

# Characterizing U.S. air pollution extremes and influences from changing emissions and climate

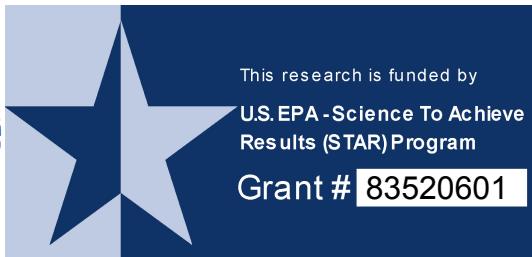
**Arlene M. Fiore**

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COLUMBIA UNIVERSITY | EARTH INSTITUTE



Project Team: Harald Rieder (LDEO), Olivia Clifton (LDEO), Gus Correa (LDEO), Lorenzo Polvani (Columbia), Larry Horowitz (GFDL), Jean-François Lamarque (NCAR)

Close Collaborators: Elizabeth Barnes (NOAA/LDEO), Yuanyuan Fang (Carnegie Institution/Stanford), Alex Turner (Harvard)



U.S. EPA STAR Research Forum:  
Extreme Events  
Arlington, VA  
February 27, 2013

# How and why might extreme air pollution events change?

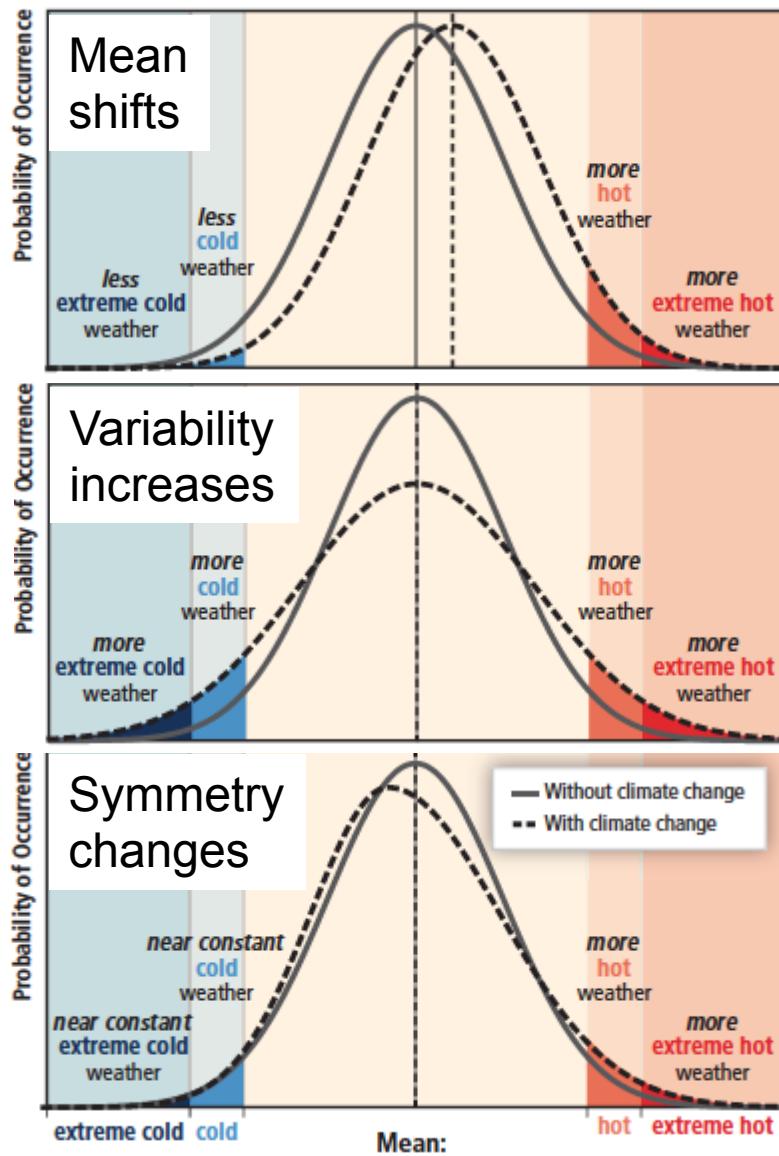


Figure SPM.3, IPCC SREX 2012  
<http://ipcc-wg2.gov/SREX/>

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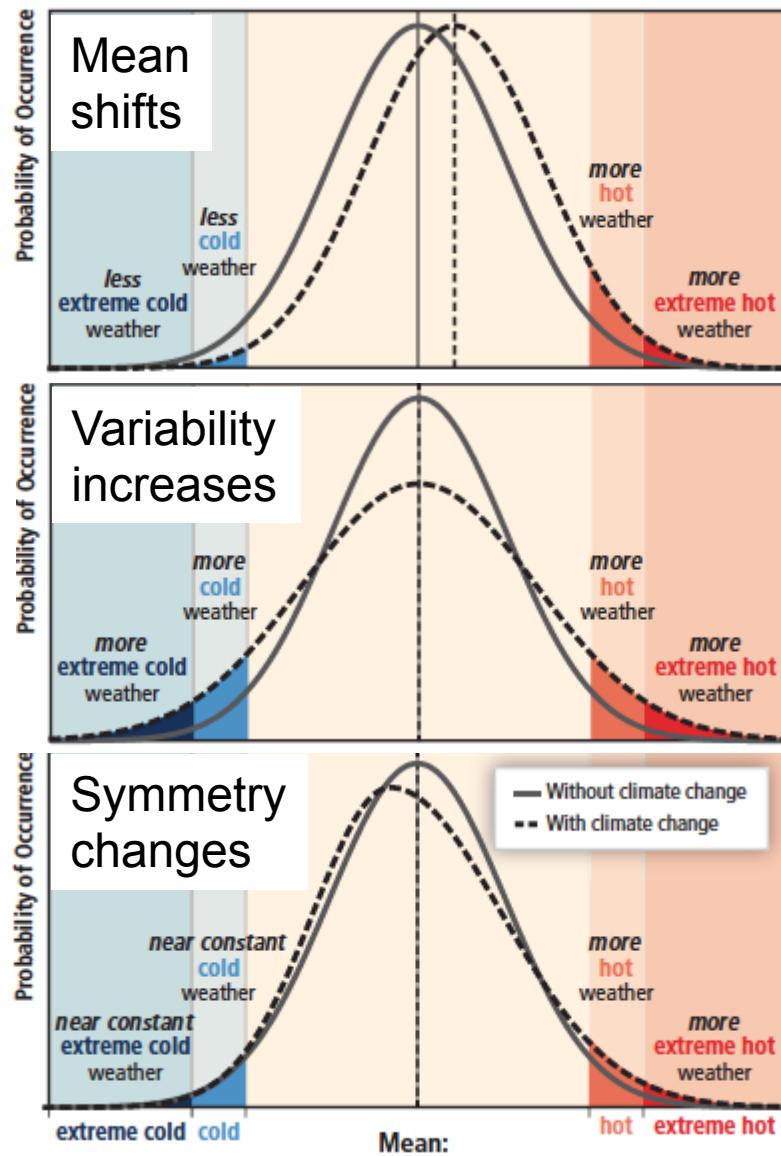
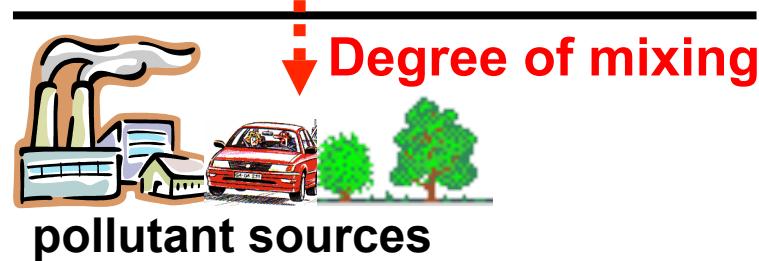


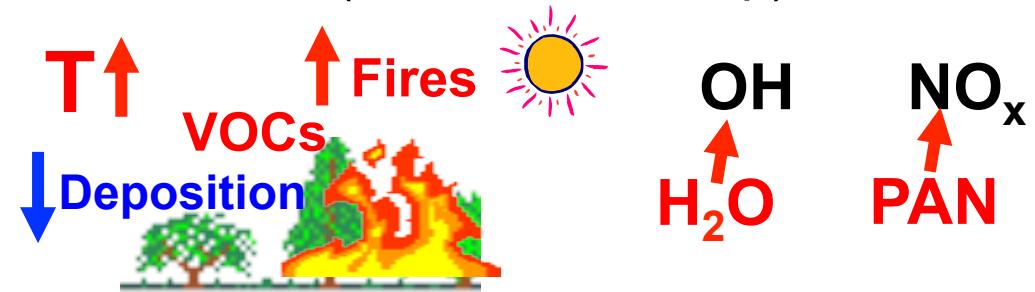
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→ Need to understand how different processes influence the distribution

- Meteorology (e.g., stagnation vs. ventilation)



- Feedbacks (Emis, Chem, Dep)



- Changing global emissions (baseline)

→ Shift in mean?

- Changing regional emissions (episodes)

→ Change in symmetry?

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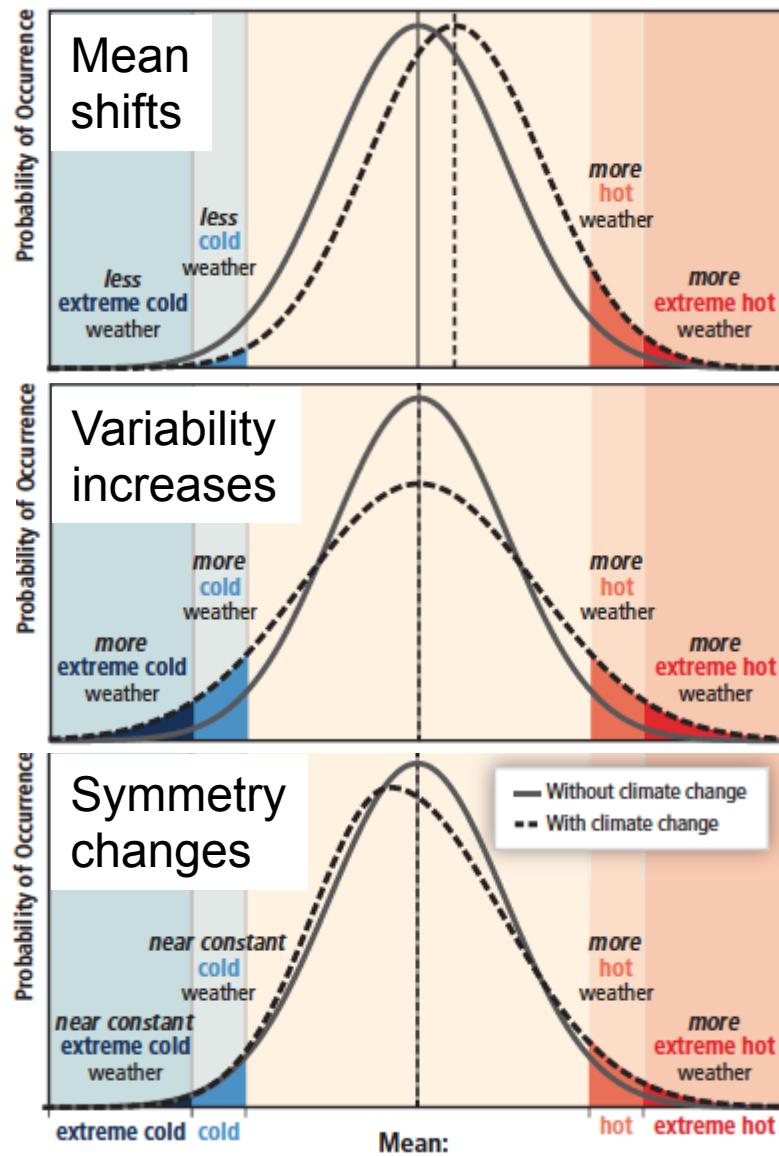
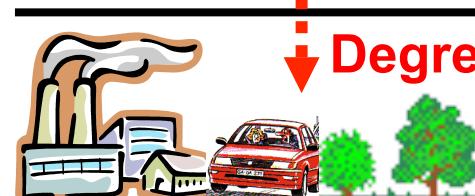


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→ Need to understand how different processes influence the distribution

- Meteorology (e.g., stagnation vs. ventilation)



Degree of mixing

- Feedbacks (Emis, Chem, Dep)

