Regional Chemistry-Climate Simulations in South Asia

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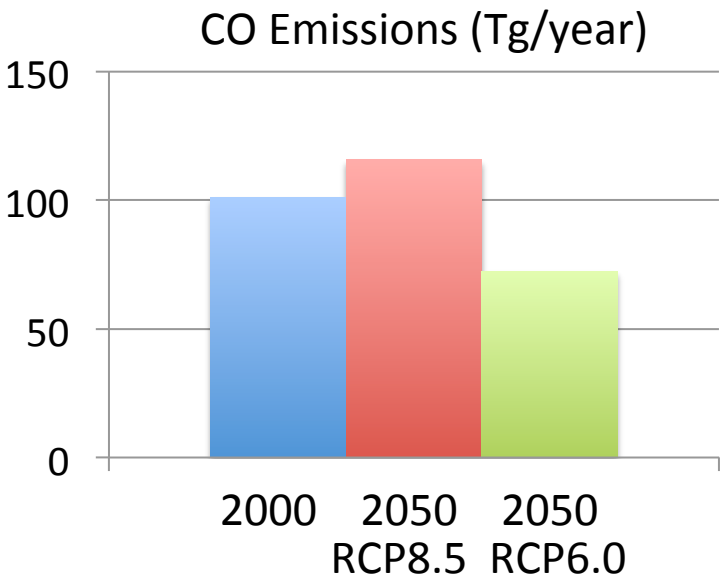
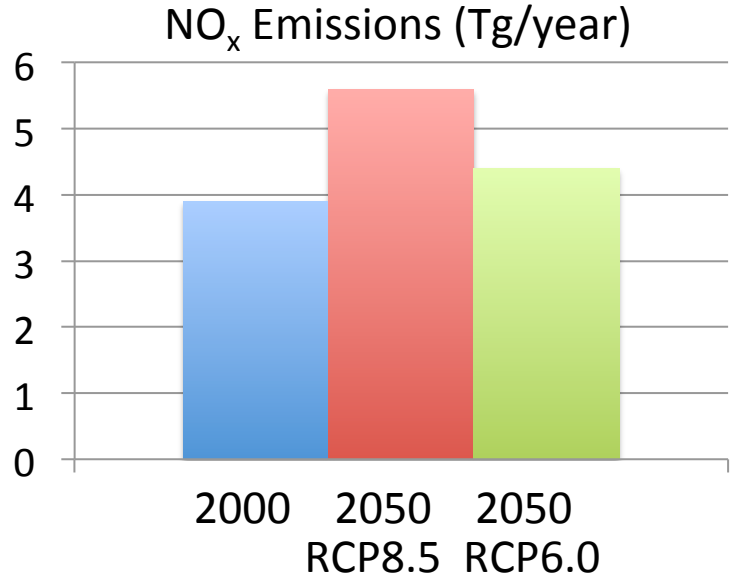
Objectives

1. How will future air quality of South Asia respond to projected changes in climate and emissions of key trace gases and aerosols?

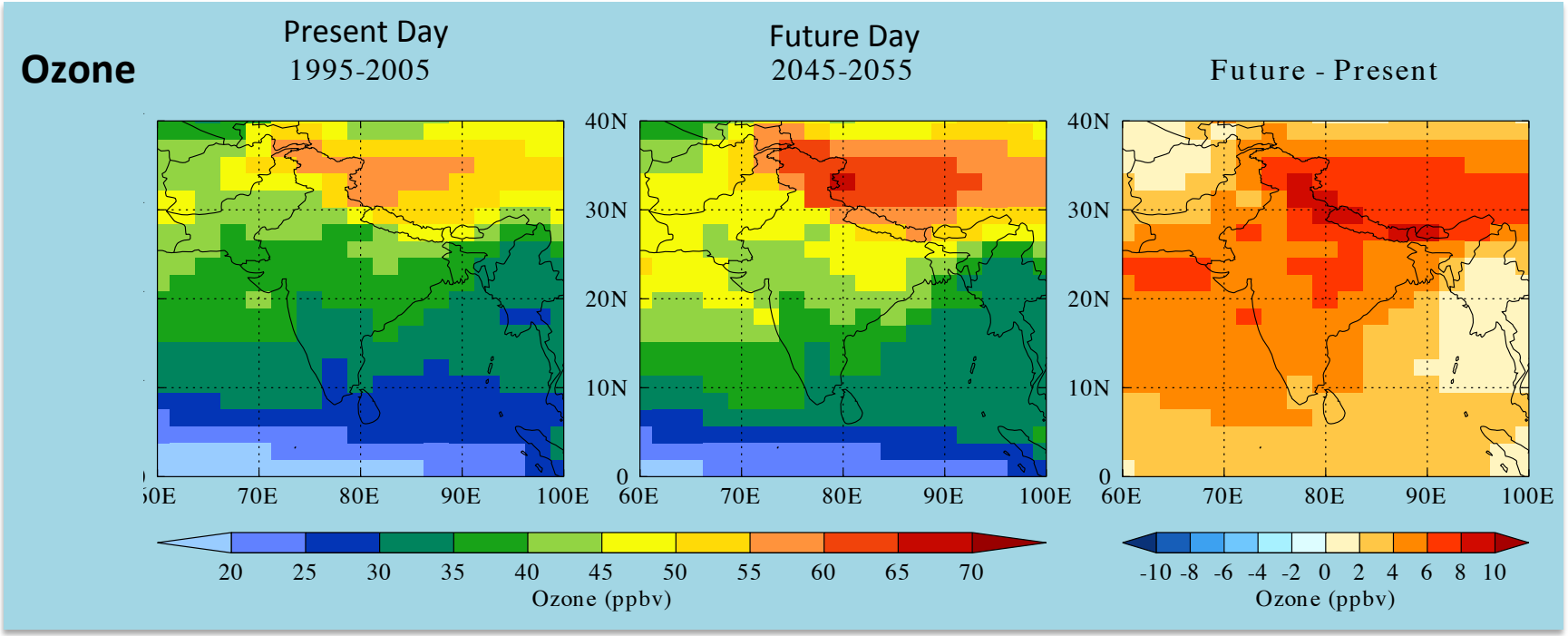




RCP = Representative Concentration Pathway

Projected Ozone for South Asia from Global Model

Based on CAM-Chem Simulations at 2.5° x 1.9°



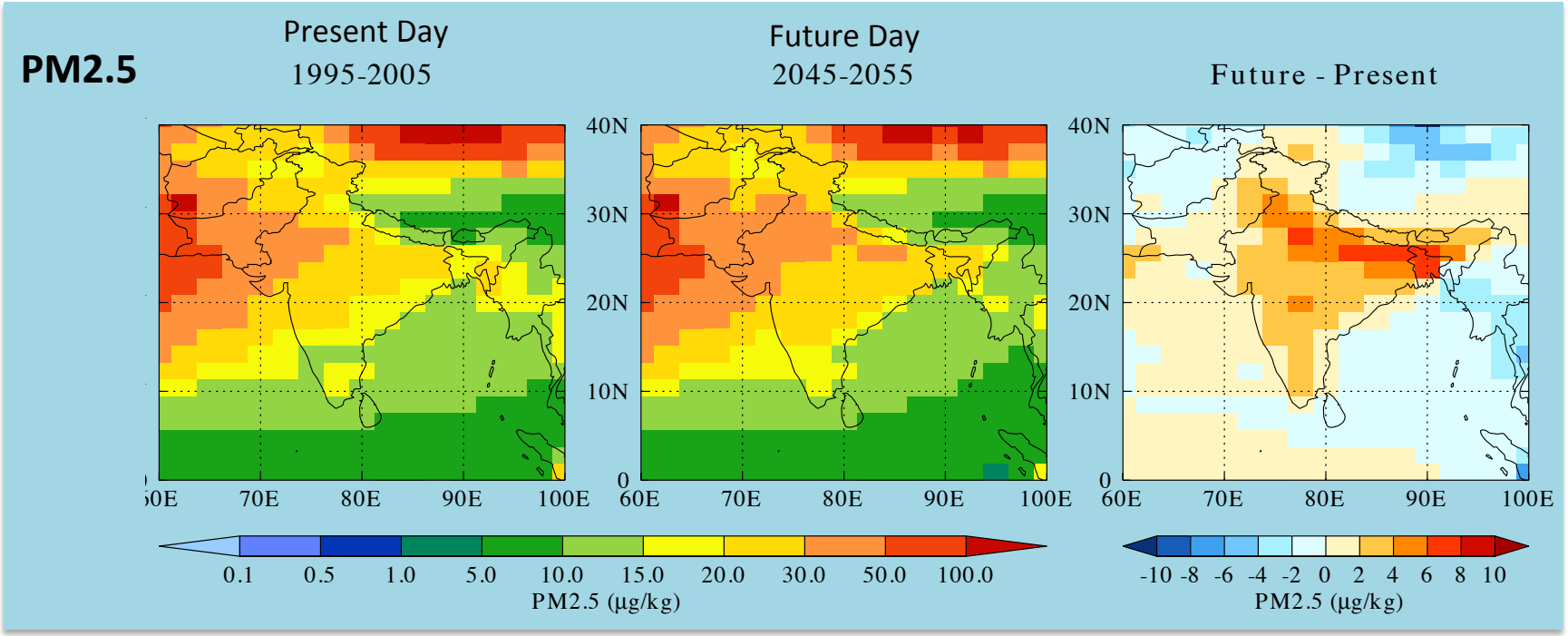
CAM-Chem projects increased ozone of 2-10 ppbv

RCP8.5 Scenario

Simulations from Jean-Francois Lamarque (NCAR)

Projected PM2.5 for South Asia from Global Model

Based on CAM-Chem Simulations at 2.5° x 1.9°



CAM-Chem projects a small increase of PM2.5 by 0-8 µg/kg in India

RCP8.5 Scenario

Simulation results from Jean-Francois Lamarque (NCAR)

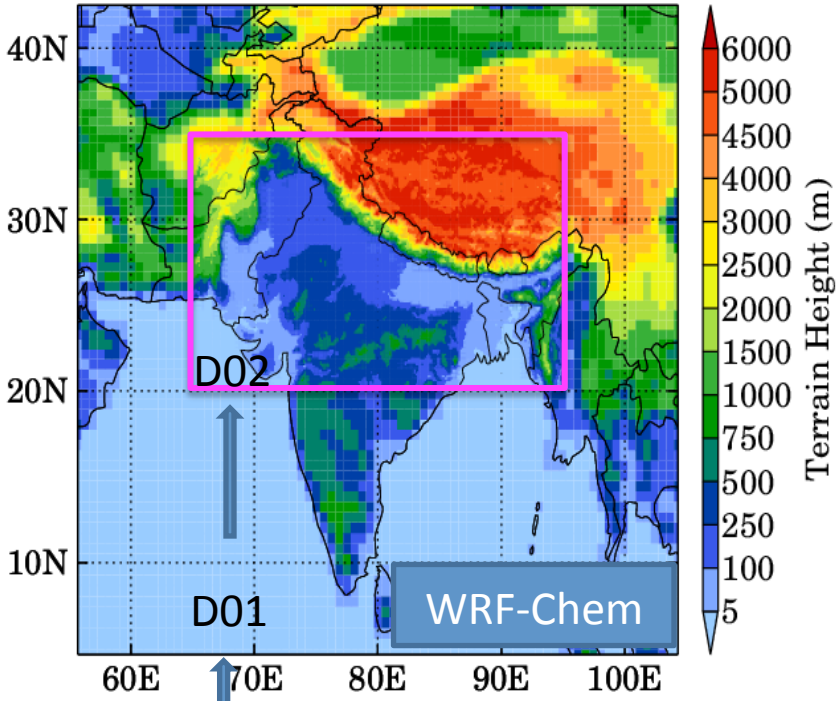
Objectives

1. How will future air quality of South Asia respond to projected changes in climate and emissions of key trace gases and aerosols?

