Increasing aerosol burden over the foothills of the Himalaya

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Outlines:

1. Motivations
2. Study region under the present work
3. Availability of ground-based data (Network)
4. Results & Discussion
5. Conclusion

Motivations:

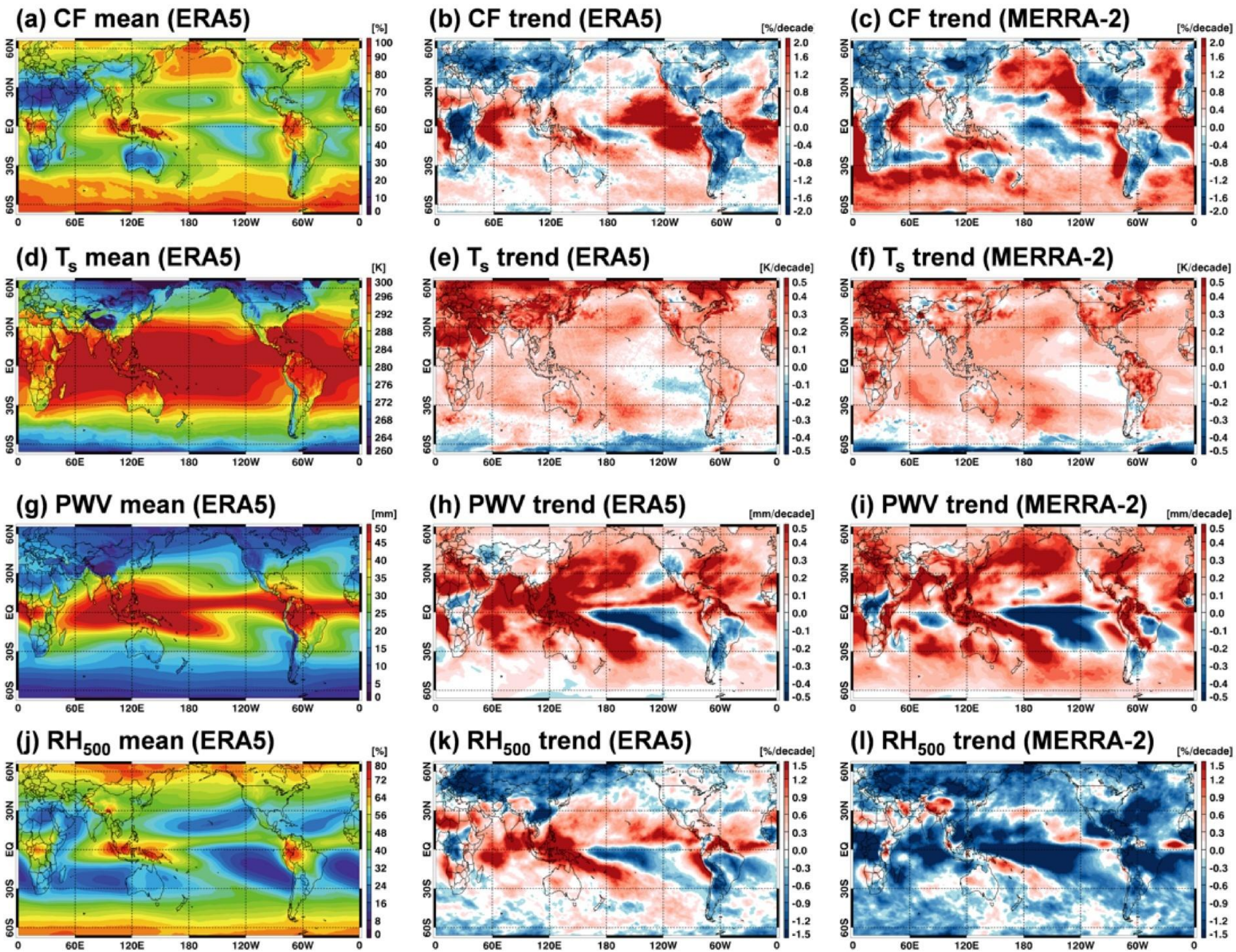
During the recent past, the Hindu Kush Himalayan (HKH) region has been experiencing an alarming impact of climate change such as rapidly melting of glaciers due to increasing surface temperature and greenhouse gases.

Unexpected heavy rainfall or cloudbursts (another devastating event) has occurred very frequently in this region during the last decade due to perturbation in the regional hydrological cycles.

However, there are lacks of ground-based high resolution (temporal and spatial) data for several atmospheric parameters to examine the impacts of such devastation. Using satellite data have several issues and uncertainties over the high-altitude mountain terrain and fragile topography.

The present work attempted to study the increasing aerosol burden over the HKH region as well as in the Indian sub-continent using long-term homogeneous reanalysis (MERRA-2) AOD data during 2000-2020.

Global moisture parameters during the last 41 years (2000-2020) data from MERRA-2/ERA5

