Multi-scale Modeling of the Effects of Global Change upon Regional Air Quality

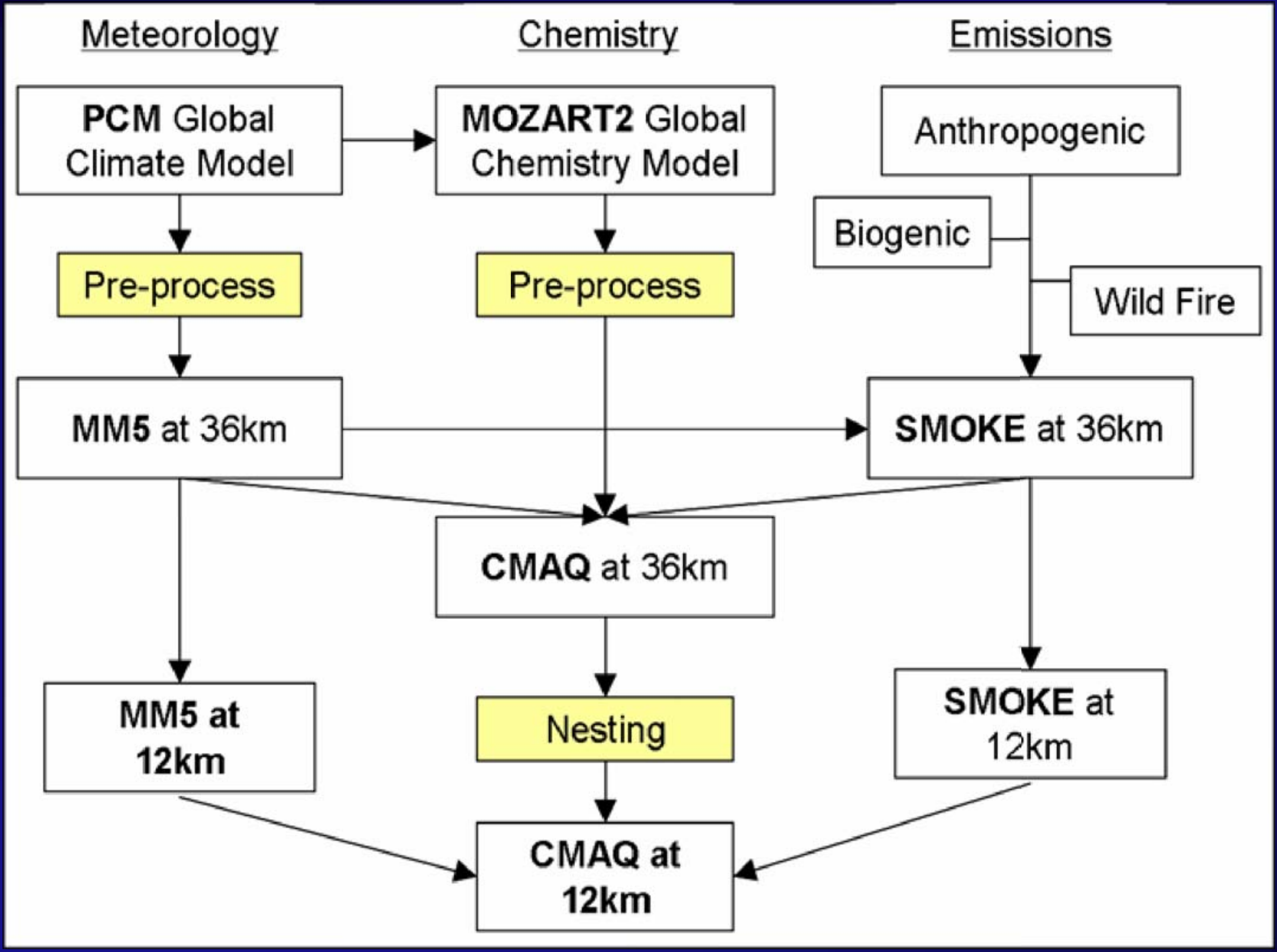
Research Team

- **WSU**: Jeremy Avise, Jack Chen, and Brian Lamb
- **UW**: Clifford Mass and Eric Salathe
- **NCAR**: Alex Guenther, Christine Wiedinmyer, and J. F. Lamarque
- **USDA – Forest Service**:   Don McKenzie and Sim Larkin
- **USDA – NRCS:** Susan O'Neill
- **CSU** – David Theobald

Global Change & Regional Air Quality

- How will global change affect regional air quality in the future?
- How will land use changes due to climate change affect air quality?
- How are biogenic emissions affected by global climate change and land management practices?
- How will changes in emissions in Asia impact U.S. air quality?
- How will the role of fire change with respect to regional air quality in the future?
- How will global change affect atmospheric deposition in sensitive ecosystems?

Global to Regional Scale Modeling

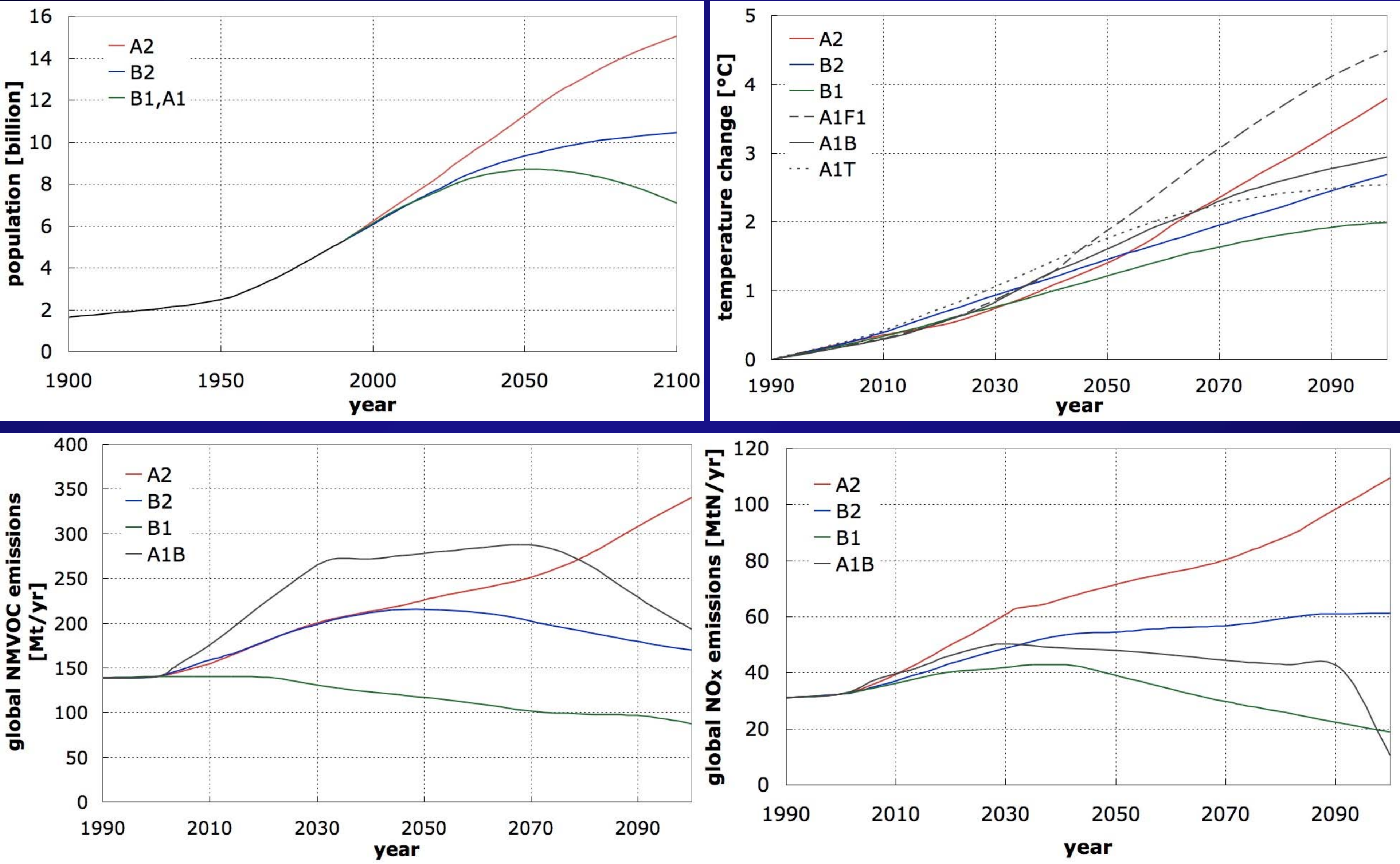


IPCC - A2 scenario
"Business as usual"

Simulate two 10-year periods

- Current
  1990 – 1999
- Future
  2045 – 2054
- Sensitivity
  Analyses
  - Emissions, meteorology & BC effects
  - Land management scenarios
  - Fire emissions

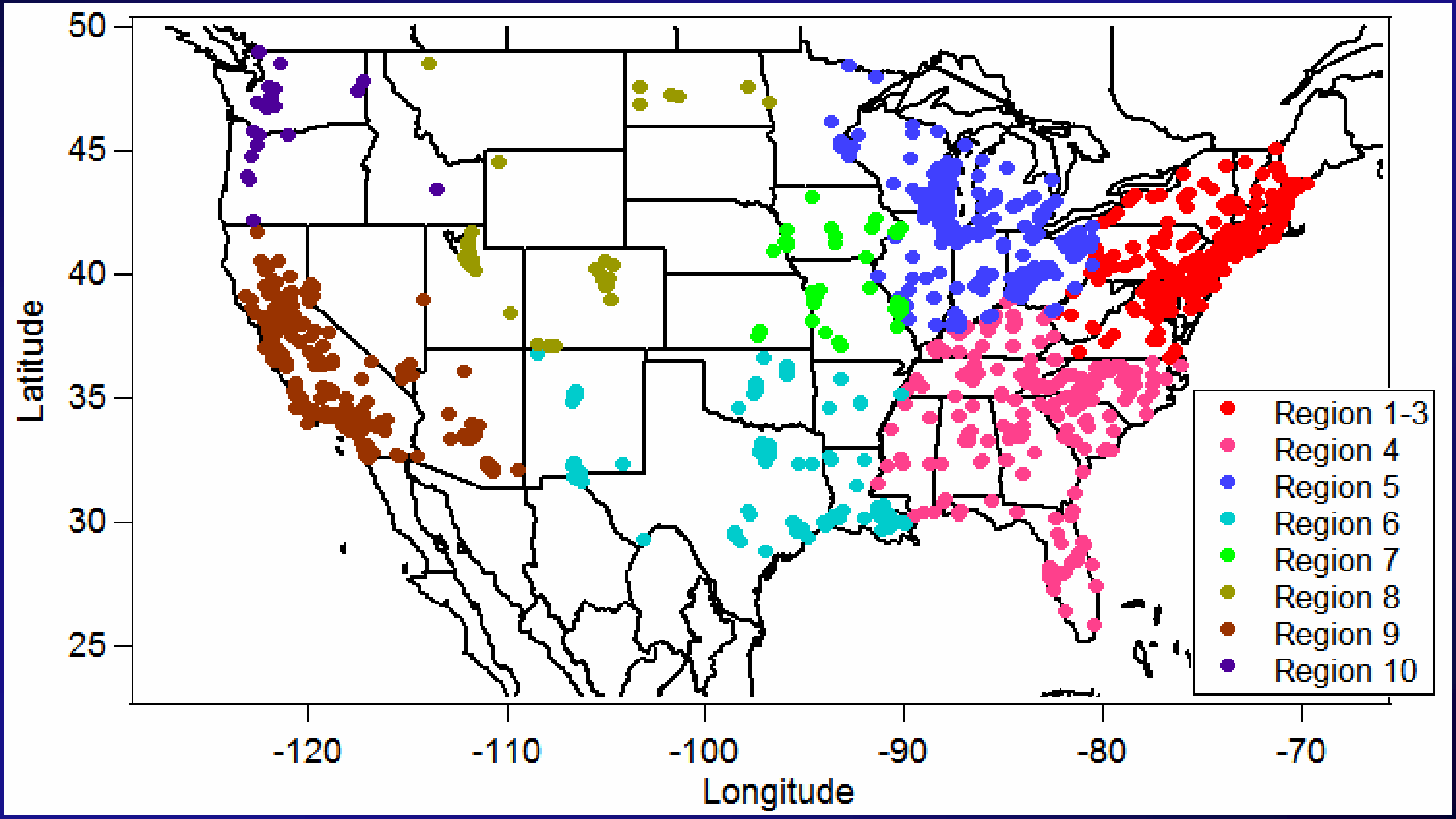
IPCC Global Emission Scenario: A2—Business as usual



Emissions development and projection

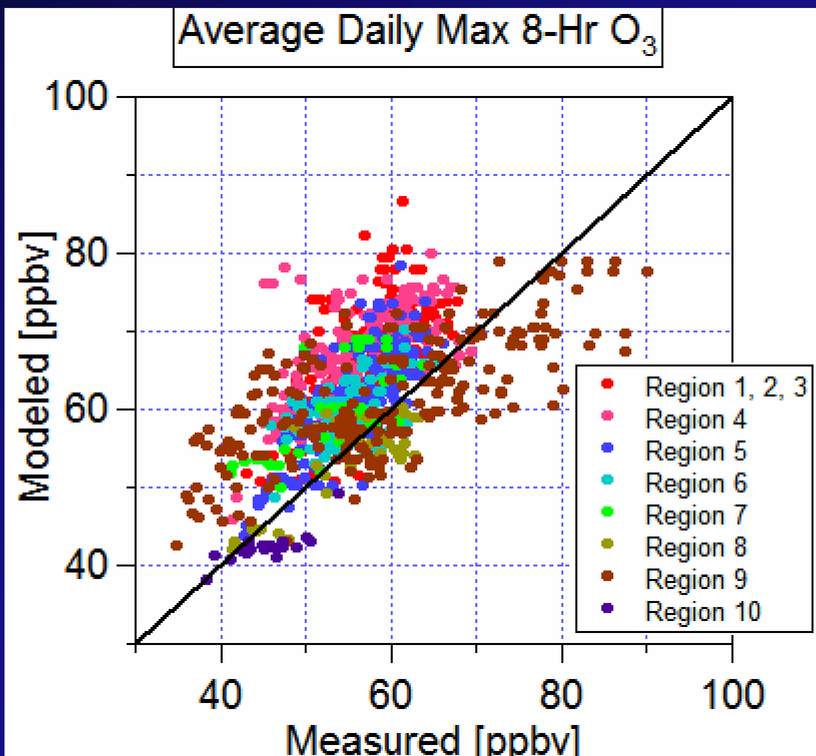
- Global emissions in MOZART2 are based on EDGAR3.2 estimates and include anthropogenic and natural emissions.
  - Future emissions consistent with IPCC A2 scenario
- US emissions processed using SMOKE
  - EPA anthropogenic emissions (1999 NEI current decade, EPA EGAS future projections)
  - NCAR MEGAN biogenic emissions
  - Fire Emissions:
    - Current decade – fire history dataset + Bluesky emissions (Bureau of Land Management fire history dataset)
    - Future decade – Fire Scenario Builder stochastic model (FSB)
- Land use change incorporates natural vegetation migration coupled with adjustments for urbanization (SERGOM) and expansion of agricultural lands in the US.

