ARL
Air Resources Laboratory
Conducting research and development in the fields of air quality, atmospheric dispersion, climate, and boundary layer

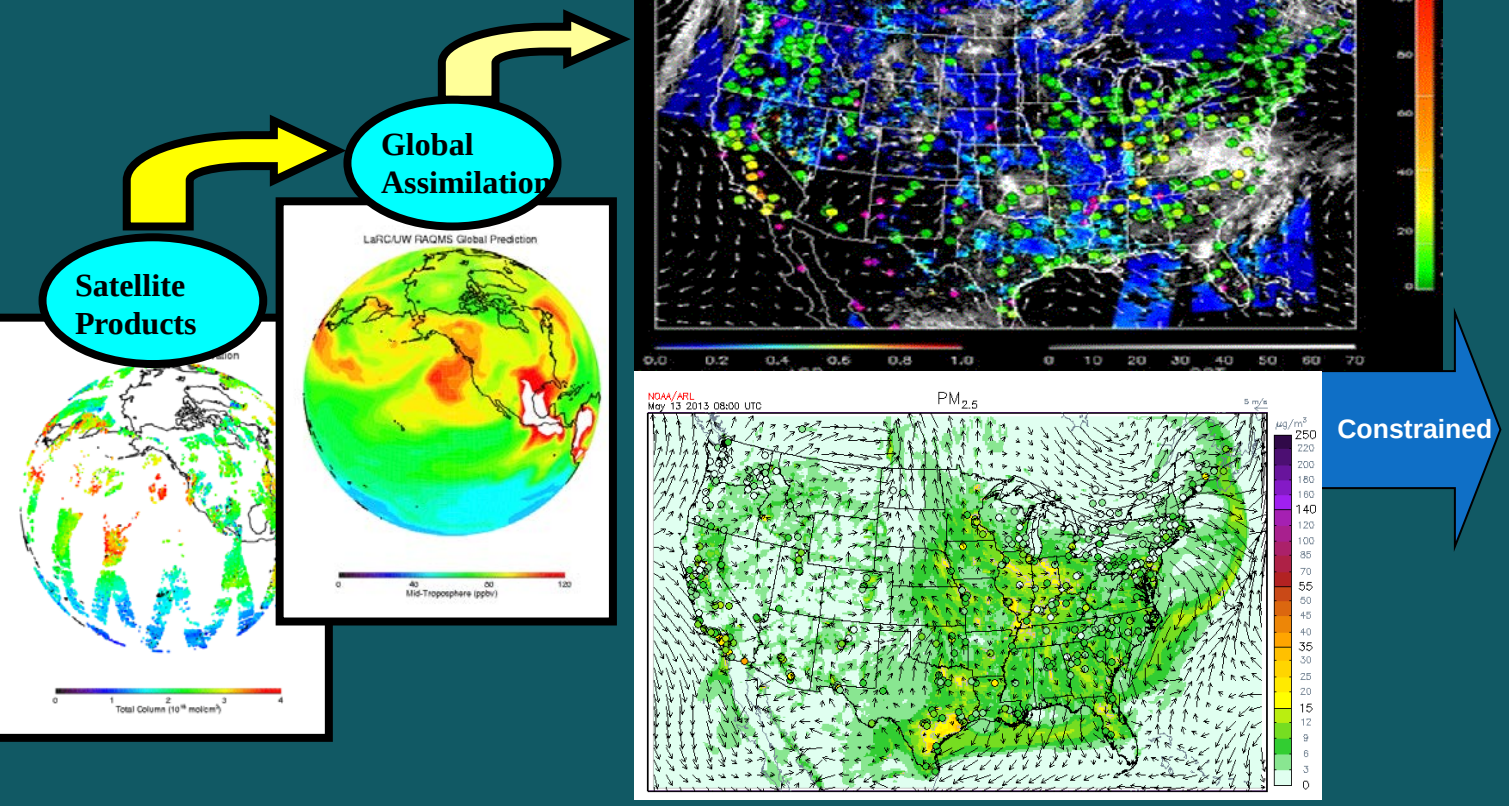
# Air Quality Forecasting and Reanalysis
## (optimizing assimilation of column AOT & sfc data)


Pius Lee[1], Youhua Tang[1], Jeff McQueen[2], Shobha Kondragunta[3], Li Pan[1], Daniel Tong[1], Hyun Kim[1], Mark Liu[3], Sarah Lu[4], Jun Wang[5], Greg Carmichael[6], Ted Russell[7], Dick McNider[8], Brad Pierce[9], Edward Hyer[10], Jim Szykman[11], Yang Liu[12], Min Huang[1], Chuanyu Xu[5], Ho-Chun Huang[5]

[1]Air Resources Lab. (ARL), NOAA Center for Weather and Climate Prediction (NCWCP), College Park, MD
[2] Environmental Modeling Center (EMC), NCEP, NCWCP, College Park, MD
[3] NOAA/ESDIS/STAR, College Park, MD
[4]State University of New York, Albany, NY
[5] I.M. Systems Group Inc. Rockville, MD
[6] College of Engineering, University of Iowa, Iowa City, IA
[7]School of Civil and Environmental Engr., Georgia Institute of Technology, Atlanta, GA
[8] Department of Atmospheric Science, University Alabama, Huntsville AL
[9] National Environmental Satellite and Information Service (NESDIS), Madison, WI
[10] Naval Research Laboratory, Monterey, CA
[11] U.S. EPA, Hampton, VA
[12] Department of Environmental Health, Emory University, Atlanta, GA

# Upcoming AQAST Project: Air Quality Reanalysis

## (*Translating Research to Services*)




+ AQ Assessments
+ State Implementation Plan Modeling
+ Rapid deployment of on-demand rapid-response forecasting; e.g., new fuel type,…, etc.
+ Health Impacts assessments
+ Demonstration of the impact of observations on AQ distributions
+ Ingestion of new AQAST products into operations

