Impact of Assimilation of Satellite-derived AOD product on PM2.5 Predictions in a Regional Community Multiscale Air Quality (CMAQ) Model

Shobha Kondragunta (NESDIS/STAR)
Qiang Zhao (IMSG)

Acknowledgements

Jeff McQueen, Pius Lee, and Sarah Lu for providing access to NCEP computing resources and required input files to do CMAQ simulations

Outline

- **Air Quality Model**
  - **CMAQ**
- **Satellite data**
  - **GOES Aerosol Optical Depth (AOD) Retrievals**
  - **MODIS Aerosol Optical Depth (AOD) Retrievals**
- **Data Assimilation Method**
  - **Cressman analysis**
- **Model Simulations**
  - **Urban/Industrial haze episode**
  - **Wildfire smoke aerosol episode**
- **Verification with**
  - **AERONET AOD Observations**
  - **AIRNOW PM2.5 Observations**
  - **CALIPSO vertical profile**

CMAQ

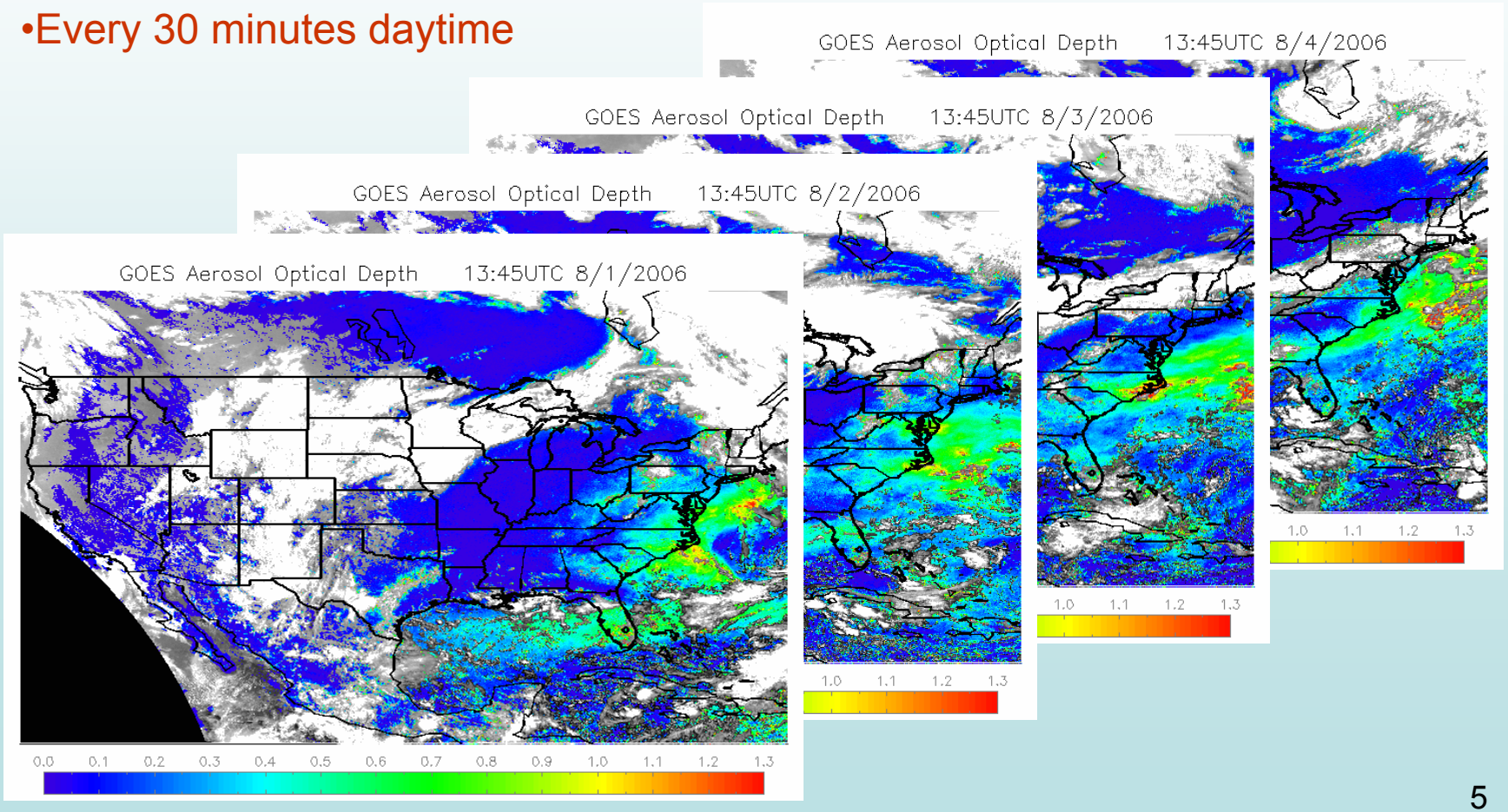
- A copy of NCEP developmental PM version of air quality forecast system (no updates since 2006)
- CONUS (5x) domain: 442x265 with 12 km resolution
- Vertical: 22 layers
- Aerosol variables: 26

Species description	Variable Name
Accumulation mode sulfate mass	ASO4J
Aitken mode sulfate mass	ASO4I
Accumulation mode ammonium mass	ANH4J
Aitken mode ammonium mass	ANH4I
Accumulation mode nitrate mass	ANO3J
Aitken mode nitrate mass	ANO3I
Accumulation mode anthropogenic secondary organic mass	AORGAJ
Aitken mode anthropogenic secondary organic mass	AORGAI
Accumulation mode primary organic mass	AORGPAJ
Aitken mode primary organic mass	AORGPAI
Accumulation mode secondary biogenic organic mass	AORGBJ
Aitken mode secondary biogenic organic mass	AORGBI
Accumulation mode elemental carbon mass	ACEJ
Aitken mode elemental carbon mass	ACEI
Accumulation mode unspecified anthropogenic mass	A25J
Aitken mode unspecified anthropogenic mass	A25I
Coarse mode unspecified anthropogenic mass	ACORS
Coarse mode marine mass	ASEAS
Coarse mode soil-derived mass	ASOIL
Aitken mode number	NUMATKN
Accumulation mode number	NUMACC
Coarse mode number	NUMCOR
Aitken mode surface area	SRFATKN
Accumulation mode surface area	SRFACC
Accumulation mode water mass	AH2OJ
Aitken mode water mass	AH2OI

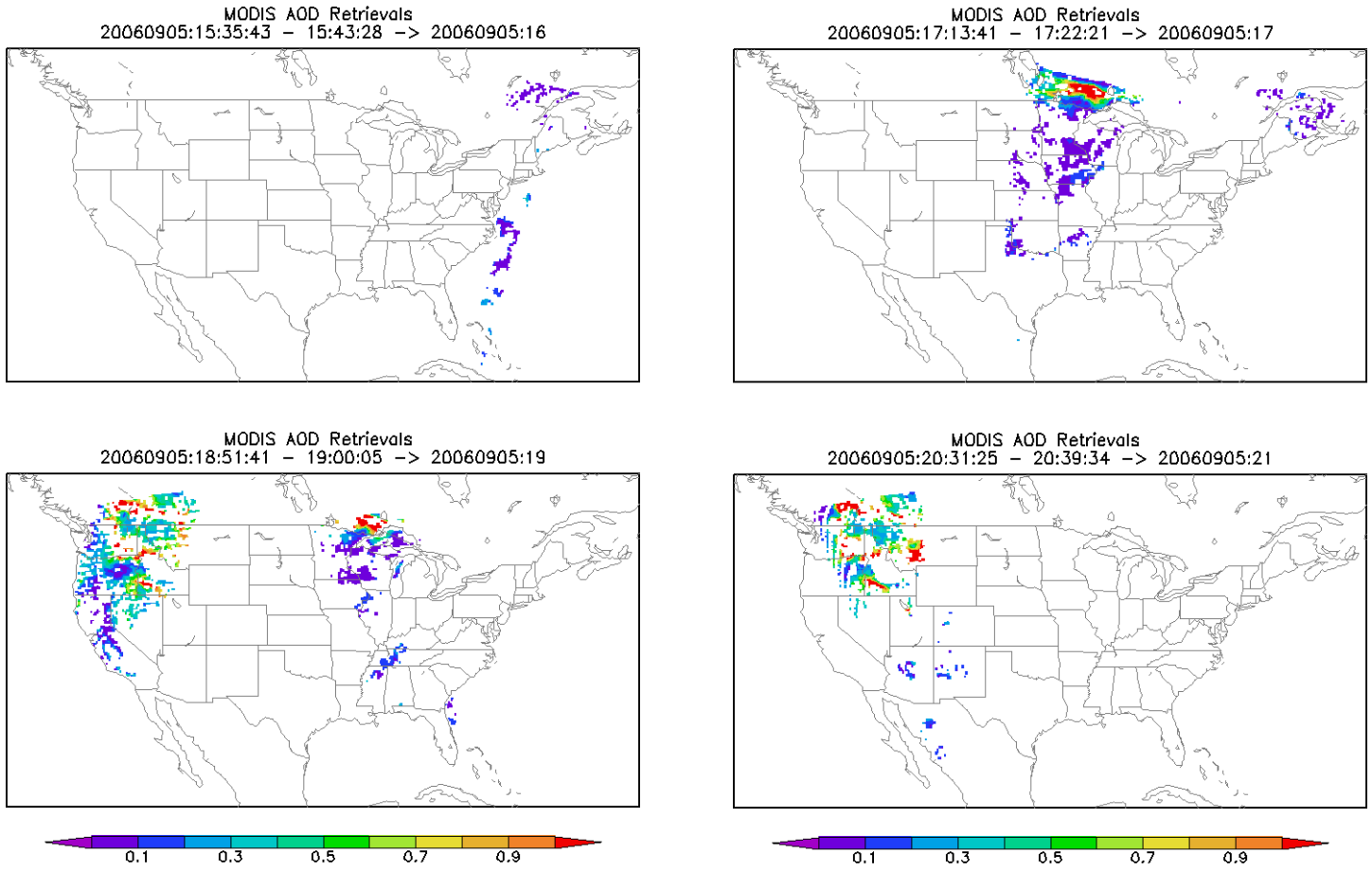
- ~7×10^7 aerosol observations required for IC !!!
- Satellite AOD provides 442*265~10^5 at most !!!