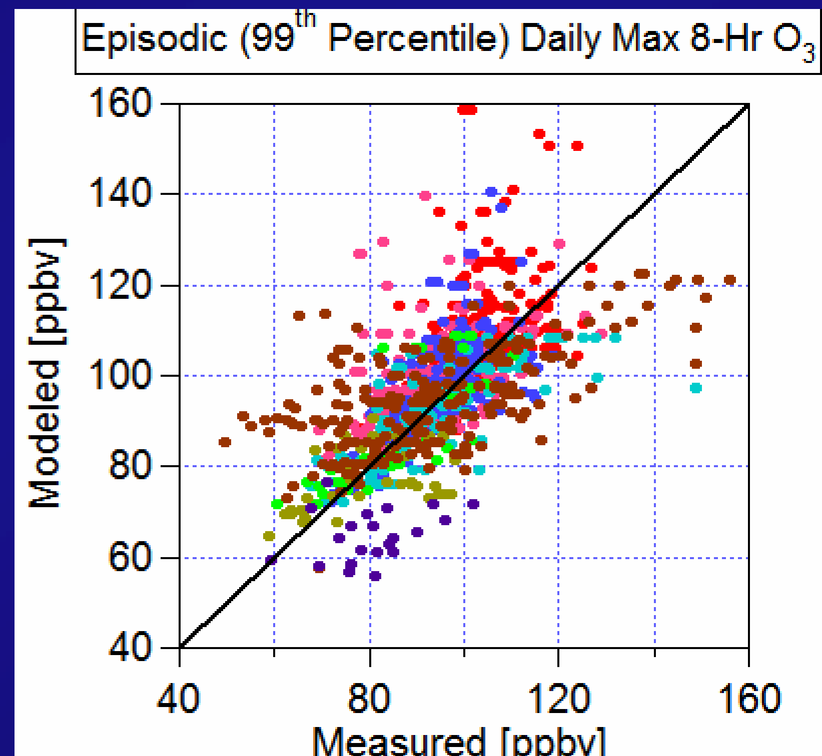
Current decade: comparison of observed and simulated ozone distributions: EPA-AIRs data



EPA – AQS ozone data for 1994-2003 Summer

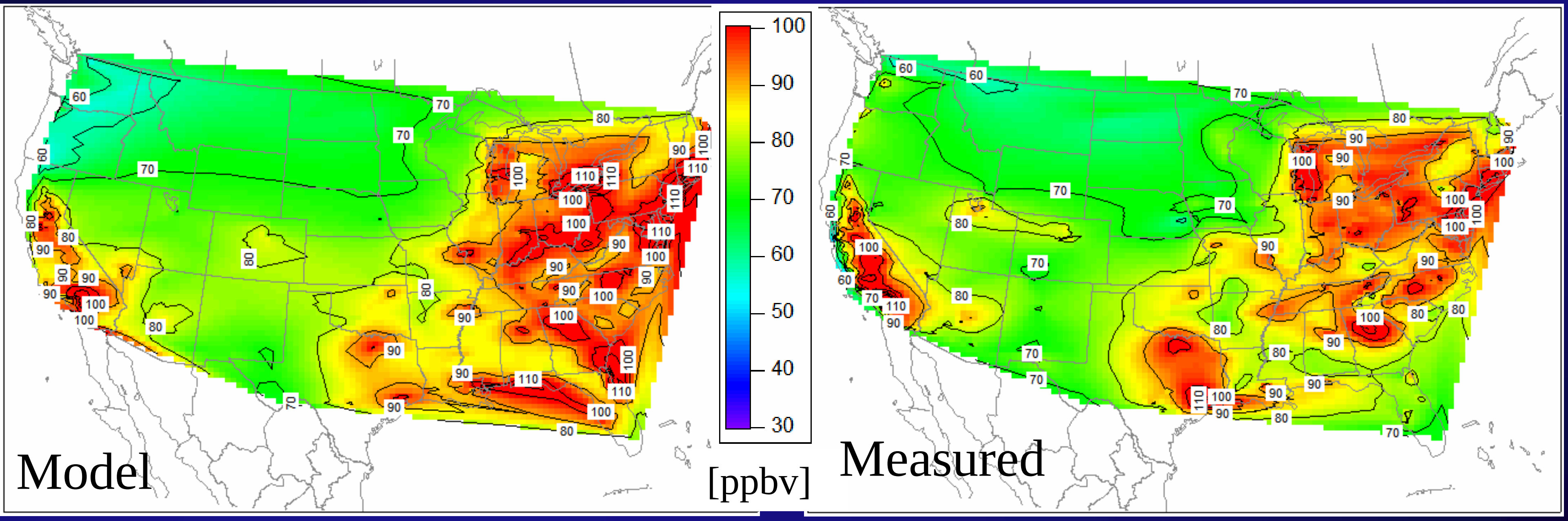
Average daily maximum 8 hr ozone and 99th percentile daily max 8 hr ozone



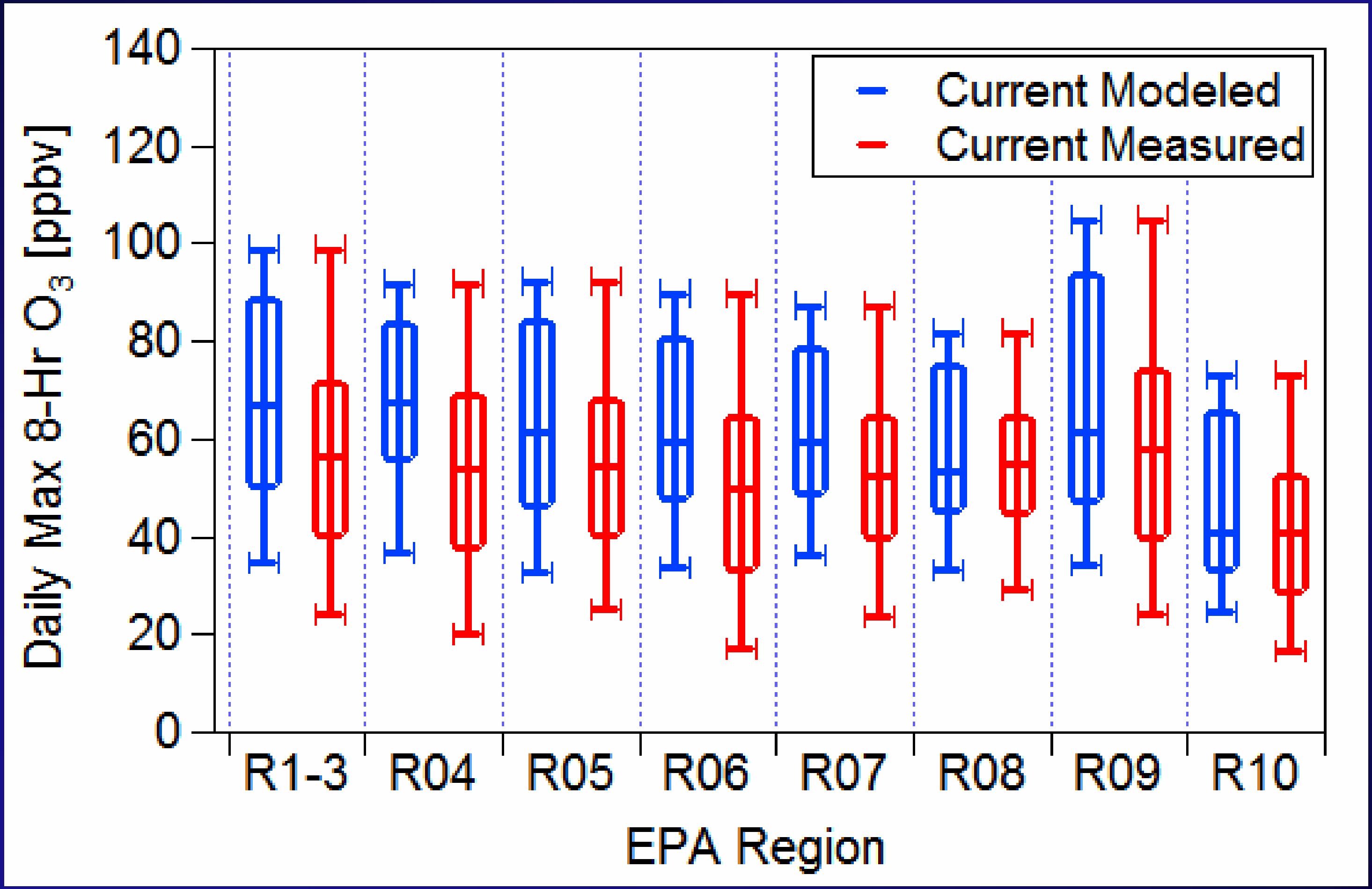


Observations & simulations from 10 summers

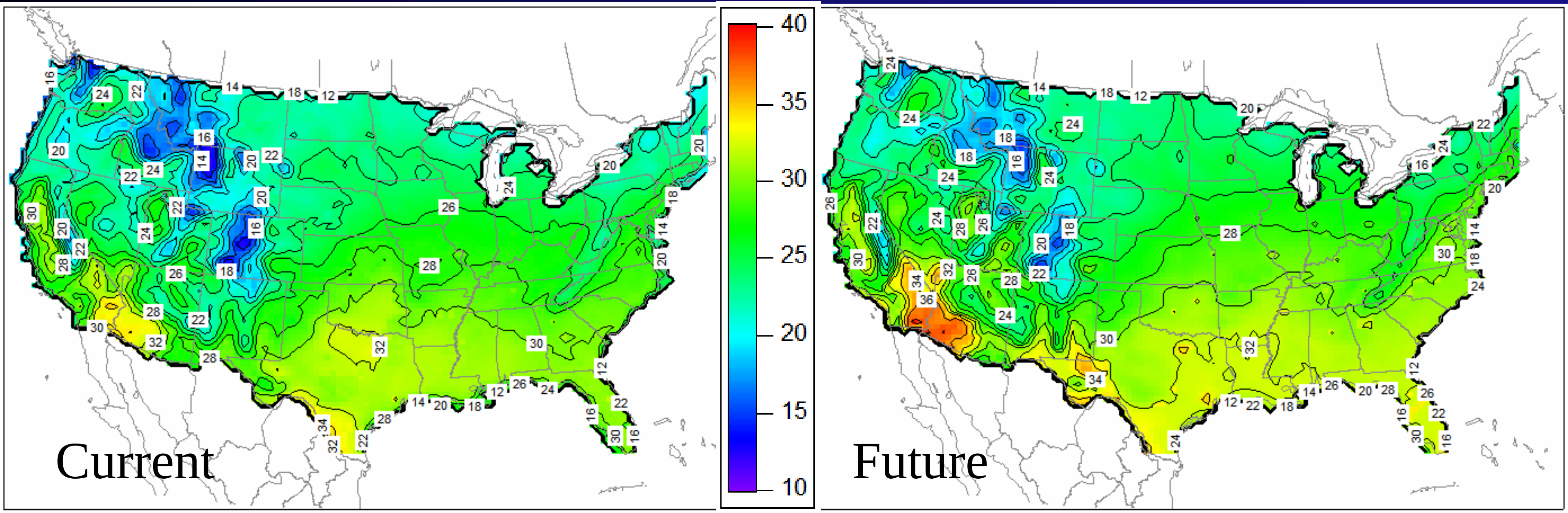
Current decade
99th percentile daily max 8-Hr ozone



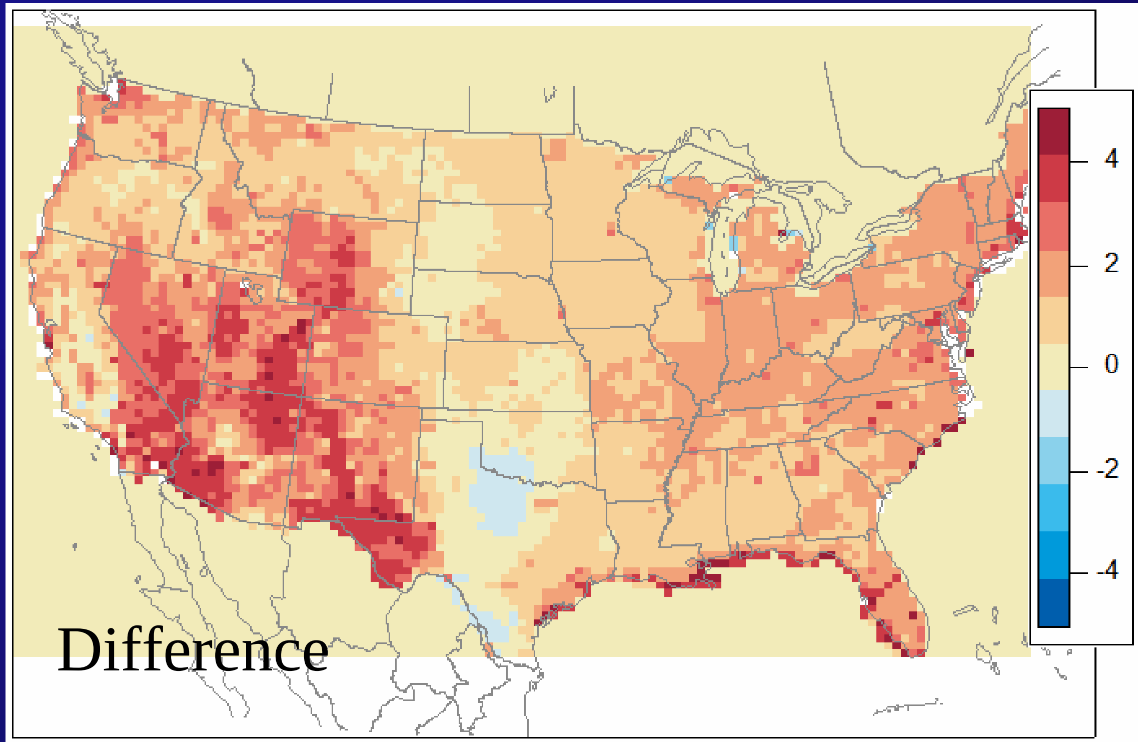
Observed and predicted distributions of daily max 8 hr ozone



99th, 80th, Average, 20th, 1st Percentile, 8-hr daily max ozone

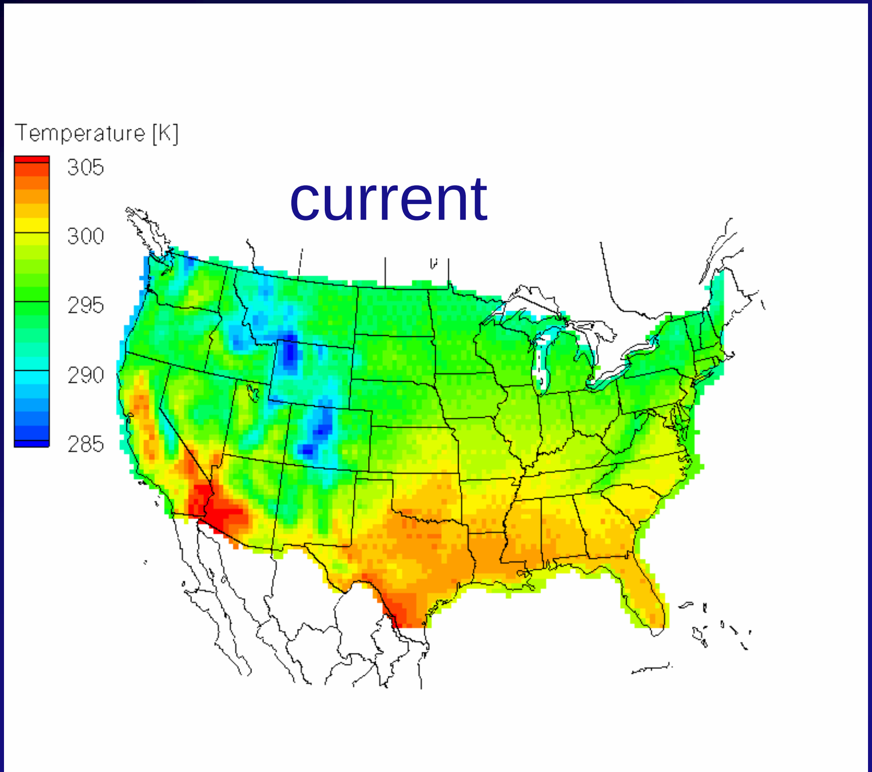


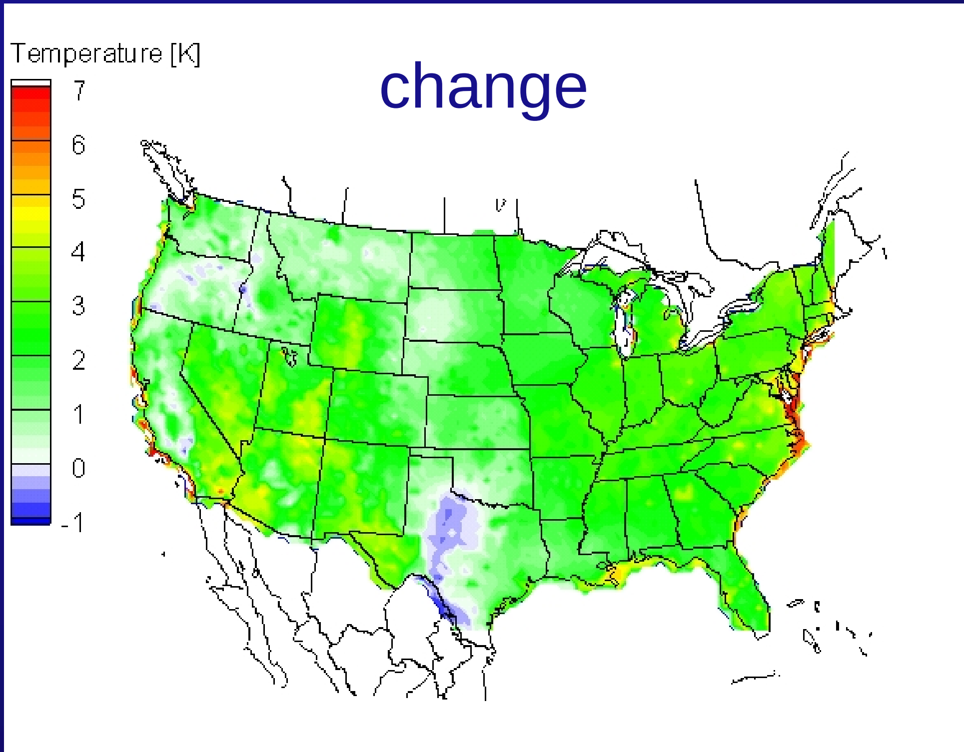
Summer Daily Max 2-m Temperature Current vs Future (deg C)