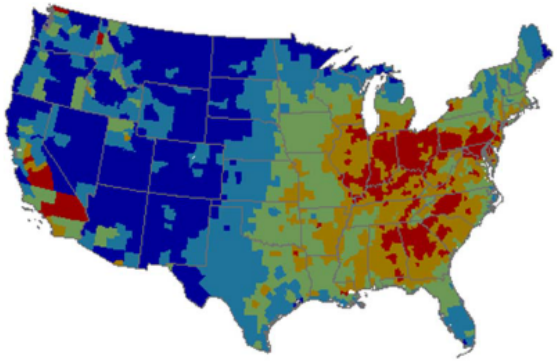
http://acmg.seas.harvard.edu/aqast/projects.html

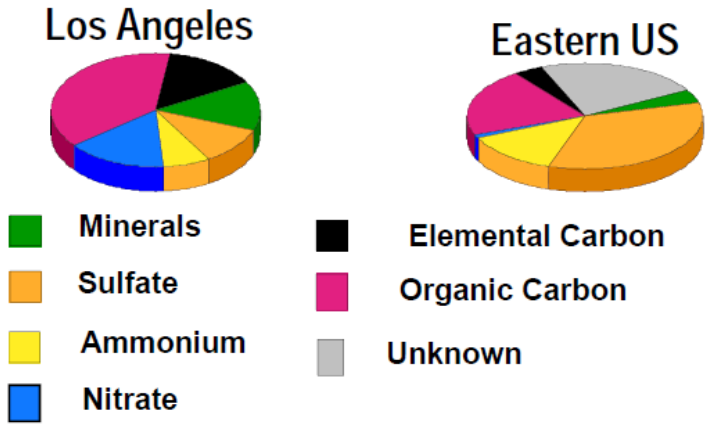
Courtesy: Dan Costa
"New Directions in Air Quality Research at the US EPA"

# Public Health Burden of $PM_{2.5}$

(Fann et al., 2011)

Percentage of $PM_{2.5}$ related deaths due to 2005 air quality levels by county

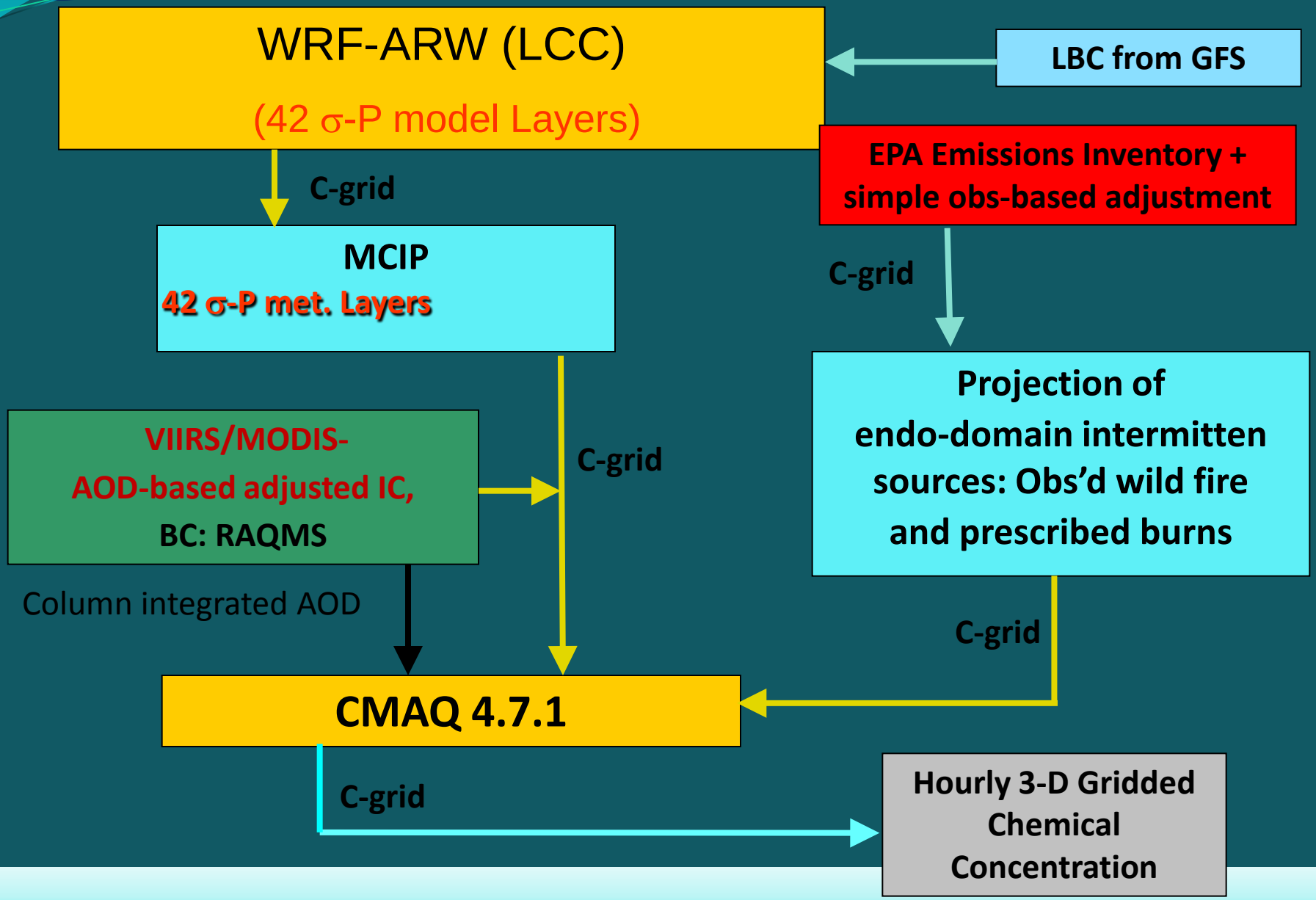





| Summary of National $PM_{2.5}$ impacts due to 2005 air quality | |
|---|---|
| Excess mortalities (adults)[A] | 130 to 320,000 |
| Percentage of all deaths due to $PM_{2.5}$[B] | 5.4% |
| ***Impacts among Children*** | |
| ER visits for asthma (<18 yr) | 110,000 |
| Acute bronchitis (age 8-12) | 200,000 |
| Exacerbation of asthma (age 6-18) | 2,500,000 |

