TCEQ

2011 Community Modeling and Assessment System (CMAS) Highlights

Jim Smith & Khalid Al-Wali
Modelers, Air Quality Division

Presented to Southeast Texas Photochemical Modeling Technical Committee
February 29, 2012

CMAS 2011

- Held October 24-26, 2011 in Chapel Hill, NC
- 258 registrants
- 87 podium presentations
- 60 poster presentations
- Included a tribute to Dr. Daewon Byun with a special session on Air Quality Modeling Applications in his memory
- Originally a forum for users of EPA's Community Model for Air Quality (CMAS), but has evolved into a forum for the entire regulatory air quality modeling community

CMAQ vs. CAMx

- While CMAS is still somewhat CMAQ-oriented, many users of CAMx and other Air Quality models participate.
- EPA recognizes CAMx to be as capable as CMAS – each has its strengths and weaknesses relative to the other.
  - For example, EPA used CAMx for its recent Transport Rule modeling because its Source Apportionment capabilities are superior to CMAQ's.
- Updates to CMAQ represent advances to the state-of-the science.
  - Many of these advances have been or will be incorporated into CAMx.

CMAQ vs. CAMx

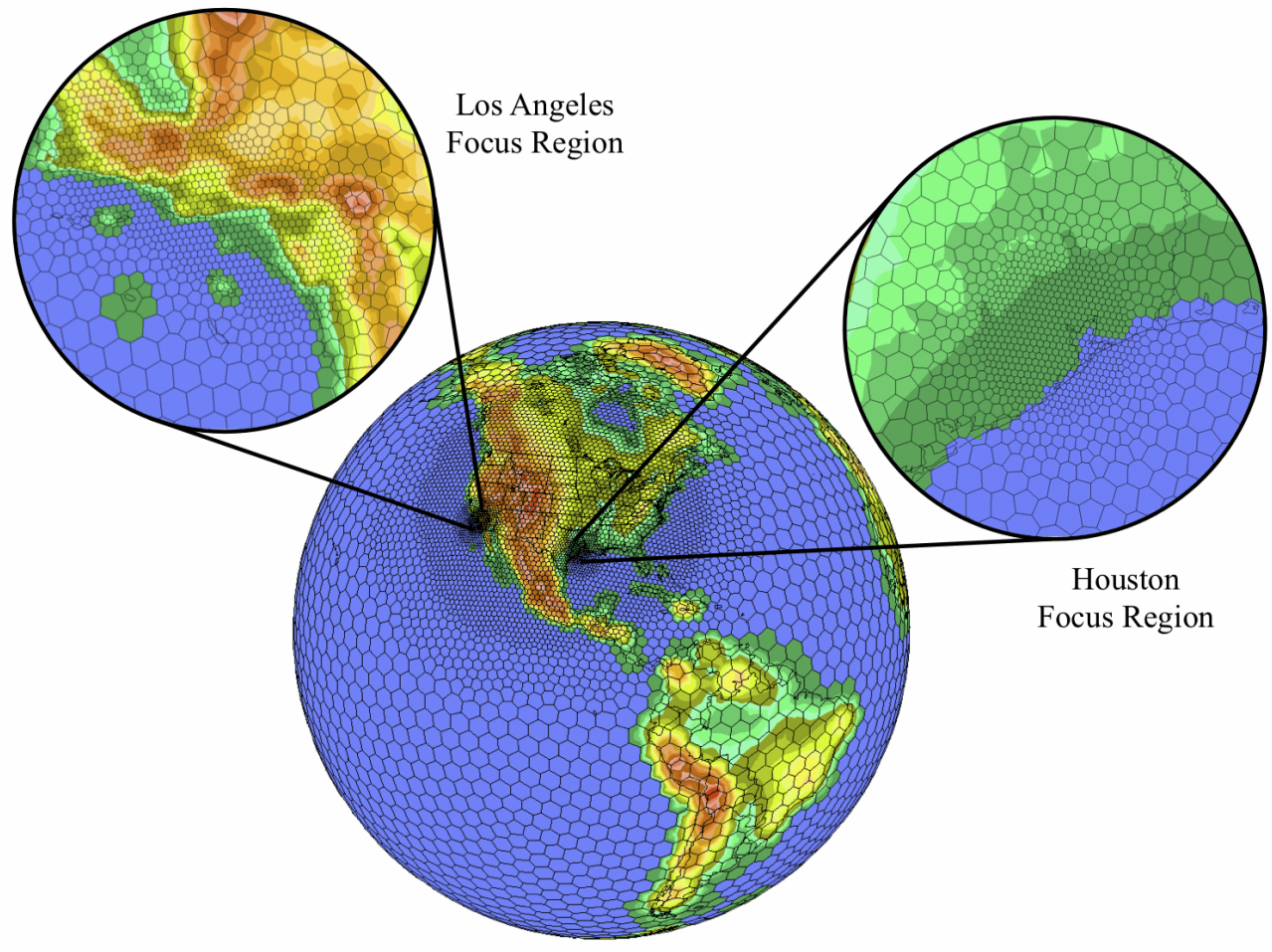
- There are several groups currently modeling areas of Texas with CMAQ, including NOAA, the University of Houston, and EPA. It is important to understand its capabilities so we will be able to interpret the results.
- On balance, there appears to be no advantage to Texas to switch to CMAQ in the foreseeable future.

CMAQ 5.0 Features
(Jon Pleim, EPA NERL)

- CMAQ 5.0
  - Incorporates many scientific advances to keep abreast of the latest research in gas chemistry, aerosol chemistry and thermodynamics, aqueous chemistry, and photolysis
  - Improved advective and turbulent transport
  - Updates to WRF for CMAQ modeling
  - The 2-way Coupled WRF-CMAQ system
  - Bi-directional surface flux for NH_3 and Hg
- Coming attractions
  - PM and ozone source apportionment
  - RACM2
  - Updated Carbon Bond mechanism
  - CMAQ adjoint

CMAQ 5.0 Features
(Jon Pleim, EPA NERL)

Global icosahedral met/chem with grid refinement
(not part of CMAQ)



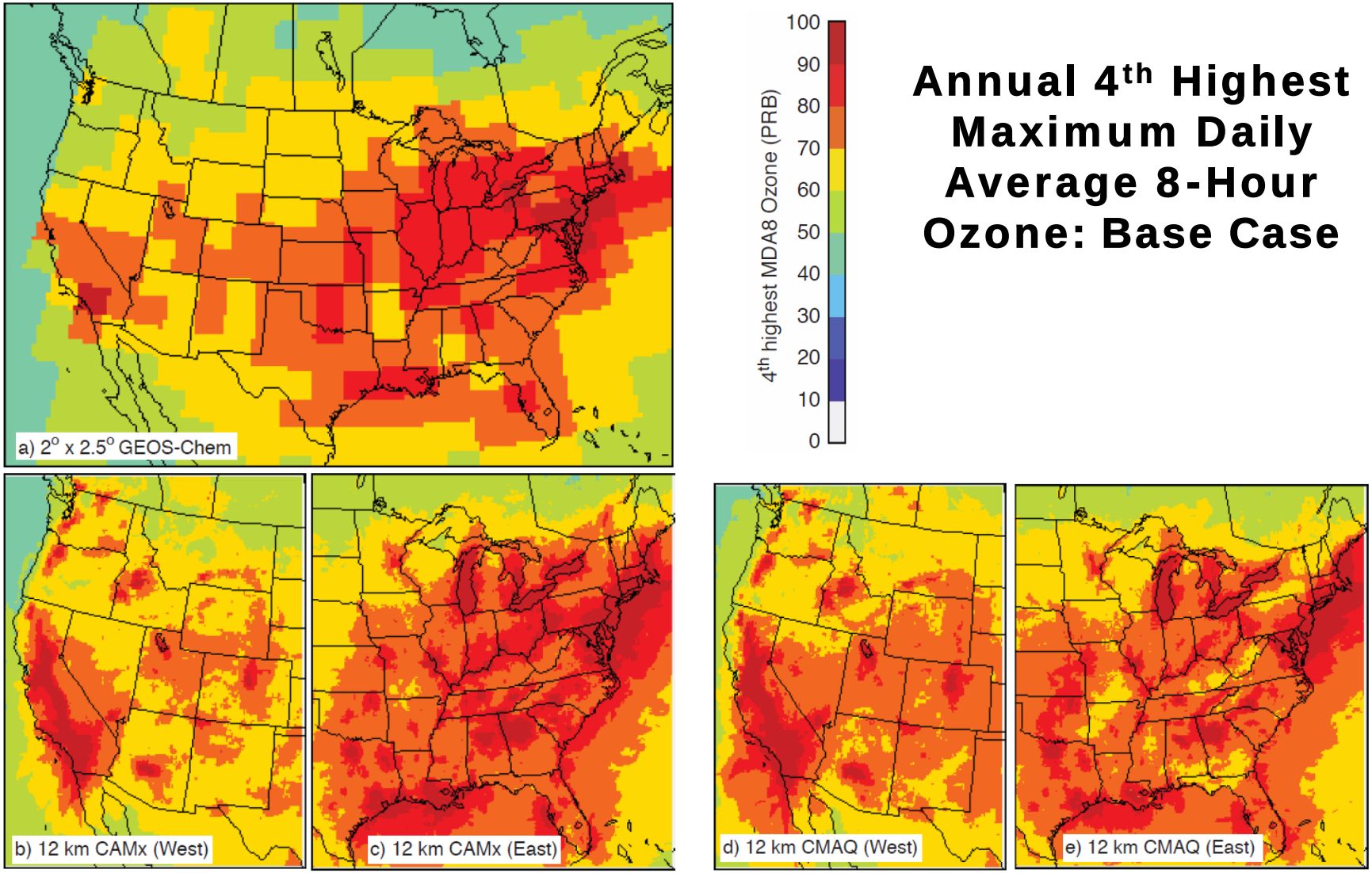
Regional/Global Modeling of PRB Ozone
Chris Emery, *et al*, Environ