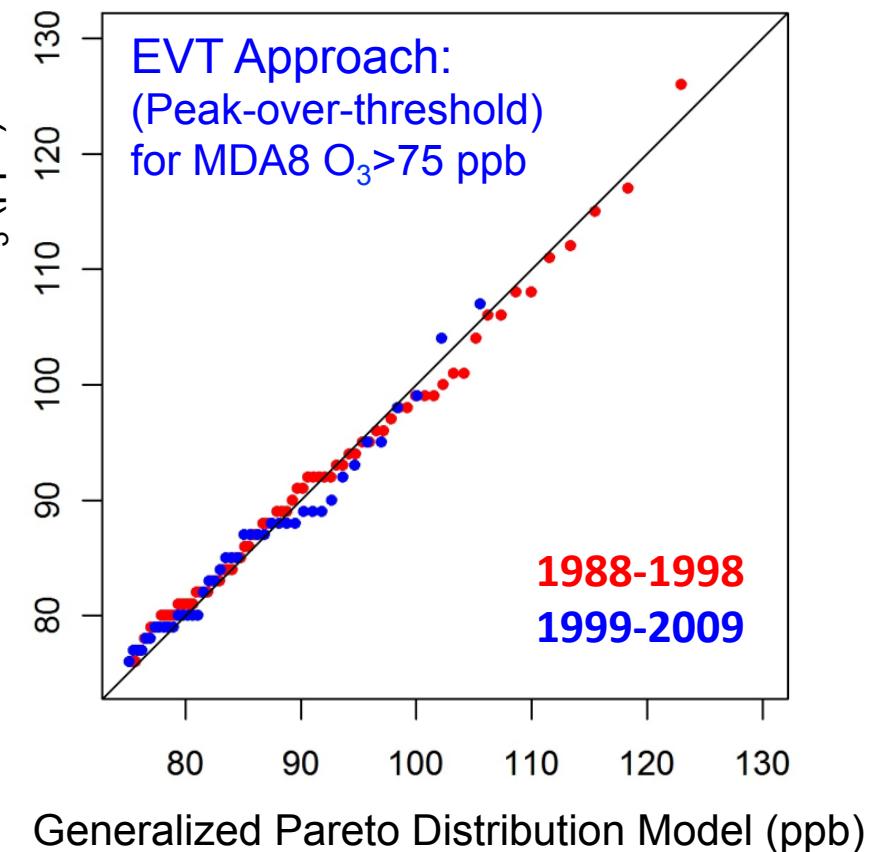
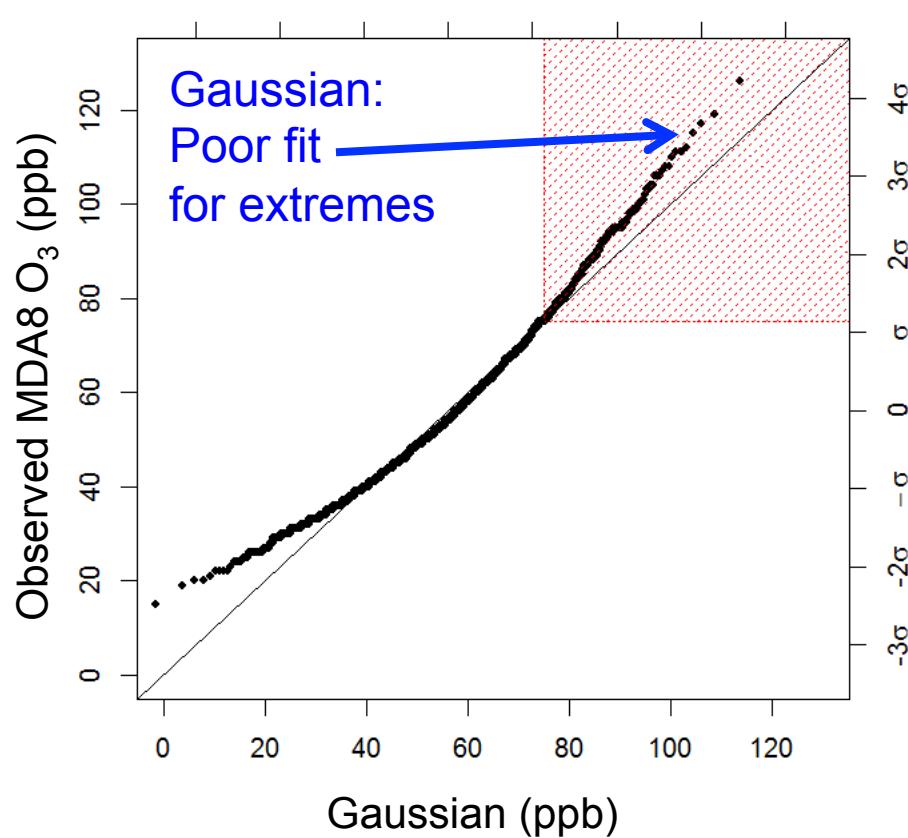


- Changing global emissions (baseline)  
→ Shift in mean?
- Changing regional emissions (episodes)  
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Today's Focus

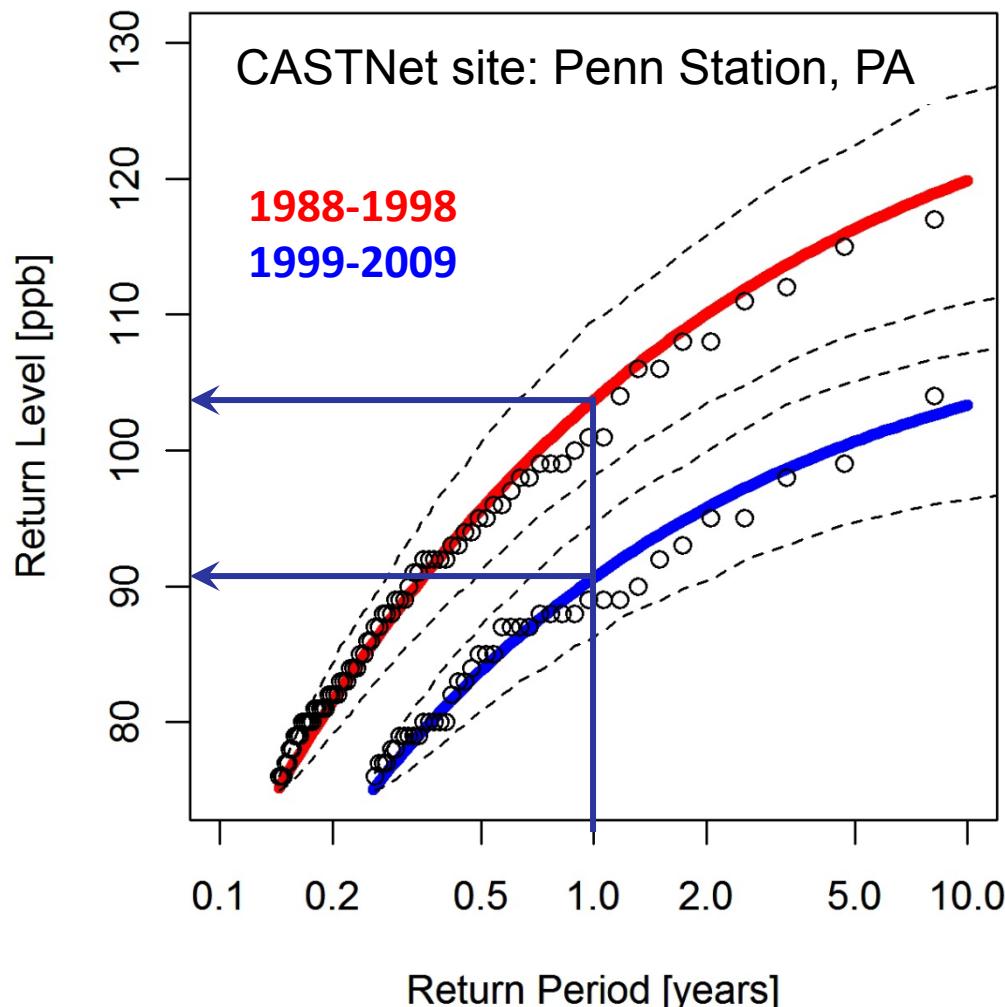
# EVT methods describe the high tail of the observed ozone distribution (not true for Gaussian)

JJA MDA8 O<sub>3</sub> 1987-2009 at CASTNet Penn State site



# EVT methods enable derivation of “return levels” for JJA MDA8 O<sub>3</sub> within a given time period from GPD fit

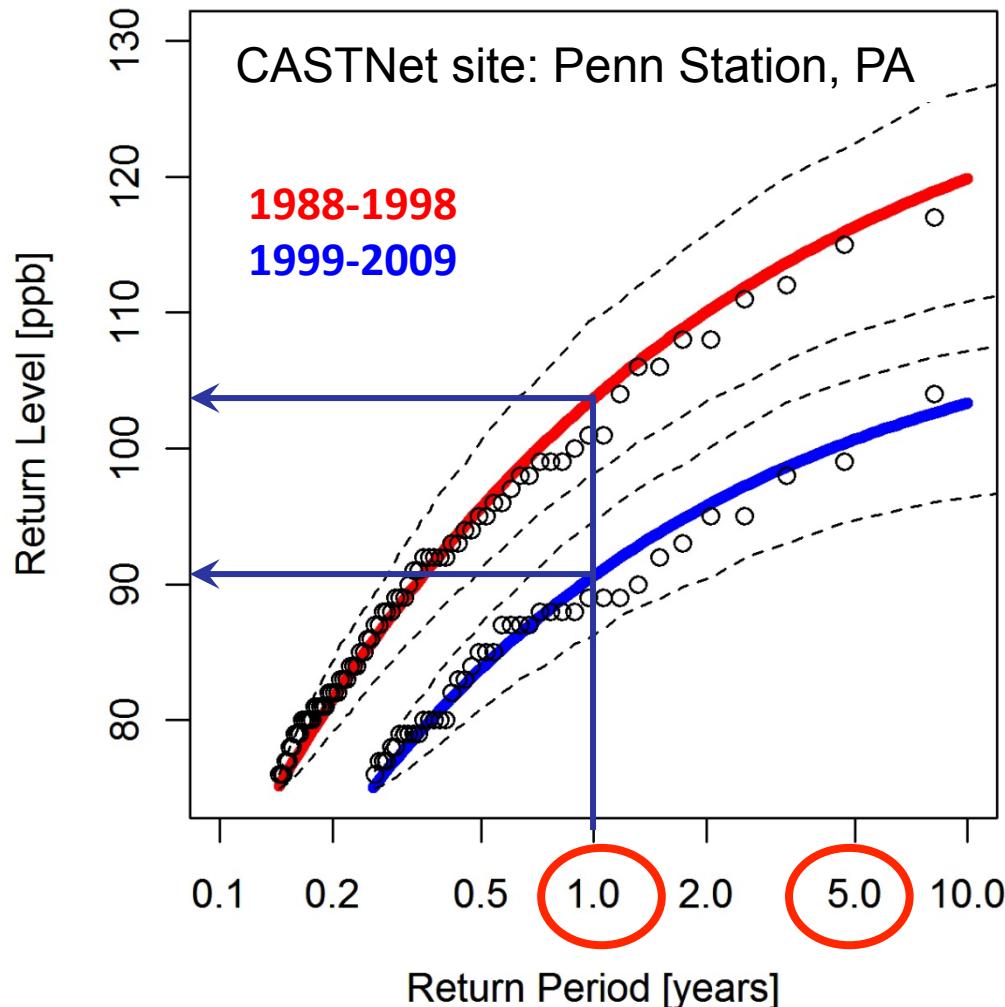
Return level = Probability of observing a value  $x$  (*level*) within a time window  $T$  (*period*)



- Sharp decline in return levels between early and later periods (NO<sub>x</sub> SIP call)
- Consistent with prior work [e.g., Frost et al., 2006; Bloomer et al., 2009, 2010]
- Translates air pollution changes into probabilistic language

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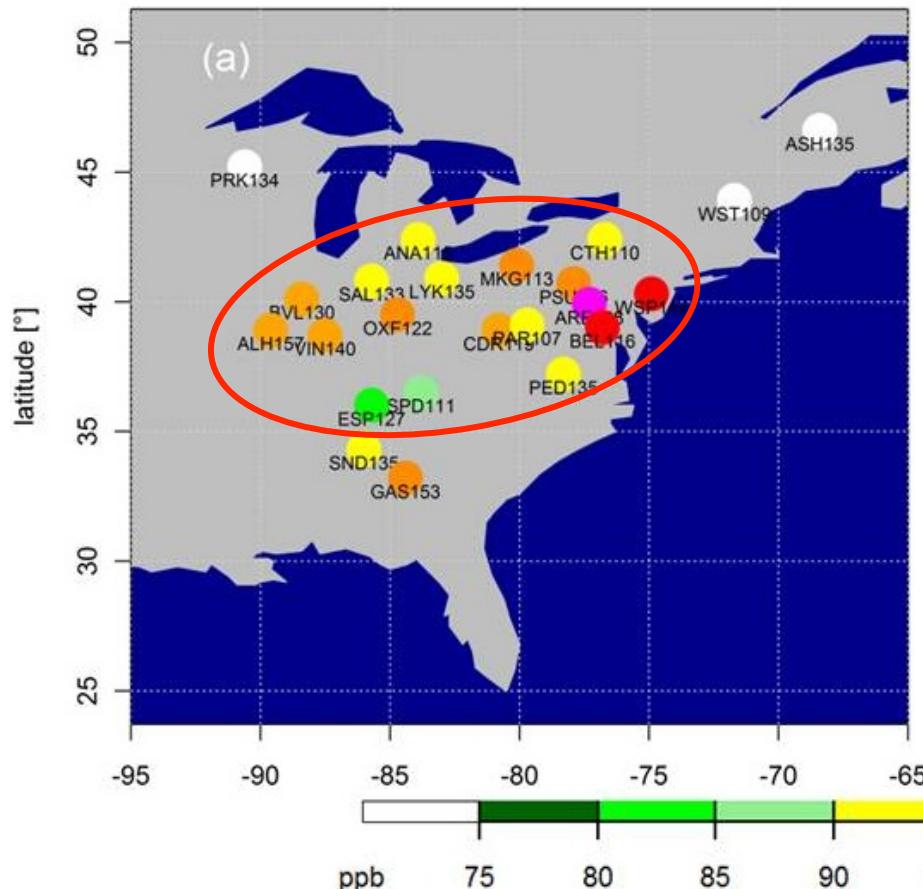