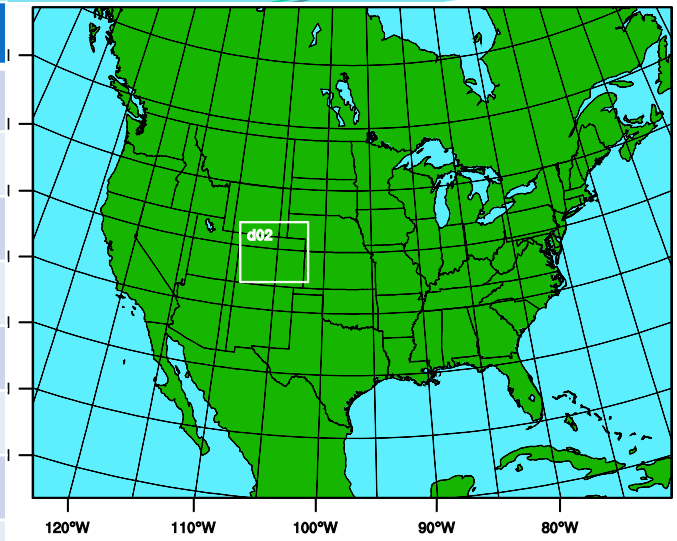
[A] Range reflects use of alternate PM mortality estimates
[B] Population-weighted value using Krewski et al. (2009) PM mortality estimates

# WRF_ARW-MCIP-CMAQ forward model



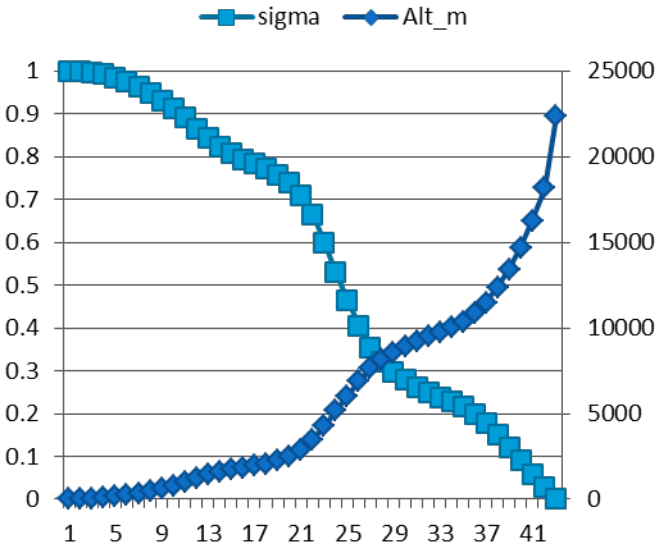
# WRF_ARW-MCIP-CMAQ model physics and chemistry options

| WRF-ARW | Both North America (12 km) & CONUS (4 km) |
|---|---|
| Map projection & grid | Lambert Conformal & Arakawa C staggering |
| Vert. co-ordinate | 42 σ-p unevenly spaced levels |
| advection | RK3 (Skamarock and Weisman (2008)) |
| SW & LW radiation | RRTMG (Iacono et al. 2008)) |
| PBL Physics | Mellor-Yamada-Janjic (MYJ) level 2.5 closure |
| Surface layer scheme | Monin-Obukhov Similarity with viscous sub-layer |
| Land Surface Model | NCEP NOAH |
| Cloud Microphysics | Thompson et al. (2008) |
| Cloud convective mixing | Betts-Miller-Janjic Mass adjustment |