- "Policy Relevant Background" (PRB) Ozone
- Now called "North American Background" in 2nd Draft Integrated Science Assessment
- Defined as ozone resulting from:
  - All natural sources (e.g., biogenic, fires, lightning, global methane)
  - Anthropogenic sources outside North America (no US/Canada/Mexico)
- EPA has relied on GEOS-Chem for PRB estimates. Observational research suggests global models:
  - Under estimate PRB peaks, short-term variability
  - Under estimate stratospheric influence

Regional/Global Modeling of PRB Ozone
Chris Emery, *et al*, Environ

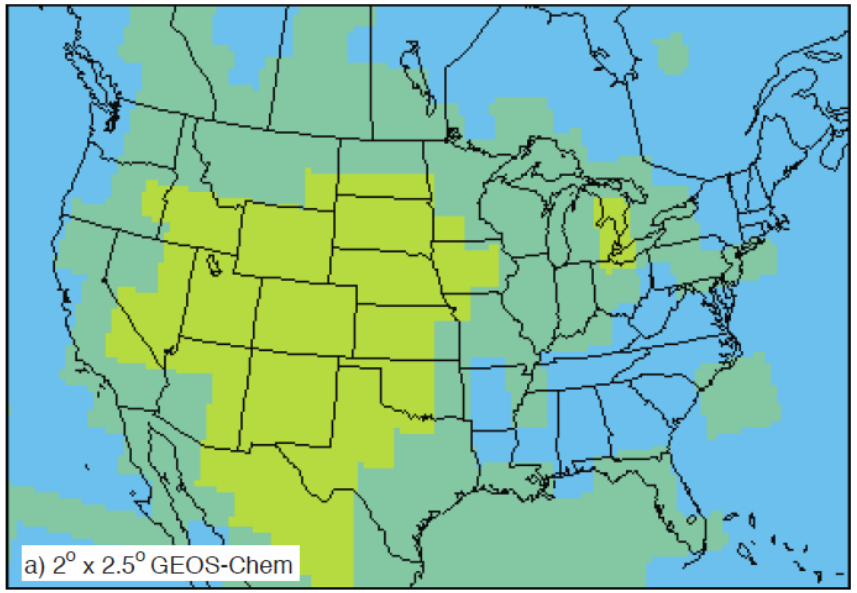
- Global modeling using GEOS-Chem (GC):
  - Provide boundary conditions for regional modeling
  - Simulate base and PRB ozone, sensitivity to:
    - Various emission sources, future projections
- Regional modeling using CAMx and CMAQ
  - Compare base and PRB ozone to GEOS-Chem
    - Higher resolution (transport dynamics, emissions, chemistry)
    - Independent met/emissions datasets
    - Different chemistry and wet/dry removal mechanisms
  - ***"Stratosphere" defined by boundary conditions***

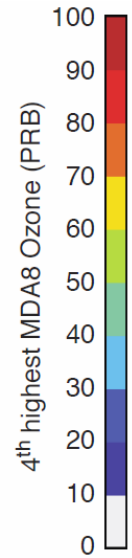
Regional/Global Modeling of PRB Ozone
Chris Emery, *et al*, Environ



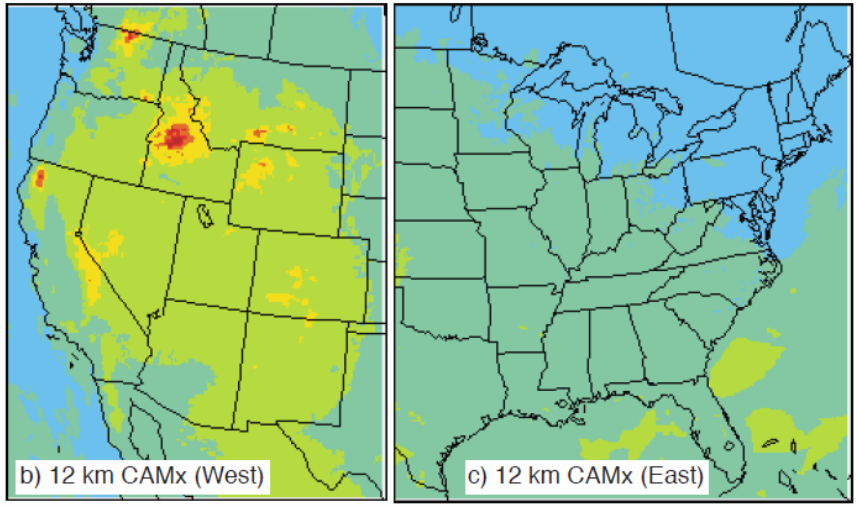
Annual 4th Highest Maximum Daily Average 8-Hour Ozone: Base Case

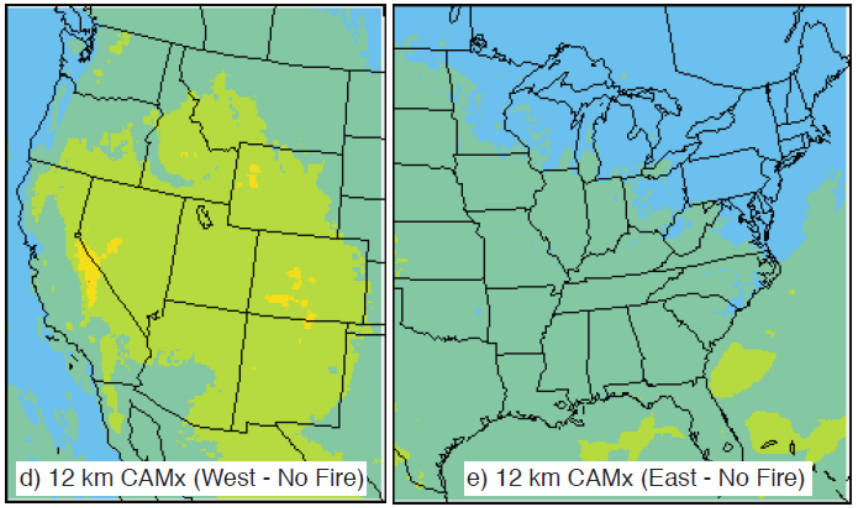
Regional/Global Modeling of PRB Ozone
Chris Emery, *et al*, Environ





Annual 4th Highest Maximum Daily Average 8-Hour Ozone: PRB Run – GC and CAMx





Regional/Global Modeling of PRB Ozone
Chris Emery, *et al*, Environ

- Base model performance (CAMx vs. GC)
  - Obvious differences due to resolution
  - CAMx predicts highest peaks better, higher correlation
  - GC tends to over predict means, under predict peaks
- PRB predictions
  - Typical range: CAMx = 25-50 ppb, GC = 20-45 ppb
  - Full PRB range is much larger:
    - Fires and Stratospheric-Tropospheric Exchange increase short-term PRB to 60-100 ppb
  - GEOS-Chem PRB never exceeds 60 ppb
  - CAMx > GC in west, Rockies by 10-15 ppb
  - CAMx ~ GC in central, CAMx > GC east by 5-10 ppb

Background Air Quality in the United States Under Current and Future Emissions Scenarios

Zac Adelman, UNC Chapel Hill

- Motivation and Objectives
  - Will U.S. background air pollutant concentrations increase in the future?
  - Objectives:
    - Gather and process latest International Panel on Climate Change (IPCC) inventories for current and future year emissions estimates
    - Use the Model for Ozone and Related Tracers, Ver. 4 (MOZART-4) to simulate future air quality resulting from climate change mitigation emissions scenarios
    - Estimate background air quality in the U.S. by “zeroing-out” North American anthropogenic emissions
    - Downscale global modeling results to produce boundary conditions for regional modeling

Background Air Quality in the United States Under Current and Future Emissions Scenarios

Zac Adelman, UNC Chapel Hill

- Conclusions
  - These results indicate that only one emissions scenario, which pursued extremely aggressive climate change mitigation, lead to reductions in global ozone burden and U.S. background ozone and $PM_{2.5}$ concentrations.
  - Annual maximum U.S. 8-hour ozone concentrations and frequency of high (> 70 ppb) 8-hour ozone events are predicted to decrease in all simulated future emissions cases, likely due to domestic emission controls.
  - Contribution of background to total U.S. ozone concentrations are predicted to increase in the future (~2-5% to annual mean and up to 10% to summer mean):
    - Combination of rise in transported ozone and drop in domestic ozone production.

