Ozone pollution extremes over the eastern USA in summer: Recent trends, future projections

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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U.S. EPA NCER/ASD Webinar
Applied Sciences Webinar Series
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How and why might extreme air pollution events change?

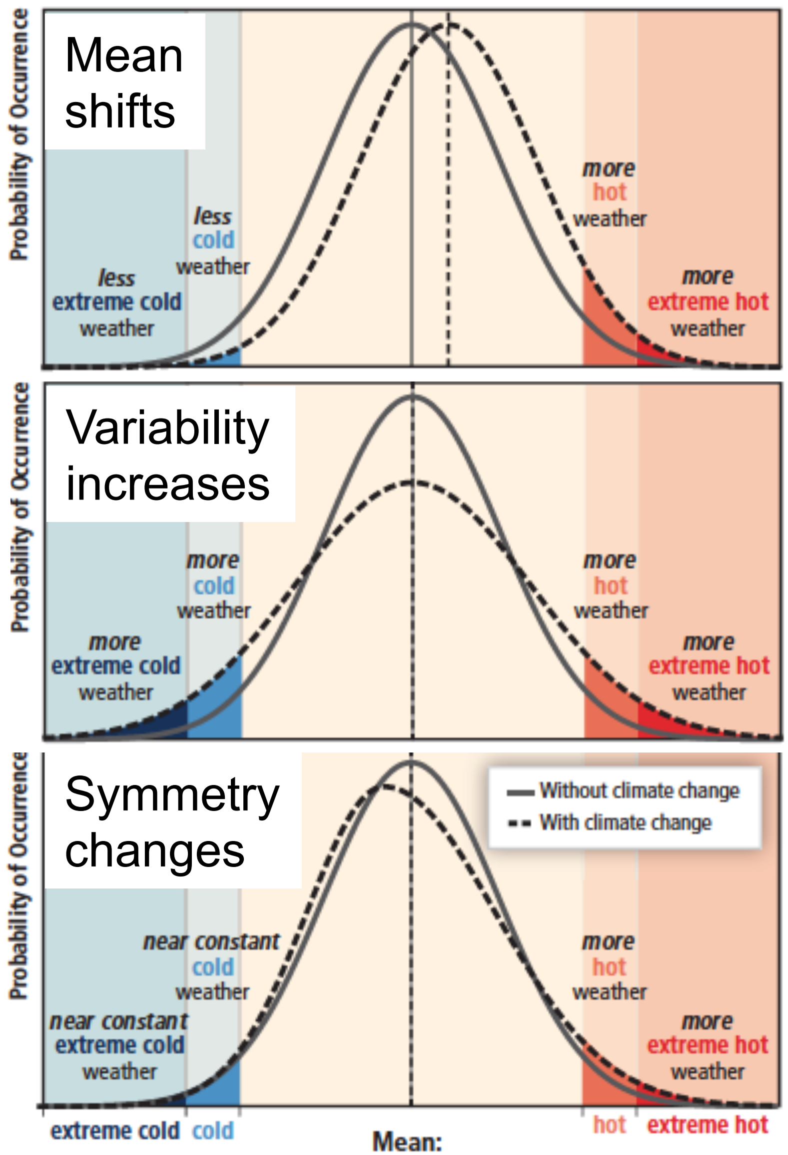
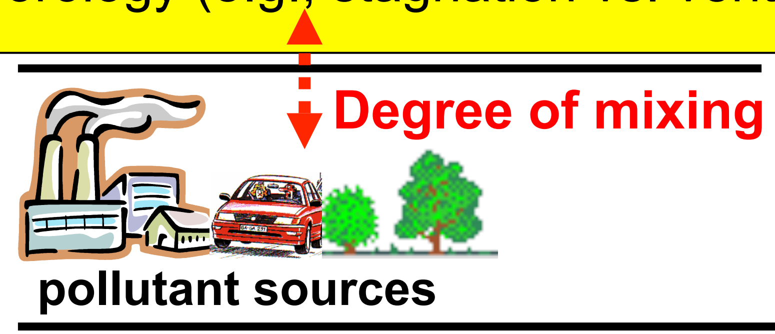


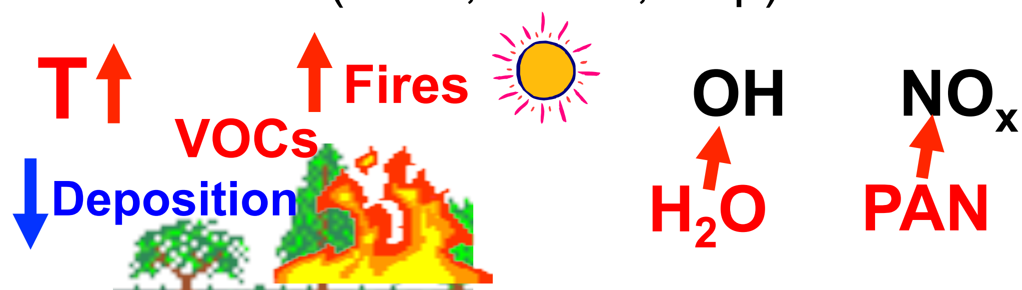
Figure SPM.3, IPCC SREX 2012
http://ipcc-wg2.gov/SREX/

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

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



- Feedbacks (Emis, Chem, Dep)

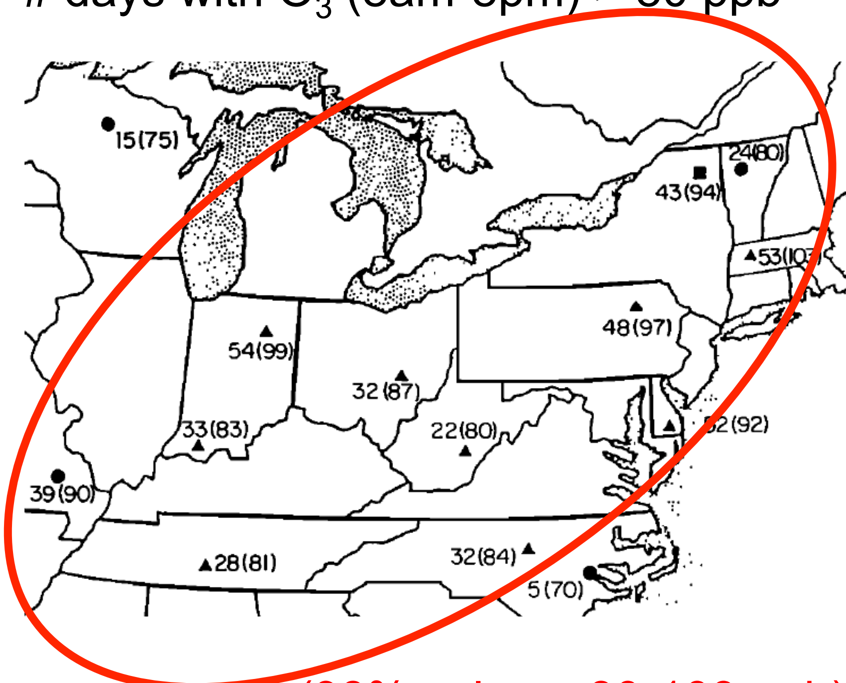


- Changing global emissions (baseline)
  → Shift in mean?
- Changing regional emissions (episodes)
  → Change in symmetry?

Today's Focus

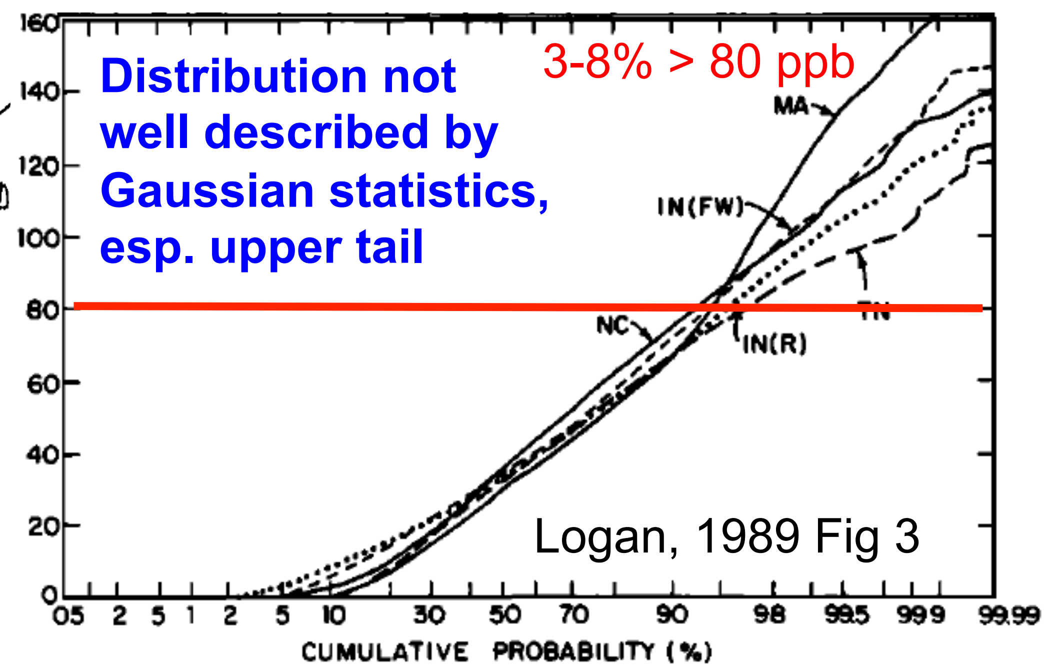
Logan, 1989: Recognized regional scale of EUS high-O_3 events; expressed urgent need for routine measurements at rural sites

