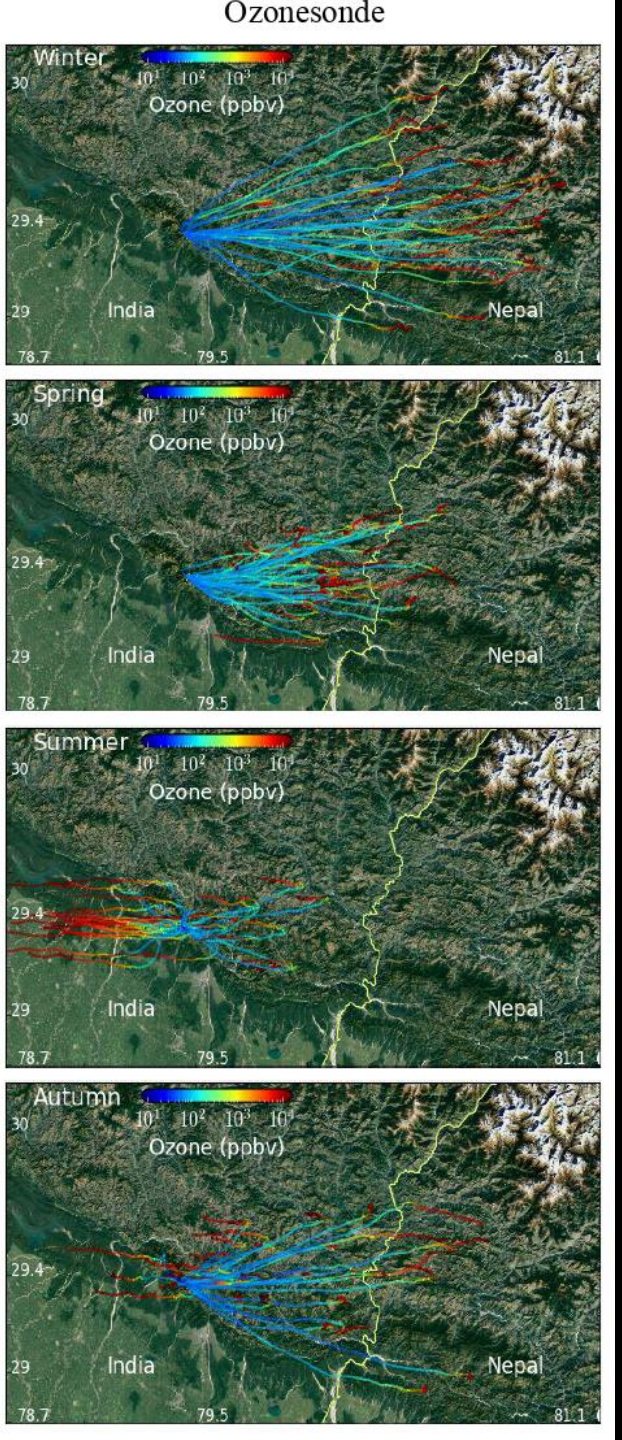


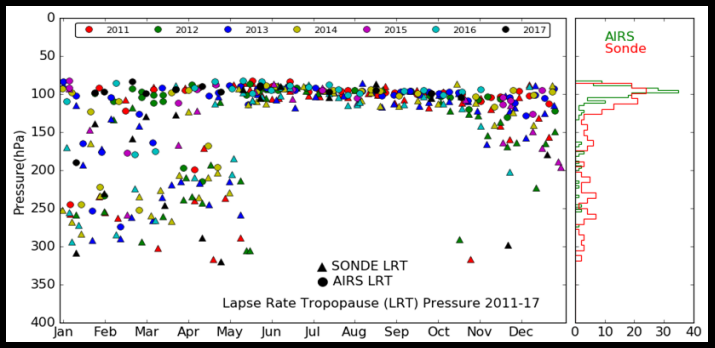
ARIES observation sites



Trace gases and Aerosols Surface observations at Mountain and IGP sites.

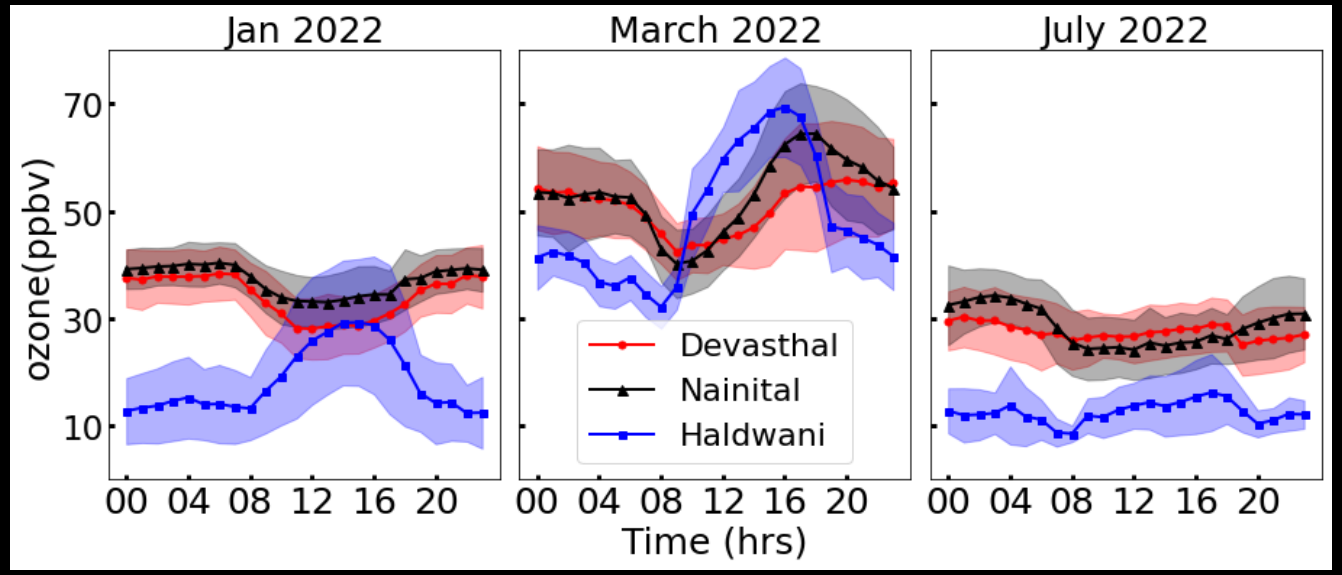
Balloon Trajectory





Tropopause Variations

Surface ozone behaviour at Nainital and Devasthal gives a clear indication of pristine region, except in spring.