2. How are these projections affected by horizontal grid resolution?

   - Evaluation with present day observations
   - Comparison of future projections at different model resolutions

Nested Regional Chemistry Climate Simulation



Two domains:
Outer: Δx = 60 km, full year
Inner: Δx = 12 km, Oct-May dry season

Present Day: 1995-2004
Future: 2045-2054

10-year simulation – to account for interannual variability

Bias Correction

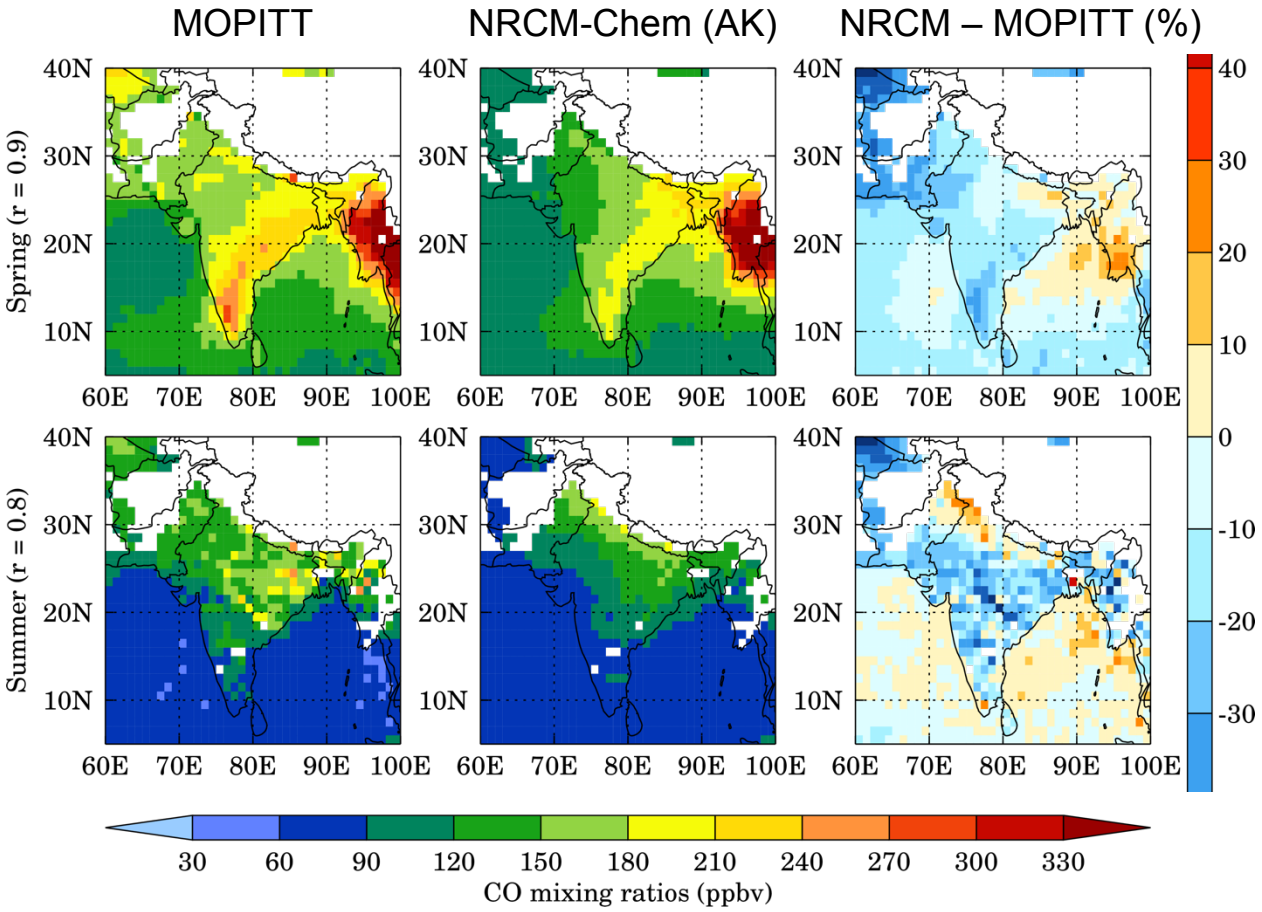
CAM-Chem

	Chemistry-Climate Simulation
1.	Present day emissions and present day climate (PRES)
2.	Future emissions and future climate (RCP8.5)
3.	Future emissions and future climate (RCP6.0)

1. Evaluation of Present Day Results

2. Importance of Model Grid Resolution

NRCM-Chem Compared to MOPITT Satellite Data

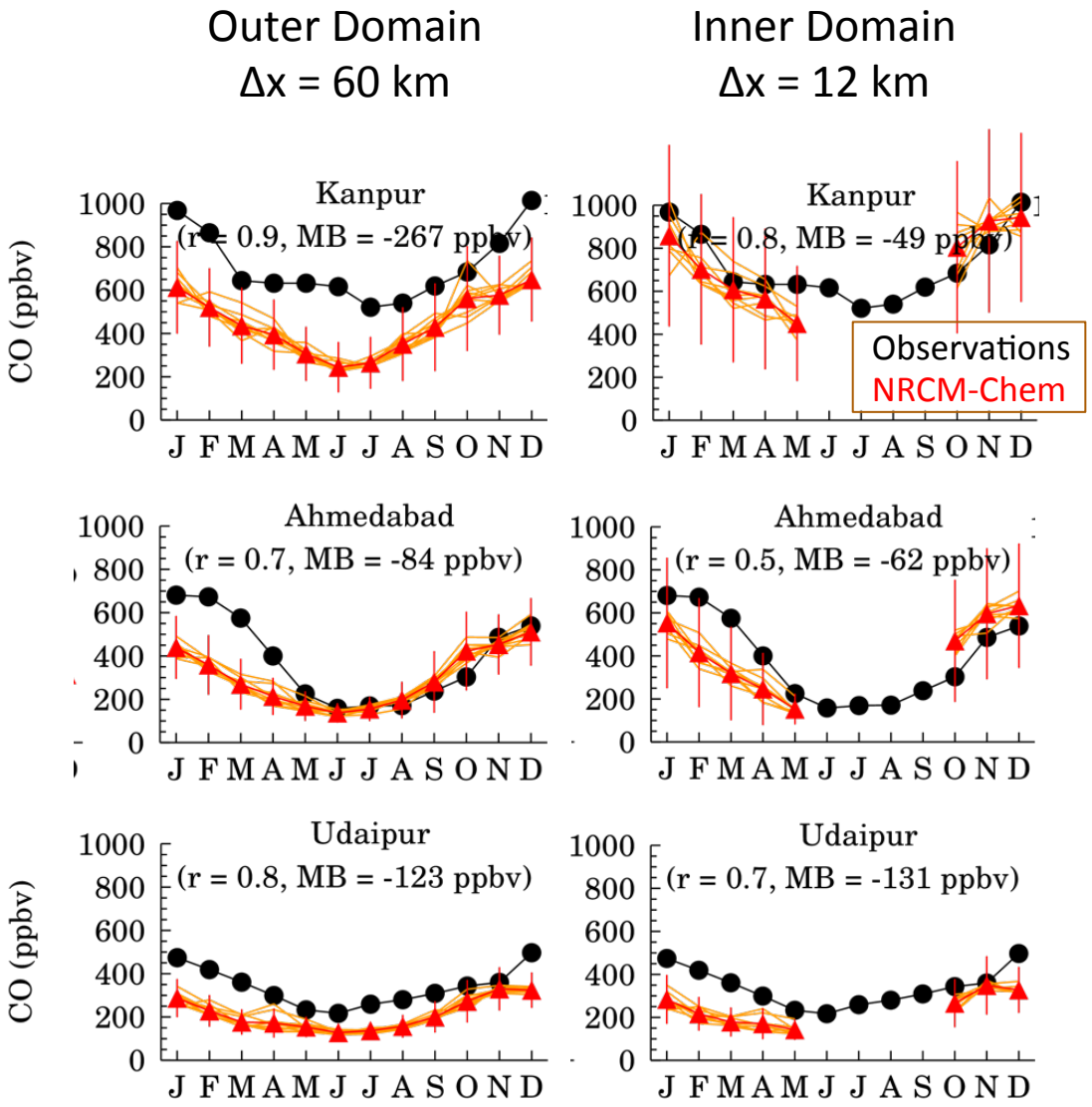


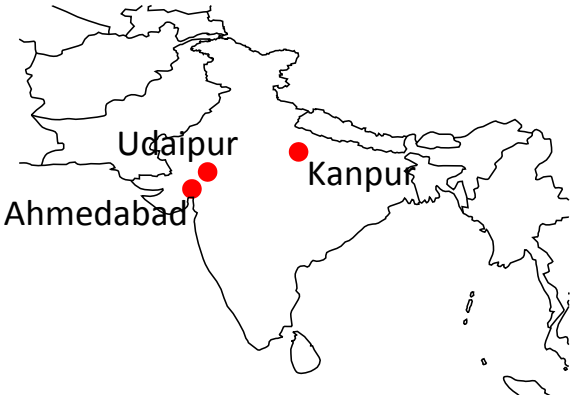
Comparison of seasonal average CO mixing ratios at 900 hPa