GASP AOD

- 4 km X 4 km horizontal resolution
- Every 30 minutes daytime

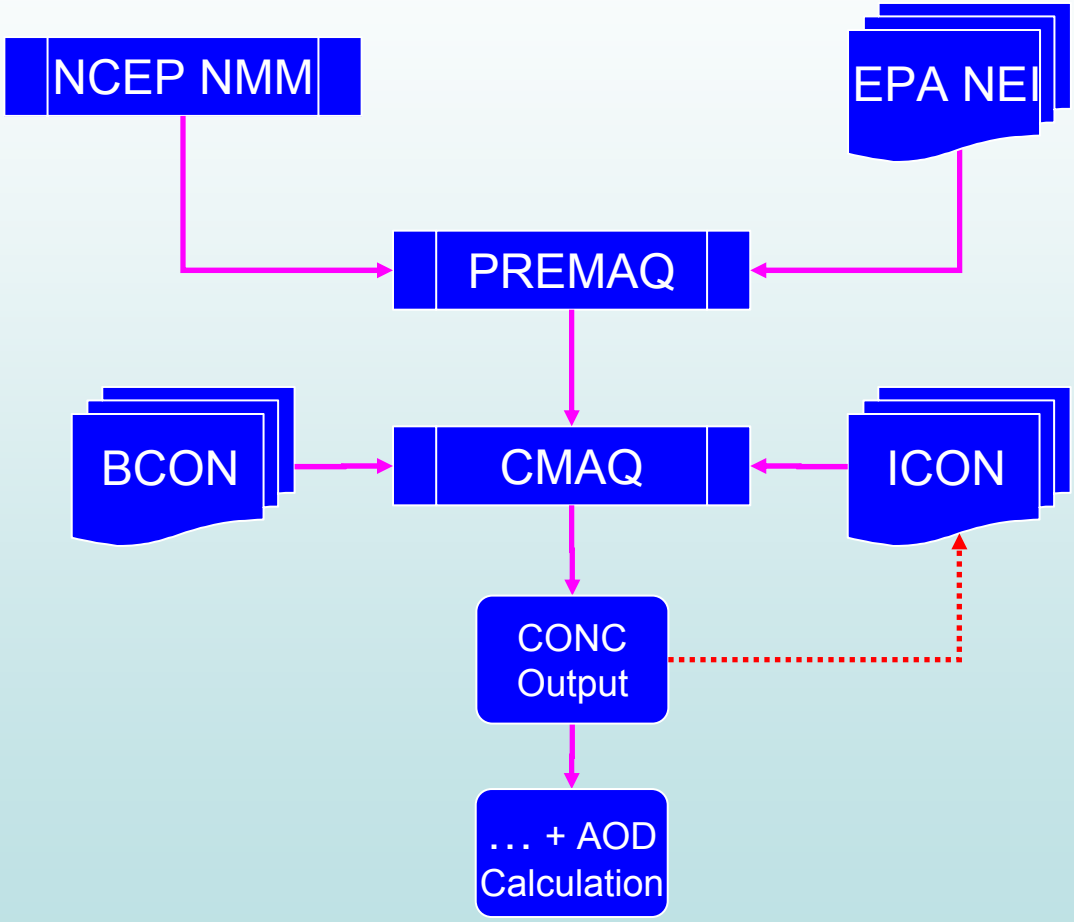


MODIS AOD

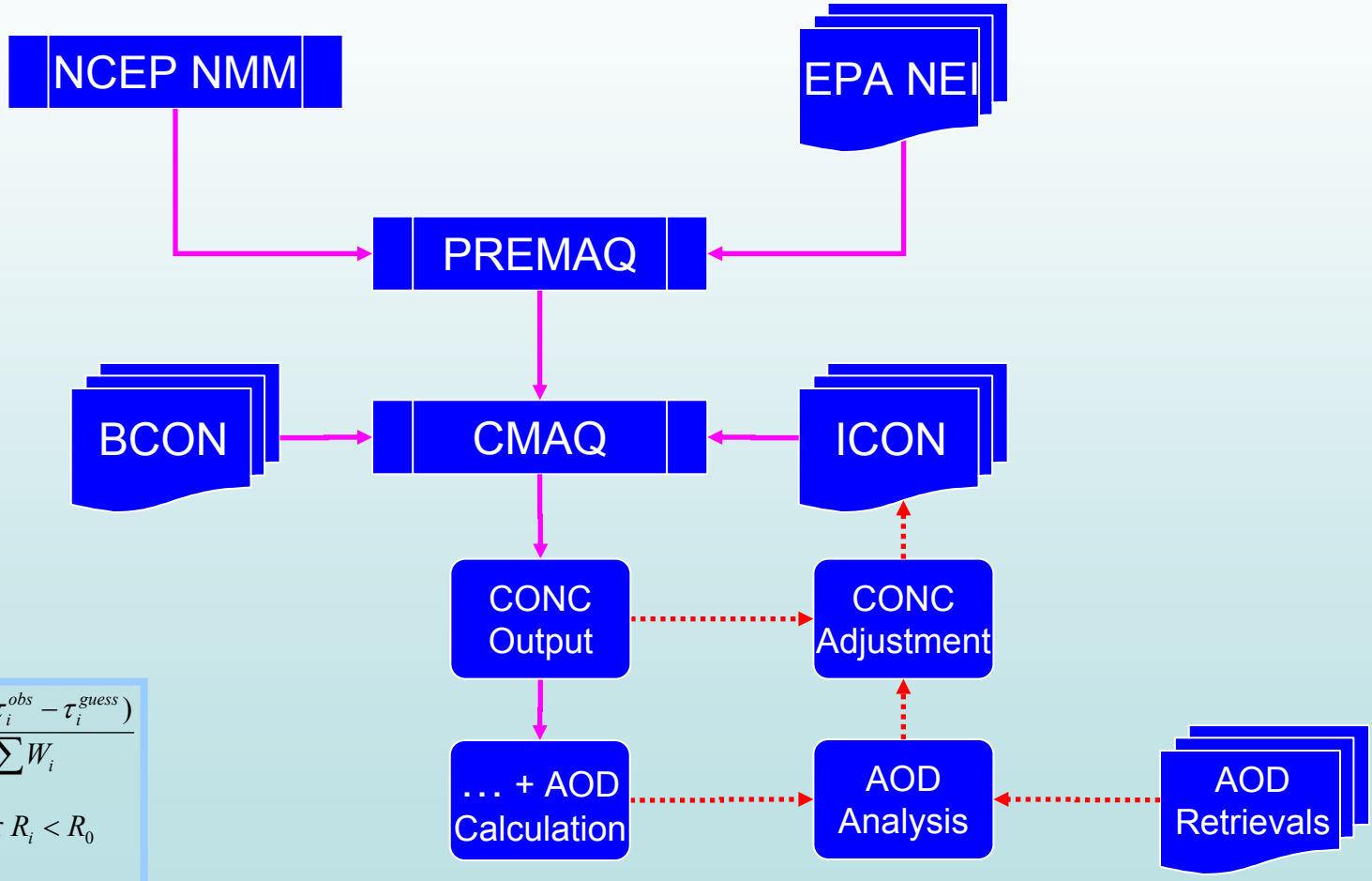


- More accurate AOD retrievals from advanced instruments
- Limited temporal resolution

Schematics of AQF System



Schematics of AQF System

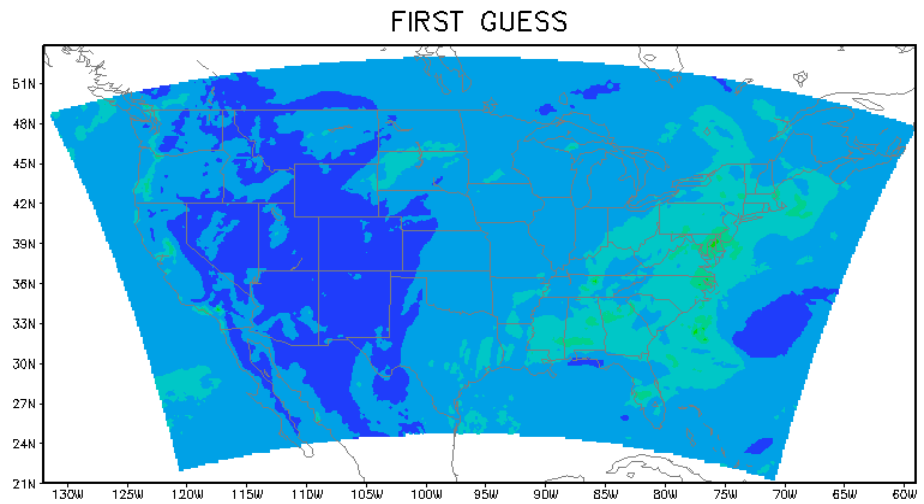


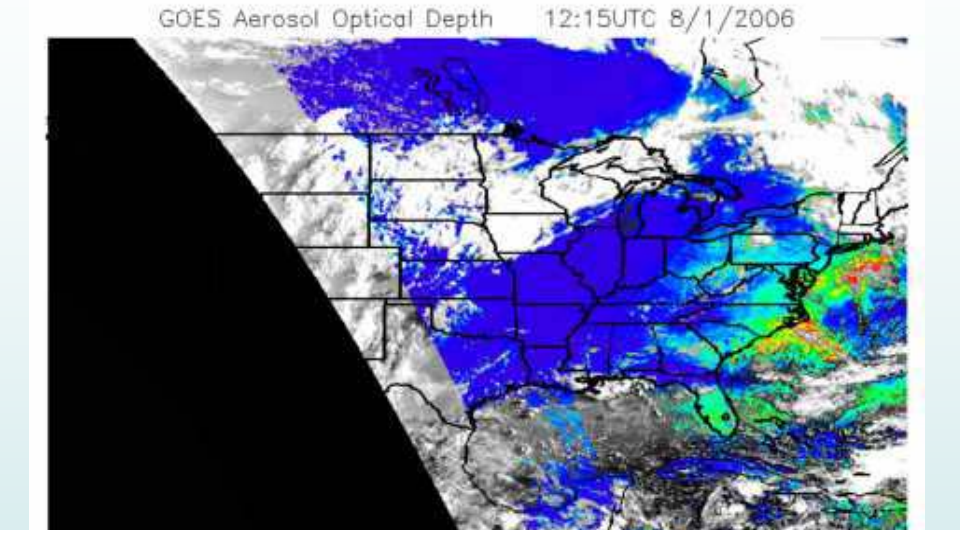
$$\tau^{ana} = \tau^{guess} + \frac{\sum W_i(\tau_i^{obs} - \tau_i^{guess})}{\sum W_i}$$

