Task Force on Hemispheric Transport of Air Pollution

JRC
EUROPEAN COMMISSION

Chapter 4: Global and regional Modelling of Ozone and Aerosols

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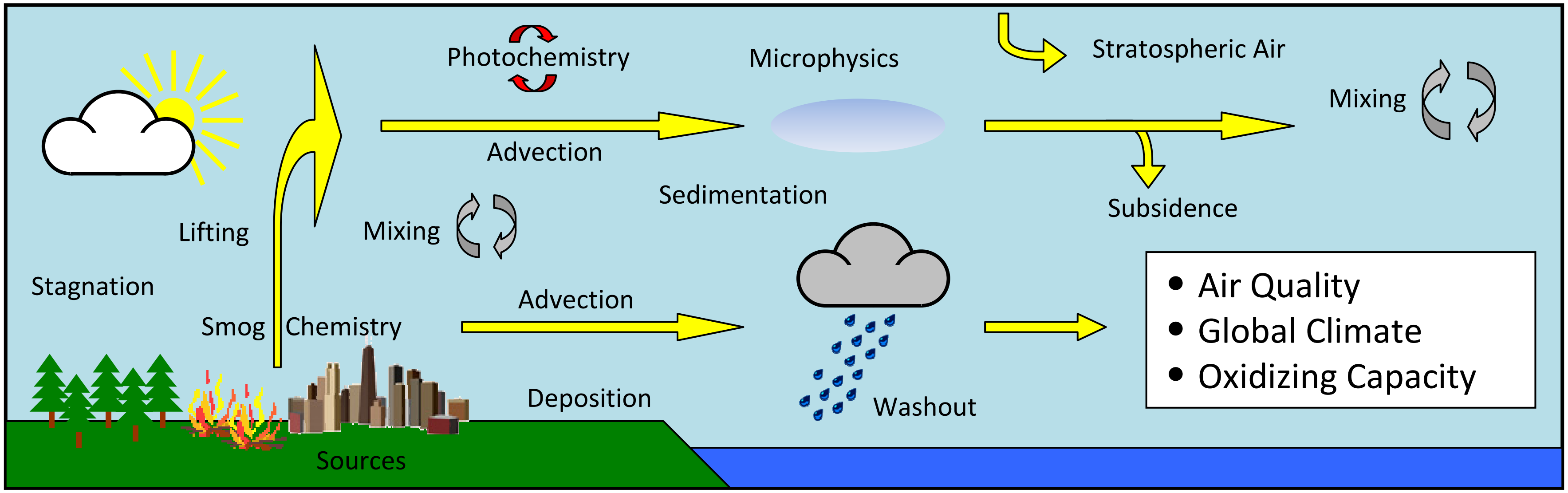
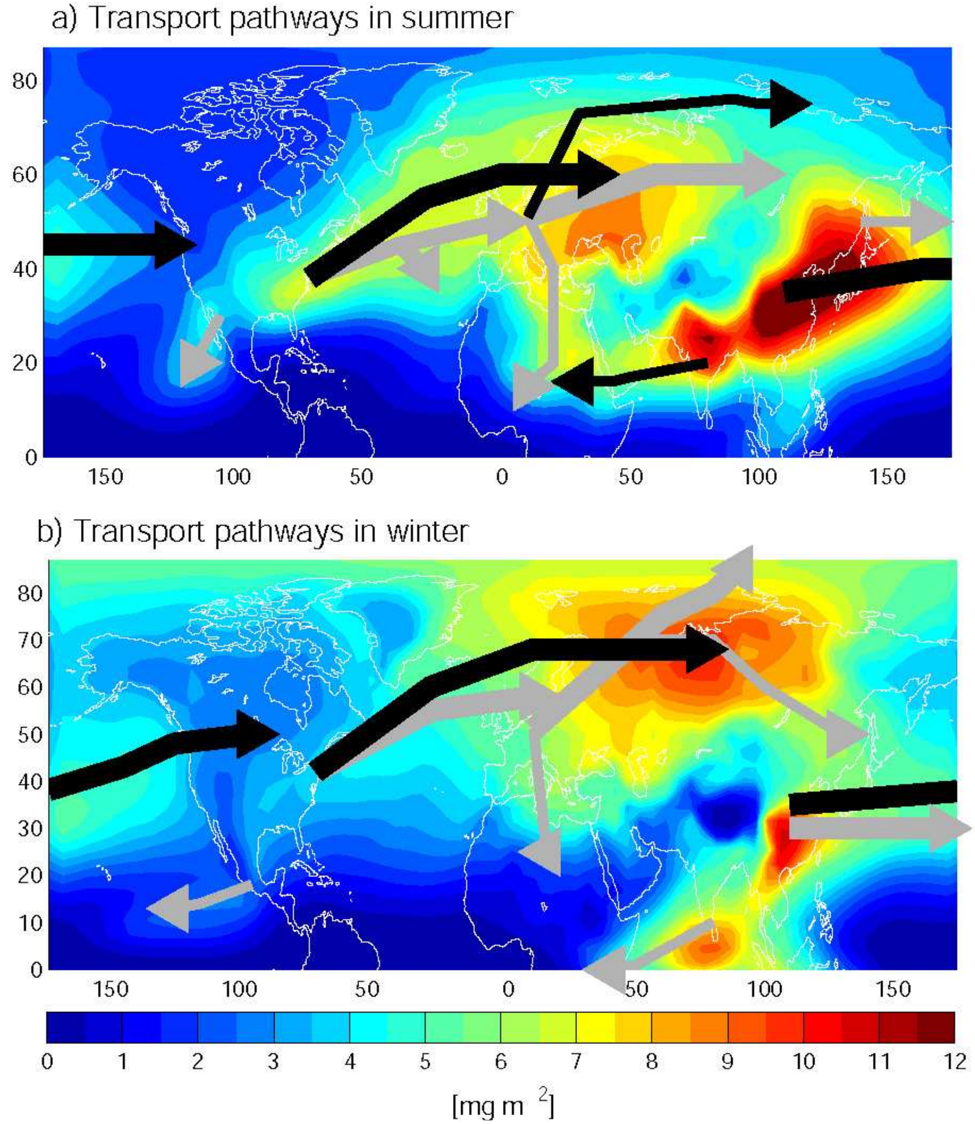
Intercontinental Transport

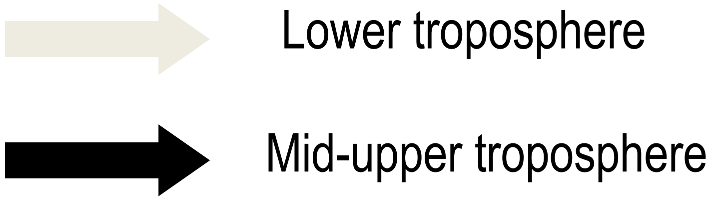


Aim: To quantify the effect of emissions from one continental source region on air quality and climate over a downwind receptor continent.

Need: To understand how transport, photo + aerosol chemistry and removal processes determine the distribution and fate of trace gases and aerosol and their regional and global impacts

Hemispheric Transport Pathways





Flexpart, A. Stohl et al, 2004

Chapter 4:

- Reviewing scientific literature on modelling of intercontinental transport of O3 and PM (precursors)
- Organising modelling studies to quantify intercontinental transport and its uncertainty
- Current and Future

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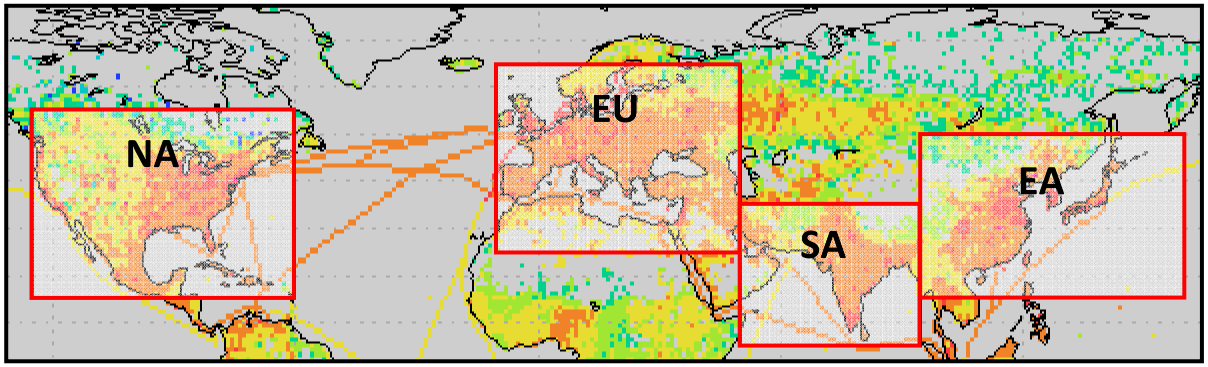
Model Intercomparison
(32 models involved)

- Source-Receptor Regions



- Model Runs
  - Present-day emissions, fixed CH_4 and 2001 meteorology (control)
  - Apply 20% reduction to global CH_4 burden (1 sensitivity run)
  - Apply 20% reduction to NO_x/VOC/CO/aerosol over each region, separately and combined (16-20 sensitivity runs)
  - Additional experiments for dust, fire and anthropogenic aerosol sources coordinated with the AEROCOM project
  - Synthetic tracers and detailed analysis of measurement campaign
- Quantify source-receptor relationships
  - How will future changes in emissions and climate affect these?

