Intercontinental Source-Receptor Relationships for Ozone Pollution

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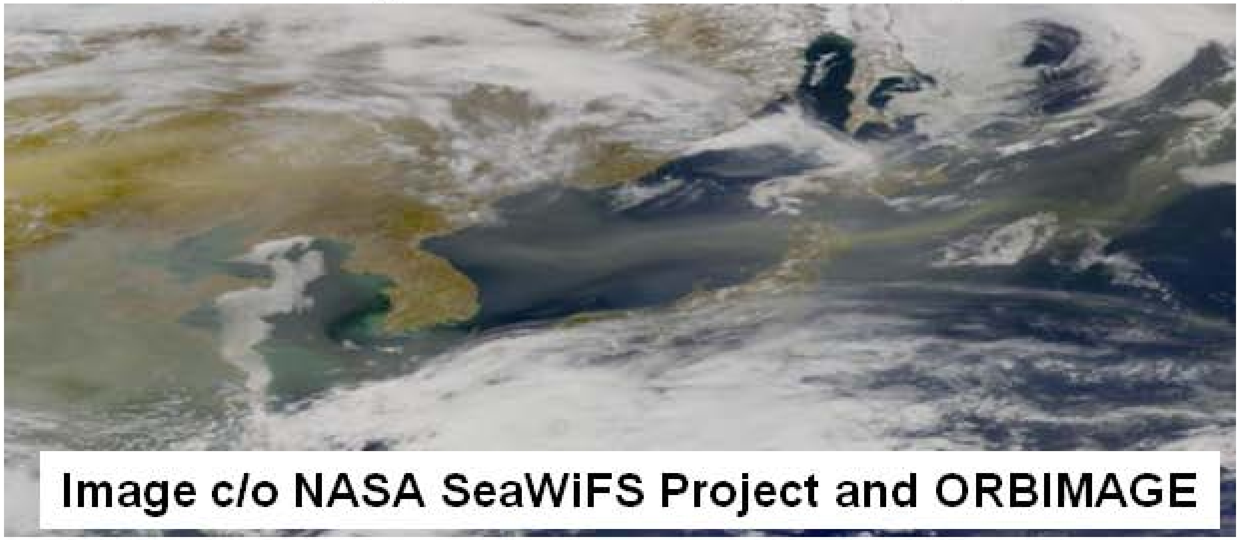
LRTAP Long-range Transboundary Air Pollution

Task Force on Hemispheric Transport of Air Pollution

40th Air Pollution Workshop and Symposium, Raleigh, NC, April 7, 2008

Evidence of intercontinental transport at northern midlatitudes: 2001 Asian dust event

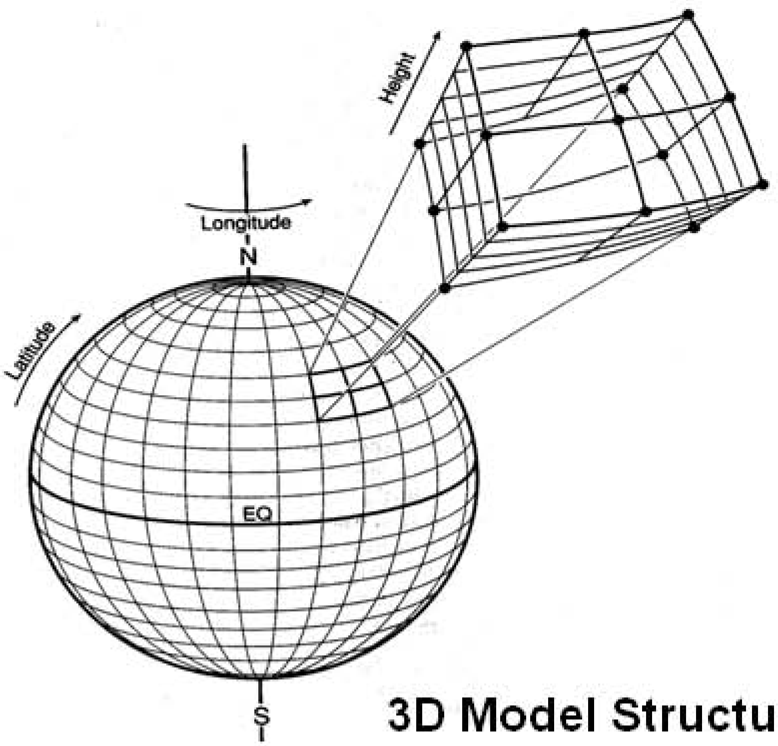
Dust leaving the Asian coast in April 2001



Reduced Visibility from Transpacific Transport of Asian Dust

How do we estimate source-receptor (S-R) relationships that describe hemispheric transport of air pollution?

Measurements at remote sites?
(Monitoring site at Yosemite NP)



3D Model Structure

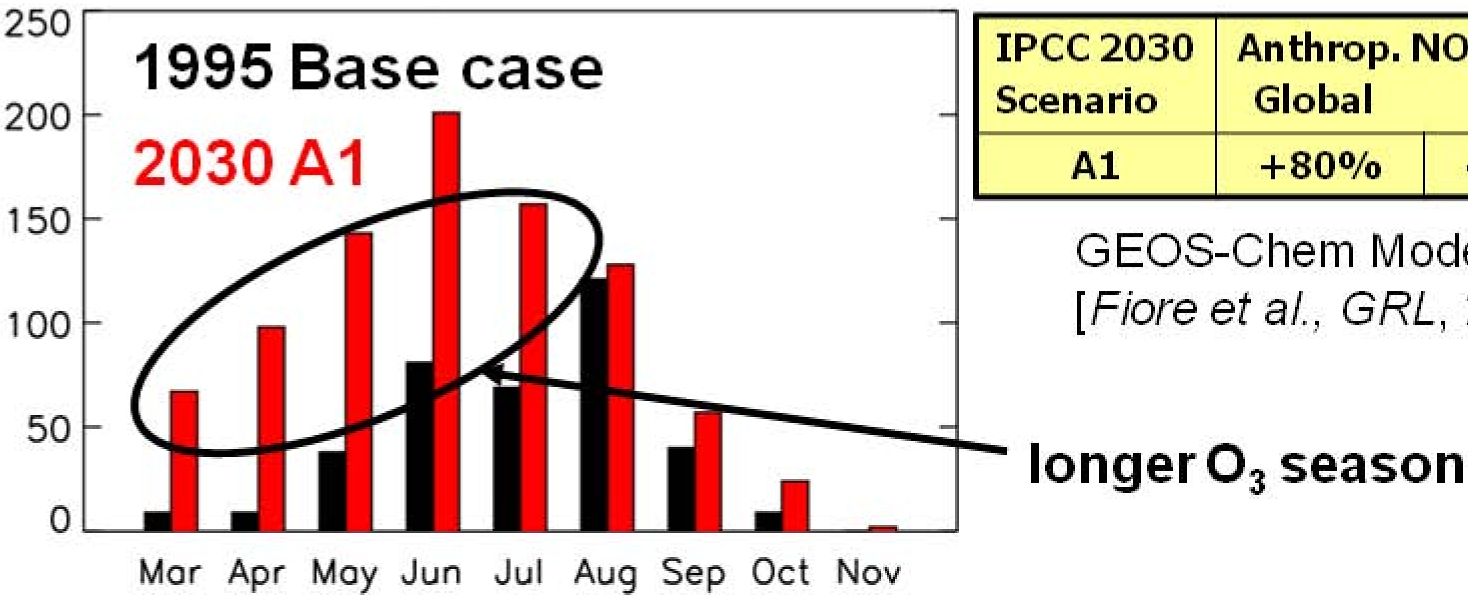
Models with anthropogenic emissions reduced in source regions?

Difficult to directly measure a region's contribution to pollution over a receptor region, particularly for ozone [*e.g. Goldstein et al.*, 2004]

Regional control efforts (even under optimistic scenarios) may be offset by increases in hemispheric ozone pollution

By 2030 under the Current LEgislation (CLE) scenario, "the benefit of European emission control measures is… significantly counterbalanced by increasing global O_3 levels…"
[*Szopa et al.*, *GRL*, 2006]

U.S. grid-square days with 1-5p.m. O_3 > 70 ppb



IPCC 2030 Scenario	Anthrop. NO_x emis. Global	U.S.	Methane emis.
A1	+80%	-20%	+30%

GEOS-Chem Model (4°x5°)
[*Fiore et al.*, *GRL*, 2002]

U.S. air quality degrades despite domestic emissions controls (A1 2030)

International approach to ozone abatement?

