Evolving Air Quality Under the Changing Climate: Enhanced Understanding through Blue Waters

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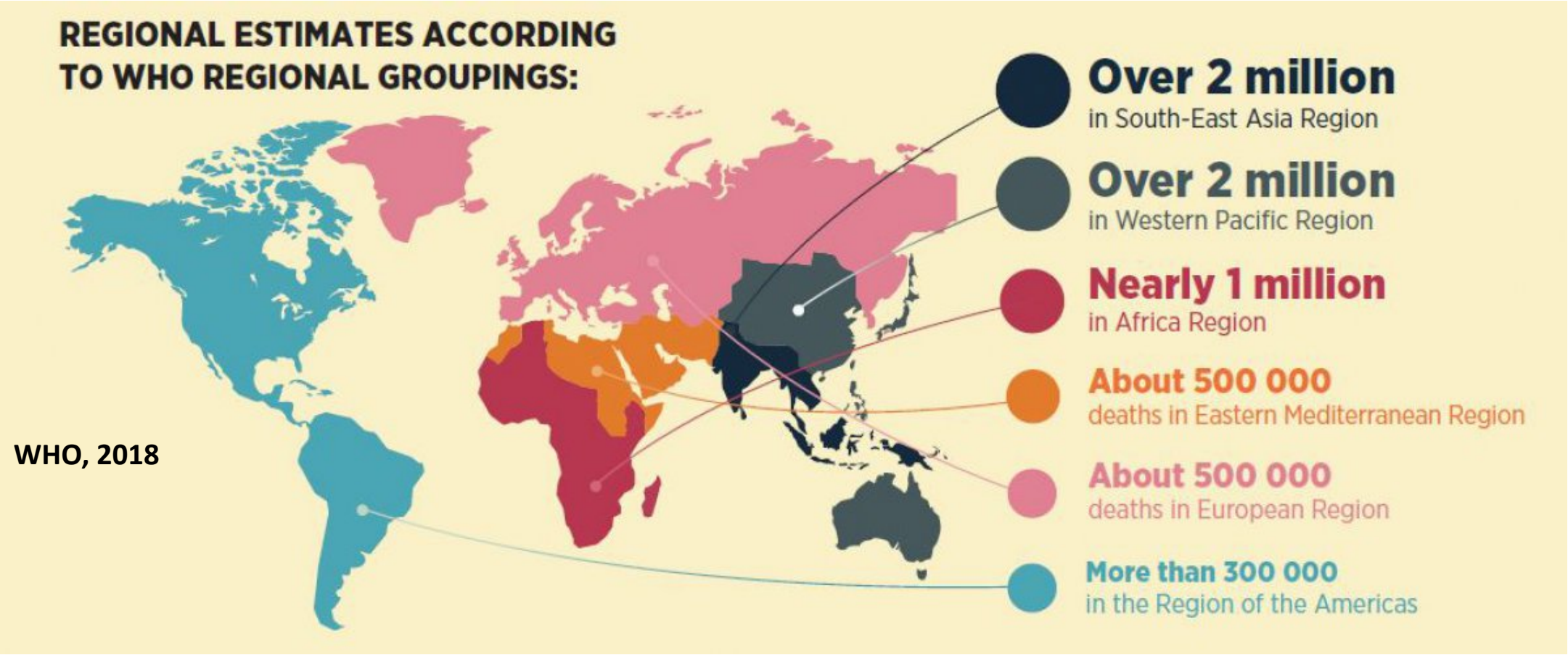
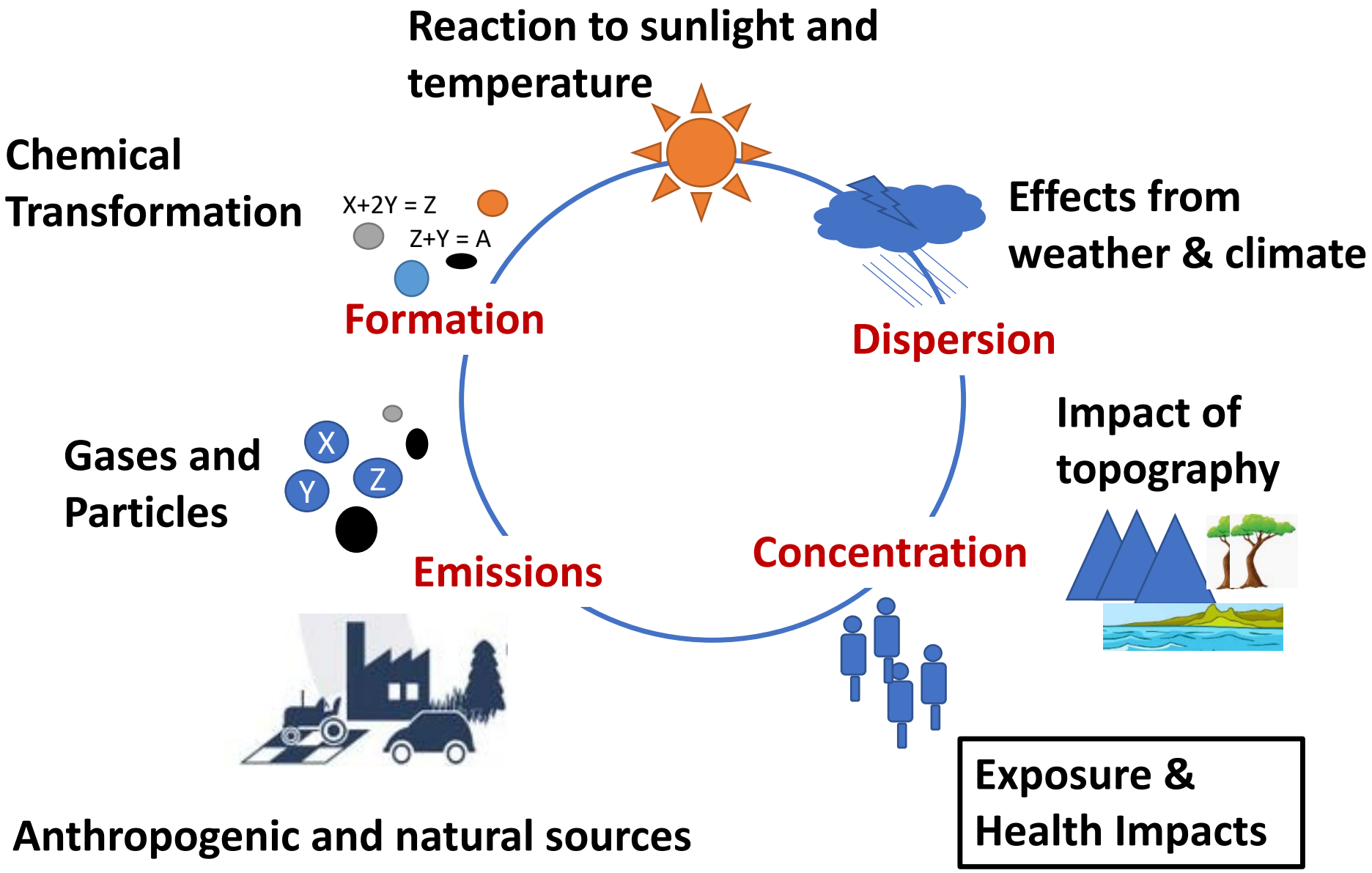
Why Do We Need Air Quality Management?



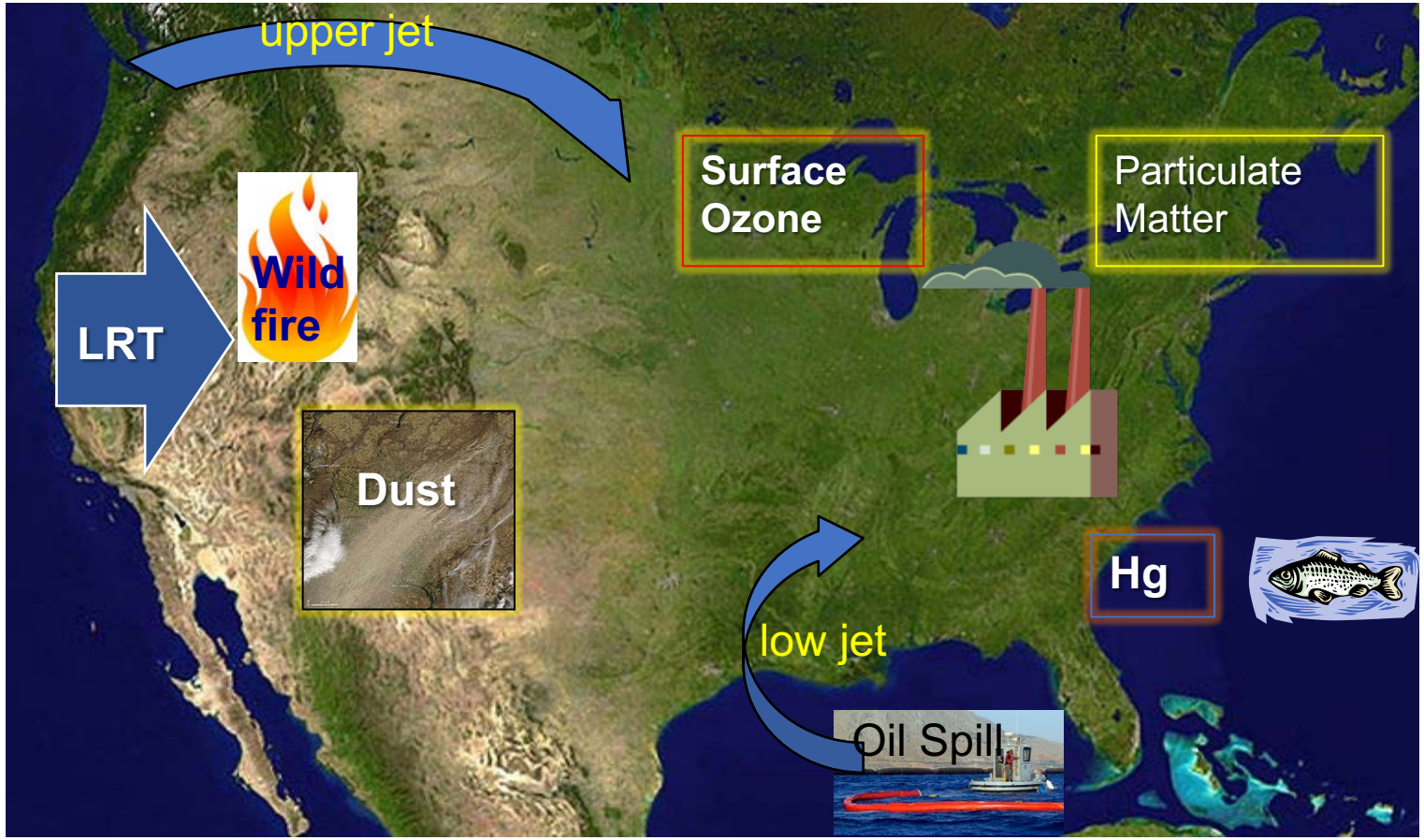
- **7 million deaths per year due to breathing polluted air (WHO).**
- ~91% of people worldwide breathe polluted air