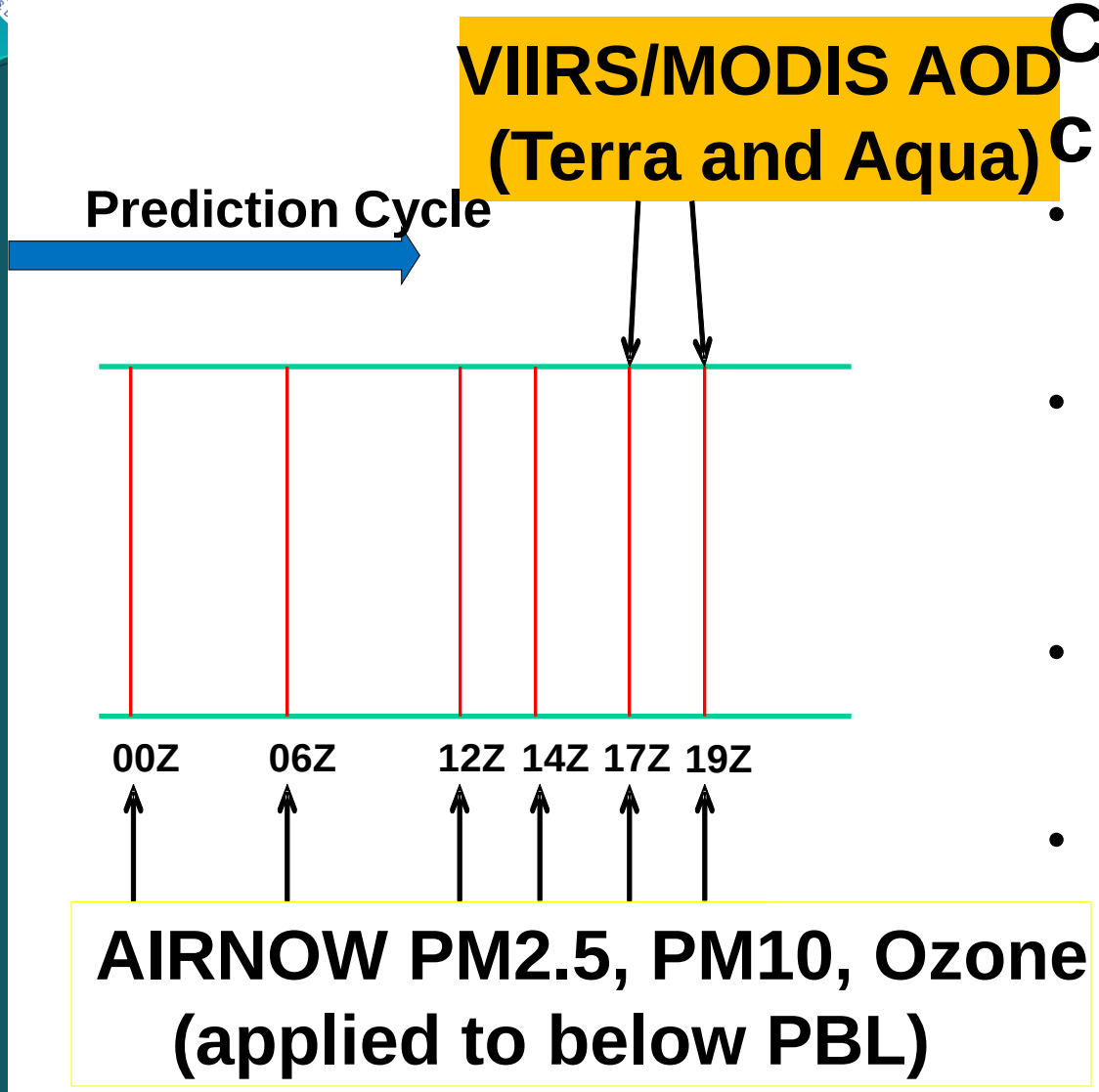

**AQ forecast: ^12 km nested to 4 km**

| CMAQ4.7.1 | Both CONUS(12 km) & SENEX (4 km) |
|---|---|
| Map projection & grid | Lambert Conformal & Arakawa C staggering |
| Vert. co-ordinate | 42 σ-p unevenly spaced levels |
| Gas chemistry | Cb05 with 156 reactions |
| Aerosol chemistry | Aero5 with updated evaporation enthalpy |
| Anthropogenic emission | 2008NEI as base year, mobile projected using AQS*, area and off-road used CSPR^, point source uses 2012 CEM data |
| | WRAP oil and gas emissions data |
| Biogenic emission | BEIS-3.14 |
| Lateral BC | RAQM (B. Pierce) |




**42 vertical layers**

# CMAQ base v5.0.2: cb05_ae5)




- 2008 anthropogenic emission inventory projected to 2011
- NOAA HMS (hazard mapping system) fire emission with Bluesky algorithm
- GOES cloud fraction adjustment provided by U. of Alabama at Huntsville
- RAQMS lateral boundary condition every 6 hours.

# Optimal Interpolation (OI)

- OI is a sequential data assimilation method. At each time step, we solve an analysis problem

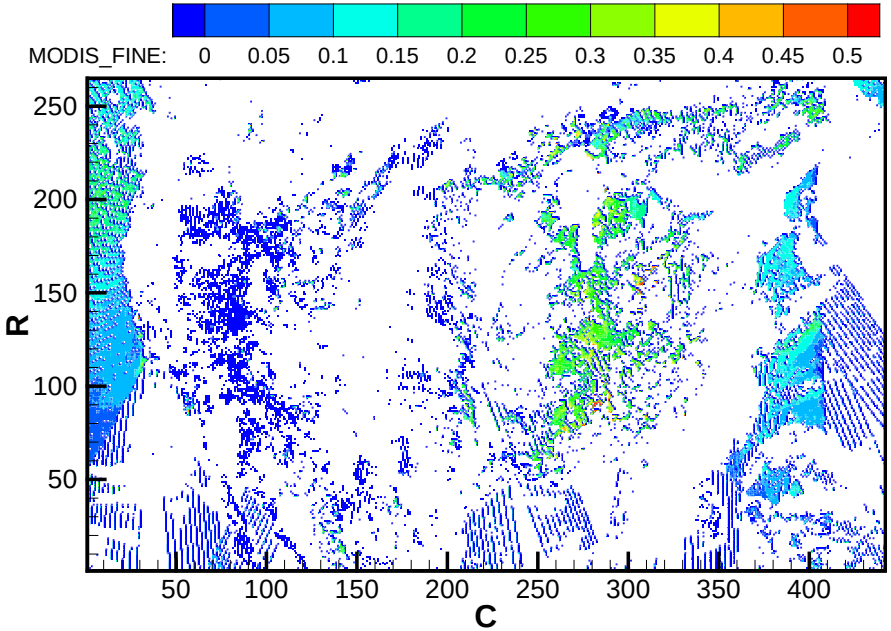
$$X^a = X^b + BH^T(HBH^T + O)^{-1}(Y - HX)$$

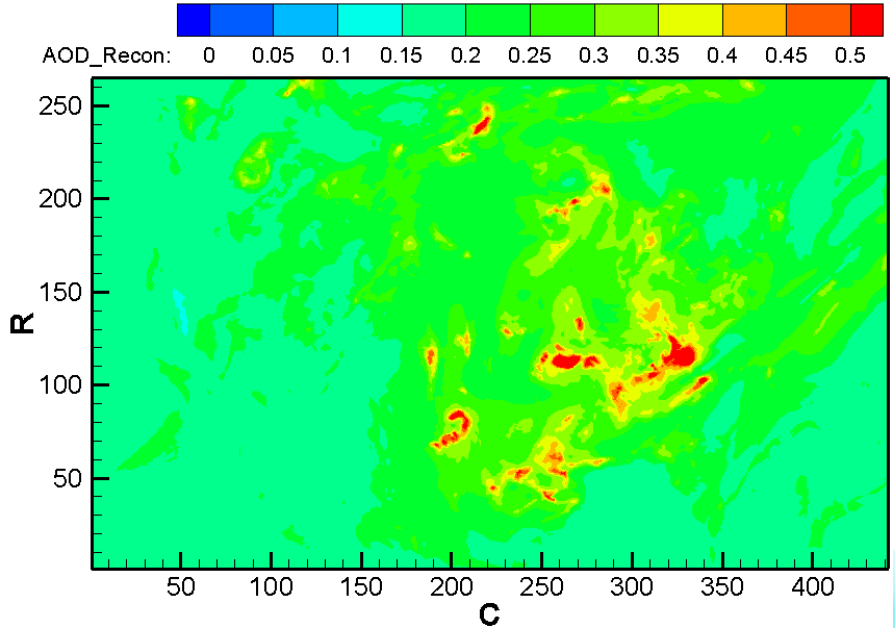
- We assume observations far away (beyond background error correlation length scale) have no effect in the analysis
- In the current study, the data injection takes place at 1700Z daily

