Impact of Covid-19 lockdown regulations on air quality over one of the top polluted city in the world

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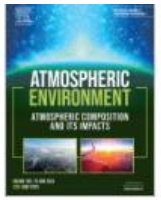
104th AMS Annual Meeting
28 January to 1 February, 2024 Baltimore, Maryland.

Atmospheric Environment
Volume 303, 15 June 2023, 119746



Impact of Covid-19 lockdown regulations on $PM_{2.5}$ and trace gases (NO_2, SO_2, CH_4, HCHO, $C_2H_2O_2$ and O_3) over Lahore, Pakistan

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Motivation

- First-time combination of in-situ air quality data, remote sensing satellite data, and backward trajectory modeling.
- Identify sources of $PM_{2.5}$ and the column amounts of six trace gases (NO_2, SO_2, CH_4, HCHO, $C_2H_2O_2$ and O_3)
- Factors influencing local emissions and long-range transport of $PM_{2.5}$.

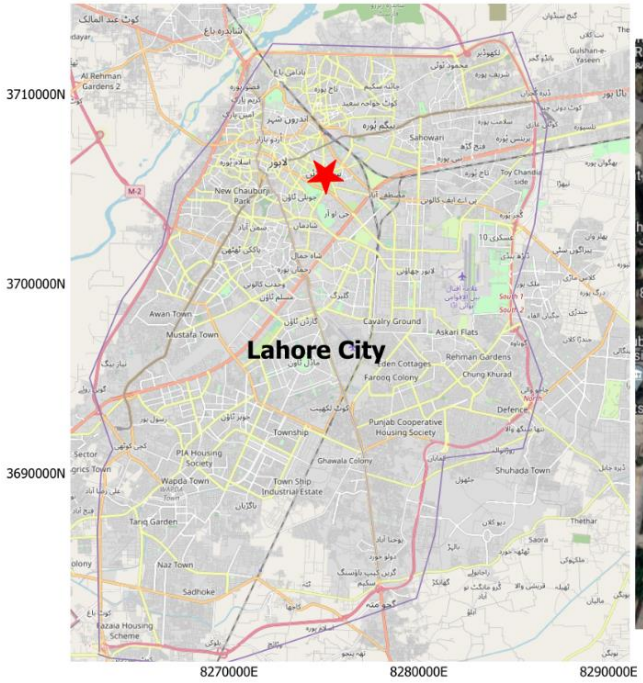
PM2.5 legend

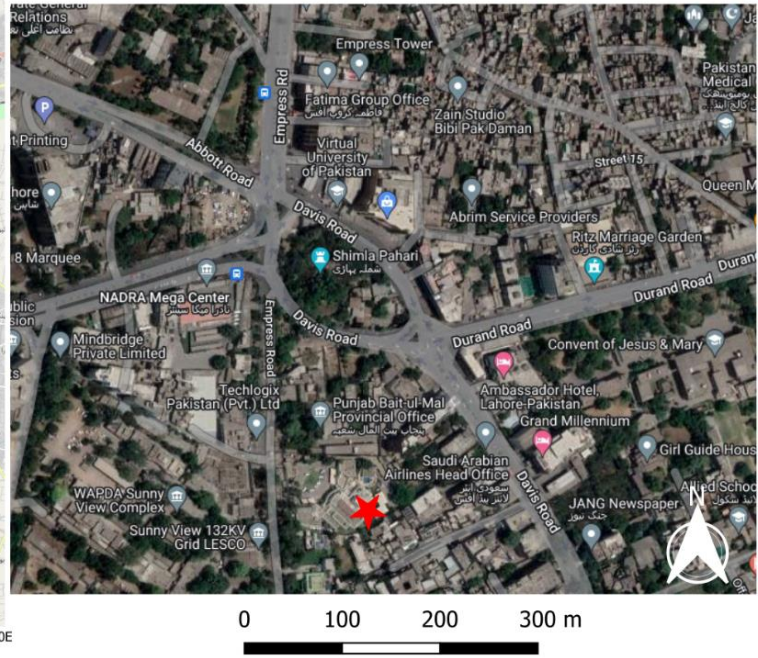
0-5	5.1-10	10.1-15	15.1-25	25.1-35	35.1-50	>50.1
Meets WHO guideline	Exceeds by 1 to 2 times	Exceeds by 2 to 3 times	Exceeds by 3 to 5 times	Exceeds by 5 to 7 times	Exceeds by 7 to 10 times	Exceeds by over 10 times

Rank	City	2022	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2021	2020
1	Lahore, Pakistan	97.4	133	102.5	85.6	69.3	60.9	52.1	47.8	46.2	64.2	123.2	190.5	192.9	86.5	79.2
2	Hotan, China	94.3	61.7	91.6	132.7	106.2	120.5	69.5	172.5	75	65.1	75	50.3	120	101.5	110.2
3	Bhiwadi, India	92.7	110.6	98	116.2	149.5	123.8	102.8	38.8	36.5	59.9	85.4	111.4	86.9	106.2	95.5
4	Delhi (NCT), India	92.6	141	100.9	91	98	73.2	56.2	34.3	31.1	38.3	99.7	176.8	171.9	96.4	84.1

https://www.iqair.com/us/world-most-polluted-cities?continent=&country=&state=&sort=-rank&page=1&perPage=50&cities=