SURE and NAPBN sites Apr-Sep 1979
days with O_3 (8am-8pm) > 80 ppb



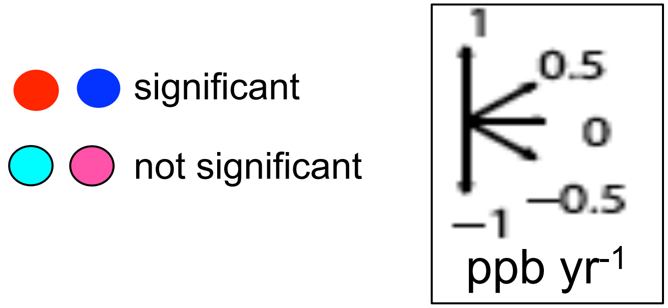
(98% values: 80-103 ppb)

April-Sept 1978-9 O_3 cumulative probability distribution
0000-2300 LT (ppb) at SURE sites

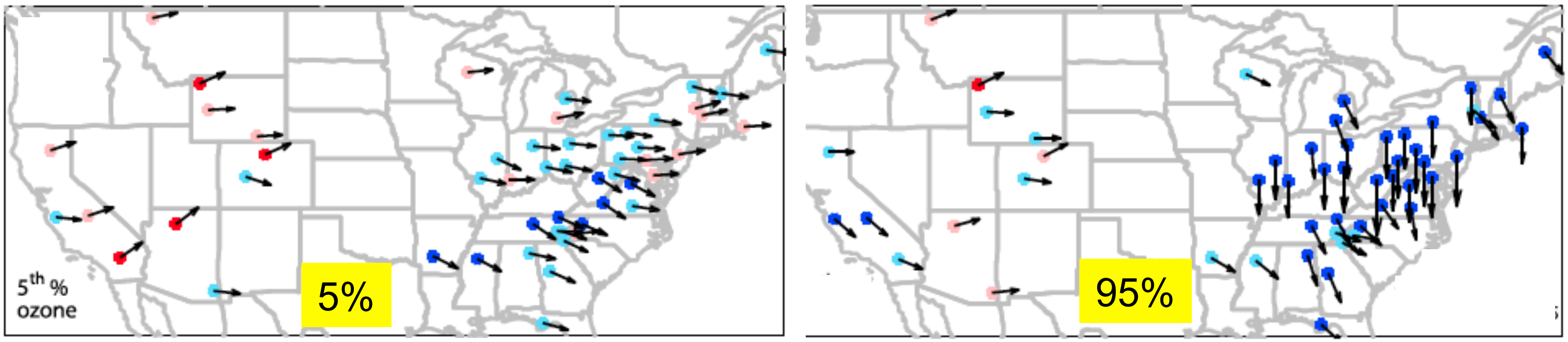


U.S. EPA CASTNet has now measured rural O_3 for over two decades
→ How has the O_3 distribution, including extreme events, changed?

Trends in summer daytime (11am-4pm) average ozone at rural U.S. monitoring sites (CASTNet): 1990 to 2010



Cooper et al., JGR, 2012

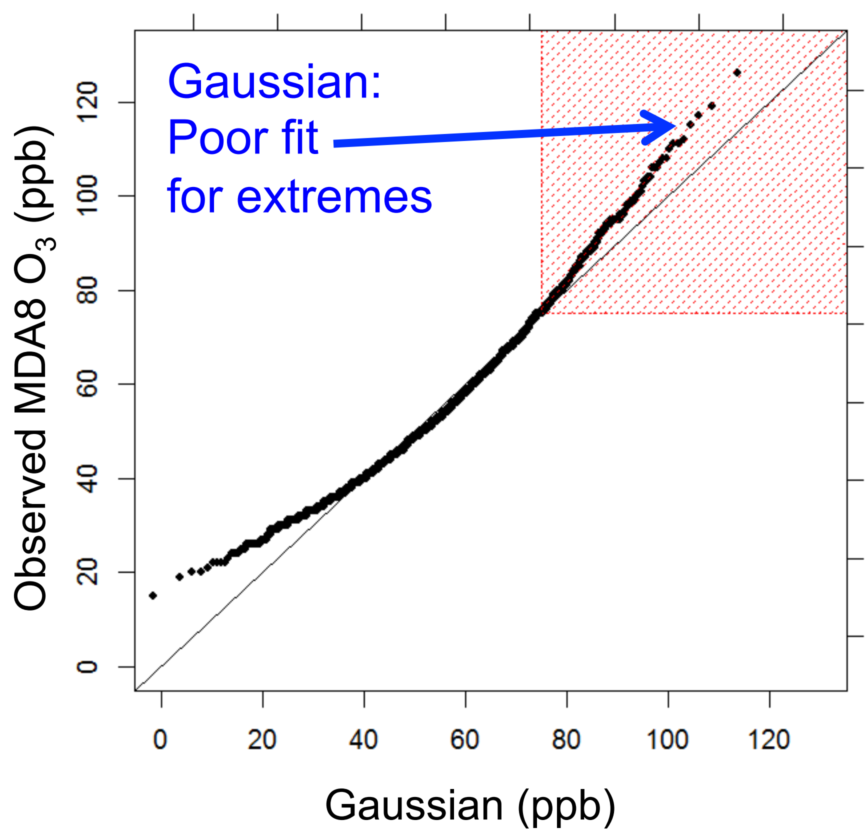


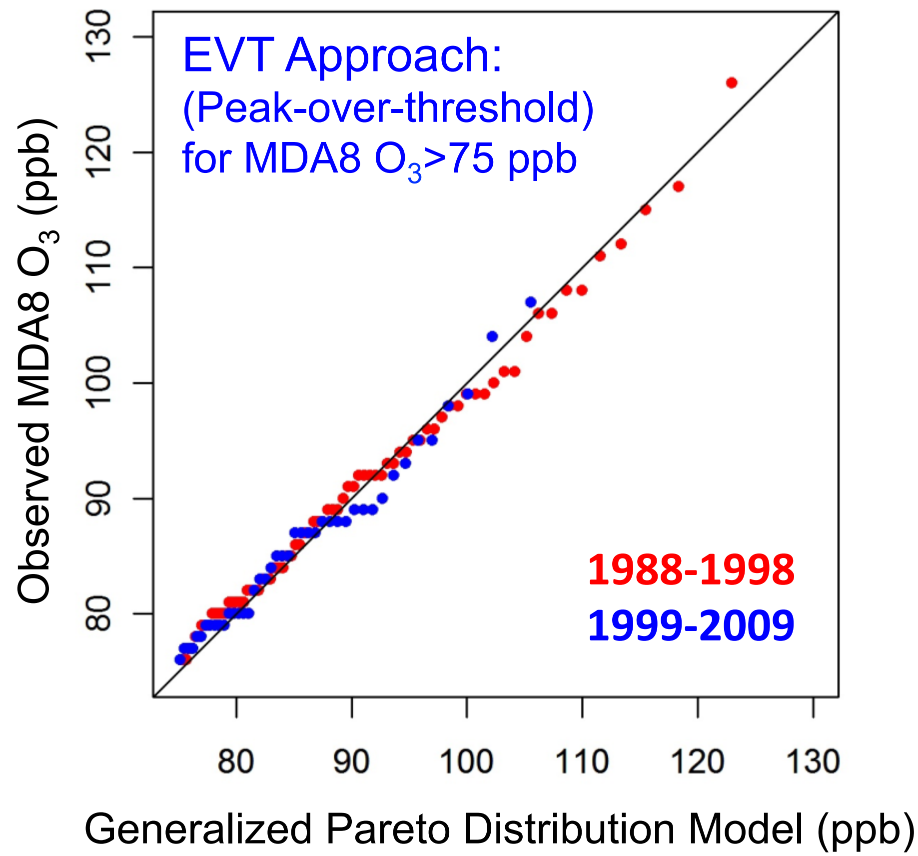
→ Success in decreasing highest levels, but baseline rising (W. USA)

→ Decreases in EUS attributed in observations and models to NO_x emission controls in late 1990s, early 2000s [e.g., Frost et al., 2006; Hudman et al., 2007; van der A. et al., 2008; Stavrakou et al., 2008; Bloomer et al., 2009, 2010; Fang et al., 2010]

