MARYLAND

Department of the Environment

Air Quality Variability in Maryland due to Climate Cycles and Emissions

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MDE

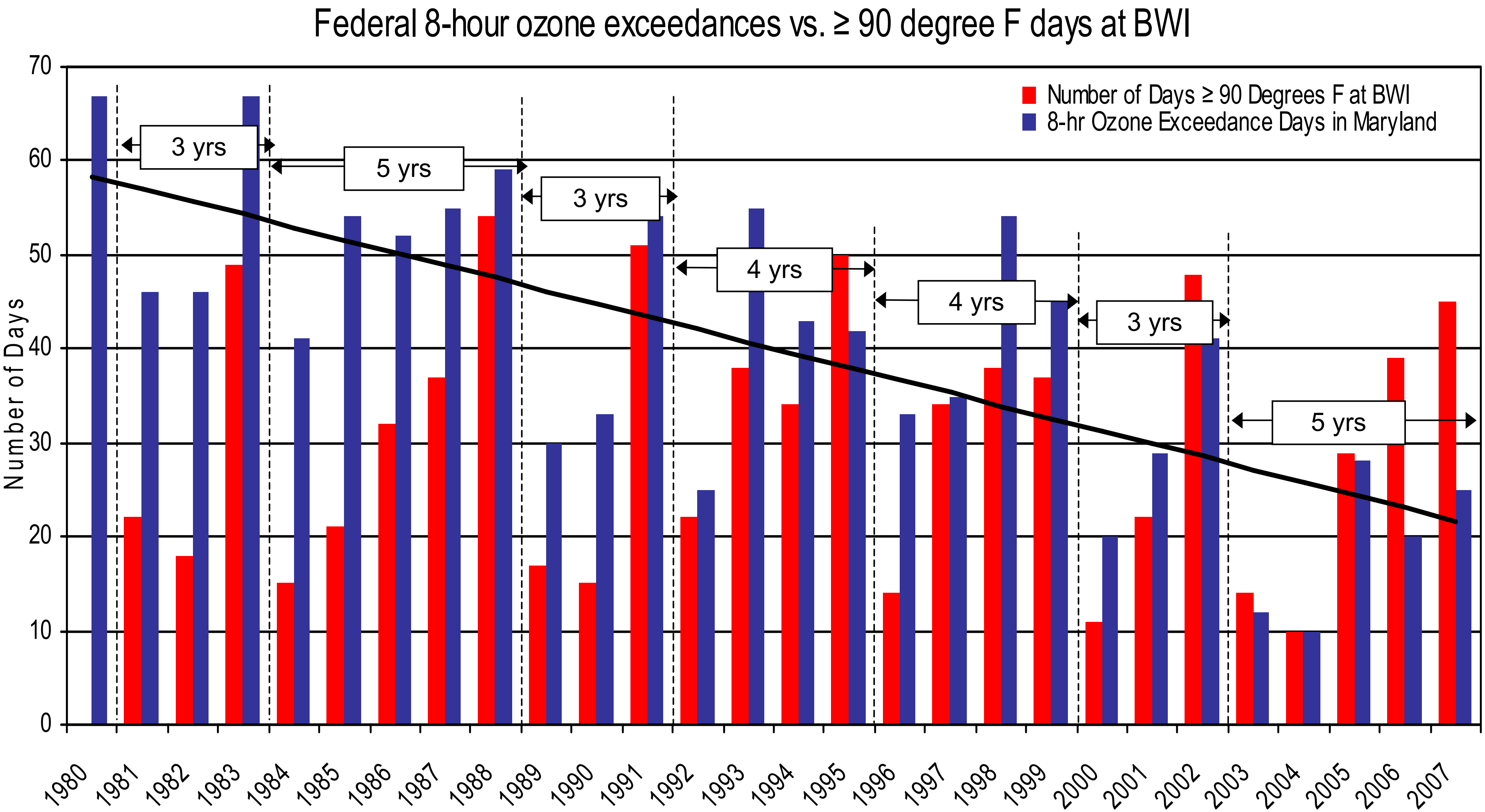
CAVEAT

Statistics in this presentation reflect the 1997 standard for 8-hour ozone of 85 ppb unless noted otherwise!

Outline

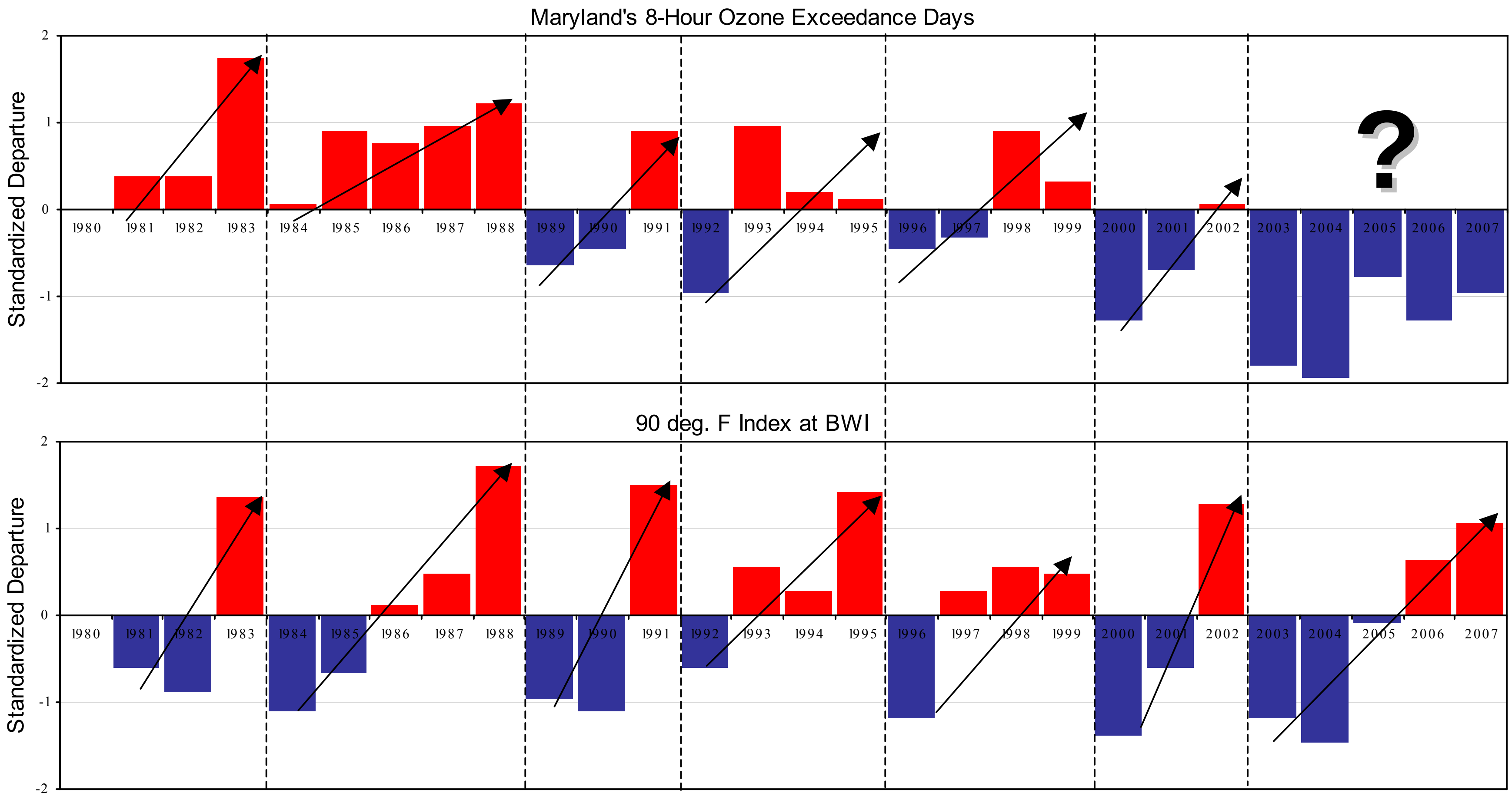
- Ozone Exceedance Days and 90° F Cycle
  - 2000-2002 Cycle and Its Impact on Air Quality
  - 2003-2007 Cycle and Its Impact on Air Quality
- **E**l **N**iño-**S**outhern **O**scillation (ENSO) Cycle and Air Quality
- Ocean Cycles and Air Quality
- Aloft Transport Pattern on Bad Air Quality Days
- Regional NO_x Controls and Its Impacts on Ozone Levels in the East
- Progress in Ozone Levels in Maryland and High-Elevation Monitors
- Maryland's Attainment Status as of 2007
- Outlook for 2008
- Summary

Federal 8-hour Exceedances vs. ≥ 90 F Days



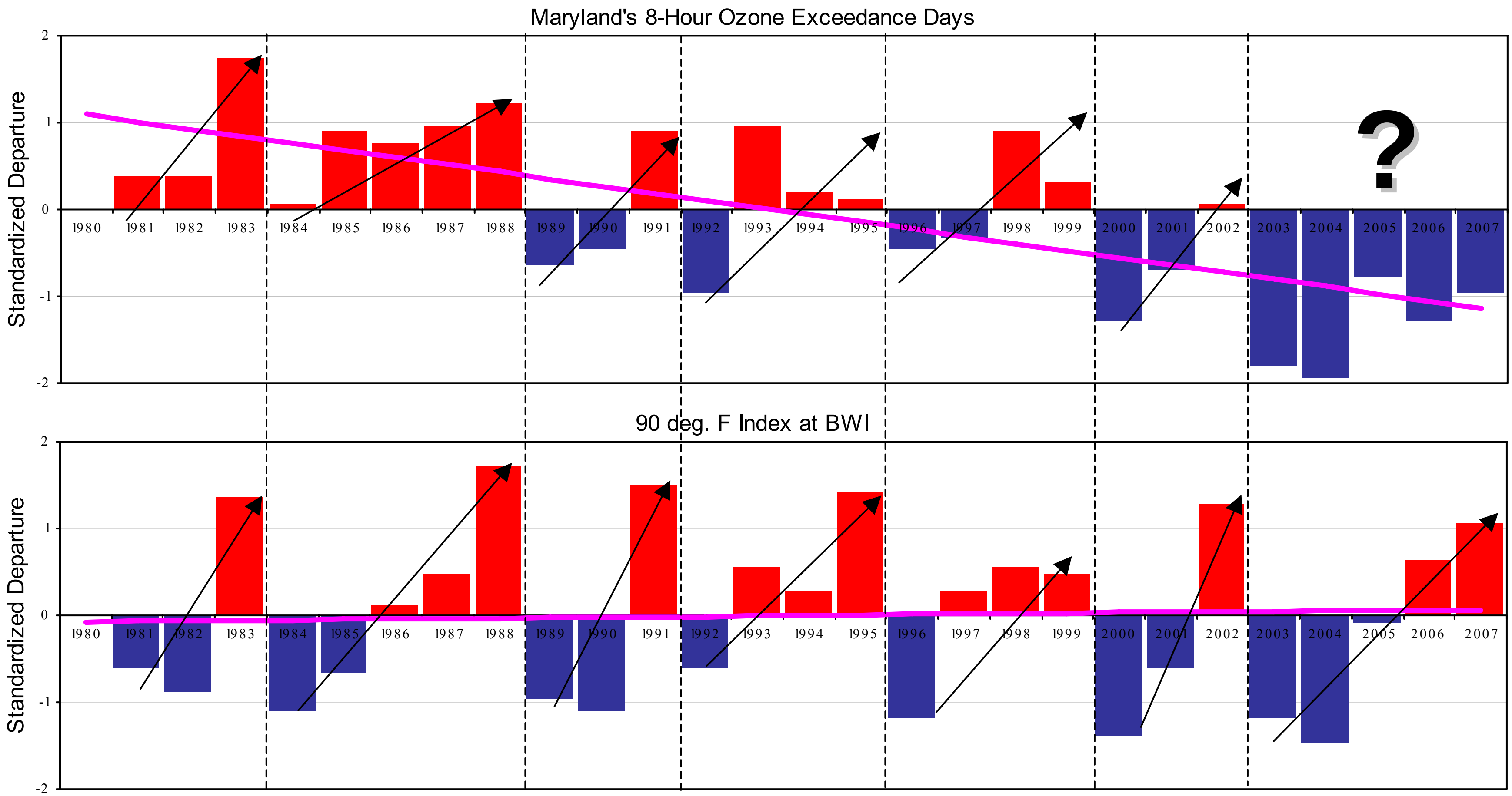
- Number of hot days (≥ 90 F) appear to have a 3-5 year cycle where the counts gradually increase through the period.
- This cycle influences the number of federal 8-hour ozone exceedances.
- Despite the year-to-year fluctuation, ozone exceedance days show a downward trend.

Ozone Exceedance Days and 90° F Cycle (1 of 2)



- Standardized departure of Maryland's **8-hour ozone** and **90 deg days** at BWI **follow a periodic cycle** through 2002. Correlation is **0.66** (This is what makes air quality forecasting possible!)
- Why are 8-hour ozone exceedance days in Maryland consistently below normal between 2003-2007 despite what the temperature data tell us otherwise?
- Possible Explanations: (a) correlation is random; (b) data set is flawed; (c) **air quality trend is entering a new phase**?
- Test **Hypothesis C** by examining trends in both data sets …

Ozone Exceedance Days and 90° F Cycle (2 of 2)



- Standardized departure of Maryland's **8-hour ozone** and **90 deg days** at BWI **follow a periodic cycle** through 2002. Correlation is **0.66** (This is what makes air quality forecasting possible!)
- Temperature data at BWI indicates a flat trend from 1981-2007. Number of hot days **Climatology doesn't change** during that time frame.
- BUT **8-hour ozone data** clearly **indicates** a **downward trend**.
- Explanation for hypothesis**: air quality trend is entering a new phase**!
- **AIR QUALITY IN MARYLAND IS IMPROVING PRIMARILY DUE TO POLLUTANT CONTROLS**.

Question

Q: Is there any meteorological/climatological phenomenon that may impact the 3-5 years cycle?

A: HYPOTHESIS – **E**l **N**iño-**S**outhern **O**scillation (**ENSO**) Cycle appears to embrace the same periodicity.
Longer Ocean Cycles (decades) also impact the magnitude of various atmospheric variables directly influence air quality.
Pacific **D**ecadal **O**scillation (**PDO**)
Atlantic **M**ulti-decadal **O**scillation (**AMO**)
North **A**tlantic **O**scillation (**NAO**)

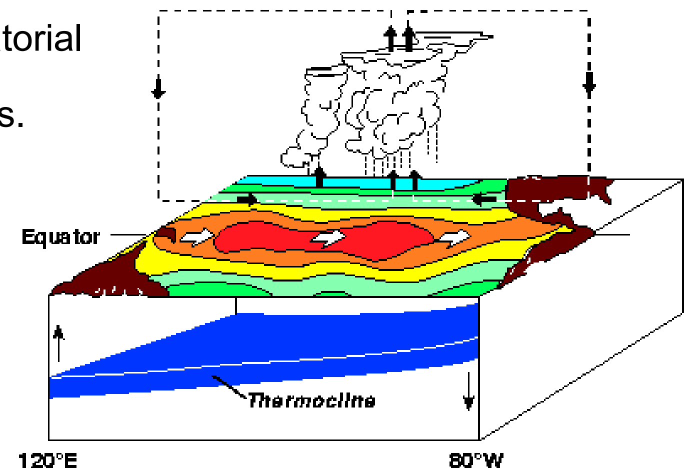
ENSO Index

- What is ENSO?
  - **ENSO** stands for **E**l **N**iño-**S**outhern **O**scillation.
  - A complex interaction of tropical Pacific Ocean and the global atmosphere.
  - Currently used by scientists to describe the irregular cycle of warming and cooling of the sea surface temperatures of Tropical Pacific Ocean (along Equator, Peru, and Chile). This warming/cooling disrupts the atmospheric heat balance and changes winds patterns mainly over the Pacific Ocean. However, the impacts can be observed regionally across the U.S. and the globe.
  - **Warm phase** of ENSO is typically known as "**El Niño**" and **cold phase** is known as "**La Niña**".
  - One cycle occurs every 3-6 years but occurs irregularly and less predictable.
  - ENSO can be described by various indexes
    - **S**outhern **O**scillation **I**ndex (**SOI) --** [Standarized Tahiti – Standarized Darwin] Sea Level Pressure
    - **S**ea **S**urface **T**emperatures indexes (**SST** [Niño 1+2, Niño 3, Niño 4, Niño 1+3, and Niño 3.5]) – weekly difference in sea surface temperatures at various locations along equatorial zones
    - **M**ultivariate **E**NSO **I**ndex (**MEI**) – Six main observed variables over the tropical Pacific (sea-level pressure, zonal (East/West) wind component, meridional (North/South) wind component, sea-surface temperature, surface temperature, and total cloudiness fraction of the sky). This variable is being used widely by research community since it's more comprehensive than any other single index.
- Why investigate this meteorological phenomenon and how that relates to air quality?
  - ENSO is a global climate cycle that have direct/indirect impacts to weather and economy.
  - Exploring its properties and how it can be related to various atmospheric variables (i.e. temperatures, winds, and moisture etc.) will be beneficial to the understanding of air quality across the U.S. and specifically Maryland.
  - Understanding its cycle will allow us to classify air quality (AQ) data into periods and be used for studying AQ trends.

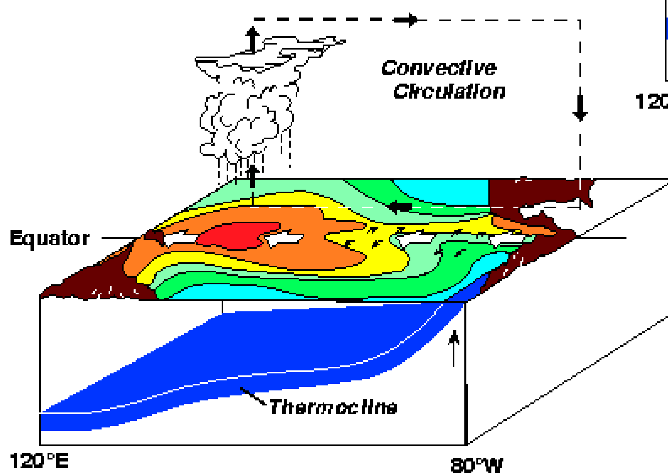
Complete ENSO Cycle – El Niño, La Niña, and Normal Conditions

El Niño Conditions

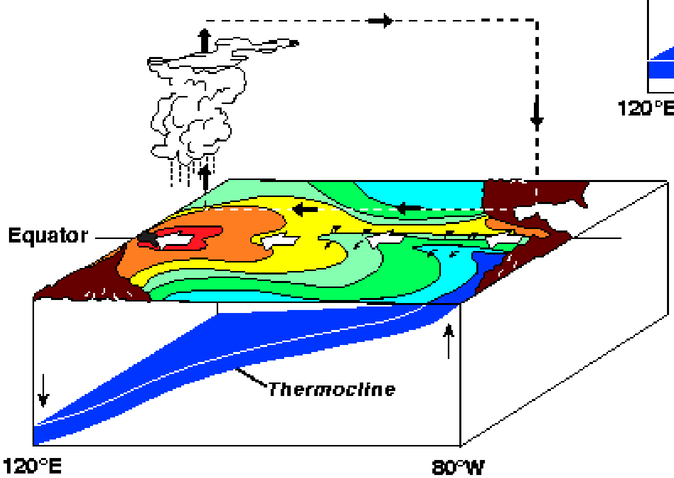
- A pool of above normal temperatures along equatorial region.
- East-west winds now reversed to west-east winds.
- Storms are now directed toward eastern Pacific Ocean.



Normal Conditions



La Niña Conditions

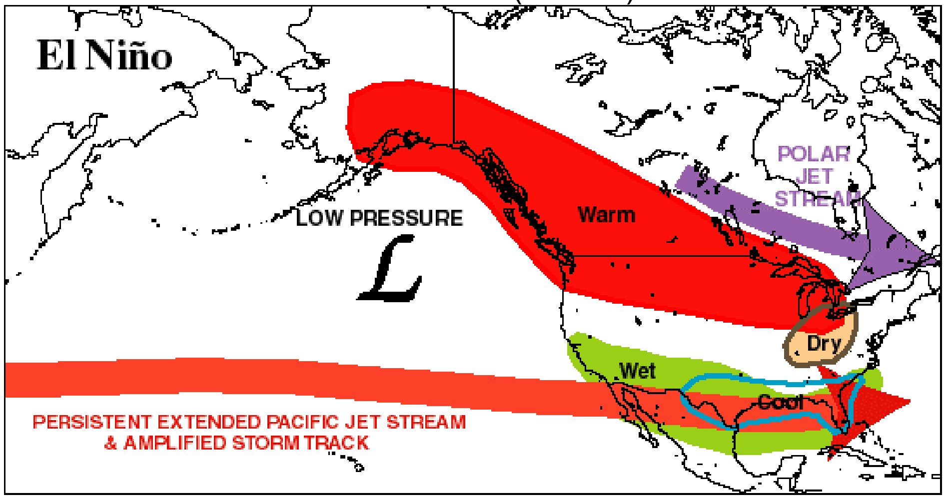


- A pool of below normal temperatures along equatorial region, especially along coast of Peru and Chile.
- East-west winds along equatorial zones are more pronounced.
- Storms are directed toward western portions of Pacific Ocean.

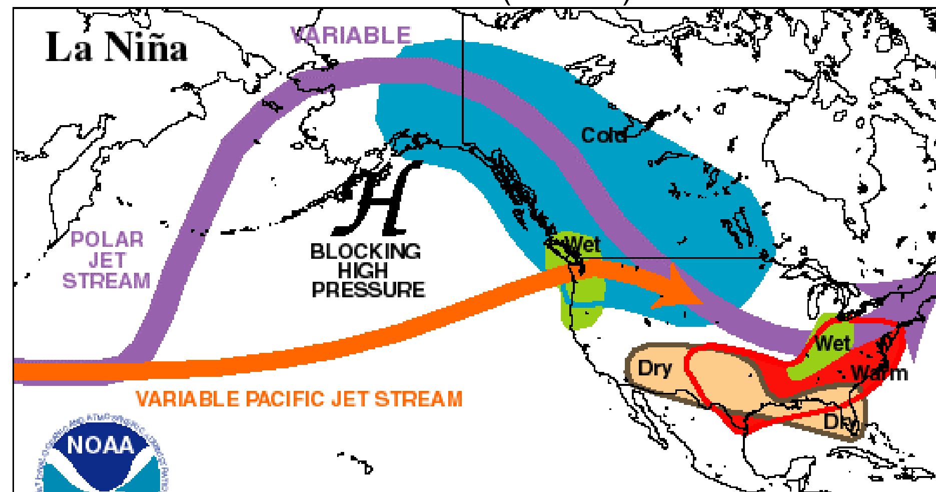
Schematics courtesy of El Niño theme page provided by NOAA/ PMEL/TAO.

Impacts of ENSO across the U.S. (Jan-Mar)

Warm Phase (El Niño)



Cold Phase (La Niña)



Climate Prediction Center/NCEP/NWS

- Persistent low-latitude jet stream across southern U.S. leading to cool and wet conditions.
- Most of the northern U.S. observed warm and dry conditions due to the polar jet stream.
- Mid-Atlantic region appear to have equal chance.
- **Dry and warm conditions during El Niño are CONDUCIVE for ground-level ozone formation.**

- Much of Mid-Atlantic, Northeast, and Mid-West experience warm and wet conditions.
- Southern regions more likely to experience dry and warm conditions.
- **Transition zone of cool/warm air-mass … but moist conditions during La Niña are LESS CONDUCIVE for ground-level ozone formation.**

So why look at impacts during Jan-Mar instead of Jun-Aug (peak summer ozone season)?

- ENSO Signal and impacts for warm phase are felt more strongly during winter months.
- Soil moisture content … set up conditions for summer months?
- Time lag responses between ocean and atmosphere?

Schematics courtesy of Climate Prediction Center / NCEP / NWS.