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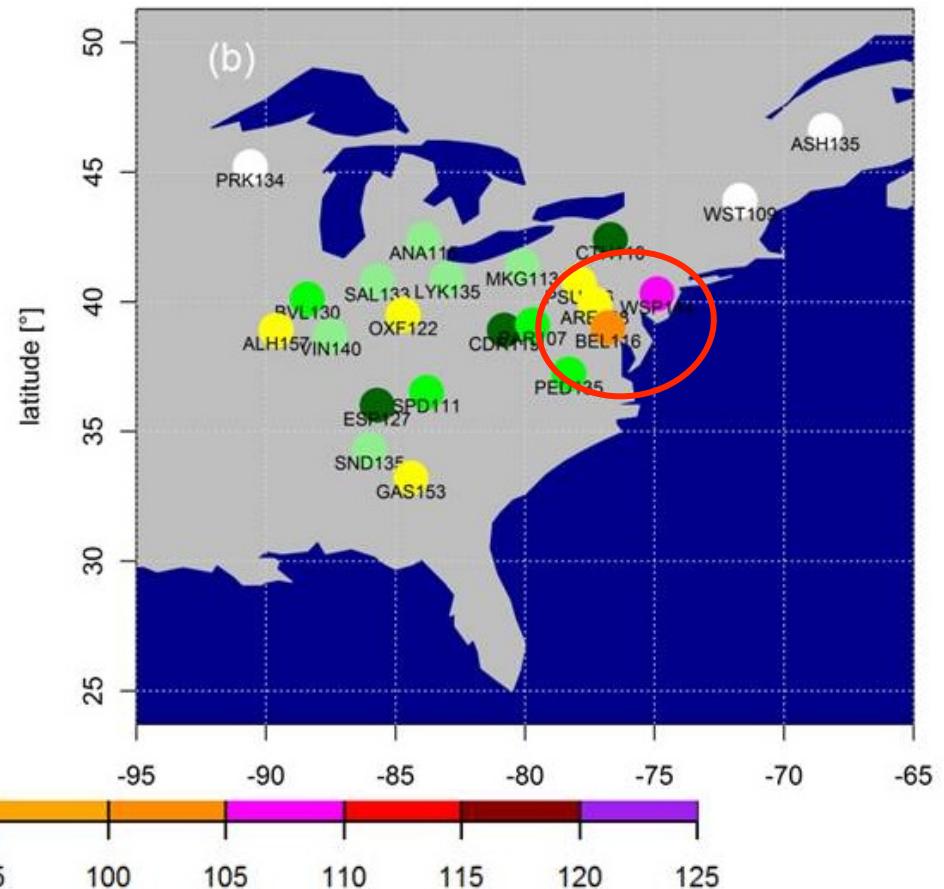
Apply methods to all EUS  
CASTNet sites to derive  
1-year and 5-year return levels

# Decreases in 1-year return levels for JJA MDA8 O<sub>3</sub> over EUS following NO<sub>x</sub> emission controls

1988-1998



1999-2009

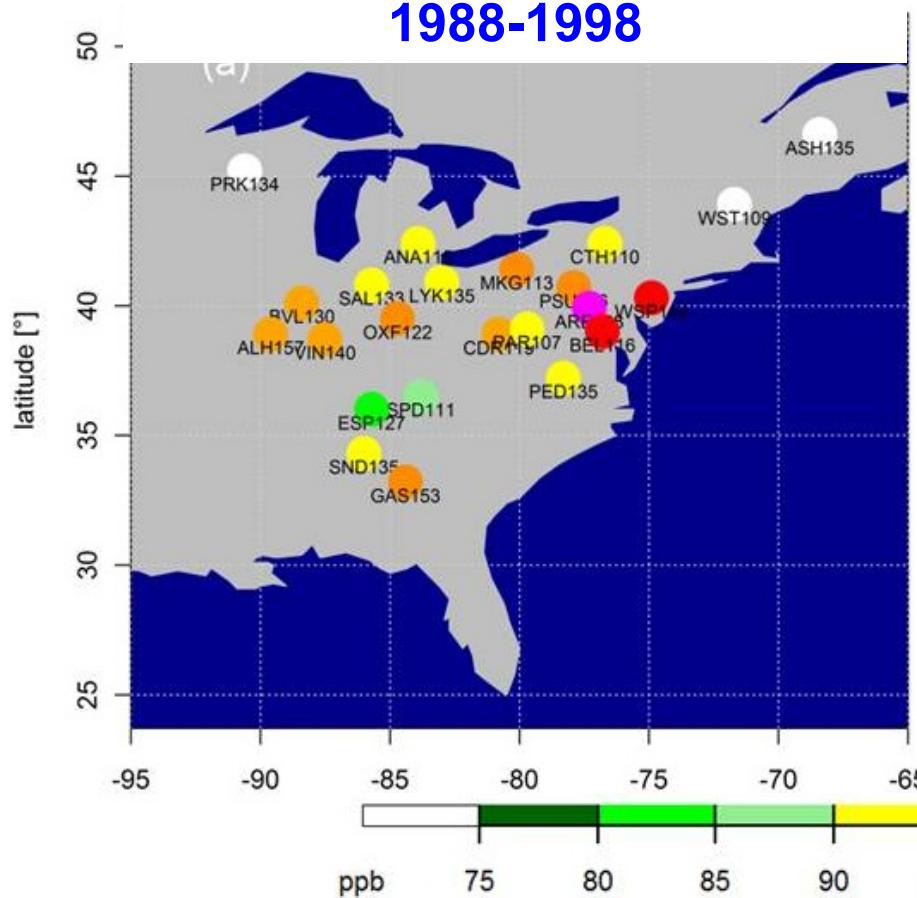


- 1-yr return level decreases by 2-16 ppb
- 1-year levels remain above the NAAQS threshold (75 ppb) across much of EUS

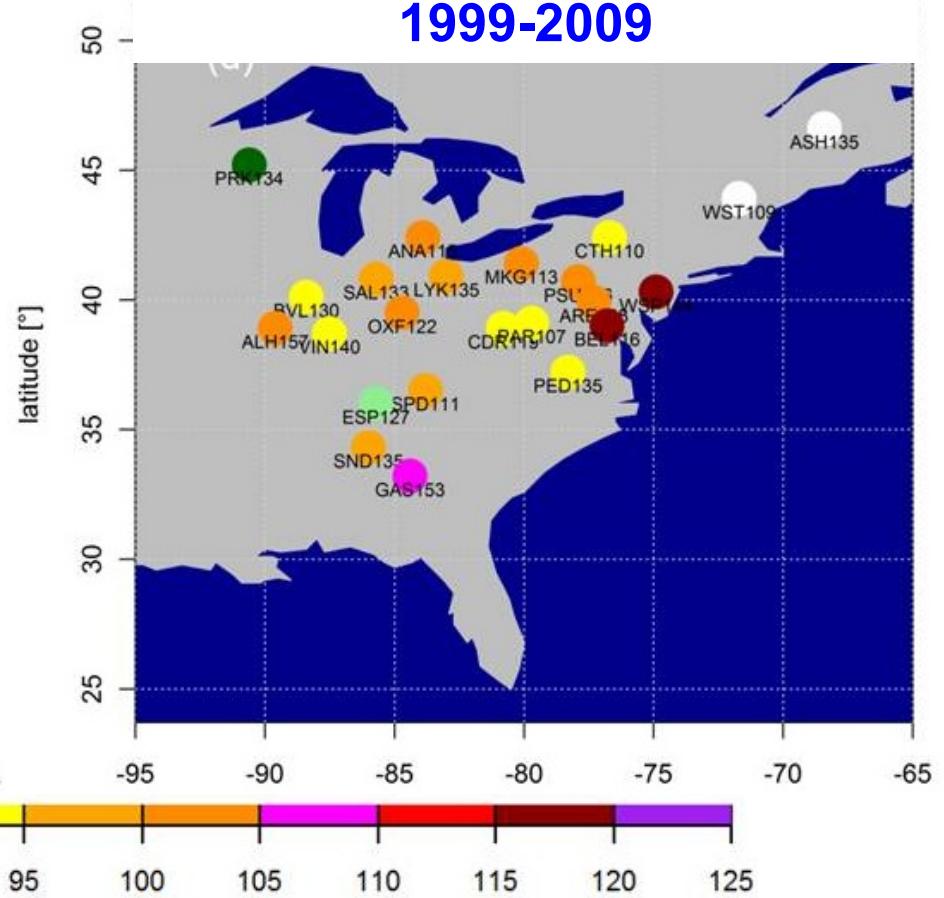
Rieder et al., ERL 2013

# 1999-2009 5-year return levels for JJA MDA8 O<sub>3</sub> over EUS now similar to 1988-1998 1-year levels

1-year Return Levels  
1988-1998



5-year Return Levels  
1999-2009

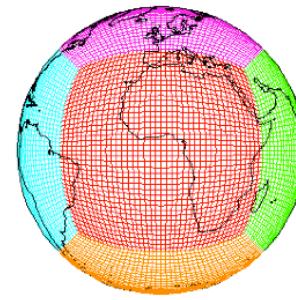


→ 5-yr return levels decrease by up to 20 ppb (not shown)

# How will high-O<sub>3</sub> events 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 ~50km<sup>2</sup> [Lin et al., JGR, 2012ab]