Important Distinction!

Source Attribution

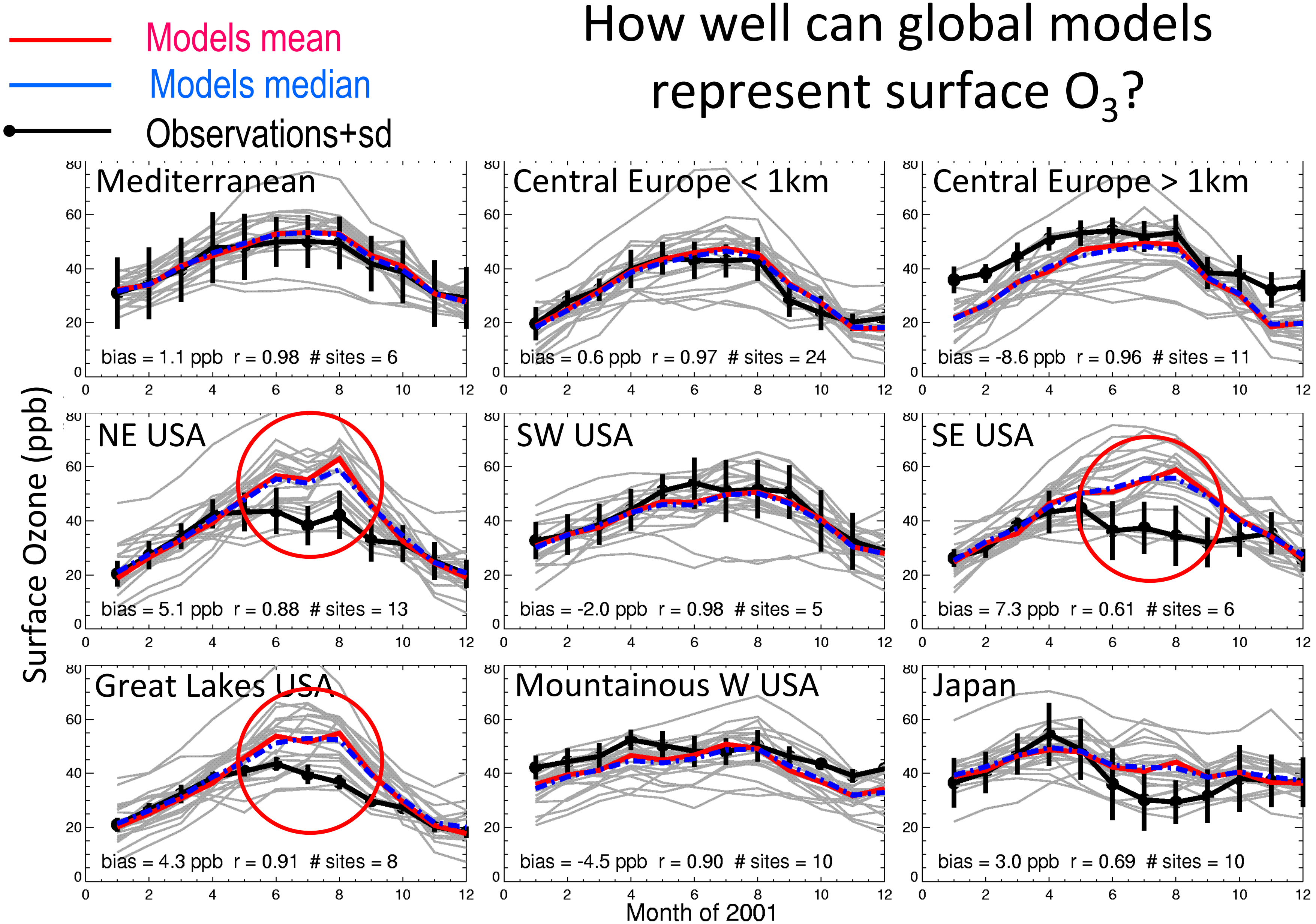
- What proportion of observed O_3 or aerosols is from a given source?
- Relevant when we need to know the total contribution from a particular source, e.g., for assessing climate impacts

Source-Receptor Relationships

- What is the effect of a given emission change on O_3 or aerosols?
- Relevant when we need to quantify the impact of likely source changes, e.g., for informing air quality policy

- For linear tracers (e.g., Rn) these two metrics are easily translatable; for secondary pollutants (or variable-lifetime primary pollutants) like O_3 and some aerosol, they are not.
- HTAP have looked at both, but places greater emphasis on S-R relationships

How well can global models represent surface O_3?



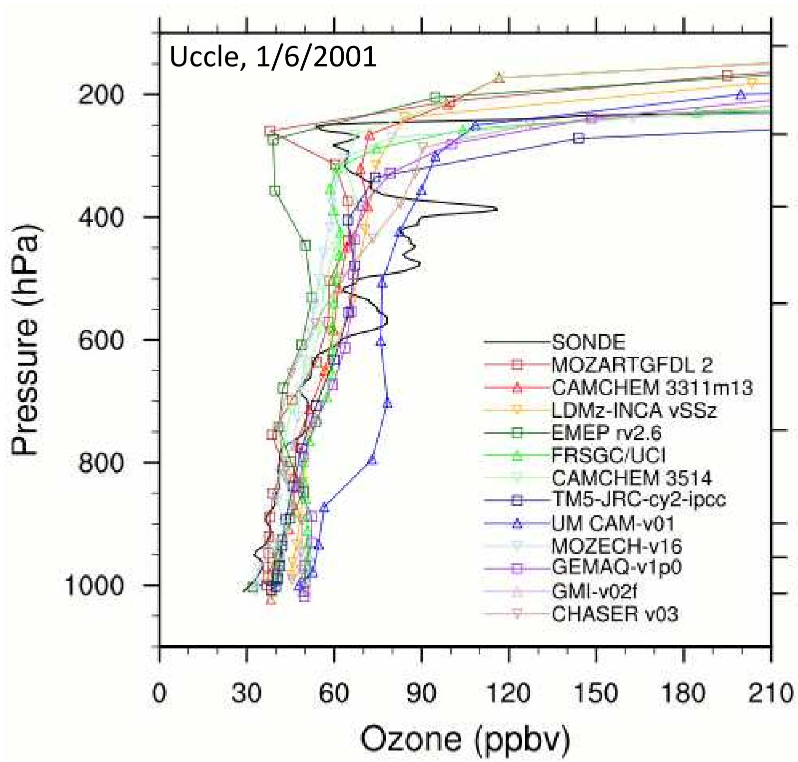
Many models biased low at altitude, high over Eastern US and Japan in summer

Good spring/late autumn simulation. Big spread in model results!

Fiore et al., 2009

Challenges for Current Models

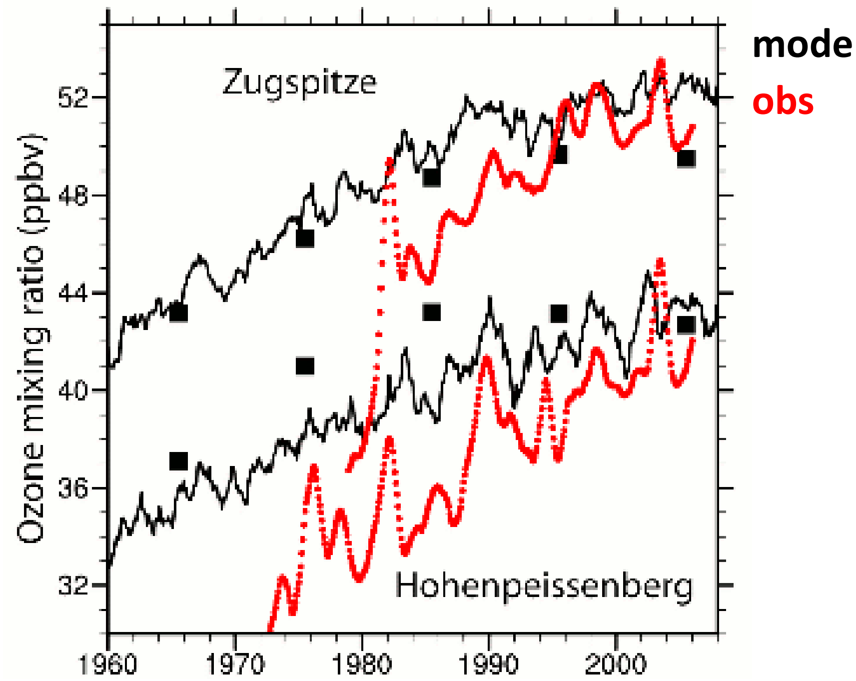
Temporal variability



— Timing of transport events
— Integrity of pollutant plumes
— Layered structures