Effects of Grid Resolution and Perturbations in Meteorology and Emissions on Air Quality Simulations Over the Greater New York City Region

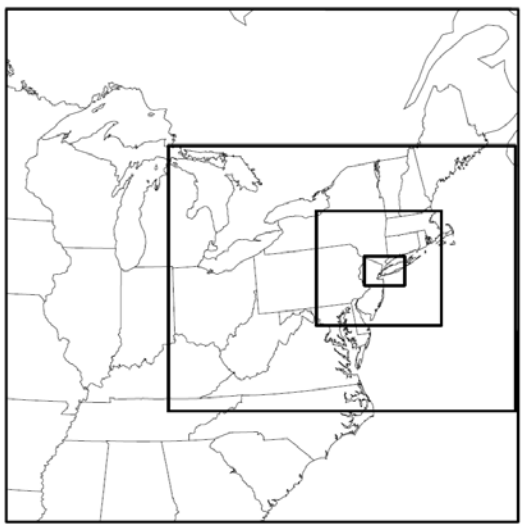
Christian Hogrefe, State of NY and Albany University

- Objectives:
  - Quantify and compare the relative impacts of perturbations in meteorology, emissions, and grid resolution on CMAQ predictions of 8-hour daily maximum ozone and 24-hour average $PM_{2.5}$
  - Evaluate the overall ensemble and three sub-ensembles (meteorology, emissions, and grid resolution) using probabilistic metrics
- Ensembles:
  - Meteorological Perturbations (12 MM5 & WRF forecasts)
  - Emission Perturbations (100 VOC, NO_X, PM perturbations)
  - Grid Resolution Perturbations (consider the 81 1.33 km cells within each 12 km cell as perturbations)

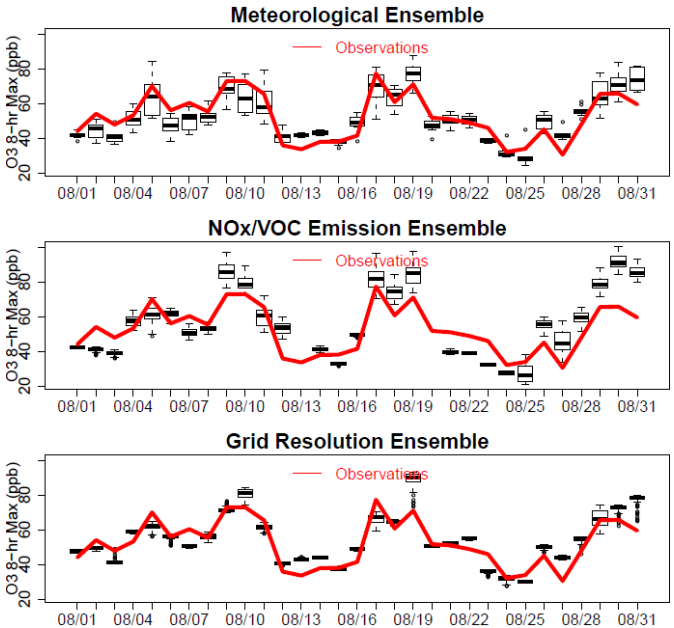
Effects of Grid Resolution and Perturbations in Meteorology and Emissions on Air Quality Simulations Over the Greater New York City Region

Christian Hogrefe, State of NY and Albany University

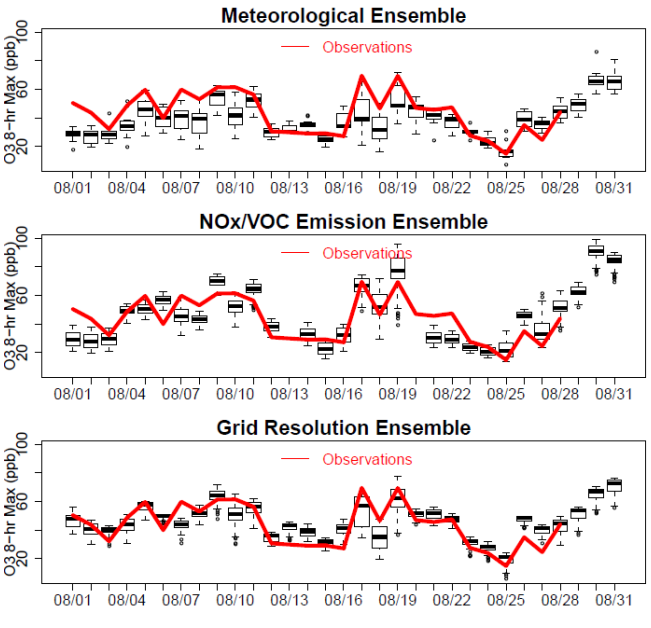
36 km, 12 km, 4 km, and 1.33 km Domains



Stratford, CT



Manhattan, NY

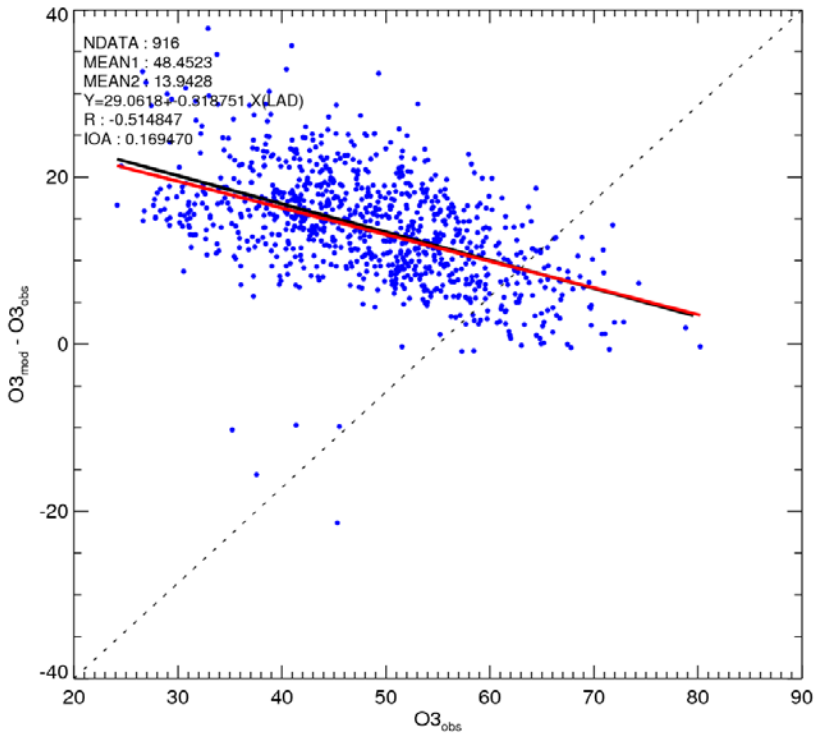


- Qualitatively, ozone fluctuations during August 2010 were captured by the various ensembles.
- Grid resolution effects are more pronounced for the Manhattan monitor than the CT monitor.
- More generally, the effects of the various ensemble perturbations vary over space and time.

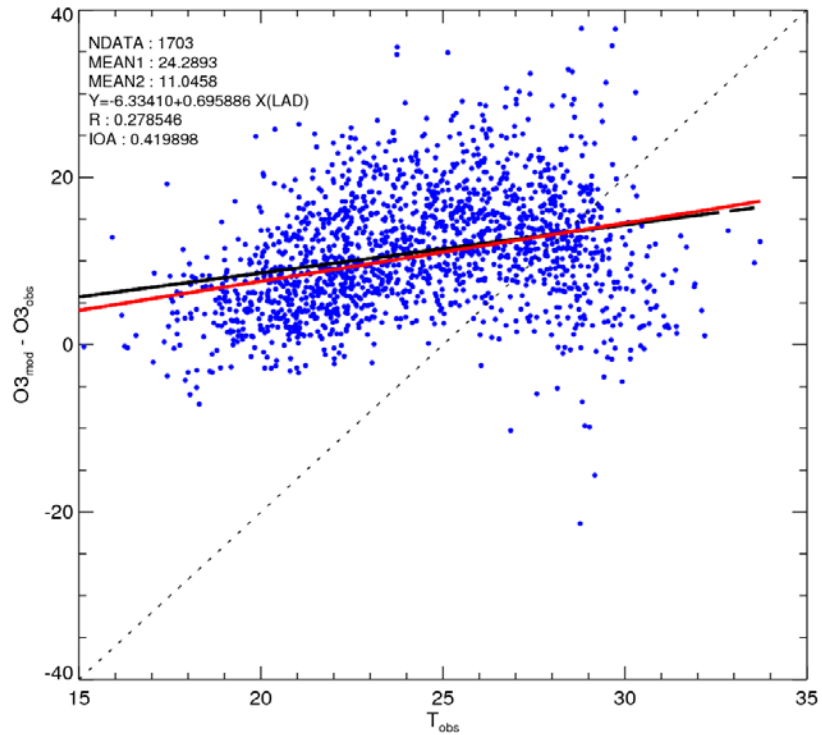
Performance Assessment of Five-year East Texas Air Quality Forecasting System (ETAQ)

Fong Ngan, NOAA ARL

Ozone bias vs. ozone level



Ozone bias vs. temperature



- Less ozone bias in high ozone level
- Positive correlation of ozone bias & temperature in lower temperature
- Large uncertainty of ozone bias in high temperature

Performance Assessment of Five-year East Texas Air Quality Forecasting System (ETAQ)

Fong Ngan, NOAA ARL

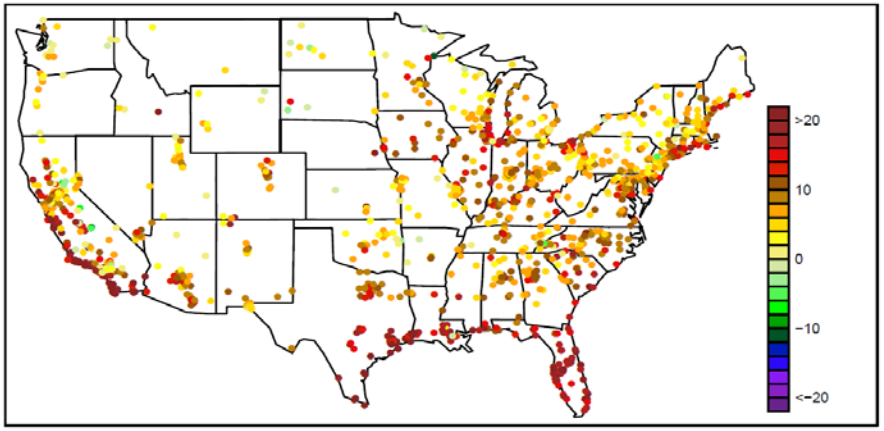
Performance Assessment of Five-year East Texas Air Quality Forecasting System (ETAQ)