Convention on Long-Range Transboundary Air Pollution (CLRTAP)

LRTAP
Long-range Transboundary Air Pollution

Task Force on Hemispheric Transport of Air Pollution

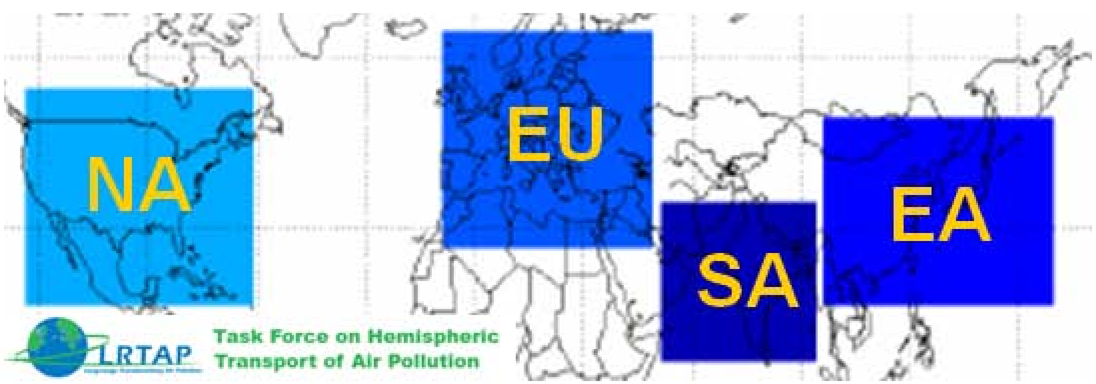
Co-chairs: Terry Keating (U.S. EPA) and André Zuber (EC)

TF HTAP Mission: Develop a fuller understanding of hemispheric transport of air pollution to inform future negotiations under CLRTAP

Multi-model assessment involving >25 modeling groups

OBJECTIVES: Quantify S-R relationships for HTAP regions **and assess uncertainties in these estimates**

HTAP S-R Regions

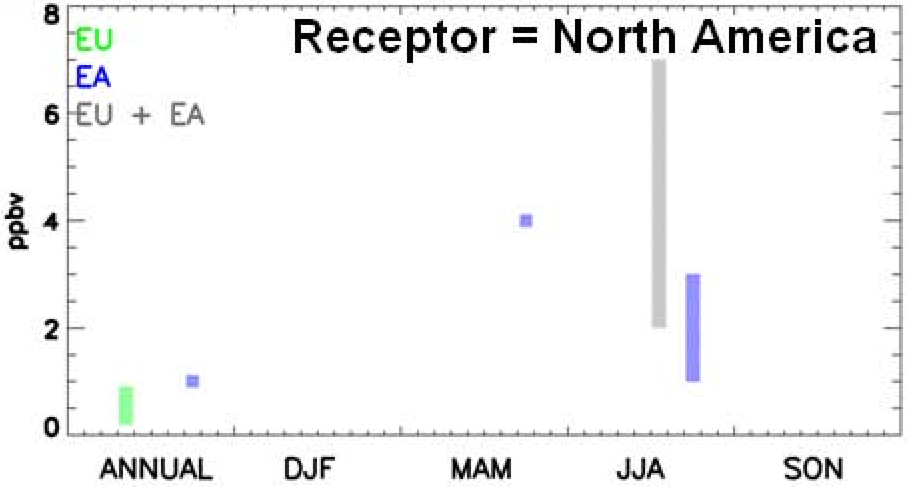


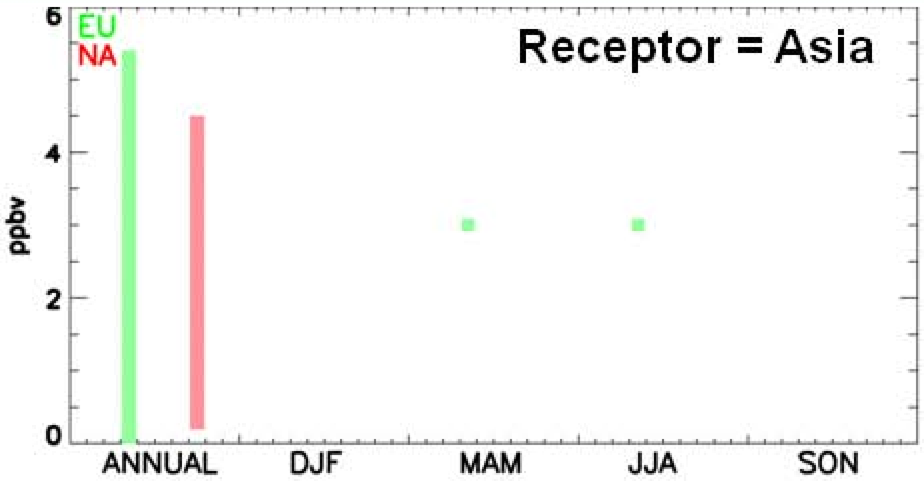
Focus species:
- **Ozone and precursors**
- **Aerosols and precursors**
- **Mercury**
- **Persistent Organic Pollutants**
- **Idealized Tracers**
- **Oxidized Nitrogen**

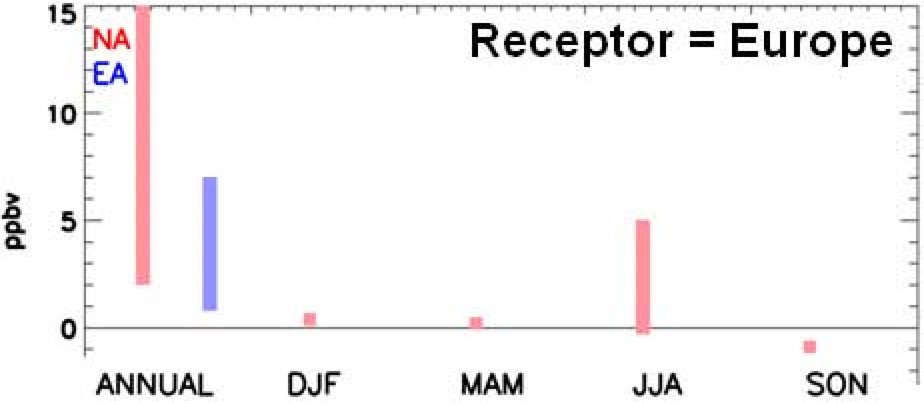
PRODUCTS: **2007 Interim Report** to inform the review of the 1999 CLRTAP Gothenburg Protocol to abate acidification, eutrophication, and tropospheric ozone (**www.htap.org**).

2009 Assessment Report to inform the CLRTAP on hemispheric air pollution and S-R relationships.

Wide range in literature estimates of mean surface O_3 S-R relationships at northern mid-latitudes







Assessment hindered by different:

1) methods
2) regional definitions
3) reported metrics
4) years (meteorology)

→ Adopt a multi-model approach
→ Consistency across models
→ Examine all seasons

Estimates are from studies cited in TF HTAP [2007] Ch5, plus new work [*Holloway et al.*, 2008; *Duncan et al.*, 2008; *Lin et al.*, 2008]

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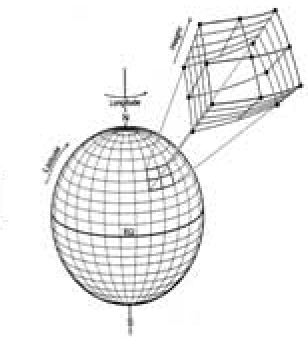
Model Setup for TF HTAP Ozone S-R Study

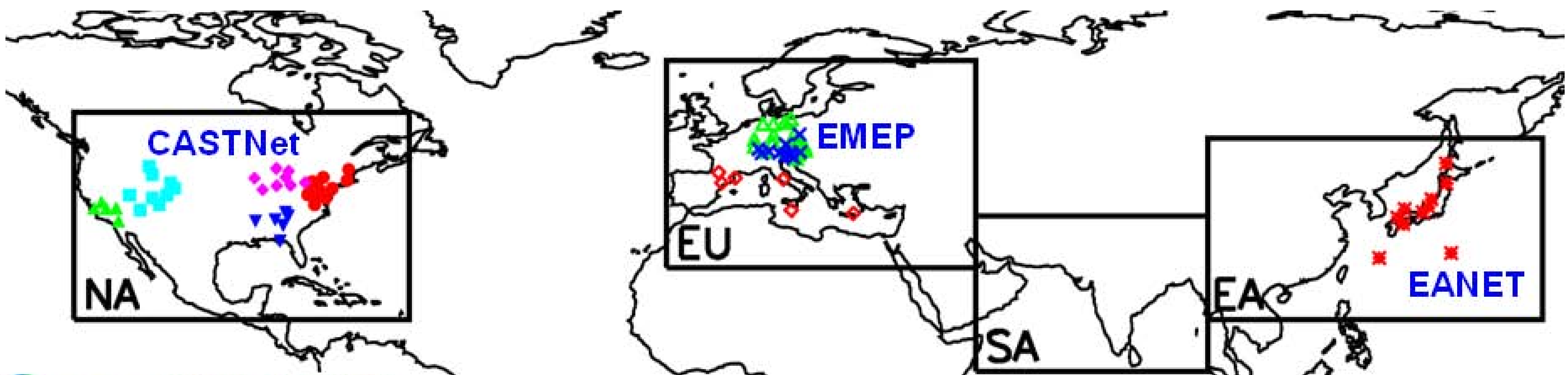
BASE SIMULATION

→ horizontal resolution of 4°x5° or finer
→ 2001 meteorology
→ each group's best estimate for emissions in 2001
→ methane set to a uniform value of 1760 ppb



