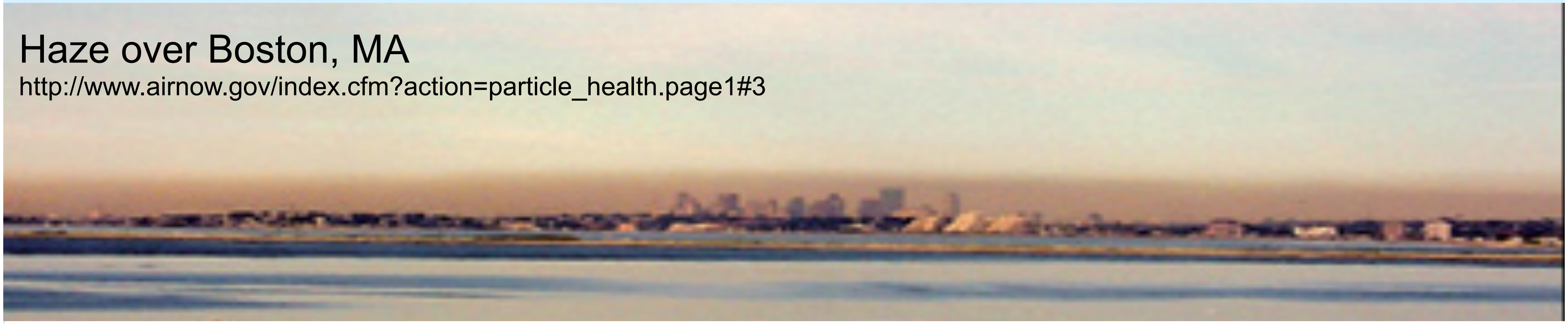

Haze over Boston, MA
http://www.airnow.gov/index.cfm?action=particle_health.page1#3

Influence of Changes in Emissions and Climate on Background and Extreme Levels of Air Pollution

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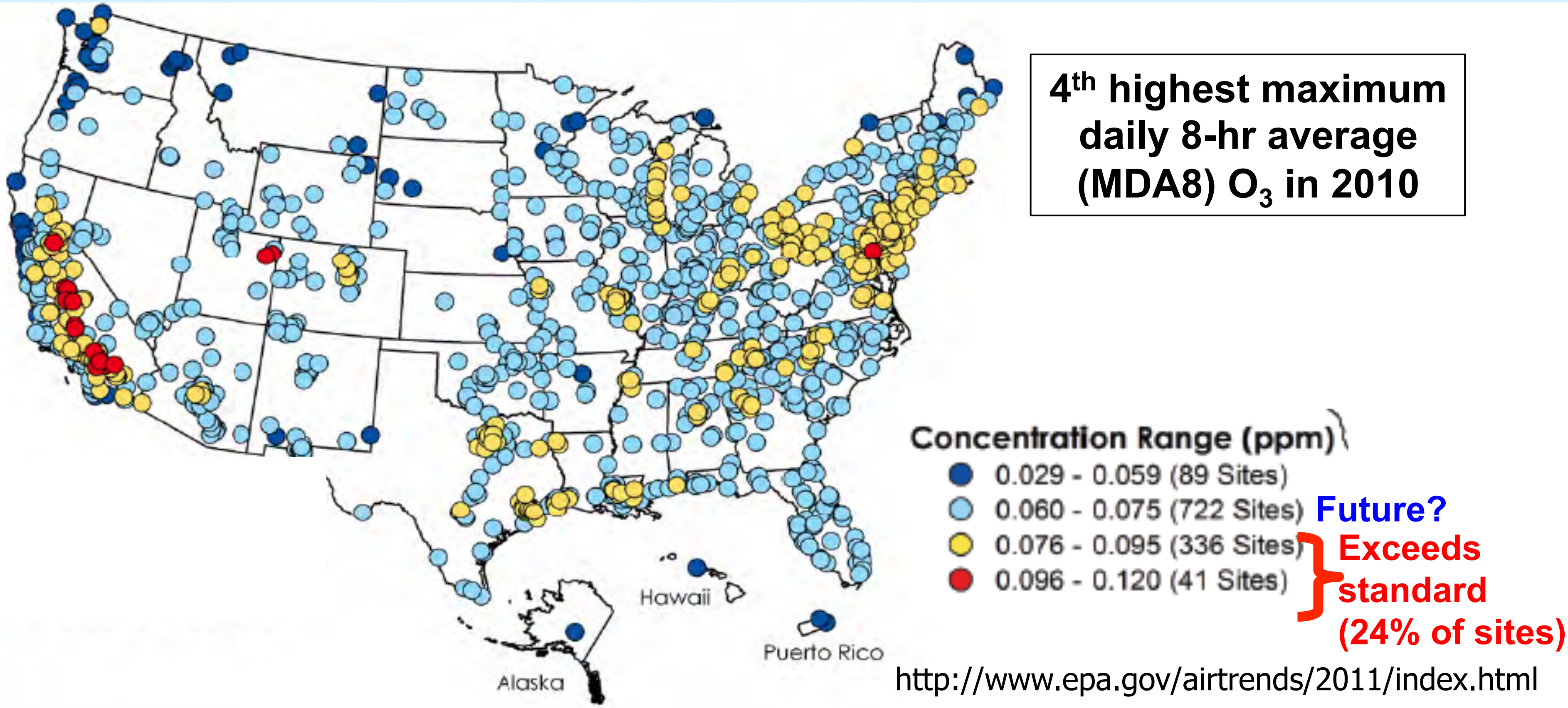
Symposium on Abrupt Climate Change in a Warming World
LDEO, Palisades, NY
May 23, 2013

The U.S. ozone smog problem is spatially widespread, affecting ~108 million people [*U.S. EPA, 2012*]



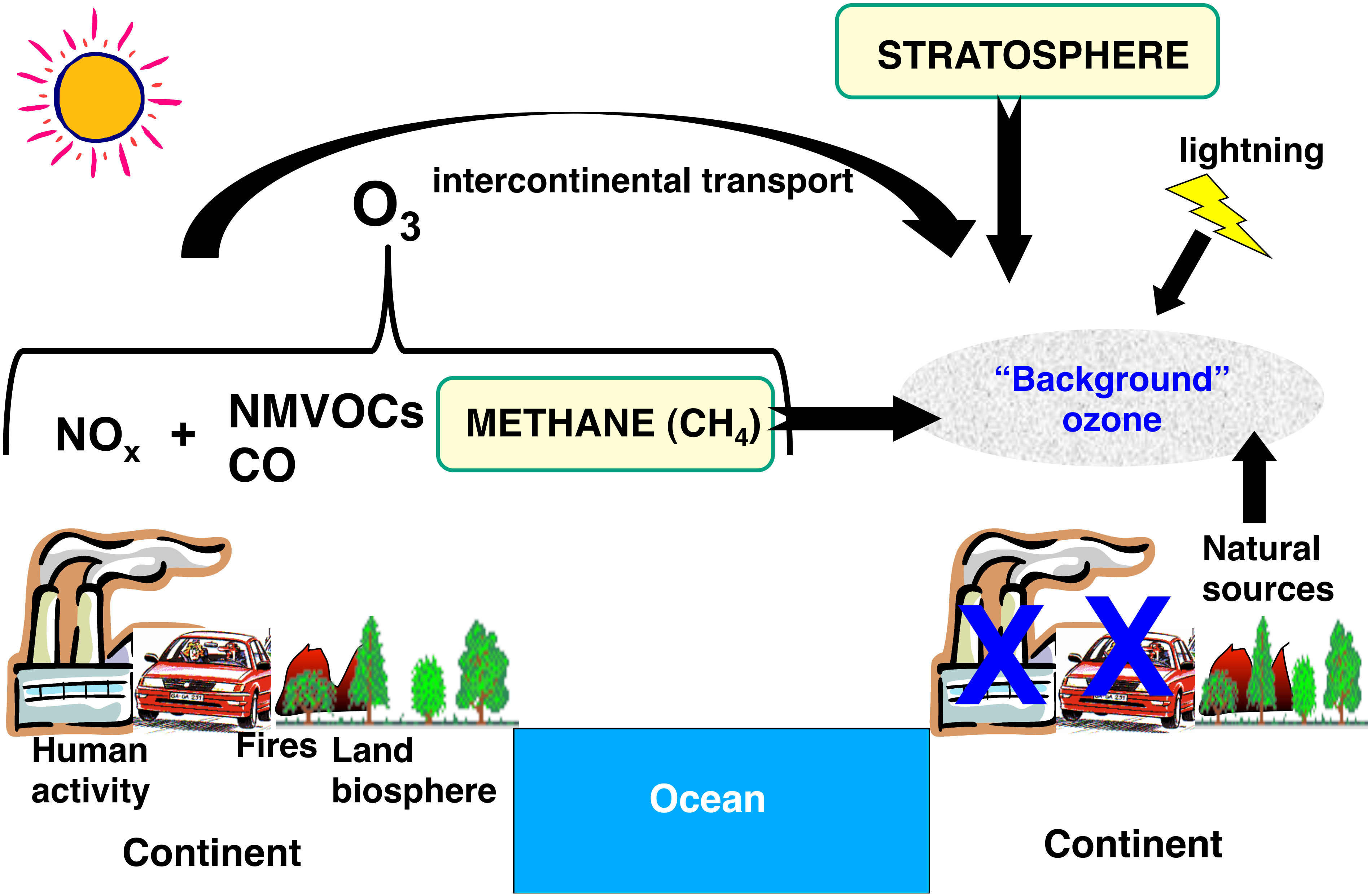
4th highest maximum daily 8-hr average (MDA8) O_3 in 2010

http://www.epa.gov/airtrends/2011/index.html

High-O_3 events typically occur in
-- densely populated areas (local sources)
-- summer (favorable meteorological conditions)