Study site





Monitoring Site, Lahore

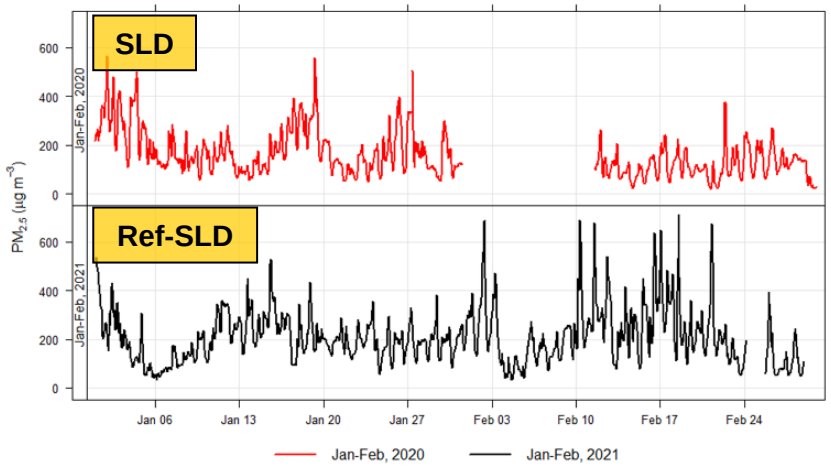
Data

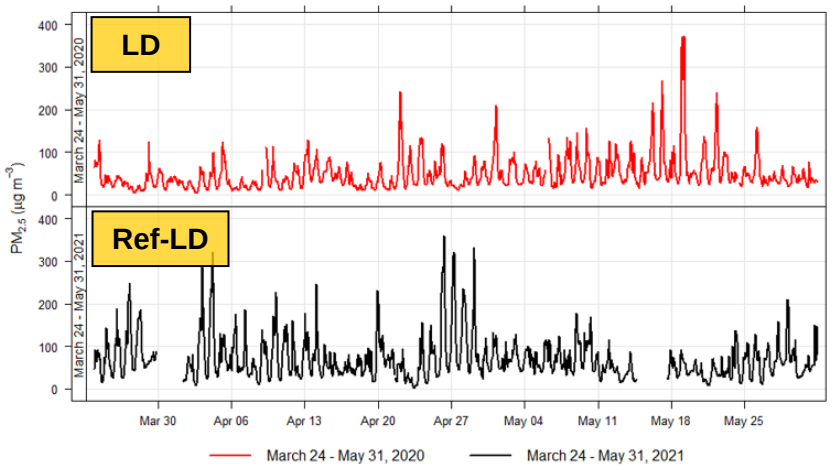
Data	Temporal/Spatial Resolution	Sources
Particulate Matter ($PM_{2.5}$); surface in-situ	Hourly, point measurement	https://pk.usembassy.gov/embassy-consulates/air-quality-data/
Nitrogen Dioxide (NO_2) Column Amount - TROPOMI (L3_NO_2)	Daily, (3.5 × 5.5 km^2)	https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S5P_NRTI_L3_NO2
Sulphur Dioxide (SO_2) Column Amount - TROPOMI (L3_SO_2)	Daily, (3.5 × 5.5 km^2)	https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S5P_NRTI_L3_SO2
Glyoxal ($C_2H_2O_2$) (VCD) GLYRETRO (GLYoxal Retrievals from TROPOMI)	Daily, 3.5 x 5.5 km^2	https://glyretro.aeronomie.be/index.php
Methane (CH_4) Copernicus Atmosphere Monitoring Service	Daily, 7° × 7°	https://eccad3.sedoo.fr/
Formaldehyde (HCHO) Column Amount-TROPOMI (L3_HCHO)	Daily, (3.5 × 5.5 km^2)	https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S5P_NRTI_L3_HCHO
Ozone (O_3) 6 km ozone column concentration-IASI(L3-O_3)	Daily 1° × 1°	https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-ozone-v1?tab=overview
Aerosol Optical Depth (AOD) (MOD08 D3 v6.1)	Daily, 1° × 1°	https://lpdaac.usgs.gov

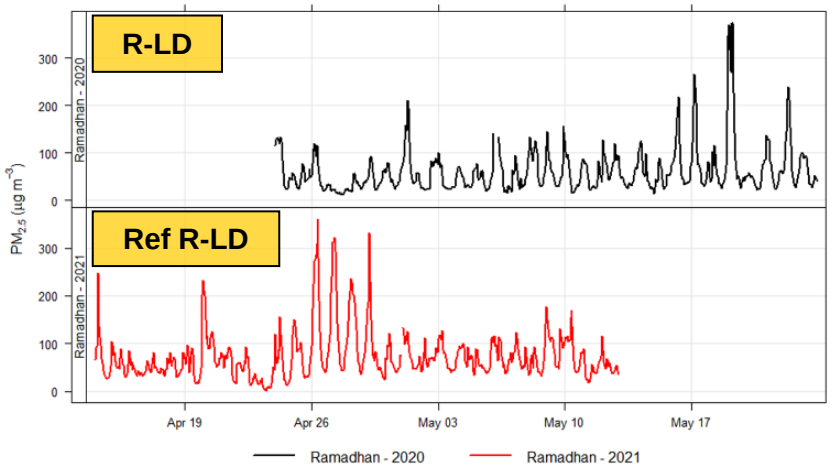
COVID 19 – lock down timelines, Lahore Pakistan

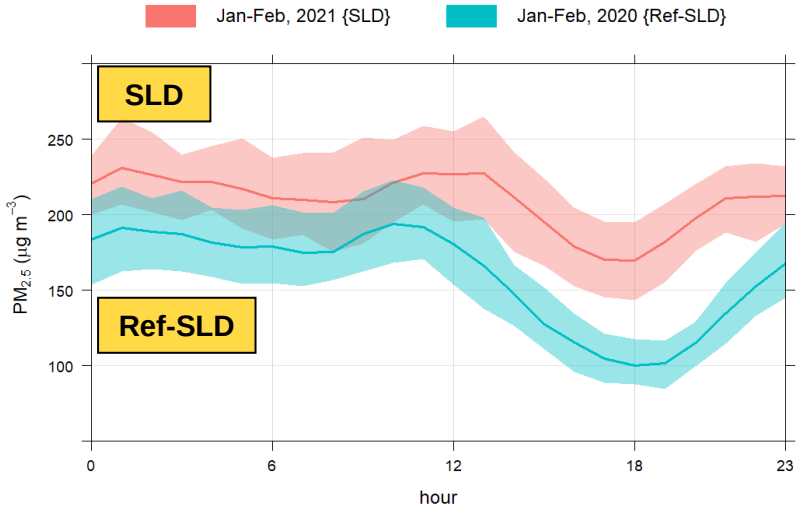
Phase	Description
Semi Lockdown (SLD) 1/1/2021 to 2/28/2021	• Office hours: 09:00 - 14:00 • Commercial markets/business activities close by 20:00 • Public transport occupancy limited to 50%, industrial activities exempted
Reference Semi Lockdown (Ref-SLD) 1/1/2020 to 2/29/ 2020	• Ref-SLD defined pre-pandemic • No restrictions on business, commercial, and routine activities “Business-as-usual"
Lockdown (LD) 3/24/2020 to 5/31/2020	• Business and commercial activities closed • Complete ban on public transport and gatherings • Ban on commercial and industrial activities
Reference to Lockdown (Ref-LD) 3/24/2021 to 5/31/2021	• Commercial activities and markets closed by 18:00 on weekdays • Complete closure on weekends • 50% office staff to work from home; industrial activities exempted
Ramadhan in LD 2020 (R-LD) 4/23/2020 to 5/23/2020	• Same as LD. Government allowed prayer congregations of up to five people.
Reference Period for Ramadhan LD (Ref-R-LD): 4/12/ 2021 to 5/12/2021	• Same as Ref-LD.

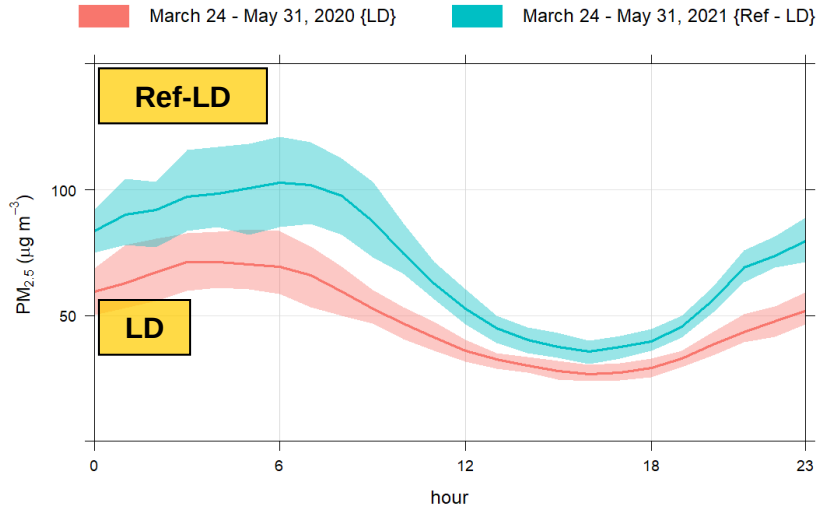
$PM_{2.5}$ time series and diurnal variation