Considerations In Air Quality Management



Impact Of Climate Change On Air Quality?

- Warmer temperatures leads to more O_3 production.
- Shifts in weather regimes like jet streams, Bermuda highs, storm activities and hydrologic extremes.
- Effects of long-range transport across national boundaries from Mexico, Canada, Asia, and North Africa.
- Increased wildfires increases O_3 and PM.
- Drier soils, more dust storms.



A Focus on Human Health: Exceedances

- **Exceedance days = days when surface concentrations > ambient air quality standard for ozone and $PM_{2.5}$**
- Exceedance days useful indicator of exposure
- United States, China and India are studied for Ozone and $PM_{2.5}$ exceedance events (historical, future RCP4.5 and RCP8.5 scenarios)
- Exceedance days measured compared to standards prescribed by the United States and by the World Health Organization

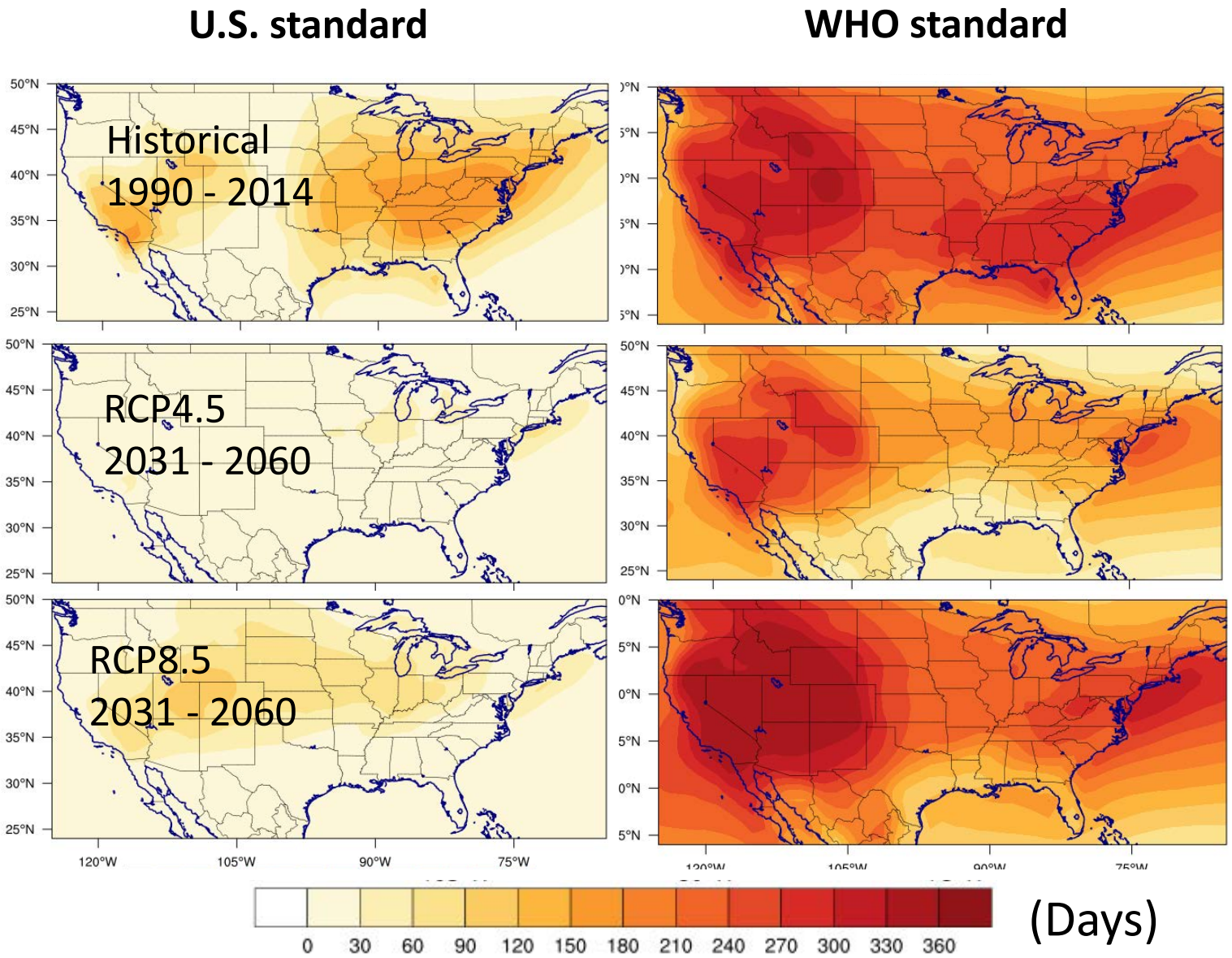
	U.S. Standard	WHO Standard
MDA8 (8 hour average) O_3	70 ppb	50 ppb
24 hour average $PM_{2.5}$	35 $\mu g/m^3$	25 $\mu g/m^3$

Project Objectives: Why Blue Waters?

Blue Waters enables high resolution simulations with the global climate system modeling with fully coupled atmospheric chemistry.

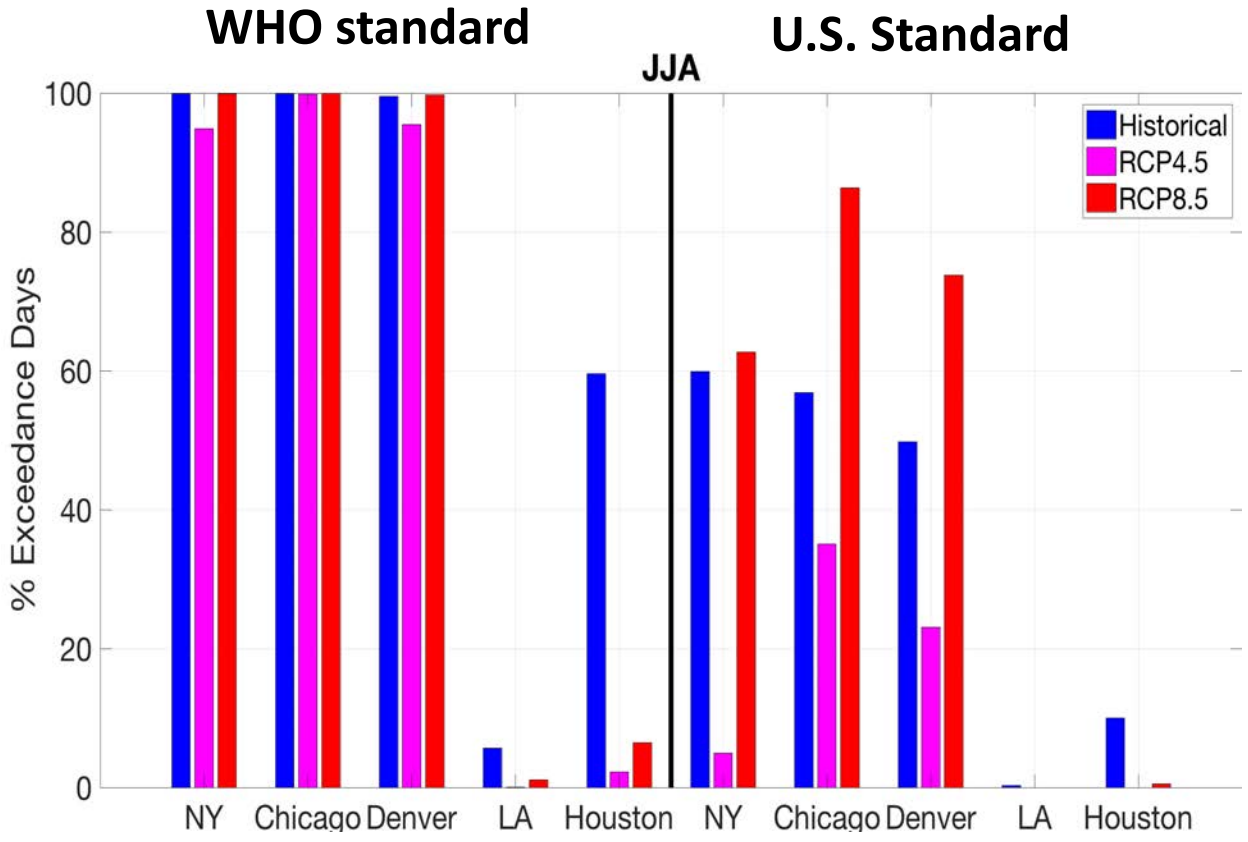
- Global climate-chemistry CESM model at 0.9^{o} x 1.25^{o} horizontal resolution
- Determine impacts from global climate and emissions changes on global air quality to 2050 under multiple scenarios.
- Additional sensitivity study for a clean energy future – no fossil fuel emissions by 2050.

