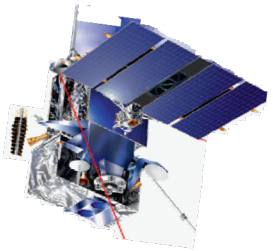

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Exploring the Trends of Aerosols and Atmospheric Pollutants in the Changing Climate of Pakistan

Muhammad Fahim Khokhar
& C-CARGO Team

Climate Change & Atmospheric chemistry Research Group
C-CARGO

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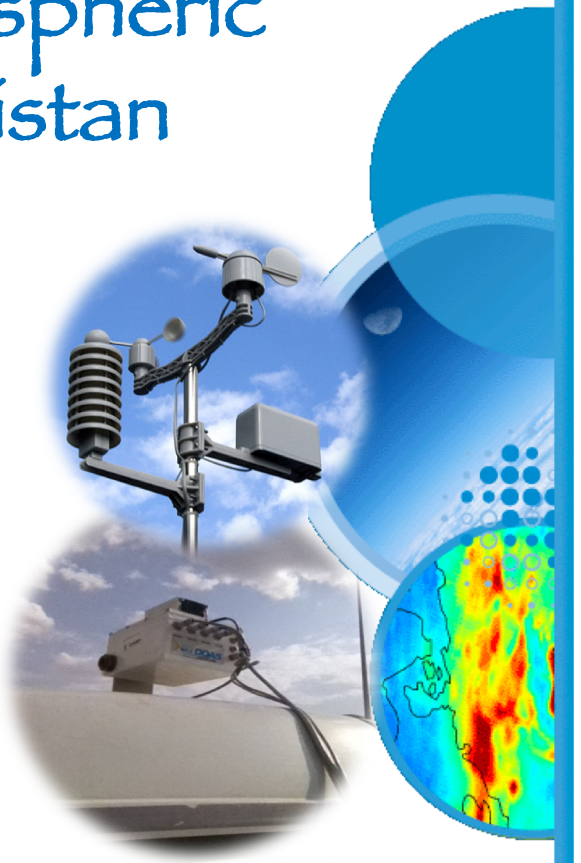

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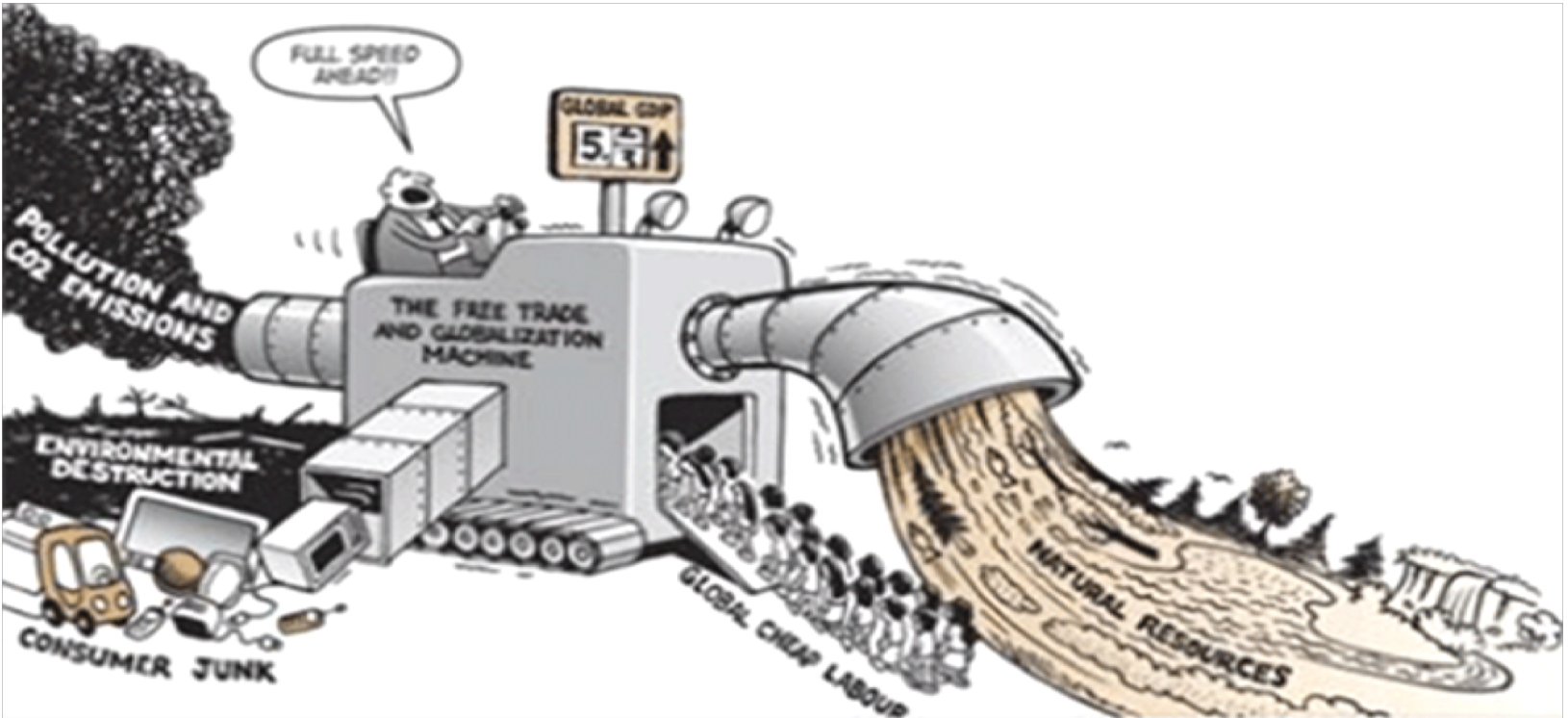
Bridging the Gaps from Local to Global

World of Exponential Growth

World's population has increased from 0.9 billions in Year 1800 to 7.6 billions in Year 2018

Substantial exploitation of Natural resources and release of GHGs and other toxic pollutants

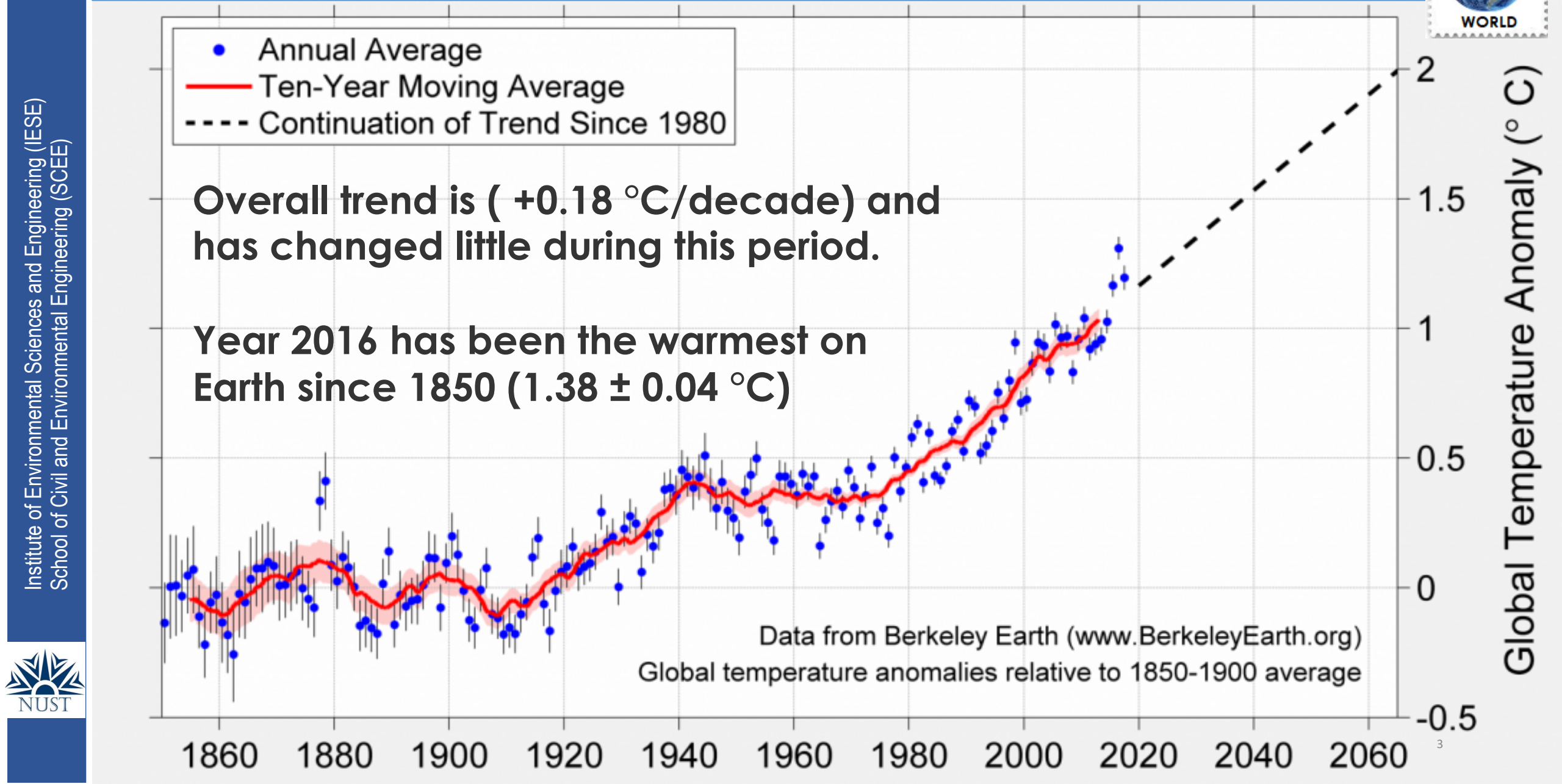
Damages to Environment e.g. Global warming



- Human activities contr to climate change by causing changes in Earth's atmosphere
- The largest known contributior comes from the burning of fossil fuels and consequent emissions of four principal GHGs: CO_2, CH_4, N_2O and CFCs gas to the atmosphere

(IPCC, 2013, 5th AR)

Global Warming Trends Since 1850 (1850-1900avg.)



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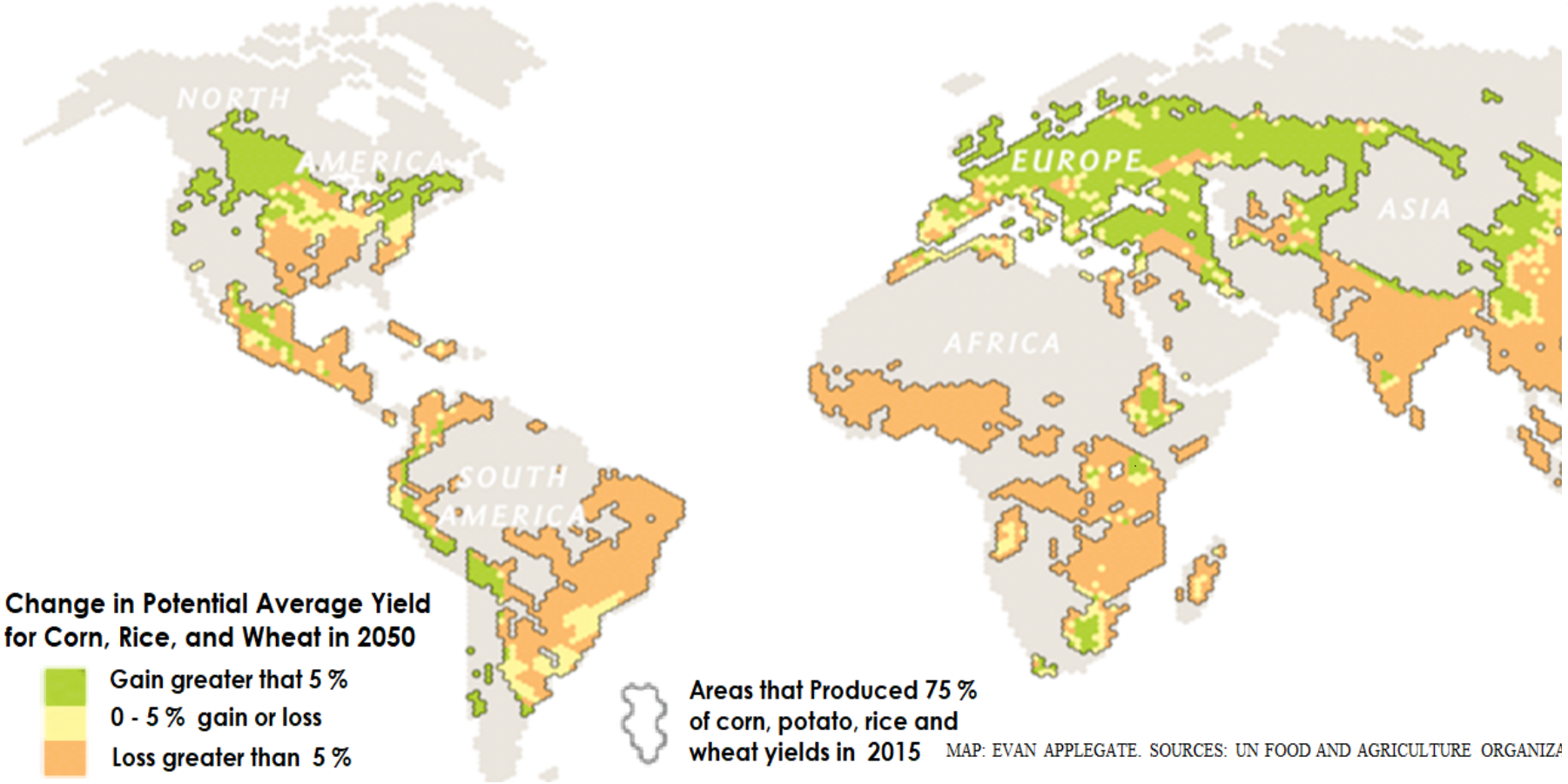
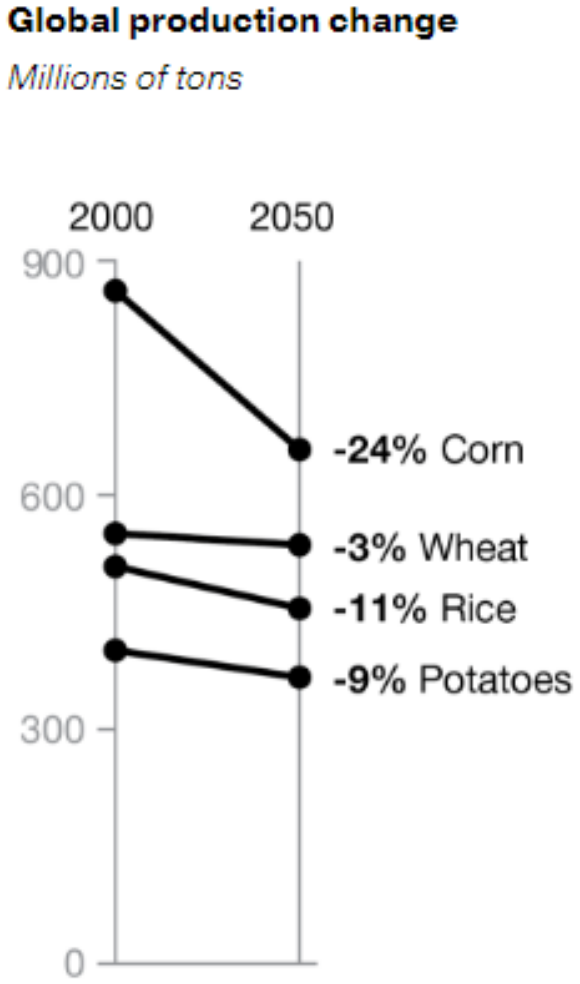
Climate Change & Agriculture

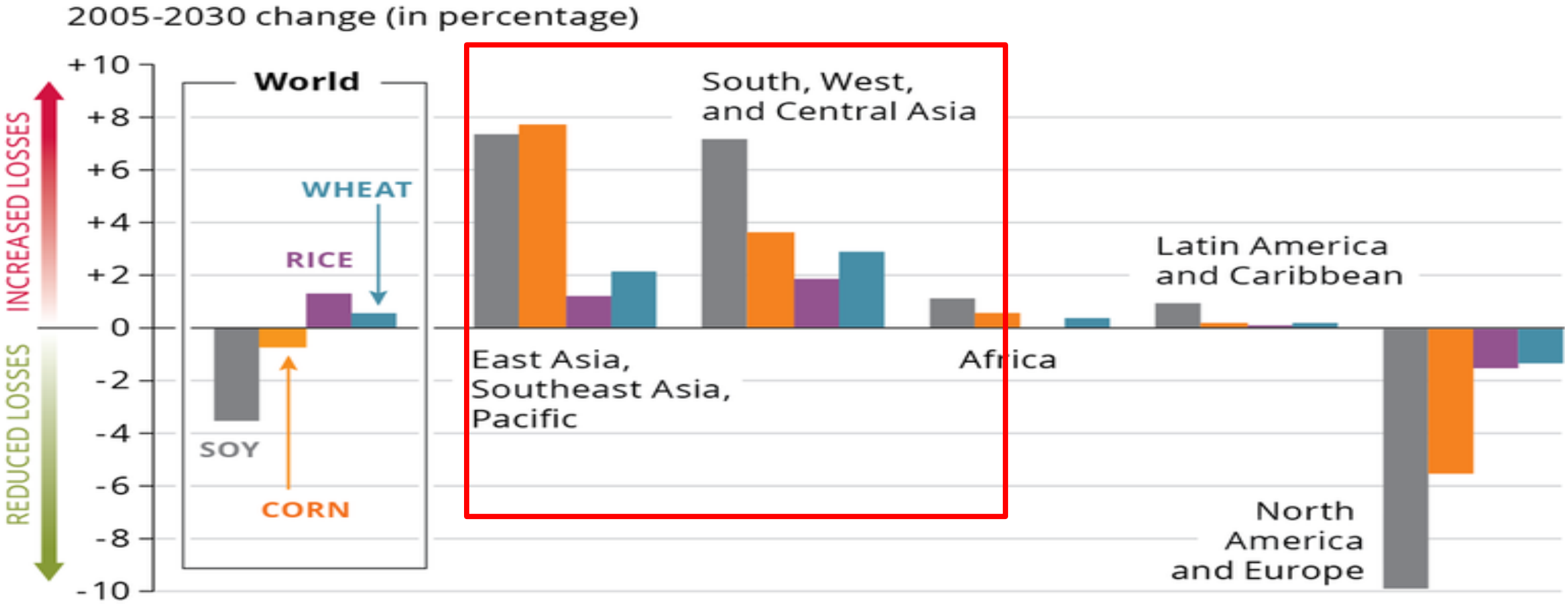
Climate change may actually benefit some plants by lengthening growing seasons and increasing carbon dioxide.