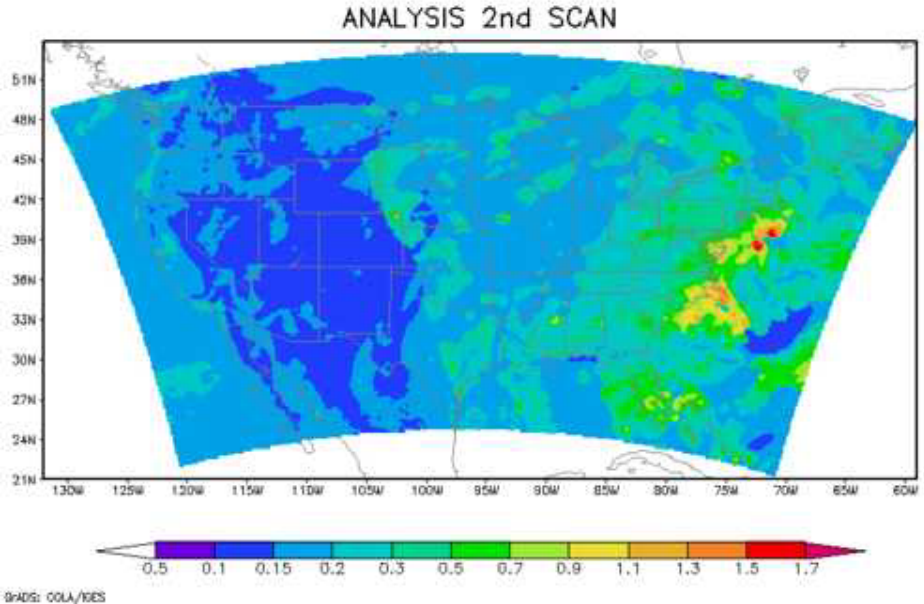
$$W_i = \frac{R_0^2 - R_i^2}{R_0^2 + R_i^2} \quad \text{for } R_i < R_0$$

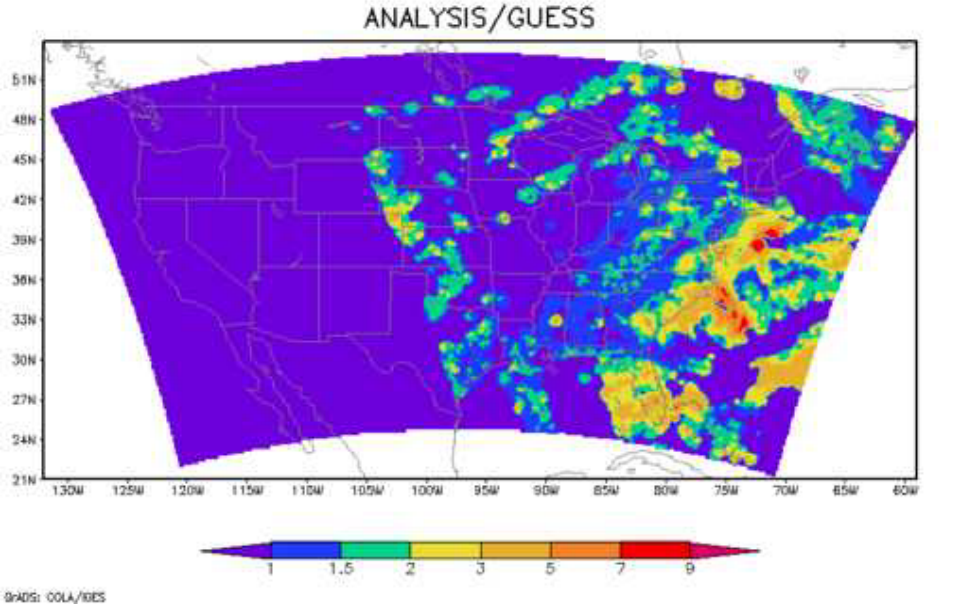
$$W_i = 0 \quad \text{for } R_i \geq R_0$$

An Example of AOD Analysis









Aerosol Concentrations Adjustment

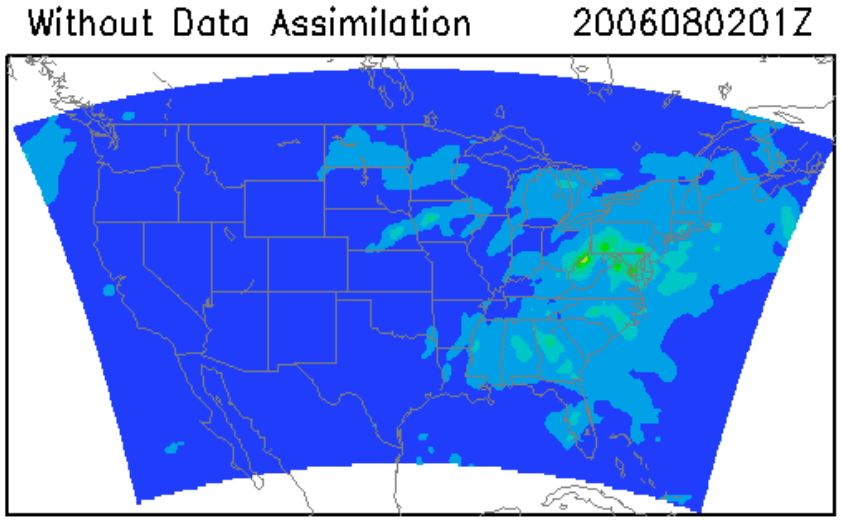
$$C^{ana} = C^{guess} \frac{\tau^{ana}}{\tau^{guess}}$$

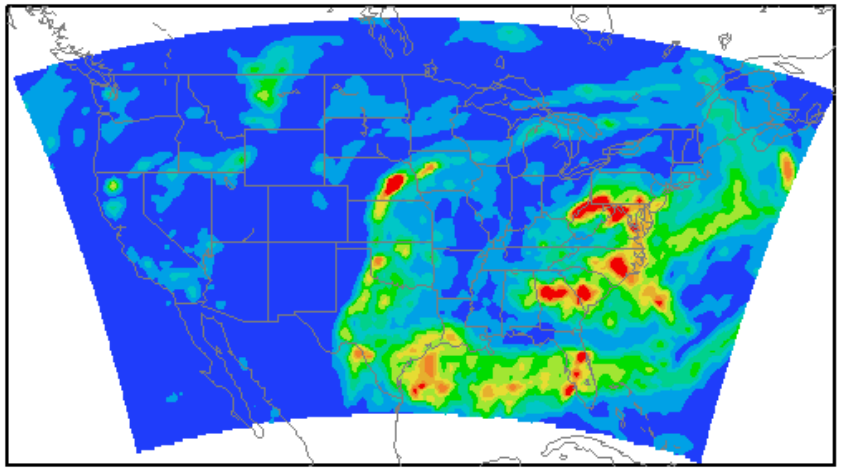
• Number, surface area and mass concentrations of all aerosol species in all layers are adjusted the same way, so that **the size, type and vertical distributions from the first guess are all kept the same**

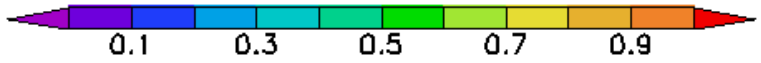
Eastern U.S. Urban/Industrial Haze Episode

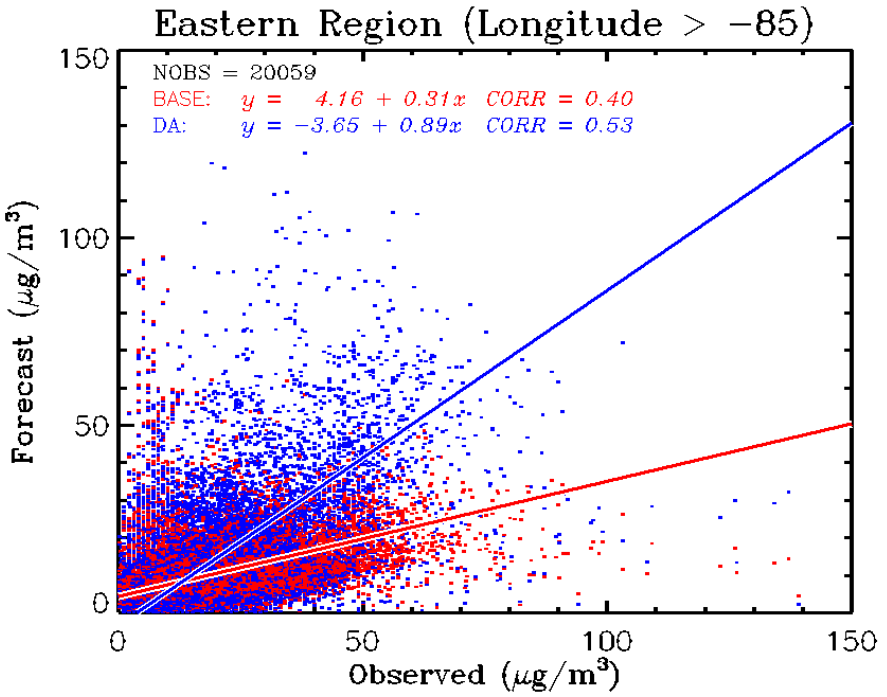
- July 30-August 6, 2006
- Eastern US
- Hot and humid weather
- Industrial Haze
  - Ozone and PM violations

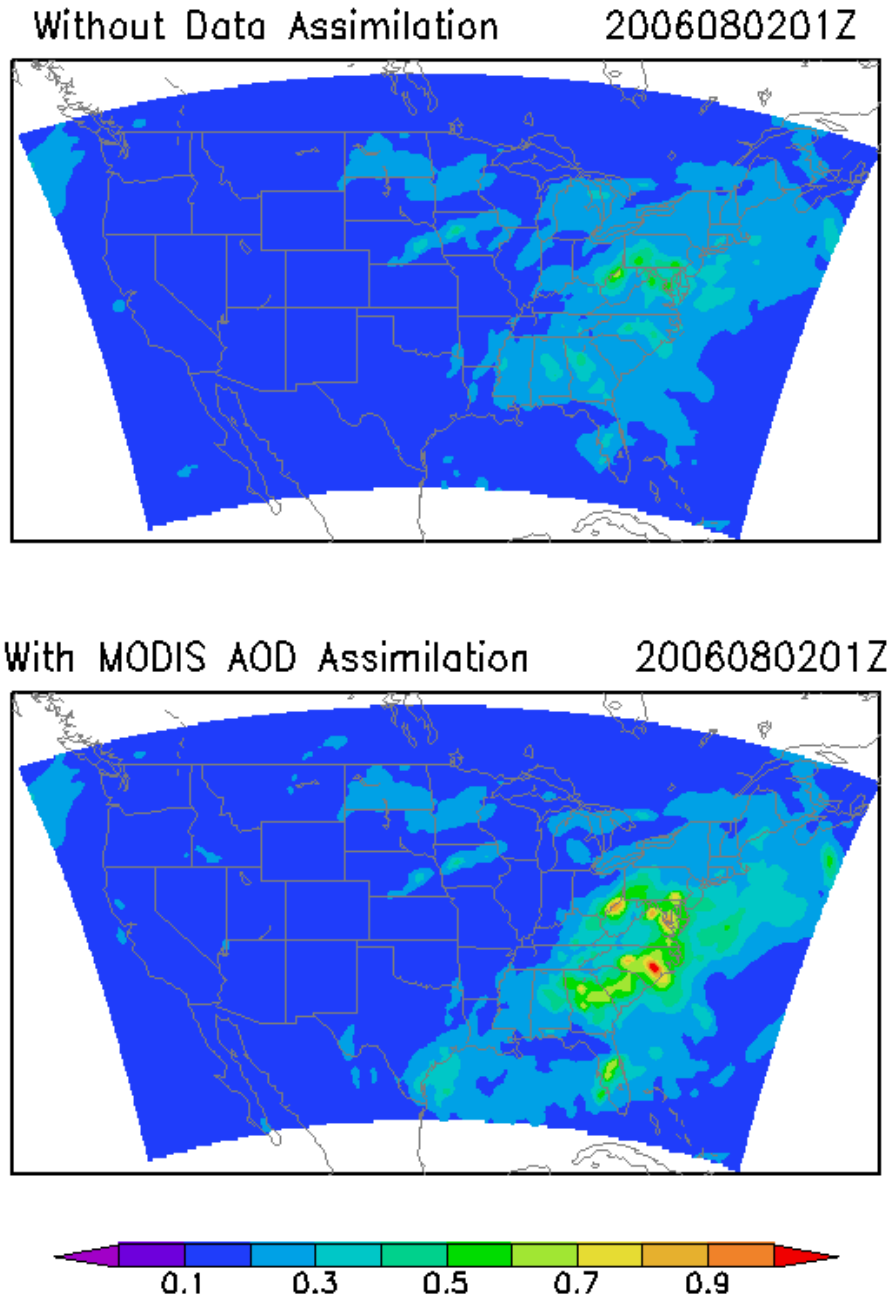
Image source, UMBC smog blog (http://alg.umbc.edu/usaq/images/20060801img.jpg)