Jonson et al., 2010

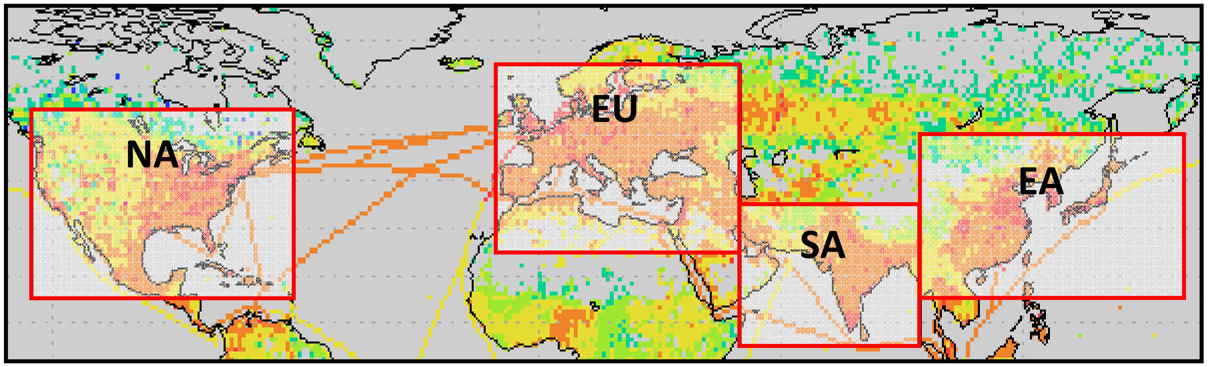
Surface O_3 Trends



— Upward trend is captured, but magnitude is underestimated.
— Are emissions wrong, or lifetimes?
— Measurements-model scale match?

Lamarque et al., 2010

Source-Receptor Relationships



Receptor:

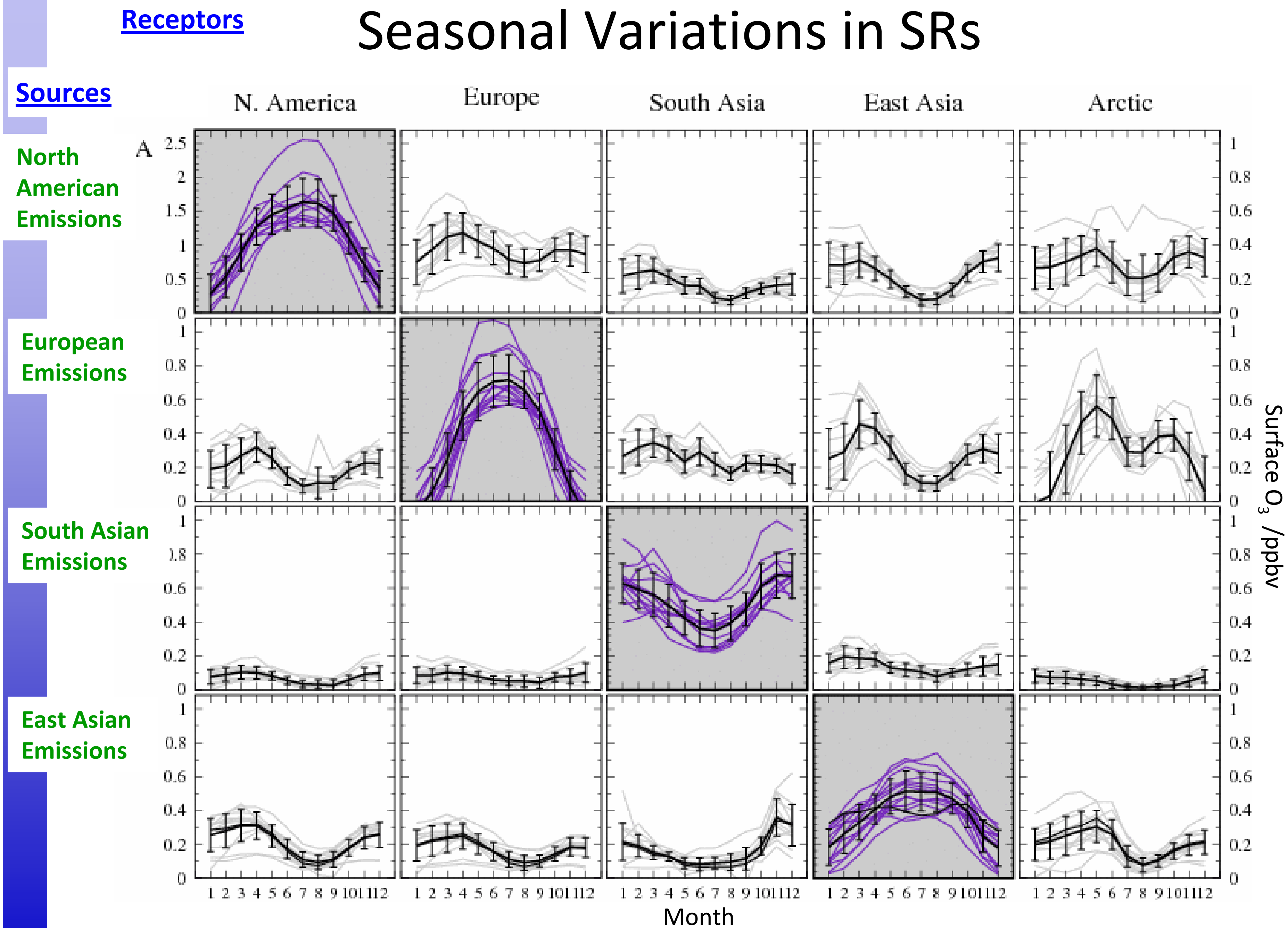
Source:

15 models	NA	EU	SA	EA
NA	**-1.04** ±0.23	-0.37 ±0.10	-0.17 ±0.04	-0.22 ±0.05
EU	-0.19 ±0.06	**-0.82** ±0.29	-0.24 ±0.05	-0.24 ±0.08
SA	-0.07 ±0.03	-0.07 ±0.03	**-1.26** ±0.26	-0.14 ±0.03
EA	-0.22 ±0.06	-0.17 ±0.05	-0.17 ±0.05	**-0.91** ±0.23

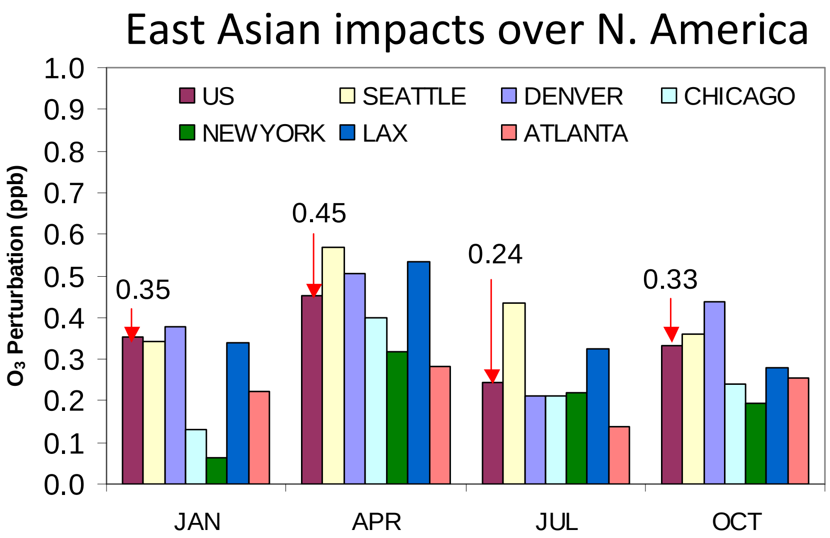
ΔO_3 (ppbv)

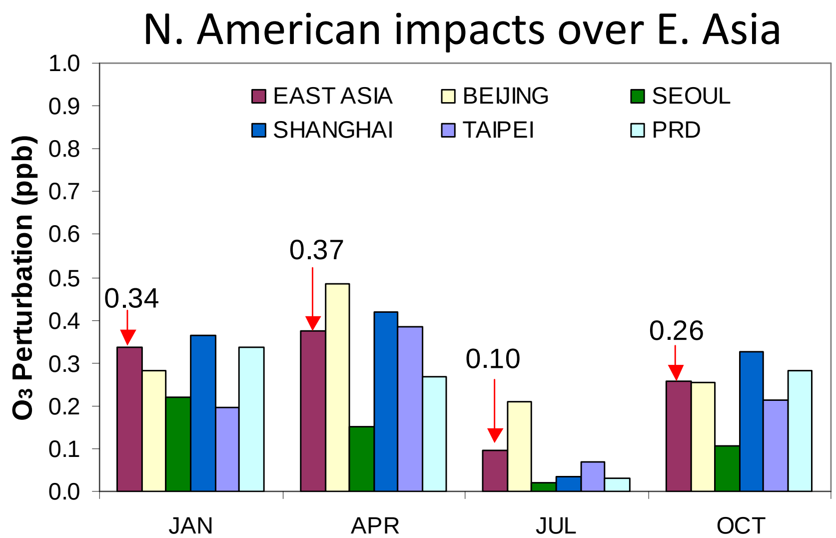
Annual mean surface O_3 change due to a 20% emissions reduction