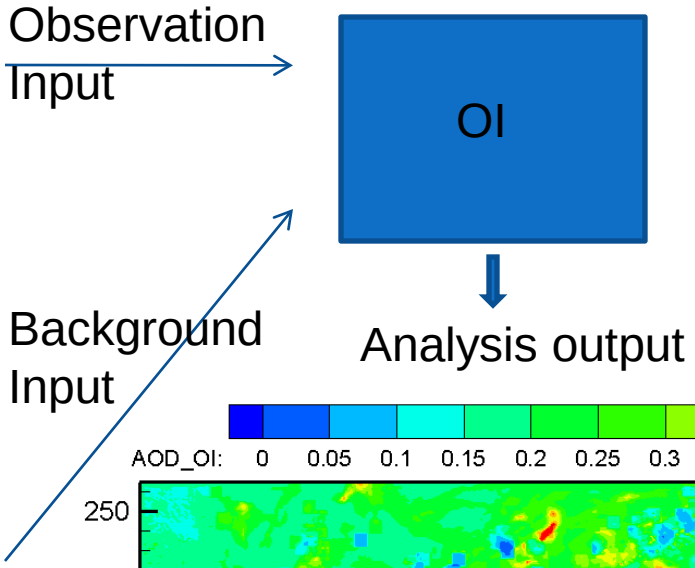
Chai et al. *JGR* 2006

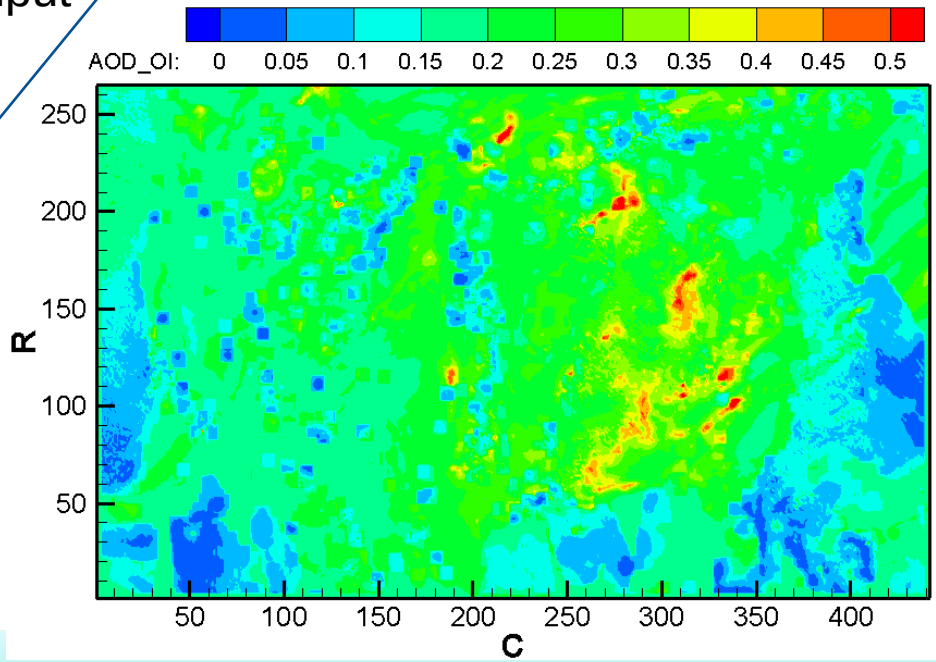
# Objective (A): Improve PM forecast

Methodology of OI: Take account for background input; Obs; and physical processes from model