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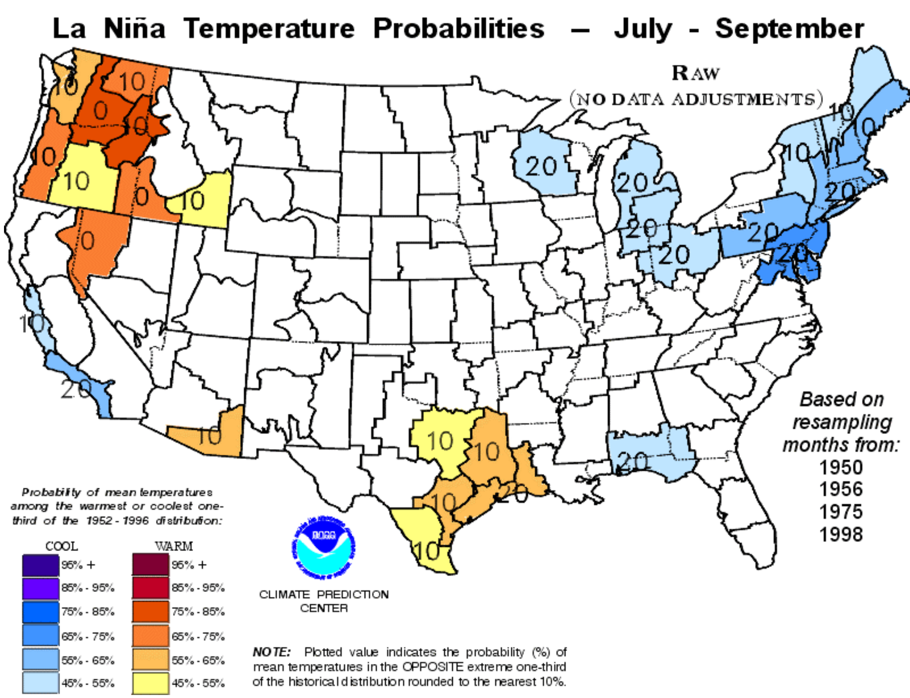
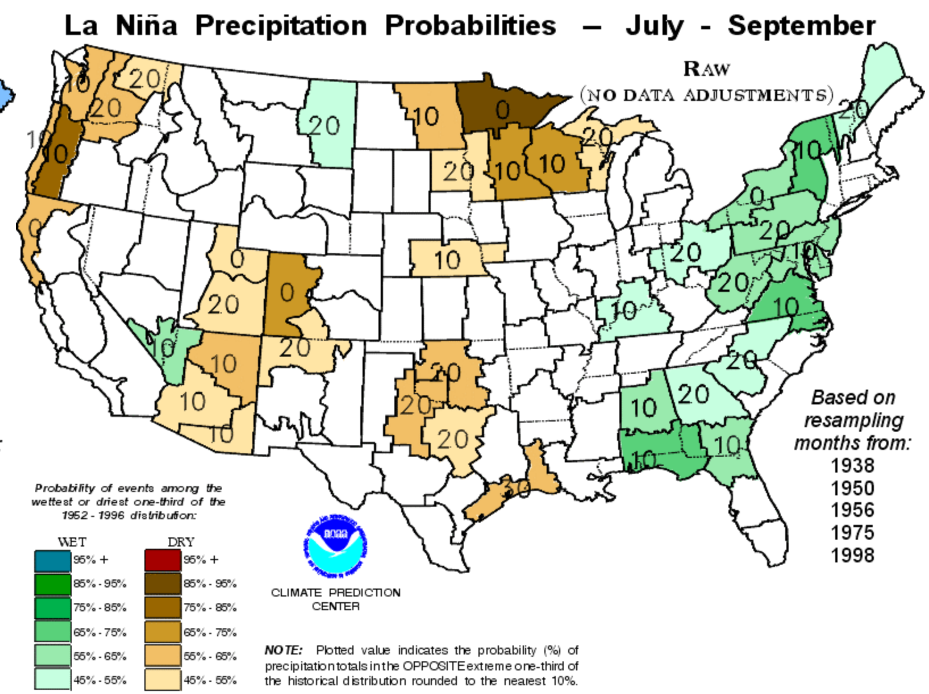
Cool ENSO Phase La Niña Impacts (Jul-Sep)





- Much of the Northeast, portions of the Mid-Atlantic, northern Ohio River Valley, and Great Lakes region are more likely to experience "cool" temperatures during cool ENSO phase (La Niña) events.
- Much of the Northeast, portions of the Mid-Atlantic, northern Ohio River Valley and Southeast region are more likely to experience wet conditions during cool ENSO phase (La Niña) events.

Cool and wet conditions are NOT CONDUCIVE for ground-level ozone formation.

MARYLAND

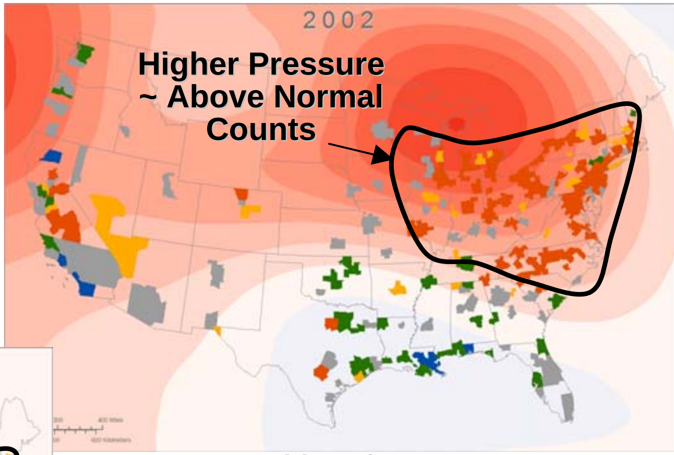
Schematics courtesy of Climate Prediction Center. Visit ENSO impacts on the U.S. page for further information.

Air Quality (8-hr Exceedances) across the U.S. during 2000-2002 Cycle

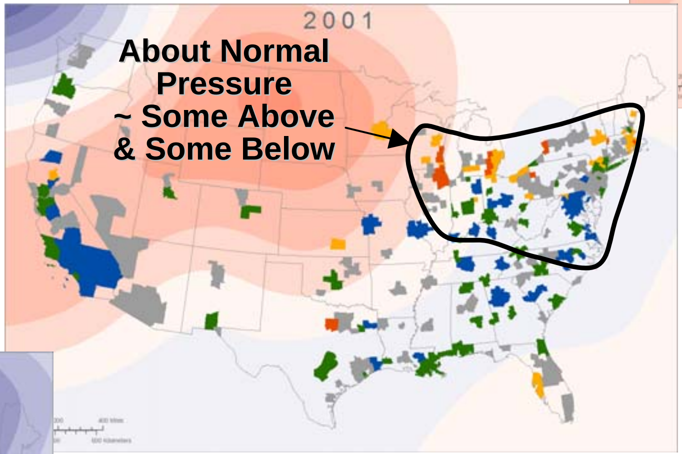
- Normal: 10-year average from 1993-2002
- Months included: Jun-Aug

General Guidelines:

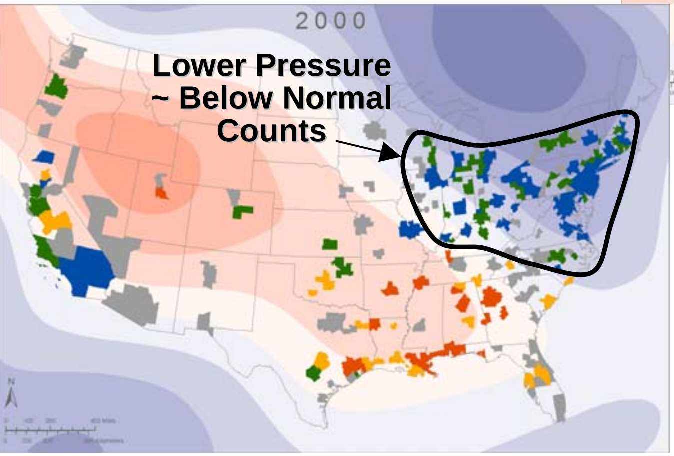
- Lower (than normal) **pressure/height** (shaded blue) ~ cooler weather ~ **less 8-hr ozone exceedance days** (blue & green)
- Higher (than normal) **pressure/height** (shaded red) ~ warmer weather ~ **more 8-hr ozone exceedance days** (orange & red)



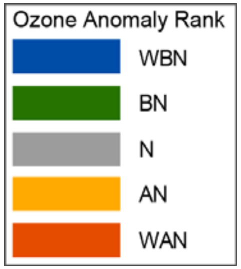
Year 3

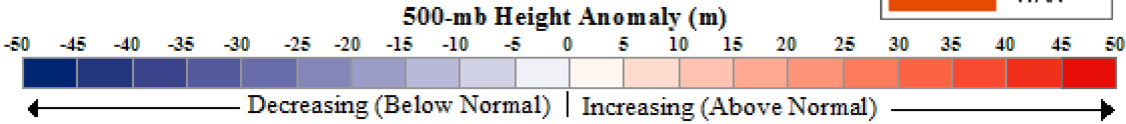


Year 2



Year 1





Data sources: AIRNowTech and ESRL CDC Plotting and Analysis
Note: Some preliminary AQ data are also included in analysis.

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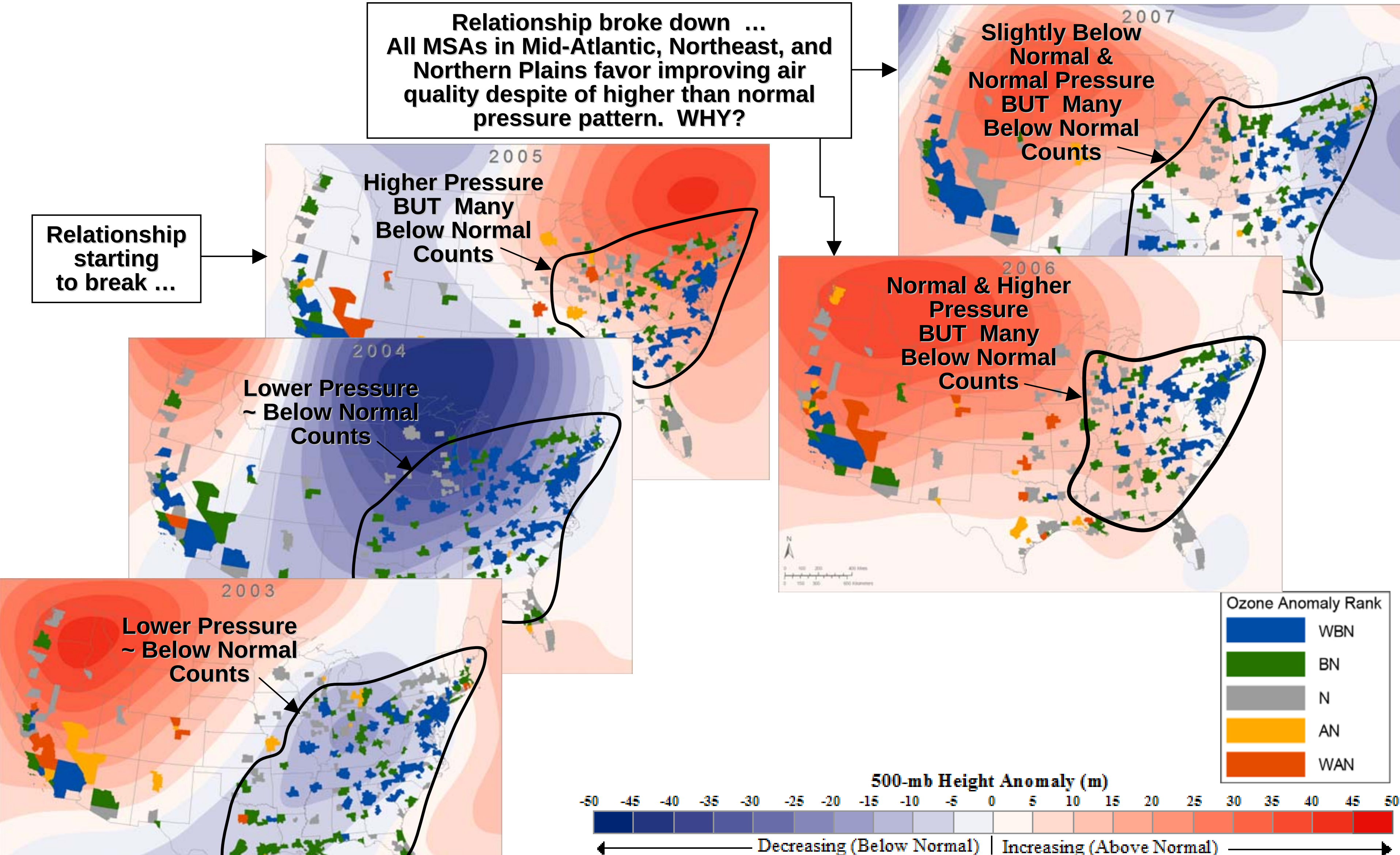
Air Quality (8-hr Exceedances) across the U.S. during 2003-2007 Cycle



Data sources: AIRNowTech and ESRL CDC Plotting and Analysis
Note: Some preliminary AQ data are also included in analysis.

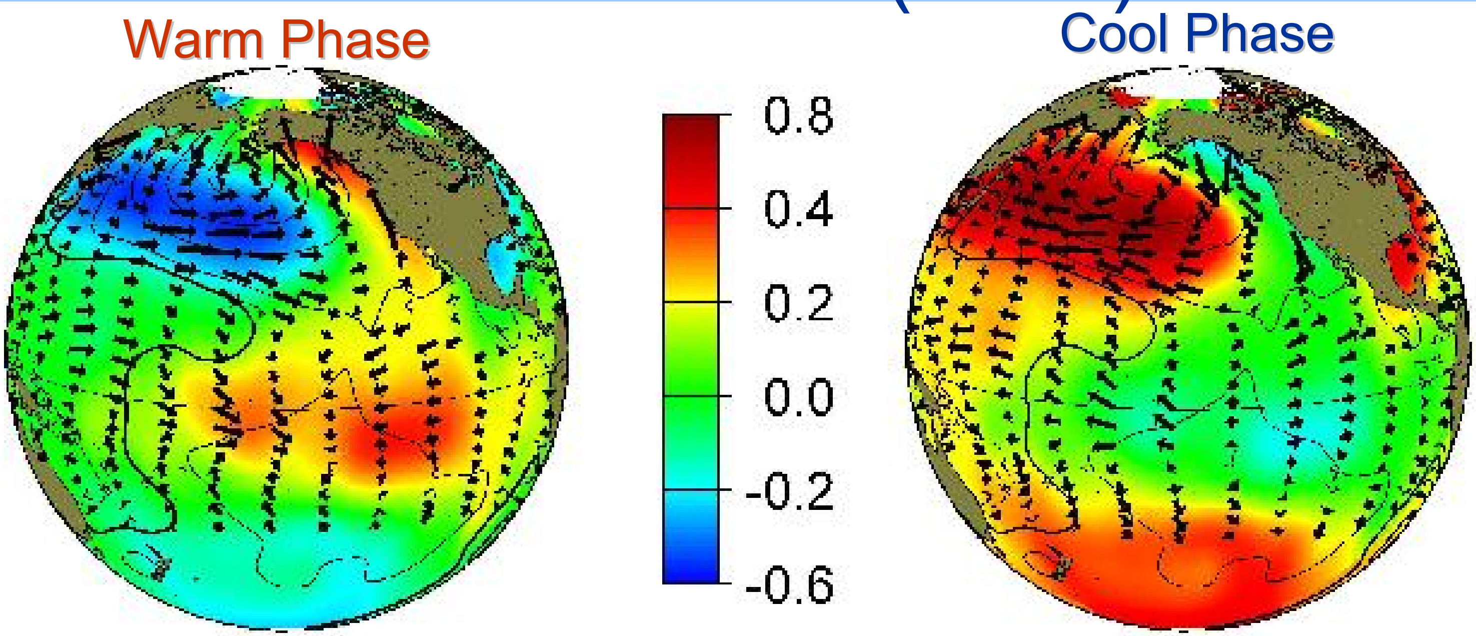
Decadal Ocean Cycles and Implications on Air Quality

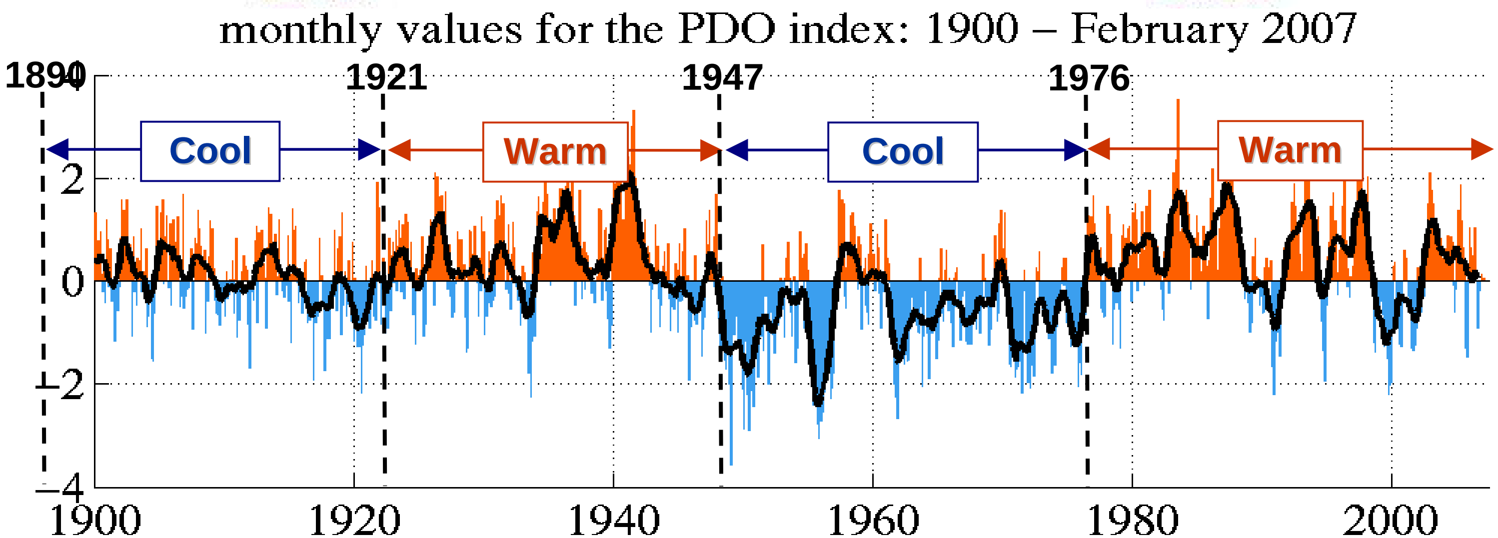
- Longer Ocean Cycles (decades) impact the magnitude of various atmospheric variables directly influence air quality.
  Pacific **D**ecadal **O**scillation (**PDO**)
  Atlantic **M**ulti-decadal **O**scillation (**AMO**) / **N**orth **A**tlantic **O**scillation (**NAO**)

- In literature, many studies have shown direct linkage between ocean cycles and their impacts on weather and/or climate, especially the eastern U.S.

- However, no direct linkage is made between ocean cycles and air quality (just yet).

Ocean Cycle – Pacific Decadal Oscillation (PDO)

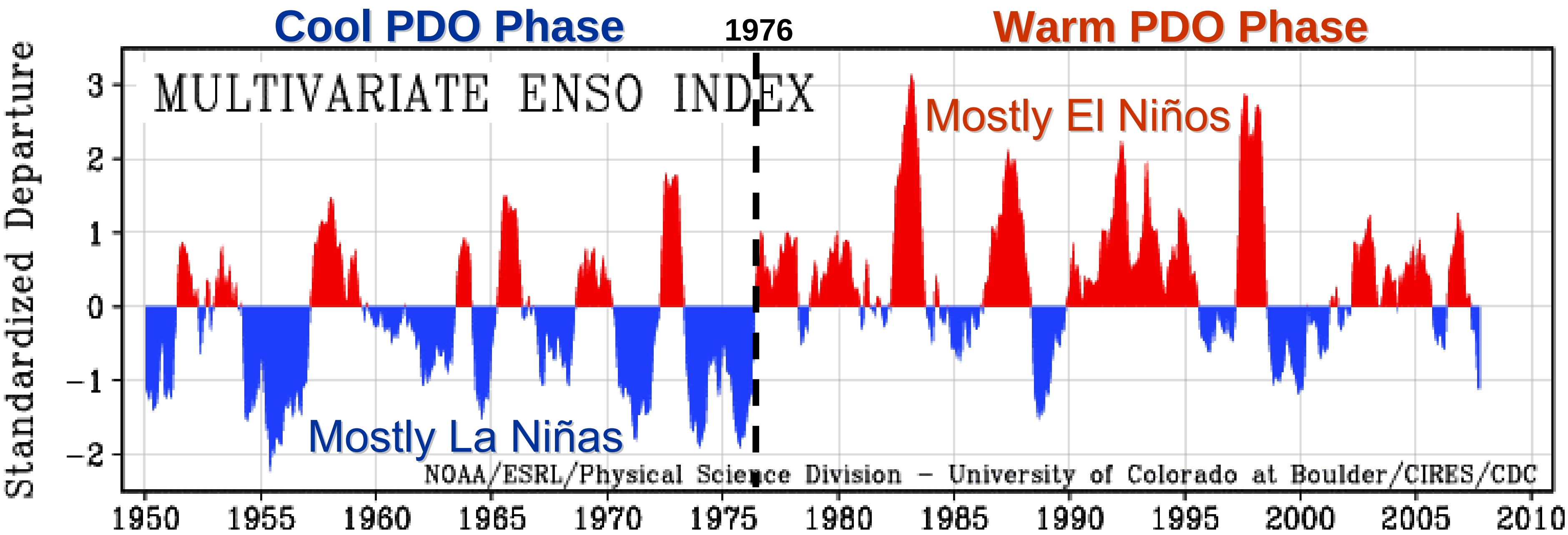




Graphics are courtesy of the [Pacific Decadal Oscillation (PDO)] webpage provided by the University of Washington.

~ 30 year cycle

Pacific Decadal Oscillation and ENSO



- Pacific Decadal Oscillation (PDO) has direct influence on ENSO.
- Cool (Warm) PDO phase favors more frequent La Niñas (El Niños).
- This implies that:
  - Cool PDO phase favors cooler conditions in the Mid-Atlantic and should result in **better air quality**.
  - Warm PDO phase favors warmer conditions in the Mid-Atlantic and should result in **worse air quality**.

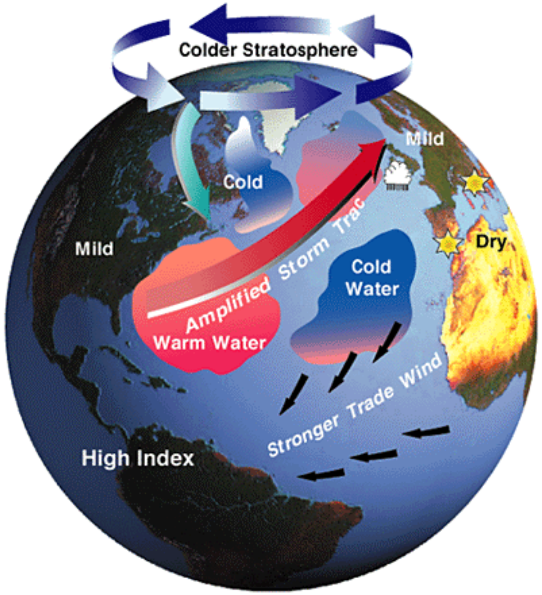
See short paper on Ocean Cycle Forecasts by Joseph D'Aleo for further information.

Ocean Cycle – Atlantic Multi-decadal Oscillation (AMO)

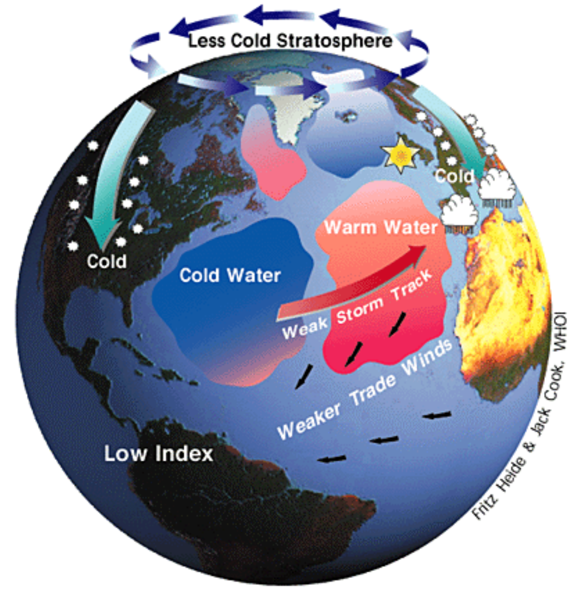
- Research is still underway to study this phenomenon → Unknown to Public.
- Facts about AMO cycle:
  - Lasts appx. 40-80 years (depends on sources).
  - Influences the state of **N**orth **A**tlantic **O**scillation (**NAO**).
  - Impact temperature and rainfall fluctuations over the eastern U.S.
  - Influence on river flows and multi-decadal drought frequency in the U.S.
  - Influence hurricane intensity and frequency in the Atlantic.

Ocean Cycle – North Atlantic Oscillation (NAO)

Warm Phase



Cool Phase



- Characterized by warmth of the North Atlantic and the Tropical Atlantic.
- Associated with above averaged temperatures in the eastern United States.

- Characterized by cool North Atlantic and Tropical Atlantic.
- Associated with below averaged temperatures in the eastern United States.

Impacts on Air Quality are to be Investigated!