Future vs Current Conditions: July Temperatures

Daily Average Maximum

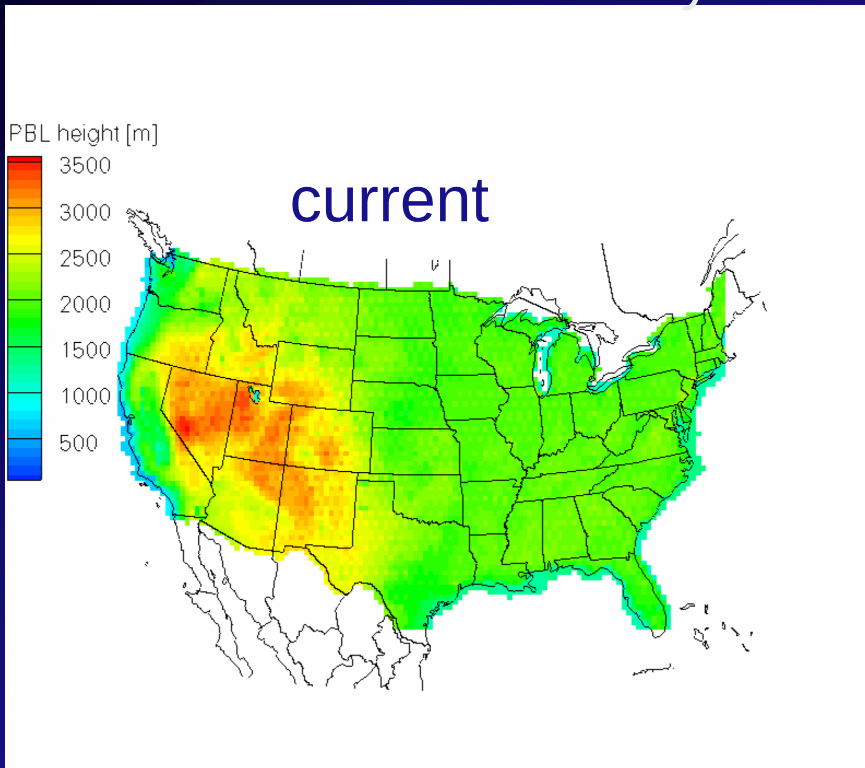




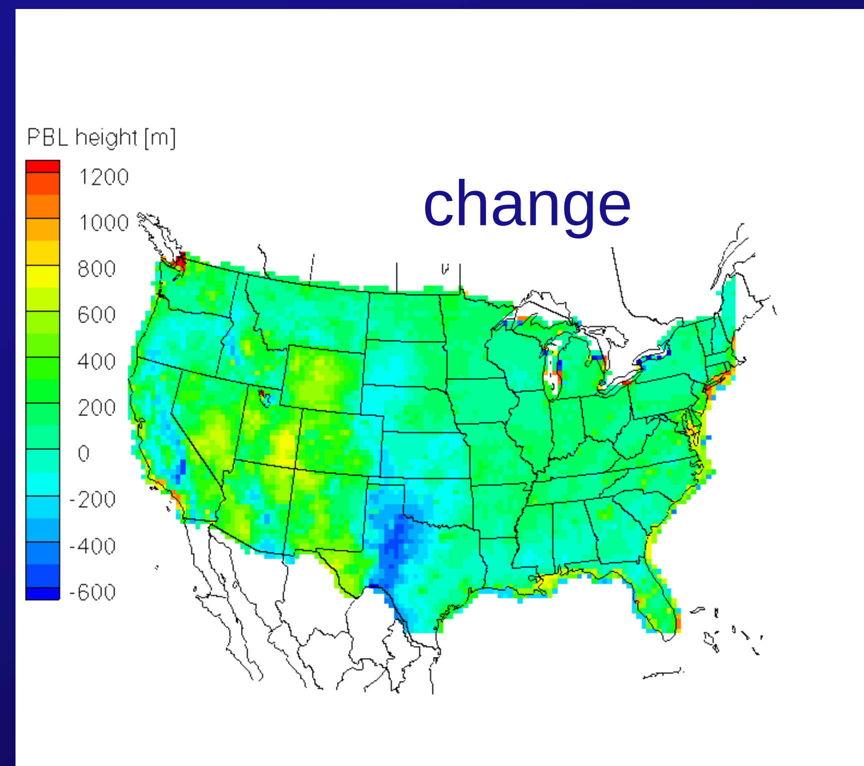
[K]	USA	Seattle	Portland	Boise
Current	303	293.4	294.8	295.5
Change	2.1	2.1	1.2	0.7

Meteorological Changes: July Mixed Layer Heights

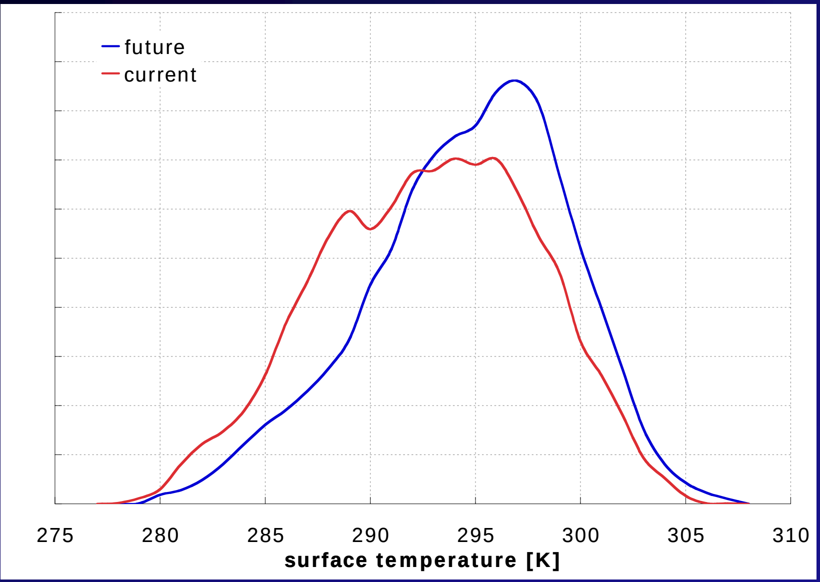
Daily Average Maximum



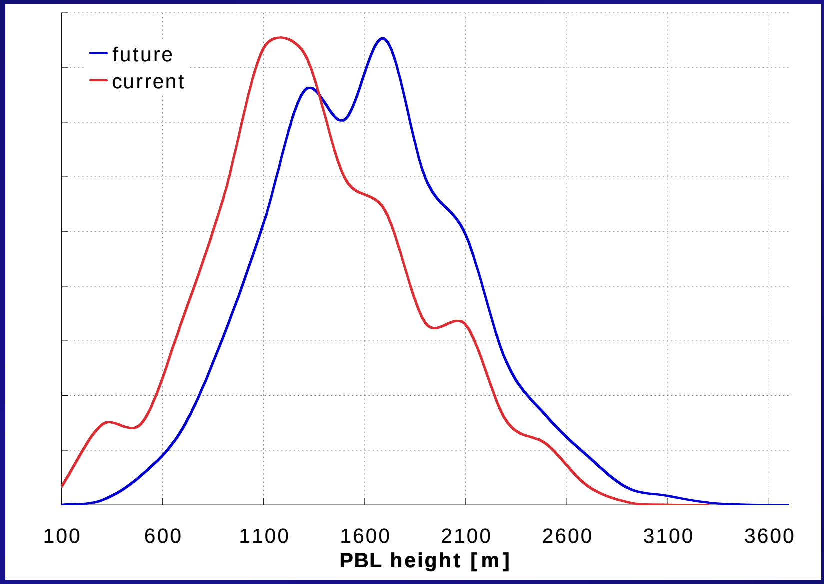
[meters]	USA	Seattle	Portland	Boise
Current	2550	1250	1150	2000
Change	90	300	150	-50

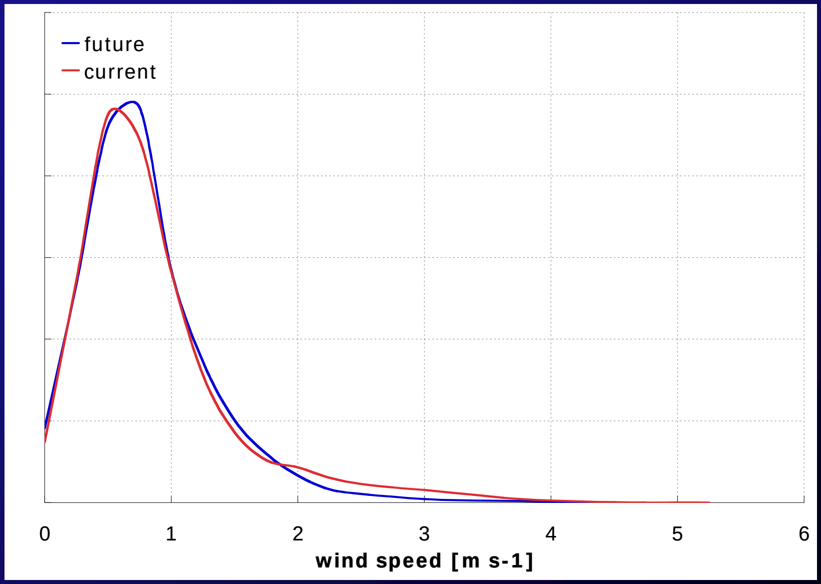


Seattle Daytime Meteorology



	average		average maximum		maximum	
	cur	fut	cur	fut	cur	fut
Temp [K]	293.3	+1.8	301.9	+1.1	307.0	+0.9
PBL [m]	1349	+260	2294	+169	3014	+434
wind speed [m s^{-1}]	1.00	-0.07	3.00	-0.92	5.05	-0.48
cloud fraction [%]	21	-4	91	-10	100	+0



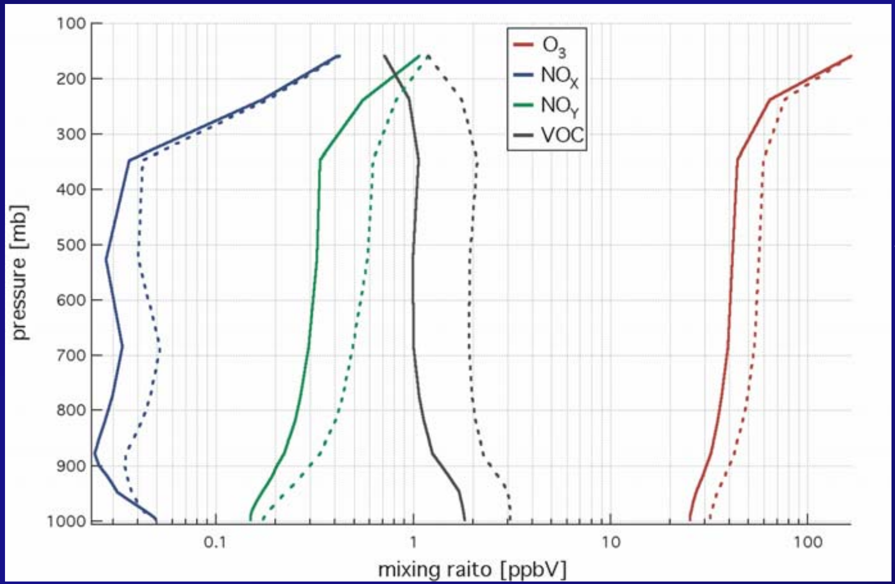


Chemical Boundary Condition Changes

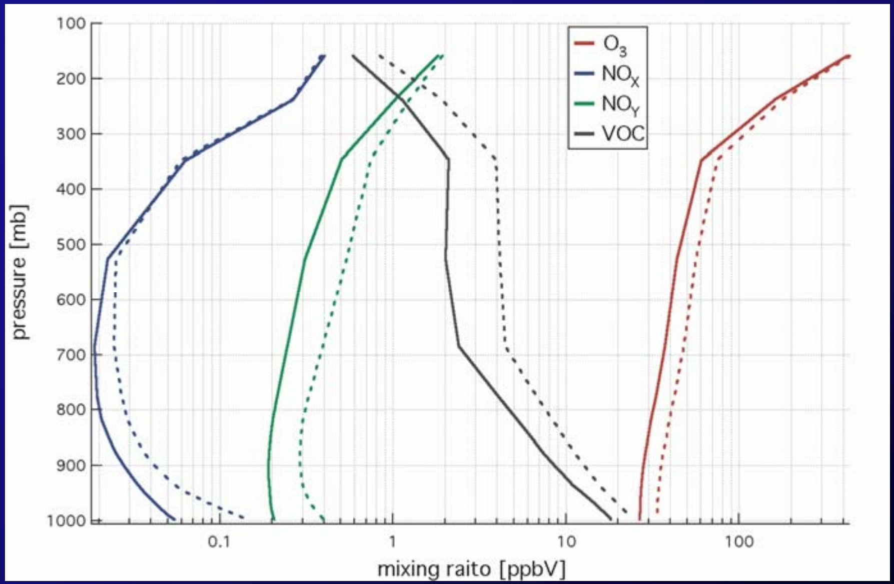
	West BC [ppbv]		
	Current	Future	% Δ
O_3	37.6	50.7	34.8
NO_X	0.030	0.043	44.1
NO_Y	0.279	0.470	68.6
VOC	1.126	2.107	87.1

up to 500 mb

	North BC [ppbv]		
	Current	Future	% Δ
O_3	37.1	47.6	28.2
NO_X	0.024	0.034	39.8
NO_Y	0.256	0.424	65.6
VOC	4.390	7.138	62.6



