Incorporating Space-borne Measurements to Improve Air Quality Decision Support Systems

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Collaborators

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2. University Space Research Association (USRA)
3. National Aeronautics and Space Administration (NASA)
4. USEPA/ORD/NERL/AMAD/AMDB
5. Harvard-Smithsonian Center for Astrophysics
6. JPL
7. NOAA

- Deceased, 9 February 2011

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Health and Air Quality Applications Program Review
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PROJECT SUMMARY

TOPIC: **Incorporating Space-borne Measurements to Improve Air Quality Decision Support Systems**

POP: 10/1/2009 – 9/30/2013 (ROSES-08-AQ)
NCE till 9/30/2014

PI: Arastoo Pour Biazar (University of Alabama – Huntsville)

Co-Is: Dick McNider (UAH), Mike Newchurch (UAH), M. Khan (USRA), Bill Koshak (NASA)

Partners: USEPA, Texas Commission on Environmental Quality (TCEQ), Georgia Environmental Protection Division (GA-EPD)

NASA Assets: NASA's GOES Product Generation System; OMI ozone, formaldehyde, and nitrogen dioxide observations; MODIS Aerosol Products; NASA Lightning NOx-production Model (LNOM)

Objective: To employ NASA assets and satellite products to improve the air quality management Decision Support Tools (DSTs) used in defining emission control strategies for attainment of air quality standards.

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Overall Objective: To Reduce the Uncertainties in Regulatory Air Quality Simulations Through the Use of NASA Science and Satellite Data Products

In SIP modeling it is imperative to reproduce the observed atmosphere. Model uncertainties translates into uncertainties in emission control strategy which has significant economic consequences.

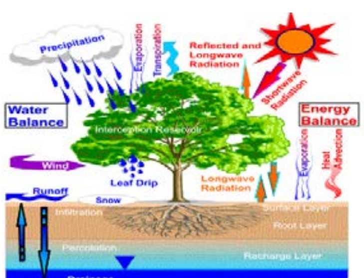
Physical Atmosphere

Models: WRF, MM5, RAMS
Recreates the physical atmosphere (winds, temperature, precipitation, moisture, turbulence etc) during the design period

Clouds and microphysical processes

Atmospheric dynamics

Boundary layer development



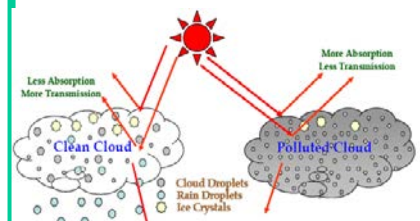
Fluxes of heat and moisture

LSM describing land-atmosphere interactions

Winds, temperature, BL height, Radiation, moisture, surface properties and fluxes, precipitation

Chemical Atmosphere

Models: CMAQ, CAMx
Recreates the chemical atmosphere



Heterogeneous chemistry, aerosol

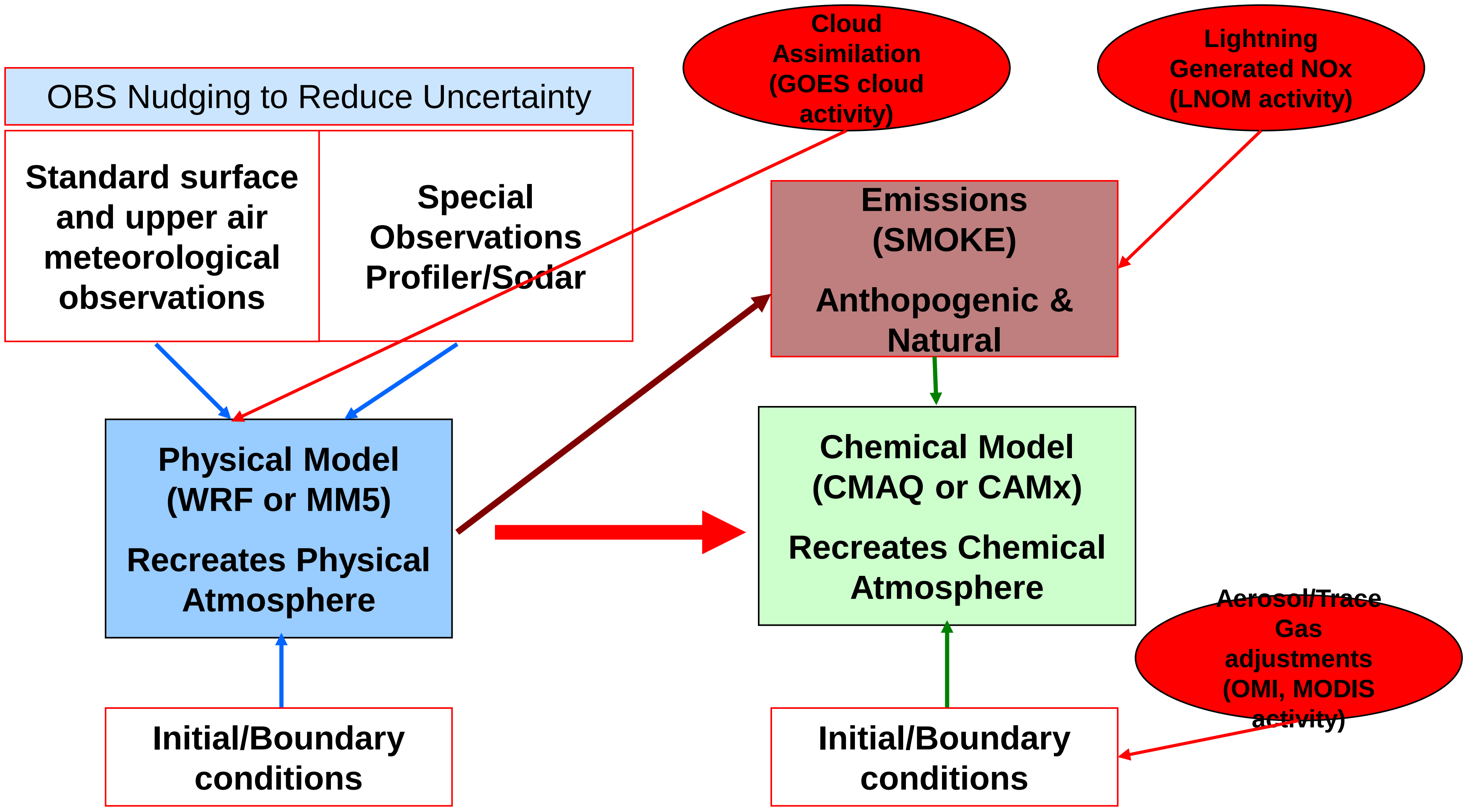
Transport and transformation of pollutants

Photochemistry and oxidant formation

Natural and antropogenic emissions, Surface removal




Contribution of This Project in Reducing Simulation Uncertainties



Specific Objectives – Three Projects in One

In This Project NASA Assets and Satellite Data Will Be Used to Improve the Quality and Accuracy of Retrospective Baseline Simulation in Which Proposed SIP Emission Reductions Are Tested

Improving Model Emissions

- **Utilization of NASA Lightning NOx-production Model (LNOM):** This activity utilizes LNOM to account for Lightning NO Production (LNOx) in convective clouds.

Improving Chemical Atmosphere

- **Satellite Trace Gas/Aerosol Utilization:** This activity improves chemical transboundary and initial conditions in the air quality model. The satellite products such as MODIS aerosol and newly available OMI ozone profiles can significantly impact the realization of the chemical state of the atmosphere.

Improving Physical Atmosphere

- **Improving Model Location and Timing of Clouds:** Clouds have a profound role in photolysis activity, boundary-layer development, and deep vertical mixing of pollutants and precursors. Satellite products will be utilized to improve model cloud simulation.

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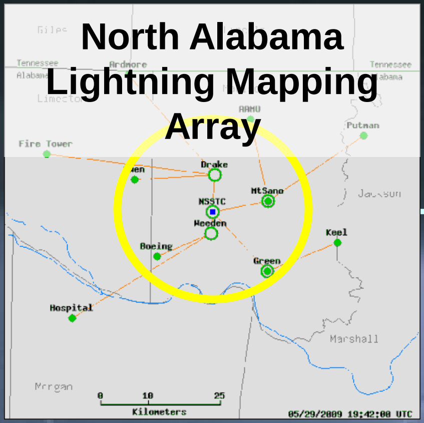
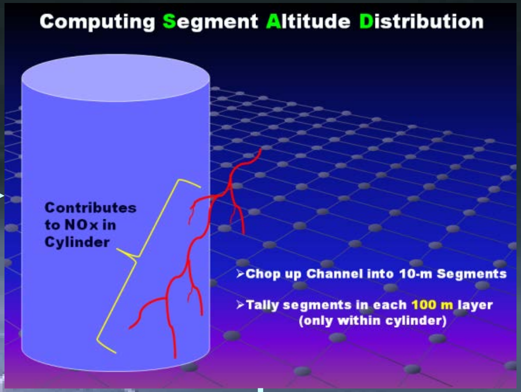
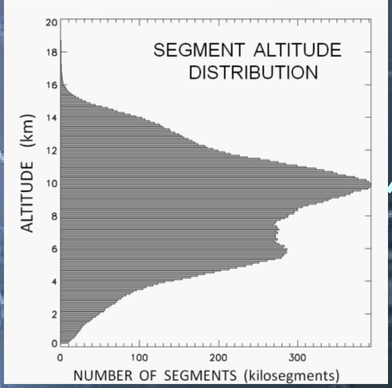
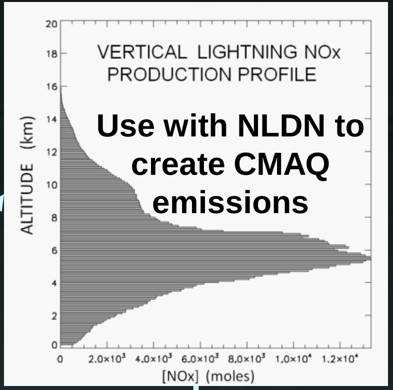
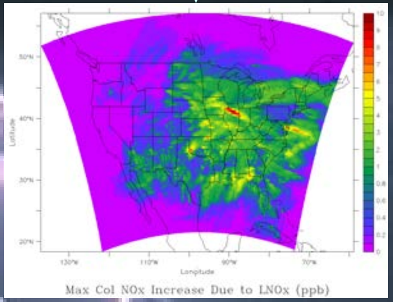
LNOM ACTIVITY (Bill Koshak)