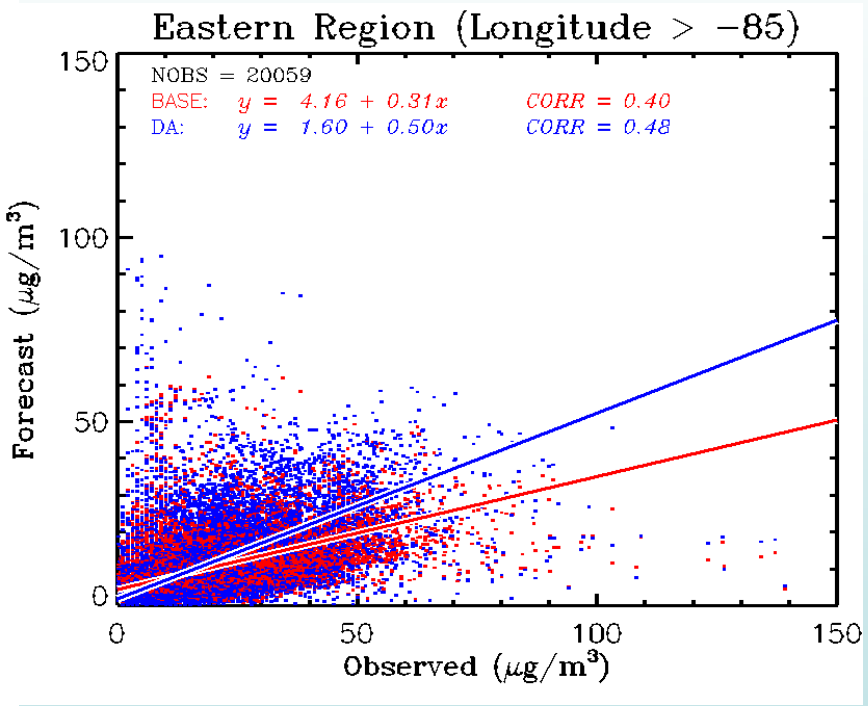

Without Data Assimilation 20060802012


With GOES AOD Assimilation 20060802012


0.1
0.3
0.5
0.7
0.9

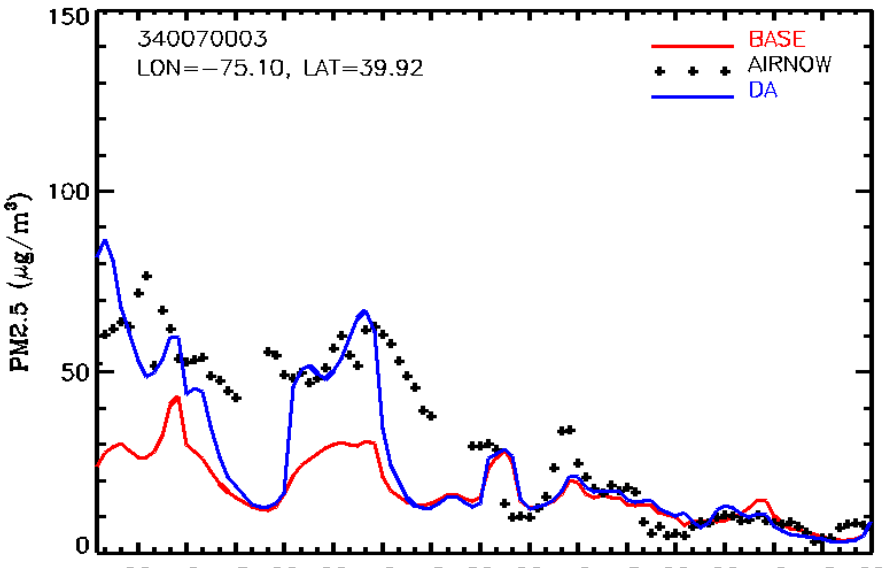

Eastern Region (Longitude > −85)
NOBS = 20059
BASE: y = 4.16 + 0.31x CORR = 0.40
DA: y = −3.65 + 0.89x CORR = 0.53
Forecast (μg/m³)
Observed (μg/m³)
0
50
100
150

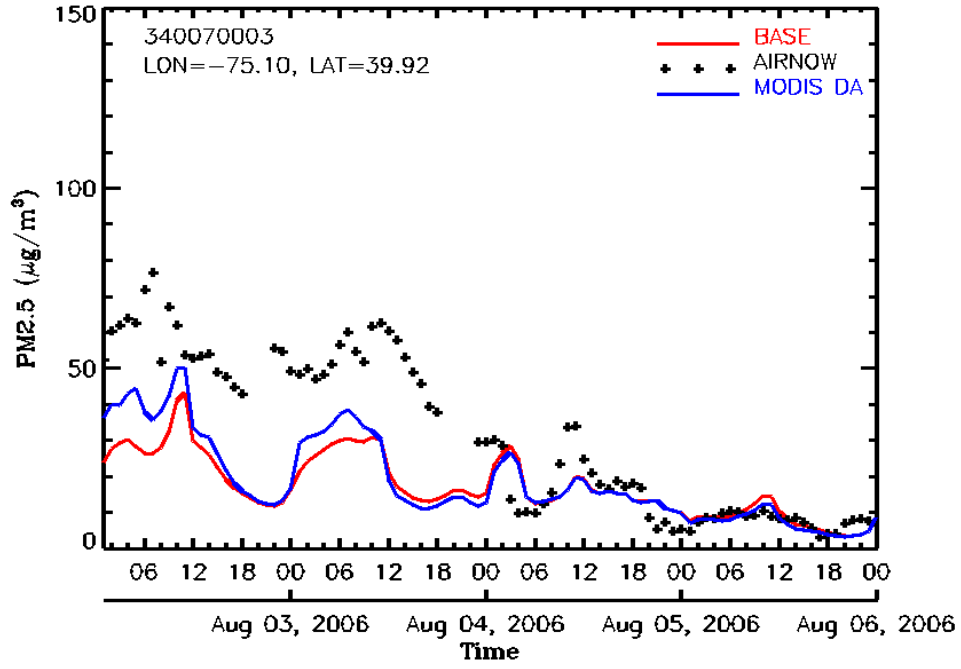

Without Data Assimilation 2006080201Z
With MODIS AOD Assimilation 2006080201Z
0.1
0.3
0.5
0.7
0.9

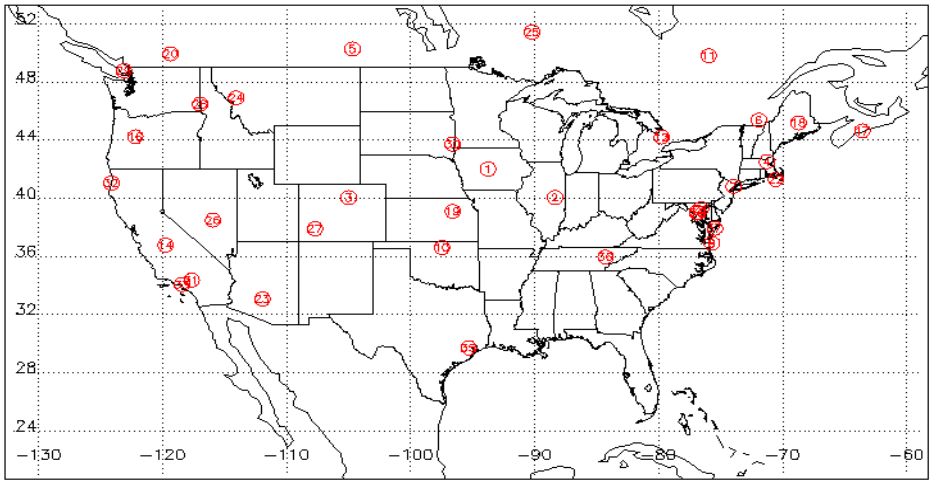

Eastern Region (Longitude > −85)
NOBS = 20059
BASE: y = 4.16 + 0.31x CORR = 0.40
DA: y = 1.60 + 0.50x CORR = 0.48
Forecast (μg/m³)
Observed (μg/m³)
0
50
100
150

Time Series of PM2.5

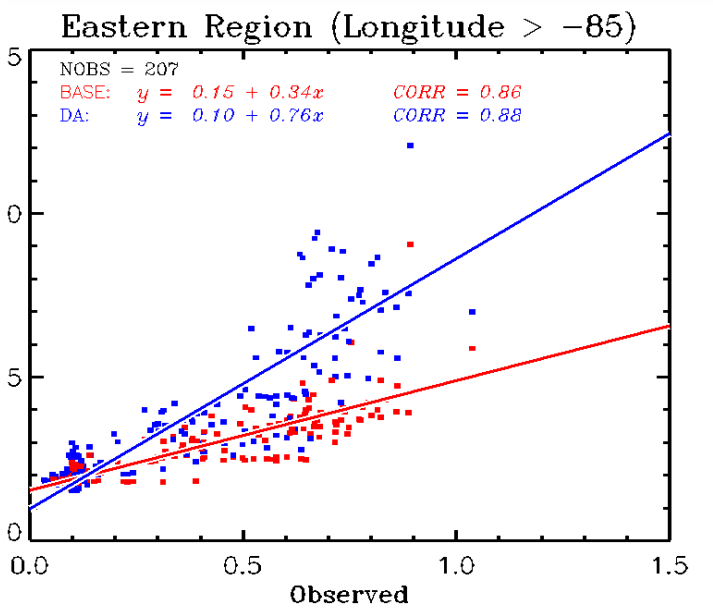
- Hourly GOES AOD assimilation improves model PM2.5 predictions compared to MODIS AOD assimilation
- Model doesn't retain the assimilated information in night time