Monthly Variations at Mountain Site

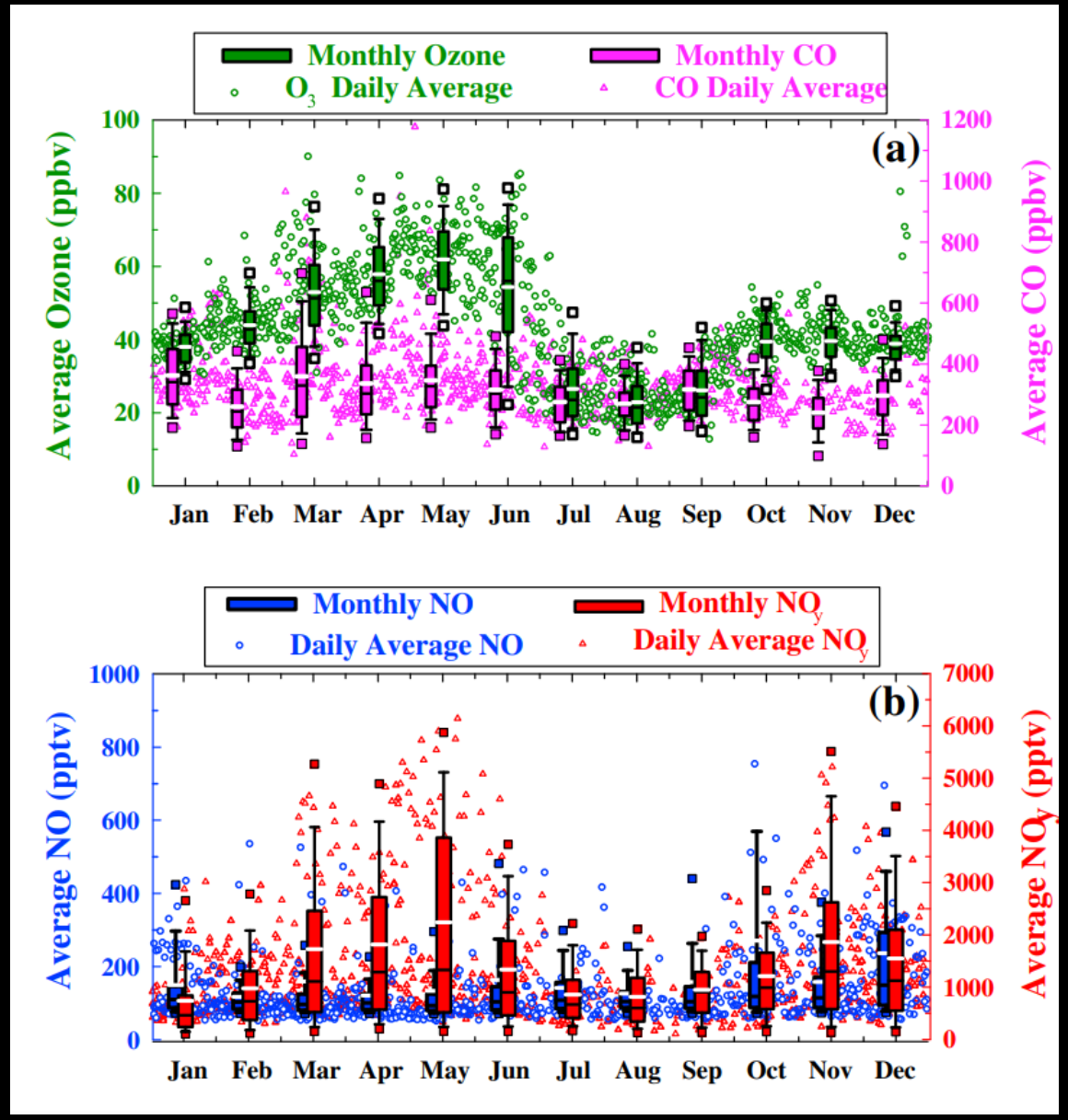
Ozone

CO

NO

NOy

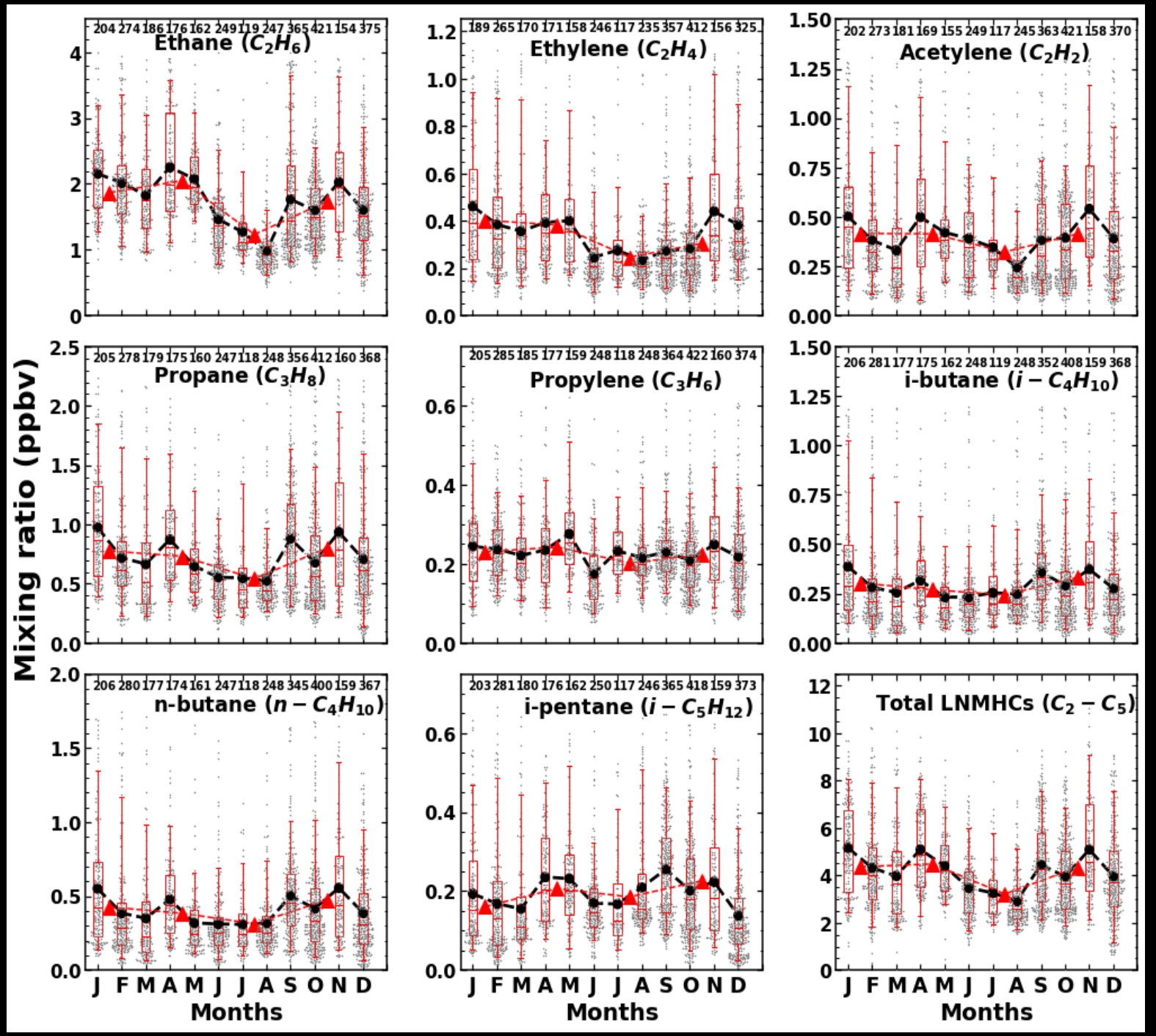
Lowest levels in Summer-Monsoon



(Sarangi, Naja et al., 2017)

NMHCs Monthly variations at Mountain site

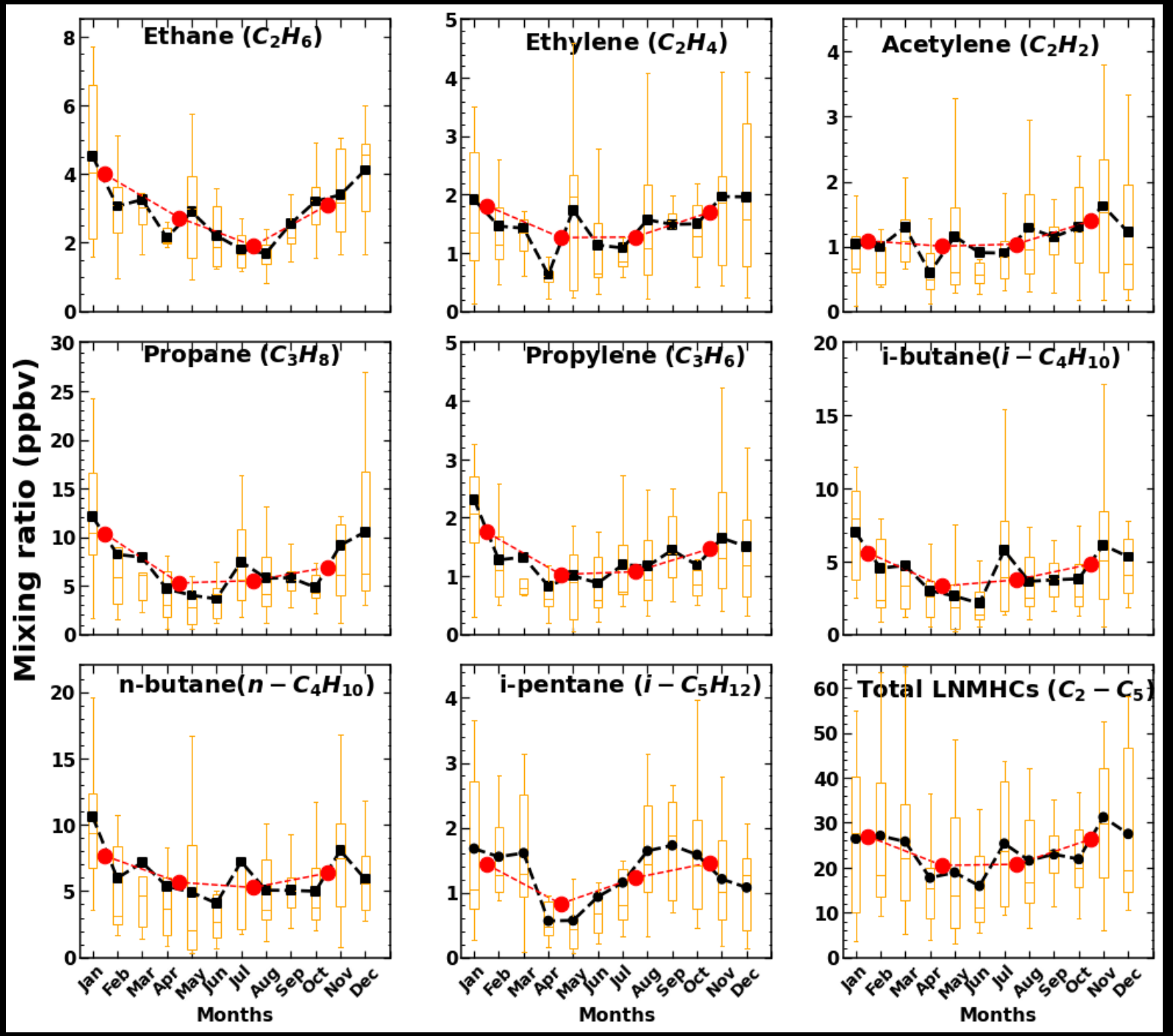
Not very high or Lowest levels in Summer-Monsoon



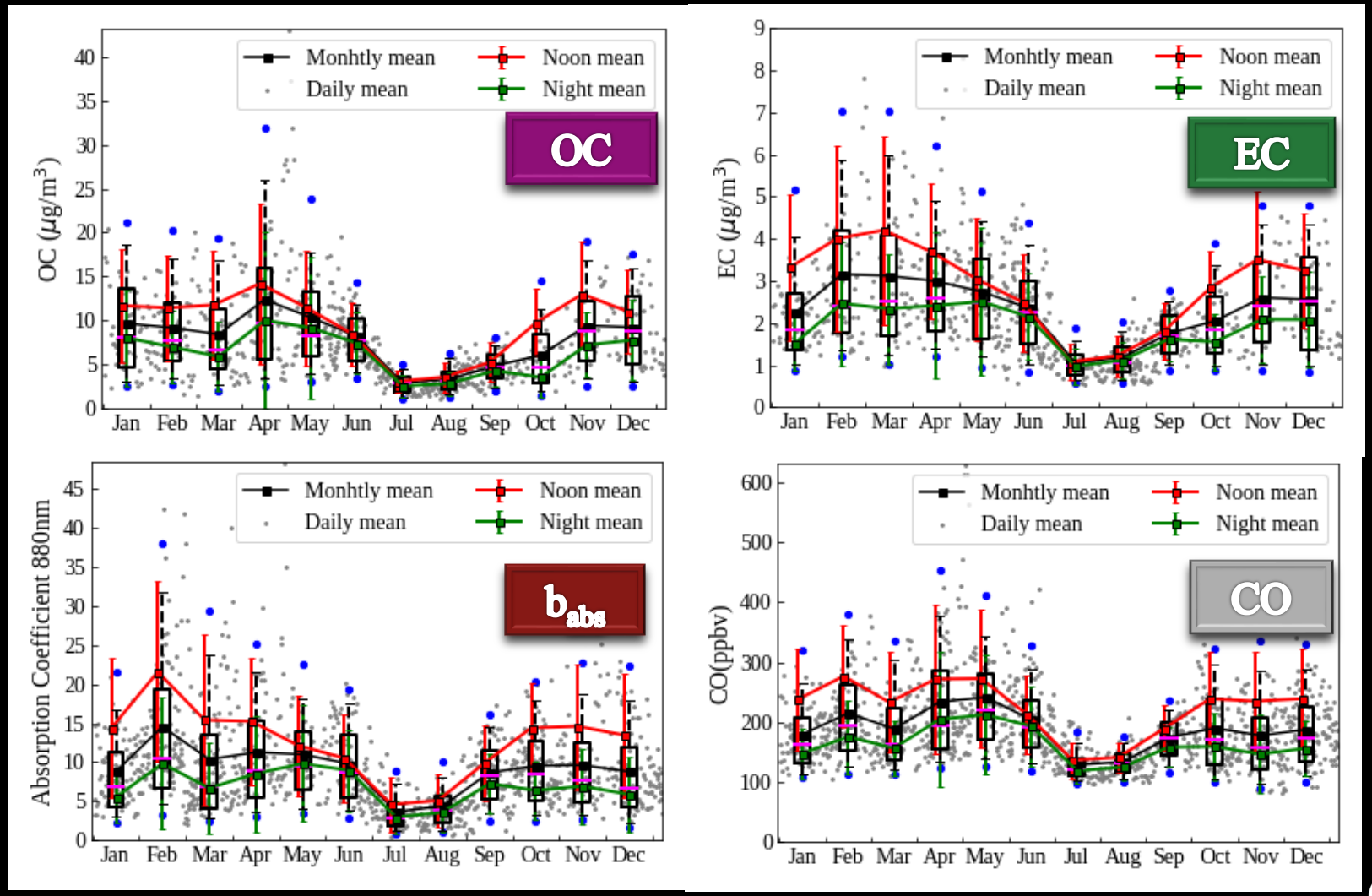
(Rajwar, Naja et al., 2024)