Seasonal Variations in SRs



Impact on Major Cities

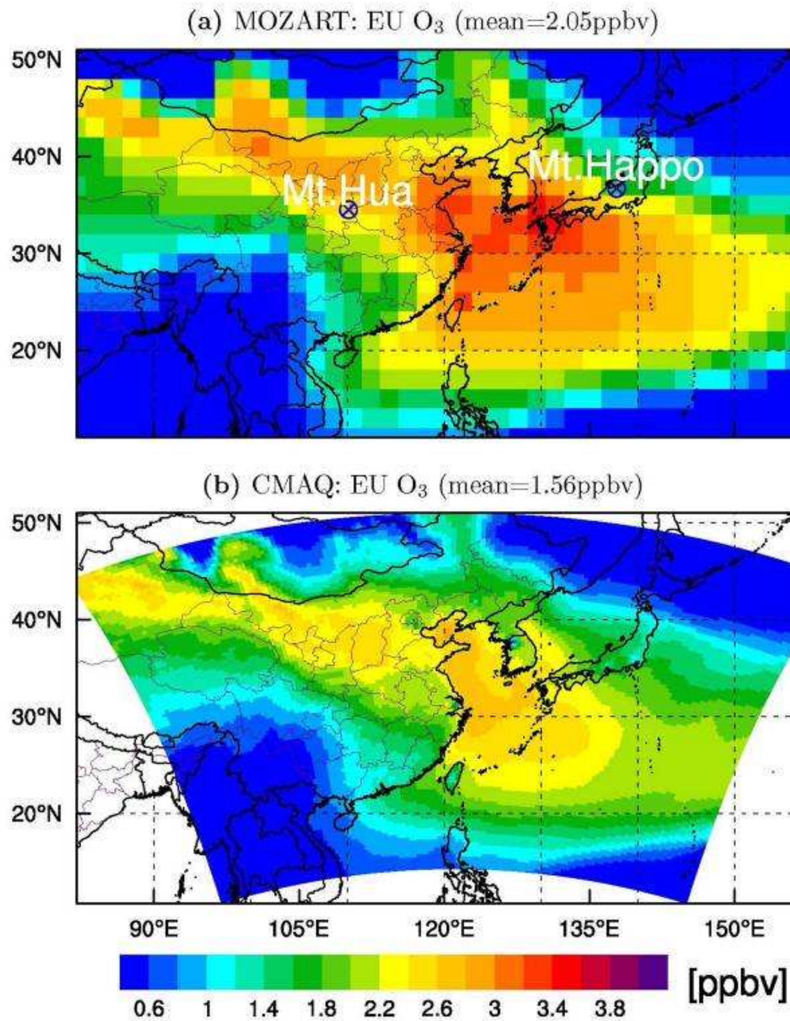




- How large are the impacts where it matters for people?
  - Relatively large: may be greater or smaller than annual regional mean
  - Caveat: global models don't represent urban-scale chemistry well!
- Does ICT influence conditions that favour build-up of local O_3?
  - Affects the whole of the ozone probability distribution
  - Impacts at high end of distribution generally slightly smaller

Joshua Fu

Regional vs. Global Models

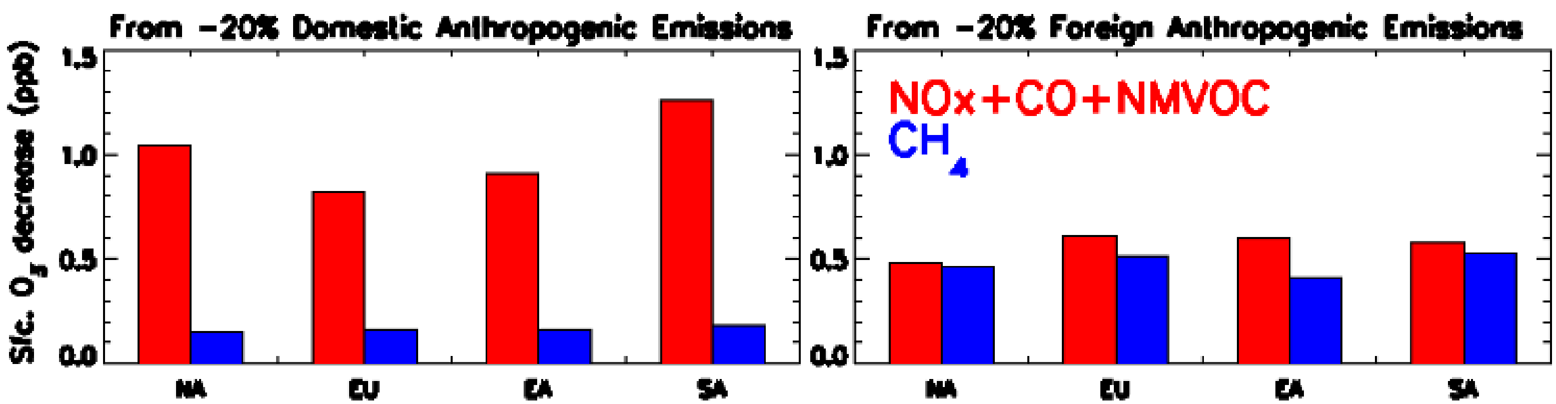


EU impacts on East Asia, March 1-15, 2001

(scaled from 20% to 100%) Lin et al., 2010

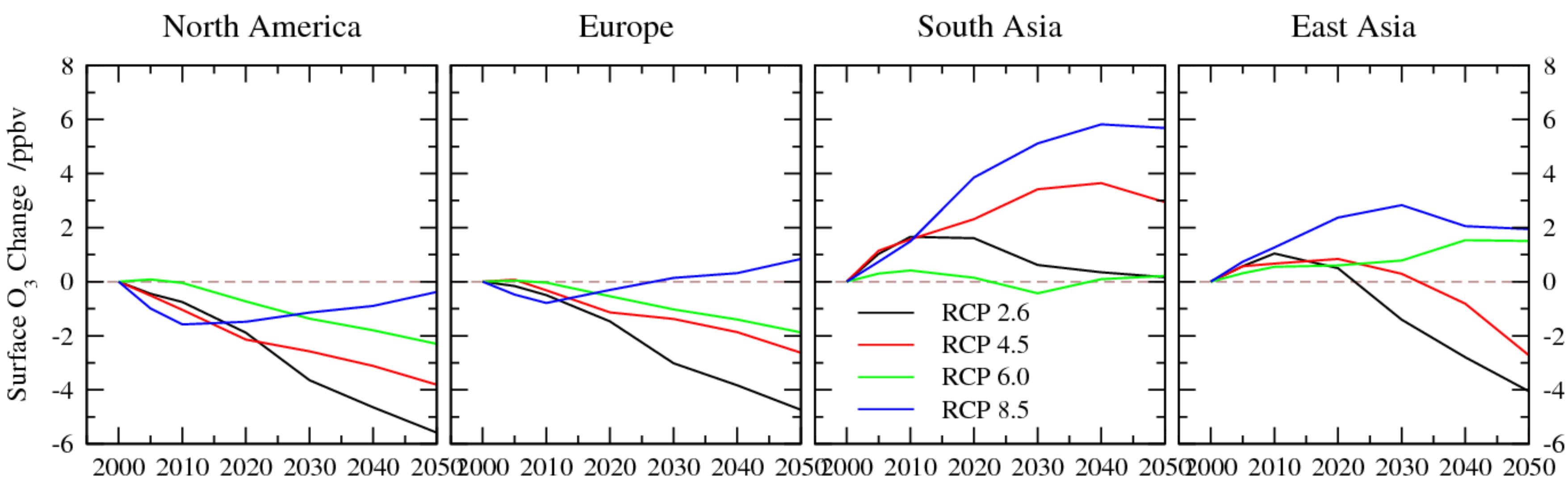
- Additional insight from regional models
  - Subgrid-scale processes (PBL mixing, convection, frontal lifting) important for pollution export
  - Differences in chemistry schemes
- Need to address scale biases
  - Important for addressing health and agricultural impacts