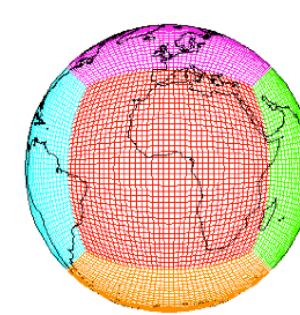


Donner et al., *J. Climate*, 2011;  
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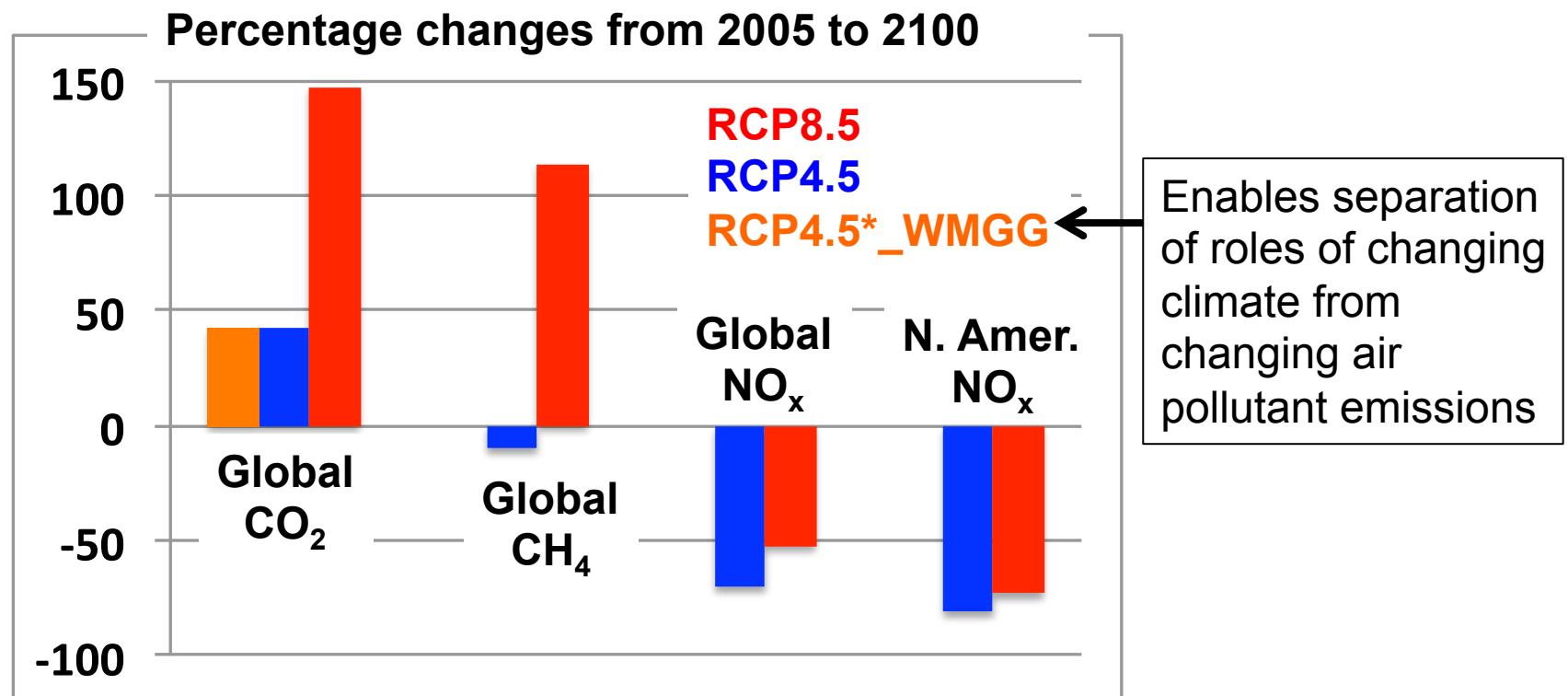
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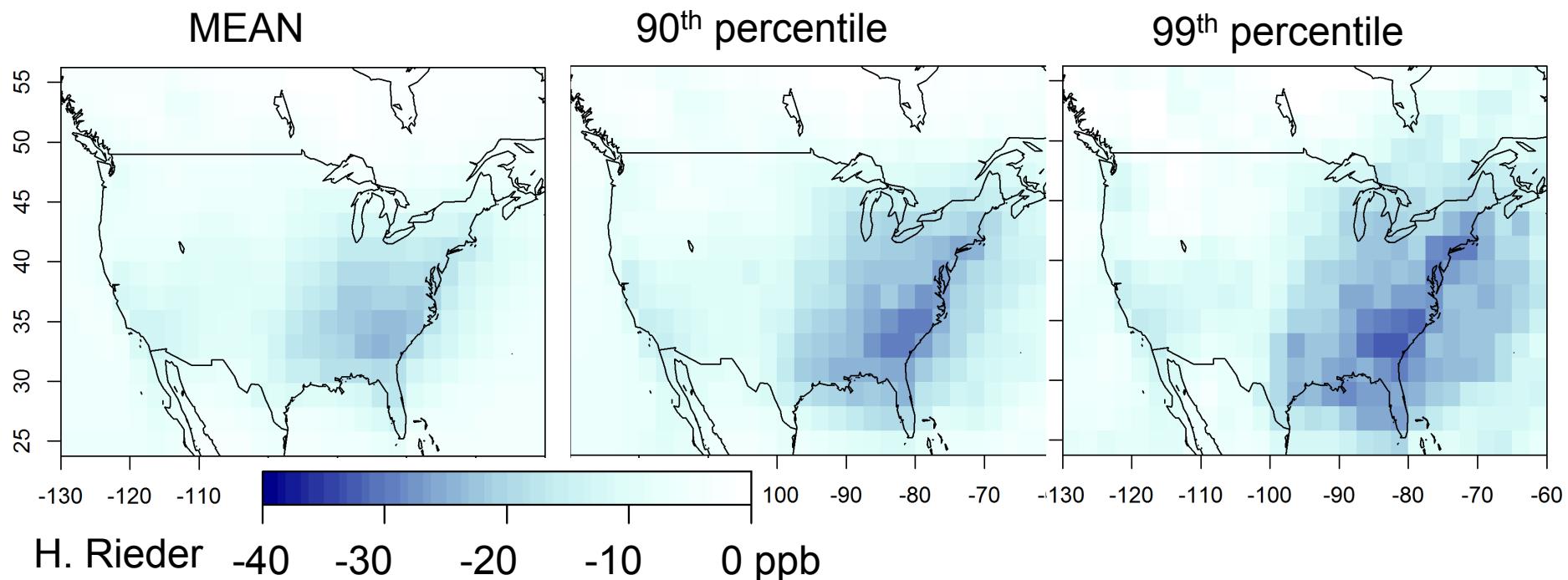
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Climate / Emission Scenarios: Representative Concentration Pathways (RCPs)



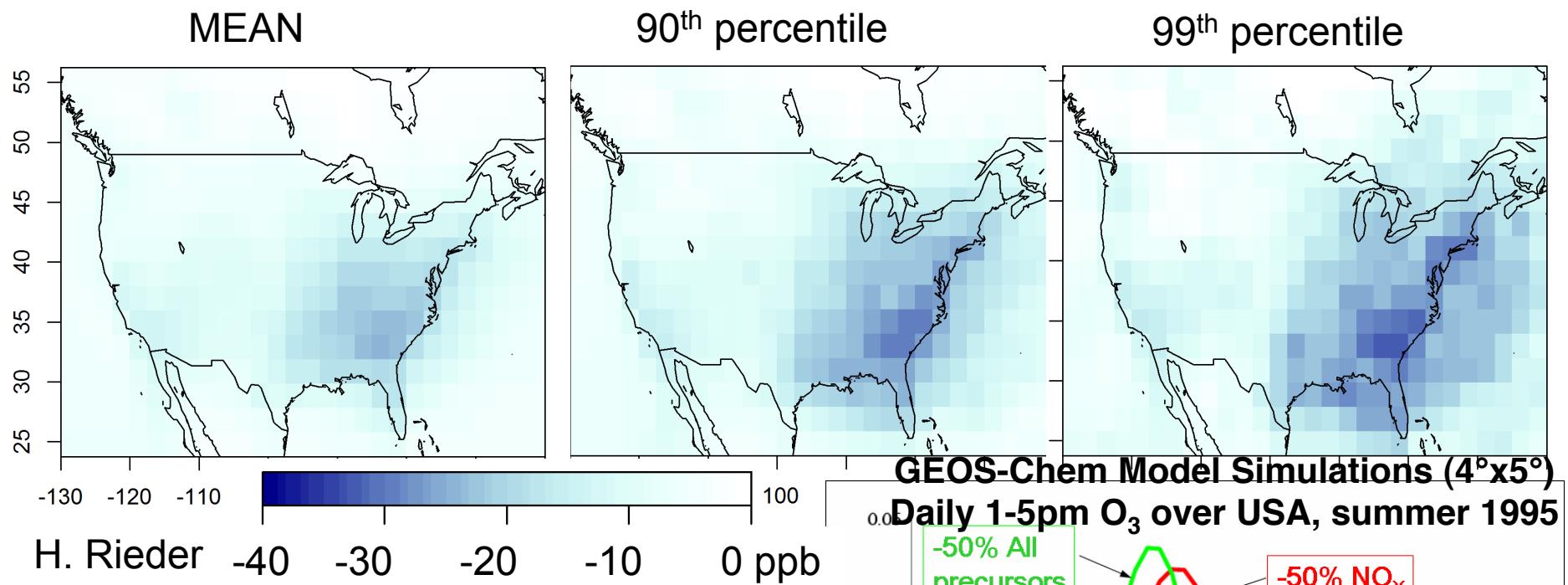
# Surface ozone decreases most at high tail

GFDL CM3 model, RCP4.5 scenario: (2046-2055) – (2006-2015)

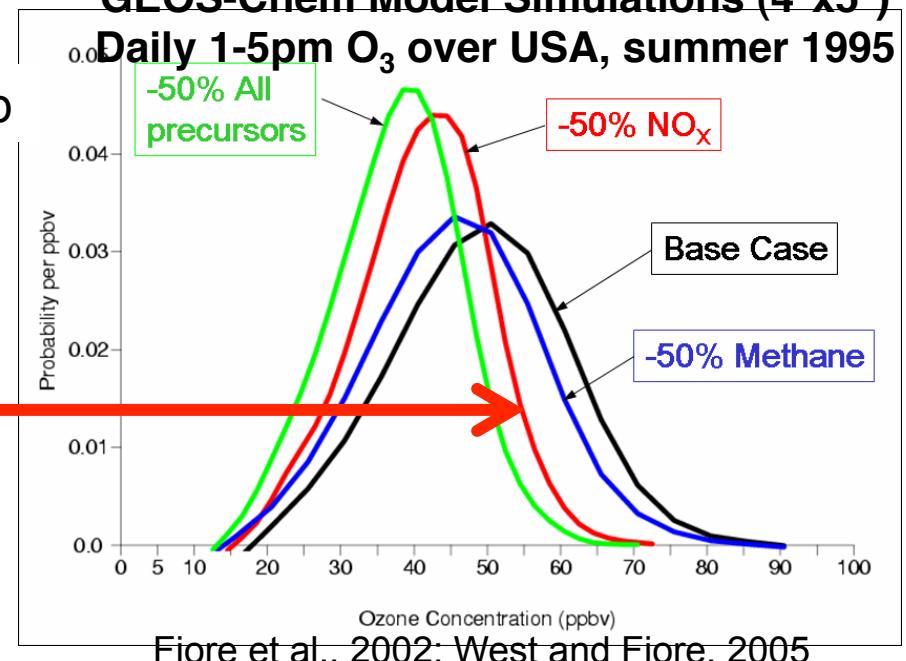


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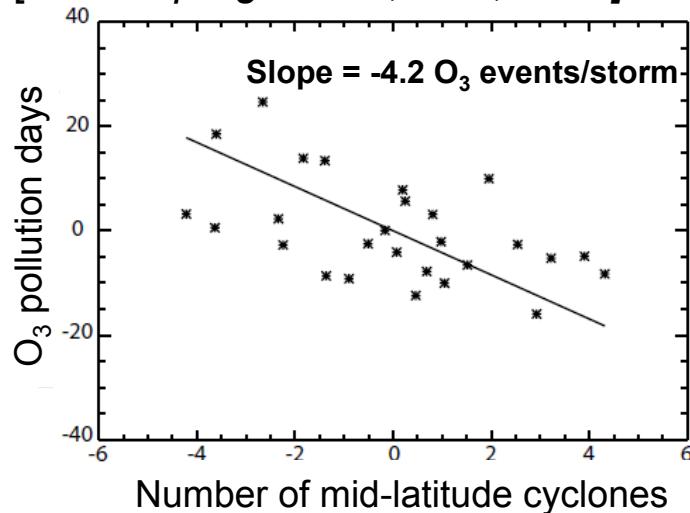


Influence of US NO<sub>x</sub> emission reductions under RCP4.5:  
 Strongly decrease regional pollution episodes



## What controls well-documented O<sub>3</sub>-Temp correlation 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]

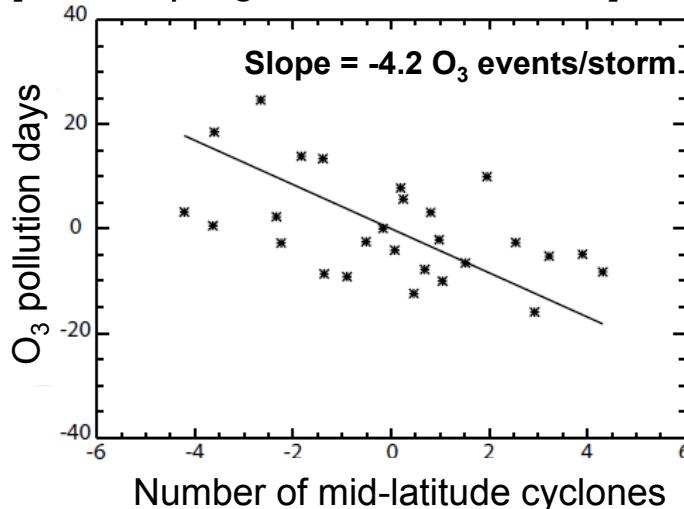
NE USA: anti-correlation between observed number of high-O<sub>3</sub> events and storm counts (both detrended)  
[Leibensperger et al, ACP, 2008]



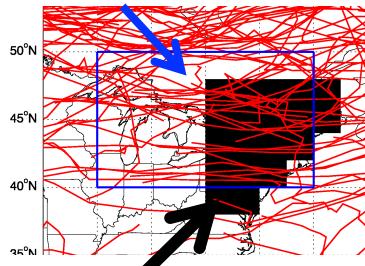
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MCMS storm tracker [Bauer et al., 2013]  
Region for counting storms



Region for counting  
O<sub>3</sub> events

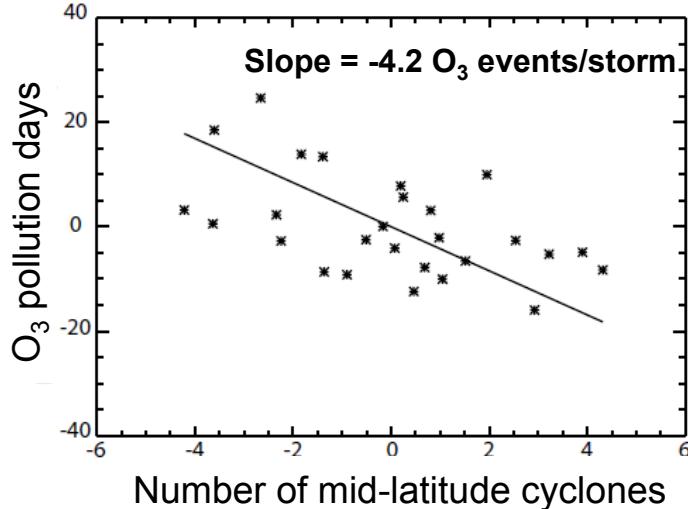
How does  
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influence  
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O<sub>3</sub> events?