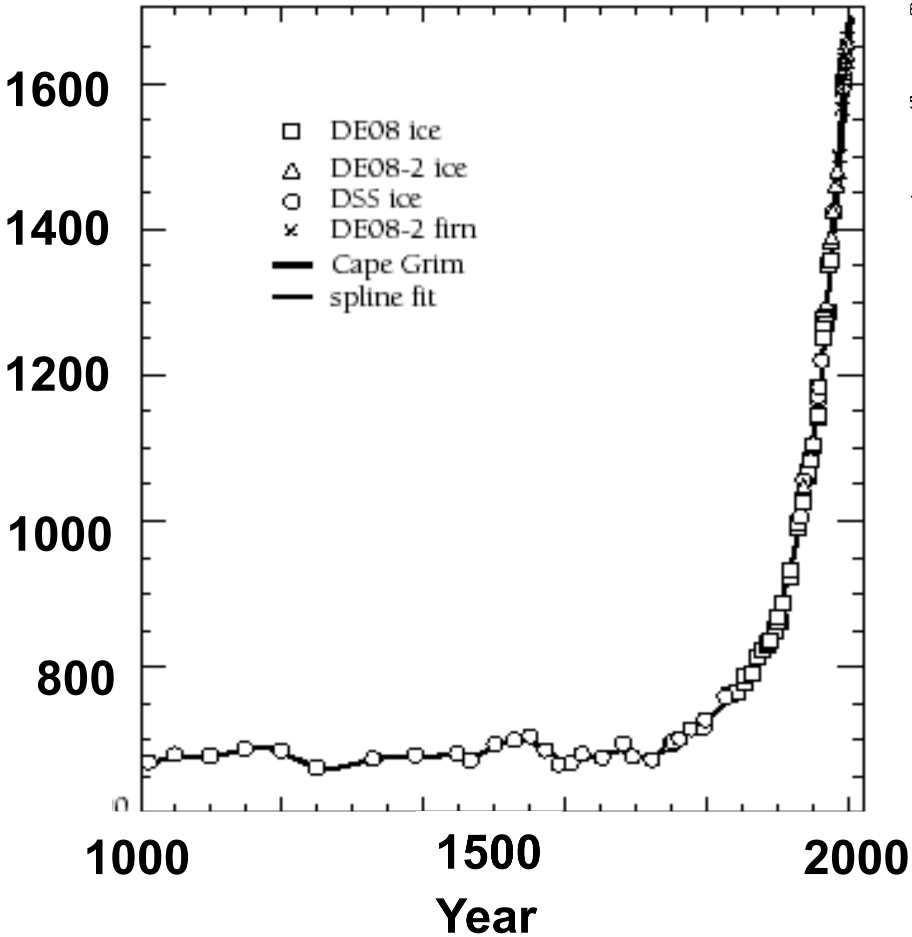
→ Lower threshold would greatly expand non-attainment regions

Tropospheric O_3 formation & "Background" contributions

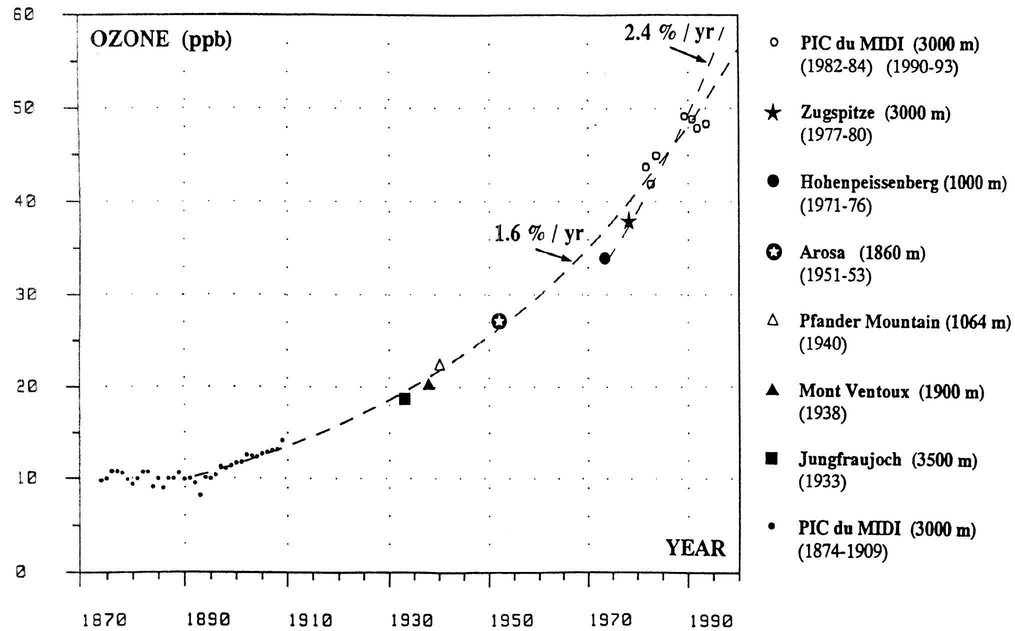


Historical increase in atmospheric methane and ozone (#2 and #3 greenhouse gases after carbon dioxide [*IPCC, 2007*])

CH_4 Abundance (ppb) past 1000 years [*Etheridge et al.*, 1998]



Ozone at European mountain sites 1870-1990 [*Marenco et al.*, 1994]



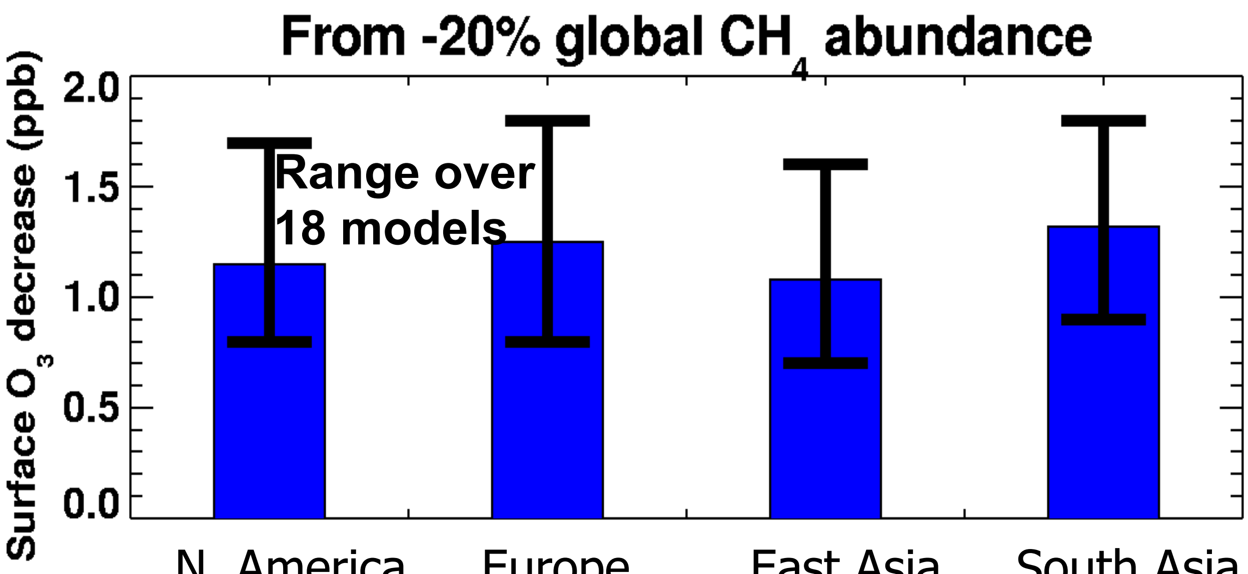
Preindustrial to present-day radiative forcing [*Forster et al.*, (IPCC) 2007]:

+0.48 Wm^{-2} from CH_4

+0.35 Wm^{-2} from O_3

Benefits of ~25% decrease in global anthrop. CH_4 emissions

OZONE AIR QUALITY



[Fiore et al., JGR, 2009; TF HTAP, 2007, 2010; Wild et al., ACP, 2012]

→ **Possible at cost-savings / low-cost** [West & Fiore 2005; West et al.,2012]

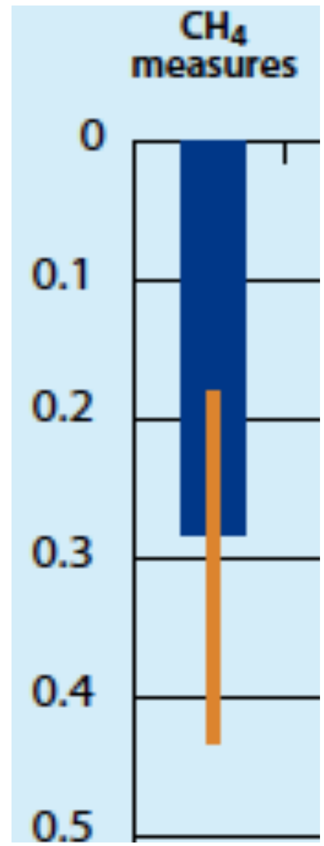
→ **$1.4 billion (agriculture, forestry, non-mortality health) within U.S. alone** [West and Fiore, 2005]

→ **7700-400,000 annual avoided cardiopulmonary premature mortalities in the N. Hemisphere**

uncertainty in concentration-response relationship only [Anenberg et al., ES&T, 2009]

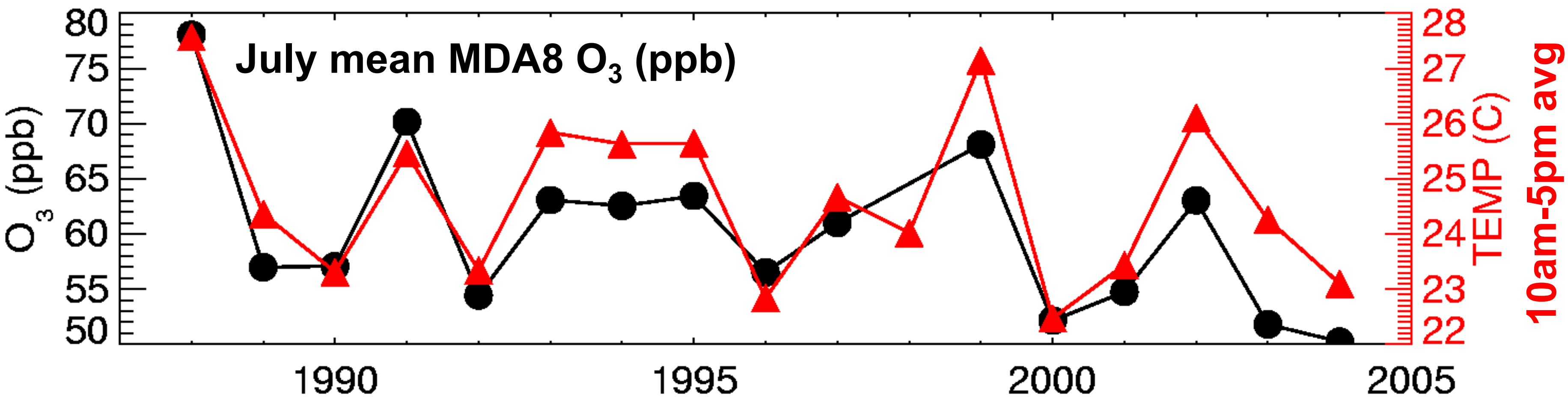
CLIMATE

Global mean avoided warming in 2050 (°C)
[WMO/UNEP, 2011]



Strong correlations between surface temperature and O_3 measurements on daily to inter-annual time scales in polluted regions [e.g., Bloomer et al., 2009; Camalier et al., 2007; Cardelino and Chameides, 1990; Clark and Karl, 1982; Korsog and Wolff, 1991]

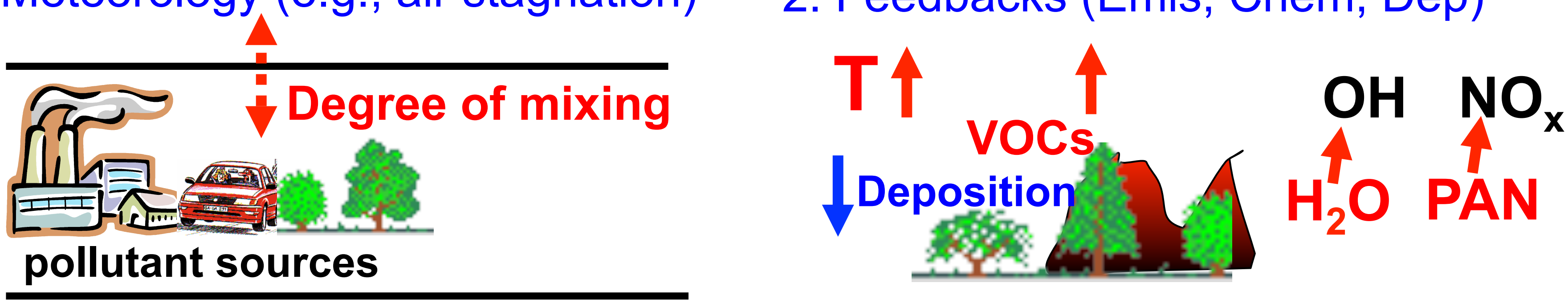
Observations at U.S. EPA CASTNet site Penn State, PA 41N, 78W, 378m



What drives the observed O_3-Temperature correlation?

1. Meteorology (e.g., air stagnation)

2. Feedbacks (Emis, Chem, Dep)

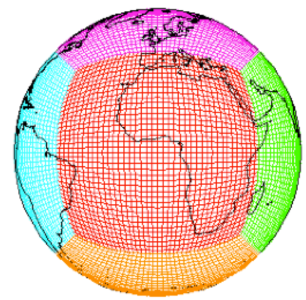


→ Implies that changes in climate will influence air quality

How will surface O_3 distributions evolve with future changes in emissions and climate?

Tool: GFDL CM3 chemistry-climate model

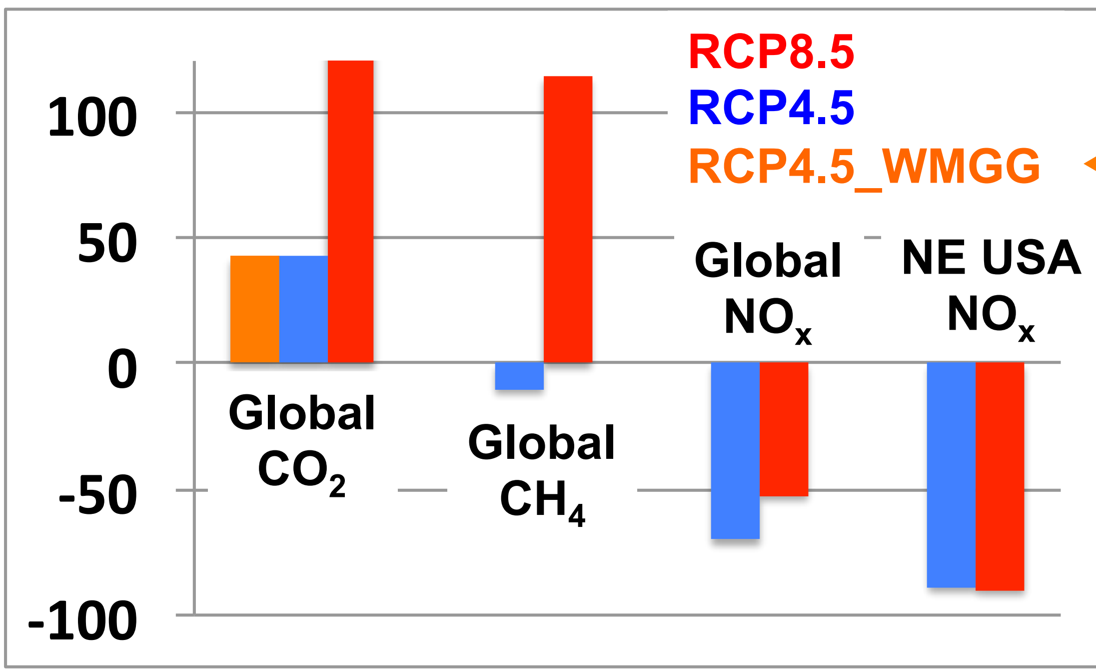
- ~2°x2°; 48 levels
- Over 6000 years of climate simulations that include chemistry (air quality)
- Options for nudging to re-analysis + global high-res ~$50 km^2$ [*Lin et al., JGR, 2012ab*]



