Interactions between Climate and Air Quality

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Acknowledgments: Steve Howard and Jenise Swall, U.S. EPA

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San Francisco, CA
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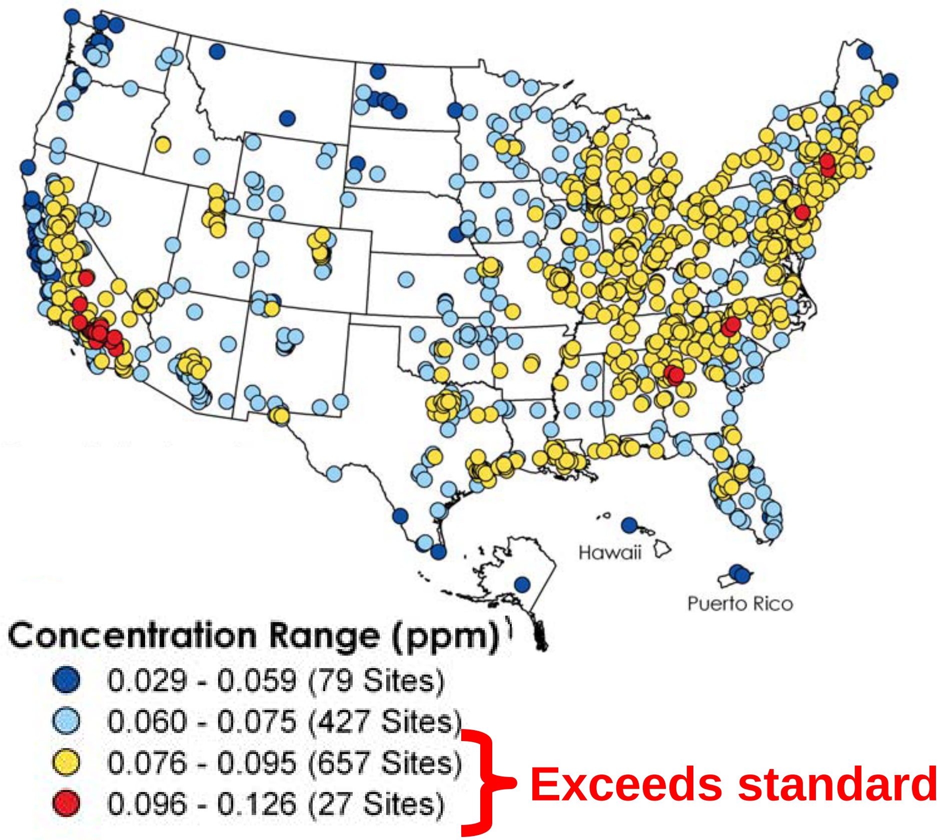
The U.S. smog problem is spatially widespread, affecting >150 million people [U.S. EPA, 2008]

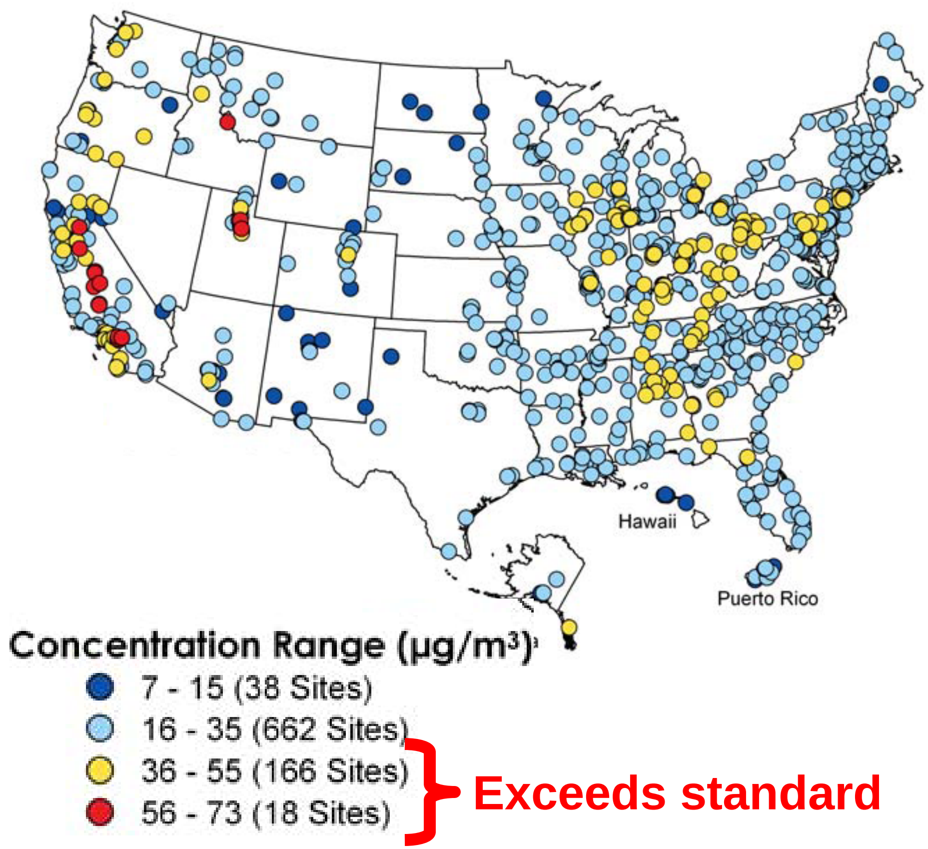
OZONE

4th highest daily max 8-hr in 2007



AEROSOLS (particulate matter)

98th percentile 24-hr $PM_{2.5}$ in 2007

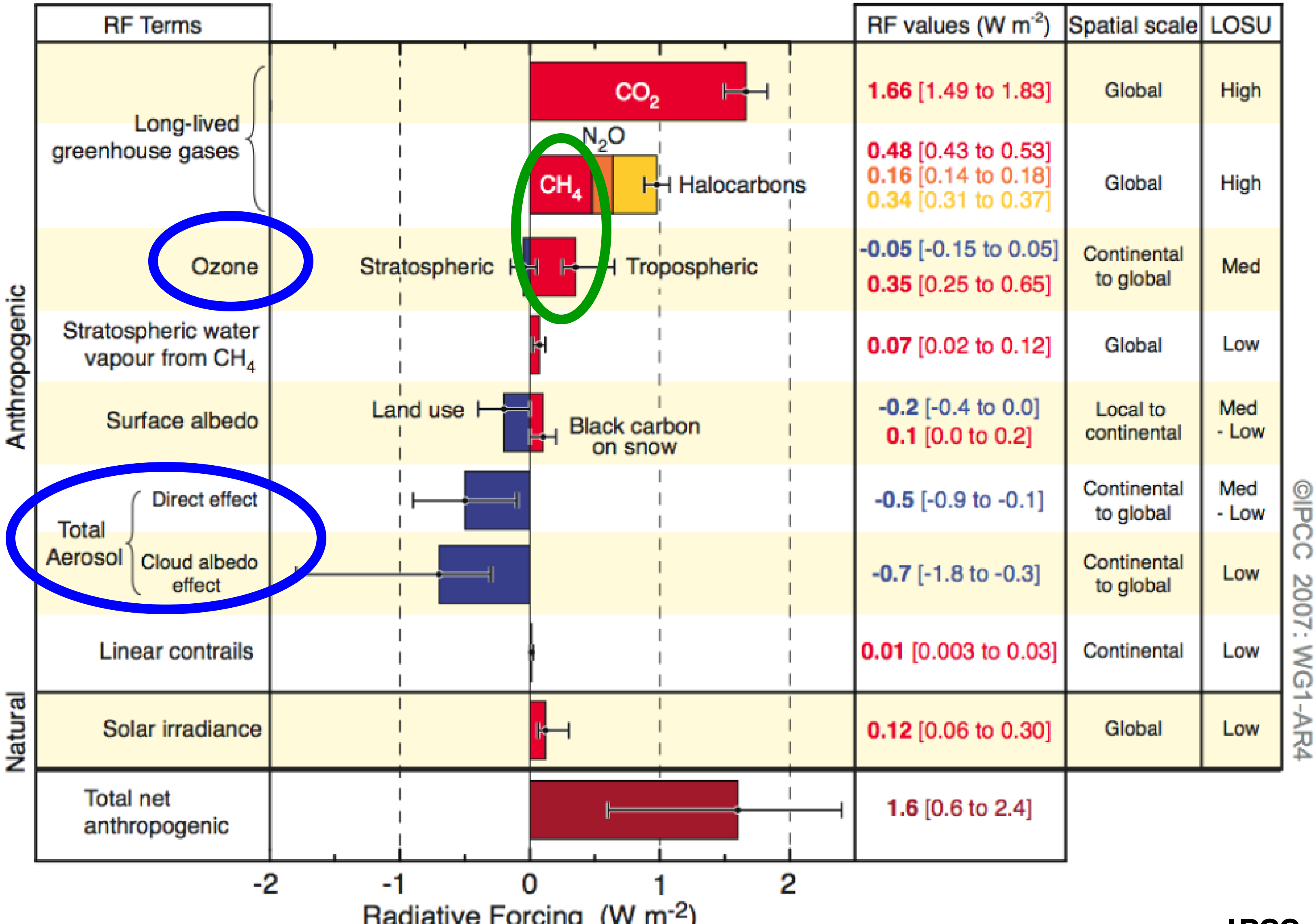


http://www.epa.gov/air/airtrends/2008/report/TrendsReportfull.pdf

Air Quality in Asia

or

Radiative forcing of climate (1750 to present): Important contributions from air pollutants



IPCC, 2007

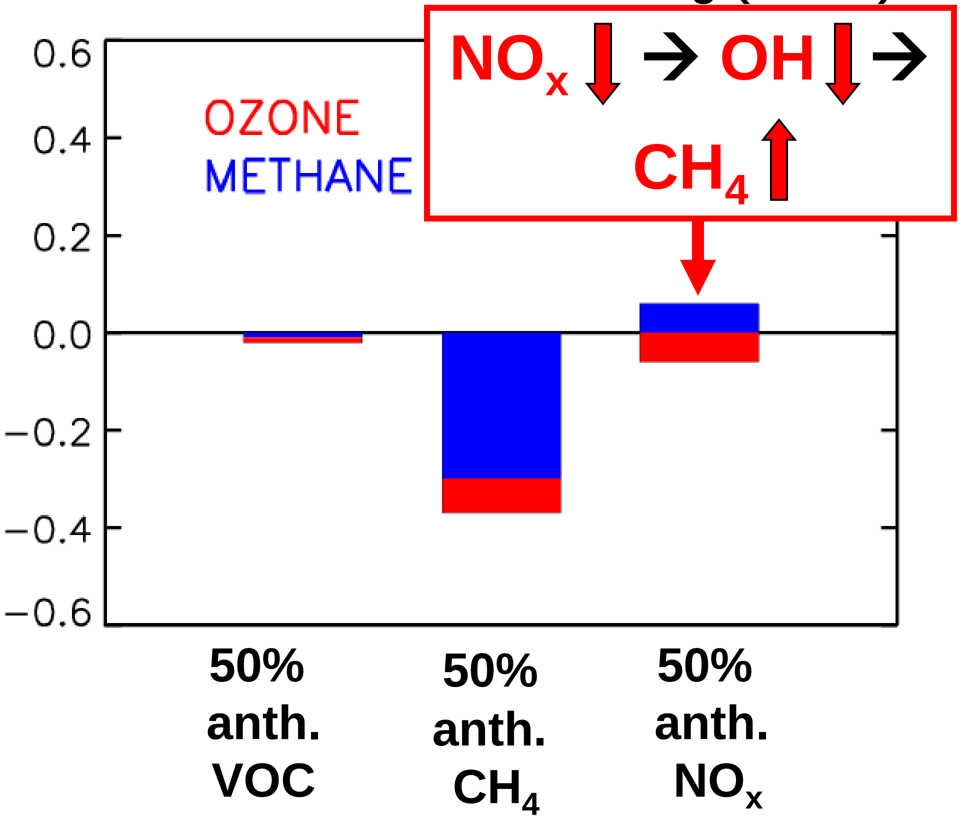
Impacts of Air Quality on Climate

Example # 1 - Double dividend of Methane Controls

(Decreased greenhouse warming and improved air quality)