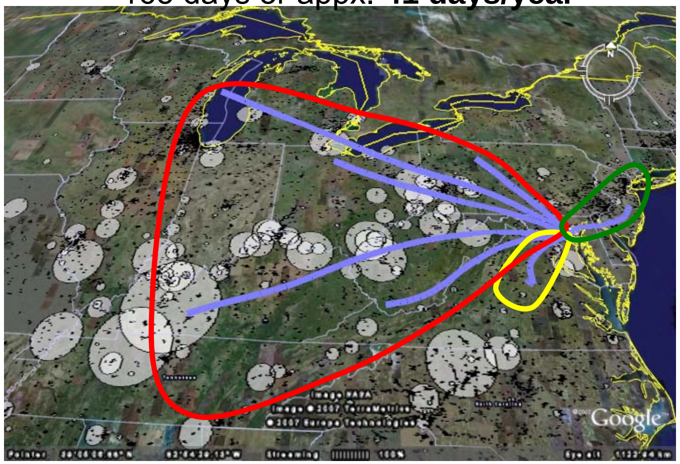
Graphics are courtesy of [The Ocean's Role in Climate] webpage provided by Woods Hole Oceanographic Institute.

Ocean Cycles – So What?

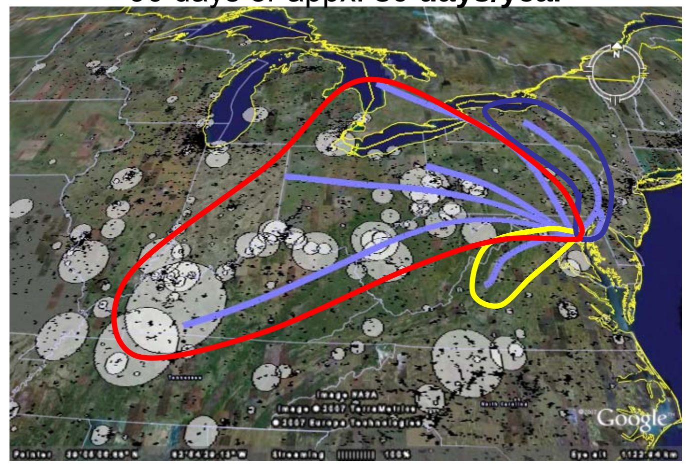
- Clearly Ocean Cycles exert greatly on the atmosphere (meteorology/climatology).
- Their influences on air quality are to be studied; however, general outlook can still be made based on CDC forecasts and on-going research-oriented seasonal-forecast products.
- Products to be used: ENSO outlook and 3-month temperature/precipitation outlook.
- Outlook for 2008 is provided at the end of presentation.

Aloft Transport Patterns on High Ozone Days

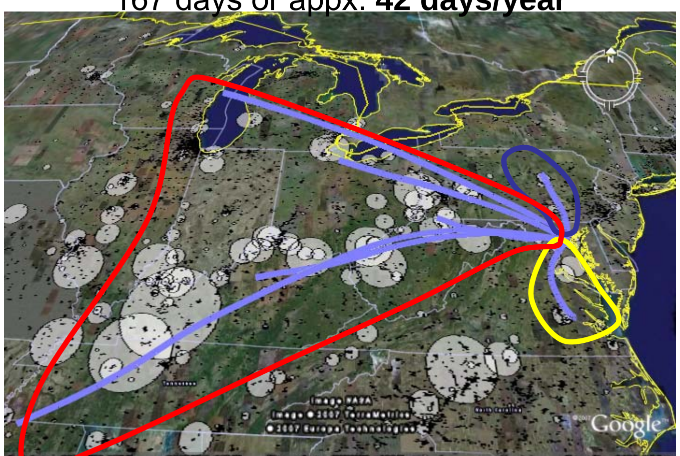
1992-1995 8-hr ozone exceedance days
165 days or appx. **41 days/year**



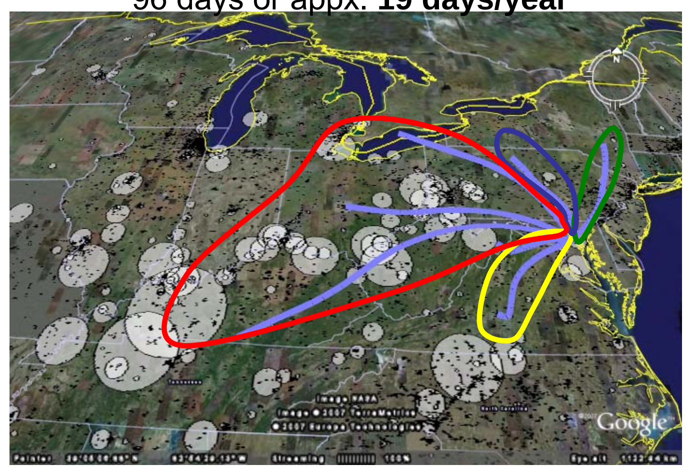
2000-2002 8-hr ozone exceedance days
90 days or appx. **30 days/year**



1996-1999 8-hr ozone exceedance days
167 days or appx. **42 days/year**



2003-2007 8-hr ozone exceedance days
96 days or appx. **19 days/year**



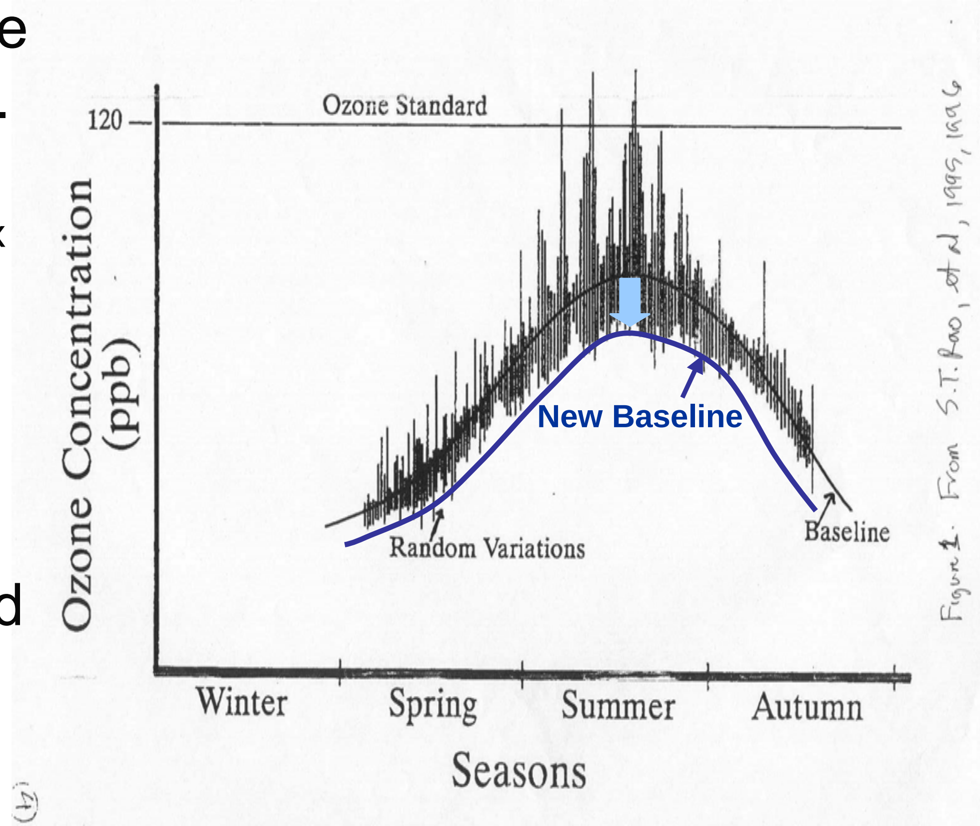
- Westerly, southwesterly, and northwesterly flow (highlighted in red) dominate all periods. These are common for long range transport (hundreds to thousands of kilometers)
- South / southeasterly flow (highlighted in yellow) are persistent in all periods. This flow pattern is a good example of short range transport (tens to hundreds of kilometers).
- North / Northwesterly flow (highlighted in blue) are persistent for periods from 1996-2006).
- Northeasterly / Reverse corridor flow (highlighted in green) are persistent during the first and last period.
- Overall **transport patterns have not changed** that much over the past 16 years.
- **Decrease** in "**bad air quality days**" through the periods are **driven primarily by controls**.

Mean clustered of 24-hr back trajectories terminating at BWI (1000 m-agl) at 11 UTC (6:00 EST).
EDAS, NGM, and Reanalysis Meteorological data.
Time ensemble trajectories for each clusters in each period can be found in Appendixes A1-A4.

Note: (a) Visit NOAA ARL HYSPLIT Model website for further information on back trajectory.
(b) Visit EPA's National Emission Inventory (NEI) Database website for further information on emission data.

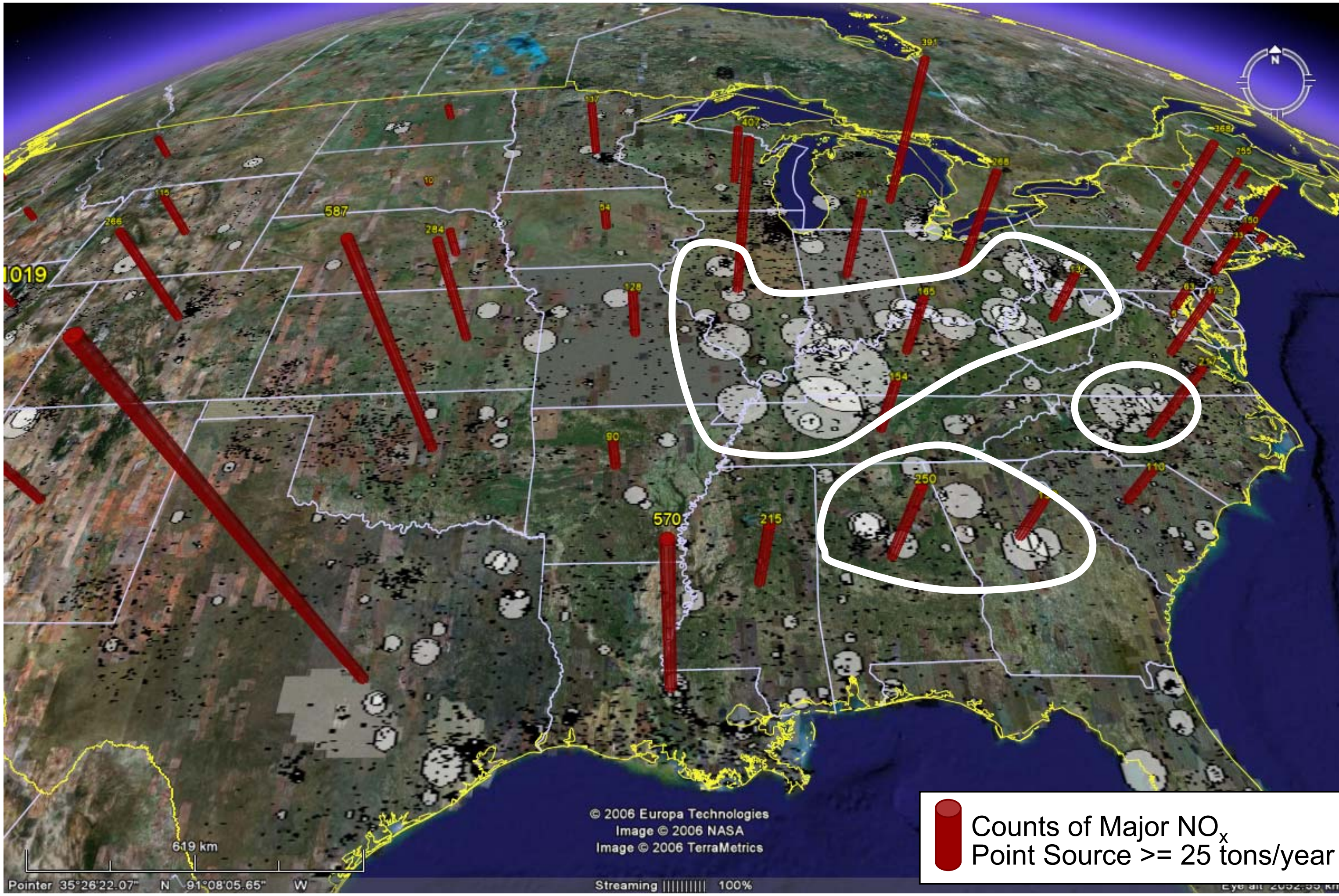
NOx Controls

- O_3 concentrations in the eastern US, outside of large urban areas, is NO_x limited.
- Reductions in regional NO_x emissions will reduce the "background" or "regional scale" O_3 concentrations.
- Local emissions and photochemistry will still lead to "spikes" in O_3, but these spikes will build on a lower base and be of reduced magnitude.



Note: Slide extracted from presentation on "Local Ozone Forecasting and the NOx SIP Call Rule" by William Ryan.

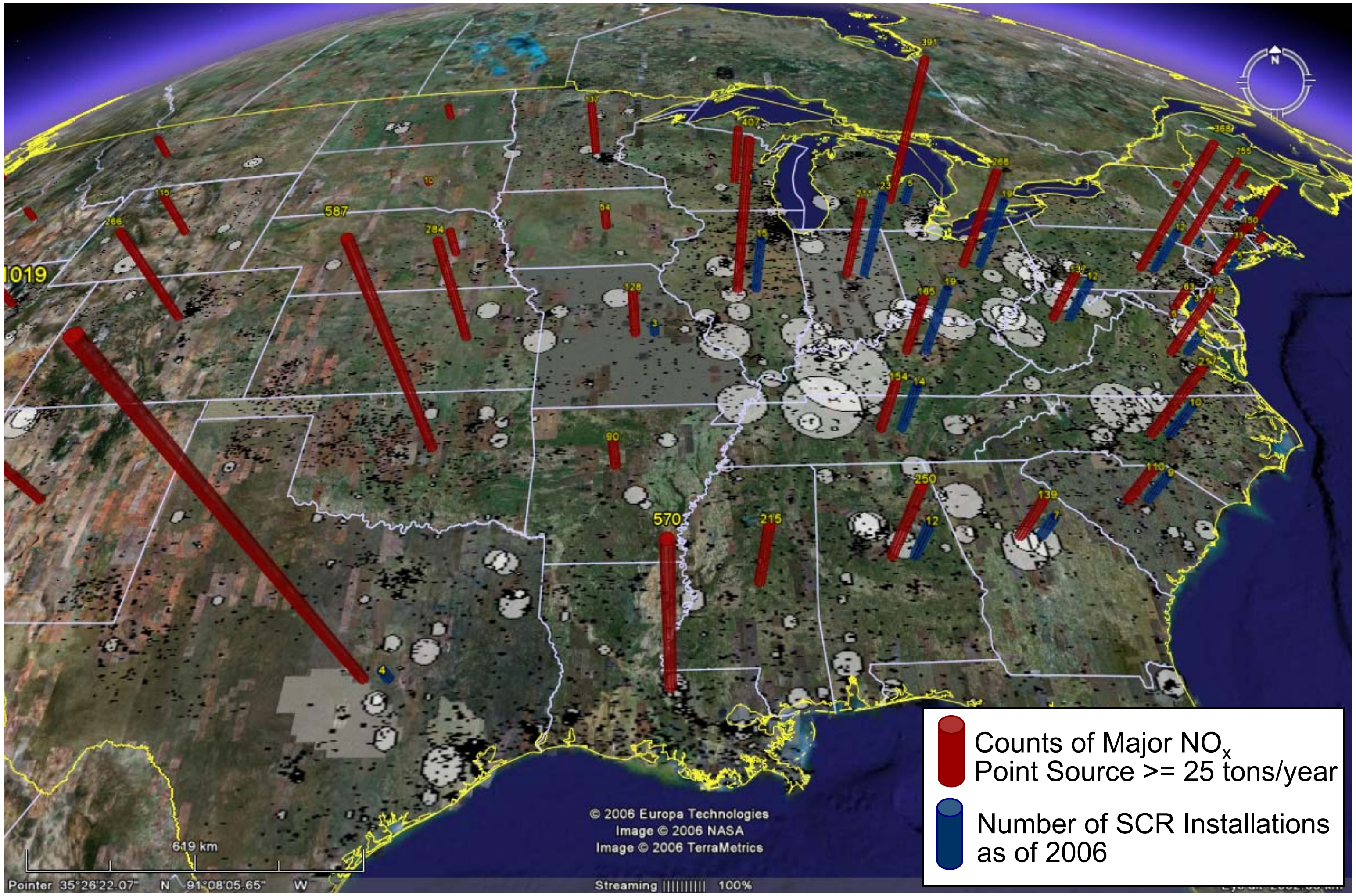
Where are Major NO_x Point Sources?



1999 emission data from NEI database show “BIG” NO_x point sources are located along the Ohio River Valley region, portions of the Southeast and the Southern Mid-Atlantic.

Note: Emission data extracted from the EPA’s National Emission Inventory (NEI) Database.

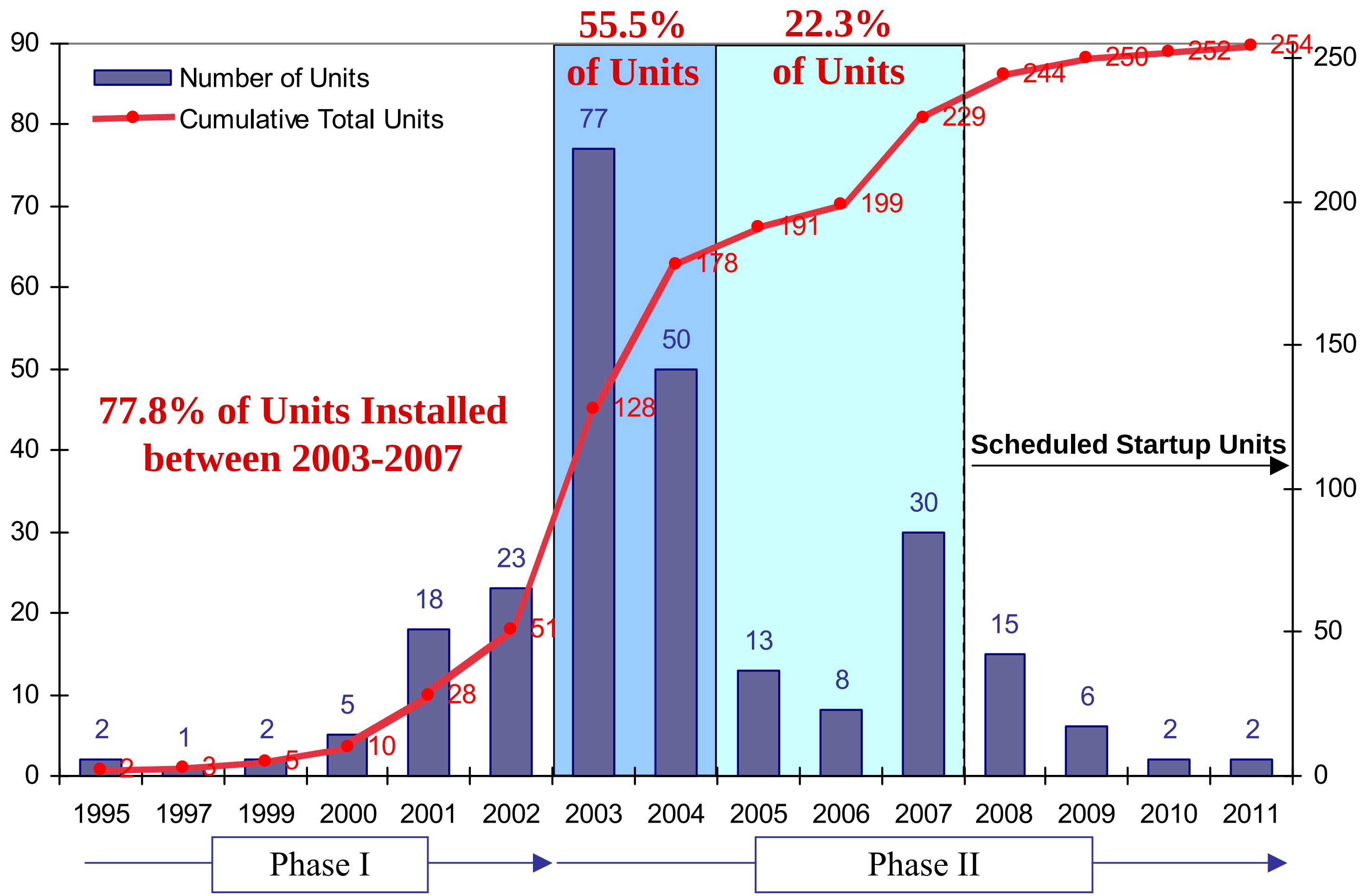
Controls in Action …
Where are SCRs installed?



Selective Catalytic Reduction (SCR) technology are implemented at many units to reduce NO_x emissions (one of the ozone precursors). Majority of **SCR installations** as of 2006 are **occurring where the controls are needed the most** (i.e. the Ohio River Valley).

Note: (a) Emission data extracted from the EPA's National Emission Inventory (NEI) Database.
(b) SCR installation data comes from the Institute of Clean Air Companies (ICAC).

Controls in Action …
SCR Units Installations (1995-2008)



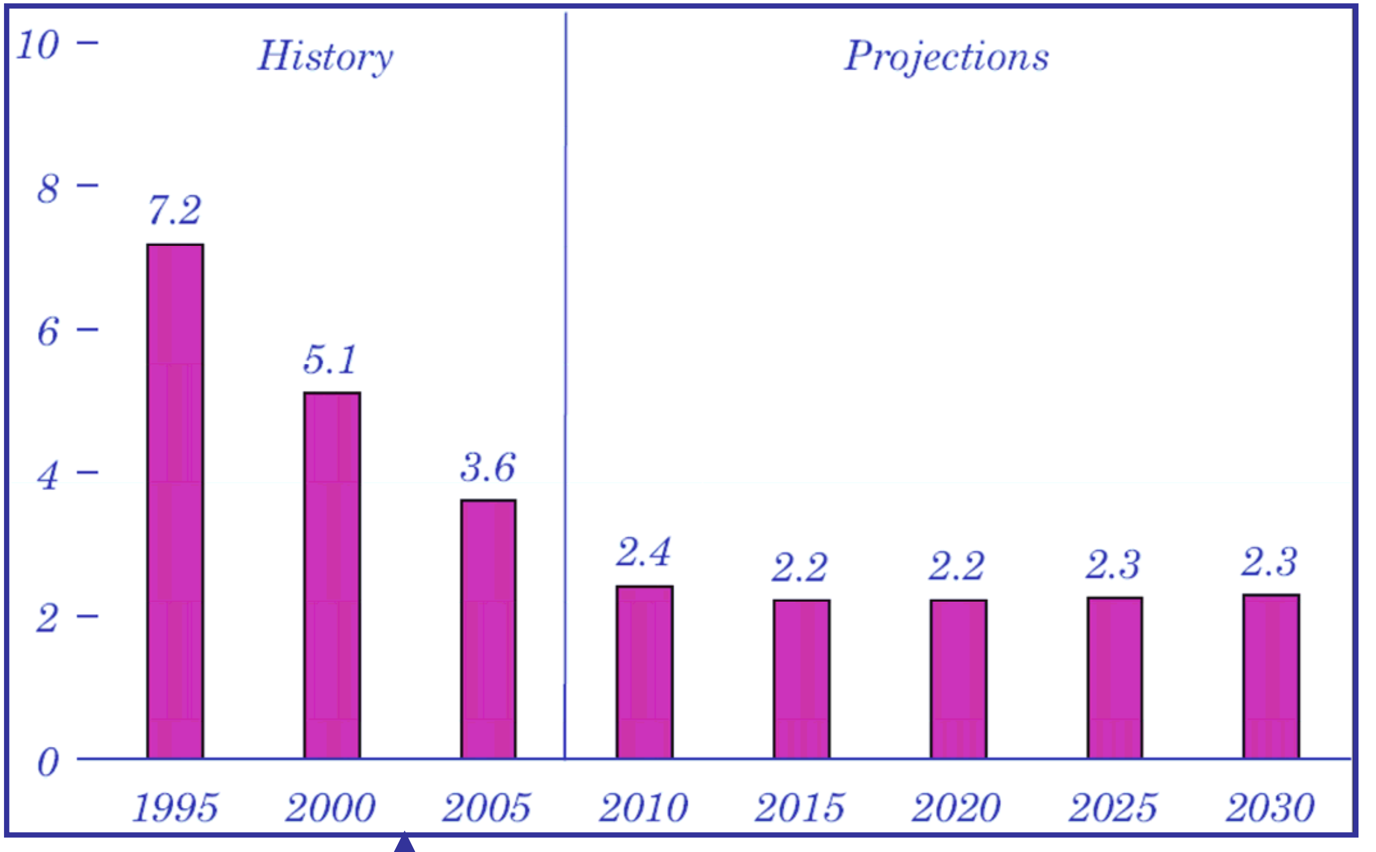
Minimal SCR Units
Expect Minimal NO_x
Reductions

Large Number of SCR Units Installed
Expect SIGNIFIANT NO_x Reductions
Especially after 2003-2004
Ground-level ozone
should decrease dramatically

Data courtesy of The Institute of Clean Air Companies (ICAC).