Effect of CH_4 Changes



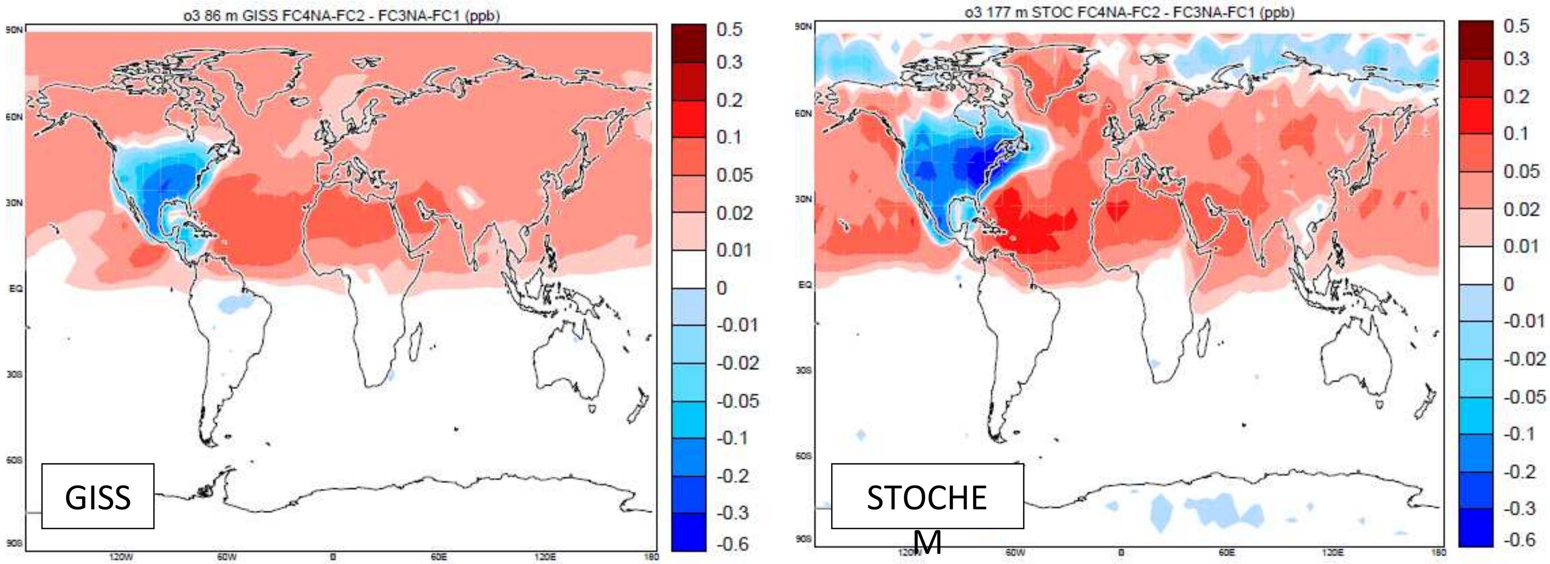
- CH_4 is an important O_3 precursor
  - Over source region, 20% emission change has relative small impact
  - Over receptor region, has comparable impact to NOx/CO/VOC
    - Impacts of CH_4 on O_3 are global in extent!
- Emphasises the importance of controlling anthropogenic CH_4

Effects of Future Emission Changes



- Anticipated changes in annual mean surface ozone
  - Base on the four RCP scenarios constructed for IPCC-AR5
  - Derive from 6 global models (using linear assumption)
- Findings
  - Big increases of O_3 in Asia matching regional development
  - Relative importance of “imported” O_3 doubles for N.America/Europe
  - Changes in CH_4 make a major contribution to observed O_3 changes

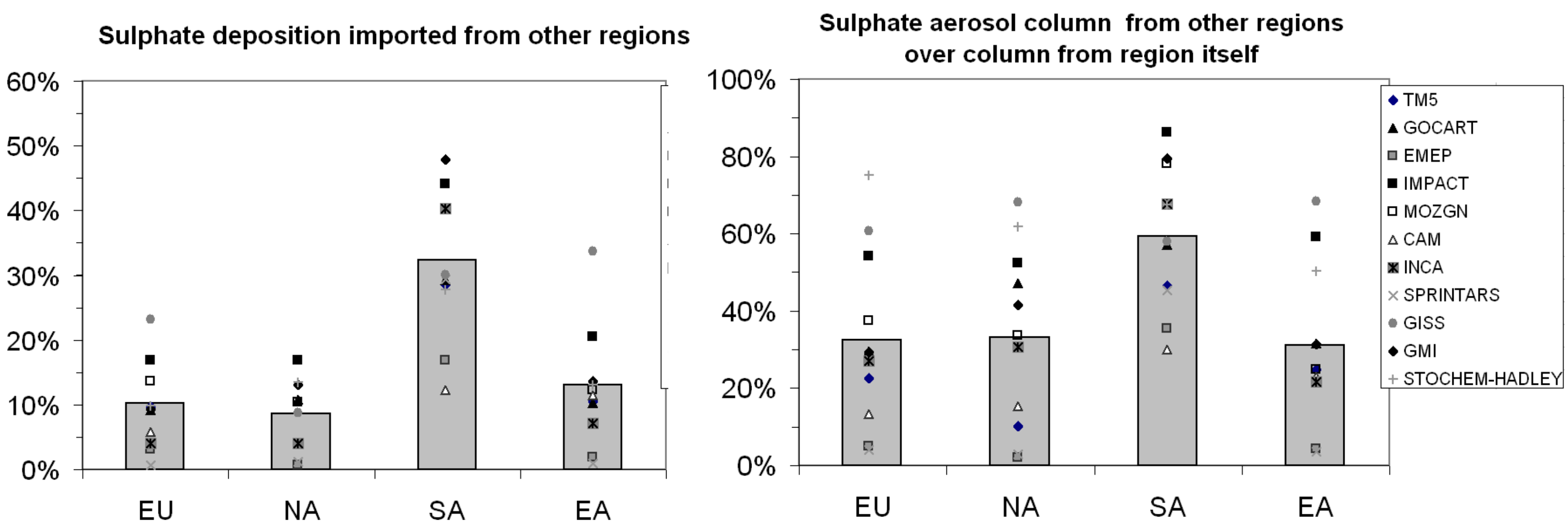
Impacts of Future Climate



Difference in the surface O_3 response to a 20% precursor emission reduction under 2090s climate vs. 2000s climate.

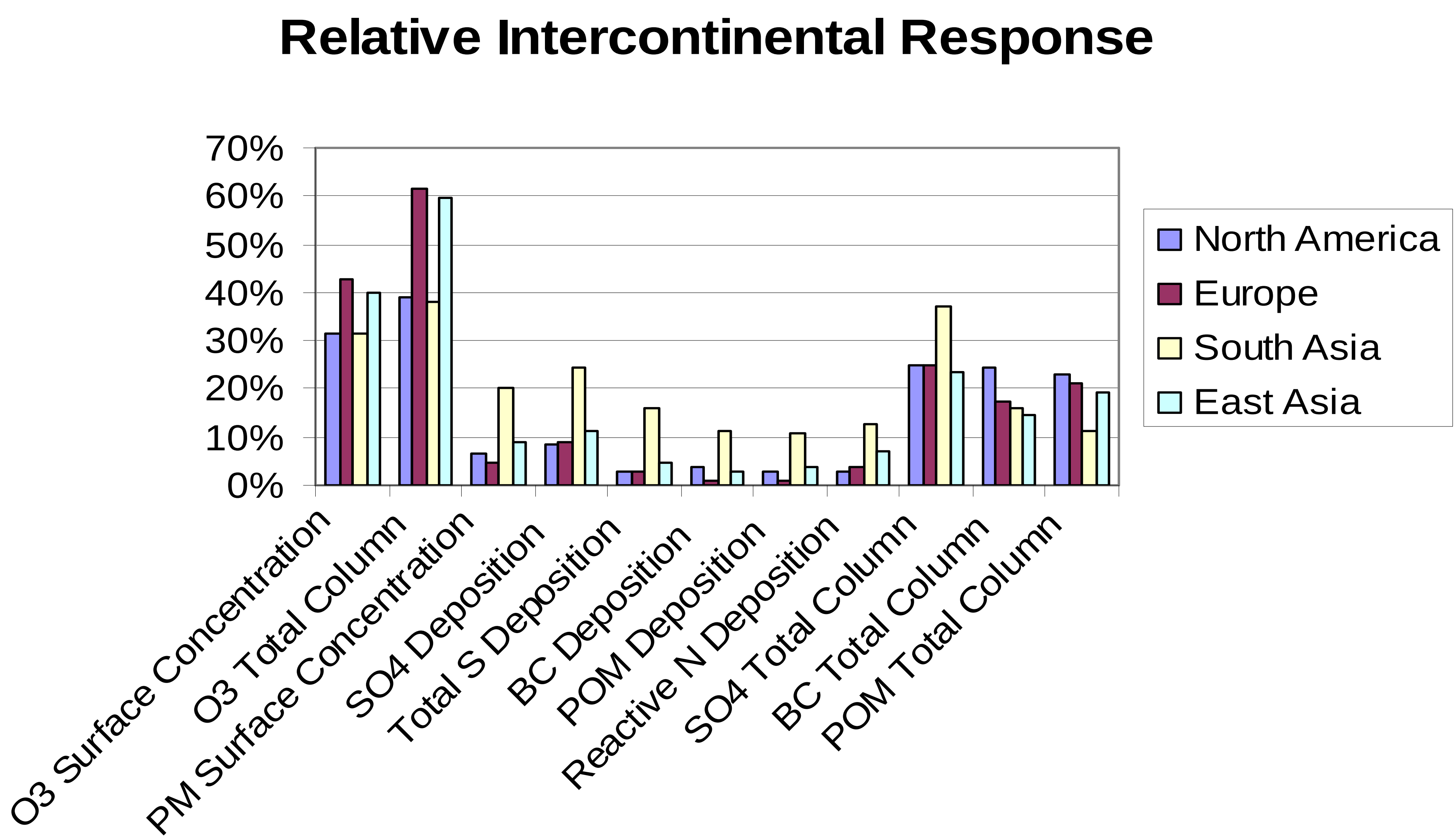
- Changes under 2090s climate
  - O_3 impacts are more localised under future climate
  - No significant impact on transport pathways evident (yet)
  - Effects of natural emission changes and other feedbacks not evaluated