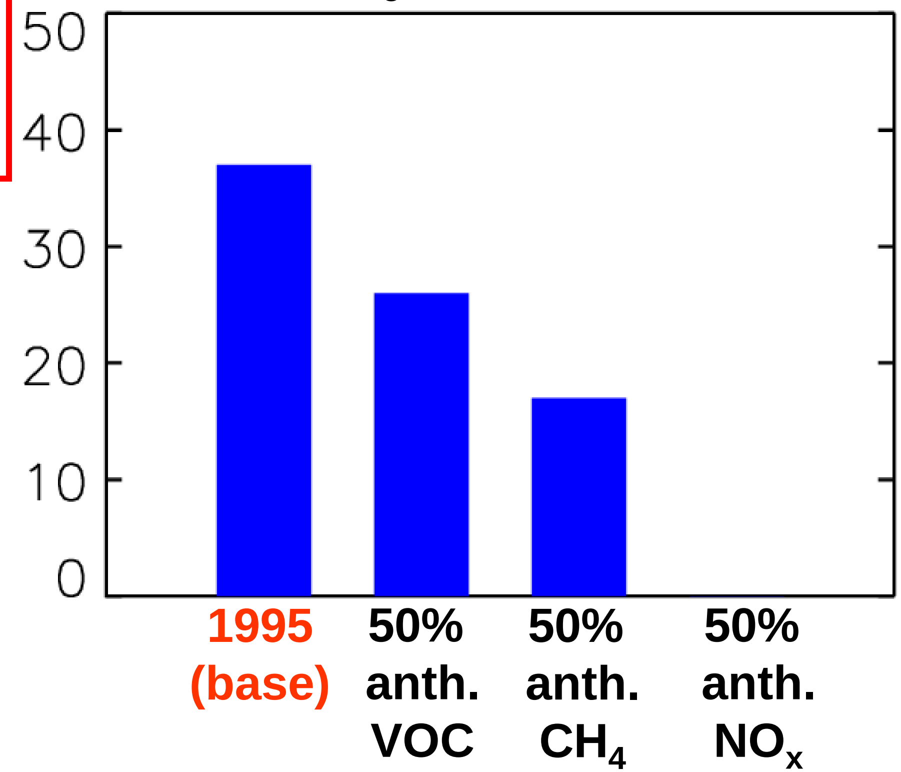
Results are from GEOS-Chem global tropospheric chemistry model (4 x5°)

CLIMATE: Radiative Forcing (W m^{-2})



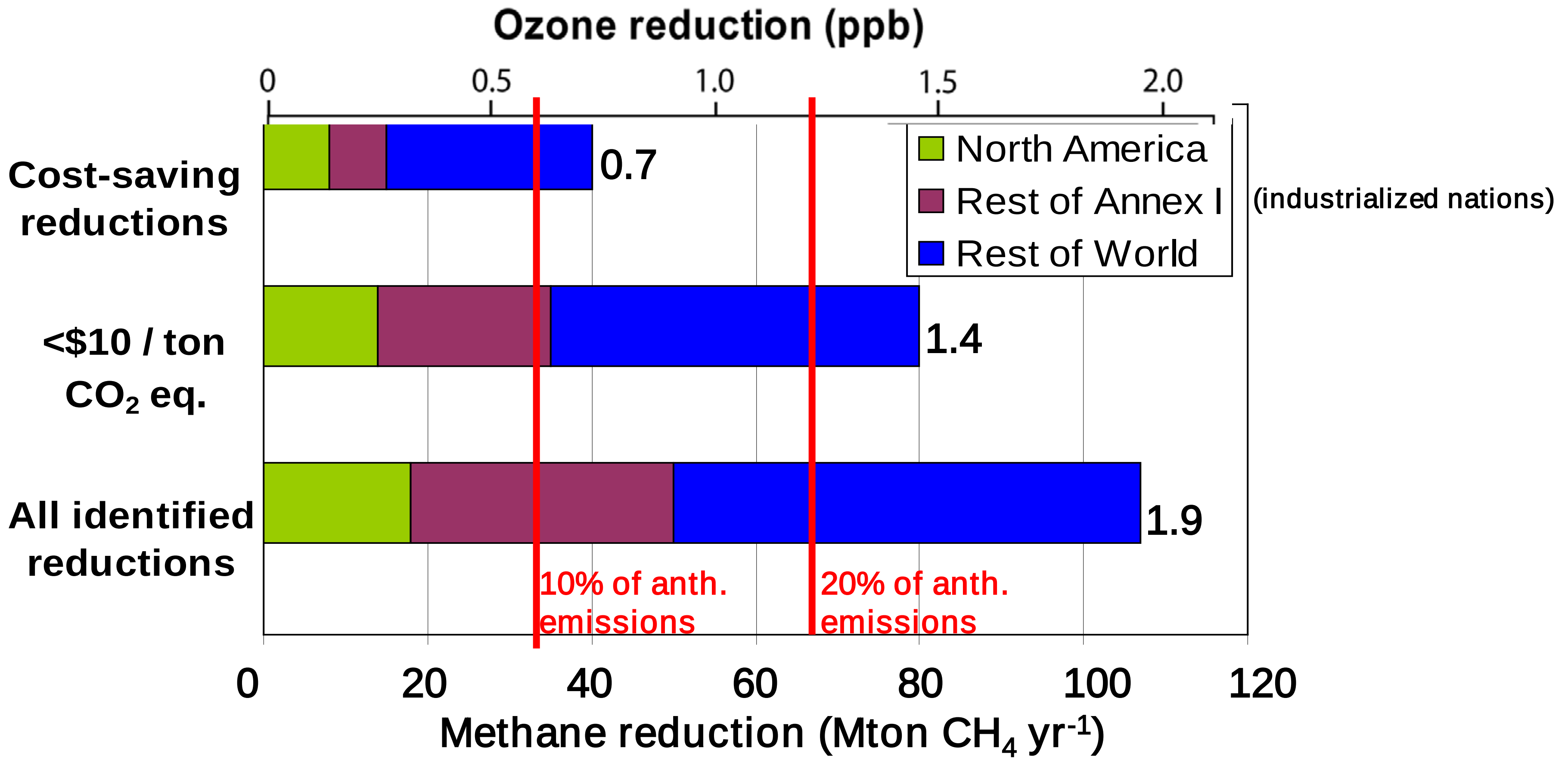
Ozone precursors

AIR QUALITY: Number of U.S. summer grid-square days with O_3 > 80 ppbv



Fiore *et al.*, *GRL*, 2002

Current Possible Methane Reductions

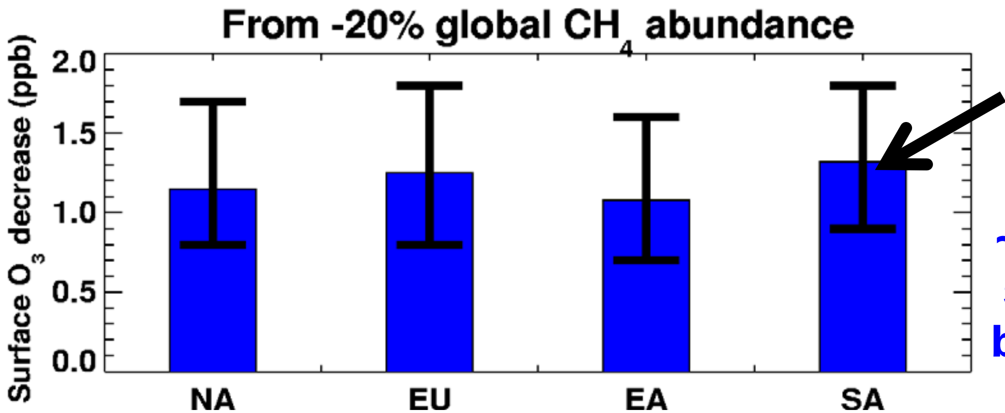


Take Home:

1. 0.7 ppb Ozone reduction at no cost
2. 1 ppb Ozone reduction via Methane control pays for itself (cost-savings + Carbon trading)
3. 1 ppb Ozone reduction over the eastern US via NOx control costs ~$1 billion yr^{-1}

West & Fiore, ES&T, 2005

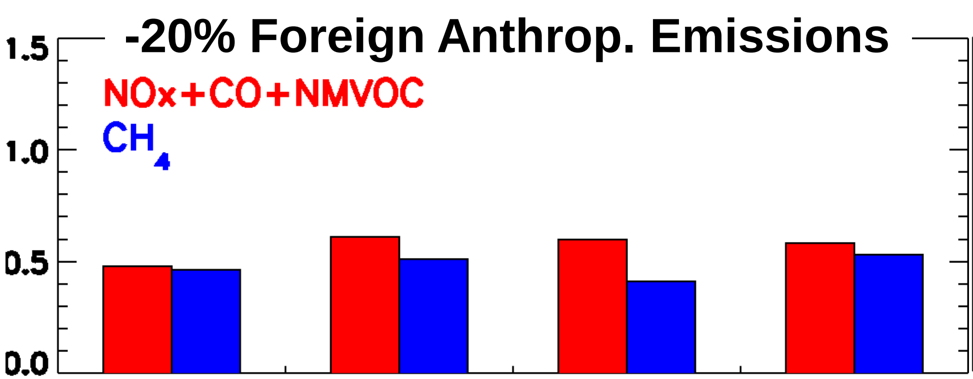
Methane Reduction Across A Range of Models



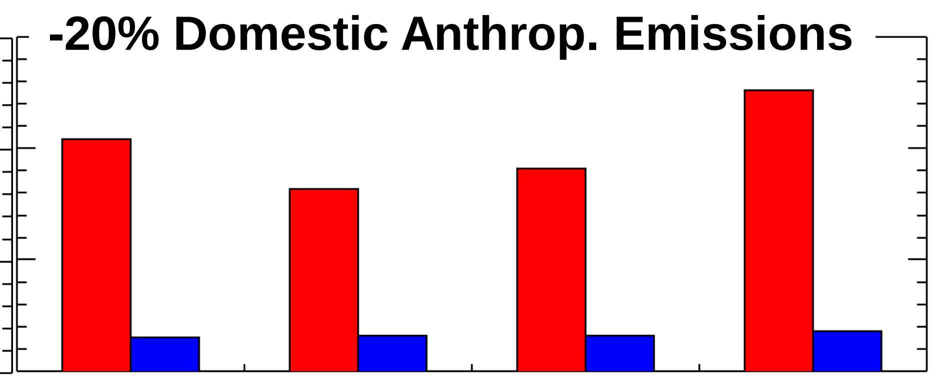
N. Amer. Europe E. Asia S. Asia

Range across 18 models

~1.2 ppb decrease in N. Hemisphere surface O_3 when CH_4 decreased by 20% (1760 to 1408 ppb)