Controls in Action …
Regional NO_x Emissions and Projections

U.S. Nitrogen Oxides (NO_x) emissions from electricity generation, 1995-2030 (million short tons)

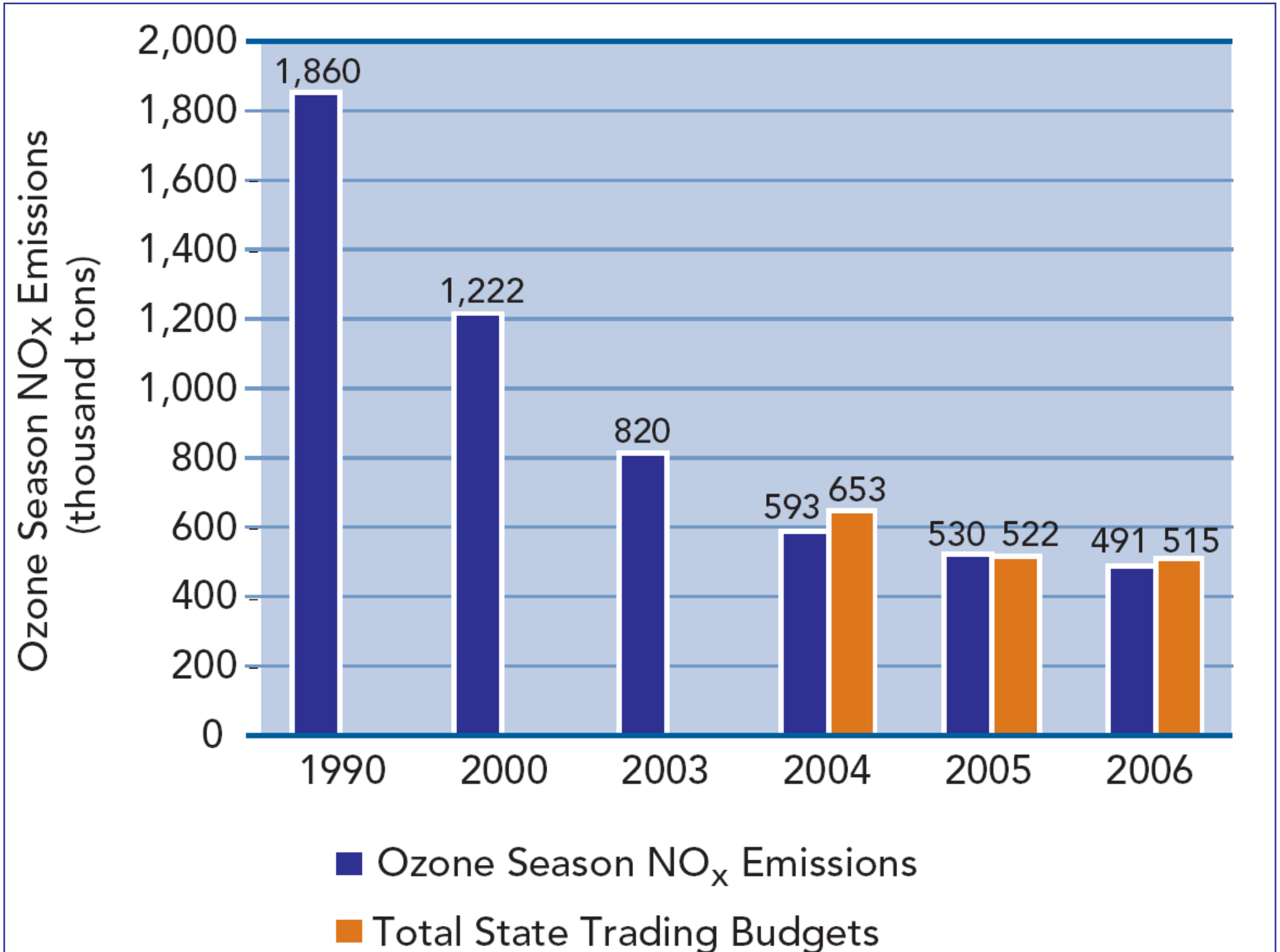


RAPID decline in NOx emissions after Phase II of NO_x Controls. It coincides with a SHARP decrease in ground-level ozone across the eastern U.S. during 2003-2007.

Figure extracted from the “Annual Energy Outlook 2007 with Projections to 2030” report.
Additional information can be found at Energy Information Administration (EIA) website.

Controls in Action …
Ozone Season NO_x Emissions

Ozone Season NO_x Emissions from All NO_x Budget Program (NBP) Sources



"**The emissions in all years represent full ozone season emissions for all states that participated in the program through 2006, including** 2003 and May 2004 emissions from **sources in non-OTC states that did not control emissions during those periods**. The rounded total emissions for 2003 have increased by 1,000 tons compared to prior progress reports, reflecting emission resubmissions by some sources." Source: EPA, 2007.

Figure extracted from EPA's NOx Budget Program 2006 Progress Report. Visit Clean Air Markets website for further details.

Controls in Action …
State-level Ozone Season NO_x Emissions

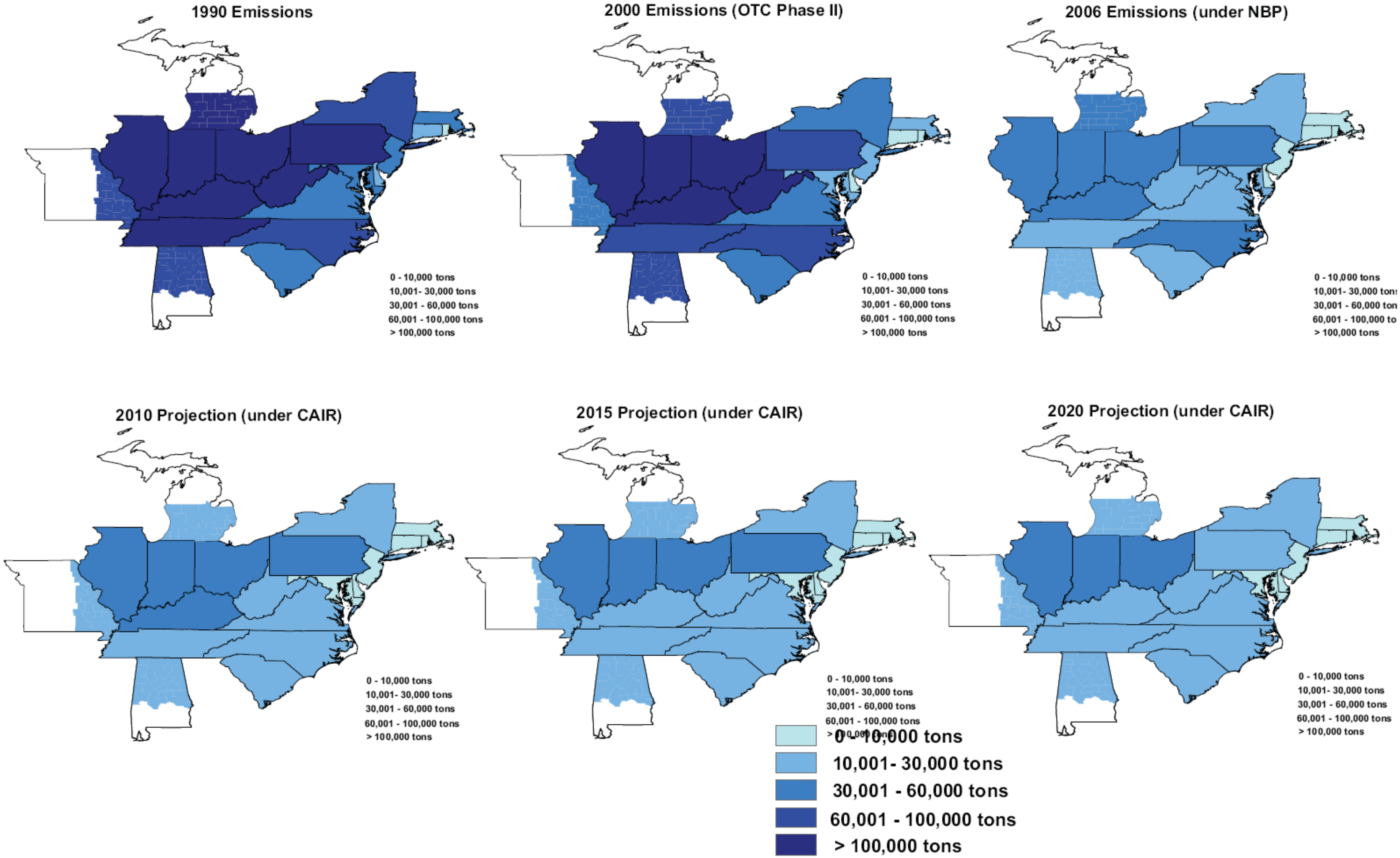
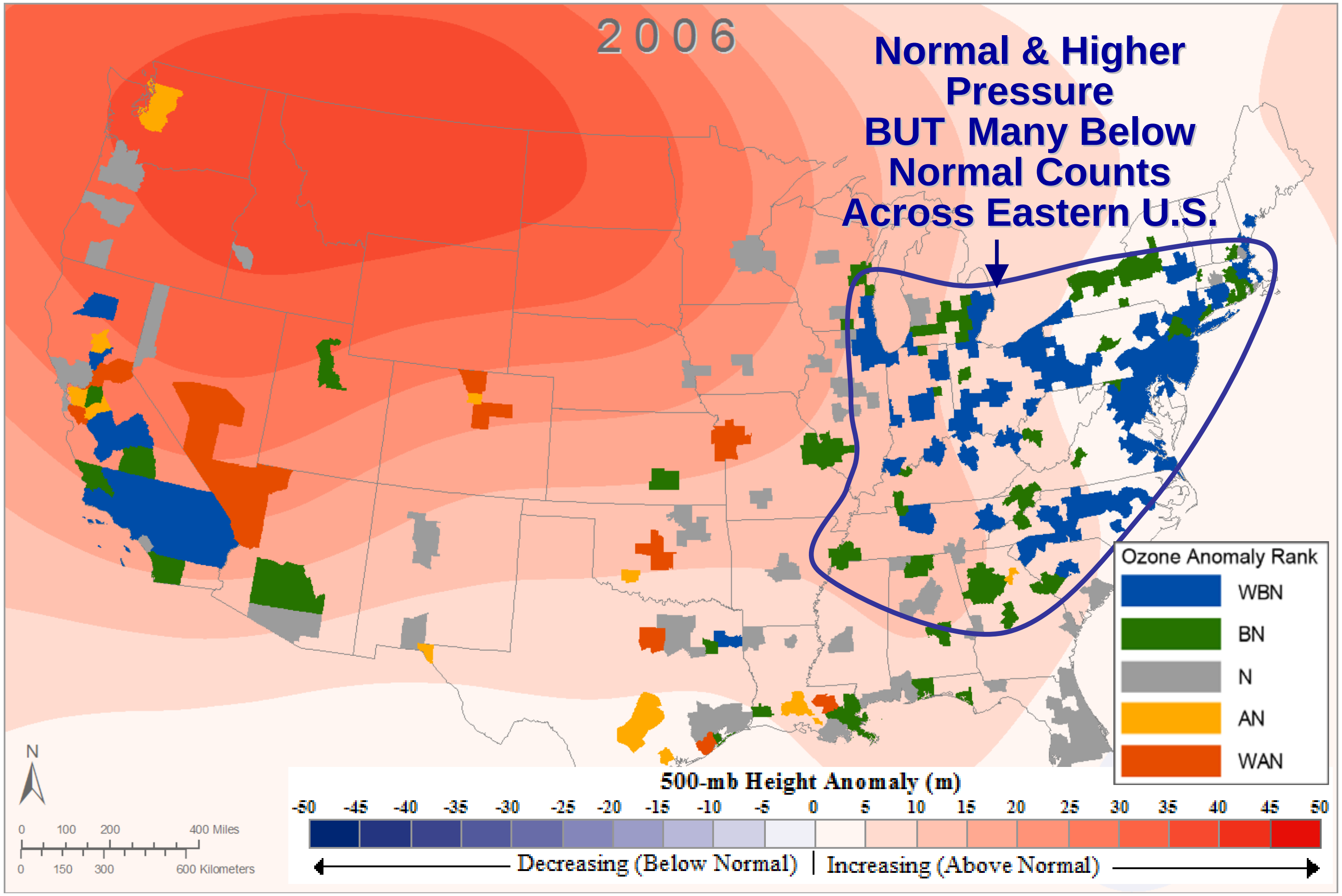


Figure extracted from EPA's NOx Budget Program 2006 Progress Report. Visit Clean Air Markets website for further details.

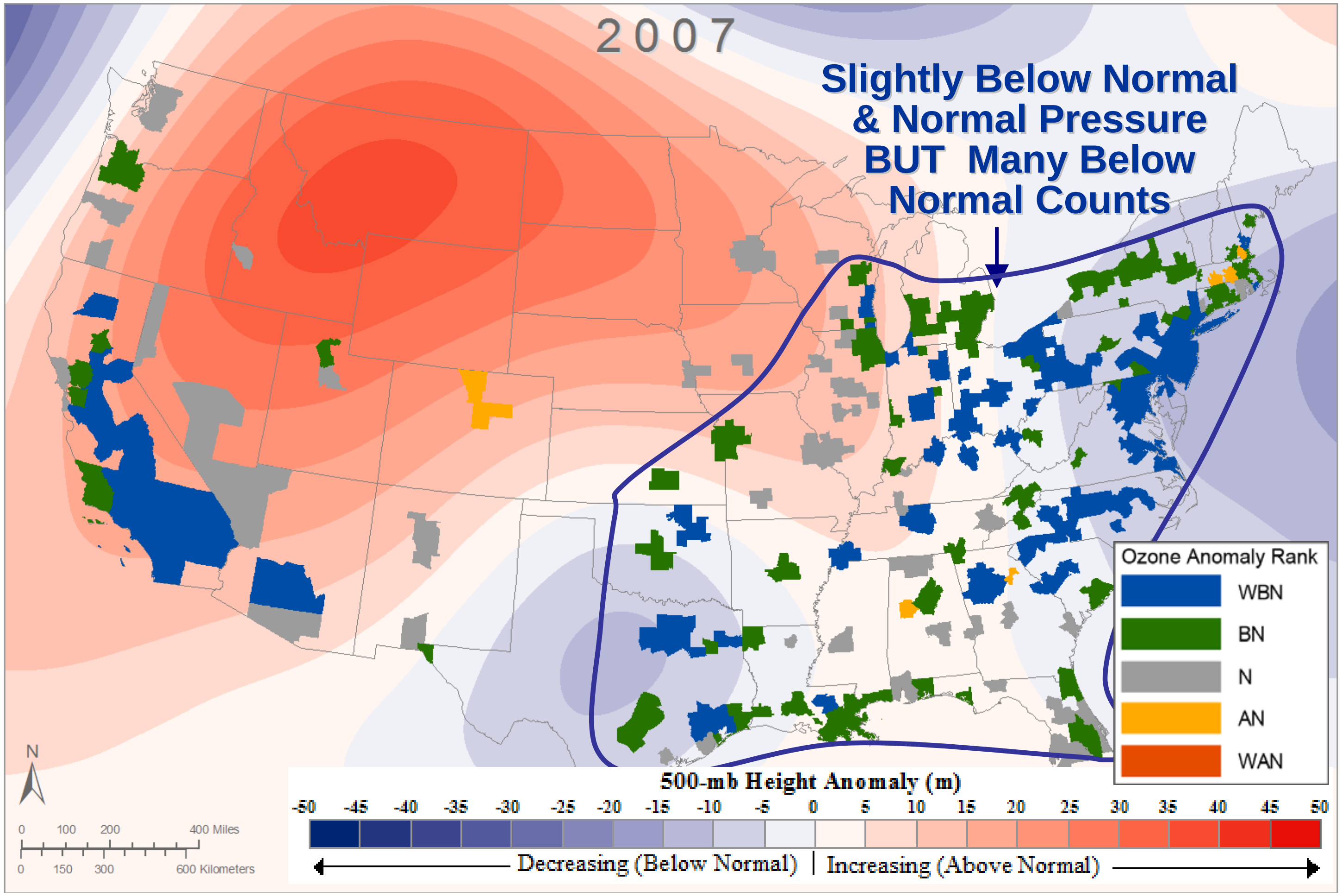
The Results of Regional NO_x Controls (1 of 2)



Despite of higher than normal pressure pattern during Jun-Aug 2006, 8-hour ozone counts are well below normal across the Northeast, Mid-Atlantic, and portions of Midwest.

Data sources: AIRNowTech and ESRL CDC Plotting and Analysis
Note: Some preliminary AQ data are also included in analysis.

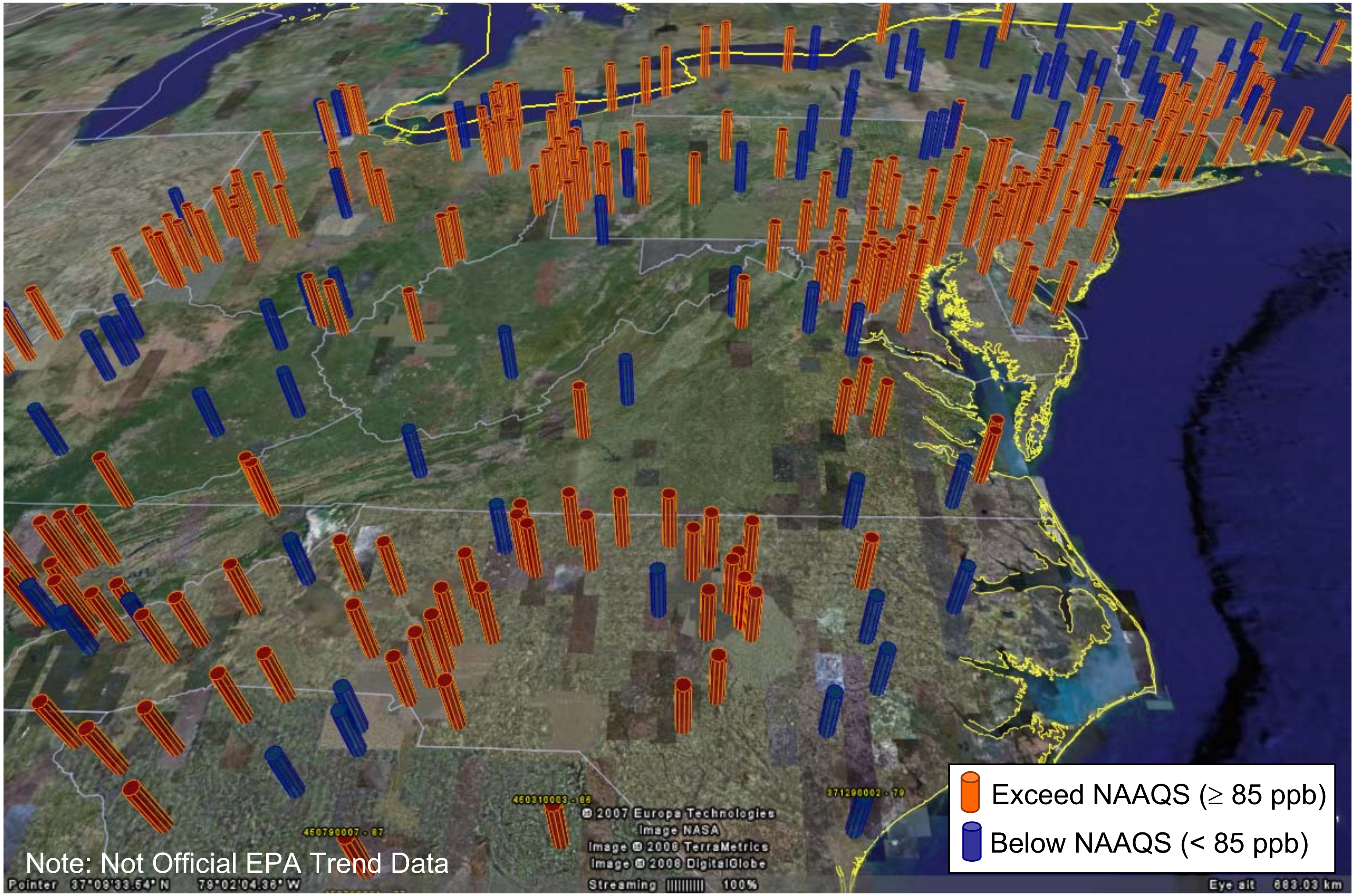
The Results of Regional NO_x Controls (2 of 2)



Slightly below normal and normal pressure patterns are observed during Jun-Aug 2007. 8-hour ozone counts continued to remain well below normal across the Northeast, Mid-Atlantic, Southeast, Plains, and Great Lakes regions.

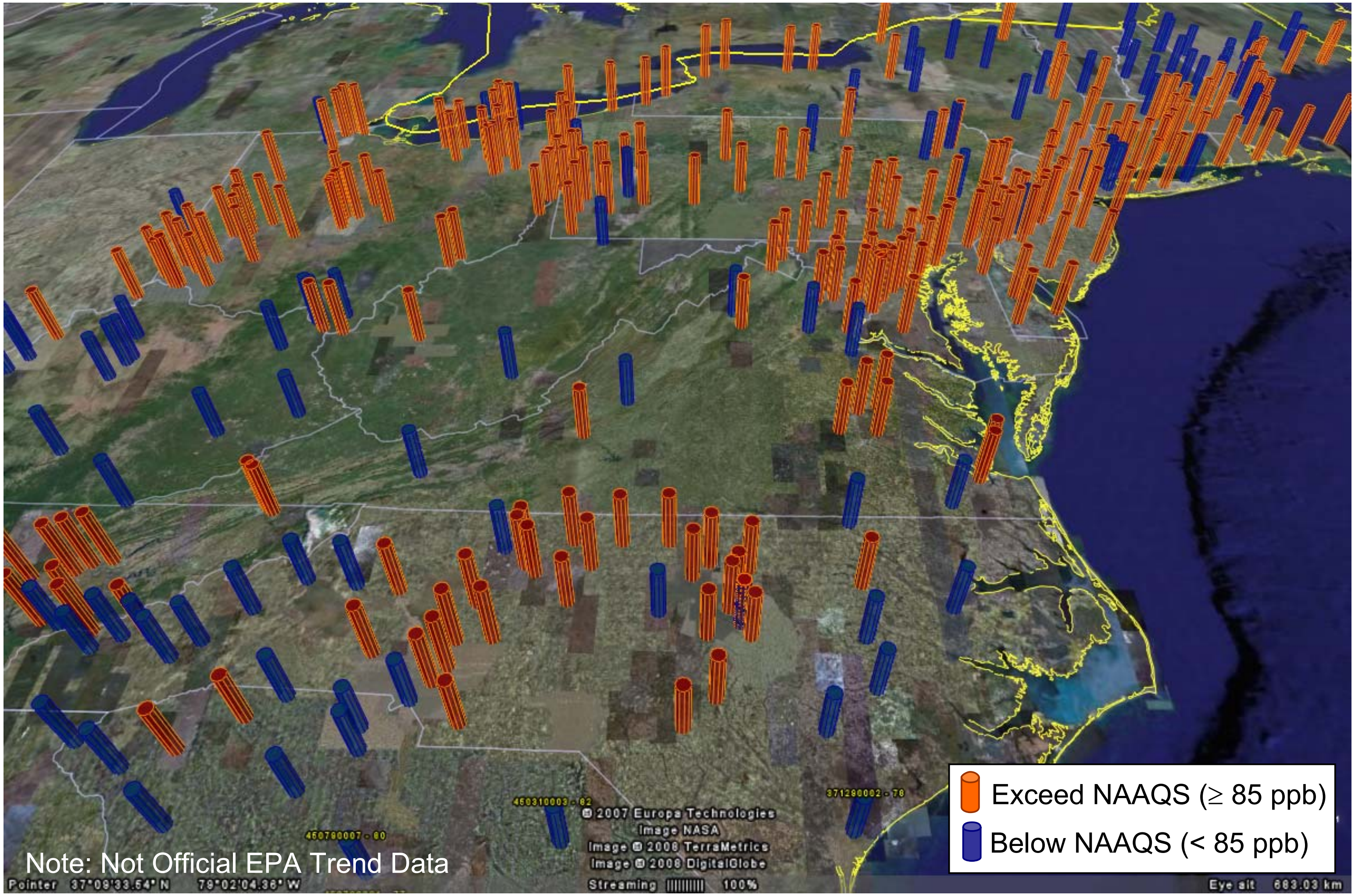
Data sources: AIRNowTech and ESRL CDC Plotting and Analysis
Note: Some preliminary AQ data are also included in analysis.

NO_x Controls and Attainment Status
8-Hour Ozone Design Values 2002



BEFORE the majority of **SCR Units were installed**, much of the **Eastern U.S. did not meet** the 8-hr **ozone standard**.

NO_x Controls and Attainment Status 8-Hour Ozone Design Values 2003



The **FIRST** year of "**Transition Phase**" when most SCR Units were installed. **No major change noted in the attainment status** for 8-hr **ozone**.

