Atmospheric Chemistry

Presented by

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Emissions of short-lived chemical compounds control abundance of surface air pollutants and radiatively active gases and aerosols.
CM3 Coupled Climate Model

Designed to address:

- Aerosol-cloud interactions
- Chemistry-climate feedbacks
- Stratosphere-troposphere coupling (high model top)

**Forcing**
- Solar Radiation
- Volcanic Aerosols
- WMGGs (CO₂, CH₄, N₂O)
- ODSs (CFC-11, CFC-12, CFC-113, HCFC-22)

**CH₄, N₂O, ODSs (as model lower boundary condition)**

**Short-lived Pollutant Emissions**
- (anthropogenic, ships, biomass burning, natural, & aircraft)

**AM3 Atmospheric Model**

**Modular Ocean Model version 4 (MOM4) & Sea Ice Model**

**Atmospheric Dynamics & Physics**
- Radiation, Convection (includes wet deposition of tropospheric species), Clouds, Vertical diffusion, and Gravity waves

**Atmospheric Chemistry**
- 86 km
  - Stratosphere
    - O₃, HO₂, NOₓ, Clᵢ, Brᵧ, and Polar Clouds
  - Troposphere
    - Gases (O₃, CO, CH₄, NOₓ, VOCs)
    - Aerosols (sulfate, carbonaceous, mineral dust, sea salt, SOA)

**Land Model version 3**
- (soil physics, canopy physics, vegetation dynamics, disturbance and land use)

**Dry Deposition**

**Aerosol-Cloud Interactions**

Donner et al. (2011)
Austin et al. (2013)
Naik et al. (2013)
Late 20th century cooling from aerosols and volcanoes in CM3

CM3 (All Forcings)
OBS (HadCRU, GISS)
Greenhouse Gases
Natural
Aerosols
Aerosol reductions warm climate over 21st century

Temperature Change (°C)

SO₂ emissions (Tg/yr)

Historical
RCP8.5
RCP6
RCP4.5
RCP2.6

Aerosol emissions held at 2005 levels

Full RCP4.5 scenario

H. Levy et al., *JGR* (2013)
Stratospheric ozone distributions and trends are well simulated.

Ozone Column

TOMS 290 DU

GFDL-CM3 305 DU

Development of Antarctic Ozone Hole

Total Ozone Column OCT 60S-90S

GFDL-CM3

IGAC/SPARC

OBS

CMIP5 models

Eyring et al., JGR (2013)
Stratospheric ozone and temperature respond strongly to volcanic eruptions

Ozone Column

Sign of ozone response to volcanic aerosols depends on atmospheric chlorine loading

Temperature

Post-volcanic warming and long-term cooling in stratosphere are well simulated by CM3

Austin et al., *J.Clim.* (2013)
Tropospheric ozone trends at Mauna Loa Observatory tied to decadal climate variability

The puzzle:
- Asian emissions increasing rapidly
- Strong transport from East Asia to MLO in spring
- Little ozone trend in spring (unlike fall)

Tracer of East Asian Pollution (spring)

E. China NO\textsubscript{x} Emissions

Weakening airflow from Asia in spring tied to recent La-Niña-like decadal cooling in the eastern equatorial Pacific.

Decadal circulation changes offset rising Asian emissions.
Inferring ice formation processes from global-scale black carbon profiles

Simulated black carbon vertical profiles are highly sensitive to assumed scavenging by snow

⇒ OBS suggest slow removal by snow in mixed-phase clouds

Removal by snow
- Slow
- Intermediate
- Fast

S. Fan et al., JGR (2012)
NOAA CalNex 2010 field campaign:
AM3 (nudged to GFS winds) compared with ozonesonde observations

Case Study: May 28, 2010

Balloon observations AM3 (~50x50km²) AM3 (~200x200km²)

Sonde sites in California, north → south

Stratospheric ozone penetrates to lower troposphere over southern California

M. Lin et al., JGR (2012)
Stratospheric sources contribute *episodically* to high-ozone events above the health-based threshold.
Conclusions

AM3/CM3 chemistry-climate model successfully applied to:

- Chemistry-climate-air quality research
  (aerosol forcing, ozone depletion, long-range transport, strat-trop exchange)
- Contributions to CMIP5, CFMIP, ACCMIP, CCMI
- Public health and economic impacts (with collaborators)

Future plans: Chemistry-Climate Model → Earth System Model

- Interactive and self-consistent biogeochemical fluxes among atmosphere, land, and ocean (e.g., reactive nitrogen)
- Emissions-based methane, stratospheric volcanic aerosols
- Higher spatial resolution (relevant for air quality)

Additional Presentations on Atmospheric Chemistry
by Jasmin John, Meiyun Lin, Vaishali Naik, and Jingqiu Mao