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

Arlene M. Fiore

Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

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)

This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # 83520601

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

How and why might extreme air pollution events change?

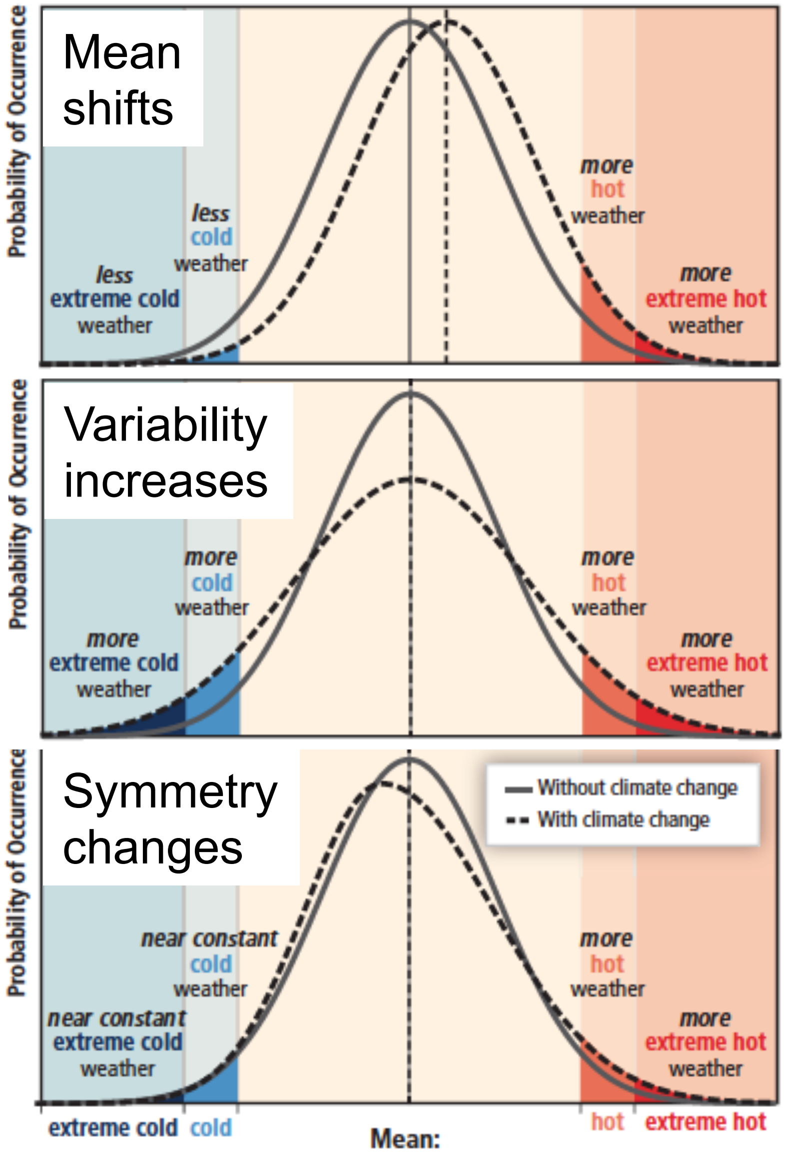


Figure SPM.3, IPCC SREX 2012
http://ipcc-wg2.gov/SREX/

How and why might extreme air pollution events change?

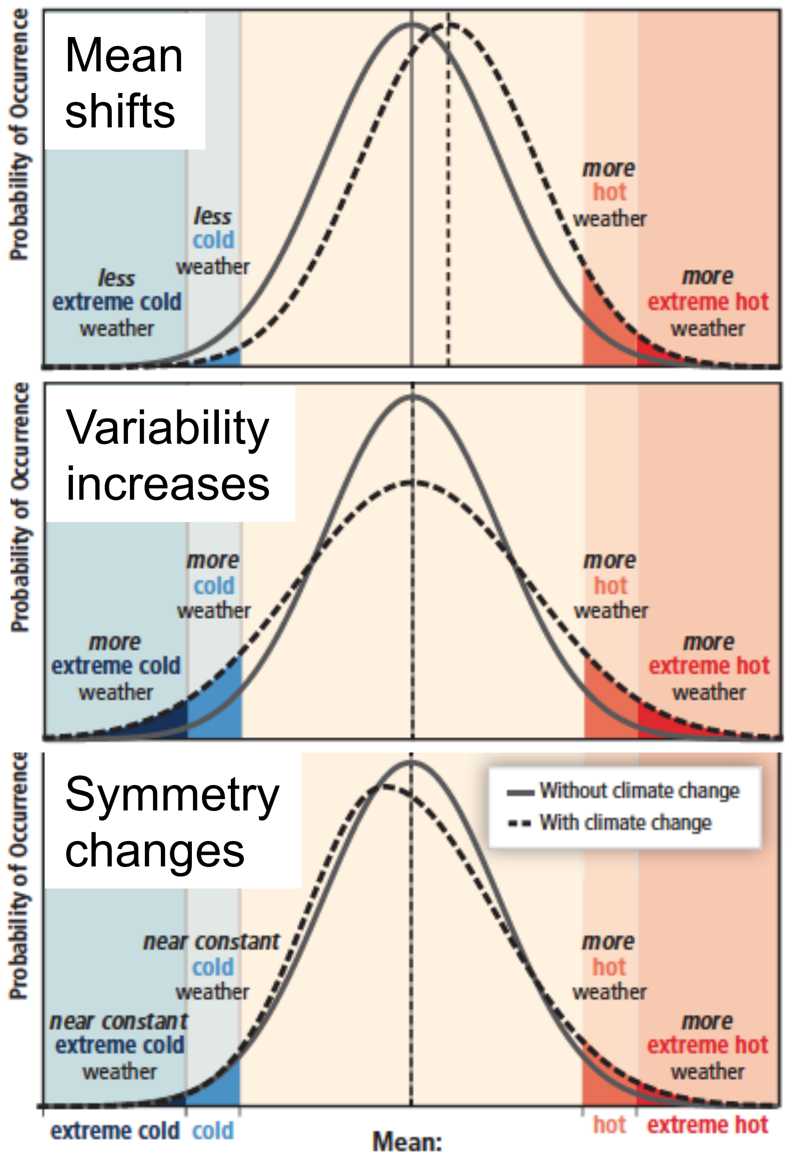
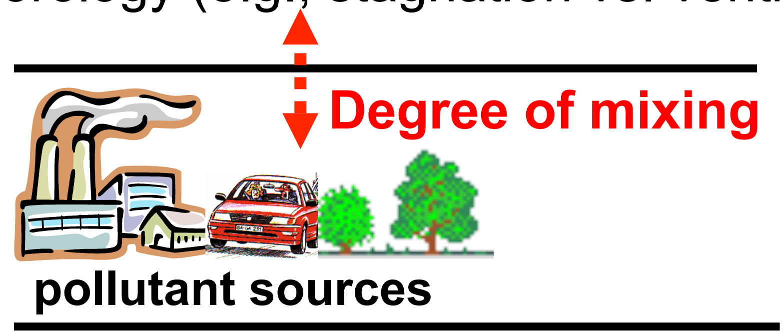


Figure SPM.3, IPCC SREX 2012
http://ipcc-wg2.gov/SREX/

→ **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?

How and why might extreme air pollution events change?

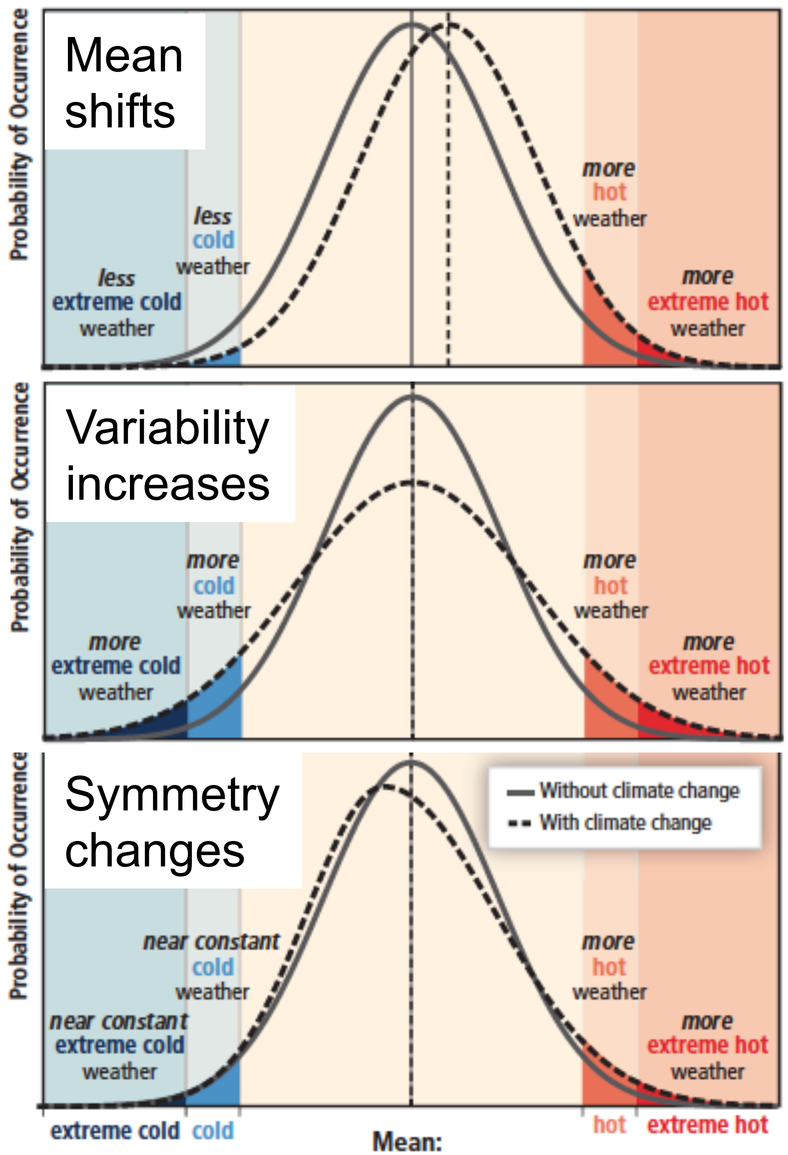
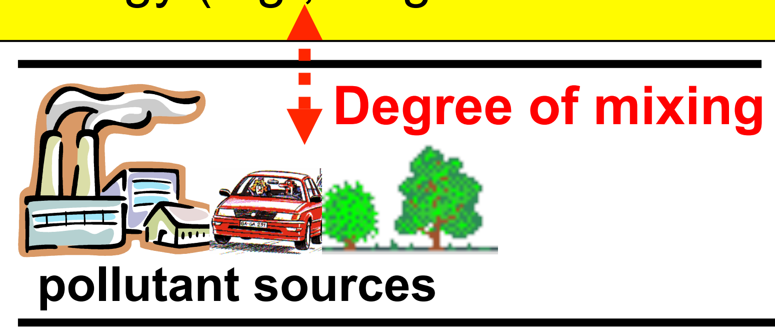


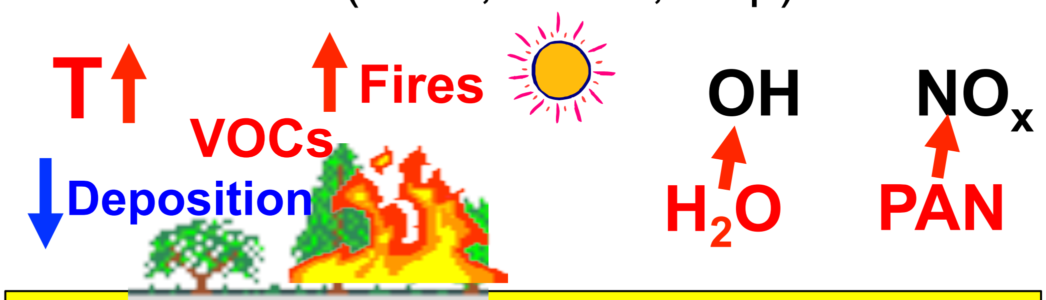
Figure SPM.3, IPCC SREX 2012
http://ipcc-wg2.gov/SREX/

→ **Need to understand how different processes influence the distribution**

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



- Feedbacks (Emis, Chem, Dep)