Extreme Value Theory (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

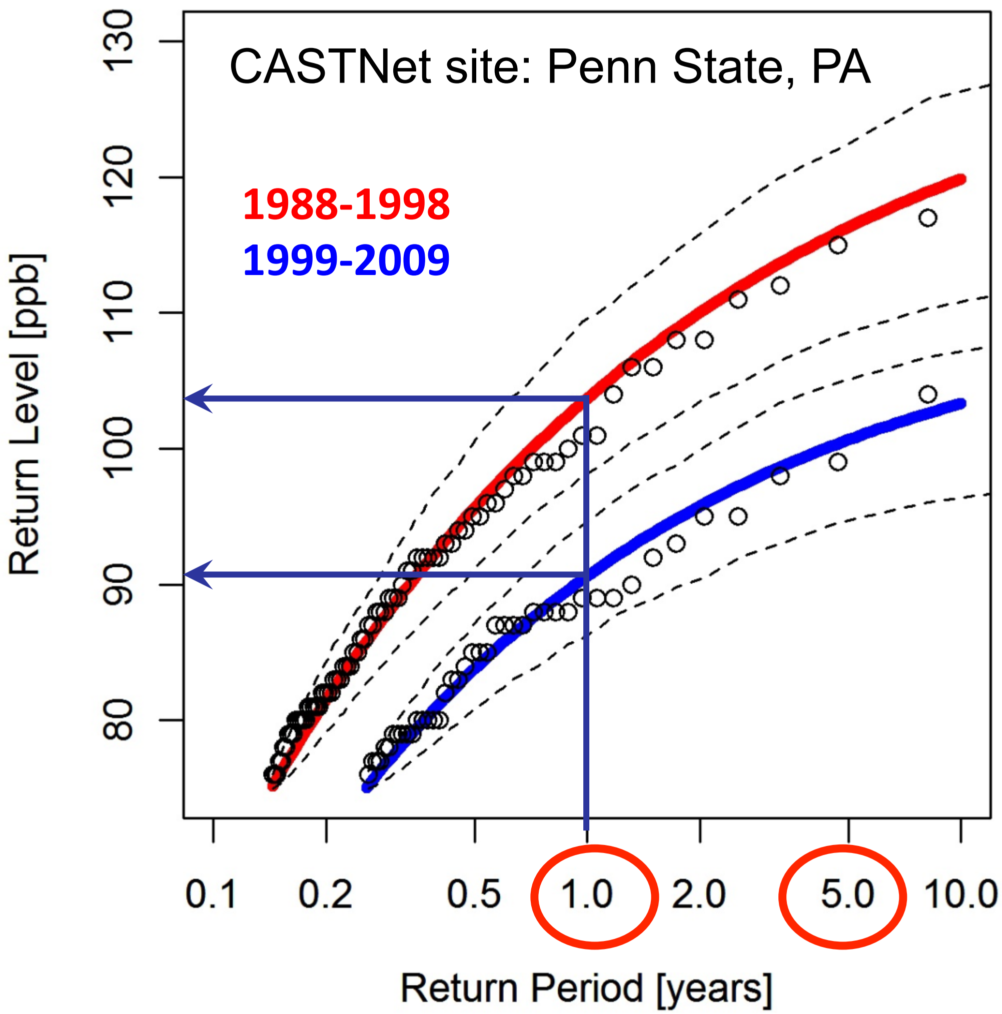




Rieder et al., ERL 2013

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

Return level: describes probability of observing value *x (level)* within time window *T (period)*

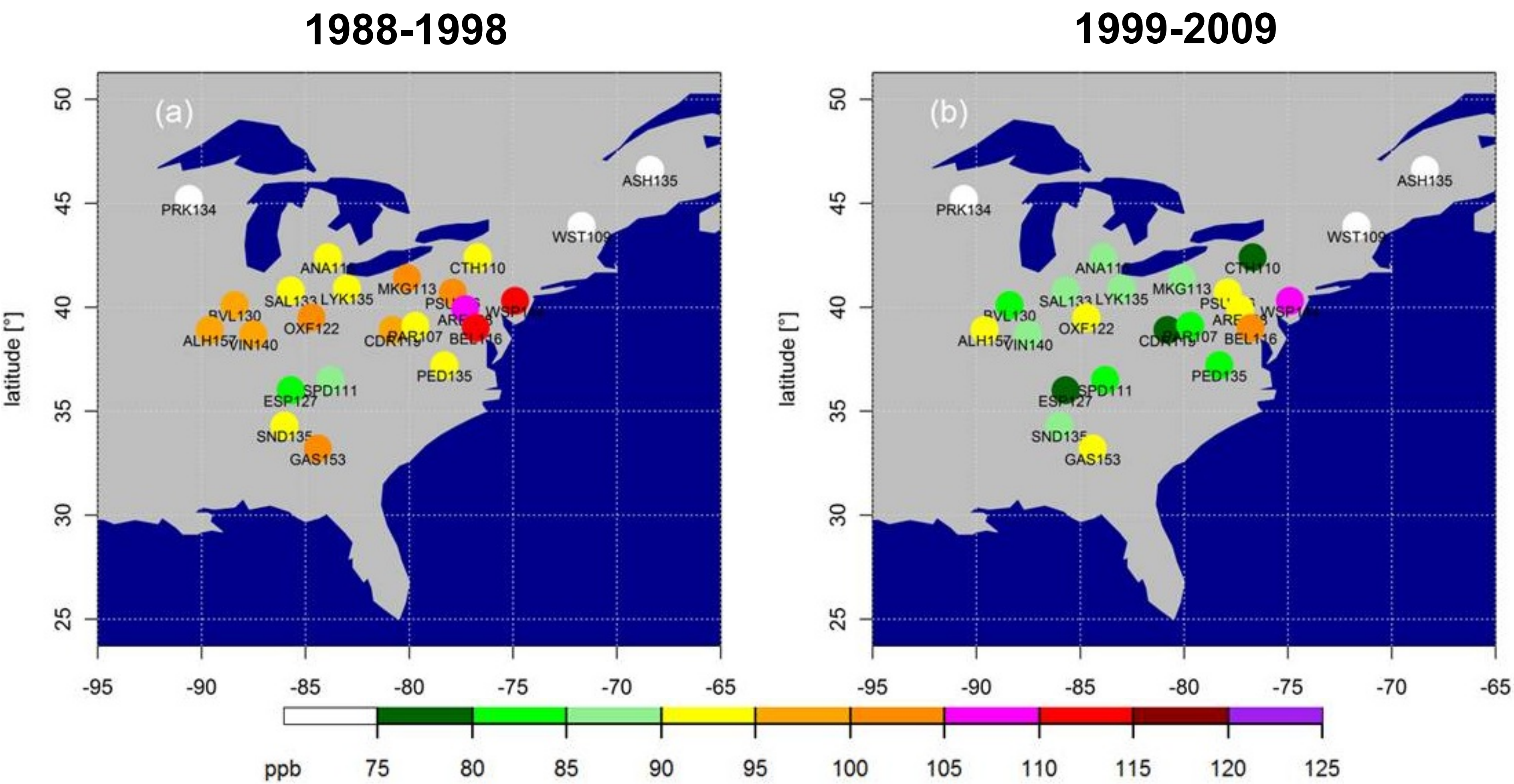


- → Sharp decline in return levels between early and later periods (NO_x SIP call)
- → Consistent with prior work [*e.g., Frost et al., 2006; Bloomer et al., 2009, 2010*]
- → Translates air pollution changes into probabilistic language

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

Rieder et al., ERL 2013

1-year return levels for JJA MDA8 O_3 over Eastern USA decrease following NO_x emission controls



→ 1-yr return levels (RLs) decrease by 2-16 ppb

→ 1-year RLs remain above the NAAQS threshold (75 ppb)

→ 5-year RLs in 1999-2009 similar to 1-year RLs in 1988-1998

Rieder et al., ERL 2013

The GFDL CM3/AM3 chemistry-climate model

Donner et al., J. Climate, 2011; Golaz et al., J. Climate, 2011

GFDL-AM3

SSTs/SIC from observations or CM3 CMIP5 Simulations

Forcing
Solar Radiation
Well-mixed Greenhouse Gas Concentrations
Volcanic Emissions

Atmospheric Dynamics & Physics
Radiation, Convection (includes wet deposition of tropospheric species), Clouds, Vertical diffusion, and Gravity wave

Ozone–Depleting Substances (ODS)

Atmospheric Chemistry
86 km

Chemistry of O_x, HO_y, NO_y, Cly, Br_y, and Polar Clouds in the Stratosphere

Chemistry of gaseous species (O_3, CO, NO_x, hydrocarbons) and aerosols (sulfate, carbonaceous, mineral dust, sea salt, secondary organic)

Aerosol-Cloud Interactions

Dry Deposition

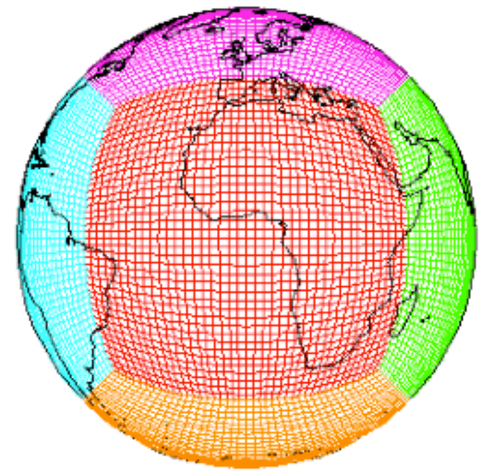
0 km

Pollutant Emissions
(anthropogenic, ships, biomass burning, natural, & aircraft)

Land Model version 3
(soil physics, canopy physics, vegetation dynamics, disturbance and land use)

Naik et al., JGR, 2013

cubed sphere grid
~2°x2°; 48 levels



6000+ years of CM3 CMIP5 simulations

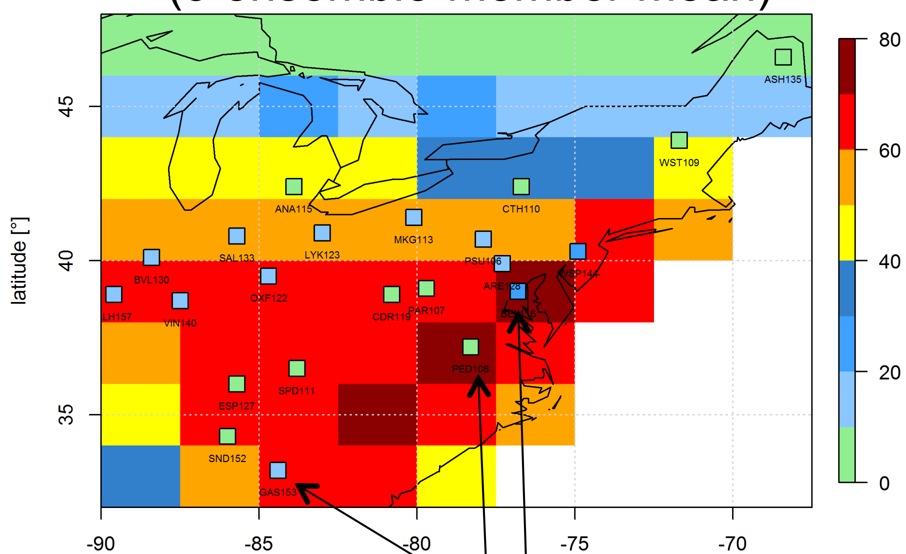
[John et al., ACP, 2012
Turner et al., ACP, 2012
Levy et al., JGR, 2013
Barnes & Fiore, GRL, 2013]