Plants might be effected by warmer world, such as more pests, droughts, and flooding, will be less benign.





Projected differences in relative yield losses for wheat, rice, maize and soy beans due to high ozone concentrations, major world regions, 2005–2030



Source: UNEP and WHO (2011)

Note: the 2030 scenario assumes the implementation of current legislation for the major world regions. Positive relative yield loss values signify increased yield losses in 2030 compared with 2005.

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Climate Change & Agriculture

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By **2030**, nine out of 10 of the major crops will experience reduced or stagnant growth rates, while average prices will increase dramatically as a result,

Data source: Farming First

Climate Change and Pakistan

- Pakistan is the sixth most populous country in the world
- is described as an 'agrarian economy'.
- 47% of the country's workforce is currently employed in the agriculture sector, contributing to 24% of the total GDP.
- Global Warming of 1 °C rise in temperature, Pakistan's wheat yield is estimated to decline by 6-9% (Mustafa, 2011)
- According to FAO, 2015 the country presently suffers from 41.4 million under-nourished people.

Pakistan 7th
most vulnerable country to climate change, says Germanwatch

Between 1997 and 2016,
Pakistan lost an average of
523.1 lives
per year due to climate change effects

Climate Change and Pakistan

The Frequency of Heat waves and Deaths related have been increased 5 folds During 1997-2016

Heat Wave in 2015 in Karachi death were increased by 1200 people

- Global warming provides favorable environment for malaria, dengue and cholera in Pakistan

  (IPCC, 2013; Mustafa, 2011)

  - **Dengue Fever >> During Year 2011, 14,000 people were infected and 350 causalities were reported**
  - **Especially, during year 2016-17, Dengue fever breakout in the northern high latitudes of Pakistan**

Pakistan has suffered 141 extreme weather events (1997-2016)

Mean annual temperatures will increase by more than 4°C in northern Pakistan and by around 4°C for southern Pakistan by the end of the 21st century.

The rate of warming is expected to be greater in the winter than in the summer (GFDRR, 2011)

Climatic Change and Socio-Economic Growth

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2010 Super Flood killed 1600 people, inundated an area of 38,600 sq. km and caused a damage worth around $10 billion

- Such events also slow down the pace of development in countries
  - With constraint economy
  - Extras stress on economy: War against terror;
    Afghan Refugees; IDPs

- It is strongly needed to implement strategies
  - efficient & cost effective

- to cope with impacts of such extreme weather events and climate change in order to avoid drastic losses

The future cost of climate impacts is estimated between $6 billion to $14 billion per year over the next 40 years.

Warming Trends >> Temperature Anomaly in Pakistan

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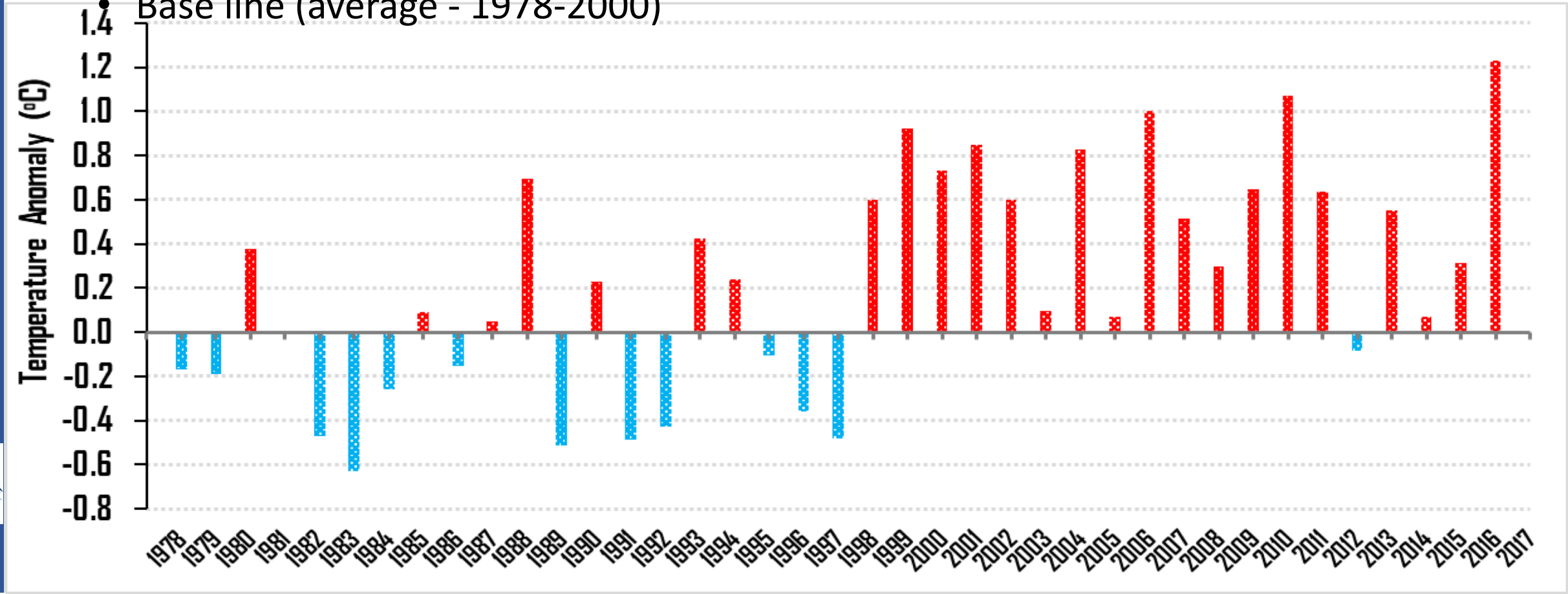
Data: Pakistan Meteorological Department (PMD) monitoring network

- Daily and Monthly averages
- 97 stations across Pakistan
- Base line (average - 1978-2000)

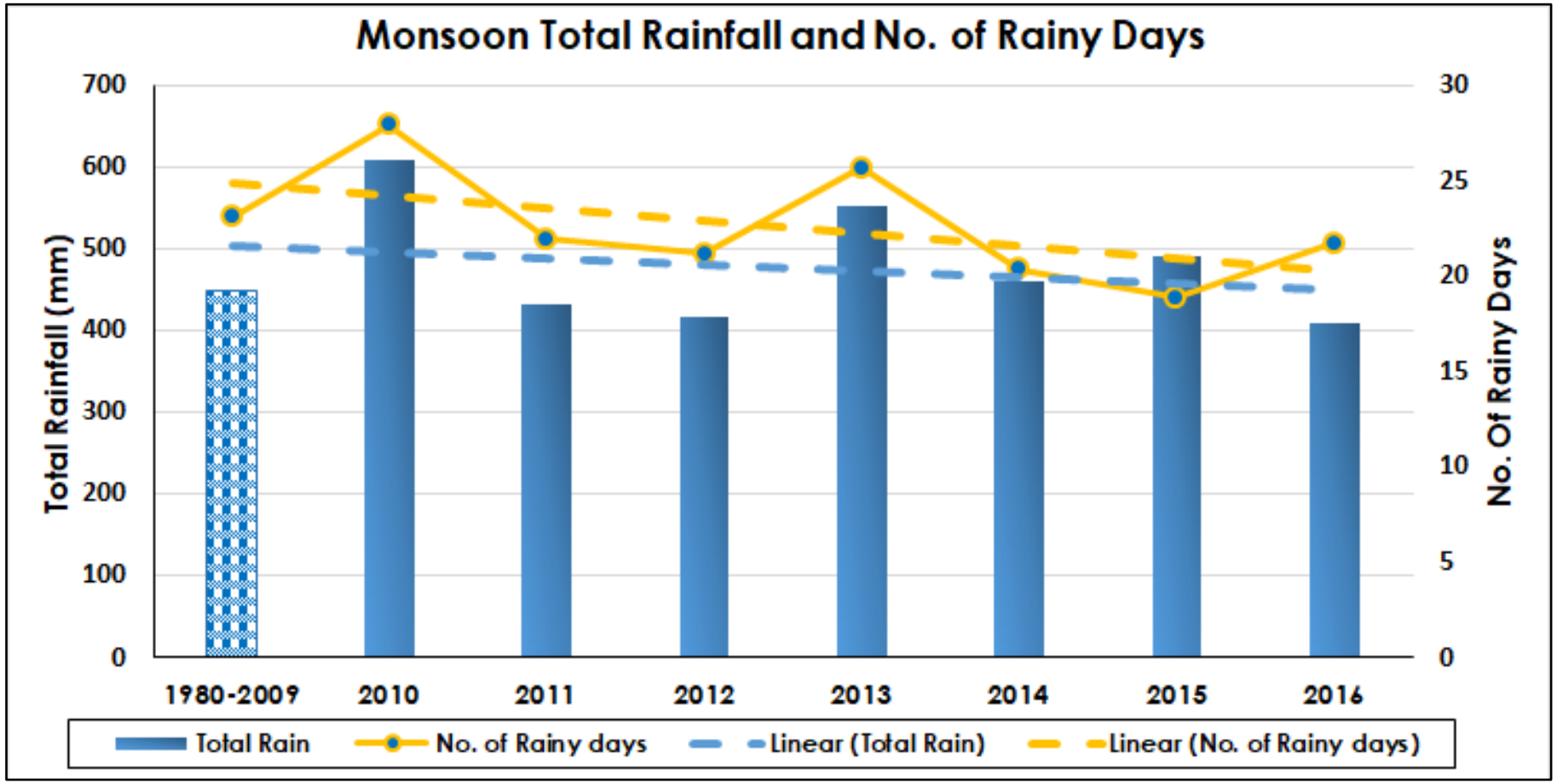
- **Pakistan recorded year 2016 as the warmest year on the record (1.2° C) since 1978**



Climate Trends >> Precipitation Anomaly in Pakistan

- Most of the rainfall over Indian subcontinent is contributed by the monsoon
- Rainfall in monsoon has become less frequent but intense rains

	Absolute Change (mm)	Yearly Abs Change (mm)	Relative Change (%)
Total Rainfall	-55	-7.81	-10.8
No Of Rainy Days	-5 day	-0.67 day	-25



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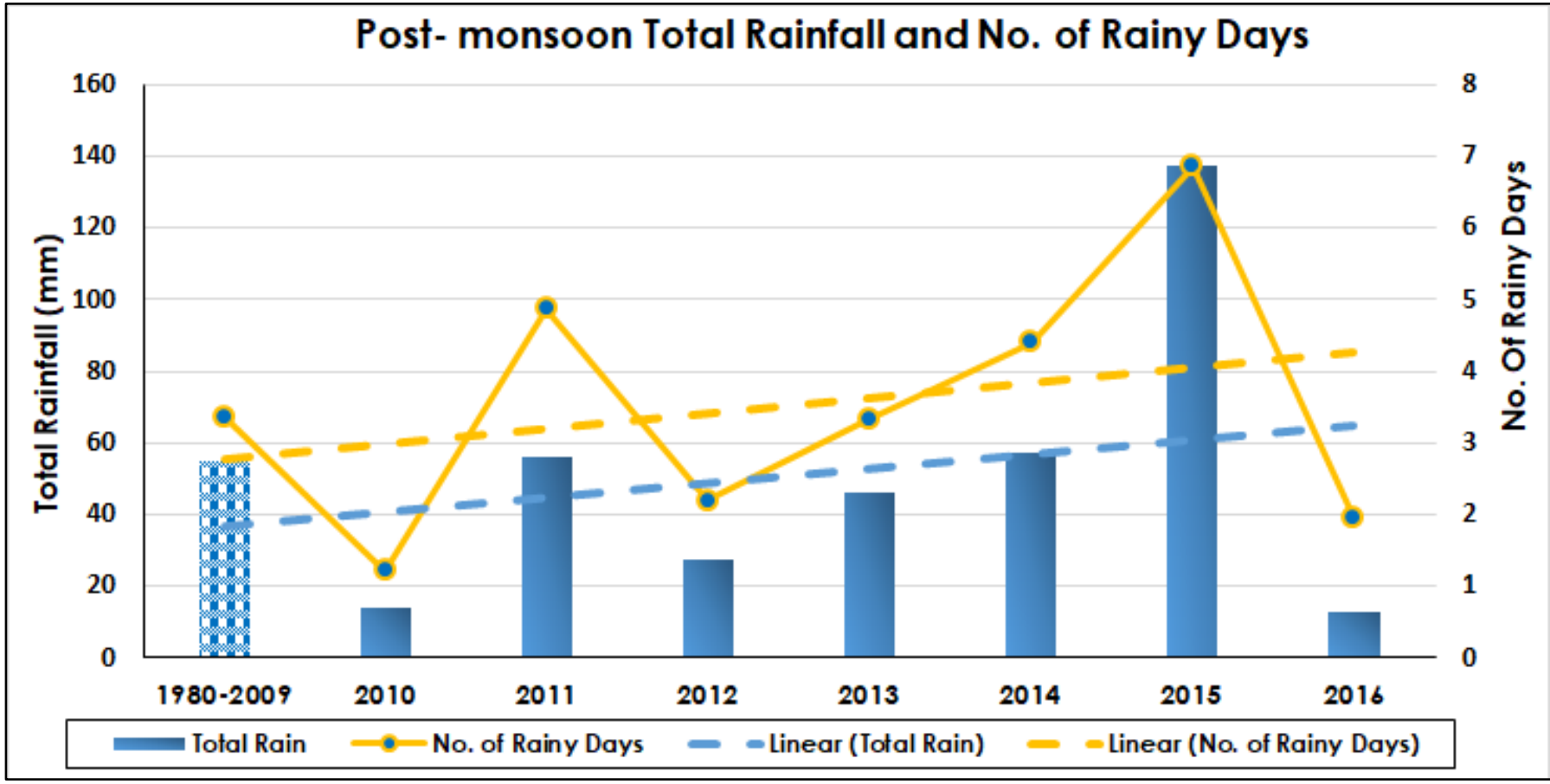
Climate Trends >> Precipitation Anomaly in Pakistan

- Most of the rainfall over Indian subcontinent is contributed by the monsoon
- Rainfall in post-monsoon has been increased along with frequency of rainy days as well

	Absolute Change	Yearly Abs Change	Relative Change (%)
Total Rainfall	28 (mm)	4 (mm)	75.7
No Of Rainy Days	1.5 (day)	0.27 (day)	53.4



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Climate Trends >> Precipitation Anomaly in Pakistan