Sulphate Aerosol



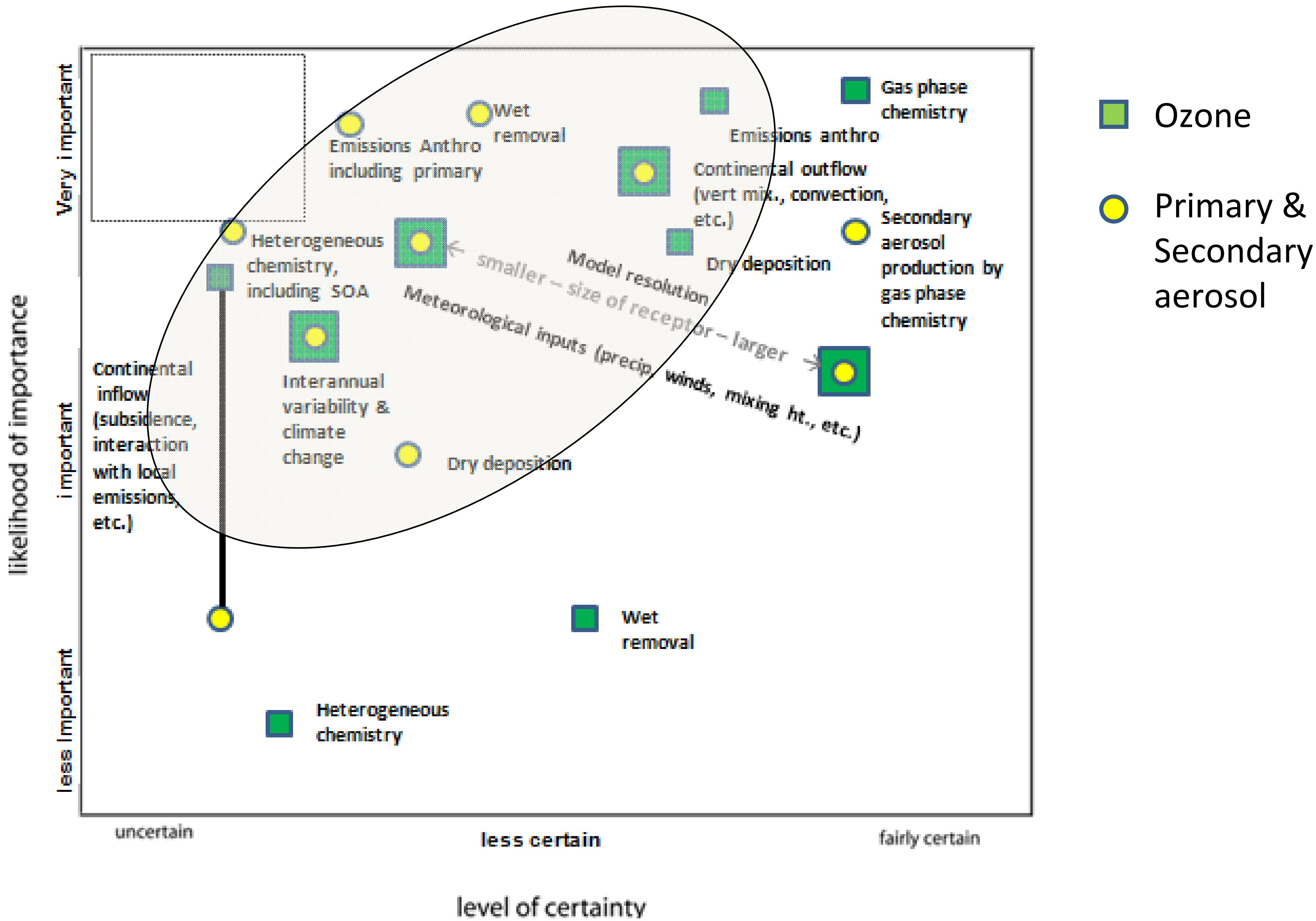
Proportion of **SO_4 deposition** (left) and **SO_4 aerosol column load** (right) from other regions into each receptor region.

- Surface concentrations of sulphate and BC are mostly (70-90%) from pollution sources within the region. However, contributions from outside the source region are increasingly important at higher altitudes.



$$\frac{\Sigma R(foreign\_regions)}{\Sigma R(all\_regions)}$$

Current Model Uncertainties for SR



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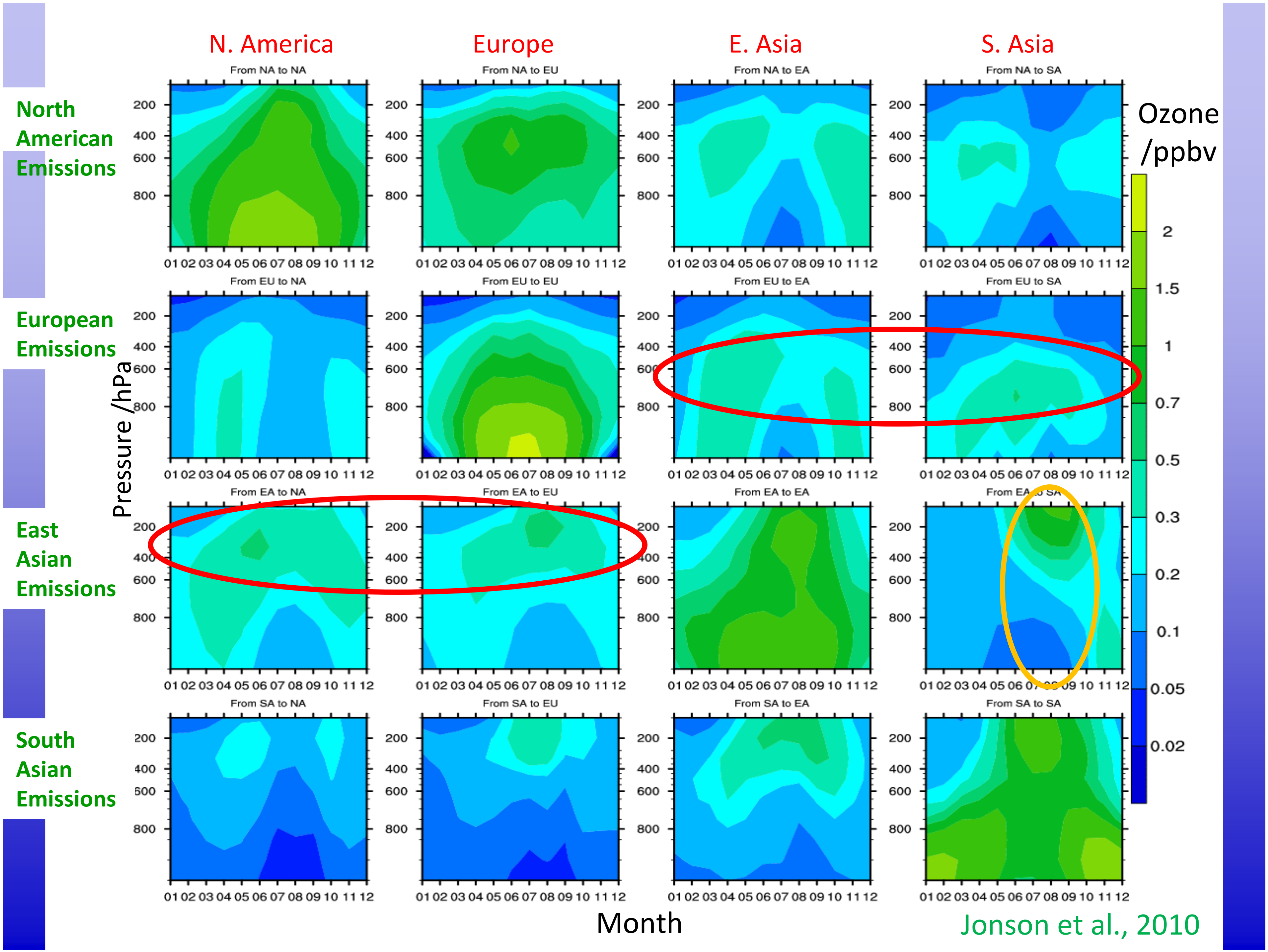
Summary