O_3 Exceedance Days Decreases for the U.S.



- Annual average exceedance days for historical and future climate scenarios over United States
- Compared to U.S. standard, both the lower and higher climate scenario, exceedance days reduces
- Compared to more stringent WHO standard, number of exceedance days increases in case of the higher scenario

Exceedance Days for U.S. Megacities

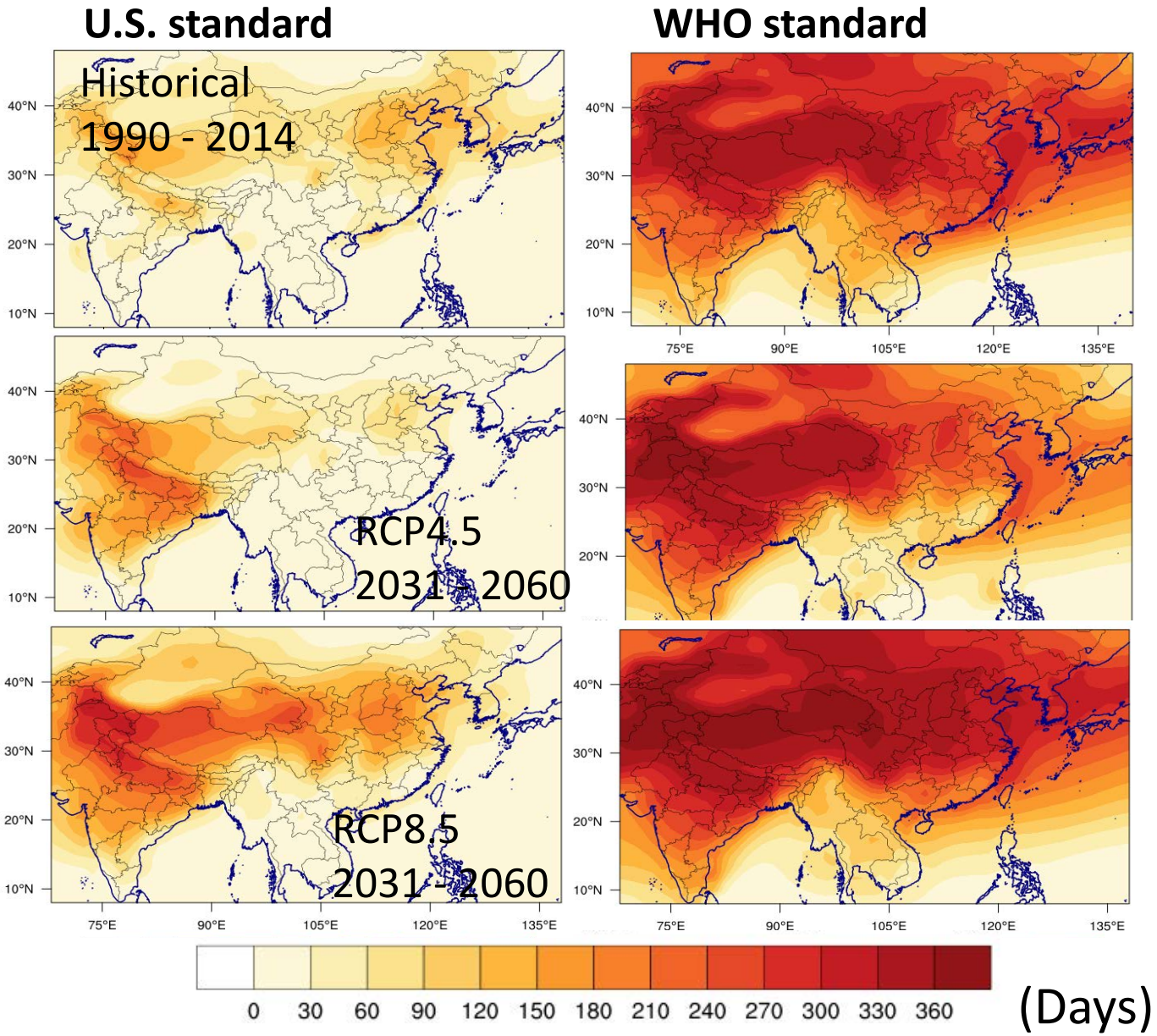


Averaged over :

- Historical: 1990 – 2014
- RCP4.5: 2031 – 2060
- RCP8.5: 2031 – 2060

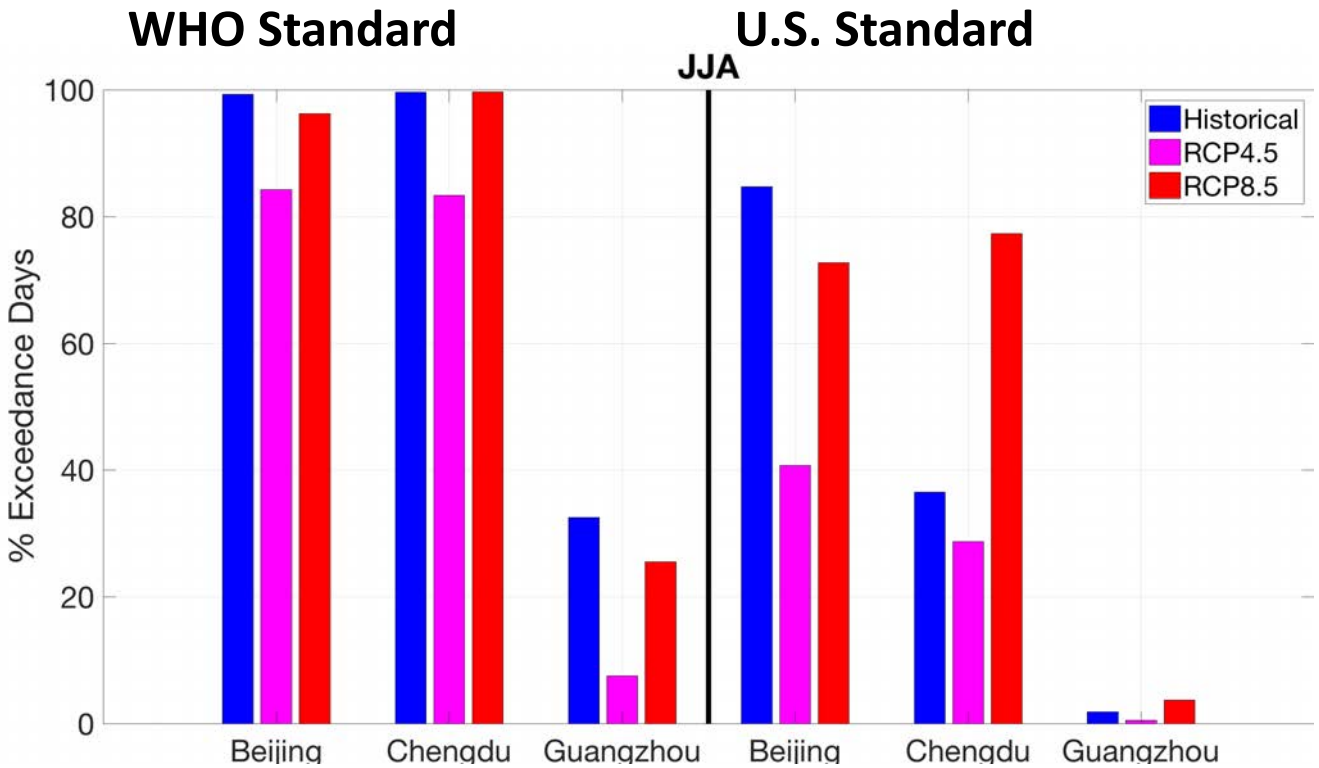
- Exceedance days higher for RCP8.5 scenario, except Los Angeles and Houston
- Exceedances underestimated for land-ocean boundary areas (e.g., Los Angeles, Houston)
- >60% days exceed U.S. standard for NY, Chicago and Denver for RCP8.5 scenario
- Winter season showing an increase in exceedance days in the future (not shown)