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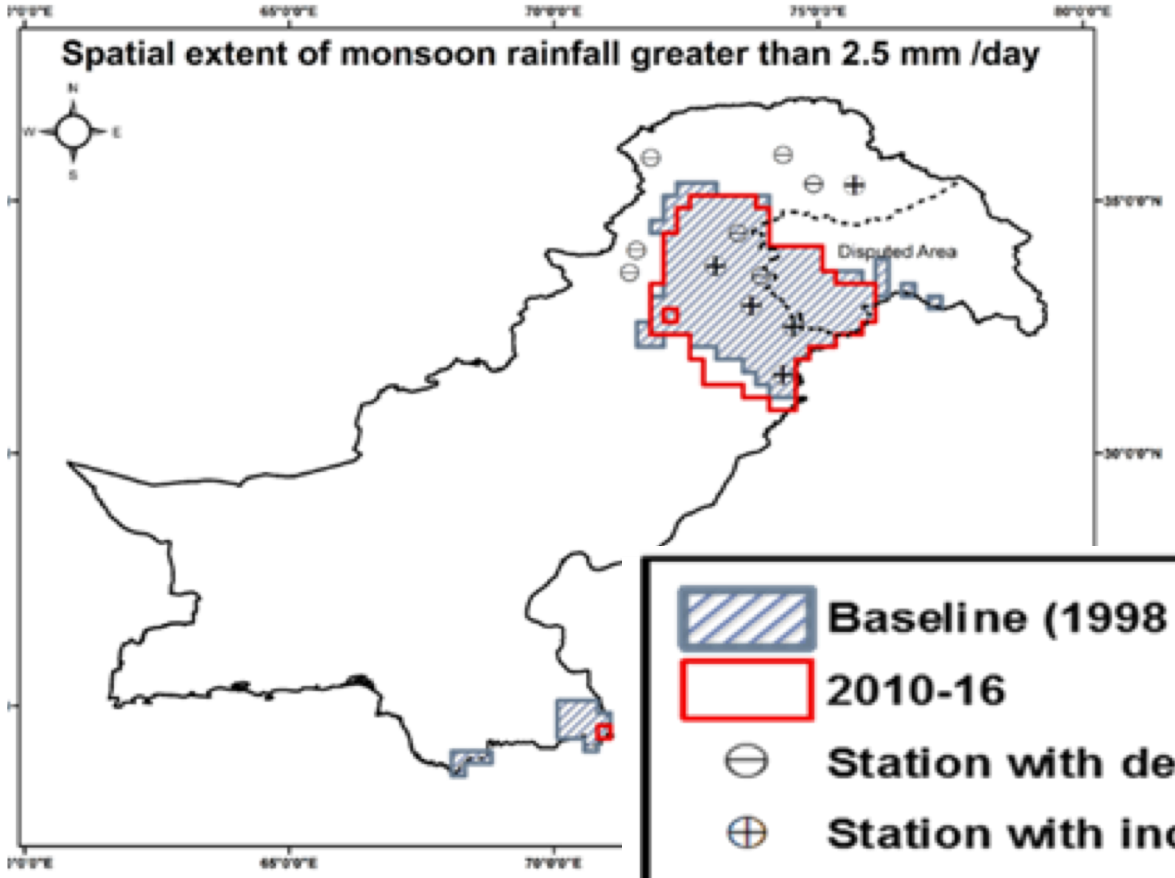
According to PMD a rainy day = 2.5 mm/day

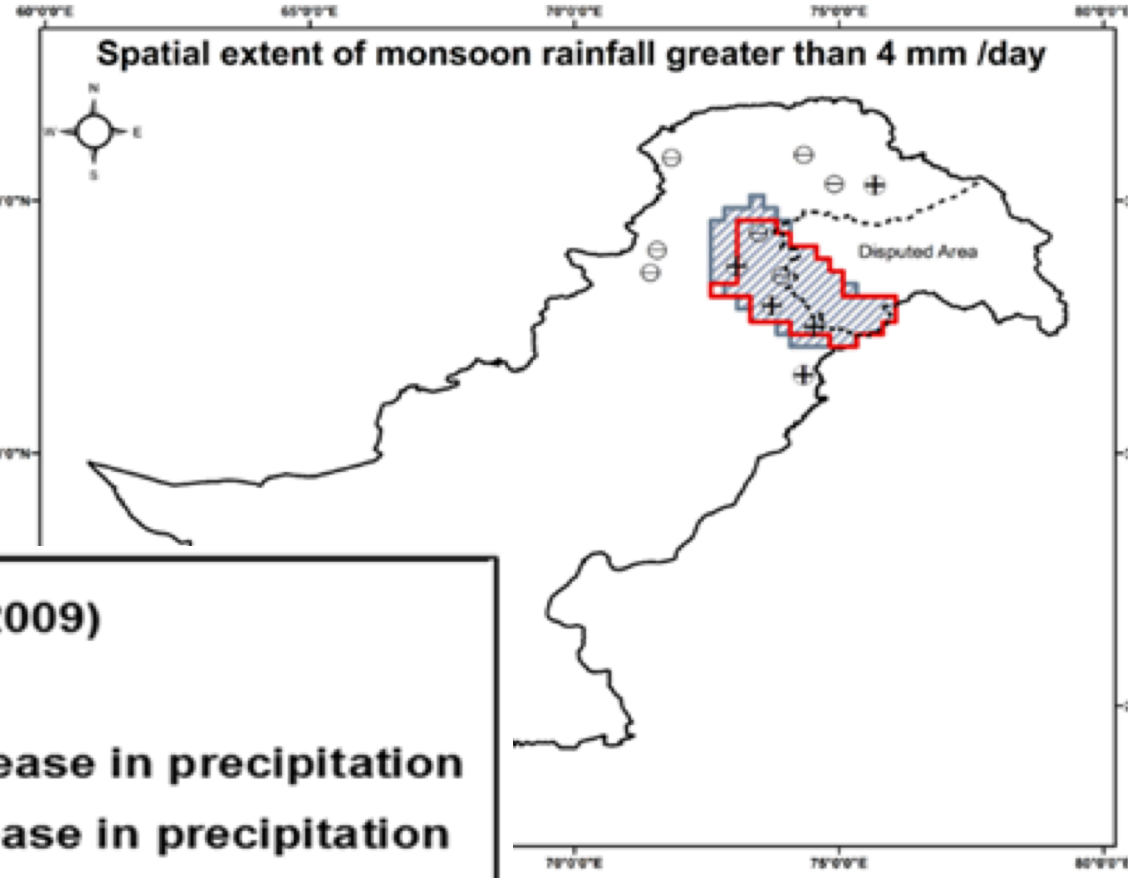
PMD Monitoring Network and TRMM observations

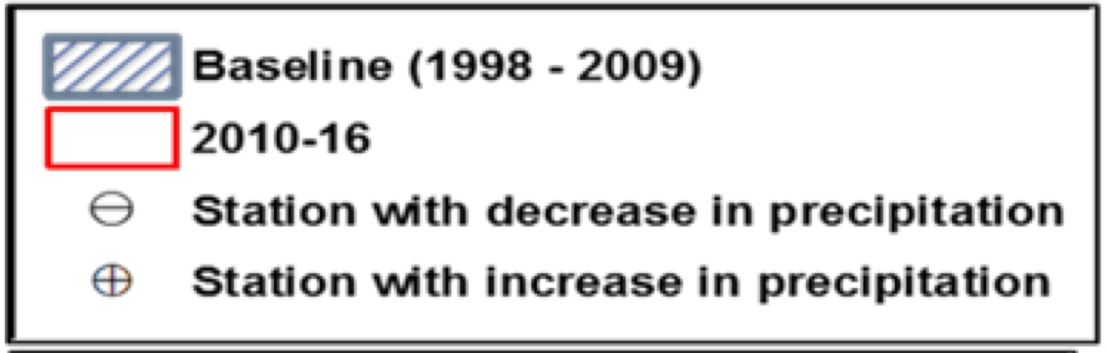
- Daily and Monthly averages of 12 stations
- Base line (1998-2009)
- Analysis (2010-2016)

Shift Observed

Rain Fall (2.5 mm/day)	S and SE
Rain Fall (4 mm/day)	South-east ward



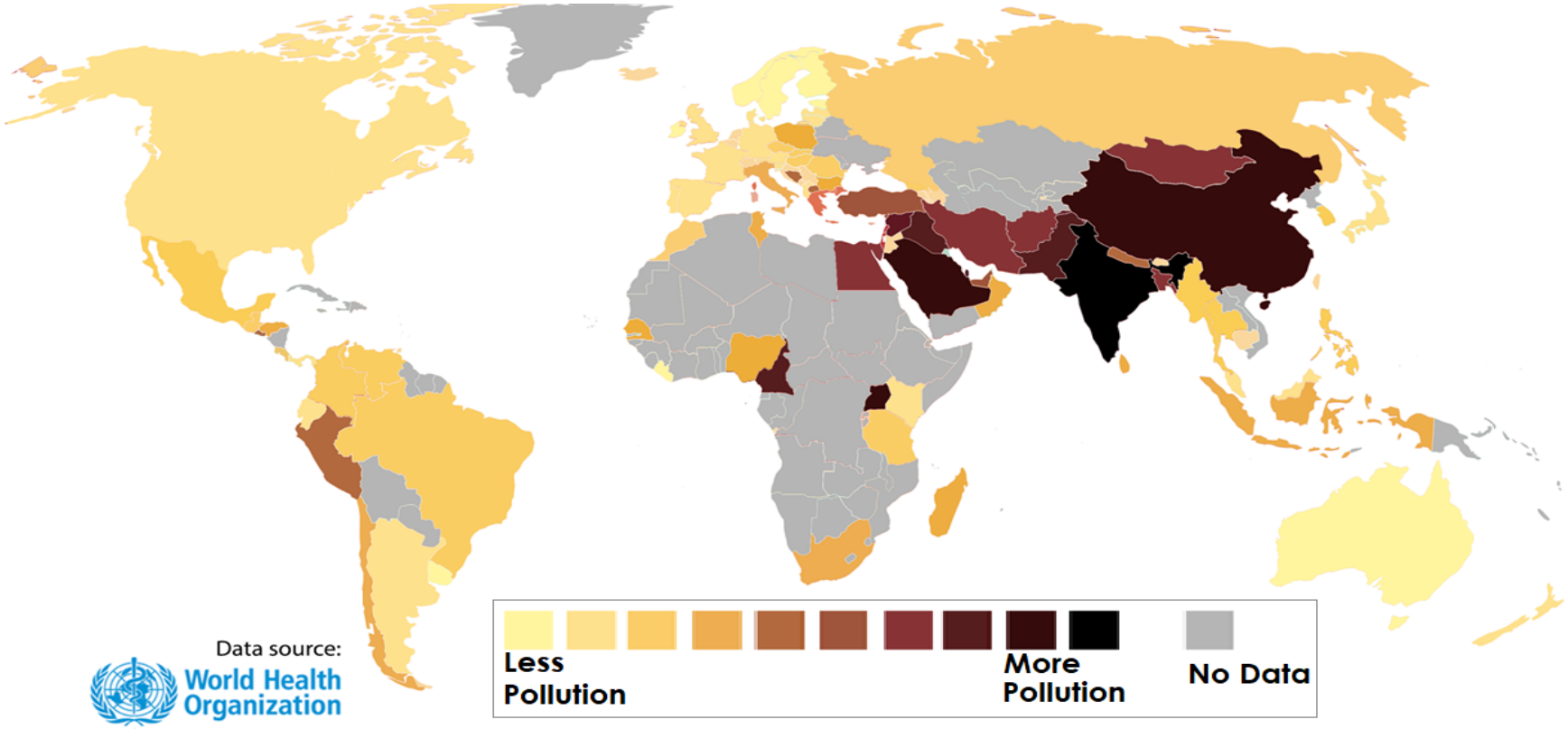


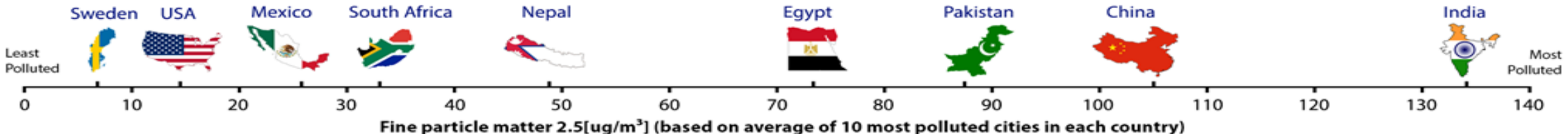


Global Air Quality and Pakistan

WHO, 2018 Report

- More than 80% of people living in urban areas are exposed to air quality levels that exceed the WHO
- 9 out of 10 people worldwide breathe polluted air but more countries are taking action
- Ranked as numbers were calculated by averaging 10 most polluted cities in each country
- 98% of cities in low- and middle income countries with more than 100,000 inhabitants do not meet WHO air quality guidelines.
- Global urban air pollution levels increased by 8% (2008-13), despite improvements in some regions





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Air Quality Trends in Pakistan

- The Air quality in Pakistan's major cities is worsening at higher rate
  - Recent economic growth and consequent energy demands
  - Rapid urbanization

- Due to the liberal leasing system adopted by the financial institutions:
  - Traffic density increased many folds
  - The present roads infrastructure cannot cater the need of growing automobiles flow.

- As a result, we are experiencing frequent
  - traffic jams,
  - road accidents
  - Exponential increase in air pollution levels in big cities and along the major national highways
  - Trans-boundary - **SMOG episodes (Year 2016, 2017)**

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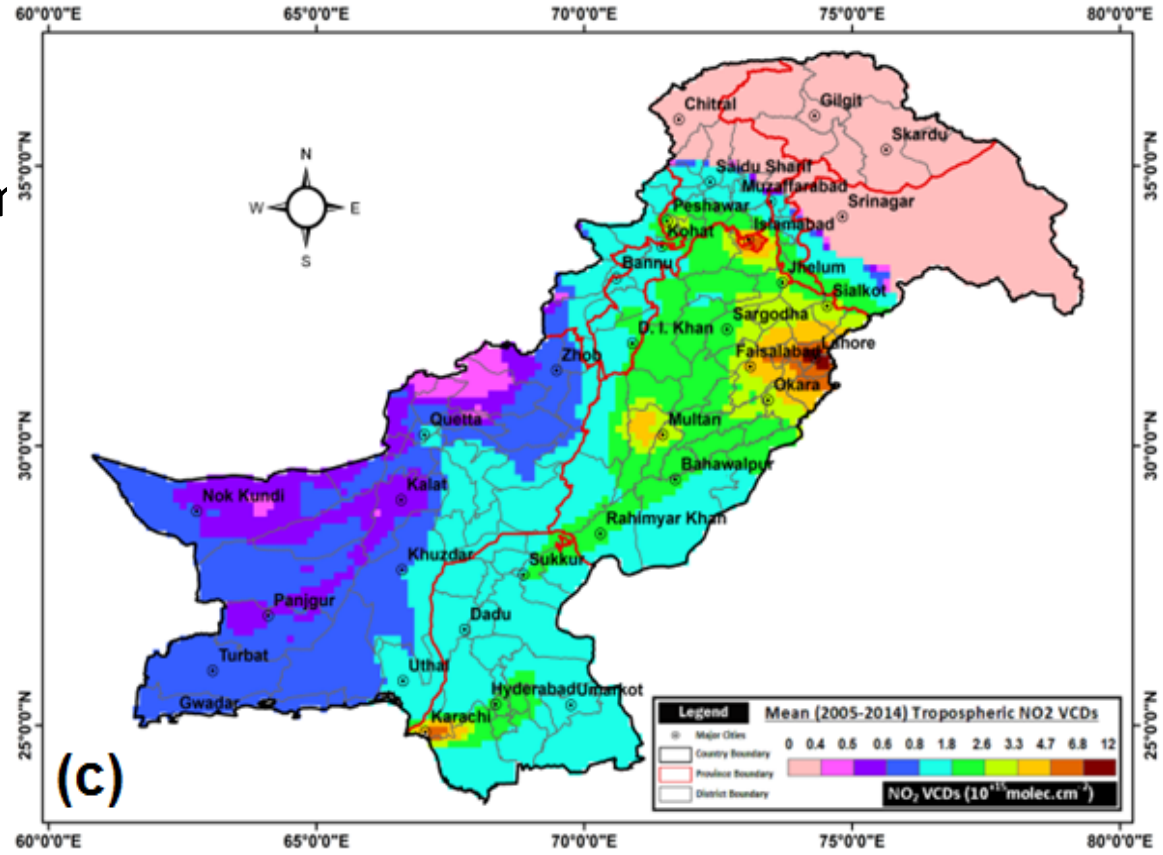
Nitrogen Dioxide in Pakistan

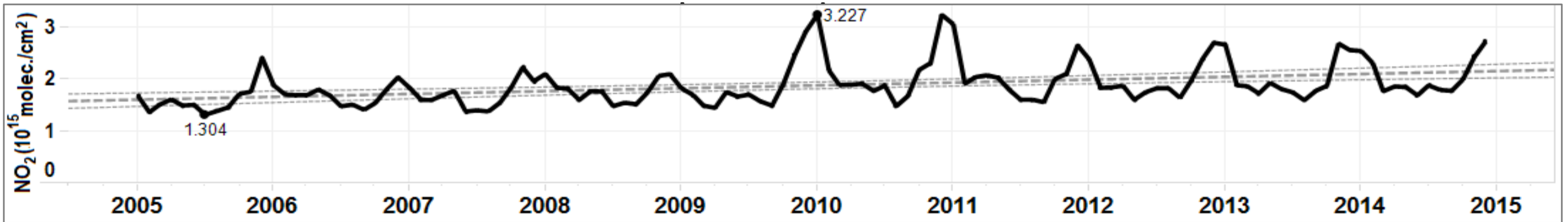
- A significant increasing trend of 28% (2005 -2015) in NO_2 is observed over Pakistan
- Absolute change of 2.7±0.03 molec./cm
- Annual increase at the rate of 2.8 %.