Options to nudge AM3 to reanalysis; also global high-res (~0.5°x0.5°) *[Lin et al., JGR*, 2012ab]

Generating policy-relevant statistics from biased models

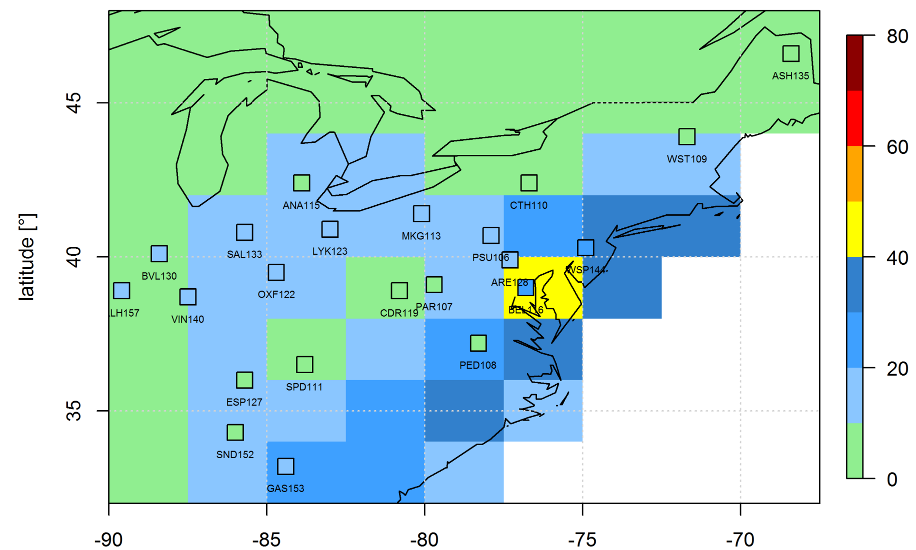
Average (1988-2005) number of summer days with O_3 > 75 ppb

CM3 Historical simulation
(3 ensemble-member mean)



CASTNet sites (observations)

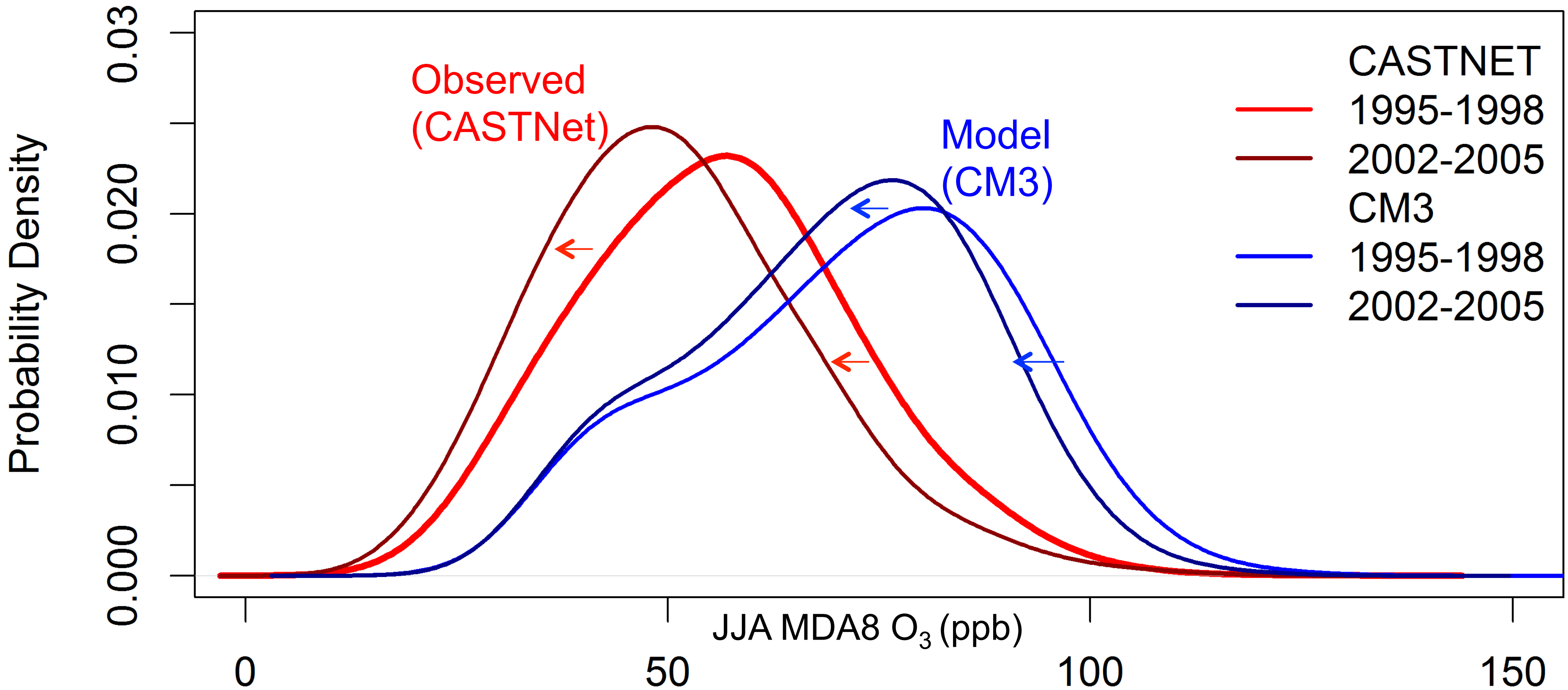
Corrected CM3 simulation
(regional remapping)



→ Applying correction to projected simulations assumes model captures adequately response to emission and climate changes

Rieder et al., in prep

GFDL CM3 generally captures NE US JJA surface O_3 decrease following NO_x emission controls (-25% early 1990s to mid-2000s)



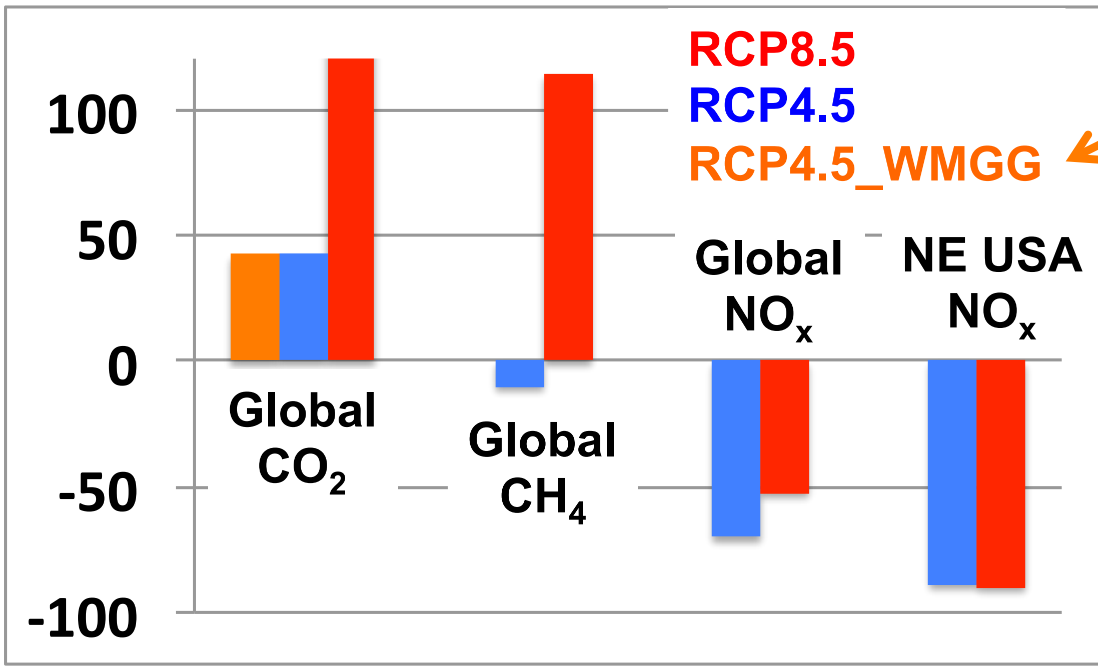
→ Implies bias correction based on present-day observations can be applied to future scenarios with NO_x changes (RCPs)

→ Caveat: Model response on low-O_3 days smaller than observed

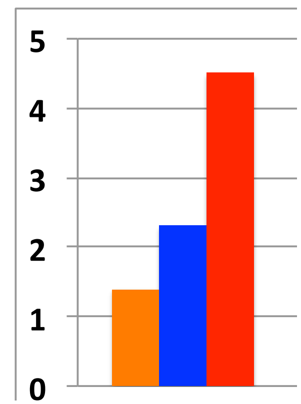
Rieder et al., in prep

Climate and Emission Scenarios for the 21st Century: Representative Concentration Pathways (RCPs)

