Use of Satellite Data to Improve the Physical Atmosphere in SIP Air Quality Decision Models

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PURPOSE

Use of Satellite Data to Improve the Physical Atmosphere in SIP Air Quality Decision Models

The purpose of this project is to employ satellite products to improve the physical atmosphere in air quality models used to define emission control strategies for attainment of air quality standards.

CONTEXT

The State Implementation Plan (SIP) Decision Making Process

Once an area exceeds the National Ambient Air Quality Standard (NAAQS) for a criteria pollutant (O_3, NO, SO_2, 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.

A design day or design period is selected usually the period when the highest pollutant levels occur.

Model simulations are carried out to determine whether the model can reasonably replicate the episode conditions and the observed pollutant values for this period.

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.

Design Period Simulations

Physical Model

MM5, RAMS

Recreates the physical atmosphere (winds, temperature, precipitation, moisture, turbulence etc) during the design period

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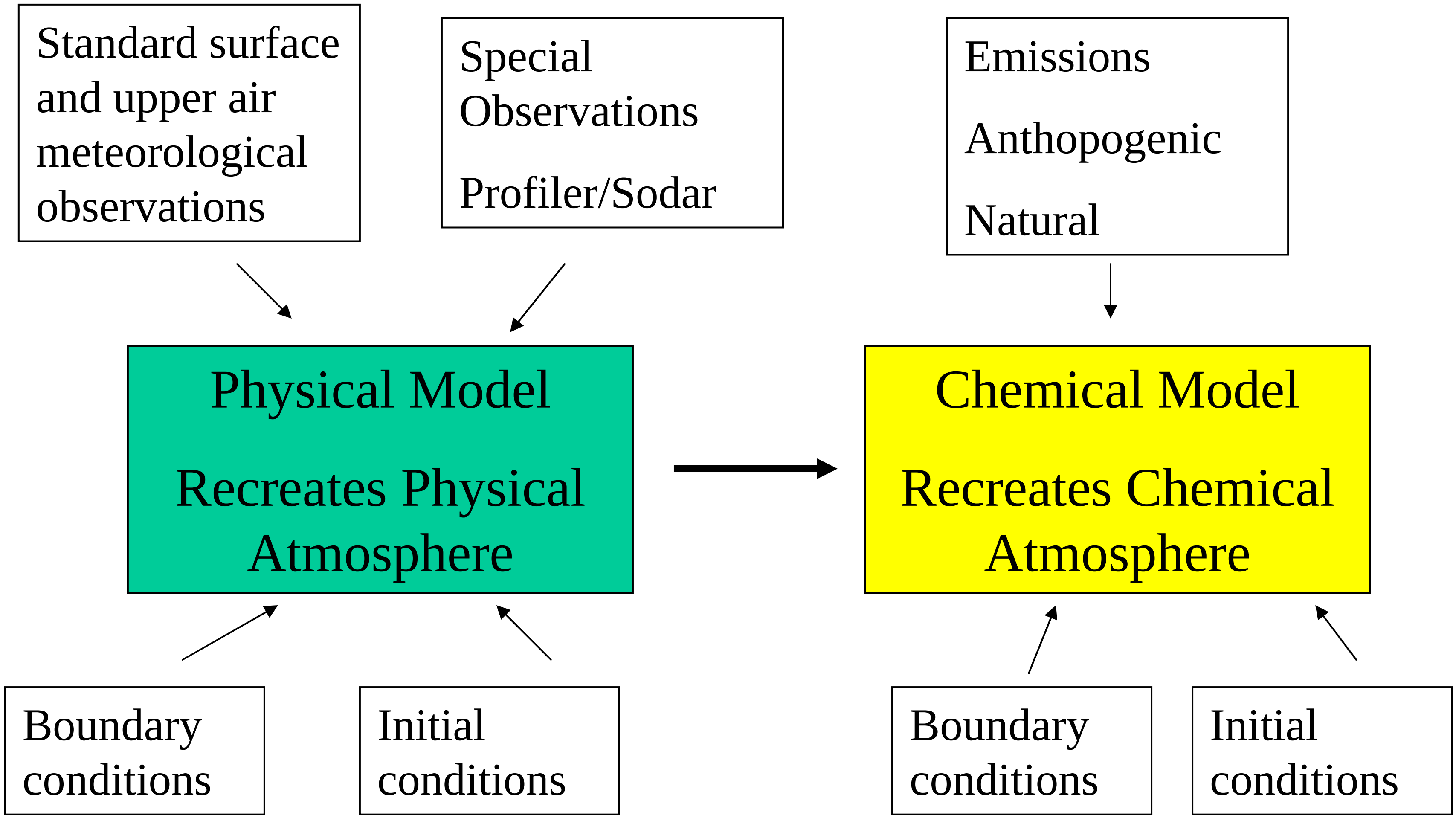
Chemical Model