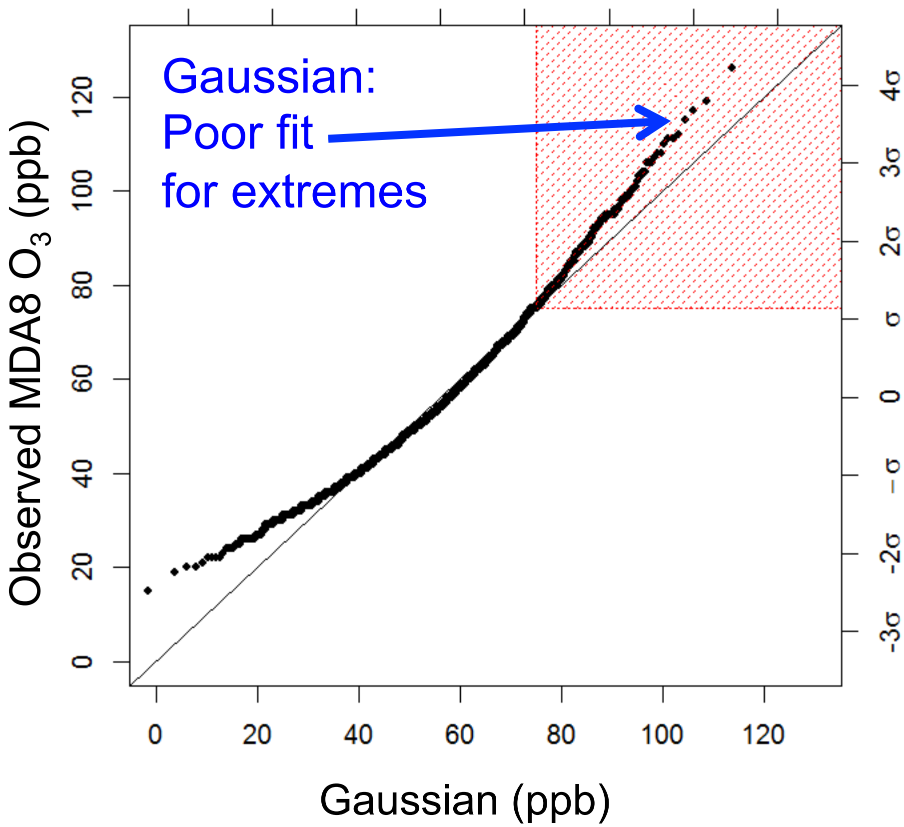


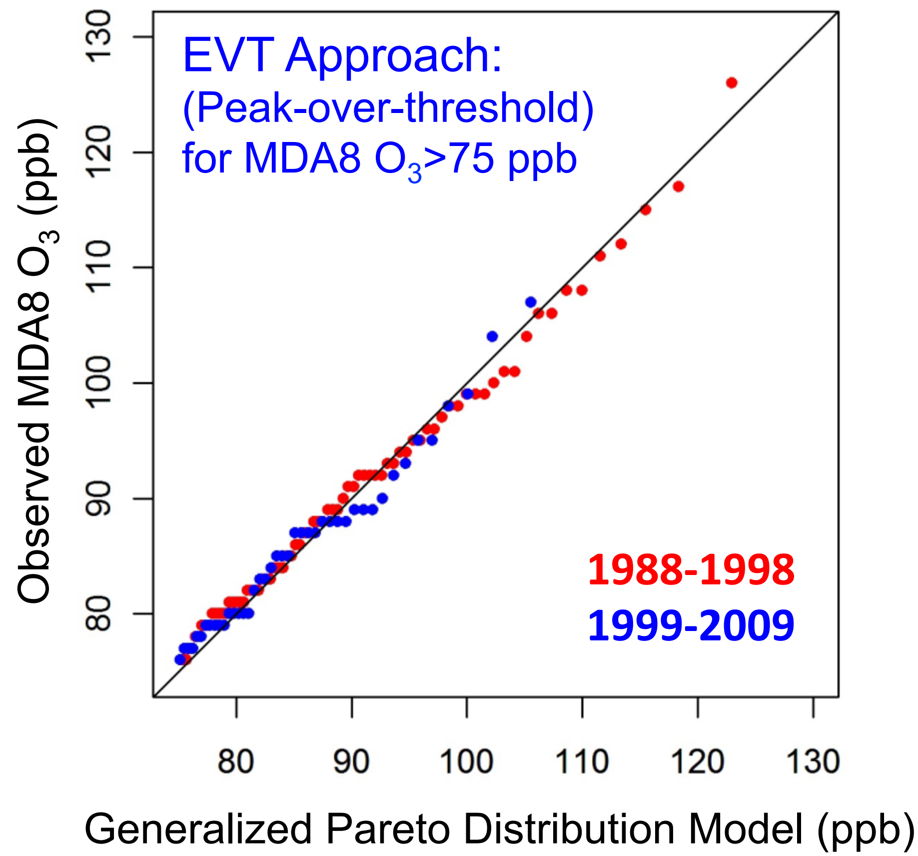
- Changing global emissions (baseline)
  → Shift in mean?
- Changing regional emissions (episodes)
  → Change in symmetry?

Today's Focus

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

JJA MDA8 O_3 1987-2009 at CASTNet Penn State site

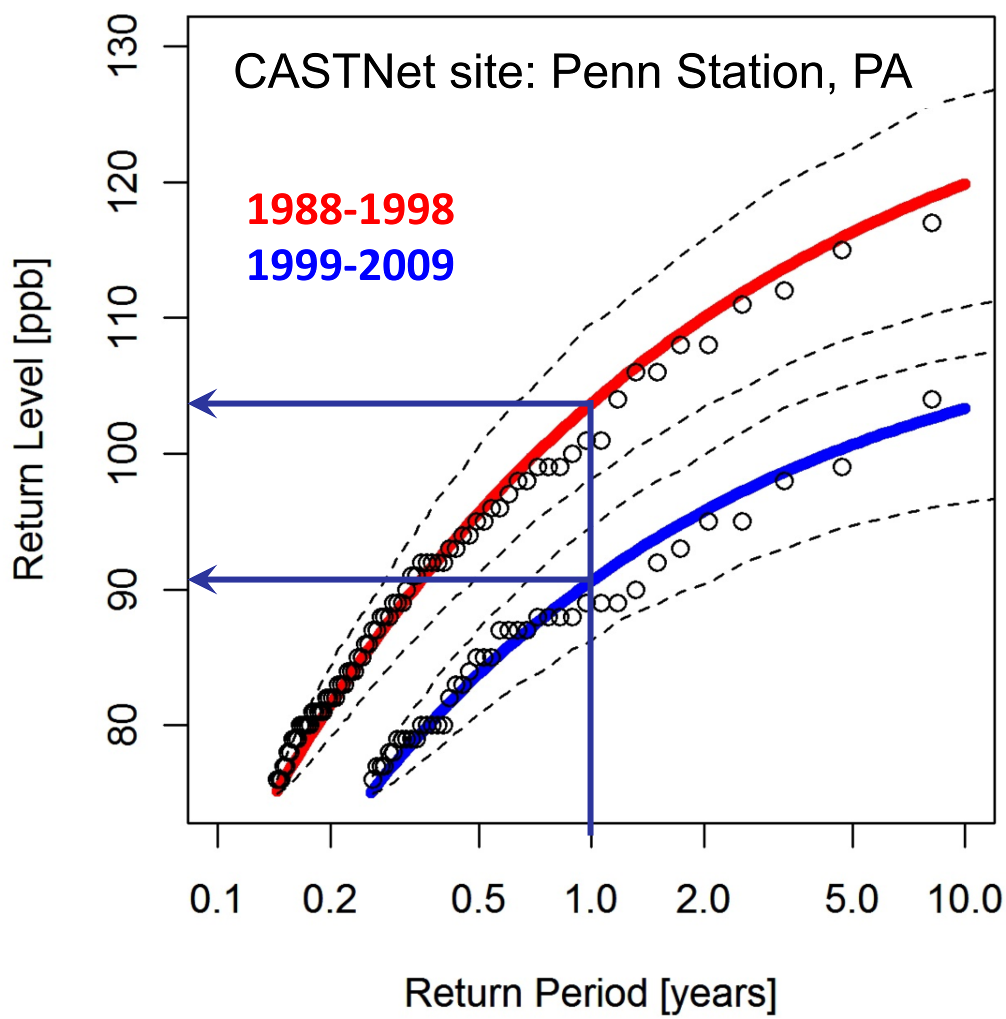




Rieder et al., ERL 2013

EVT methods enable derivation of "return levels" for JJA MDA8 O_3 within a given time period from GPD fit

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

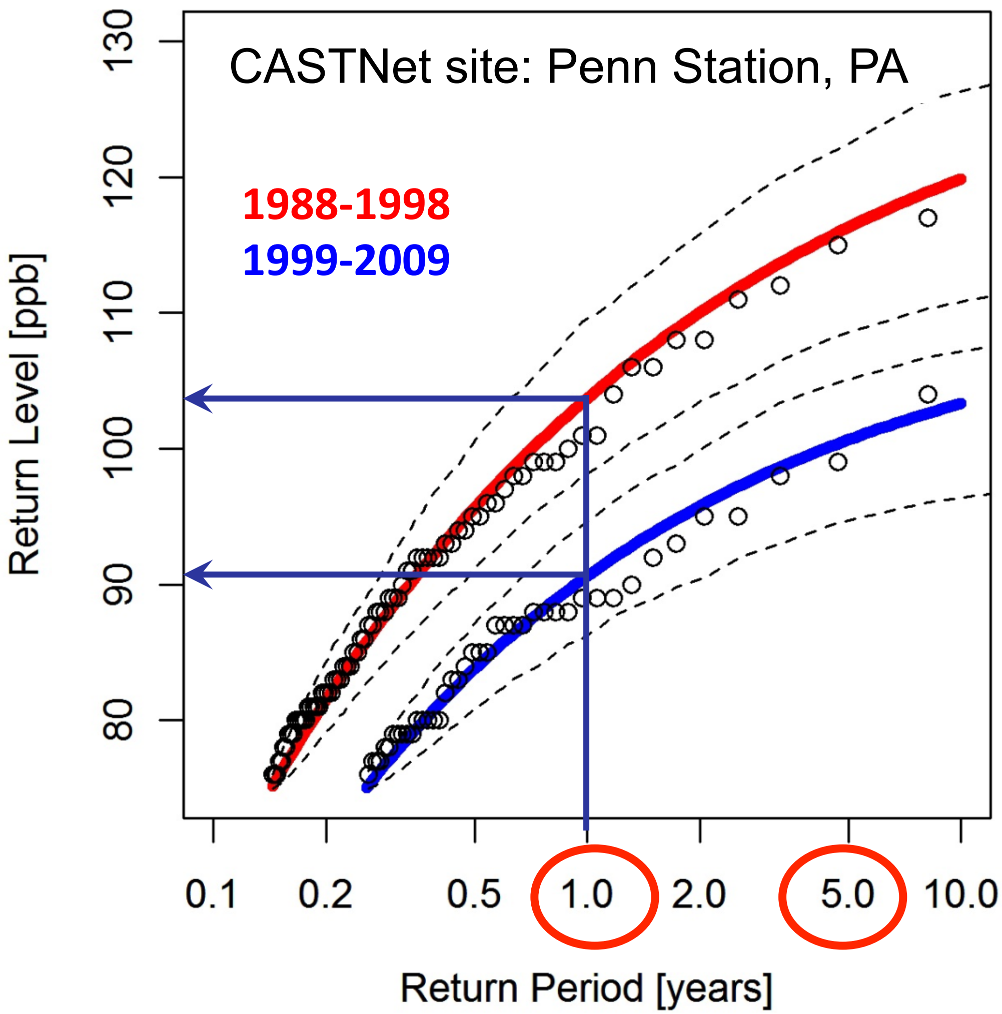


- → Sharp decline in return levels between early and later periods (NO_x SIP call)
- → Consistent with prior work [*e.g., Frost et al., 2006; Bloomer et al., 2009, 2010*]
- → Translates air pollution changes into probabilistic language

Rieder et al., ERL 2013

EVT methods enable derivation of "return levels" for JJA MDA8 O_3 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_x SIP call)