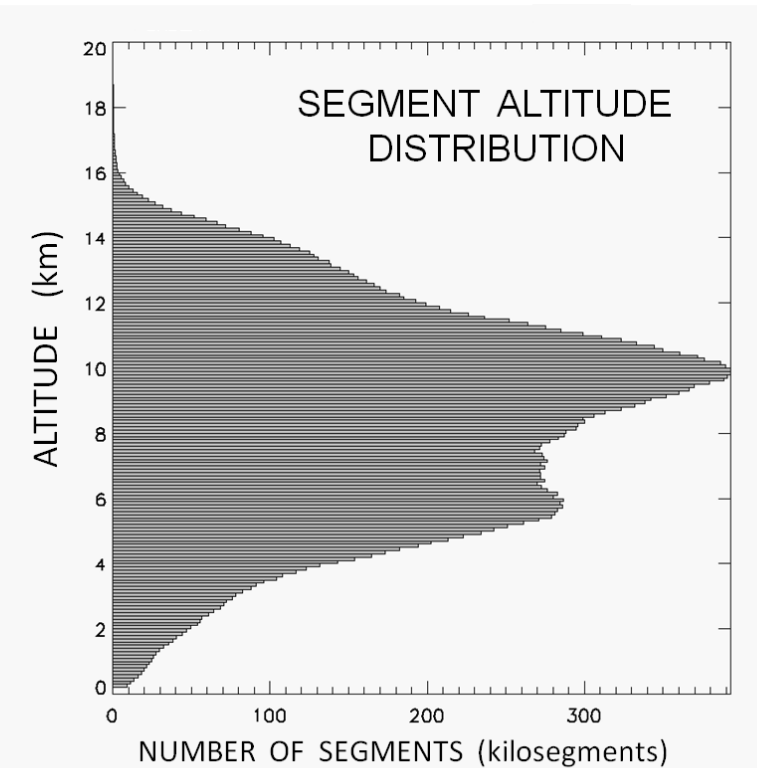






LNOM ACTIVITY

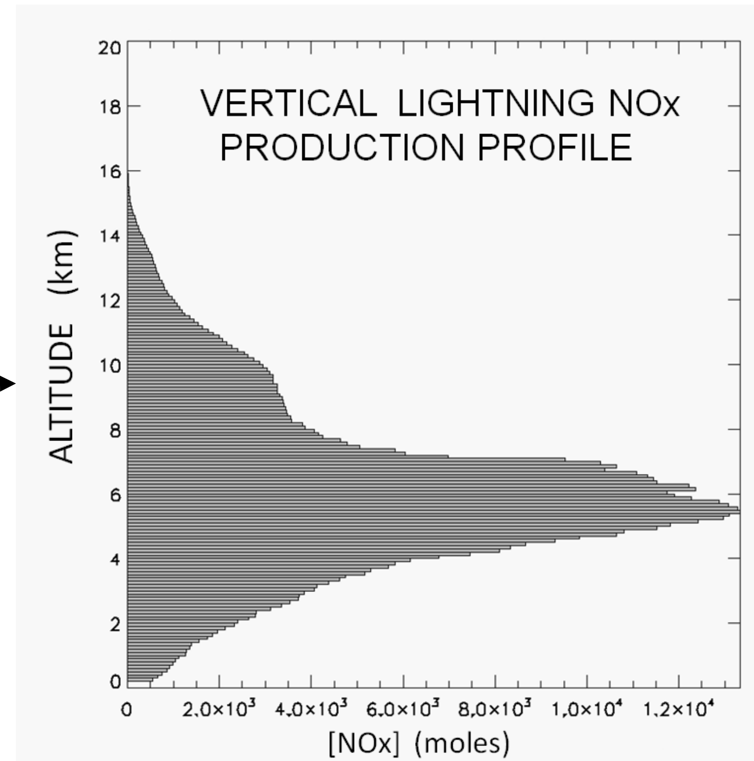
- Five year August statistics (2005-2009) used to construct the profile.
- CG: 484 mole/flash; IC: 35 mole/flash; Average: 101 mole/flash



Wang et al. (1998) (laboratory)

→

Cooray et al. (2009) (theoretical)



Texas Commission on Environmental Quality

NSSTC

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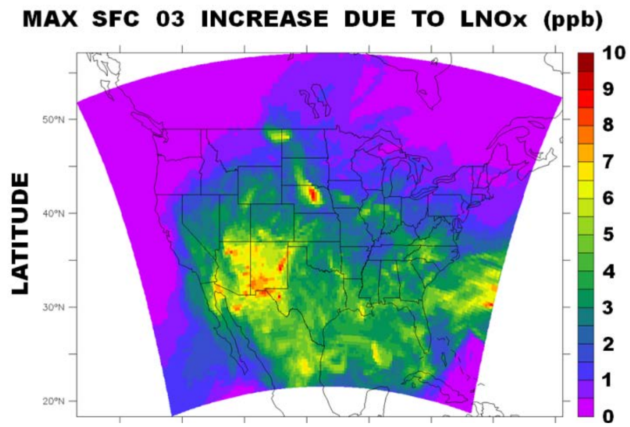
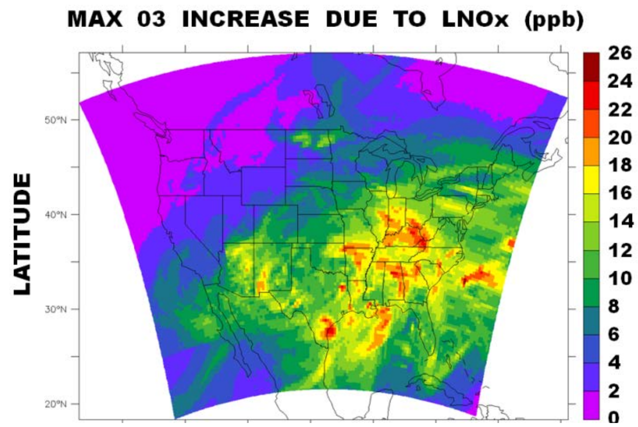
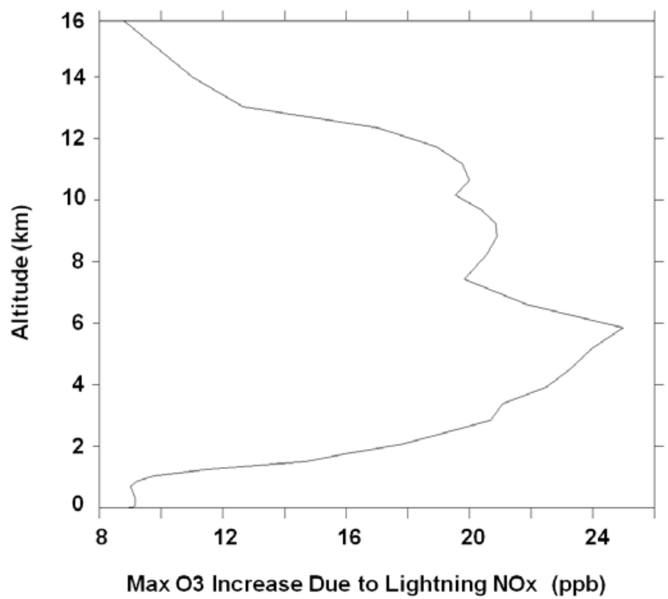
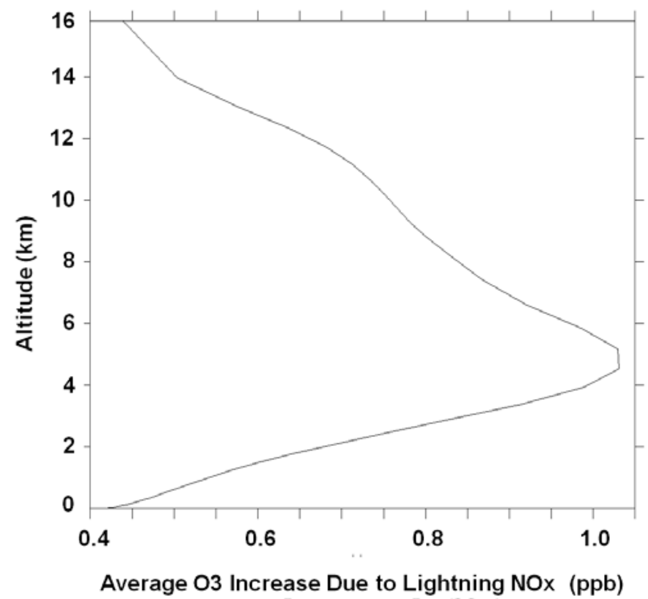
LNOM ACTIVITY

- Implemented in WRF/CMAQ and evaluated the impact on ozone
- Collaborating with Ken Pickering for incorporation in official release of CMAQ