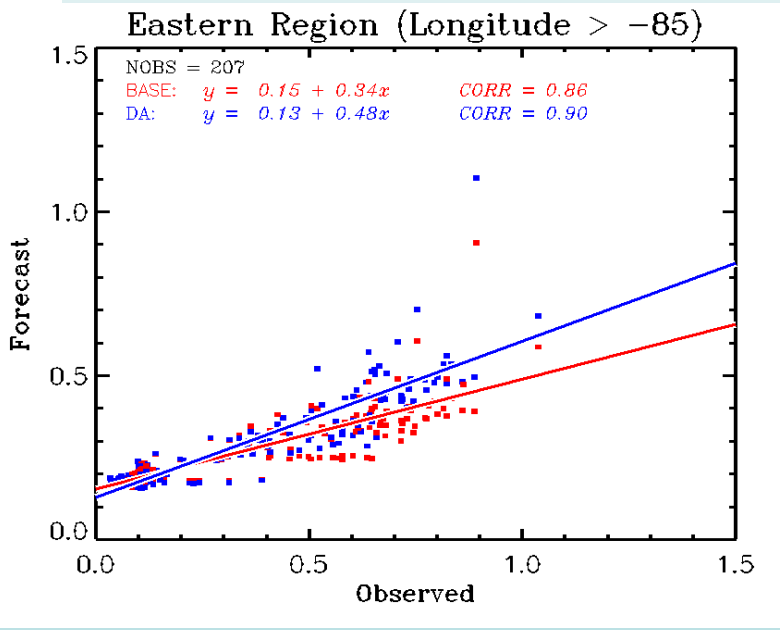






① Ames
② BONDVILLE
③ BSRN_BAO_Boulder
④ Billerica
⑤ Bratts_Lake
⑥ CARTEL
⑦ CCNY
⑧ COVE
⑨ COVE_SEAPRISM
⑩ Cart_Site
⑪ Chapais
⑫ Egbert
⑬ Egbert_X
⑭ Fresno
⑮ GSFC
⑯ HJAndrews
⑰ Halifax
⑱ Howland
⑲ KONZA_EDC
⑳ Kelowna
㉑ MD_Science_Center
㉒ MVCO
㉓ Maricopa
㉔ Missoula
㉕ Pickle_Lake
㉖ Railroad_Valley
㉗ Red_Mountain_Pass
㉘ Rimrock
㉙ Saturn_Island
㉚ Sioux_Falls
㉛ TABLE_MOUNTAIN_CA
㉜ Trinidad_Head
㉝ UCLA
㉞ USDA−BARC
㉟ Univ_of_Houston
㊱ Walker_Branch
㊲ Wallops





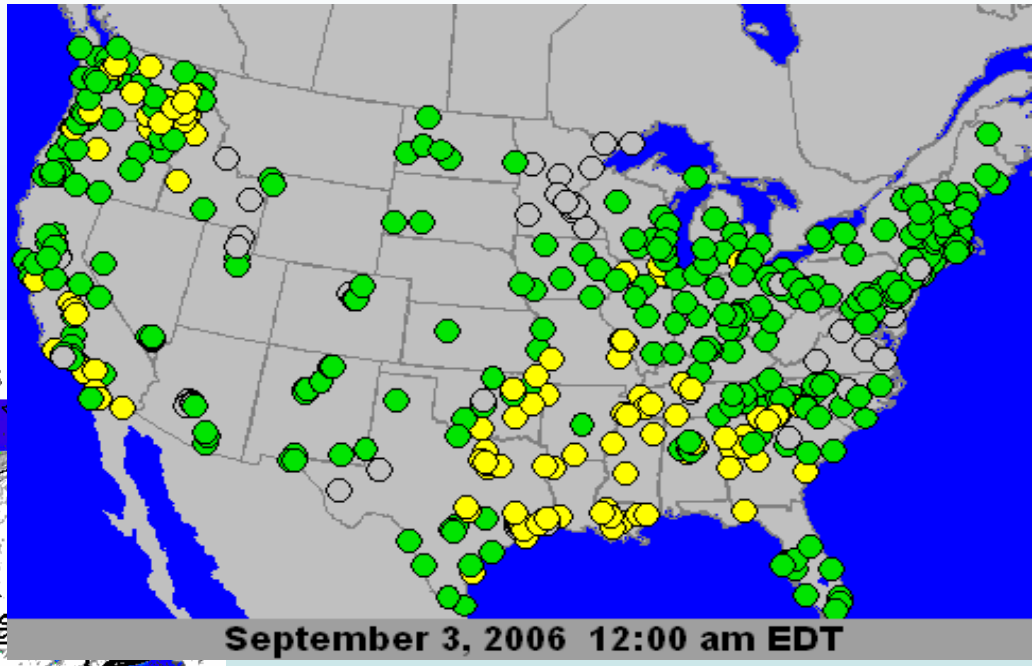
CMAQ VS AERONET (AOD)