N. Amer. Europe E. Asia S. Asia



N. Amer. Europe E. Asia S. Asia

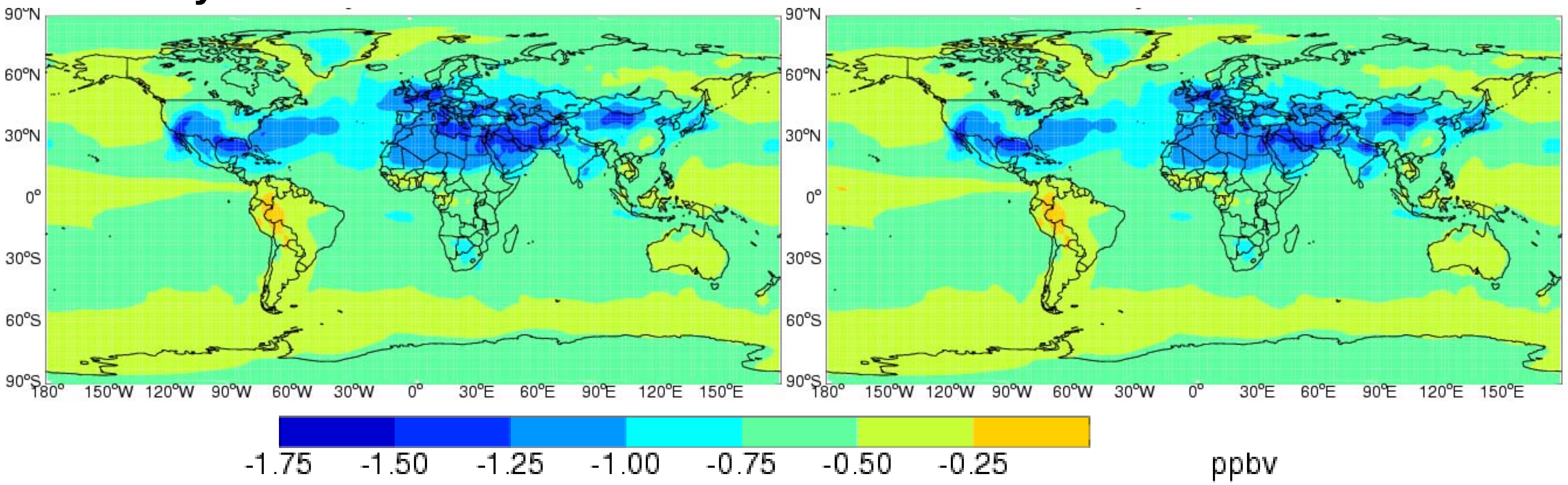
Key Results – Robust across models

1. Decreasing methane lowers global surface O3 background
2. Comparable local surface O_3 decreases (ppb) from -20% intercontinental emissions of CH_4 and NO_x+NMVOC+CO;
3. "Traditional" local precursors more effective within source region

Results from TF HTAP model intercomparison; Fiore et al., JGR, 2009

July surface O_3 reduction from 30 % decrease in anthropogenic CH_4 emissions

Globally uniform emission reduction | **Emission reduction in Asia**

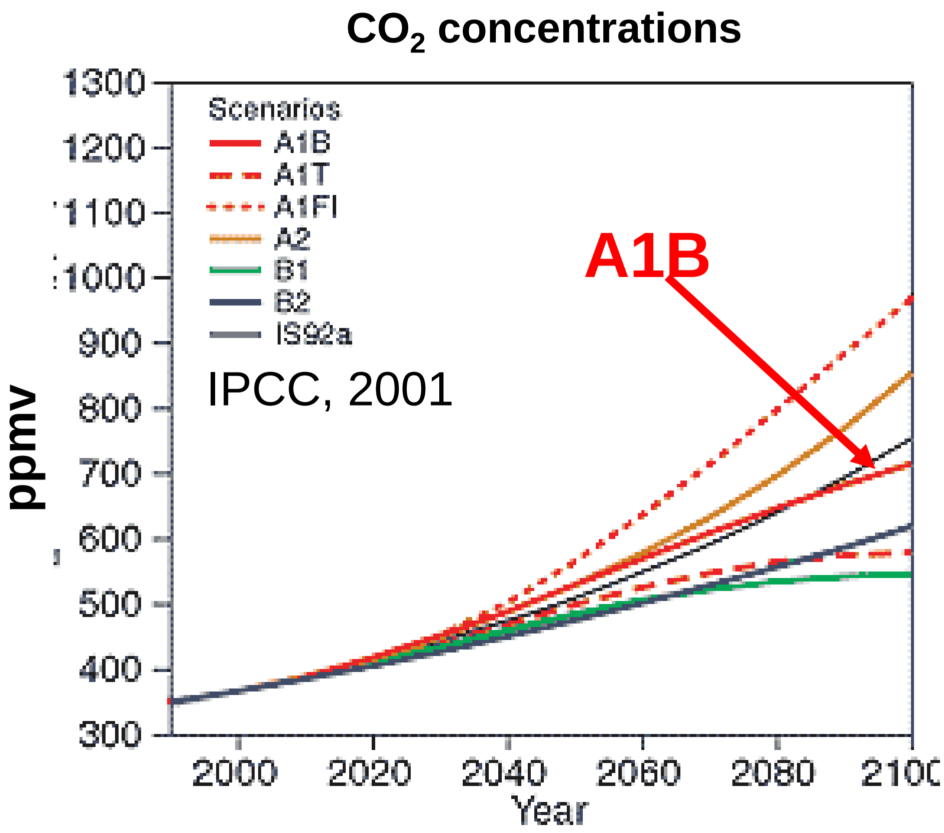


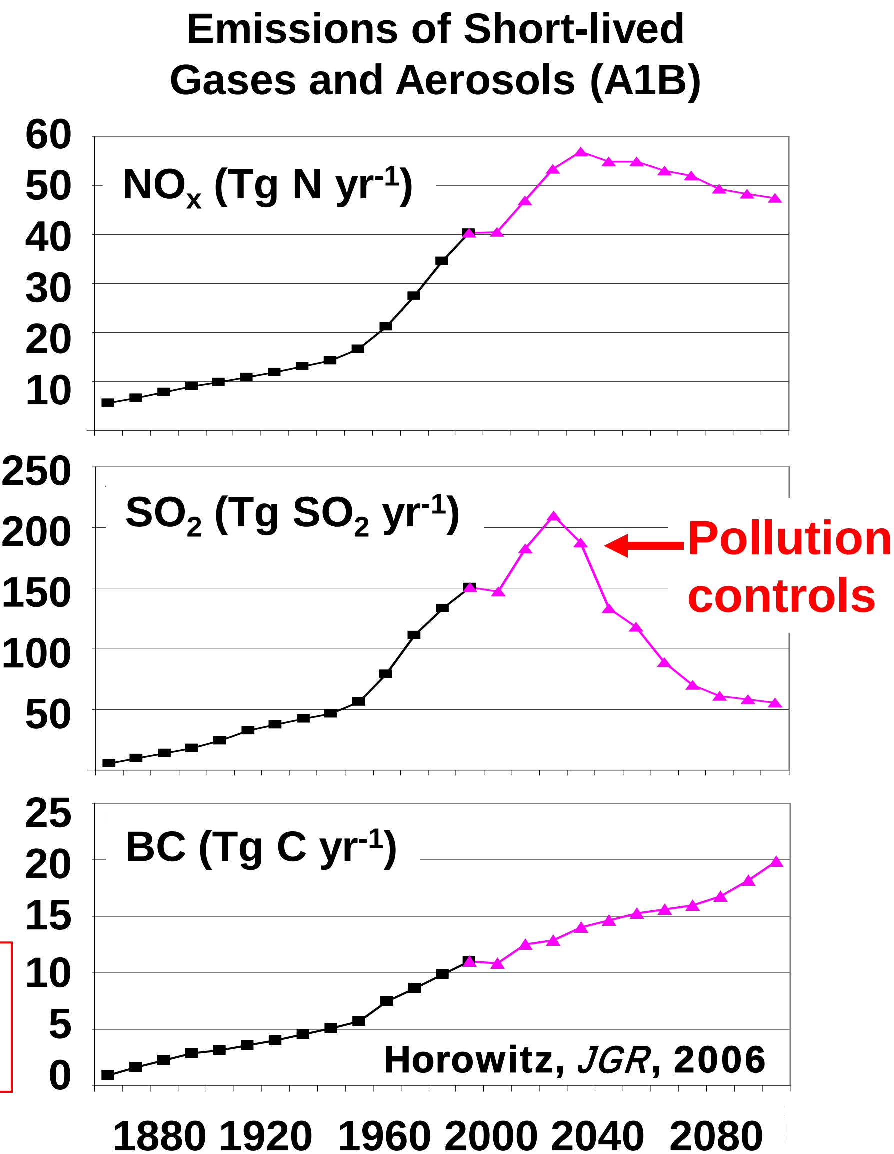
1. Ozone reduction is independent of location of methane reduction
   [pick the cheapest option]
2. Ozone reduction is generally largest in polluted regions
   [high nitrogen oxides]
3. Methane reduction is a win-win for climate and air quality

Fiore et al., JGR, 2008

Example #2 - Direct Effect of Aerosols on Climate

Scenarios for CO_2 and short-lived greenhouse species



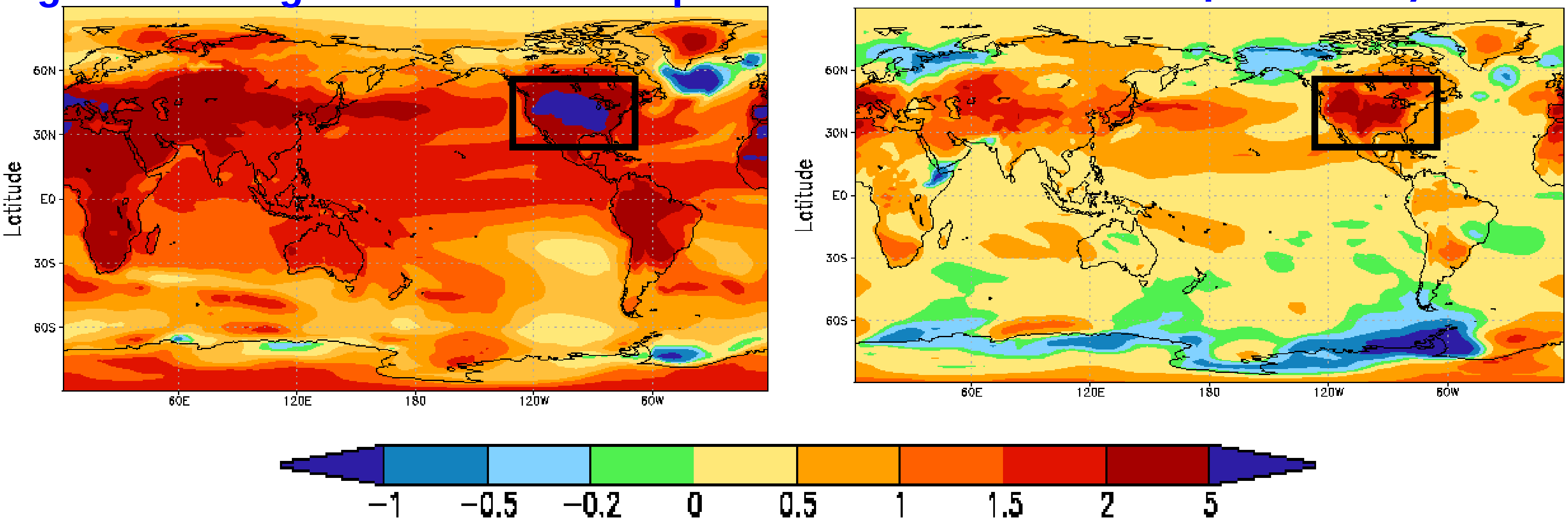


Large uncertainty in future emission trajectories for short-lived species

Up to 40% of U.S. warming in summer (2090s - 2000s) from changes in short-lived species