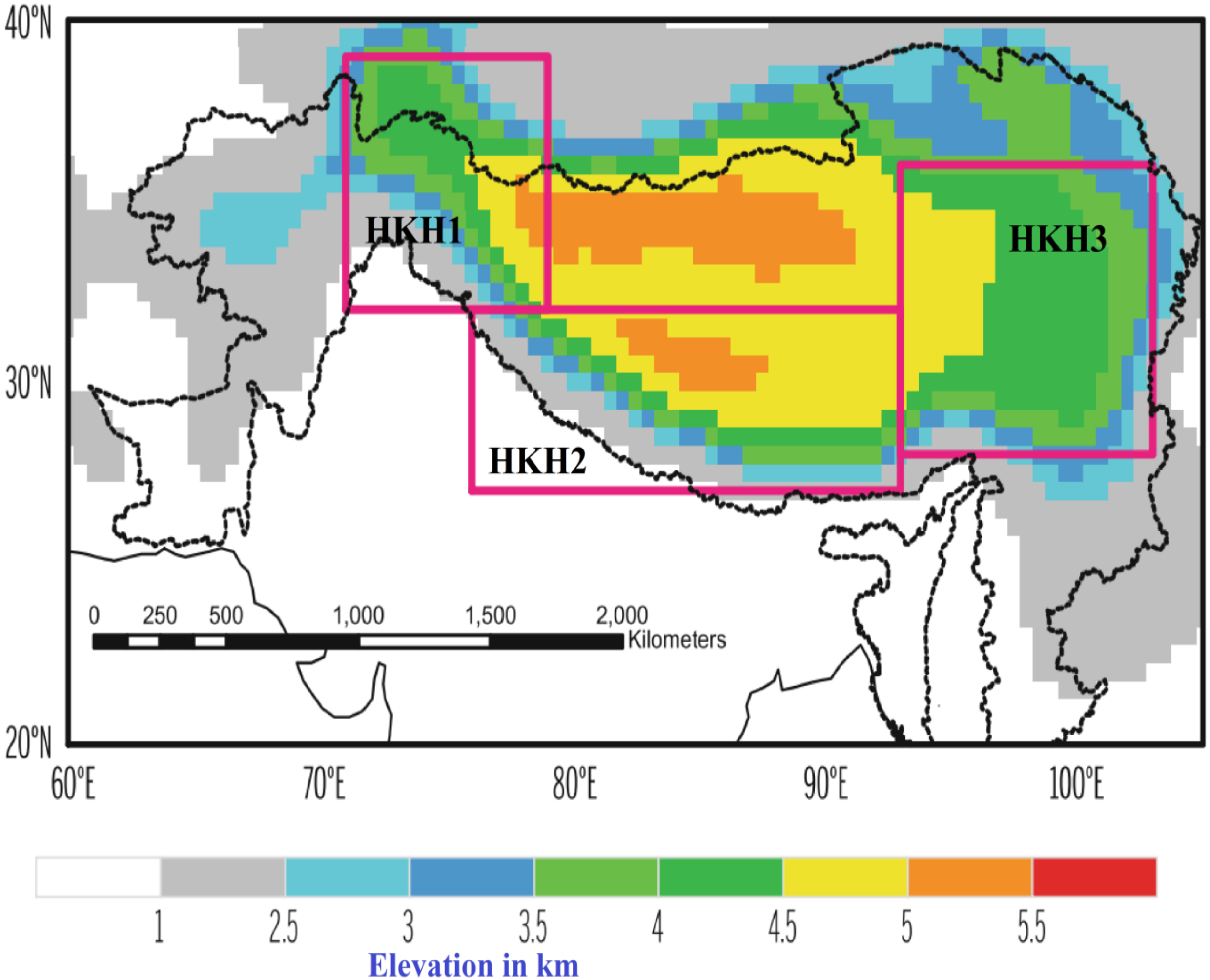


Ningombam et al., 2021a

Overview of the Hindu Kush Himalayan region

The total population in the ten major river basins with their headwaters in the HKH is around 1.9 billion, including the 240 million in the mountain and hills of the HKH. (Sources: The Hindu Kush Himalaya Assessment, https://doi.org/10.1007/978-3-319-92288-1_1).

Study region of HKH under the present work

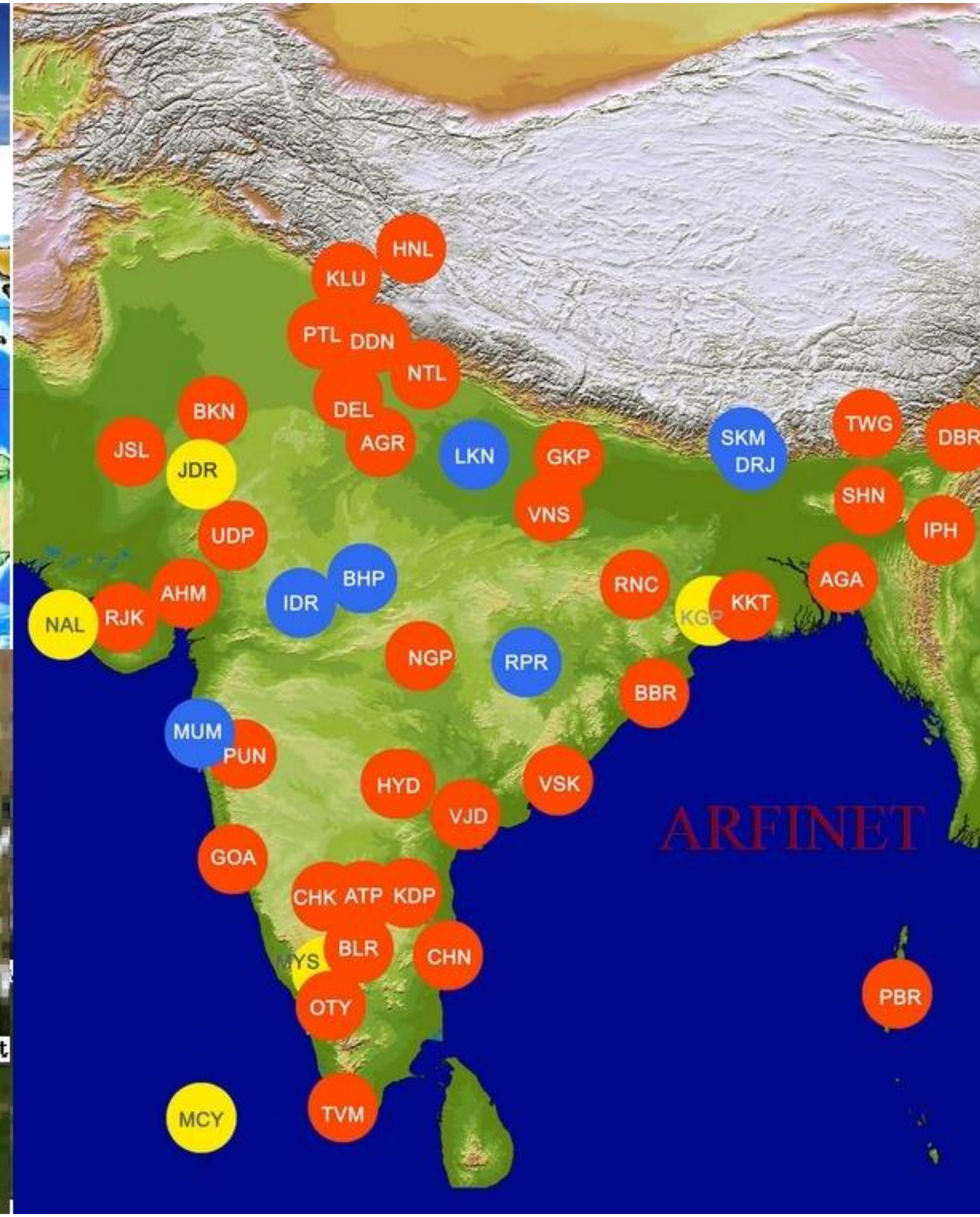


According to recent HKH assessment report (Sanjay et al., 2017), the western trans-Himalayan region has been less explored in terms of radiation budget, atmospheric heating and cloud microphysics. Due to lack of ground based data, expanding aerosols measuring facilities are urgently needed over the entire region.

Map shows Hindu Kush Himalayan (HKH) region and its sub-regions (HKH1: 32-39N, 71-79E; HKH2: 27-32N, 76-93E; and HKH3: 28-36N, 93-103E) with elevation in km.

Source: Sanjay et al., Advances in Climate Change Res. 2017.

Availability of ground-based aerosol measurement (Network) from the Indian sub-continent



