Multi-scale Mechanisms Affecting Hemispheric Chemistry & Transport

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November 23, 2009
NOAA GFDL & Princeton University
Regional air pollution meteorology

- Enhanced incoming marine flow by sea breezes
- Pollution lofting through upslope/up-valley flow

Adapted from NOAA CalNex 2008
Regional air pollution meteorology

- Low-level jet
- Interacts with downslope
- Entrain possibly polluted FT air to BL

Adapted from NOAA CalNex 2008
Challenges in evaluating air quality impacts from large-scale GCM-CTMs

**Strengths:**
- General atmospheric circulations
- Describe changes in the background and in intercontinental transport

**Limitations & Challenges:**
- Coarse spatial/temporal resolutions
- Possibly simplified model physics
- Inadequate to simulate small-scale met. features and its sensitivity to climate change
- Inadequate to resolve chemical non-linearities relevant to air quality
Dynamic downscaling with RCM-CTMs

Global Met. Analysis (NCEP/NCAR, FNL ...)

Regional Climate-Chemistry Models (MM5, WRF-Chem)

Regional AQM (CMAQ)

Global CTMs (MOZART ...)

Nudging Met. IC/BC

Chem. IC/BC

Archived. Met.
Motivating Questions:

How do regional atmos. processes affect
-urban air quality
-pollution export/import
-effect of climate change?

- Correlations of ozone with regional weather
- Surface pollutants export processes
- Transpacific transport & chemical evolution
Vertical stratification of urban pollution

Afternoon O₃ in June

Nighttime chemistry:
- Nocturnal VOC oxidation
- N₂O₅ hydrolysis
- Ozone loss and formation of secondary aerosols

Lin et al., 2009, ACP
Strong correlation of elevated ozone with stagnant weather

- Influence of up-slope/up-valley polluted airflow during the day
- De-couple of dry dep. at mountain sites above the nocturnal inversion

Lin et al., 2009, ACP
21st century climate change

- Decrease in mid-latitude cyclone frequency
- Increase in the frequency and duration of stagnation/heat wave episodes

Differences in annual mean surface temperatures for 2080-2099 vs. 1980-1999

*IPCC AR4 (Climate Change 2007: The Physical Science Basis)*
Effect of climate change on ozone in polluted regions

The hottest summer on record, 1988

D. J. Jacob and D. A. Winner, 2009
Implications for ozone changes in polluted regions

- Climate change increases surface ozone in polluted regions
- Stronger emission controls will be needed to meet a certain air quality standard

But how many? Uncertainties in large-scale models?

- Missing extreme events?
- Non-linear chemical processing?
- Nocturnal inversion & nighttime chemistry
Changes in the background?

Surface-to-free troposphere exchange affecting continental outflow from Asia

(MOZART vs. WRF-Chem)
United Nations Task Force on Hemispheric Transport of Air Pollution (HTAP; www.htap.org)

- ~20 global models participated in the HTAP source-receptor relationships experiments

- Will S/R relationships change if we use high-resolution models?
Mid-latitude cyclones & pollutants lofting

CO mixing ratios and horizontal flux at 5-km, 2001-03-07

WRF-Chem

[ppbv]
Enhancement of deep convection in the leading edge of the convergence band is missing in MOZART Global Model (2x2°, driven with 6-hr NCEP reanalysis).

Online Regional Model (36x36 km, 3-min climate modeling driven with 6-hr NCEP FNL analysis).
Comparison with TRACE-P measurements

02UTC
04UTC
06UTC
08UTC

MOZART CO

WRF-Chem CO

ppbv

Altitude (km)

Altitude (km)

2001-03-07 (UTC)
Differences in zonal fluxes in the middle & upper troposphere

Figure 2. Comparison of MOZART and WRF-Chem calculated zonal fluxes of CO and PAN along 140°E that is integrated over 4-8.5km altitudes and 25°-40°N latitudes. Episodes of cold frontal passages in March 2001 are highlighted in gray.

Lin et al., 2009, ACP
Implications for changes in the background

- Large-scale models tend to underestimate Asian outflow through rapid convective transport.

- The pollutants lofted to the upper troposphere can undergo long-range transport.

- The range of intercontinental S-R estimates with global models is likely to underestimate the true uncertainty.

For details, please refer to:

Lin, M., Holloway, T., Carmichael, G., Fiore, A., 2009, ACP, to be submitted
Transpacific Transport & Chemical Evolution

- Cold frontal passages
- Orographic forcing
- Deep convection
- Escape of SO$_2$ from cloud processing
Low-level (altitude) outflow of SO$_2$ from China

- EANET Obs
  - MM5-CMAQ/81km
  - Nested MM5-CMAQ/27km

Lin et al. 2008a, AE
Transpacific Transport & Chemical Evolution

- Transport in the warm conveyor belts
- Splitting over the northeast Pacific
- Additional $O_3$ production driven by PAN decomposition
Chemical evolution over the Pacific

INTEX-B
April–May 2006

Transpacific Transport & Chemical Evolution

- Orographic effects
- Recirculation through land-ocean breezes
- FT→BL entrainment
- Mixing with local short-lived species
Asian pollutant plumes over the NA west coast

INTEX-B
April–May 2006

Remarkable difference in model performance over land and ocean
Uncertainties in hemispheric transport

Likely underestimate
Uncertainties in hemispheric transport

TRACE-P/INTEX-B Flight Tracks

Generally well reproduced
Uncertainties in hemispheric transport

Not well understood
Uncertainties in hemispheric transport

TRACE-P/INTEX-B Flight Tracks

Hemispheric WRF-Chem (36x36km)

Nested WRF-Chem (12x12km)
Conclusions

• Strong correlation of air quality with regional/local meteorology & non-linear chemistry
• This presents a particular challenge in evaluating the effect of climate change on regional air quality using GCM-CTMs
  -- sensitivities in regional climate
  -- air quality effects in polluted regions
  -- changes in the background

**Recommended approaches for future research**

• Global high-resolution GCM-CTMs
  - *resolution vs. physics induced uncertainties*
• Dynamic downscaling with RCM-CTMs
  - *two-way nesting*
  - *maintain consistency in model physics*
Thank You!

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- Holloway group, University of Wisconsin – Madison
- Arlene Fiore, NOAA Geophysical Fluid Dynamics Laboratory
- Louisa Emmons, National Center for Atmospheric Research
- Peter Hess, Connell University
- Greg Carmichael, University of Iowa
- NASA TRACE-P & INTEX-B science team
- EANET / ADORC, Japan