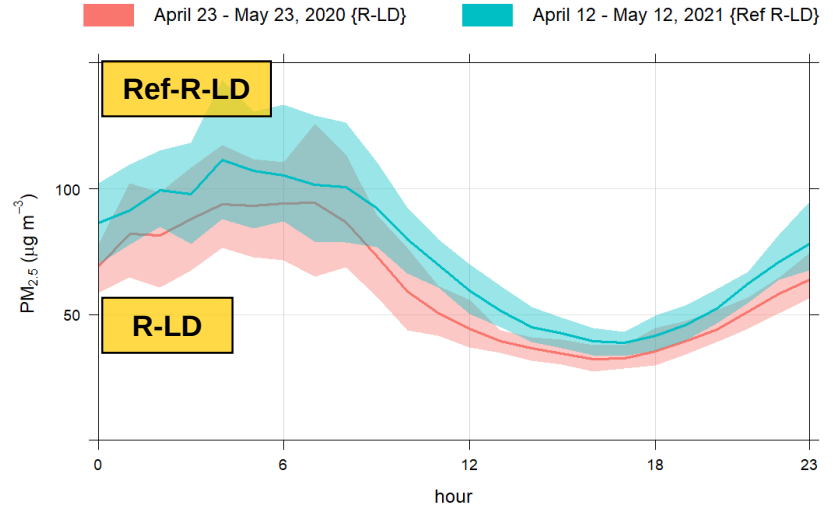




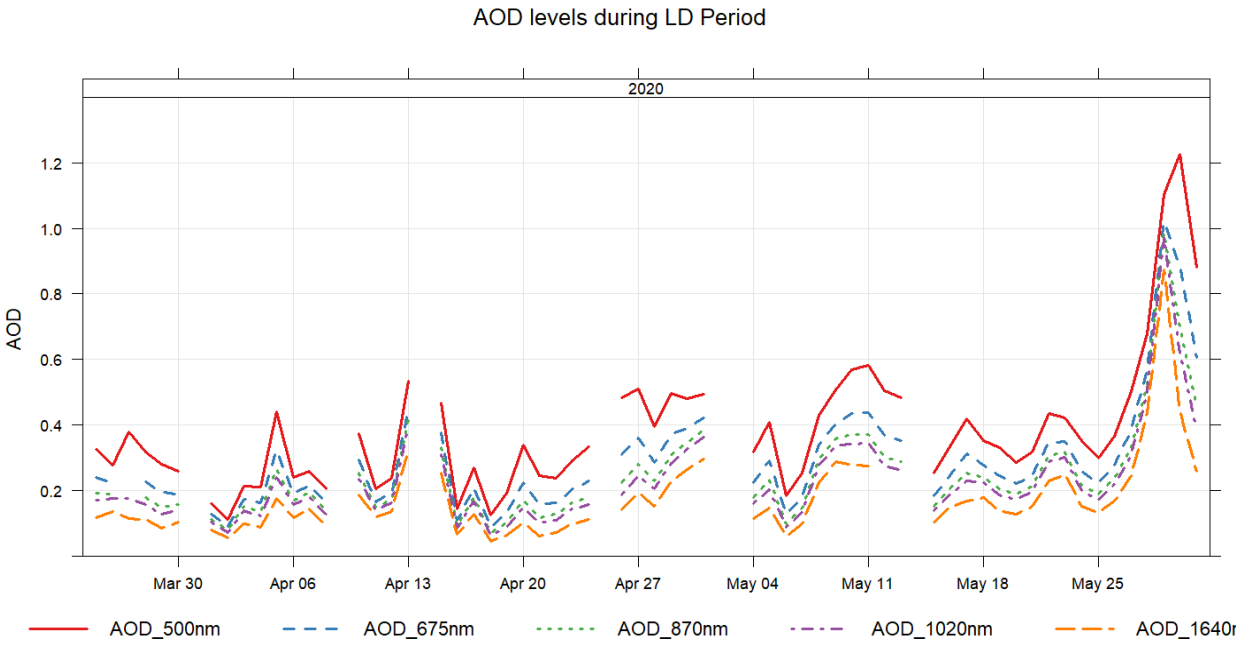




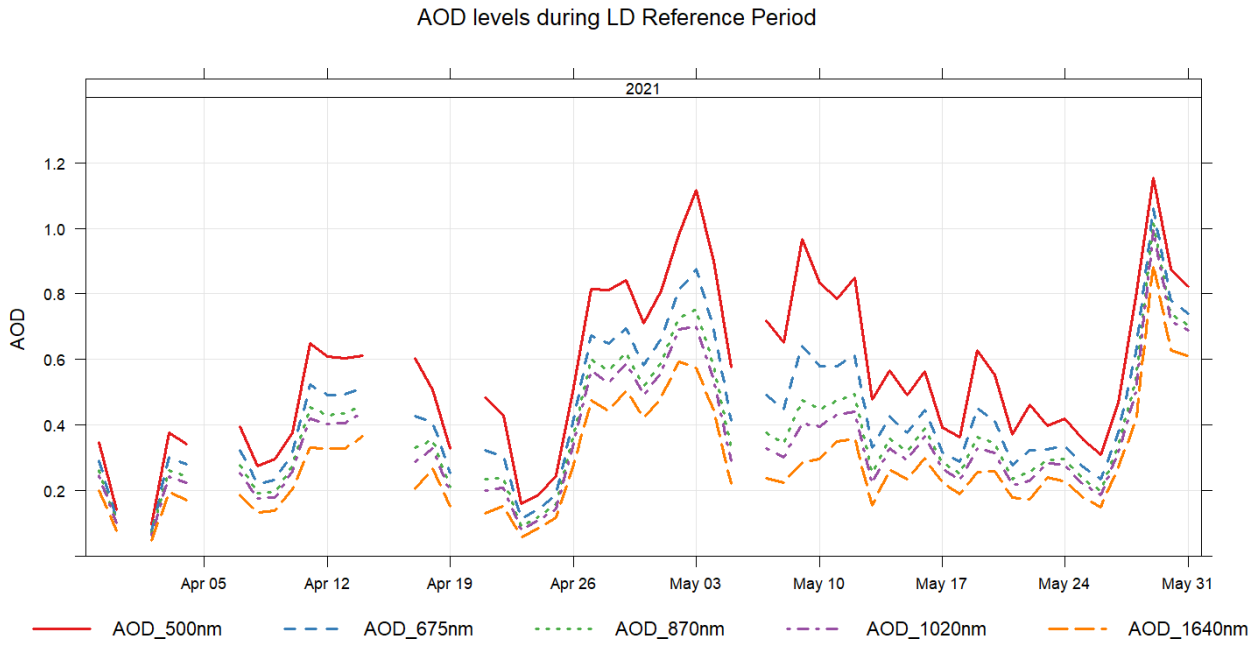




AERONET – Aerosol Optical Depth (AOD)