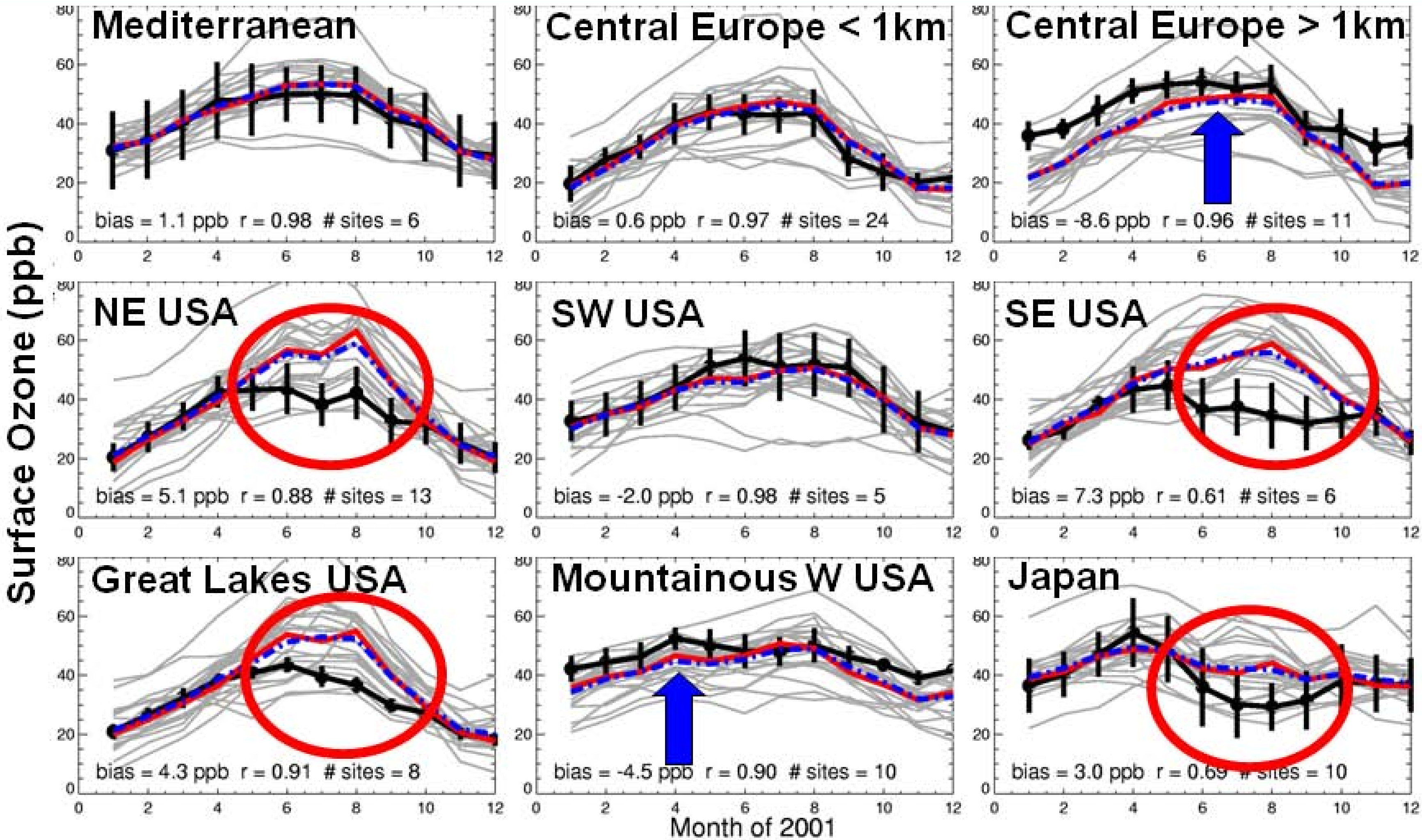
SENSITIVITY SIMULATIONS (17 total) with sustained 20% decreases in

→ regional anthrop. NO_x, CO, NMVOC emis. individually (4x3)
→ regional anthrop. emis. of all O_3 and aerosol precursors (4)
→ global methane (to 1408 ppb)



HTAP REGIONS

Large inter-model range; 21-model mean generally captures observed monthly mean surface O_3



→ Many models biased low at altitude, high over EUS+Japan in summer

→ Good springtime/late fall simulation

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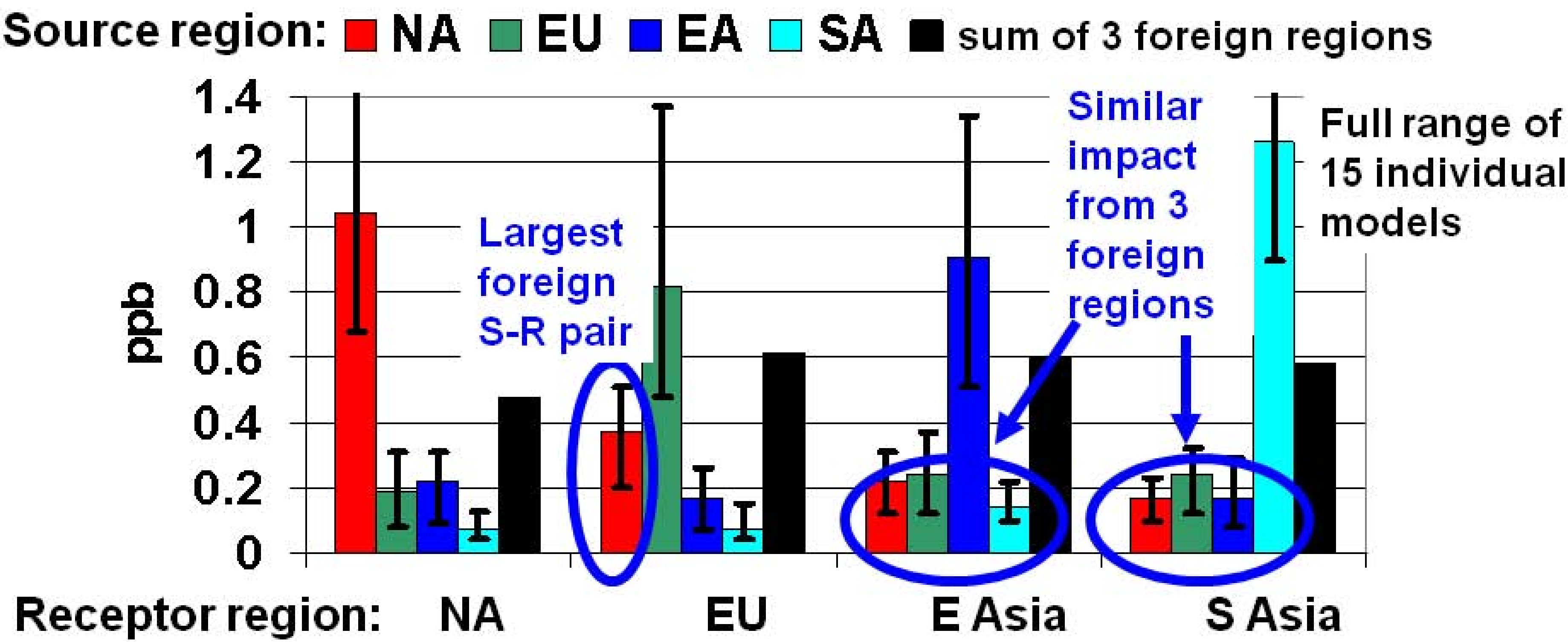
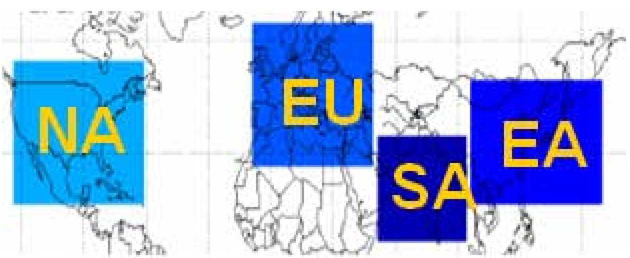
Estimates of S-R relationships: Annual mean surface O_3 decrease from 20% reductions in anthropogenic NO_x+CO+NMVOC emissions





$$\frac{\Sigma(-20\%\ \text{foreign anthrop. emis.})}{-20\%\ \text{domestic anthrop. emis.}} = 0.45\text{-}0.75$$

"import sensitivity"

→ But… seasonality in sensitivity to domestic vs. foreign sources?