O_3 Exceedance Days Changes In South Asia



- Annual average exceedance days for historical and future climate scenarios over China and India
- Compared to U.S.A standard, the number of exceedance days in China for lower scenario, but increases over wester central China for higher scenario
- Exceedance days increases for both the scenarios over India. The Gangetic plain has the highest number of exceedance events

Exceedance Days for Megacities In China

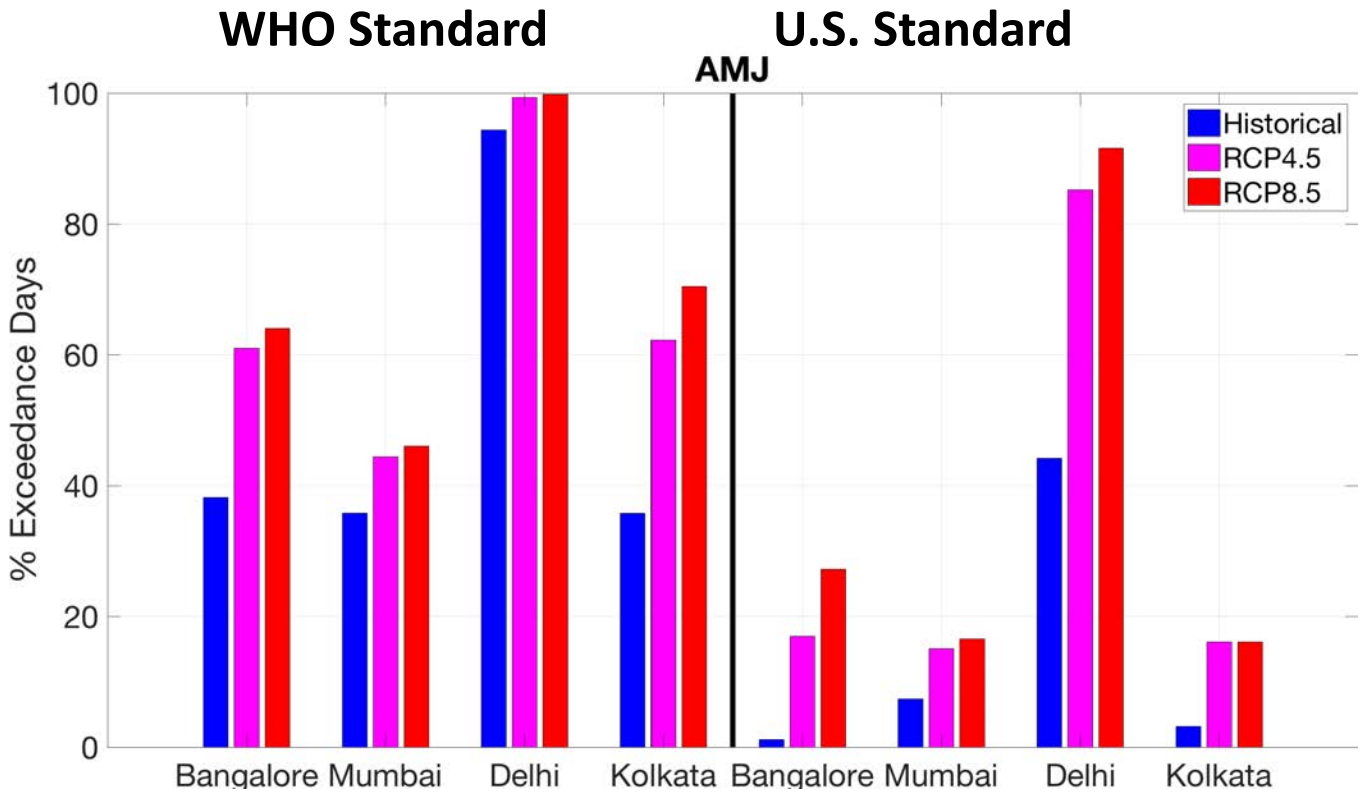


- Exceedance days decreases for all the cities in the RCP4.5 scenario
- In case of Chengdu (west central China) increases for RCP8.5 scenario
- With WHO standard, all cities show significantly larger number of exceedance days

Averaged over :

- Historical: 1990 – 2014
- RCP4.5: 2031 – 2060
- RCP8.5: 2031 – 2060

Exceedance Days for Megacities In India

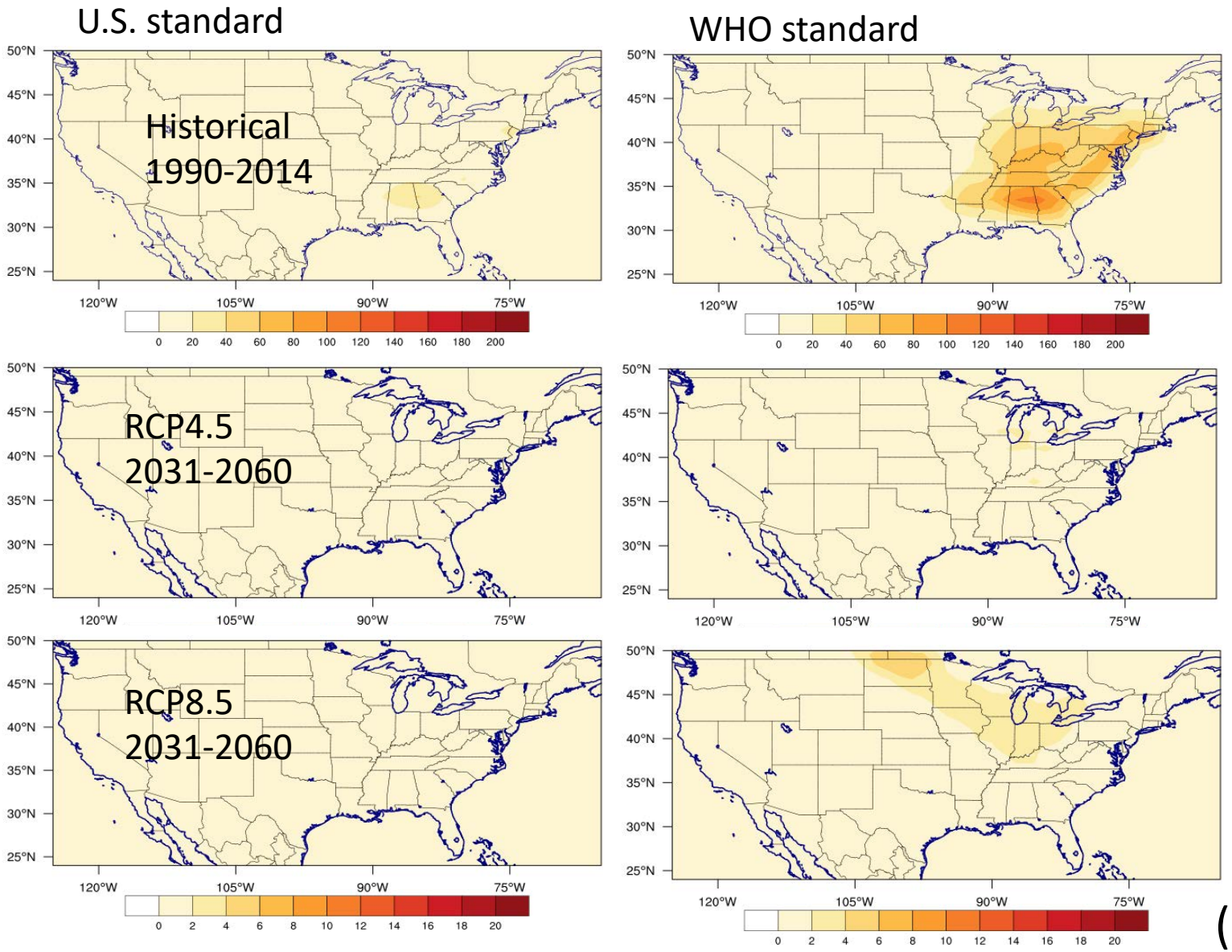


Averaged over :

- Historical: 1990 – 2014
- RCP4.5: 2031 – 2060
- RCP8.5: 2031 – 2060

- Increases in future for both the scenarios
- Monsoon has the least exceedance days, due to washout of pollutant
- Delhi still has high % exceedance days during monsoon season