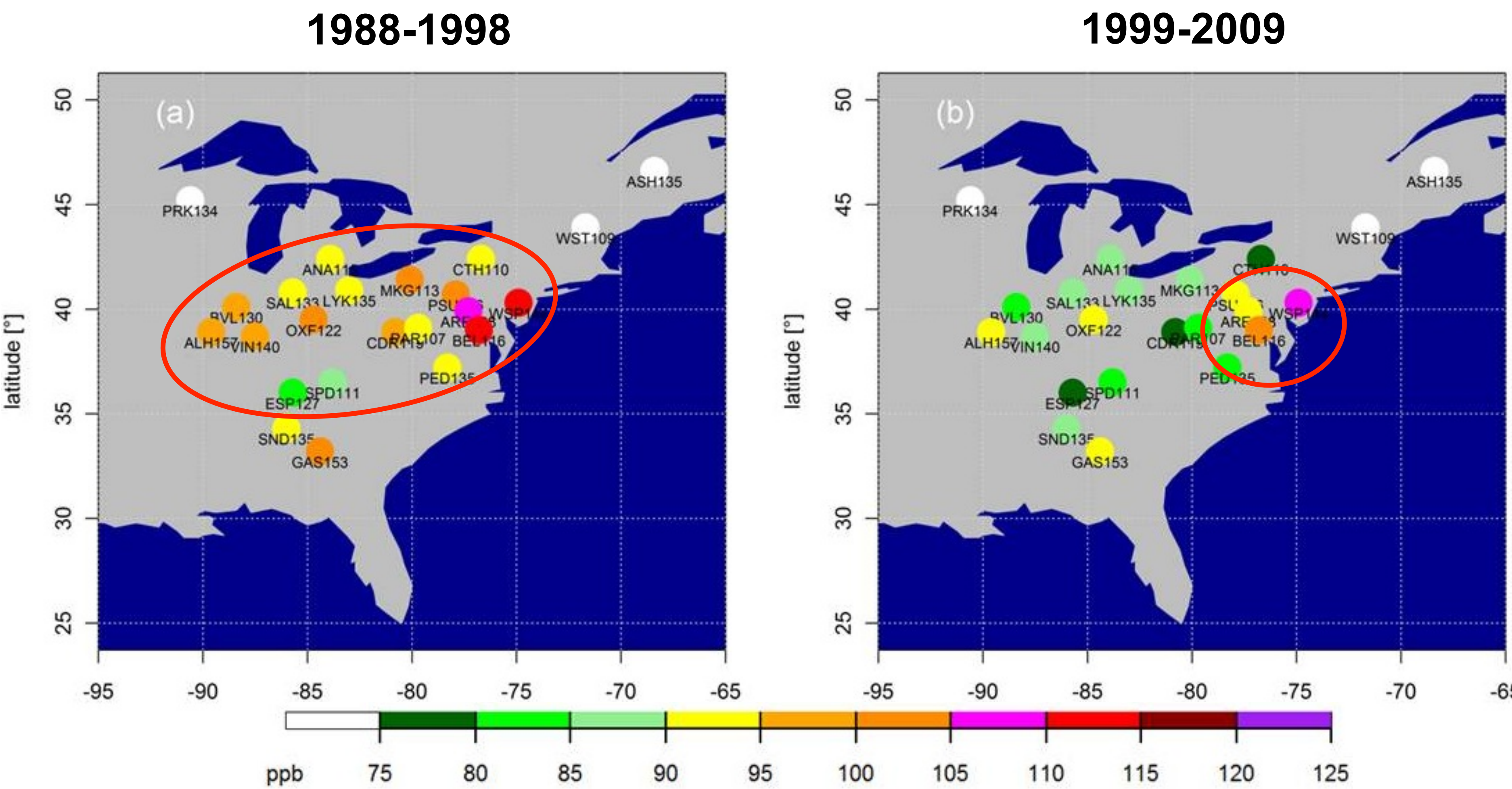
→ Consistent with prior work [*e.g., Frost et al., 2006; Bloomer et al., 2009, 2010*]

→ Translates air pollution changes into probabilistic language

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

Rieder et al., ERL 2013

Decreases in 1-year return levels for JJA MDA8 O_3 over EUS following NO_x emission controls



→ 1-yr return level decreases by 2-16 ppb

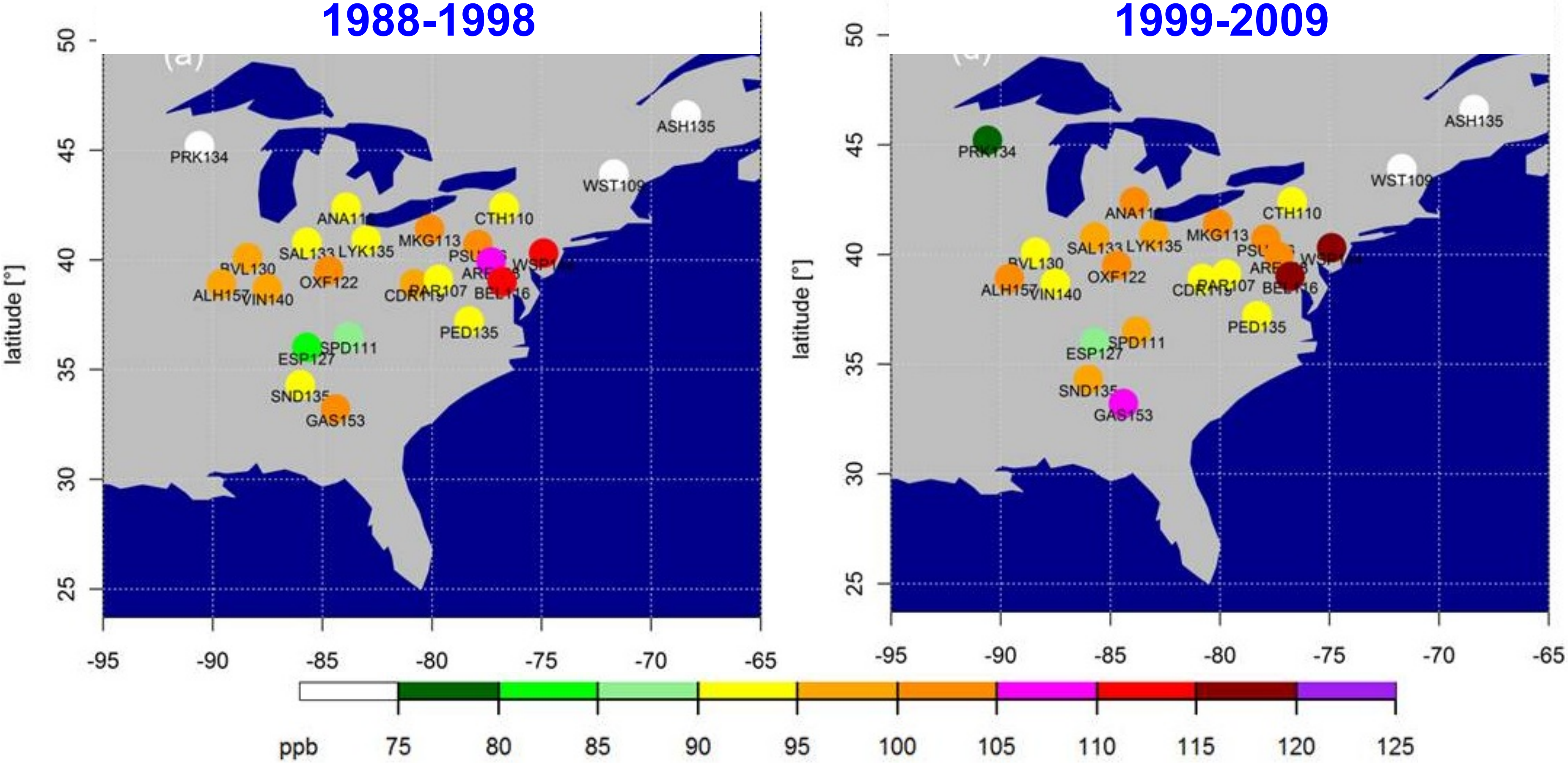
→ 1-year levels remain above the NAAQS threshold (75 ppb) across much of EUS

Rieder et al., ERL 2013

1999-2009 5-year return levels for JJA MDA8 O_3 over EUS now similar to 1988-1998 1-year levels

1-year Return Levels 1988-1998

5-year Return Levels 1999-2009



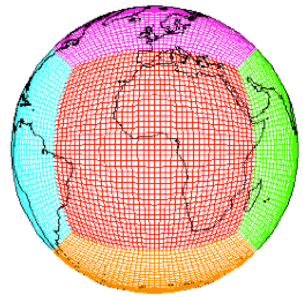
→ 5-yr return levels decrease by up to 20 ppb (not shown)

Rieder et al., ERL 2013

How will high-O_3 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^2 [*Lin et al., JGR, 2012ab*]

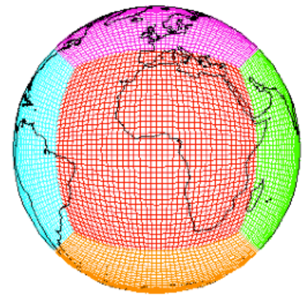


Donner et al., J. Climate, 2011; Golaz et al., J. Climate, 2011; Naik et al., submitted Horowitz et al., in prep

How will high-O_3 events evolve with future changes in emissions and climate?

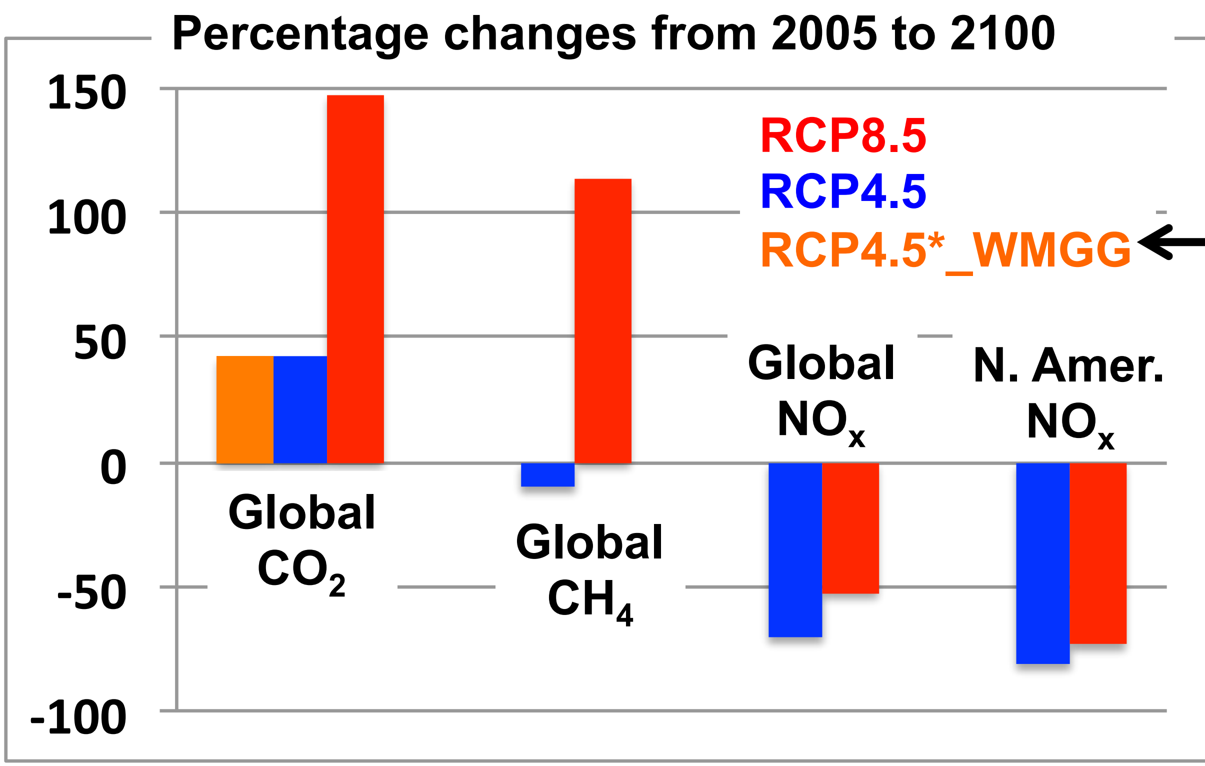
Tool: GFDL CM3 chemistry-climate model

- ~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^2 [*Lin et al., JGR, 2012ab*]



Donner et al., J. Climate, 2011;
Golaz et al., J. Climate, 2011;
Naik et al., submitted
Horowitz et al., in prep

