Air Quality Projects: NOAA/UMD cooperation

Russell R. Dickerson The University of Maryland
Xinrong Ren, NOAA and UMD
The crime.
The Guilty Parties
ARL and UMD work together to identify the gaps in our knowledge of the fundamental meteorology and chemistry that impede our ability to attain the Air Quality Standards, then to put this new knowledge into practice.
We are drowning in information, while starving for wisdom. The world henceforth will be run by synthesizers, people able to put together the right information at the right time, think critically about it, and make important choices wisely.

E. O. Wilson
I. Development of NOAA HYSPLIT (HYbrid Single Particle Lagrangian Integrated Trajectory) Inverse Modeling System;  
   **Task Leader**: Dr. Tianfeng Chai.

II. Field measurements of mercury and related variables.  
   **Task Leader**: Mr. Paul Kelley

III. Top-down estimation of natural and anthropogenic emissions.  
   **Task Leader**: Dr. Hyun Cheol Kim

IV. Support for dispersion modeling at the Air Resources Laboratory.  
   **Task Leader**: Dr. Fong “Fantine” Ngan

V. Trace gases and HYSPLIT.  
   **Task Leader**: Dr. Xinrong Ren

VI. AOSC JPSS Initiative for Improving Volcanic Hazard Monitoring and Forecasting  
   **Task Leader**: Dr. Allison Ring

VII. Air Quality Prediction Improvement, Data Assimilation and Emission Development  
   **Task Leader**: Dr. Youhua Tang
Outline

• Air Quality
  • Forecast. Fly/nofly. (Pius Lee)
  • SIP (State Implementation Plan), MDE (Maryland Dept. Environment)
  • OWLETS and LISTOS (NASA and NESCAUM; New York)
  • NASA AQAST AND HAQAST

• Trajectories and dispersion (HYSPLIT)
  • Power Plant Plumes
  • Tracing sources; Actionable intelligence
  • Sea and bay breeze (micrometeorology)

• Greenhouse Gases and NIST
  • Emissions of natural gas twice as high as in inventory
  • GHG Reduction Act.
Surface obs from the Baltimore/Washington region – suffered severe ozone for decades.

Initial VOC & CO controls had little effect.

Region-wide NOx controls worked.

From Sandra Roberts’ preprint.
Air Quality Trends in Maryland

**Ozone**

*Preliminary Data*

**Particles**

*Preliminary Data*
Using surface obs and a box model, calculated rate of production of ozone in the Balt/Wash area went up before it went down.

Region-wide NOx controls worked.

From Sandra Roberts’ preprint.
UMD Cessna 402B Research Aircraft

**GPS Position** (Lat, Long, Altitude)

**Met** (T, RH, P, wind speed/direction)

**Trace gases:**
- \( \text{O}_3 \): UV Absorption, modified TECO
- \( \text{SO}_2 \): Pulsed Fluorescence, modified TECO
- \( \text{CH}_4/\text{CO}_2/\text{CO}/\text{H}_2\text{O} \): Cavity Ringdown, Picarro
- \( \text{NO}_2 \): Cavity Ring Down, Los Gatos
- \( \text{NO} \): Chemiluminescence, modified TECO
- VOCs: whole air samples
- HCHO: Fluorescence (Hanisco)

**Aerosol Optical Properties:**
- Scattering: \( b_{\text{scat}} (@450, 550, 700 \text{ nm}) \), Nephelometer
- Absorption: \( b_{\text{ap}} (565 \text{ nm}) \), PSAP

**Aerosol Chemistry:**
- Black Carbon: Aethalometer
- Major ions and SOA: filter samples
NASA P-3 during DISCOVER-AQ 2011 over Maryland’s eastern shore. AQAST and HAQAST

Photo by J. Stehr
More ozone over the Bay

Fair weather cumulus (humilis) often form over the warm land but not over the Bay.

Abatement of regional ozone allows us to tailor new measures see Ring’s et al., 2019; Hembeck et al., 2019.