ARL PROGRESS

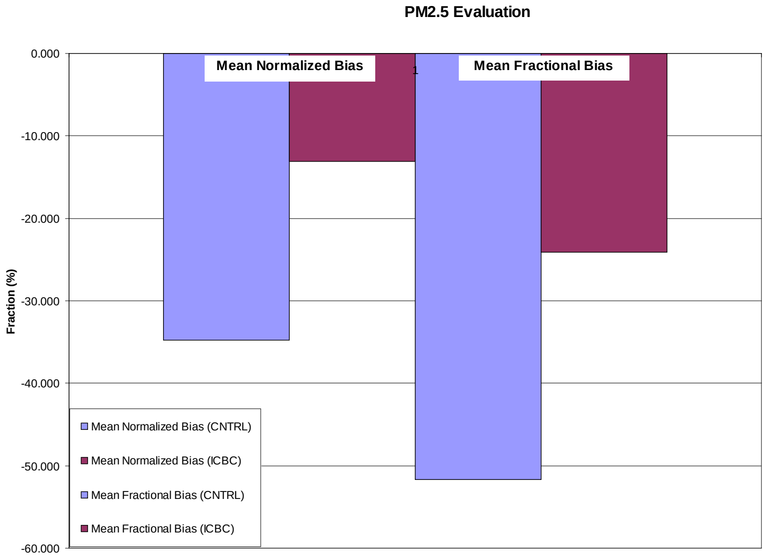
LNOM Activity	FY10	FY11	FY12	FY13
Starting ARL	1	2	3	4
Ending ARL	2	3	4	5

ARL 5: Validation in Relevant Environment (Potential Determined)

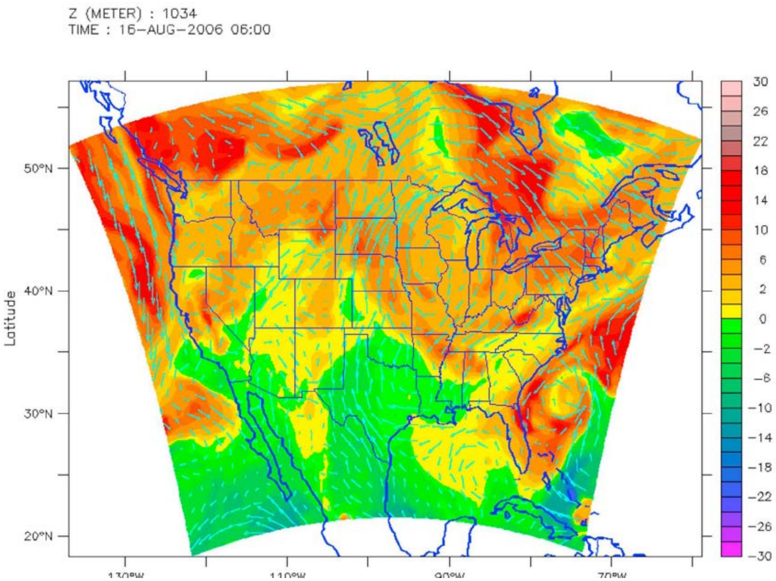
- Application components integrated into a functioning prototype application system with realistic supporting elements: The data and documentations are readily availble at: http://ghrc.nsstc.nasa.gov/uso/ds_docs/ldar/ldar_dataset.html
  - LNOM LNOx was included in WRF/CMAQ simulations for August 2006.
- The application system's potential to improve the decision making activity determined and articulated: The results were evaluated and the impact on ozone predictions were demonstrated. The technique and its application within WRF/CMAQ is documented in Wang et al., 2013 and Koshak et al., 2013.
  - Koshak, William, Harold Peterson, Maudood Khan, Arastoo Biazar, Lihua Wang: The NASA Lightning Nitrogen Oxides Model (LNOM): Application to Air Quality Modeling. *Atmos. Res.* (2013) http://dx.doi.org/10.1016/j.atmosres.2012.12.015.
  - Wang, Lihua, M.J. Newchurch, Arastoo Pour-Biazar, Shi Kuang, Maudood Khan, Xiong Liu, William Koshak, Kelly Chance (2013): Estimating the influence of lightning on upper tropospheric ozone using NLDN lightning data and CMAQ model, *Atmospheric Environment*, **67**, 219-228. http://dx.doi.org/10.1016/j.atmosenv.2012.11.001.

Satellite Trace Gas/Aerosol Activity

- Utilization of OMI ozone and MODIS Aerosol products
  - The observations were successfully incorporated in CMAQ
  - The improvements for SIP applications were documented in Pour-Biazar et al., 2011, and Wang et al., 2011.



Incorporation of MODIS aerosol products in CMAQ substantially reduced model error with respect to PM2.5. Mean Fractional Bias was reduced by about 30%

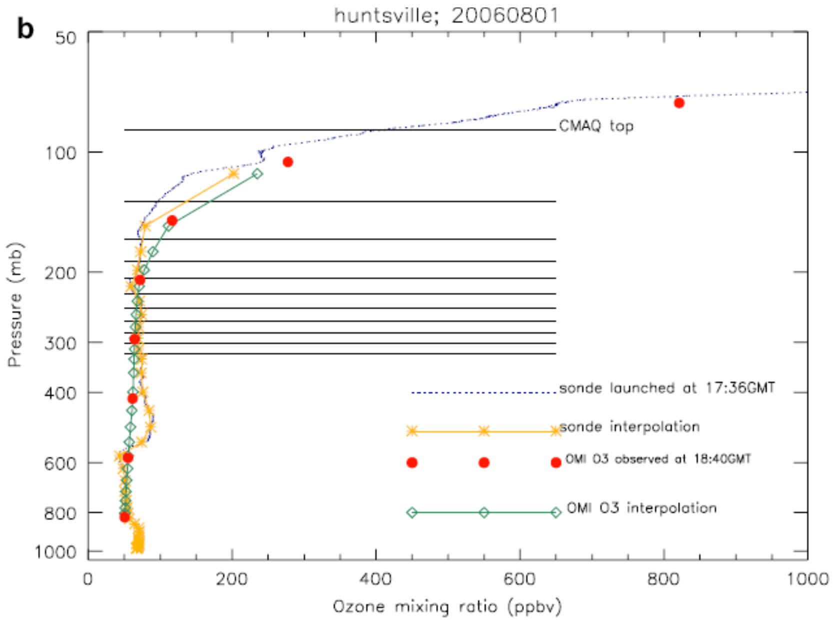


The impact of incorporating OMI observations in CMAQ simulation on the boundary layer ozone for August 16, 2006.

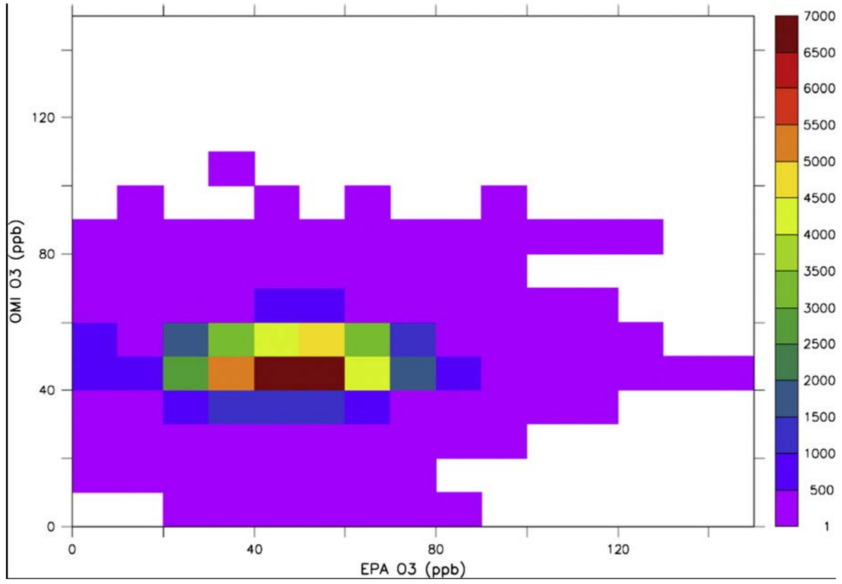
Pour-Biazar, A., M. Khan, L. Wang, Y. Park, M. Newchurch, R. T. McNider, X. Liu, D. W. Byun, and R. Cameron (2011), Utilization of satellite observation of ozone and aerosols in providing initial and boundary condition for regional air quality studies, J. Geophys. Res., 116, D18309, doi:10.1029/2010JD015200.

Satellite Trace Gas/Aerosol Activity

OMI is able to explain mid./upper tropospheric ozone. An example of re-sampling ozonesonde and OMI ozone profiles onto CMAQ's 39 vertical layers at Huntsville, AL on August 1, 2006.



OMI is not able to neither explain elevated surface concentrations nor the large variations experienced by the surface monitors. The correlation coefficient is 0.14.



Wang, L., M. J. Newchurch, A. Biazar, X. Liu, S. Kuang, M. Khan, and K. Chance (2011), Evaluating AURA/OMI ozone profiles using ozonesonde data and EPA surface measurements for August 2006, Atmos. Environ., 45(31), 5523-5530.

ARL PROGRESS

Trace Gas/Aerosol Assimilation

	FY10	FY11	FY12	FY13
Starting ARL	1	2	3	4
Ending ARL	2	3	4	5

ARL 5: Validation in Relevant Environment (Potential Determined)

- Application components integrated into a functioning prototype application system with realistic supporting elements: OMI ozone profiles and MODIS aerosol products are readily available. Data products were successfully incorporated in MM5/CMAQ air quality modeling system

- The application system's potential to improve the decision making activity determined and articulated: The results were evaluated and the impact on ozone predictions were demonstrated. The technique and its application within MM5/CMAQ is documented in Pour-Biazar et al., 2011 and Wang et al., 2011.

  - Pour-Biazar, A., M. Khan, L. Wang, Y. Park, M. Newchurch, R. T. McNider, X. Liu, D. W. Byun, and R. Cameron (2011), Utilization of satellite observation of ozone and aerosols in providing initial and boundary condition for regional air quality studies, J. Geophys. Res., 116, D18309, doi:10.1029/2010JD015200.
  - Wang, L., M. J. Newchurch, A. Biazar, X. Liu, S. Kuang, M. Khan, and K. Chance (2011), Evaluating AURA/OMI ozone profiles using ozonesonde data and EPA surface measurements for August 2006, Atmos. Environ., 45(31), 5523-5530.

Impact of Physical Atmosphere on SIP Control Strategies

Clouds:

- Impact photolysis rates (impacting photochemical reactions for ozone and fine particle formation).
- Impact transport/vertical mixing, LNOx, aqueous chemistry, wet removal, aerosol growth/recycling and indirect effects.