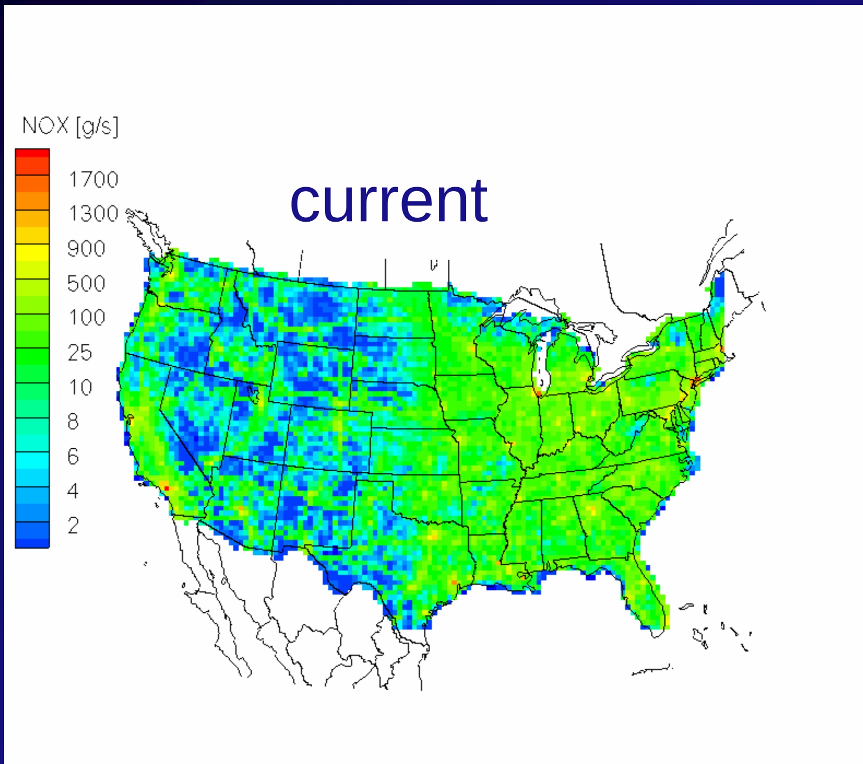
west



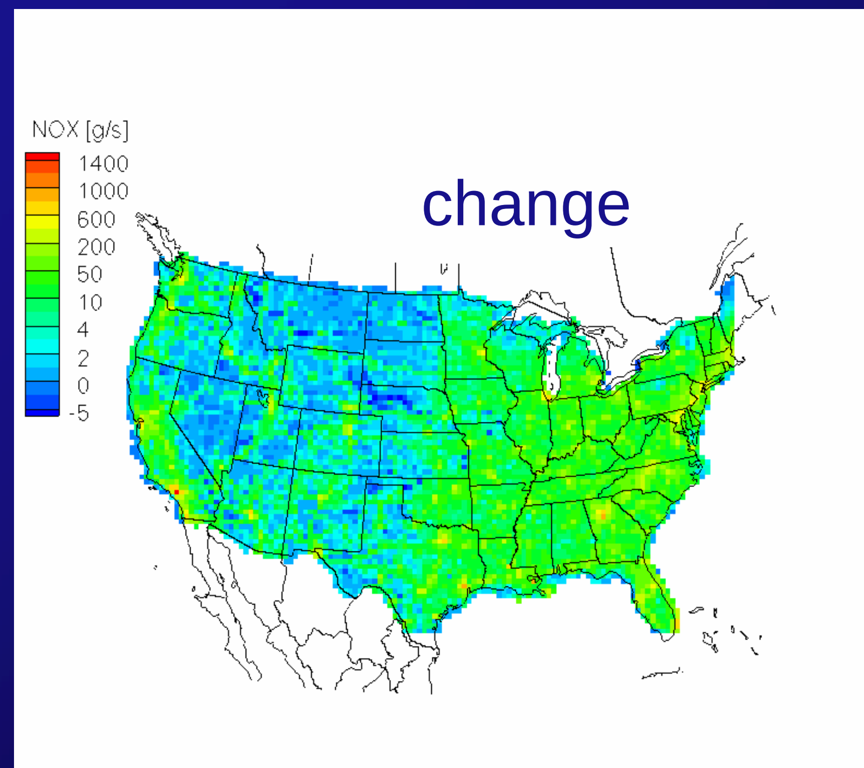
north

July Emission Changes: NO_X

anthropogenic

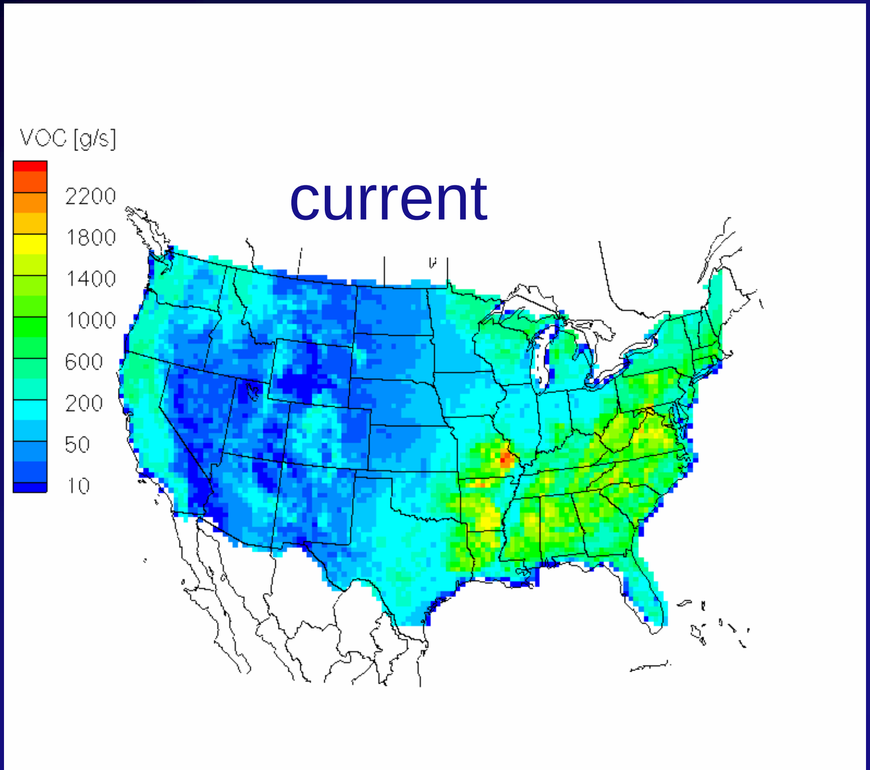


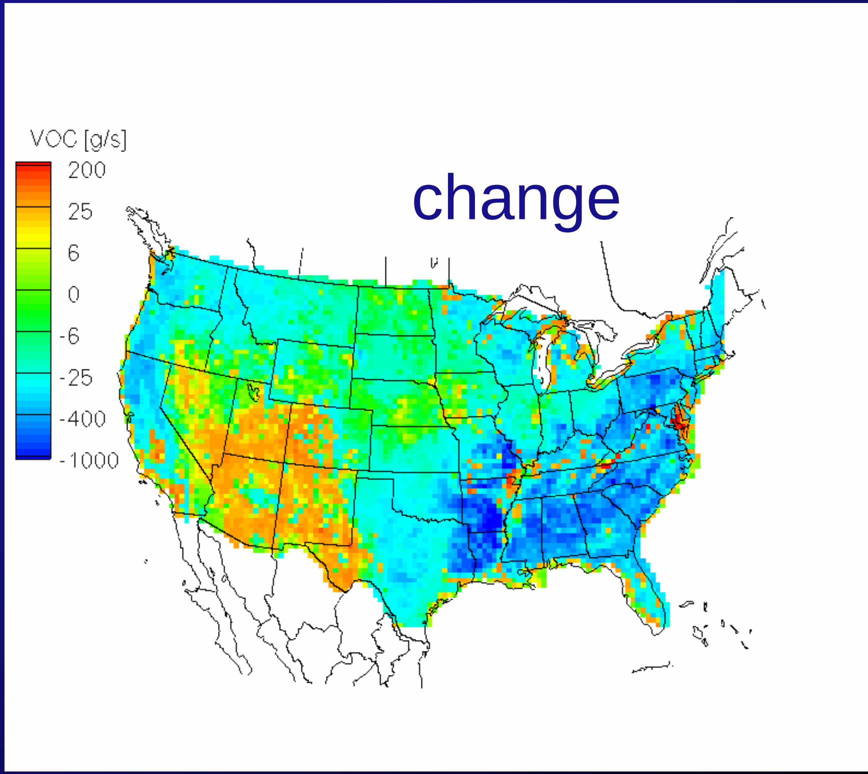
current emissions (percent change)	USA [1000's ton/day]	
	NO_2	NO
anthropogenic	1.9 (61)	23.8 (61)
biogenic	0 (0)	4.0 (2)



July Emission Changes: VOC

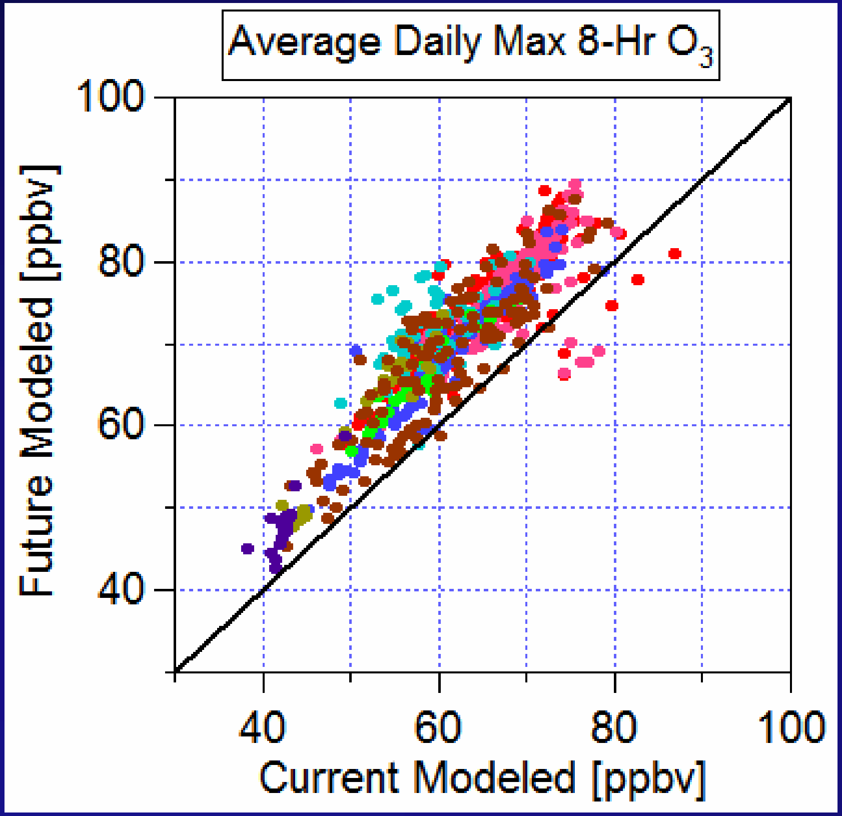
biogenic

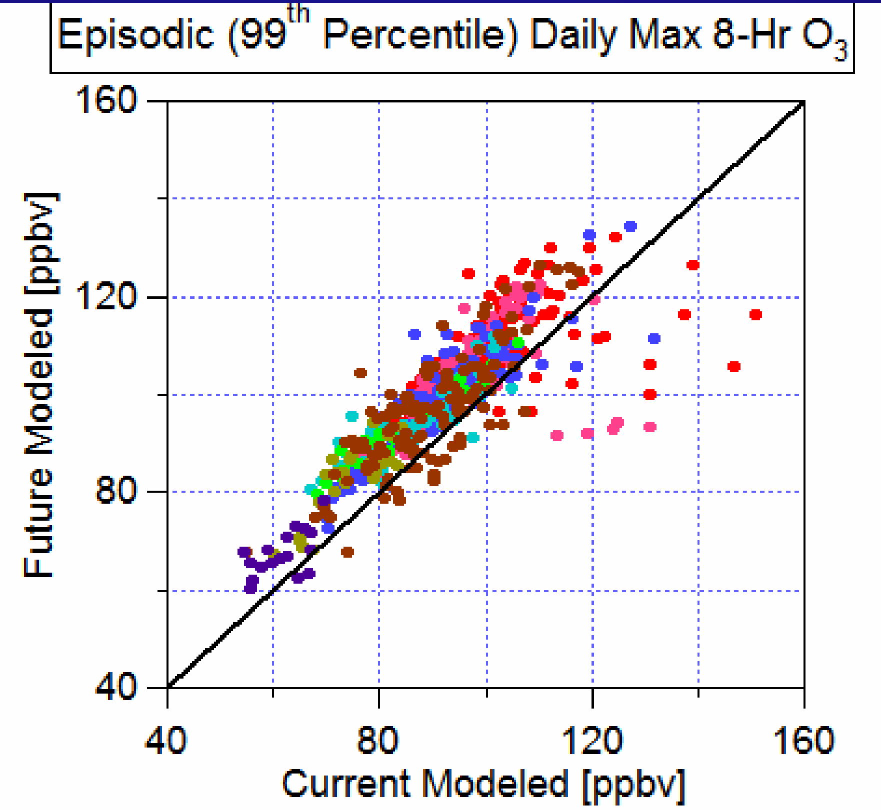


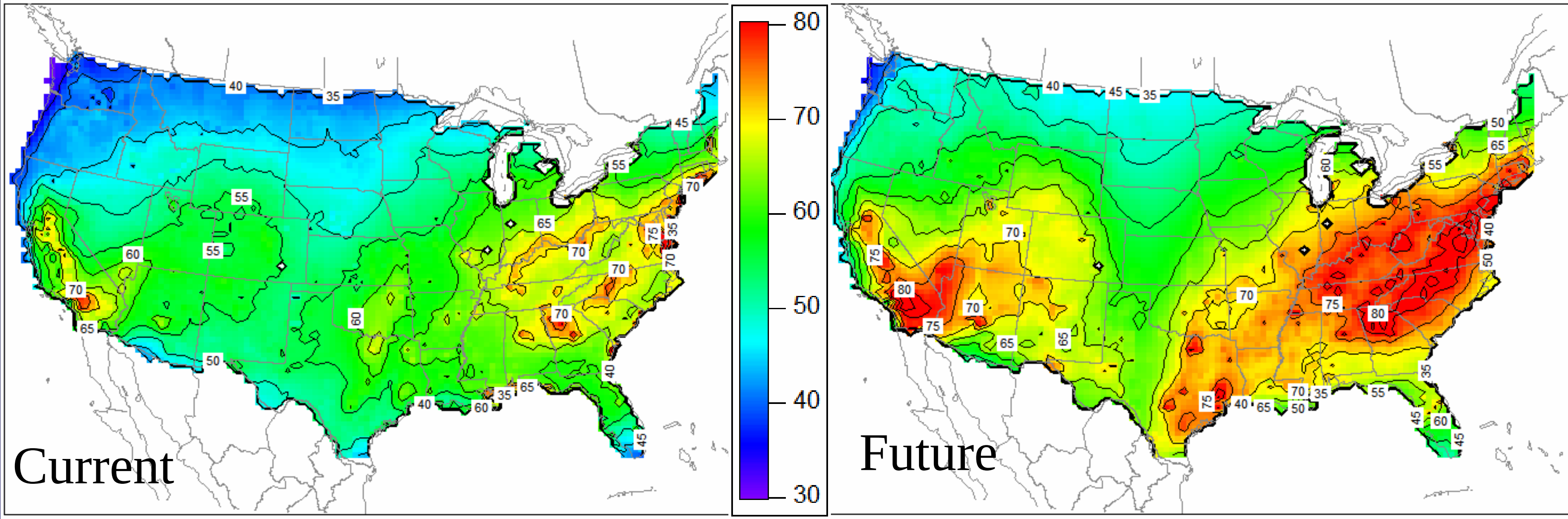


current emissions (percent change)	USA [1000's tonC/day]
	VOC
anthropogenic	32.9 (85)
biogenic	160.1 (-38)

Future changes in average daily max 8 hr ozone and 99th percentile 8 hr daily max ozone