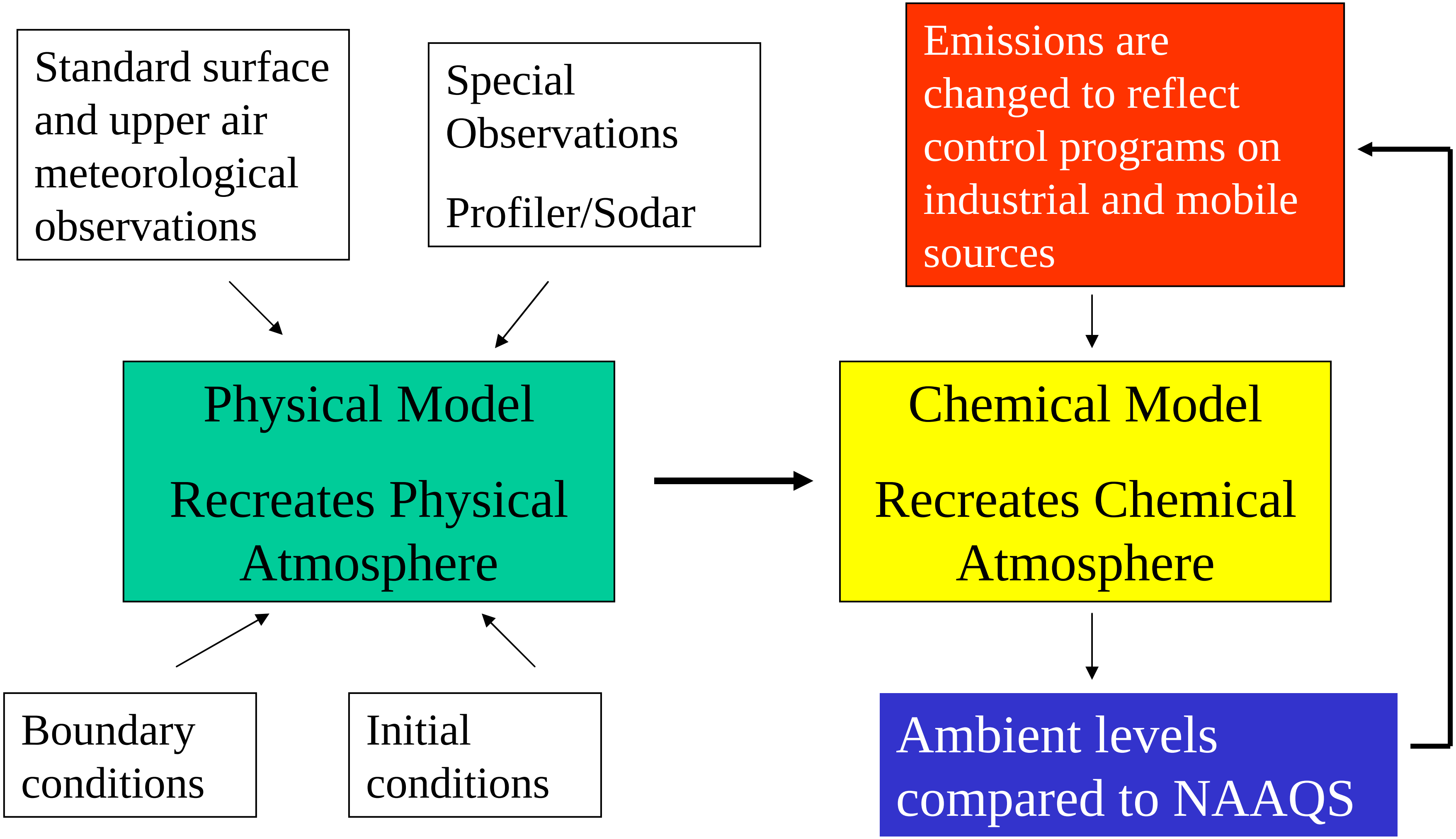
CMAQ, UAM

Recreates the chemical atmosphere both the pollutant of interest and precursor chemicals