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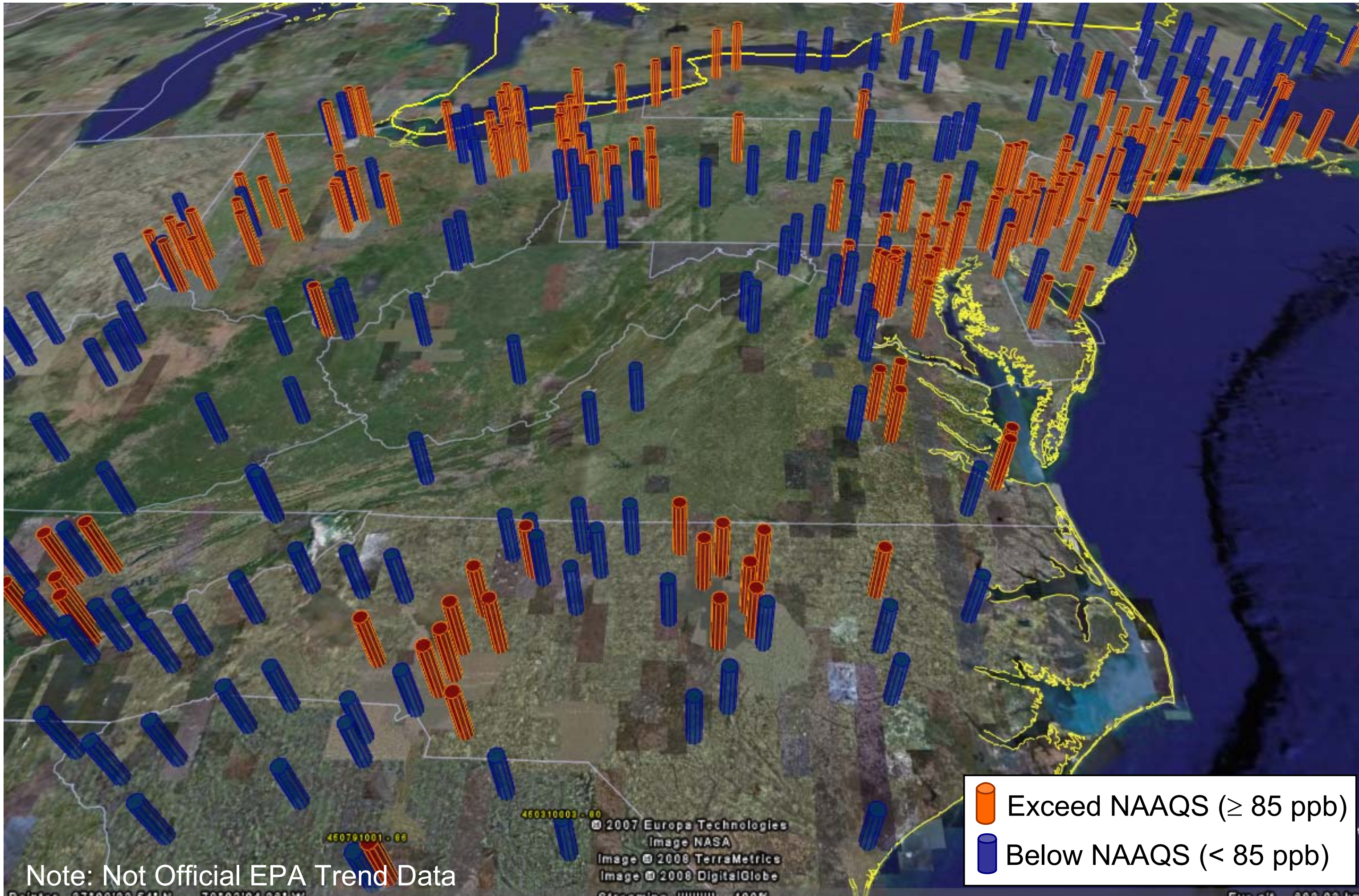
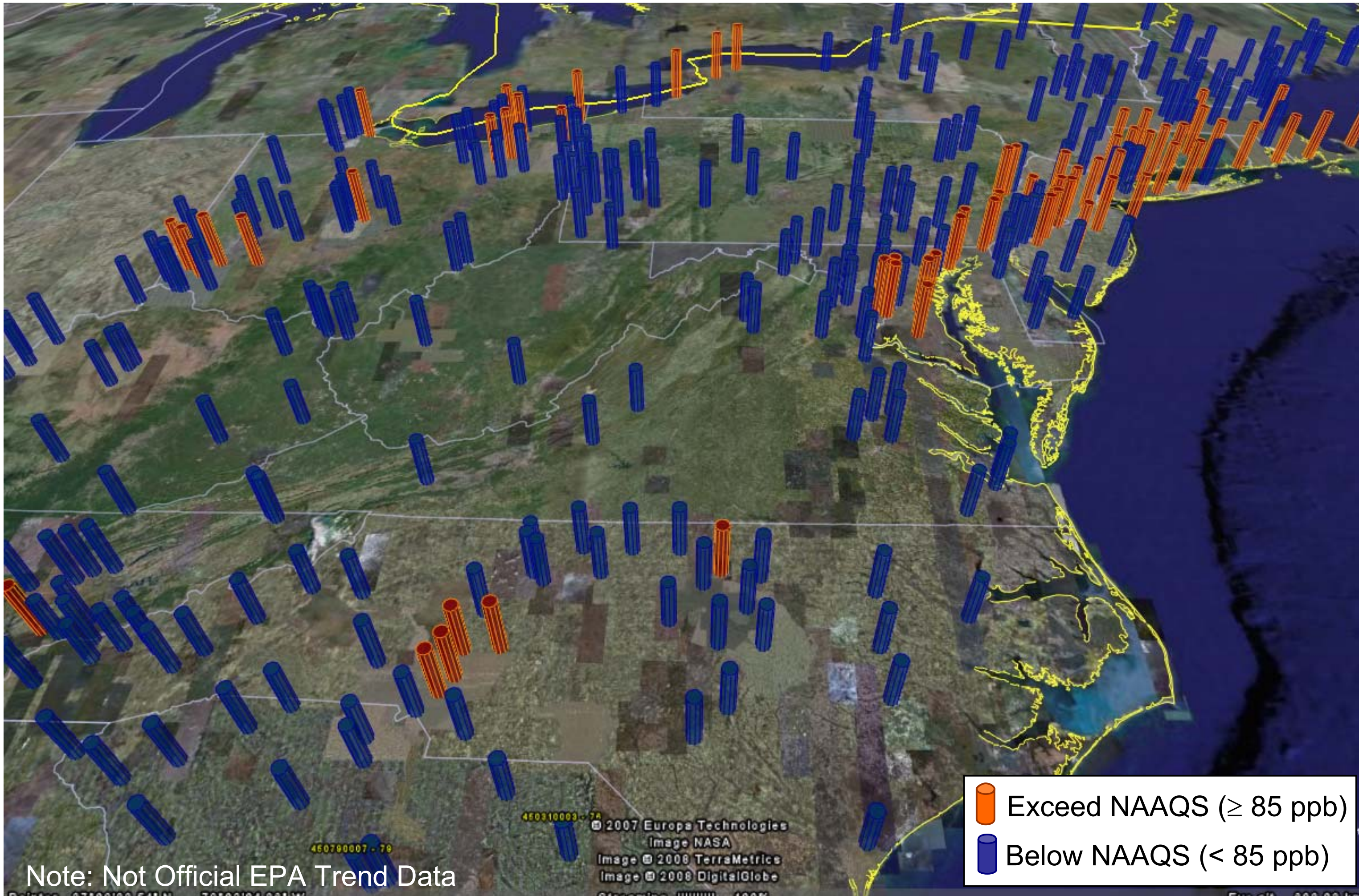
NO_x Controls and Attainment Status 8-Hour Ozone Design Values 2004



The **SECOND** year of "**Transition Phase**" when most SCR Units were installed. A **notable number of monitors went into attainment**. Although temperatures and precipitation during the summer of 2004 were not conducive for ground-level ozone formation, they were not the sole reason for reduced ozone.

MARYLAND

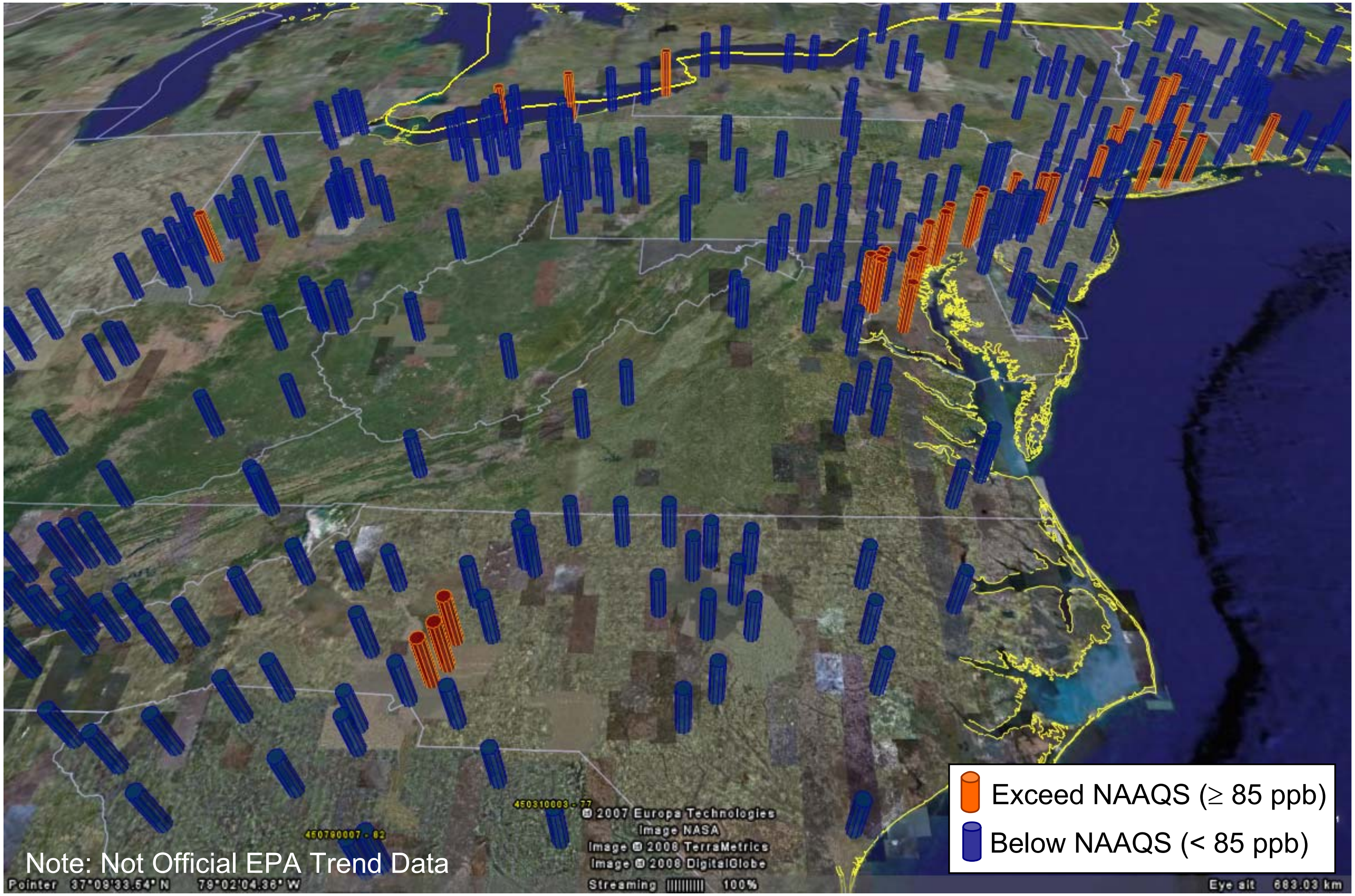
NO_x Controls and Attainment Status 8-Hour Ozone Design Values 2005



AFTER the **majority of SCR Units** were **installed**, **much of the Eastern U.S. went into attainment**. Temperatures and precipitation data for the summer of 2005 were conducive for ground-level ozone formation. However, strong decrease in regional ozone concentrations (design values) occurred.

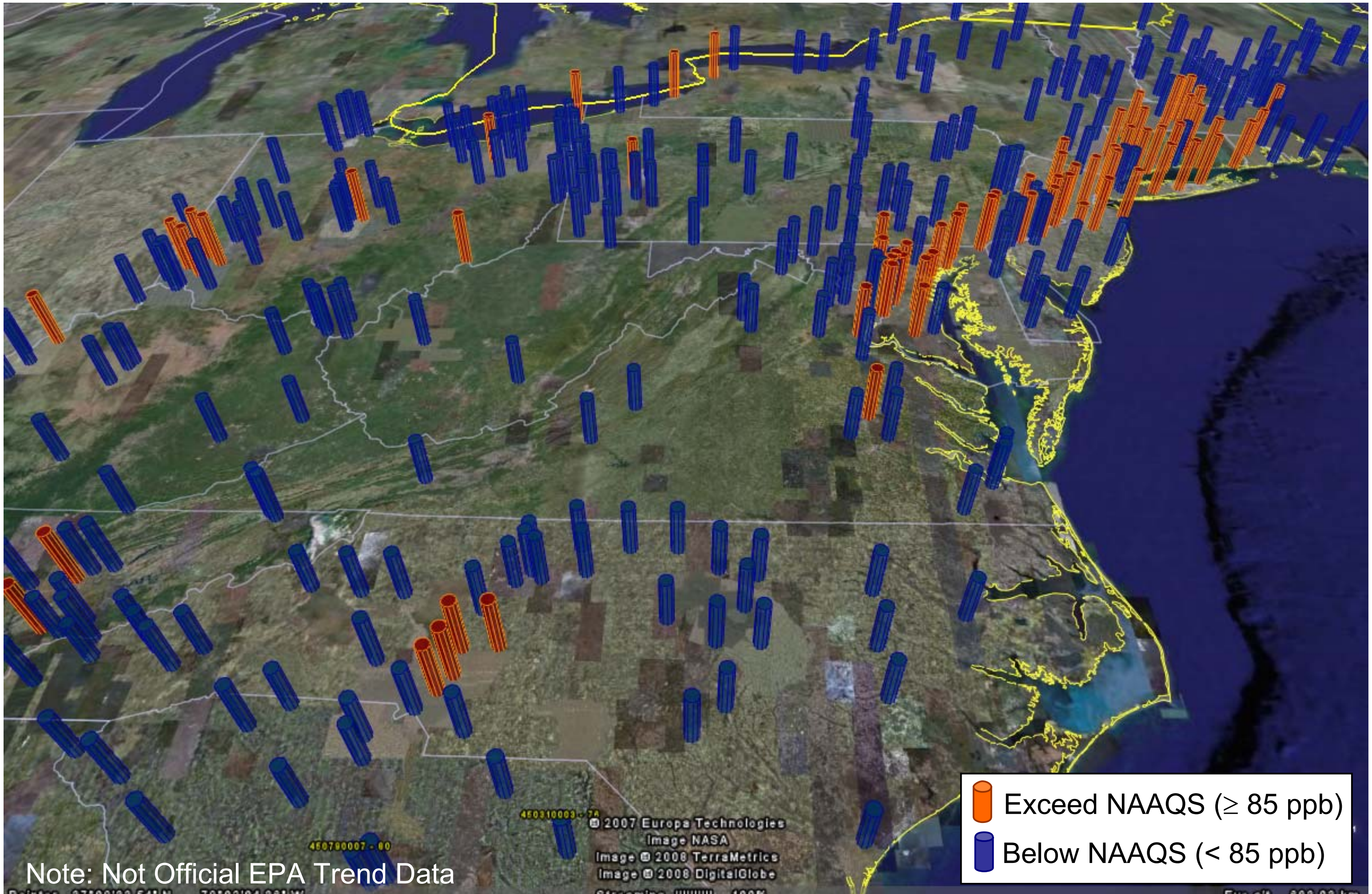
MDE

NO_x Controls and Attainment Status 8-Hour Ozone Design Values 2006



Ground-level **ozone** (design value) in the **Eastern United States continues to show significant improvements** in 2006, despite meteorological conditions that favored poor air quality. 8-hour ozone design values for many **monitors along the I-95 corridor**, **especially downwind of Maryland**, **went from non-attainment status in 2005 to attainment status in 2006**.

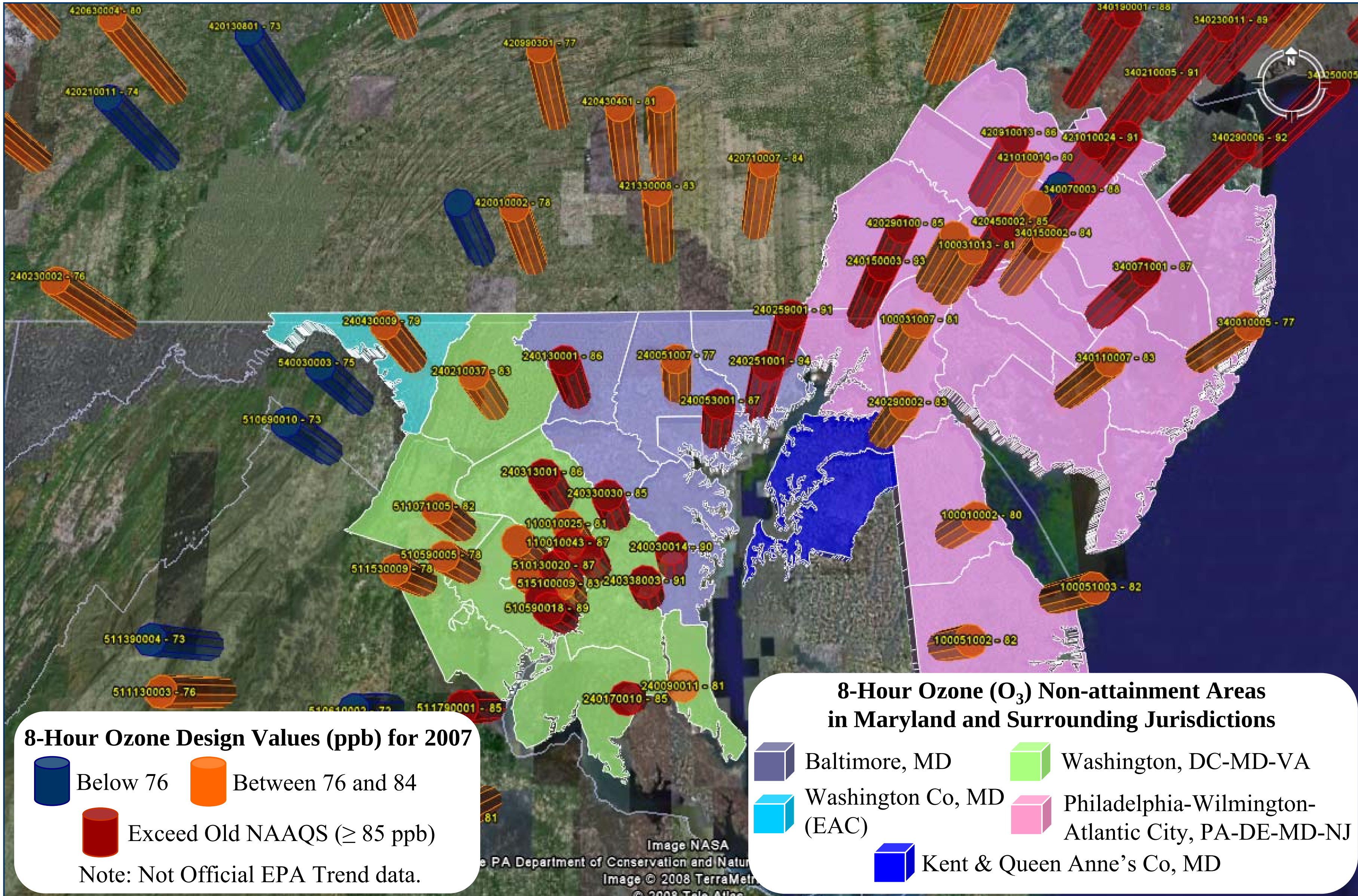
NO_x Controls and Attainment Status
8-Hour Ozone Design Values 2007



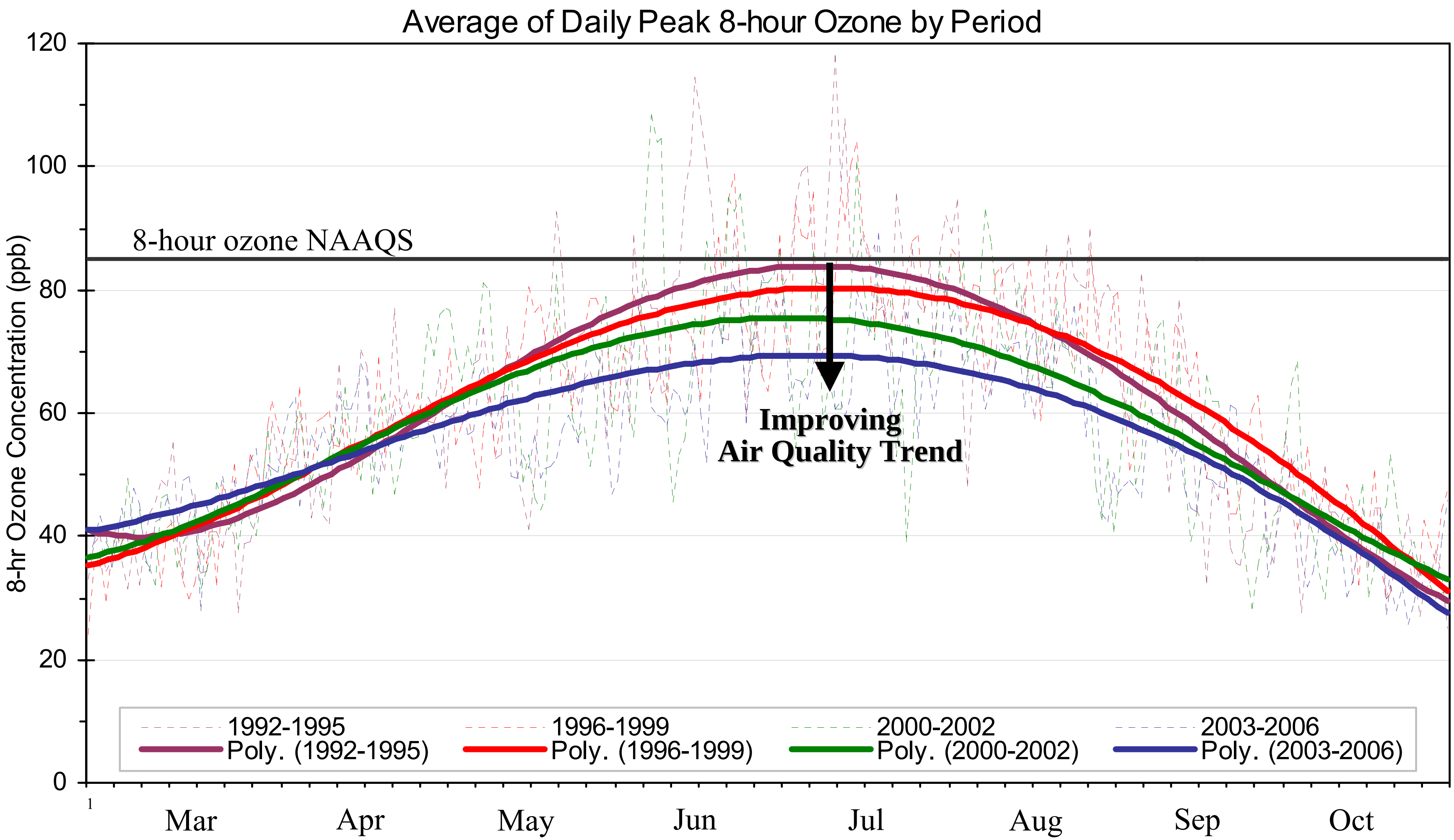
Ground-level **ozone** (design value) in the **Eastern United States shows a slight increase** in 2007. The ozone plume (as denoted by areas exceeding the NAAQS) had increased somewhat downwind of Maryland (along the I-95 corridor). However, **the overall trend towards 8-hour ozone attainment due to NO_x Control Program is still very visible**.