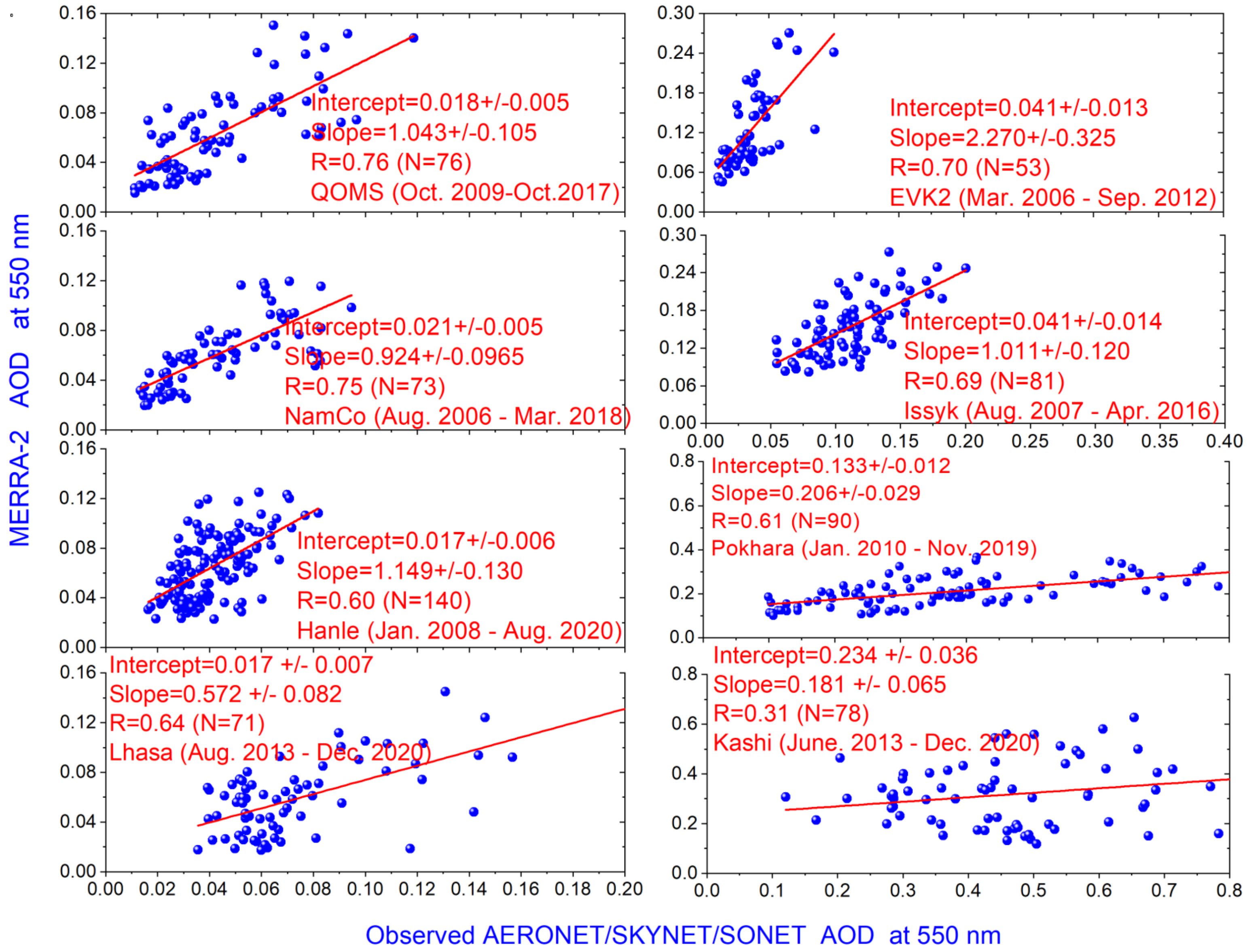
Limitations of ground-based/satellite data at high-altitude sites across the globe

The number of available data set (%) for night-time MODIS (Terra) cloud fraction at few high-altitude sites (astronomical observatories) at spatial resolution of 0.20 degree to 0.05 degree during March, 2000 to December, 2020.

Sites	Elevation (m)	Lat.	Long.	0.20°x0.20°	0.10°x0.10°	0.05°x0.05°
SALT, Sutherland, South Africa	1798	32.38S	20.81E	97.9	85.5	50.3
Devasthal, Nainital, India	2450	29.36N	79.68E	97.1	85.6	52.1
Paranal, Chile	2635	24.63S	70.40W	92.7	80.6	50.5
NAO, Mexico	2800	31.04N	115.46W	96.8	82.4	50.3
Merak (NLST), Ladakh, India	4310	33.80N	78.62E	97.8	86.6	51.1
Hanle (IAO), Ladakh, India	4500	32.78N	78.96E	97.7	85.3	52.0
Ali, Shiquanhe Observatory, China	5100	32.63N	80.00E	97.8	86.7	50.9
TAO, Chile	5640	22.98S	67.74W	92.4	80.8	51.8

Ningombam et al., 2021a

Scatter AOD plots between MERRA-2 and ground based data



Ningombam et al., 2021a

Increasing AOD trend at HKH region (1980-2020) using MERRA-2 data

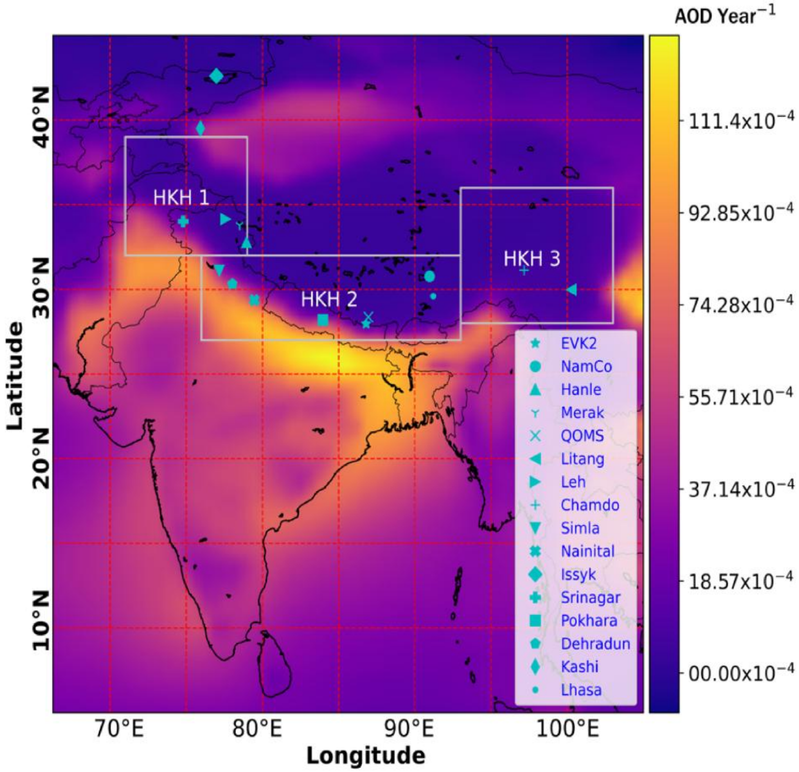


Table 1 Yearly AOD (550 nm) trend (AOD year^{-1}) at different sub-regions in the Hindu Kush Himalayan region in 1980–2020 using MERRA-2 reanalysis data. The results also show a Pearson correlation coefficient (R) and confidence level (t).