Design Period Simulations – Inputs



Control Strategy Simulations - Inputs



Control Strategy Decisions made with MM5/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.

Design Period Simulations – Satellite Inputs

Retrospective – Data Assimilated for all Integration Period

Geostationary Satellite Observations –
- Insolation
- Skin temperatures
- Cloud Properties

MODIS
- Surface emissivity
- Surface albedo
- Skin temperatures

Satellite derived properties for photolysis rates

Physical Model

Recreates Physical Atmosphere

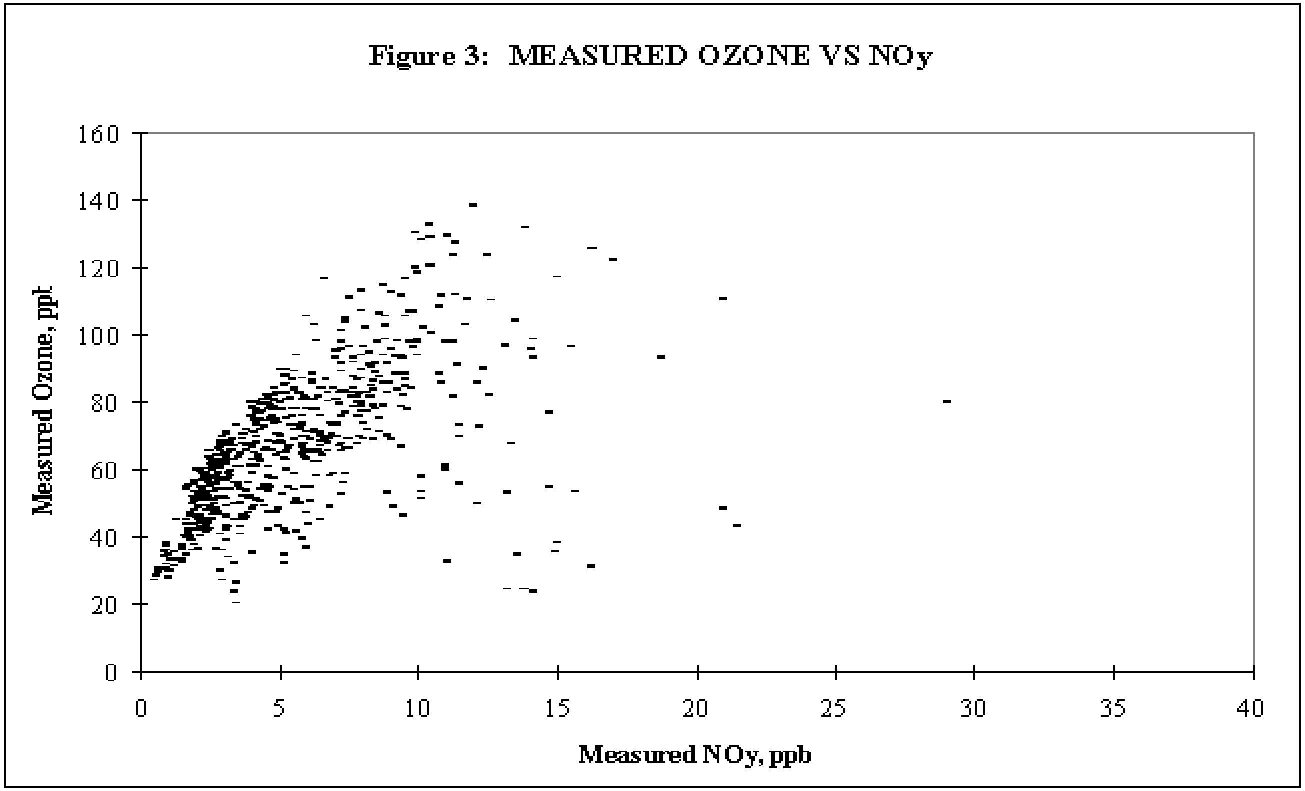
→

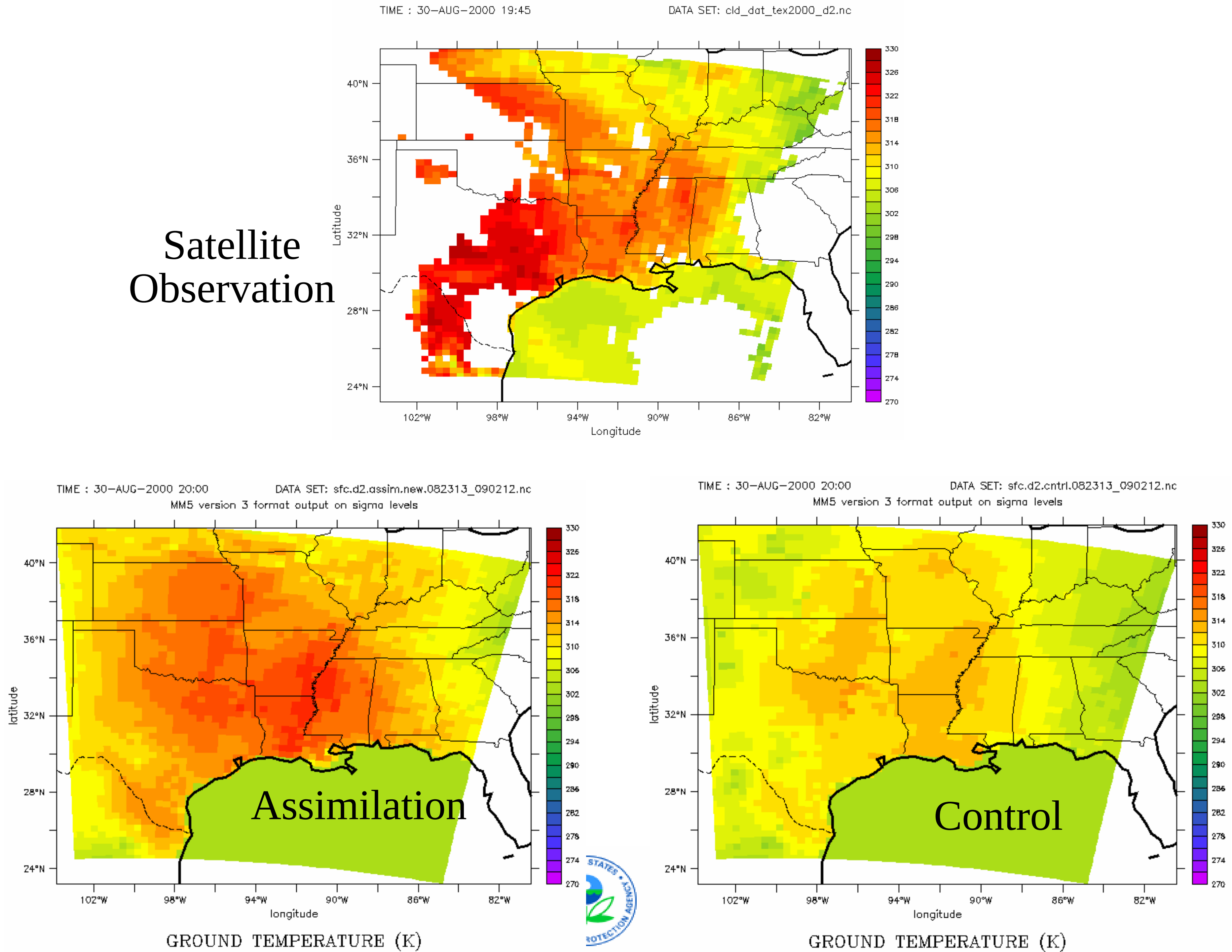
Chemical Model

Recreates Chemical Atmosphere

