Recent trends and 21st Century projections of ozone pollution extremes over the Northeastern USA during summer

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Motivation

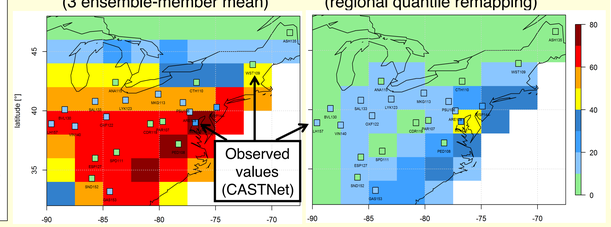
- **Nitrogen Oxide (NO_x) emissions from eastern U.S. point sources decreased by ~50% between 1999 and 2004 [*Frost et al., 2006*], leading to decreases in surface ozone (O_3) documented in several recent studies [*e.g., Bloomer et al., 2009, 2010; Cooper et al., 2012*].**
- **U.S. NO_x emissions are projected to decline further in the coming decades [*e.g., van Vuuren et al., 2011*] but rising global emissions, including methane, could offset air quality improvements attained with domestic controls on ozone precursor emissions [*e.g., Jacob et al., 1999; Fiore et al. 2002*].**
- ***Wu et al. [2008]* point out that a warming climate could exacerbate ozone pollution (a 'climate penalty'), with several modeling systems robustly indicating that the northeastern United States (NE USA) is particularly susceptible [*e.g., Weaver et al., 2009; Fiore et al., 2012*]**

How do changing emissions and climate influence the distribution of surface ozone (O_3) , including extreme pollution events, over the NE USA?
How should we communicate such changes in extreme O_3 pollution events?

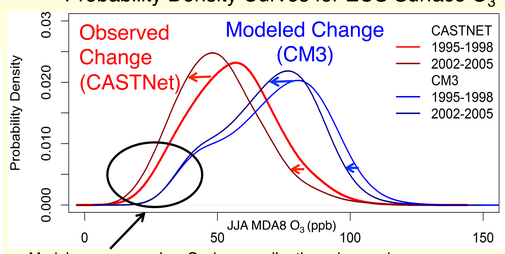
GFDL CM3 chemistry-climate model: Surface O_3 evaluation and bias correction

- **See schematic on Clifton et al. poster**
- Global atm-ocean-sea ice-land GCM [*Donner et al., 2011*]
- Atmospheric component has ~2°x2° horizontal resolution with 48 vertical levels
- Fully coupled chemistry in troposphere + stratosphere [*Austin et al., 2013; Naik et al., 2013*] & aerosol-warm cloud interactions [*e.g., Golaz et al., 2011*]
- **6000+ years of simulations for IPCC AR5 report for chemistry-climate-air pollution interactions used here** and elsewhere [*John et al., 2012; Turner et al., 2012; Levy et al., 2013; Rasmussen et al., 2012; Barnes and Fiore, 2013*].

Average (**1988-2005**) number of summer days with O_3 > 75 ppb



Probability Density Curves for EUS Surface O_3

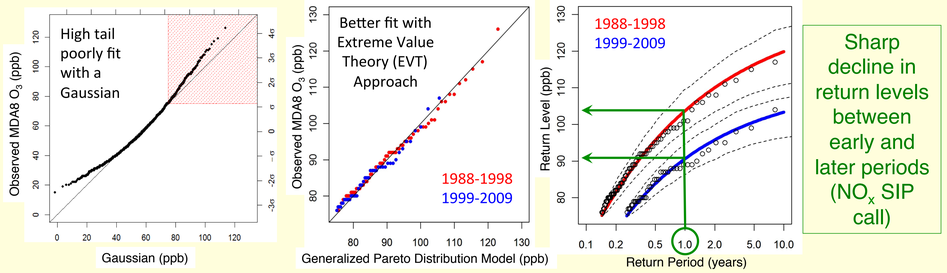


Model response on low-O_3 days smaller than observed

→ GFDL CM3 generally captures NE US JJA surface O_3 decrease following ~25% decrease in NO_x emissions
→ Implies bias correction based on present-day observations can be applied to future scenarios with NO_x changes