Temperature:

- impacts biogenic emissions (soil NO, isoprene) as well as anthropogenic evaporative losses.
- Affects chemical reaction rates and thermal decomposition of nitrates.

Moisture:

- Impacts gas/aerosol chemistry, as well as aerosol formation and growth.

BL Heights:

- Affects dilution and pollutant concentrations.

Winds:

- Impacts transport/transformation

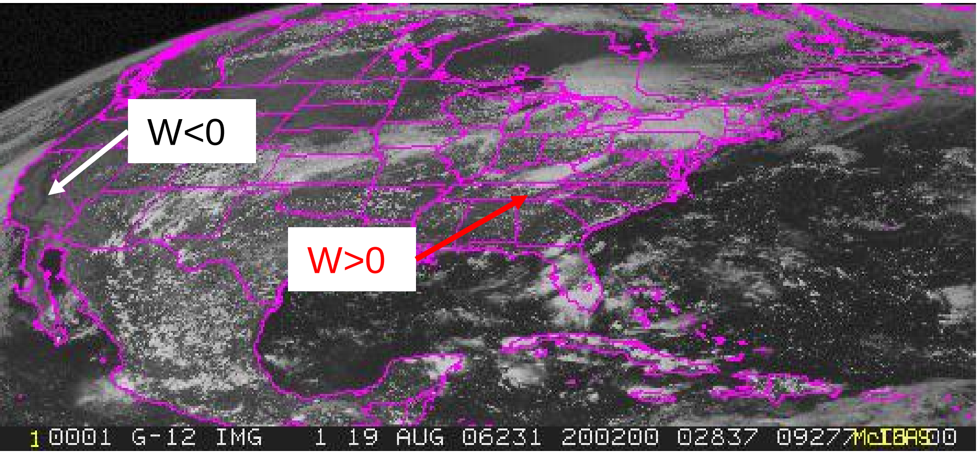
Texas Commission on Environmental Quality

The University of Alabama in Huntsville

Cloud Correction Activity

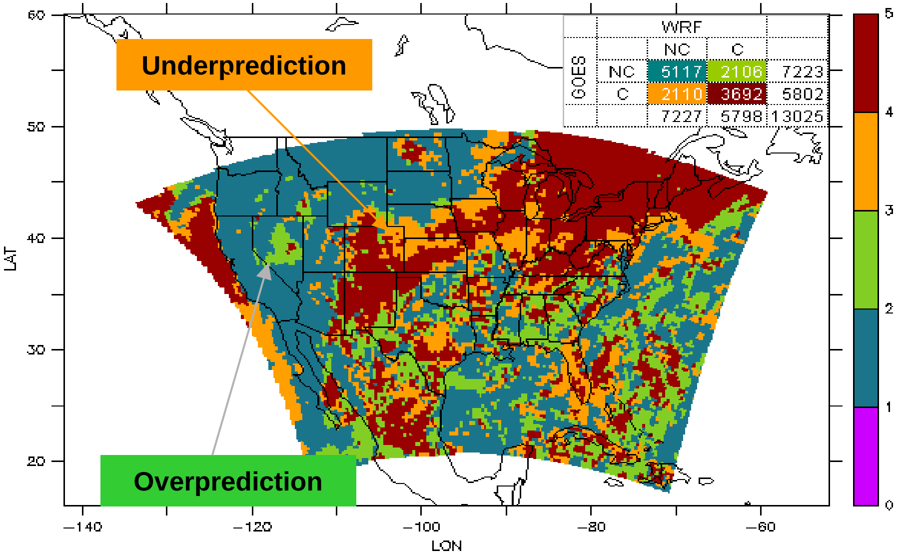
Fundamental Approach

Satellite



0.65um VIS surface, cloud features

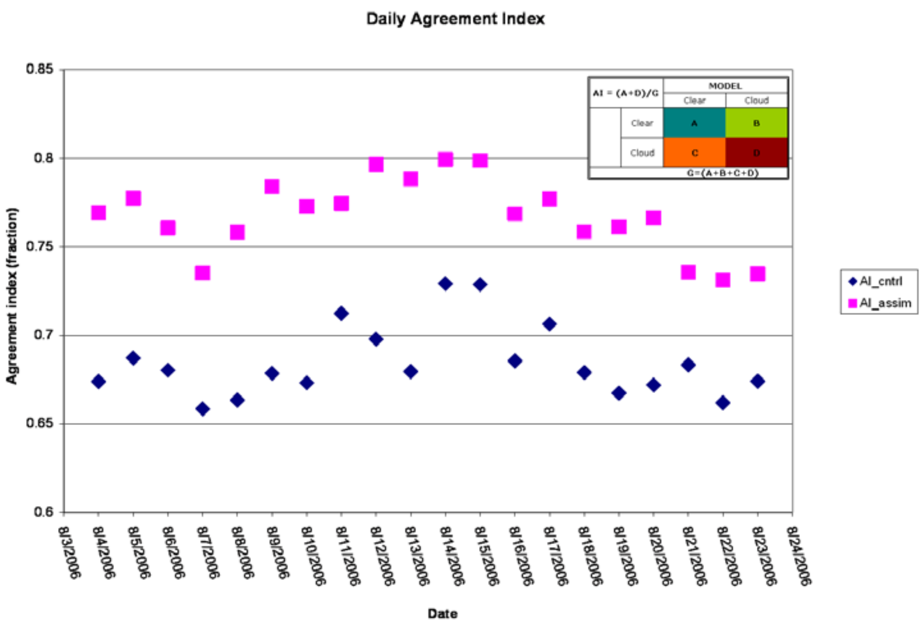
Model/Satellite comparison



- Use satellite cloud top temperatures and cloud albedoes to estimate a **TARGET VERTICAL VELOCITY (Wmax)**.
- Adjust divergence to comply with Wmax in a way similar to O'Brien (1970).
- Nudge model winds toward new horizontal wind field to sustain the vertical motion.
- Remove erroneous model clouds by imposing subsidence (and suppressing convective initiation).

Cloud Correction

- Improved Characterization of Clouds
  - The most difficult activity among three component of this project.
  - The technique was implemented in WRF modeling system.
  - Simulations for August 2006 were performed.
  - TCEQ continues to provide complementary funding for this work.

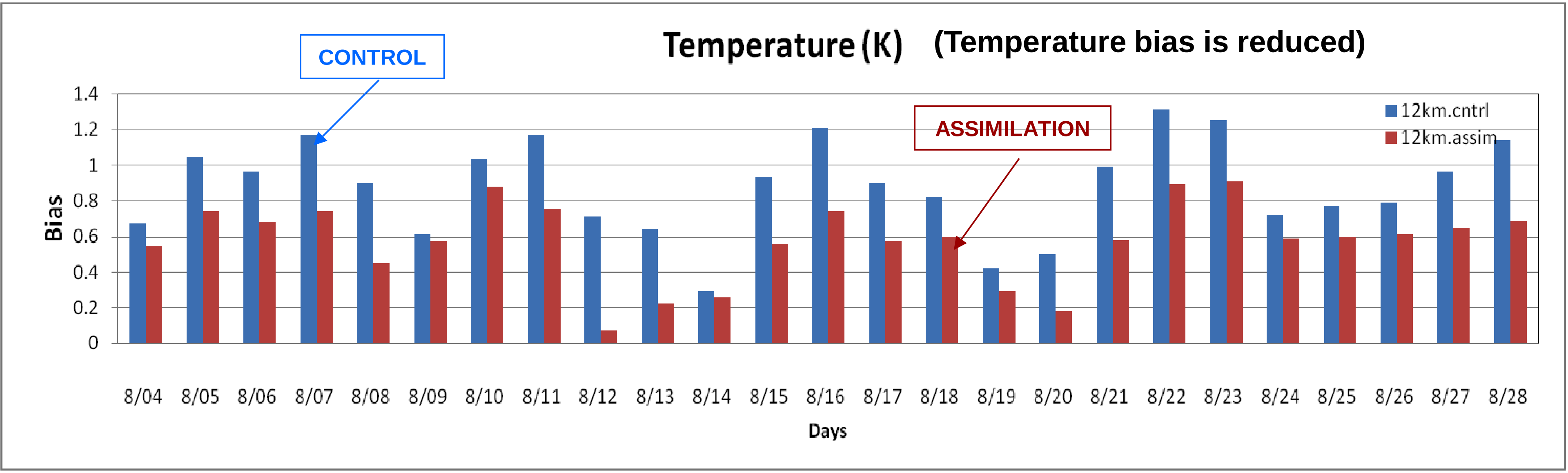


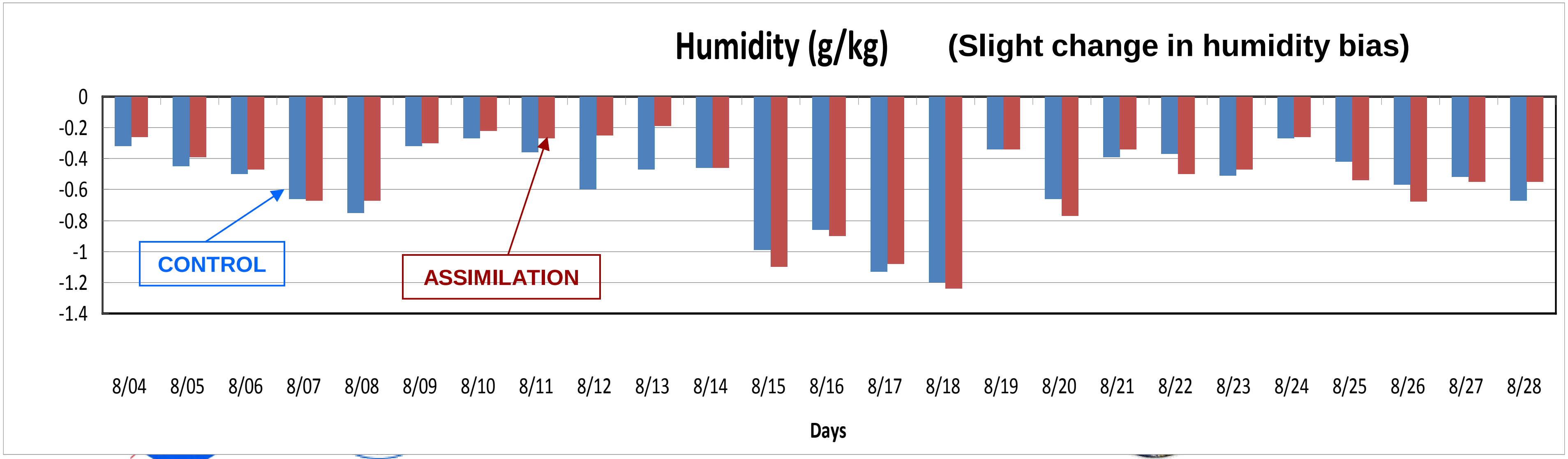
Model performance with respect to cloud simulation was improved by 7-10% for August 2006 as measured by Agreement Index.