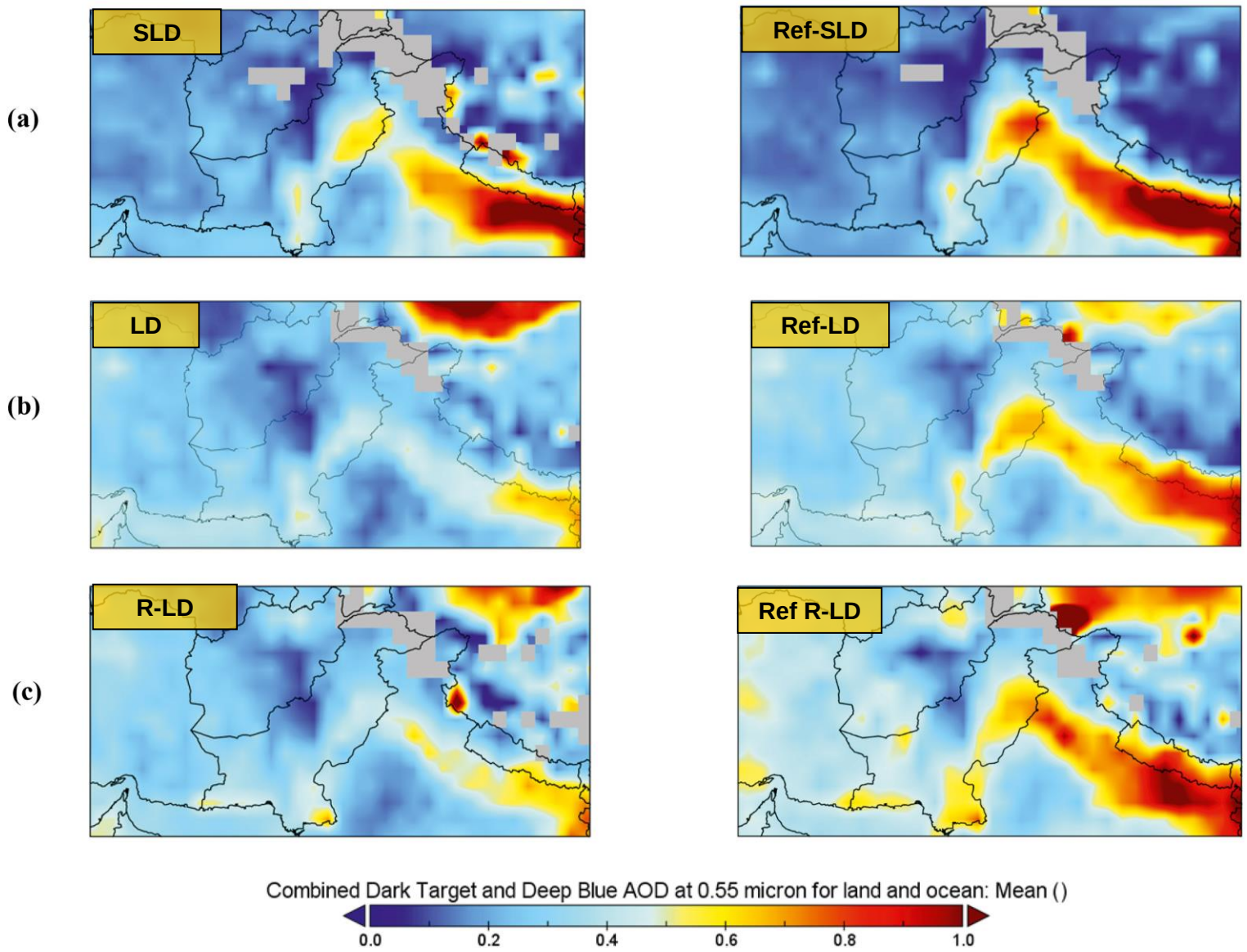


LD

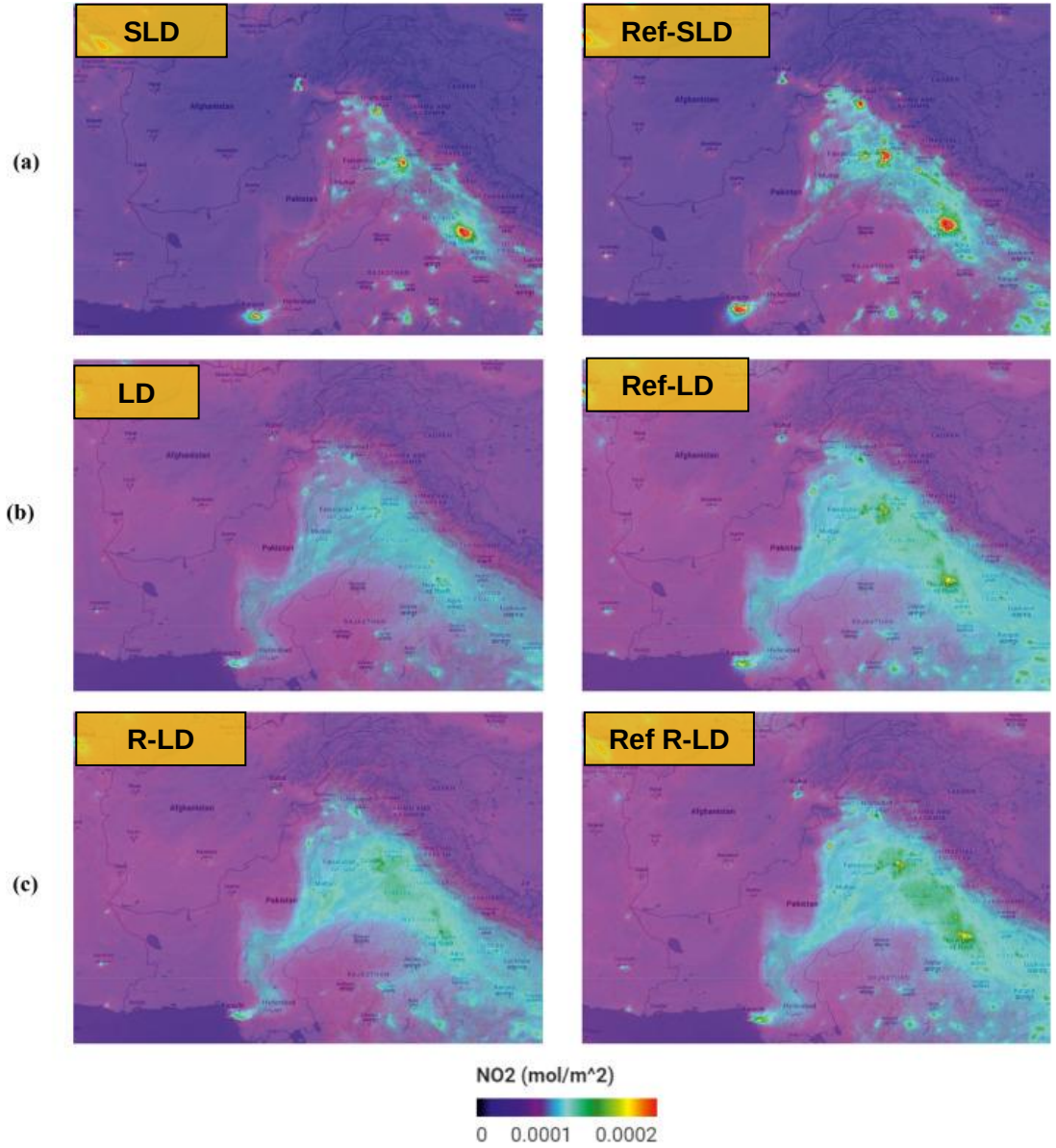


Ref-LD

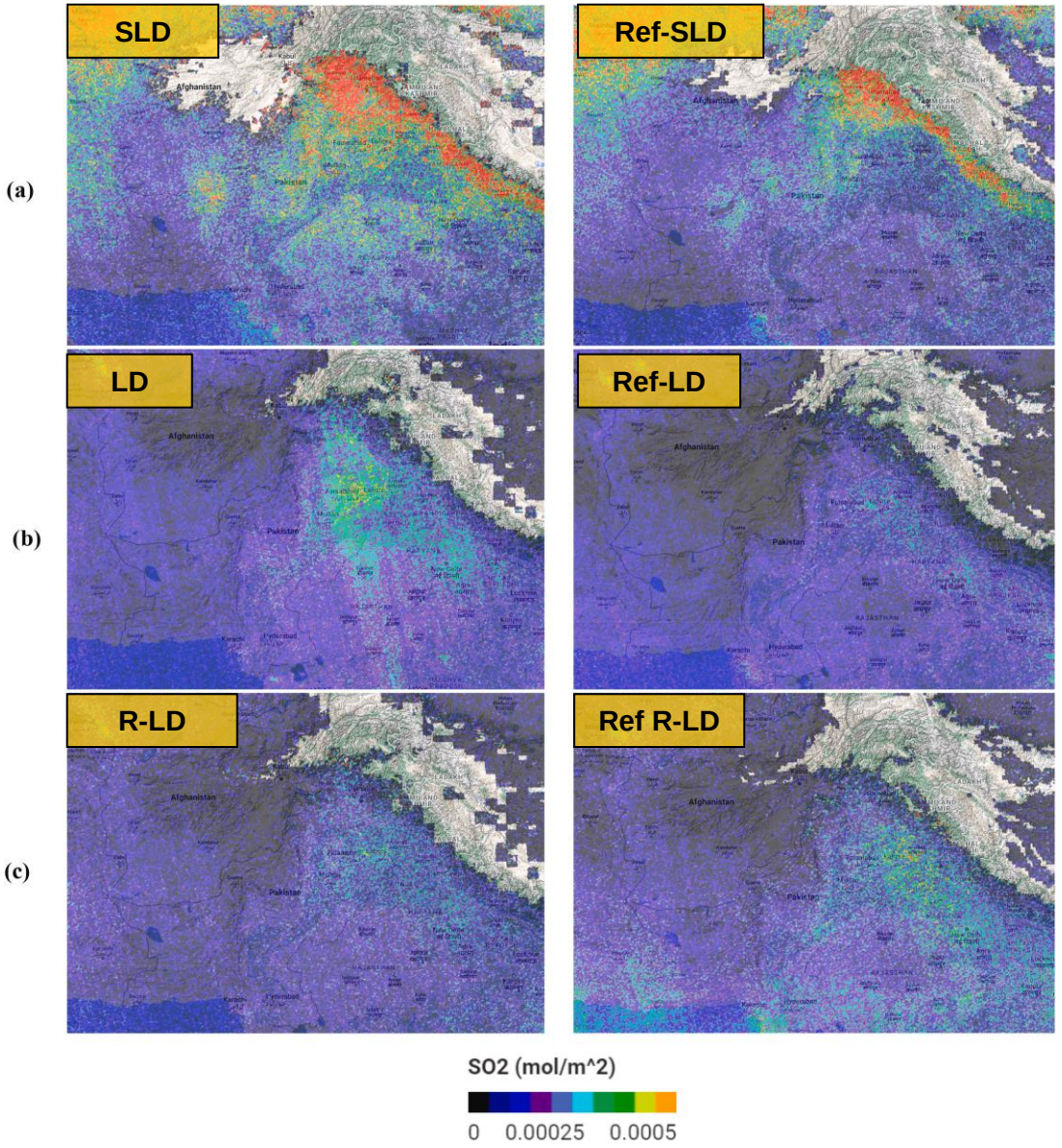
Aerosol Optical Depth



NO_2

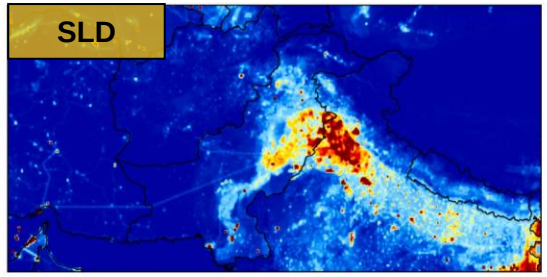

(a)
SLD
Ref-SLD
(b)
LD
Ref-LD
(c)
R-LD
Ref R-LD
NO2 (mol/m^2)
0 0.0001 0.0002

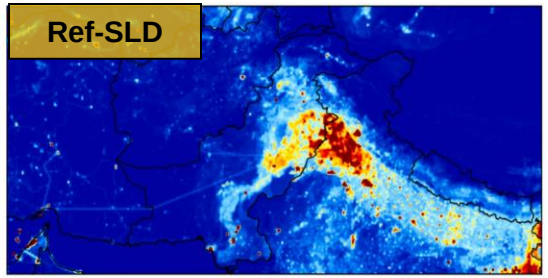
SO_2


(a)
SLD
Ref-SLD
(b)
LD
Ref-LD
(c)
R-LD
Ref R-LD
SO2 (mol/m^2)
0 0.00025 0.0005

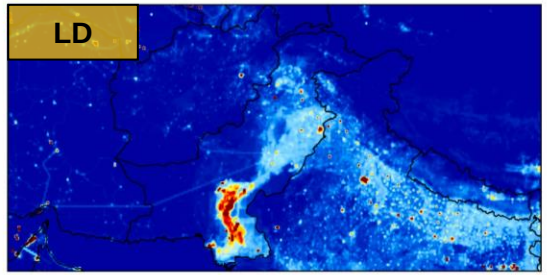