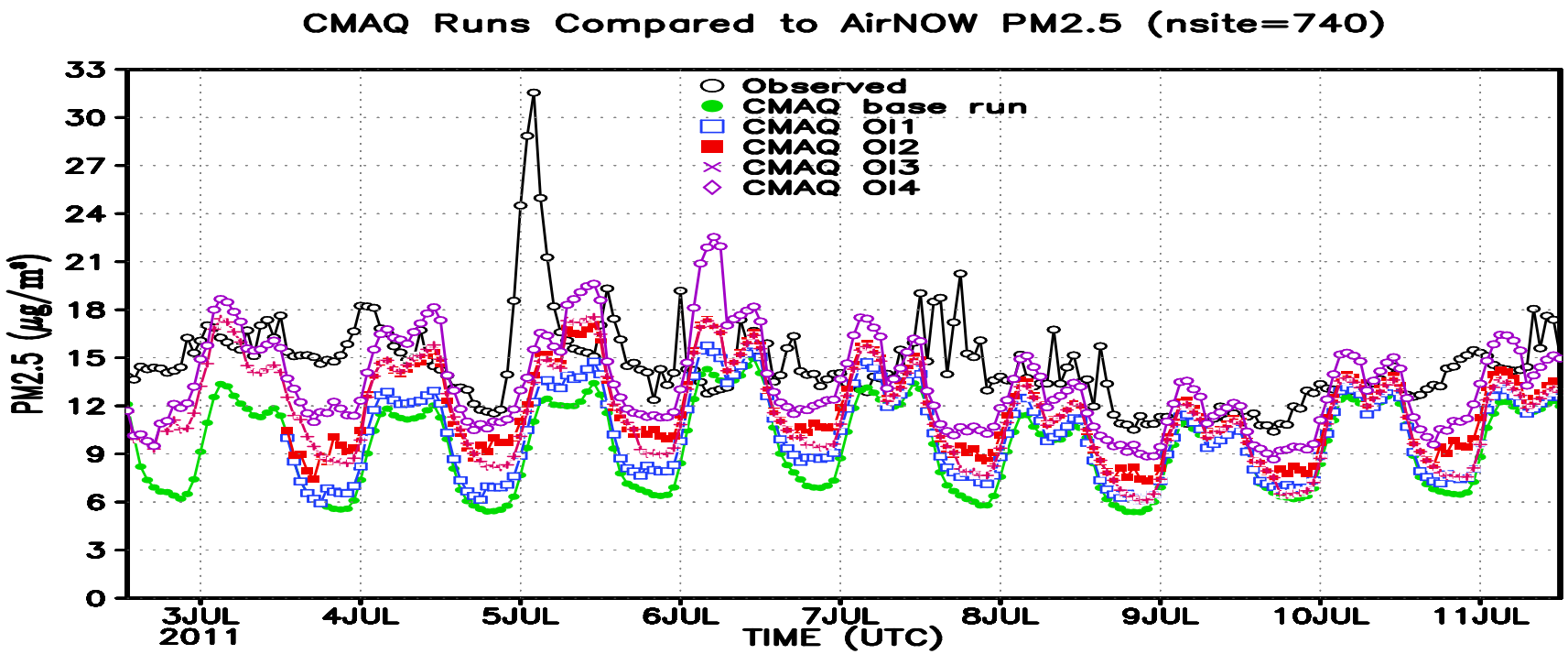



**Hourly Statistic Results for CONUS 12Z, 07/06/2011- 12Z, 07/07/2011**

| Cases | $O_3$ | PM2.5 |
|---|---|---|
| Base case | R=0.53 MB=2.54 | R=0.23 MB= -7.14 |
| OI1 | R=0.56 MB=2.36 | R=0.24 MB= -2.63 |
| OI2 | R=0.58 MB=1.06 | R=0.39 MB= -1.33 |
| OI3 | R=0.52 MB=2.08 | R=0.36 MB= -1.89 |
| OI4 | R=0.56 MB=1.55 | R=0.40 MB= -0.11 |



| | Aqua-MODIS | Suomi NPP-VIIRS |
|---|---|---|
| **Orbit altitude** | 705 km | 824 km |
| **Equator crossing time** | 13:30 LT | 13:30 LT |
| **Granule size** | 5 minutes | 86 seconds |
| **Swath** | 2330 km | 3040 km |
| **Sensor zenith angle range** | ±64° | ±70° |
| **Valid solar zenith angle (for high quality)** | < 82° | ≤ 65° |
| **Sensor bands used for aerosol retrieval** | 0.412, 0.466, 0.554, 0.646, 0.856, 1.24, 1.63, 2.11 μm | 0.412, 0.445, 0.488, 0.555, 0.672, 0.746, 0.865, 1.24, 1.61, 2.25 μm |
| **Pixel size, nadir** | 0.25, 0.5, and 1 km | 0.375 and 0.75 km |
| **Bow-tie effects** | Yes | No |
| **Product resolution, nadir** | 10 km | 6 km (AOT and Angstrom exponent)<br>0.75 km (Suspended matter) |
| **Product resolution, edge** | 40 km | 10 km (AOT and Angstrom exponent)<br>1.2 km (Suspended matter) |
| **Products, land (vegetated regions)** | AOT (Dark Target Approach) | AOT, Angstrom exponent, Suspended matter |
| **Product, land (deserts, urban regions)** | AOT, Angstrom exponent, Dust single scattering albedo (Deep Blue Approach) | None |
| **Products, ocean** | AOT (7 wavelengths), Size (fine mode fraction) | AOT (11 wavelengths), Angstrom exponent, Suspended matter |
| **Global gridded product** | Level 3 daily, 8-day, monthly mean | None |

Courtesy: C. Hsu et al.

## Summary

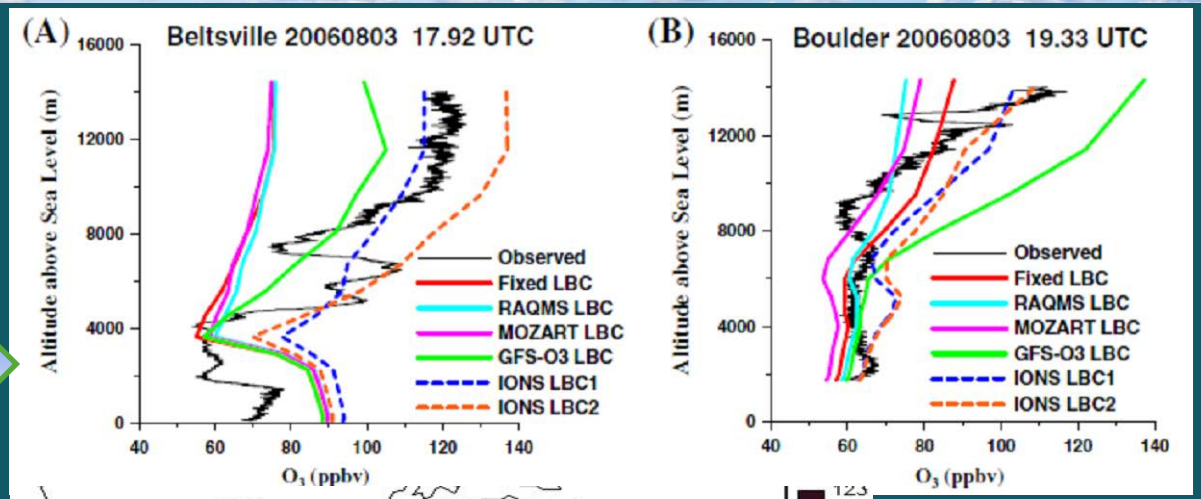
- The optimal interpolation (OI) assimilation combining AirNOW surface measurements and VIIRS/MODIS AOD yielded significantly better results than the base case, especially on reducing mean biases, and the OI technique is sensitive to its uncertainty setting.
- The assimilation relies on the temporally and spatially available measurement data, which is always limited.
- Some of our assumptions, such as the aerosol speciation ratios and vertical distribution, need to be further verified.