Stations	Mean AOD	Trend ($\times 10^{-4}$)	R	t
HKH1	0.18 ± 0.05	23.33± 2.28	0.87	10.22
Hanle	0.06 ± 0.02	2.66± 0.93	0.45	2.85
Merak	0.06 ± 0.02	2.57± 0.96	0.43	2.67
Leh	0.08 ± 0.03	3.59± 1.04	0.52	3.47
Issyk	0.16 ± 0.04	2.85± 1.72	0.28	1.65
Srinagar	0.16 ± 0.04	15.85± 2.21	0.78	7.16
Kashi	0.29 ± 0.09	34.69± 3.88	0.85	8.95
HKH2	0.17 ± 0.04	32.20± 2.58	0.91	12.47
EVK2	0.06 ± 0.03	6.76± 1.00	0.77	6.74
Nam Co	0.06 ± 0.02	3.40± 0.92	0.55	3.71
QOMS	0.05 ± 0.02	4.28± 0.87	0.66	4.91
Lhasa	0.06 ± 0.03	4.76± 0.95	0.66	4.99
Shimla	0.29 ± 0.10	51.53± 4.99	0.88	10.33
Nainital	0.26 ± 0.09	53.15± 3.94	0.92	13.50
Pokhara	0.25 ± 0.08	55.75± 3.76	0.93	14.85
Dehradun	0.23 ± 0.08	39.16± 4.08	0.86	9.61
HKH3	0.09 ± 0.03	9.48± 1.21	0.81	7.82
Litang	0.06 ± 0.03	5.70± 0.90	0.75	6.34
Chamdo	0.06 ± 0.03	5.60± 1.01	0.70	5.53

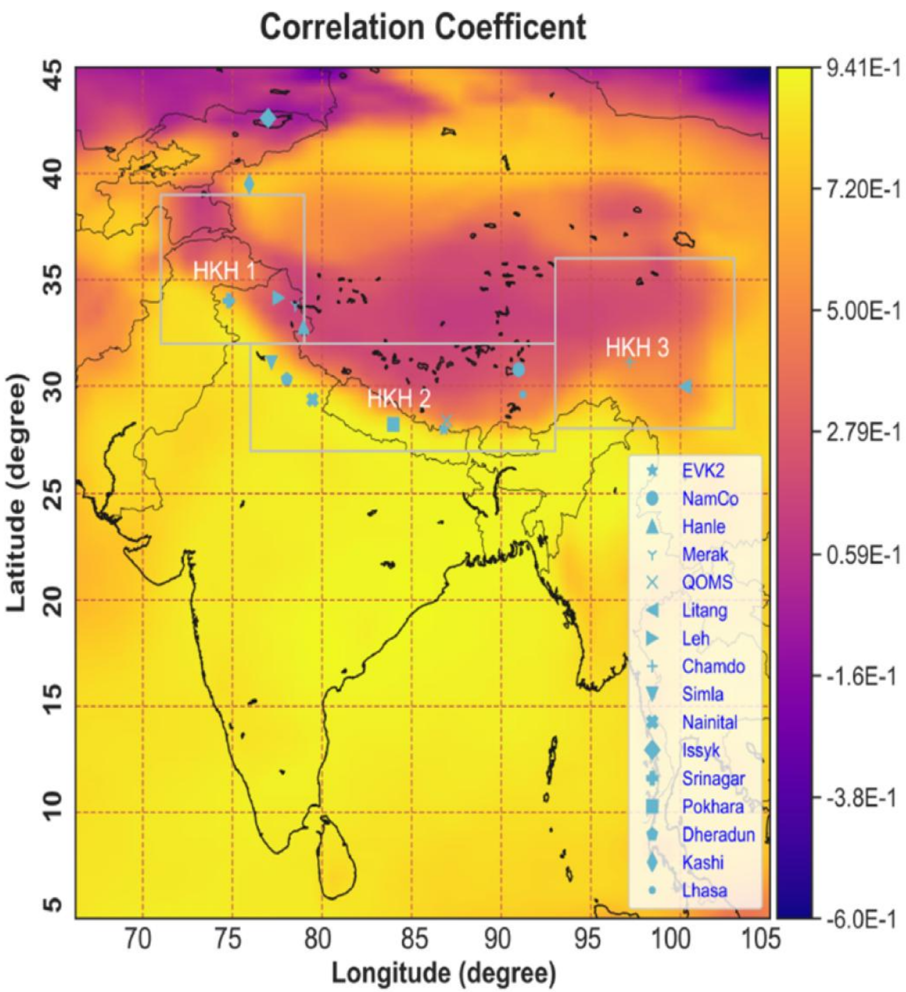
Table 2 Stations located in the HKH region as well as the three sub-regions of HKH considered in the present study for AOD trend estimation.

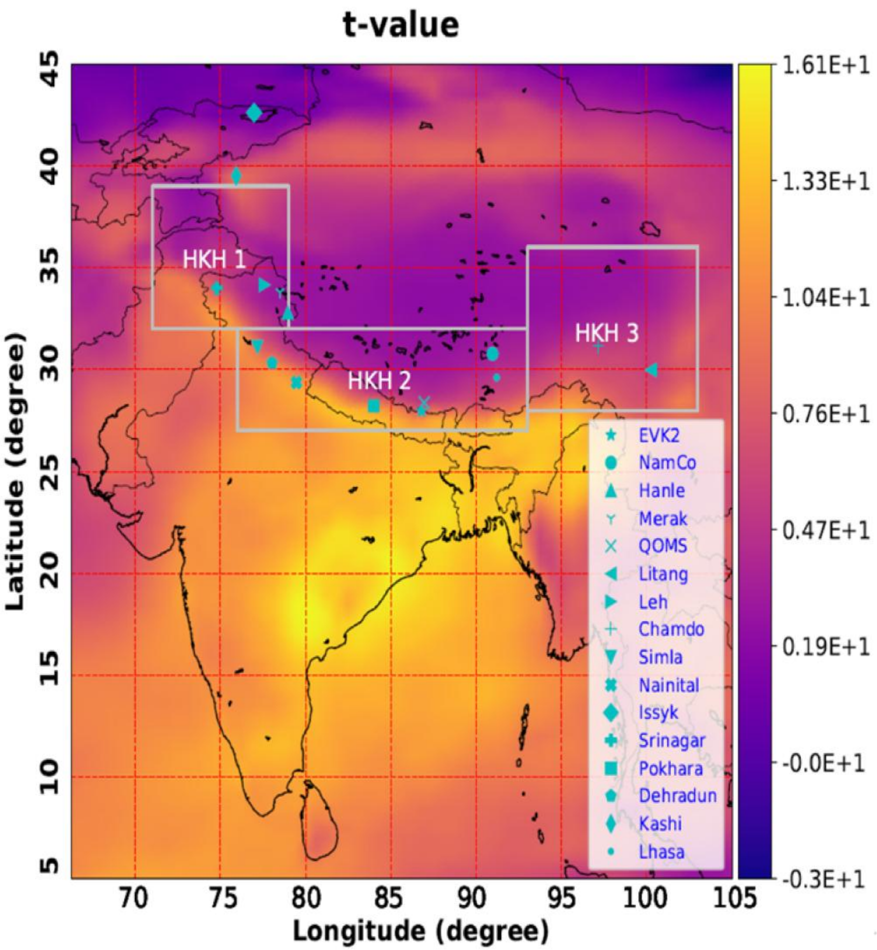
Site Name	Type of Sites	Lat.	Long.	Elevation (m)
HKH1	background & non-background	32–39	71–79	~1000–5000
Hanle	background	32.78	78.95	4500
Merak	background	33.80	78.62	4310
Leh	background	34.15	77.58	3500
Issyk	non-background	42.60	76.98	1650
Srinagar	non-background	34.01	74.80	1590
Kashi	non-background	39.50	75.93	1320
HKH2	background & non-background	27–32	76–93	~300–5000
EVK2	background	27.96	86.80	5080
Nam Co	background	30.77	90.96	4750
QOMS	background	28.37	86.95	4280
Lhasa	background	29.60	91.20	3680
Shimla	non-background	31.11	77.17	2280
Nainital	non-background	29.36	79.46	1940
Pokhara	non-background	28.19	83.97	800
Dehradun	non-background	30.32	78.03	430
HKH3	mostly background	28–36	93–103	~1000–5000
Litang	background	29.98	100.26	3930
Chamdo	background	31.13	97.17	3240

Among the sub-regions, significant enhancement of AOD trend is observed at several potential sites of HKH-2, located in the foothills of the Himalaya such as Dehradun, Shimla, Nainital and Pokhara by 39.16 +/- 4.08, 51.53 +/- 4.99, 53.15 +/- 3.94 and 55.75 +/- 3.76 (x10^{-4}) AOD per year, respectively. The highest AOD trend in the sub-continent is observed in the IGP region with ~130 x 10^{-4} AOD per year. However, in the sub-regional scale, HKH1, HKH2 and HKH3 exhibit 23.33 +/- 2.28, 32.20 +/- 2.58 and 9.48 +/- 1.21 (x10^{-4}) AOD per year, respectively.