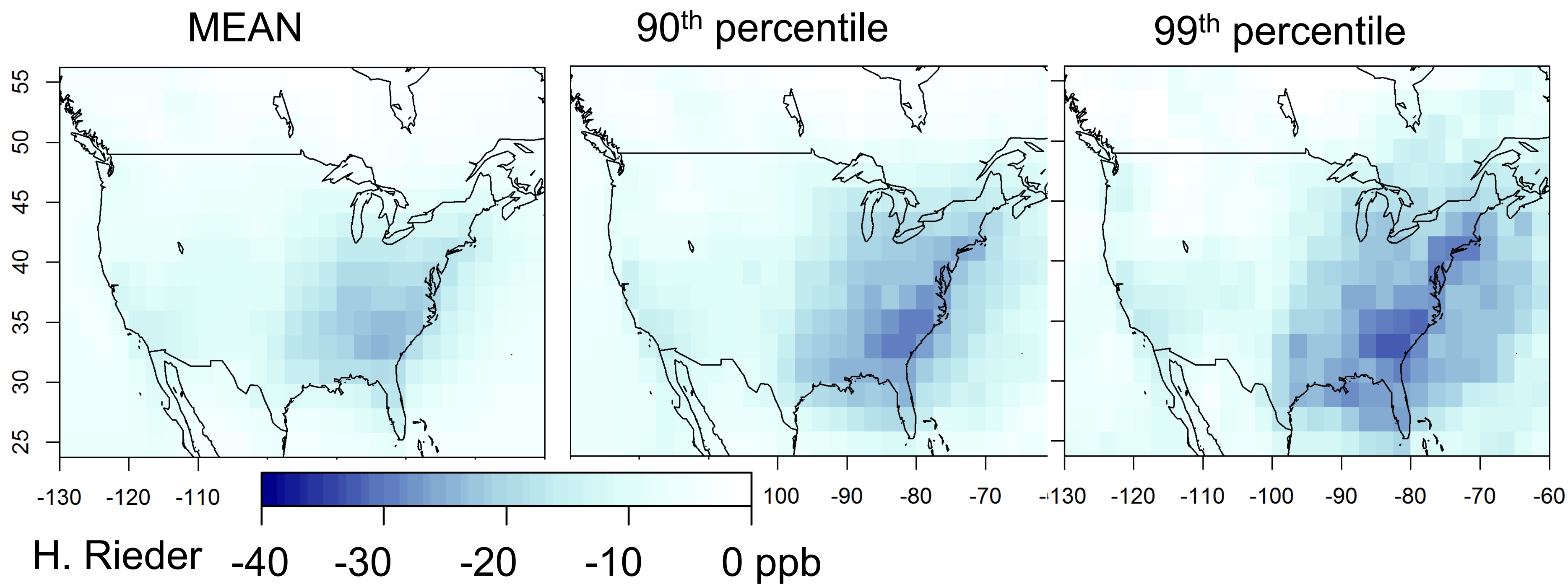
Climate / Emission Scenarios: Representative Concentration Pathways (RCPs)



Enables separation of roles of changing climate from changing air pollutant emissions

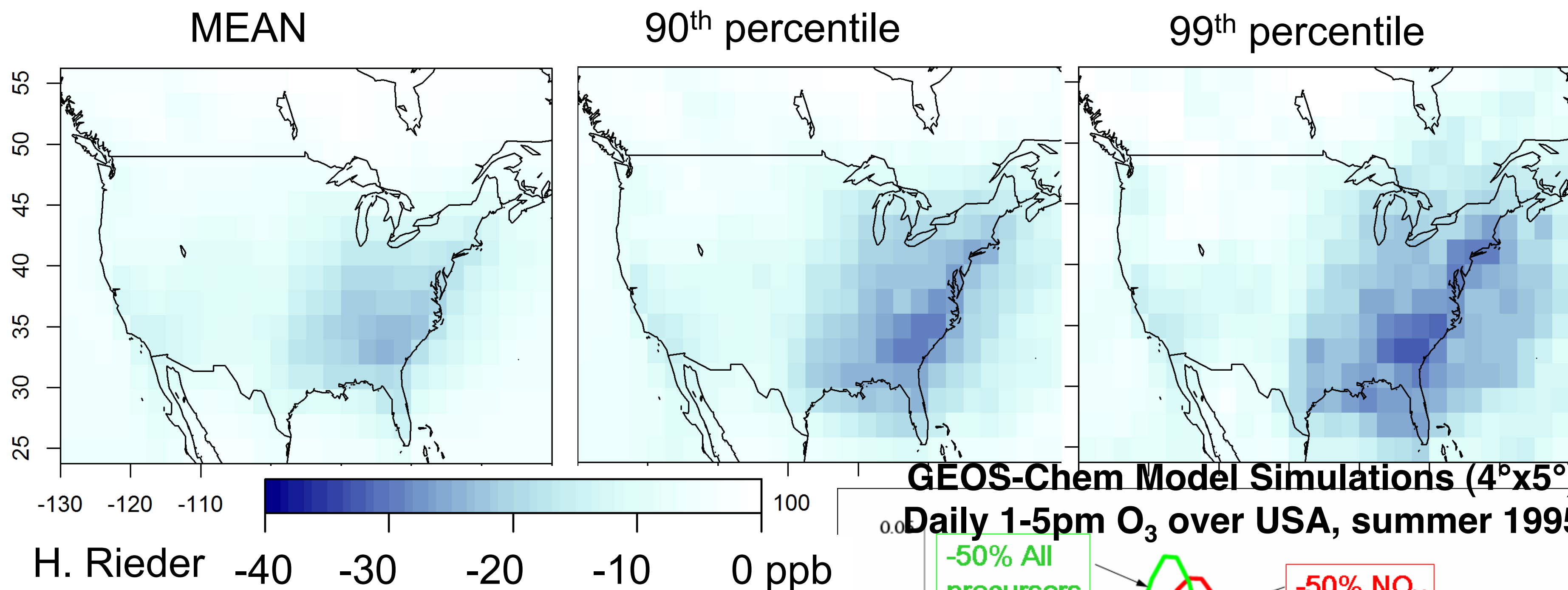
Surface ozone decreases most at high tail

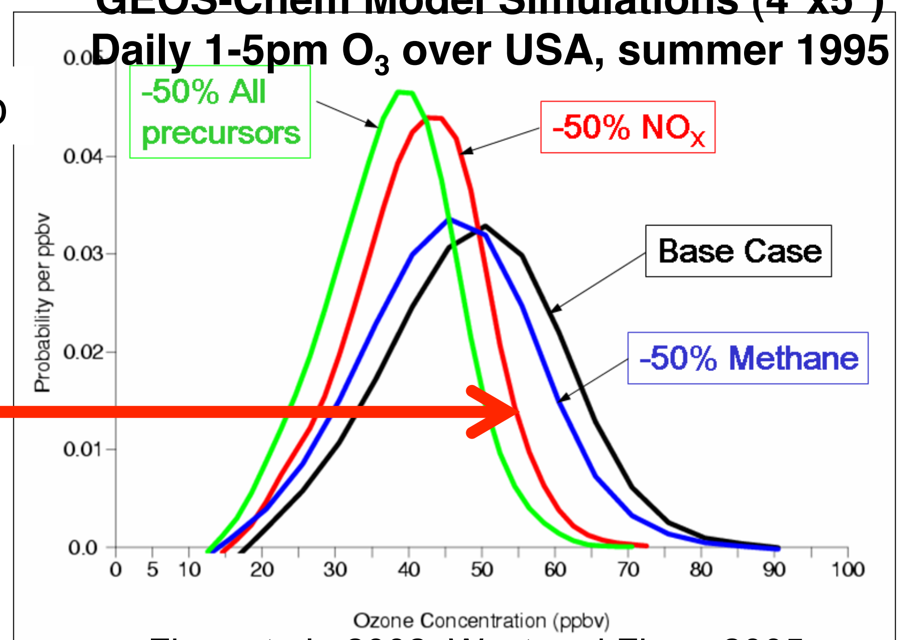
GFDL CM3 model, RCP4.5 scenario: (2046-2055) – (2006-2015)



Surface ozone decreases most at high tail

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





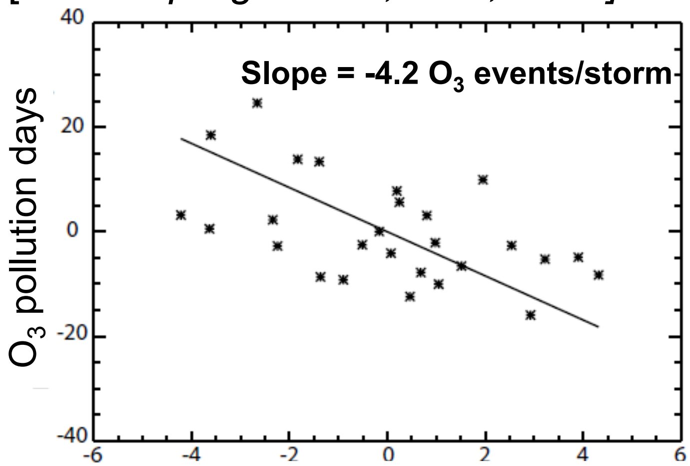
Fiore et al., 2002; West and Fiore, 2005

Influence of US NO_x emission reductions under RCP4.5: Strongly decrease regional pollution episodes

What controls well-documented O_3-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_3 events and storm counts (both detrended) [*Leibensperger et al, ACP, 2008]*

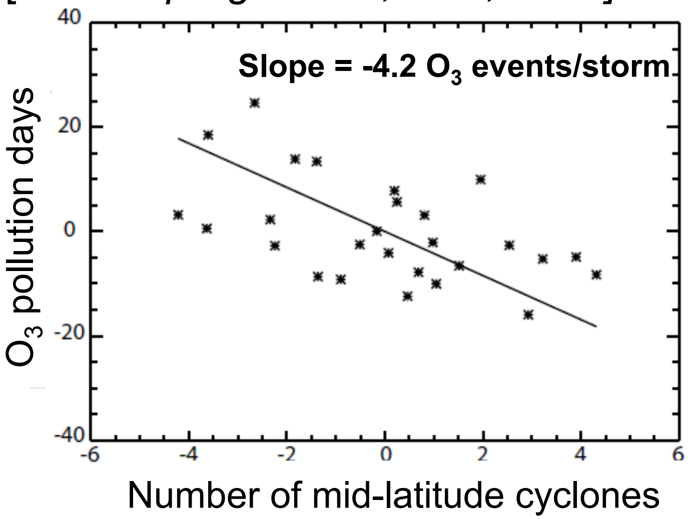


Turner et al., ACP, 2013

What controls well-documented O_3-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_3 events and storm counts (both detrended) [*Leibensperger et al, ACP, 2008]*



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

Region for counting O_3 events

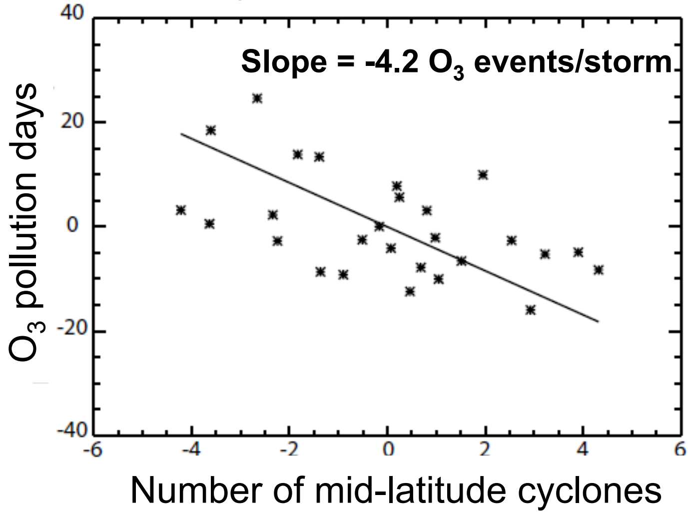
How does climate warming influence storms and O_3 events?

Turner et al., ACP, 2013

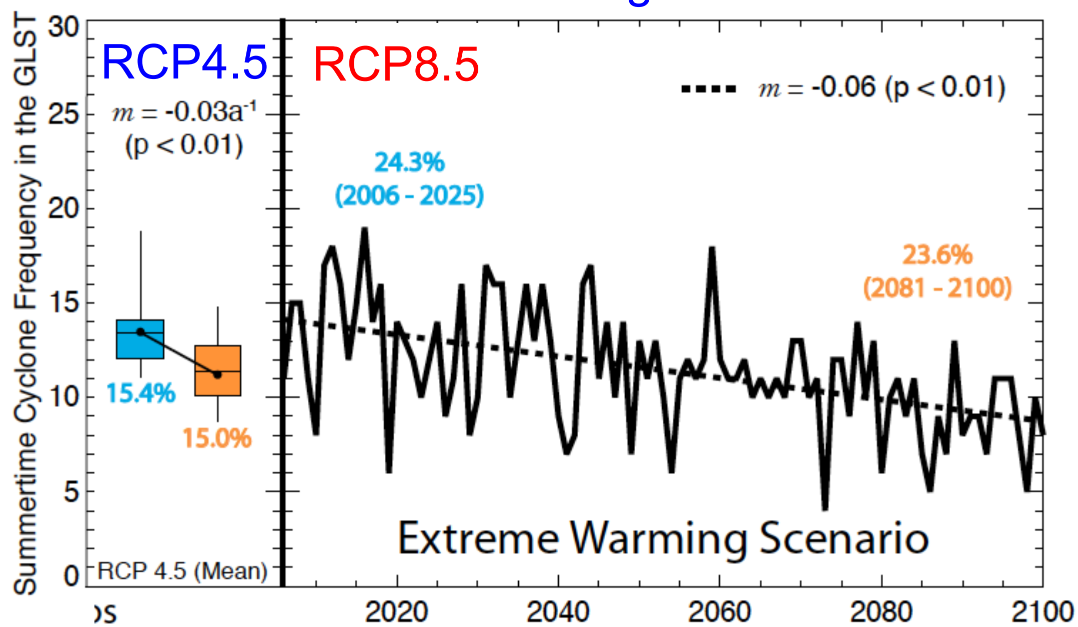
What controls well-documented O_3-Temp correlation in polluted regions?