MDE

Maryland's Attainment Status (Ozone for 2007)

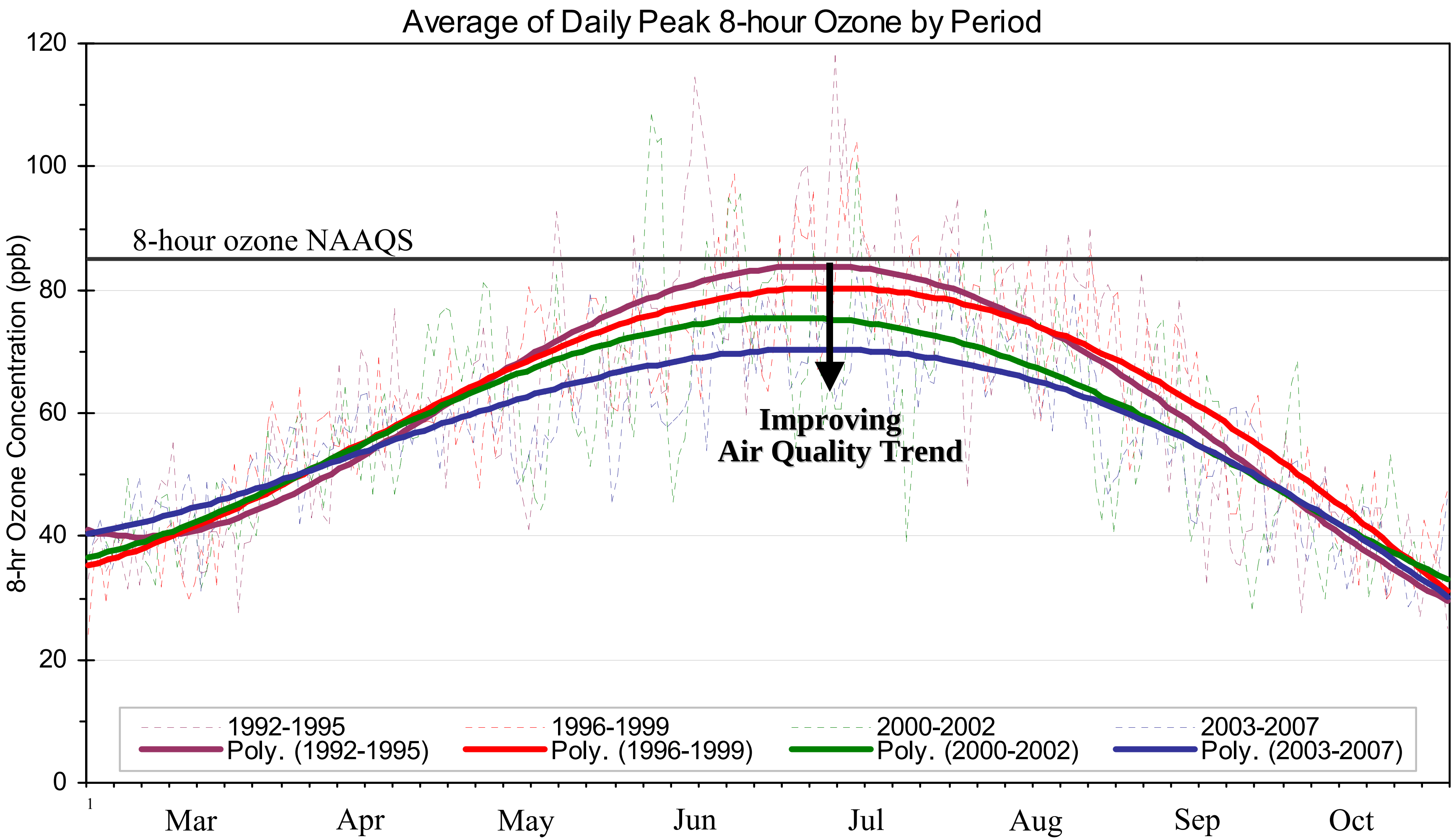


Regional Ozone Reductions Monitored in Maryland (1992-2006)



- During the 1990s, 8-hr ozone data in Maryland showed a slight improvement (~4 ppb decrease).
- After implementation of regional NO_x controls (after 2000), a notable decrease of 10 ppb were observed.
- **Approximately 15 ppb decrease was observed from 1990s to 2000s**.

Regional Ozone Reductions Monitored in Maryland (1992-2007)



- 2007 data shifted the trend line for the last period (2003-2007) slightly upward.
- However, the overall progress remains good with a **decrease of approximately 14 ppb as observed from 1990s to 2000s**.

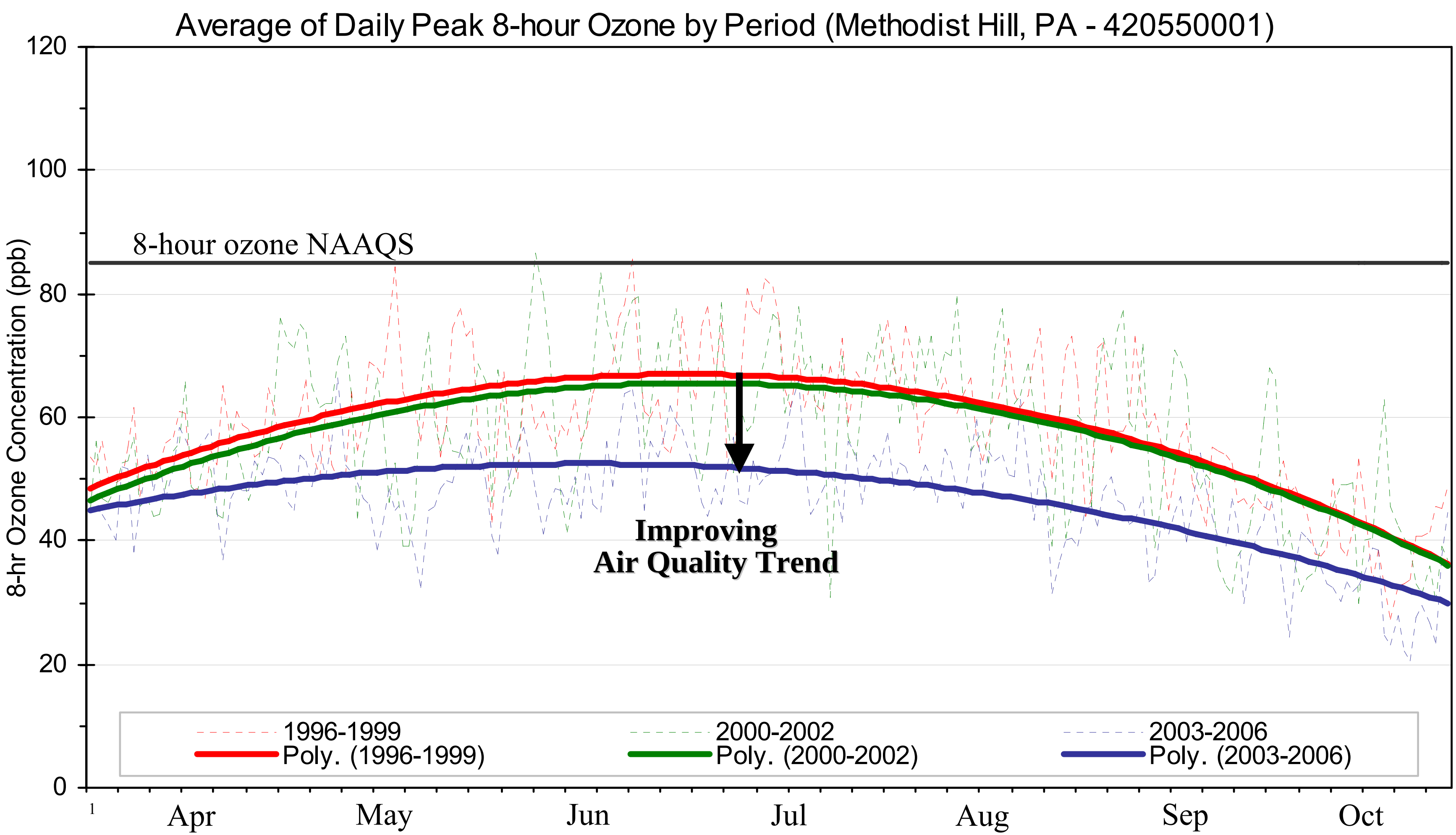
Benefits Observed in Maryland from Base Period of 1992-1995

Period	Equation	R^2	Graph Max	Net Benefit	Ozone Plume Area Under Curve (Mar-Oct)		Ozone Plume Area Under Curve (Jun-Aug)	
			[ppb]	[ppb | %]	[ppb-season]	Change [%]	[ppb-JJA]	Change [%]
1992-1995	$1.873E\text{-}07X^4 - 1.023E\text{-}4X^3 + 0.01472X^2 - 0.2682X + 41.199$	0.7228	84	n/a	15093	n/a	7234	n/a
1996-1999	$7.426E\text{-}08X^4 - 4.428E\text{-}05X^3 + 0.005364X^2 + 0.2361X + 34.976$	0.7952	80	**-4 | -5.0**	15143	+0.3	7031	**-2.8**
2000-2002	$9.856E\text{-}08X^4 - 5.141E\text{-}05X^3 + 0.005831X^2 + 0.1944X + 36.448$	0.6047	76	**-8 | -9.5**	14408	**-4.5**	6570	**-9.2**
2003-2007	$4.974E\text{-}08X^4 - 3.101E\text{-}05X^3 + 0.003857X^2 + 0.1437X + 40.436$	0.7366	70	**-14 | -16.7**	13945	**-8.2**	6193	**-14.4**

- BENEFITS (decrease in ozone levels) were observed through all periods (except for 1996-1999) when considering March – October data.
- Majority of the BENEFITS occurred during core summer months (JJA) suggesting that the NO_x SIP Call works!

Note: If you have a good approach for quantifying uncertainty, please let the authors know!

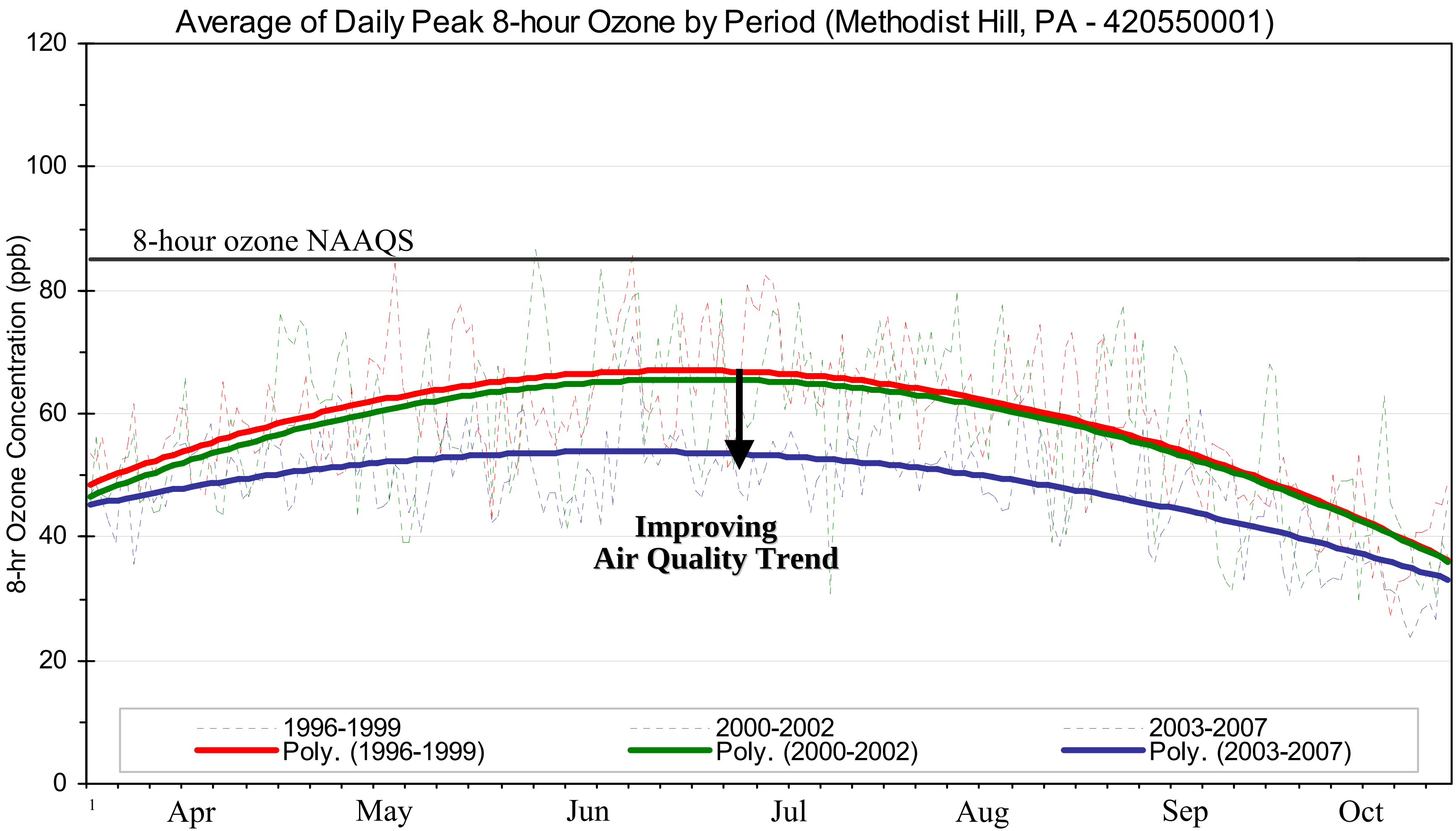
Regional Ozone Reductions Monitored at High Elevations (1996-2006)



- Reductions in regional ground-level ozone were also observed at elevated monitors (Methodist Hill, PA).
- Slight improvement of ~2ppb occurred during the 1990s.
- After implementation of regional NO_x controls (after 2000), a notable decrease of 13 ppb were observed.
- **Approximately 15 ppb decrease was observed from 1990s to 2000s**.

Note: 2006 data are preliminary.

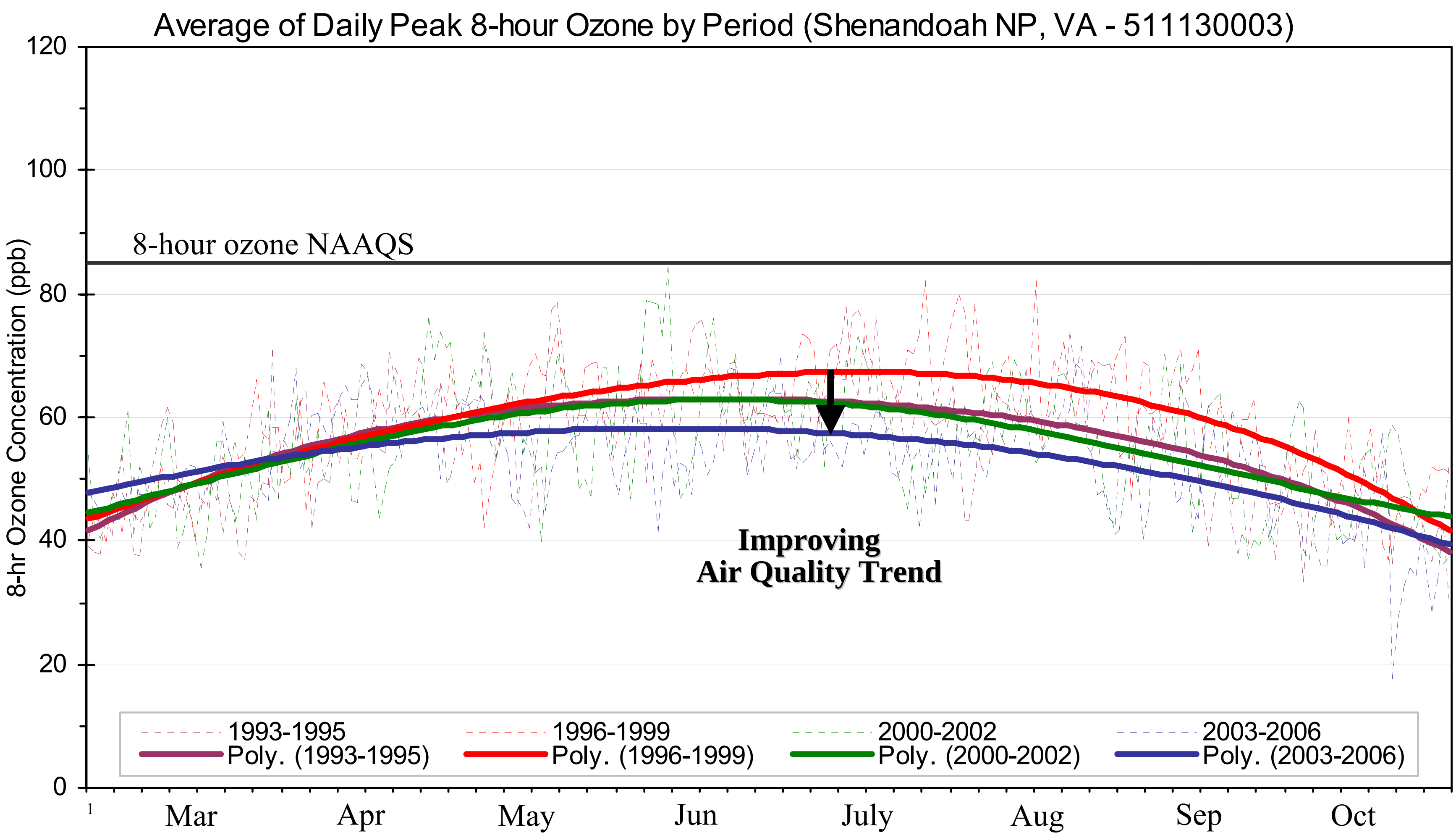
Regional Ozone Reductions Monitored at High Elevations (1996-2007)



A slight upward shift in the 2003-2007 trend line was observed.
However, the overall progress is still good with a decrease of ~**13 ppb from 1990s to 2000s.**

Note: 2006 & 2007 data are preliminary.

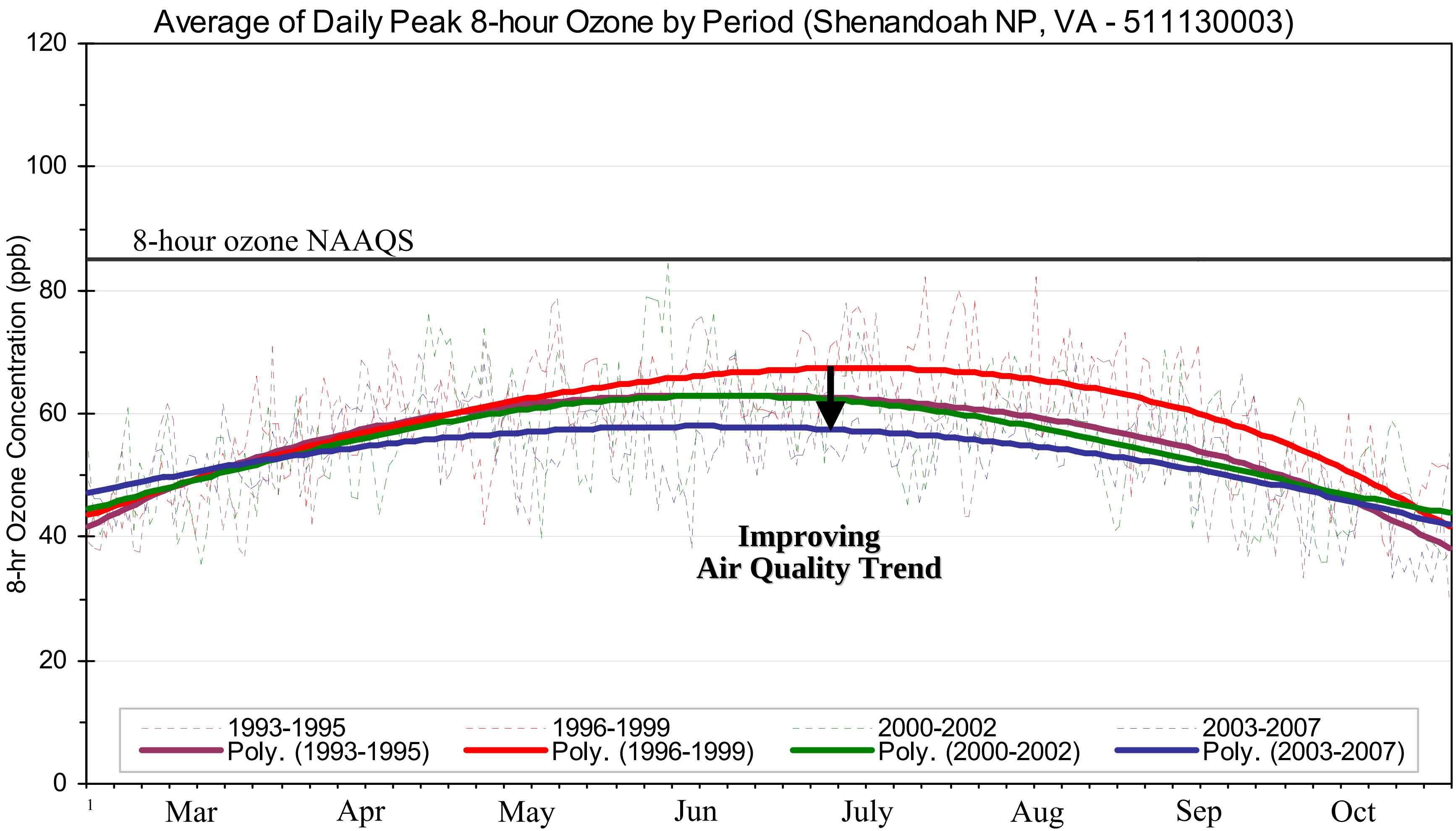
Regional Ozone Reductions Monitored at High Elevations (1993-2006)



- Reductions in regional ground-level ozone were also observed at Shenandoah NP, VA but to a lesser extent.
- An improvement of ~5 ppb occurred during the 1990s.
- After implementation of regional NO_x controls (after 2000), another 5 ppb were observed.
- **Approximately 10 ppb decrease was observed from 1990s to 2000s**.

Note: 2006 data are preliminary.

Regional Ozone Reductions Monitored at High Elevations (1993-2007)



- 2007 data had little or no impact in the overall progress at Shenandoah NP, VA.
- **10 ppb decrease was observed from 1990s to 2000s**.
- A slight decrease/increase were observed at the beginning and end of the reason respectively. Possible explanation: Weather conditions were COOLER at the start of the season and WARMER at the end of the season.

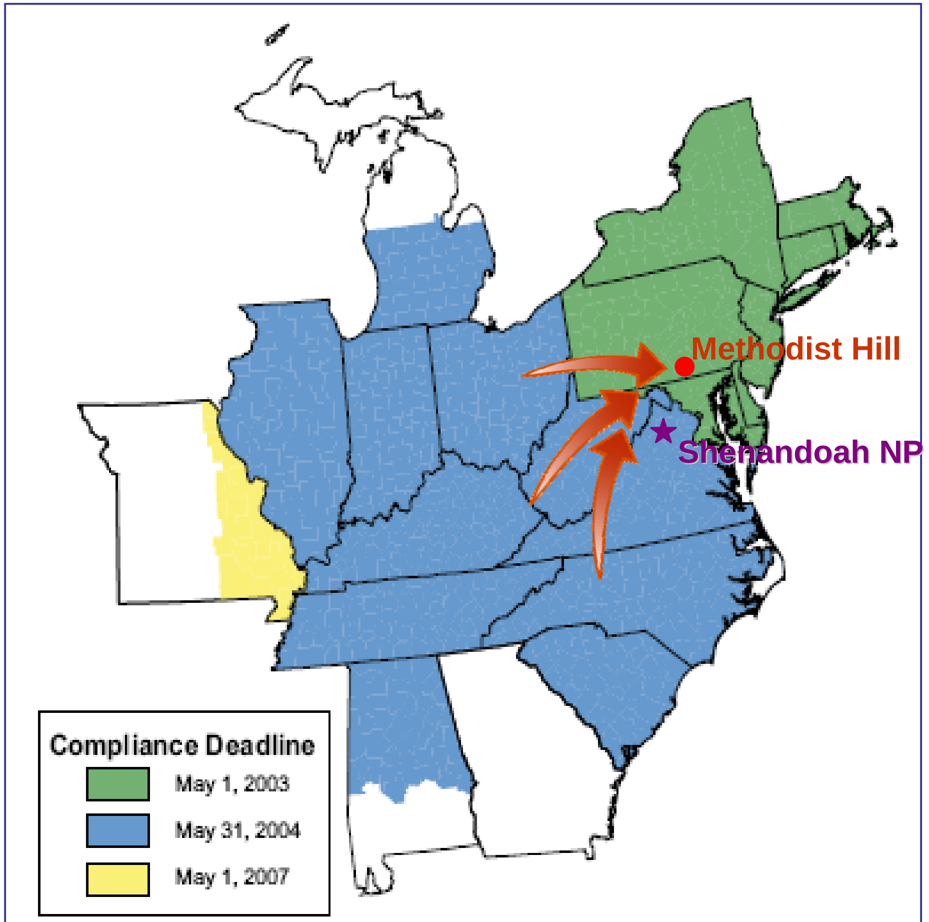
Note: 2006 & 2007 data are preliminary.

Why Less Ozone Reductions at Shenandoah NP?