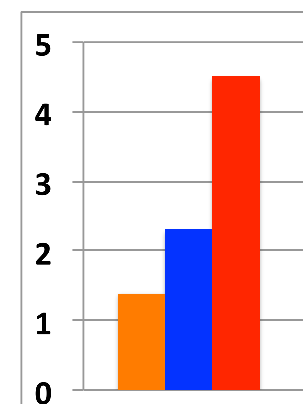
Donner et al., J. Climate, 2011;
Golaz et al., J. Climate, 2011;
John et al., ACP, 2012
Turner et al., ACP, 2012
Naik et al., submitted
Horowitz et al., in prep

Climate / Emission Scenarios: Representative Concentration Pathways (RCPs)

Percentage changes from 2005 to 2100

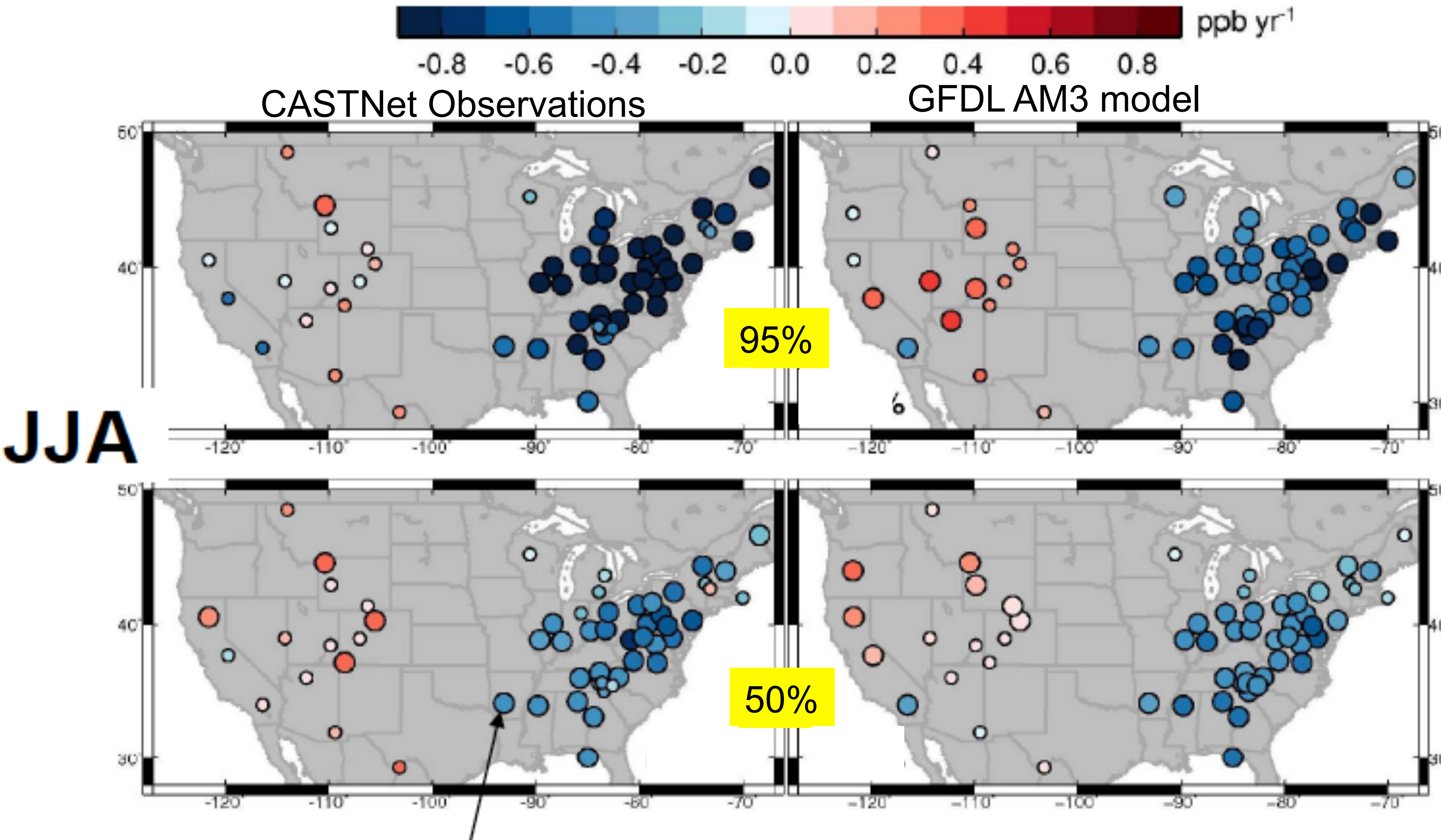


Enables separation of roles of changing climate from changing air pollutants



Global T (°C) (>500 hPa)

GFDL AM3 model captures key features of observed surface O_3 trends (1988-2012): larger decreases in 95% vs. 50% over EUS; increases in WUS



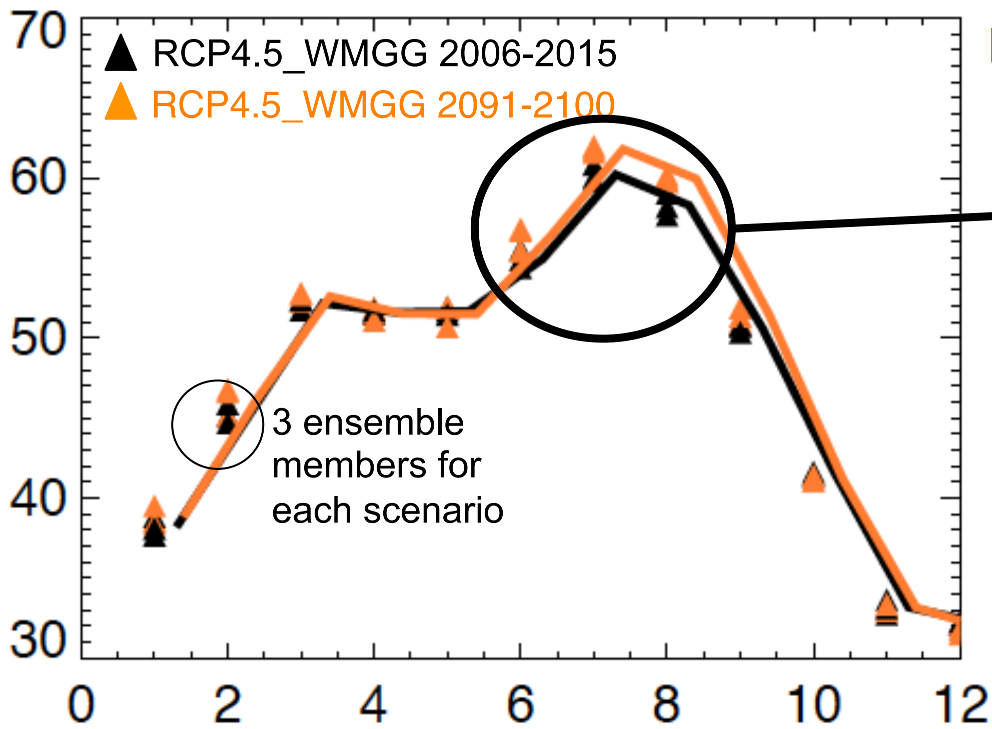
Larger circles indicate statistically significant trends (*P<0.05*)