Monthly variations at IGP site

Not very high or Lowest levels in Summer-Monsoon



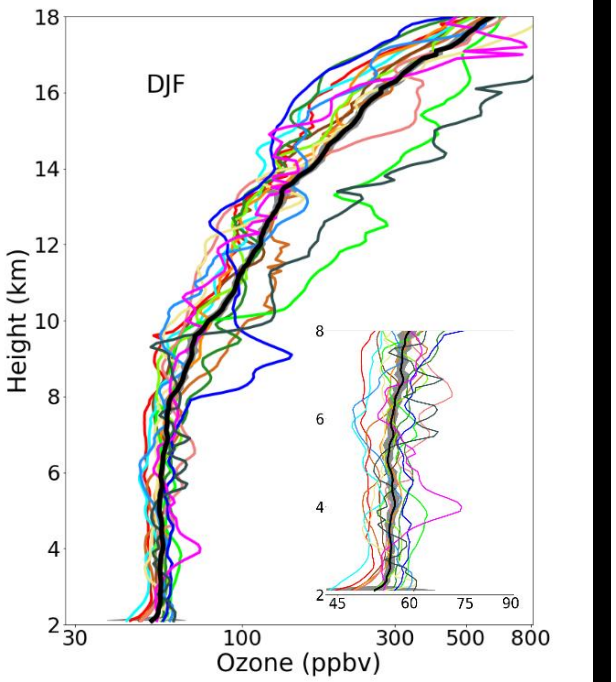
(Rajwar, Naja et al., 2024)



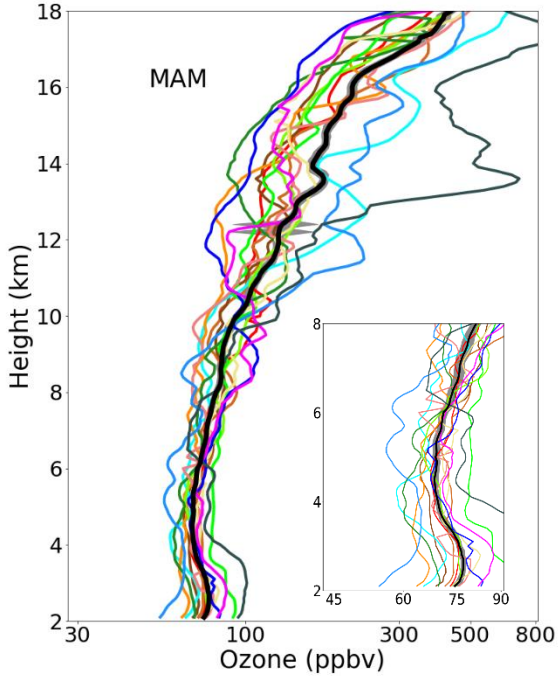
Seasonal variations at mountain site

(Srivastava, Naja et al., 2022)

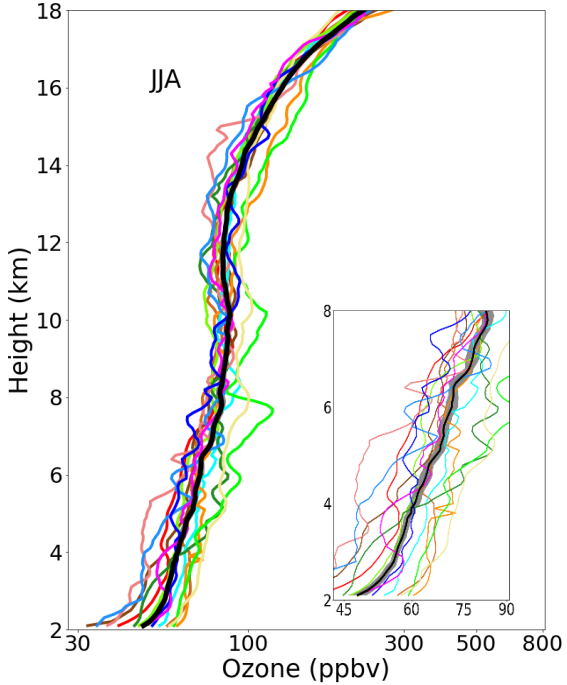
Winter (DJF)



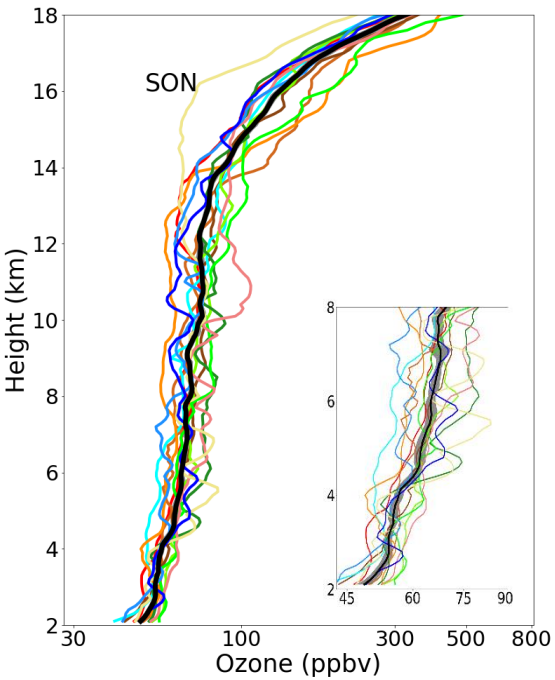
Spring (MAM)

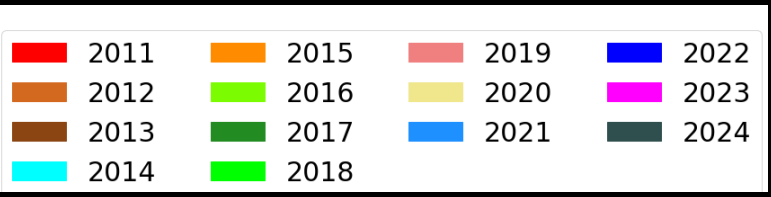


Summer-monsoon (JJA)



Autumn (SON)

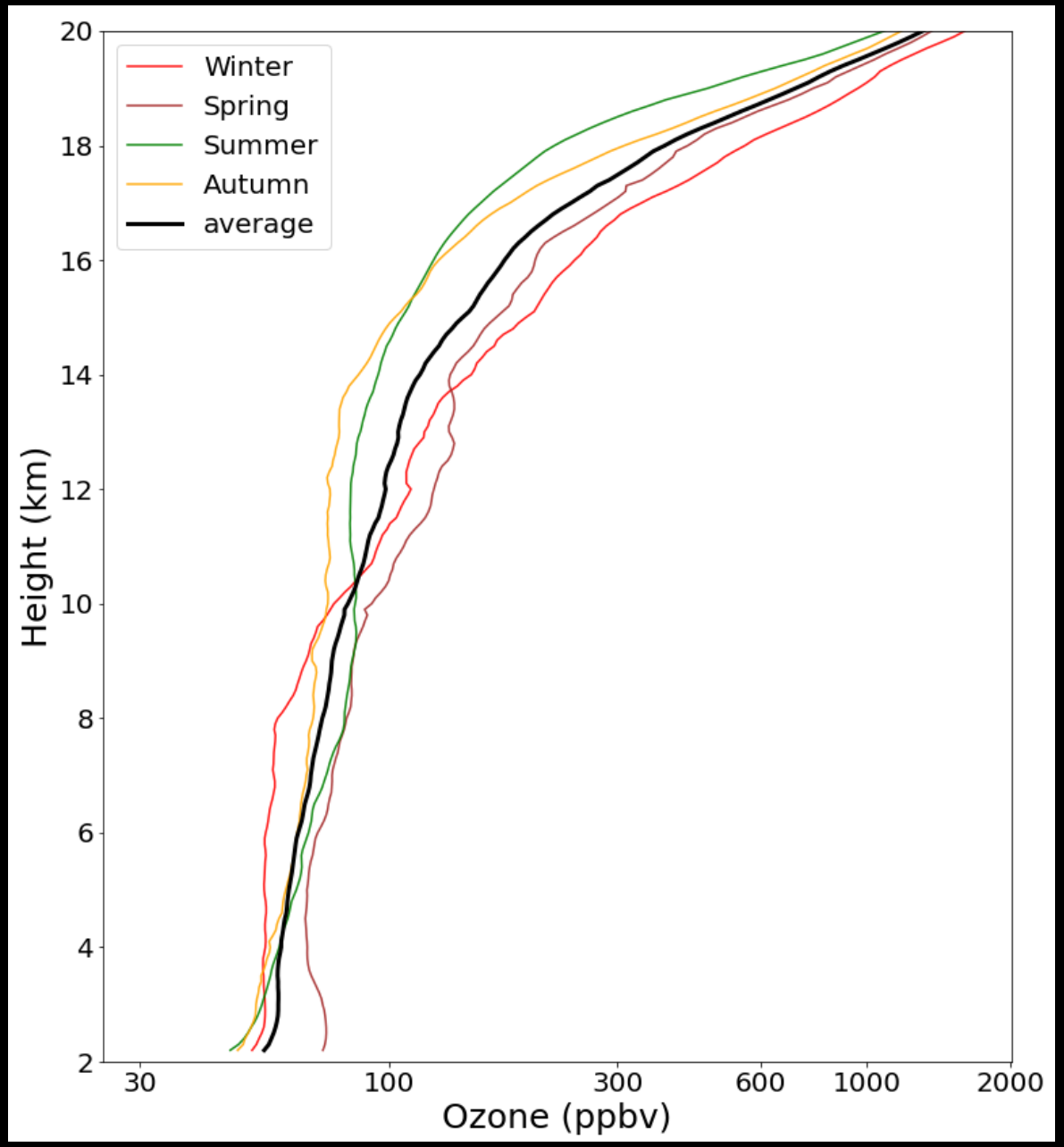




- Annual average ozone profiles (2011-2023) during four seasons.
- Winter and Spring showed greater variabilities in middle to upper troposphere.
- The lower tropospheric ozone is maximum in spring