Percentage changes from 2005 to 2100



Enables us to isolate role of changing climate

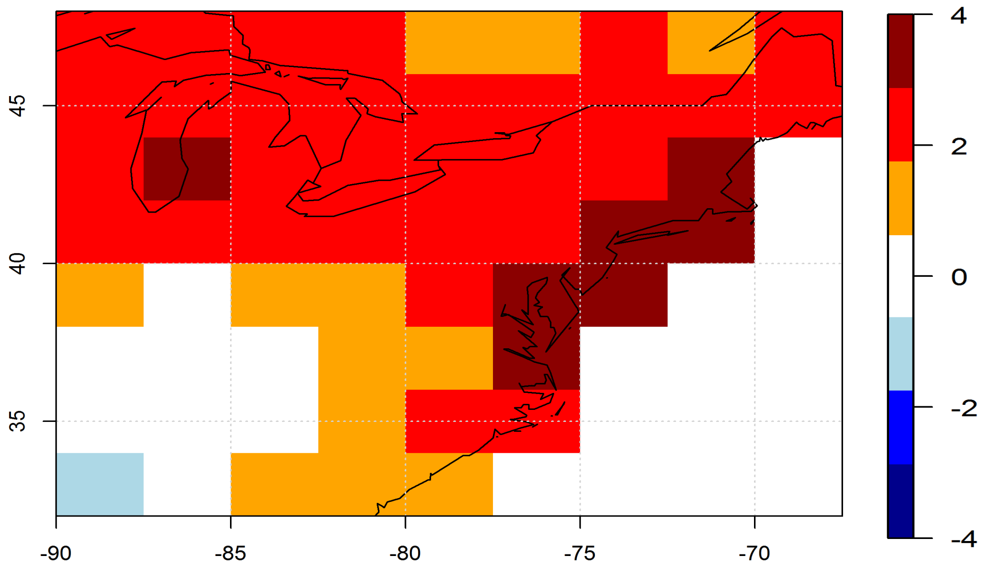


Change in Global T (°C) 2006–2025 to 2081–2100 (>500 hPa) in GFDL CM3 chemistry-climate model [*John et al., ACP, 2012*]

How will surface O_3 distributions over the NE US evolve with future changes in emissions and climate?

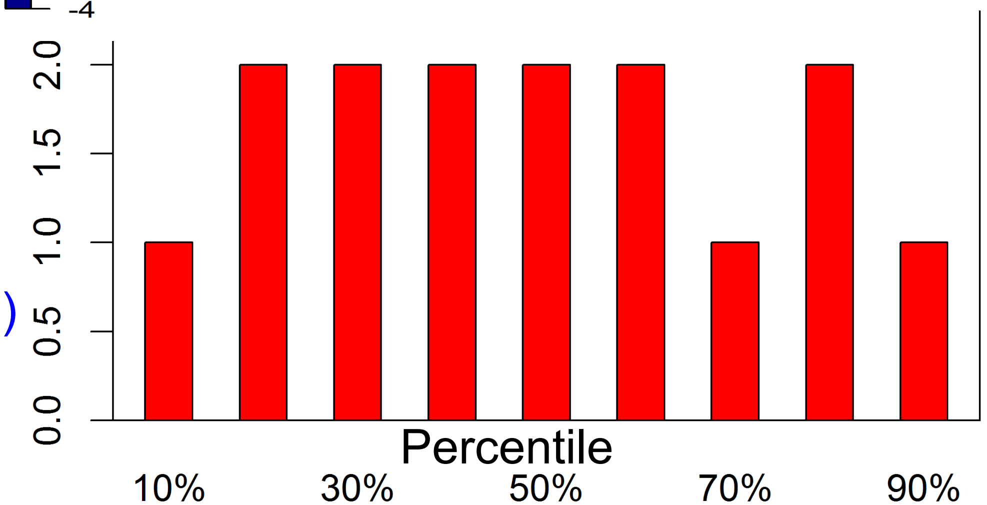
Impact of changes in climate on summertime surface O_3 under 'moderate' warming scenario over NE USA

Change ((2091-2100) – (2006-2015)) in mean summertime MDA8 O_3 (ppb) in **CM3 RCP4.5_WMGG** simulation (3 ensemble-member average; 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 this region 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])

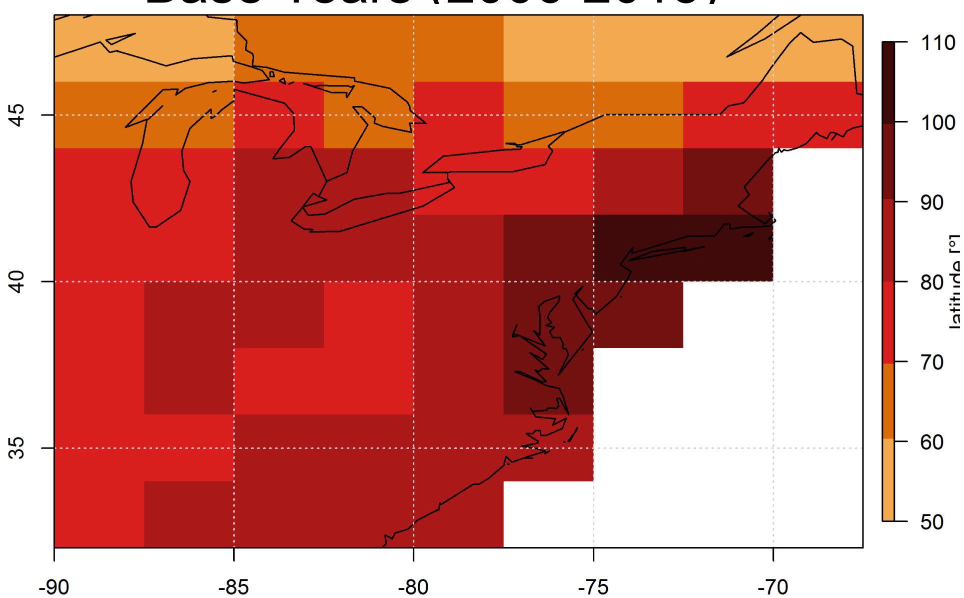


Rieder et al., in prep

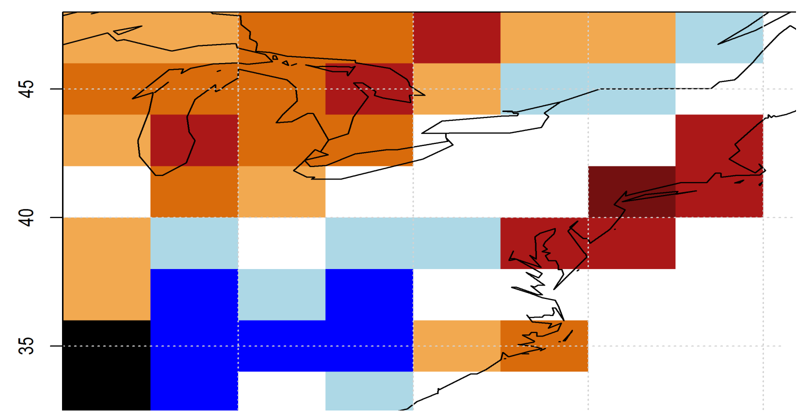
How does climate warming change extreme O_3 events over the NE USA?

1-year MDA8 O_3 Return Levels in GFDL CM3 **RCP4.5_WMGG** (corrected)

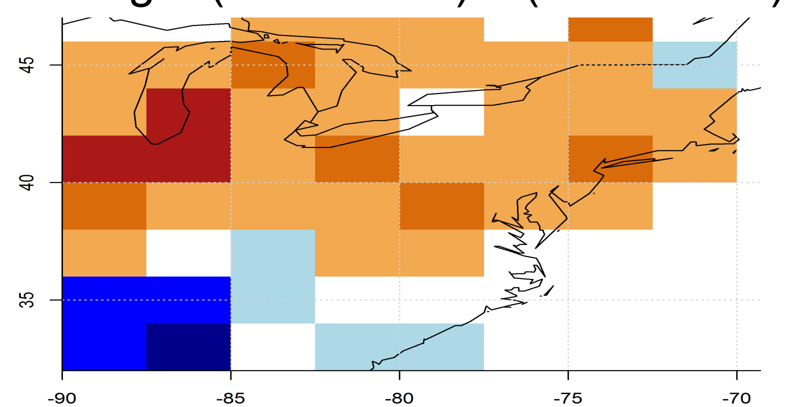
Base Years (2006-2015)

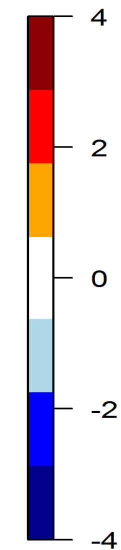


Change: (2091-2100) – (2006-2015)



Change: (2091-2100) – (2046-2055)





