Hemispheric Transport of Ozone Pollution: Multi-model Assessment of the Role of Methane and the Conventional Ozone Precursors

Arlene M. Fiore (arlene.fiore@noaa.gov)


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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

Glen Canyon, Arizona, USA

Clear Day

April 16, 2001
Regional control efforts (even under optimistic scenarios) may be offset by increases in hemispheric ozone pollution.

By 2030 under the CLE scenario (considers air pollution regulations), “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 > 70 ppb

1995 Base case

2030 A1

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)

51 parties in Europe, North America, and Central Asia

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

www.htap.org for more information + 2007 TF HTAP Interim Report
Wide range in prior estimates of intercontinental surface ozone source-receptor (S-R) relationships

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]
Objective: Quantify & assess uncertainties in N. mid-latitude S-R relationships for ozone

BASE SIMULATION (21 models):
- horizontal resolution of 5 x5° or finer
- 2001 meteorology
- each group’s best estimate for 2001 emissions
- methane set to 1760 ppb

SENSITIVITY SIMULATIONS (13-18 models):
- -20% regional anthrop. NO$_x$, CO, NMVOC emissions, individually + all together (=16 simulations)
- -20% global methane (to 1408 ppb)
Large inter-model range; multi-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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North America as a receptor of ozone pollution: Annual mean foreign vs. domestic influences

Annual mean surface $O_3$ decrease from -20% NOx+CO+NMVOC regional anthrop. emissions

Source region: NA EU EA SA EU+EA+SA

Full range of 15 individual models

“(1.64)”

“import sensitivity”

$\sum$ 3 foreign

(domestic) = 0.45

Seasonality?
North America as a receptor of ozone pollution: Seasonality of response to -20% foreign anthrop. emissions

Spring (fall) max due to longer O₃ lifetime, efficient transport [e.g., Wang et al., 1998; Wild and Akimoto, 2001; Stohl et al., 2002; TF HTAP 2007]

Similar response to EU & EA emissions Apr-Nov (varies by model)

Spring max

SUM OF 3 FOREIGN REGIONS

15- MODEL MEAN SURFACE O₃ DECREASE (PPBV)
North America as a receptor of ozone pollution: Seasonality of response to -20% foreign anthrop. emissions

Wide range in EU anthrop. NMVOC inventories → large uncertainty in the estimated response of NA $O_3$
North America as a receptor of ozone pollution: Seasonality in “import sensitivity”

Surface O₃ response to -20% domestic (NA NOₓ+NMVOC+CO) anthrop. emis.

-20% domestic
\[ \sum (-20\% \text{ foreign}) \]

0.4-0.8 during spring “high transport season”

~0.2 when domestic O₃ production peaks in summer

Response to -20% Foreign > Domestic (winter)

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Estimates of S-R relationships for surface O$_3$ pollution

Annual mean surface O$_3$ decrease from -20% NOx+CO+NMVOC regional anthrop. emissions

Source region:  
- NA
- EU
- EA
- SA
- sum of 3 foreign regions

Receptor region:  
- NA
- EU
- E Asia
- S Asia

Import sensitivity:  
- NA: 0.45
- EU: 0.75
- E Asia: 0.65
- S Asia: 0.45

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

- **Source region:** SUM3  NA  EA  EU  SA
  - NA > EA > SA over EU (robust across models)
  - Response typically smallest to SA emis. (robust across models)
  - NA & EU often > SA/EA on each other (dominant region varies by model)
Monthly mean import sensitivities

SA fairly constant ~0.5

1.1 (EA) during month with max response to foreign emissions

0.2-0.3 during month of max response to domestic emissions

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Application of S-R relationships: Consistency between background O₃ trends and reported changes in Asian emissions?

**SPACE-BASED NO₂ → NOₓ EMISSIONS**

- **ASIA: +40%**

**OBSERVED:** +0.1-0.5 ppb yr⁻¹ in background surface O₃ [TF HTAP, 2007]

**Fig 3.6 from TF HTAP [2007]**

Assuming +10% yr⁻¹ Asian emissions, our results imply an O₃ increase over NA and EU of at most 0.15 ppb yr⁻¹

**OUR CAVEATS:**
- assumes SA+EA, + other emissions follow NOₓ
- continental-avg vs. “west coast” obs

**Fig 3.6 from TF HTAP [2007]**
Addressing Uncertainties: Quantifying model differences due to transport (vs. emissions and chemistry)

Example: SA $\rightarrow$ EA for CO

Emissions, chemistry, transport vary

Only transport varies

Model results averaged from surface to 1 km

POSTER by Martin Schultz et al.:
Passive tracer simulations in the context of the TF HTAP multi-model assessment activity

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Surface ozone response to -20% global [CH$_4$]: similar decrease over all regions

Full range of 18 models

1 ppbv O$_3$ decrease over all regions
[Dentener et al., 2005; Fiore et al., 2002, 2008; West et al., 2007]

Estimate O$_3$ response to -20% regional CH$_4$ anthrop. emissions to compare with O$_3$ response to NOx+NMVOC+CO:

1. -20% global [CH$_4$] $\approx$ -25% global anthrop. CH$_4$ emissions
2. Anthrop. CH$_4$ emis. inventory [Olivier et al., 2005] for regional emissions
3. Scale O$_3$ response (linear with anthrop. CH$_4$ emissions [Fiore et al., 2008])
Tropospheric $O_3$ responds approximately linearly to anthropogenic $CH_4$ emission changes across models. Anthropogenic $CH_4$ contributes $\sim50$ Tg ($\sim15\%$) to tropospheric $O_3$ burden $\sim5$ ppbv to surface $O_3$.

Fiore et al., JGR, 2008
Comparative annual mean surface $O_3$ response to -20% foreign anthropogenic emissions of $CH_4$ vs. $NO_x+NMVOC+CO$

Sum of annual mean ozone decreases from 20% reductions of anthropogenic emissions in the 3 foreign regions

(Uses $CH_4$ simulation + anthrop. $CH_4$ emission inventory [Olivier et al., 2005] to estimate $O_3$ response to -20% regional anthrop. $CH_4$ emissions)
Conclusions: Hemispheric Transport of O₃

Benchmark for future: Robust estimates + key areas of uncertainty

“Import Sensitivities” (Δ O₃ from anthrop. emis. in the 3 foreign vs. domestic regions): 0.5-1.1 during month of max response to foreign emis; 0.2-0.3 during month of max response to domestic emissions

Our estimates + emis. trends → low end of observed surface O₃ trends

Comparable O₃ decrease from reducing equivalent % of CH₄ and NOx+NMVOC+CO over foreign regions (0.4-0.6 ppb for 20% reductions)

ADDITIONAL QUESTIONS (TF HTAP work ongoing for 2010 report):
How well do models capture the relevant processes (e.g. export, chemical evolution, transport, mixing)?
Can we scale our estimated O₃ responses to other combinations and magnitudes of emission changes?
What is the contribution of hemispheric transport to metrics relevant to attainment of O₃ air quality standards?