# *EXTRA SLIDES*

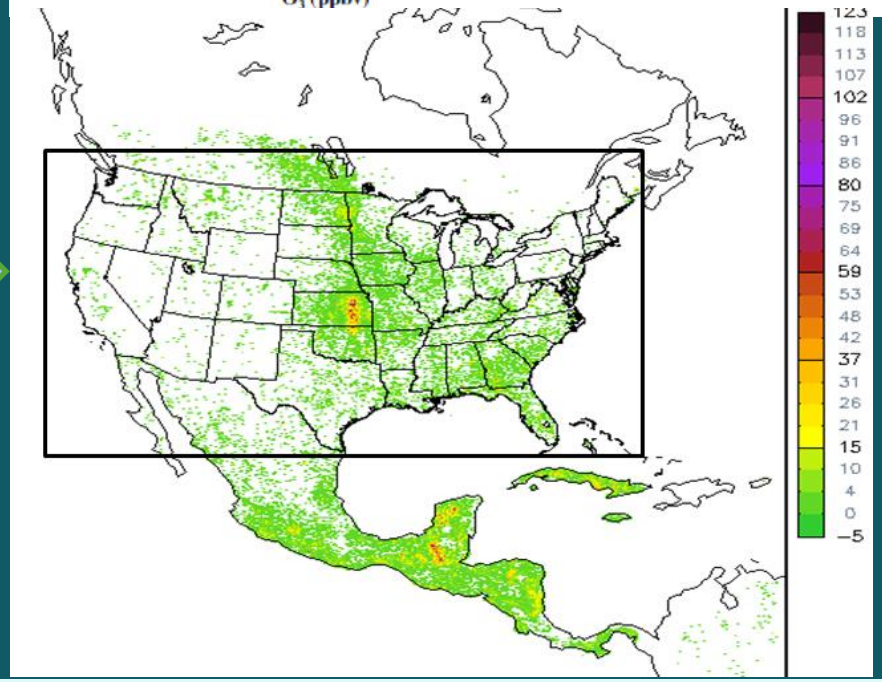
Contact:
Pius.Lee@noaa.gov
http://www.arl.noaa.gov/

**Next data set**
**To be include**
**In data assimilation?**

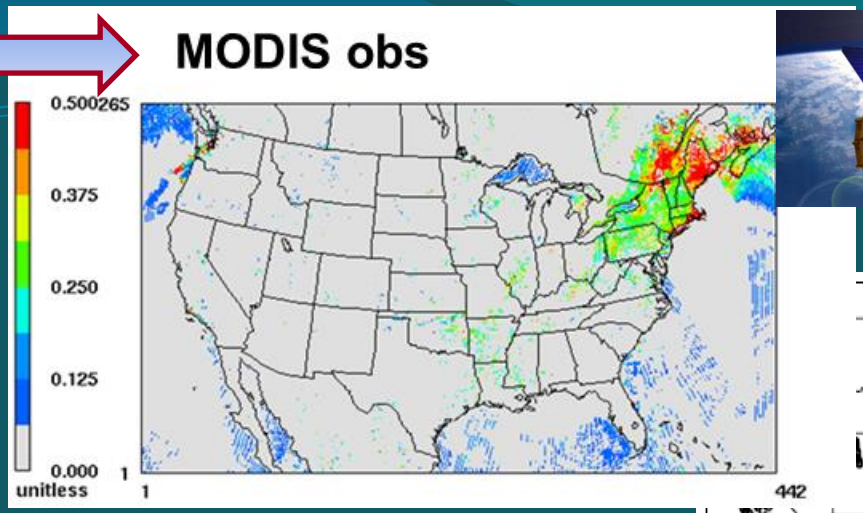
**MLS & MODIS AOD from global Model: e.g., RAQMS**



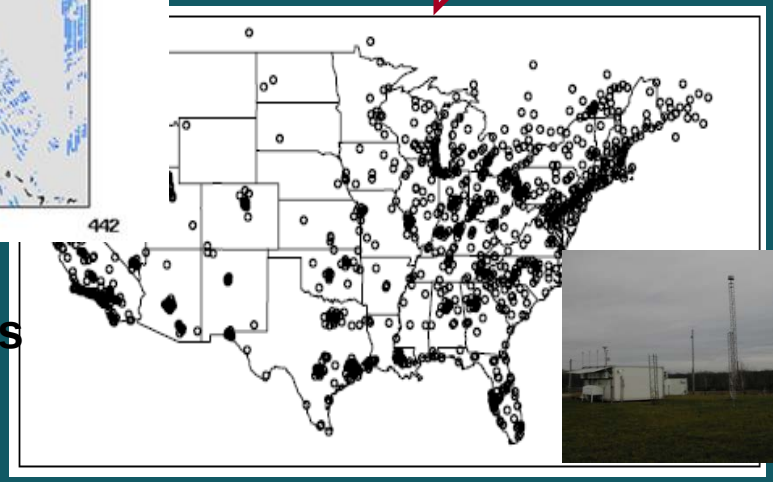

**Exo-domain as well as endo-domain wild fires & prescribed burns**



# MODIS obs



# AIRNow



# Cloud-obs Photolysis rates

**GOES-MCIP INTERFACE**

Cloud transmissivity (calculated from satellite retrieved cloud albedo), cloud top pressure, and cloud fraction are prepared for input to MCIP

**MODIFIED MCIP**

GOES retrievals replaces MM5 cloud information being passed to CMAQ. Cloud fraction, transmissivity, cloud base and top heights are passed to CMAQ.

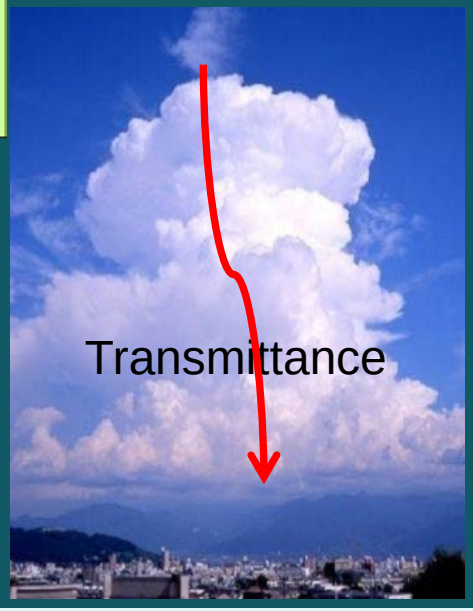
**PHOT in CMAQ**

In subroutine PHOT, clear sky photolysis rates will be adjusted for cloud cover based on GOES cloud fraction and cloud transmissivity information.

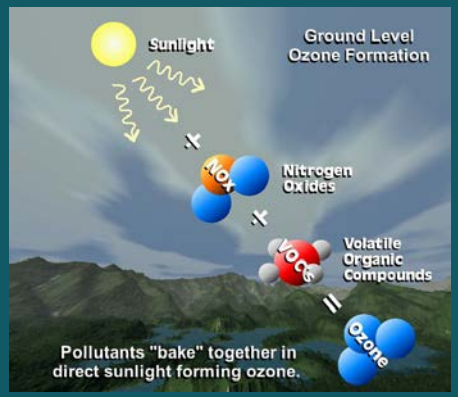
Interpolated in between.