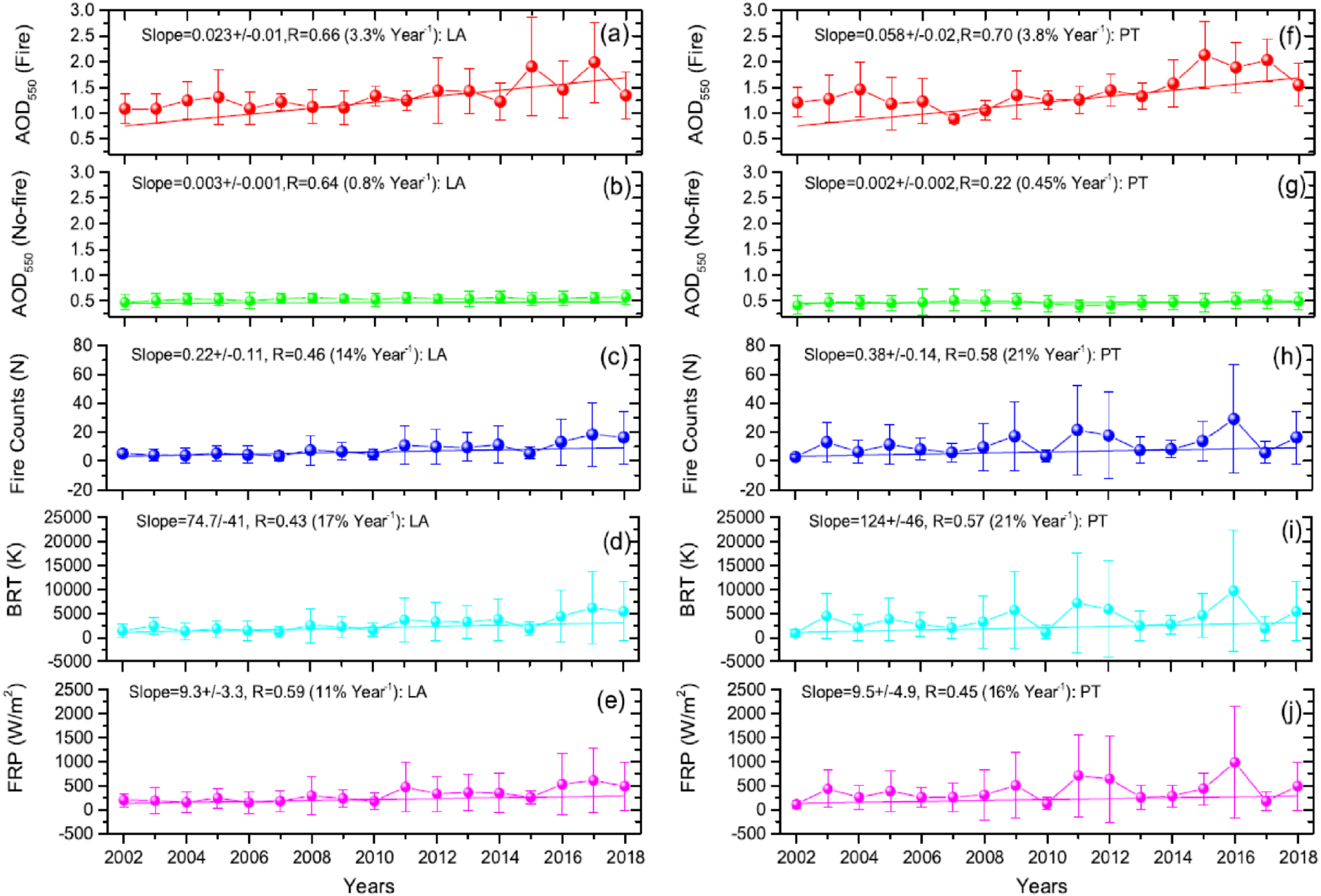
Ningombam et al., 2021b

Statistical parameters (R, t) of the AOD trend estimation

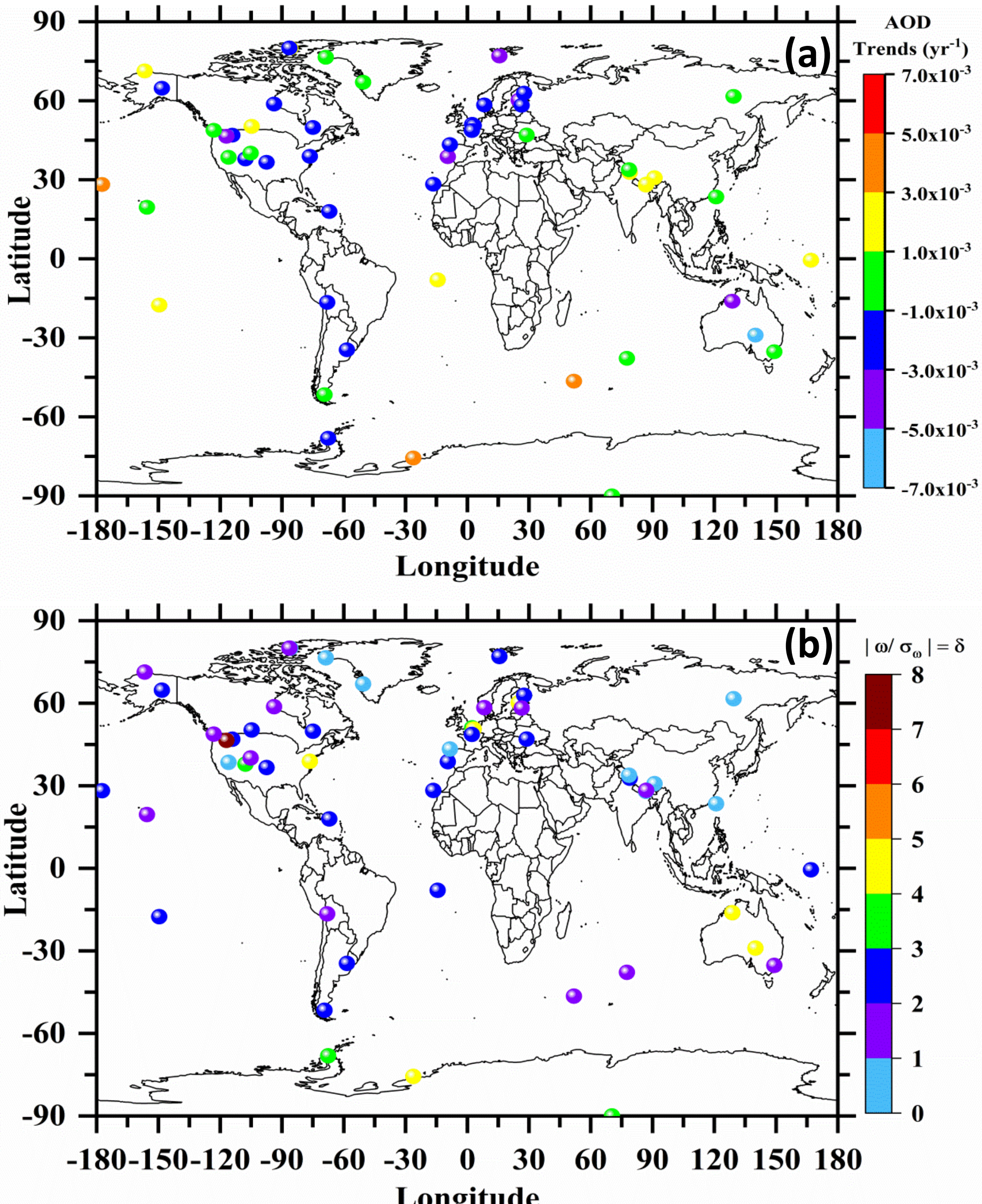




Impacts of biomass burning in the IGP region