❑ Spatial Trends:

- ❖ Khyber Pakhtunkhwa (24 % - KPK)
- ❖ Punjab (23 %)
- ❖ Balochistan (22 %)
- ❖ Sindh (17 %)

- Highest NO_2 concentration January, 2010





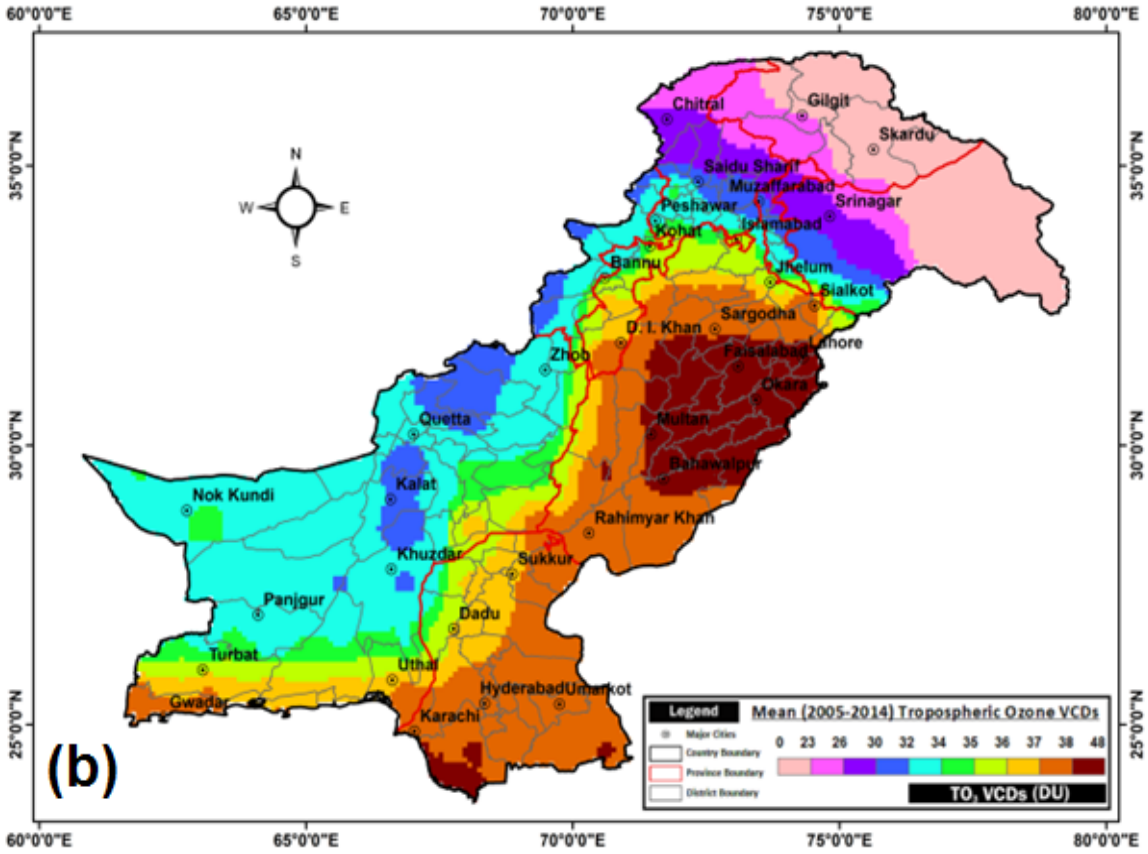
Tropospheric Ozone in Pakistan

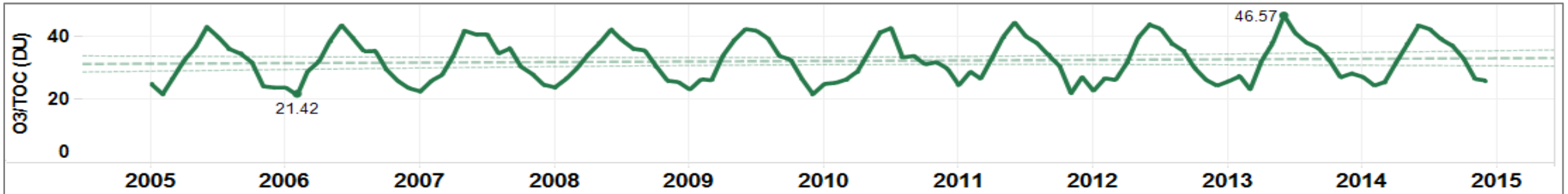
- A significant increasing trend of 10.4% (2005 -2014) in TO_3 is observed over Pakistan
- Absolute change of 3.2±2.2 DU
- Annual increase at the rate of

❑ Spatial Trends:

- ❖ Khyber Pakhtunkhwa (7 % - KPK)
- ❖ Punjab (7 %)
- ❖ Balochistan (6 %)
- ❖ Sindh (13 %)

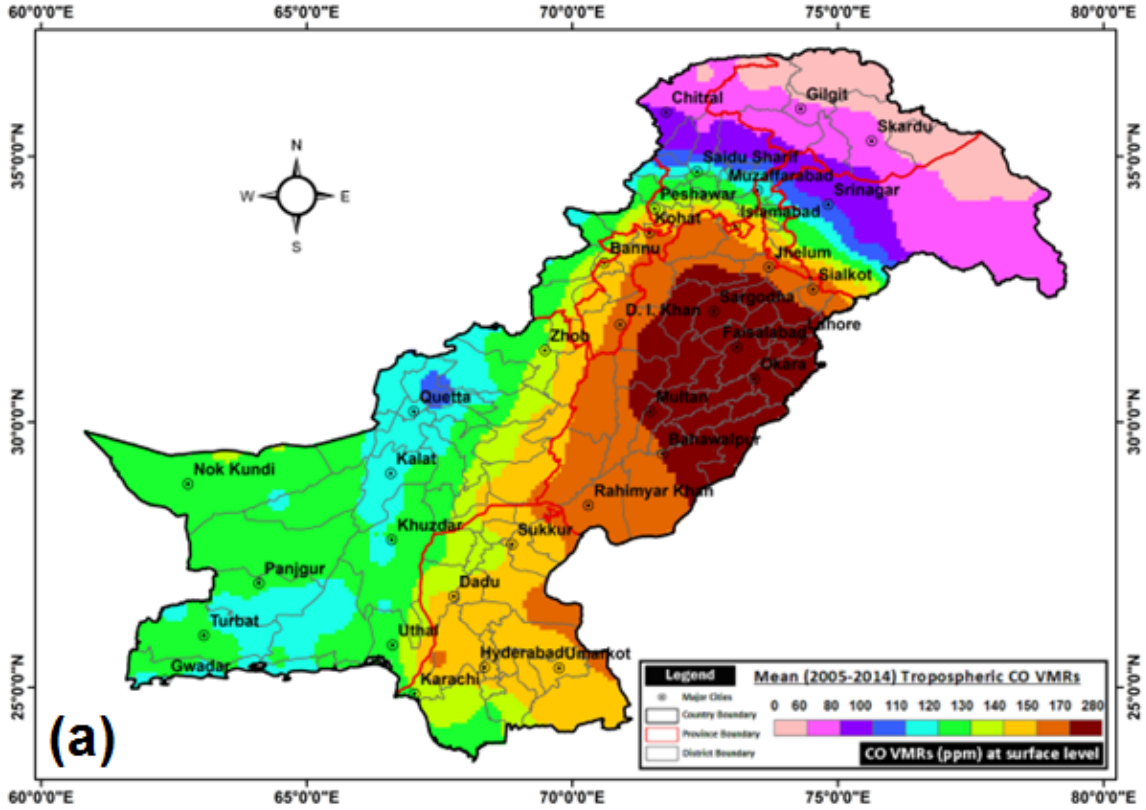
- Highest TO_3 concentration June, 2013
- Minimum concentration was observed in Feb. 2006

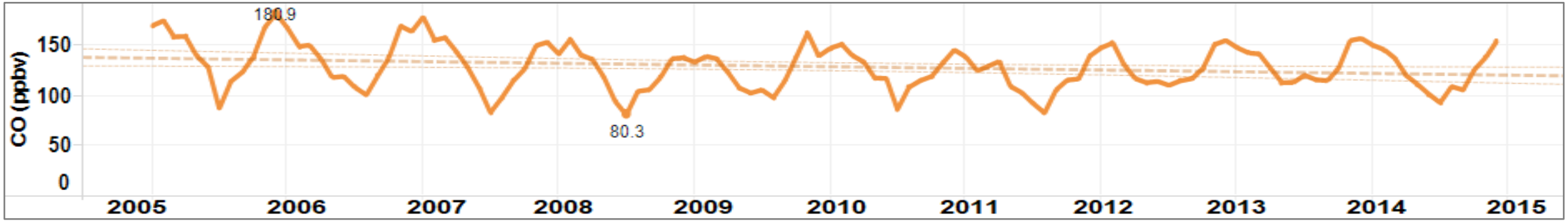




Carbon Monoxide in Pakistan

- A significant decreasing trend of 13% (2005 -2014) in CO is observed over Pakistan
  - Absolute change of -18±1.2 ppbv
  - Annual decrease at the rate of 1.3 %.
- Highest CO concentration (180.9 ppbv) December, 2005
- Minimum (80.3 ppbv) concentration was observed in July 2008





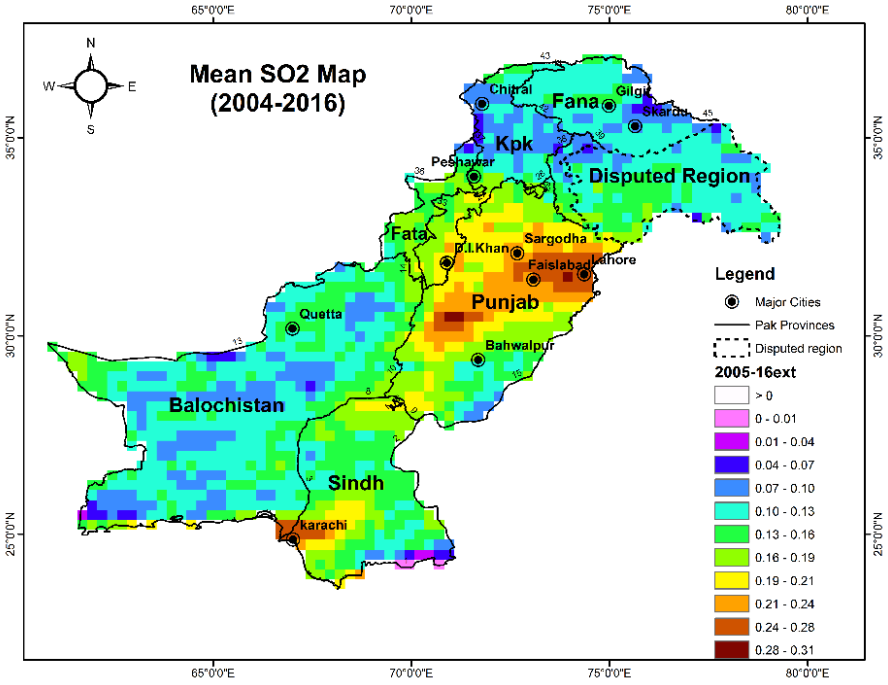
Sulfur Dioxide in Pakistan

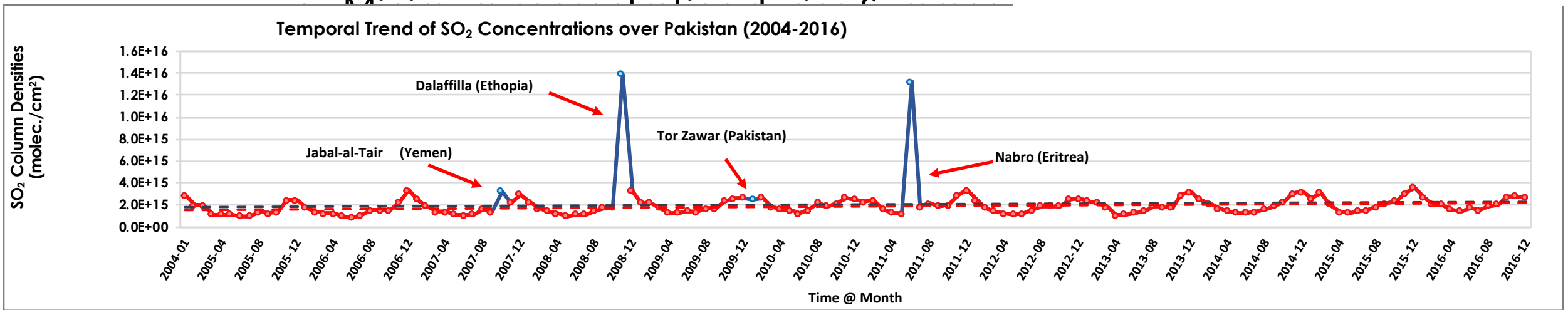
- A significant increasing trend of 38% (with volcano) and 46 % (w.o. volcano) in SO_2 is observed over Pakistan (2005 -2016)

❑ Spatial Trends:

- ❖ Khyber Pakhtunkhwa (58 % - KPK)
- ❖ Punjab (43 %)
- ❖ Balochistan (31%)
- ❖ Sindh (33 %)

  - Highest SO_2 concentration during Winter months



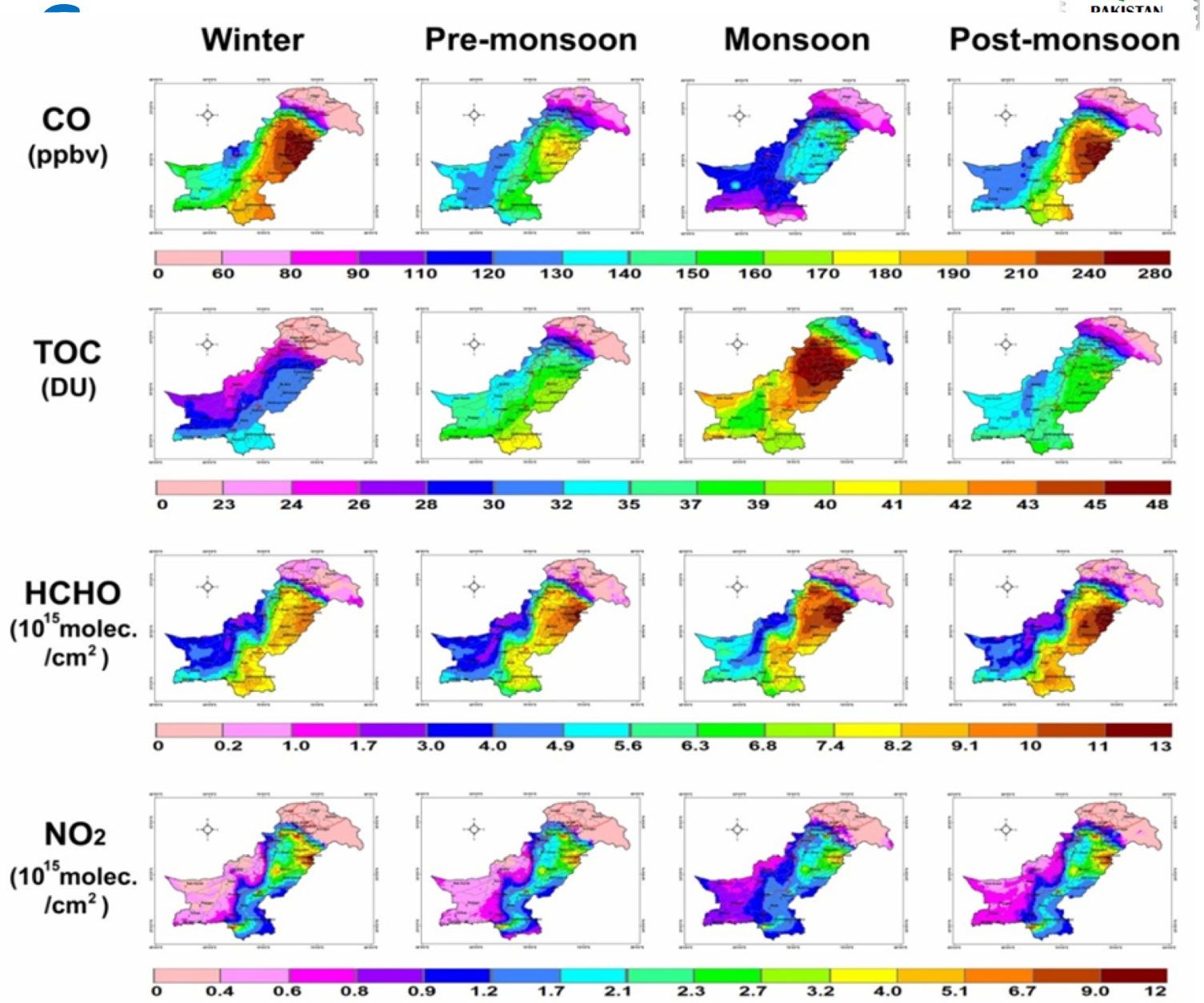


Seasonal Variation of Different Trace Gases

- Two Distinct Seasonal Trends:

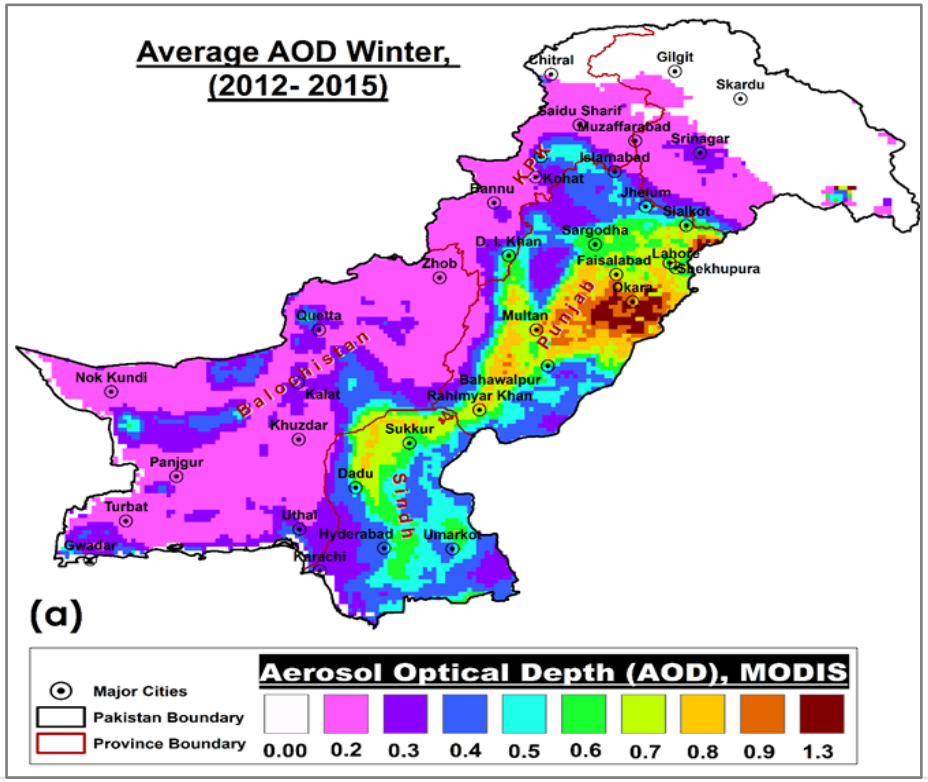
1. Post-monsoon and Winter Seasons
   - Atmospheric composition is dominated by CO yield

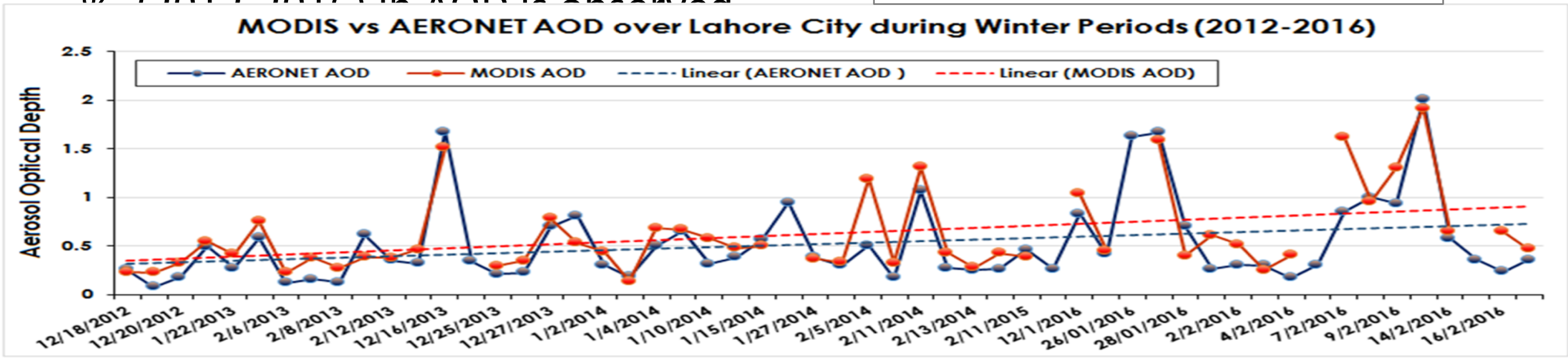
2. Pre-monsoon and Monsoon Seasons
   - Atmospheric composition is dominated by TO_3 yield



Aerosols over Pakistan

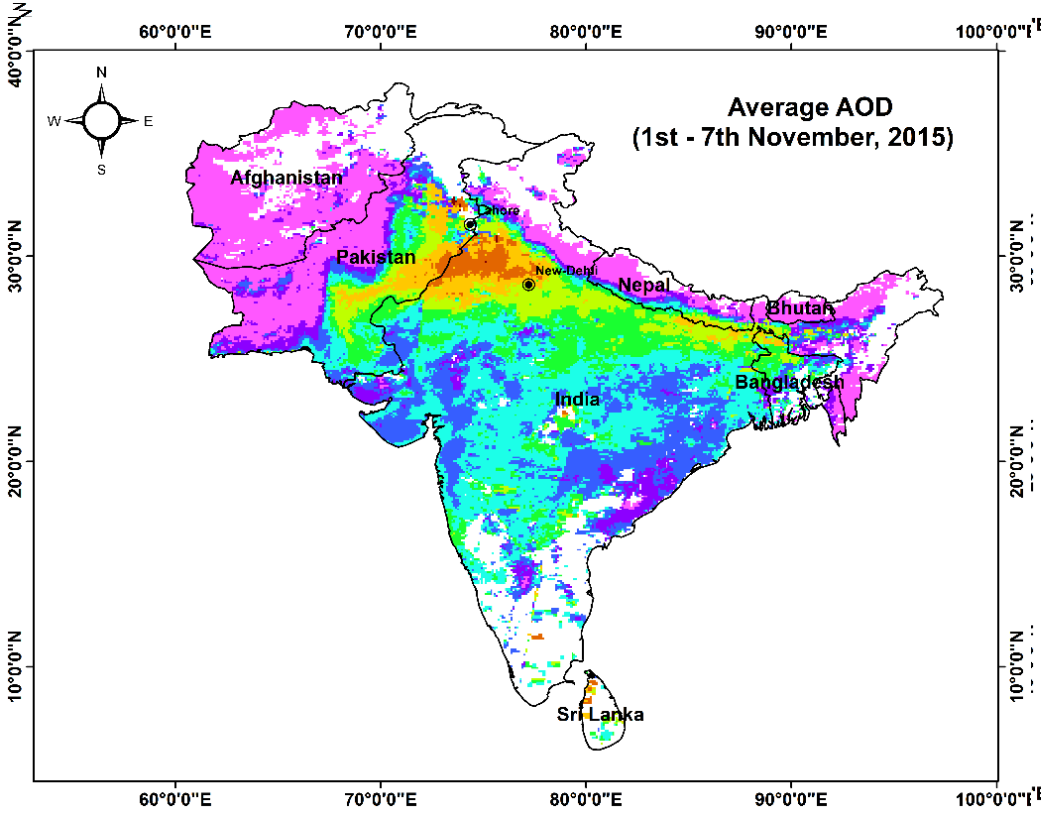
- Besides, several limitations, AOD can be taken as proxy for Particulate Matter
- Correlation between PM and AOD is improved in clear sky condition
- A significant increasing trend of 118 % (2013-2016) in AOD is observed

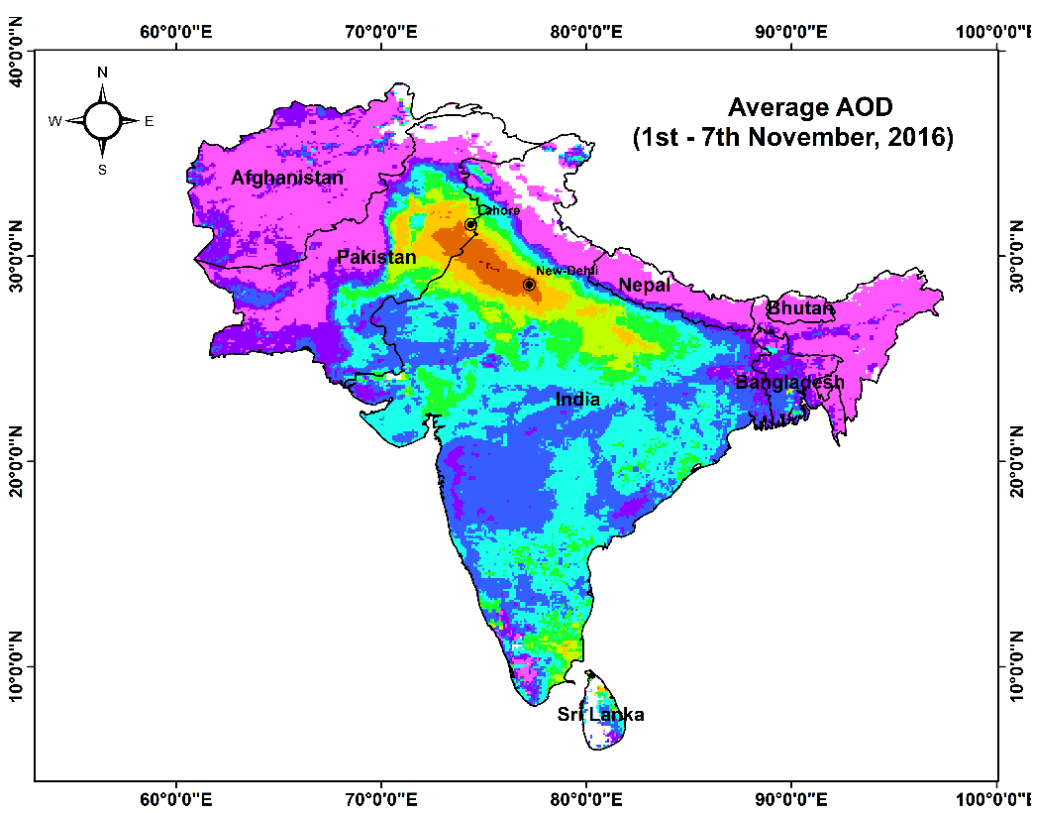




Recent SMOG Episodes in South Asia: Year 2016

- Max AOD was observed over Punjab regions from both sides of the border between India and Pakistan for Nov. 2016 >> (MODIS Obs. collection 6)
- Lahore >> maximum aerosol load is observed on between 01to 04 Nov. 2016
- Aerosol plume was dissipated and shifted southward





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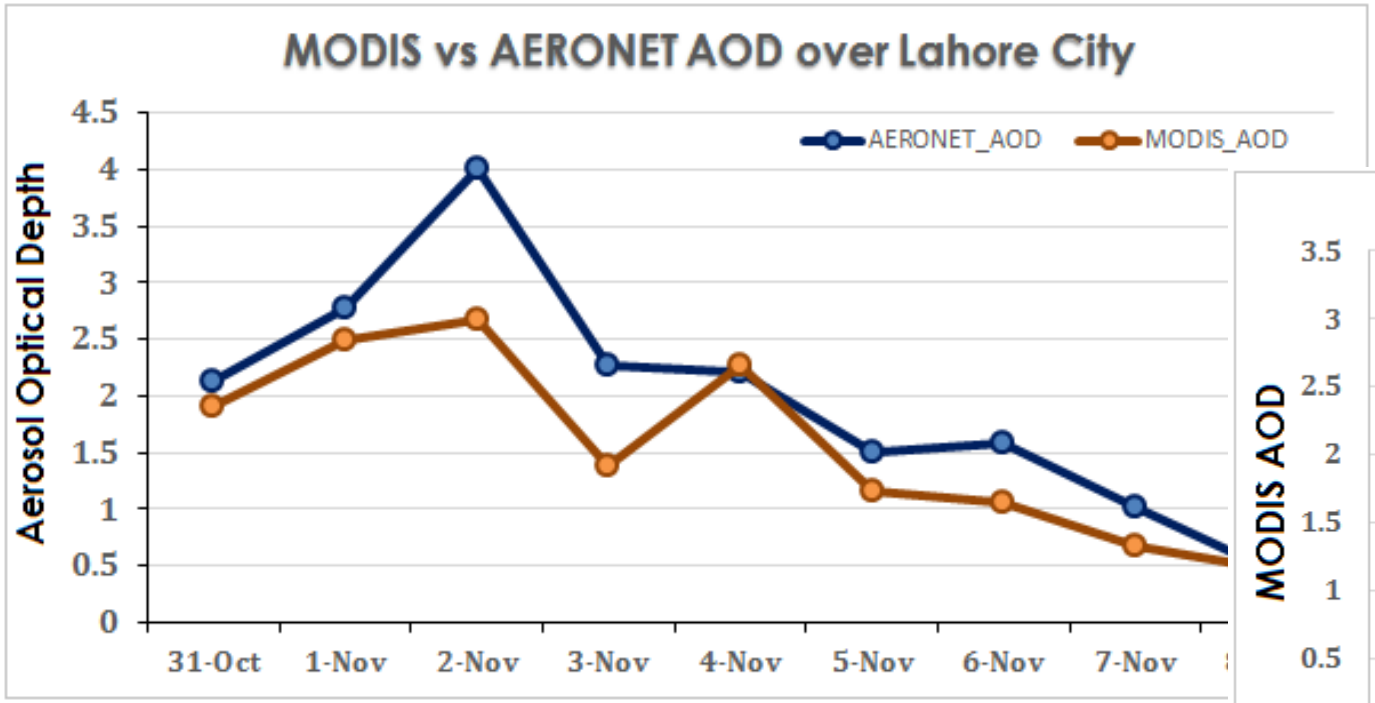
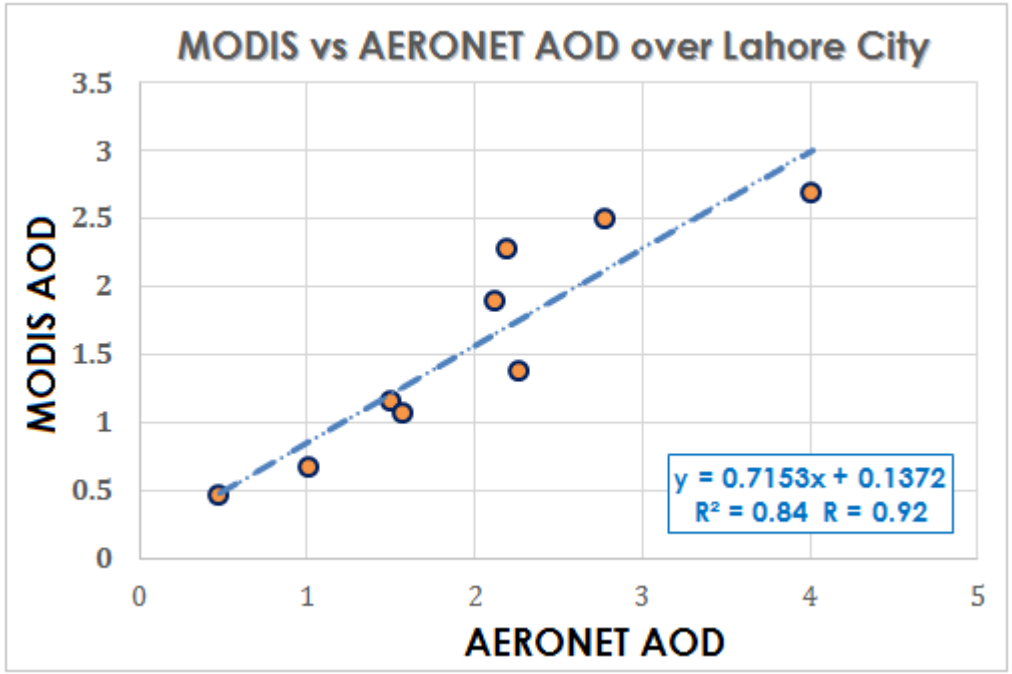
Year 2016: Aerosol Optical Depth - MODIS vs AERONET Observations