Park, Yun-Hee, A. Pour-Biazar, R. T. McNider, B. Dornblaser, M. Khan, K. Doty, Assimilation of Satellite Data to Improve Cloud Simulation in WRF model: Statistical Approach (to be submitted to AE)

Pour-Biazar, A., Y. Park, R. T. McNider, B. Dornblaser, M. Khan, K. Doty, Assimilation of Satellite Data to Improve Cloud Simulation in WRF model: Analytical Approach (to be submitted to AE)

The Impact on Surface Temperature and Humidity





ARL PROGRESS

	Improved Characterization of Clouds			
	FY10	FY11	FY12	FY13
Starting ARL	2	3	4	5
Ending ARL	3	4	5	5

DST: WRF/CMAQ Modeling System

ARL 5: Application components integrated into a prototype system and potential to improve the decision-making activity has been determined and articulated.

- Application components integrated into a functioning prototype application system with realistic supporting elements: The technique was integrated into the DST (WRF modeling system).
- The application system's potential to improve the decision making activity determined and articulated: Simulations for August 2006 were performed, tested, evaluated, and demonstrated improvement in cloud simulation.
- We are in the process of documenting and transitioning the codes to TCEQ to be tested independently and used in an operational setting.

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RISKS & ISSUES

- During testing of Spatial Allocator we noticed a navigation error (surface albedo did not conform to coastal boundaries).
  - To address the issue we brought NASA/MSFC SPoRT, UAH, and Community Modeling and Analysis (CMAS) together.
  - The problem was that the Earth's radius used (and the SW corner) from the GRIB header was not consistent with the internal workings of McIdas.
  - Resolution: From next month, the data will be distributed in ASCII format along with a geolocation file containing the location of data points.
- Easy access to data and tools (for manipulation and re-mapping satellite data) remains a major concern for the user community.
  - We are working on a new web interface to acquire user input about the domain/resolution/format of interest and provide the data in a model friendly (DST compatible) format to the user.

SCHEDULE / MILESTONES

Major Tasks	FY10	FY11	FY12	FY13
Cloud Dynamical Support, Implementation/Test & Evaluation/Transition	Preparation, transition from MM5 to WRF	TCEQ Test/Feedback	Revised and Re-Evaluated	Transition to TCEQ started
OMI/TES ozone and MODIS aerosols, Implementation/Test & Evaluation	Case study identified, data processed, model configured	Model simulation performed, results analyzed	Implemented in CMAQ, Paper Published	
Lightning Generated Nitrogen Oxide from LNOM, Implementation/Test & Evaluation		Data Released to Public, Paper Submitted *	Paper published.	Test in CMAQ.
Website Development for Dissemenating Tools & Data				Major overhaul to data format/tools/distribution
Training Workshop for User Community				Spatial Allocator navigation problem
Benchmarking (multiple activities)		Ozone/Aerosol, Cloud	LNOM, Cloud	Cloud Evaluation for nests
Transition Activities (CMAS, EPA, TCEQ)			CMAS Activity Started	Holdup due to SA problems

* http://ghrc.nsstc.nasa.gov/uso/ds_docs/ldar/ldar_dataset.html

Completed
Ongoing
Future

BUDGET

	UAH	CMAS	NASA/USRA
Total	$855,932	$139,000	$272,911
Balance	$20,050	$33,803	

- Requested NCE and it was approved. POP extended to 9/30/2014.
- The balance will be used to complete the transition to CMAS and hold a workshop.
- TCEQ is providing additional funding of $150K for documentation/transition to TCEQ. This brings the total complementary funding from TCEQ to $500K.

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Future Tasks

- Resolve the issues with CMAS and hold a workshop.
- Complete transitioning to CMAS and TCEQ.
  - Complete documentation.
  - Work with TCEQ for independent evaluation of tools and techniques.
- Upgrade the current web based data delivery system for the new data format.
- Respond to user community's request for Photosynthetical Active Radiation (PAR).
  - We had requests from Dave Allen's group at University of Texas-Austin, Russ Dickerson at University of Maryland and Rice University.

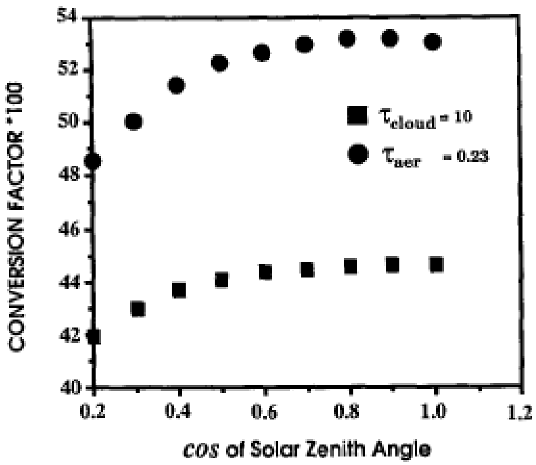
What is PAR

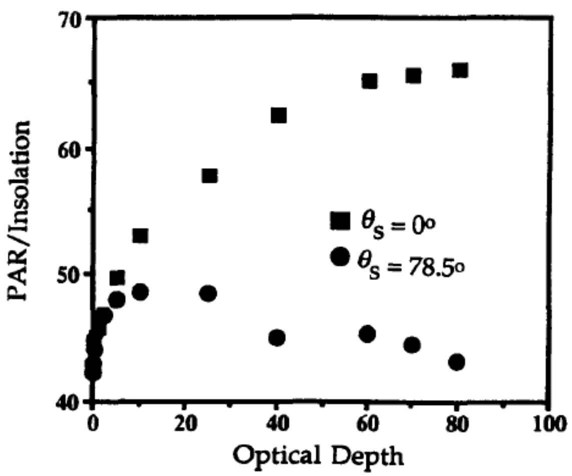
$$PAR = \int_{.4}^{.7} I(\lambda)d\lambda \qquad (W\,m^{-2})$$

$$PAR = \frac{1}{hc}\int_{.4}^{.7} I(\lambda)d\lambda \qquad (quanta\,m^{-2}s^{-1})$$

- In most applications (e.g., agriculture related) a conversion factor CF is used:

$$CF = \frac{PAR}{Insolation}$$





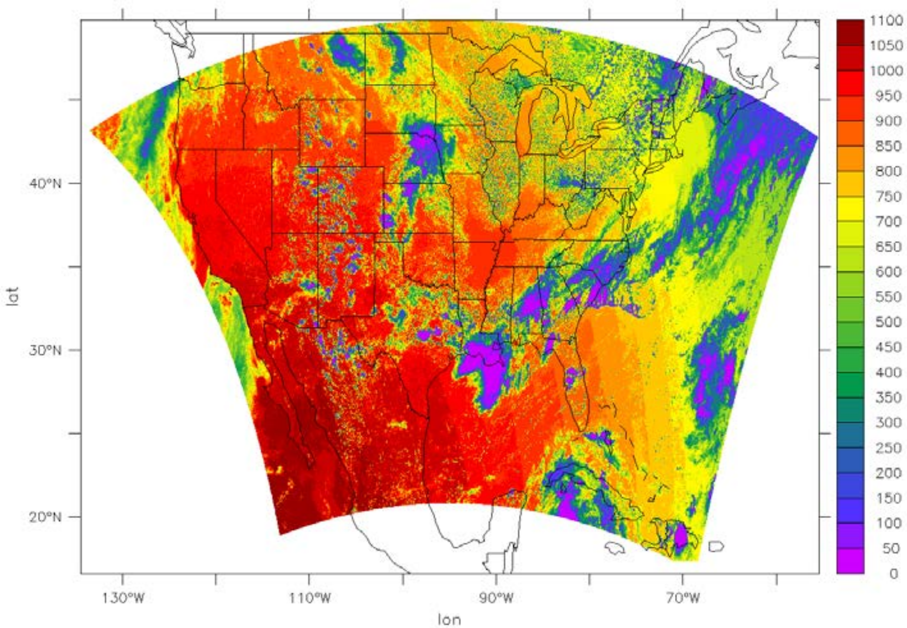
Direct and diffuse light differences: Highest sensitivity to clouds/aerosols and zenith angle, but not in the same direction. *(Adapted from: Frouin and Pinker, 1994; Pinker and Laszelo, 1991)*

