Air Quality over the Mid Atlantic: Basic and Applied Science Issues

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College Park
Photo shot from UMD Research Aircraft
Marufu, Doddridge, Taubman, et al.
Outline

• Customers for NASA data?

  **EPA and States**

• Air Quality issues for the Eastern US – science and policy.

• RAMMPP: emissions, modeling, measurements.

  (currently MDE and NOAA support)

• Chemical Climatology of trace gas and aerosol profiles.

• New capabilities of UMD Cessna 402B aircraft.

• High Resolution WRF.

• Satellite obs. vs. Model (CMAQ).

• Former ozone standard 85 ppb for 8 hr
  Maryland, Washington, & Virginia should comply soon(?).

• Proposed ozone standard 60-70 ppb (2010)
  Many or most cities in North America will violate.

• Eutrophication of Chesapeake Bay.

• Current PM2.5 (aerosol) standards
  15 μg m\(^{-3}\) annual average – Maryland is close (~14, sulfate dominates)
  35 μg m\(^{-3}\) daily average – Maryland will exceed on ~3% of days.

• Haze standard – return to pre-industrial levels by 2064.
  Must show steady progress.

• Spatial disconnect.

• Effective abatement strategy needs reliable model simulations.

• Is ozone formation an urban or regional process?

• What is the role of Secondary Organic Aerosol (SOA) in PM2.5 and visibility?

• Role of atmospheric N (NOy and NHx) deposition to Chesapeake Bay.

• How best to reduce greenhouse “gas” emissions (RGGI)?
Testable Hypotheses

- NOx reservoir species such as isoprene nitrates sequester and recycle NOx to increase substantially the lifetime and area for ozone production.
- Multiphase processes convert $N_2O_5$ to ClNO$_2$ to increase the lifetime of NOx.
- MOBILE-6 overestimates NOx emissions from vehicles, but CBIV and CB05 remove NOx too quickly.
- Aging in the troposphere increase the absorption of radiation by organic aerosols within the typical residence time over eastern North America.
- Aerosol single scattering albedo decreases with altitude over the eastern US because the relative fraction of particles containing BC and their degree of coating increase.
- Subgrid-scale cumulus convection vents the PBL to mix with the LFT.
**Regional Atmospheric Measurement Modeling & Prediction Program**

Balanced Theory & Observations

**WRF (WRF-Urban)**
- Dynamical Model
- 12 to 0.5 km Resolution
- Forecasting

**Chem/Trans Models**
- CMAQ
  - Modular
  - Open Code
  - Collaborative w/EPA
  - or
  - WRF-Chem
- Photochem.
- Aerosols
- On-line interactions

**Observations**
- **Surface:**
  - Shenandoah National Park, VA
  - Beltsville, MD
  - Greenbelt, MD
  - Piney Run, MD
- **Aloft**
  - Cessna Aircraft
  - Profiler
  - Sondes
- **Remote (NASA)**
  - OMI (O$_3$, SO$_2$, NO$_2$)
  - MOPITT (CO)
  - MODIS (particles)
  - SCIA/GOME
    - (SO$_2$, NO$_2$, H$_2$CO…)

**Input**
- Emissions Inventories
- Emissions Models
  - (Chem Engineering)
Summer observations over eastern North America

General Study Area & Spiral Locations 1992 -2005

- General subsidence (Bermuda High)
- Cloud pumping through fair weather cumulus.
- Aircraft and satellite observations.
How do the measured CO, O₃ and SO₂ profiles compare to numerical simulations by CMAQ?
CMAQ under-predicts $O_3$ by 10% (6 ppb) between 600 and 2600 m. (Hains, Doddridge, et al., )
SO$_2$ emissions at US coal-fired power plants in 2005-2007
Average (2005-2006) SO$_2$ burdens over USA,