Much of region sees 'penalty' but also some 'benefit', of up to 4 ppb

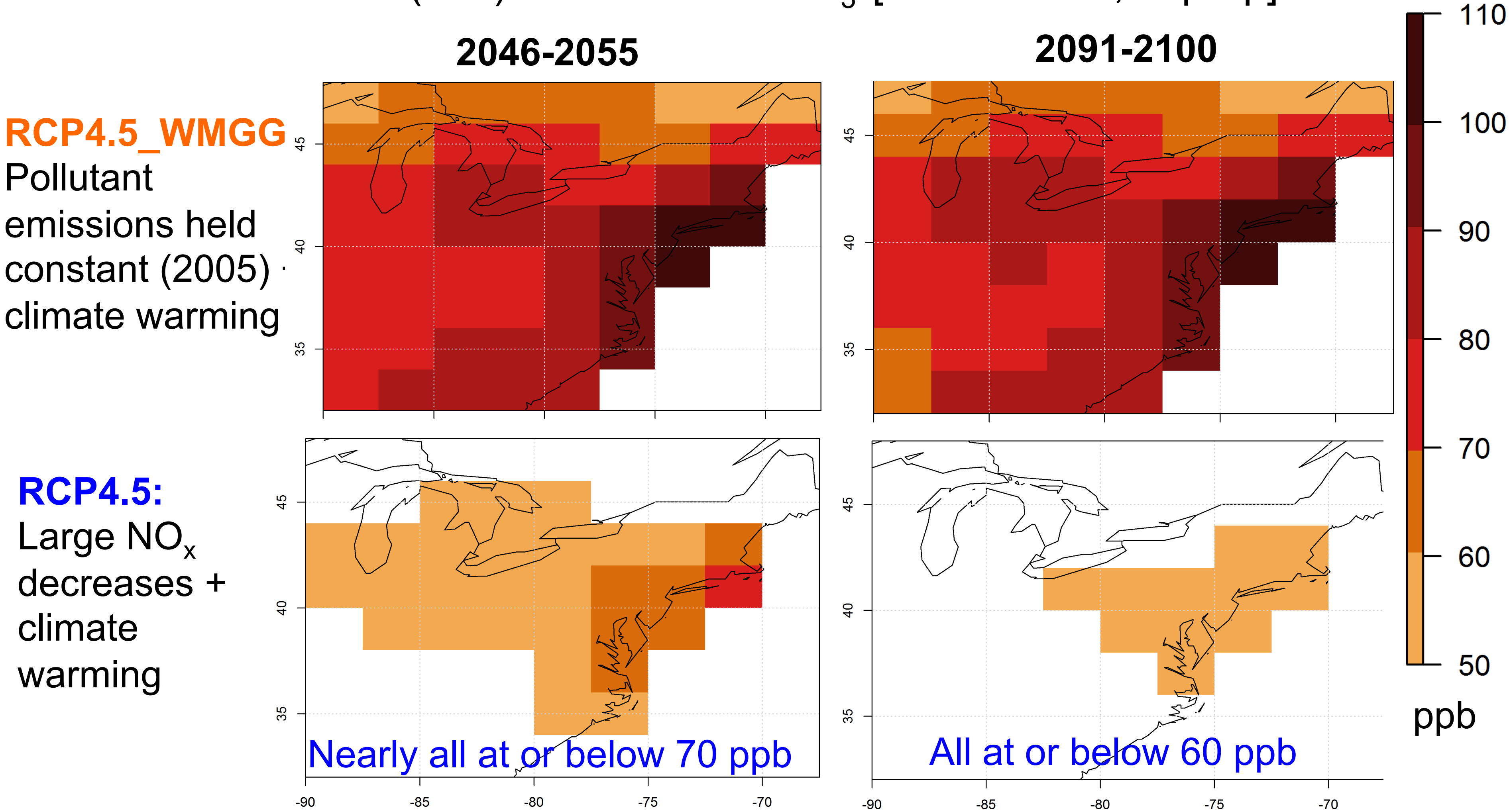
→ Signal from regional 'climate noise' with only 3 ensemble members?

→ Robust across models?

Rieder et al., in prep

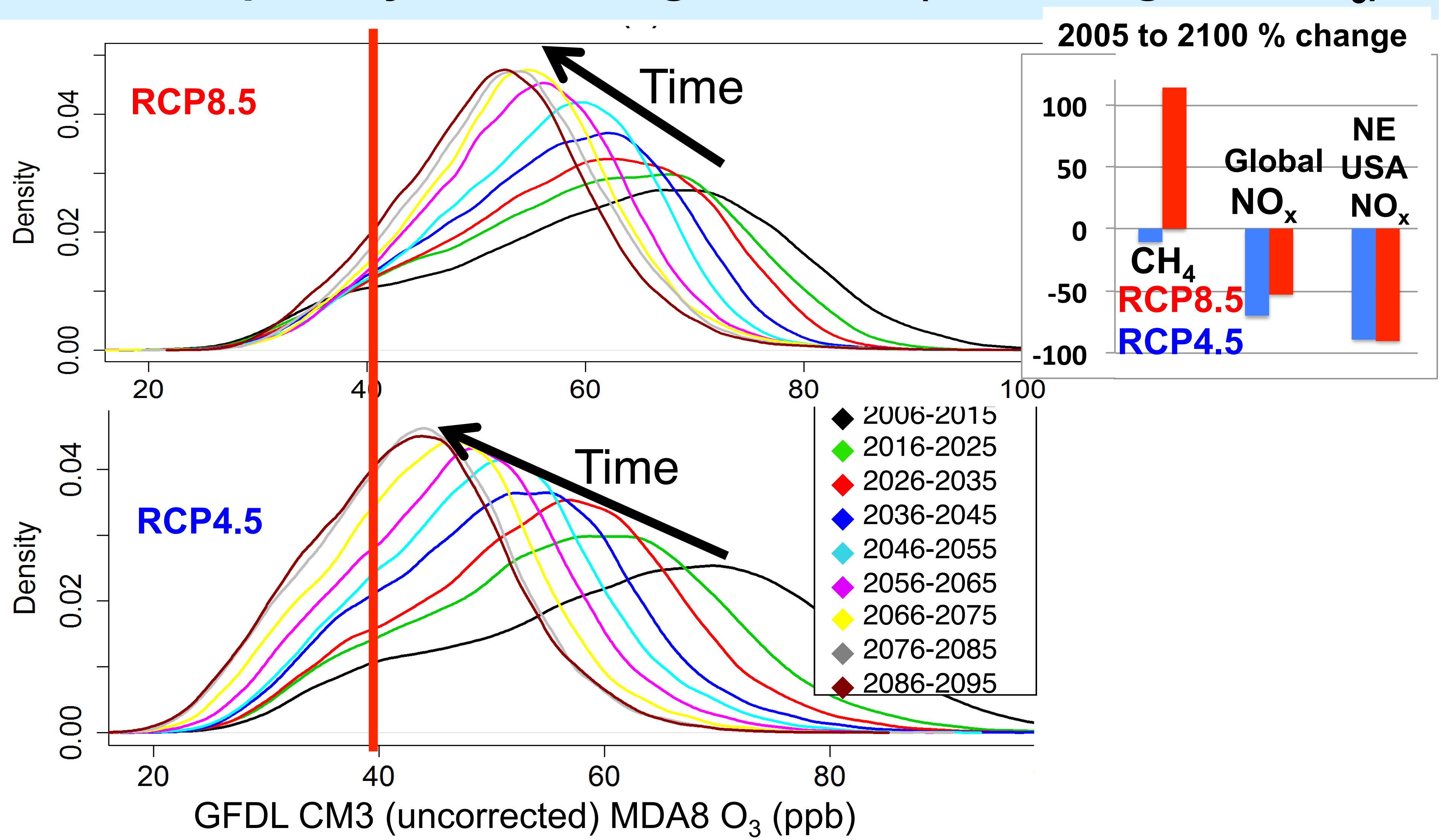
Large NO_x reductions offset climate penalty on O_3 extremes

1-year Return Levels in CM3 chemistry-climate model (corrected)
Summer (JJA) MDA8 Surface O_3 [Rieder et al., in prep]



→ Ongoing work examining relationship between NO_x reductions and Return Levels

Under RCPs, NE USA high-O_3 events decrease; beware 'penalty' from rising methane (via background O_3)



→ Rising CH_4 in RCP8.5 partially offsets O_3 decreases otherwise attained with regional NO_x controls (RCP4.5)

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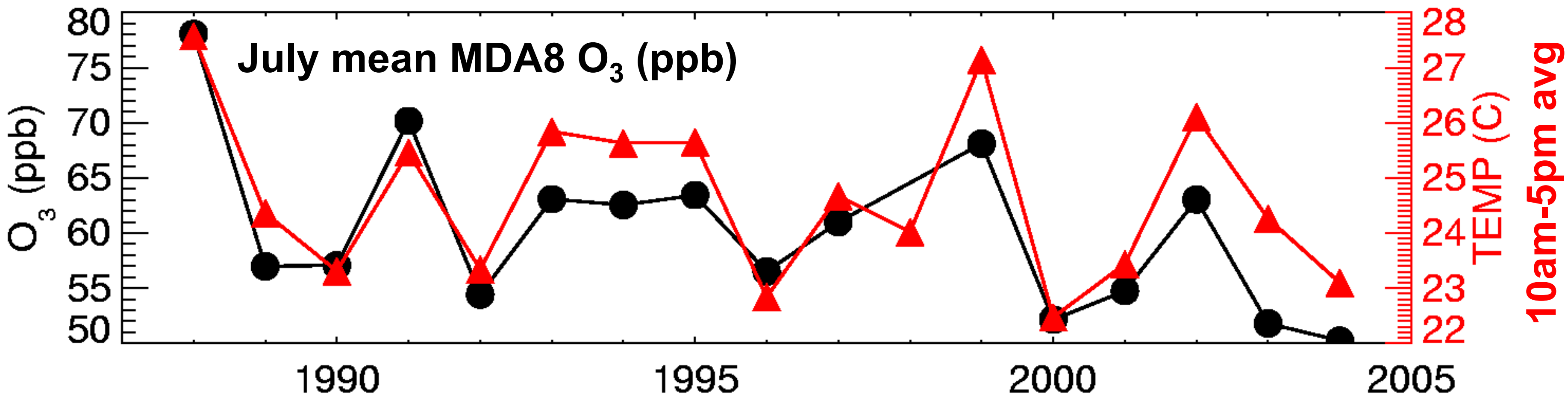
Strong correlations between surface temperature and O_3 measurements on daily to inter-annual time scales in polluted regions [e.g., Bloomer et al., 2009; Camalier et al., 2007; Cardelino and Chameides, 1990; Clark and Karl, 1982; Korsog and Wolff, 1991]