Methane

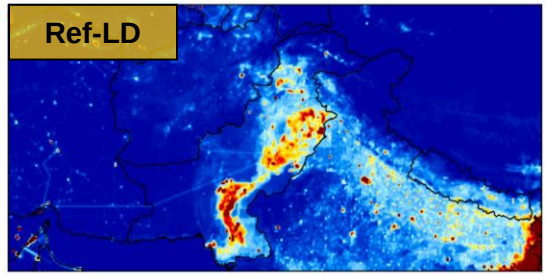
(a)





(b)





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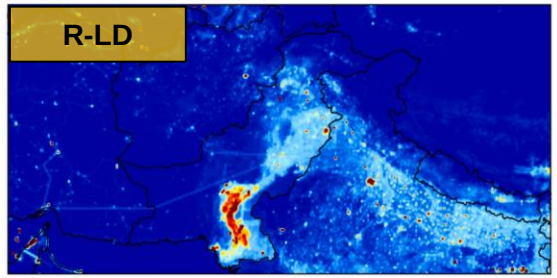
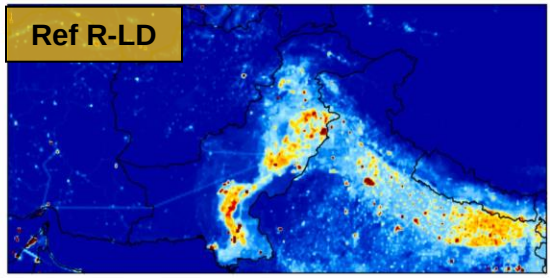
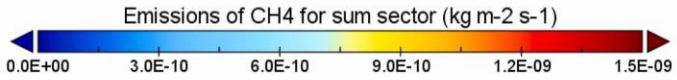
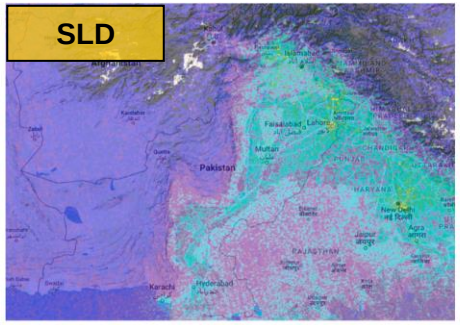


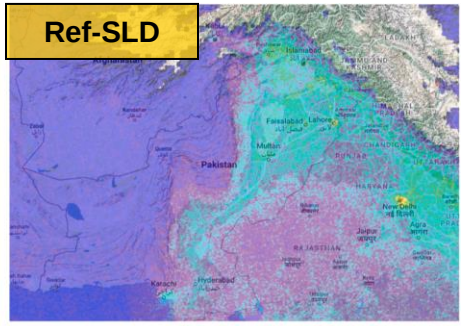




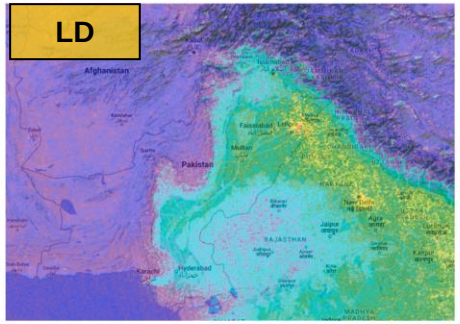
Formaldehyde

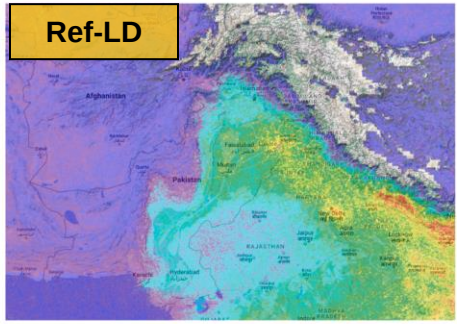
(a)





(b)