Turner et al., ACP, 2013

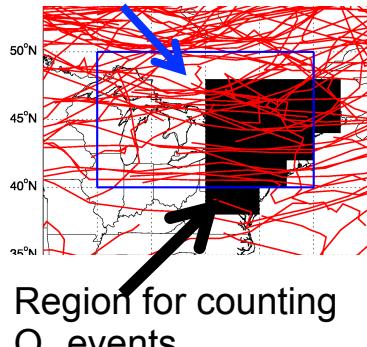
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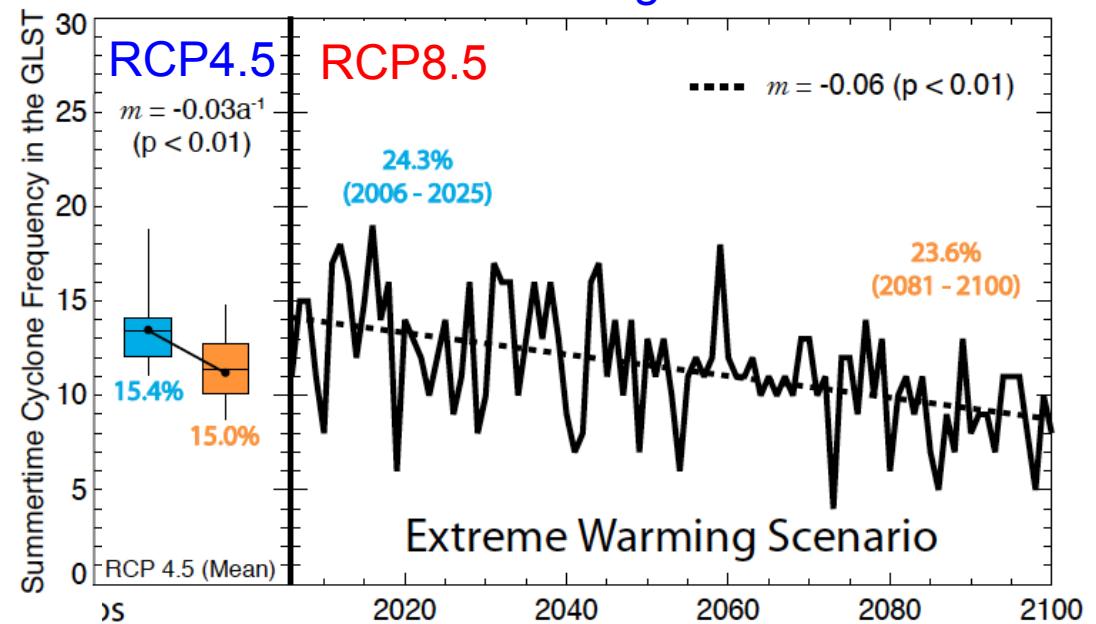
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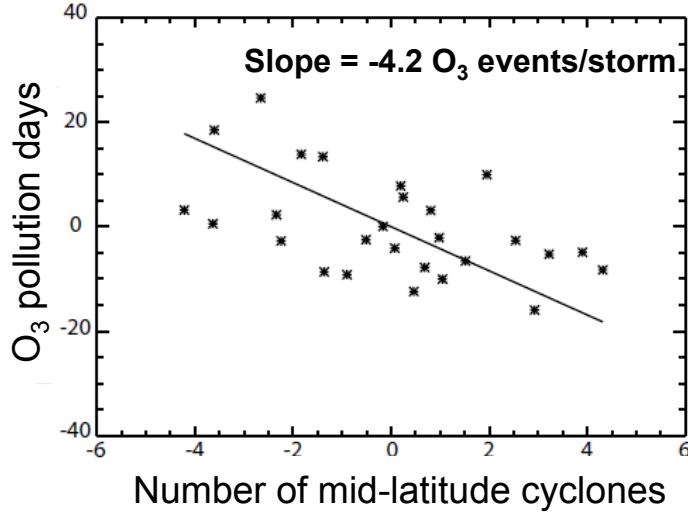
GFDL CM3 model projects declines in storm counts with climate warming...



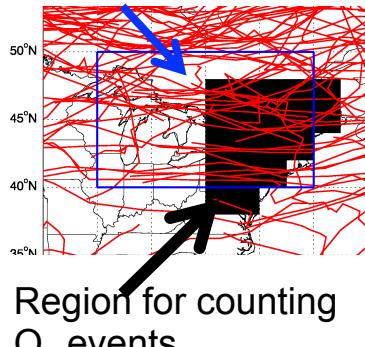
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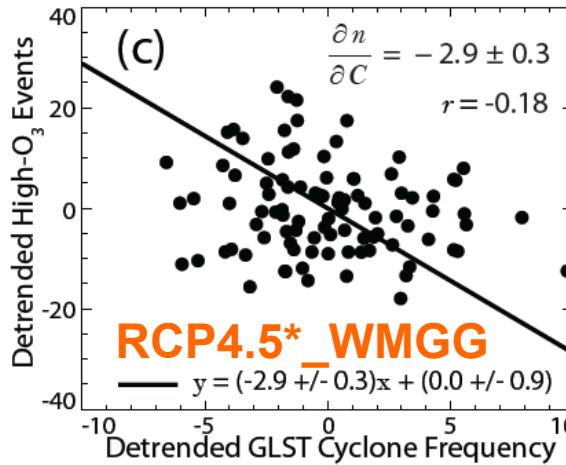
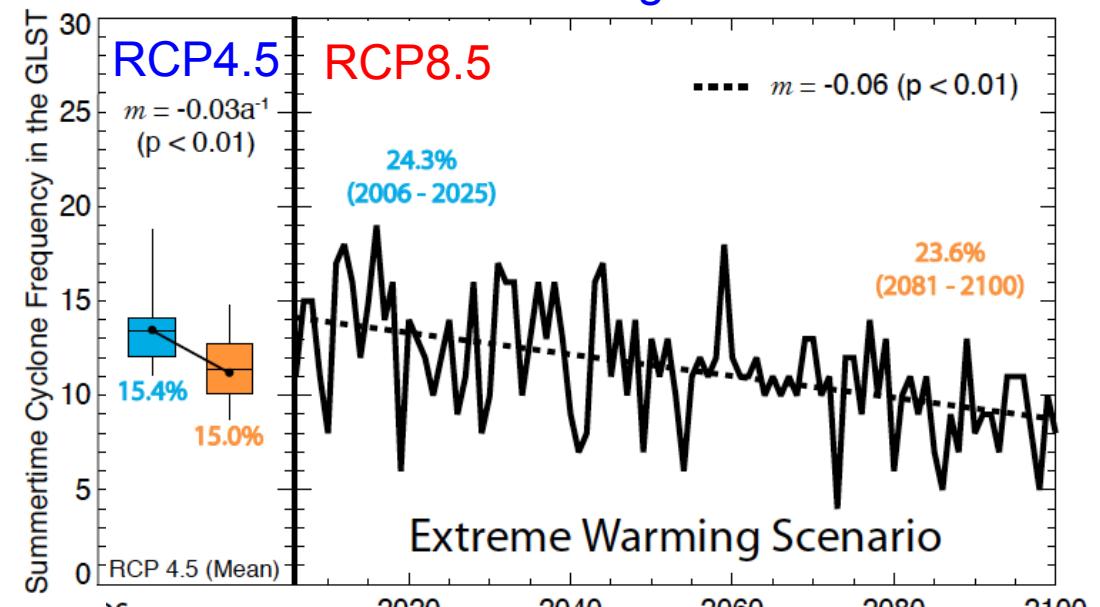


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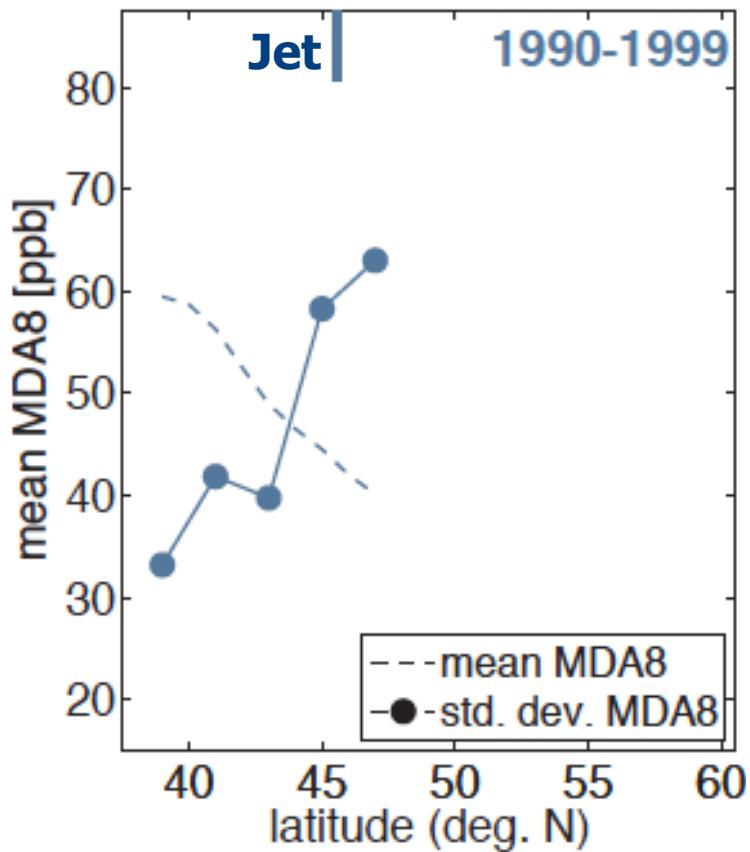
Turner et al., ACP, 2013

...but weak relationship with high-O<sub>3</sub> events:  
model problem?  
change in controlling factors?

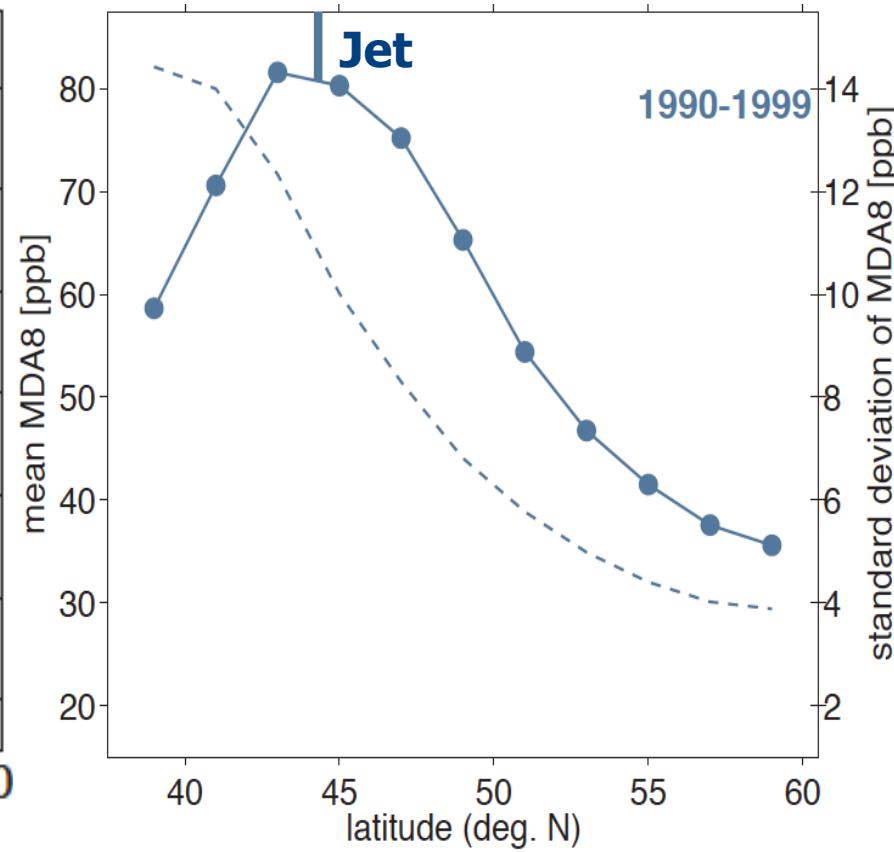
Simpler diagnostic of large-scale circulation changes?