- AERONET AOD was extrapolated to 550 nm
- Lahore >> maximum aerosol load is observed on 2nd Nov. 2016
- Both observations are in good agreement , R = 0.92





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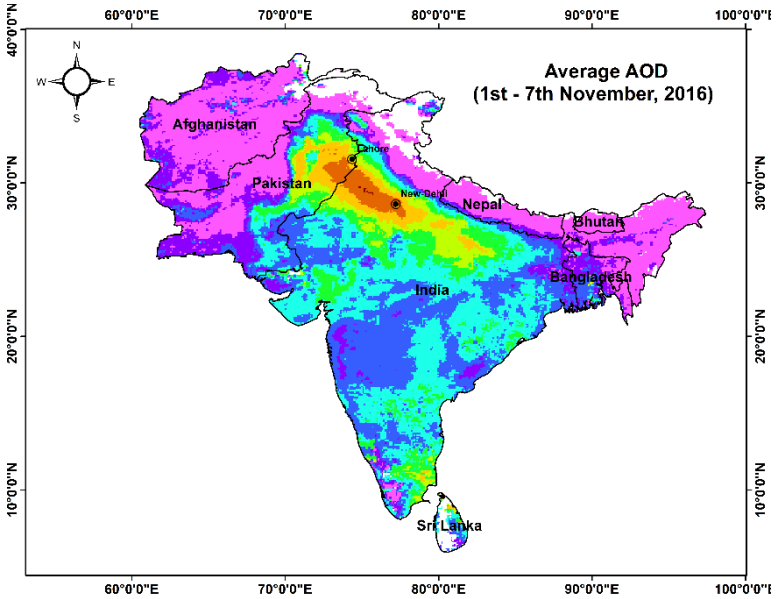
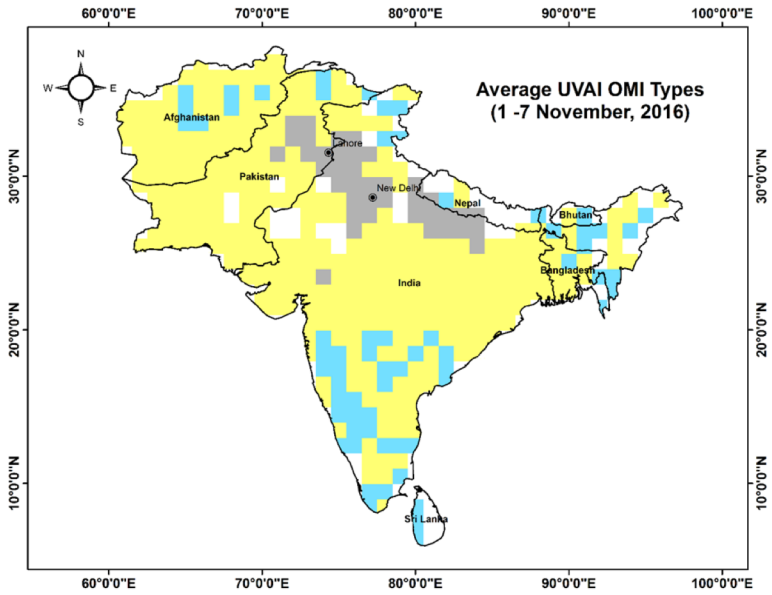
Year 2016: AEROSOL - Characterization

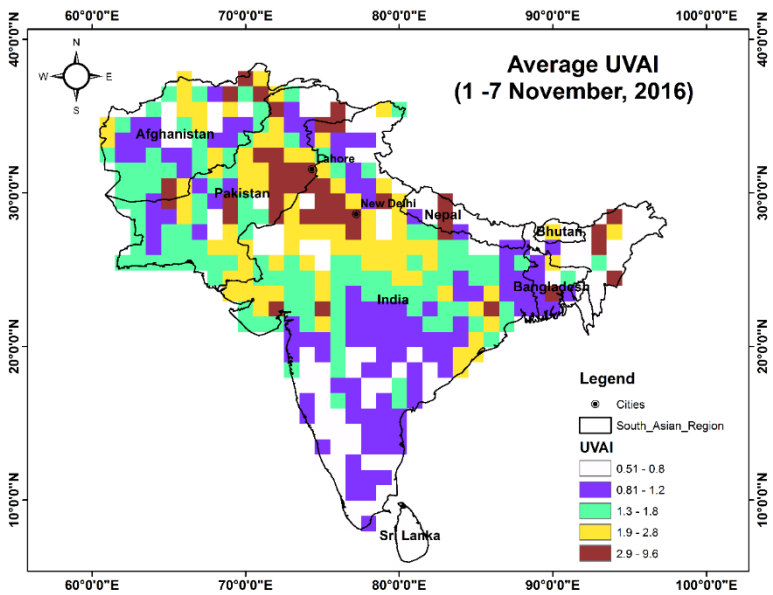
- active fire counts were also plotted (red circles)

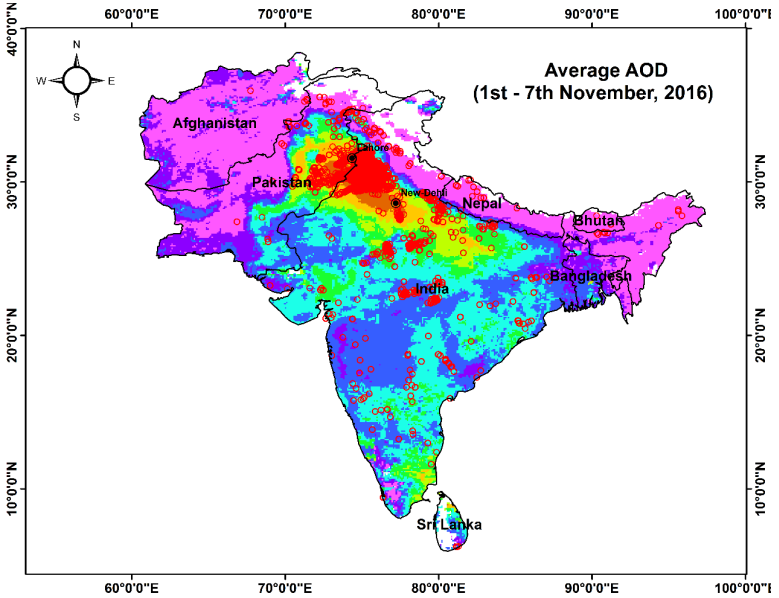
UVAAI:

- +ve values for absorbing aerosols (smoke, dust)
- -ve values for non-absorbing aerosols (sea salt, sulfate/nitrates etc.).
- indicate a strong coincidence with smoke type of aerosols.









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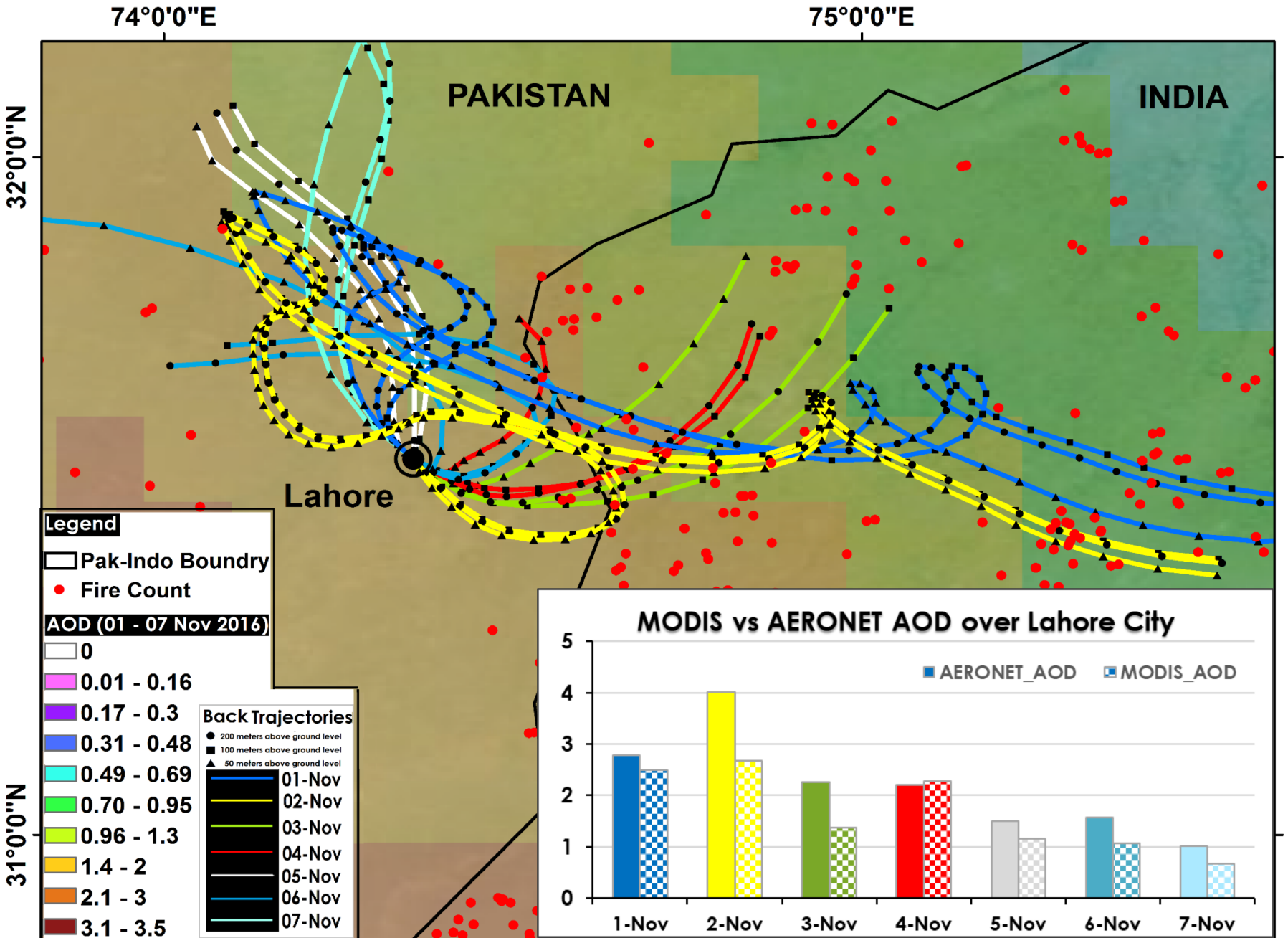
HYSPLIT MODEL - Lahore City – Year 2016

- Back Trajectory Analysis for 02 and 04 of November 2016
- Smog remained stationary in Lahore city generally.
- It did not have any vertical mixing



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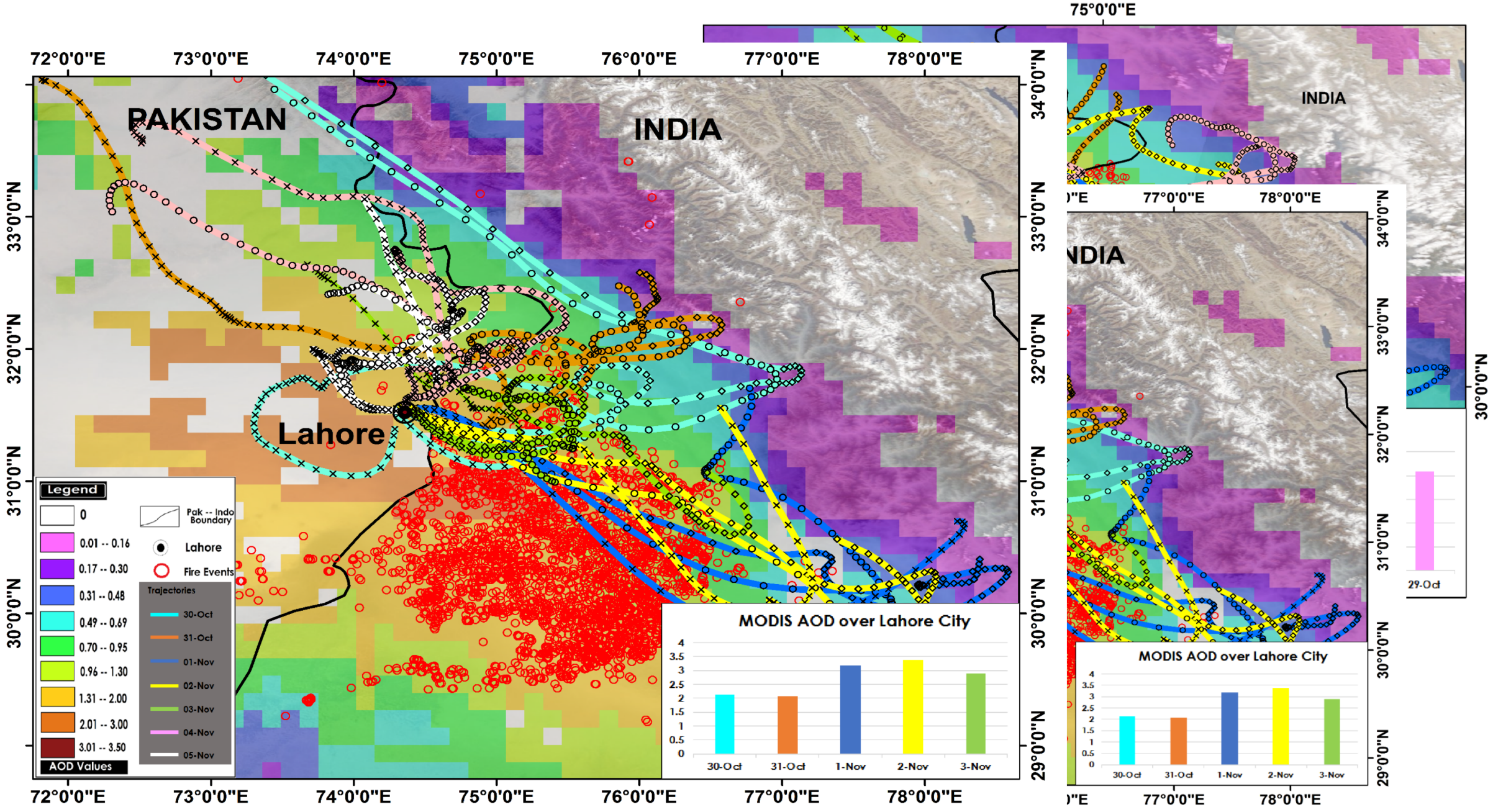
SMOG/SMOKE Choked life in Lahore/Punjab during Oct - November 2017