Possible Explanations:

- ❑ Later Installation Date of SCRs
- ❑ Not in path of Westerly Transport

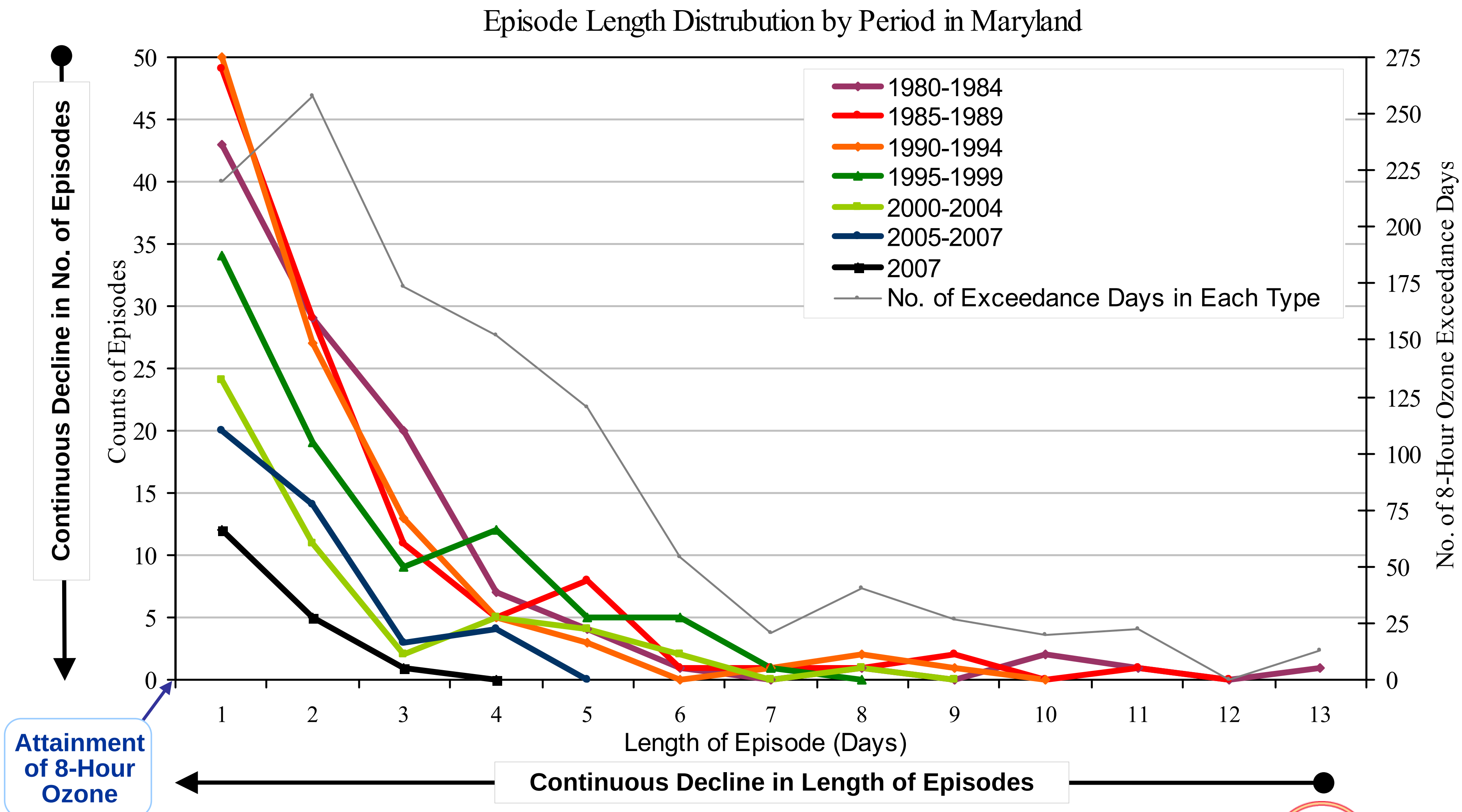
NO_x SIP Call Program Implementation



Source: EPA, 2007.

Figure extracted from EPA's NOx Budget Program 2006 Progress Report. Visit Clean Air Markets website for further details.

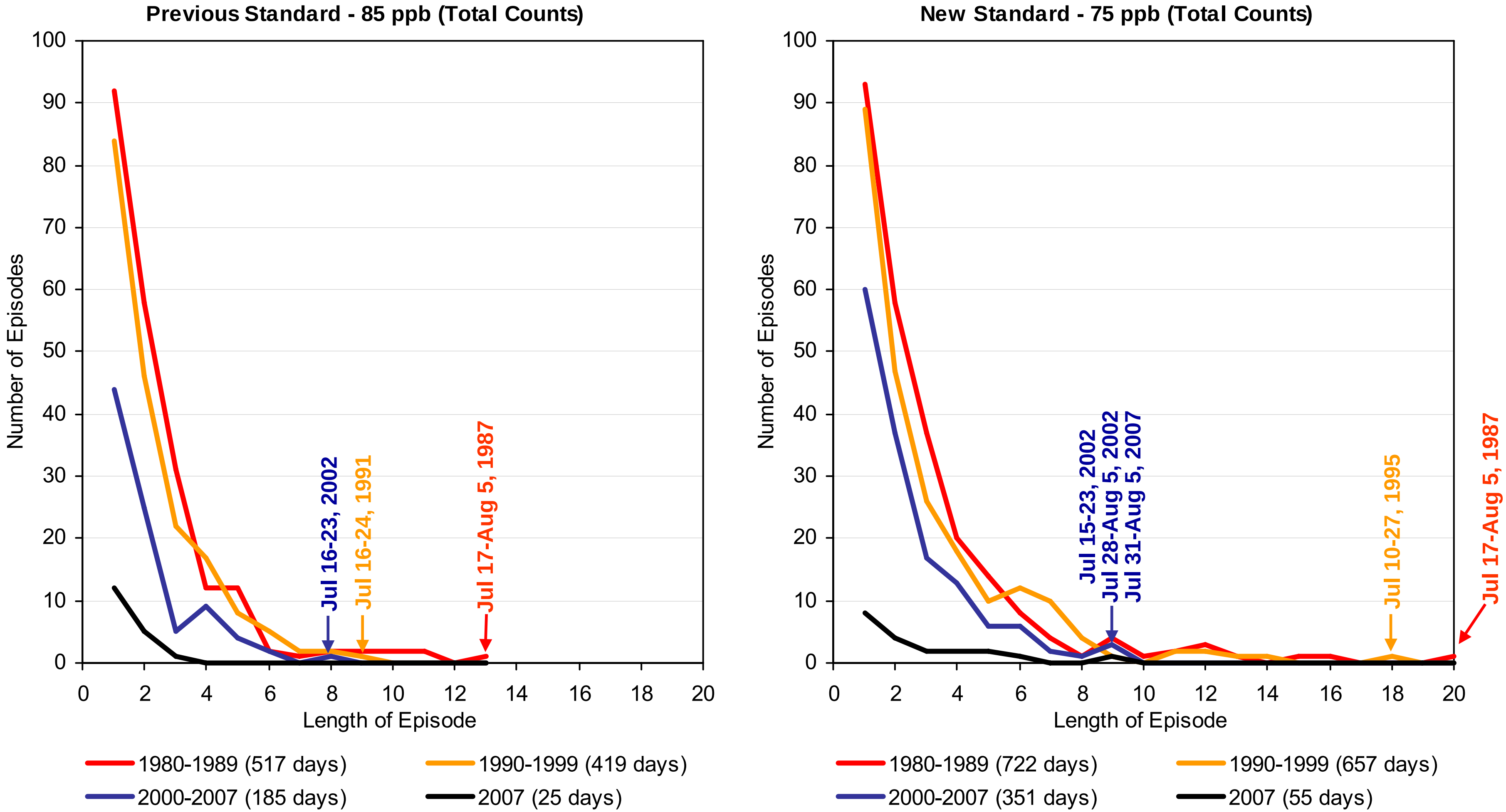
Episode Length Distribution by Period in Maryland (Old Standard)



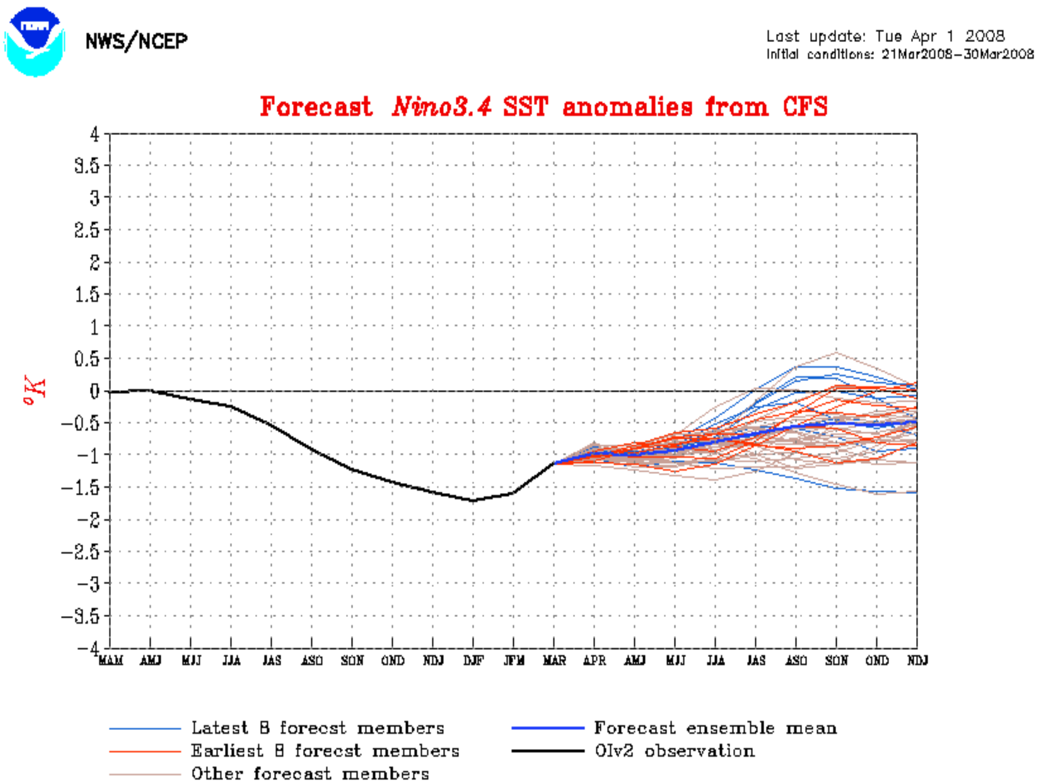
Air quality episodes have shrunk in both duration and counts of events.
This is the evidence that ozone plume has been shrinking.

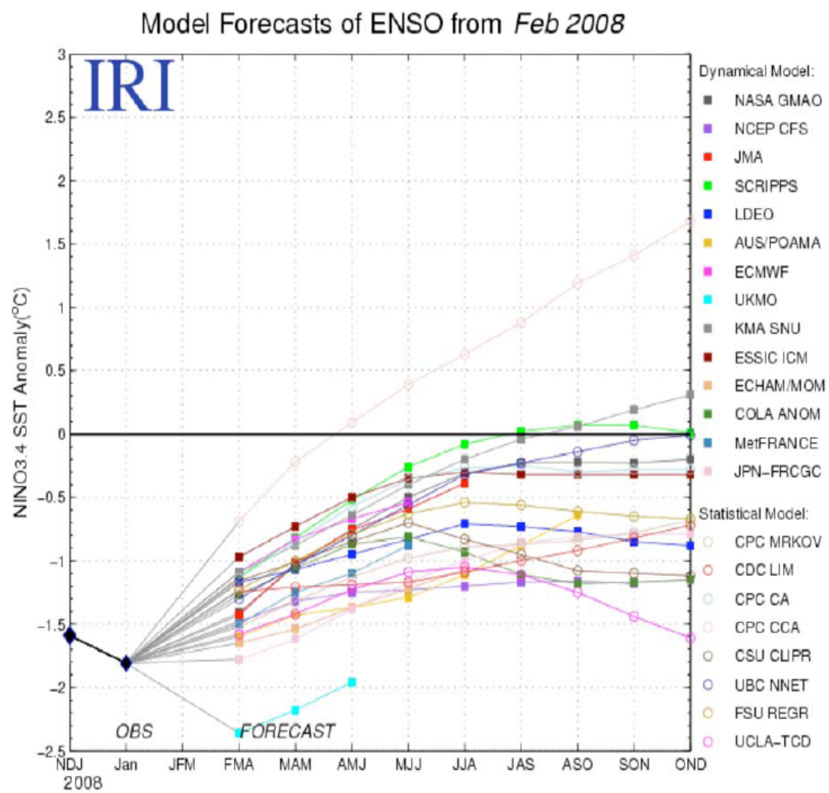
Note: 2007 data are preliminary.

Episode Length Distribution (Old vs New)



Outlook for 2008 (1 of 2)

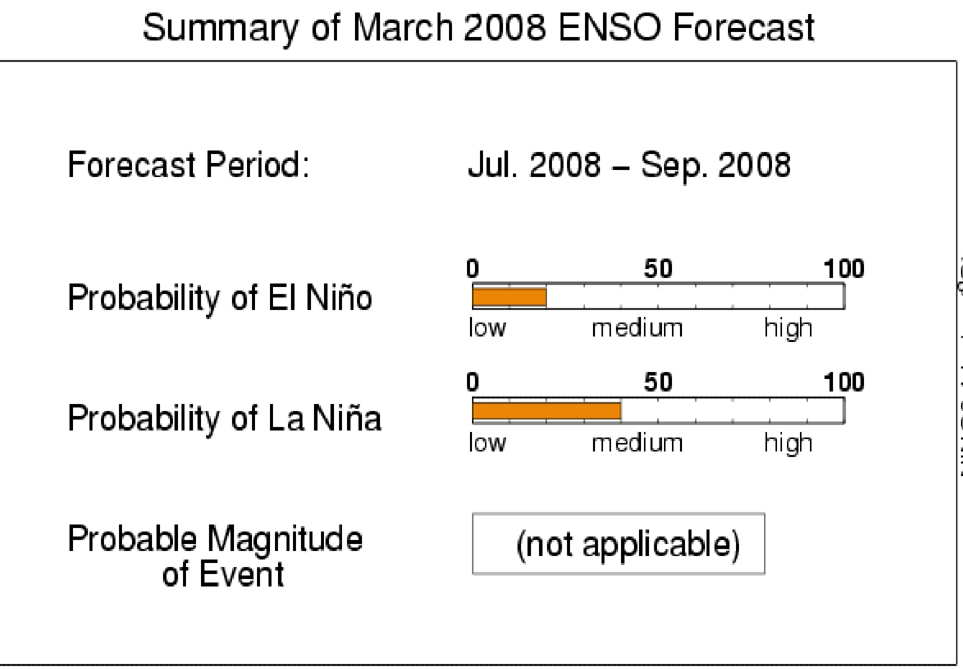


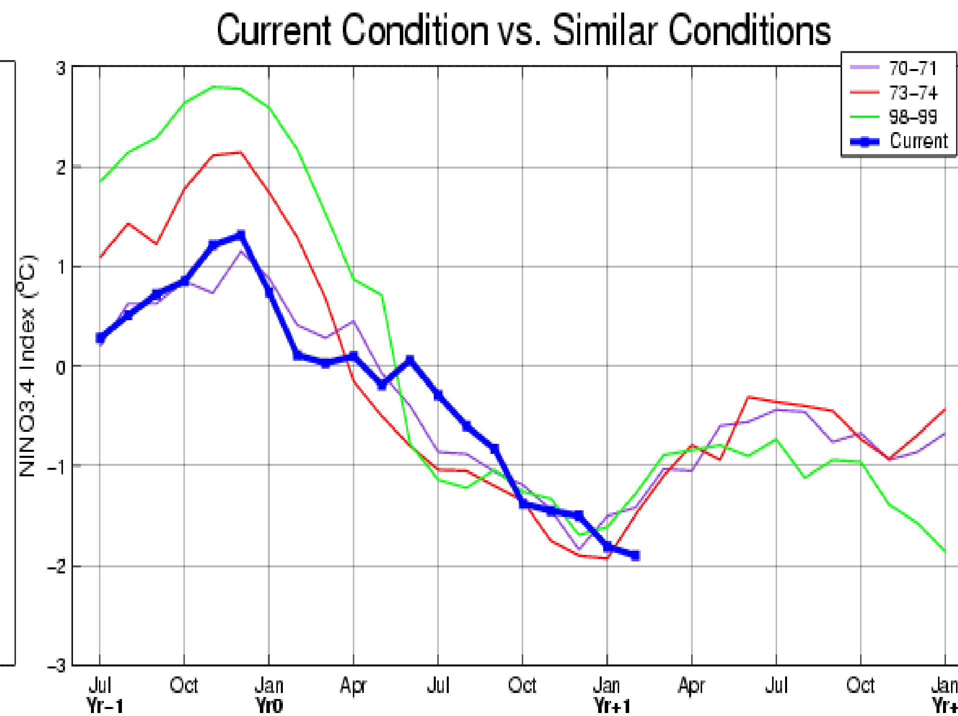


- Latest ENCEP coupled forecast system (CFS) predicts Cool ENSO (La Niña) conditions for the remainder of 2008.
- Various other models also indicates Cool ENSO is likely to continue through the summer of 2008 air quality season.
- If forecasts verify the **Mid-Atlantic** region will likely be experiencing **cool** and possibly moist **conditions during the summer of 2008**.

Sources: (a) ENSO Diagnostic Discussion website provided by the Climate Prediction Center.
(c) CFS Forecast of Seasonal Climate Anomalieswebsite by the Climate Prediction Center.
(b) ENSO Information website by the International Research Institute for Climate and Society (IRI) at the University of Columbia.

Outlook for 2008 (2 of 2)





- Medium probability for a weak La Niña to persist through the summer of 2008 air quality season.
- Historical data for similar conditions also suggest La Niña conditions.
- Much of the Eastern United States (Northeast, Mid-Atlantic, and Ohio River Valley) should **experience a relief in air quality** (below normal counts for 8-hour ozone exceedances) **in 2008 due to the combined effects of cooperating meteorological conditions, the regional NO_x control program, and other local control programs**.

Sources: ENSO Information website by the International Research Institute for Climate and Society (IRI) at the University of Columbia.

Summary (1 of 2)

- Ozone levels in Maryland have improved significantly.
  - Approximately 14 ppb decrease in peak seasonal ozone concentrations were observed from 1990s to 2000s.
  - Majority of the BENEFITS occurred during core summer months (JJA) suggesting that the NO_x SIP Call works!
- Regional transport patterns over the past 15 years have not changed drastically suggesting that improvements in “bad air quality days” through the each of the periods are driven primarily by controls.
- Air quality data in Maryland can be broken down into 3-5 year periods, trending with the the 90 degree days cycle to minimize the year-to-year fluctuations in meteorology. Ozone concentrations by each periods showed continuous improvements. Significant improvements are observed after implementation of a large-scale multi-state NO_x control program (NO_x SIP Call).
  - Before major implementation of Selective Catalytic Reduction (SCR) technology (2003-2004), many of ground-level ozone monitors across the Eastern United states were not in attainment.
  - After installation of SCR technology across the upwind states (Mid-West, Great Lakes, Ohio River Valley and some Southeast states), only small pockets from northern Virginia to Massachusetts concentrated along the I-95 corridor were just outside attainment. **A majority of the Ozone Transport Region (OTR) monitors came into attainment**.

Summary (2 of 2)

- ENSO (**E**l **N**iño-**S**outhern **O**scillation) appears to influence the 3-5 year air quality cycle in Maryland.
  - Warm ENSO (El Niño) typically leads to warm and dry conditions in the Mid-Atlantic and resulting in worse air quality.
  - Cool ENSO (La Niña) typically leads to cool and possibly moist conditions in the Mid-Atlantic and resulting in better air quality.
- Ocean Cycles on multi-decadal time scale impact general warming or cooling of ocean and atmosphere and greatly impact air quality.
  - Pacific Decadal Oscillation (PDO) in the order of ~30 year cycle greatly influence the frequency of El Niño/La Niña. Warm (Cool) PDO leads to more frequent El Niño (La Niña) and resulting in generally worse (better) air quality.
  - Atlantic Multi-decadal Oscillation (AMO) influences the state of the North Atlantic Oscillation (NAO) and typically lasts ~40-80 years. Its impact on air quality need to be studied.
- ENCEP coupled forecast system (CFS) predicts La Niña conditions to likely persist through the summer of 2008 air quality season. If forecast verifies, the Mid-Atlantic should experience a relief in air quality in 2008 due to the combined effects of cooperating meteorological conditions, the regional NO_x control program, and other local control programs.

Contacts

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Special Thanks Senior Staff:
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Tad Aburn, Air Director

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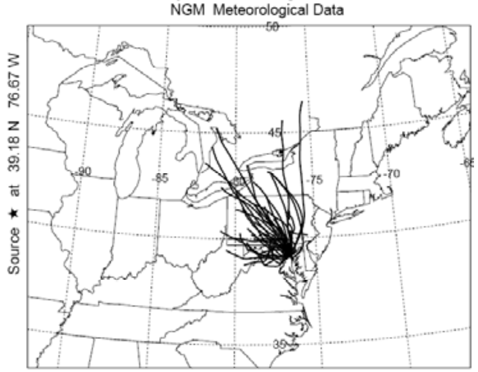
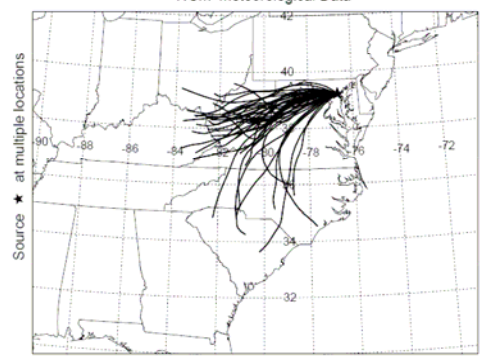
14. Pacific Decadal Oscillation (PDO) web page provided by Washington State University. Website (http://jisao.washington.edu/pdo/).
15. Schematic of typical January-March Weather anomalies and atmospheric circulation during moderate to strong El Niño & La Niña. Website (http://science.nasa.gov/headlines/images/elnino/jetstream.gif).
16. Selective Catalytic Reduction (SCR) statistics by the Institute of Clean Air Companies (ICAC). Website (http://www.icac.com).
17. William, R., 2007. Local Ozone Forecasting and the NOx SIP Call Rule. Presented at 2007 National Air Quality Conference, Orlando, FL. Online access at: http://www.epa.gov/airnow//2007conference/monday/ryan-nox-sip_monday.ppt

Appendix A1: Back Trajectory Clusters on 8-hr Ozone Exceedance Days (1992-1995)

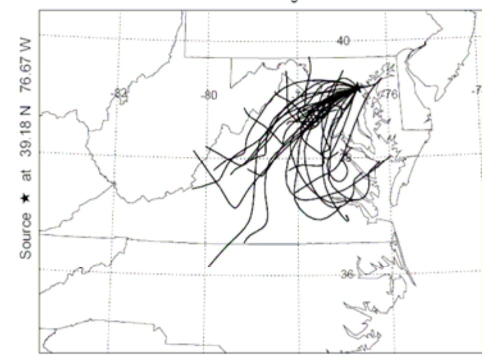
Cluster 1 of 7 - 1992-1995 (>= 85ppb)
Backward trajectories ending at various times
NGM Meteorological Data



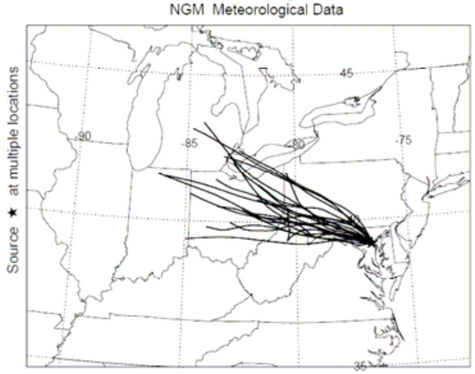
Cluster 2 of 7 - 1992-1995 (>= 85ppb)
Backward trajectories ending at various times
NGM Meteorological Data



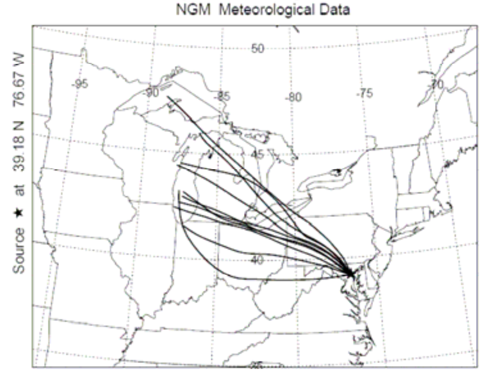
Cluster 3 of 7 - 1992-1995 (>= 85ppb)
Backward trajectories ending at various times
NGM Meteorological Data



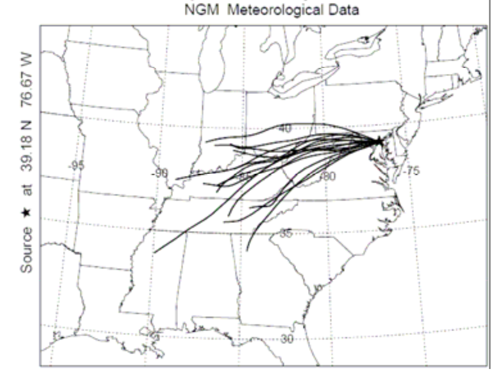
Cluster 4 of 7 - 1992-1995 (>= 85ppb)
Backward trajectories ending at various times
NGM Meteorological Data



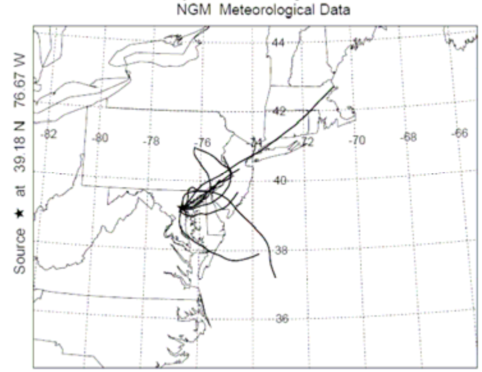
Cluster 5 of 7 - 1992-1995 (>= 85ppb)
Backward trajectories ending at various times
NGM Meteorological Data



Cluster 6 of 7 - 1992-1995 (>= 85ppb)
Backward trajectories ending at various times
NGM Meteorological Data



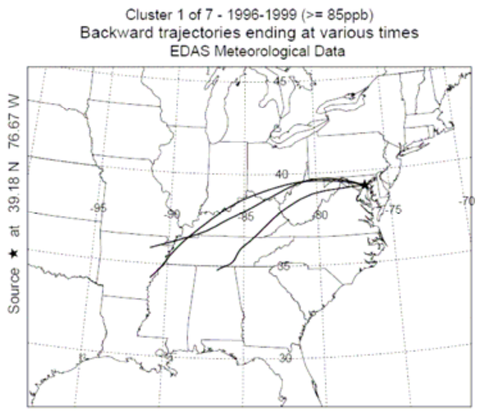
Cluster 7 of 7 - 1992-1995 (>= 85ppb)
Backward trajectories ending at various times
NGM Meteorological Data

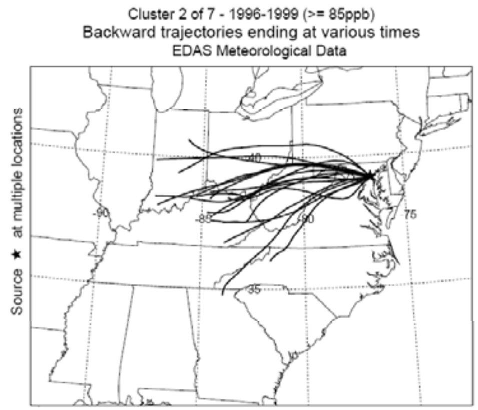


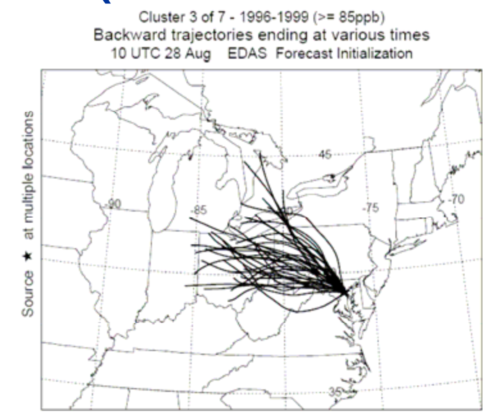
Note: Visit NOAA ARL HYSPLIT Model website for further information on trajectory clustering method.