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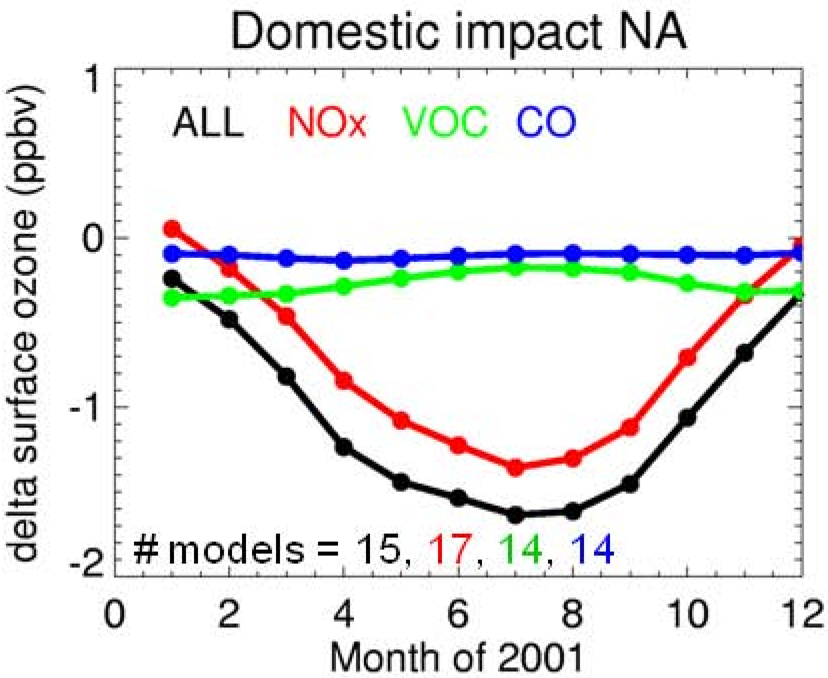
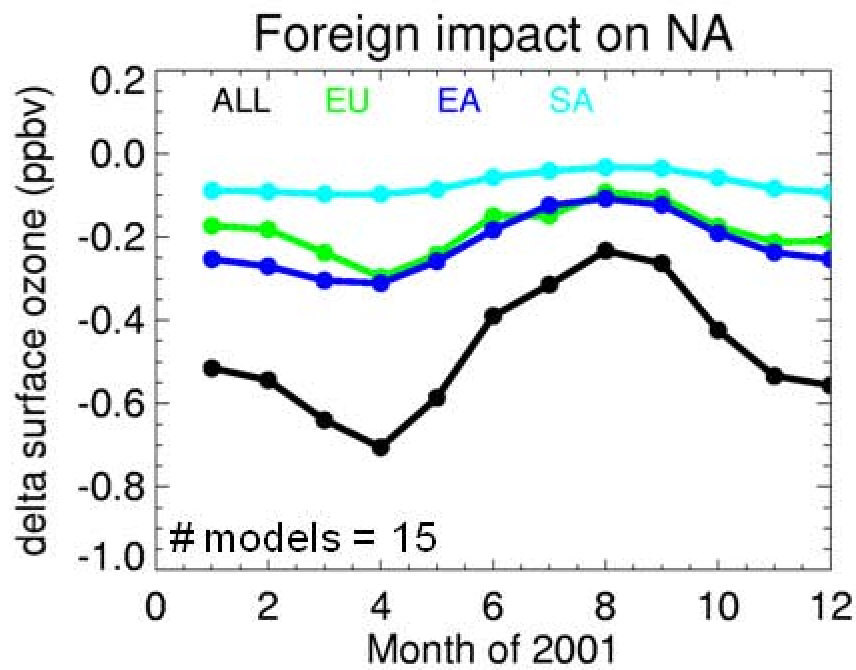
Model ensemble mean surface O_3 response over NA to decreases in anthropogenic emissions of O_3 precursors

-20% anthrop. NOx+CO+NMVOC emis.





- Max influence in summer (NO_X)
- Max NMVOC contribution in winter

- Max foreign influence spring + late fall
- SA contributes least
- EU + EA contribute similarly Apr-Nov (but depends on model)

→ Import Sensitivity for NA in July ~ 0.2, in April ~ 0.6

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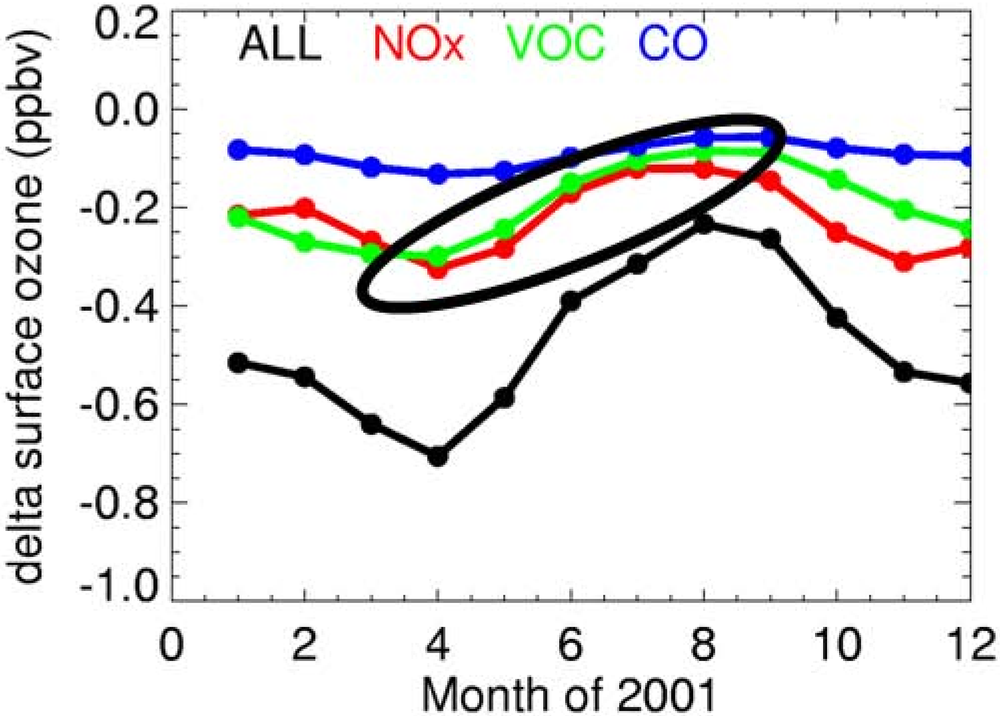
Model ensemble mean surface O_3 response over NA to decreases in anthropogenic emissions of O_3 precursors

Foreign impact on NA

(sum of O_3 responses to -20% anthrop. emis. in the 3 foreign regions)



Model ensemble mean indicates a comparable influence from foreign NOx and NMVOC…

…but relative importance varies across models

Wide range in EU anthrop. NMVOC inventories used in the models → large uncertainty in the estimated response of NA O_3 to EU emissions

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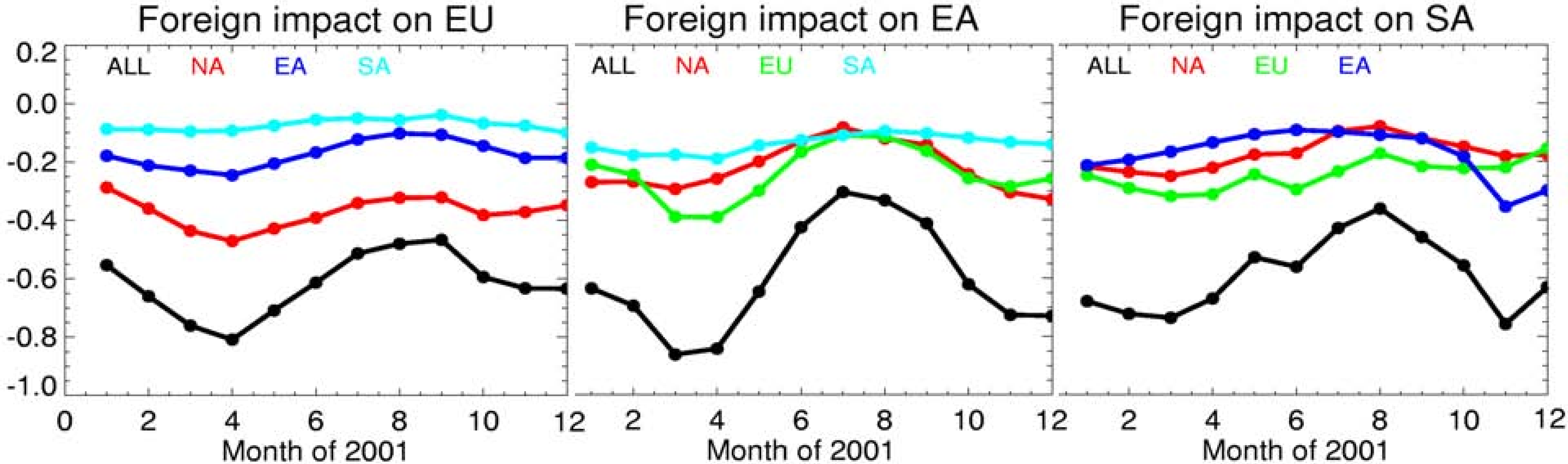
Summary: Intercontinental S-R relationships for O_3 and conventional O_3 precursors

- **Identified robust estimates + key areas of uncertainty**
  - Model ensemble mean overestimate vs. obs in summer EUS and Japan
  - Robust: NA→EU largest; SA→others smallest
  - Uncertainty in relative roles of EU/EA → NA
  - Uncertainty in exported EU O_3 from EU AVOC emissions inventories

Import sensitivities in other regions?