Fong Ngan, NOAA ARL

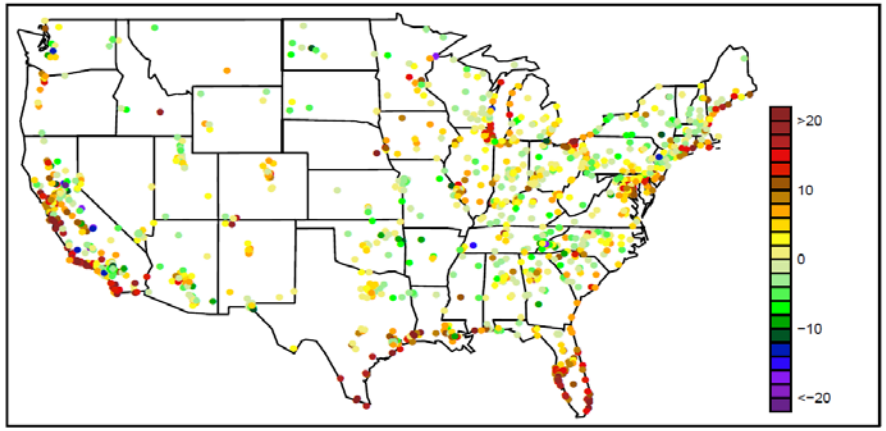
Policy-Driven Priorities for Improvements to the CMAQ Photochemical Modeling System

Heather Simon, EPA OAQPS *et al*

Ozone: CMAQv4.7.1 bias in max 8-hour average ozone



CMAQv4.7.1 average bias in daily max 8-hour ozone in July/August 2006



CMAQv4.7.1 average bias in highest 10% of max 8-hour ozone days in July/August 2006

Policy-Driven Priorities for Improvements to the CMAQ Photochemical Modeling System

Heather Simon, EPA OAQPS *et al*

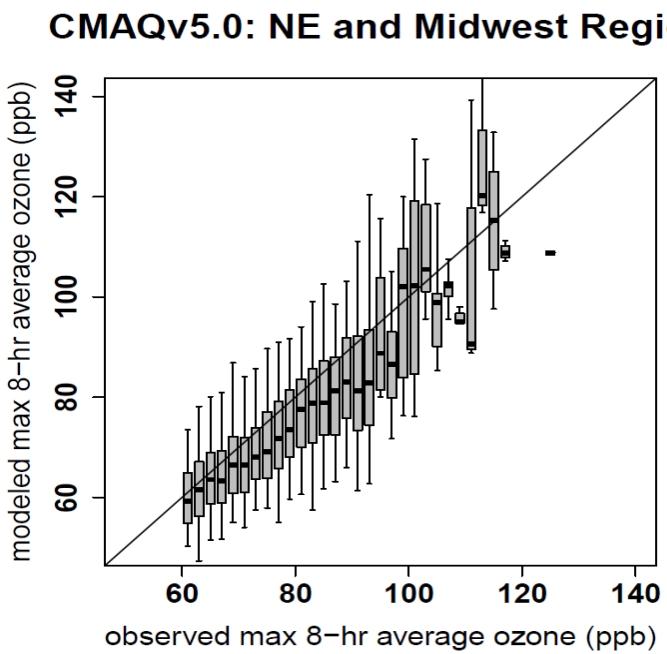
- Improved model inputs:
  - Improved data assimilation of wind speeds (particularly improved simulation of nocturnal jet in Northeast)
  - Lightning-generated NO emissions
  - New stable boundary layer scheme in WRF and CMAQ
  - Higher vertical resolution near the surface in WRF and CMAQ (20 m 1st layer)

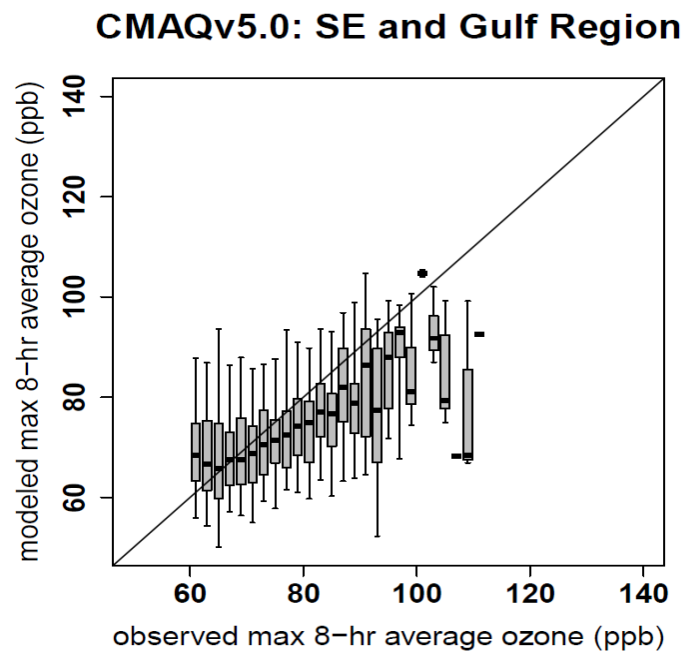
- Chemistry improvements:
  - Updated CB05 chemistry
  - Updated in-line photolysis (includes aerosol loading effects)

Policy-Driven Priorities for Improvements to the CMAQ Photochemical Modeling System

Heather Simon, EPA OAQPS *et al*

Observed vs modeled ozone for top 10% of max 8-hour ozone days in July/August 2006



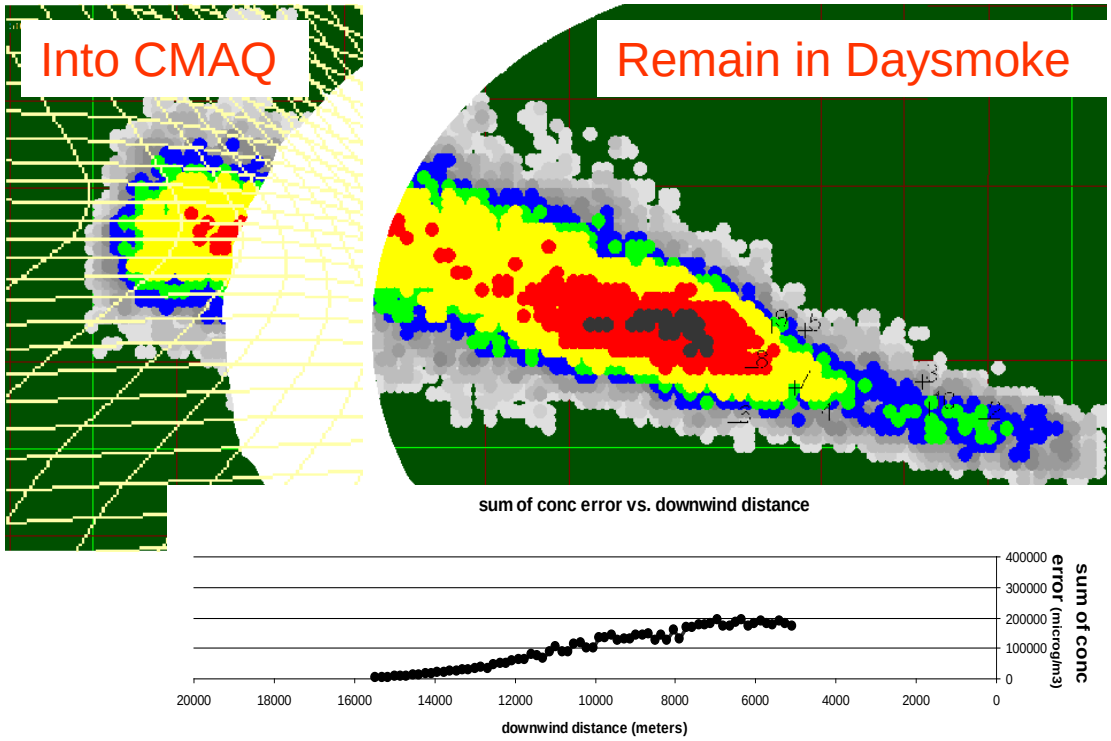


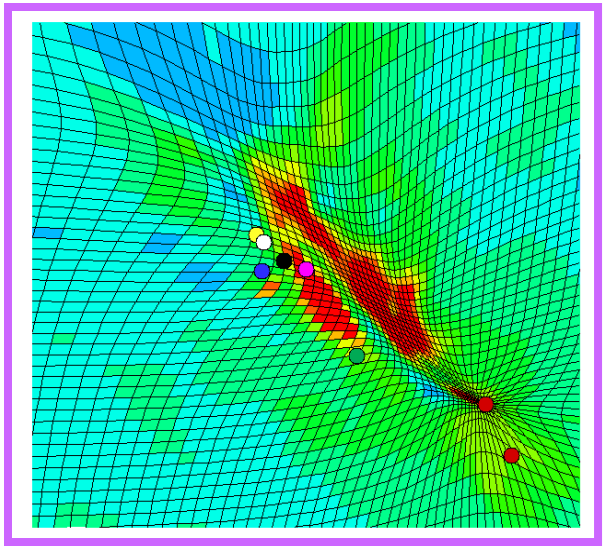
In southeastern and Gulf states, overestimation at the low end of the ozone distribution and underestimation at the high end is more pronounced than in other regions of the east.