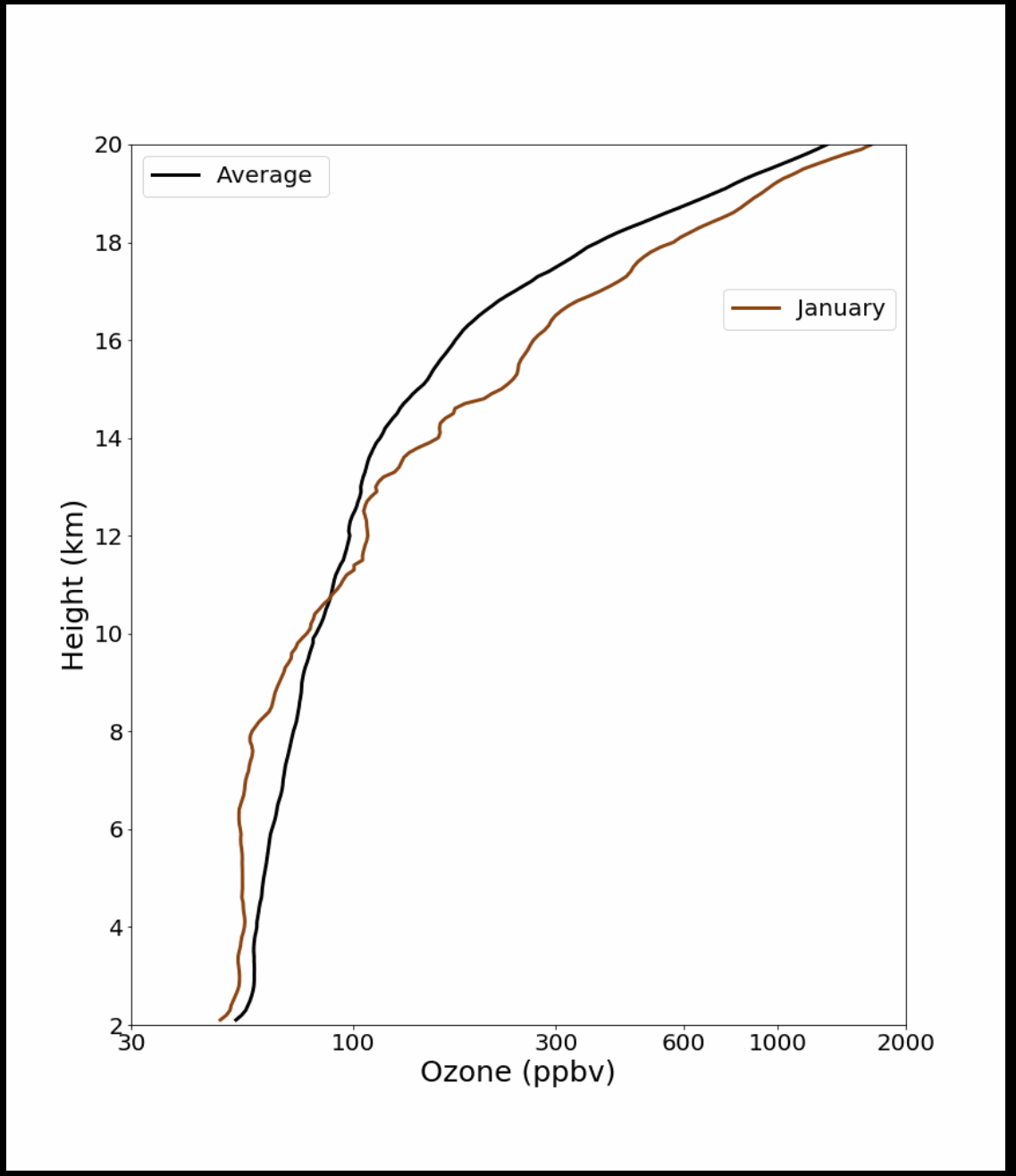
Average ozone profile (2011-2023) over Nainital

- Winter and spring, higher ozone in mid to upper troposphere and lower in summer and autumn.
- Lower ozone in summer and autumn could be due to convection – injection of higher water vapor and NOx that lead to ozone loss or titration.
- Winter and spring higher ozone are understood to be due to downward transport.



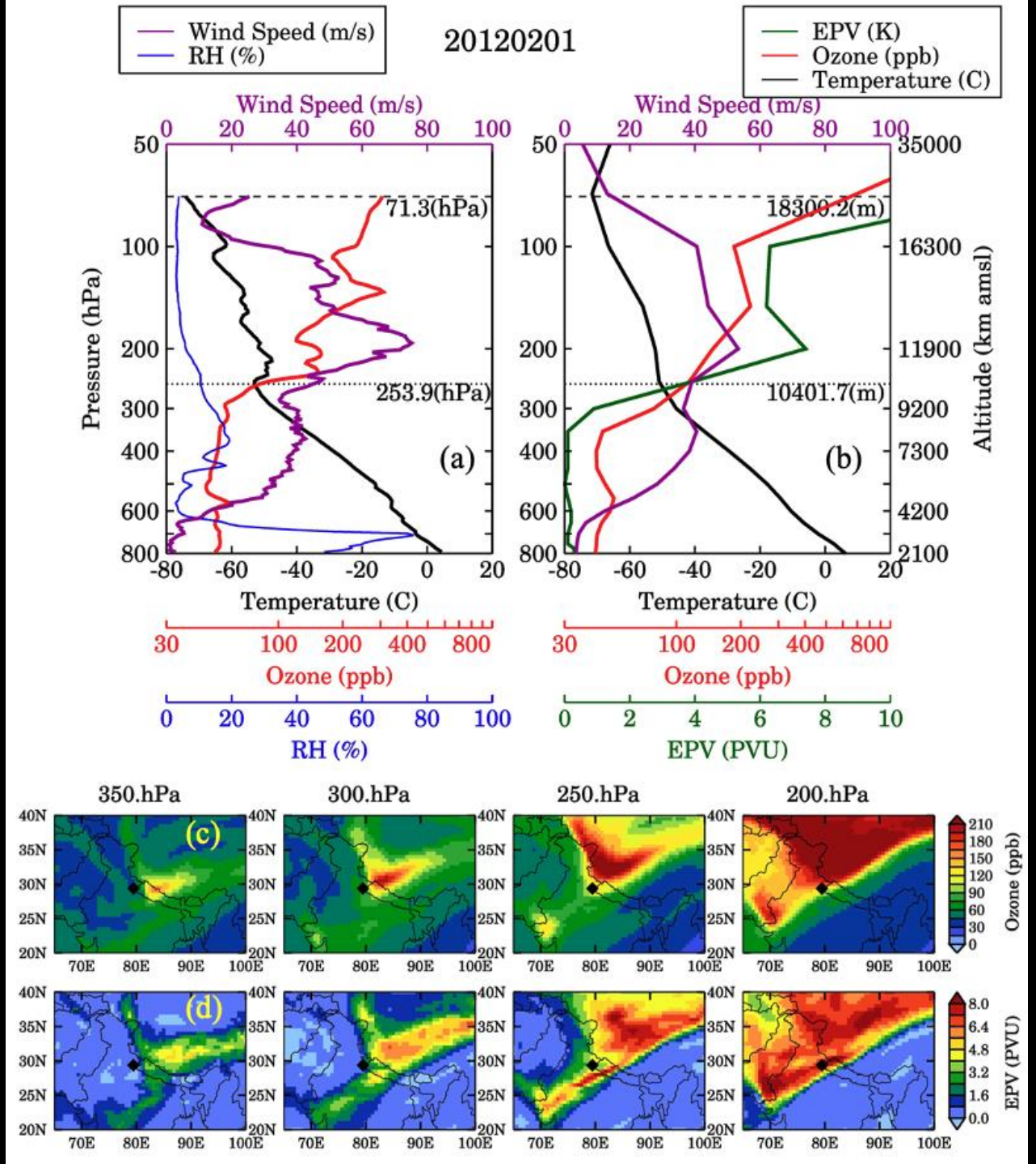
Assessment of downward ozone transport (Winter – Spring)

- Events with higher ozone variabilities (more than 3 sigma) in ozone in the 2 km altitude bands.
- Greater numbers of cases are seen from **December to April**