$PM_{2.5}$ Exceedance Days in U.S. Decrease

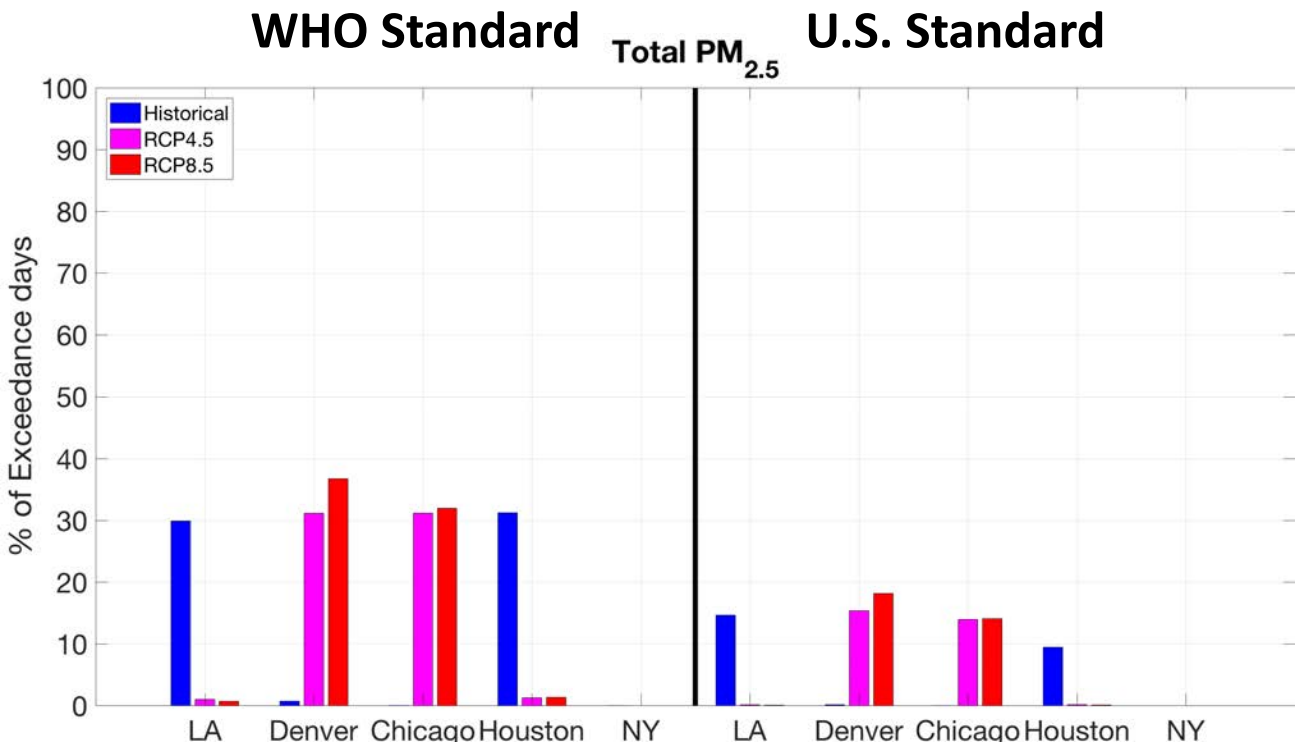


Mean annual exceedance days for anthropogenic $PM_{2.5}$ (does not include natural sources: dust and sea salt)

- Total and human PM decreases in both scenarios.

(Days)

Exceedance Days In Megacities In The United States

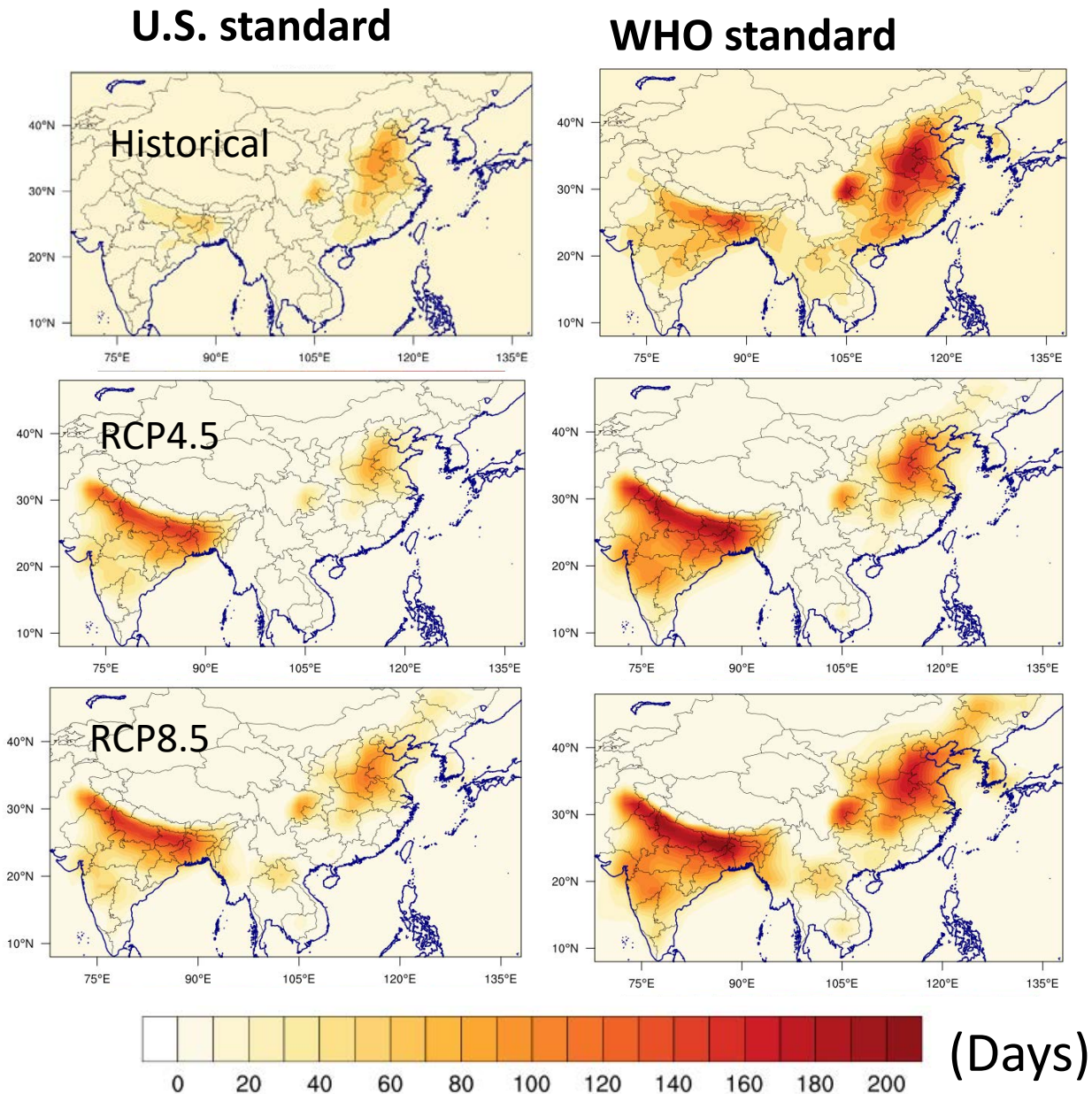


- Exceedances underestimated for land-ocean boundary areas (e.g., Los Angeles, Houston)
- Total $PM_{2.5}$ includes dust and sea-salt
- # of exceedance days increases for Chicago and Denver in the future scenarios

Averaged over :

- Historical: 1990 – 2014
- RCP4.5: 2031 – 2060
- RCP8.5: 2031 – 2060

$PM_{2.5}$ Exceedance Days Increase In South Asia



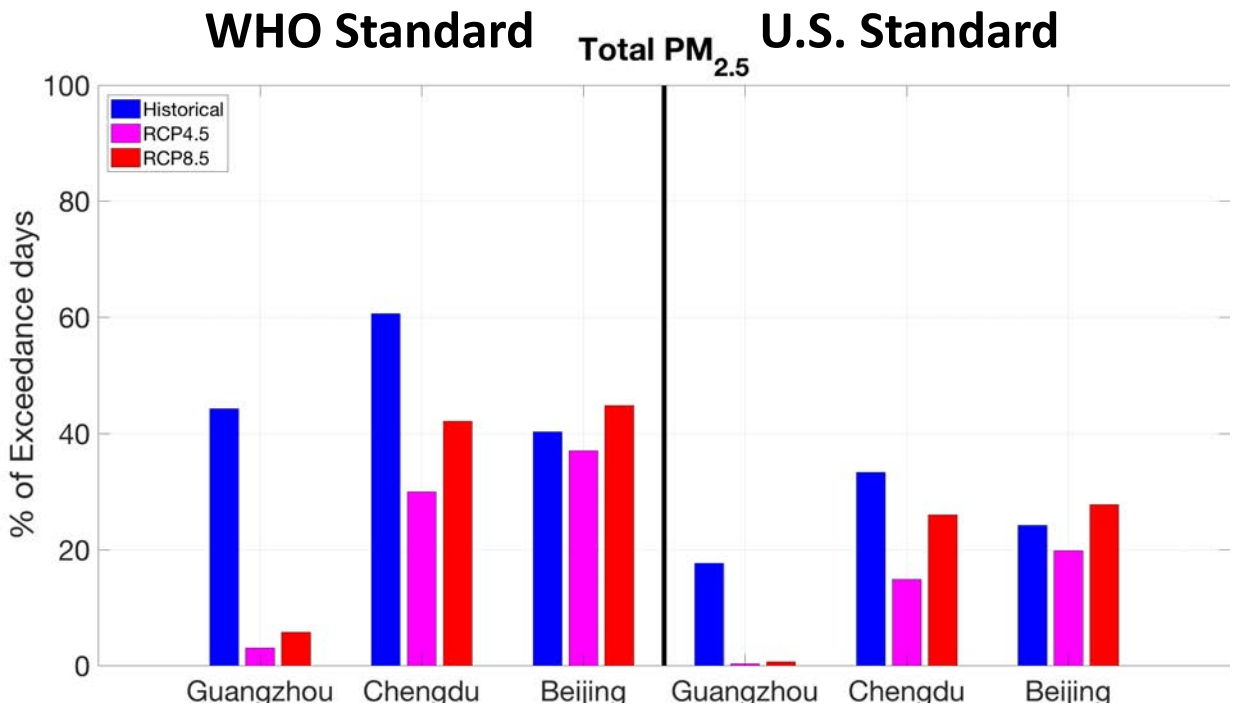
Mean annual exceedance days for anthropogenic $PM_{2.5}$ (does not include dust and sea salt)

