A Brief Review of Recent Air Quality Seasons

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Topics

• Frequency of high $O_3$ cases decreased across the region in 2008. Difficult to assess 2008 in terms of $PM_{2.5}$ climatology.

• Weather conditions during Summer 2008
  – Was lower $O_3$ due to the weather? Yes and No.

• An interesting, long-lasting, poor air quality episode in June, 2008.

• Comments on Recent Air Quality Seasons: 2005 and 2007.
National Look At 2008 Ozone

2008 Ozone Season Review
(May 1 through September 30)

Figure courtesy of EPA AirNow, Scott Jackson
Reductions in O₃ Episode Frequency and the Regional NOₓ SIP Rule

Color Code Frequency (Revised AQI) in the Metropolitan Philadelphia Area
Code Purple O₃ Cases in Philadelphia
Ozone Episodes in the Mid-Atlantic (2008)

Number Monitors > Code Orange

High PM$_{2.5}$

High PM$_{2.5}$

Preliminary data!
2008 Summer Season Dry in the Mid-Atlantic
2008 Summer Season Also Warm
Summer Season (JJA) Average Geopotential Height at 850 mb

Below:
Change from normal. Blue = lower heights
Wind Velocity at 850 mb

Red boxes are areas with higher than normal rain.
August 2008: Where Was the Bermuda High?

Mean sea level pressure field for August
Sustained Northwest Flow in August Suppresses Rainfall
Tropical Storm Fay

Tropical Storm Fay
August 17-29, 2008
4275 sites

Maximum: 27.65" Melbourne 8 NW, FL
June 7-13, 2008 Poor Air Quality Episode

• Both PM$_{2.5}$ and O$_3$ concentrations reached the Code Orange range.
• Fires in Eastern NC.
• Large day to day swings in O$_3$ concentrations:
  – The question each day is: How much is deterioration in air quality is due to smoke?
June Episode: Bermuda High
Average Height and Winds in the “Transport Layer” During the Episode

While winds near the surface tended to be light southwest, winds aloft are stagnant near the center of the 850 mb (~ 5K ft) high (in NC) and westerly for the rest of the mid-Atlantic.
Lightning Strike Started Fires in Peat Bogs in eastern NC on June 1, 2008. Several Pulses of Smoke Affected Mid-Atlantic Region.
June 7 was one of the smoggiest days of the year in terms of a combination of all pollutants.

The forecast for June 8 was continued hot and humid weather with transport from the Ohio River Valley – the classic high O₃ and PM₂.₅ pattern.

It was, in fact, just as hot (93°F) and more humid but both O₃ and PM₂.₅ concentrations fell!

It was a Sunday but was that all?
Sunny, Hot, Humid Weather with Westerly Transport are Necessary, But Not Sufficient, for High Ozone Region-wide

The southern edge of a squall line on the evening of June 6.

Develops into a meso-scale convective system (MCS), that reaches a regional scale in just a few hours. Outflow boundaries reach KY, WV.
Meso-Scale Convective System Dropped into the Ohio River Valley on June 7th

9 am June 7
Remnants of Convection Cross I-95 Sunday with Strong Winds Observed Aloft

Visible Satellite Image
Sunday morning, June 8
Same Transport Pattern for June 9

Visible Satellite Image
Monday, June 9, Afternoon
High O$_3$ Returns Along I-95 on June 9
Pockets of High PM$_{2.5}$ – NC Especially
Is Poor Air Quality on June 9 Fire Related?

Forward trajectories starting June 8

Back trajectories ending June 9
Forward Trajectories Initialized on June 11
Show Fire Smoke Re-Circulates Inland
Fire Smoke on June 12 Creeps Northward As Well
PM Concentrations Extreme in NC
Central NC Observes Peak Smoke Levels
Morning of June 12

[Graph showing hourly PM2.5 levels with peak on June 12]

Plotted: 12/11/2009 11:36 AM PST
Greensboro in Northwestern NC Observed Peak Concentrations Just After Midnight on June 13
Smoke Creeps Up Eastern Slope of Appalachians Later on June 13
Western VA Observes $\text{PM}_{2.5}$ in the Code Red Range by late Morning on June 13

Albemarle = Charlottesville
Round Hill = Roanoke
Butler = Rest, VA (Shenandoah Valley)
Approaching Cold Front Sweeps Smoke and Haze East on June 14
Burst of High PM$_{2.5}$ Along the I-95 Corridor from Beltsville, MD to Philadelphia
July 2008 Episode

• Long period of stagnation over the mid-Atlantic.
• Tropical Storm Cristobal moved slowly north along the Atlantic coast.
• Subsidence (downward motion) at the periphery of Cristobal limited vertical mixing.
• Very clean conditions within the circulation of Cristobal itself.
Widespread High O$_3$ on July 16

Ozone AQI

Code Orange PM$_{2.5}$ by evening in southern Mid-Atlantic
Stagnation Continues on July 17

Ozone AQI

Widespread Code Orange
PM$_{2.5}$ also on July 17
Inter- and Intra-Regional Transport

NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 17 Jul 08
EDAS Meteorological Data
“Reverse” Corridor Transport and Subsidence on Periphery of Cristobal
Tropical Air Creeps Northward
Haze Pushed Westward on July 18
Tropical Circulation Well Onshore by July 19
PM$_{2.5}$ Pattern Similar to O$_3$
Comments on Summer 2005

• Record early tropical season – entire season unusually active.
• Impacts of frequent tropical systems on weather patterns and climatology.
• Challenges to numerical weather and coupled chemistry models posed by frequent tropical systems.
• Bad air episodes did occur between tropical systems and were generally of the “standard” form.
Unusually Active Hurricane Season
Mean Sea Level Pressure: Summer of 2005

Bermuda High is present but anomalous low pressure found in the eastern Gulf of Mexico
Summer Season Moisture

Moisture in the atmosphere much higher than normal in the southeastern U.S.
Presence of Numerous Tropical Systems Leads to Much Weaker Westerly Winds

Below: Difference from normal wind velocity at 850 mb (~ transport level)

Much weaker westerlies
Tropical Systems and Coupled Models

- Tropical systems exhibit complex circulation at all levels
  - Standard meteorological models do not handle tropical systems well. “Hurricane” models have unique characteristics.