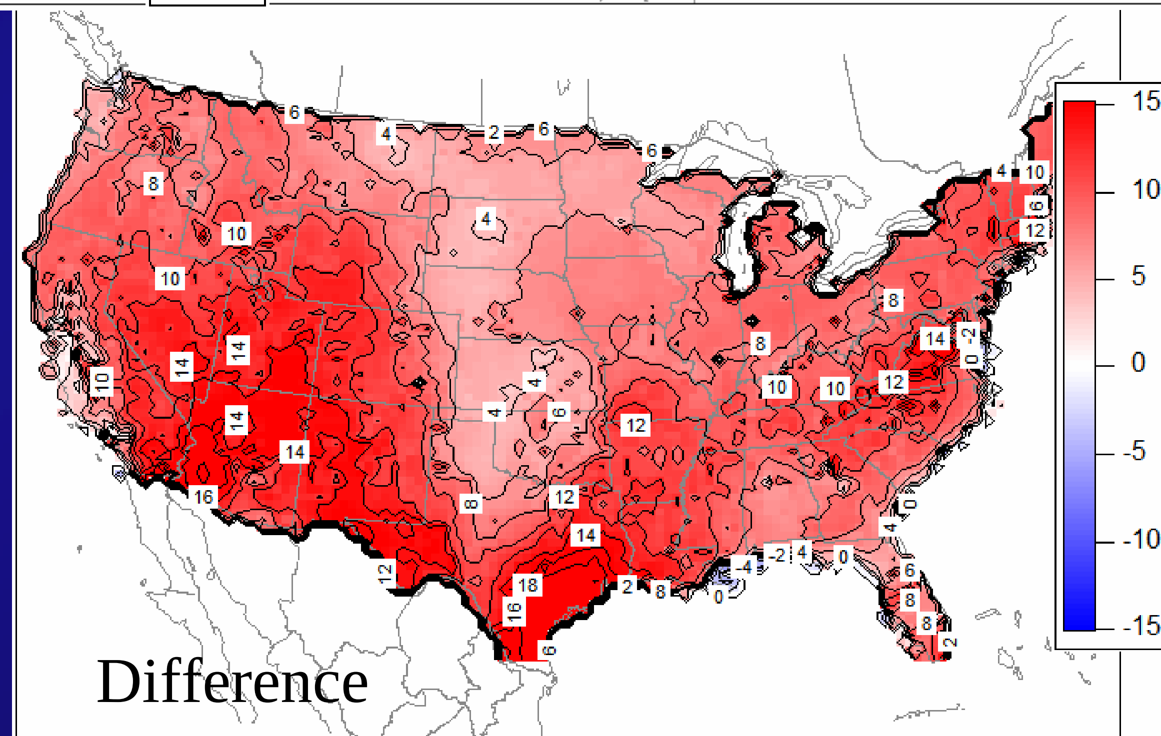


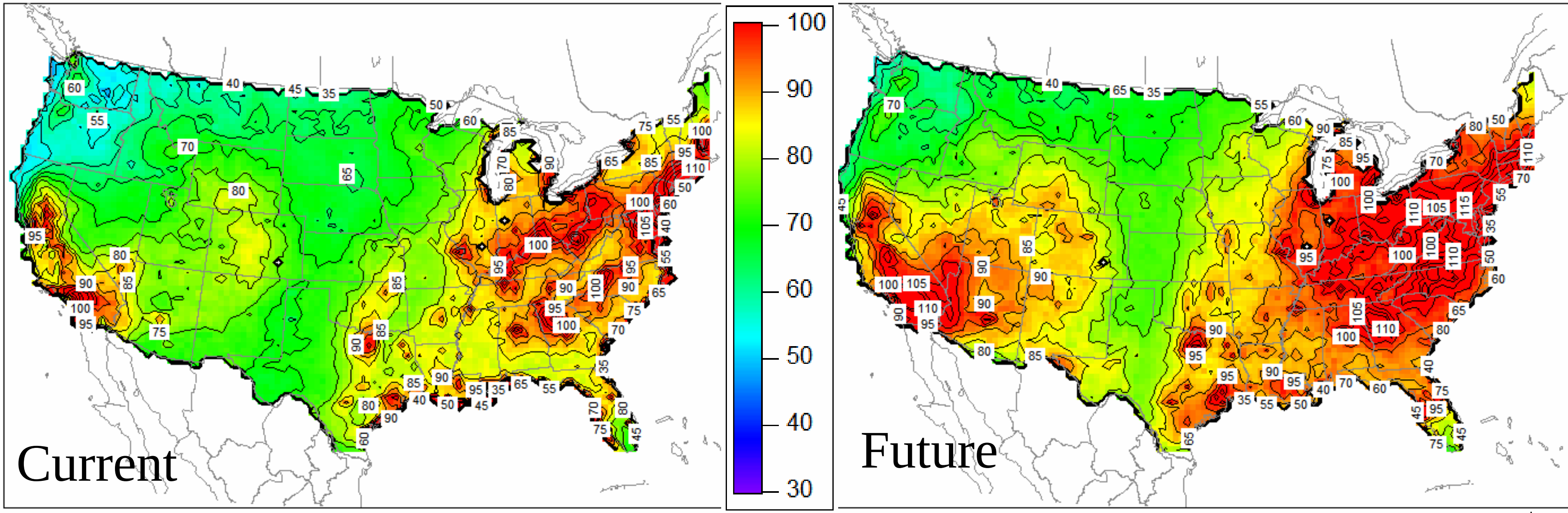




Future changes

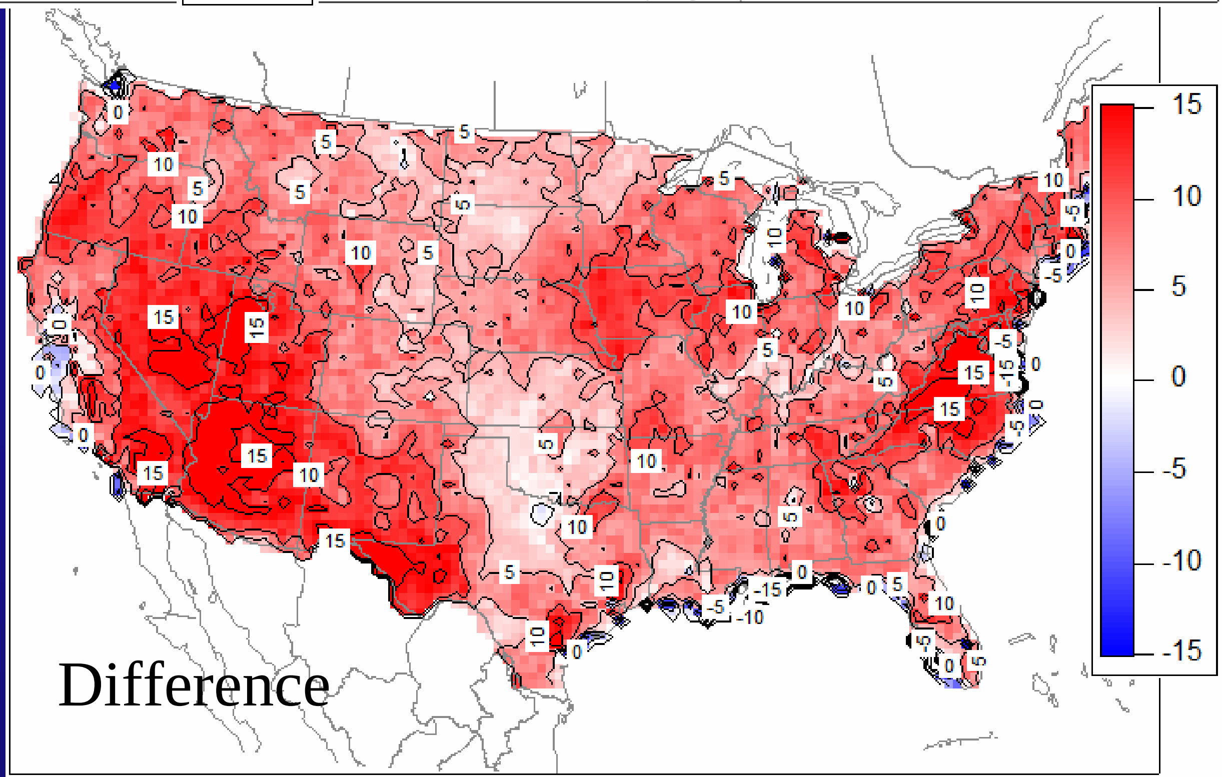
Average Daily Max 8-Hr Ozone [ppbv]



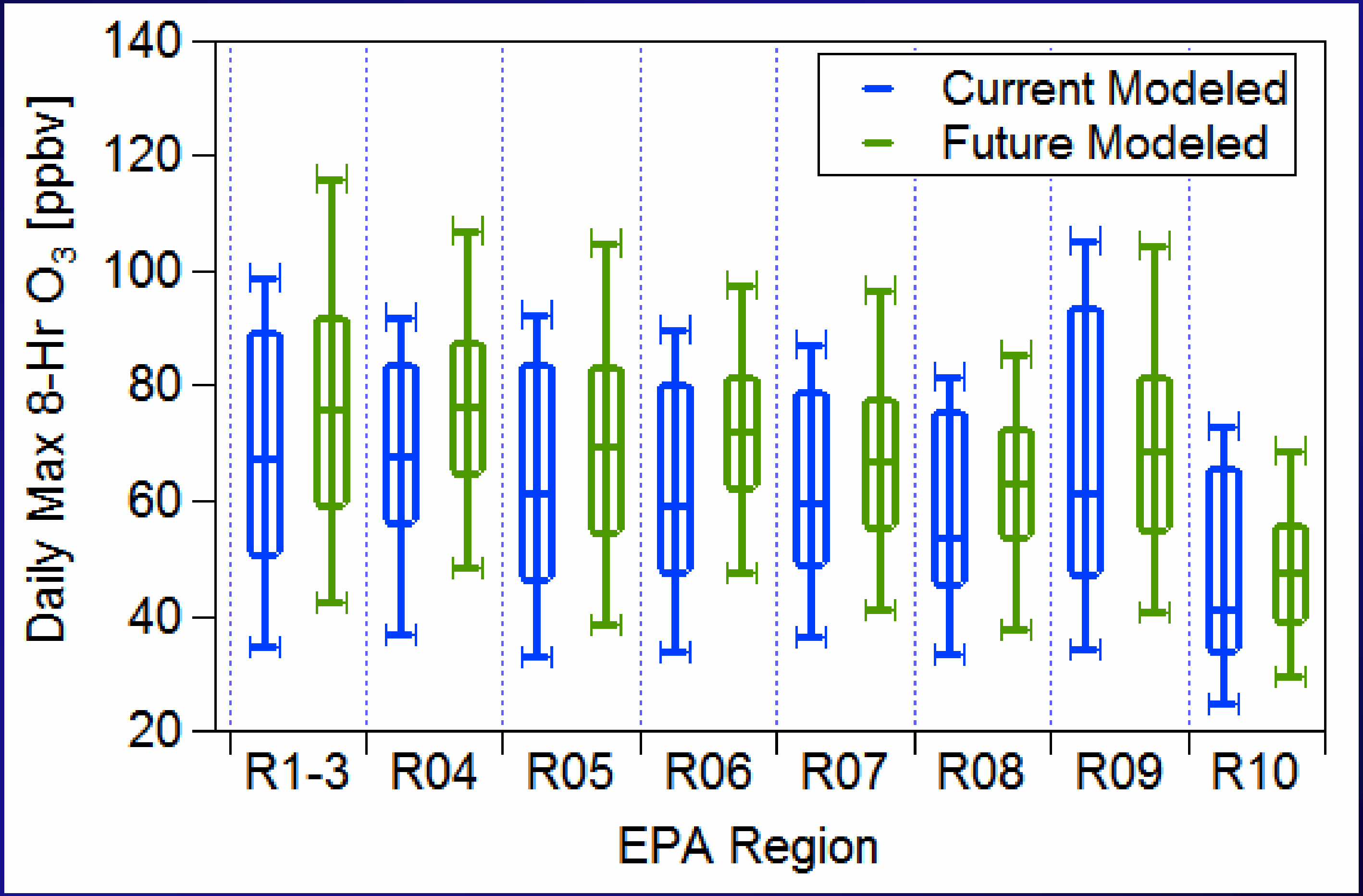


Future Changes

Daily Max 8-Hr Ozone (Episodic Condition - 99th Percentile) [ppbv]