- India: the number of days increases for both scenarios
- China: the number of days increases in the high scenario

Averaged over :

- Historical: 1990 – 2014
- RCP4.5: 2031 – 2060
- RCP8.5: 2031 – 2060

Exceedance Days for Megacities in China

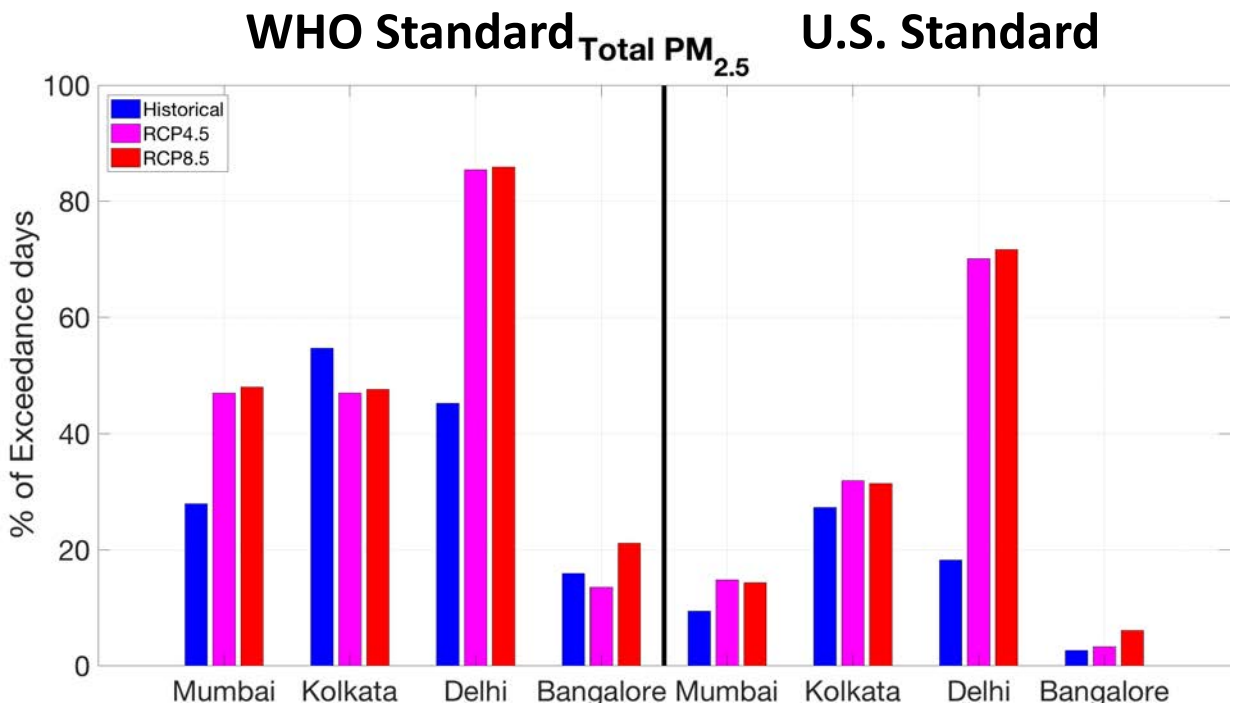


- Total $PM_{2.5}$ includes crustal materials dust and sea-salt
- Exceedance event increases only in Beijing for RCP8.5
- Exceedance days decreases further for both present and future when compared with the U.S. standard

Averaged over :

- Historical: 1990 – 2014
- RCP4.5: 2031 – 2060
- RCP8.5: 2031 – 2060

Exceedance Days for Megacities In India



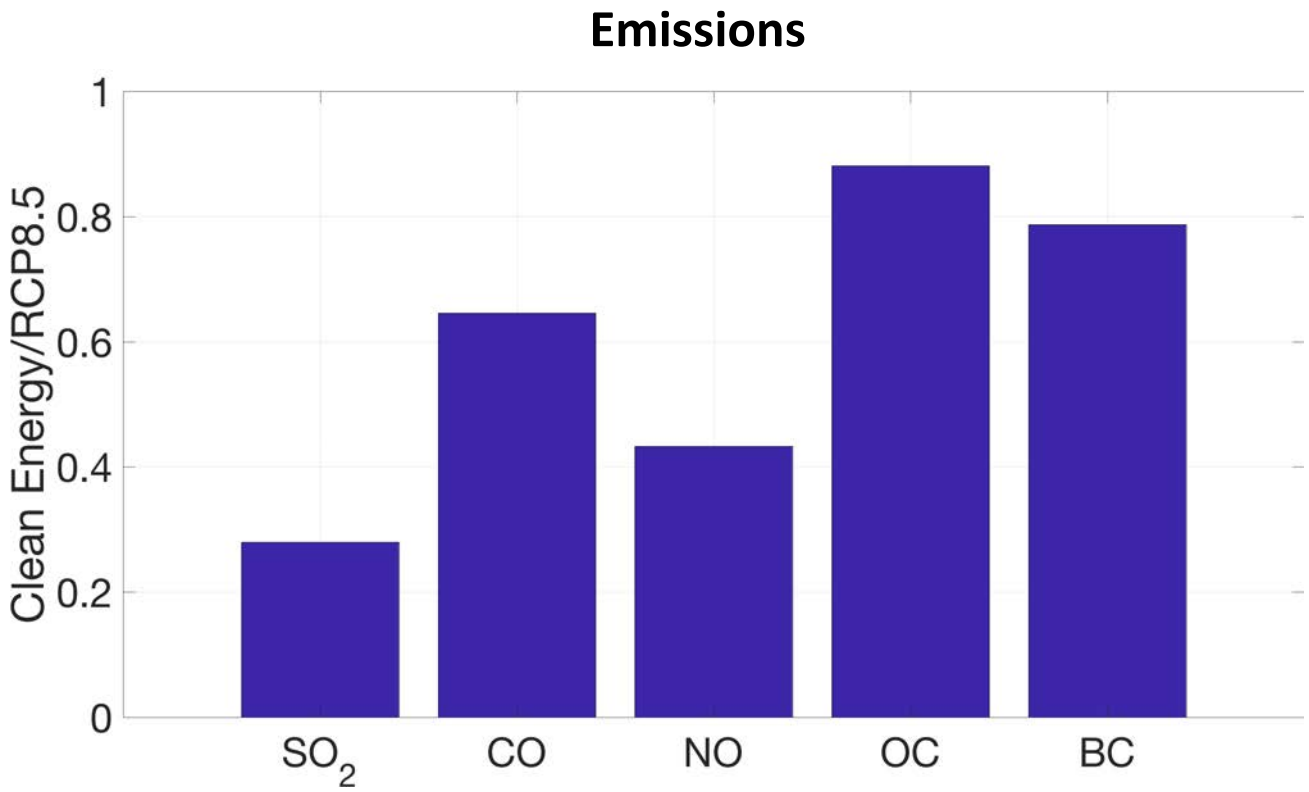
- Total $PM_{2.5}$ includes dust and sea-salt
- Delhi (in the northern Gangetic plain) had the highest number of exceedance days for both scenarios
- In case of Mumbai, total $PM_{2.5}$ increases in the future scenarios (note that Mumbai is a coastal city with influence of sea-salt).

Averaged over :