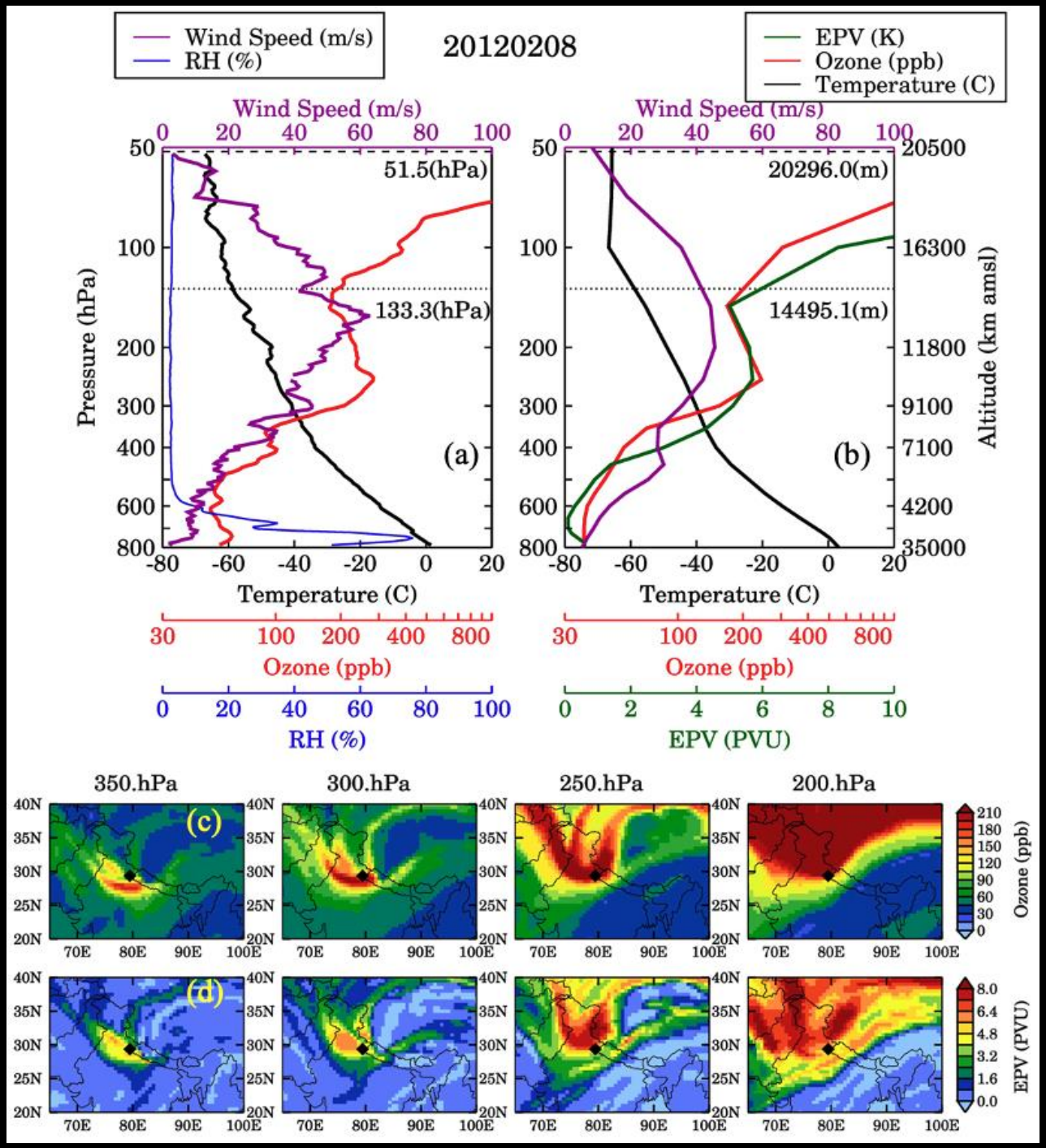
An event of shallow tropopause fold

Enhancement in ozone up to 250 hPa

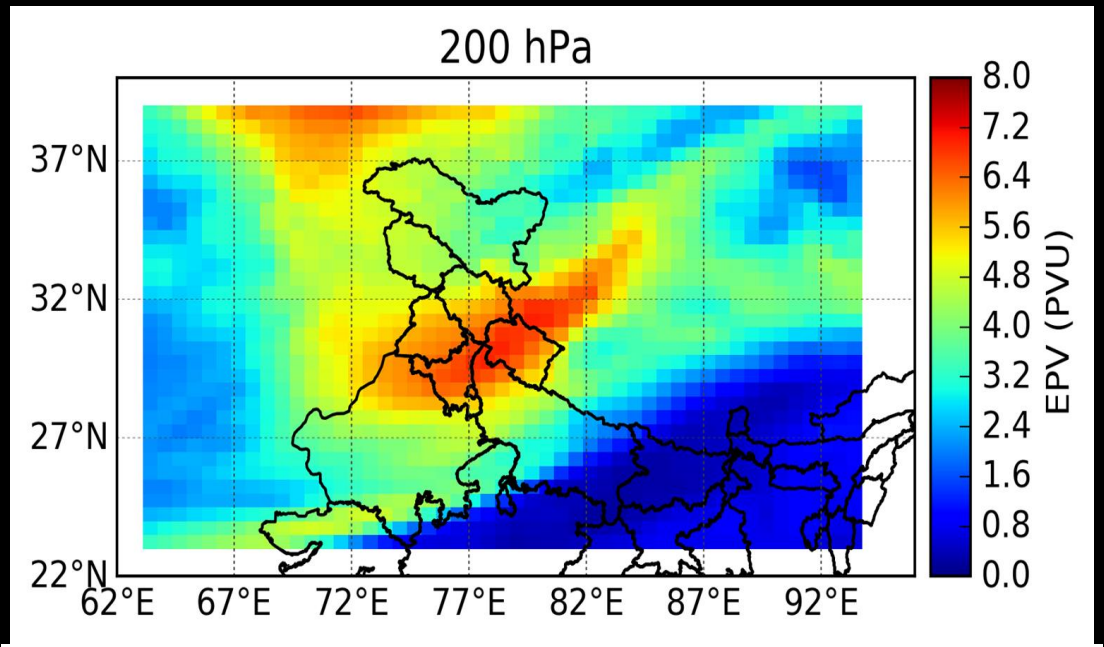


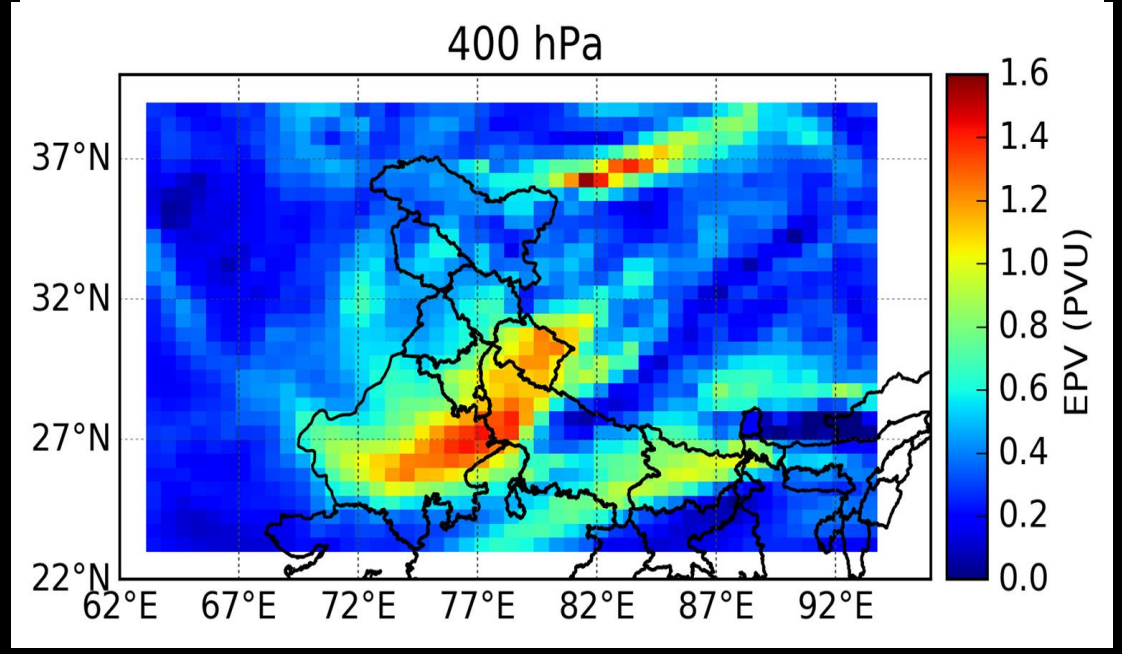
An event of deep tropopause fold

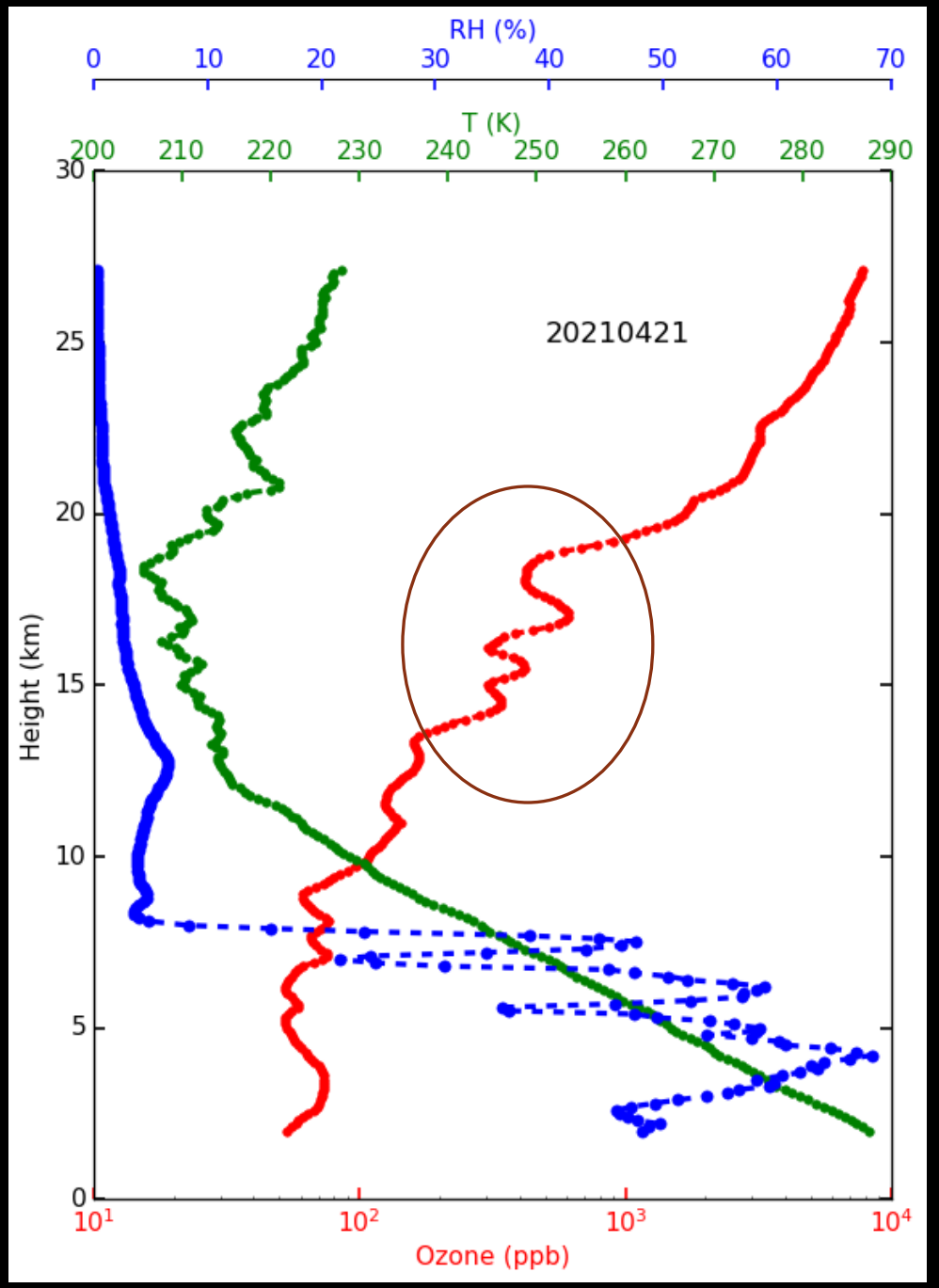
Enhancement in ozone up to 300-350 hPa



21 APRIL 2021

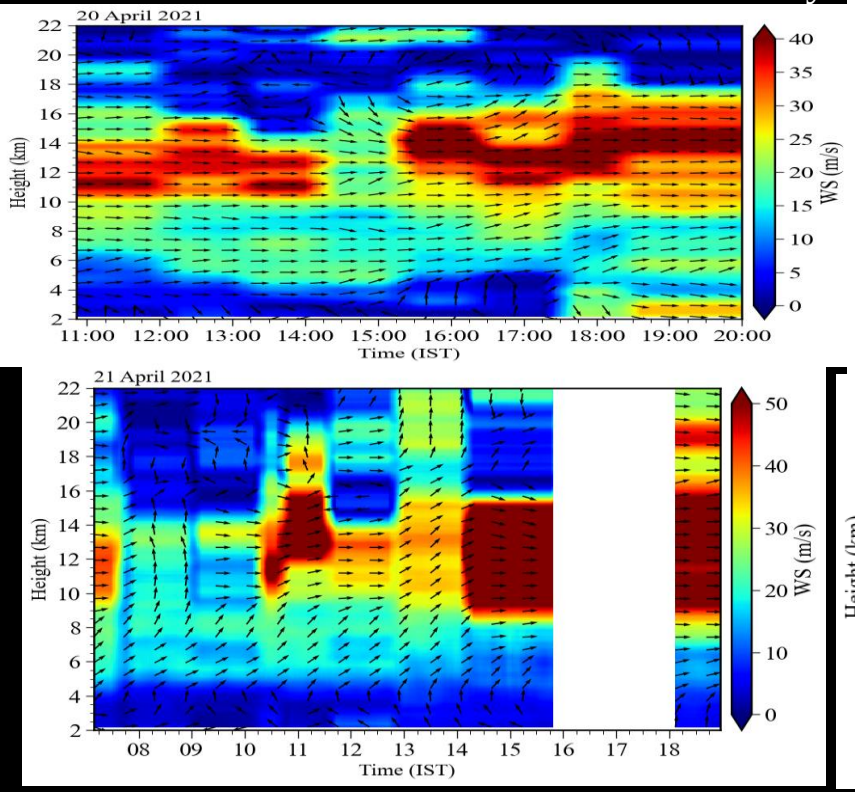