From changing emissions of well-mixed greenhouse gases +short-lived species

From changing emissions of short-lived species only



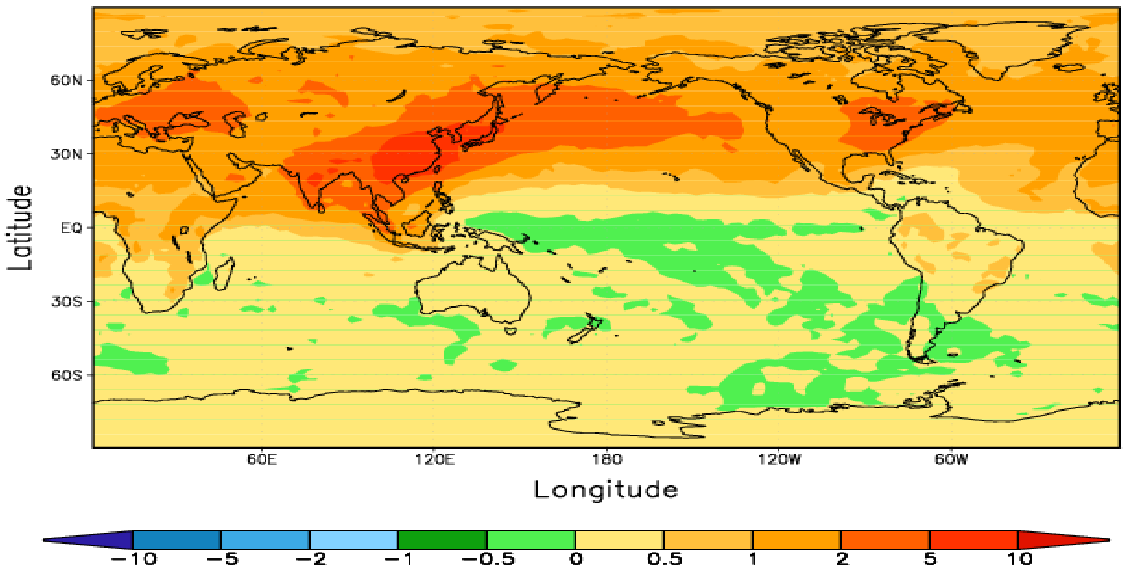
Change in Summer Temperature 2090s-2000s (C)

Note: Warming from increases in BC + decreases in sulfate; depends critically on highly uncertain future emission trajectories

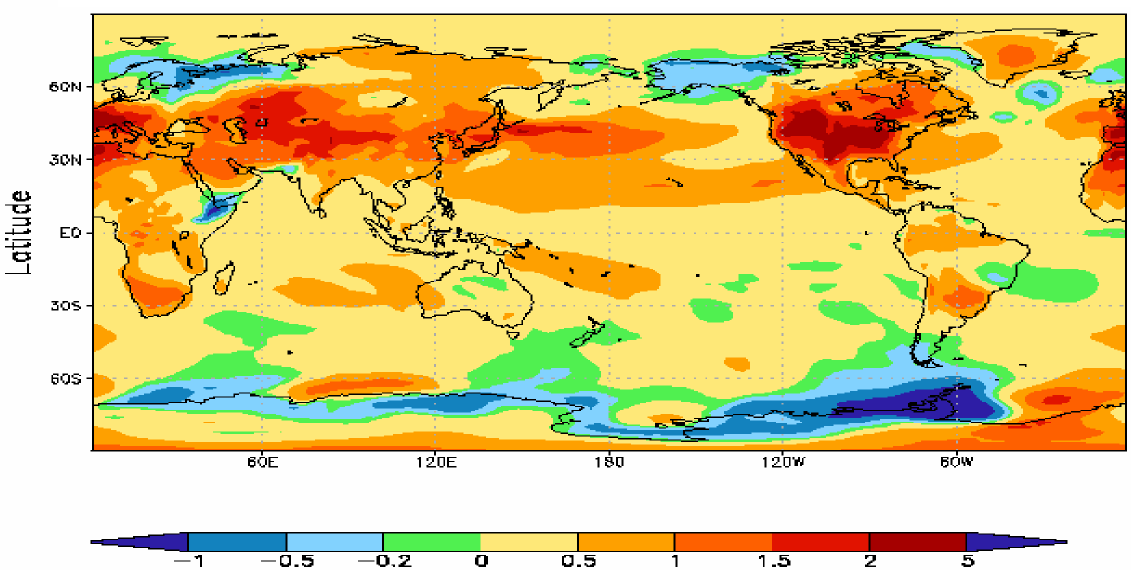
Results from GFDL Climate Model [Levy *et al*., 2008]

Regional Radiative Forcing vs. Regional Temperature Response

Radiative Forcing (2100 – 2001) Due To Short-lived Species



Summer 2100 Surface Temperature Change
Due To Short-lived Species



global pattern-correlation coefficient of -0.172.

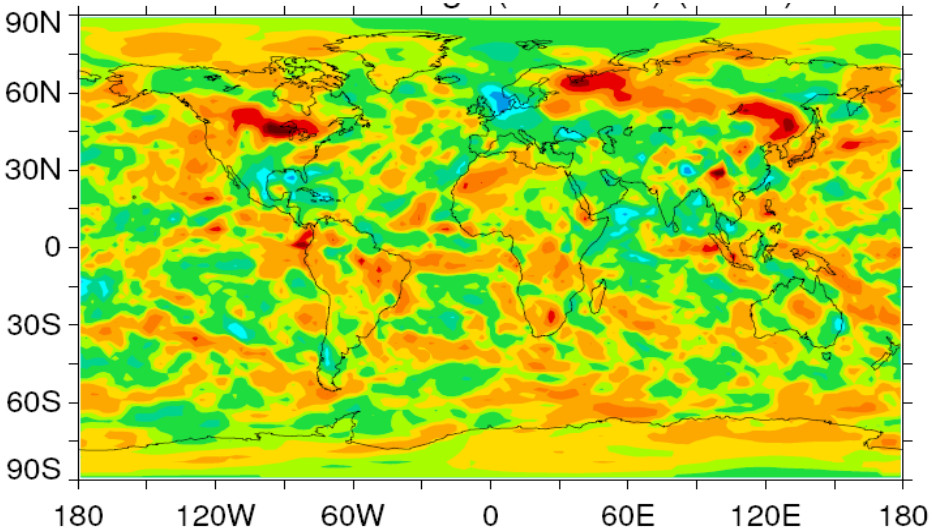
Three Main Points:

1. Summertime central US appears to be very sensitive to climate change.
2. Radiative forcing and climate response are not spatially correlated
3. Asian emission controls may significantly impact US summertime warming

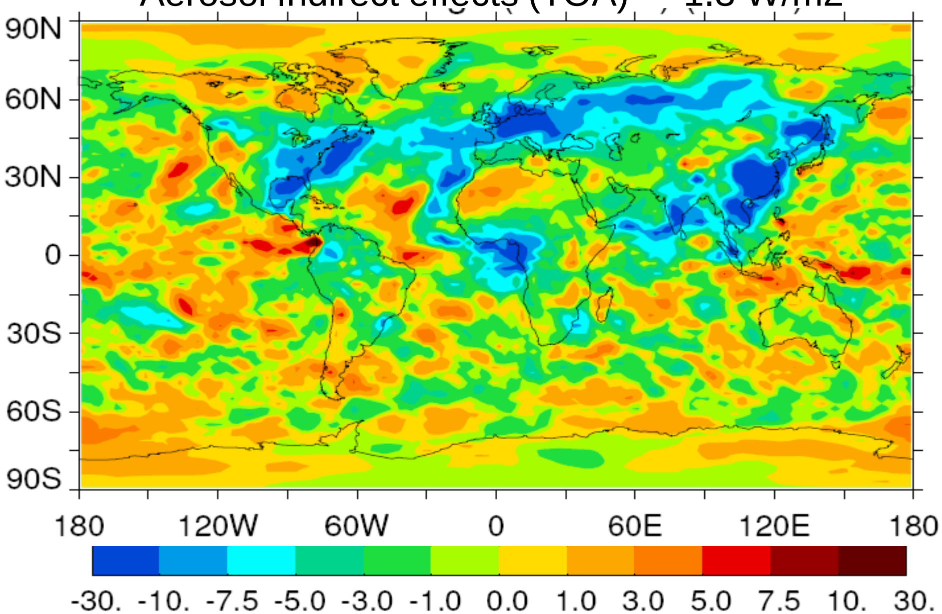
Levy et al., JGR, 2008

Example #3 - From Emissions to Clouds via Aerosol Indirect Effects

Aerosol Direct Effects (TOA) ~0 W/m2



Aerosol Indirect effects (TOA) ~ -1.3 W/m2



Key Issues - Post IPCC 2007

1. Now strong cooling from aerosol interactions with clouds (indirect effects).

2. Internal mixtures now reduce TOA direct aerosol effect to ~ 0.

3. Climate and Aerosols (emissions, chemical reactions, transport and removal) now all interact strongly through clouds.

4. Critical measurements are needed: optical properties of aerosols; magnitude of aerosol indirect effects.

5. Indirect effects may have significantly non-linear influences on temperature and precipitation.

SUMMARY OF Air Quality → Climate

1. Methane reduction is a win-win for both air quality and climate.

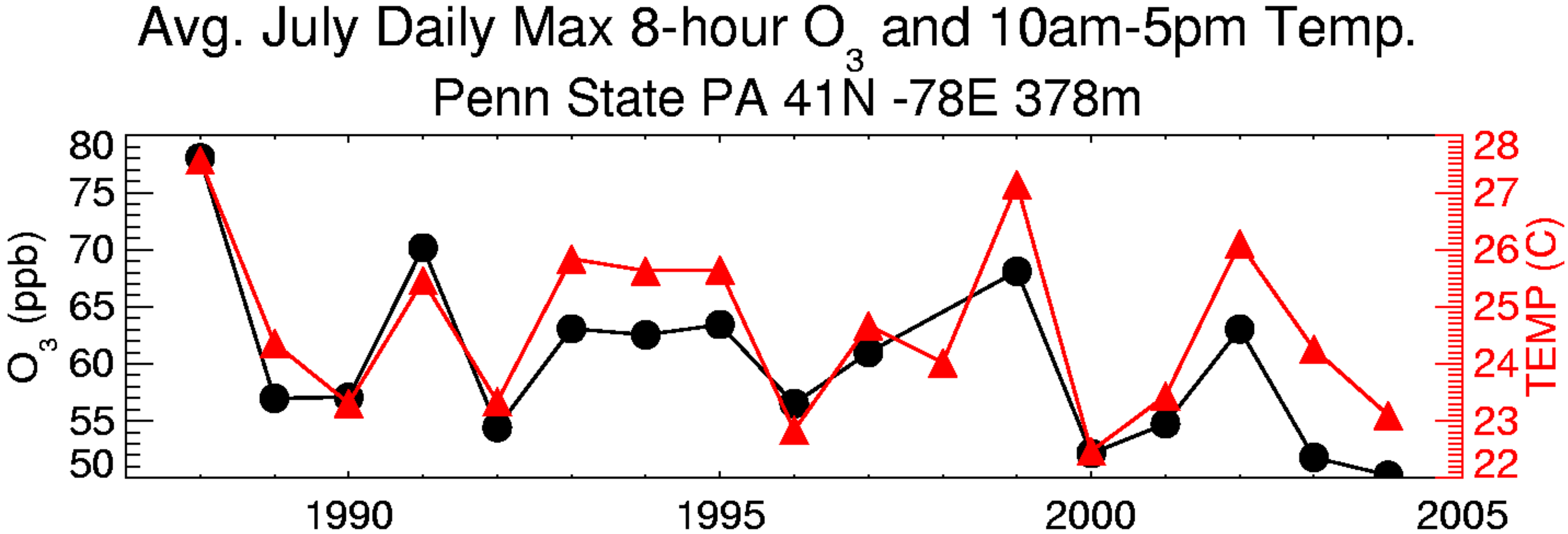
2. Aerosol reduction is a double edged sword.

3. Indirect effects have introduced a major uncertainty in our quantitative understanding of the role played by aerosols.