Spatial correlation coefficient is >0.8

Percentage difference show 0-20% differences

NRCM-Chem Compared to CO Monitoring Stations



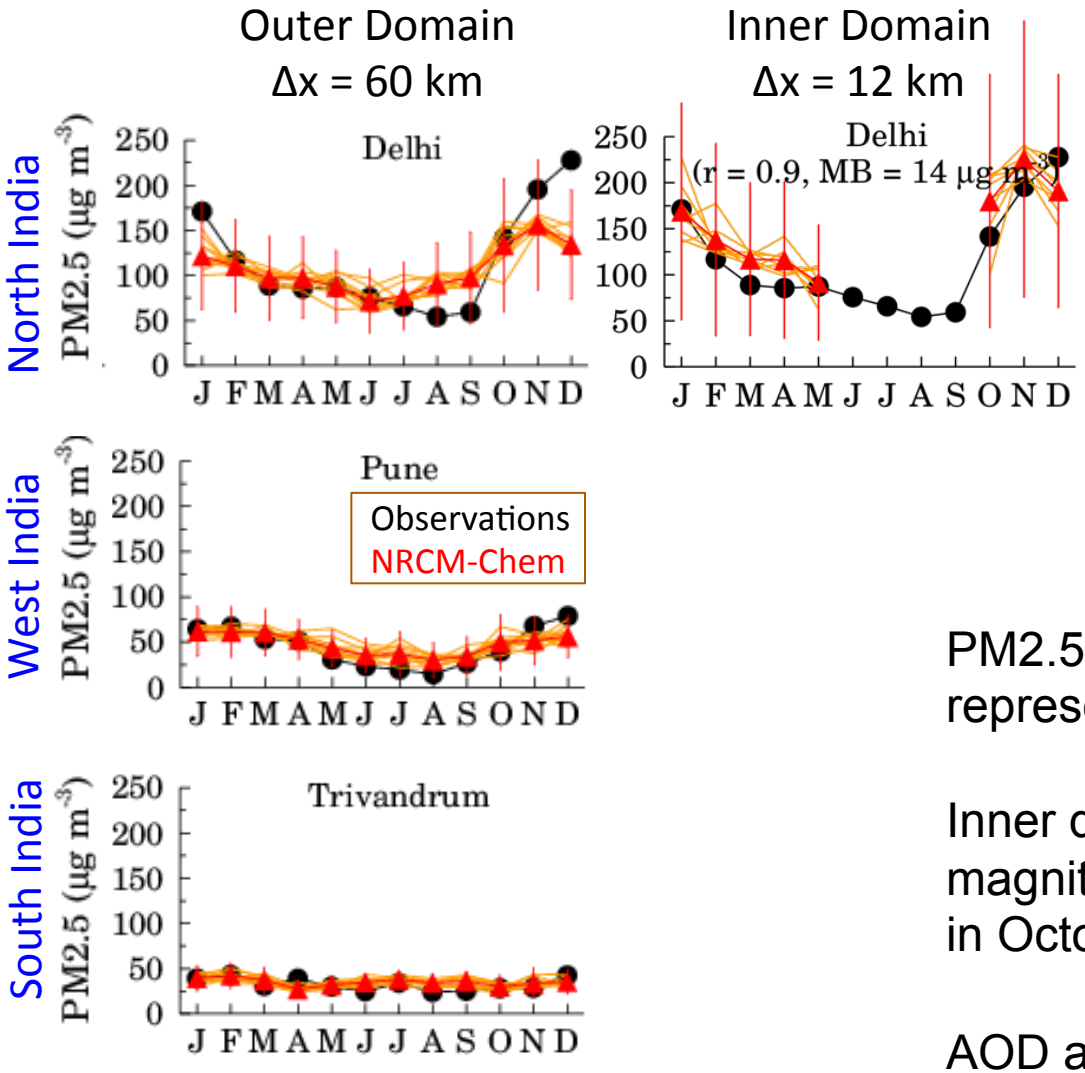


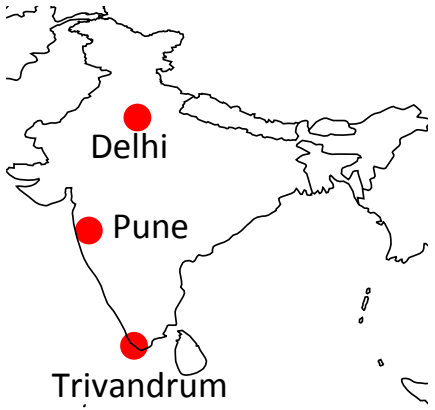
CO seasonal cycle is well represented

Inner domain at Δx = 12 km predicts magnitude better than coarse domain

The same is true for NO_x

NRCM-Chem Compared to PM2.5 Monitoring Stations



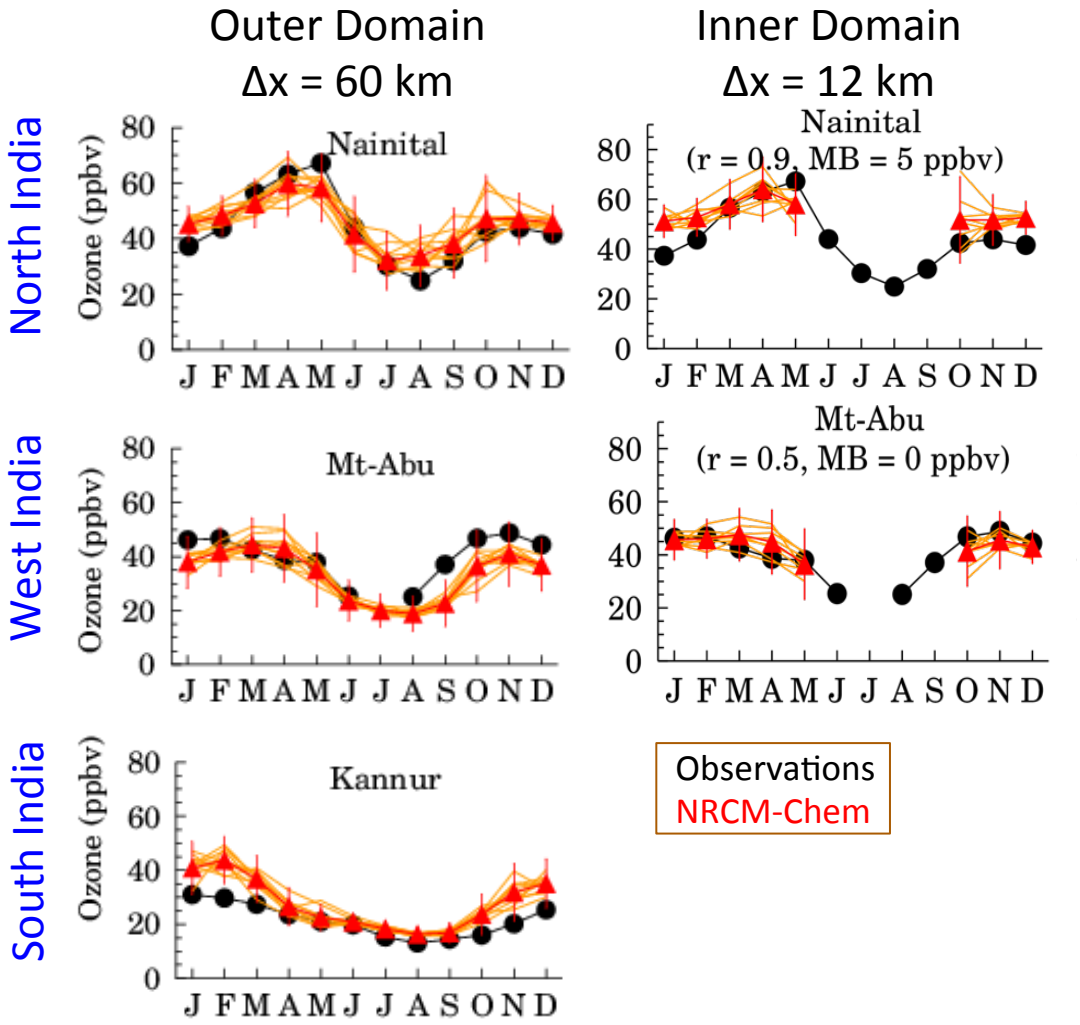


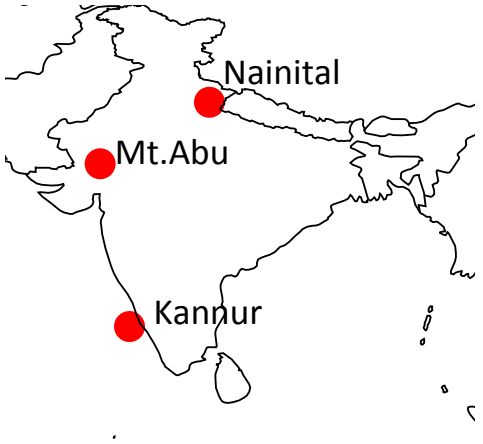
PM2.5 seasonal cycle is fairly well represented

Inner domain at Δx = 12 km predicts magnitude better than coarse domain in October-February