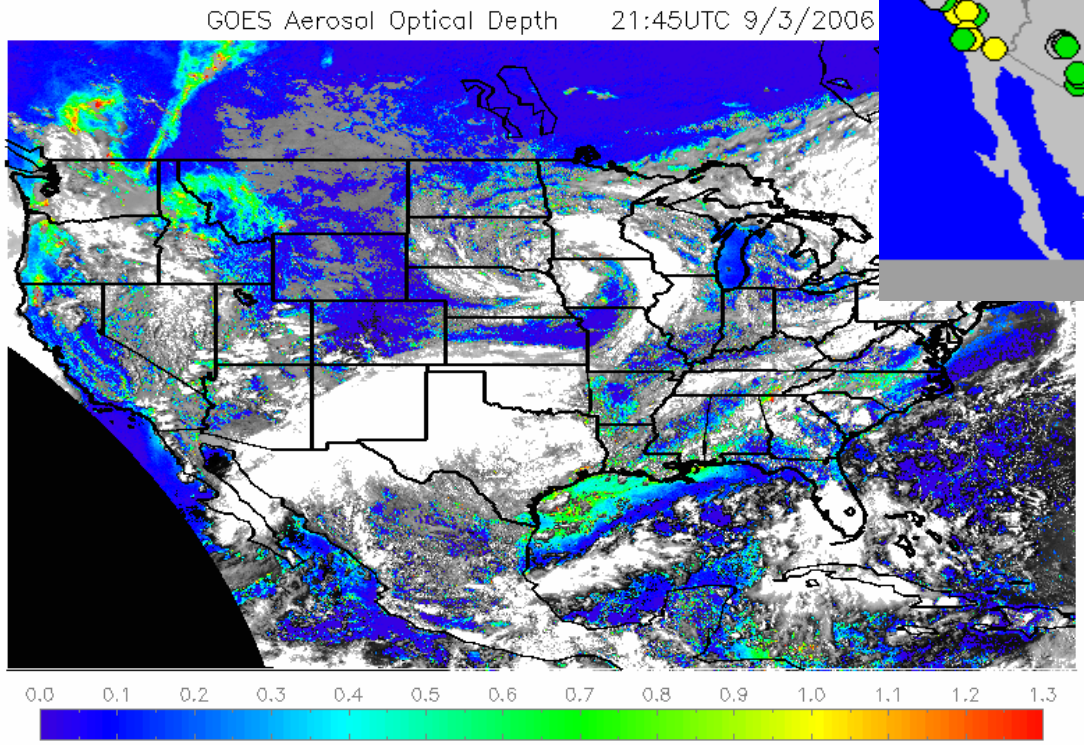
Top right panel: GOES assimilation

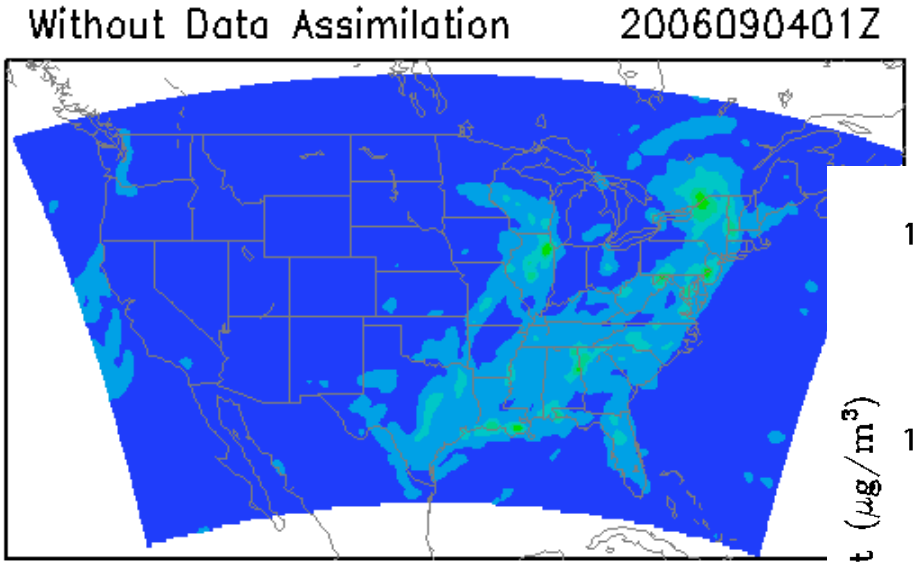
Bottom right panel: MODIS assimilation

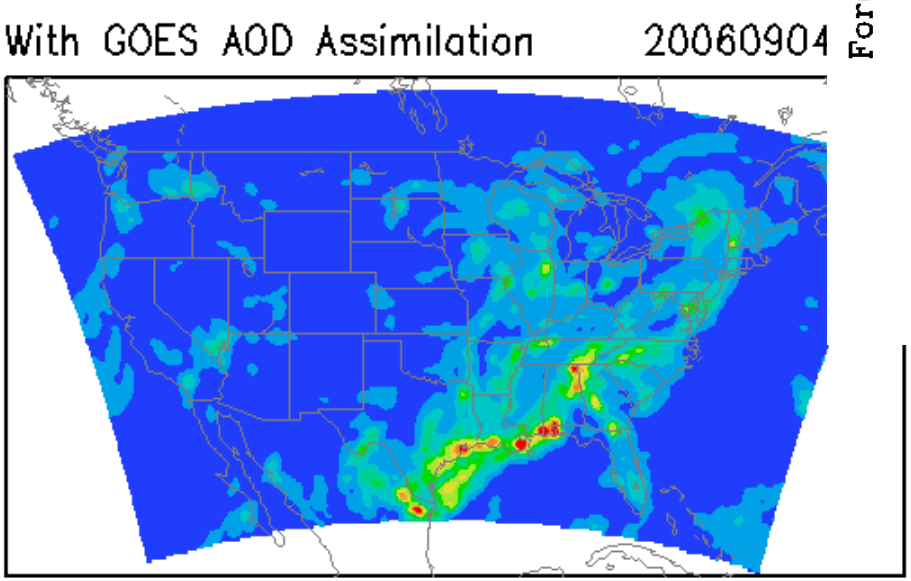
A Wildfire Episode

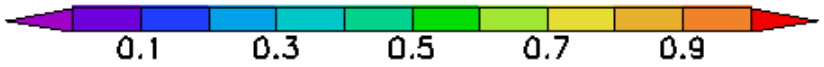
- Sept. 01-09, 2006
- US NW Region

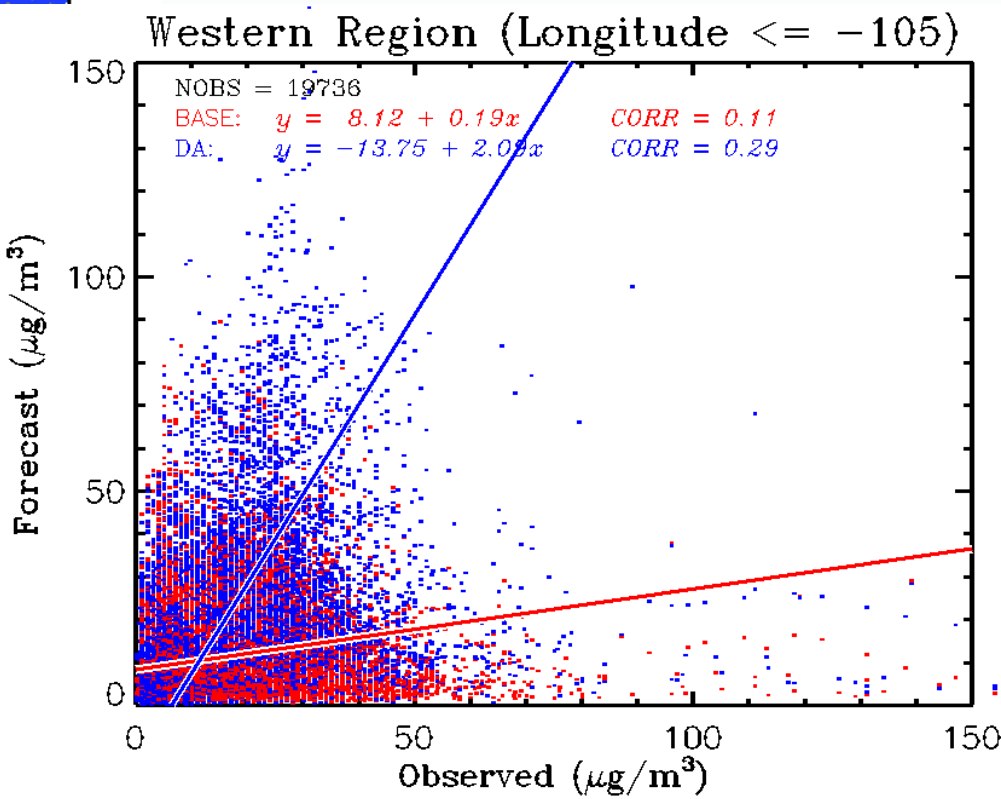


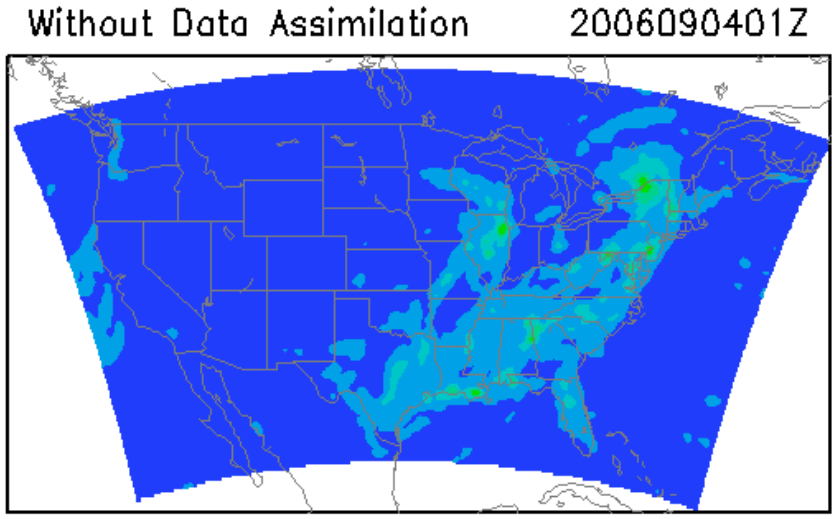


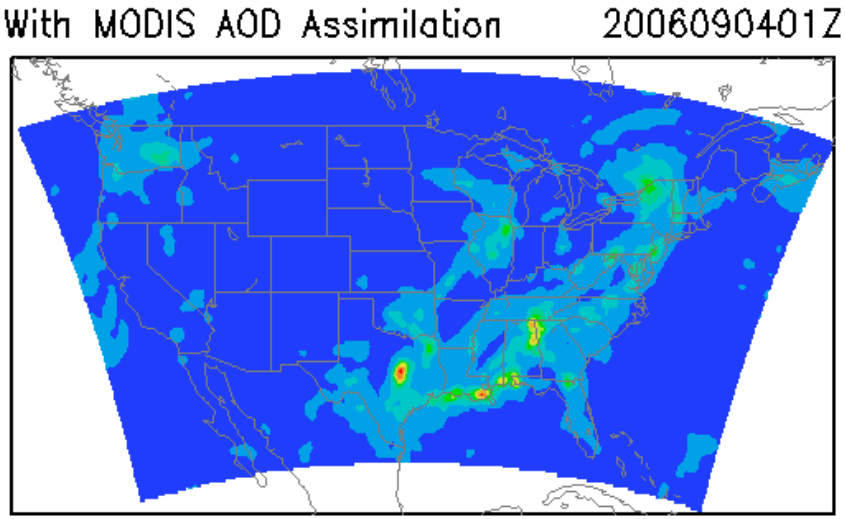

Without Data Assimilation 2006090401Z

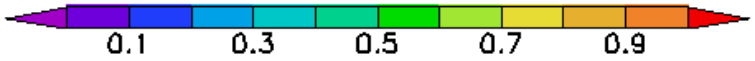

With GOES AOD Assimilation 20060904

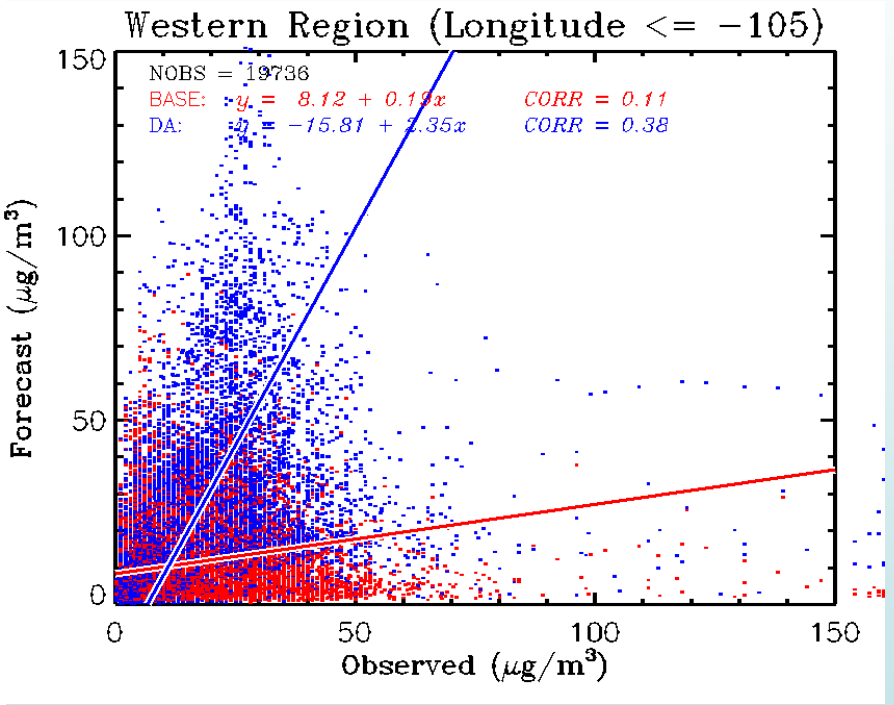

0.1
0.3
0.5
0.7
0.9

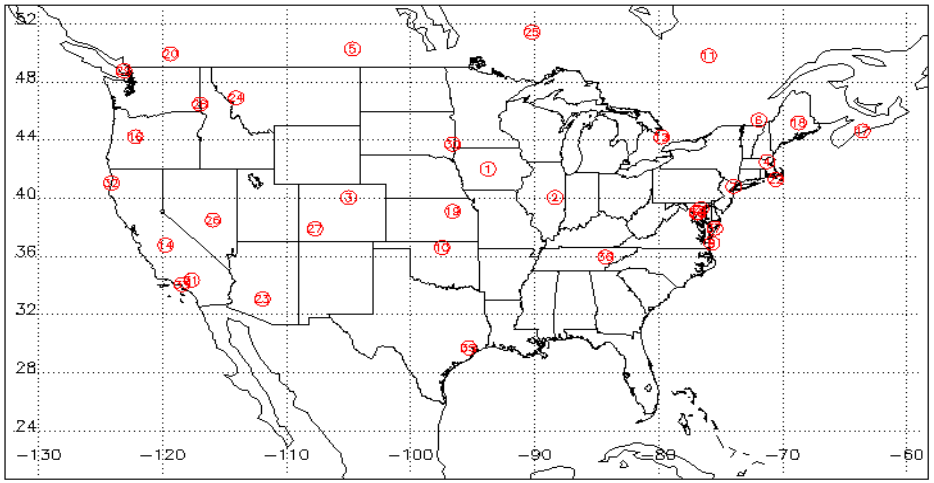

Western Region (Longitude <= −105)
NOBS = 19736
BASE: y = 8.12 + 0.19x
CORR = 0.11
DA: y = −13.75 + 2.08x
CORR = 0.29
Forecast (μg/m³)
Observed (μg/m³)
0
50
100
150