Stauffer et al., 2012; Goldberg et al. 2014; Loughner et al., 2014; Mazzuca et al., 2017, 2018.

* You are here

**Fig. 13.** Visible image from the MODIS satellite at 1610Z (2:10 PM local time) on July 20, 2011 showing the presence of low-level cumulus clouds only over the land.
Coastal areas are subject to sea/bay breezes as a result of the land-water temperature contrast.

- Higher O$_3$ concentrations over water than the adjacent land (Goldberg et al., 2014)
- Bay breezes can advect high O$_3$ from water to land (Stauffer et al., 2012, Loughner et al., 2014)
- Thunderstorms interact the Bay breezes and don’t always kill ozone events (Mazzuca et al., 2018).
- Baltimore NOx emissions (CEMS) highest on ozone days at Hart-Miller Island (Dreessen et al., AGU 2018).

MODIS vis. image of Shallow-cu along the Chesapeake bay breeze front

Higher O$_3$ conc. observed by the UMD Cessna over the Chesapeake Bay at low altitudes.
E. R. : emission rate (flux)
[C] : concentrations (downwind)
[C]_b : concentration in background
U_⊥ : perpendicular wind speed

\[ E \cdot R_{CH_4} = \int_{-x}^{x} \int_{0}^{z_i} ([C] - [C]_b) \times U_\perp \, dx \, dz \]

Mass Balance Method (NIST)

Can also ratio short-lived pollutants such as NOx to CO2 to test emissions inventories (Anderson et al. 2014; Salmon et al. 2018).

CH4 emissions twice MDE (all) inventories.
Atmospheric Chemistry in New York

Amazing progress has been made on air quality in the US, but we have miles to go before we sleep.
Connecticut Coast
Xinrong Ren photo 2017
LISTOS in One Picture

NASA Langley Research Center
May 18, 2017 Afternoon Flight

Ozone forecast

The ozone episode was well forecast by the ARL model!
Measurement vs. forecast model (ARL) **ozone** comparison for flights of 2017

Ozone from CMAQ with UMD Aircraft Obs. (5/17/17)

Ozone from CMAQ with UMD Aircraft Obs. (5/18/17)

Ozone from CMAQ with UMD Aircraft Obs. (5/18/17)

CMAQ Avg 1km O3 at hr17 and RF1 Flight

CMAQ Avg 1km O3 at hr10 and RF2 Flight

CMAQ Avg 1km O3 at hr15 and RF3 Flight

**Forecast episode verified!**

Ring et al. (in prep)
July 2 from Above

View from UMD airplane over Manhattan
July 2, 2018 Compared to Clean Day
NYC Bad Air Day: July 2, 2018

- Highest ozone since 2006:
  - 8 hr: 115 ppb
  - 1 hr: 143 ppb
Yellow arrows show WD (southerly) and relative WS. Spirals near Flax Pond and the Rutgers site.

Max. 1 min $[O_3]$ ~ **150 ppb** to the north of NYC.
UMD Cessna LISTOS Flights on Monday, 7/2/2018

Afternoon Flight (~3:00-6:30 PM)

- Still high NO$_2$ and CO concentrations in the NYC outflow
Ground truth for remote sensing
NASA Aircraft Flight Grid July 2
3. NASA GeoTASO (TEMPO Satellite Test-bed)  
NYC July Heat Wave Day 3: July 2, 2018  
Credit: NASA Langley, NOT FOR DISTRIBUTION
Is NYC area here?
UMD Cessna LISTOS Flights on Monday, 7/2/2018

Spirals near Flax Pond during the afternoon flight

- $[O_3]$ (ppb)
- $[NO_2]$ (ppb)
- $[CO]$ (ppb)
- $[CH_4]$ (ppbv)
- Bsp @ 550nm (m$^{-1}$ x10$^4$)
- Bscat @ 550nm (m$^{-1}$)

10-20 µg/m$^3$
UMD Cessna LISTOS Flights on Monday, 7/2/2018

Spirals near Rutgers during the afternoon flight
En route descent (red) was over the LIS between Flax Pond and Groton (New London) airport.