AOD and Ångström Exponent seasonal variations reproduced well

NRCM-Chem Compared to Ozone Monitoring Stations

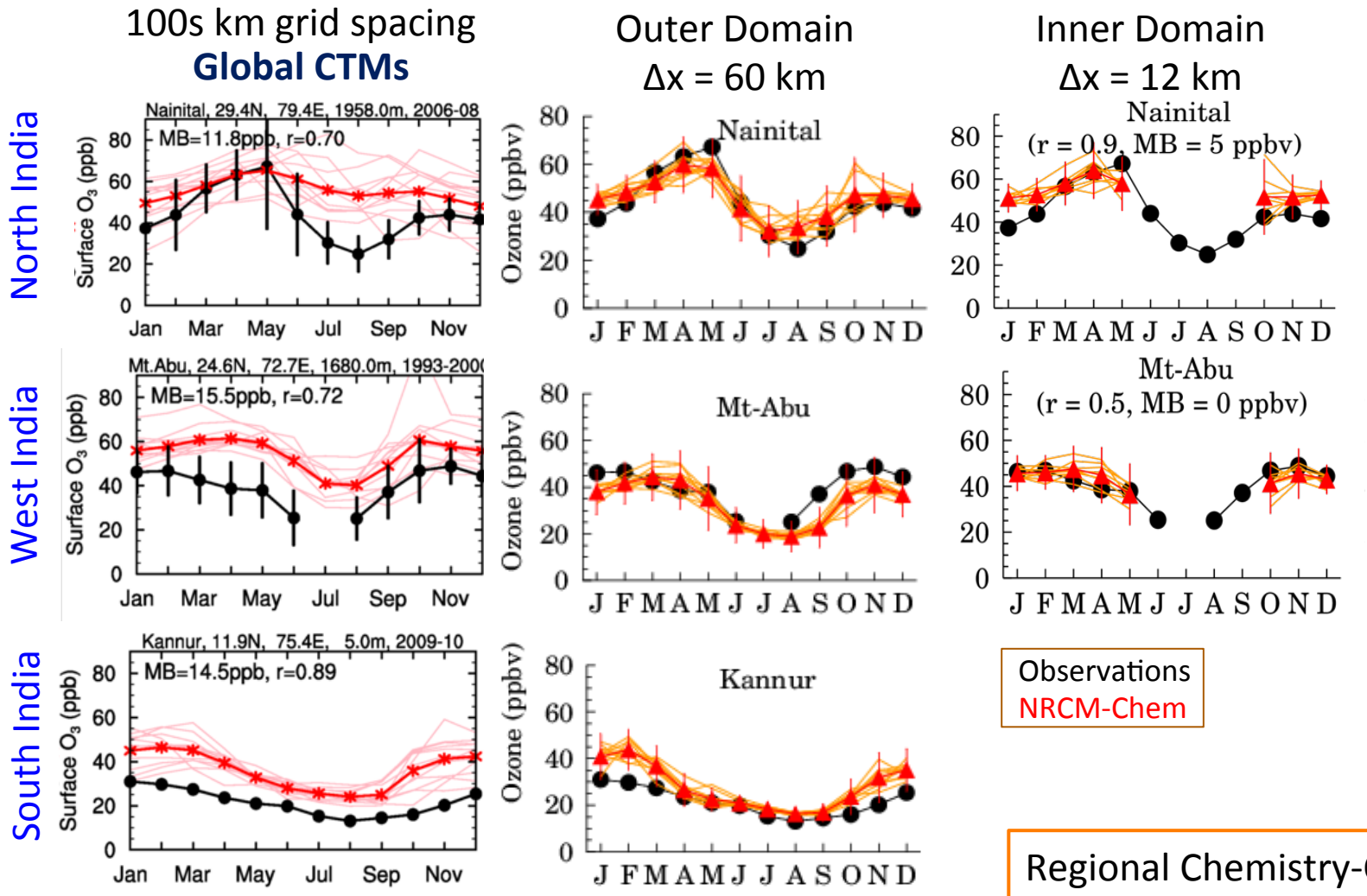




Ozone seasonal cycle is represented well

Inner domain predicts magnitude similarly or somewhat better than outer domain

NRCM-Chem Compared to Ozone Monitoring Stations



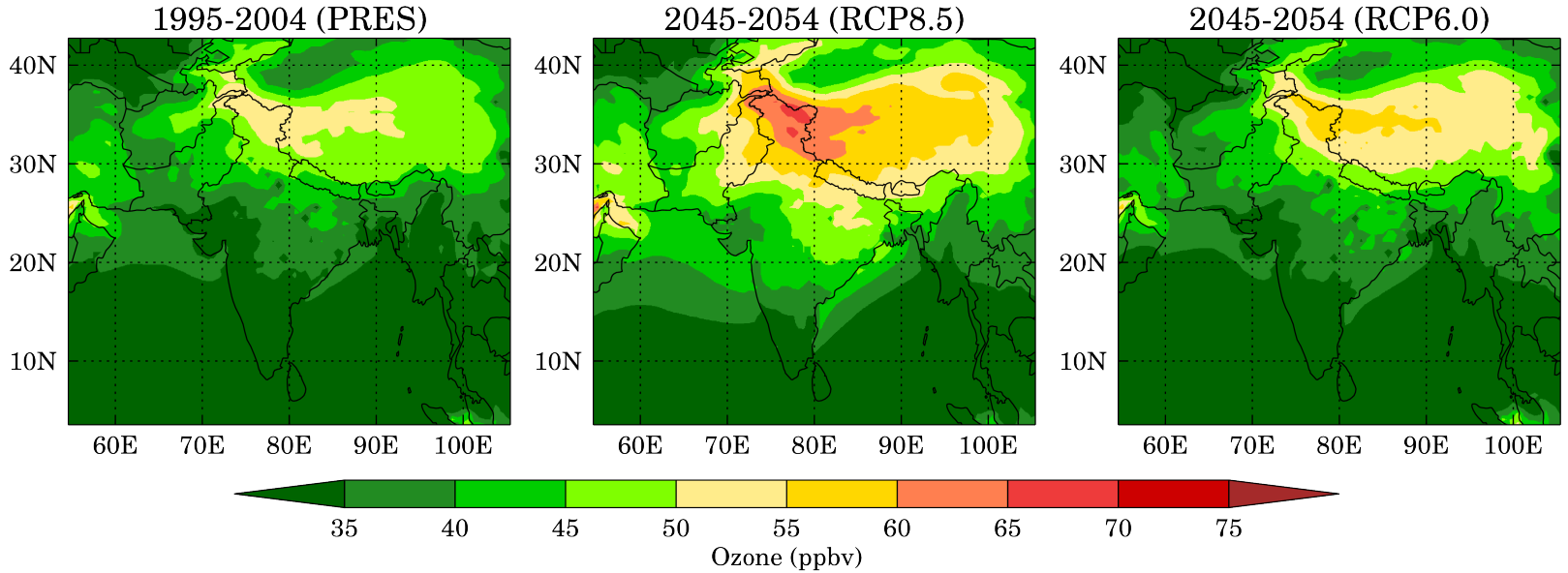
From TOAR chapter 7, under review

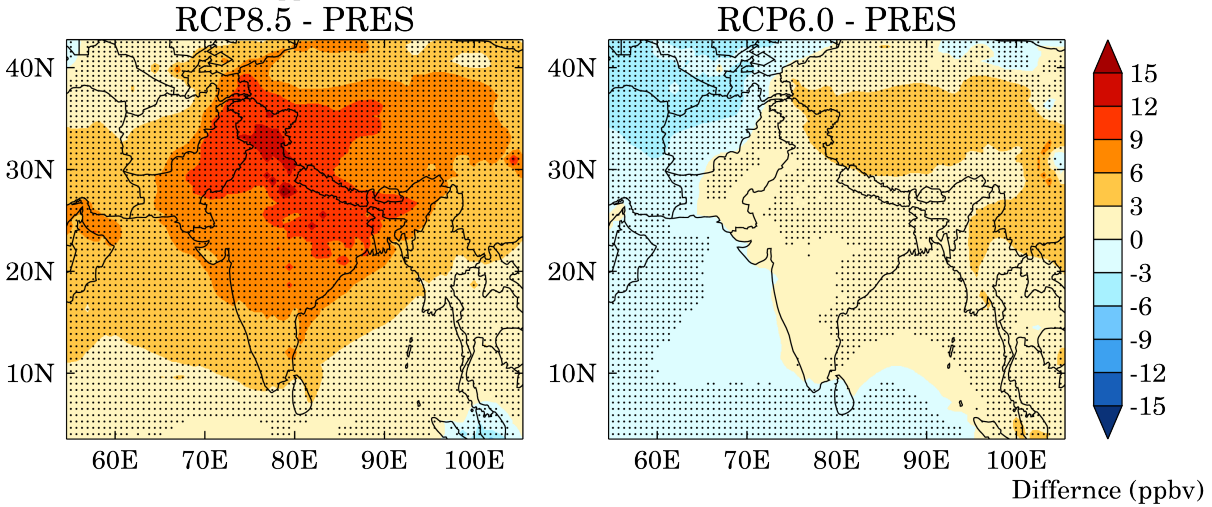
Regional Chemistry-Climate Model performs much better than Global CTMs

Objectives

1. How will future air quality of South Asia respond to projected changes in climate and emissions of key trace gases and aerosols?

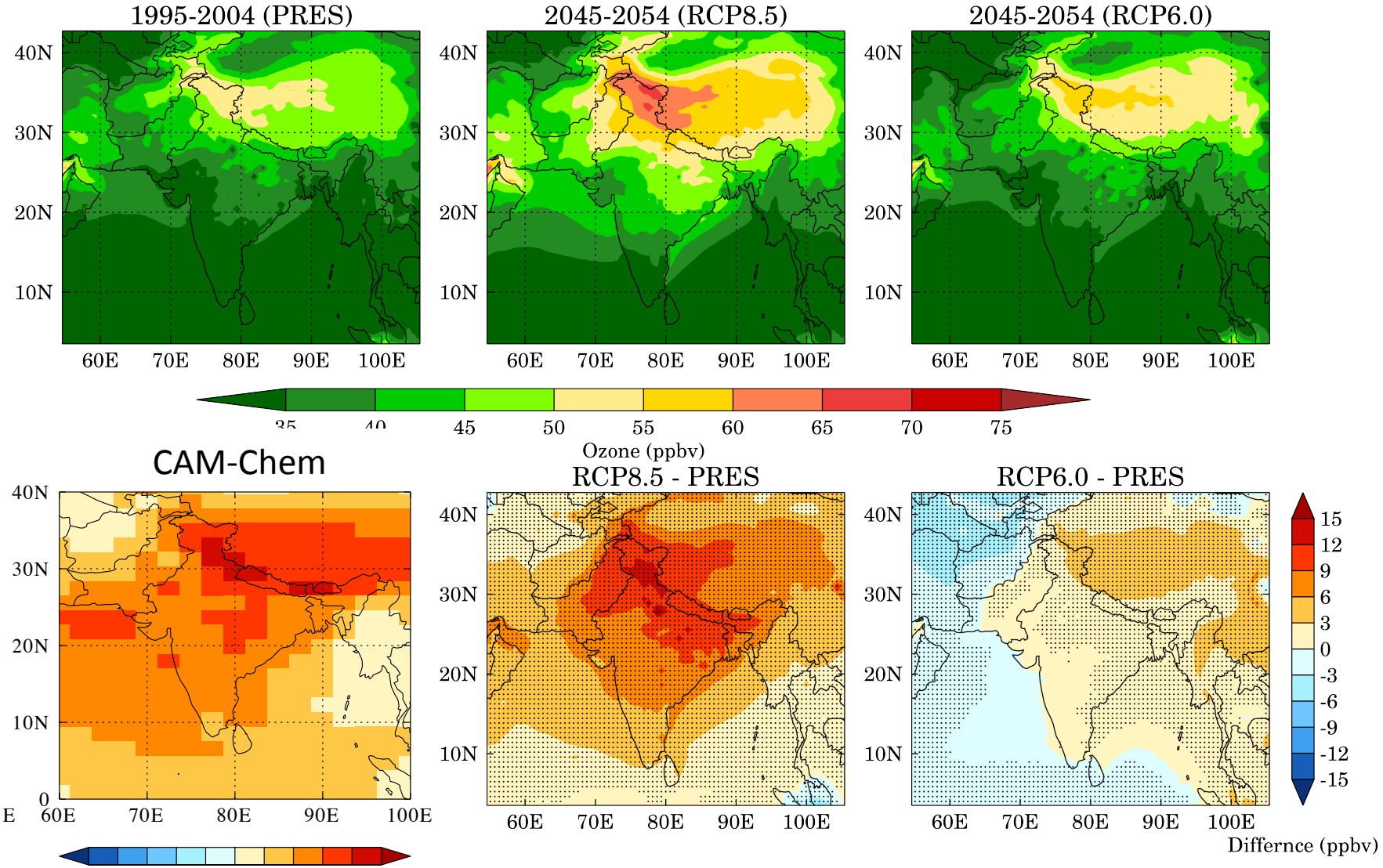
Annual Average, Maximum Daily 8-hour Average (MDA8h) **surface ozone** across scenarios





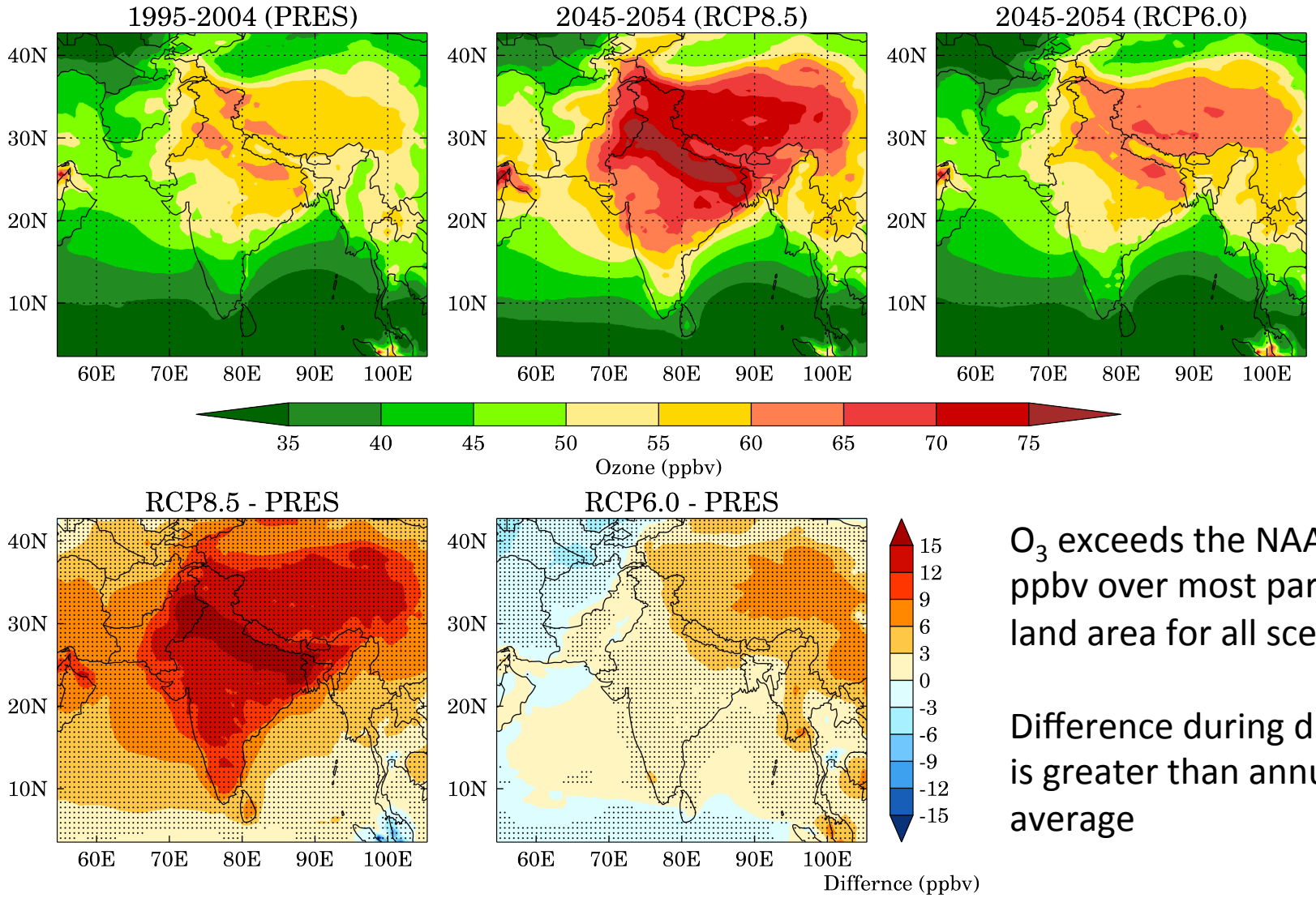
- O_3 increases in both RCP8.5 and RCP6.0 scenarios
- O_3 remains below the National Ambient Air Quality Standard (NAAQS) of 50 ppbv over most parts of the domain