Meiyun Lin, Princeton/GFDL

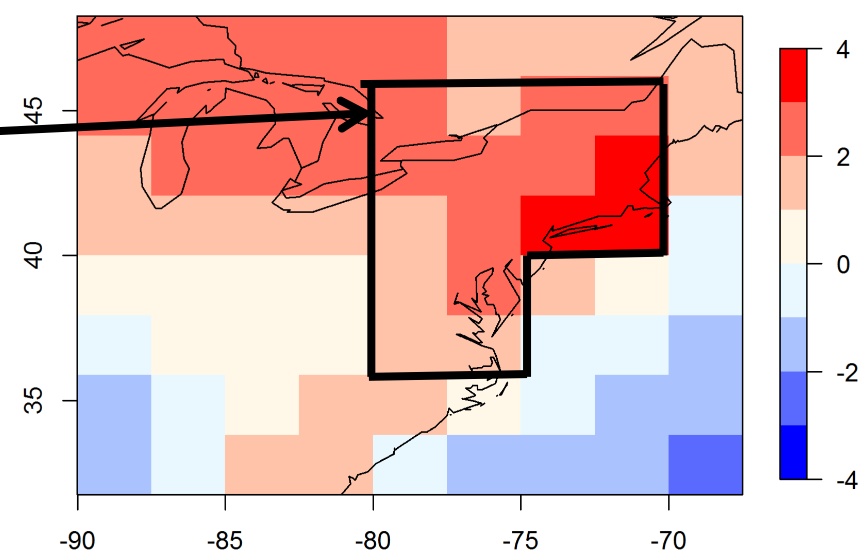
Regional climate change over the NE USA leads to higher summertime surface O_3 ("climate penalty" [Wu et al., JGR, 2008])

GFDL CM3 chemistry-climate model

Monthly mean surface O_3 over NE USA



(2091-2100) – (2006-2015)
RCP4.5_WMGG 3 ens. member mean:



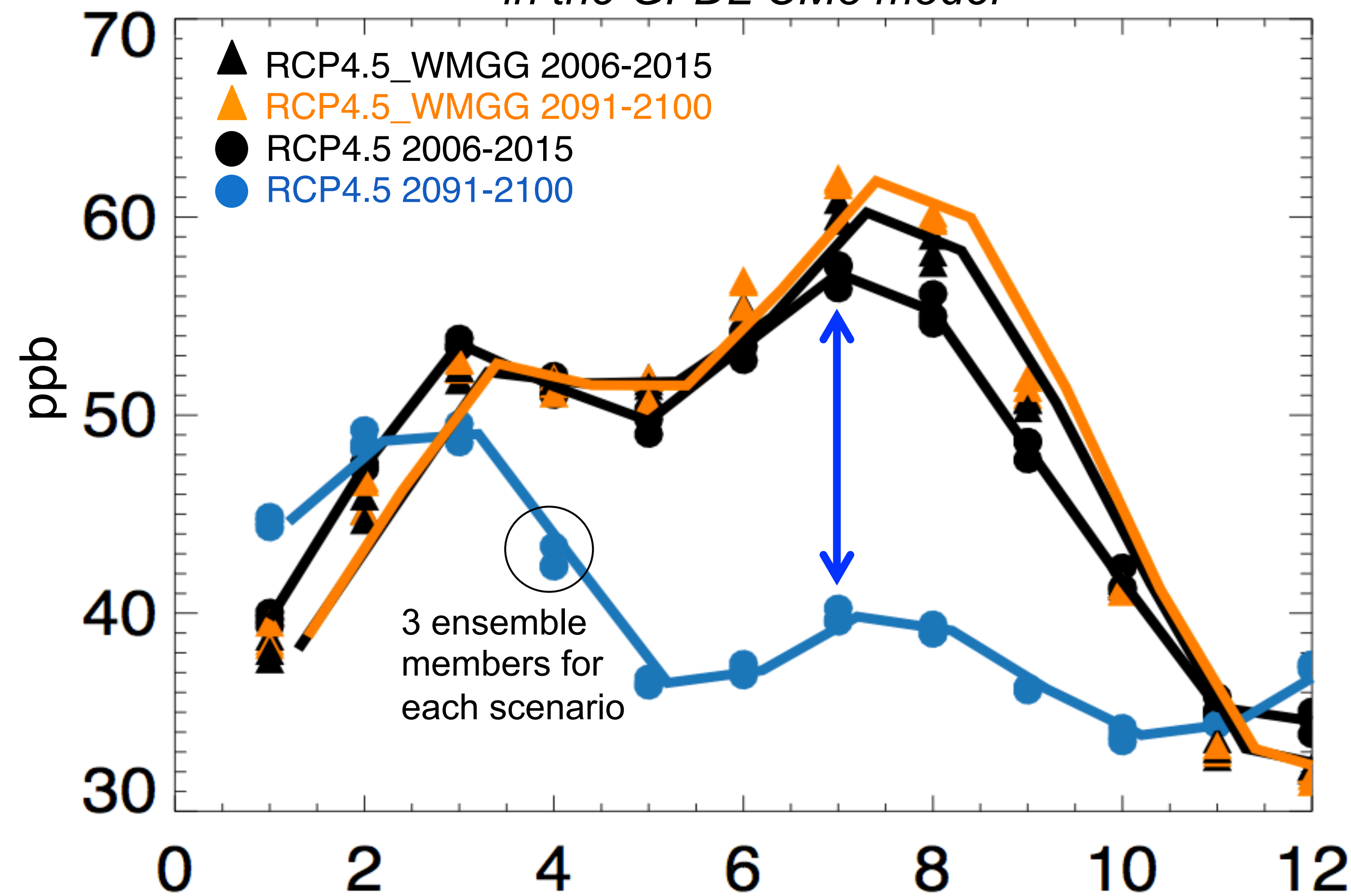
Moderate climate change increases NE USA surface O_3 1-4 ppb in JJA
(agreement in sign for this region across prior modeling studies)

How does NE USA O_3 respond to changing regional and global emissions?

O. Clifton/H. Rieder

Large NO_x decreases fully offset any 'climate penalty' on surface O_3 over NE USA under moderate warming scenario

Monthly mean surface O_3 (land only) over the NE USA (36-46N, 70-80W)
in the GFDL CM3 model



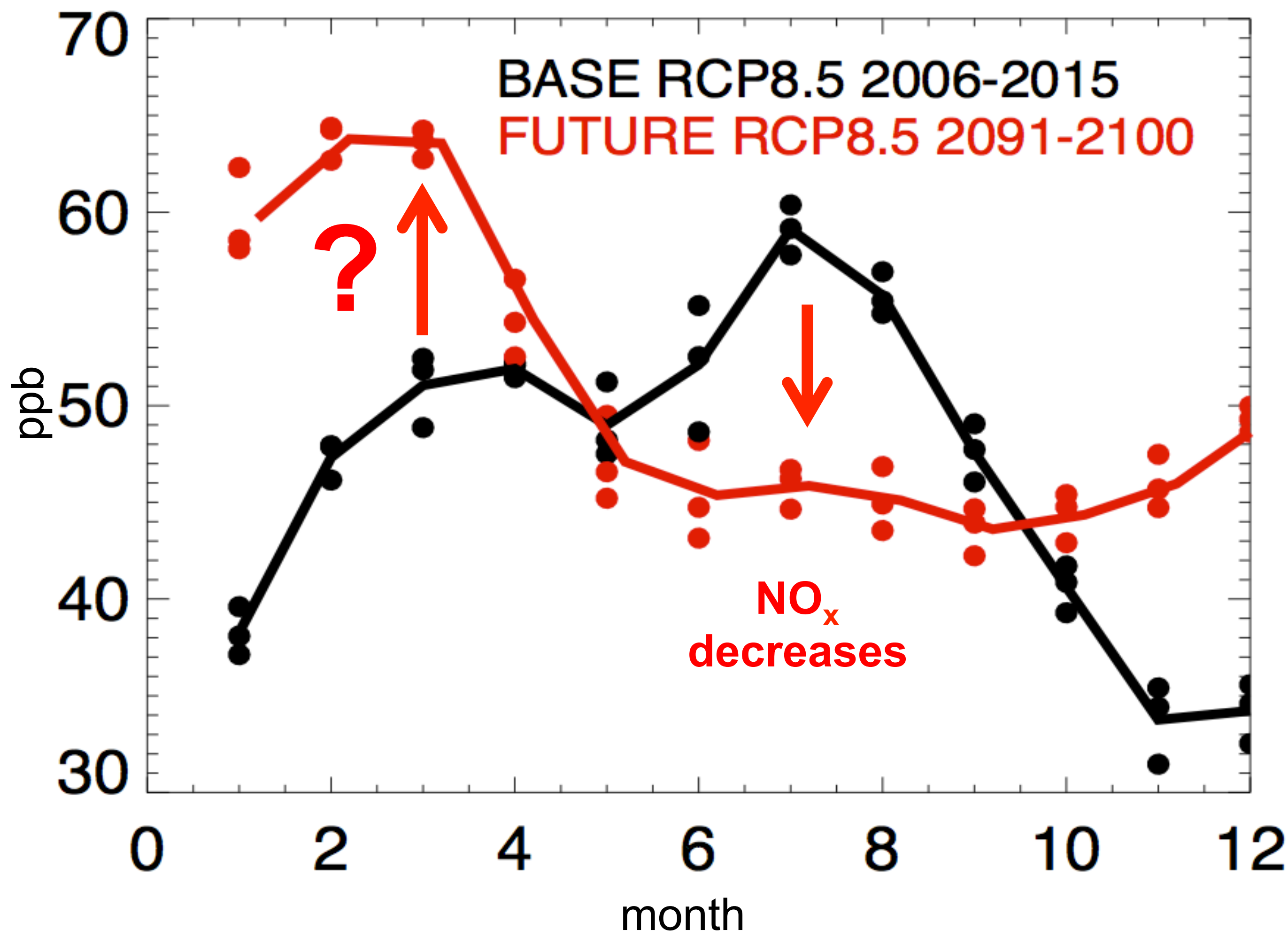
→ Seasonal cycle reverses; NE US looks like a remote background site!
→ Signatures of changing emissions in observed shifts in seasonal cycles
[Parrish et al., GRL, 2013]?