[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_3 events and storm counts (both detrended) [*Leibensperger et al, ACP, 2008]*



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



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

Region for counting O_3 events

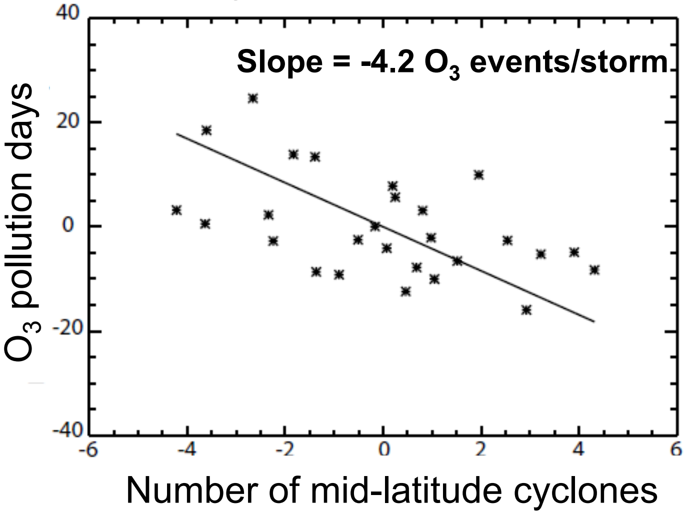
How does climate warming influence storms and O_3 events?

Turner et al., ACP, 2013

What controls well-documented O_3-Temp correlation in polluted regions?

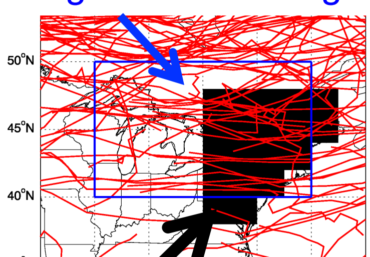
[e.g., Bloomer et al., 2009; Camalier et al., 2007; Cardelino and Chameides, 1990; Clark and Karl, 1982; Korsog and Wolff, 1991]

NE USA: anti-correlation between observed number of high-O_3 events and storm counts (both detrended) [*Leibensperger et al, ACP, 2008]*



MCMS storm tracker [*Bauer et al*., 2013]

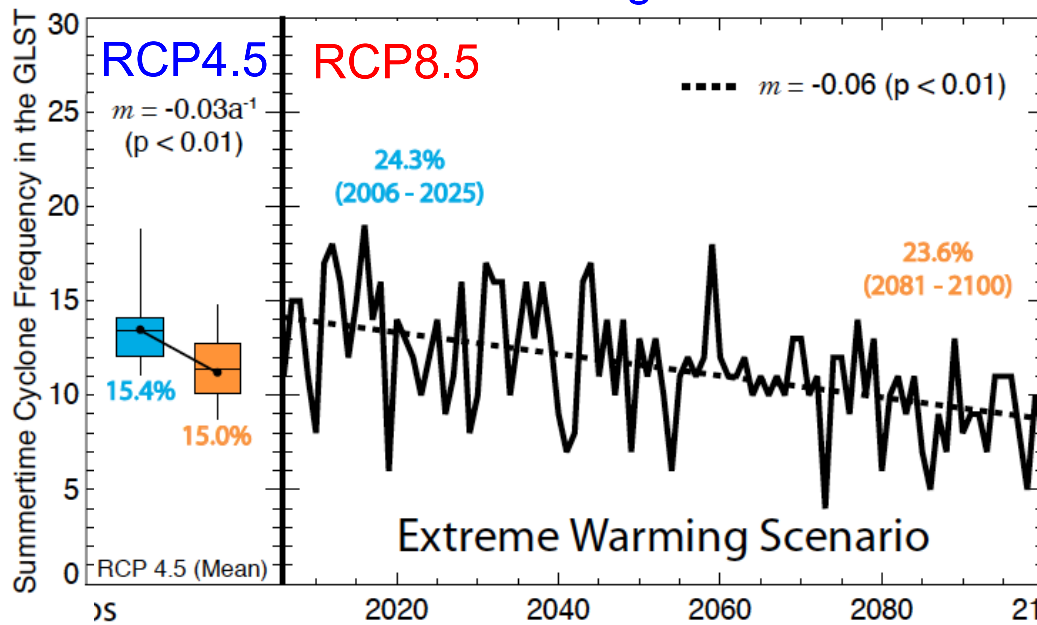
Region for counting storms

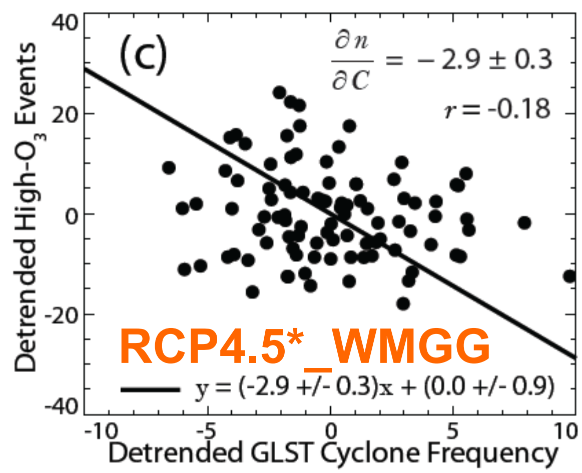


Region for counting O_3 events

How does climate warming influence storms and O_3 events?

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





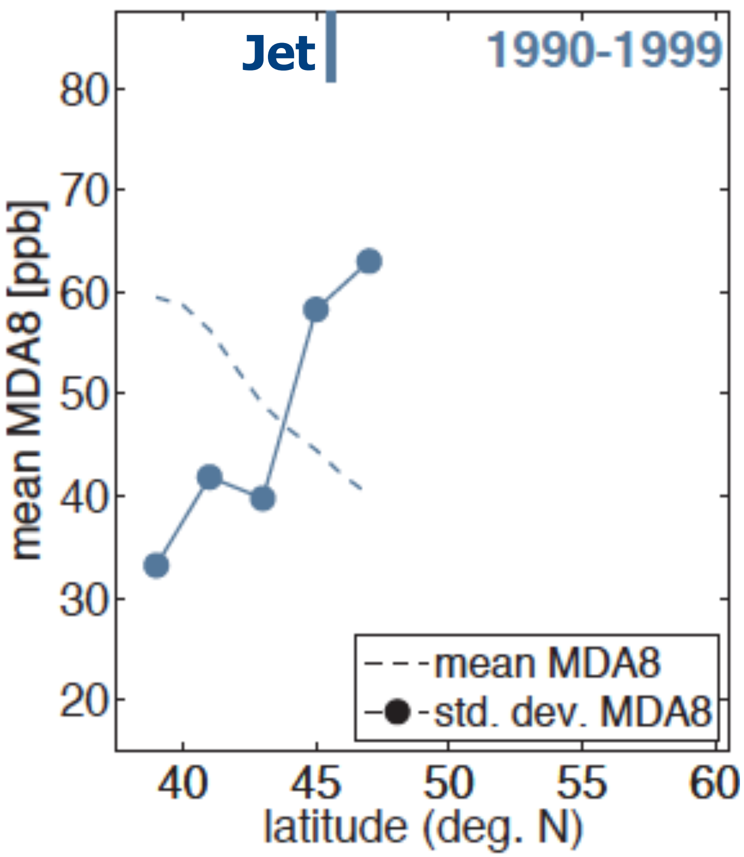
…but weak relationship with high-O_3 events: model problem? change in controlling factors?

Simpler diagnostic of large-scale circulation changes?

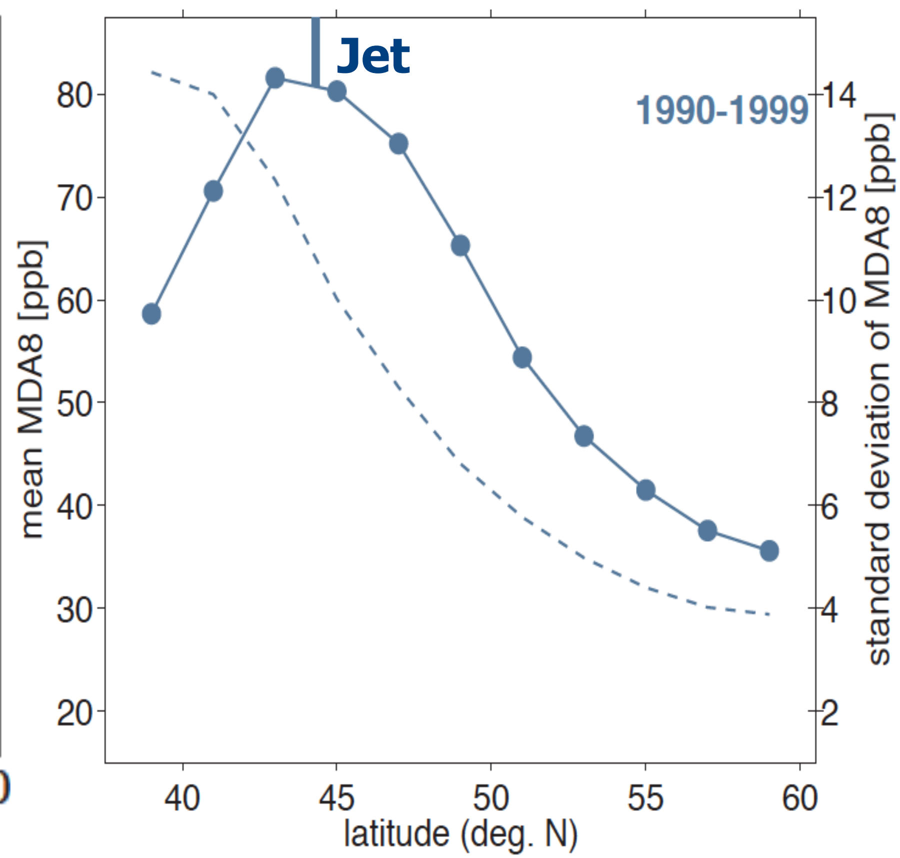
Turner et al., ACP, 2013

Summertime surface O_3 variability aligns with the 500 hPa jet over Eastern N. America

Observations
(CASTNET + MERRA reanalysis)