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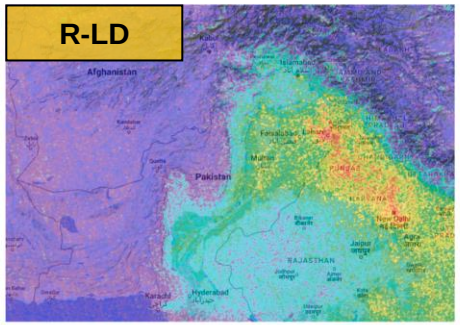
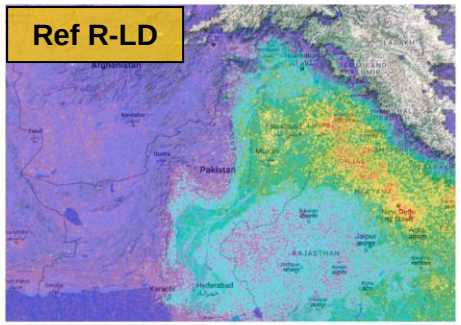
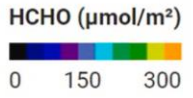
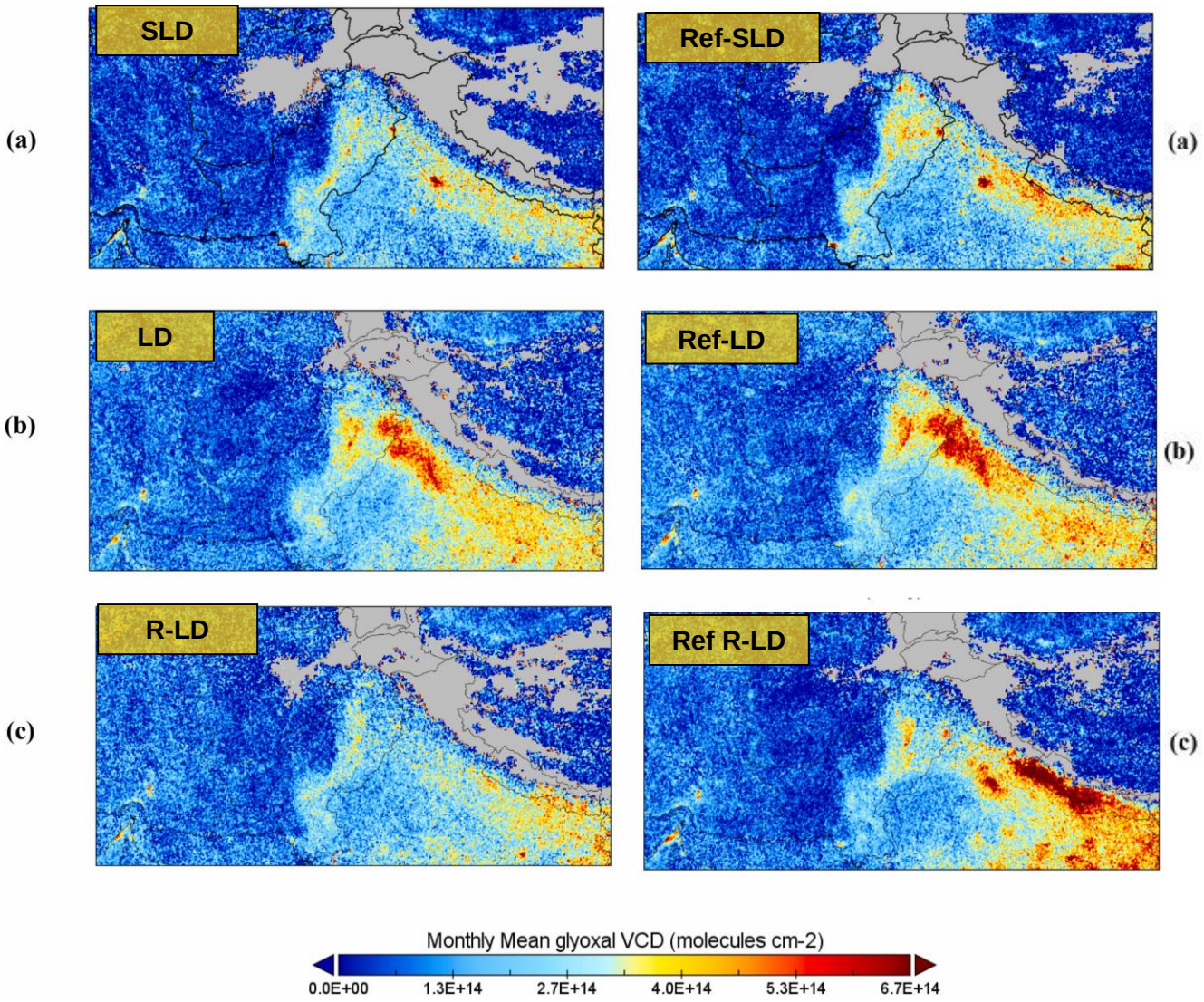