# Summertime surface O<sub>3</sub> variability aligns with the 500 hPa jet over Eastern N. America

Observations  
(CASTNET + MERRA reanalysis)

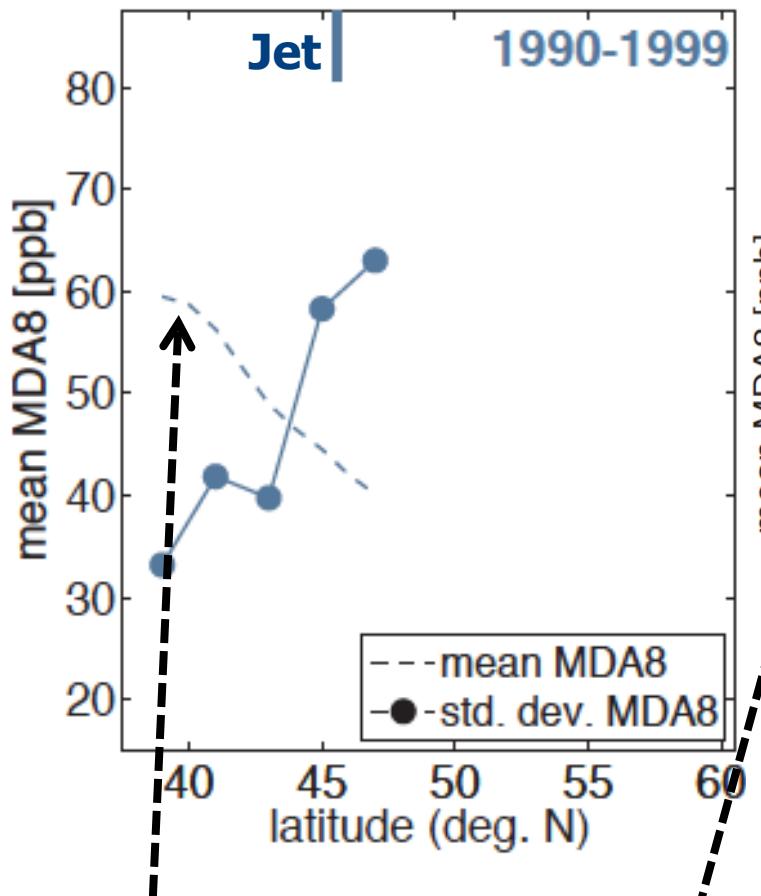


GFDL CM3 model  
Historical simulations



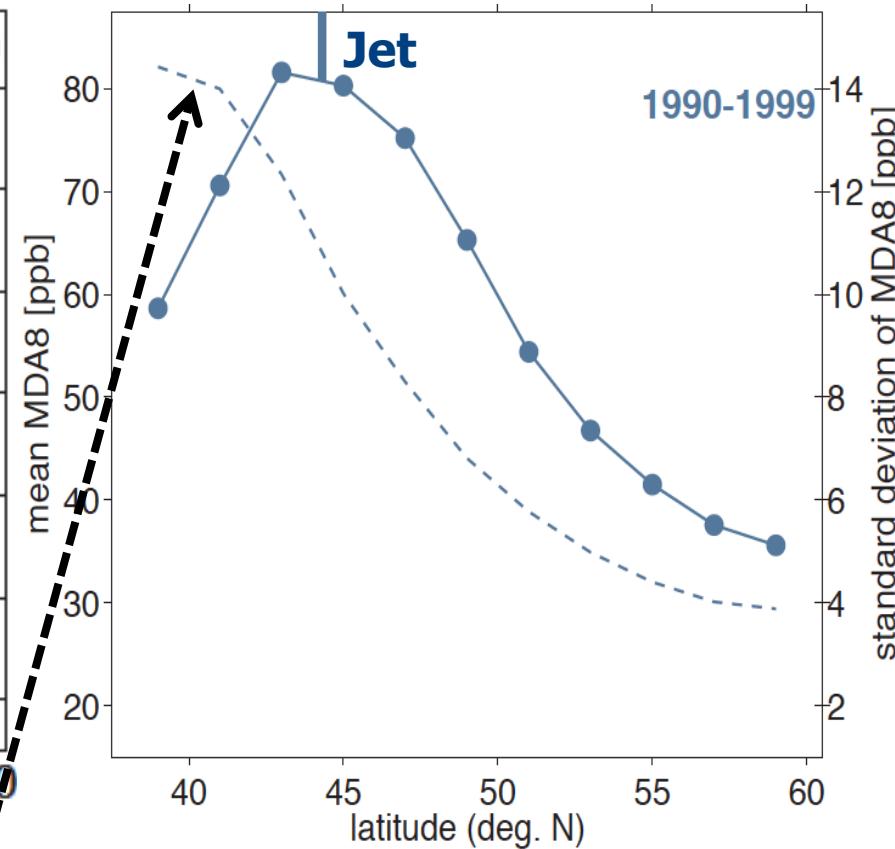
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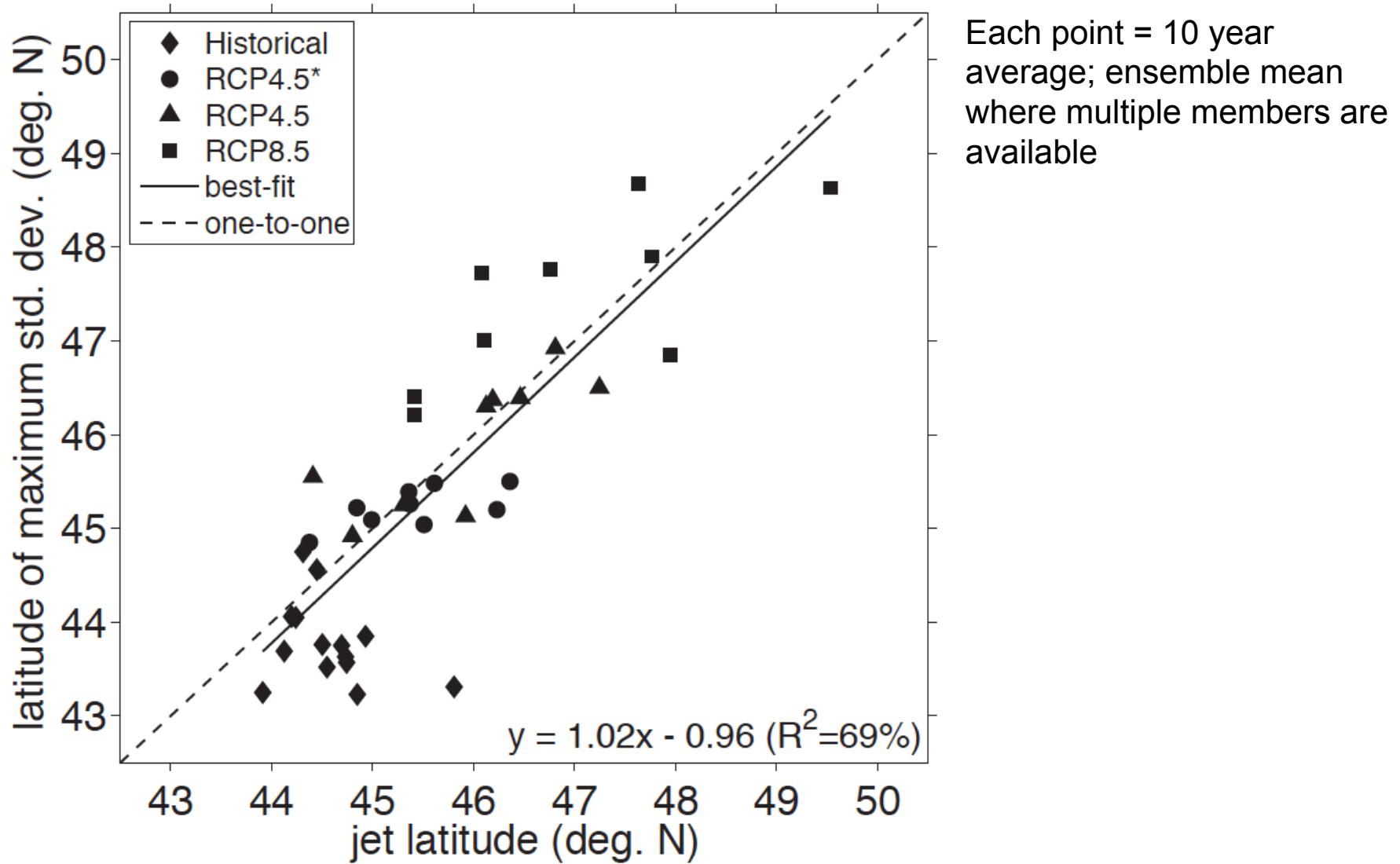
NO<sub>x</sub> emissions peak south of jet  
where mean MDA8 O<sub>3</sub> highest

GFDL CM3 model  
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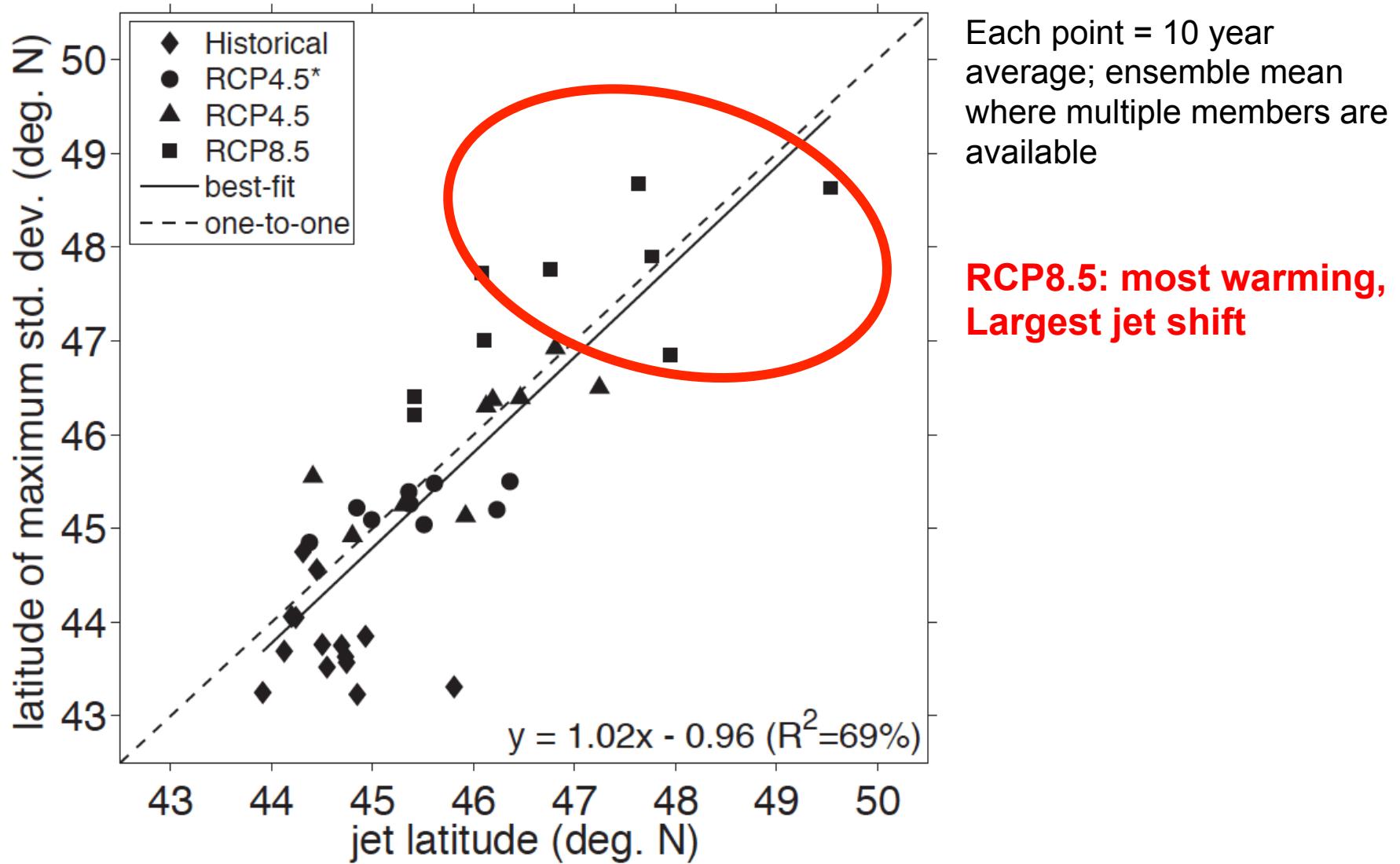


Standard deviation of zonally  
averaged JJA MDA8 O<sub>3</sub>  
→ Max at the jet latitude

# Peak latitude of summertime surface O<sub>3</sub> variability over Eastern N. America follows the jet as climate warms



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Each point = 10 year average; ensemble mean where multiple members are available