Aircraft summer mean 0.3 DU

Thanks
Nick!
The average CMAQ SO₂ column content (14 mg m⁻²) is 1.5 times larger than the aircraft column content (9 mg m⁻²) (CMAQ sampled at the same times and places).
Fair weather cumulus
1 pm EST July 7, 2007,
a smoggy day
PBL venting preferentially through fair weather Cumulus
Carbon monoxide provides a good tracer for dynamics and test of emissions inventories.
Turbulent transport is modeled with an eddy diffusion coefficient ($K_z$, m$^2$/s)

\[ \frac{\partial c_i}{\partial t} \bigg|_{VDIFF} = \frac{\partial}{\partial z} K_z \frac{\partial c_i}{\partial z} \]

Analogous to molecular diffusivity

$K_z$ may be overestimated
Model Performance of CO in CMAQ
Aerosol Scattering

Median Scattering profiles for morning and afternoon flights (2001-2004)

Median scattering (m⁻¹) with 25th and 75th percentiles
New Aircraft: Cessna 402B
New Inlets

- FAA approved flight testing.
- Candy-cane for gases
- Shrouded for aerosols: 50% efficiency at ~5 μm
- Credit: L. Brent, J. Stehr
Side by side picture of inlets

Current inlet

Limited to collection of submicron particles

New shrouded inlet

Has been found to reliably collect particles up to 4-5μm
# Cessna Configuration

<table>
<thead>
<tr>
<th>Nose</th>
<th>Left side</th>
<th>Right side</th>
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</thead>
<tbody>
<tr>
<td></td>
<td><strong>NO₂</strong></td>
<td><strong>Aethalometer</strong></td>
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<tr>
<td></td>
<td><strong>O₃</strong></td>
<td><strong>Nephelometer</strong></td>
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<td><strong>CO</strong></td>
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<td></td>
<td><strong>SO₂</strong></td>
<td><strong>CPC</strong></td>
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<td></td>
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<td><strong>Grab cans: VOC’s</strong></td>
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</table>

| Tail |
Aethalometer

- Has been flown once
- Need to fine tune valve settings so that it is optimized for aircraft analysis

UV 370 nm
Blue 470 nm
Green 520 nm
Yellow 590 nm
Red 660 nm
IR-1 880 nm
IR-2 950 nm
• NO$_2$ via Cavity Ringdown
• Detection Limit: ~60 ppt
• Response time: 10 s
• 80 watts