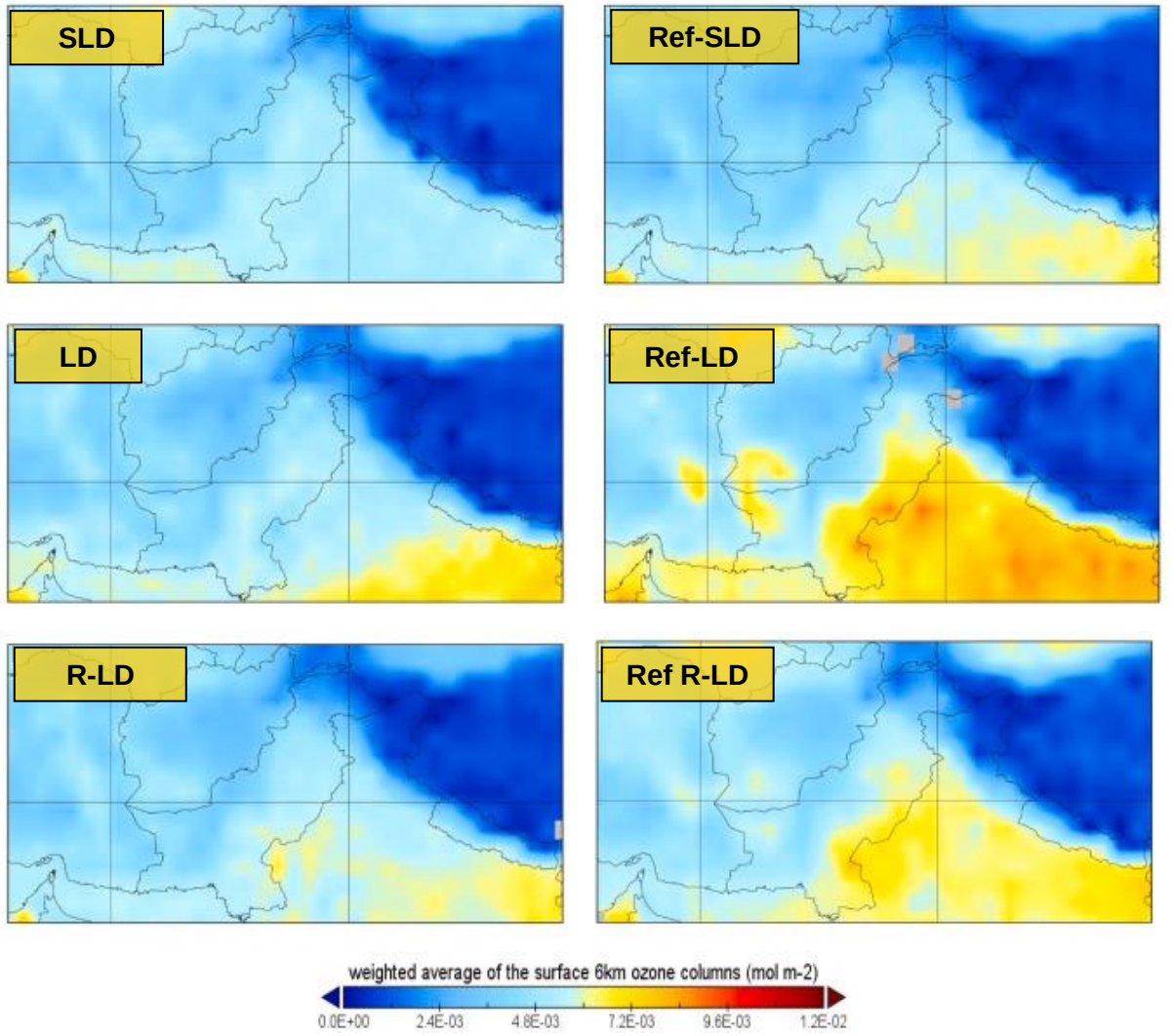




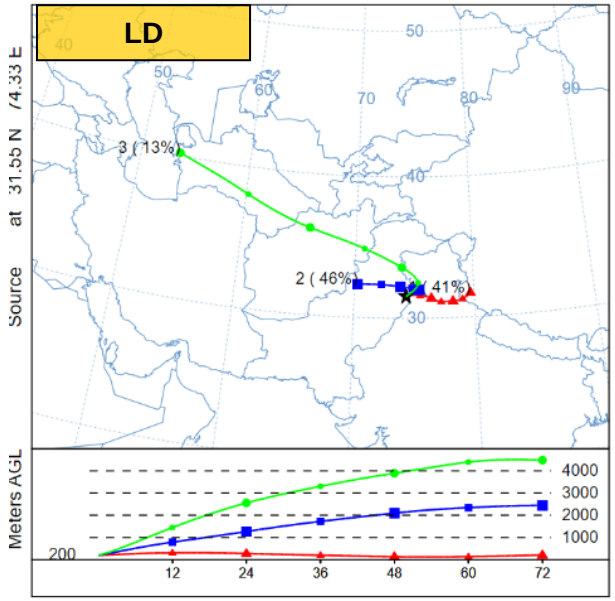
Glyoxal

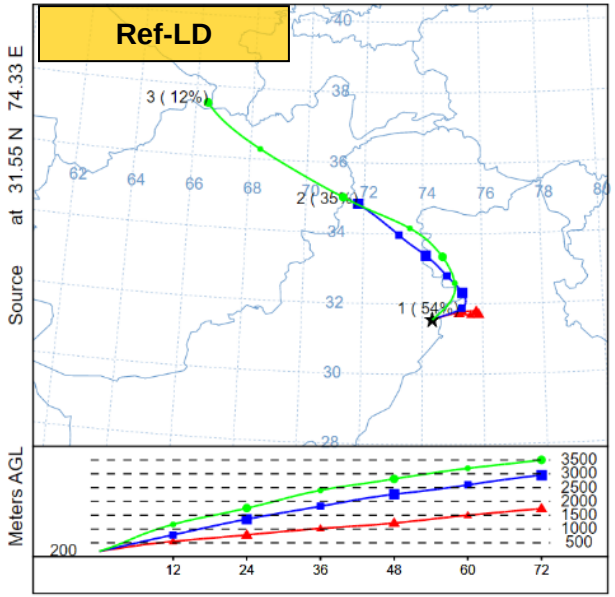


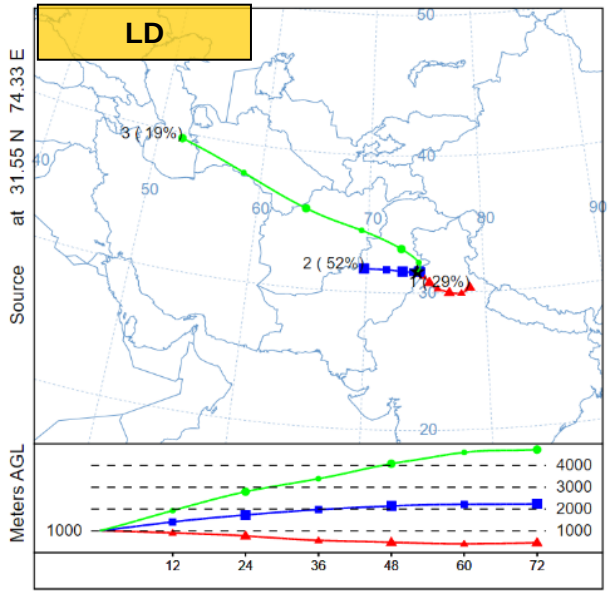
Ozone

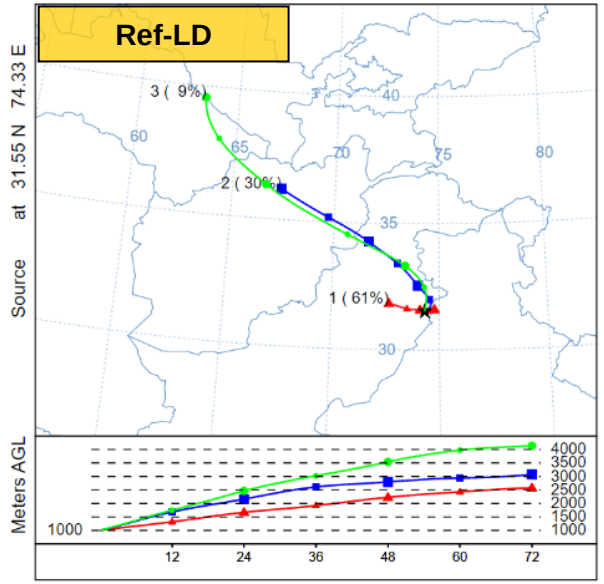


HYSPLIT

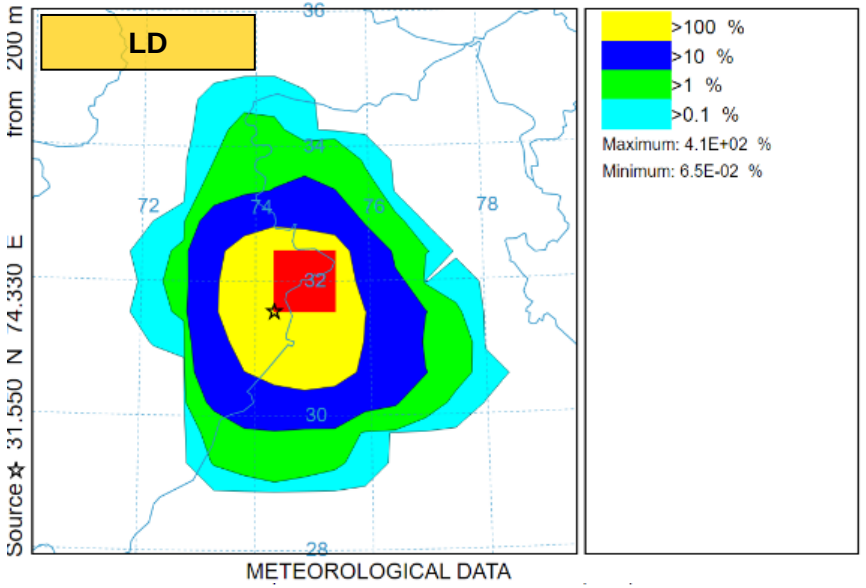

LD
Source at 31.55 N 74.33 E
3 (13%)
2 (46%)
(41%)
Meters AGL
4000
3000
2000
1000
200
12
24
36
48
60
72