Cloud Base According to Lifting Condensation Level

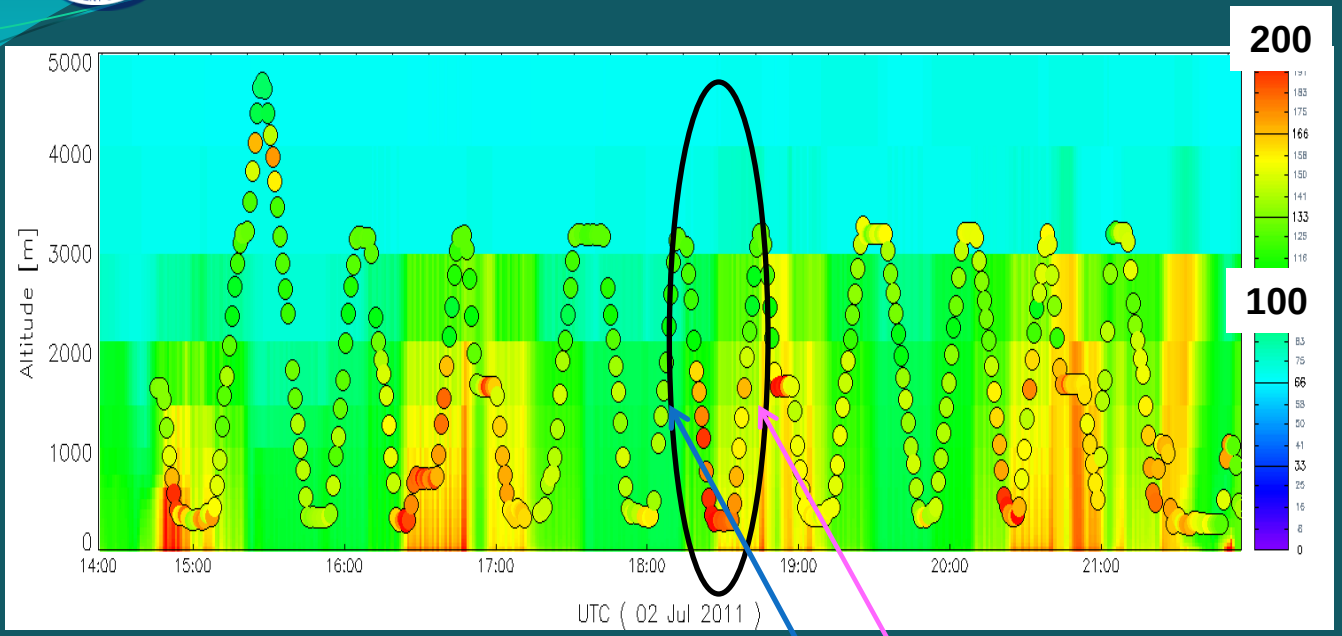
$$T_c = B / \ln\left[\frac{A\varepsilon}{wp_0}\left(\frac{T_0}{T_c}\right)^{1/\kappa}\right]$$




# Isoprene & PAR



# CO (ppb) along the P3 Flight – July 2 2011: AOD_DA case vs. Obs




P3 Three and a half loops:

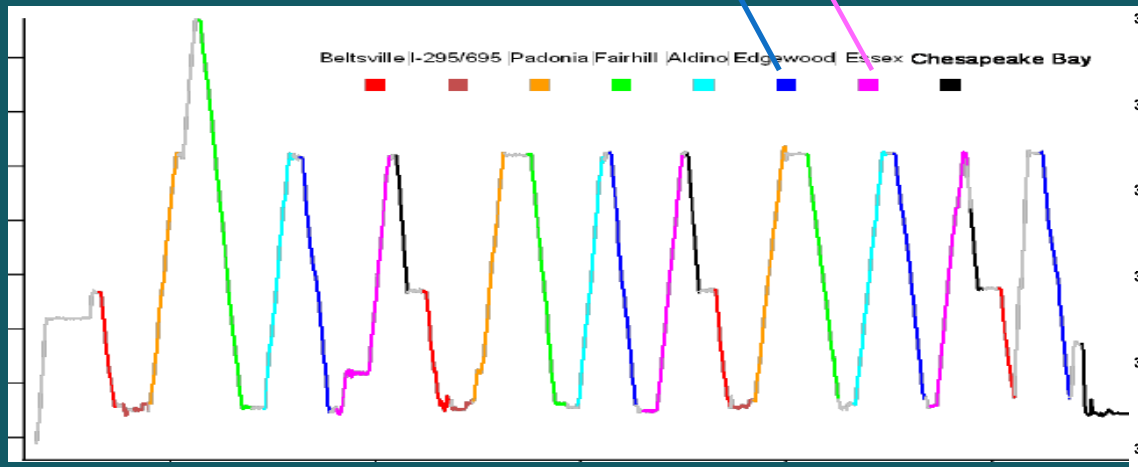
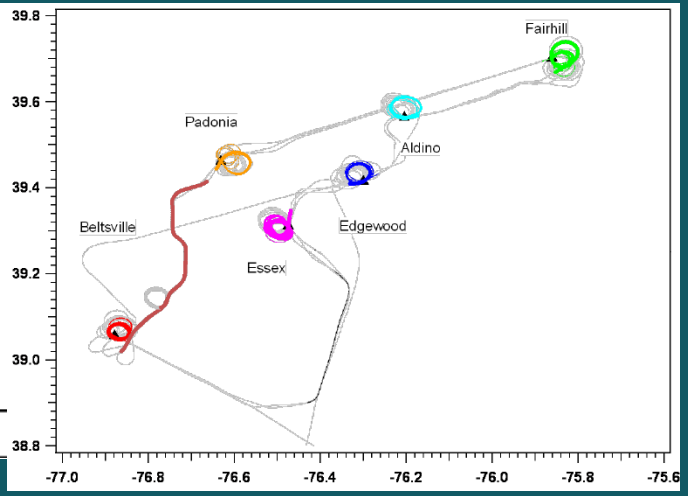
Beltsville

Padonia

Fairhill

Aldino

Edgewood

Essex

Chesapeake Bay