Comparison with prior literature?

Surface O_3 response to decreases in foreign anthropogenic emissions of O_3 precursors



Robust conclusions:

→NA>EA>SA on EU ozone

→NA and EU often > SA or EA on each other;
dominant contributor varies across models

→ Ozone over foreign regions generally least sensitive to SA emissions

Import sensitivities during month of max. domestic or foreign sensitivity:
EU: 0.7 (APR) 0.3 (JUL) EA: 1.1 (MAR) 0.2 (JUL) SA: 0.5 (NOV)

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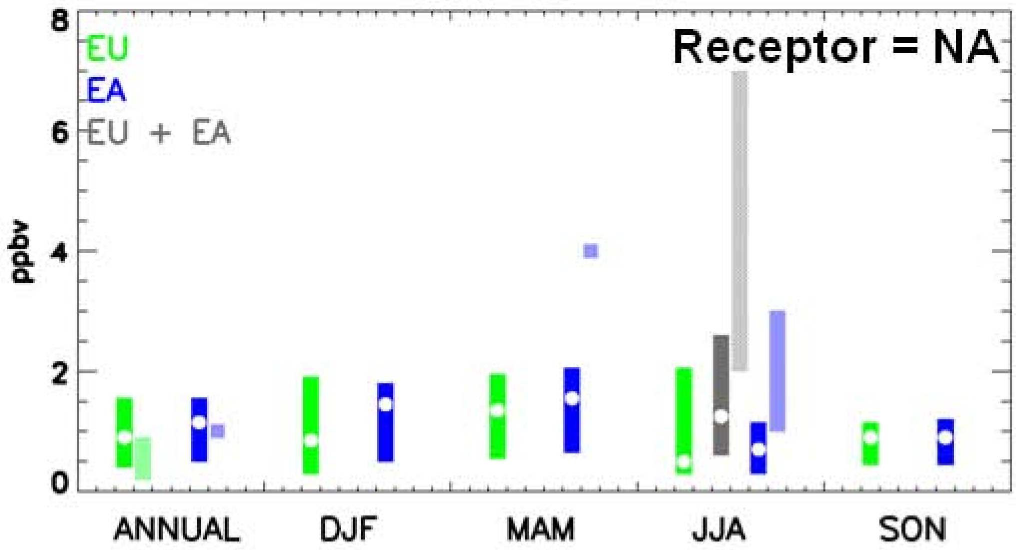
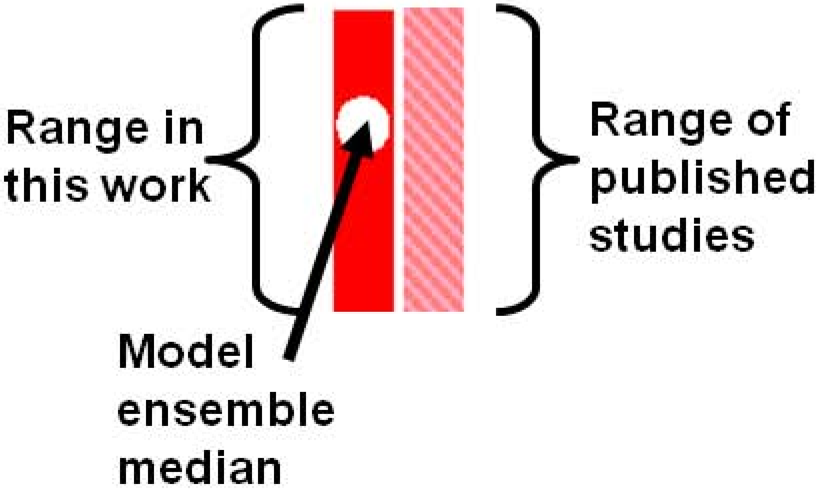
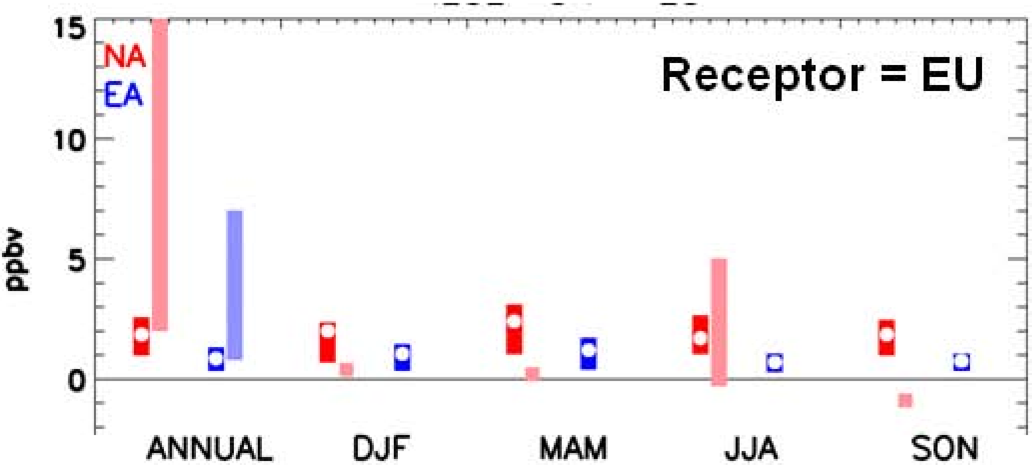
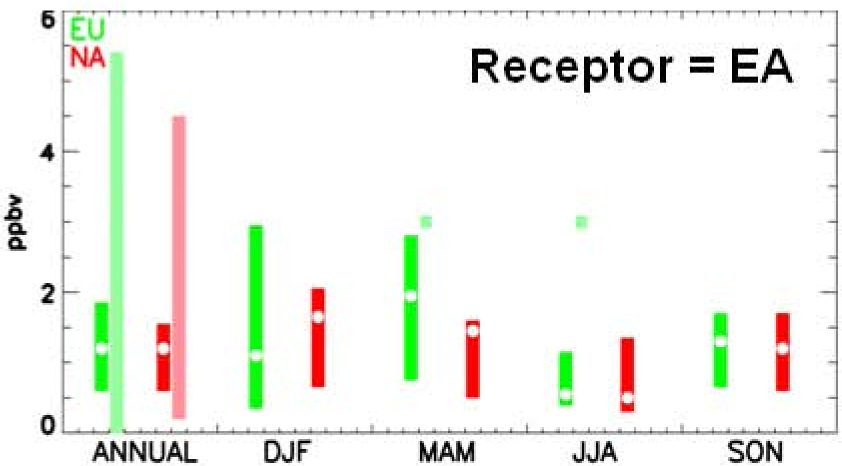
Range of estimated S-R relationships narrows from that in the literature with consistently applied HTAP approach