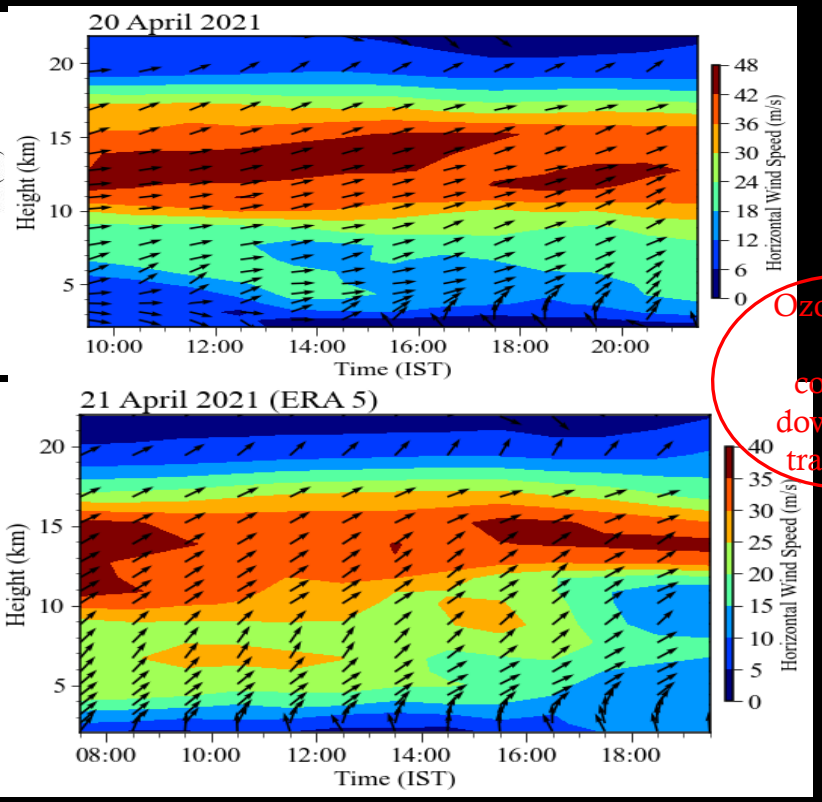


Winds observations from ARIES ST Radar

ASTRAD Horizontal Wind Velocity

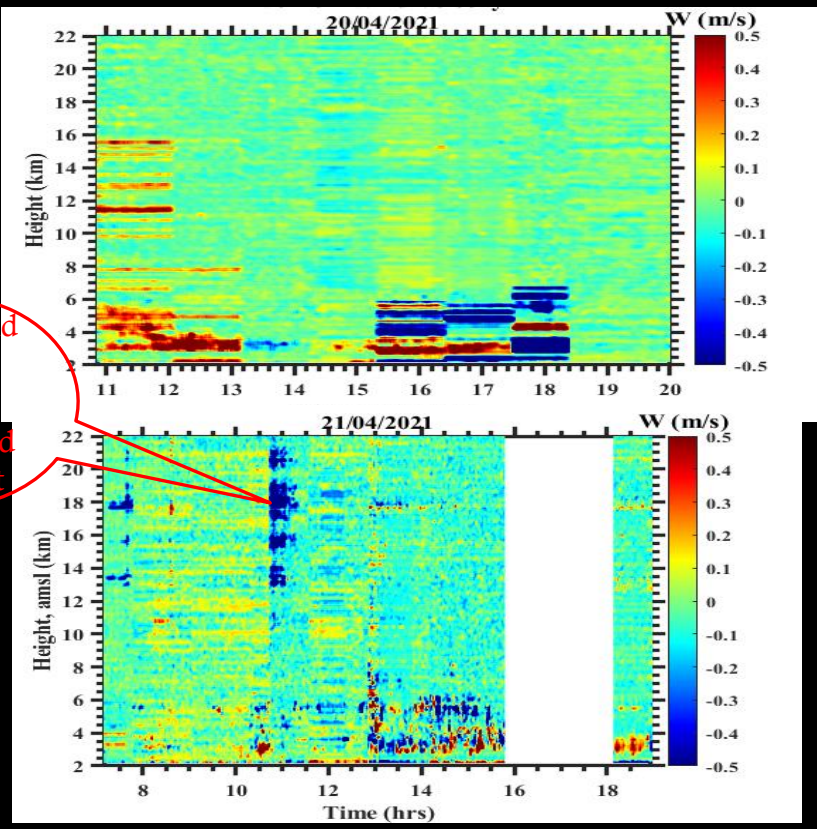


ERA5 Horizontal Wind



Ozone and PV confirm downward transport

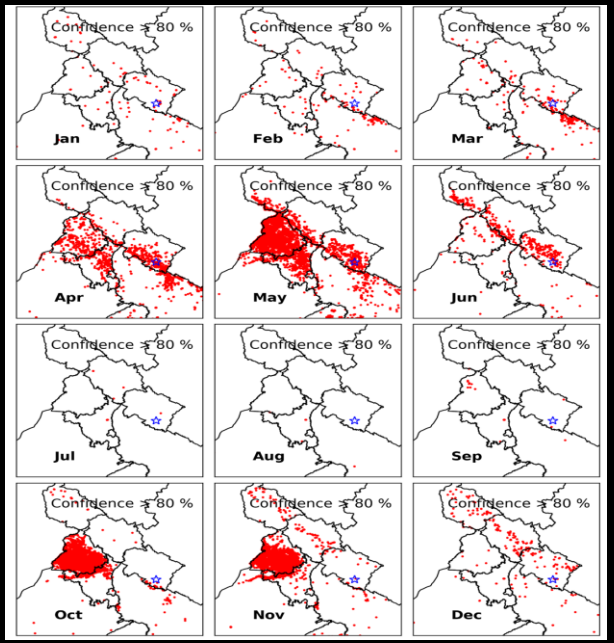
ASTRAD Vertical Wind

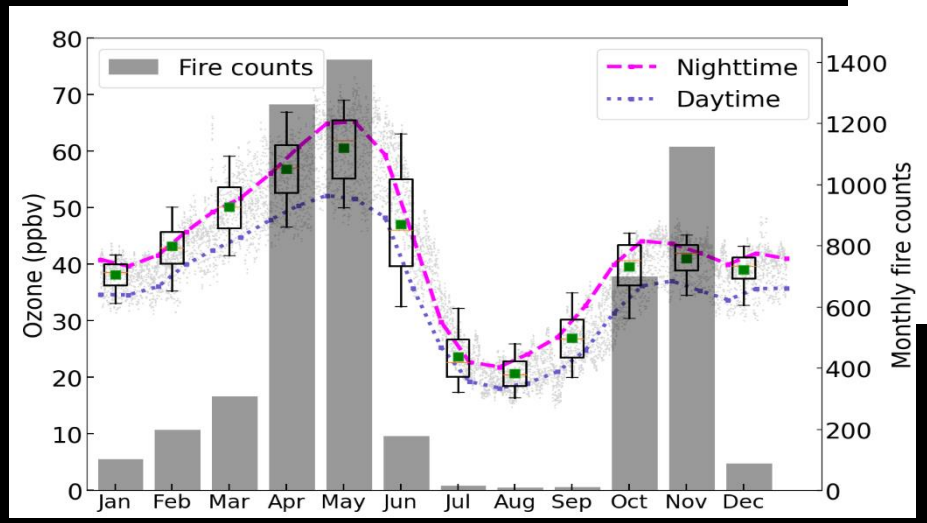


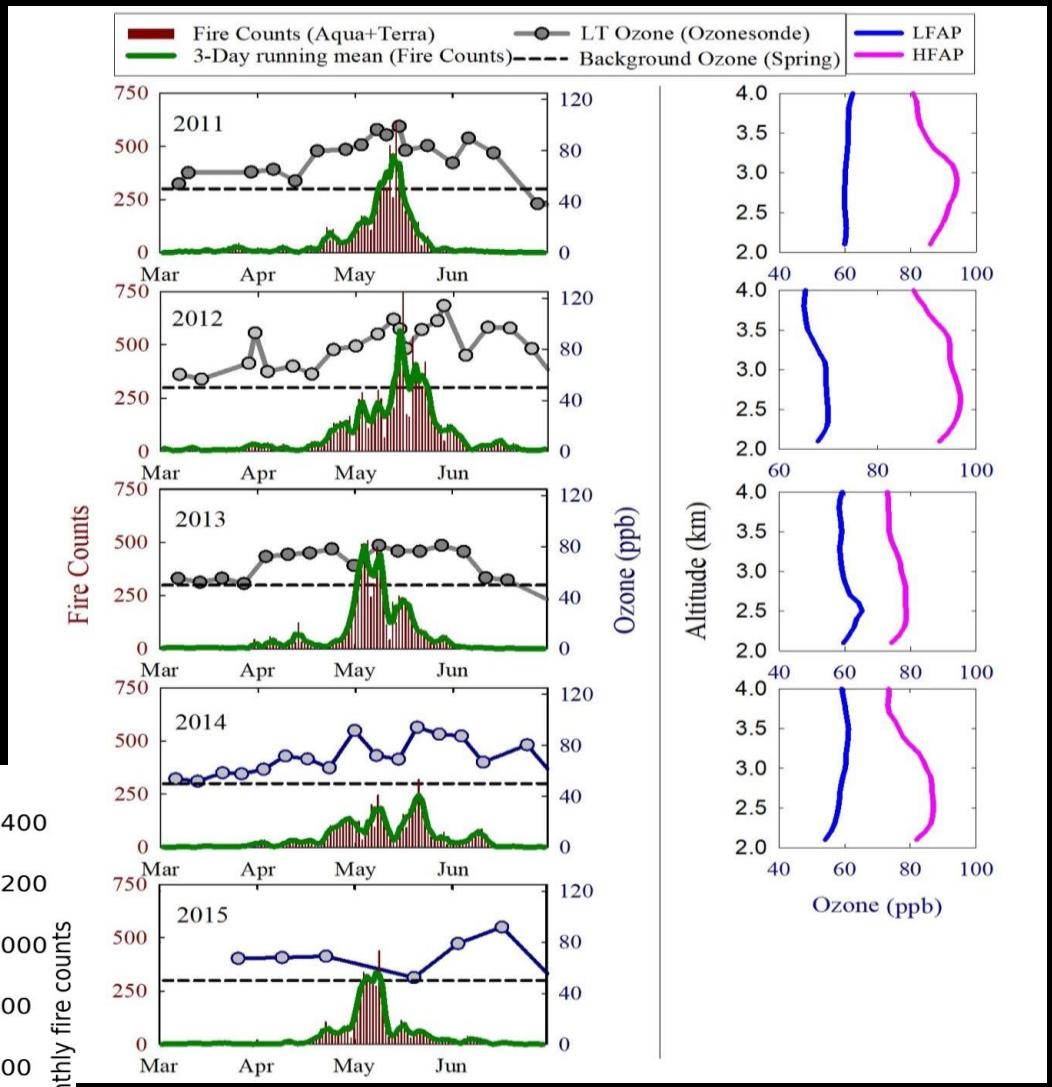