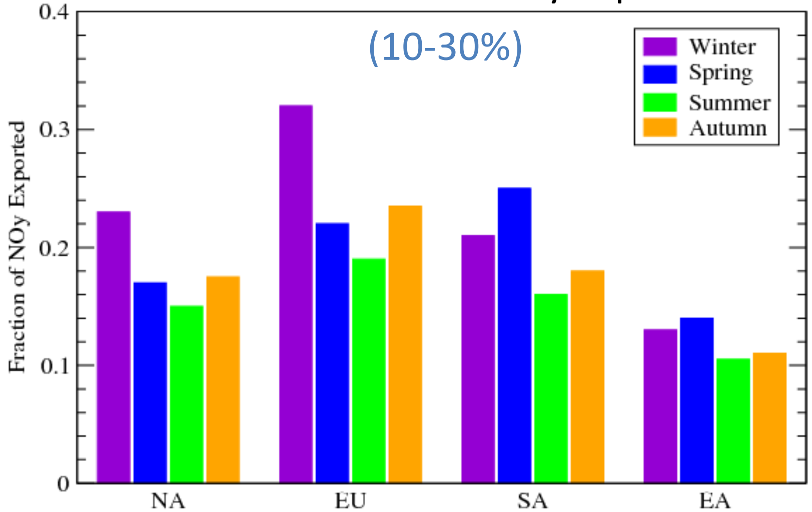
- Clear quantification of S-R relationships for O_3 and aerosol
  - Wide range of estimates in literature narrowed under HTAP setup
    - For O_3, 20% emission changes lead to 0.1-0.4 ppb changes downwind LARGE REGION and YEARLY AVERAGE.
    - For aerosol, effects are smaller, but still significant for column loading
  - Future changes influenced by both emissions and climate
- Identified processes with greatest uncertainty
  - Deposition, scavenging, vertical transport, VOC and SOA chemistry
  - Model weaknesses associated with resolution need to be addressed
- Need better comparison vs. observations
  - Future model intercomparisons need to be more process-focussed
  - Closer systematic integration of in situ observations, models and satellite observations



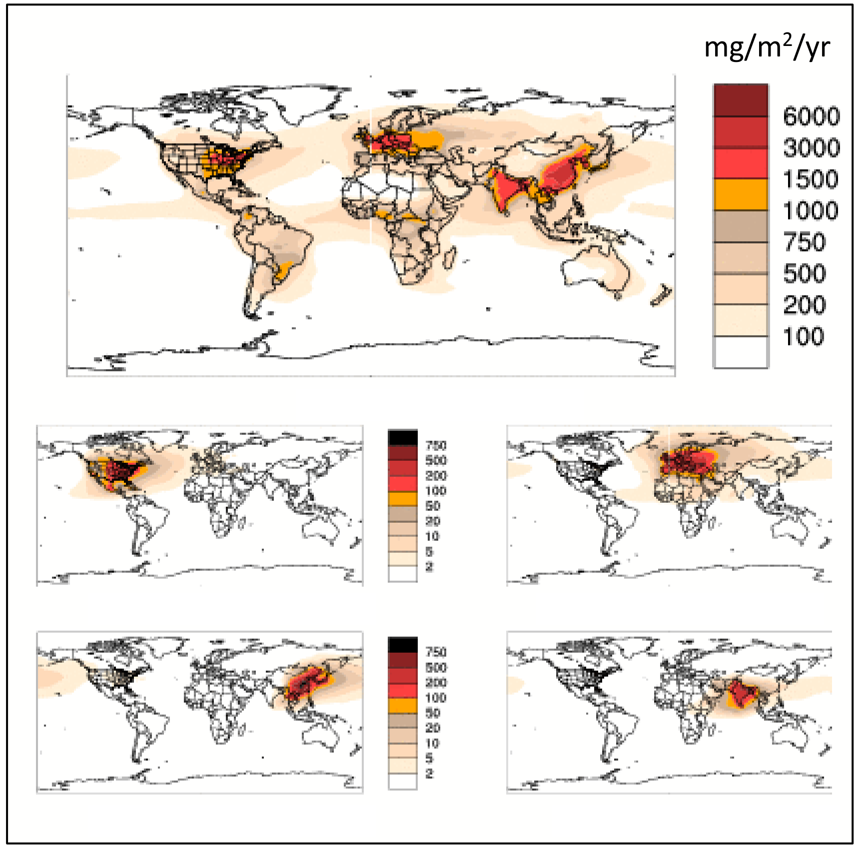
N. America
Europe
E. Asia
S. Asia
North American Emissions
European Emissions
East Asian Emissions
South Asian Emissions
From NA to NA
From NA to EU
From NA to EA
From NA to SA
From EU to NA
From EU to EU
From EU to EA
From EU to SA
From EA to NA
From EA to EU
From EA to EA
From EA to SA
From SA to NA
From SA to EU
From SA to EA
From SA to SA
Pressure /hPa
200
400
600
800
01 02 03 04 05 06 07 08 09 10 11 12
Month
Ozone /ppbv
2
1.5
1
0.7
0.5
0.3
0.2
0.1
0.05
0.02
Jonson et al., 2010

Fate of Emitted Nitrogen

Fraction of Emitted NOy Exported



Nitrogen Deposition



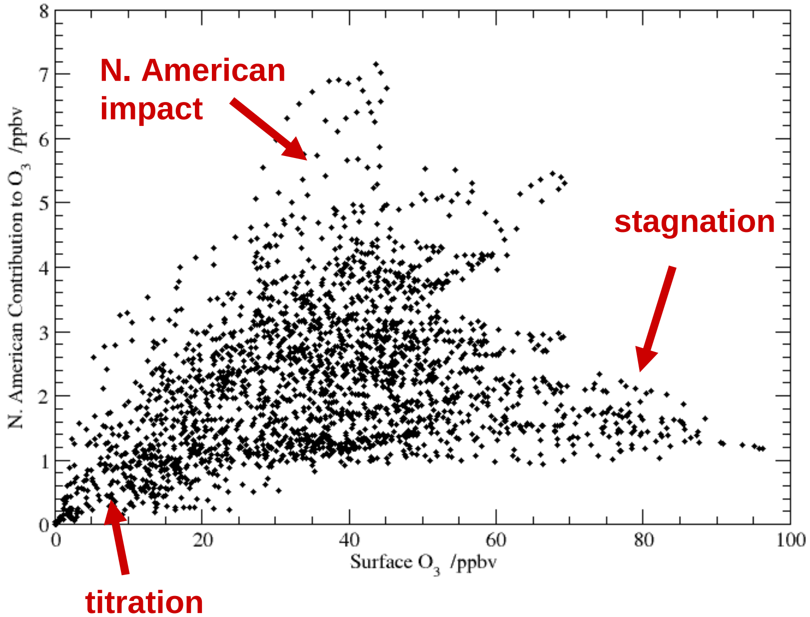
Fractional Contribution to Total Regional N_r Deposition

Source Region	Deposition Region			
	EU	**NA**	**SA**	**EA**
EU	**0.961**	0.009	0.076	0.033
NA	0.028	**0.974**	0.020	0.013
SA	0.005	0.003	**0.881**	0.025
EA	0.006	0.014	0.033	**0.929**

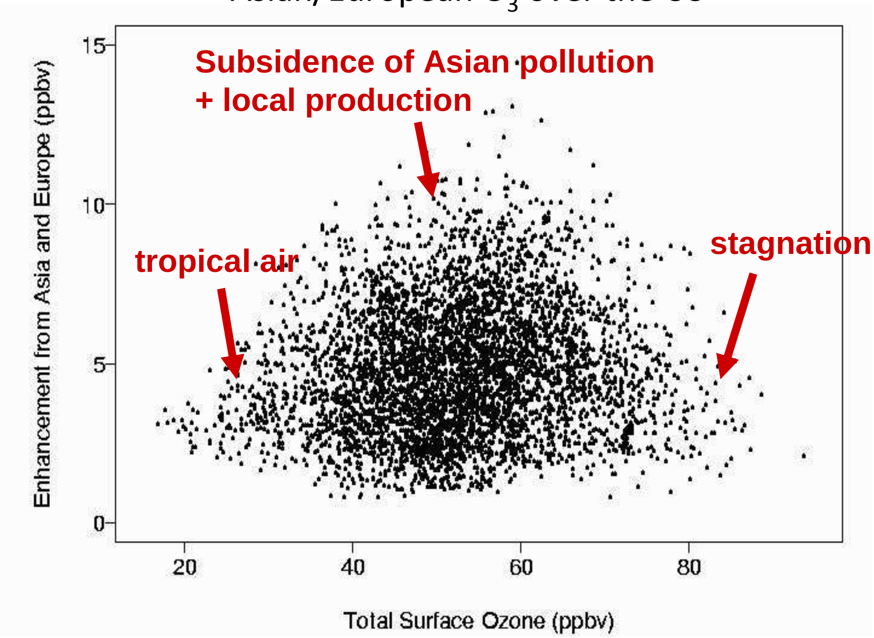
Haven't yet assessed the effects of this extra N_r deposition on sensitive ecosystems!