4. Future emission projections are highly uncertain at best.

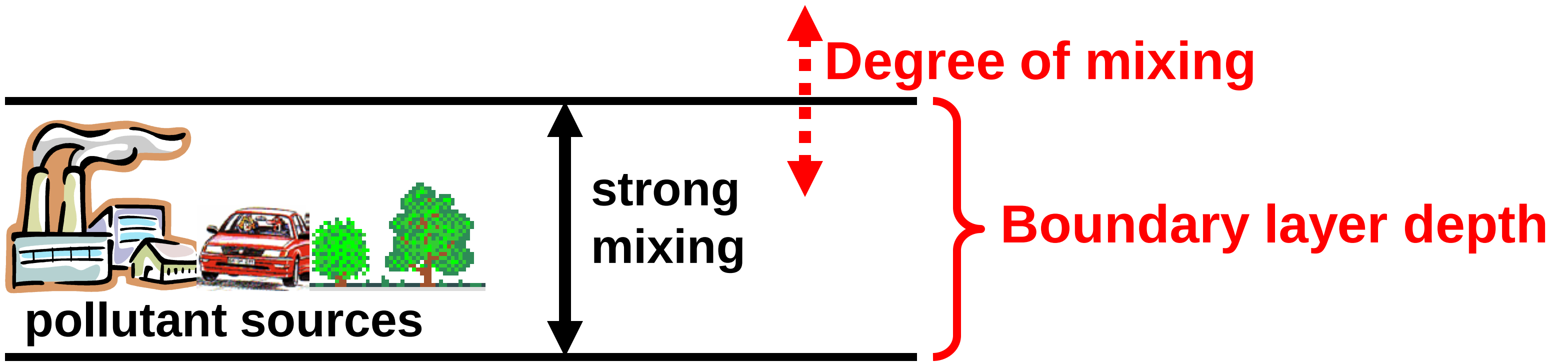
Impact of Climate on Air Quality

Strong relationship between weather and pollution implies that changes in climate will impact air quality

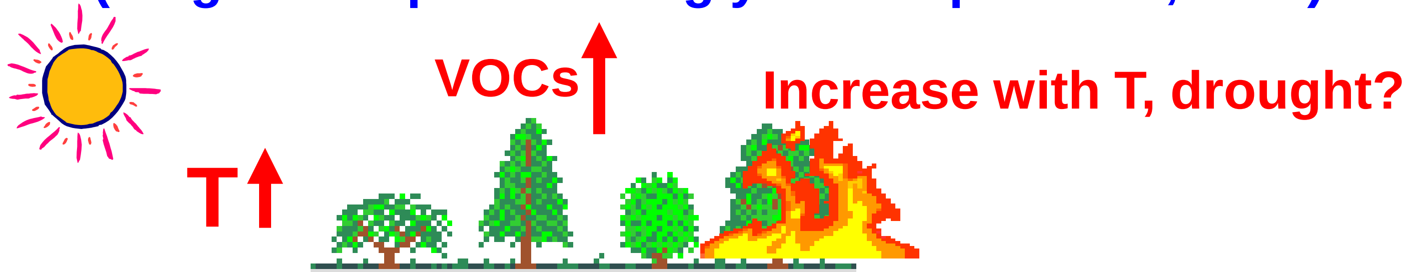


How does climate affect air quality?

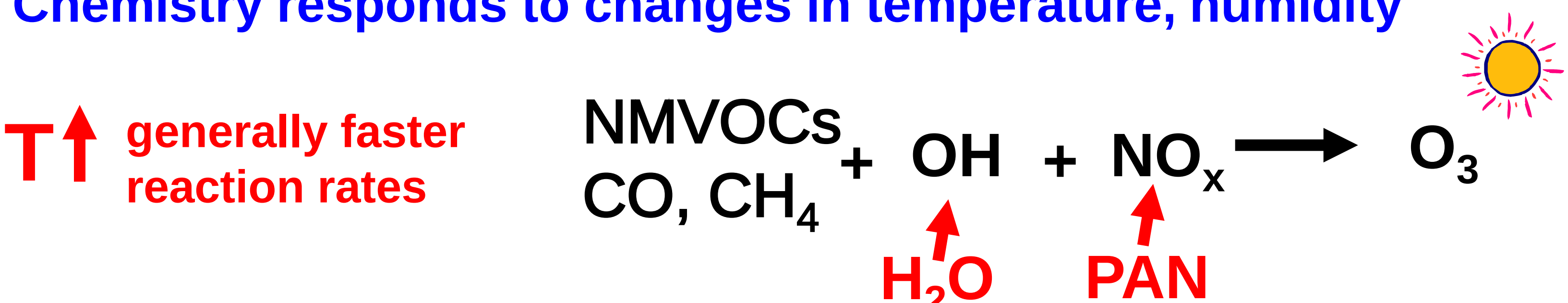
(1) Meteorology (stagnation vs. well-ventilated boundary layer)



(2) Emissions (biogenic depend strongly on temperature; fires)



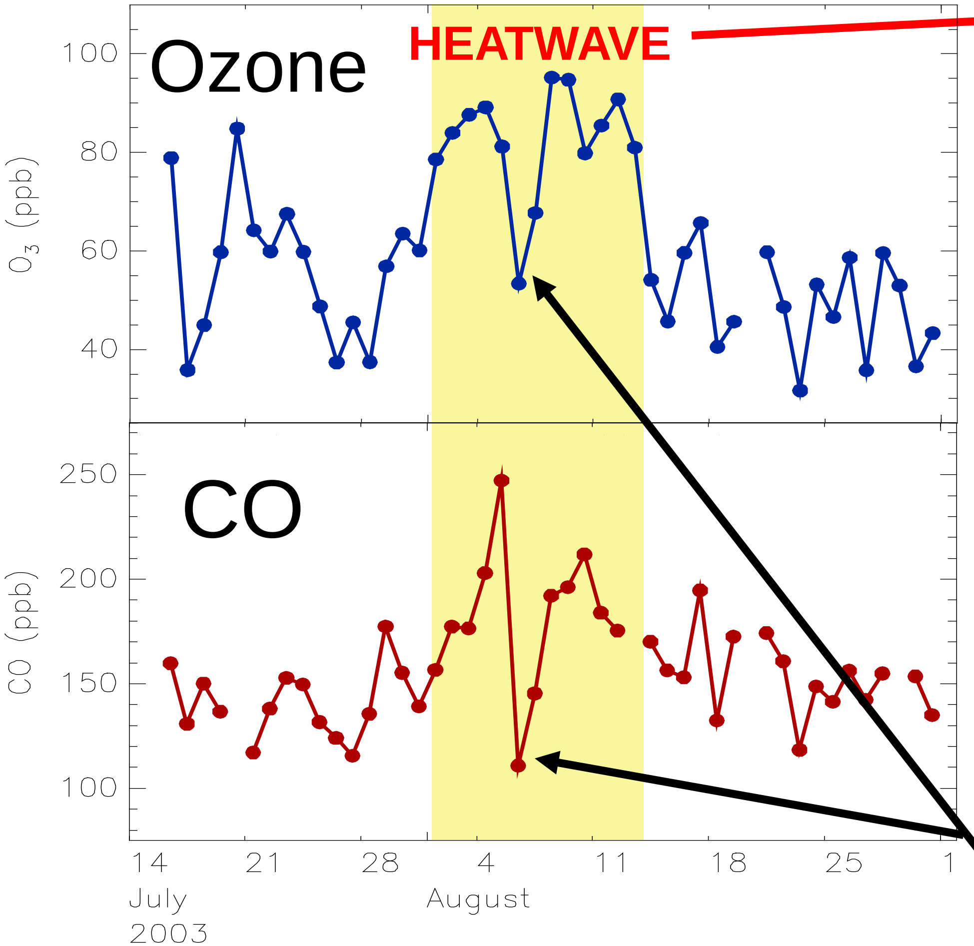
(3) Chemistry responds to changes in temperature, humidity



Pollution build-up during 2003 European heatwave

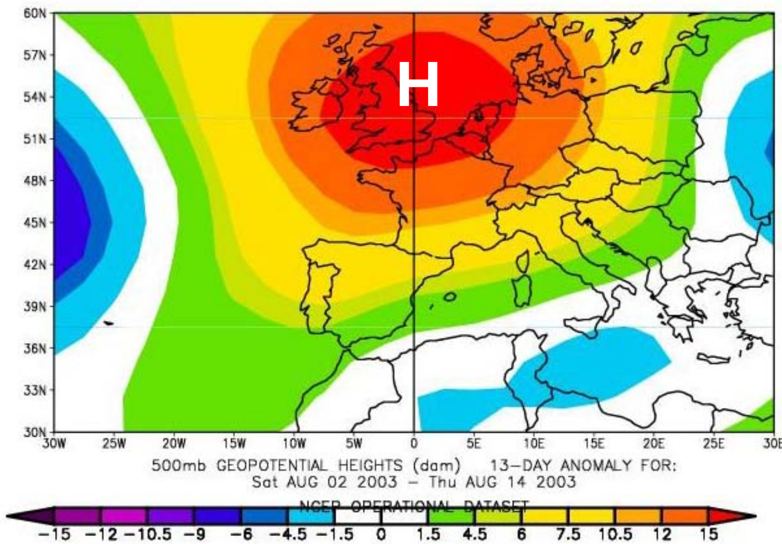
CO and O_3 from airborne observations (MOZAIC)

Above Frankfurt (850 hPa; ~160 vertical profiles



Stagnant high pressure system over Europe

(500 hPa geopotential anomaly relative to 1979-1995 for 2-14 August, NCEP)

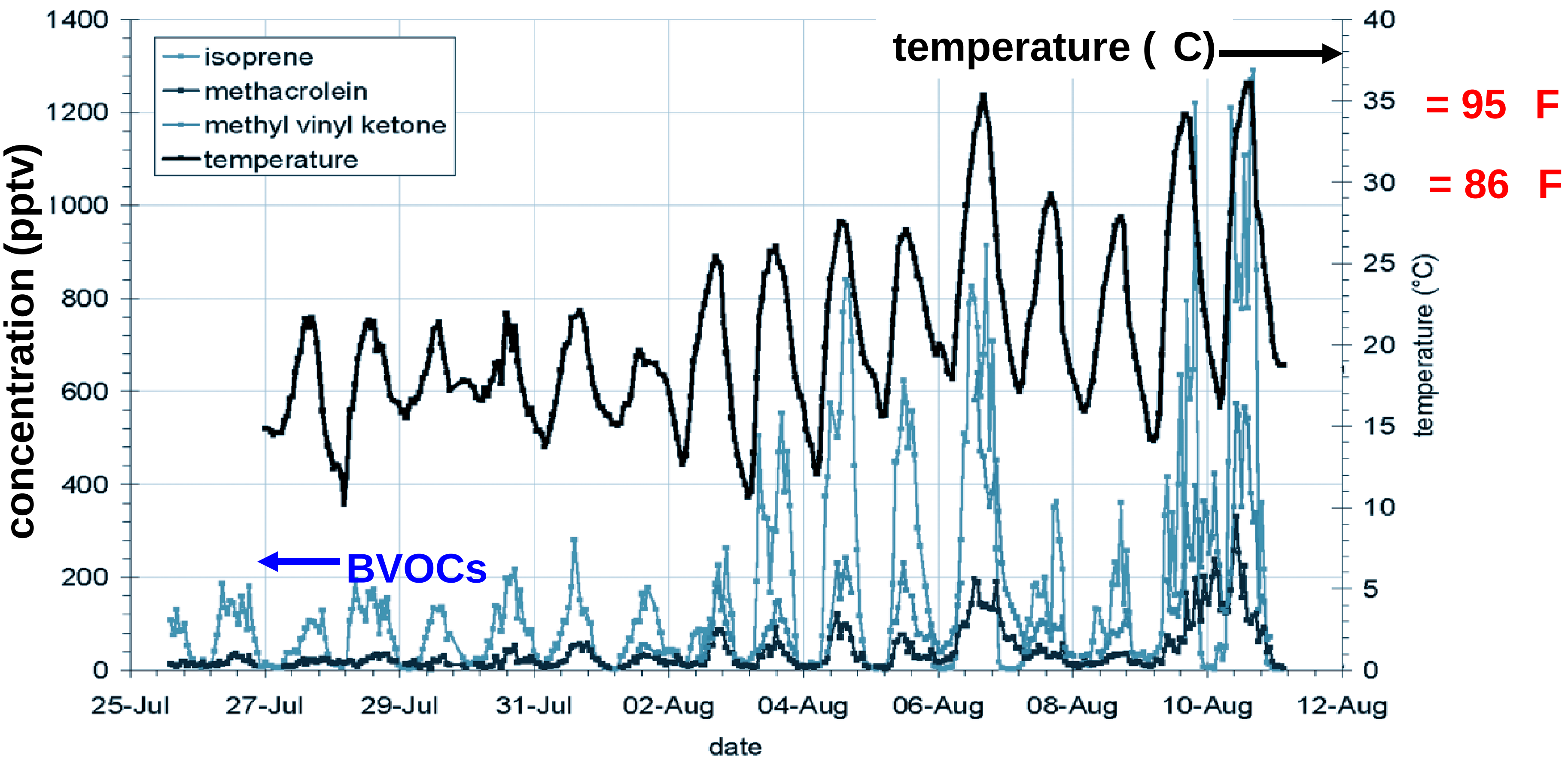


Ventilation (low-pressure system)