Coupling a sub-grid scale plume model for biomass burns with adaptive grid CMAQ

Aika Yano, Georgia Tech, et al

- Coupled the DAYSMOKE fire plume model with Georgia Tech's adaptive-grid version of CMAQ





Some Other Notable Papers

- **A Screening Method for Ozone Impacts of New Sources Based on High-Order Sensitivity Analysis of CAMx Simulations for Sydney -** Greg Yarwood, Environ
  - Used CAMx HDDM to estimate sensitivity of ozone concentrations to adding new sources in selected locations
- **Fine-Scale CMAQ Model Application to Houston –** Golem Sarwar, USEPA National Exposure Lab, et al
- **Evaluation of the CMAQ Model with TexAQS 2006 Upper Air Measurements –** James Godowitch, USEPA National Exposure Lab, et al
  - Both used the National Emissions Inventory to model Houston and saw very large NO_X discrepancies. They should have used our inventory…

Some Other Notable Papers

- **Bayesian Analysis of Uncertainties in Ozone Response Estimates -** Antara Digar, Rice University, et al
  - AQRP Project 10-008 - Factors Influencing Ozone-Precursor Response in Texas Attainment Modeling
- **Application of Satellite and Ozonesonde Data to the Study of Nighttime Tropospheric Ozone Impacts and Relationship to Air Quality -** Greg Osterman – Jet Propulsion Laboratory
  - TCEQ Grant Project: Improving the Characterization of Pollution Transported into Texas (June 30, 2011 SIM Presentation by J. Smith)

Overview of the *Two-way Coupled* WRF-CMAQ Modeling System

Rohit Mathur, et al, U.S. EPA

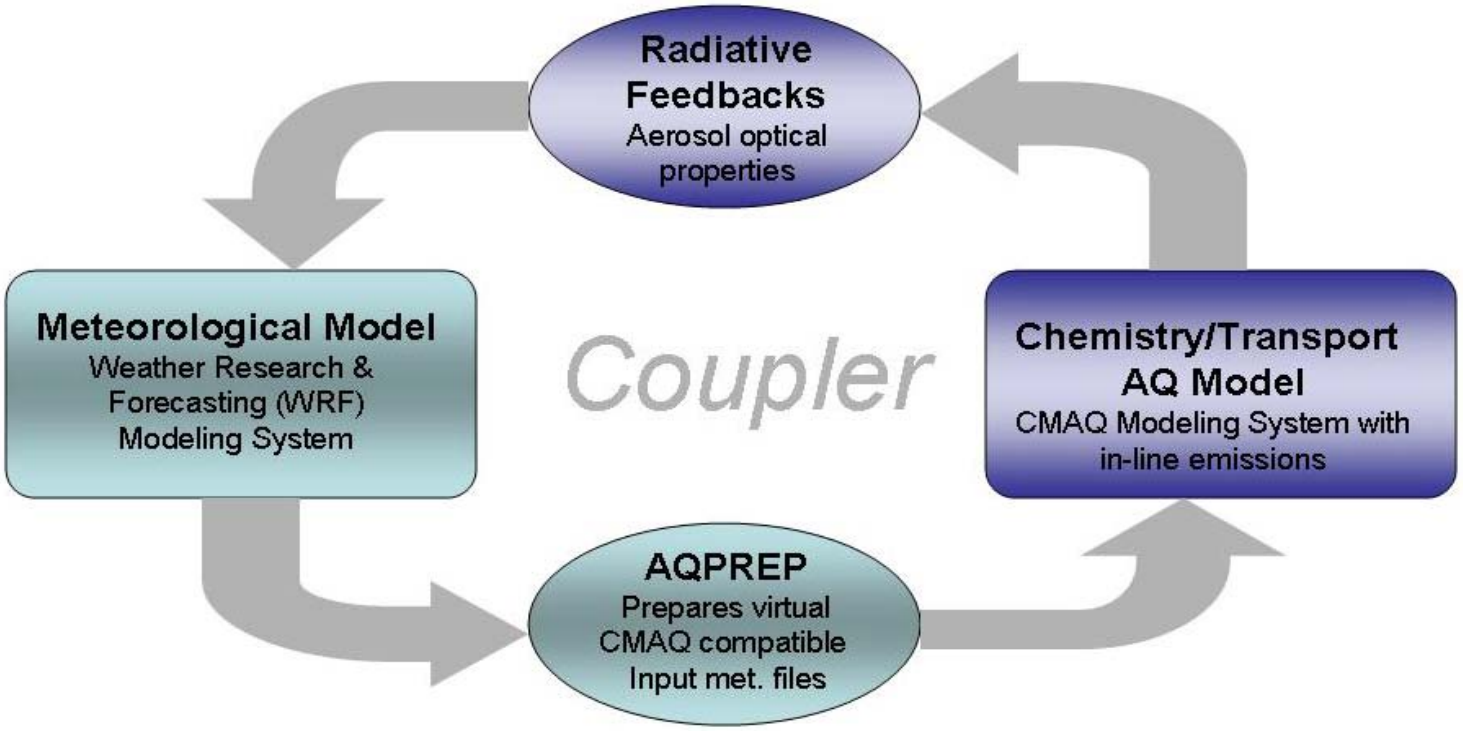
2-Way Coupled Meteorology / Air Quality Modeling: Rationale

- Concurrent meteorology and chemistry-transport calculation
  - ***High frequency communication*** between dynamical and chemical calculations - Requisite for finer scale urban modeling/exposure applications
- Represent and assess the potentially important ***radiative effects of pollutant loading*** on simulated dynamical features and air quality
- ***Consistent treatment*** of dynamical processes in meteorological and AQ models; reduces redundant calculations

Overview of the *Two-way Coupled* WRF-CMAQ Modeling System

Rohit Mathur, et al, U.S. EPA

Two-Way Coupled WRF-CMAQ Modeling System: Design and Model Features



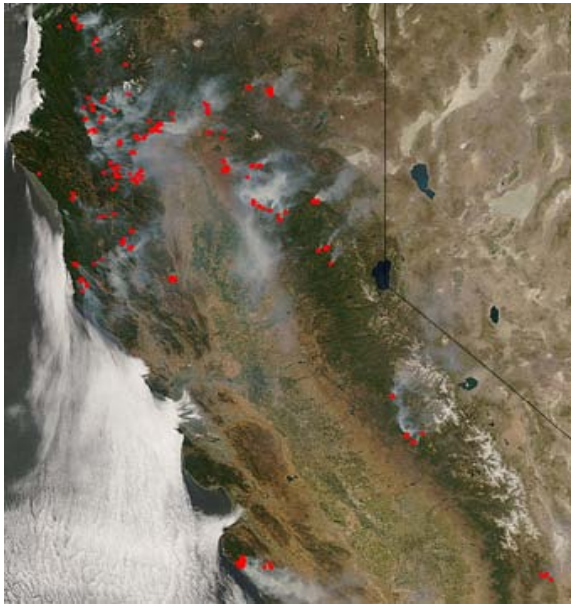
Overview of the *Two-way Coupled* WRF-CMAQ Modeling System

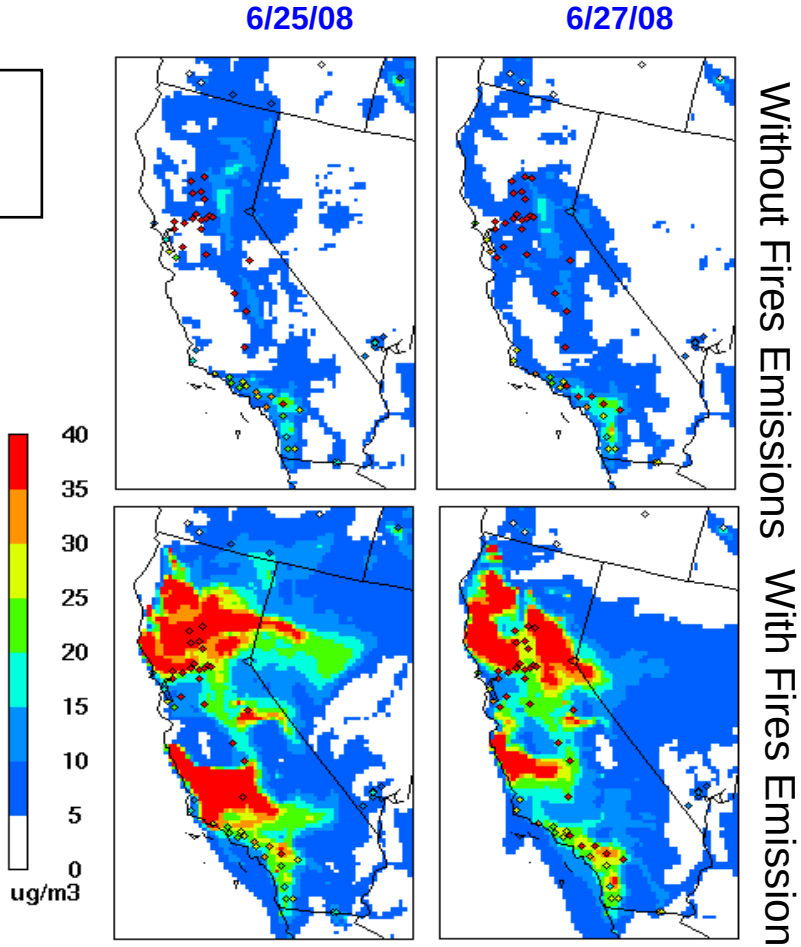
Rohit Mathur, et al, U.S. EPA

California Wildfires

A High aerosol Loading Case

Widespread wildfires resulted in significant PM pollution during mid/late June 2008 in California and surrounding states