Assume linearity, scale response to -20% to 100% to estimate total contribution









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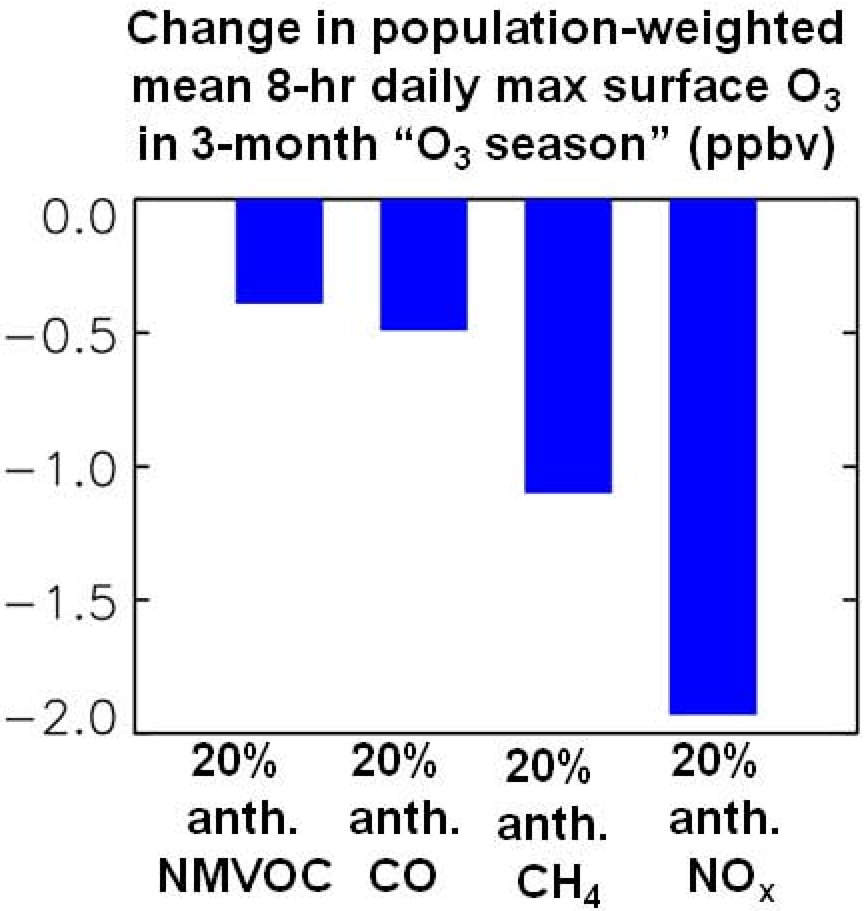
Summary: Intercontinental S-R relationships for O_3 and conventional O_3 precursors

- **Identified robust estimates + key areas of uncertainty**
  - Uncertainty in exported EU O_3 from EU AVOC emissions inventories
  - Robust: NA→EU largest; SA→others smallest
  - Uncertainty in relative roles of EU/EA → NA; EU/NA→EA/SA
  - Model ensemble mean overestimate vs. obs in summer EUS and Japan
- **Estimated "import sensitivities"**
  - 0.2-0.3 July EA/NA/EU (max domestic production)
  - 0.6-0.9 April EA/NA/EU (max foreign influence)
  - 0.5 November SA (max foreign+domestic influence)
- **Narrowed range of estimates from that in the literature**

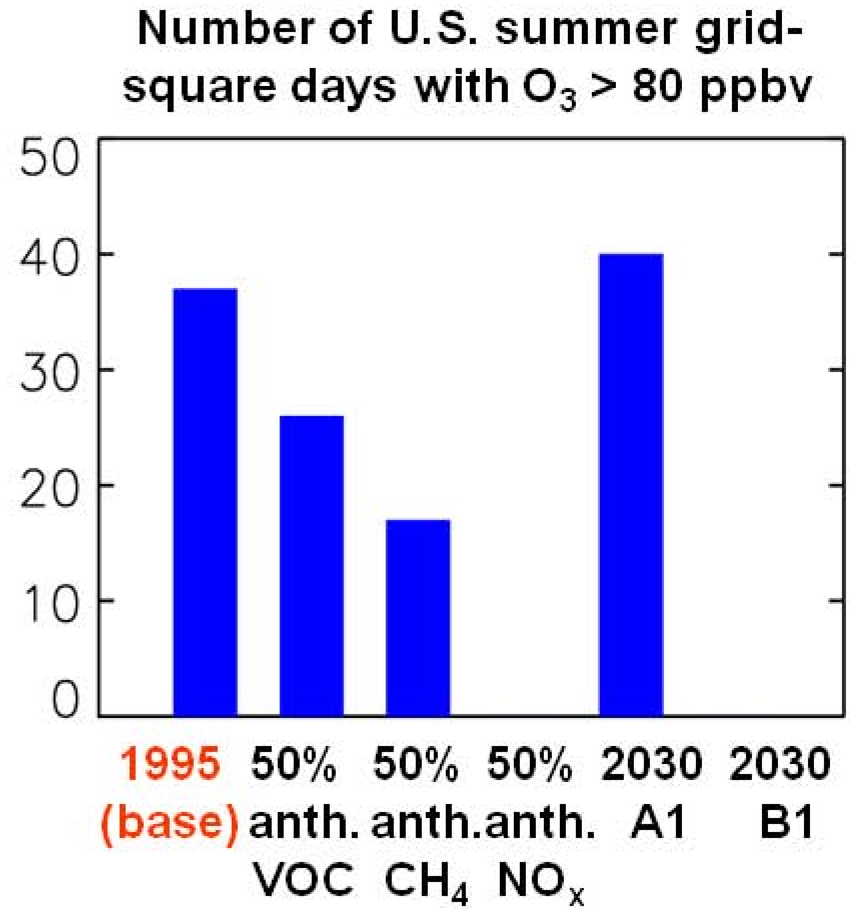
How does role of CH_4 compare with NO_x+CO+NMVOC?

Globally reducing methane decreases surface ozone everywhere



Steady-state results from MOZART CTM

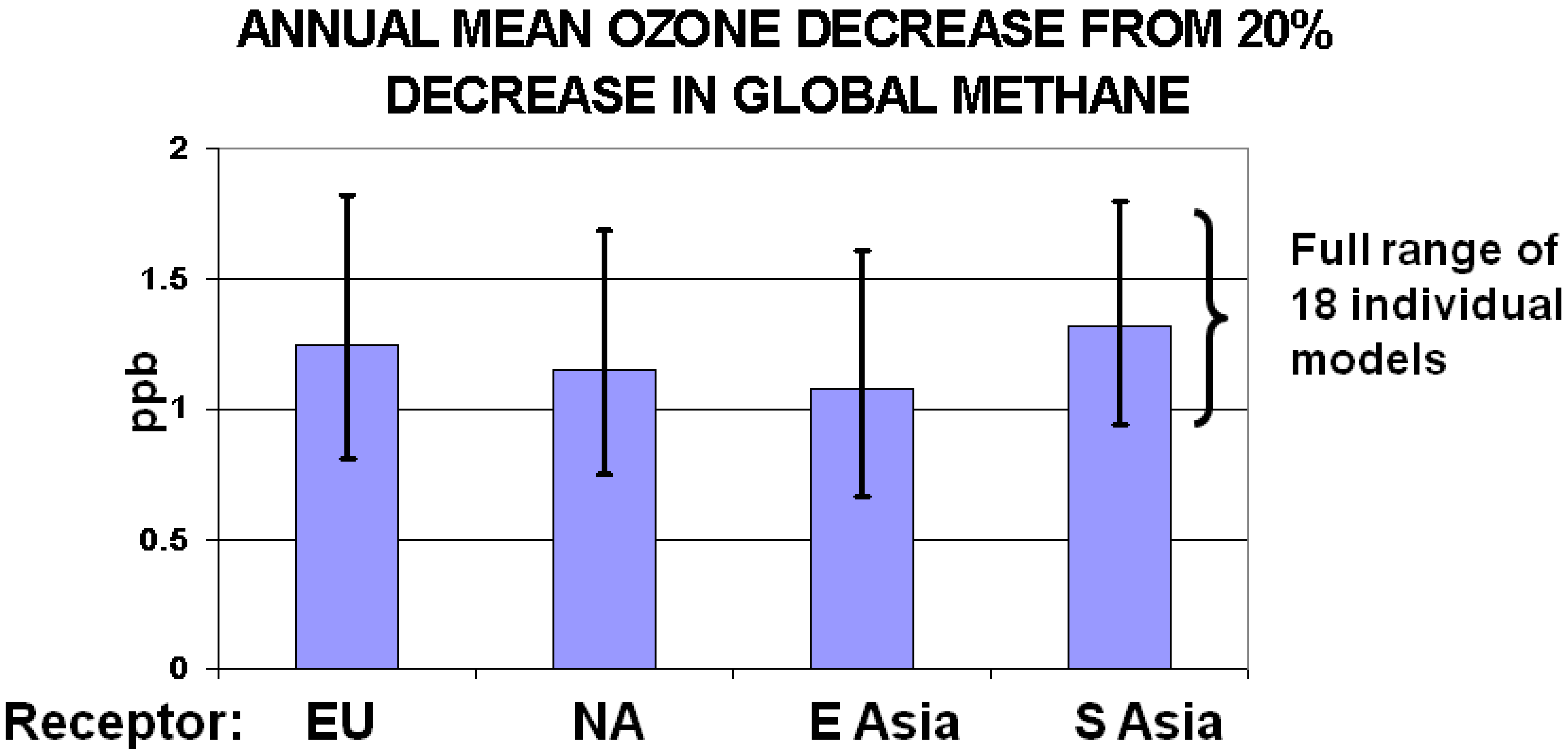
West et al., GRL, 2007



GEOS-Chem results
Fiore et al., GRL, 2002

→ Examine role of CH_4 vs. NO_x+CO+NMVOC in multi-model context

Surface ozone decreases similarly in all HTAP regions when global methane is reduced



→ ~1 ppbv O_3 decrease over all NH receptor regions
→ Consistent with prior studies

Can we scale these results to 20% reductions in regional anthrop. CH_4 emissions to compare with conventional O_3 precursors?