Simple PAR calculation

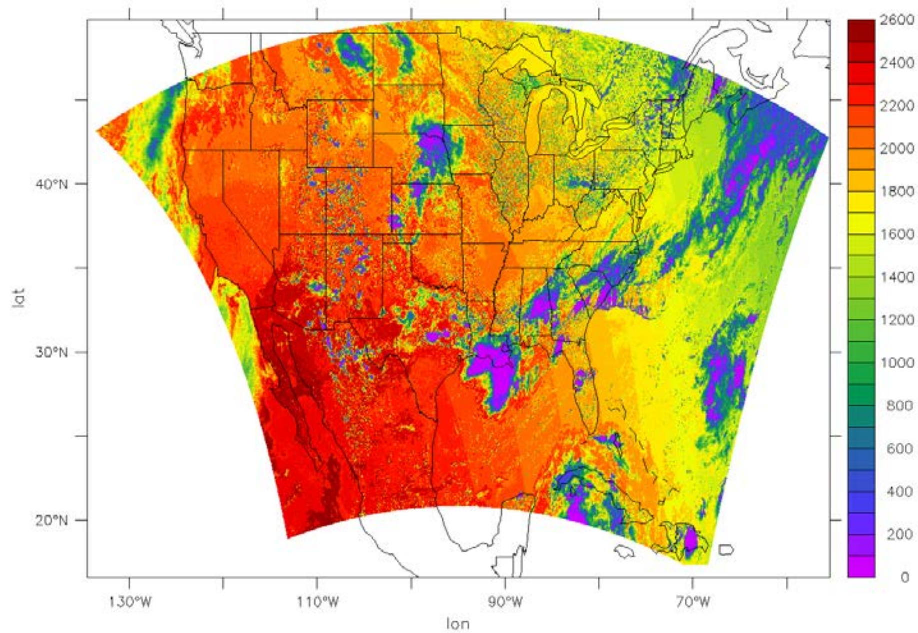
$$CF = \frac{PAR}{Insolation} = .48 + .17 * Cfactor * Zfactor$$

$$Where \quad Cfactor = \sqrt{1-(\alpha_c - 1)^2}$$

α_c is cloud albedo



Insolation (W/m~2)



PAR (umol/(m~2.s))

NASA

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Publications

Journal Publications:

Koshak, William, Harold Peterson, Maudood Khan, Arastoo Biazar, Lihua Wang, 2012: The NASA Lightning Nitrogen Oxides Model (LNOM): Application to Air Quality Modeling. *Atmos. Res.* (2013) http://dx.doi.org/10.1016/j.atmosres.2012.12.015.

Kuang, S., J. F. Burris, M. J. Newchurch, S. Johnson, S. Long (2010), Differential Absorption Lidar to Measure Sub-hourly Variation of Tropospheric Ozone Profiles, IEEE Trans. Geosci. Remote Sens., 49 (1), 557-571, ISSN**:** 0196-2892, DOI:10.1109/TGRS.2010.2054834

Kuang, Shi, M.J. Newchurch, John Burris, Lihua Wang, Patrick I. Buckley, Steve Johnson, Kevin Knupp, Guanyu Huang, Dustin Phillips, Wesley Cantrell (2011), Nocturnal ozone enhancement in the lower troposphere observed by lidar, *Atmos. Environ.*, Volume 45, Issue 33, Pages 6078-6084, ISSN 1352-2310, DOI:10.1016/j.atmosenv.2011.07.038.

Mackaro, S., R.T. McNider, A. Biazar (2011), Some Physical and Computational Issues in Land Surface Data Assimilation of Satellite Skin Temperatures, Pure and Applied Geophysics, Vol. 167, No. 11, p. 1-14, Doi: 10.1007/s00024-011-0377-0. Url: http://dx.doi.org/10.1007/s00024-011-0377-0

Ngan, F., D. W. Byun, H. C. Kim, B. Rappenglueck and A. Pour-Biazar, 2012: Performance Assessment of Retrospective Meteorological Inputs for Use in Air Quality Modeling during TexAQS 2006. *Atmos. Environ.*, **54**, 86-96.

Pour-Biazar, A., M. Khan, L. Wang, Y. Park, M. Newchurch, R. T. McNider, X. Liu, D. W. Byun, and R. Cameron (2011), Utilization of satellite observation of ozone and aerosols in providing initial and boundary condition for regional air quality studies, J. Geophys. Res., 116, D18309, doi:10.1029/2010JD015200.

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Wang, L., M. J. Newchurch, A. Biazar, X. Liu, S. Kuang, M. Khan, and K. Chance (2011), Evaluating AURA/OMI ozone profiles using ozonesonde data and EPA surface measurements for August 2006, Atmos. Environ., 45(31), 5523-5530.

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Publications

Proceedings:

Koshak, William, Maudood Khan, Harold Peterson, Lihua Wang, Arastoo Biazar, The Lightning Nitrogen Oxides Model (LNOM): status and recent applications. 91st American Meteorological Society Meeting, Seattle, WA, January, 2011.

Koshak, W., H. Peterson, M. Khan, A. Biazar, L. Wang, The NASA Lightning Nitrogen Oxides Model (LNOM): Application to Air Quality Modeling, XIV International Conference on Atmospheric Electricity, Rio de Janeiro, Brazil, August 8-12, 2011.

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ACRONYMS

CMAQ	EPA's Community Multiscale Air Quality (CMAQ) Model
CMAS	Community Modeling and Analysis System
EPA	Environmental Protection Agency
LNOx	Lightning Generated Nitrogen Oxides
LNOM	Lightning Nitrogen Oxides Model
NASA	National Aeronautics and Space Administration
SIP	State Implementation Plan
TCEQ	Texas Commission on Environmental Quality

Thank You

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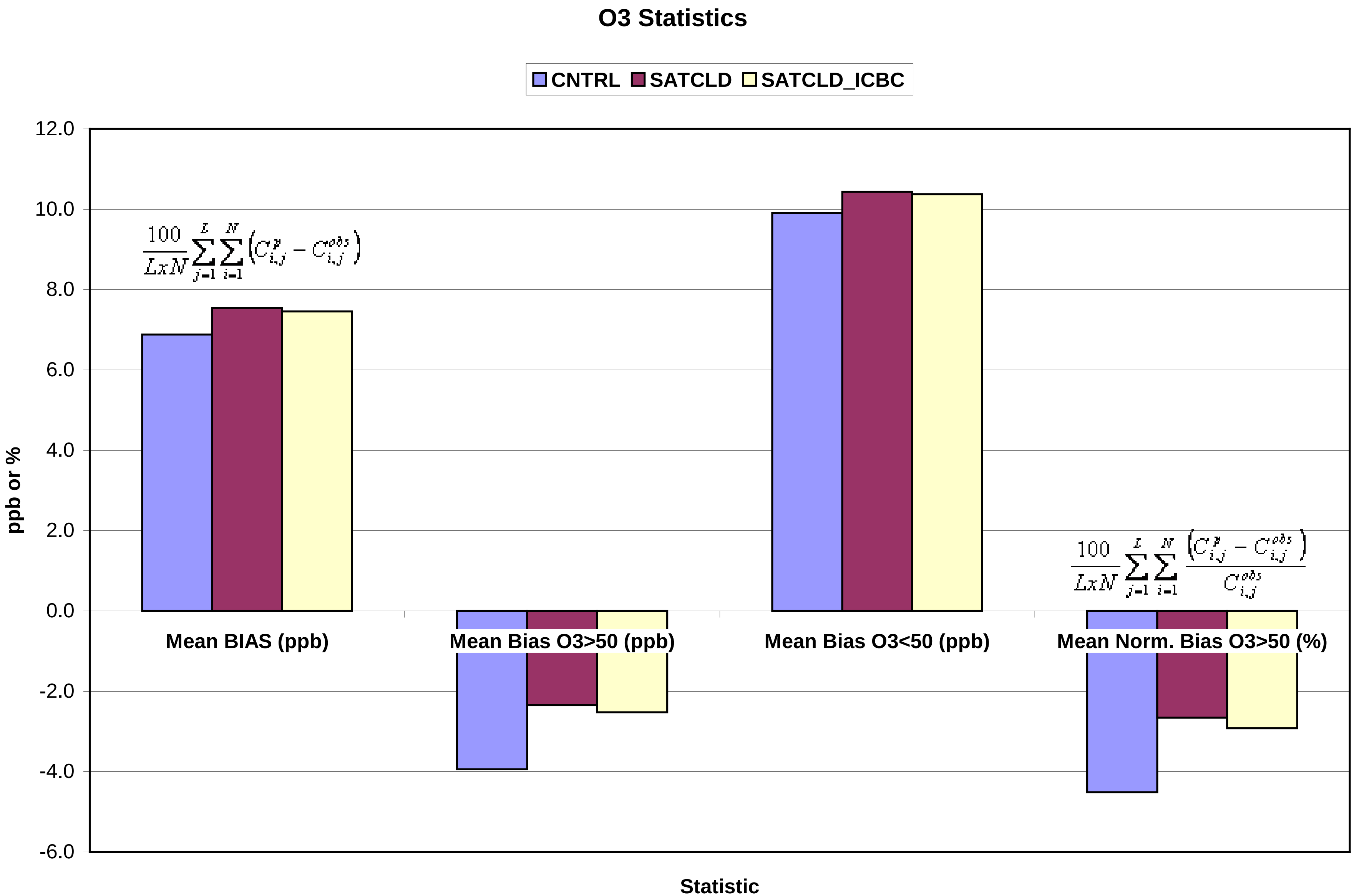
ADDITIONAL SLIDES