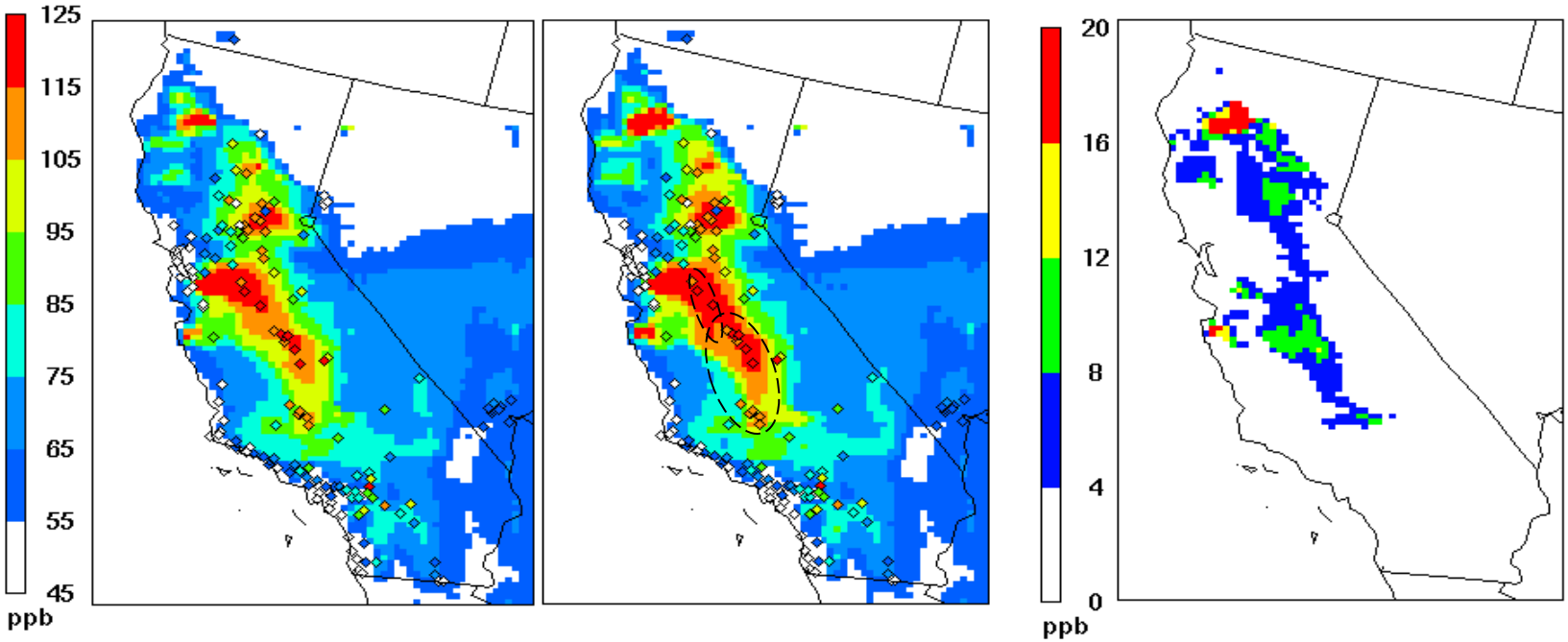


Daily-avg. $PM_{2.5}$

Overview of the *Two-way Coupled* WRF-CMAQ Modeling System

Rohit Mathur, et al, U.S. EPA

Maximum 8-hour ozone: June 27 2008



Without Feedback **With Feedback**

Enhancement due to feedback at locations where $[O_3]$ > 75ppb

Reduction in PBL heights results in increased ozone

Feedback effects could have important air quality impacts

Summary

- A computationally efficient and flexible coupled meteorology-atmospheric chemistry modeling system based on the WRF and CMAQ models has been developed.

- Direct feedback of aerosols on shortwave radiation has been tested:
  - Effects can be large in regions with significant aerosol loading.
  - Preliminary comparisons with limited measurements show improvements in simulation skill for SW radiation and 2-meter temperatures.
  - *Air pollutant concentrations can be significantly increased due to reductions in PBL height.*

Satellite Assimilation to Improve Cloud Simulation in WRF Model

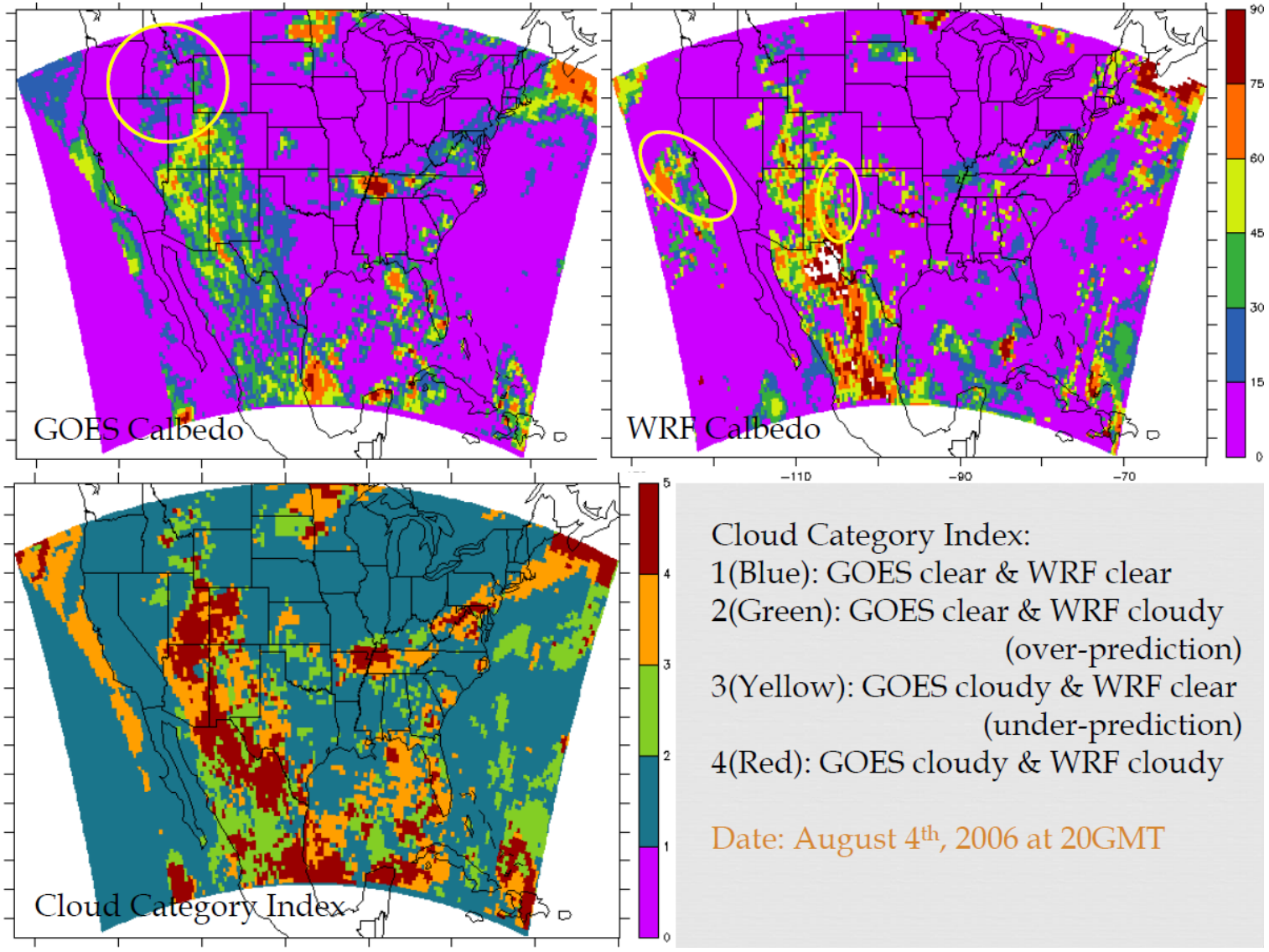
Yun Hee Park, UAH, et al

Process to assimilate data:

1. Compare cloud locations of the observation to the model.
2. Identify discrepancies between the observation and the model clouds.
   - Separate over-prediction and under-prediction.
3. Based on the observation, estimate target vertical velocities.
4. Adjust horizontal winds to sustain target vertical velocities.

Satellite Assimilation to Improve Cloud Simulation in WRF Model

Yun Hee Park, UAH, et al

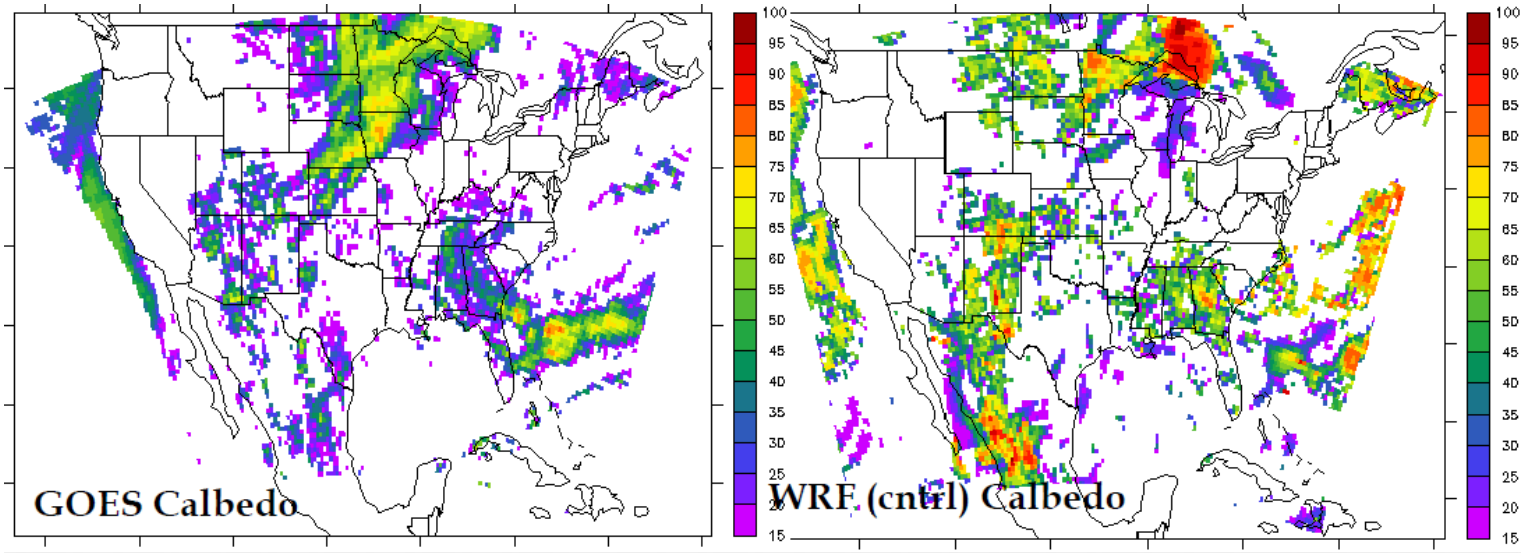


Cloud Category Index:
1(Blue): GOES clear & WRF clear
2(Green): GOES clear & WRF cloudy (over-prediction)
3(Yellow): GOES cloudy & WRF clear (under-prediction)
4(Red): GOES cloudy & WRF cloudy