Annual Average, Maximum Daily 8-hour Average (MDA8h) **surface ozone** across scenarios



CAM-Chem has similar pattern for 24-hour average and somewhat smaller magnitude compared to NRCM-Chem

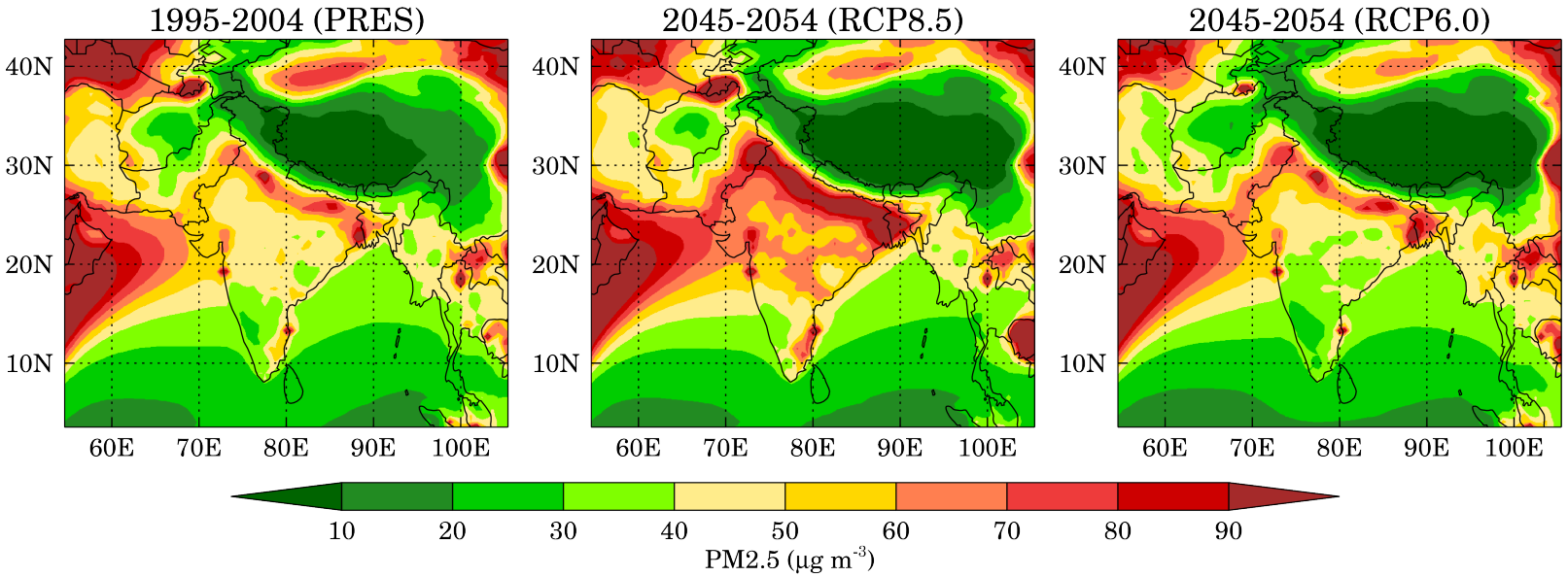
Dry season (Oct-May) average MDA8h **surface ozone** across scenarios

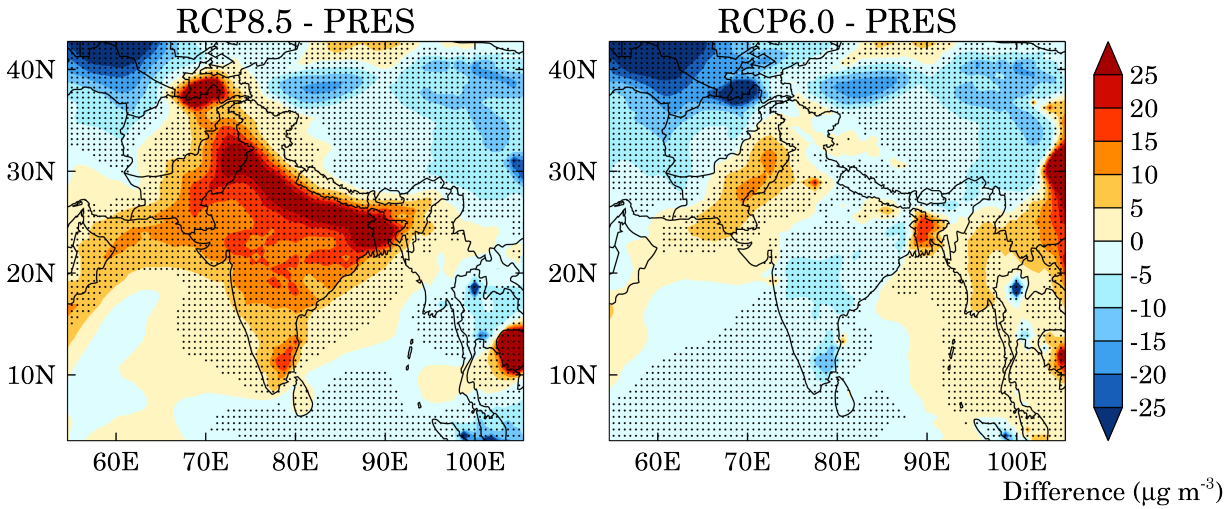


O_3 exceeds the NAAQS of 50 ppbv over most parts of the land area for all scenarios

Difference during dry season is greater than annual average

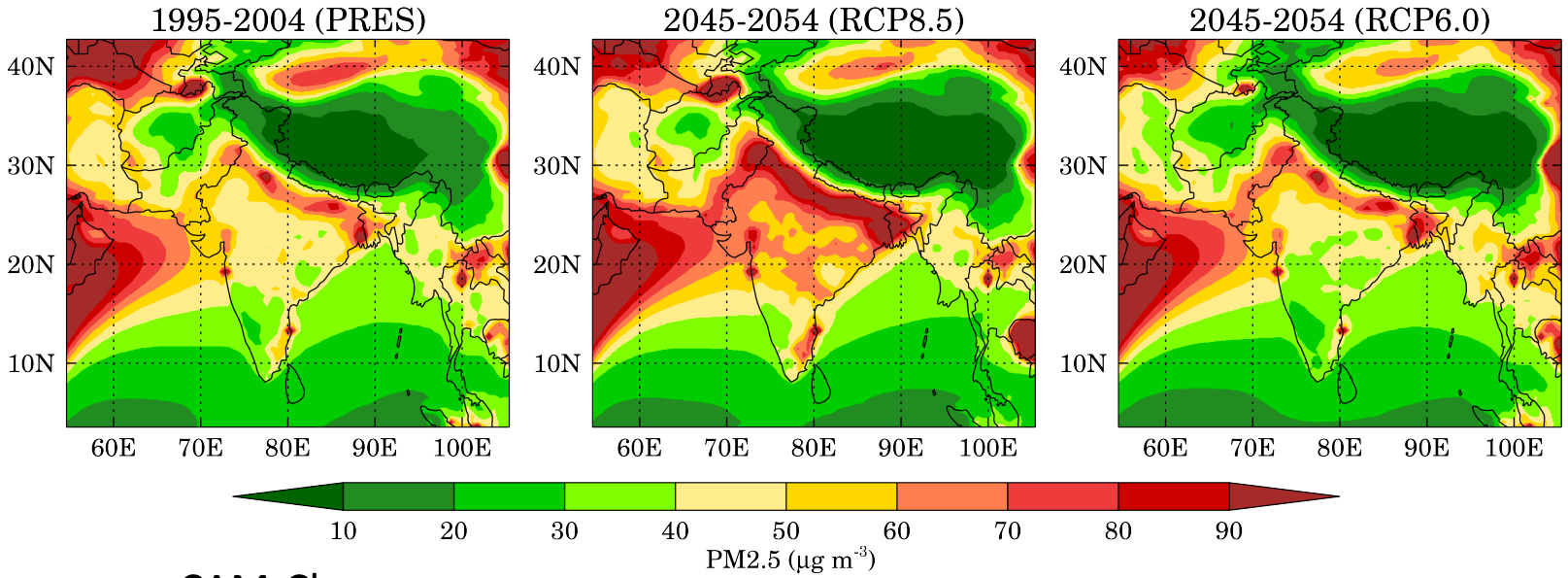
Annual Average **PM2.5** across scenarios

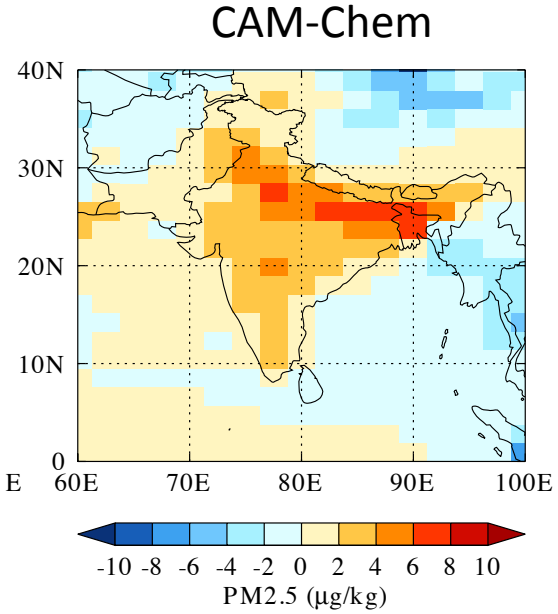


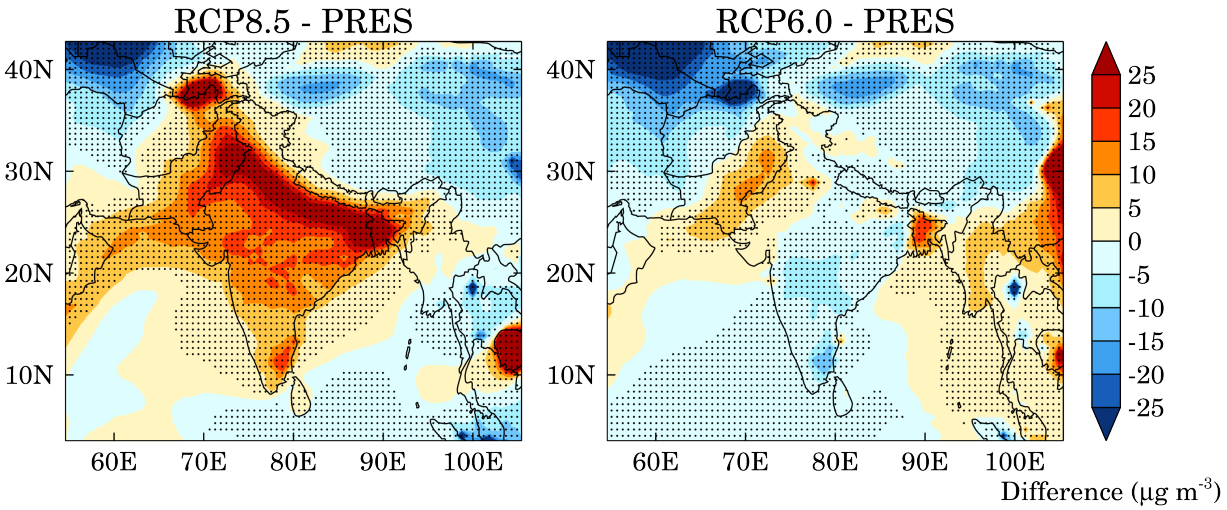


- Increase in RCP8.5
- Decrease in RCP6.0
- PRES and RCP8.5 exceed NAAQS of 40 μg/m^3