Without Data Assimilation 2006090401Z

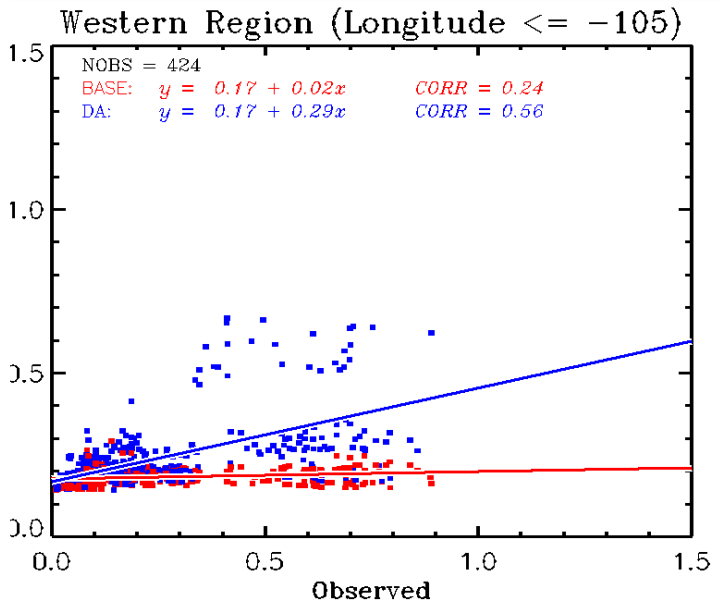

With MODIS AOD Assimilation 2006090401Z

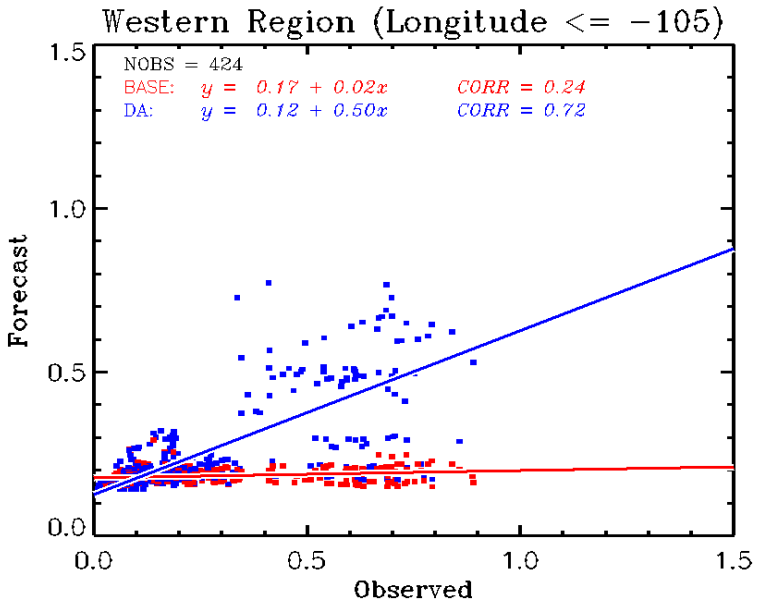

0.1
0.3
0.5
0.7
0.9


Western Region (Longitude <= −105)
NOBS = 19736
BASE: y = 8.12 + 0.19x
CORR = 0.11
DA: y = −15.81 + 2.35x
CORR = 0.38
Forecast (μg/m³)
Observed (μg/m³)
0
50
100
150



① Ames
② BONDVILLE
③ BSRN_BAO_Boulder
④ Billerica
⑤ Bratts_Lake
⑥ CARTEL
⑦ CCNY
⑧ COVE
⑨ COVE_SEAPRISM
⑩ Cart_Site
⑪ Chapais
⑫ Egbert
⑬ Egbert_X
⑭ Fresno
⑮ GSFC
⑯ HJAndrews
⑰ Halifax
⑱ Howland
⑲ KONZA_EDC
⑳ Kelowna
㉑ MD_Science_Center
㉒ MVCO
㉓ Maricopa
㉔ Missoula
㉕ Pickle_Lake
㉖ Railroad_Valley
㉗ Red_Mountain_Pass
㉘ Rimrock
㉙ Saturn_Island
㉚ Sioux_Falls
㉛ TABLE_MOUNTAIN_CA
㉜ Trinidad_Head
㉝ UCLA
㉞ USDA−BARC
㉟ Univ_of_Houston
㊱ Walker_Branch
㊲ Wallops



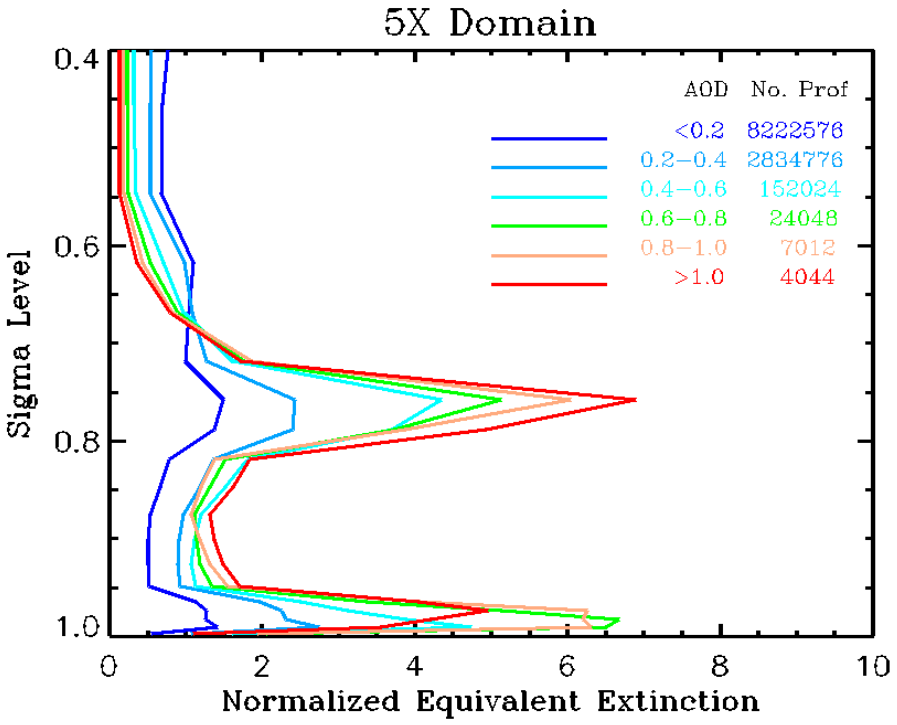


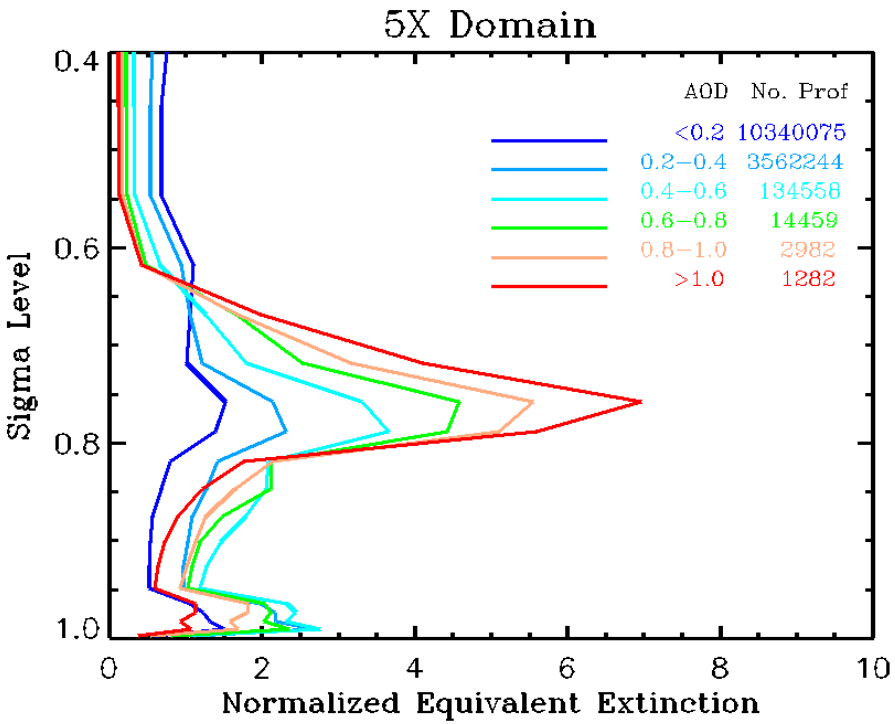
CMAQ VS AERONET (AOD)

Top right panel: GOES assimilation

Bottom right panel: MODIS assimilation

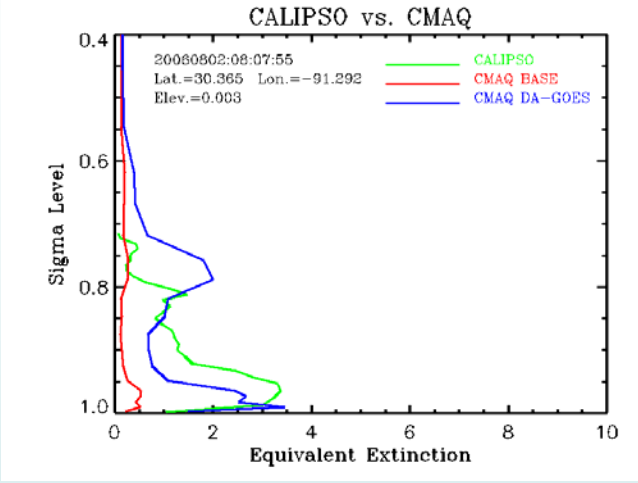
Aerosol Vertical Distribution

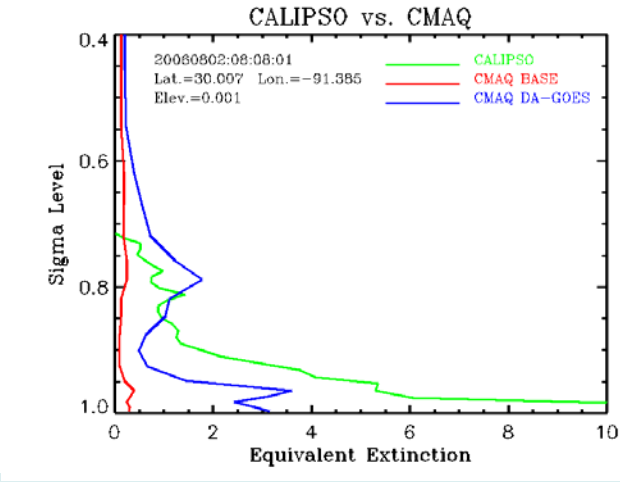


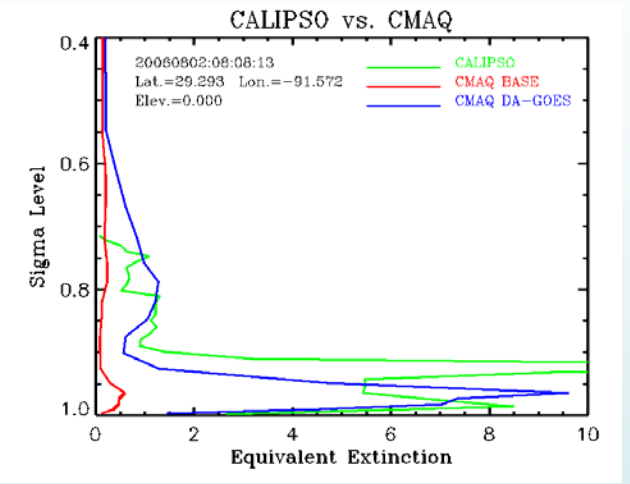


- In general, CMAQ aerosols have a gaussian distribution with two peaks. One near the surface and one near 850 mb
- This profile needs evaluation. Since aerosol sources are near the surface (with some exceptions), there should be a vertical gradient in aerosols with peak concentrations near the surface