Describing Recent Changes in Extreme O_3 Events

Summer (JJA) MDA8 O_3 1987-2009 Observed at Pennsylvania State CASTNet site

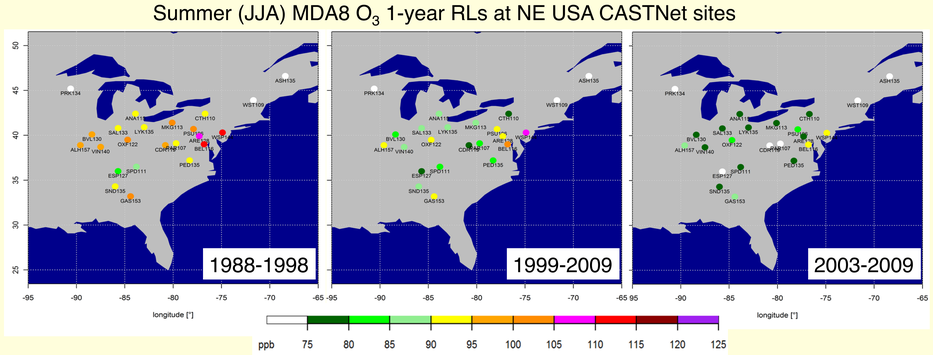


Sharp decline in return levels between early and later periods (NO_x SIP call)

→Modeled EVT fit allows translation to probabilistic framework (**1-year O_3 event**) and estimates of "**return levels**", analogous to the "100-year flood" commonly used to assess flood risks

→**Return levels (RLs)** describe the probability of observing value x (LEVEL) within a given time window (PERIOD)

Summer (JJA) MDA8 O_3 1-year RLs at NE USA CASTNet sites



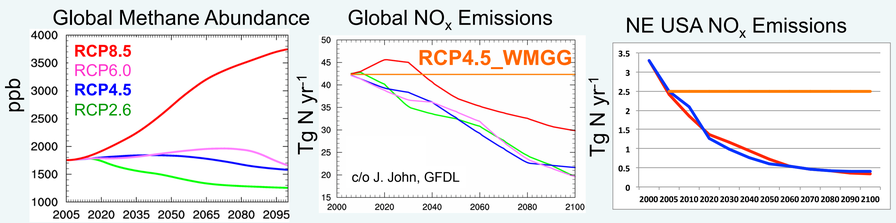
→**1-year RLs decrease by 2-16 ppb from 1988-1998 to 1999-2009 but mostly remain above the O_3 NAAQS threshold (75 ppb); 5-year RLs in 1999-2009 are similar to 1-year RLs in 1988-2009 (not shown)**

→**After full implementation of the NO_x SIP Call (2003-2009), 1-year Return Levels decline further**

Please see *Rieder et al. [2013]* for further information.

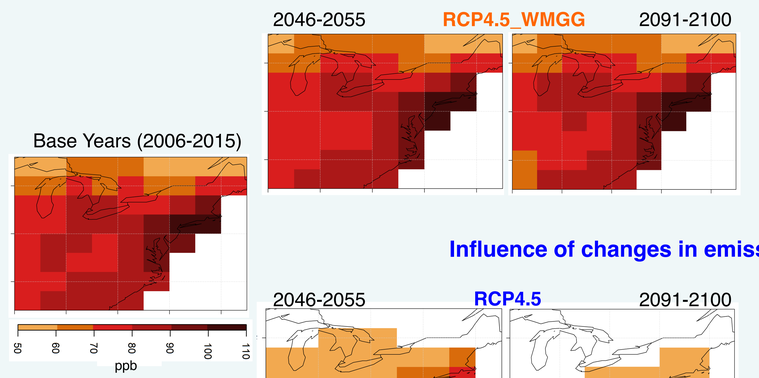
21st Century Changes in Extreme O_3 Events