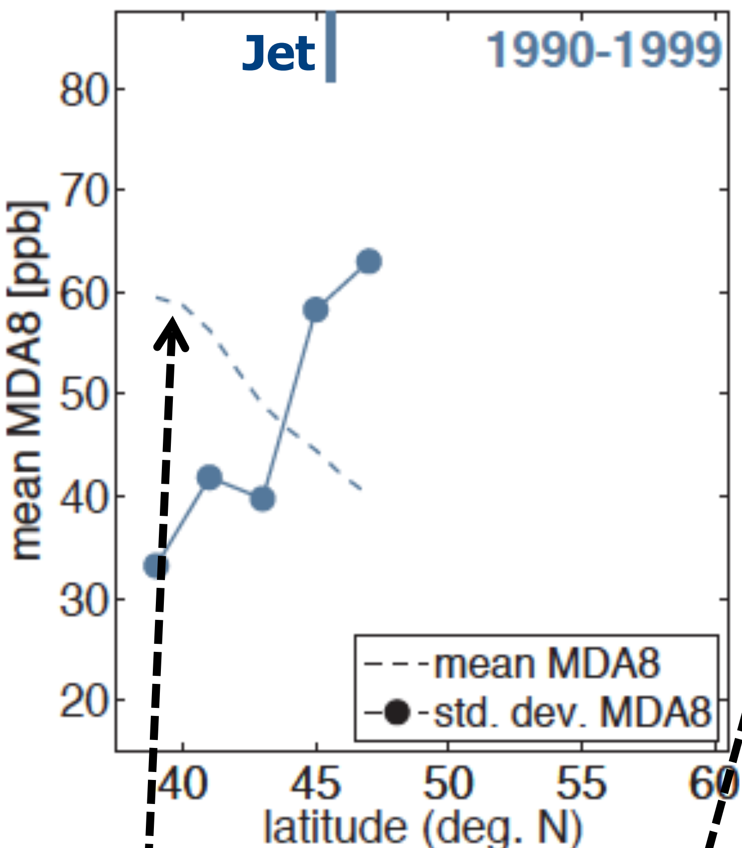
GFDL CM3 model
Historical simulations



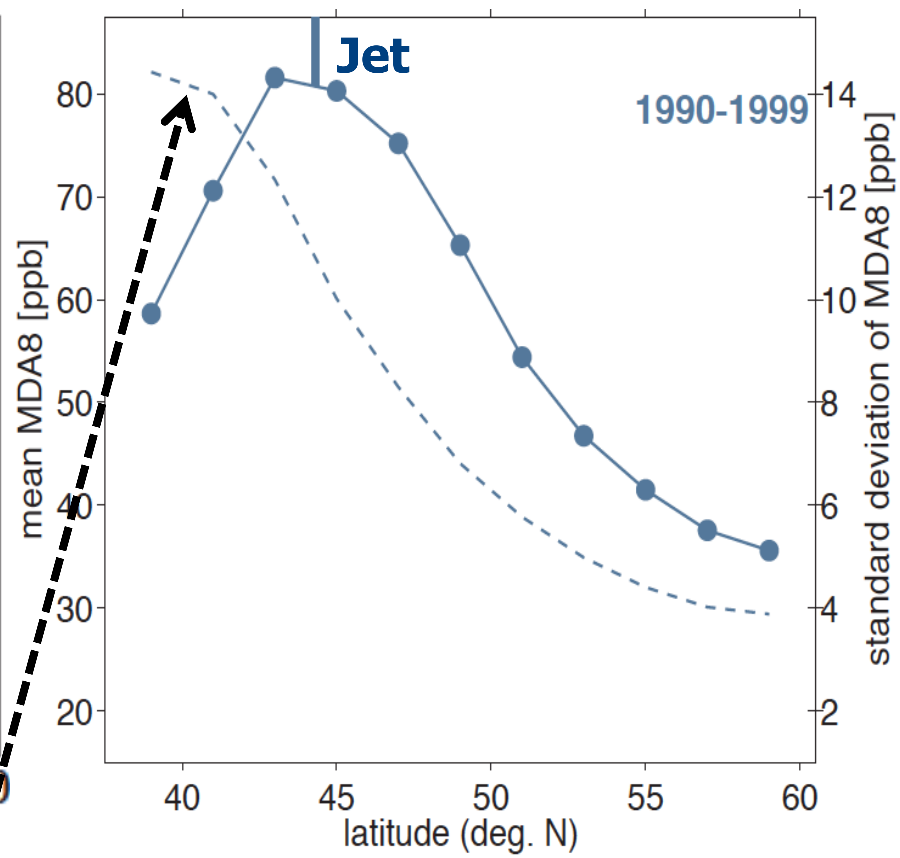
Barnes & Fiore, submitted

Summertime surface O_3 variability aligns with the 500 hPa jet over Eastern N. America

Observations (CASTNET + MERRA reanalysis)



GFDL CM3 model Historical simulations

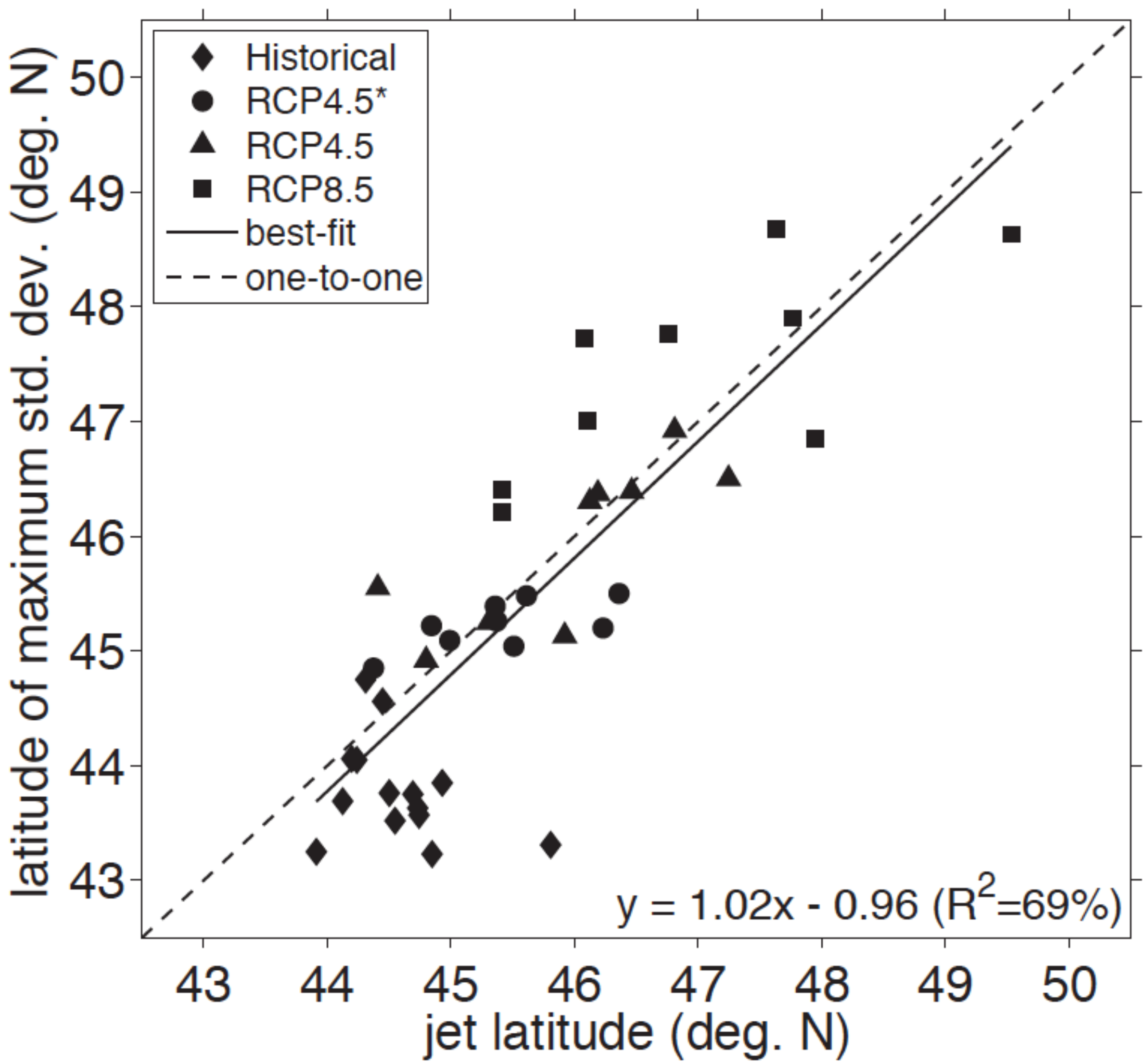


NO_x emissions peak south of jet where mean MDA8 O_3 highest

Standard deviation of zonally averaged JJA MDA8 O_3
→ **Max at the jet latitude**

Barnes & Fiore, submitted

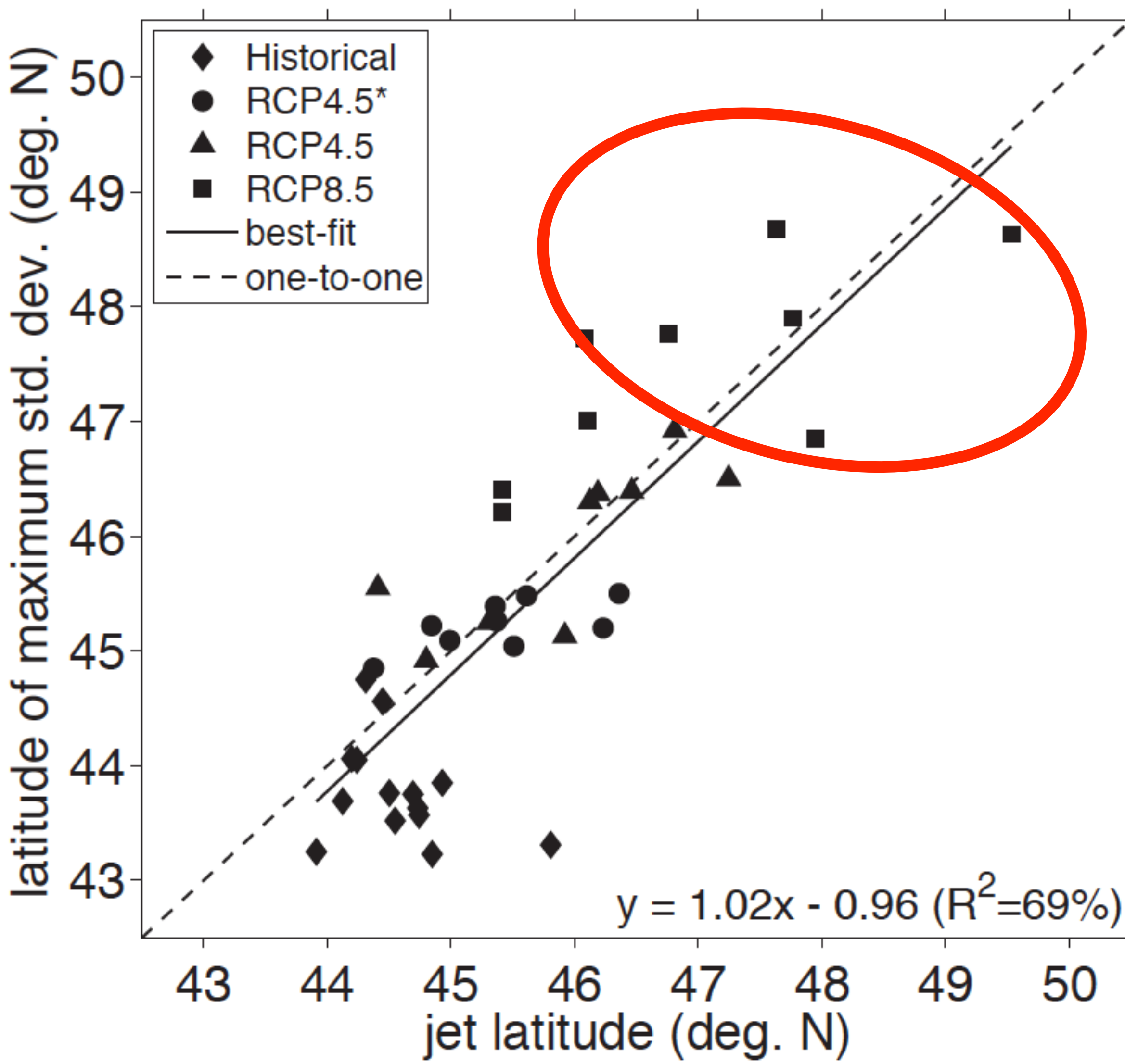
Peak latitude of summertime surface O_3 variability over Eastern N. America follows the jet as climate warms