Carlos Ordóñez, Toulouse, France Contribution to GEMS

GEMS-GRG, subproject coordinated by Martin Schultz

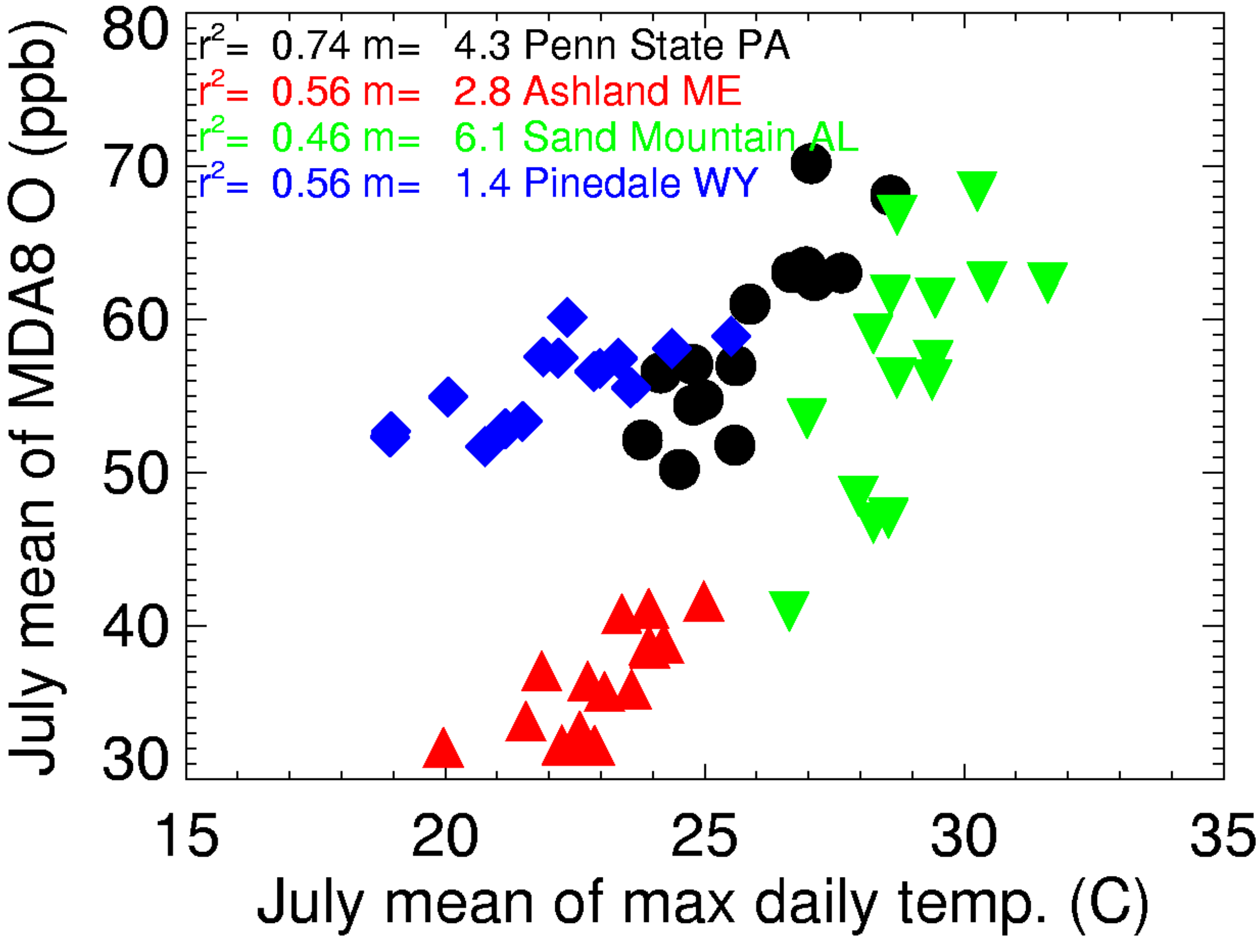
Observations during 2003 European heatwave show enhanced biogenic VOC concentrations



Measurements from August 2003 Tropospheric Organic Chemistry Experiment (TORCH) in Essex, UK, during hottest conditions ever observed in the UK to date
c/o Dr. Alistair Lewis, University of York, UK

Hogrefe *et al.*, *EM*, 2005

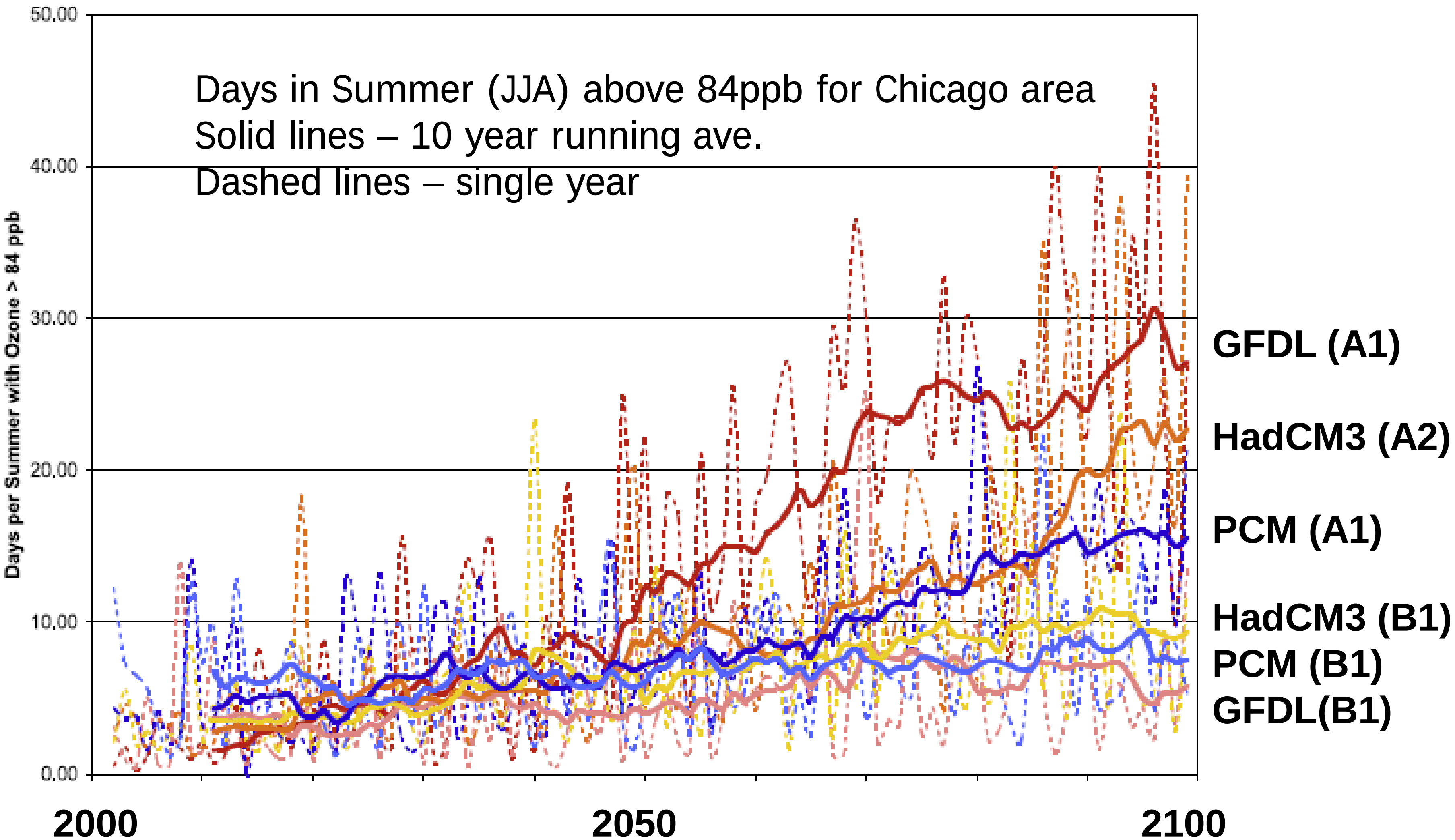
Observed O_3-temperature relationships: a useful test for building confidence in models?



→ Example of information needed for statistical downscaling

A. Fiore, private communication

Application of statistical downscaling to predict air quality response to future climate change

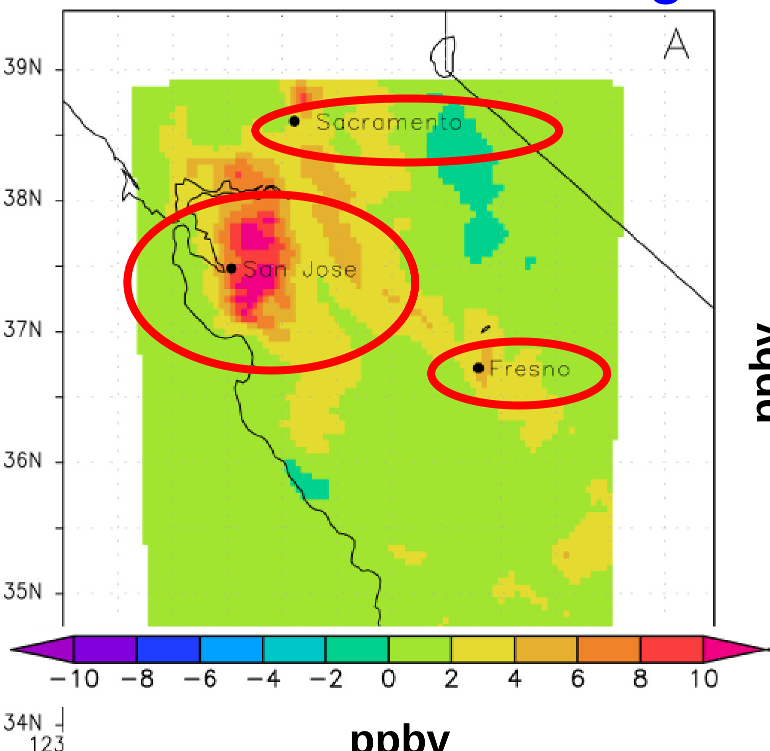


Results based on historically observed meteorology-ozone relationships applied to climate model output for the Chicago area – Holloway et al., 2008