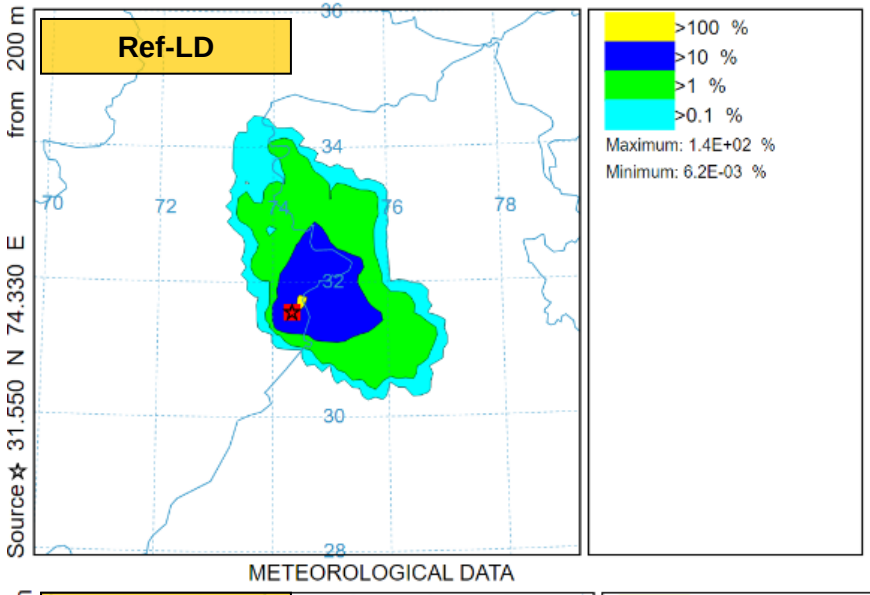

Ref-LD
Source at 31.55 N 74.33 E
3 (12%)
2 (35%)
1 (54%)
Meters AGL
3500
3000
2500
2000
1500
1000
500
200
12
24
36
48
60
72

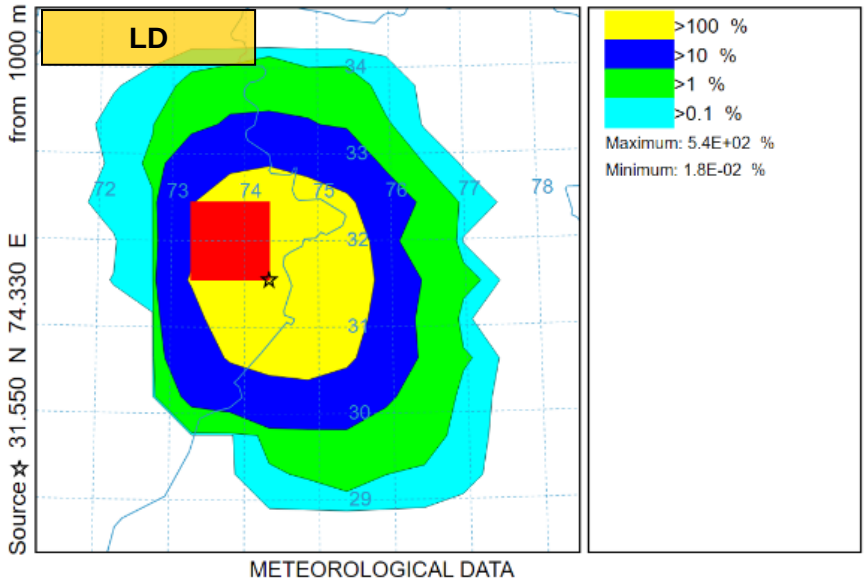

LD
Source at 31.55 N 74.33 E
3 (19%)
2 (52%)
(29%)
Meters AGL
4000
3000
2000
1000
1000
12
24
36
48
60
72

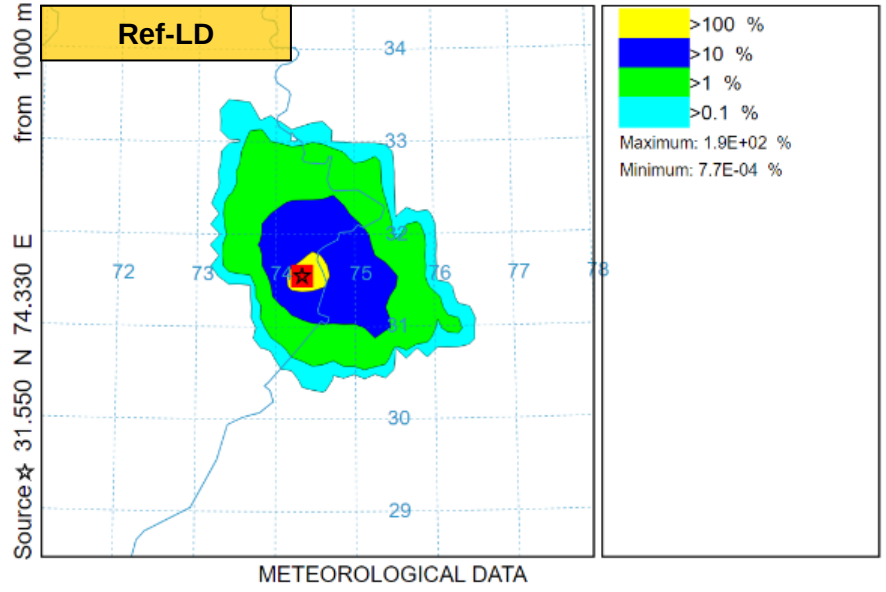

Ref-LD
Source at 31.55 N 74.33 E
3 (9%)
2 (30%)
1 (61%)
Meters AGL
4000
3500
3000
2500
2000
1500
1000
1000
12
24
36
48
60
72

HYSPLIT


LD
>100 %
>10 %
>1 %
>0.1 %
Maximum: 4.1E+02 %
Minimum: 6.5E-02 %
from 200 m
Source ☆ 31.550 N 74.330 E
METEOROLOGICAL DATA


Ref-LD
>100 %
>10 %
>1 %
>0.1 %
Maximum: 1.4E+02 %
Minimum: 6.2E-03 %
from 200 m
Source ☆ 31.550 N 74.330 E
METEOROLOGICAL DATA


LD
>100 %
>10 %
>1 %
>0.1 %
Maximum: 5.4E+02 %
Minimum: 1.8E-02 %
from 1000 m
Source ☆ 31.550 N 74.330 E
METEOROLOGICAL DATA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>10 %
>1 %
>0.1 %
Maximum: 1.9E+02 %
Minimum: 7.7E-04 %
from 1000 m
Source ☆ 31.550 N 74.330 E
METEOROLOGICAL DATA

Conclusion

- **Lockdown Impact:**
  Significant (38%) PM2.5 reduction in Lahore during COVID-19 lockdown.

- **Chemical Regime Shifts:**
  Varied responses in trace gases; notable declines in NO_2, CH_4, and O_3

- **HYSPLIT**: Reveals stable regional flows in lockdown and reference periods.
  1. Local and Regional Impact: Lower altitudes show local emissions and eastward transport.
  2. Altitude Influence: Higher altitudes experience limited impact and westerly flows

- **Future Outlook:**
  Emphasize need for emission control, technical solutions without stringent personal restrictions.

Acknowledgement:

1. $AERONET_{AOD}$ NASA Goddard Space Flight Center AERONET Project (http://aeronet.gsfc.nasa.gov)
2. $PM_{2.5}$ Data retrieval, US EPA (https://www.airnow.gov/)
3. NOAA HYSPLIT Backward trajectories (https://www.ready.noaa.gov/hypub-bin/trajtype.pl?runtype=archive)
4. $MODIS_{DB}$ AOD NASA Giovanni website (http://Giovanni.gsfc.nasa.gov/giovanni)
5. TROPOMI for NO_2, SO2, HCHO and C2H2O2 data retrieval, IASI for ozone and CAMS for CH_4

References:

Karim, I., Rappenglück, B., 2023. Impact of Covid-19 lockdown regulations on PM2.5 and trace gases (NO_2, SO_2, CH_4, HCHO, $C_2H_2O_2$ and O_3) over Lahore, Pakistan. Atmospheric Environment 303, 119746. https://doi.org/10.1016/j.atmosenv.2023.119746