O. Clifton

Surface O_3 seasonal cycle over NE USA reverses – cold season increases- under extreme warming scenario (RCP8.5)

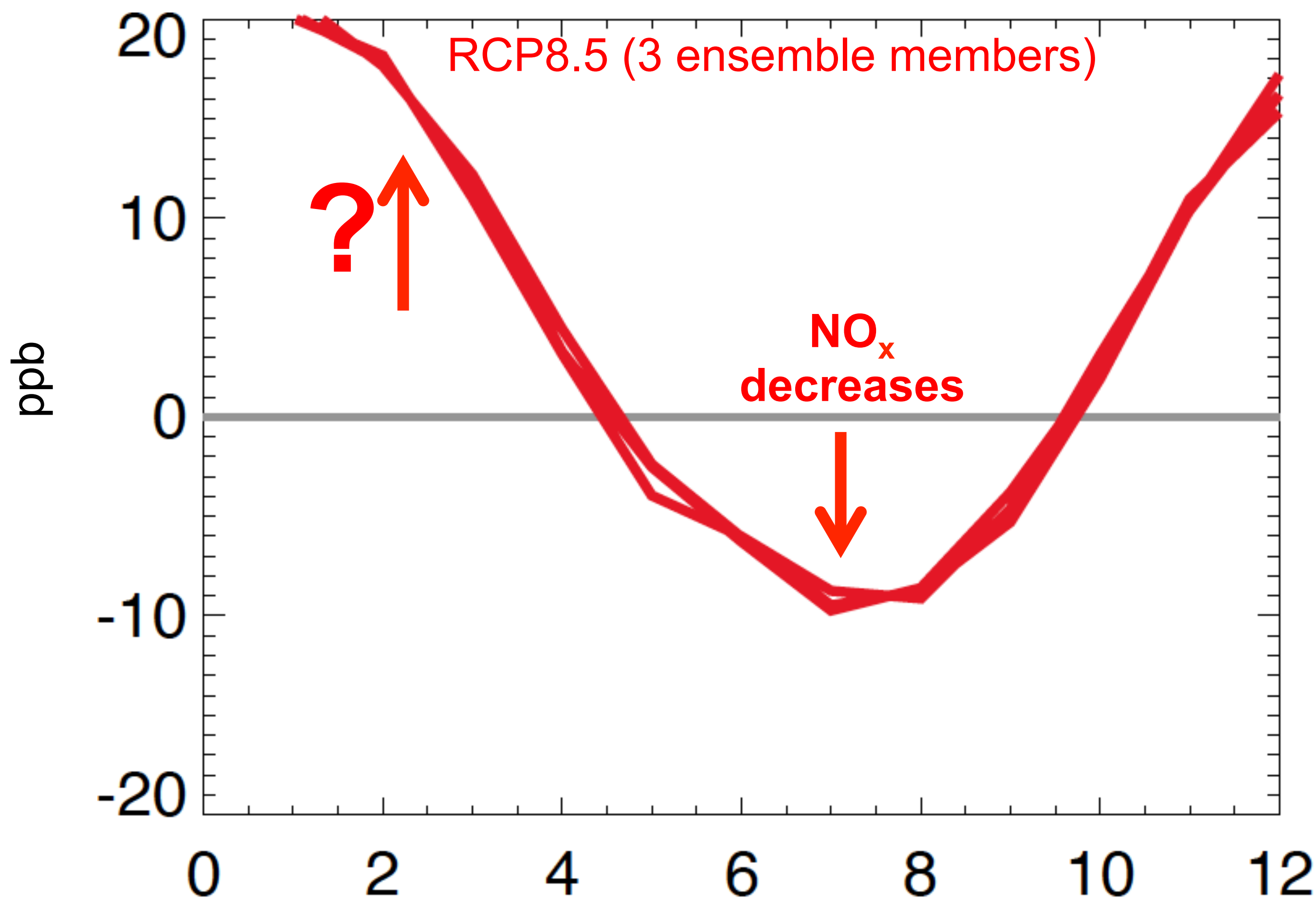
Monthly mean surface O_3 (land only) over the NE USA (36-46N, 70-80W)

in the GFDL CM3 model



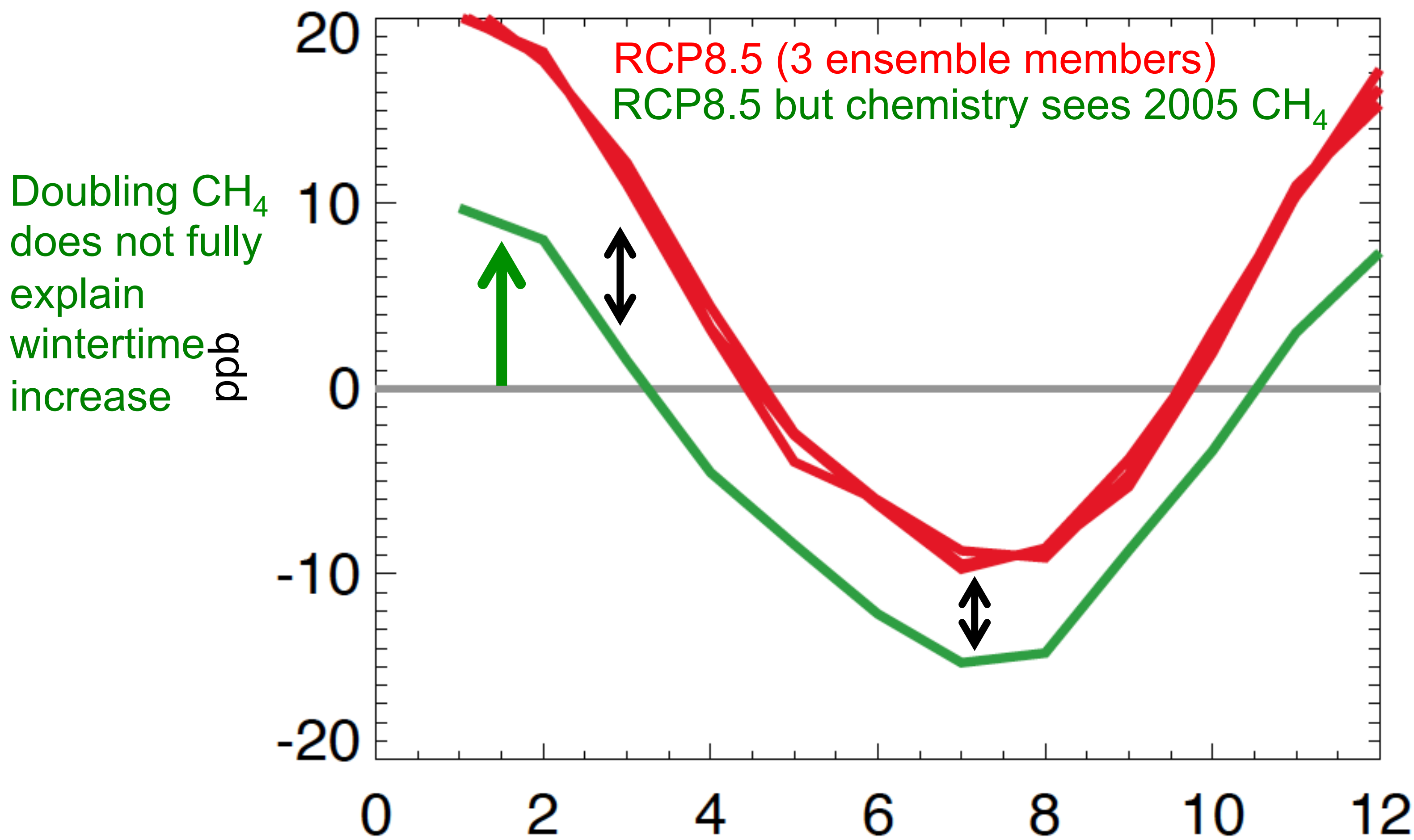
Why does surface O_3 increase in winter/spring over NE USA under RCP8.5?