HCHO, CO, PM aloft from Calif fires.

Well mixed PBL.
Correlation among CO, CO$_2$ and CH$_4$ over NYC

Afternoon Flight on May 18, 2017

Observed CO and CO$_2$, CH$_4$ and CO$_2$ as well as CH$_4$ and CO are well correlated.

CO and CO$_2$ emissions look good, but CH$_4$ emissions may be underestimated by a factor of 2-3.
Conclusions

• Collaboration between NOAA ARL and UMD AOSC has been fruitful!
• Many publications
• Graduate students Ahn, Benish, Goldberg, Mazzuca, Loughner, Ring et al.
• Field experiments indicate that sea breezes play a major role in air quality.
• High resolution models can capture this.
• Region-wide controls of NOx emissions worked to improve O3.
• Mass balance flights improve understanding of GHG emissions in Balt/Wash/NYC and Marcellus.
• Urban CO2 emissions inventories are pretty close, but CH4 underestimated (Ren et al. 2018, 2019; Plant et al., 2019; Huang et al., 2019)
• Needed policy relevant science,
• Ozone got worse before it got better.
• Relative strength of NOx sources:
The End

Fear the Turtle!

Reprints can be found at http://www.atmos.umd.edu/~russ/recent_pubs.html
UMD Cessna LISTOS Flights on Monday, 7/2/2018 heavy primary pollution

Morning Flight (~9:00-12:30 EDT)

- Max. $[\text{NO}_2]$~42 ppb observed over Hudson River at 650 m altitude.
- 800-900 ppbv CO over Hudson River @ 650 m
- ~500 ppbv CO downwind of NYC at ~350m.
Mercury

The people who are making the measurements

Winston Luke
Principal Investigator, NOAA Air Resources Lab

Jake Walker
Site Operator, Grand Bay NERR

Paul Kelley
Instrument engineer, data acquisition and management, NOAA Air Resources Lab

Gulf of Mexico Alliance Mercury Forum, May 10-12, 2010, Mote Marine Lab, Sarasota, Florida
Motivation

SODAR wind direction (background colors) and surface trace gas concentration (lines) Edgewood, MD 07-22-2011 (bottom)

July 22, 2011 at Edgewood, MD

Wind direction shifted from ~240° (offshore) to ~190° (onshore)

Ozone ~120 ppbv during bay breeze

Trace gas concentrations decrease immediately after due to deep convection
Methods
Bay Breeze Detection Algorithm

Bay breeze detection technique using wind only

- Apply a low-pass filter to the 1-minute u & v components of the wind for June, July, and August 2011-2016 at Edgewood, MD

- Create a “microscale+mesoscale” signal and a “diurnal+synoptic” signal

- Bay breeze flag = yes when the following occur:
  - Wind direction is from the water
  - The microscale+mesoscale signal deviates from diurnal+synoptic signal
  - Winds are not out of the NNE/NNW
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Isoprene is not dominant
Does not yet include oxygenates or consumer VOCs.
Outline

• Problem: What are the gaps in our knowledge of the fundamental meteorology and chemistry that impede achieving the Air Quality Standards?

• Until recently, Edgewood Maryland on the Chesapeake Bay (downwind of Baltimore and Washington) had the worst ozone air pollution in the eastern US.

• Abatement policy was complicated by nonlinearities and mesoscale meteorology involving the Bay, but we are (finally) winning the battle.

• Even with reduced emissions, coastal Connecticut (downwind of New York City) has gotten worse.

• Recent results from field experiments.

• What recommendations might we have?
  • Need a deeper understanding of the meteorology and chemistry to inform policy.
  • Leverage GHG measurements to understand better SO\(_2\), NOx and VOC emissions.