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



→ Weather variability is a key driver of observed O_3-Temperature correlations

→ Implies worse O_3 pollution in a warmer climate… but stationarity in locally observed O_3:T relationships? (See box in *Weaver et al., BAMS, 2009*)

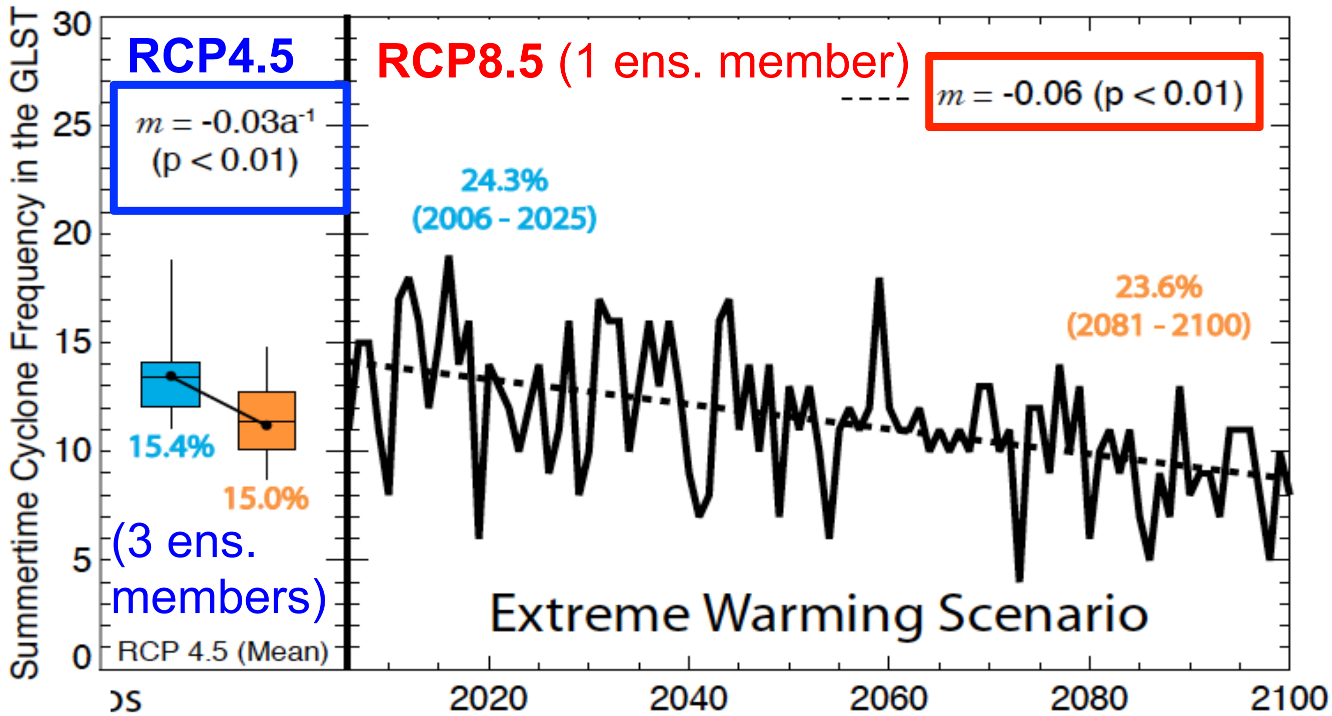
→ Need to understand underlying processes

- Anticorrelation between observed number of storms over SE Canada/ NE US and high-O_3 events [*Leibensperger et al., ACP, 2008*]

  → Will storm frequency change with climate warming?

Frequency of summer migratory cyclones over NE US decreases as the planet warms…

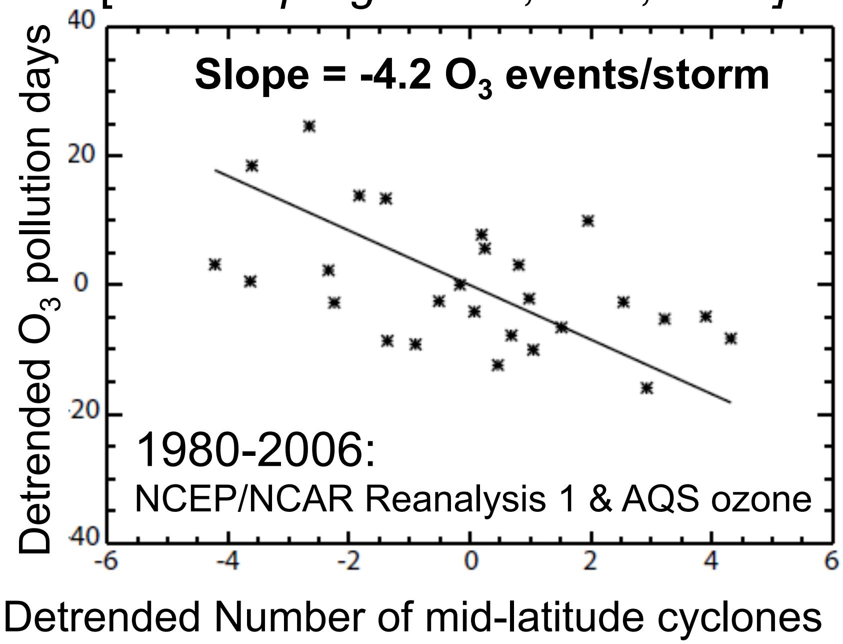
Number of storms per summer in the GFDL CM3 model, as determined from applying the MCMS storm tracker [*Bauer et al., 2013*] to 6-hourly sea level pressure fields



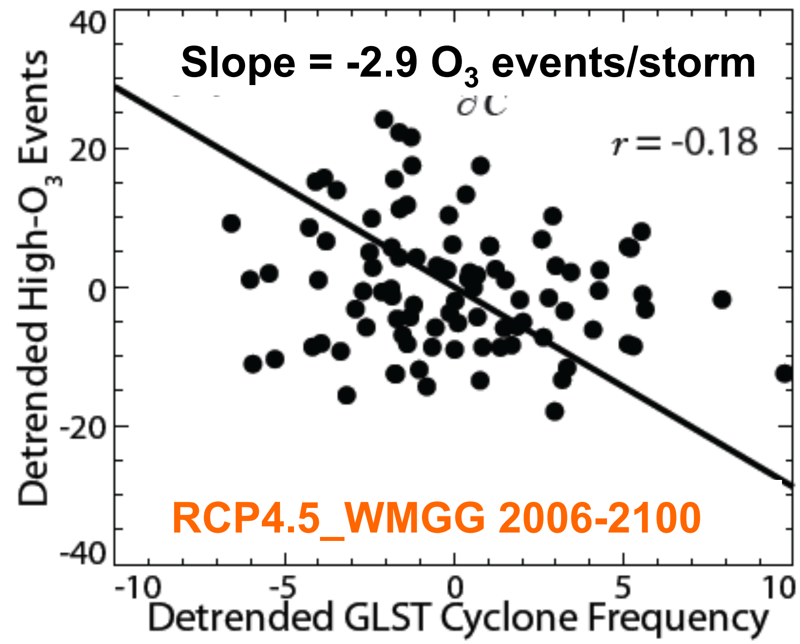
Turner et al., ACP, 2013

…but the storm count – O_3 event relationship is weaker than derived from observations