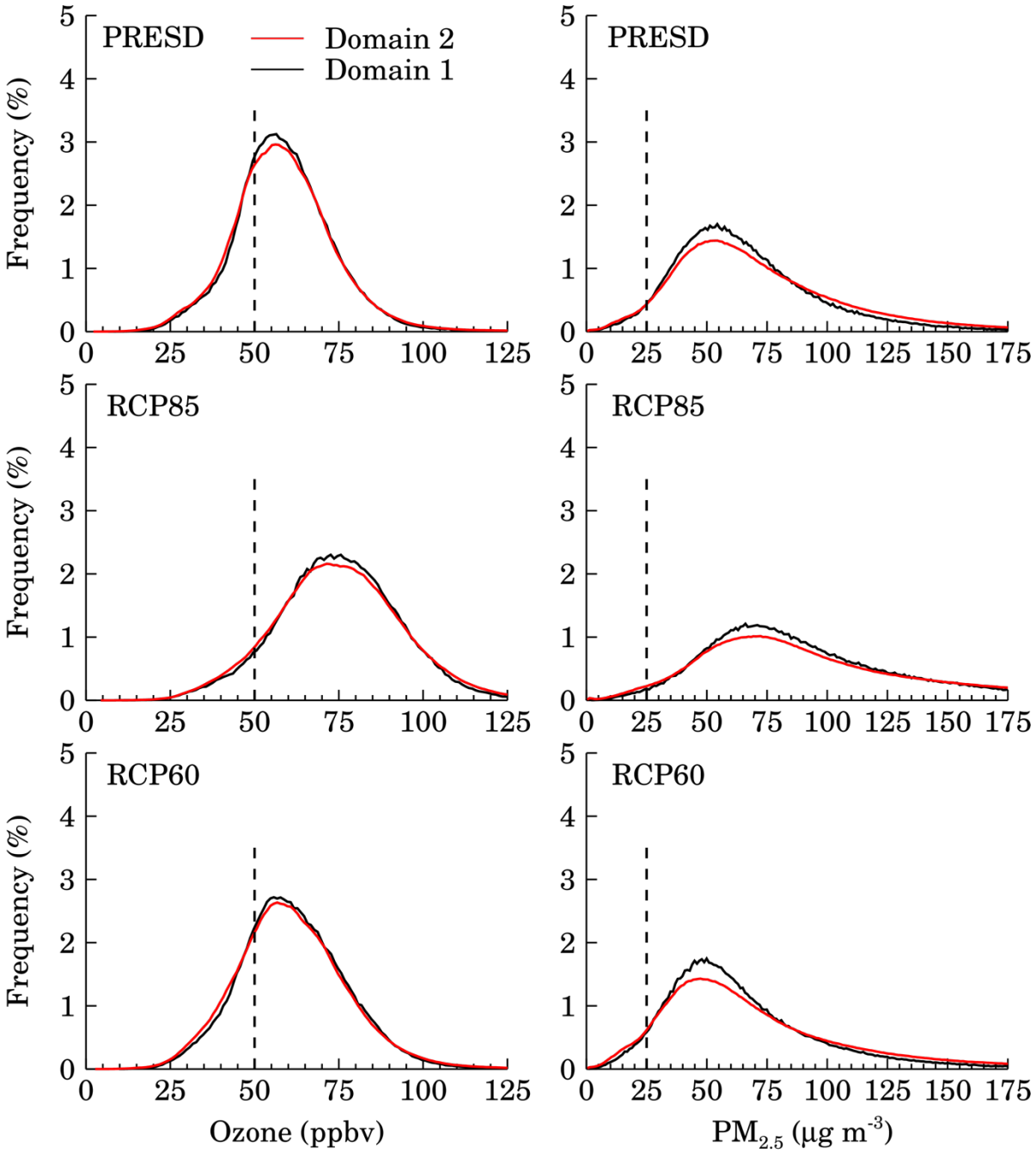
Annual Average **PM2.5** across scenarios







CAM-Chem has much weaker signal compared to NRCM-Chem



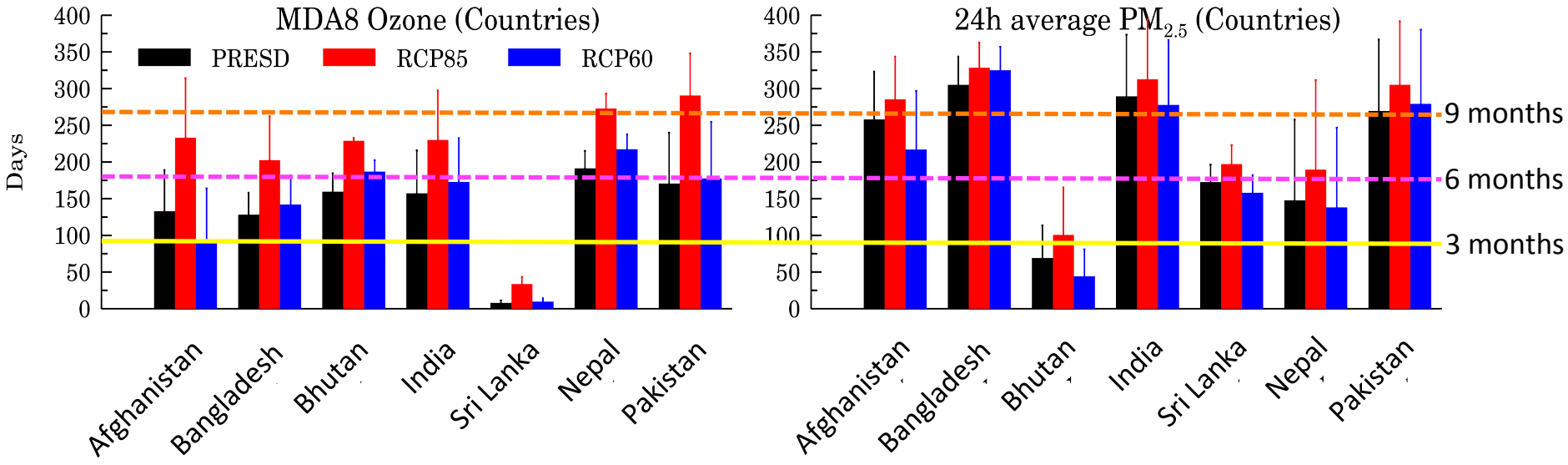
Frequency distributions of D01 and D02 MDA8 ozone and 24-h average $PM_{2.5}$ for the Indian states located in the Indo-Gangetic Plain during dry-season

→ Approximately same results for Δx=60km Outer domain and Δx=12km Inner Domain

→ For regions where emissions occur throughout the region, coarser grid resolution simulations represent ozone and PM2.5 well

Number of Days Country Exceeds WHO Limits

(50 ppbv O_3 ; 40 µg/m^3 PM2.5)



- Number of days MDA8 **ozone** exceeds WHO limits increases for RCP8.5
- Number of days DA24 **$PM_{2.5}$** exceeds WHO limits moderately increases for RCP8.5
- RCP6.0 results similar to or less than present day results

Summary

1. How will future air quality of South Asia respond to projected changes in climate and emissions of key trace gases and aerosols?

- Increase in Annual Average of Maximum Daily 8-hour Ozone Average
  - especially from present day to RCP8.5 projection (only a small increase for RCP6.0 scenario)
  - especially in dry season
- Increase in Annual Average of 24-hour PM2.5 Average for RCP8.5 projection but a decrease for RCP6.0 projection
- Exceedance days for ozone and PM2.5
  - increase significantly in RCP8.5 scenario
  - remain similar to present day in RCP6.0 scenario