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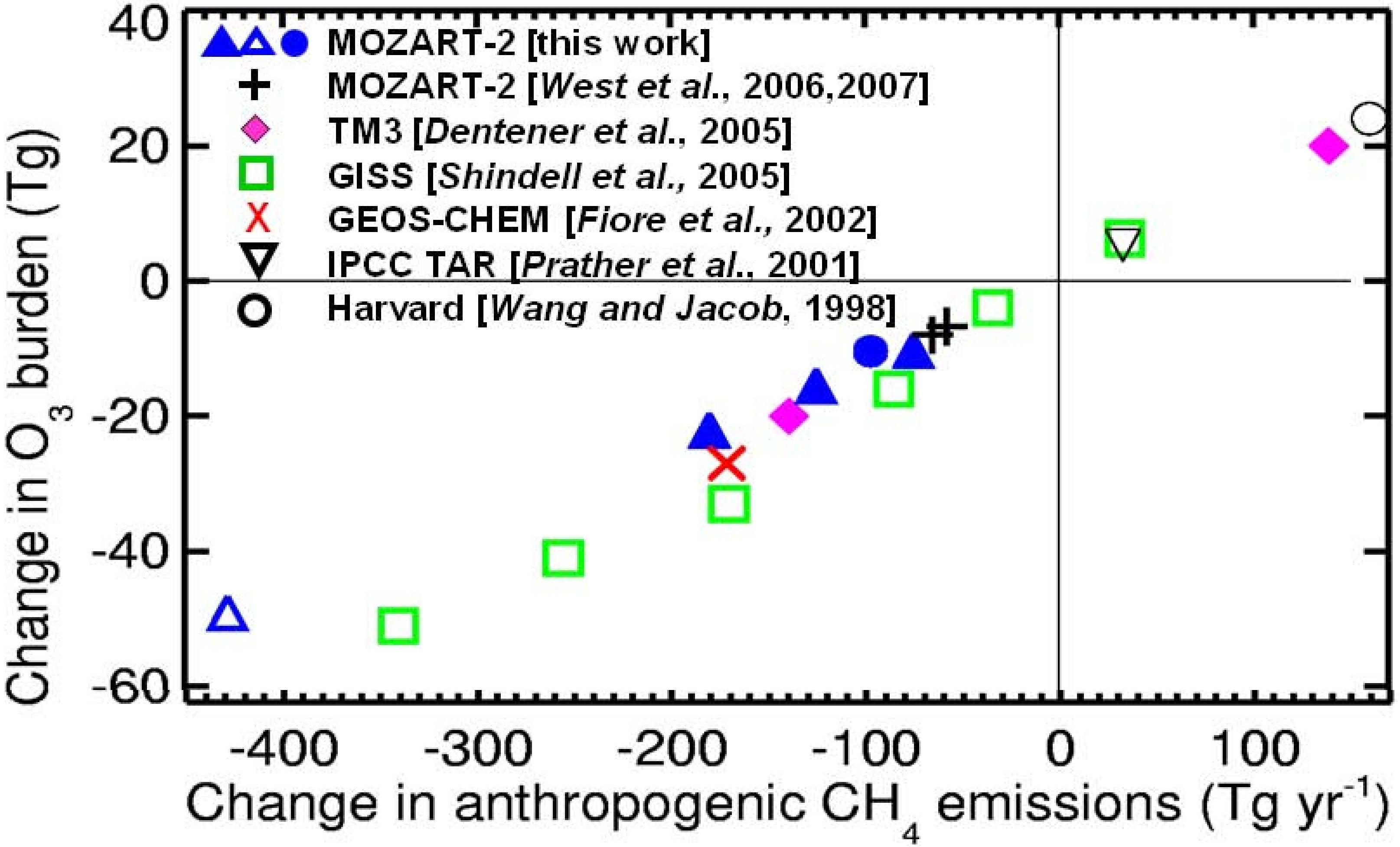
Tropospheric O_3 responds approximately linearly to anthropogenic CH_4 emission changes across models

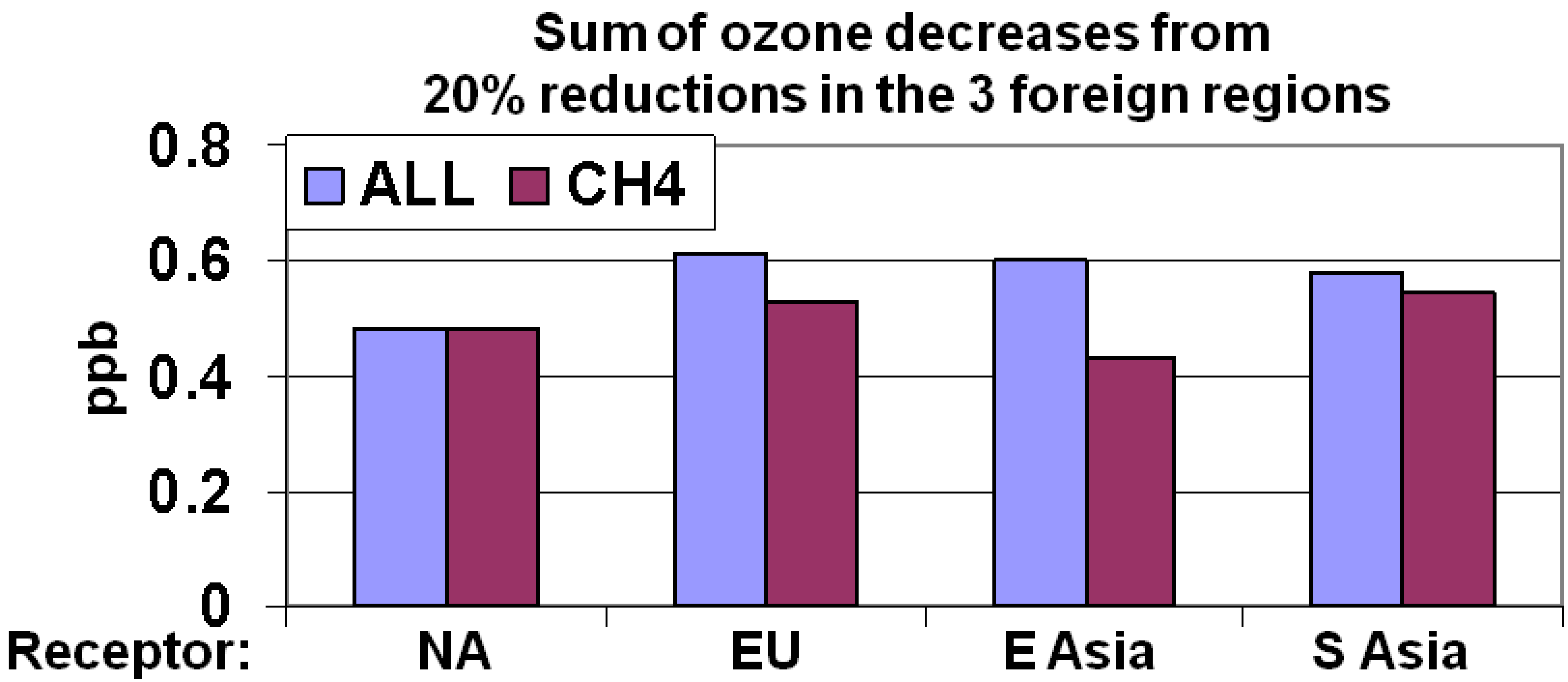


Anthropogenic CH_4 contributes ~50 Tg (~15%) to tropospheric O_3 burden
~5 ppbv to surface O_3

Fiore et al., *JGR*, 2008

Comparable annual mean O_3 decrease from 20% reductions in foreign CH_4 emissions and NO_x+NMVOC+CO

Use CH_4 simulation + EDGAR 3.2 FT2000 CH_4 emissions [*Olivier et al.*, 2005] to estimate O_3 response to -20% regional anthrop. CH_4 emissions



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Conclusions: Intercontinental S-R Relationships for O_3