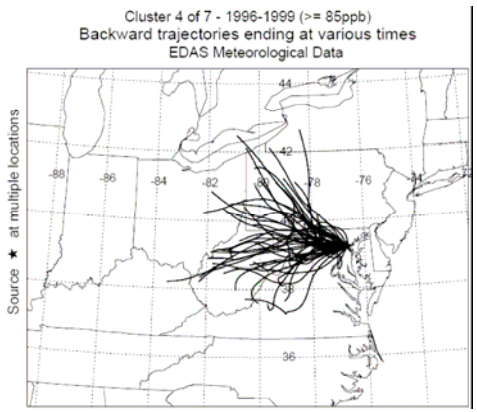
Trajectory Clusters

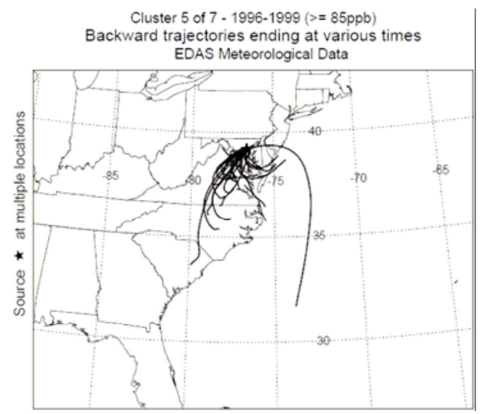
Appendix A2: Back Trajectory Clusters on 8-hr Ozone Exceedance Days (1996-1999)

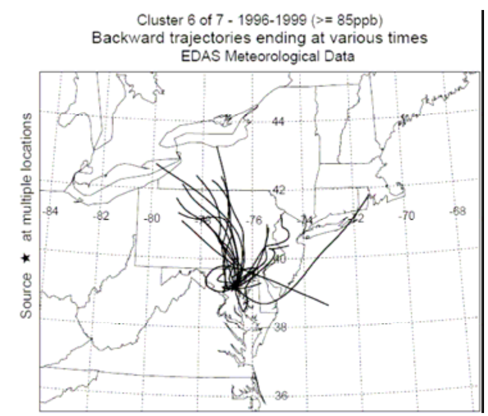


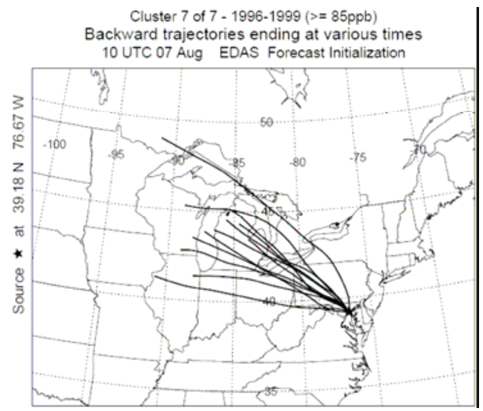










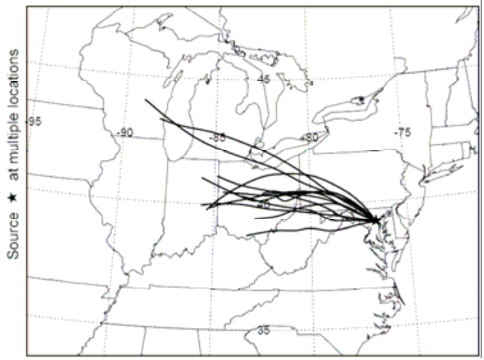


Note: Visit NOAA ARL HYSPLIT Model website for further information on trajectory clustering method.

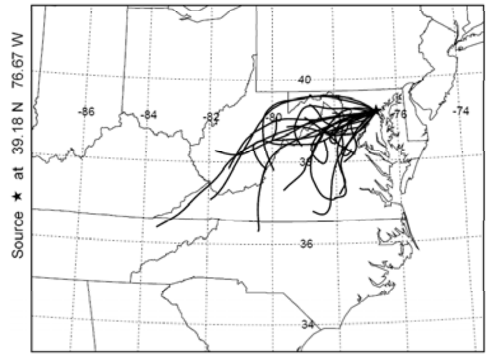
Trajectory Clusters

Appendix A3: Back Trajectory Clusters on 8-hr Ozone Exceedance Days (2000-2002)

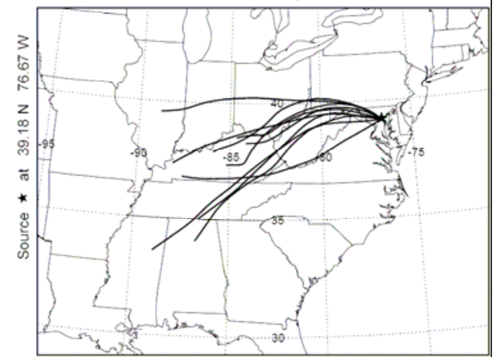
Cluster 1 of 7 - 2000-2002 (>= 85ppb)
Backward trajectories ending at various times
EDAS Meteorological Data



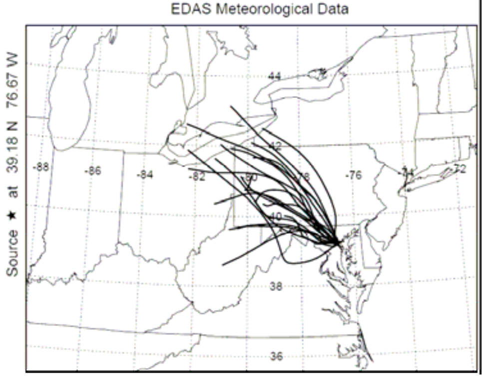
Cluster 2 of 7 - 2000-2002 (>= 85ppb)
Backward trajectories ending at various times
EDAS Meteorological Data



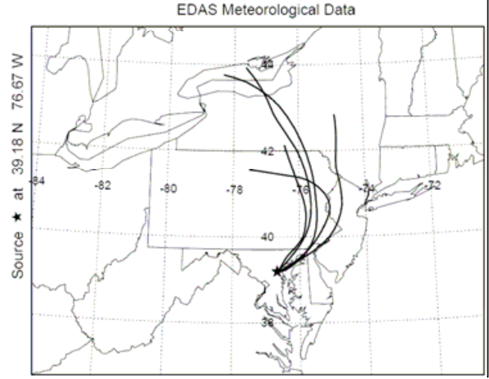
Cluster 3 of 7 - 2000-2002 (>= 85ppb)
Backward trajectories ending at various times
EDAS Meteorological Data



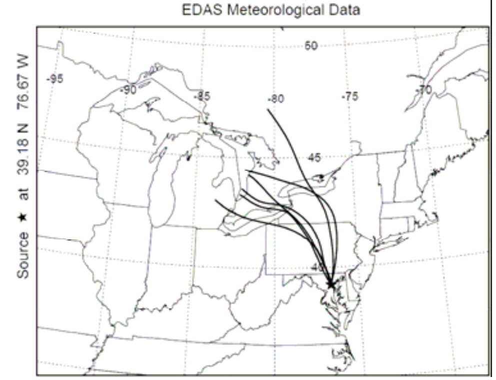
Cluster 4 of 7 - 2000-2002 (>= 85ppb)
Backward trajectories ending at various times
EDAS Meteorological Data



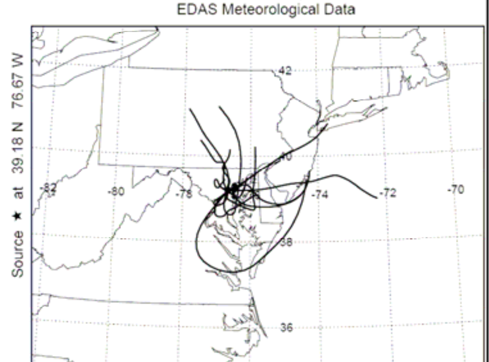
Cluster 5 of 7 - 2000-2002 (>= 85ppb)
Backward trajectories ending at various times
EDAS Meteorological Data



Cluster 6 of 7 - 2000-2002 (>= 85ppb)
Backward trajectories ending at various times
EDAS Meteorological Data



Cluster 7 of 7 - 2000-2002 (>= 85ppb)
Backward trajectories ending at various times
EDAS Meteorological Data



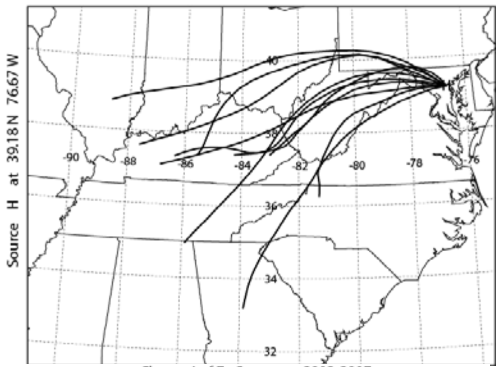
Note: Visit NOAA ARL HYSPLIT Model website for further information on trajectory clustering method.

Trajectory Clusters

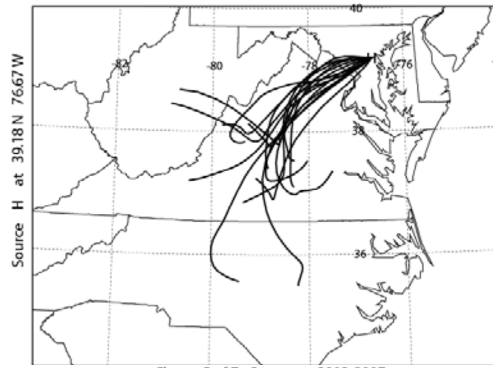
Appendix A4: Back Trajectory Clusters on 8-hr Ozone Exceedance Days (2003-2007)

MDE

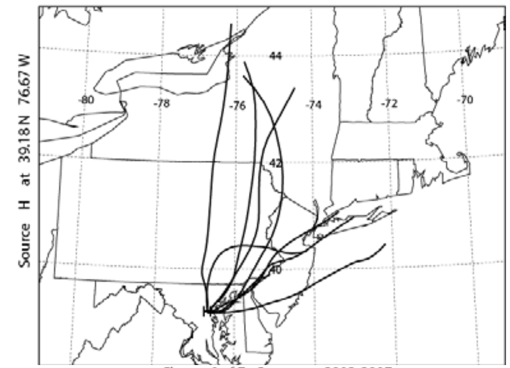
Cluster 1 of 7 - Summers, 2003-2007
Backward trajectories ending at various times
EDAS Meteorological Data



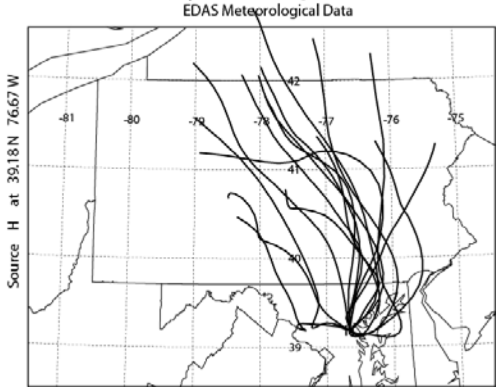
Cluster 2 of 7 - Summers, 2003-2007
Backward trajectories ending at various times
EDAS Meteorological Data



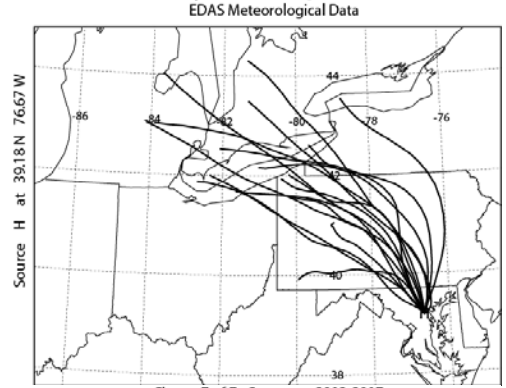
Cluster 3 of 7 - Summers, 2003-2007
Backward trajectories ending at various times
EDAS Meteorological Data



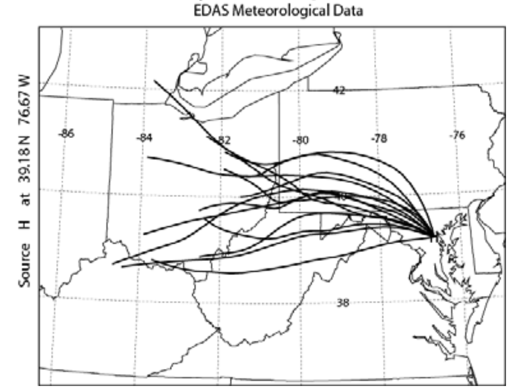
Cluster 4 of 7 - Summers, 2003-2007
Backward trajectories ending at various times
EDAS Meteorological Data



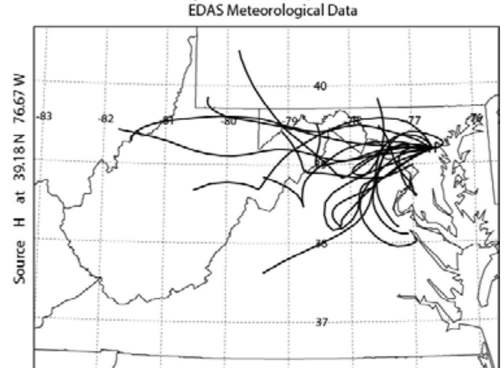
Cluster 5 of 7 - Summers, 2003-2007
Backward trajectories ending at various times
EDAS Meteorological Data



Cluster 6 of 7 - Summers, 2003-2007
Backward trajectories ending at various times
EDAS Meteorological Data



Cluster 7 of 7 - Summers, 2003-2007
Backward trajectories ending at various times
EDAS Meteorological Data



Note: Visit NOAA ARL HYSPLIT Model website for further information on trajectory clustering method.

Trajectory Clusters

MARYLAND

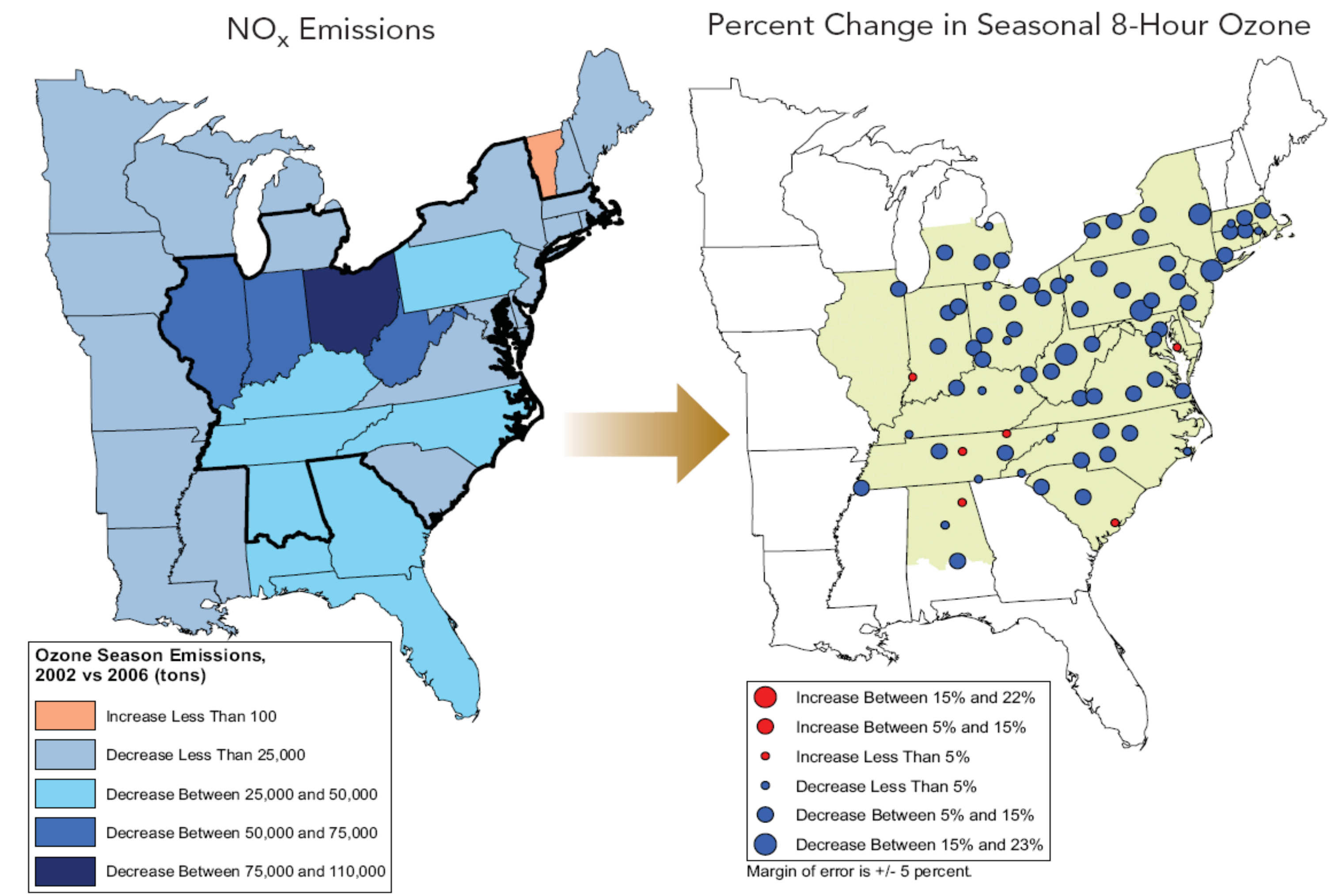
Extra Slides …

Results from EPA's NOx Budget Program 2006 Progress Report are compared to MDE's results

…

Reductions in NO_x Emissions and Percent Change in 8-Hour Ozone (2002 vs 2006)

MDE



Notes:

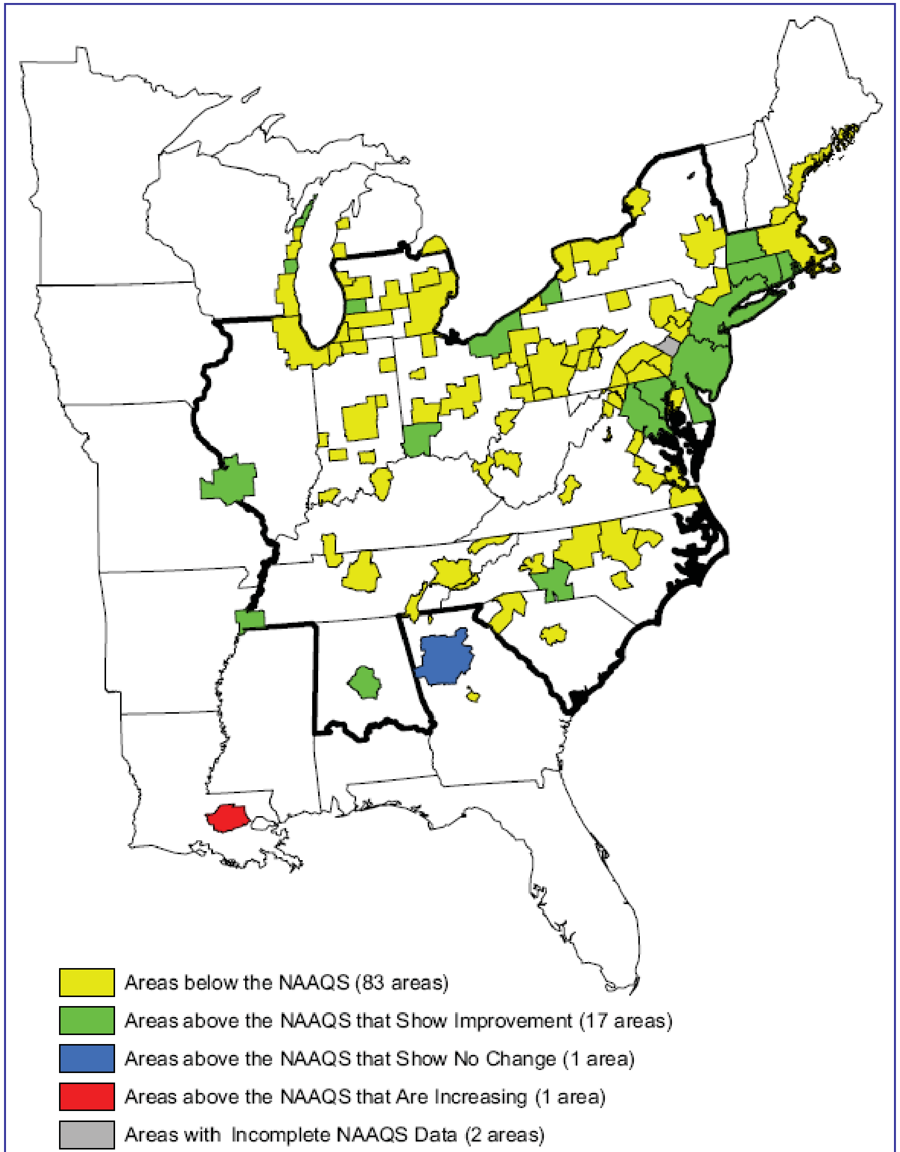
- States participating in the NBP in 2006 are shown inside the black boundary line on the emission map (left). NBP states are shaded in green in the ozone percent change map (right).
- From 2002 to 2006, Vermont (35 tons) shows a small increase in ozone season NO_x emissions.

Source: EPA, 2007.

Large reductions in 8-hour ozone (adjusted for Meteorology) is linked to large NO_x reductions!

Figure extracted from EPA's NOx Budget Program 2006 Progress Report. Visit Clean Air Markets website for further details.

Changes in 8-Hour Ozone Nonattainment Areas in the East 2001-2003 vs 2004-2006



- Majority of areas in the East were in attainment as of 2006 (83 areas or 79.8%).
- All areas along I-95 from northern VA to MA showed improvements but still in nonattainment as of 2006.
- The only one area showed increasing NAAQS is outside of the states participating in NOx Budget Program (outlined in dark black).
- **Results from this EPA report agree with MDE's analysis**.

Figure extracted from EPA's NOx Budget Program 2006 Progress Report. Visit Clean Air Markets website for further details.