- Presence of Subtropical Westerly Jet (SWJ) in 10 -15 km region with wind speed 30 -50 m/s.
- Vertical winds showed a clear downward motion in 12-20 km region.

Role of biomass burning in the lower troposphere

Ozone enhancement of about 20 ppbv



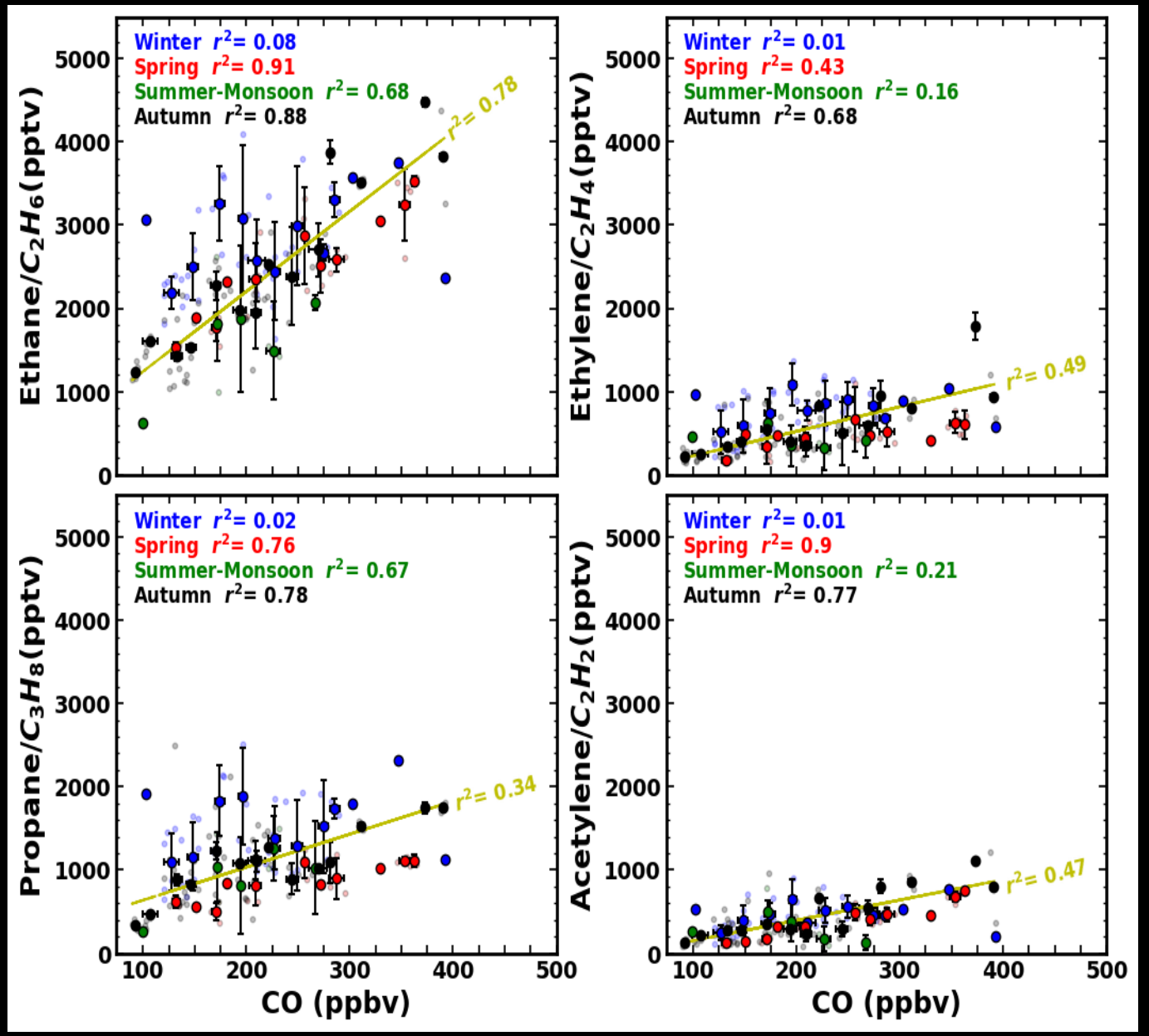




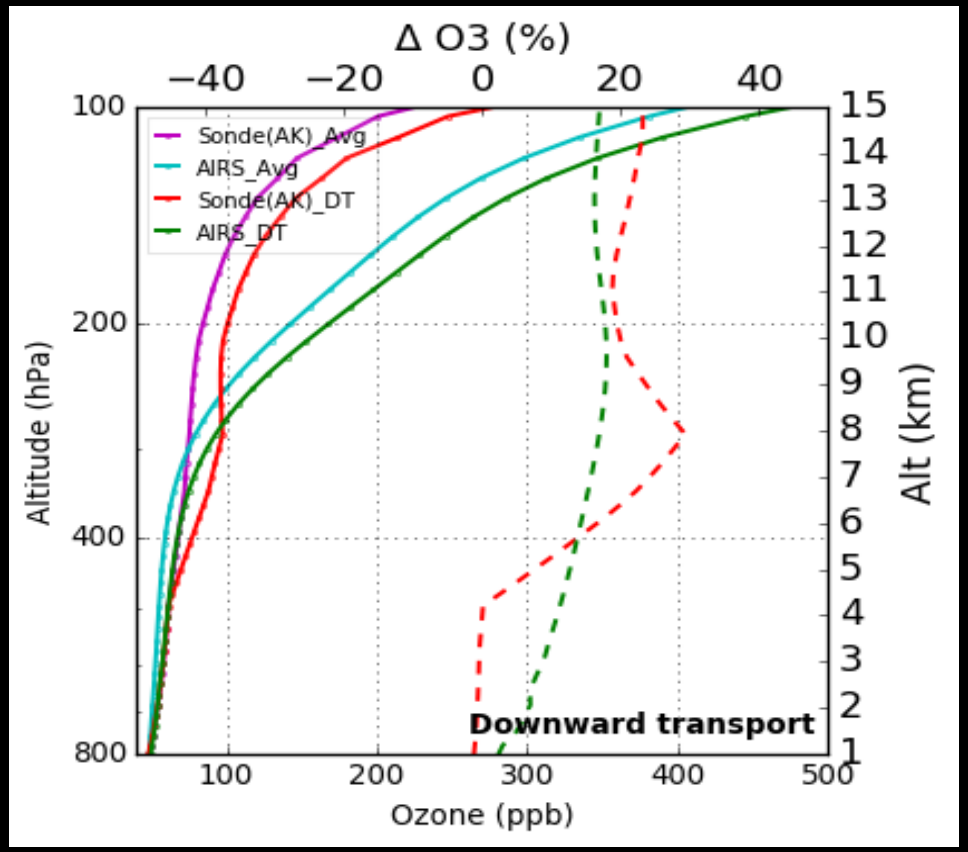
(Bhardwaj, Naja et al., 2020)