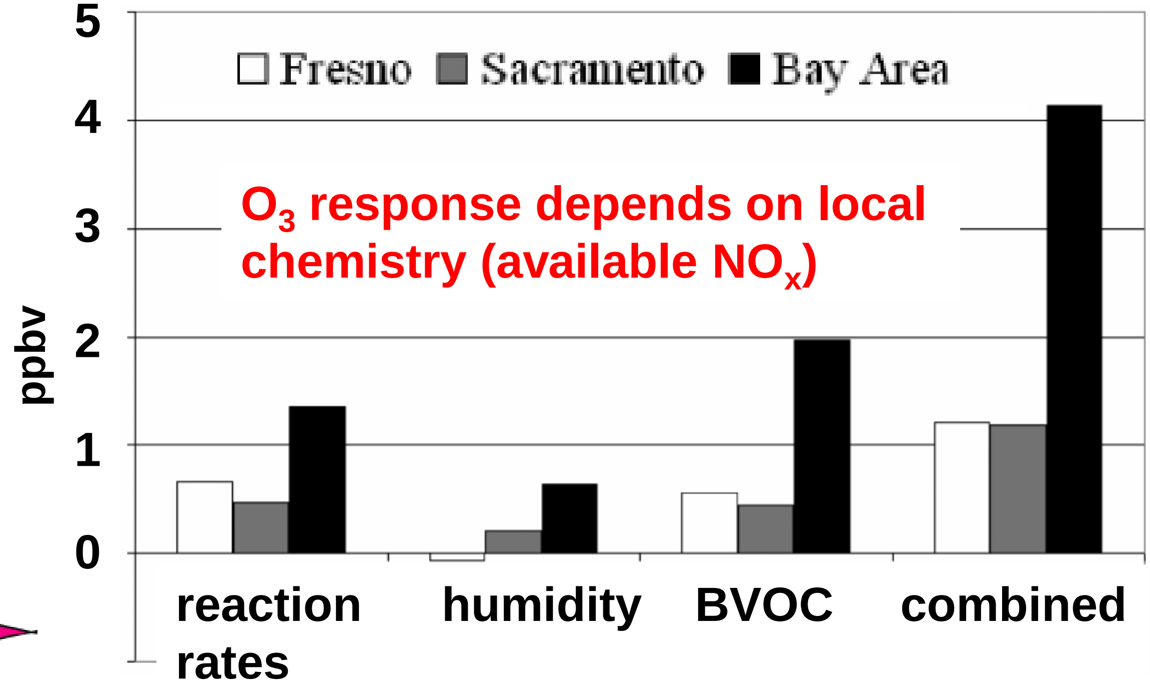
Impacts on surface O_3 from T-driven increases in reaction rates, humidity, and BVOC emissions

3 p.m. O_3 change (ppbv) in 3-day O_3 episode with CMAQ model (4x4 km^2), applying **T change from 2xCO_2 climate** (changes in meteorology not considered)

Surface ozone change



normalized to a +1 C



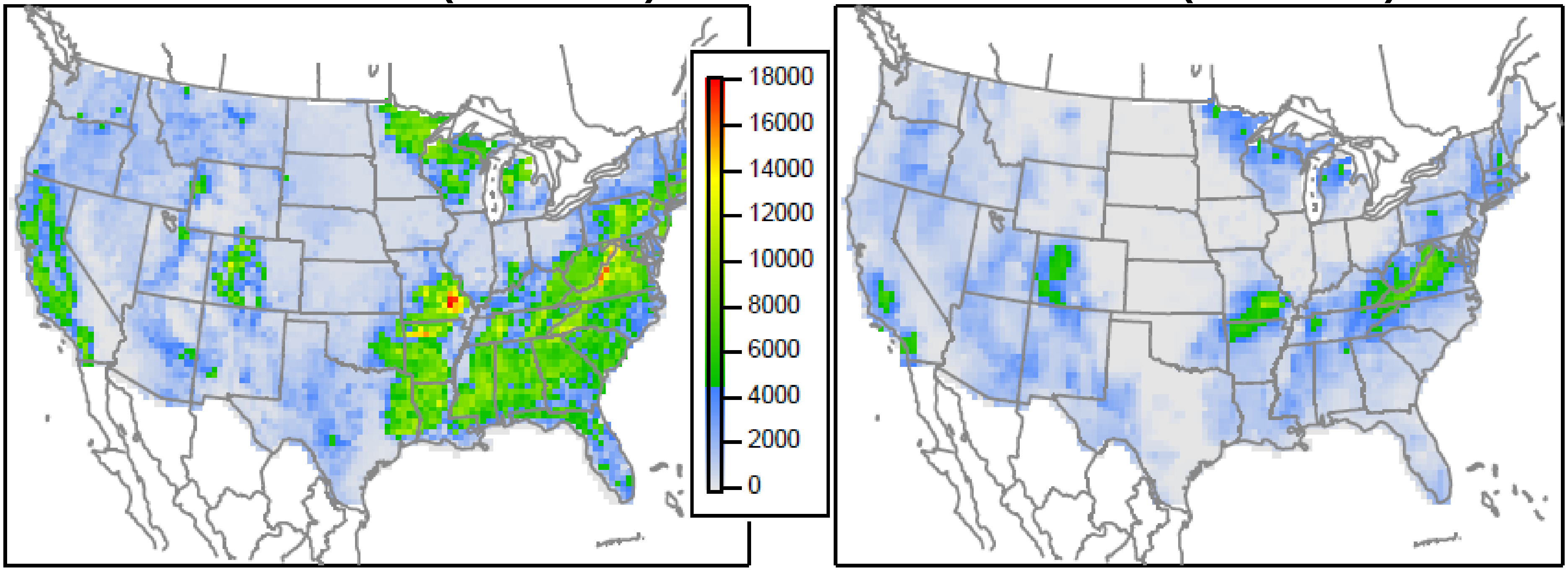
Climate-driven O_3 increases may counteract air quality improvements achieved via local anthropogenic emission reductions

[Steiner *et al*., *JGR*, 2006]

Changes in land-use could have a large impact on future air quality (biogenic emissions)

July isoprene emission capacity, normalized to 30°C ($\mu g\ m^{-2}\ h^{-1}$)

PRESENT DAY (1990-1999) **FUTURE (2045-2054)**

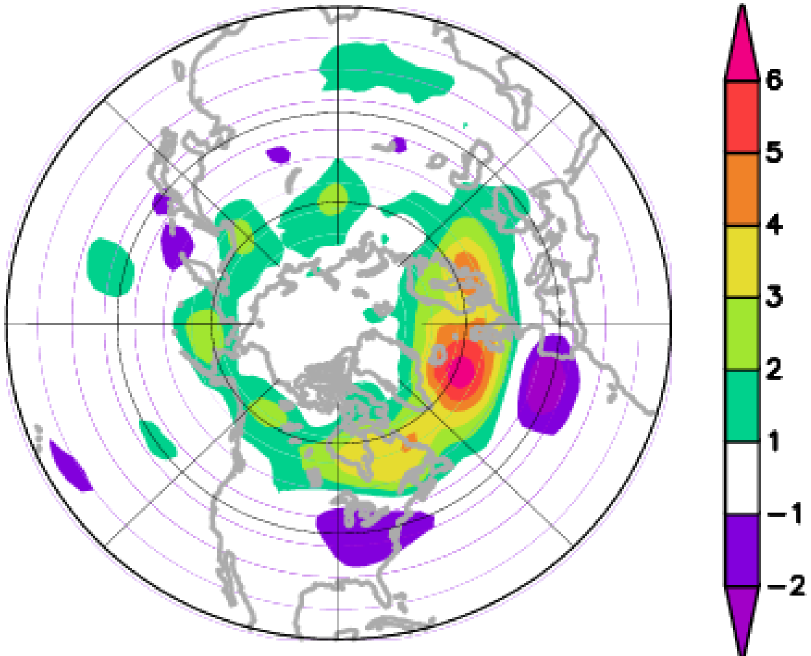


→Conversion of forests to grasslands and crops decreases isoprene emissions (IPCC SRES A2 scenario)

[Avise et al., ACP, 2009; Chen et al., ACP, 2009]

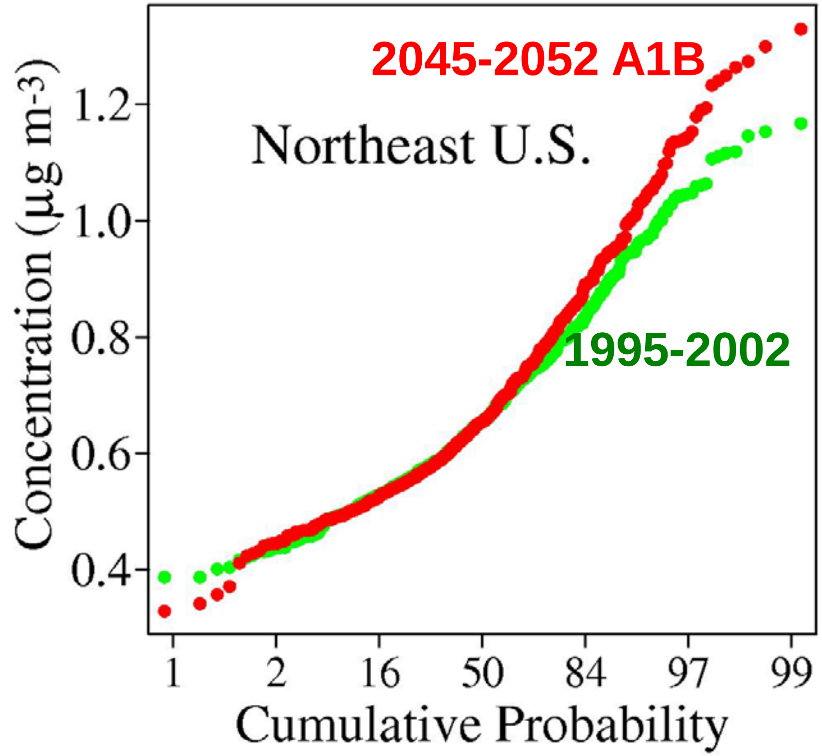
Models including impacts of changing climate on meteorology suggest increase in eastern U.S. pollution events due to fewer ventilating mid-latitude storms

Poleward shift in northern hemisphere summertime storm tracks for 2xCO_2



GFDL CM2.1 climate model

Tracer of anthropogenic pollution (July-August)



e.g. in GISS global model (4°x5°)

[Mickley *et al*., *GRL*, 2004]

See also: Hogrefe et al., 2004, 2005; Jacob and Winner, 2009 and references therein

Isolate Climate Impact:

Examine air quality in present vs. future climate in the newest GFDL atmospheric chemistry-climate model (AM3)

Present Day Simulation (20 years)

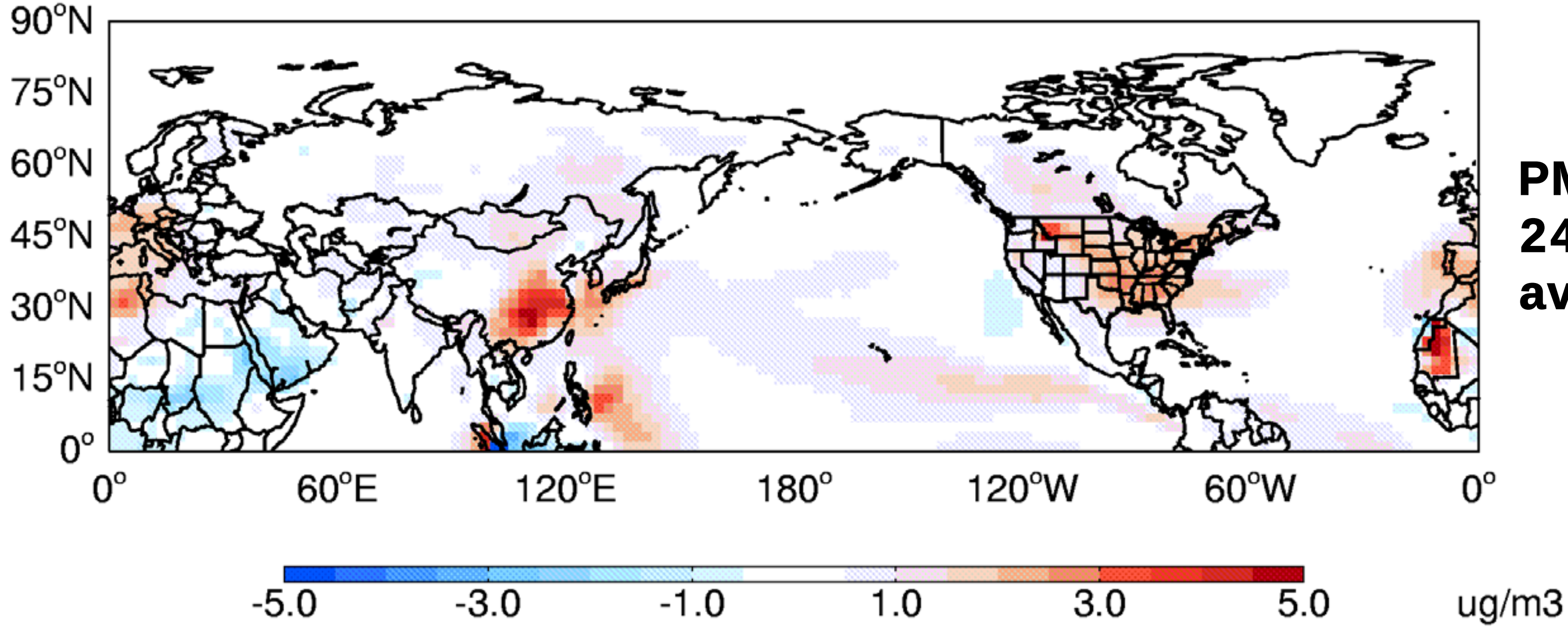
Climatological (1981-2000 mean) observed SSTs and sea ice (HadISST)
Greenhouse gases at 1990 values