Intercontinental Impacts on Air Quality

N. American O_3 over London

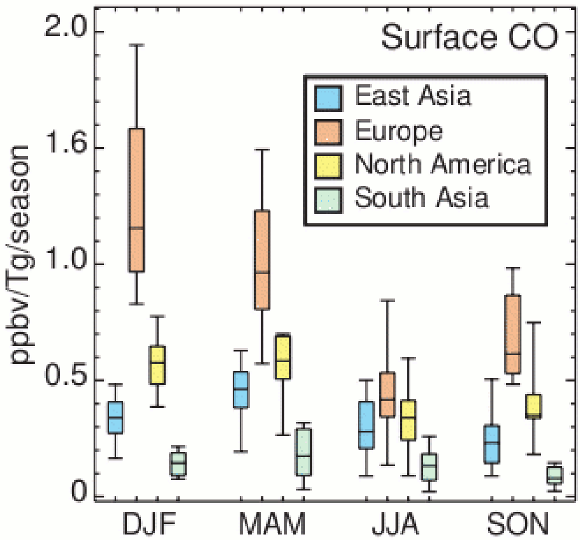


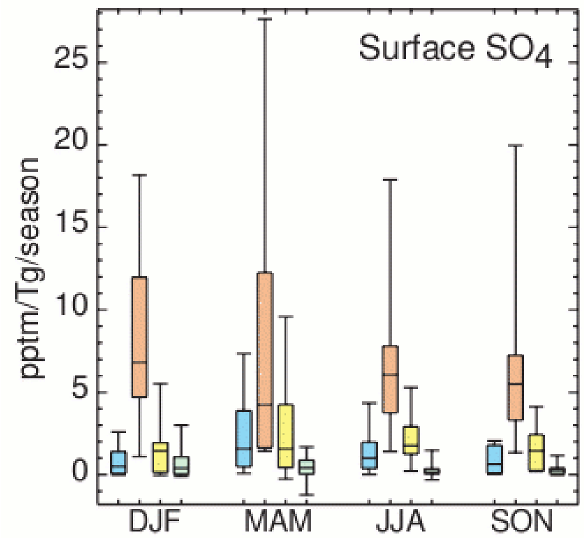
Asian/European O_3 over the US

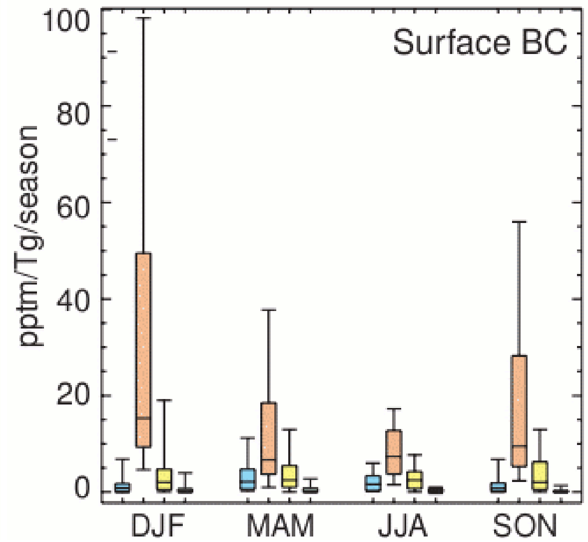


- Do transport events make a significant contribution to pollution episodes?
  - Maximum enhancements occur at intermediate O_3 levels (40-60 ppbv)
  - Still 1-2 ppbv present when O_3 is at its highest

Impacts on the Arctic



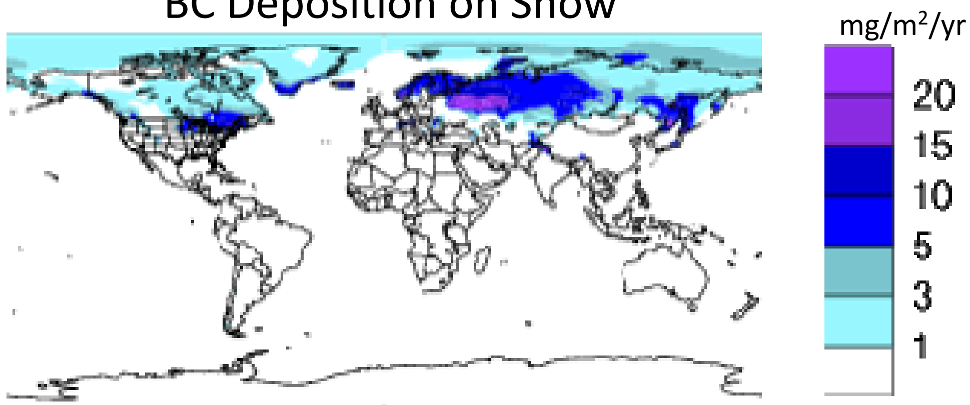




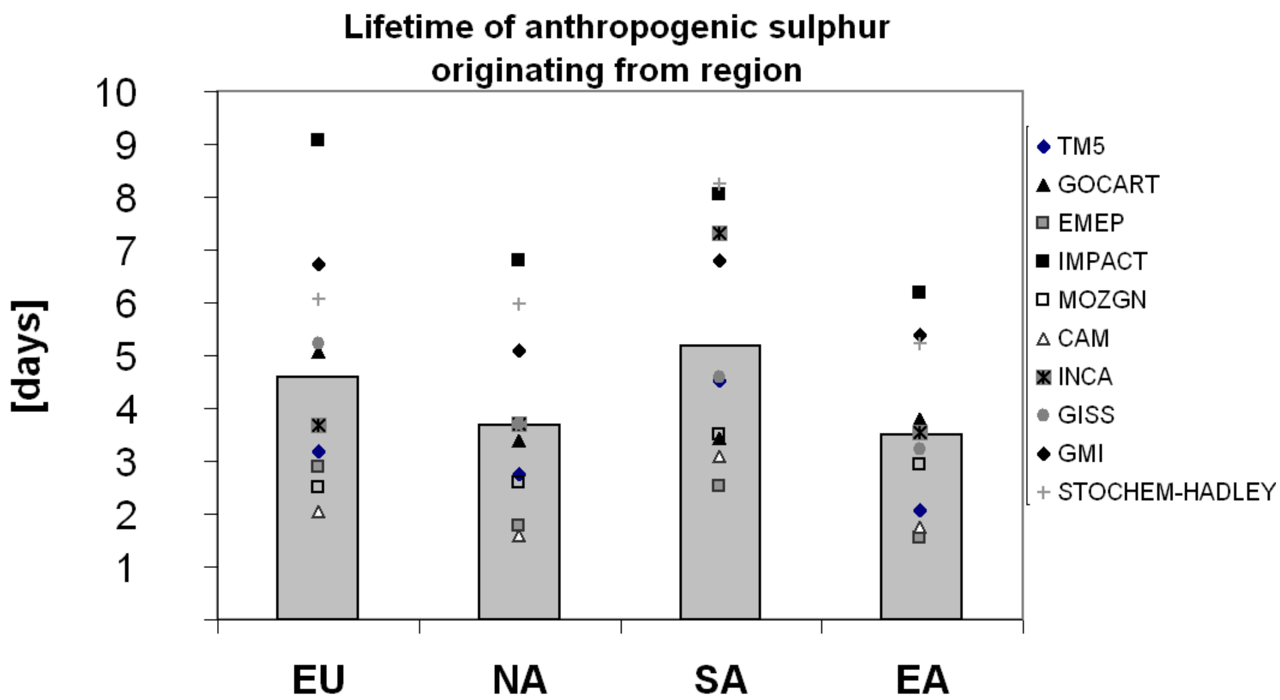
Effects on Arctic, normalised by emissions intensity. European impacts are largest (and most variable) for most tracers. Eurasian biomass burning (not shown) is greatest for BC, POM.

Shindell et al., 2008

BC Deposition on Snow



Differences in Lifetime



The differences in sulphur lifetimes over the models for a given region is considerable (a factor of four), and reflects differences in process-level model formulations (particularly the timing and magnitude of deposition)

Secondary Impacts

- Changes in chemical environment due to changes in anthropogenic NOx, CO and VOC emissions may lead to indirect impacts for aerosols and O_3
  - Changes in O_3 precursors (esp. NOx) affect atmospheric OH and thus affect the lifetime of CH_4, causing a long-term O_3 response. Fiore et al., 2009
  - Transport and subsequent deposition of PAN enhances O_3 production over receptor regions substantially. This accounts for as much as 20% of the impact of European sources on O_3 over East Asia in Spring. Lin et al., 2010
  - US emissions of NOx and CO may increase surface PM in Europe and East Asia by up to 0.5 µg m^{-3} due increased oxidants enhancing production of secondary aerosols during transport and in the receptor region.

Liebensperger et al., submitted

Import Fractions for Aerosol

Receptor region:	EU	NA	SA	EA	No. of models
Surface Concentration Import					
PM	5% (±4%)	7% (6%)	25% (12%)	10% (9%)	9
O_3 (for comparison)	74%	46%	46%	66%	15
Deposition Import					
SO_4	10% (±7%)	9% (5%)	32% (11%)	13% (9%)	11
Sulphur (SO_2+SO_4)	3% (±2%)	3% (3%)	19% (8%)	5% (3%)	11
BC	1% (±1%)	4% (2%)	13% (24%)	3% (1%)	8
POM	1% (±1%)	3% (2%)	12% (24%)	4% (1%)	8
Column Load Import					
SO_4	33% (±23%)	33% (23%)	59% (19%)	31% (21%)	11
BC	21% (±14%)	32% (23%)	19% (3%)	17% (5%)	7
POM	27% (±21%)	30% (24%)	13% (5%)	24% (6%)	7

$$\text{Import Fraction} = \frac{\text{Sum of contributions from other regions}}{\text{Contributions from a given region}}$$

Michael Schulz