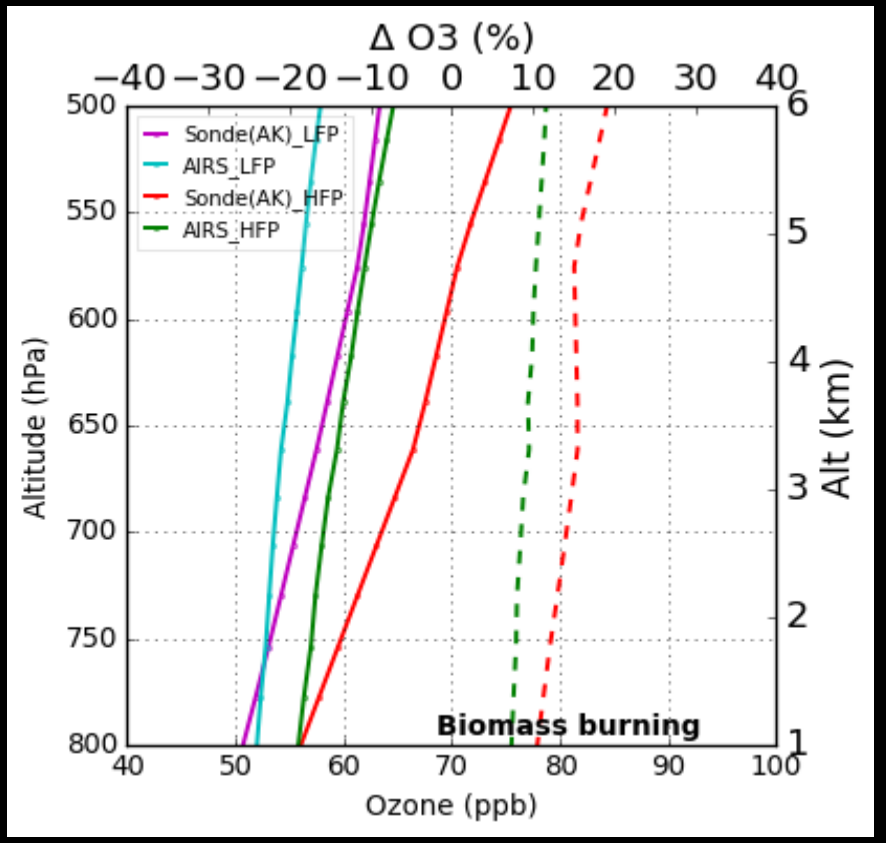
➢ A good correlation of ethane and acetylene with CO in spring (r^2>0.90; r^2>0.90) and autumn (r^2>0.85; r^2>0.75) emphasizes the influence of biomass burning and forest fire activities during spring and autumn.

(Rajwar, Naja et al., 2024)



Biomass Burning and Downward Transport (Ozonesonde and Satellite)





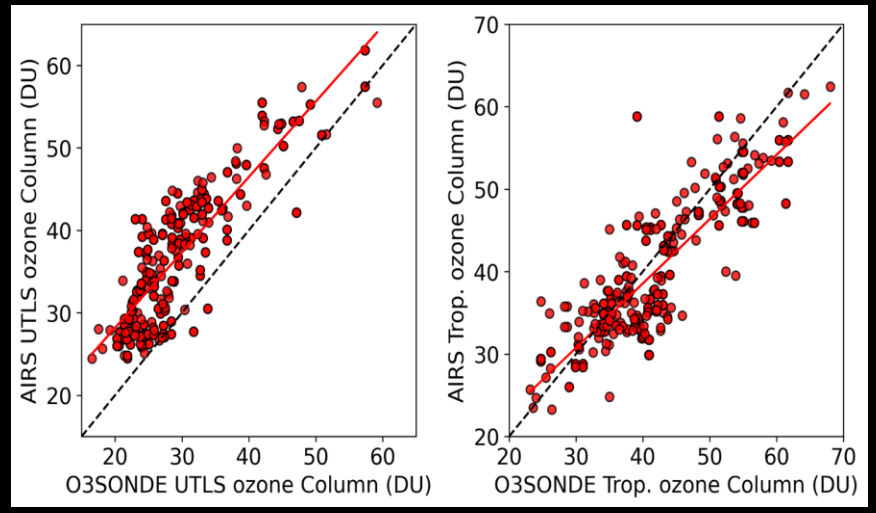
- Downward transport shows ozone enhancement by 0 - 30 %.

- Biomass burning shows ozone enhancement by 10-20% up to 6 km.

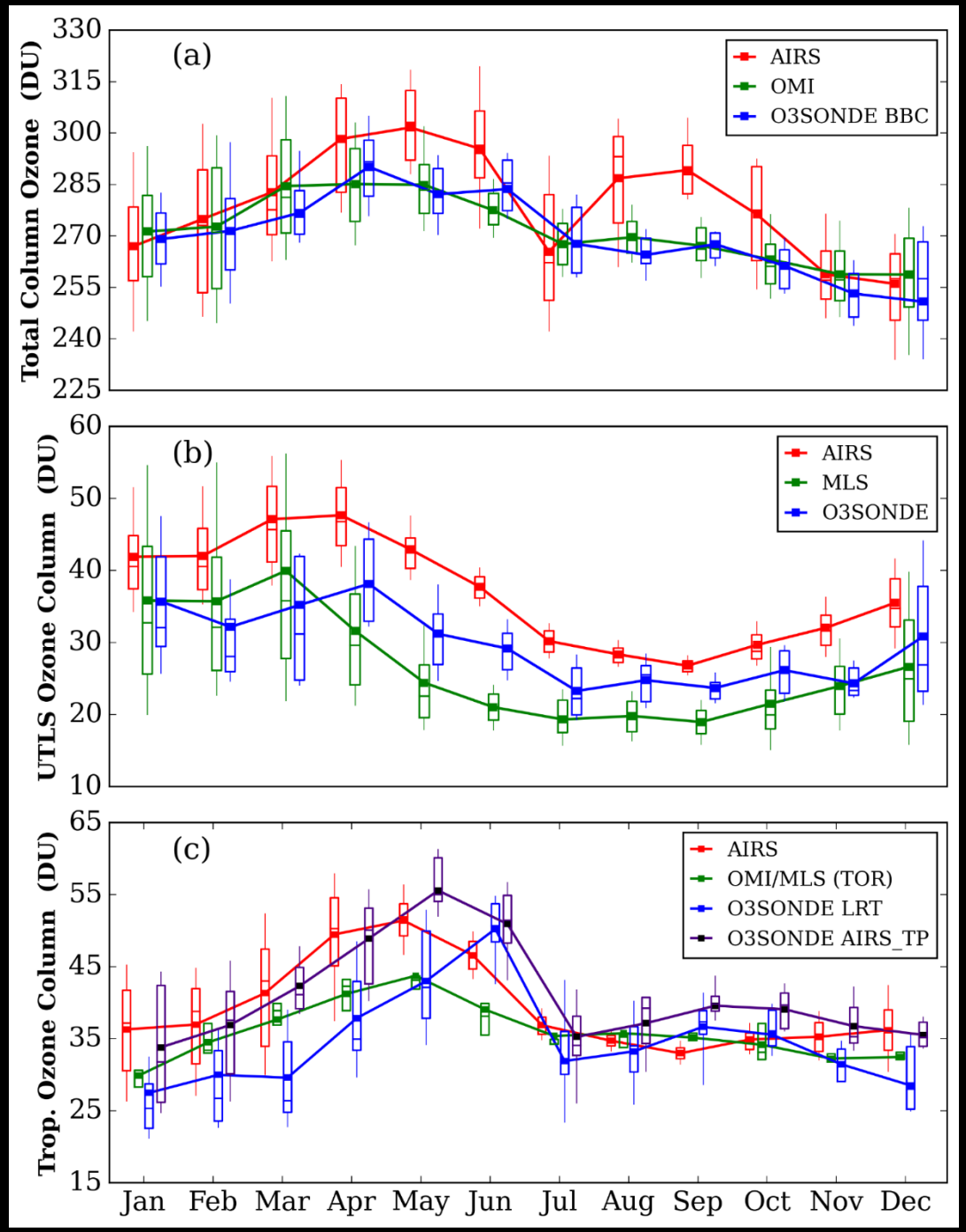
Rawat, Naja et al. (2022)

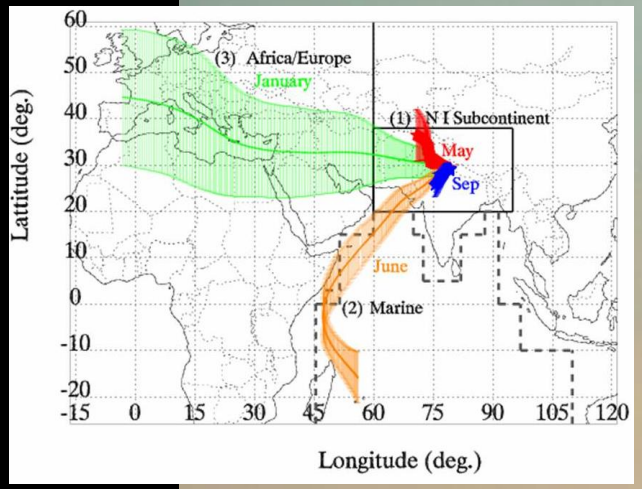
- AIRS total column ozone is higher and showed a dip in July.

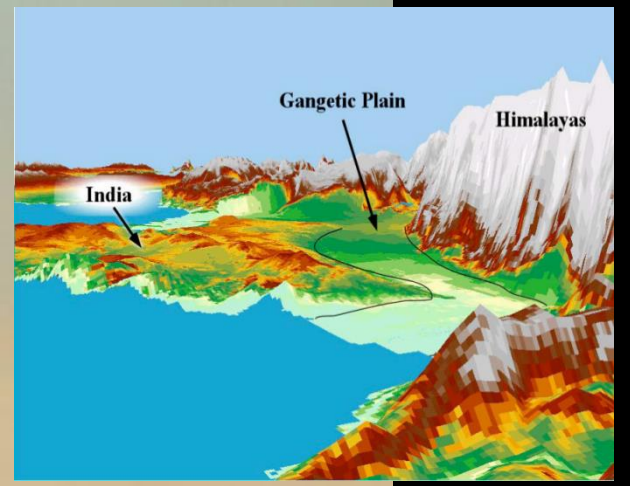
- AIRS ozone is also higher in UTLS, but not in the troposphere.



Rawat, Naja et al. (2022)







ARIES (Nainital)

A Natural Laboratory in the Central Himalayas

Thank you very much .....