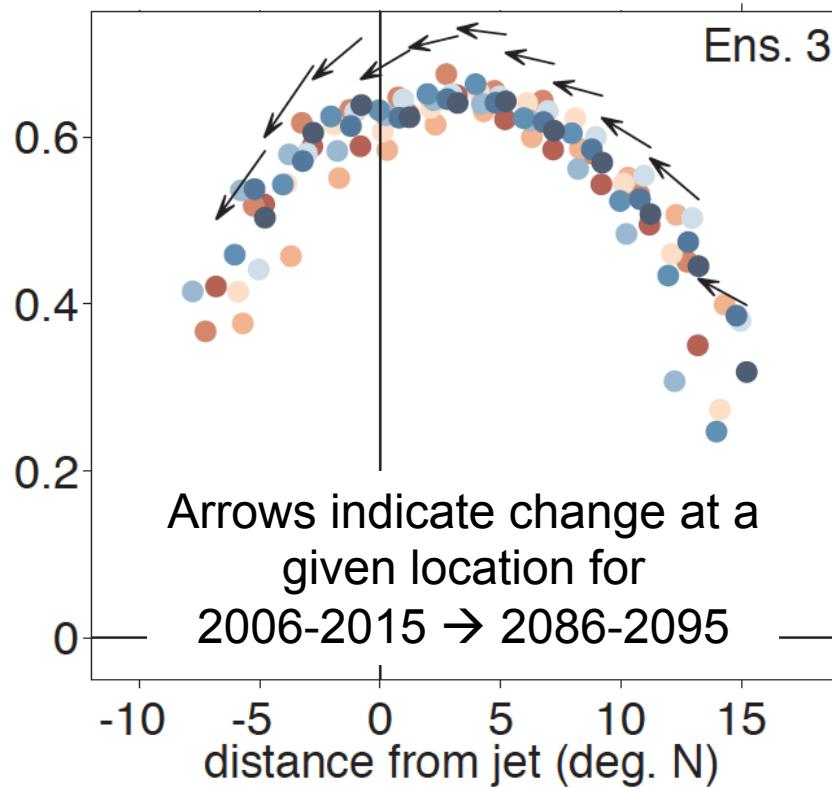
**RCP8.5: most warming,  
Largest jet shift**

# Ozone relationship with temperature varies with jet location

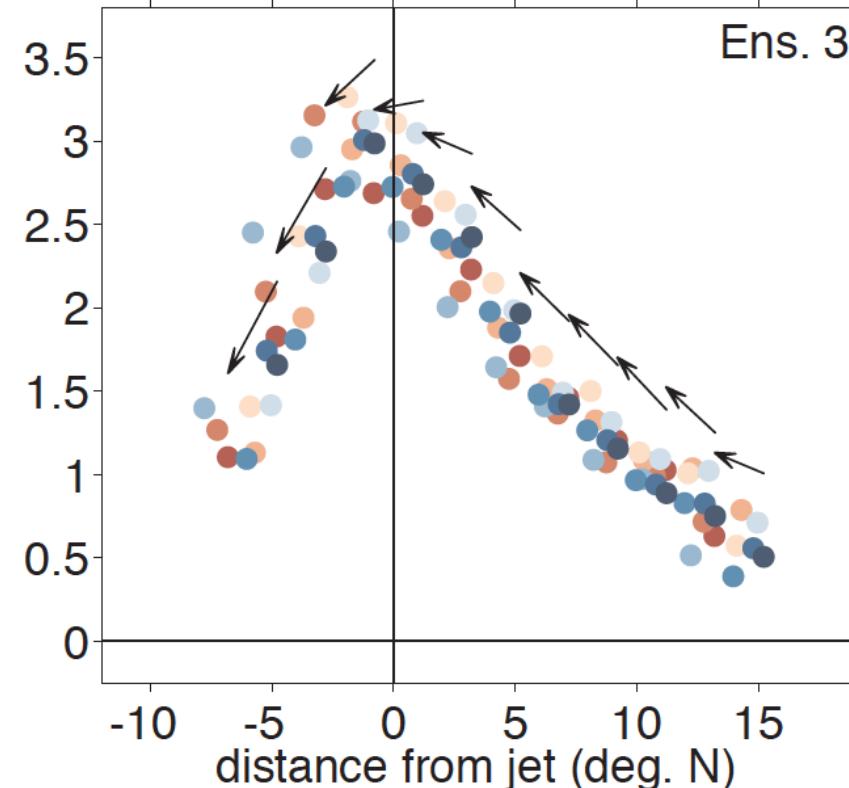
Barnes & Fiore, submitted

GFDL CM3 RCP4.5\* WMGG (air pollutants at 2005 levels): Decadal averages

Correlation (MDA8, Tmax)



OLS Slope (MDA8, Tmax)

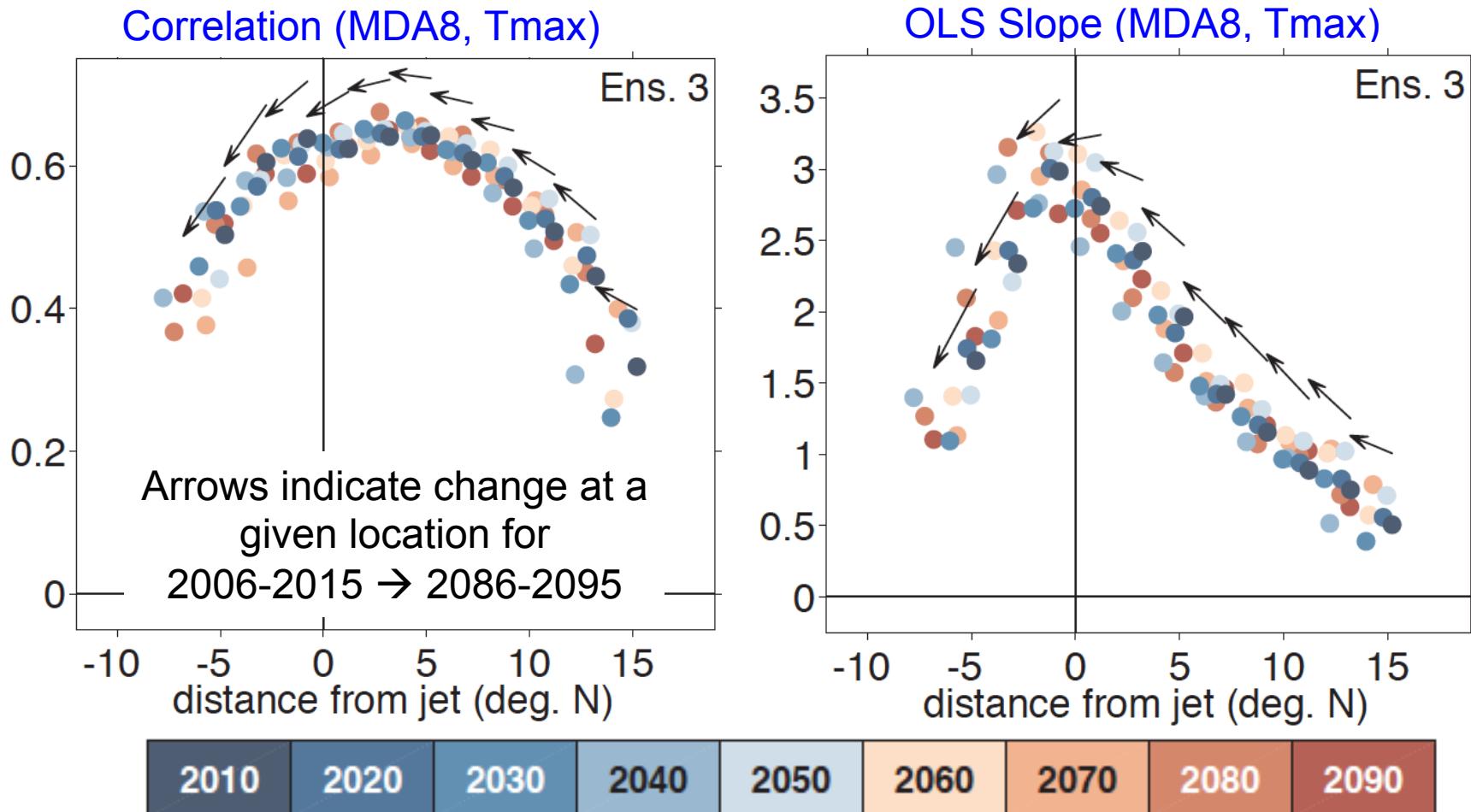


2010	2020	2030	2040	2050	2060	2070	2080	2090
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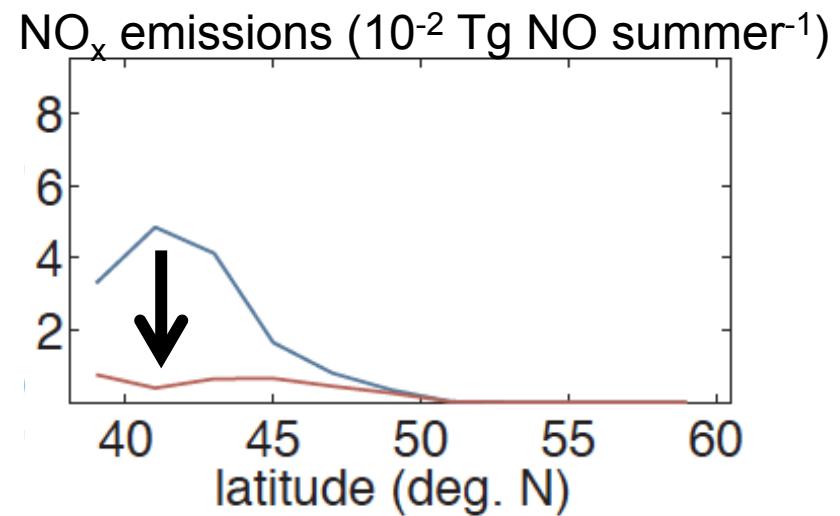
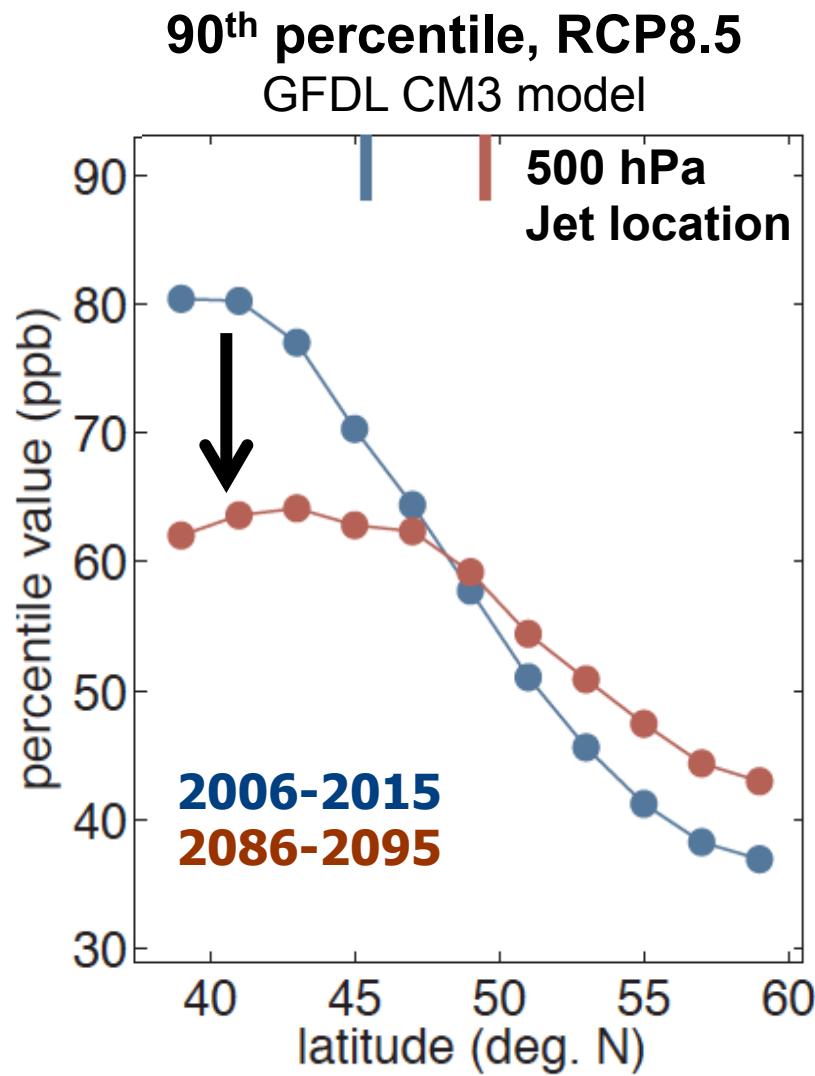
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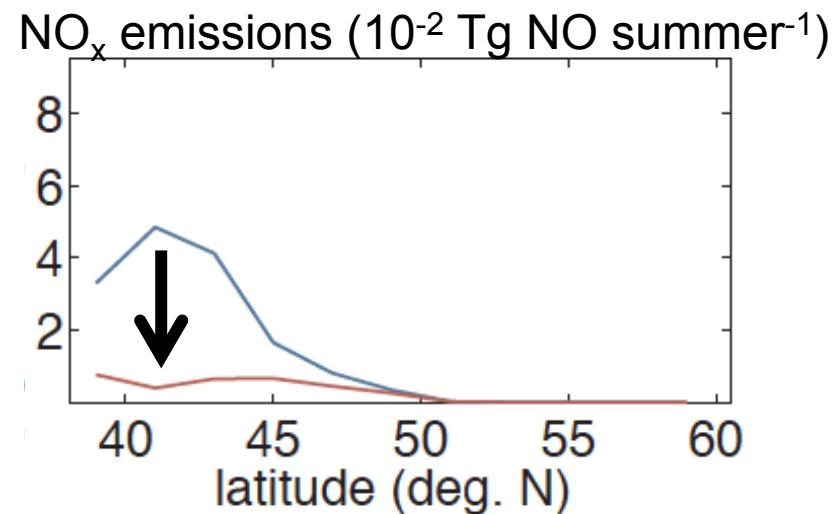
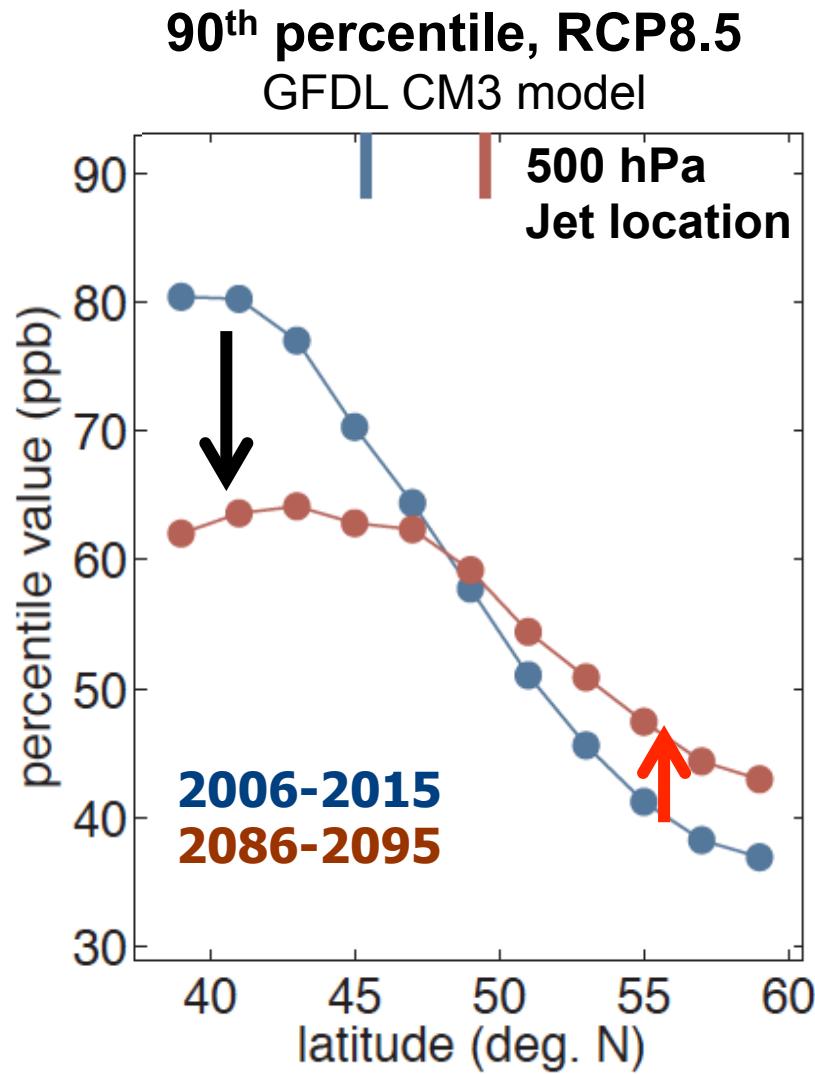
- Observed local  $O_3$ :T relationships may not hold if large-scale circulation shifts
- Differences in simulated jet positions → model discrepancies in  $O_3$  responses?
- Is a jet location a useful predictor? i.e., quantitative relationships?