- Historical: 1990 – 2014
- RCP4.5: 2031 – 2060
- RCP8.5: 2031 – 2060

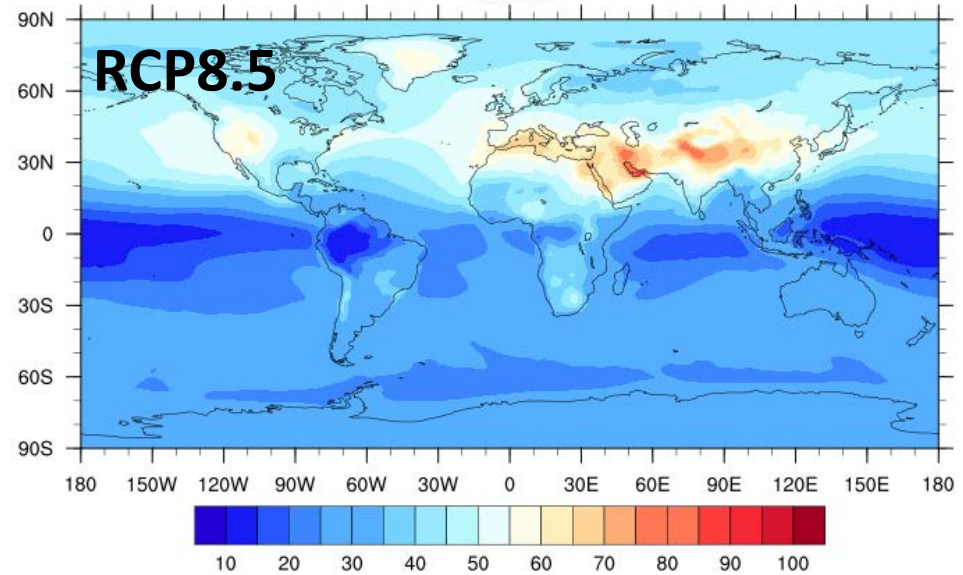
Clean Energy Scenario

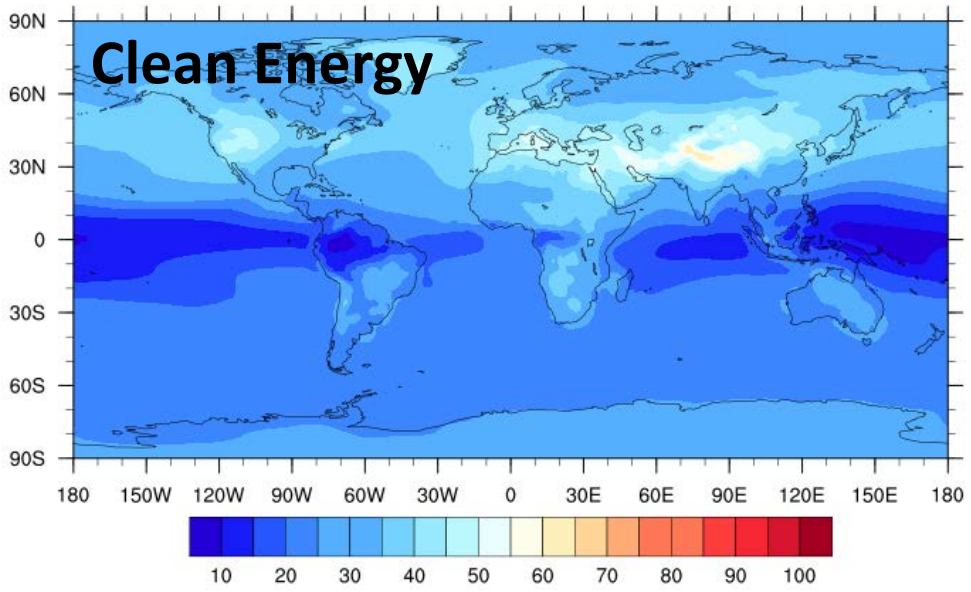
- At present 80-85% of total energy comes from fossil fuel combustion and biomass burning
- **Clean Energy scenario**
- No emissions from fossil fuels by mid-century (2050), but still include emissions from use of biofuels, and from oceans and other natural sources



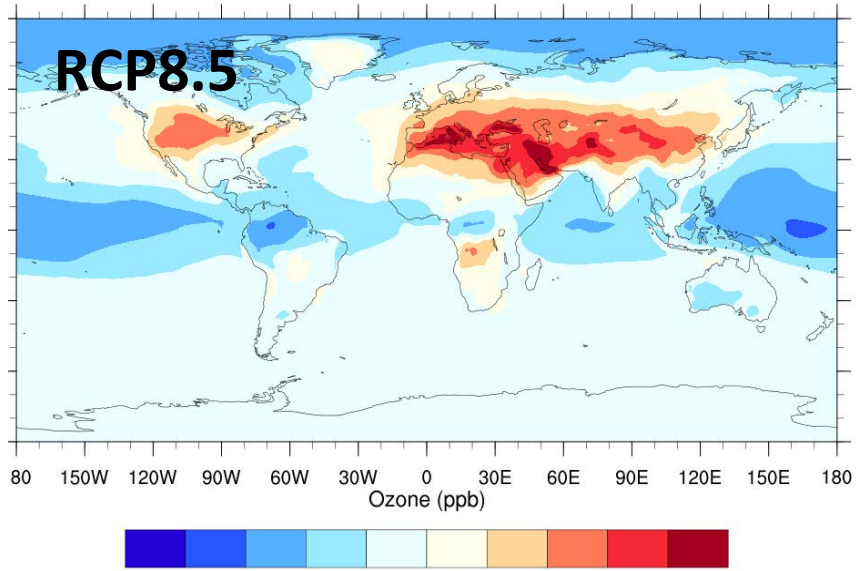
Clean Energy: Ozone Concentrations Decrease

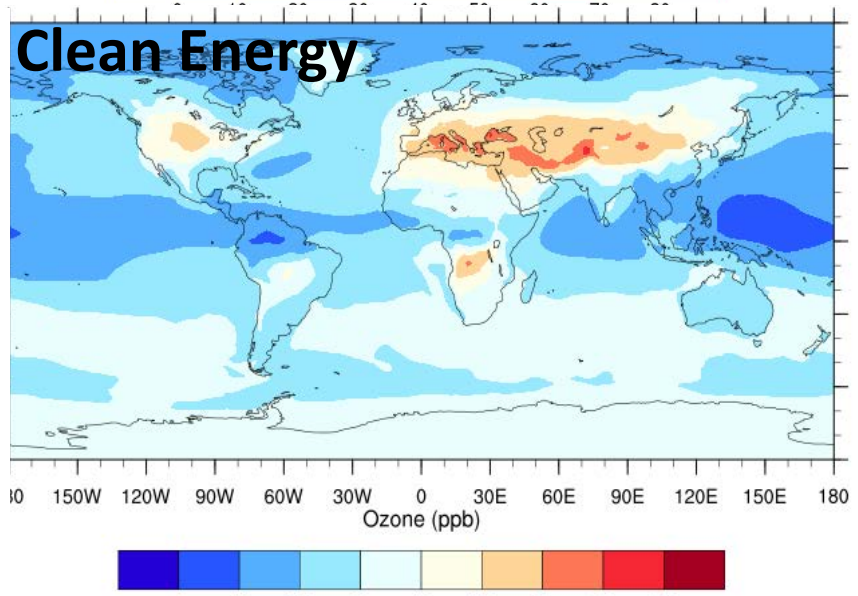
Annual Average Concentration





Mean Summer Concentration



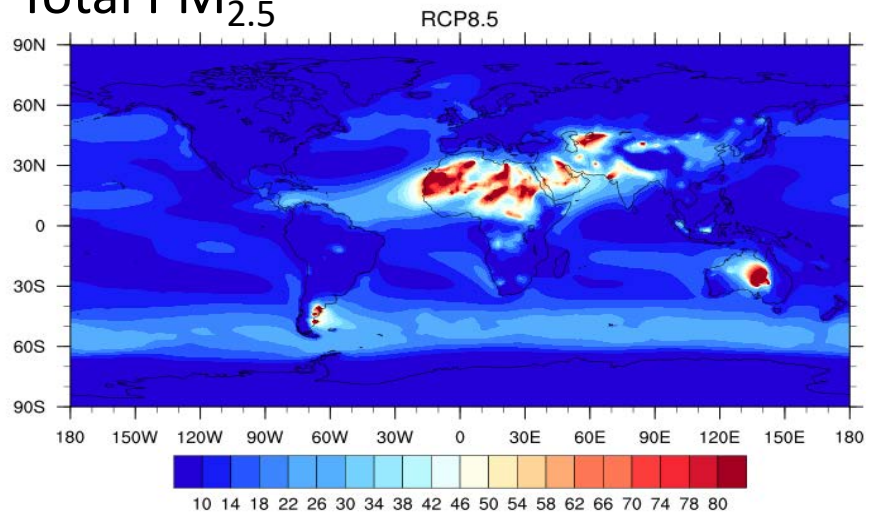


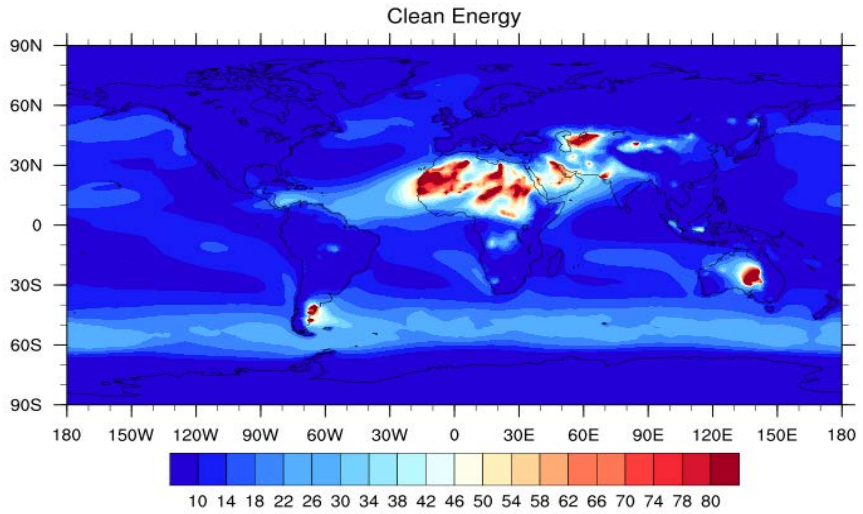
- The hotspot regions remain the same
- Eliminating fossil fuel emission reduces the burden of O_3 precursors thus reducing overall surface ozone concentration