- Tropical air mass characteristics
  - Do standard boundary/initial conditions apply?

- Subsidence at periphery of tropical circulations
  - Has a significant impact on air quality at large distance from center of circulation – see, Cristobal in 2008.

- Unusual moisture conditions in both atmosphere and surface
  - Surface, and below surface, moisture is a critical feature in meso-scale models. Especially critical for boundary layer development and clouds/precipitation.
Example: Hurricane Dennis
Example: Hurricane Dennis and the NOAA NAQFS Model

Model identifies subsidence at edges of tropical circulation but over-predicts impact on O₃ concentrations.

July 12
Tropical Storm Arlene: Moisture Impacts

Affects U.S. June 8-15
In August: Katrina

Affects U.S. August 24-September 1
Katrina: Significant Rainfall from LA to ME
In September, Hurricane Ophelia
Between Tropical Systems Had Short Periods of Poor Air Quality

- Most of these episodes followed the “standard” poor air quality pattern
  - Center of surface high pressure in “sweet spot” in southern Appalachians.
  - Westerly transport aloft
  - Low level transport often along with I-95 Corridor.
  - Both inter- and intra-regional transport.
July Episode: “Classic” Pattern
First of Two August Episodes
Second of Two August Episodes
June 2005 Episode: Coastal Trough

Above: Trough of low pressure along SE Coast. Often can form tropical depression. Not in this case but onshore winds keep SE clean.
2007 Summer Season

• Overall weather patterns close to normal.
  – But do we care about seasonal average?
• Tropical season active but little impact on the eastern US
• Significant smoke from fires in the northern Rockies
  – Impact at surface in eastern US?
  – Smoke observed but does it matter?
850 mb Geopotential Height Summer Average
2007 ~ Normal with Respect to Humidity

2005: Difference from normal in specific humidity

2007: Difference from normal in specific humidity
2007: Transport Pattern for Poor Air Quality Days in Philadelphia

925 mb Height

925 mb Winds

Worst O₃ Days

Worst PM₂.₅ Days
High $\text{O}_3$ Cases Tend to Have Less Clouds
High PM$_{2.5}$ Episode in Early August
Clouds Cover Suppresses $O_3$
Has Less Impact on $PM_{2.5}$
“Standard” Mid-Atlantic Bad Air Case

Episode Average Winds

NOAA HYSPLIT MODEL
Backward trajectories ending at 12 UTC 26 Jun 07
EDAS Meteorological Data

Meteosat Visible Wind (m/s) Composite Mean
5/26/07 Met 5/26/07
NCEP/NCAR Realanalysis

Job ID: 3333899
Job Start: Thu Aug 30 18:20 14 GMT 2007
Source lat: 39.88 lon: -75.25 hgs: 1500, 1000, 500 m AGL
Trajectory Direction: Backward
Duration: 24 hrs
Model Vertical Velocity
Produced with HYSPLIT from the NOAA ARL Website (http://www.arl.noaa.gov/hysplit)
Late June: Mix of High $O_3$ and $PM_{2.5}$
Thunderstorms can Significantly Affect Local Peak Concentrations for both O$_3$ and PM$_{2.5}$
Smoke From Northern Rockies Fires

Extensive, persistent fires in Idaho and Montana during 2007

Analyzed Smoke from Fires
Lidar at UMBC can observe aerosols, and clouds, aloft. On these two August days, smoke is at 3-7 km. The usual mixing depth (black line) is ~ 2km. Location of cumulus cloud base (right panel) shows top of mixed layer on that day.
Winter Season $\text{PM}_{2.5}$

- Neither winter seasons of 2005 or 2007 are remarkable for $\text{PM}_{2.5}$.
- Winter season $\text{PM}_{2.5}$ episodes in the mid-Atlantic typically a function of:
  - Strong surface inversion
    - Enhanced by snow cover, warm fronts
  - Light winds
    - Surface high pressure overhead
  - Westerly transport aloft
    - Often precedes peak $\text{PM}_{2.5}$ and followed by stagnation
  - High relative humidity
    - Enhances both nitrate and sulfate formation
Maryland Winter Season PM$_{2.5}$

Worst Cases (2000-2005)

Average sea level pressure
Stagnation along I-95

Back trajectories include westerly transport and recirculation. Sulfate concentrations increase though less than summer magnitudes.
Baltimore: 90th Percentile Summer and Winter Cases - Winter cases feature lower concentrations but enhanced effect of morning rush hour.

Single Case: February 19, 2003 Baltimore (Old Town) Afternoon background/regional load ~ 25 μg/m³ Effect of morning rush hour extends to noon.
Conclusions

• Air quality in the summer of 2008 was near normal in post-NOx SIP Rule world.
  – Exception: Clean August with anomalous northwest flow and weak Bermuda High.

• Smoke from NC fires affected regional air quality significantly on several occasions during June.

• Overall, 2007 is more representative of “normal” conditions than 2005.