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

Barnes & Fiore, submitted

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



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

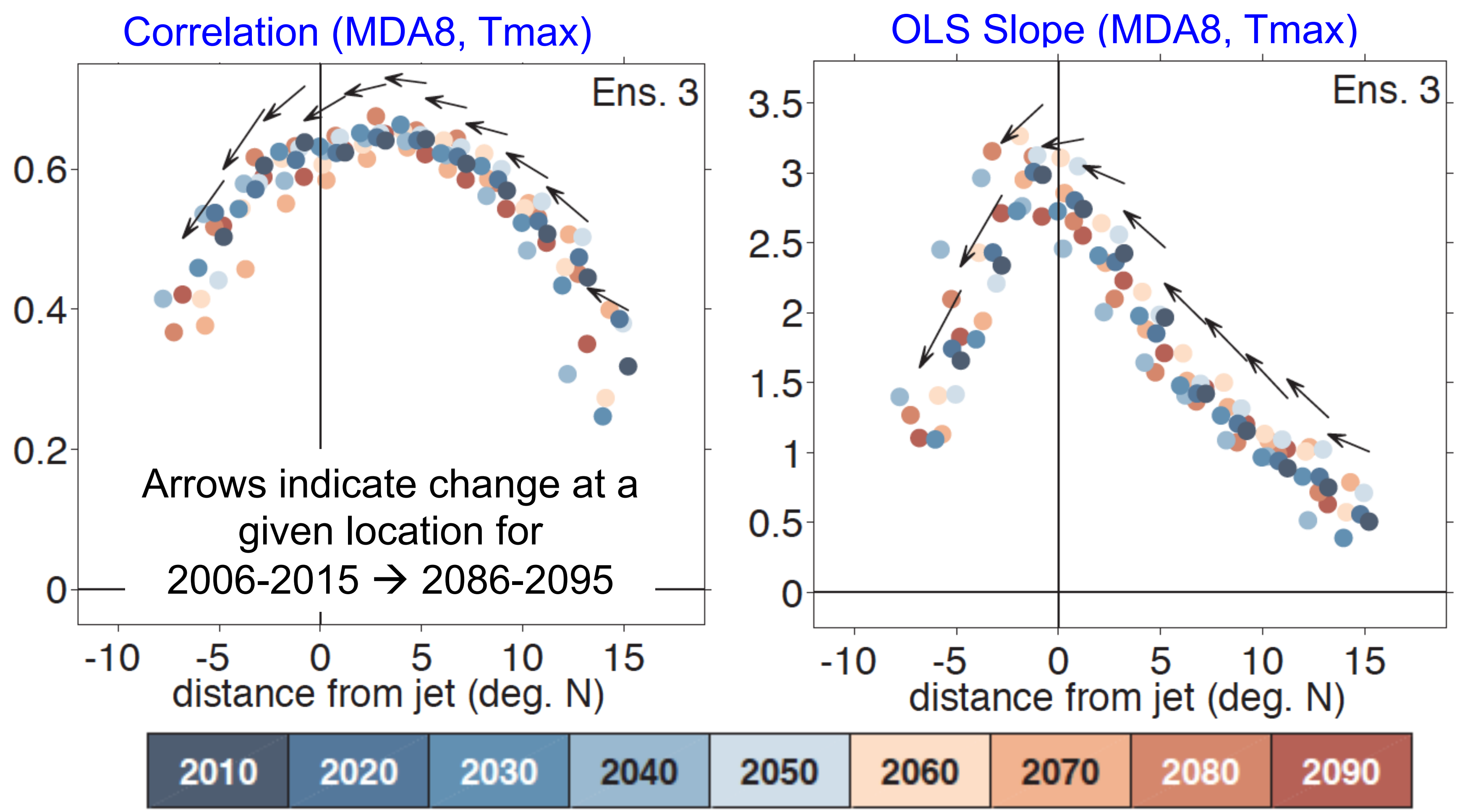
RCP8.5: most warming, Largest jet shift

Barnes & Fiore, submitted

Ozone relationship with temperature varies with jet location

Barnes & Fiore, submitted

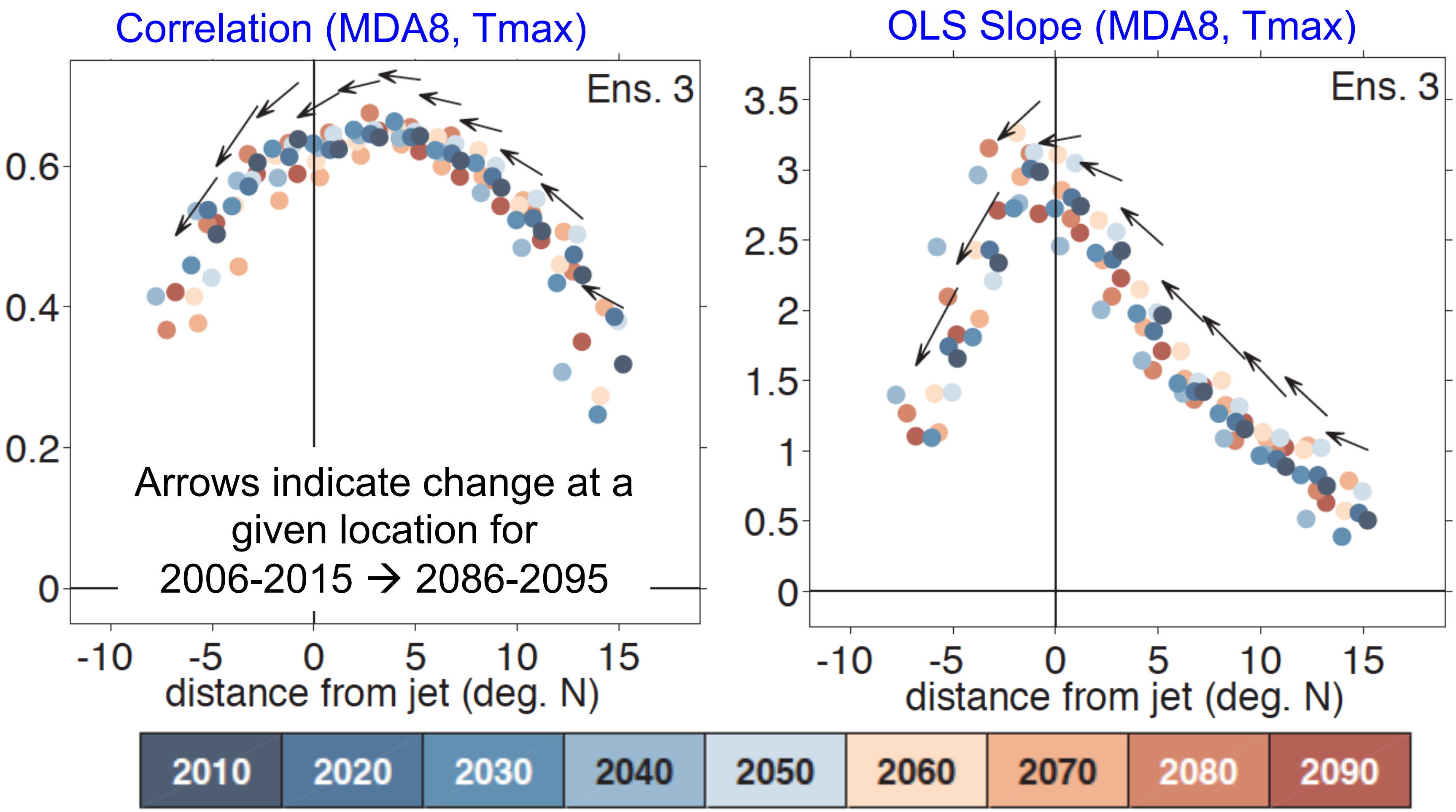
GFDL CM3 RCP4.5*_WMGG (air pollutants at 2005 levels): Decadal averages



Ozone relationship with temperature varies with jet location

Barnes & Fiore, submitted

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



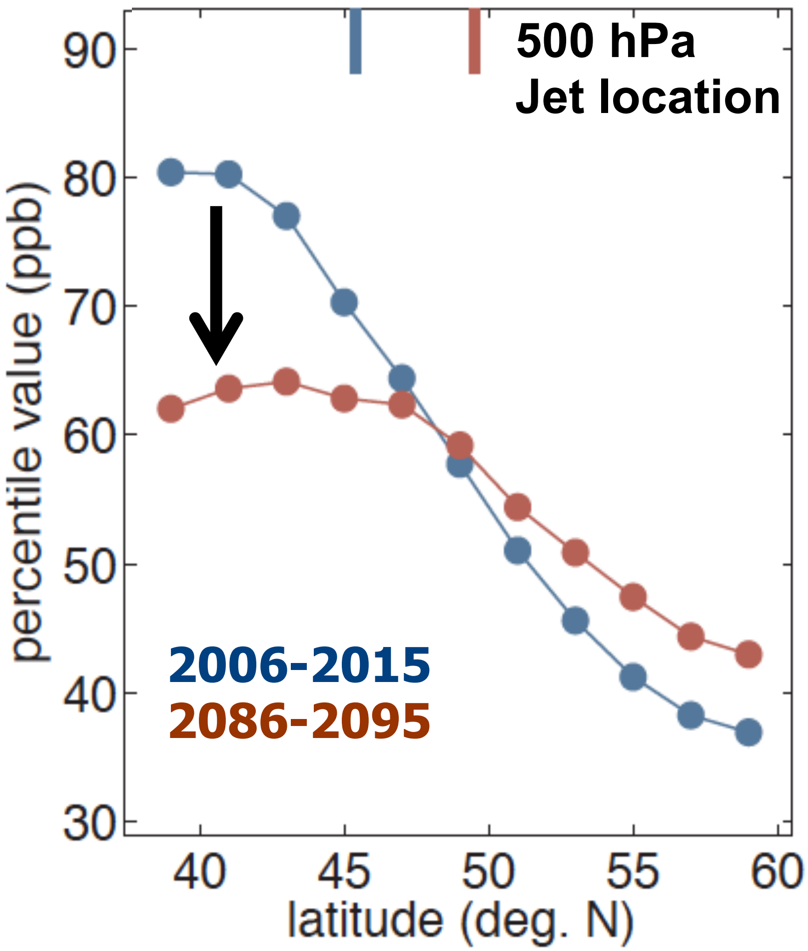
→ Observed local O_3:T relationships may not hold if large-scale circulation shifts

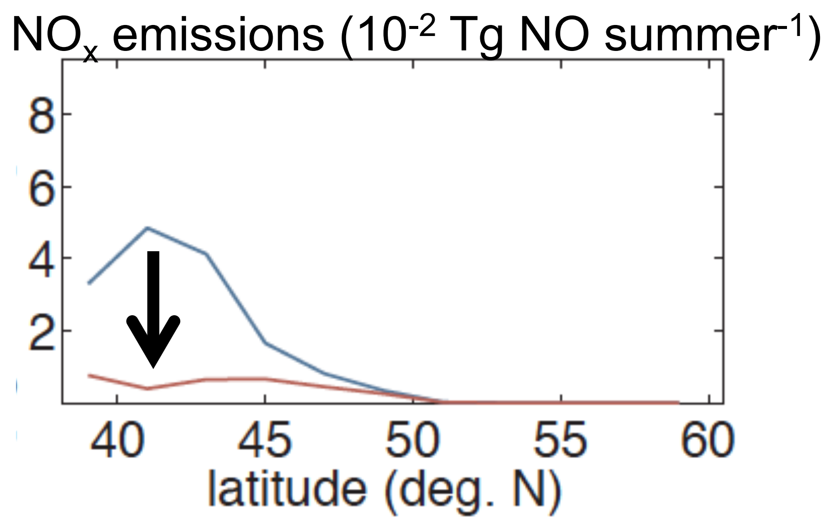
→ Differences in simulated jet positions → model discrepancies in O_3 responses?

→ Is a jet location a useful predictor? i.e., quantitative relationships?

Shifting jet: Implications for extreme air pollution events?

90th percentile, RCP8.5
GFDL CM3 model



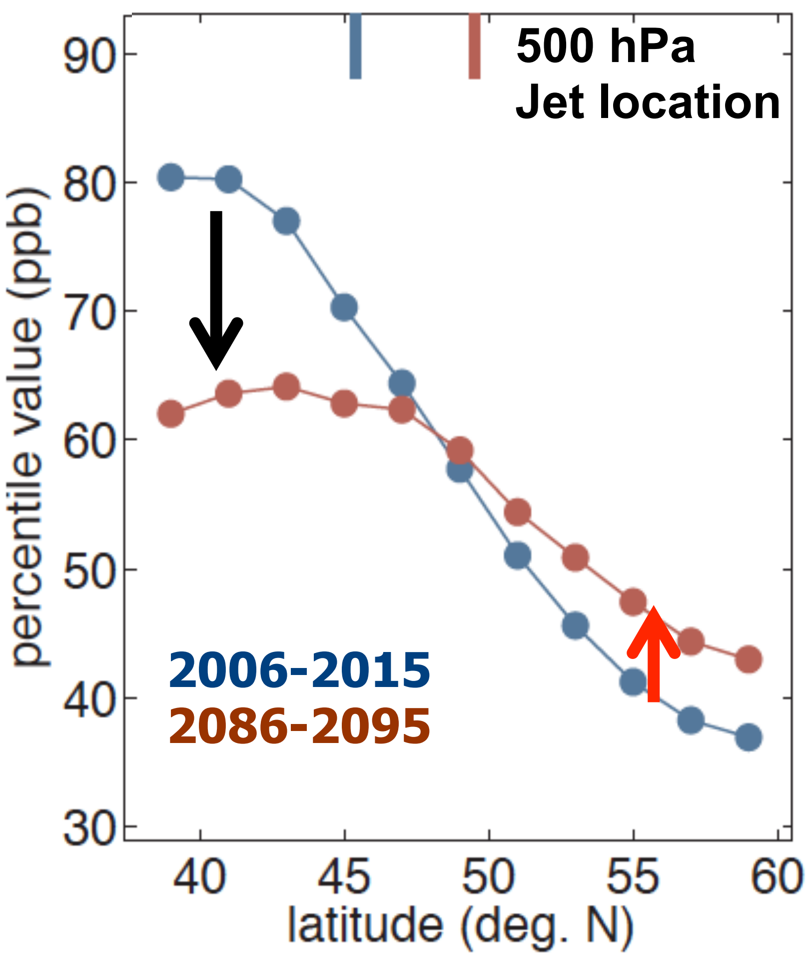


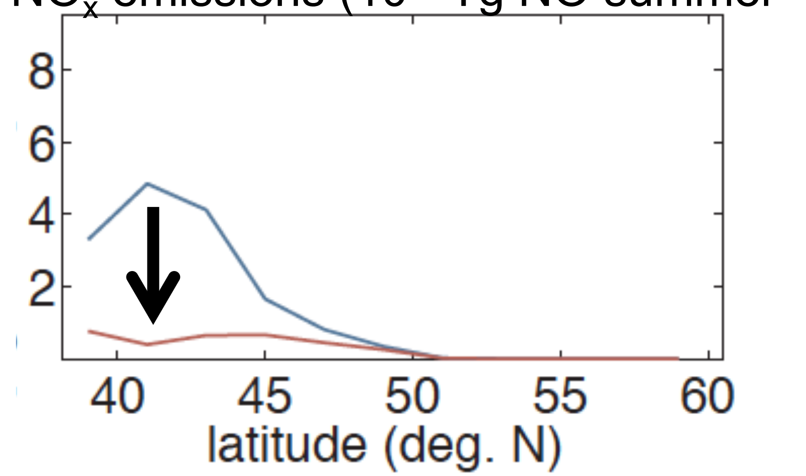
Regional NO$_x$ emission reductions decrease 90th percentile values

Barnes & Fiore, submitted

Shifting jet: Implications for extreme air pollution events?