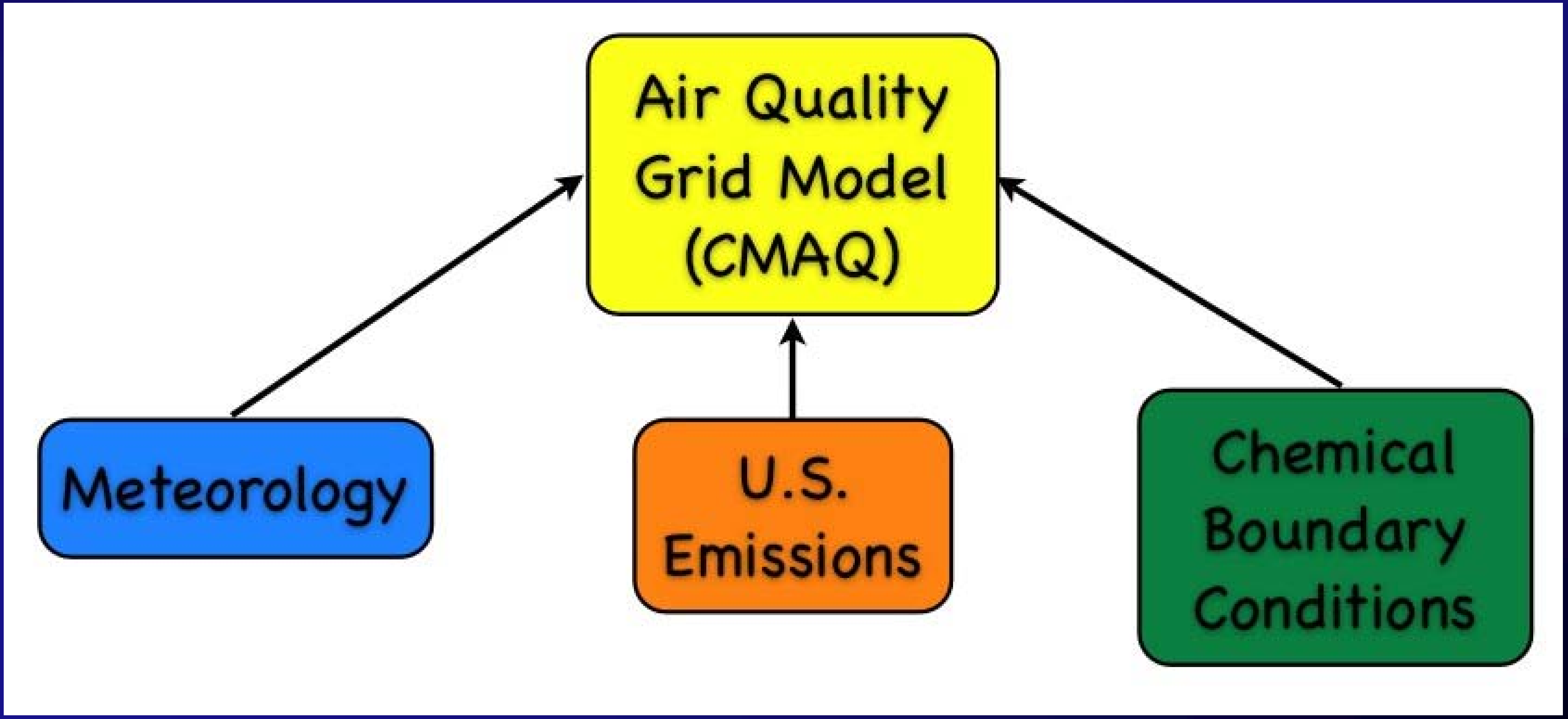


Future changes in distributions of daily max 8 hr ozone

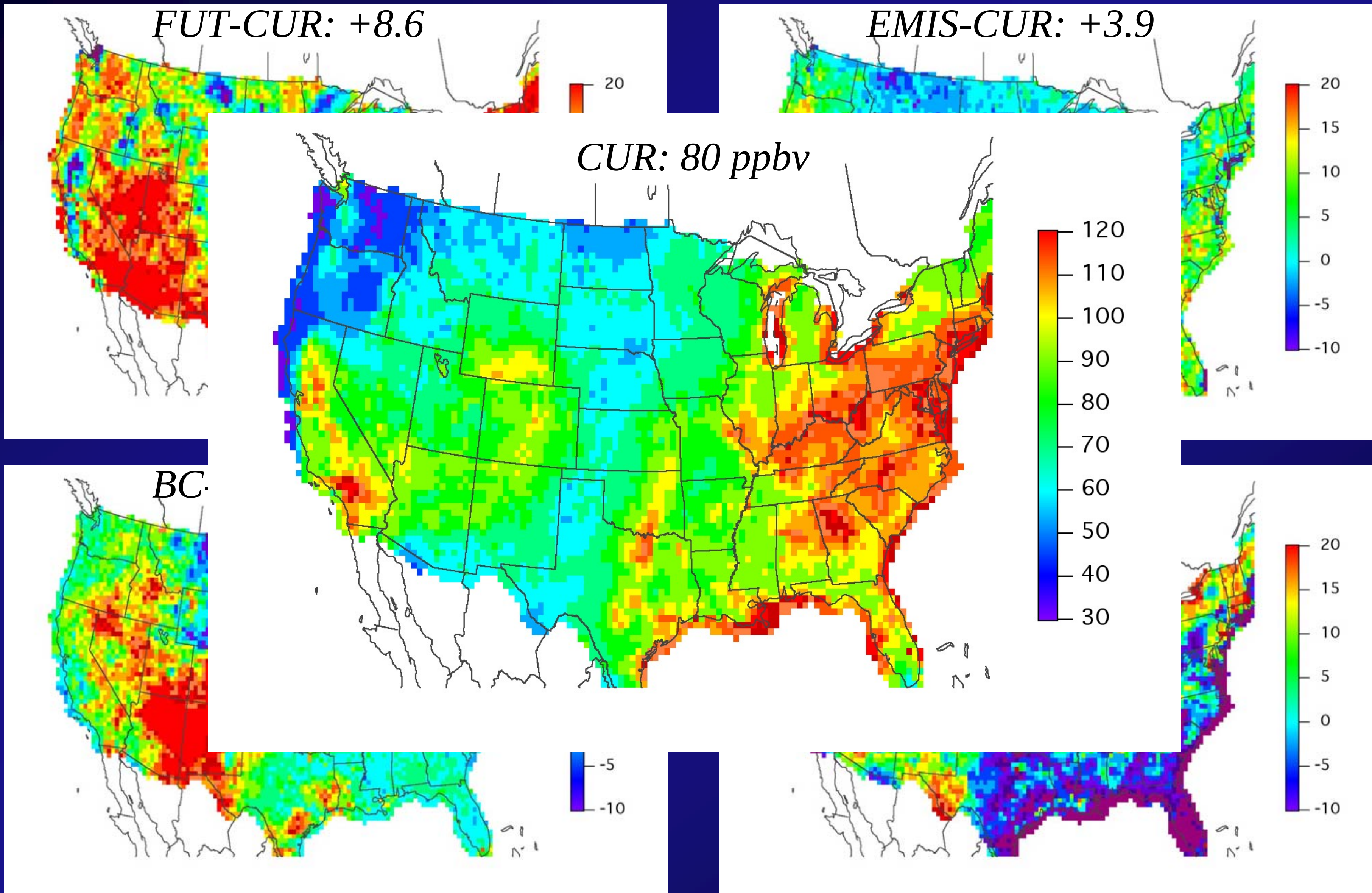


Attribution Study: 5 current/future July's

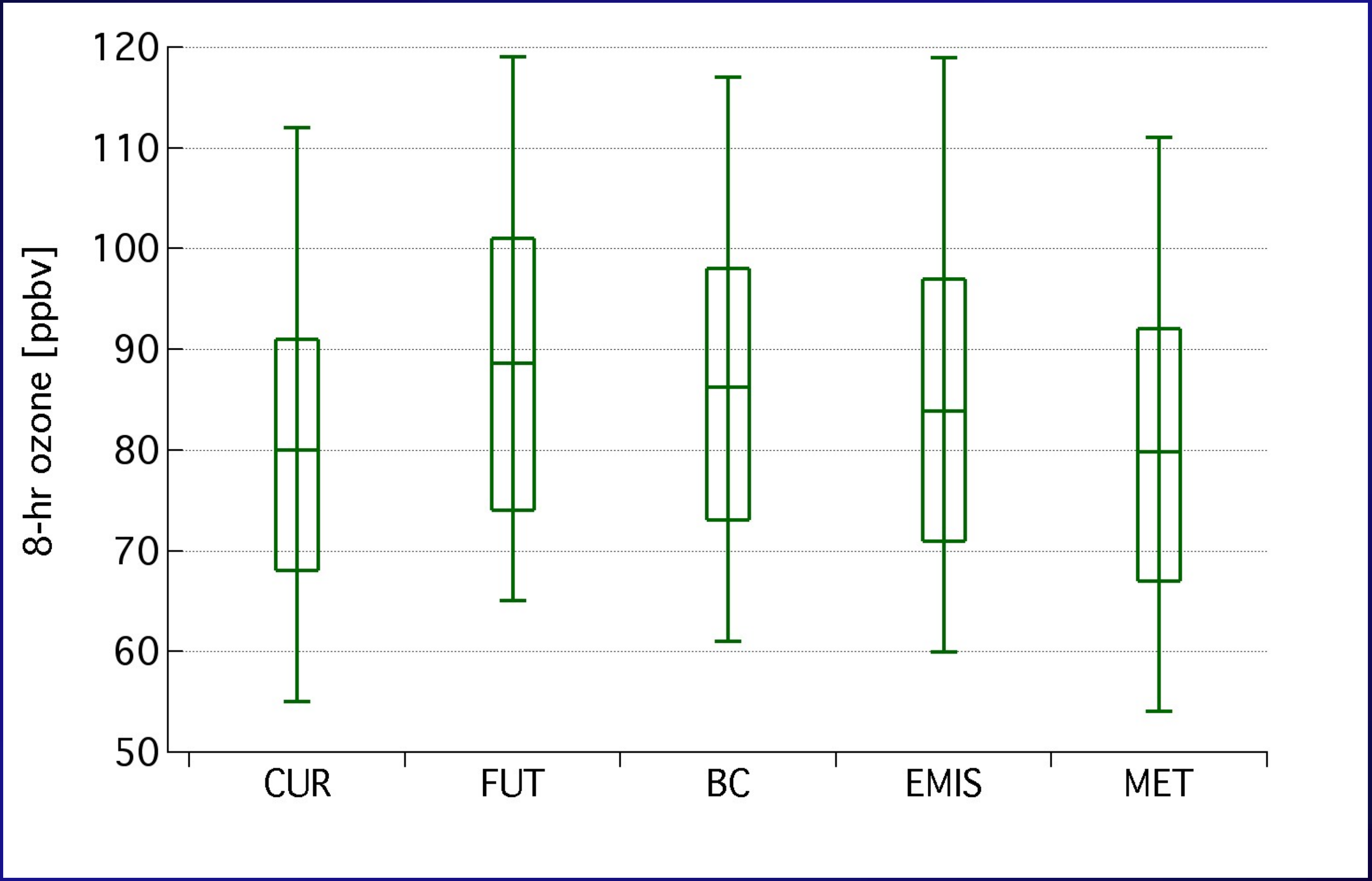
CUR	current met	current BC	current US emissions
FUT	future met	future BC	future US emissions
MET	future met	current BC	current US emissions
BC	current met	future BC	current US emissions
EMIS	current met	current BC	future US emissions



Results: July 8-hr O_3 98th percentile

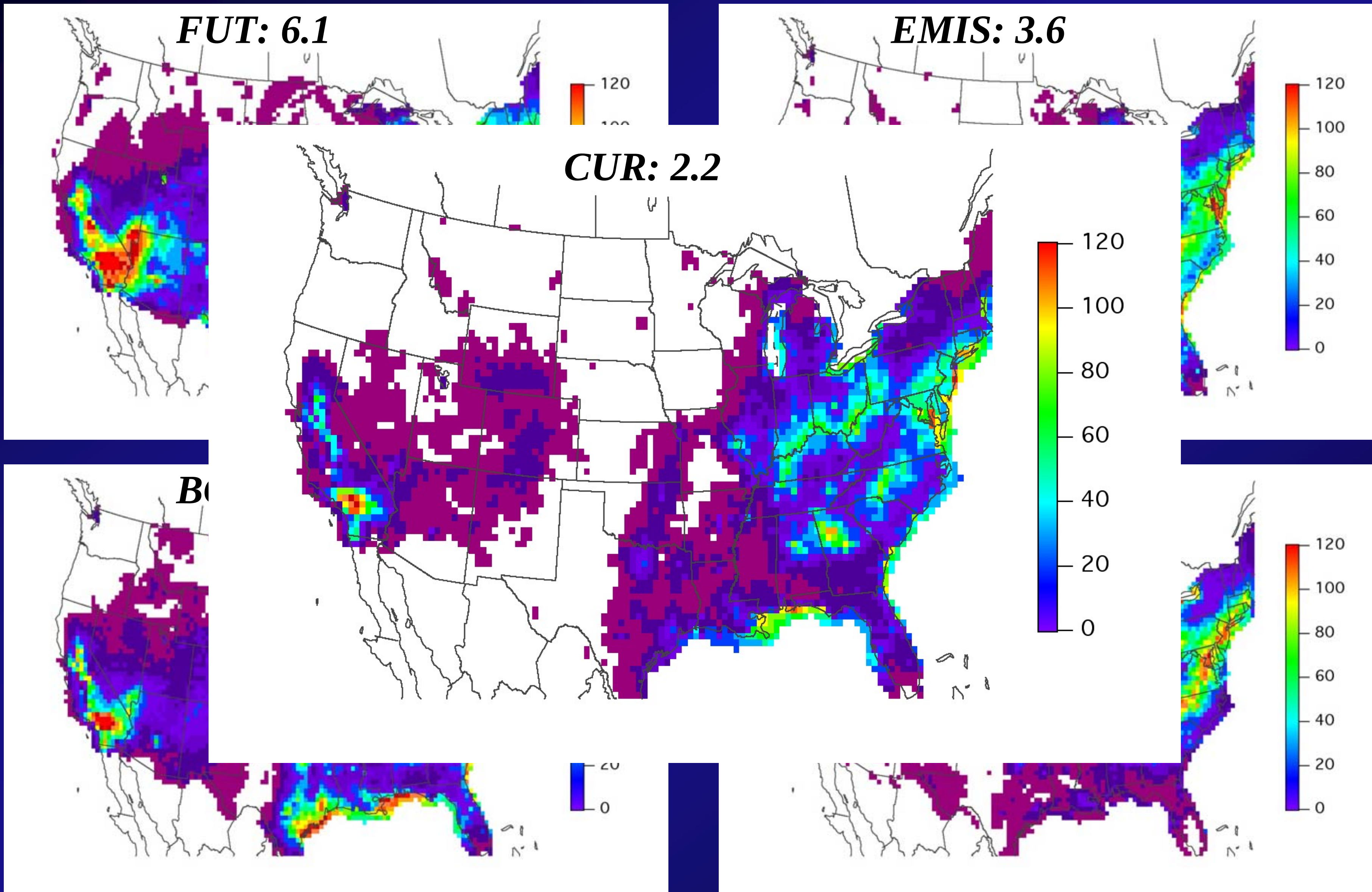


Attribution results:
July 8-hr O_3 distributions



2nd percentile, 20th percentile, average, 80th percentile, 98th percentile

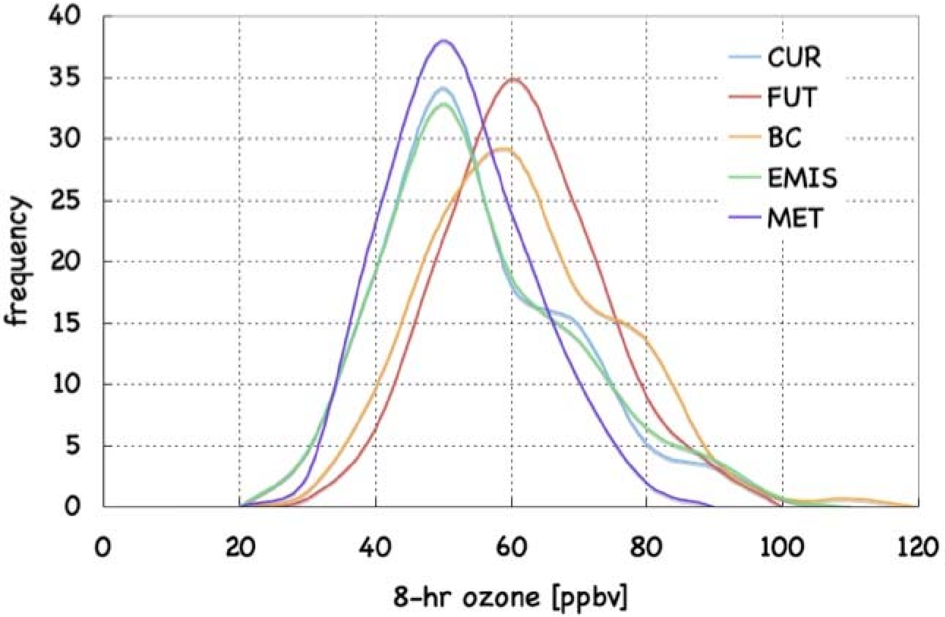
Results: July 8-hr O_3 80 ppbv exceedances