Flown successfully in Jan. 2010
### Aircraft Instruments on the Cessna 402B

<table>
<thead>
<tr>
<th>Variable</th>
<th>Temporal Resolution</th>
<th>Detection Limit</th>
<th>Technique (Instrument)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>10 s</td>
<td>15 m</td>
<td>GPS (Garmin GPS90)</td>
</tr>
<tr>
<td>Static Pressure</td>
<td>10 s</td>
<td>0.2 mbar</td>
<td>Capacitance Barometer (Vaisala PTU300; BAROCAP)</td>
</tr>
<tr>
<td>Temperature</td>
<td>10 s</td>
<td>0.2°C</td>
<td>Platinum Resistance Thermistor (Vaisala PTU300; Pt100 RTD 1/3 Class B IEC 751)</td>
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<tr>
<td>Relative Humidity</td>
<td>10 s</td>
<td>1%</td>
<td>Thin film Capacitive (Vaisala PTU300; HUMICAP 180)</td>
</tr>
<tr>
<td>U, V wind components</td>
<td>1 s</td>
<td>0.2 ms⁻¹</td>
<td>Differential GPS (AIMMS-10)</td>
</tr>
<tr>
<td>O₃</td>
<td>9 s</td>
<td>1 ppbv</td>
<td>UV photometry (TEI 49C)</td>
</tr>
<tr>
<td>NO₂</td>
<td>10 s</td>
<td>60 ppt</td>
<td>Cavity Ringdown Spectroscopy (Los Gatos Research RMT-200)</td>
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<tr>
<td>Aircraft Instruments on the Cessna 402B (cont)</td>
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<td>-----------------------------------------------</td>
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<tr>
<td><strong>CO</strong></td>
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<tr>
<td>Time: 1 min*</td>
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<tr>
<td>Measurement: 20 ppbv</td>
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<tr>
<td>Method: Modified NDIR/GFC (TEI 48)</td>
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<tr>
<td><strong>SO₂</strong></td>
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<tr>
<td>Time: 1 min*</td>
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<tr>
<td>Measurement: 100 pptv</td>
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<tr>
<td>Method: Modified pulsed-fluorescence (TEI 43C)</td>
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<tr>
<td><strong>Aerosol Absorption</strong></td>
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<tr>
<td>Time: 2 min</td>
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<tr>
<td>Measurement: 0.1 μg/m³</td>
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<td>Method: 7 Wavelength Aethalometer (Magee Scientific AE31)</td>
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<tr>
<td><strong>Aerosol Scattering</strong></td>
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<tr>
<td>Time: 1 min</td>
<td></td>
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<tr>
<td>Measurement: 0.1-0.4 x 10⁶ m⁻¹</td>
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<tr>
<td>Method: Integrating Nephelometer (TSI 3563)</td>
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<tr>
<td><strong>Particle counts</strong></td>
<td></td>
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<tr>
<td>Time: 10 s</td>
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<tr>
<td>Measurement: 0.01 μm</td>
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<tr>
<td>Method: Condensation Particle Counter (TSI 3007)</td>
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<tr>
<td><strong>Aerosol size (0.3-10 μm)</strong></td>
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<tr>
<td>Time: 1 min</td>
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<tr>
<td>Measurement: N/A**</td>
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<tr>
<td>Method: Custom laser based optical (MetOne 9012)</td>
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<tr>
<td><strong>Aerosol composition</strong></td>
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<td>Time: varies</td>
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<tr>
<td>Measurement: varies</td>
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<tr>
<td>Method: Collection on filter followed by laboratory analysis.</td>
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</table>
Aerosol speciation
In collaboration with NIST

– $\text{SO}_4^{2-}$, $\text{NO}_3^-$, oxalic acid and other RCOOH, $\text{PO}_4^{3-}$, $\text{X}^-$
– Current SRM certificates do not verify concentrations of these anions.
– Use of AS17 column allows for verification of $\text{NO}_3^-$ and oxalic acid
11 Organic Acids

Monoacids

Diacids

Polyacid

Lacey Brent, UMD & NIST
WRF-URBAN 0.50 km Resolution
Model Verification - Skin Temperature and Surface winds
(Da-Lin Zhang et al. 2009; not funded for 2011)

2007-07-09-1745UTC

MODIS (Satellite) Temps
Simulated
From 500 m resolution WRF run (D-L Zhang)
GOES visible satellite image and average cloud liquid water content from the 13.5 and 0.5km sensitivity simulations at 2000 UTC July 7, 2007.
Surface to 215mb SO$_2$ column at 1200 UTC July 8, 2007 averaged Balt/Wash.

- Higher resolution WRF runs produce more small clouds, faster removal of SO$_2$ and better agreement with observations.
Tropospheric Column NO$_2$

- Evaluate the regional nature of pollution episodes, modeled by CMAQ, through comparison with satellite data,
- Understand the limitations of current spaced based observations in terms of understanding air quality.
- Thanks to Tim Canty.
The tropospheric column of NO$_2$ observed by OMI shows hot spots near cities.

The ratio of urban to rural is about 3, in rough agreement with surface monitors.

The tropospheric column of NO$_2$ predicted by CMAQ shows hot spots near cities.

The ratio of urban to rural is about 9, higher than surface monitors.

Credit: Tim Canty.
NOx: Models vs. surface measurements.

At urban sites → CMAQ overestimates NOx.

At rural sites → CMAQ underestimates NOx.
Take Home Messages

• UMD with support from MDE and NOAA (NASA Air Qual and EPA Pending) will fly in 2010.

• CMAQ must be used for State Implementation Plans

• CMAQ has trouble with
  – NOx Chem
  – Sub grid convection
  – VOC and SOA

• DISCOVER-AQ will provide a rich data set that will be useful for years.
The End

Fear the Turtle!