Future Simulation (20 years)

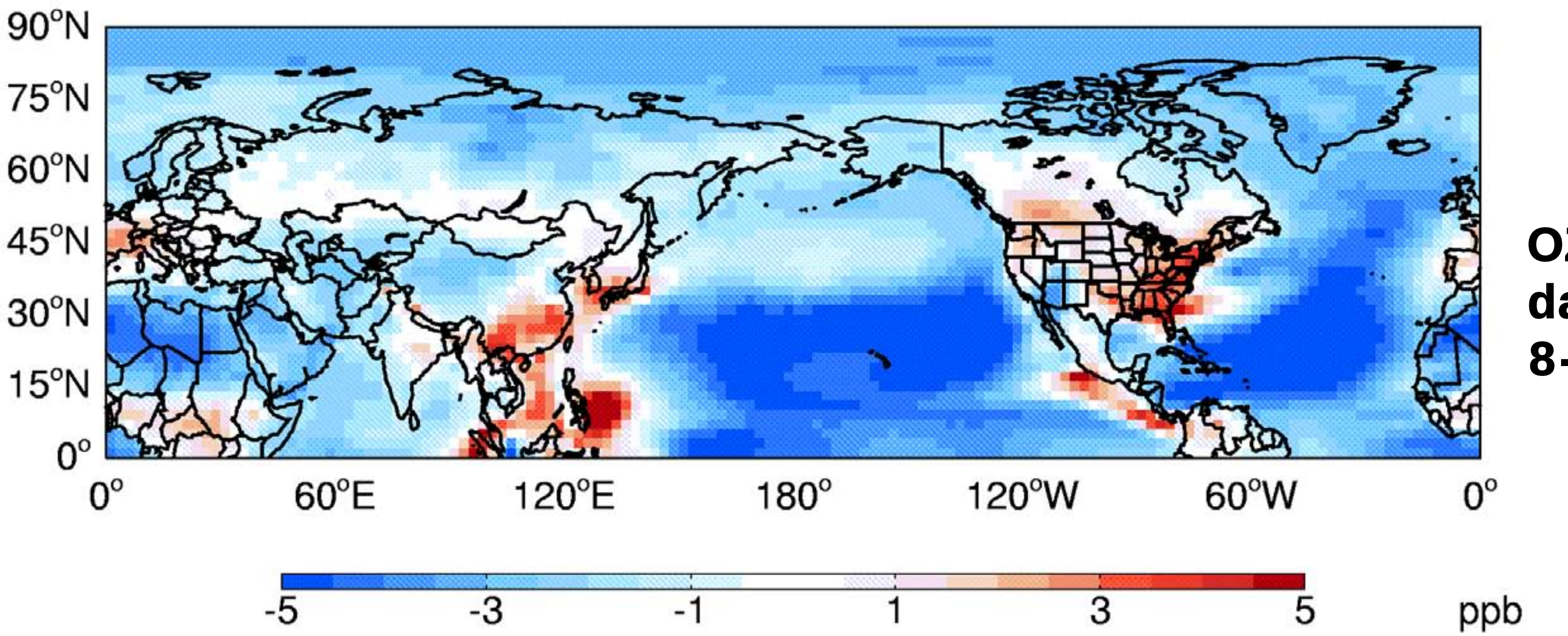
Present day 20 year mean SSTs, sea ice + IPCC AR-4 19-model mean changes for A1B scenario for 2081-2100
Greenhouse gases at 2090 values

All simulations use annually-invariant emissions of ozone and aerosol precursors (except for lightning NOx), to isolate role of climate change

CHANGES IN SUMMER (JJA) PM2.5 AND 8-HOUR OZONE (FUTURE – BASE)



PM2.5 24 hr. avg.



OZONE daily max 8-hour avg.

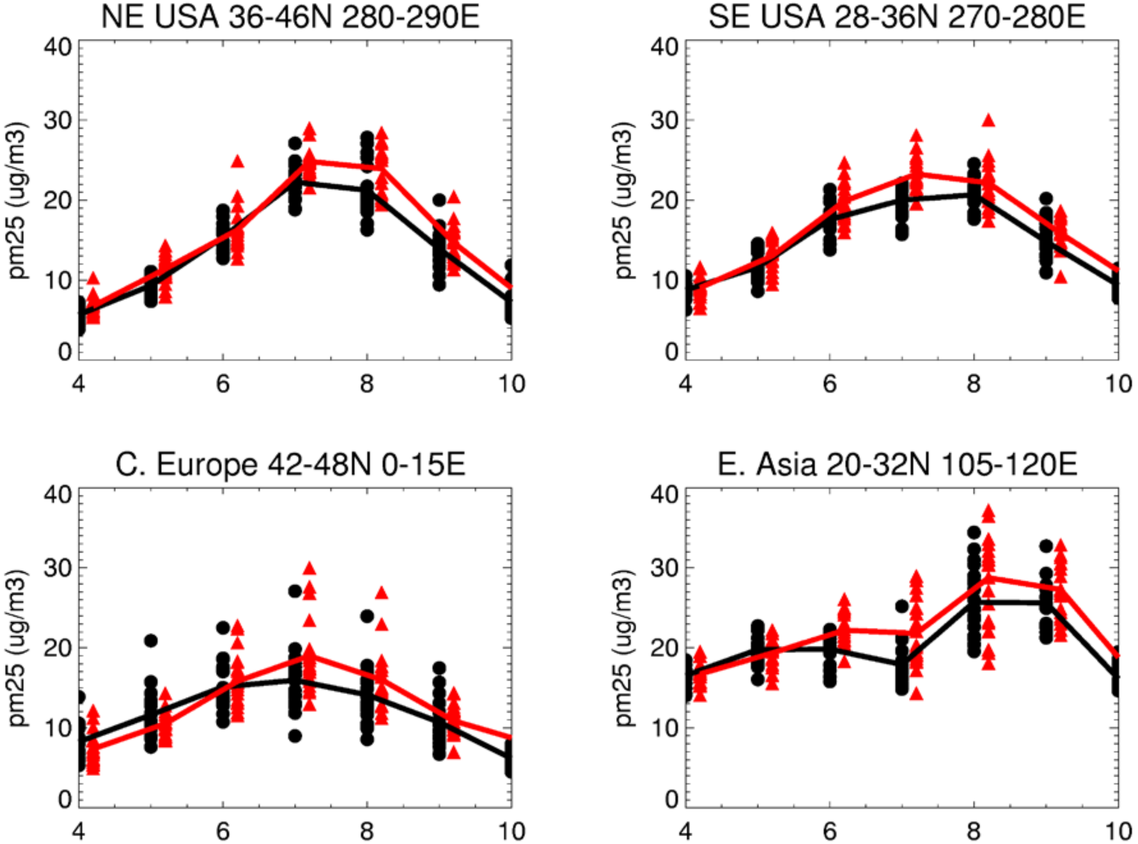
AEROSOLS IN SURFACE AIR

Future: 2081-2100 (climatological) **Present: 1991-2000 (climatological)**

Individual symbols = individual years

Line = 20-year average value

24-h monthly mean PM2.5



April through October

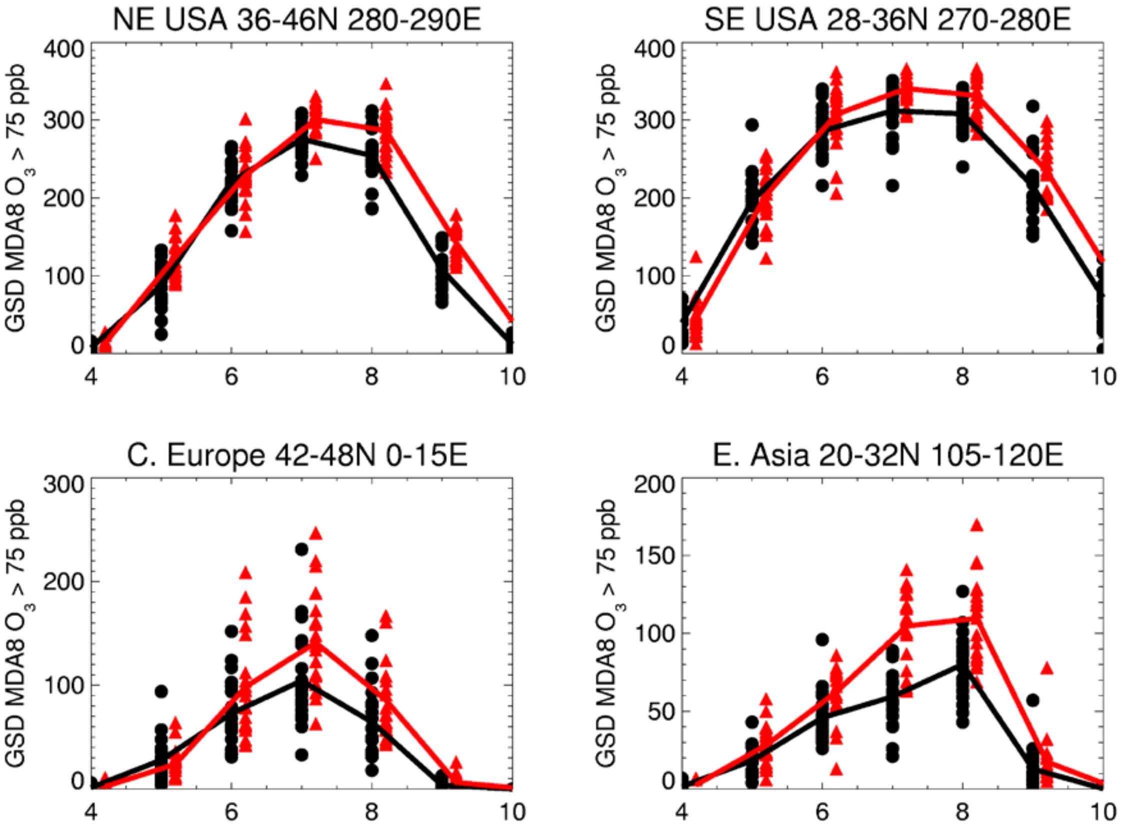
OZONE IN SURFACE AIR

Future: 2081-2100 (climatological) Present: 1991-2000 (climatological)

Individual symbols = individual years

Line = 20-year average value

Number of grid-square days with MDA8 ozone >75 ppb



April through October

SUMMARY: Climate → Air quality

1. Many possibilities for future air quality sensitivity to climate change (temperature, transport, BL mixing, biogenic sources, fires, ...)

However

2. Quantitative understanding is highly uncertain.
   - a. emission projections - (Who can predict 2050 conditions?)
   - b. regional climate projections – (nothing in the last IPCC)
   - c. aerosol-cloud indirect effects – (We have just started.)
   - d. the next surprise – (There is always another one.)

3. My/our best current guess – Global warming won’t help.