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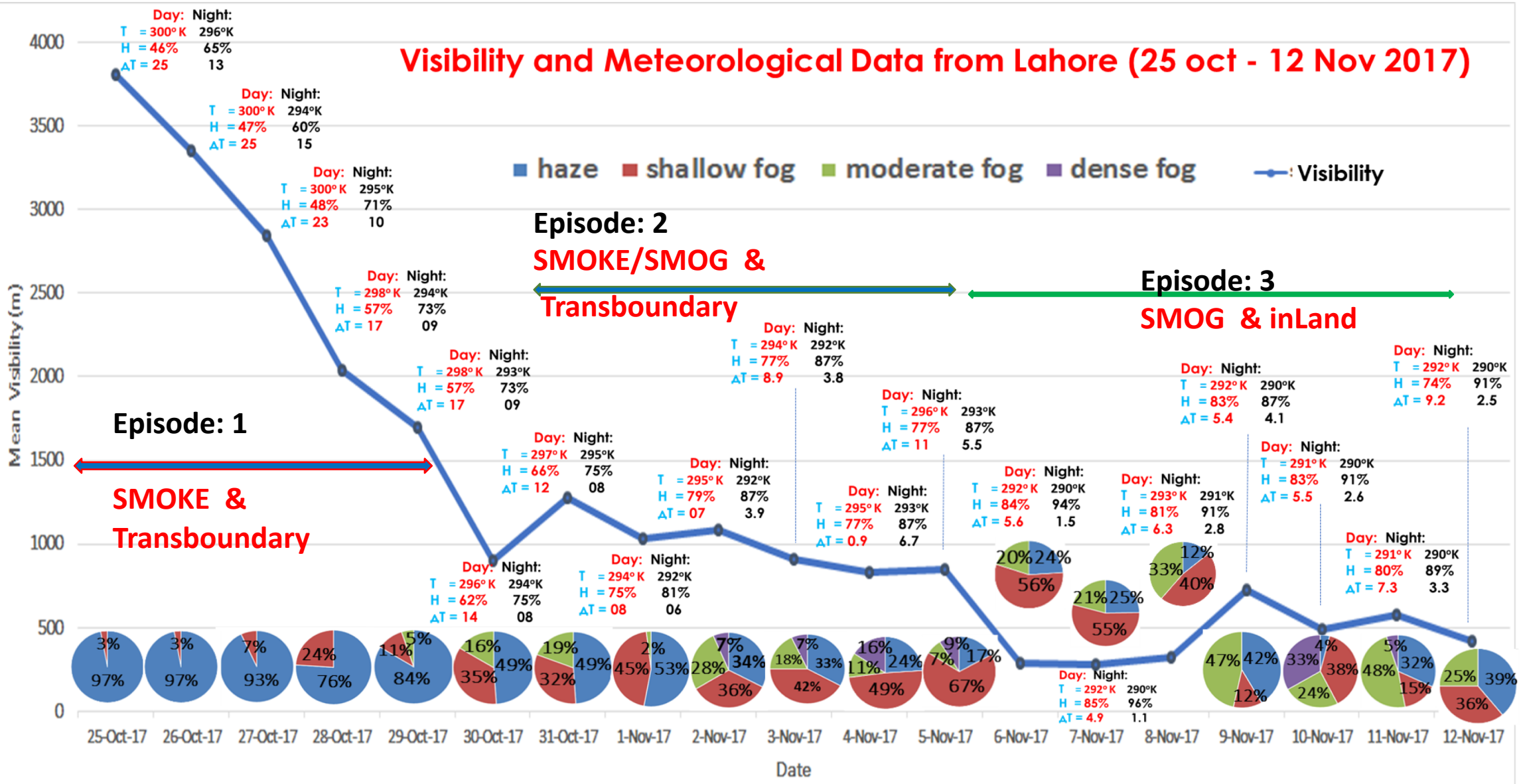
SMOG/SMOKE Choked life in Lahore/Punjab during Oct- November 2017



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Year 2018: There was no such sever SMOG/Smoke Event

- Meteorological conditions didn't favored
- Several Precautionary and Preventive measures were taken in both Punjab on either side of border
- Punjab, Pakistan:
  - Closure of brick kilns across the Province
  - Ban on agriculture fires
  - Ban on dirty fuel burning

Q: Whether Air Quality Conditions were improved this Year?

Ans: NO

Air Quality Lahore – Oct. 2018

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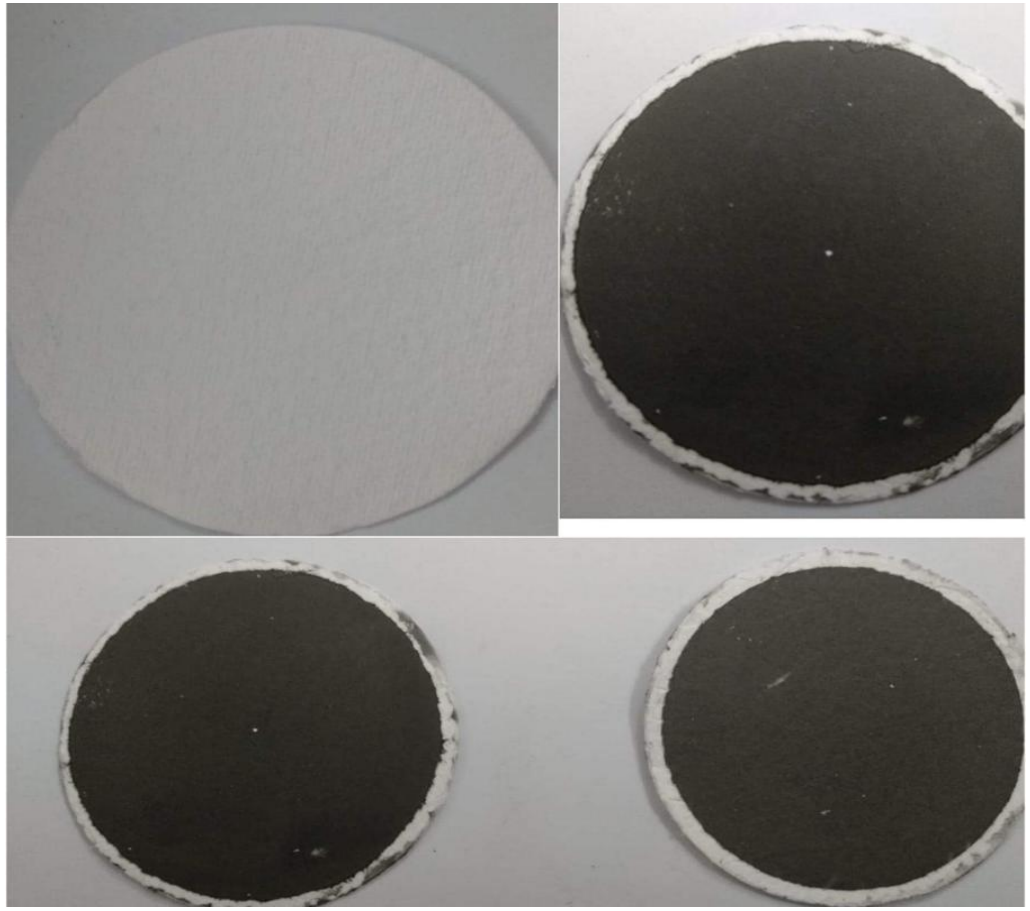
HEC funded Project: Exploring the spatial extent, causes, composition and intensity of winter smog over plains of Punjab

28 October 2018, GCU Lahore

Night time (2300 -0800 hrs)

PM 2.5 (left) = 268 ug/m^3
PM10 (right) = 542 ug/m^3

Comparison among fresh filter paper (white) and the same filter papers after being exposed to PM-10 (Small dust particles) Sampler for 8 hours at Lahore, as part of HEC NUST and GCU, Lhr joint research project aiming to measure air quality of Punjab with special emphasis on smog episodes.
Look at quality of Air we breathing and Smog has not kicked in yet.....!



SUMMARY – Climate & Air Quality Trends in Pakistan

- Mean Temperature has increased over Pakistan
- (1.2° C) Year 2016 being the Warmest Year since 1978
- Warming trend in Pakistan for all seasons except Post-Monsoon (1978-2016)
- Both Temporal and Spatial shift is observed in monsoon basin of Pakistan
- The intensity of rainfall is increased but frequency has been decreased during monsoon period, but increased in post-monsoon period

Atmospheric levels GHG over Pakistan increasing trend (2003-2017)

- CO_2 = 7.5%
- CH_4 = 2.7 %

Atmospheric Trace Gases Exhibited increasing trends over Pakistan (2004-2015)

- HCHO = 8 %
- NO_2 = 28 %
- TO_3 = 10 %

Global Warming can be reduced effectively by mitigating the GHGs and Air pollutants

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  - TEMIS project for OMI observations
  - TRMM for precipitation
  - MODIS Team
  - Pakistan Meteorological Department for Temp and Precipitation
  - NUST – Pakistan

  - Higher Education Commission of Pakistan
  - GCU Lahore and BZU Multan

  - C-CARGO Team Members: Fasiha Safdar, Naila Zeb, Zunaira Jabeen, Tehreem Mustansar, Aimon Tanveer

- Travel Support from :
  - ACAM organizing Committee and Sponsors
  - NASA
  - UKM

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Bridging the Gaps from Local to Global

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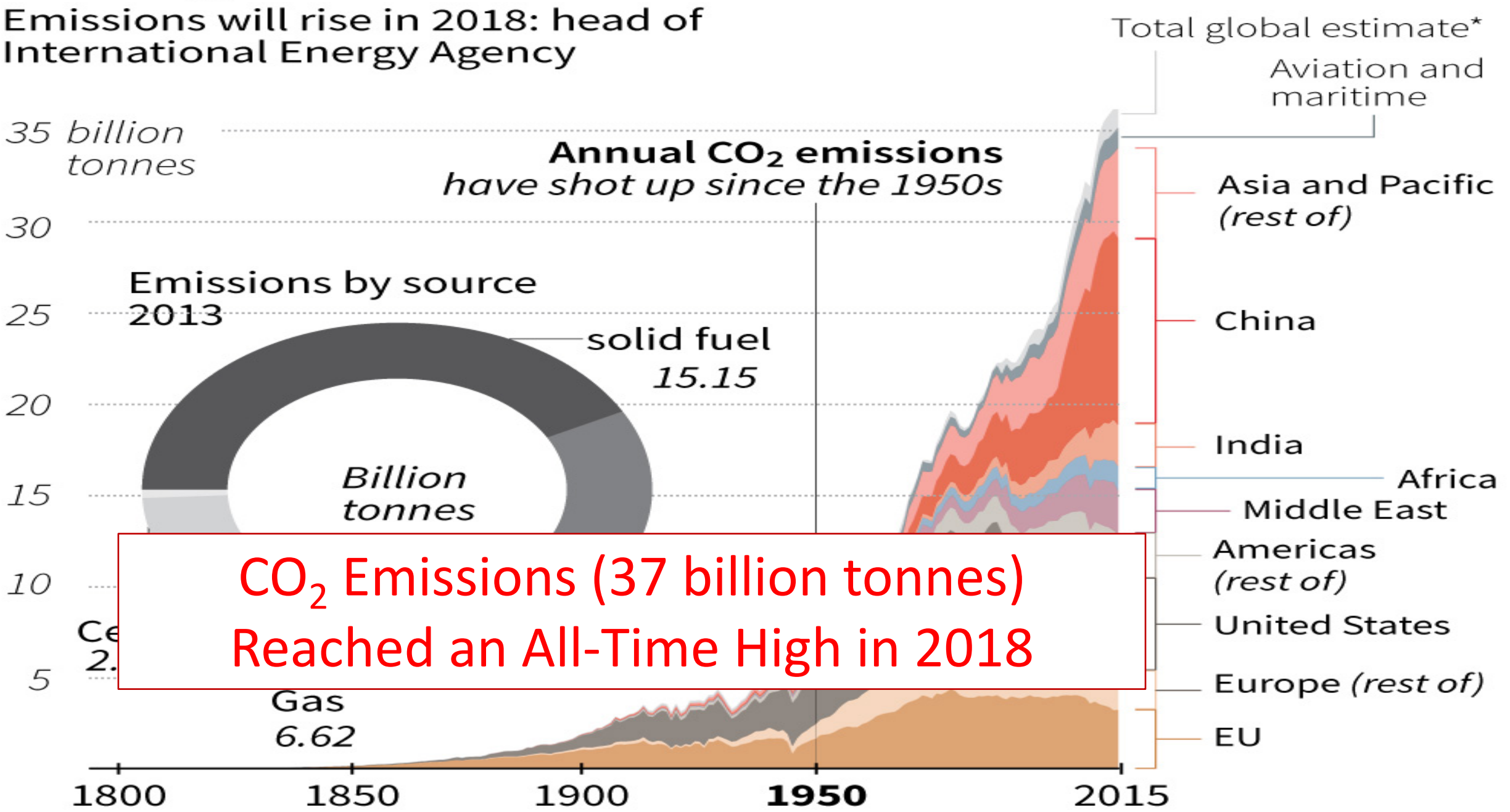
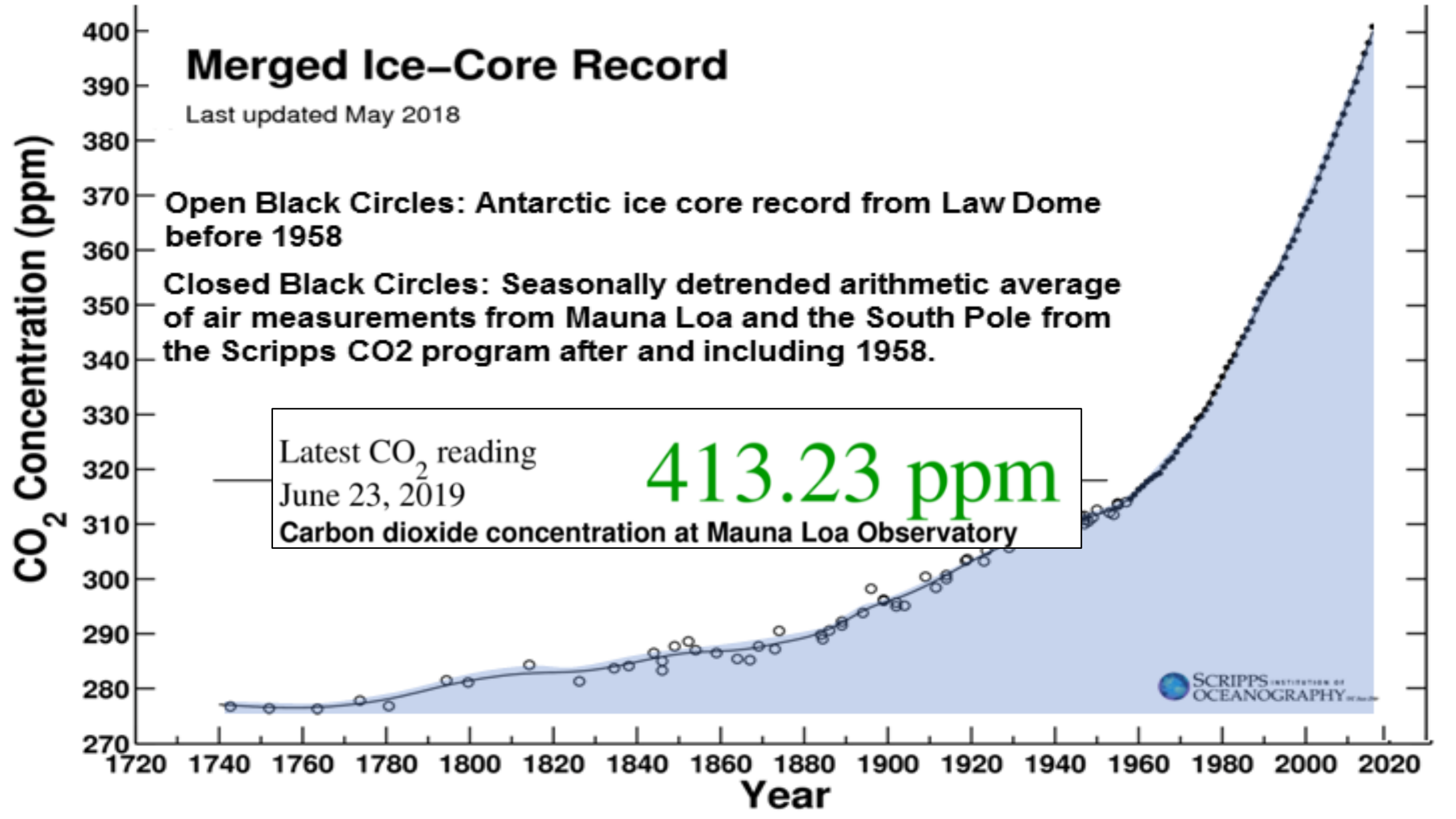
Rising carbon dioxide



CO_2 Emissions (37 billion tonnes)
Reached an All-Time High in 2018


Merged Ice–Core Record
Last updated May 2018
Open Black Circles: Antarctic ice core record from Law Dome before 1958
Closed Black Circles: Seasonally detrended arithmetic average of air measurements from Mauna Loa and the South Pole from the Scripps CO2 program after and including 1958.
Latest CO_2 reading
June 23, 2019
413.23 ppm
Carbon dioxide concentration at Mauna Loa Observatory
SCRIPPS INSTITUTION OF OCEANOGRAPHY
CO_2 Concentration (ppm)
400
390
380
370
360
350
340
330
320
310
300
290
280
270
1720 1740 1760 1780 1800 1820 1840 1860 1880 1900 1920 1940 1960 1980 2000 2020
Year

Warming Trends under IPCC Representative Concentration Pathways (RCPs)