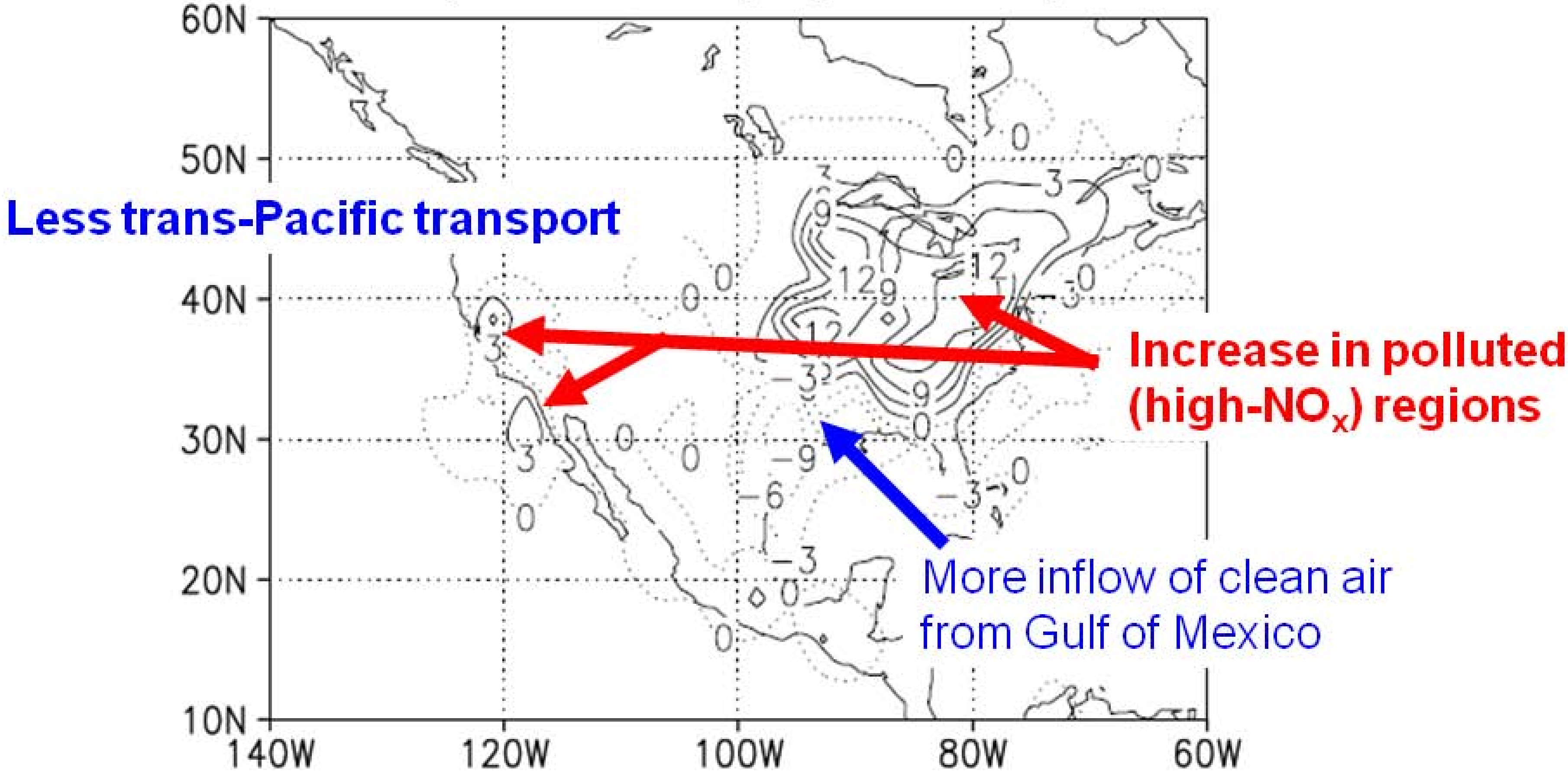
- Identified robust estimates + key areas of uncertainty
  - Model ensemble mean overestimate vs. obs in summer EUS and Japan
  - Robust: NA→EU largest; SA→others smallest
  - Uncertainty in relative roles of EU/EA → NA
  - Uncertainty in exported EU O_3 from EU AVOC emissions inventories
- Estimated "import sensitivities"
  - 0.2-0.3 July EA/NA/EU (max domestic production)
  - 0.6-0.9 April EA/NA/EU (max foreign influence)
  - 0.5 November SA (max foreign+domestic influence)
- Narrowed range of estimates from that in the literature under HTAP setup
- Combined reductions in regional anthropogenic CH_4 + conventional O_3 precursors roughly double the O_3 decrease over foreign regions

How might climate change affect hemispheric transport of air pollution?

Are our S-R relationships consistent with rising Asian emissions driving a 0.1-0.5 ppb yr^{-1} surface O_3 increase (as derived from observations)?

Global background ozone may decrease in a warmer, more humid climate

Mean annual change in number of days where daily max 8-hr O_3 > 80 ppbv (2090-2100 A1) – (1990-2000)



MOZART-2 global tropospheric chemistry model with meteorology from NCAR climate model [Murazaki and Hess, *J. Geophys. Res.*, 2006]

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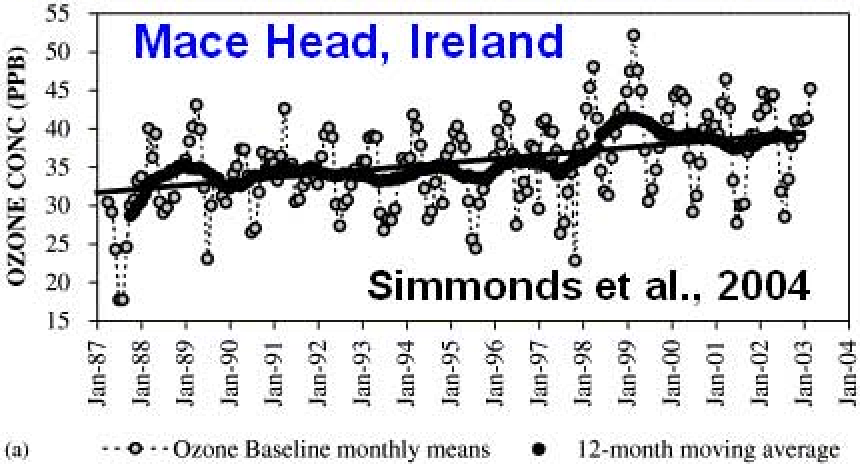
Apply S-R relationships to address hypothesis of rising background O_3 driven by increasing Asian emissions

OBSERVED: +0.1-0.5 ppb yr^{-1} in background surface O_3 [TF HTAP, 2007]



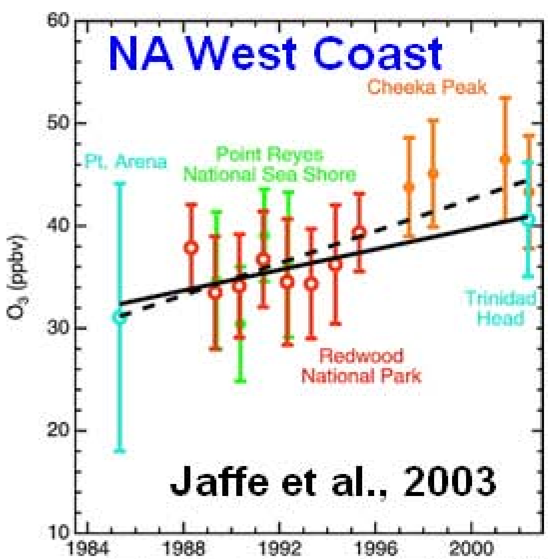
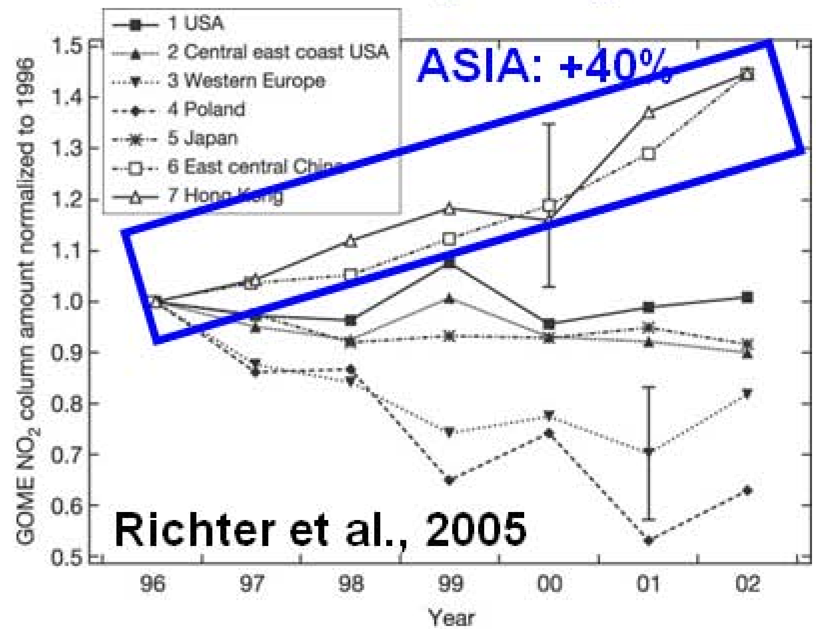


Fig 3.6 from TF HTAP [2007]

SPACE-BASED NO_2 → NO_x EMISSIONS



Assuming +10% yr^{-1} Asian emissions, our results imply an O_3 increase over NA and EU that falls at the low end of observed rise at the most

OUR CAVEATS:

-- assumes SA+EA, + other emissions follow NO_x

-- continental-avg vs. "west coast" obs

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