Change in monthly mean surface O_3 (land only) over the NE USA (36-46N, 70-80W)
(2091-2100) – (2006-2015)



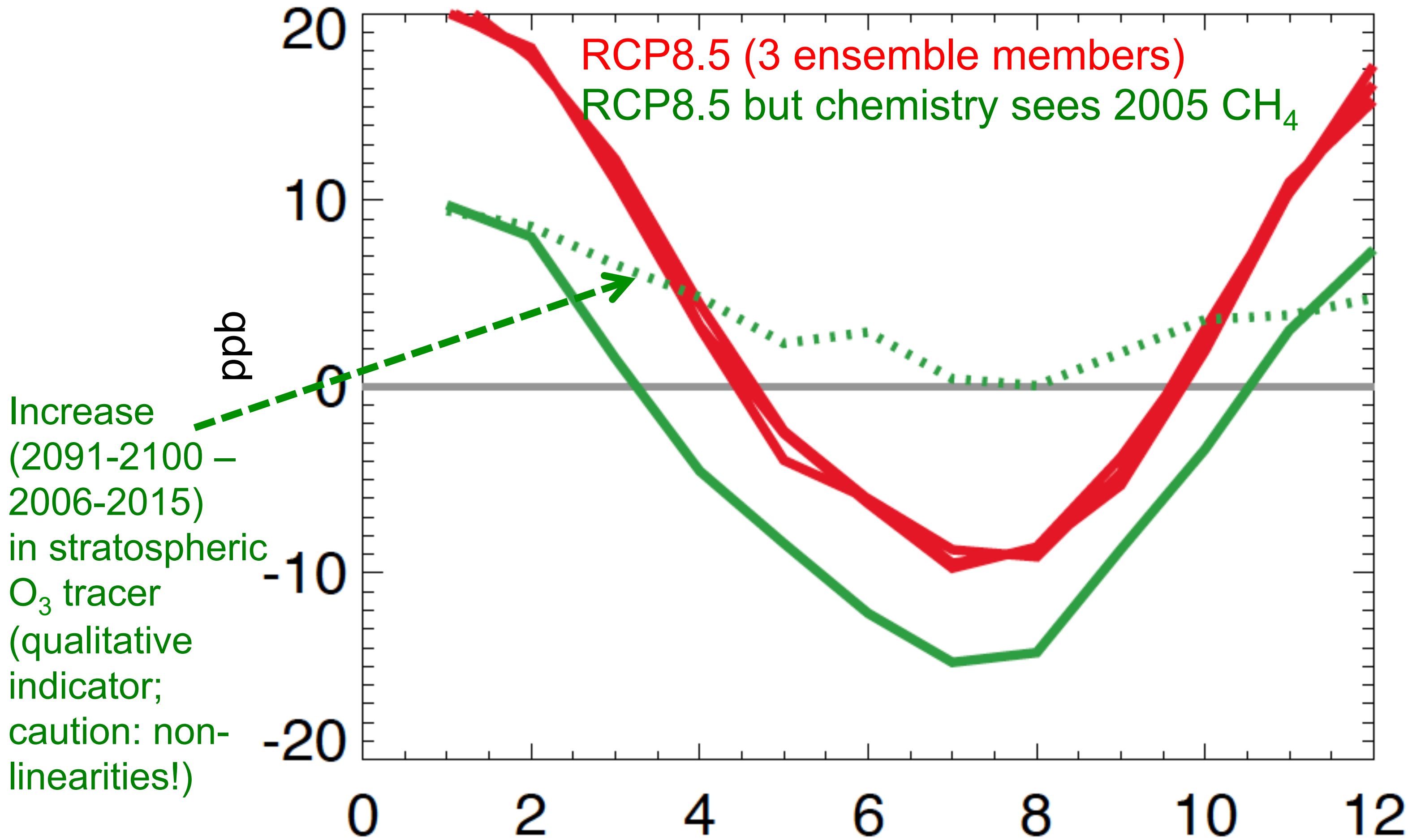
Doubling methane raises surface O_3 over NE USA ~5-10 ppb

Change in monthly mean surface O_3 (land only) over the NE USA (36-46N, 70-80W)
(2091-2100) – (2006-2015)



A contribution from enhanced stratosphere-to-troposphere ozone transport?

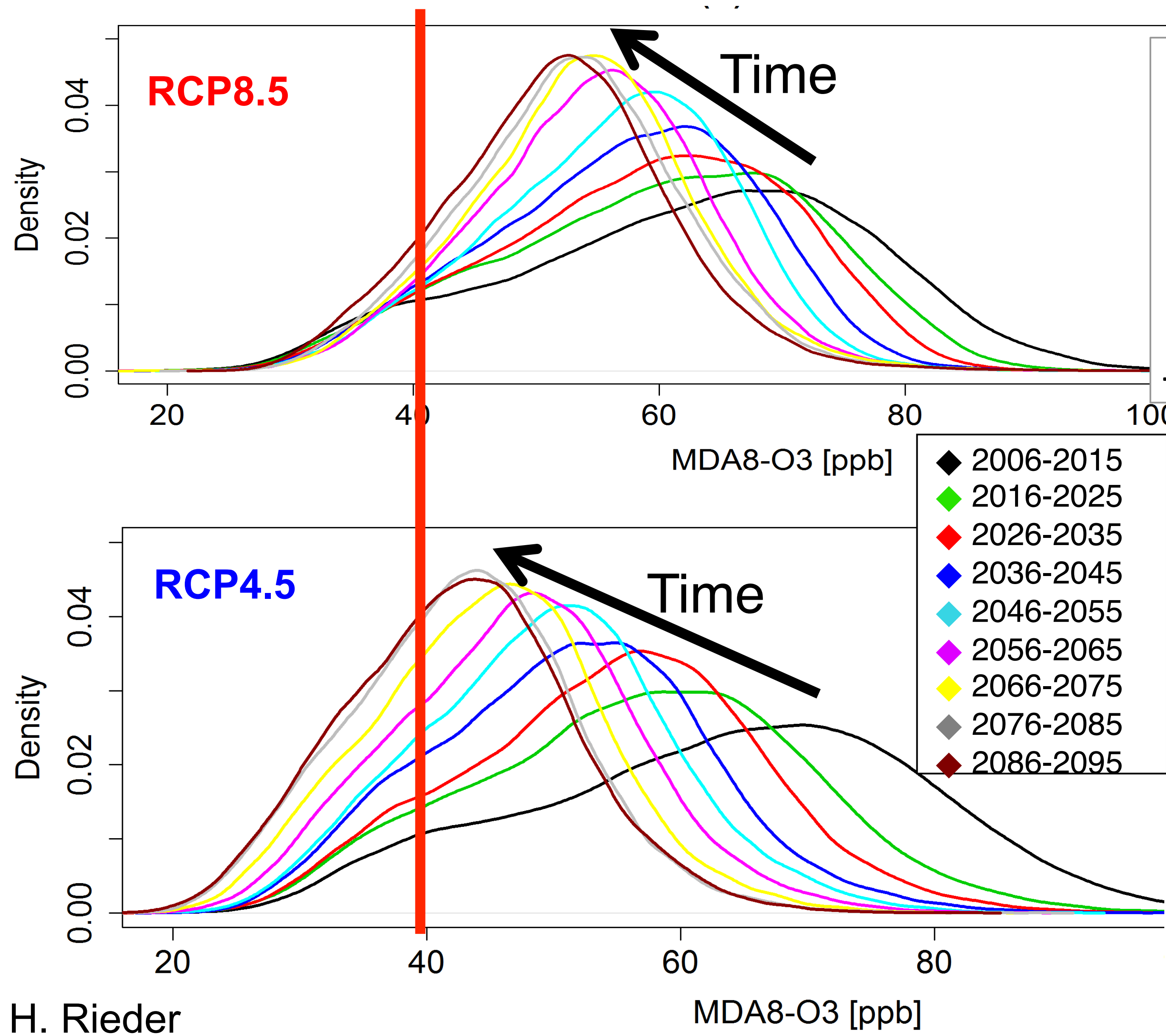
Change in monthly mean surface O_3 (land only) over the NE USA (36-46N, 70-80W)
(2091-2100) – (2006-2015)