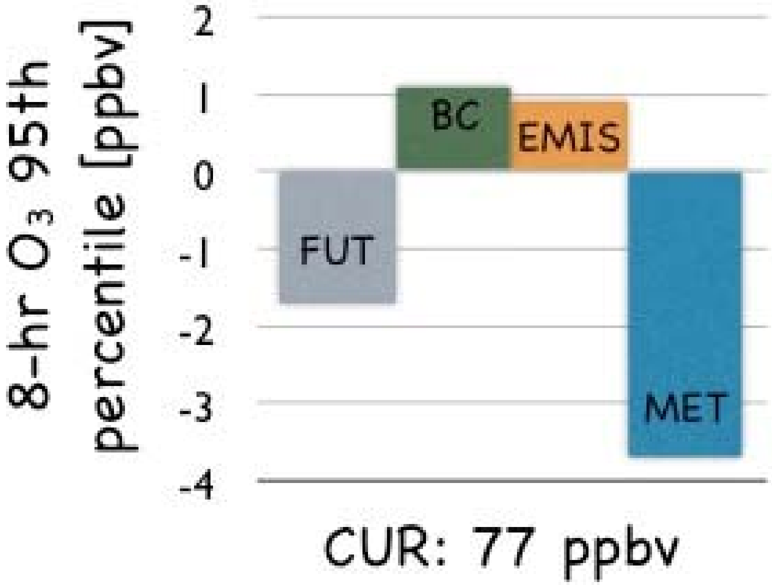


Average # exceedences / July / US grid

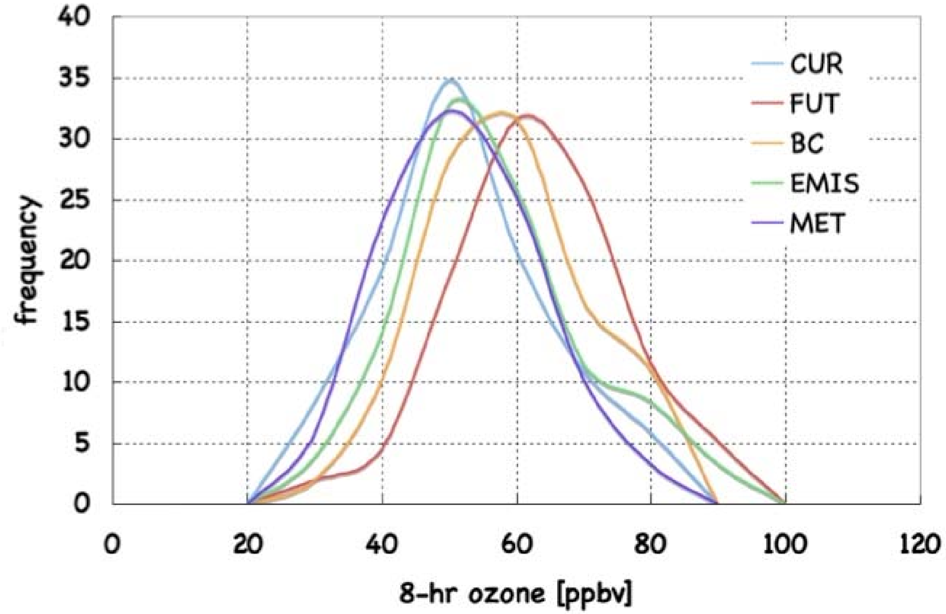
8-hr O3 95th percentile

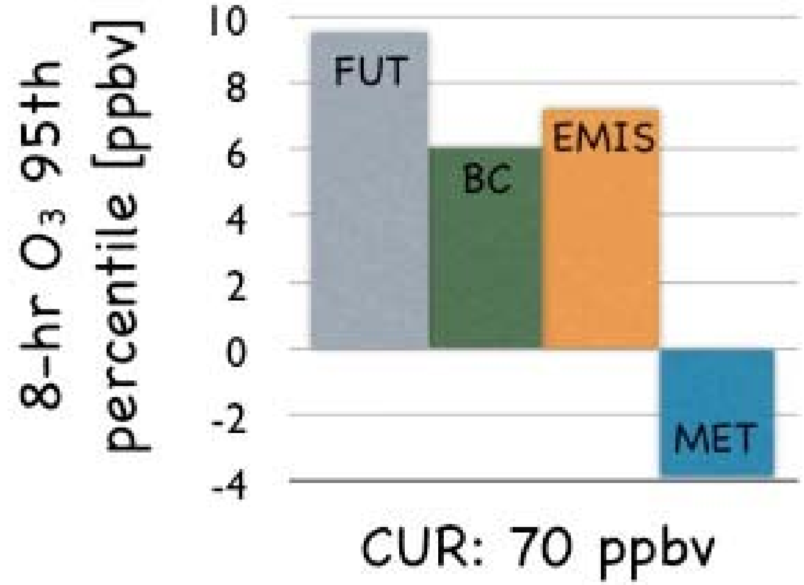
Seattle





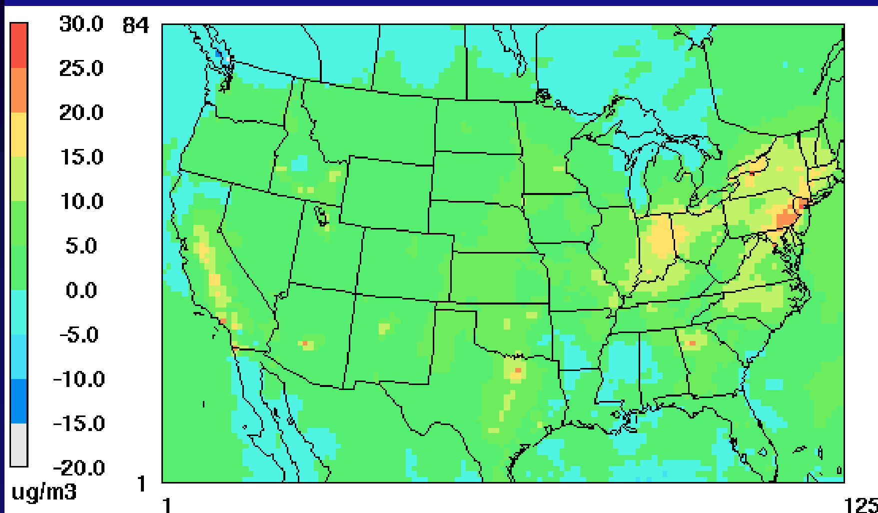
Portland



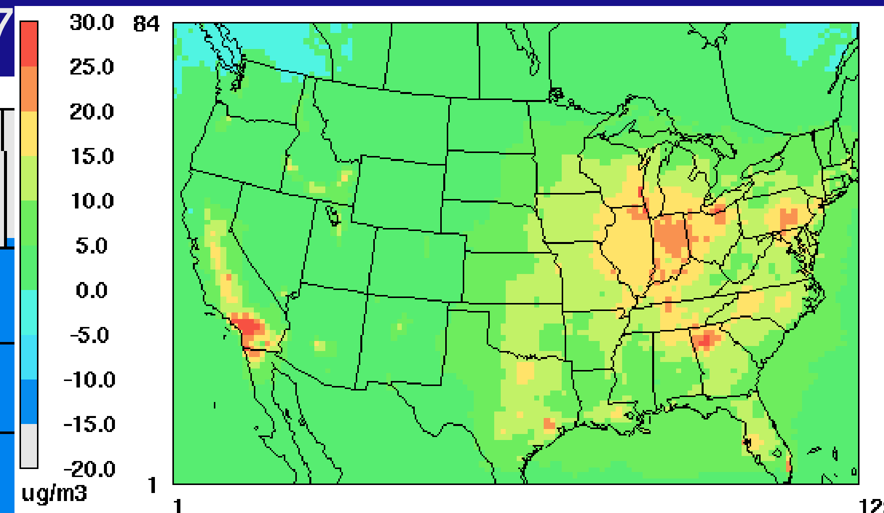


Results: 1-hr $PM_{2.5}$ 95th percentile

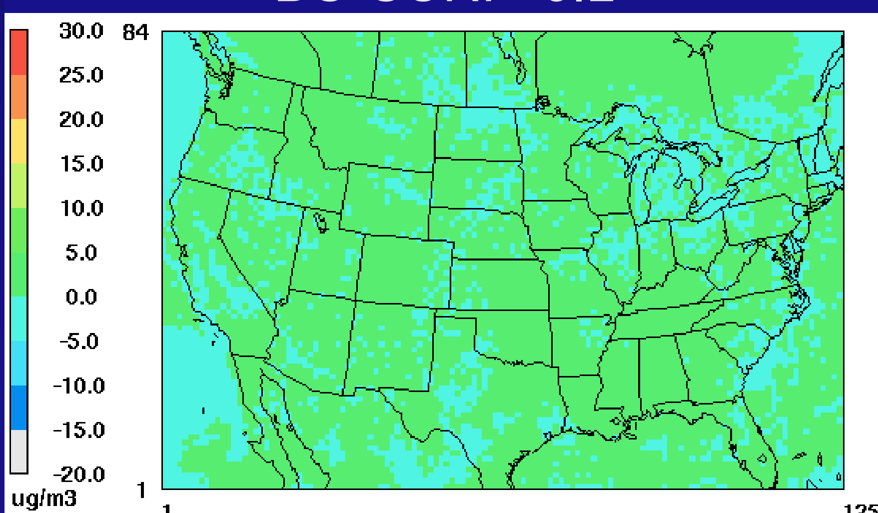
FUT-CUR: +5.7



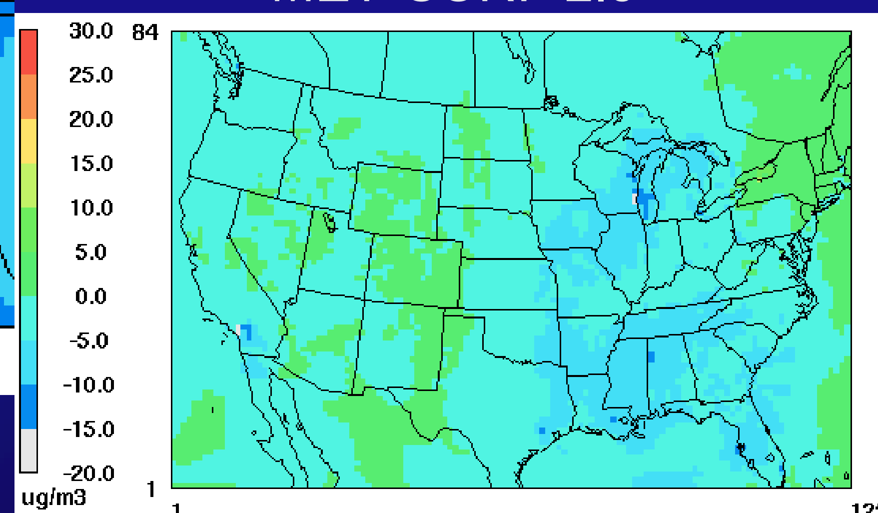
EMIS-CUR: +10.0



BC-CUR: +0.1

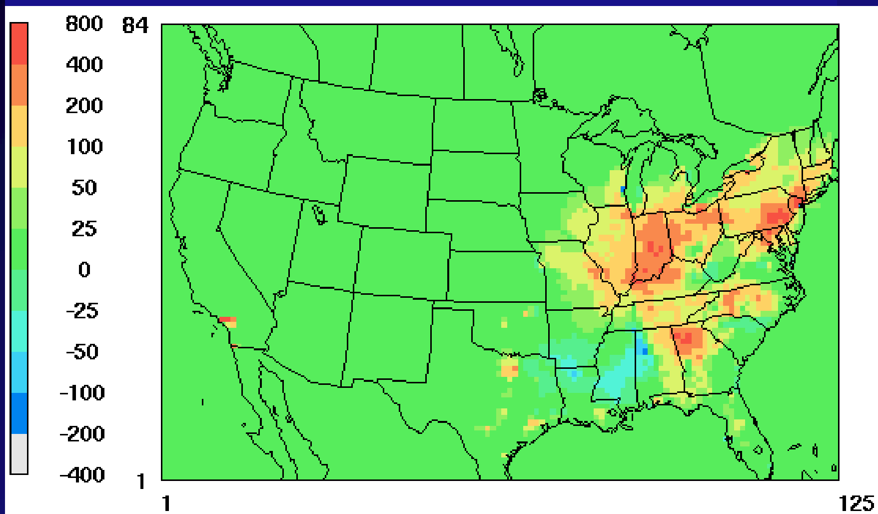


MET-CUR: -2.9

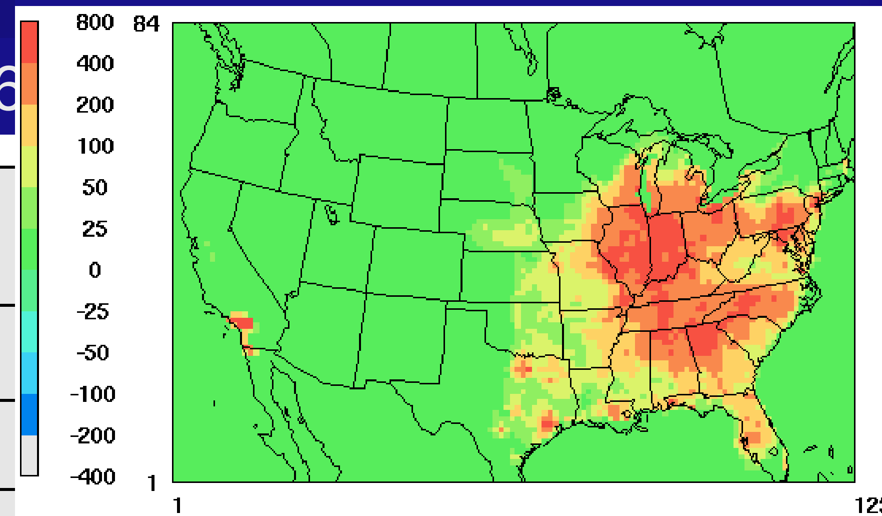


Results: 24-hr $PM_{2.5}$ 35 $\mu g/m^3$ exceedances

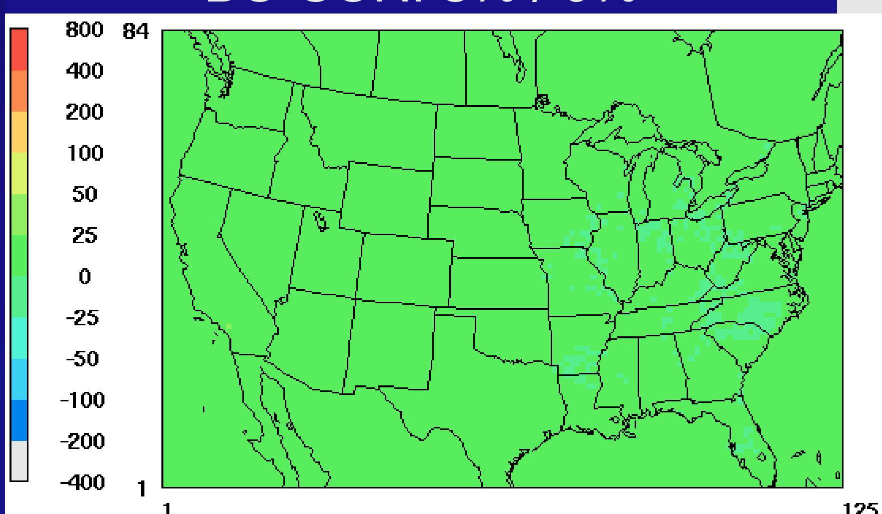
FUT-CUR: 400% / 64%



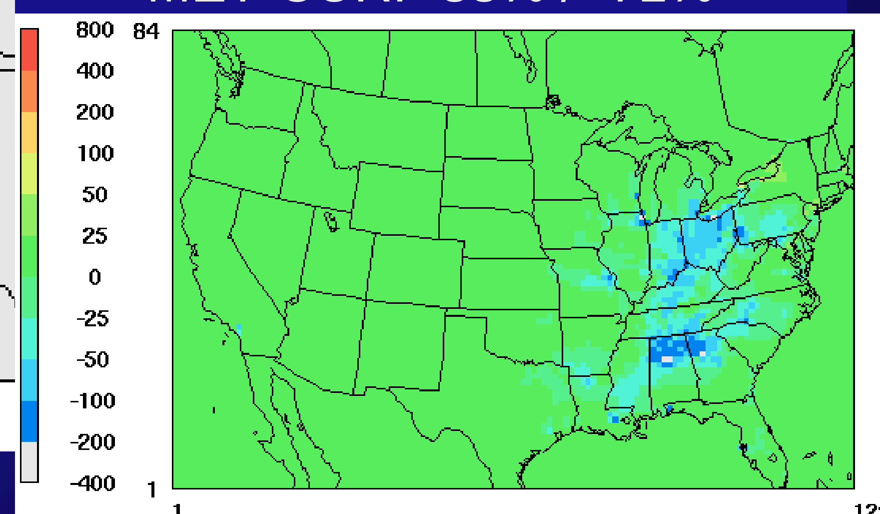
EMIS-CUR: 1117% / 163%



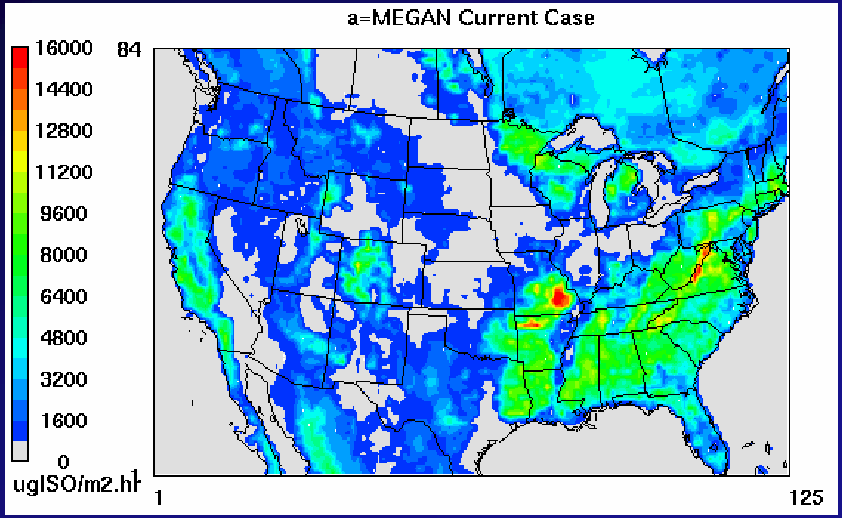
BC-CUR: 3% / 0%



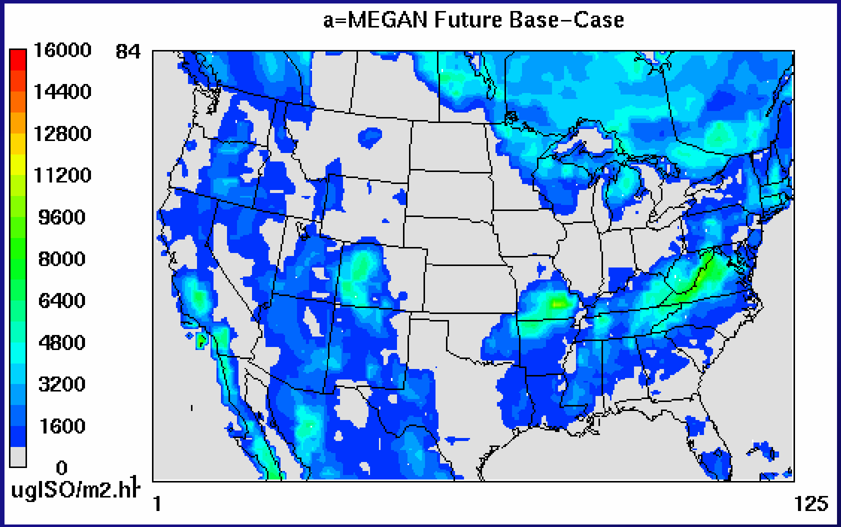
MET-CUR: -83% / -71%



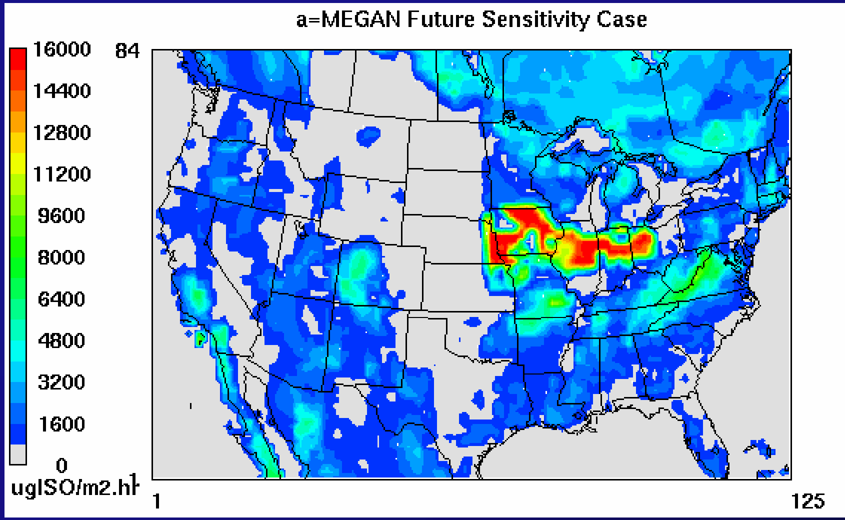
Land Management Scenario: Widespread Use of Tree Plantations July Isoprene Emission Capacity (30 ^oC)



Current



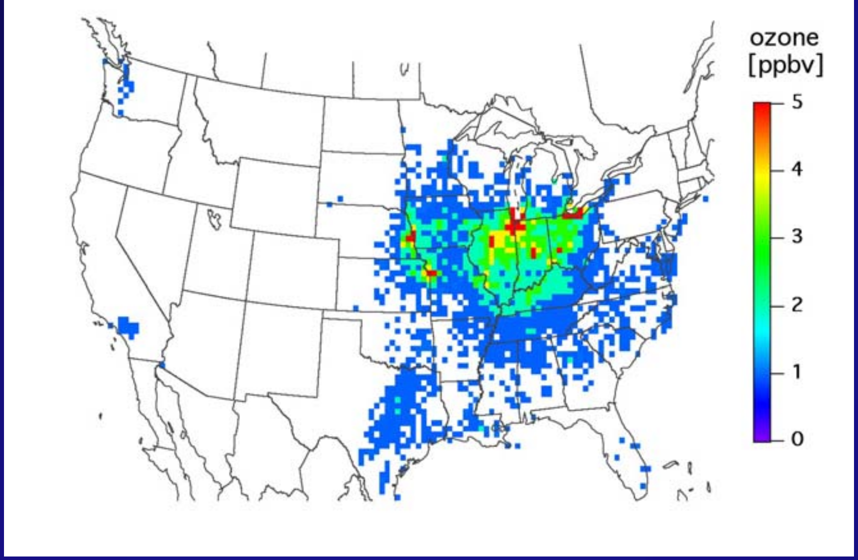
Future



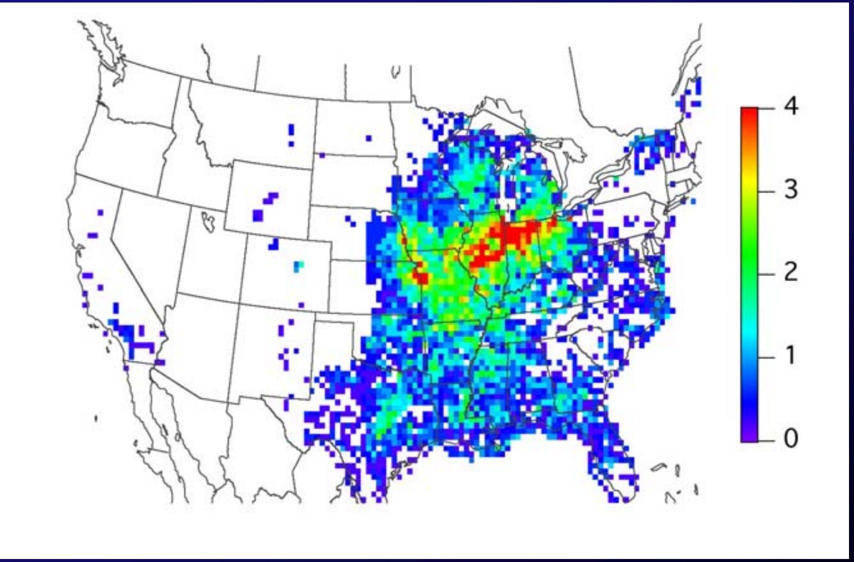
Future with Plantations

Changes in 8-hr ozone concentrations for enhanced tree plantations in the future

Increase in peak 8-hour average ozone associated with increasing tree plantations



Increase in the days per July that the 8-hour average ozone exceeds 80 ppbv due to increasing tree plantations



Summary

- Comparison to current observations
  - PCM temperatures are biased low
  - 8 hr daily max O3 peak values are correctly captured, low end of the distribution is overestimated
- Future changes:
  - Peak O3 increases of 5 to 15 ppbv
  - significant increases in occurrences above 80 ppbv
  - PM2.5 significant increases--5.7 ug/m^3 above 20 ug/m^3 currently
  - Large increase in number of PM2.5 exceedences of new 24 hr standard
- Attribution Analyses:
  - future O3 changes mainly due to changes in chemical BC and US anthropogenic emissions
  - Changes in meteorology (climate) have a secondary effect on future ozone concentrations for the emission projections in this work
- Landuse changes
  - Increases in BVOC emissions due to climate change are offset by reduction in forested areas
  - Enhanced use of tree plantations for C sequestration has significant impact on isoprene emissions and ozone concentrations for the future decade.