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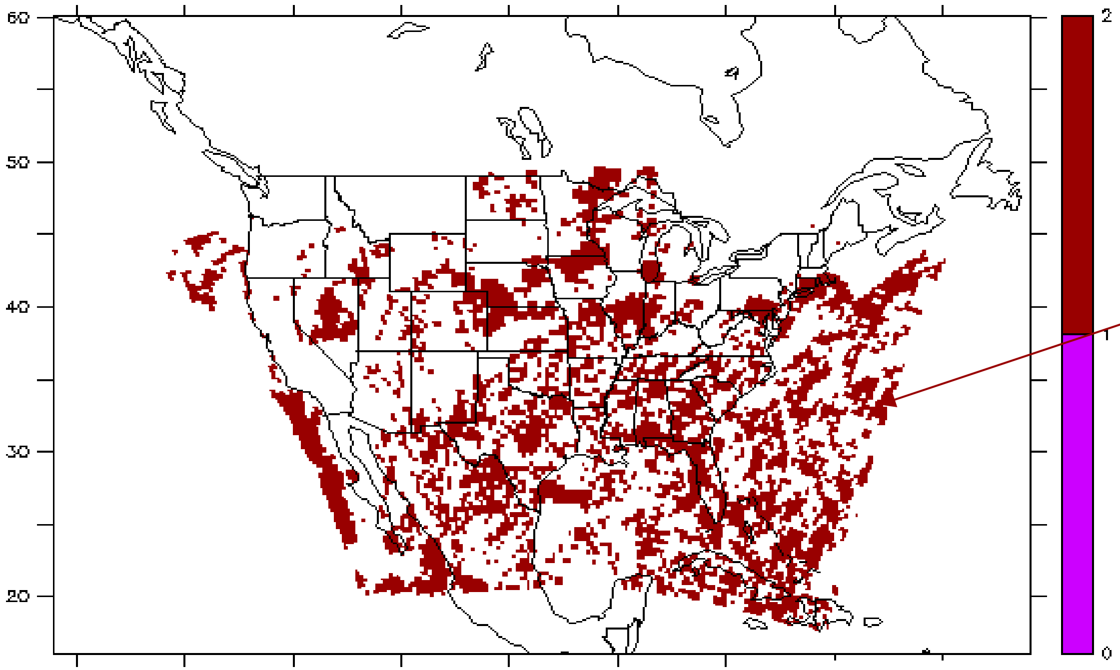
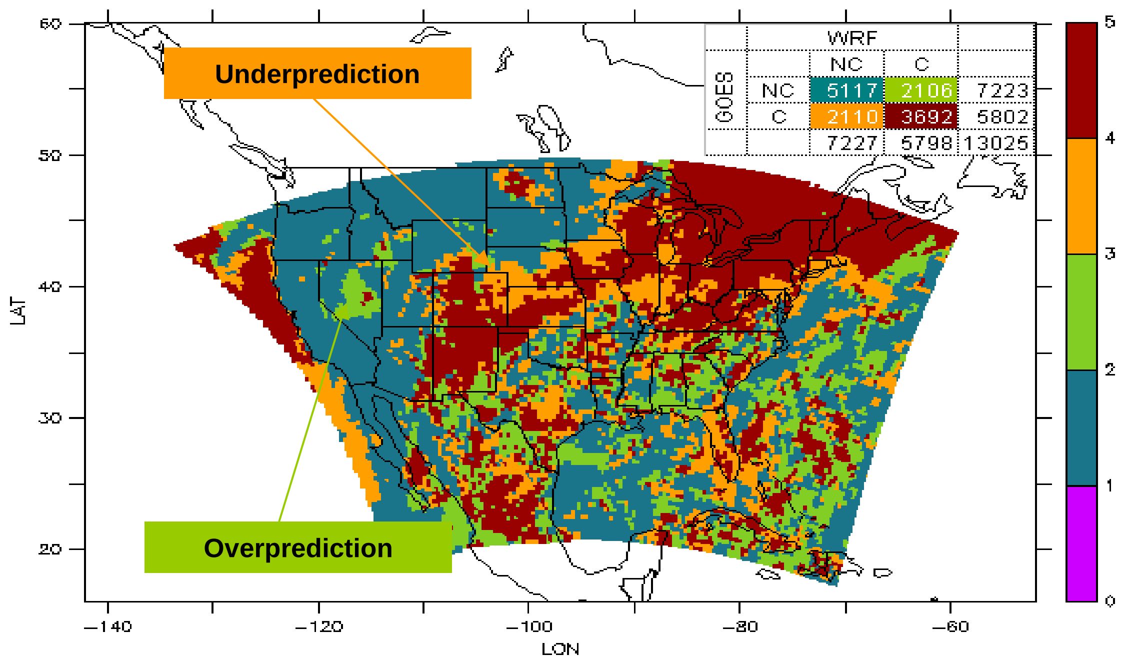
Cloud Correction: Identifying Areas of Under-/Over-prediction for Correction



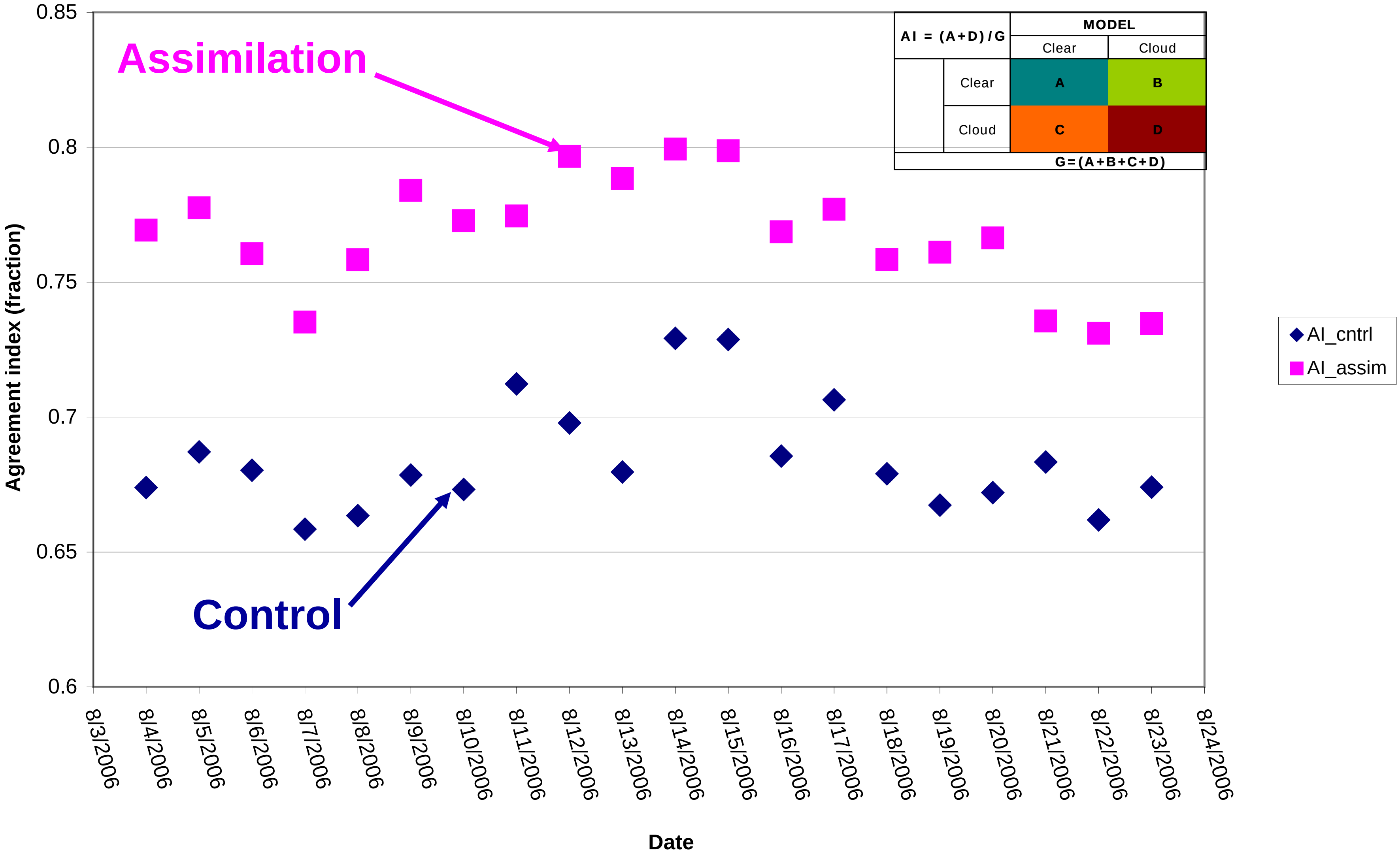
Areas of disagreement between model and satellite observation

A contingency table can be constructed to explain agreement/disagreement with observation

AI = (A+D)/G		MODEL	
		Clear	Cloud
	Clear	A	B
	Cloud	C	D
		G=(A+B+C+D)	



Cloud Correction: Agreement Index = (# of cloudy/clear grids in agreement) / (Total # of grids)



Agreement index increased by 7-10%

Overview of the Data Archive & Delivery system

NSSTC Satellite Ground Station & Data Link

↓

NSSTC Satellite Data Processing & Product Generation

- Insolation
- Skin Temperature
- Surface Albedo
- Cloud Albedo
- Cloud Top Temperature/Pressure
- Cloud Transmittance
- MODIS Emissivity

↓

Web Based Satellite data delivery system (SAT_ASSIM.NSSTC.UAH.EDU)