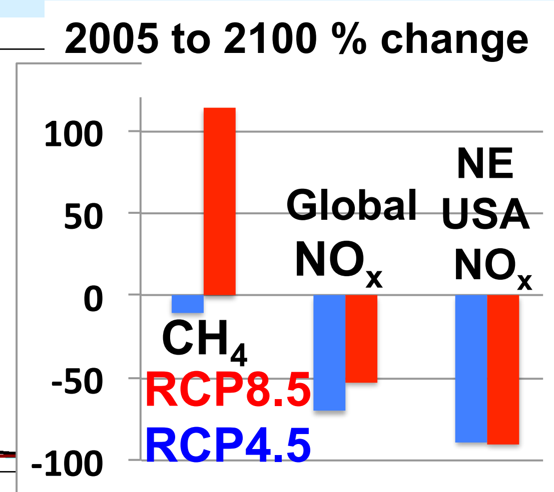


Recovery + climate-driven increase in STE? [*e.g.,Butchart et al., 2006; Hegglin&Shepherd*, 2009; *Kawase et al.*, 2011; *Li et al.*, 2008; *Shindell et al.* 2006; *Zeng et al.*, 2010]

Will the NE USA resemble present-day remote, high-altitude W US sites by 2100?

Extremes: The highest summertime surface O_3 events over NE USA decrease strongly under NO_x controls

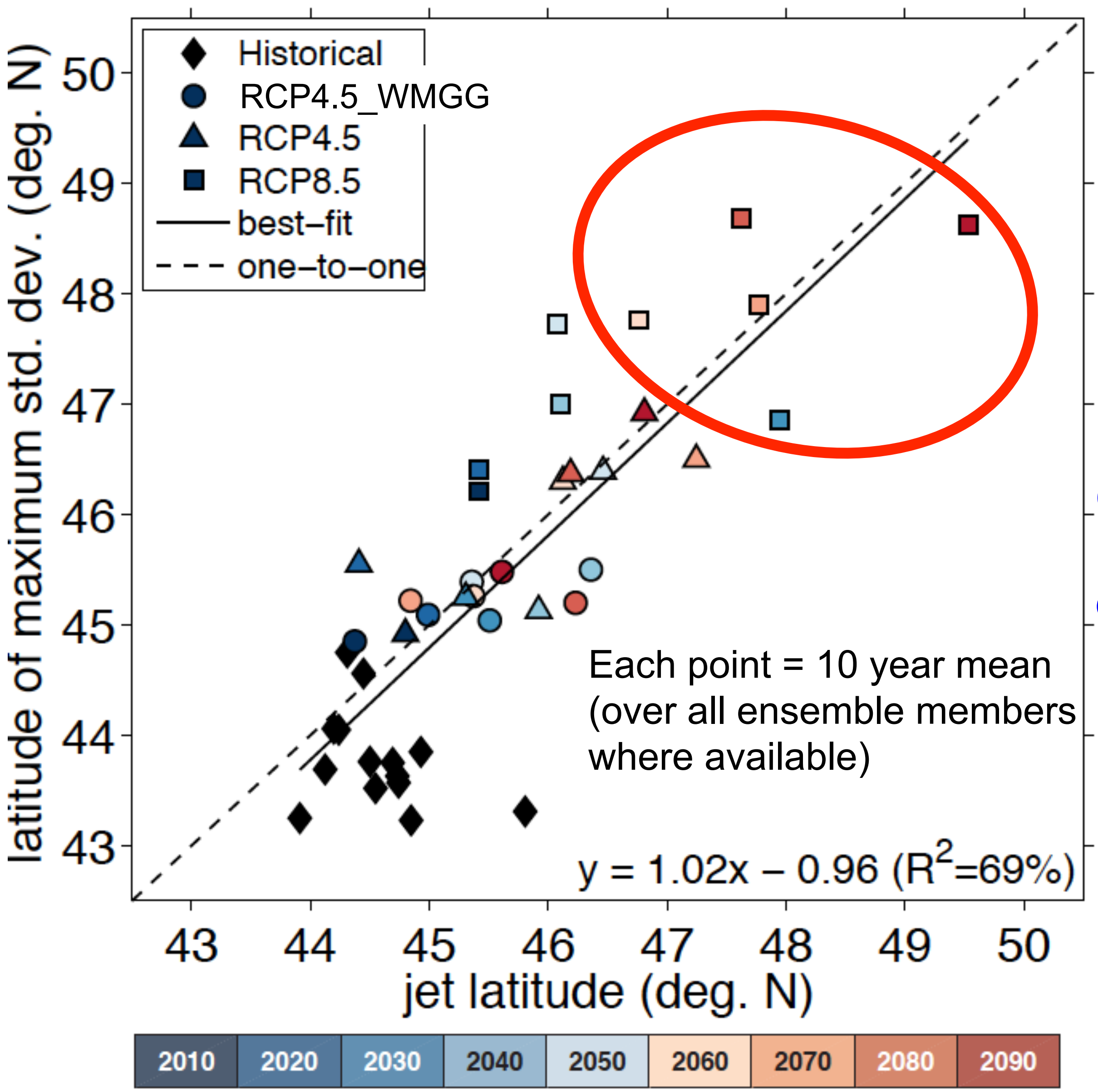




RCP8.5 vs. RCP4.5: Rising CH_4 increases surface O_3, at least partially offsetting gains otherwise attained via regional NO_x controls

H. Rieder

Peak latitude of summertime surface O_3 variability over Eastern N. America follows the jet as climate warms

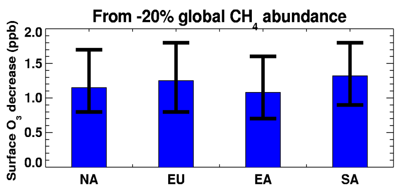


RCP8.5: most warming, Largest jet shift

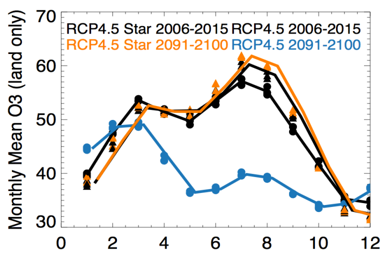
Could different simulated jet positions explain cross-model disagreement in regional O_3 response to climate change?

Barnes & Fiore, GRL, in press

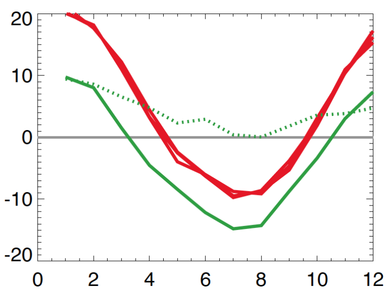
Influence of Changes in Emissions and Climate on Baseline and Extreme Levels of Air Pollution: Summary and Next Steps



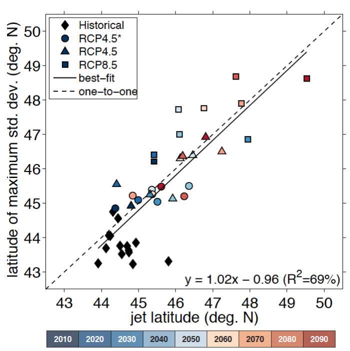
- Methane controls: 'win-win' for climate, air quality; also economic
  - → Climate and Clean Air Coalition (http://www.unep.org/ccac/)
  - → Observational constraints on CH_4 oxidation (and resulting O_3)?



- Climate change may increase O_3 over NE USA but can be offset by NO_x reductions which preferentially decrease the highest O_3 events
  - → Other regions, seasons, with a focus on extremes
  - → Develop robust connections to changes in meteorology



- NO_x reductions combined with rising CH_4 & strat-to-trop O_3 transport fully reverse O_3 seasonal cycle over NE USA
  - → Ongoing evaluation of key processes (recent decades)
  - → Long-term measurements crucial [*e.g., Parrish et al., 2013*]



- Zonal O_3 variability aligns with the 500 hPa jet over NE N. America
- Jet shifts can influence O_3:T [*Barnes & Fiore, in press GRL*]
  - → Decadal shifts in jet; hold on shorter timescales?
  - → Explore predictive power and extend beyond O_3
  - → Relevant to model differences in O_3 response to climate?

  [*Weaver et al., 2009; Jacob & Winner, 2009; Fiore et al., 2012*]