Observed relationship
[*Leibensperger et al, ACP, 2008]*



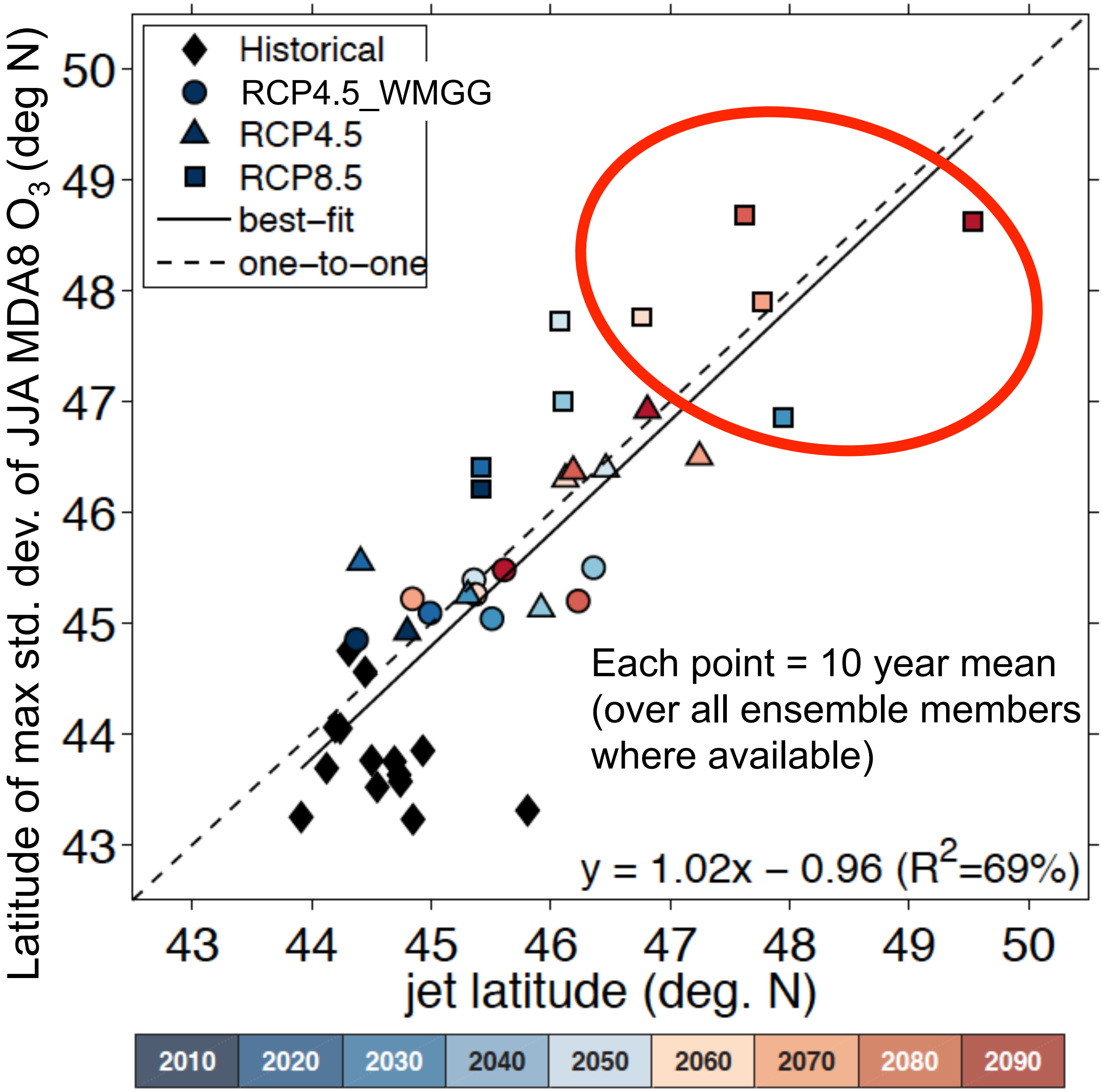
Simulated relationship (GFDL CM3)
[*Turner et al., ACP, 2013*]



→ **Model problem (bias/process representation)?**
→ **Change in drivers (under warming climate)?**
→ **Decadal variability in strength of relationship?**

Can we find a simpler diagnostic of large-scale circulation changes?

Peak latitude of summertime surface O_3 variability over Eastern N. America follows the jet (500 hPa) as climate warms



RCP8.5: most warming, Largest jet shift

→ **Decadal variability**

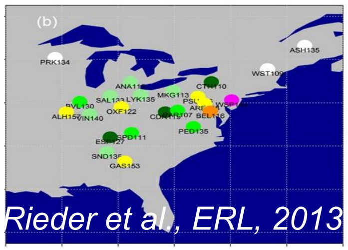
→ **Relevance to shorter periods (i.e., year-to-year variability?)**

O_3-Temperature relationship (not shown) also aligns with jet latitude

→ **Historically observed relationships may not hold if large-scale circulation shifts**

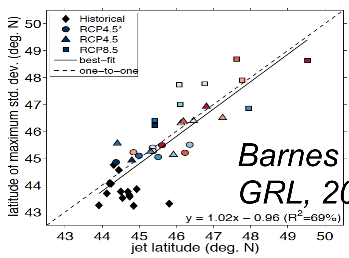
Barnes & Fiore, GRL, 2013

Recent trends + future projections in surface O_3 extremes over the eastern USA in summer: Summary and Next Steps



- New metric ("1-year event") for quantifying success of NO_x controls
- Model bias correction for estimates of threshold-based statistics

→ Apply to $PM_{2.5}$, precipitation; examine event persistence



Barnes & Fiore GRL, 2013

- Declining NE US storm frequency in a warmer climate [Turner et al., 2013]
- Zonal O_3 variability (and O_3:T) aligns with the 500 hPa jet

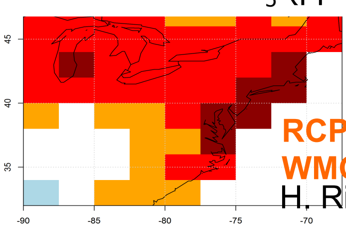
→ Decadal shifts in jet; hold on shorter timescales?

→ Model bias: impact on relationship with storm counts/jet latitude?

→ Relevant to model differences in O_3 response to climate?

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

Change over 21st C in mean JJA MDA8 O_3 (ppb)



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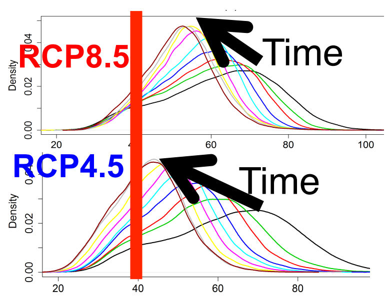
- "Climate penalty" over NE USA in CM3 model (cf. earlier studies)
- More "noise" at regional level; need ensemble for 'signal'

→ Not just trend; consider inter-annual variability

→ Identify connections to meteorology + feedbacks with biosphere



GFDL CM3 (uncorrected) MDA8 O_3 (ppb)

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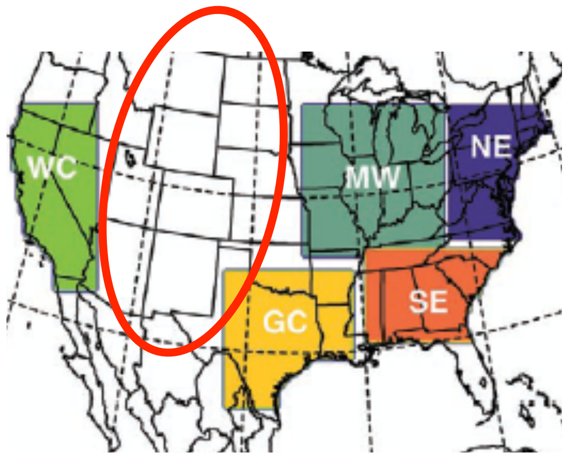
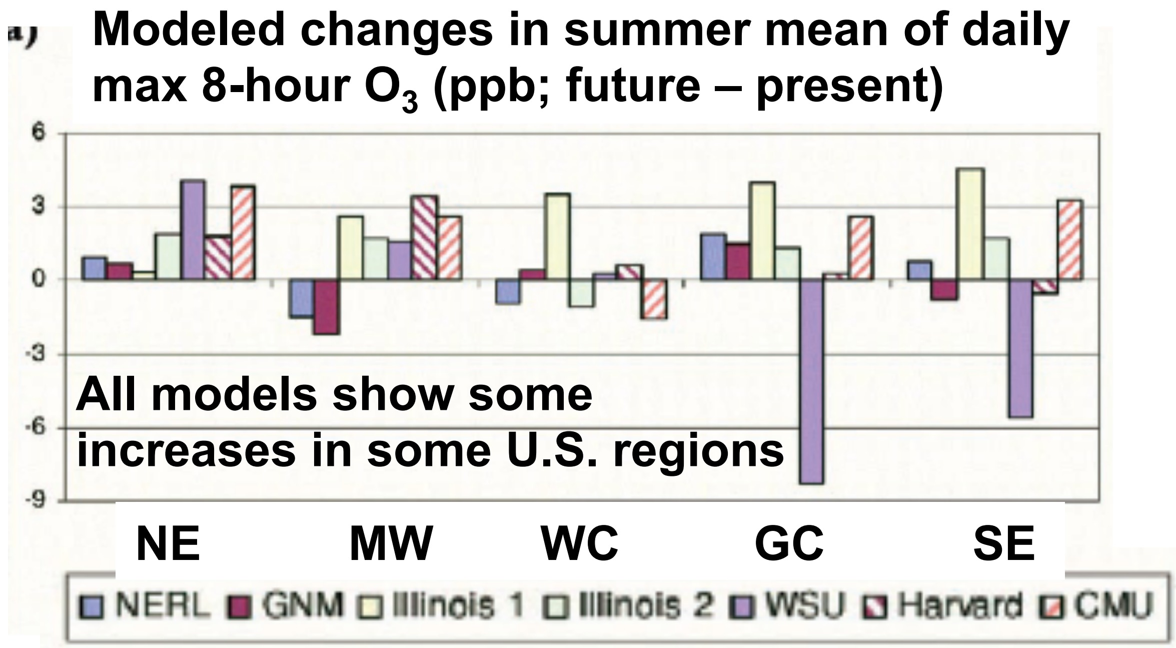
- Projected regional NO_x reductions in RCP scenarios (-80% by 2100) lead to large decreases in high O_3 events over NE USA
- Rising CH_4 + NO_x controls shift balance of regionally produced vs. transported O_3 (CH_4 controls a "win-win" for climate + air quality)

→ Extend to other regions, seasons, $PM_{2.5}$

Looking beyond the NE US: Gap in analysis of climate change impacts over Mountainous West



Weaver et al., BAMS, 2009



- **Uncertainties in regional climate responses (and feedbacks) to global warming**
- **Unique aspects of high-altitude Western US ozone**
  → Higher background O_3; how will this change?
  (e.g., frequency of fires, strat. intrusions)