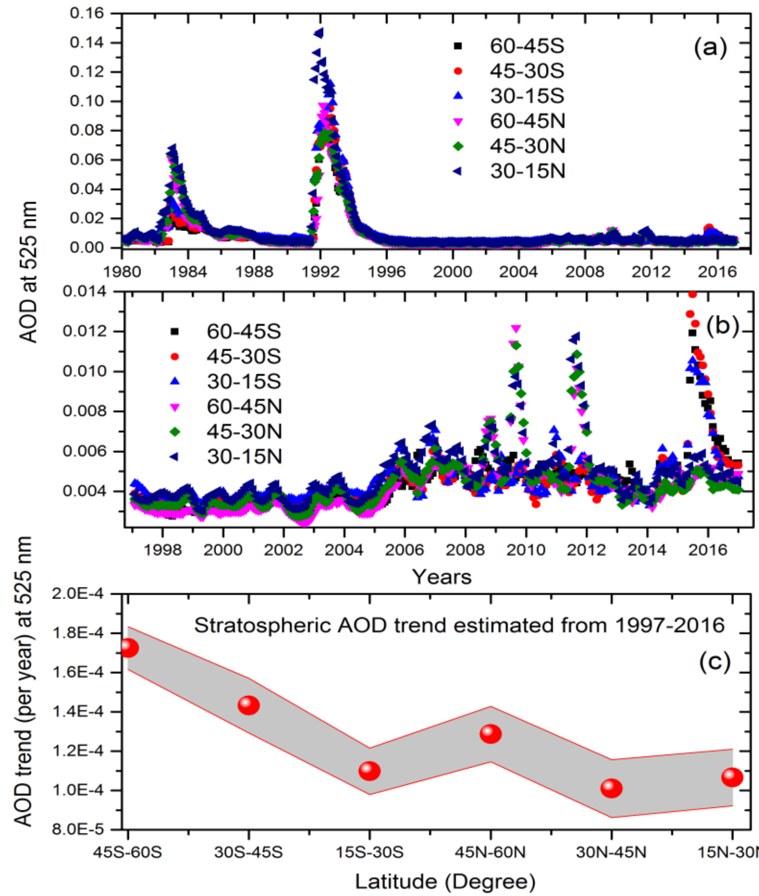


Ningombam et al., 2020



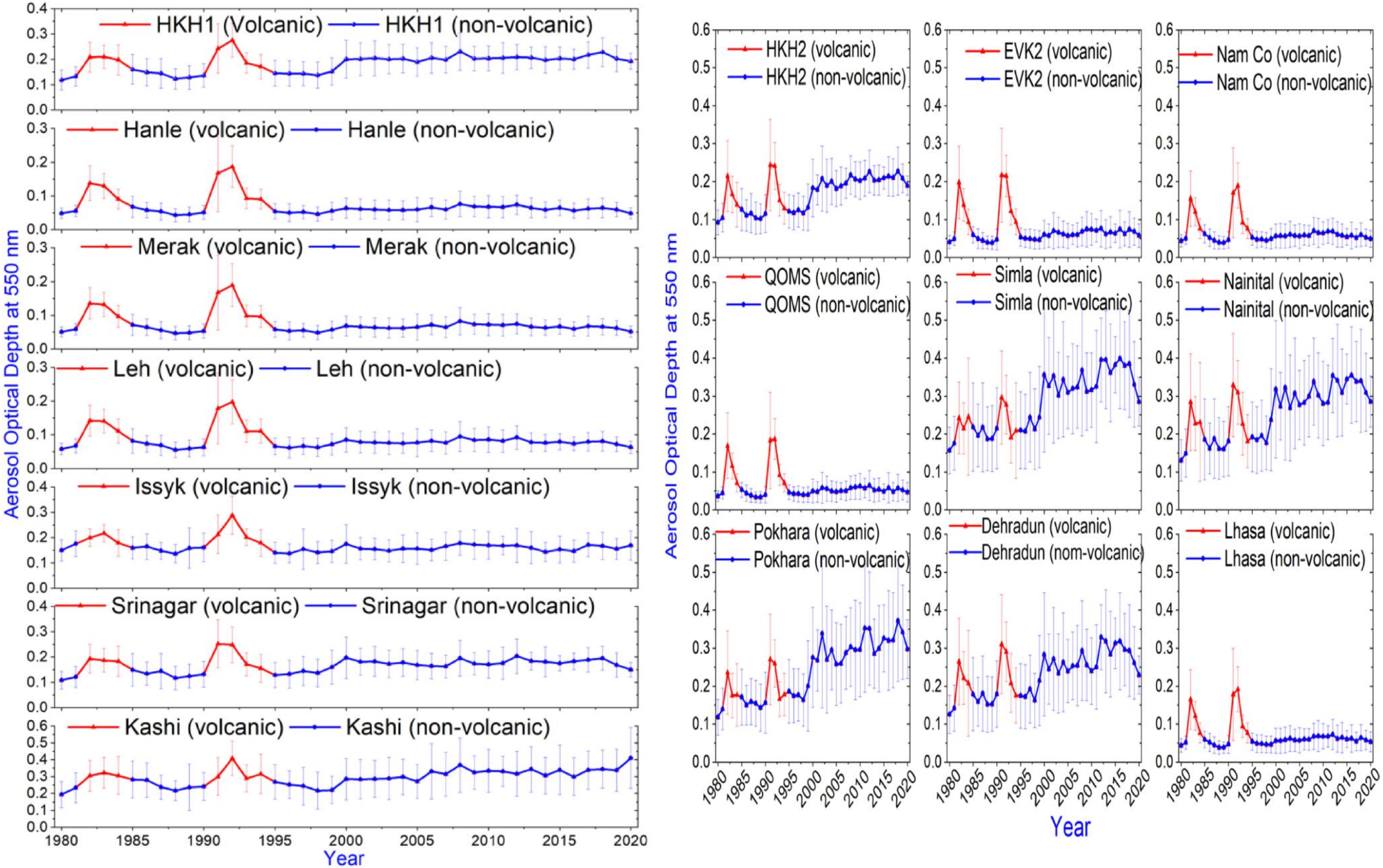
AOD trends over aged-background sites across the globe during 1996-2018

