21st Century Reversal of the Surface Ozone Seasonal Cycle over the Northeastern United States

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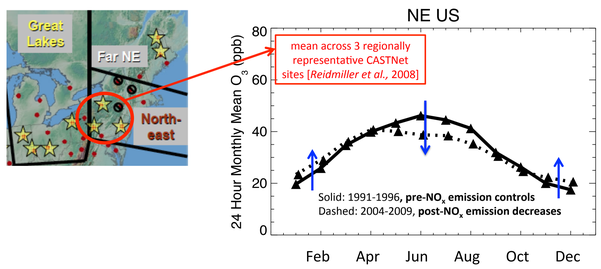
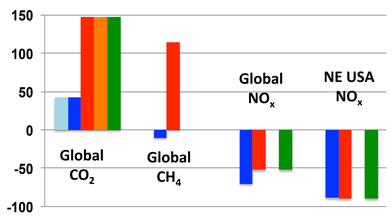
Motivation: Change in observed seasonal cycle of surface O_3 over Northeastern United States (NE US) following a ~25% decrease in regional NO_x emissions



How will the surface O_3 seasonal cycle over the NE US respond to further changes in regional and global precursor emission changes, as well as climate, during the rest of 21st Century?

21st Century Scenarios



RCP8.5 (3 ensemble members)
RCP4.5 (3)
→ CMIP5/AR5 [van Vuuren, 2011; Lamarque et al., 2011; Meinshausen et al., 2011]

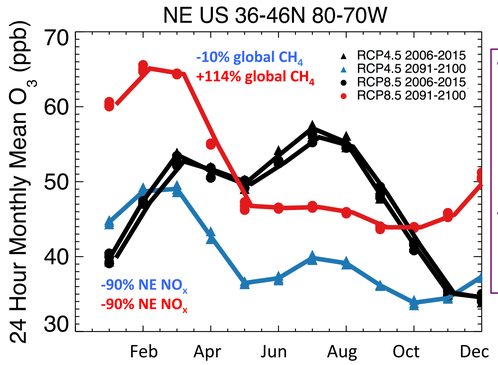
RCP8.5_WMGG (3)
RCP4.5_WMGG (3)
→ Isolate role of warming climate

Natural emissions (except lightening NO_x) held constant

RCP8.5_2005CH4 (1)
RCP8.5_2005CH4_chem (1)
RCP8.5_2005CH4_rad (1)
→ Quantify role of rising global CH_4 (vs. RCP8.5)

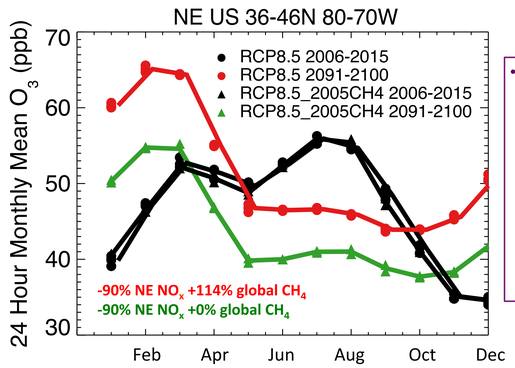
Surface O_3 seasonal cycles at the beginning and end of the 21st C

under RCP4.5 and RCP8.5



- NE resembles baseline O_3 conditions by end of 21st C [*NRC*, 2009; *Parrish et al.*, 2013]
- Reversal of the NE surface O_3 seasonal cycle during 21st C

under RCP8.5 and a sensitivity simulation holding all CH_4 at 2005 levels

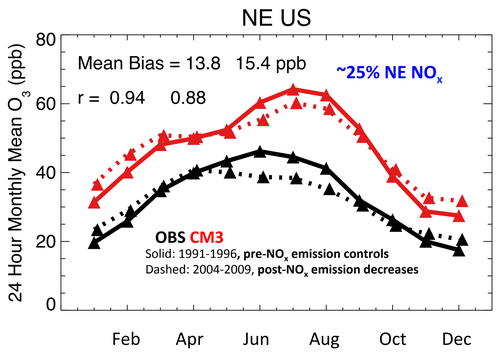


- The doubling of global methane abundance raises surface ozone in all months by about 6-11 ppb, with the greatest differences between **RCP8.5** & **RCP8.5_2005CH4** during January through March

- Reduced NO_x emissions play a role in increasing surface O_3 during the winter in polluted regions [*US EPA*, 2014]
- While NO_x exerts a dominant influence on the shape of the surface O_3 seasonal cycle, global CH_4 abundance influences the baseline surface O_3 abundance during all months

Evaluation of NOAA GFDL CM3 with surface O_3 observations over NE US

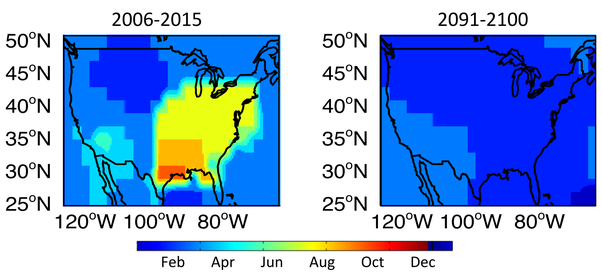
atmosphere cubed sphere grid (c48) ~2°x2°; 48 levels (to 86km)