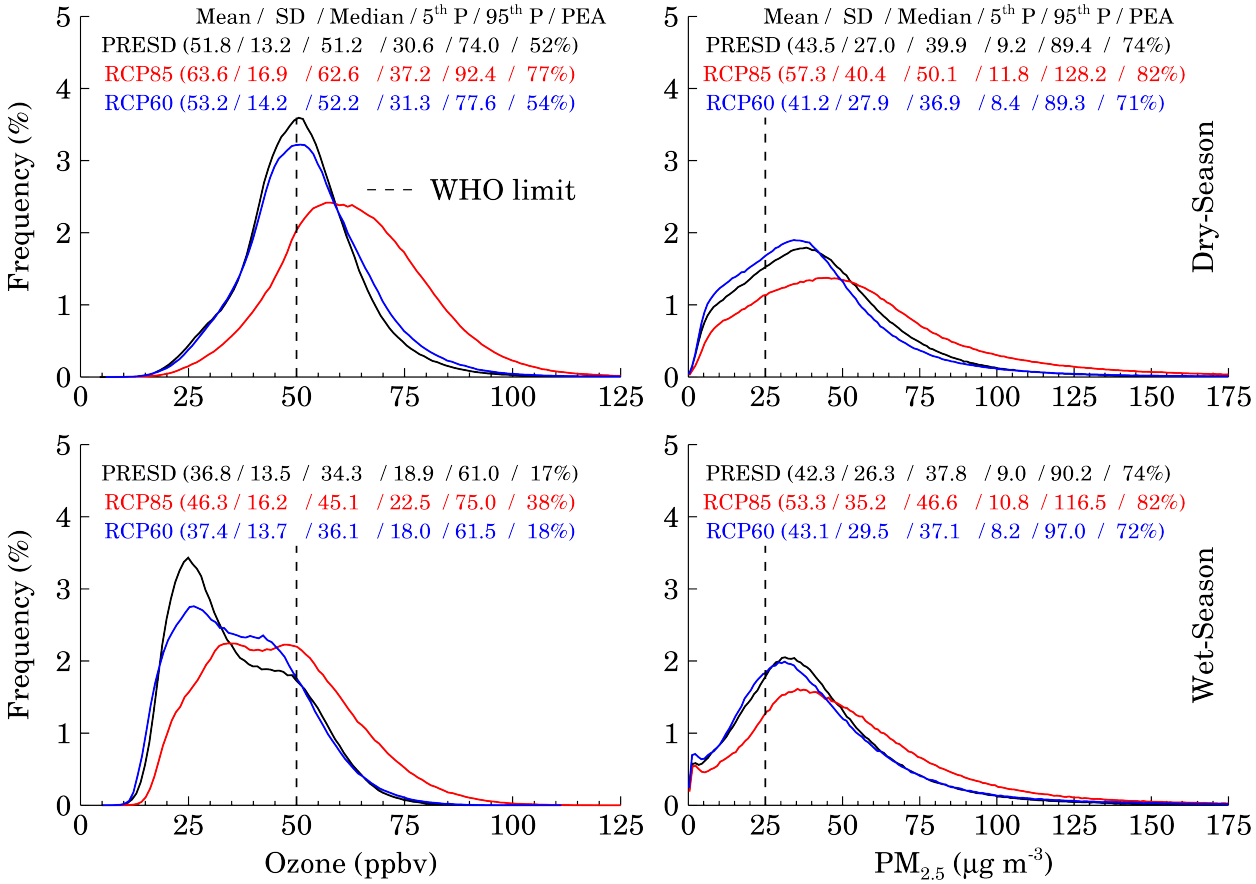
Summary

2. How are these projections affected by horizontal grid resolution?

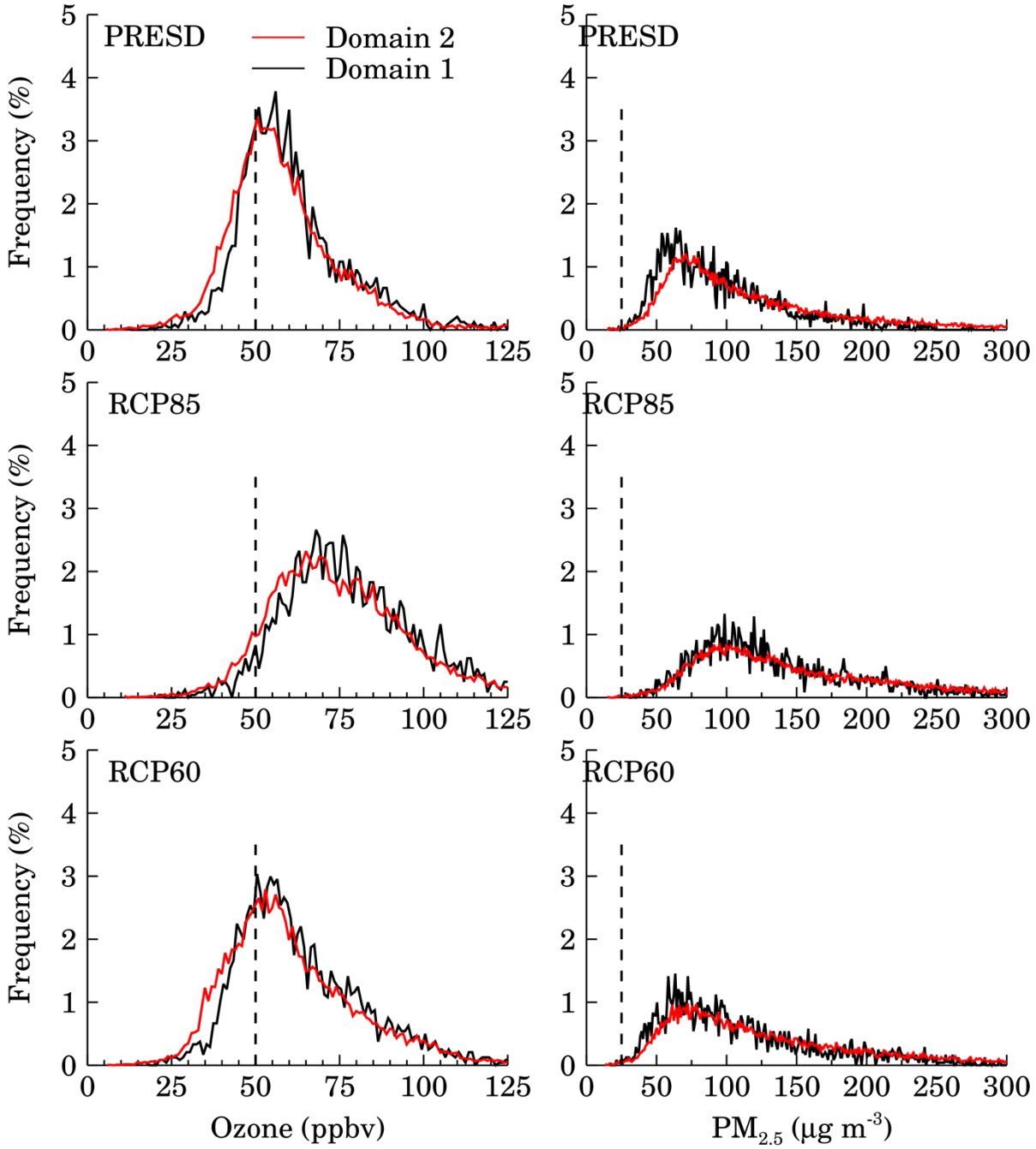
- NRCM-Chem able to capture seasonal variability of both ozone and PM2.5 at both grid resolutions
- While Δx=12 km inner domain shows better agreement than Δx=60 km outer domain with observations of CO and NO_x, their results were similar for ozone and PM2.5
- Differences between future scenarios and present day were similar for both Δx=12 km inner domain and Δx=60 km outer domain
- Global-scale model predicts same pattern but weaker signal compared to regional-scale model results

Air pollution is a major environmental problem in South Asia and will remain so by the mid century irrespective of the Representative Concentration Pathway

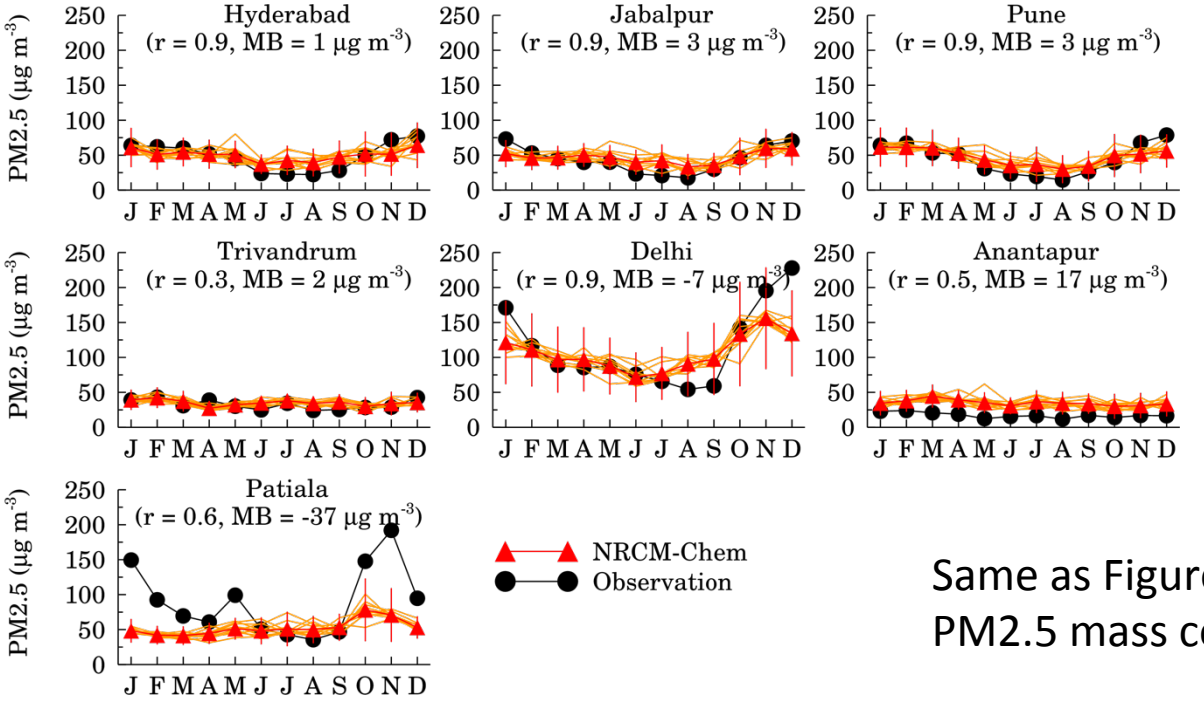
Extra slides



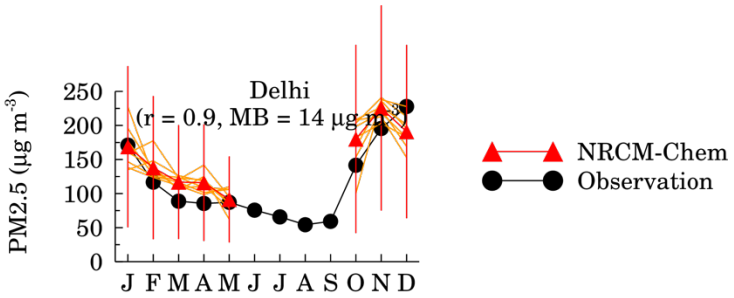
Frequency distributions of MDA8 ozone and DA24 $PM_{2.5}$ for the South Asian land areas during dry- and wet-seasons. Maldives and other islands are not included in this analysis because of inability of 60 km grid spacing to resolve these areas adequately. Mean, standard deviation (SD), median, 5th and 95th percentiles and percentage of exceedance (PEA) areas in South Asia where MDA8 ozone and 24 h average $PM_{2.5}$ exceed the WHO limits are also listed.



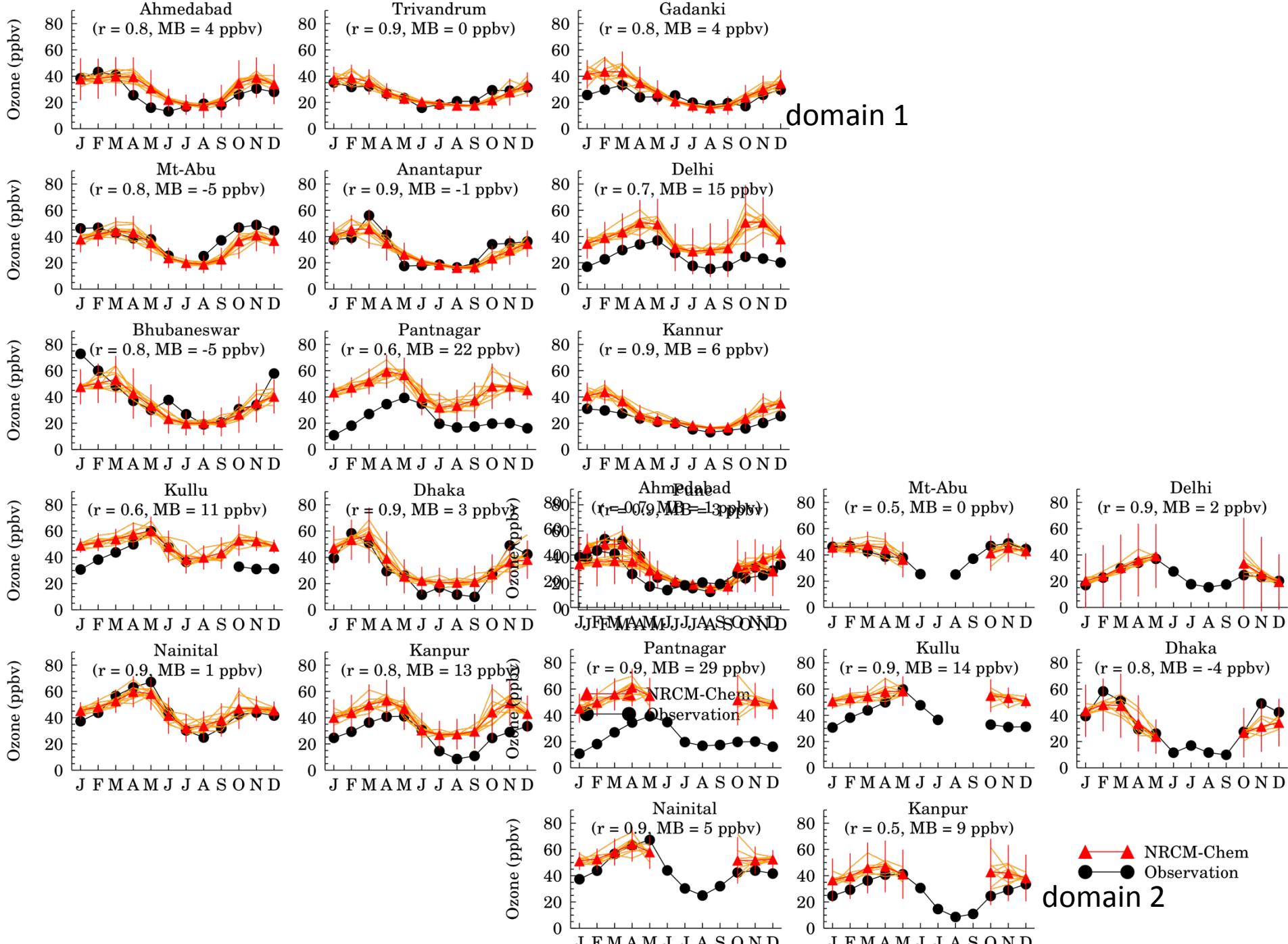
Frequency distributions of D01 and D02 MDA8 ozone and 24-h average $PM_{2.5}$ for Delhi during dry-season. Dotted lines represent the WHO limit for ozone and $PM_{2.5}$.