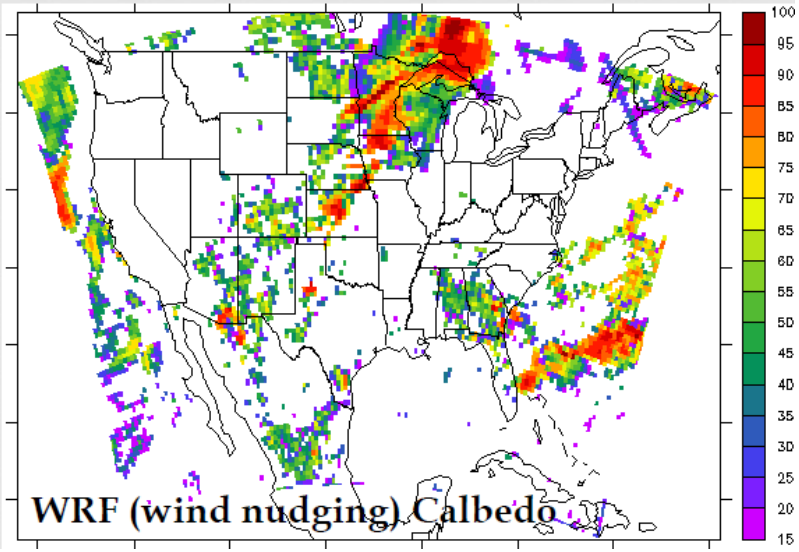
Date: August 4th, 2006 at 20GMT

Satellite Assimilation to Improve Cloud Simulation in WRF Model

Yun Hee Park, UAH, et al



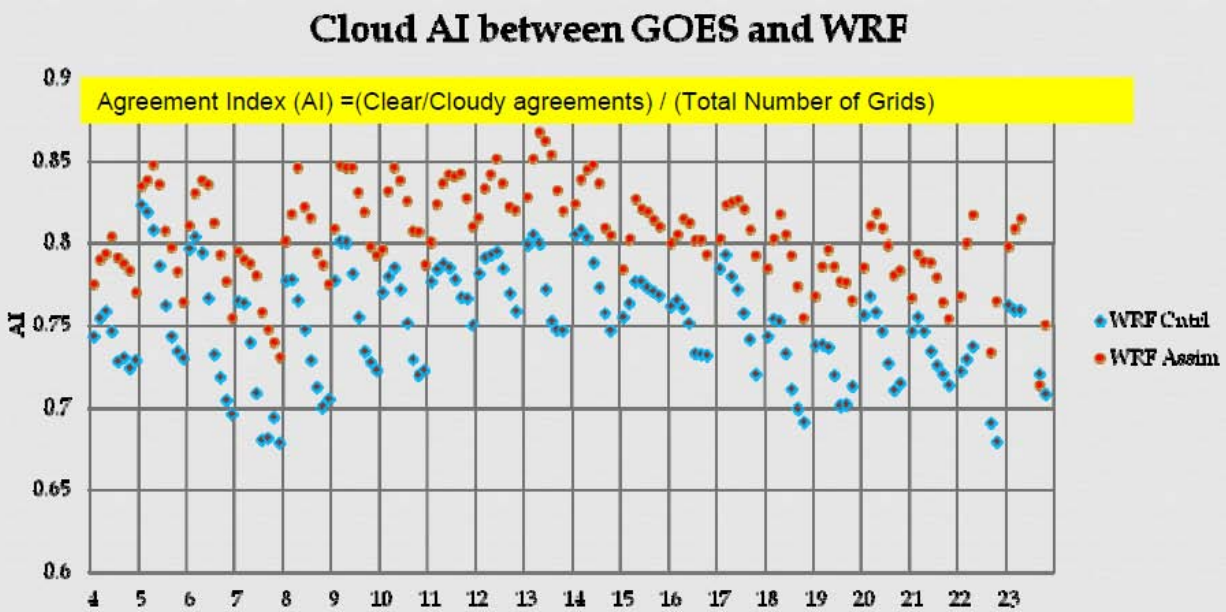
Date: August 13th , 2006 at 19 UTC



Satellite Assimilation to Improve Cloud Simulation in WRF Model

Yun Hee Park, UAH et al

Time series for cloud evaluation



Each day, AI for 8 hours (16~23UTC) is distributed. Overall, AI between the observation and the model is increased by about 7%.

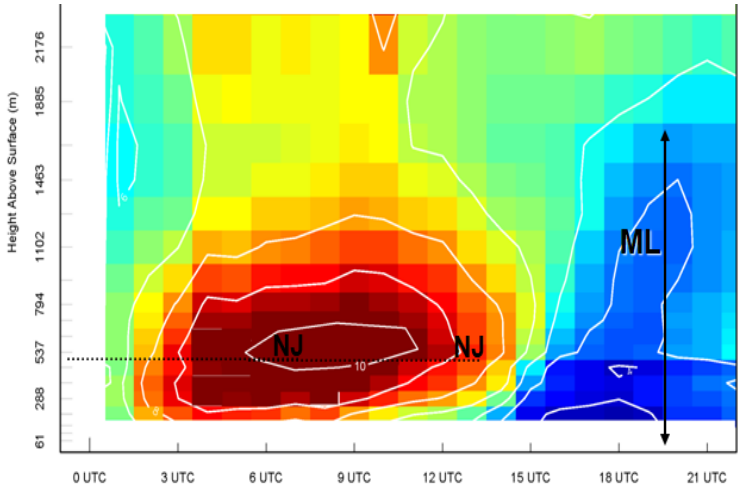
Conclusions

- Analytical approach helped to improve cloud simulation in the model. Index of Agreement is increased by about 7~10%.
- Dynamical adjustment improves clearing of clouds, but is not sufficient to generate clouds because of a lack of moisture.
- This work is continuing with a focus on moisture assimilation and higher grid resolution.

Improving Transport in AQ Models Using Alternative FDDA Techniques

Rob Gilliam, U.S.EPA, et al

- Even a perfectly designed air quality model will produce poor solutions if meteorological transport fields have excessive uncertainty.
- Nocturnal jets and residual layer winds are important features in regional pollution transport that have often been inadequately simulated in the past, thus, a main focus of this study.

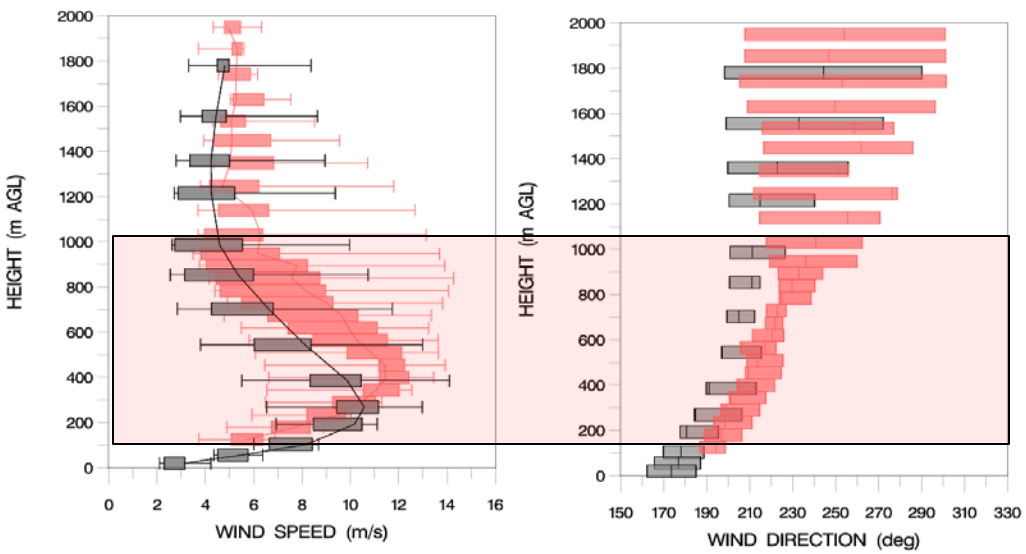


Improving transport in AQ models using alternative FDDA techniques

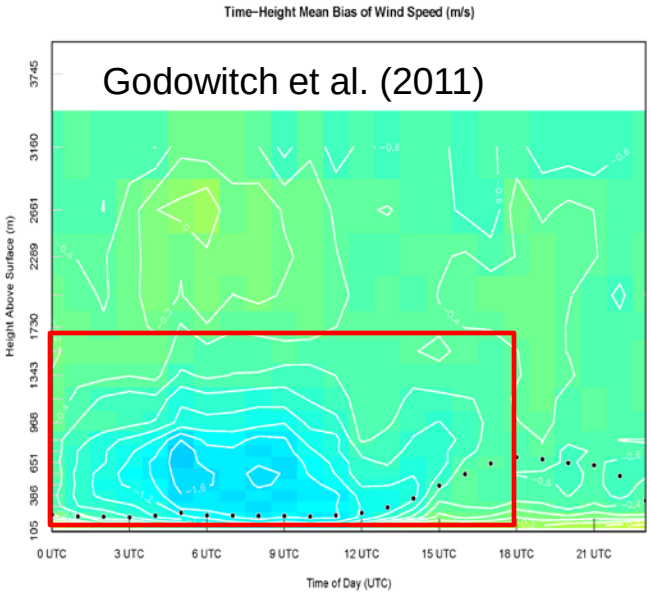
Rob Gilliam, U.S.EPA, et al

Current Transport Issues in WRF

Recent evaluations of modeled winds in the lower troposphere (<1000 m), have clearly shown biases in wind, which is likely injecting considerable uncertainty in CMAQ's transport.