Comparison of CMAQ and CALIPSO Vertical Profiles of Aerosols (Sulfate Episode)

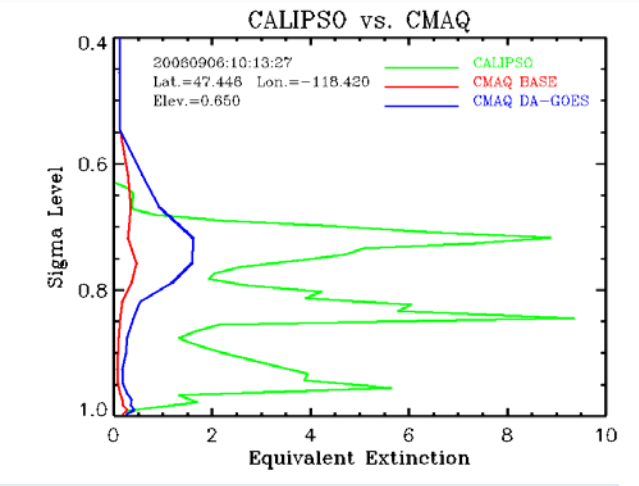


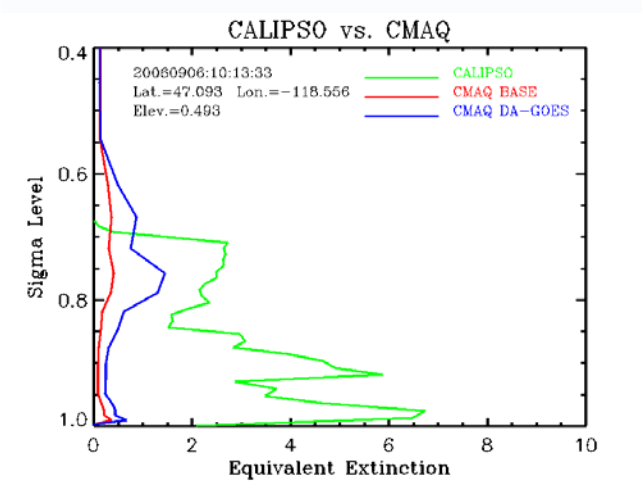


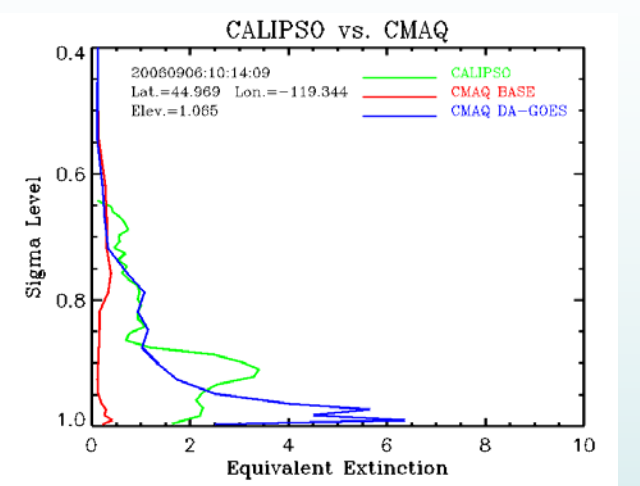


- Since assimilation tunes the profile by same ratio everywhere and aerosols were confined to the boundary layer, improvements at the surface are observed.

Comparison of CMAQ and CALIPSO Vertical Profiles of Aerosols (Wildfire Episode)



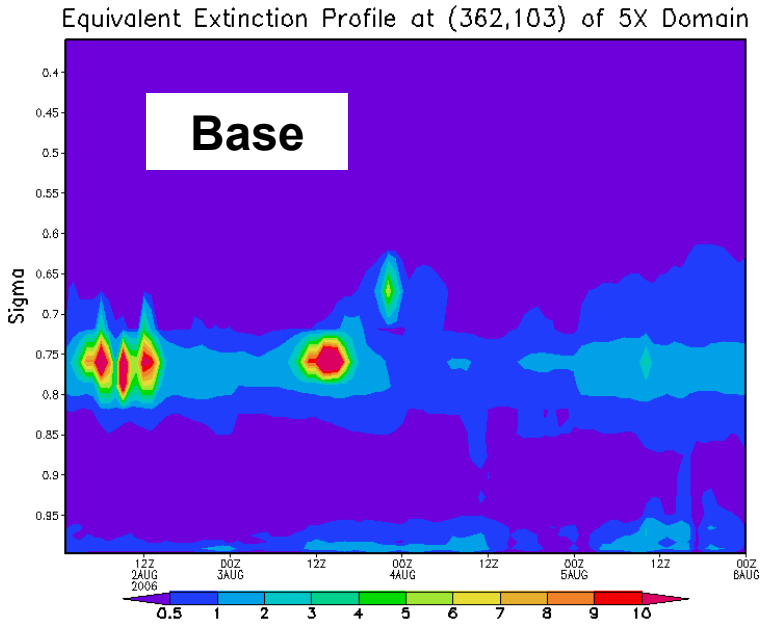


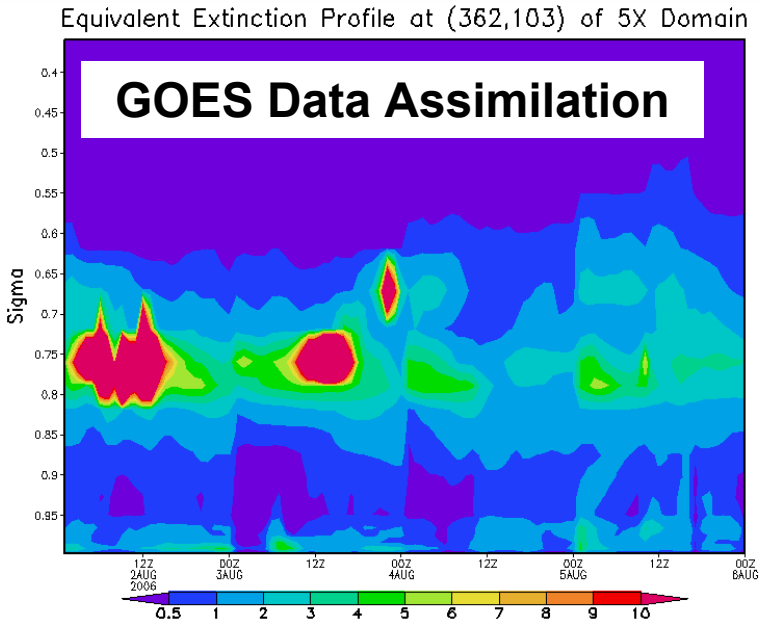


- Assimilation tunes aerosol concentrations based on CMAQ aerosol vertical profile
- Since assimilation tunes the profile by same ratio everywhere, aerosol concentrations are amplified in the region where aerosols peak. Thus, aerosol concentrations near the surface can be underestimated/overestimated despite data assimilation

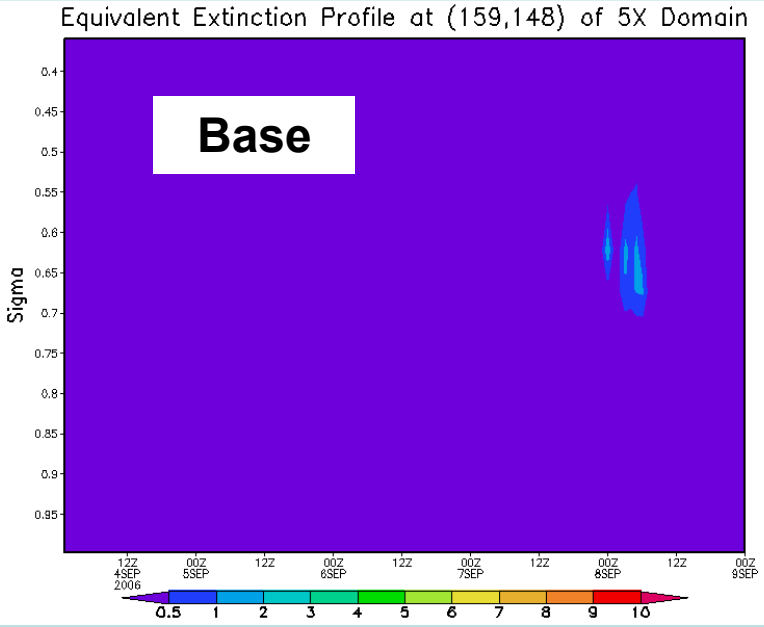
Height – Time Cross-section of Aerosol Extinction

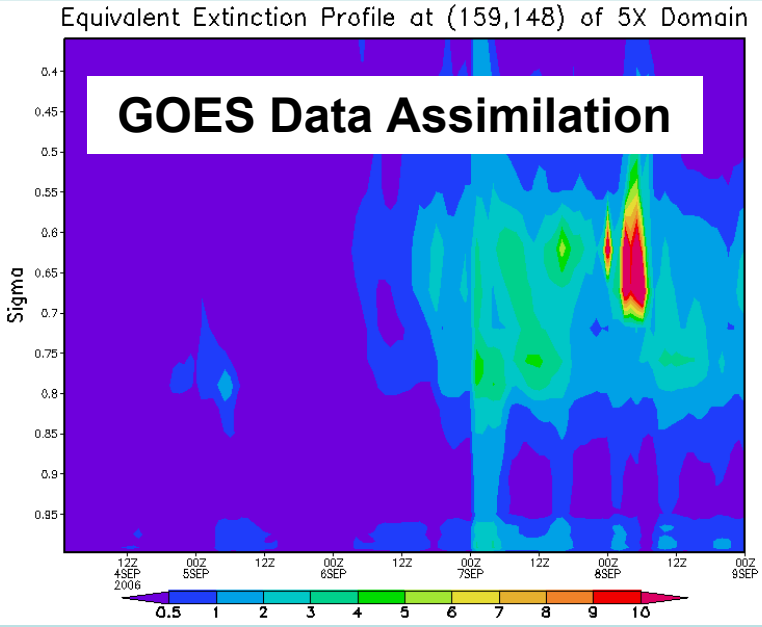
Sulfate Episode





Wildfire Episode





Conclusions

- Aerosol assimilation studies show a big impact on CMAQ PM2.5 predictions
  - GOES AODs have a bigger impact on PM2.5 predictions than MODIS. Specifically due to frequent updates of CMAQ initial conditions with GOES compared to MODIS
  - Improvements depend on
    - Original CMAQ aerosol vertical profile
    - Quality of satellite data
  - An objective way to determine altitude dependent tuning of aerosol concentrations is required
    - Investigate how to use OMI AI for this application
- Assimilation using GSI methodology is currently under development