- Archive and Distribute Data
- Regridding Software
- Data Processing Software

↓

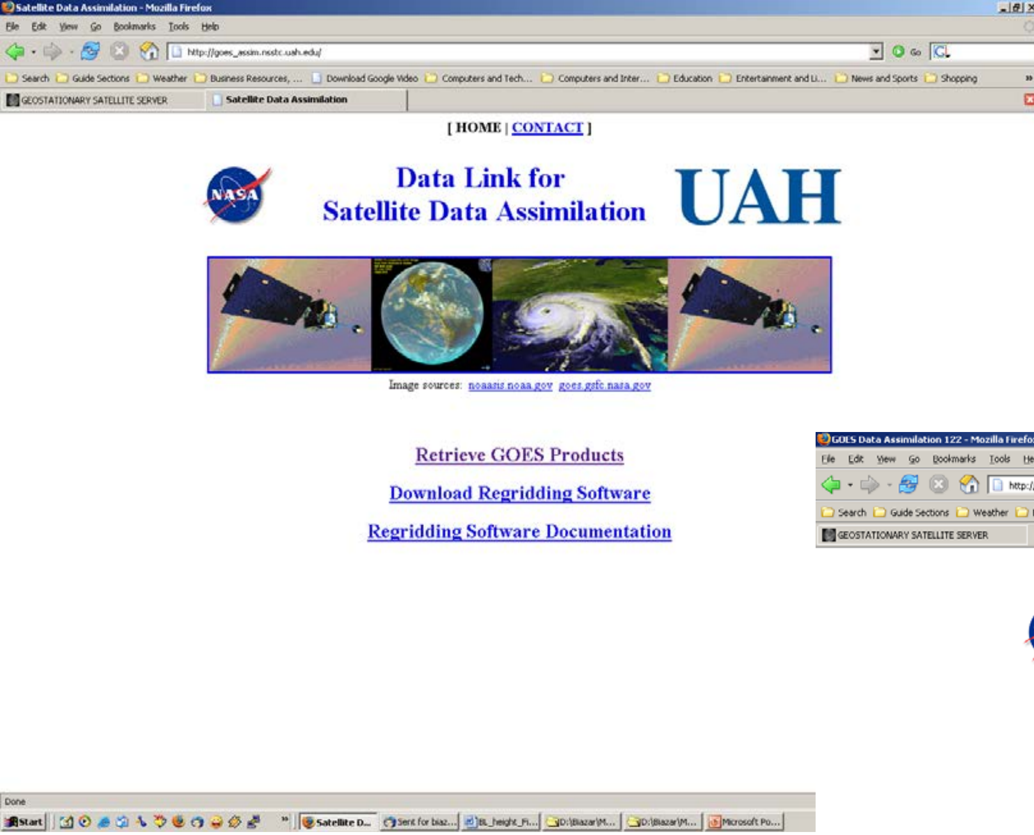
Decision Support Tools

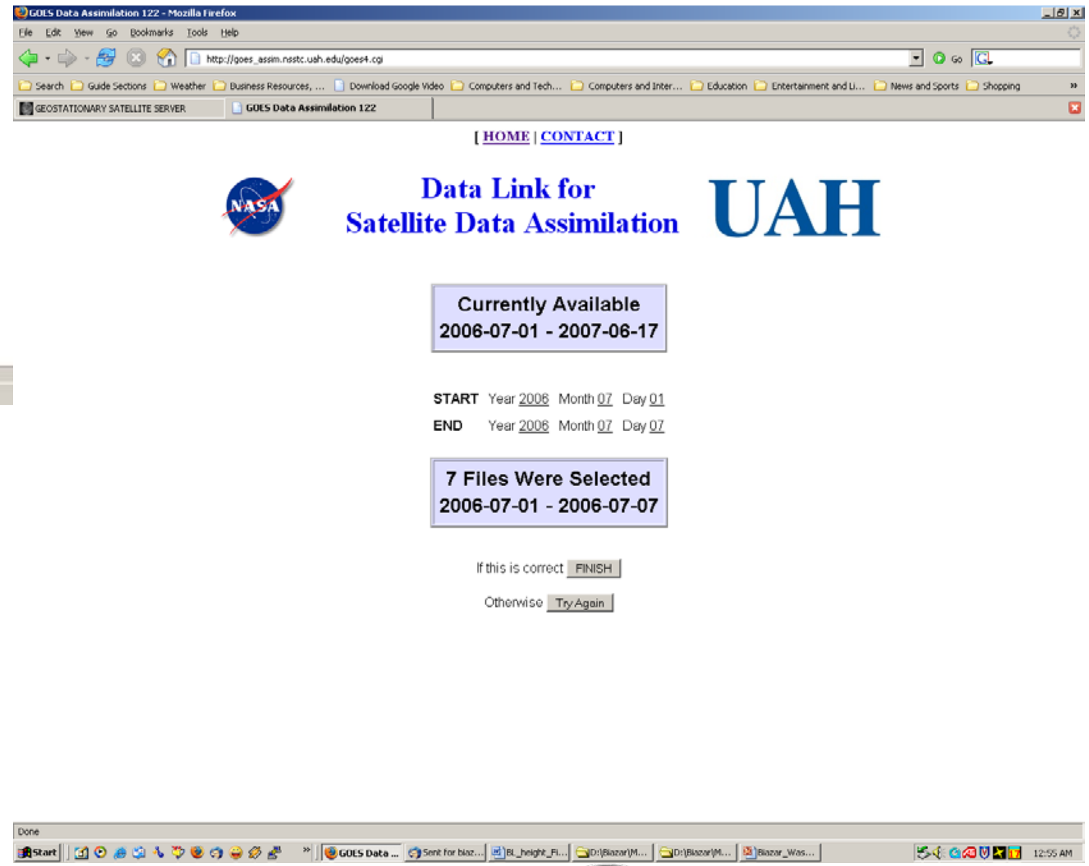
MM5/WRF → CMAQ/WRFCHEM

↓

State, Local & Private Sector Users

Web Based Delivery System





sat_assim.nsstc.uah.edu

Username: levl

Password: sparkx

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What is SIP

The State Implementation Plan (SIP) Decision Making Process

- Classification: Once an area exceeds the National Ambient Air Quality Standard (NAAQS) for a criteria pollutant (e.g., O3, NO2, SO2, particulate matter) and is listed by the USEPA as **non-attainment** the state must develop a plan or strategy to lower the pollutant levels to meet the NAAQS.
- Design Period: A design day or design period is selected (usually the period when the highest pollutant levels occur).
- Best Modeling Practice: Model simulations are carried out to determine whether the model can reasonably replicate the atmospheric conditions for such episode and the observed pollutant values for that period.
- Emissions Reduction: Next various emission reduction scenarios in these models are carried out to determine the most efficient strategy for meeting the air quality standards for the design period. **This defines the SIP**.

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Control Strategy Simulations - Inputs

Standard surface and upper air meteorological observations

Special Observations Profiler/Sodar

Emissions are Changed to Reflect Control Programs on Industrial and Mobile Sources

Physical Model

Recreates Physical Atmosphere

Chemical Model

Recreates Chemical Atmosphere

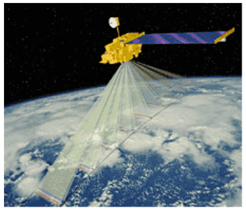
Initial/Boundary conditions

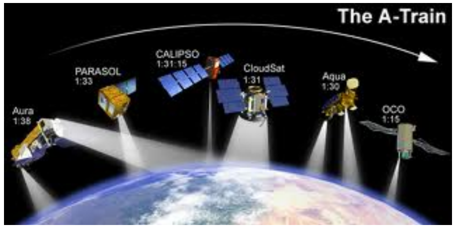
IC/BC

Ambient Levels Compared to NAAQS

Design Period Simulations – Satellite Inputs

Retrospective – Data Assimilated for all Integration Period





Geostationary Satellite
- •Insolation
- •Cloud Properties
- •Skin Temperature

MODIS
- •Surface emissivity
- •Surface albedo
- •Skin temperatures

Satellite derived Cloud properties for photolysis rates

Satellite trace gas and aerosol observations

ASSIMILATION

Physical Model

Recreates Physical Atmosphere

Chemical Model

Recreates Chemical Atmosphere

Geostationary and Polar Orbiting Observations for Evaluation

Control Strategy Decisions Made With WRF/CMAQ Can Amount to Billions of Dollars

- Under the Southern Oxidant Study it was estimated that SIP control decisions involved $5 billion for 6 southeastern states

- In Texas the cost of the ozone SIP for Houston alone was estimated to be over $1 billion.

- Nationally these SIPs amount to ten’s of billions in control costs (http://www.epa.gov/oar/sect812/feb11/fullreport.pdf).

NASA

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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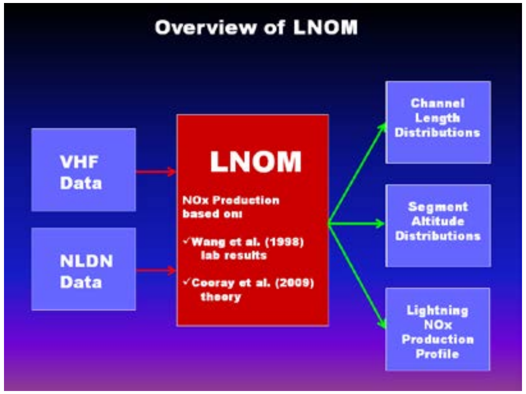
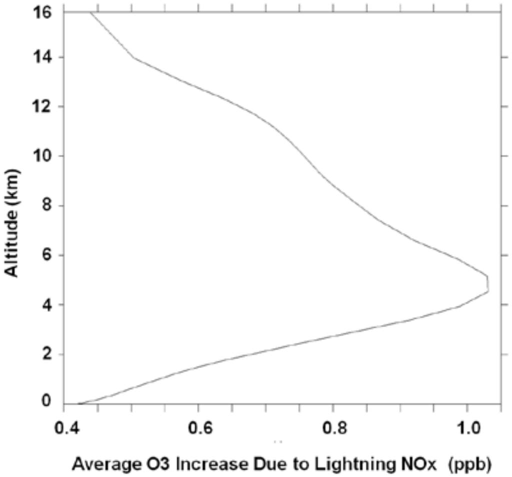
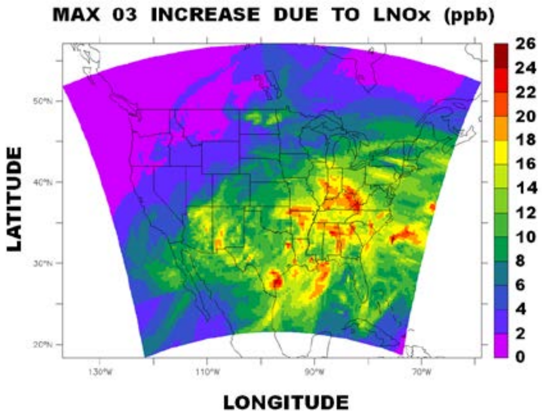
SUMMARY of PROGRESS – LNOM LNOx Activity

- LNOM LNOx Activity
  - The method and its first application within WRF/CMAQ have been documented (Koshak et al., 2012).
  - Simulations over 4 summers are underway, quantifying the model error due to lack of LNOx in default CMAQ configuration.
  - The data and documentations are now available at (http://lightning.nsstc.nasa.gov/data/index.html#LNOM_DATA)







(Adapted from Koshak et al., 2012)