Ensemble modeling of global change and regional air quality: Next steps

- develop a quantitative measure of the uncertainty in our modeling framework using ensemble modeling methods in comparison to current decade observations;
- project these uncertainties into the future for the period 2045-2054 and quantitatively address the uncertainties that accompany projections of future emissions, both global and in the U.S., including changes in landcover and the effects of change on urbanization, biogenic emissions, and the role of fire in air quality; and
- continue to address our overall research questions that will help determine the consequences of global change upon U.S. air quality.

Global/regional ensemble members: current decade uncertainty analyses

Runs	GCM	Regional Meteorology 220 / 36 /12 km domains
1	CCSM	WRF1
2		WRF2
3		WRF3
4	Echam	WRF1
5		WRF2
6		WRF3
7	HadCM	WRF1
8		WRF2
9		WRF3

Most representative current decade GCM/WRF meteorological runs to drive CMAQ

Table 1. Ensemble members for global/regional meteorological modeling for the current decade.

Future decade ensemble simulations

Runs	IPCC SRES Scenario	GCM/Regional Meteorology 220 / 36 /12 km domains
1	A2	GCM/WRF 1
2		GCM/WRF 2
3		GCM/WRF 3
4	B1	GCM/WRF 1
5		GCM/WRF 2
6		GCM/WRF 3

Two cases of A2 GCM/WRF meteorology to drive CMAQ

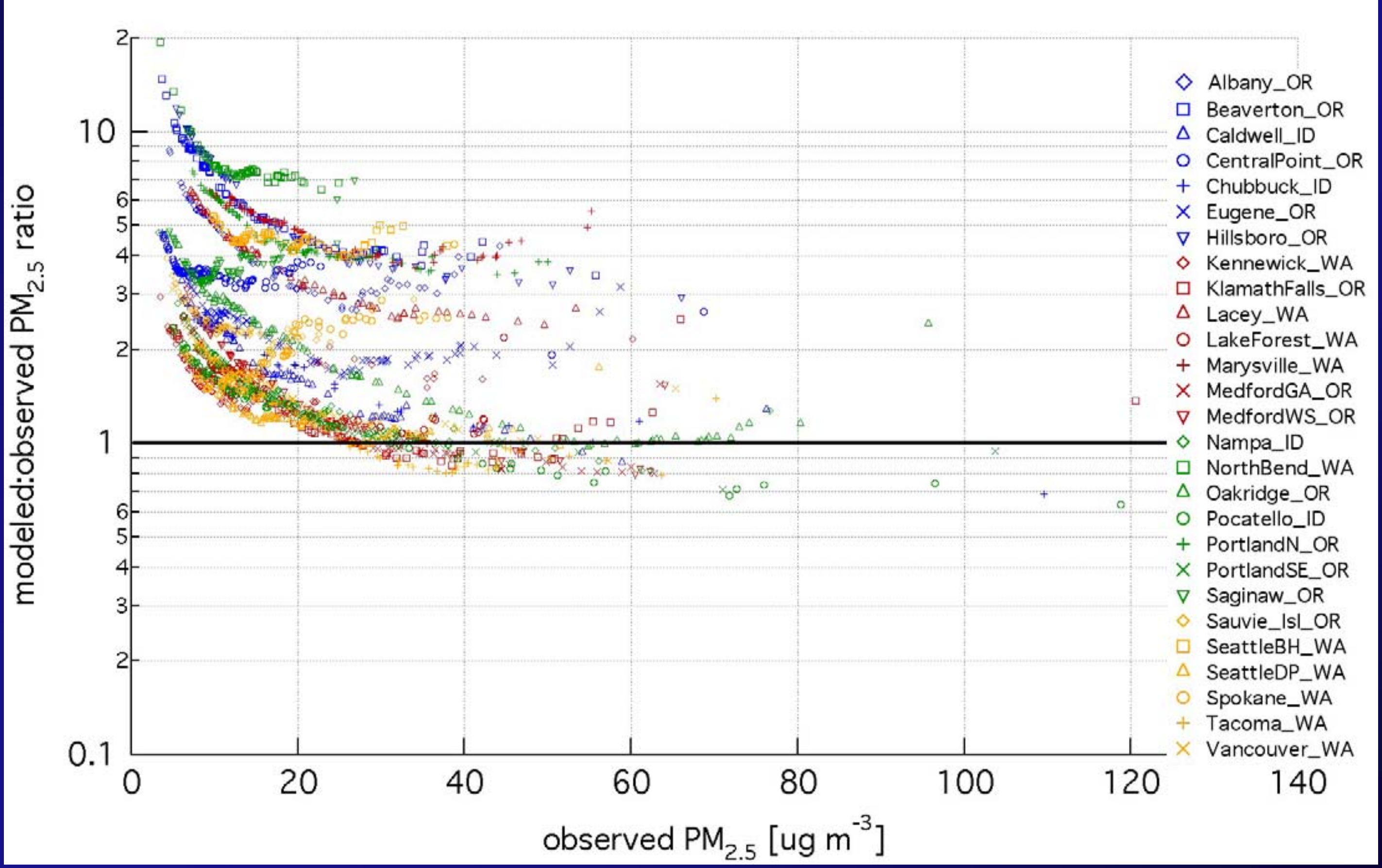
Two cases of B1 GCM/WRF meteorology to drive CMAQ

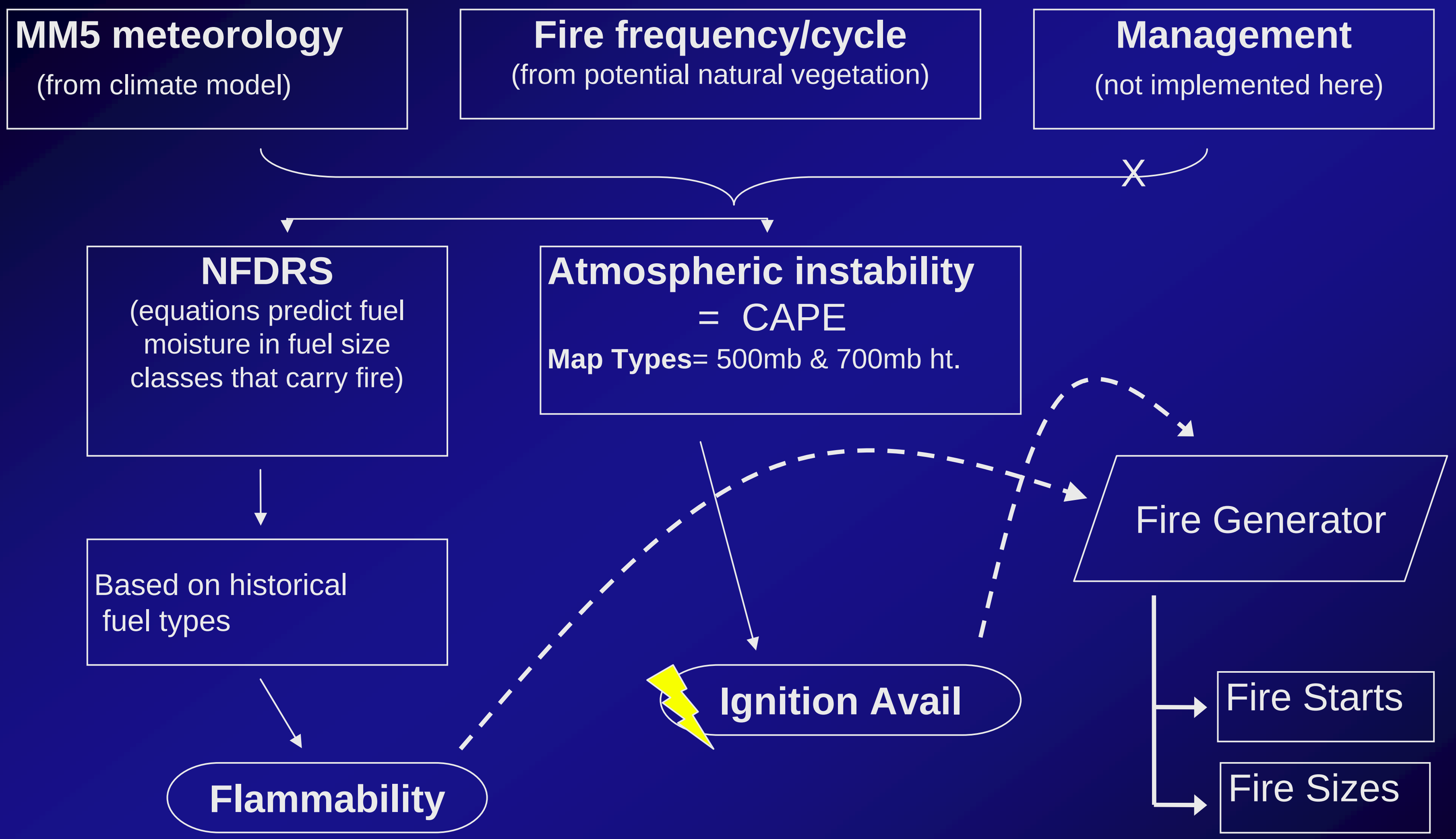
Table 2. Ensemble members for global/regional meteorological modeling for the future decade.

Future decade sensitivity simulations

<table>
<tr><th>IPCC Scenario</th><th>CMAQ Meteorology</th><th>Hemispheric/Regional CMAQ 220 / 36 km domains</th><th>CMAQ Hemispheric Emission Sensitivity 220 / 36 km domains</th><th>CMAQ Regional Emission Sensitivity 12 km domain</th></tr>
<tr><td>A2</td><td>GCM/WRF (A2)</td><td>A2 Hemispheric/Regional Emissions</td><td rowspan="2">Emission sensitivity simulations on changes in Asian emission</td><td rowspan="2">Additional emission sensitivity simulations from changing LU/LC</td></tr>
<tr><td>A2</td><td>GCM/WRF (A2)</td><td>A2 Hemispheric/Regional Emissions</td></tr>
<tr><td>B1</td><td>GCM/WRF (B1)</td><td>B1 Hemispheric/Regional Emissions</td><td rowspan="2">Emission sensitivity simulations on changes in Asian emissions</td><td rowspan="2">Additional emission sensitivity simulations from changing LU/LC</td></tr>
<tr><td>B1</td><td>GCM/WRF (B1)</td><td>B1 Hemispheric/Regional Emissions</td></tr>
</table>

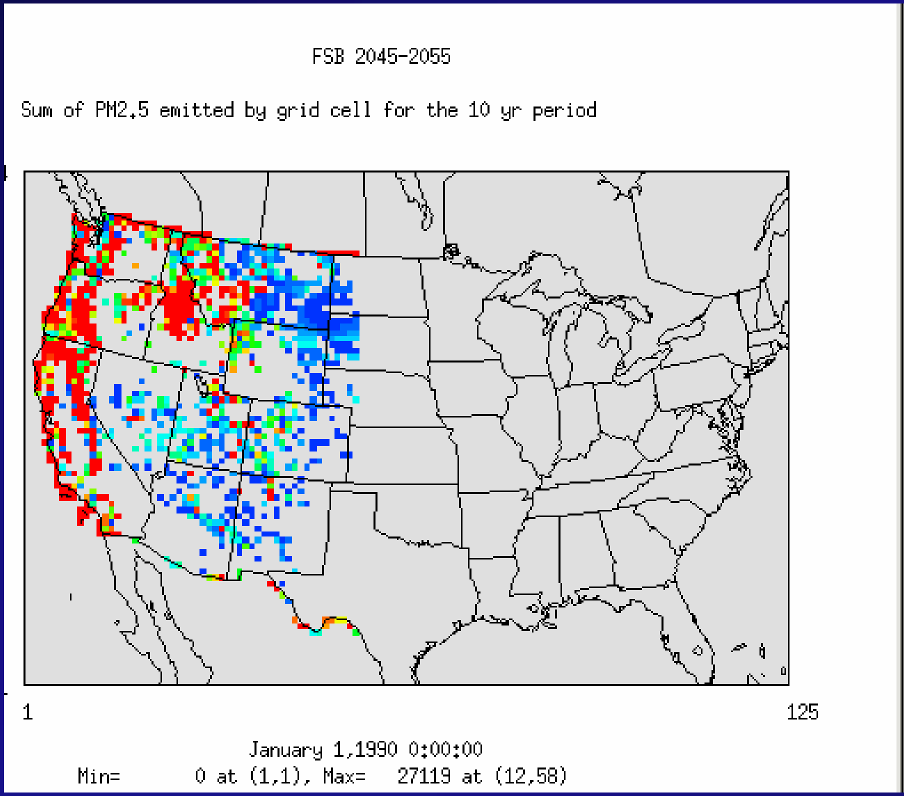
PM2.5 Model/Obs for the Pacific Northwest



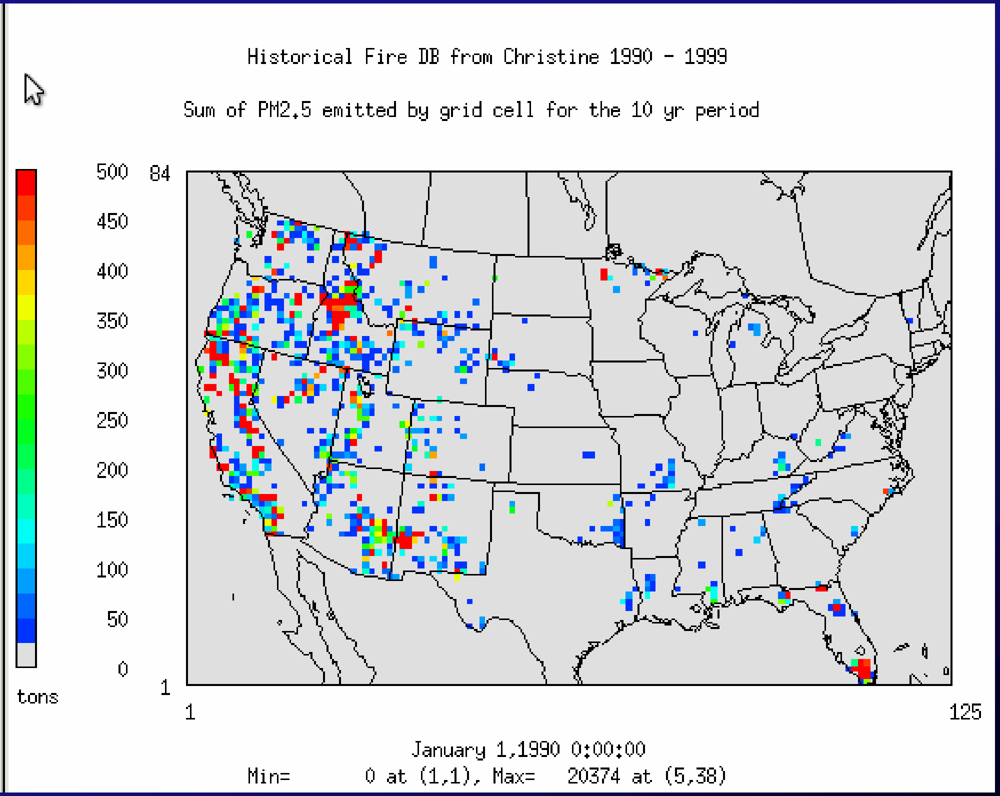


Fire Scenario Builder

Comparing $PM_{2.5}$ emissions from current decade with simulated future fires



Simulated future fires



Current decade fires

PCM comparison to observations: unrealistic wintertime cold outbreaks