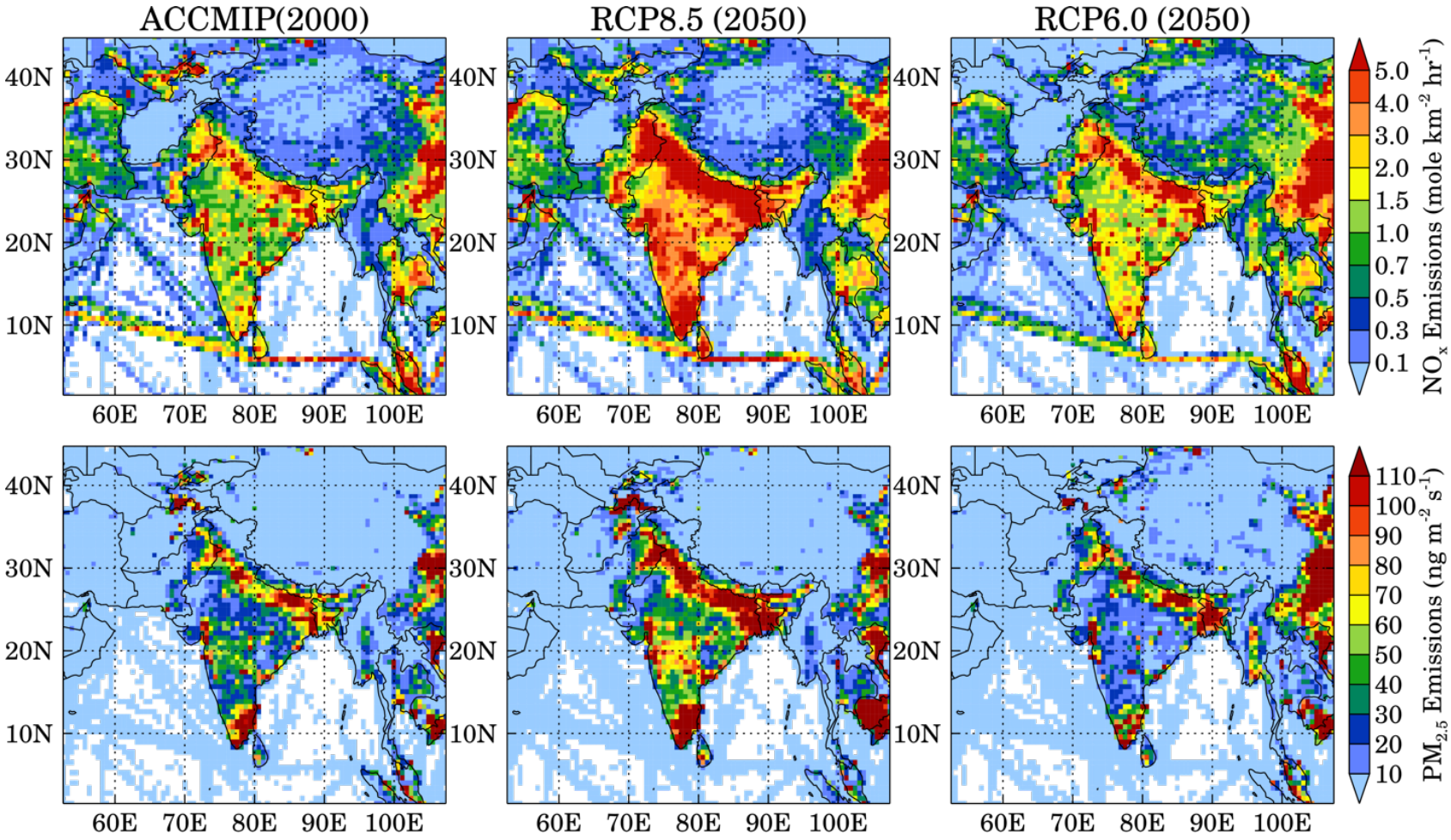


Same as Figure S4 but for surface PM2.5 mass concentrations



Same as Figure 11 but domain 2


Ahmedabad
(r = 0.8, MB = 4 ppbv)
Trivandrum
(r = 0.9, MB = 0 ppbv)
Gadanki
(r = 0.8, MB = 4 ppbv)
Mt-Abu
(r = 0.8, MB = -5 ppbv)
Anantapur
(r = 0.9, MB = -1 ppbv)
Delhi
(r = 0.7, MB = 15 ppbv)
Bhubaneswar
(r = 0.8, MB = -5 ppbv)
Pantnagar
(r = 0.6, MB = 22 ppbv)
Kannur
(r = 0.9, MB = 6 ppbv)
Kullu
(r = 0.6, MB = 11 ppbv)
Dhaka
(r = 0.9, MB = 3 ppbv)
Ahmedabad
Pune
Mt-Abu
(r = 0.5, MB = 0 ppbv)
Delhi
(r = 0.9, MB = 2 ppbv)
Nainital
(r = 0.9, MB = 1 ppbv)
Kanpur
(r = 0.8, MB = 13 ppbv)
Pantnagar
(r = 0.9, MB = 29 ppbv)
NRCM-Chem
Observation
Kullu
(r = 0.9, MB = 14 ppbv)
Dhaka
(r = 0.8, MB = -4 ppbv)
Nainital
(r = 0.9, MB = 5 ppbv)
Kanpur
(r = 0.5, MB = 9 ppbv)
Ozone (ppbv)
J F M A M J J A S O N D
domain 1
NRCM-Chem
Observation
domain 2



Annual averaged total anthropogenic emissions of NO_x and $PM_{2.5}$ over the outer model domain for present-day (ACCMIP, 2000) and future (RCP8.5 and RC6.0, 2050) time periods.

Motivation

- 1/7th of world's population in South Asia.
- Severe air pollution with economic development and urbanization.
- 13 out of 20 most polluted cities are located in South Asia [WHO] with Delhi being the most polluted city.
- Surface ozone and PM2.5 are estimated to kill ~0.5 million people prematurely.
- Surface ozone is estimated to destroy food enough to feed 94 million people.

Projected changes in greenhouse gas concentrations and short-lived species emissions

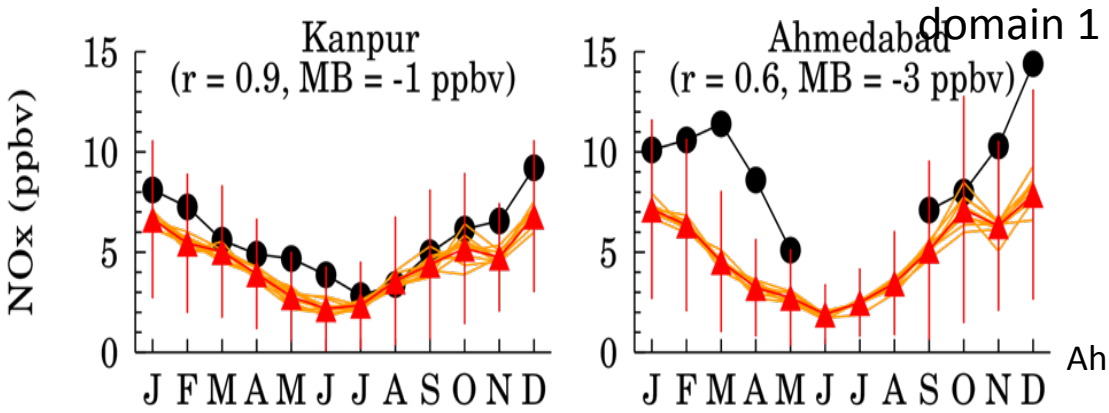
Projected changes in GHG concentrations

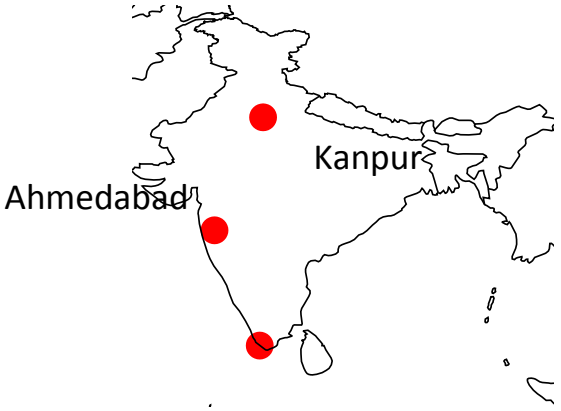
Species	2000	2050 (RCP8.5)	2050 (RCP6.0)
CO2 (ppmv)	**369**	**541 (47%)**	**478 (30%)**
N2O (ppbv)	316	367 (16%)	355 (12%)
CH4 (ppbv)	1751	2739 (56%)	1895 (8%)

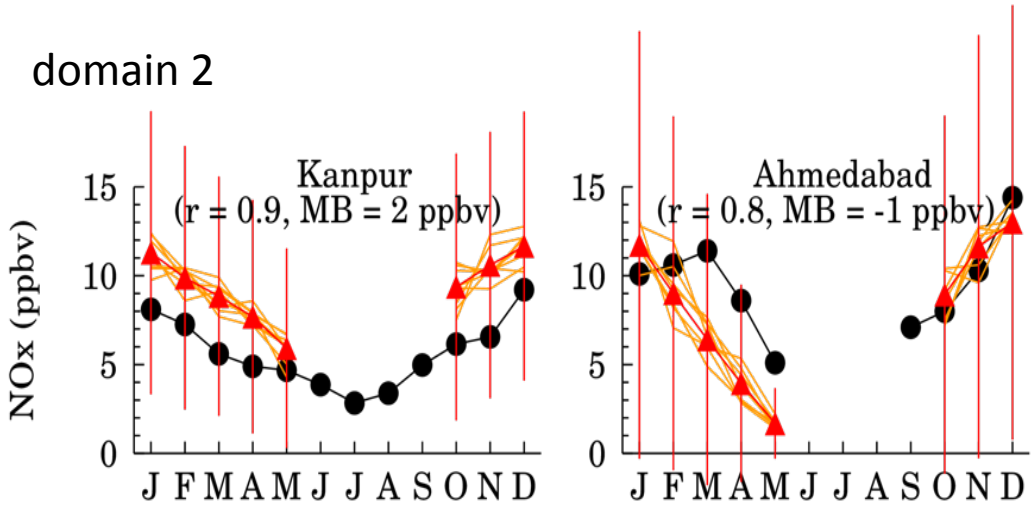
Projected changes in emissions (Tg/year) of short-lived species over South Asia

Species	2000	2050 (RCP8.5)	2050 (RCP6.0)
CO	**100.7**	**115.6 (15%)**	**72.1 (-28%)**
NOx	**3.9**	**5.6 (41%)**	**4.4 (11%)**
NMVOCs	12.2	18.1 (48%)	11.9 (-2%)
OC	2.1	2.6 (24%)	2.3 (8%)
BC	0.65	0.77 (18%)	0.68 (4%)
SO2	**6.2**	**10.3 (67%)**	**10.0 (61%)**
NH3	5.0	8.6 (74%)	8.3 (66%)

NRCM-Chem Compared to NOx Monitoring Stations







Seasonal cycle is represented well

Inner domain at Δx = 12 km predicts magnitude better than coarse domain

Exceedance days for both ozone and PM2.5

→ ozone will increase significantly in RCP8.5 scenario and will remain similar to present day in RCP6.0 scenario.