Representative Concentration Pathway Scenarios (RCPs [van Vuuren et al., 2011]**)**



We use **RCP4.5 (moderate)**, **RCP8.5 (extreme)**, and **RCP4.5_WMGG (moderate;** greenhouse gases follow RCP4.5 but pollutant emissions are held at 2005 levels) scenarios in CM3, each of which includes 3 ensemble members

1-year Return Levels in CM3 (bias-corrected) Summer (JJA) MDA8 Surface O_3

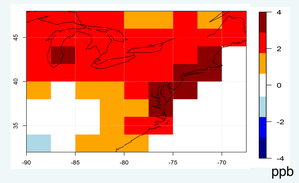


→ **Large NO_x reductions as in RCP4.5 offset climate penalty on O_3 extremes**

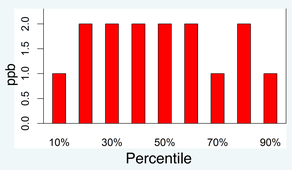
→ **Ongoing work examining relationship between NO_x decreases and return levels**

Influence of climate change on surface O_3

Change in mean summertime MDA8 O_3 (2091-2100) – (2006-2015) in RCP4.5_WMGG CM3 simulation (bias-corrected)

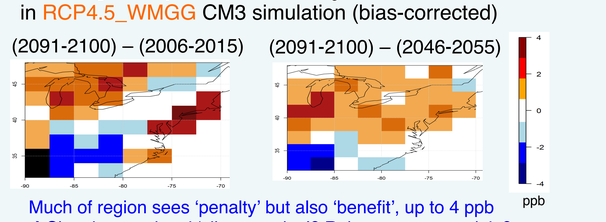


"Climate penalty" [*Wu et al., 2008*]**: Moderate climate change increases NE USA surface O_3 1-4 ppb in JJA** (agreement in sign for NE USA across prior modeling studies [*Weaver et al., 2009*])



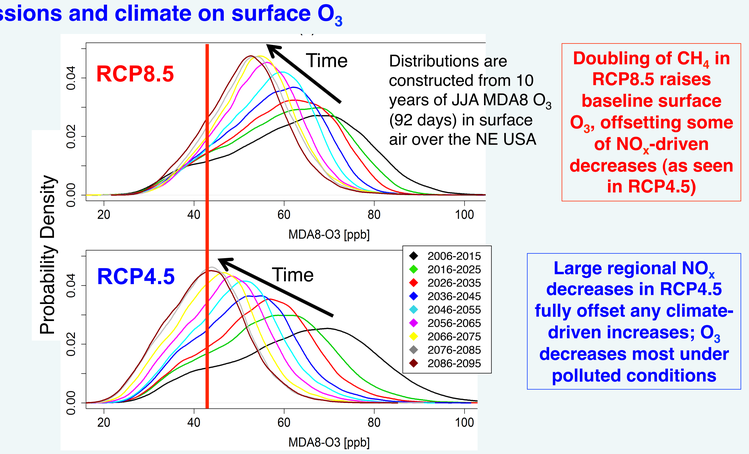
Similar impacts throughout the O_3 distribution (several models find larger impacts at high tail; *e.g.*, 95th% [*Weaver et al., 2009*])

Change in 1-year JJA MDA8 O_3 Return Levels in RCP4.5_WMGG CM3 simulation (bias-corrected)



Much of region sees 'penalty' but also 'benefit', up to 4 ppb
→Signal vs. regional 'climate noise'? Robust across models?

Influence of changes in emissions and climate on surface O_3



Doubling of CH_4 in RCP8.5 raises baseline surface O_3, offsetting some of NO_x-driven decreases (as seen in RCP4.5)

Large regional NO_x decreases in RCP4.5 fully offset any climate-driven increases; O_3 decreases most under polluted conditions

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