PM2.5 Improvement In Clean Energy Scenario

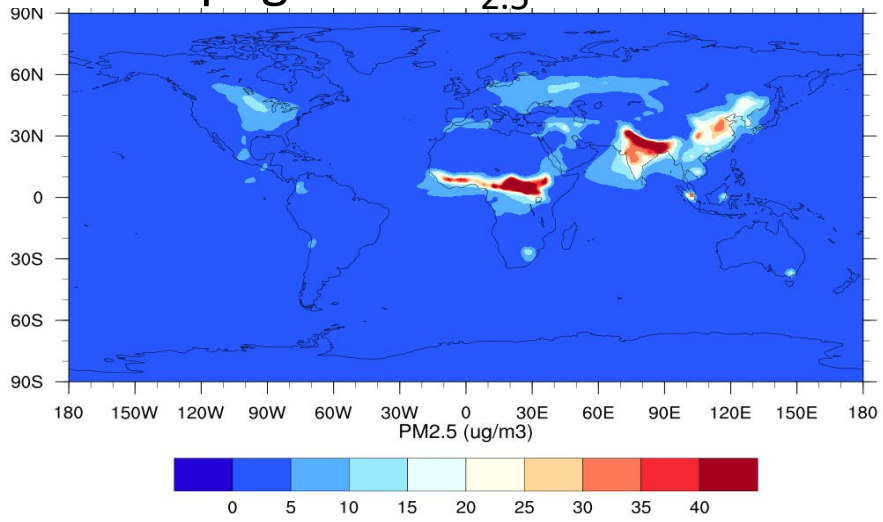
RCP8.5 | **Clean Energy**

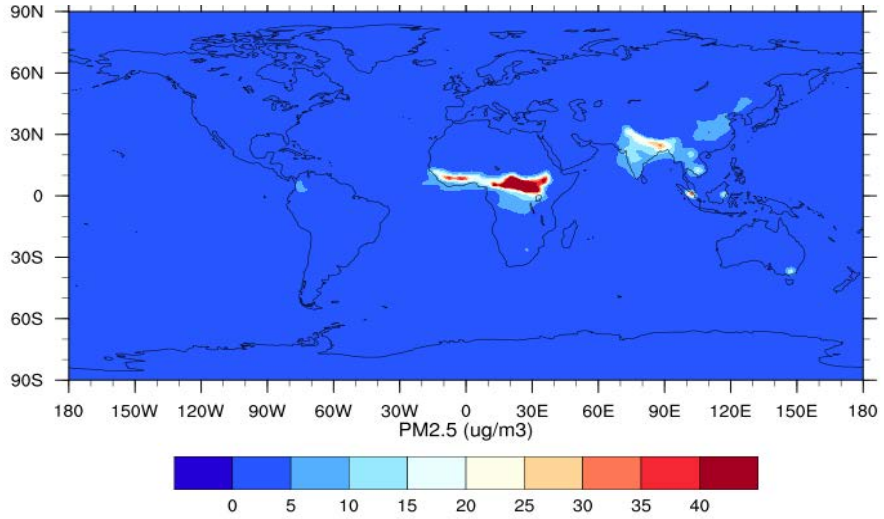
Total $PM_{2.5}$





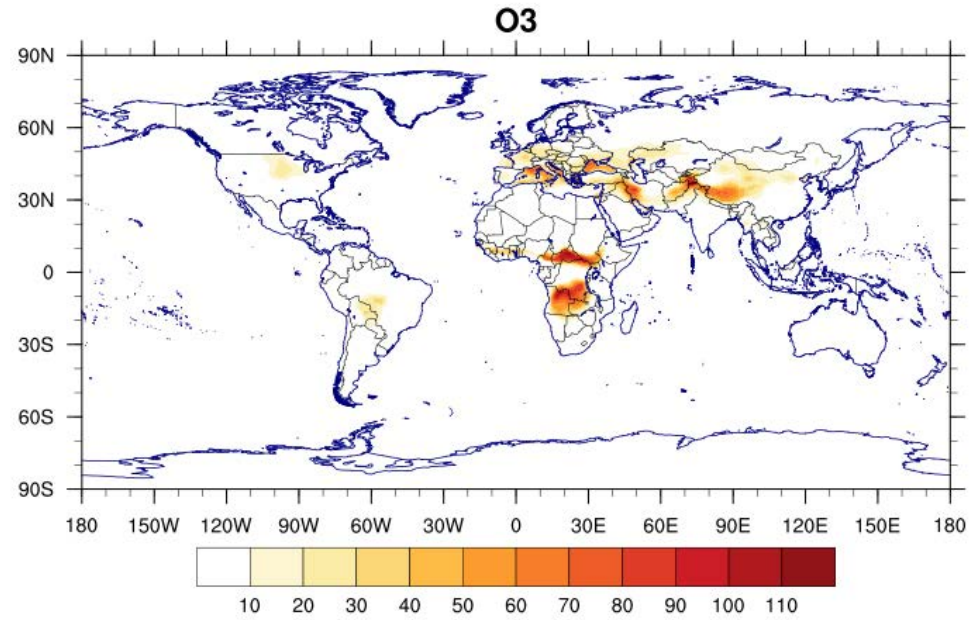
Anthropogenic $PM_{2.5}$

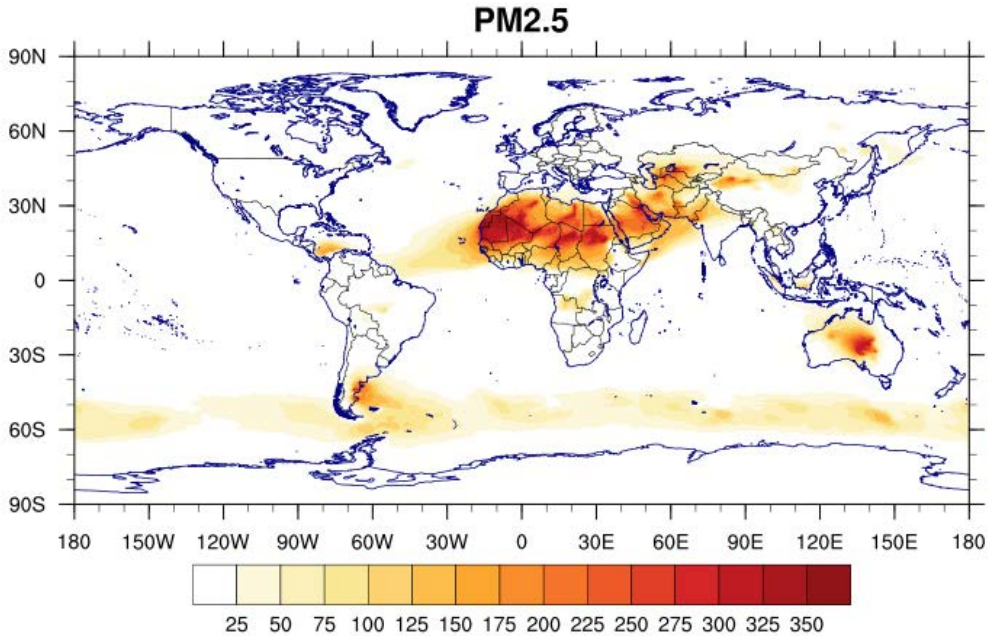




- $PM_{2.5}$ reduces significantly over South Asia and Indo Gangetic plains
- Change in total $PM_{2.5}$ is dominated by sea salt and dust
- Anthropogenic $PM_{2.5}$ from biomass burning is reflected in high concentration found in mid-Africa

Clean Energy: Health Improves (Exceedances decr.)





- Exceedance days decreases globally
- Surface ozone concentrations are reduced by 40-50% annually and in the summer by 30-50%, reducing exceedance days over the hotspot regions by 70-100%
- Total $PM_{2.5}$ concentration reduces by 20% specially over South Asia
- Removing fossil fuel completely improves air quality significantly throughout the planet
- Exceedance days over northern Africa is dominated by dust

Color bar shows number of exceedance days

Conclusions

- Focused on health impacts of a changing climate on air quality
  - How changing climate impact air quality in the United States, China, and India focusing on exceedance events for surface ozone and particulate matter
  - Impact of an idealized clean energy world on air quality in the mid-century
- For the high (RCP8.5) scenario, air quality degrades in India and in China and exceedance days increases from the present regionally
- Air quality generally improves over the United States, even for the high scenario.
- The clean energy future scenario results in a world with significantly improved air quality, resulting in a significant reduction in air quality related health issues.

Thank you!

Summary for Ozone

- Ozone concentrations decreases over the United States for all seasons in the lower scenario, but increases in different regions for summer and winter for the higher scenario.
- In case of China, concentration decreases for all the season except winter in case of the lower scenario, but increases during all seasons.
- In case of India for both scenarios, concentrations increase (except for monsoon).
- Increase in exceedance days in high scenario for China and India, but decreases for United States.
- There is an increase in exceedance days for winter and spring.

Summary for $PM_{2.5}$

- $PM_{2.5}$ concentrations decrease over the United States for both future scenarios, but increase in India
- $PM_{2.5}$ concentrations increase in China for the high scenario
- Anthropogenic $PM_{2.5}$ (as well as total $PM_{2.5}$) also exceeds WHO standard (and U.S. standard) overall and in the megacities

Summary: Clean Energy Study

- Under the clean energy scenario, surface ozone concentrations are reduced by 40-50% annually and in the summer by 30-50%.
- Anthropogenic $PM_{2.5}$ shows a reduced concentration ranging between 40-75%.
- For total $PM_{2.5}$, annually a reduction by 10-20% is derived over South Asia.
- Removing fossil fuel completely improves air quality significantly throughout the planet.