90th percentile, RCP8.5
GFDL CM3 model





Regional NO_x emission reductions decrease 90th percentile values

Jet shift + rise in baseline O_3 (methane)?

→ Targeted simulations to separate roles of rising CH_4, decreasing NO_x from large-scale circulation changes

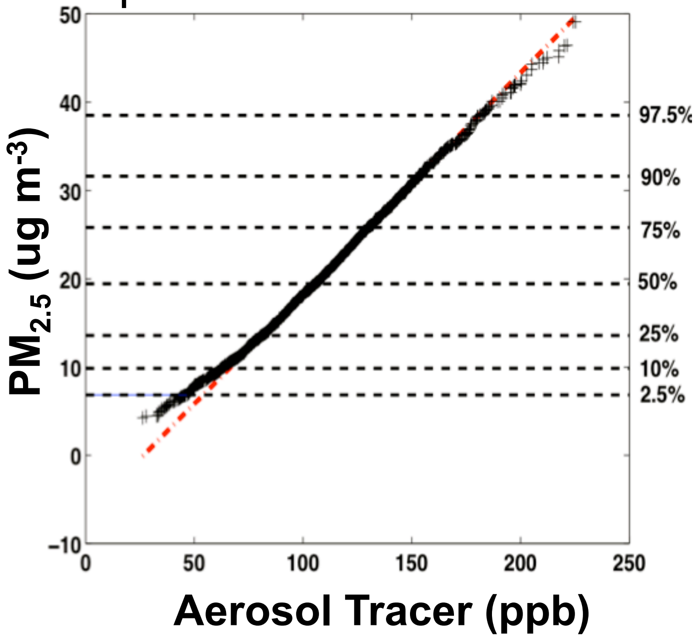
Barnes & Fiore, submitted

Simple tracer mimics climate-driven changes in summertime $PM_{2.5}$ over polluted N. mid-latitude regions

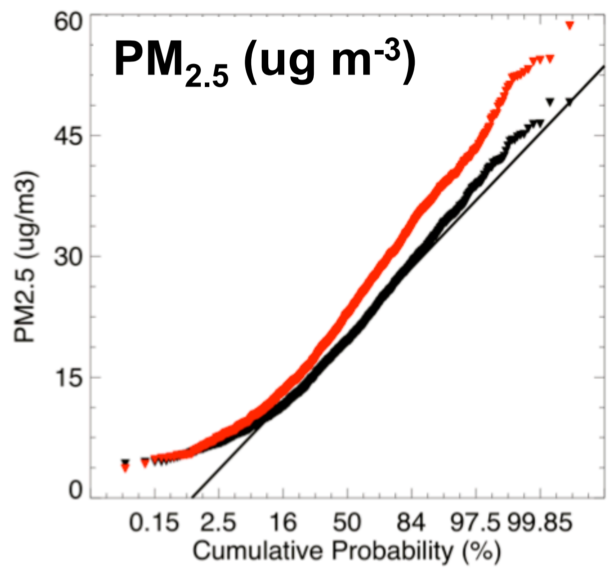
CLIMATE CHANGE ONLY AM3 idealized simulations (20 years)

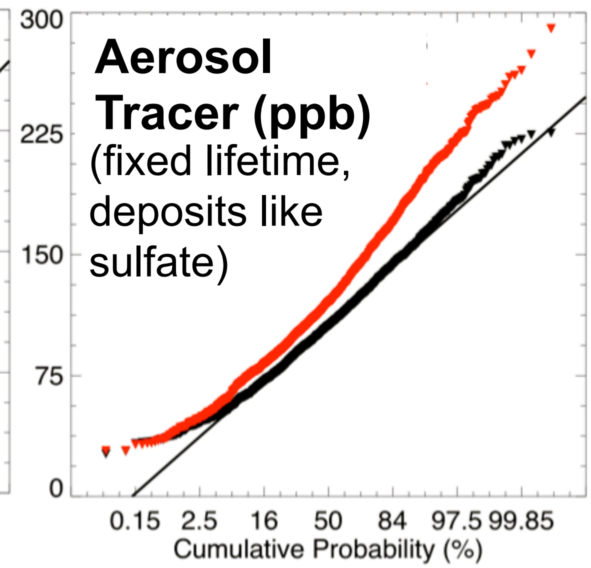
JJA daily mean over Northeast USA

Comparison of 1990s distribution



Change from **1990s** to **2090s** due to warming climate





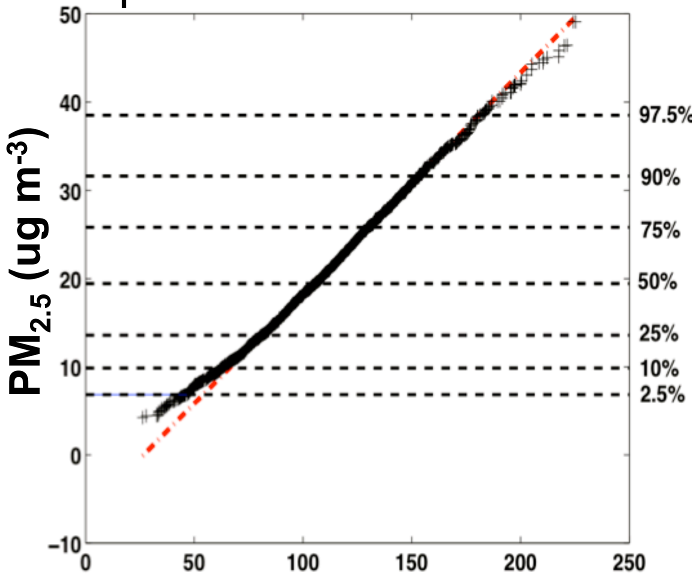
Fang et al., GRL, 2013

Simple tracer mimics climate-driven changes in summertime $PM_{2.5}$ over polluted N. mid-latitude regions

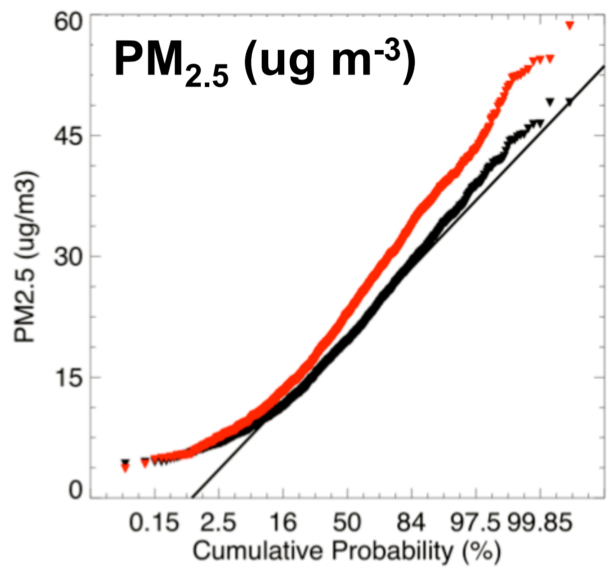
CLIMATE CHANGE ONLY AM3 idealized simulations (20 years)

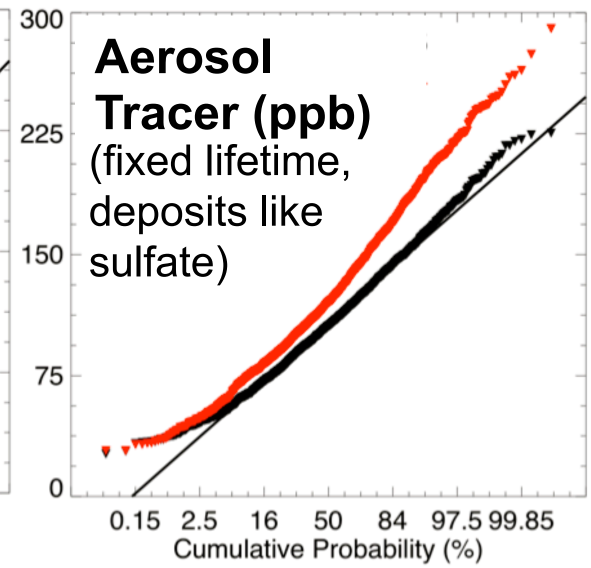
JJA daily mean over Northeast USA

Comparison of 1990s distribution



Change from **1990s** to **2090s** due to warming climate



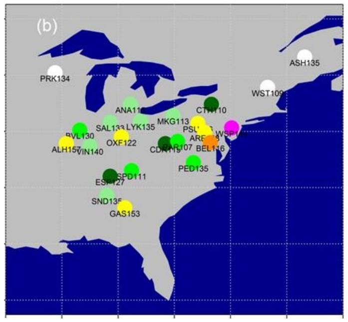


→Cheaper option to reconstruct AQ info from simple tracer in physical climate models (e.g., high res)

→Opportunity to further test utility in ongoing chemistry-climate simulations (CCMI effort: http://www.igacproject.org/CCMI)

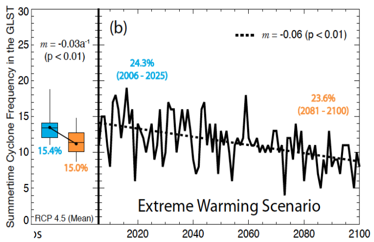
Fang et al., GRL, 2013

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



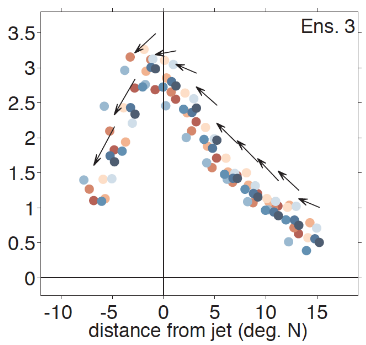
- Applied EVT to derive return levels for O_3 observed over EUS
- New metric for quantifying success of NO_x emission controls [*Rieder et al., ERL, 2013*]

→ Apply to $PM_{2.5}$, precipitation, future model projections
→ Event persistence? Model bias correction?



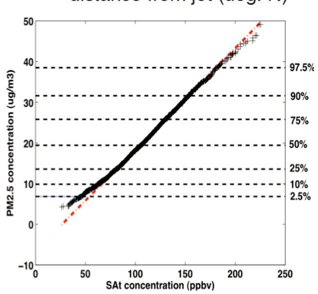
- NEUS summer cyclones decline in GFDL CM3 warming simulations
- Weak relationship with high-O_3 events [*Turner et al., ACP, 2013*]

→ Connect with large-scale circulation changes
→ Identify key drivers of extreme events in other regions



- O_3 variability aligns with the 500 hPa jet over NE N. America
- Jet shifts can influence O_3:T [*Barnes & Fiore, submitted*]

→ Tease apart role of climate vs. emissions (NO_x and CH_4)
→ 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*]



- Synthetic aerosol tracer captures climate-driven change (wet deposition) in $PM_{2.5}$ distribution [*Fang et al., GRL, 2013 (in press)*]

→ Assess robustness across models (CCMI effort)
→ Computationally cheap AQ info from GCMs?