Stratospheric AOD trend:



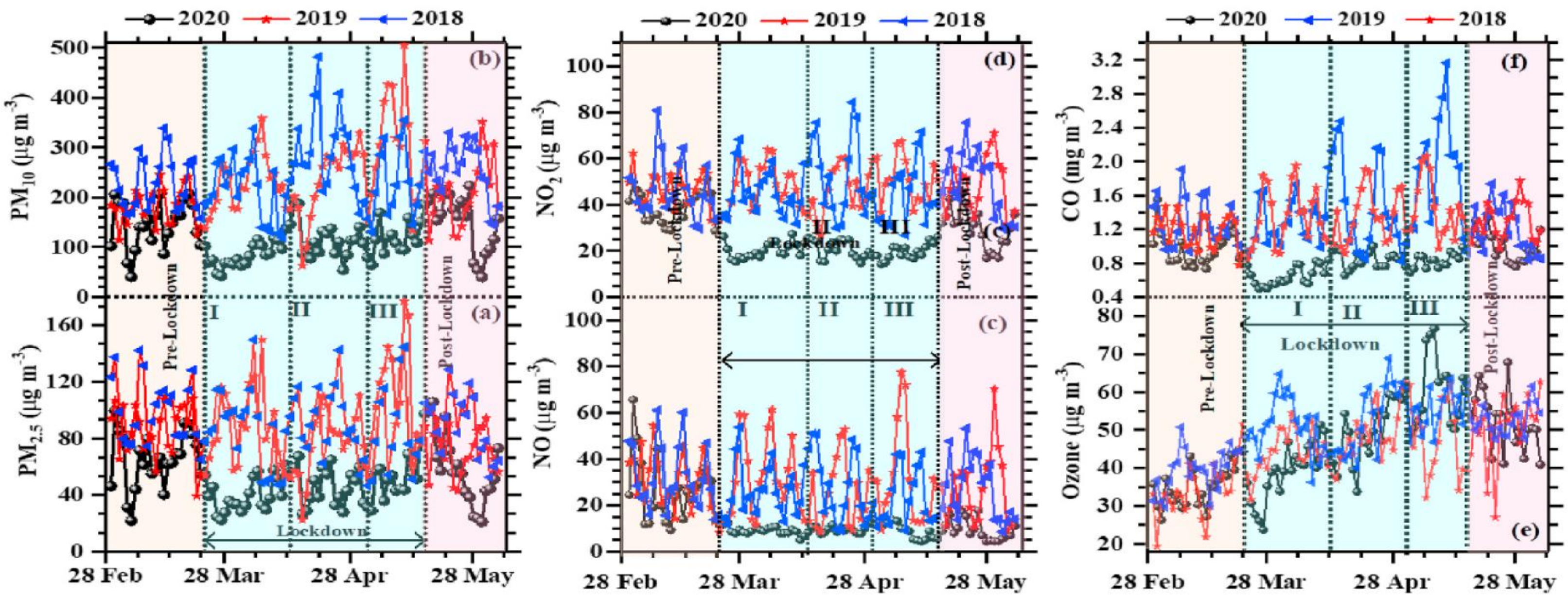
Ningombam et al., 2019

Impacts of last two major volcanic eruptions

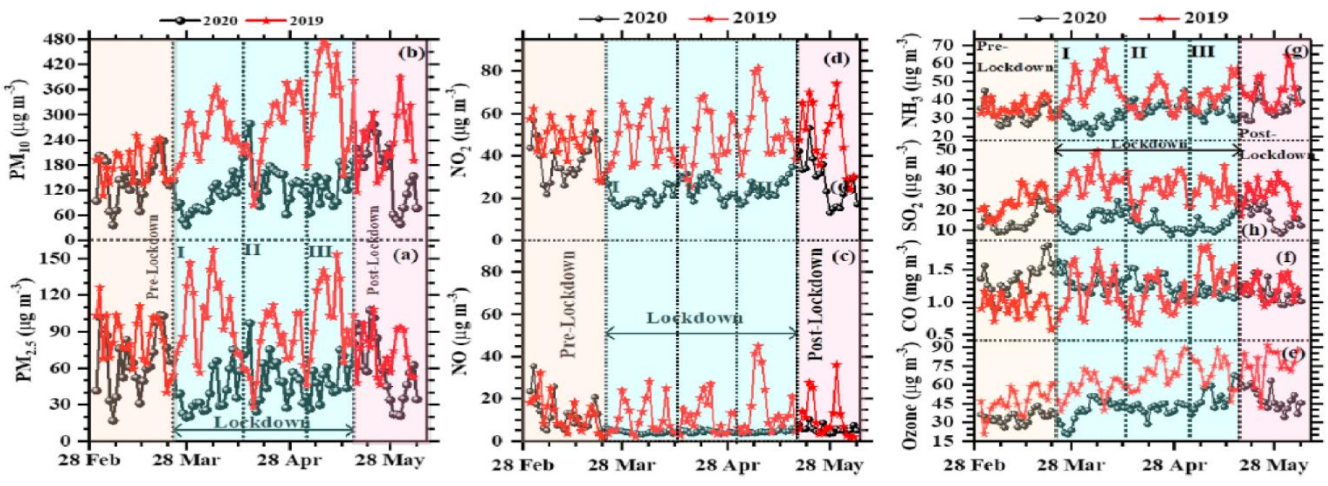


Ningombam et al., 2021b

Impacts of Covid-19 lockdown over the Indian sub-continent



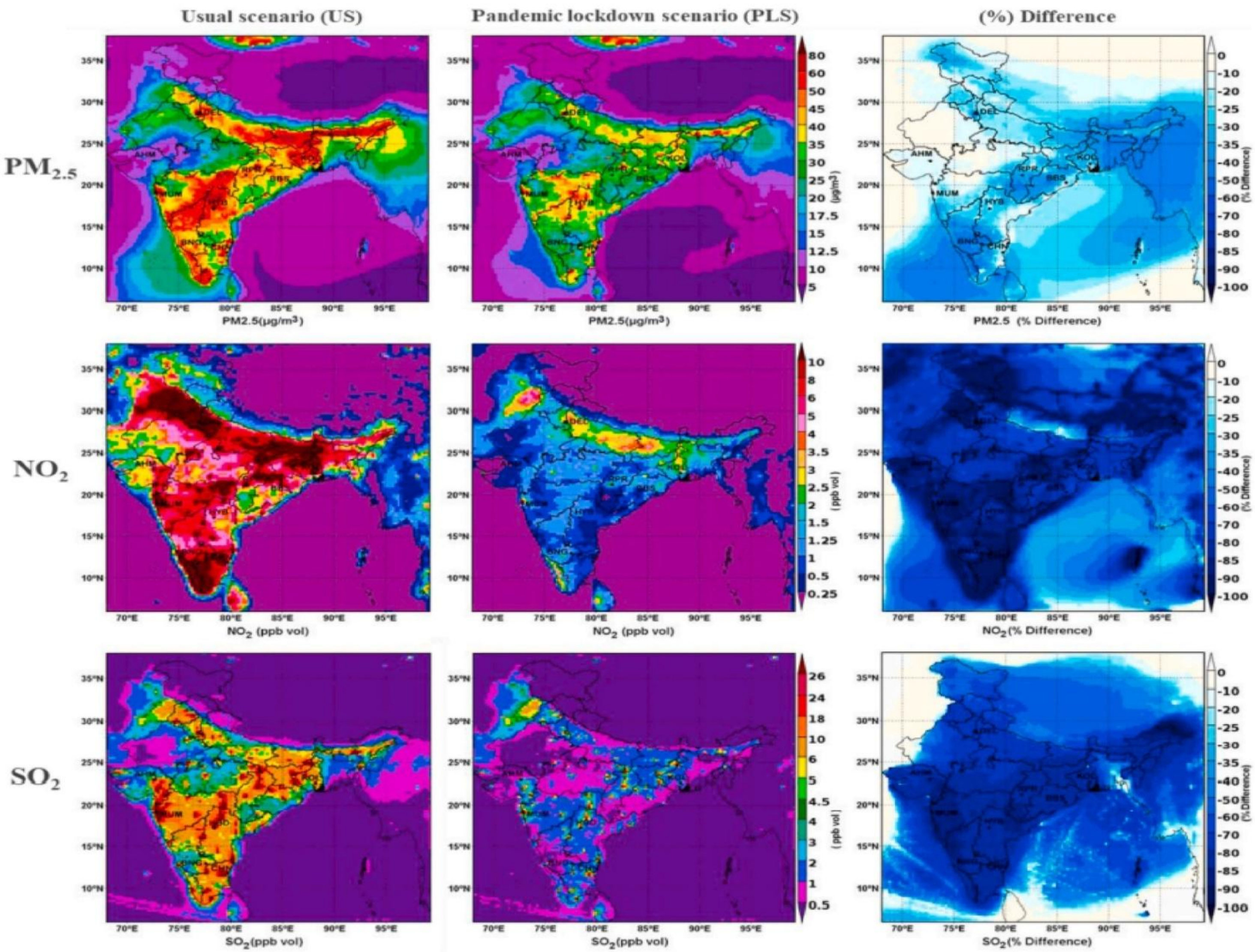
New Delhi



Uttra Pradesh (UP) State

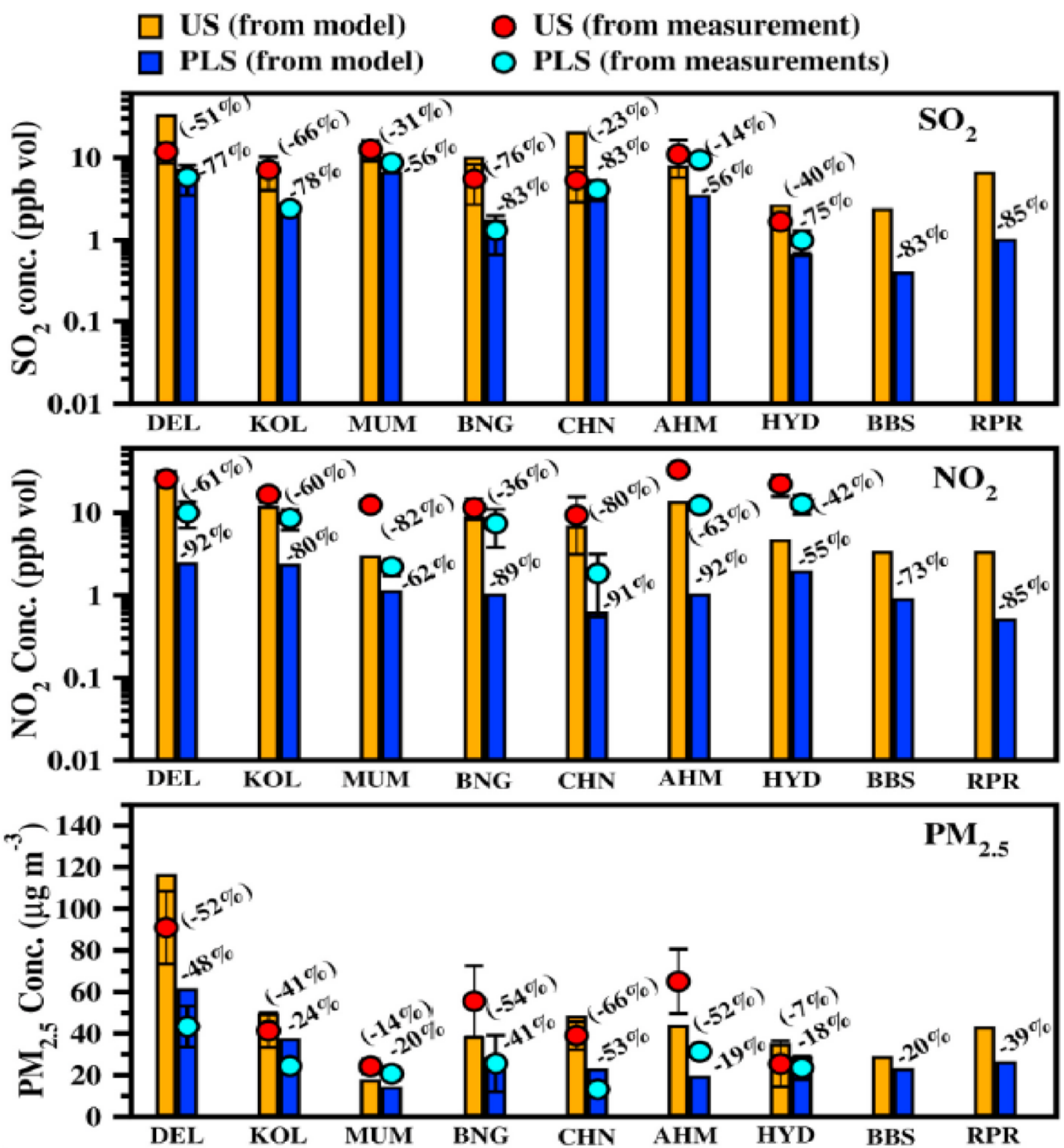
Dumka et al., 2020

Impacts of Covid-19 lockdown over the Indian sub-continent



WRF-CHIMERE model simulations of PM2.5, NO2, and SO2 concentration during usual and pandemic scenarios over the Indian sub-continent

Impacts of Covid-19 lockdown



Conclusion:

1. A significant increasing AOD trend is observed in the foothills of the Himalaya in the HKH region during the last 21 years with ~39 to 55 x 10^{-4} AOD per year. On the other hand, the highest AOD trend is observed in the IGP region (or in the Indian sub-continent) is ~130 x 10^{-4} AOD per year. The estimated trends are statistically significant.

2. AOD trends in the high-altitude sites located far away from the IGP region exhibit weak and statistically insignificant trends which may attributes to:

   (i) There are decreasing AOD trends during last few years (5-6), coupled with the improvement of air quality due the impacts of COVID-19 lockdown.

   (ii) Impact of the two major volcanic eruptions has enhanced AOD loading at high-altitude stations which makes the weakening of the trend estimation.

3. There is minimum impact of the two major volcanic eruptions for the sites located in the foothills of the Himalayan in the HKH-region.

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Thanks for your kind attention !!!