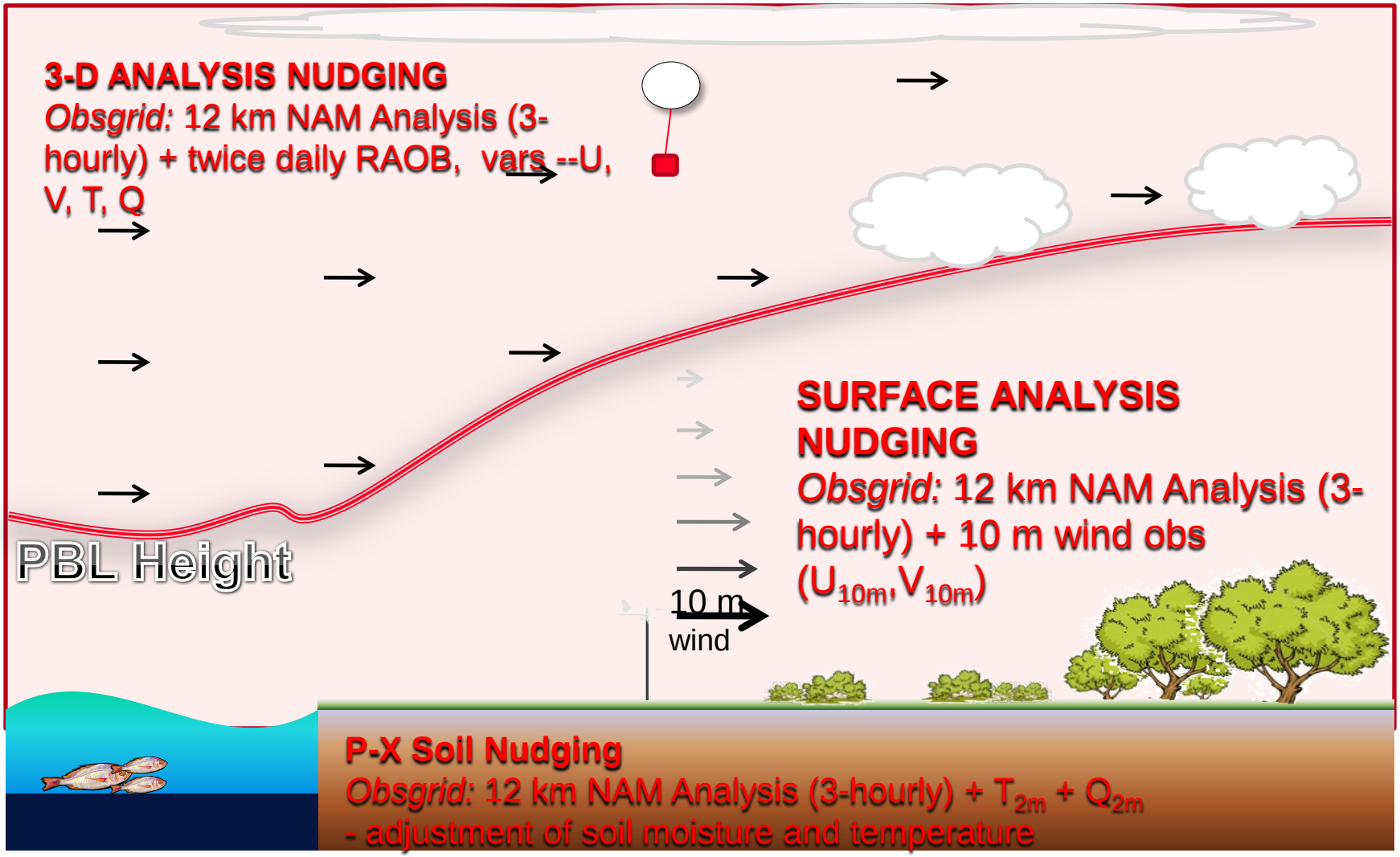


Godowitch et al. (2011)



Improving transport in AQ models using alternative FDDA techniques

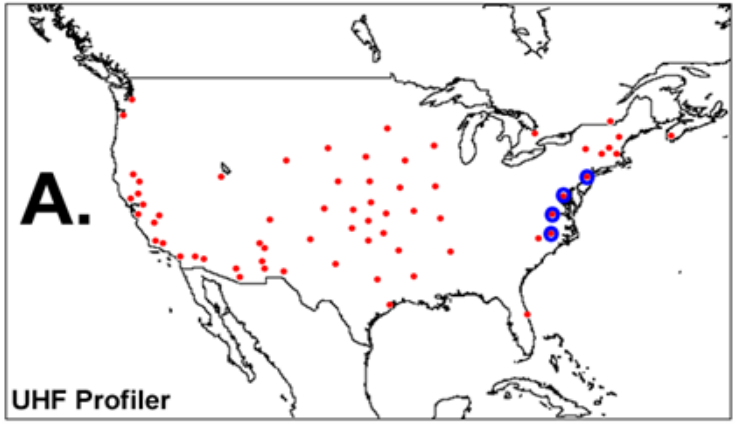
Rob Gilliam, U.S.EPA, et al



Improving transport in AQ models using alternative FDDA techniques

Rob Gilliam, U.S.EPA, et al

Unused wind profiler observations are available that could improve FDDA



UHF Profiler

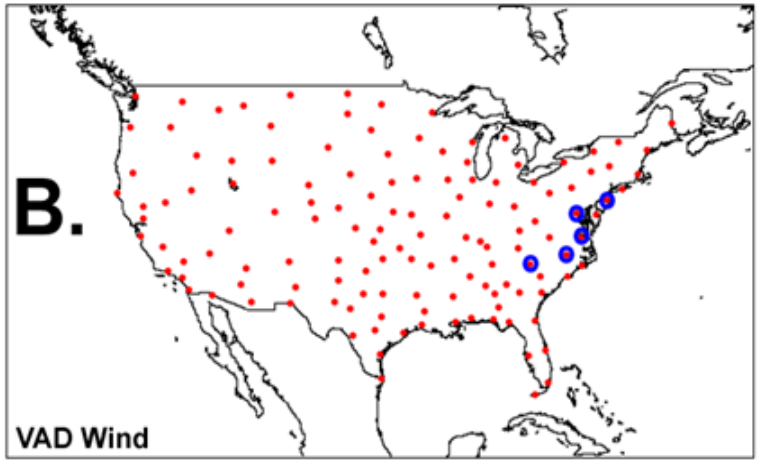
Pros: high vertical (10's of m) and temporal resolution (sub-hourly), good coverage in the more critical airsheds

Cons: inconsistent spacing

Velocity Azimuth Display (VAD)

Pros: Consistent and full US spatial coverage, sub-hourly and easily accessible

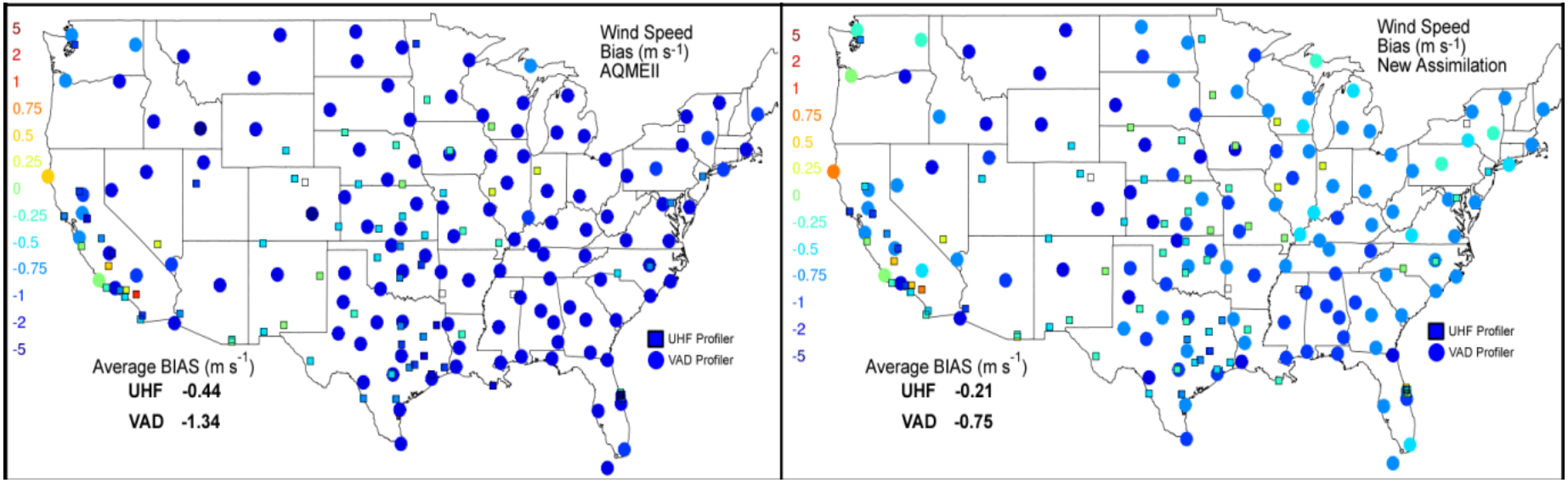
Cons: Coarse vertical resolution, can be influenced by birds and precipitation



Improving transport in AQ models using alternative FDDA techniques

Rob Gilliam, U.S.EPA, et al

Jun-Aug 2006 Wind Speed Bias (300-1000 m)



Conclusions

- Assimilation of UHF and VAD winds above the PBL were independently shown to improve model representation of the nocturnal jet and residual layer.
- Convective boundary layer winds were improved by eliminating all PBL nudging and refining the geostropic forcing at the top of the PBL using UHF and VAD observations - a top down approach.
- No PBL nudging will allow PBL models to interact with the land-surface model freely without the artificial nudging.

More Information

- Presentations and abstracts available at

  http://www.cmascenter.org/conference/2011/agenda.cfm