- Despite high bias, CM3 captures the overall structure of the seasonal surface O_3 changes over the NE & thus the response of surface O_3 to the NO_x emission controls

CM3: Donner et al. [2011]; Golaz et al. [2011]; Levy et al. [2013]; Naik et al. [2013]; Austin et al. [2013]; John et al. [2012]

Month in which peak monthly mean surface O_3 occurs under RCP8.5

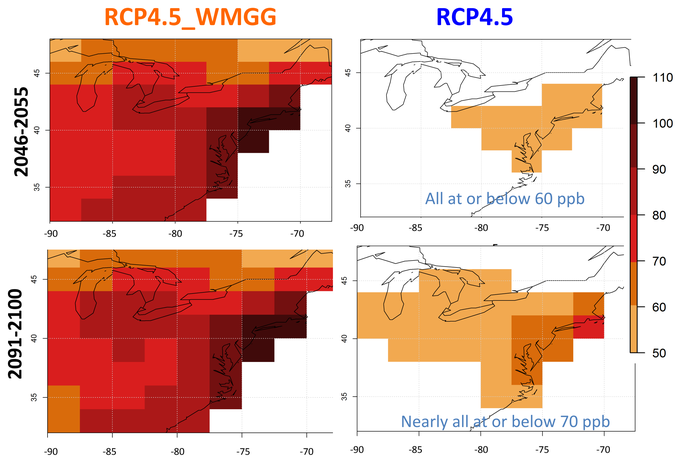


- Clear shift in the peak from summer to winter/early spring over Eastern US

Large NO_x reductions offset climate penalty on O_3 extremes

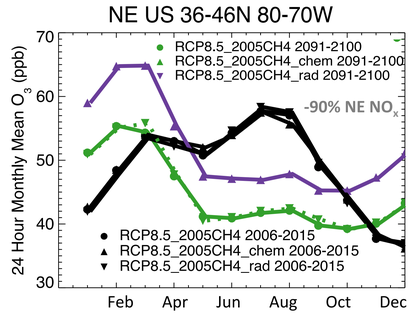
1-year Return Levels in CM3 chemistry-climate model (bias-corrected): Summer (JJA) MDA8 Surface O_3

Rieder et al., *to be submitted to JGR*



- EVT methods enable derivation of probabilistic "return levels" for JJA MDA8 O_3 within a given "return period" [Rieder et al., *ERL, 2013]*
- We find a simple relationship between NO_x reductions and 1-year return levels

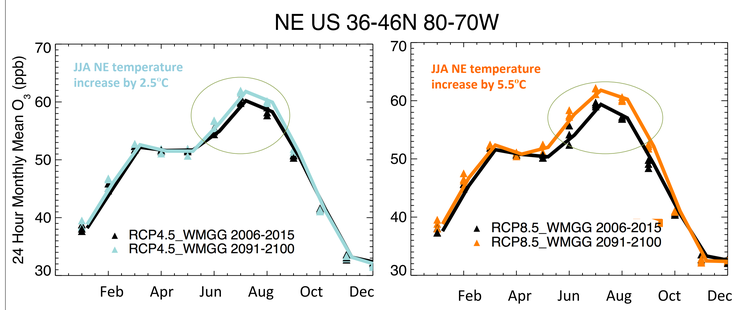
Does climate forcing from the doubling of CH_4 under RCP8.5 have any detectable influence on the surface O_3 response over the NE US?



RCP8.5_2005CH4_rad: CH_4 does not affect radiation and thus does not contribute to climate forcing, but does contribute to raising trop O_3
RCP8.5_2005CH4_chem (dashed): CH_4 used by the chemical mechanism remains at 2005 levels, but evolves along RCP8.5 in the radiation scheme and thus contributes to 21st C climate forcing

- Effective Radiative Forcing from 2000 to 2100 due to CH_4 is 0.6 W/m^2 compared to 4.7 W/m^2 from CO_2 (IPCC, 2013: Annex II)
- The CH_4 impact on surface O_3 in the model occurs primarily though atmospheric chemistry, rather than through the additional climate forcing from CH_4

RCP4.5_WMGG & RCP8.5_WMGG isolate impacts from changing climate on the surface O_3 seasonal cycle



General increases in summertime surface O_3 over NE reflect **"Climate change penalty"**
- *Wu et al.*, 2008
- need for stricter emission controls to achieve a given level of air quality due to warming climate (but in absence of precursor emission changes)

- Under RCP8.5_WMGG, broadening of the summertime peak over the NE with similar levels of surface O_3 in June-August, as opposed to a clear peak in July

- Climate change penalty predominantly affects surface O_3 during the photochemically active season, May-September, in regions with sufficiently high anthropogenic NO_x emissions

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