# Shifting jet: Implications for extreme air pollution events?



Regional NO<sub>x</sub> emission reductions decrease 90<sup>th</sup> percentile values

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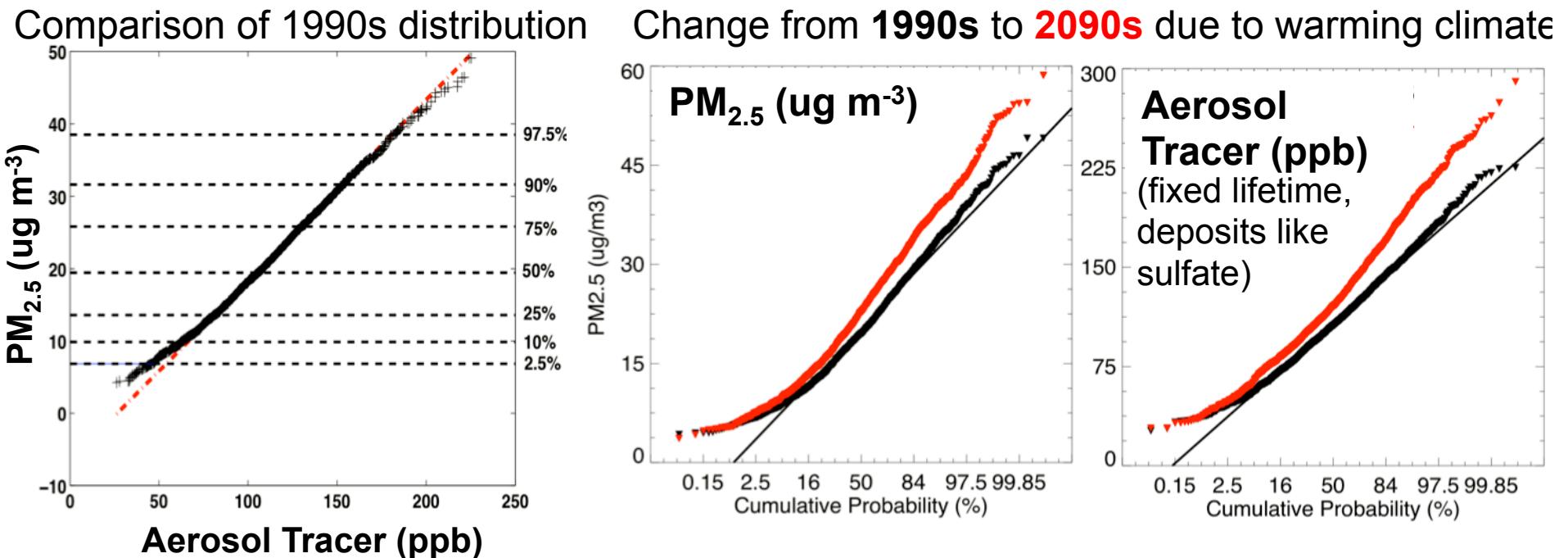
Jet shift + rise in baseline O<sub>3</sub> (methane)?

→ Targeted simulations to separate roles of rising CH<sub>4</sub>, decreasing NO<sub>x</sub> from large-scale circulation changes

# Simple tracer mimics climate-driven changes in summertime PM<sub>2.5</sub> over polluted N. mid-latitude regions

CLIMATE CHANGE ONLY AM3 idealized simulations (20 years)

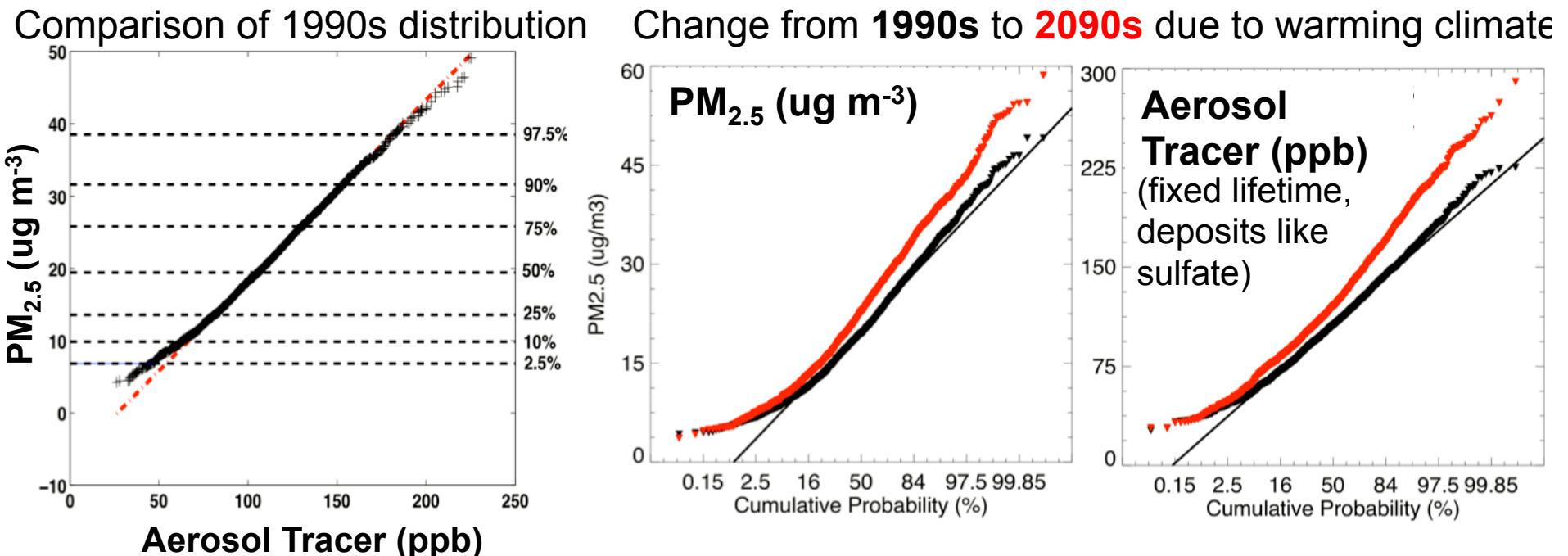
JJA daily mean over Northeast USA



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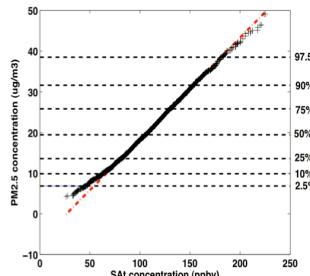
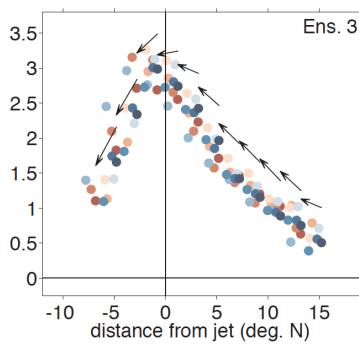
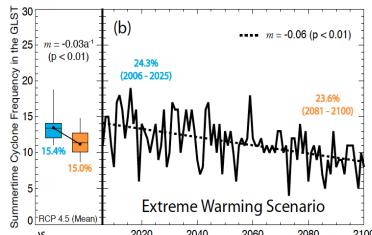
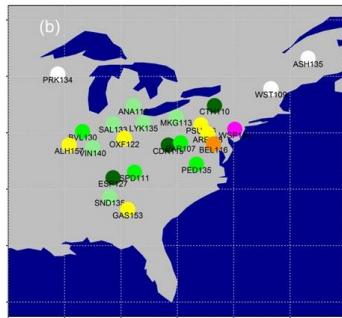
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- Cheaper option to reconstruct AQ info from simple tracer in physical climate models (e.g., high res)
- Opportunity to further test utility in ongoing chemistry-climate simulations  
(CCMI effort: <http://www.igacproject.org/CCMI>)

Fang et al., GRL, 2013

# Characterizing U.S. air pollution extremes and influences from changing emissions and climate: Summary and Next Steps



- Applied EVT to derive return levels for O<sub>3</sub> observed over EUS
- New metric for quantifying success of NO<sub>x</sub> emission controls  
*[Rieder et al., ERL, 2013]*
  - Apply to PM<sub>2.5</sub>, precipitation, future model projections
  - Event persistence? Model bias correction?
- NEUS summer cyclones decline in GFDL CM3 warming simulations
- Weak relationship with high-O<sub>3</sub> events [*Turner et al., ACP, 2013*]
  - Connect with large-scale circulation changes
  - Identify key drivers of extreme events in other regions
- O<sub>3</sub> variability aligns with the 500 hPa jet over NE N. America
- Jet shifts can influence O<sub>3</sub>:T [*Barnes & Fiore, submitted*]
  - Tease apart role of climate vs. emissions (NO<sub>x</sub> and CH<sub>4</sub>)
  - Explore predictive power and extend beyond O<sub>3</sub>
  - Relevant to model differences in O<sub>3</sub> response to climate?  
*[Weaver et al., 2009; Jacob & Winner, 2009; Fiore et al., 2012]*
- Synthetic aerosol tracer captures climate-driven change (wet deposition) in PM<sub>2.5</sub> distribution [*Fang et al., GRL, 2013 (in press)*]
  - Assess robustness across models (CCMI effort)
  - Computationally cheap AQ info from GCMs?