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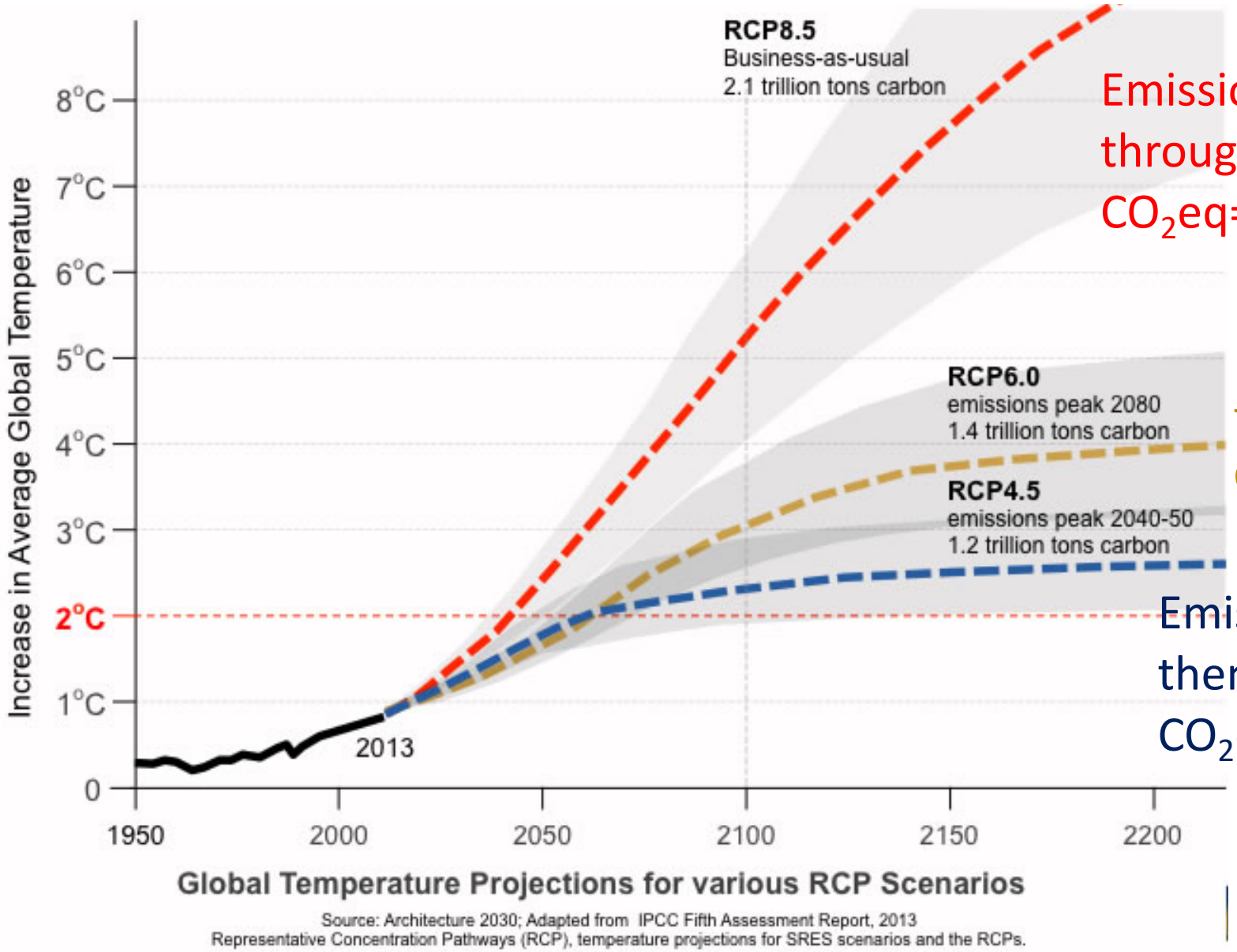


Global Temperature Projections for various RCP Scenarios

Source: Architecture 2030; Adapted from IPCC Fifth Assessment Report, 2013
Representative Concentration Pathways (RCP), temperature projections for SRES scenarios and the RCPs.

Emissions continue to rise throughout the 21st century
CO_2eq=1370 ppm

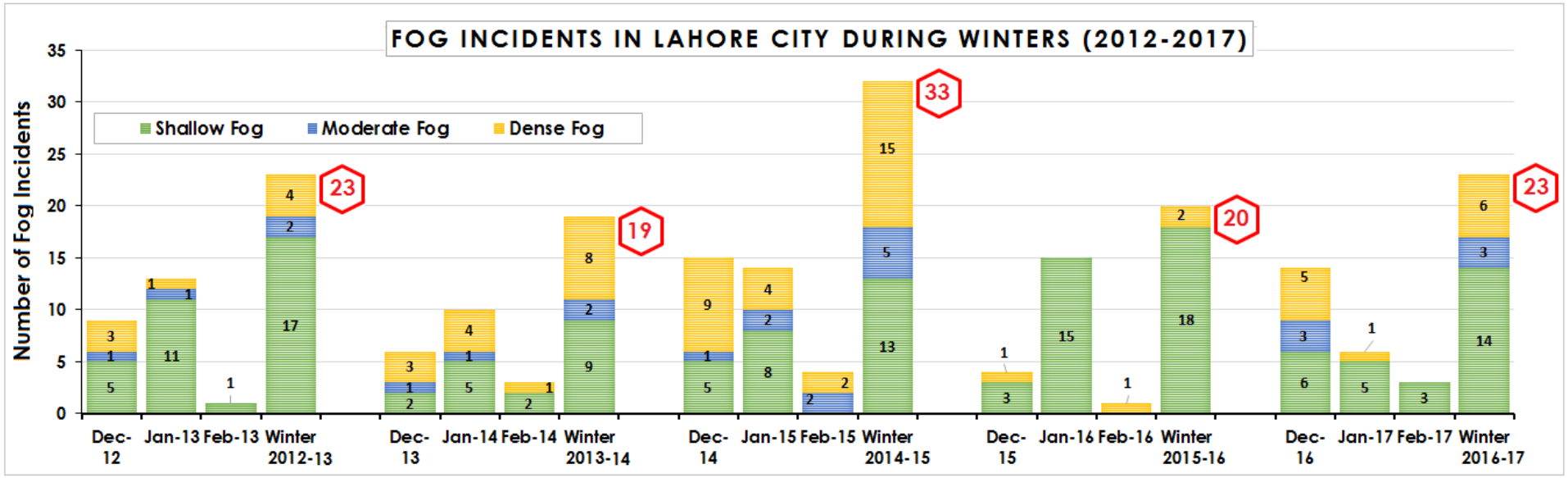
Emissions peak around 2080, then substantial decline.
CO_2eq=850 ppm

Emission peak around 2040, then substantial decline
CO_2eq=650 ppm

Outcome

1- number of Fog incidents in Lahore, Pakistan decreased during last two winters

>> Attributed to onset El-Nino 2015



GHGs Trends >> CO_2 Emissions in Pakistan

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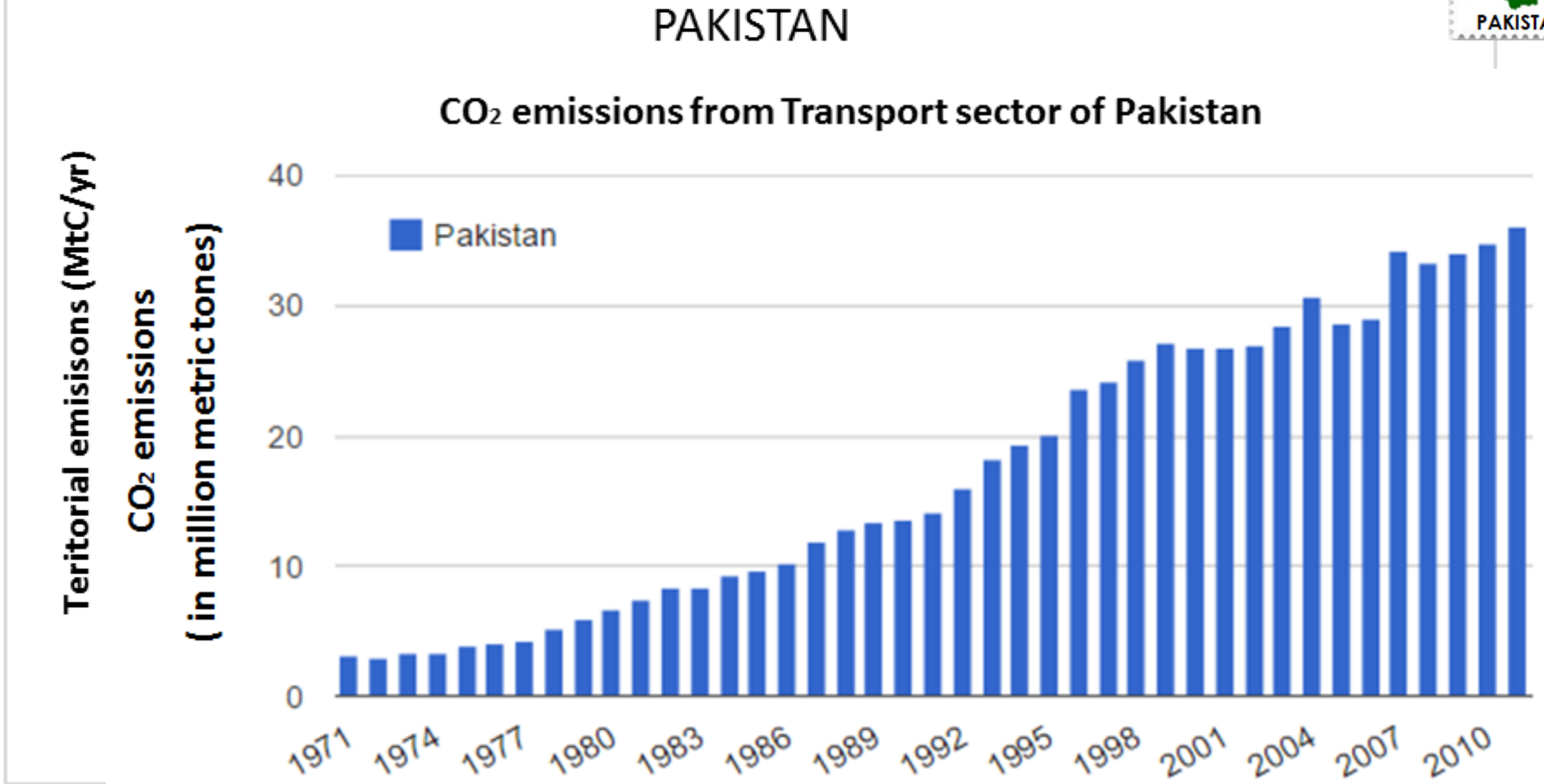

data source: world bank

Mitigation option – Renewable Energy

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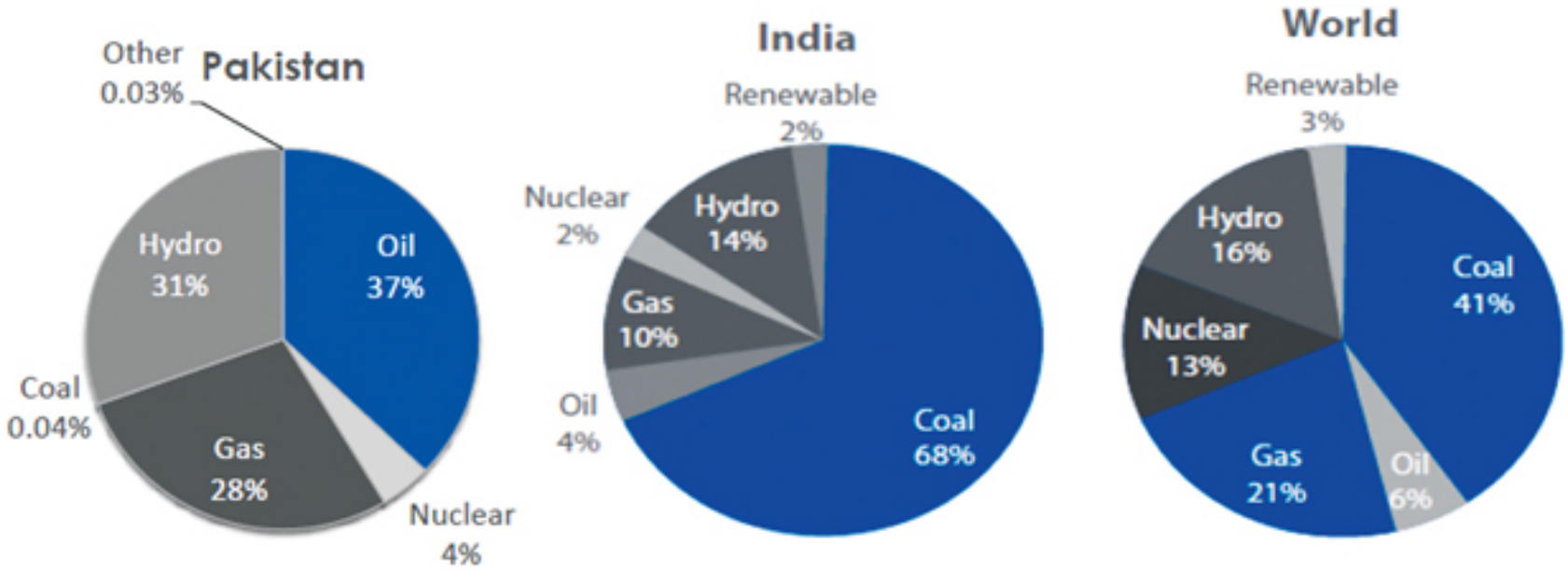
Current Energy Mix of Pakistan:

- Installed capacity of electricity in i 2012-13 = 22,812 MW and in 2018 = 29,573 MW
- During the period 2013 to 2018, thirty nine 39 projects with cumulative capacity of 12,230 MW have been added (Economic Survey of Pakistan 2017-18)
- Costly energy >>
for Thermal Power generation, Pakistan has to depend on expensive oil from international market and transfer cost to consumers
- immediate solution is:
To change the energy Mix and shift to Renewables and /or cost-effective means of electricity production



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Visuals from the City of Lahore
01- 07 November 2016

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Air Quality Monitoring in Lahore (November 2016)

- Most of the time pollutant levels were exceeding the PEQS
- $PM_{2.5}$ and NO_2 was higher than prescribed safety levels
- Temperature ranged 19 to 22 **°C**
- Calm winds prevailed

Date	NO	NO_2	SO_2	O_3	CO	$PM_{2.5}$	PM_{10}	W.Sp	R.H	Air.T
UNITS	µg/m³	µg/m³	µg/m³	µg/m³	mg/m³	µg/m³	µg/m³	m/sec	%	°C
PEQS/ GUIDELINE	40	80	120	130	5	35	150	-	-	-
2-Nov-16	306.61	74.82	32.49	28.39	21.29	104.06	119.57	0.05	89.31	19
3-Nov-16	59.72	120.9	247.87	63.87	6.76	62.31	126.87	0.25	68.51	23.31
4-Nov-16	134.6	89.8	113.1	18.3	4.47	55.33	93.23	0.04	82.6	19.3
5-Nov-16	132	119.4	70.81	24.4	4.54	62.82	94.37	0.2	71.97	21.51
6-Nov-16	43.29	90.64	189.9	52.4	4.72	44.6	124.2	0.22	57.2	22.43
7-Nov-16	25.7	105.7	72.9	34.98	2.81	37.31	64.49	0.22	54.2	21.8

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Hazards Related to SMOG incident during November 2016

- "fine particulate matter" was reported four times the World Health Organization's recommended level, exceeding 104 ug/m^3 in the worst-hit parts of the city of around 10 million.
- Hundred thousands of citizens of Lahore, complained of breathing difficulties and eye irritation
- Visibility plunged to less than 20 meters and citizens wore face masks to help with breathing.
- Separately, at least 13 people were killed and nearly 100 wounded in two pile-ups involving 16 vehicles on the Lahore-Islamabad motorway due to dense smog on 4 Nov 2016
- Sections of M2 and M3 motorways were closed
- Warnings were issued to avoid the outdoor activities

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SMOG Choked life in Delhi during November 2016

The Smog in India Is So Bad Right Now, You Can See It From Space, This is terrifying.

BEC CREW, 9 NOV 2016

- Earlier this week, the Indian government declared a national emergency, as air pollution in its capital, New Delhi, reached levels more than 16 times the safe limit.
- Schools closed, locals began to flee
- Delhi's chief minister compared the city to a "gas chamber".
- System of Air Quality and Weather Forecasting and Research (SAFAR), New Delhi experienced PM10 hit 876 μm/m^3, and PM2.5 hit 680 μm/m^3 earlier this week.