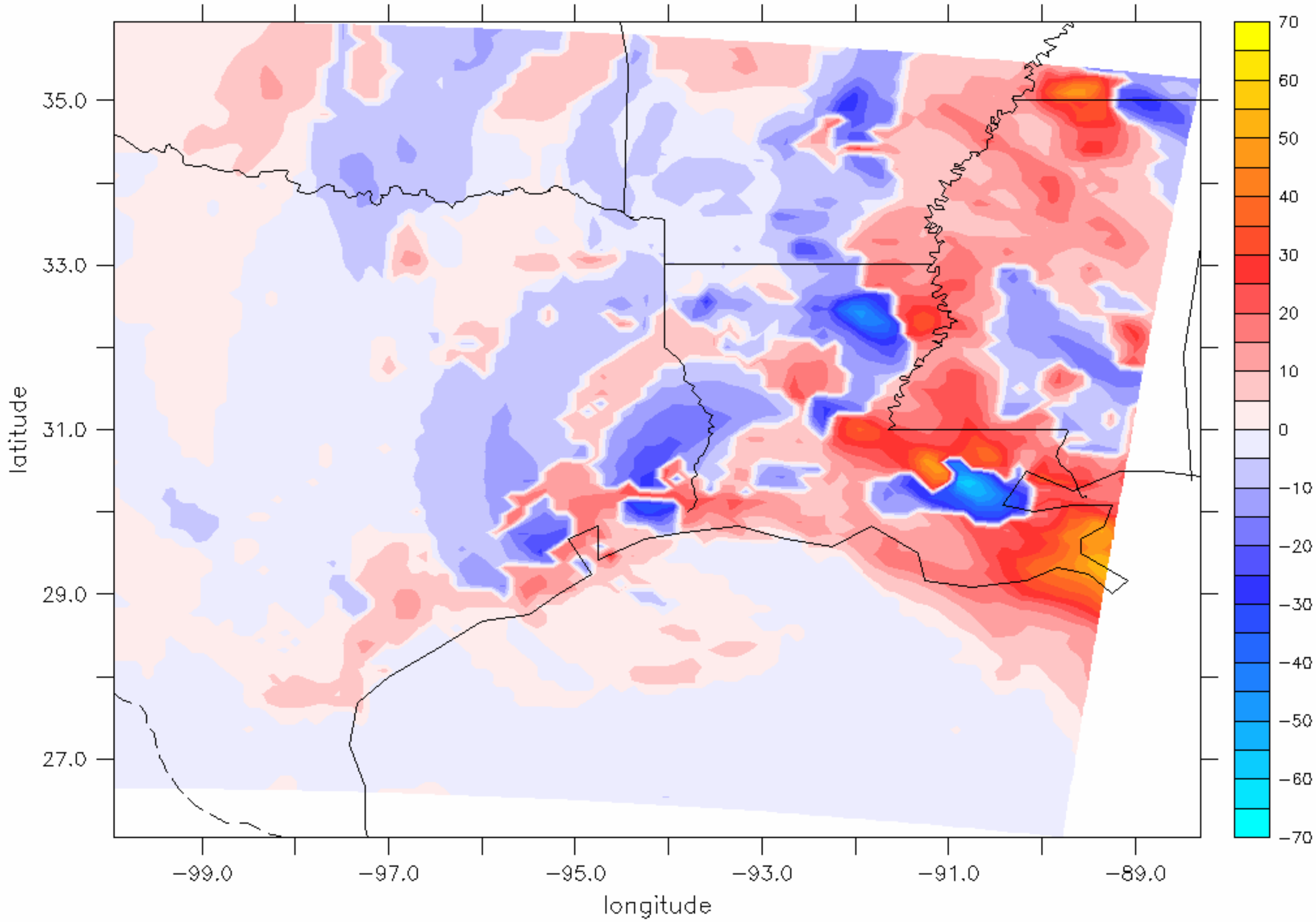
Impact of Physical Atmosphere on SIP Control Strategies

Temperature – over prediction of temperature can bias ozone controls toward NOx controls as thermal decomposition and increases slope of ozone/NOy curves. Additionally, biogenic emissions will be overestimated.



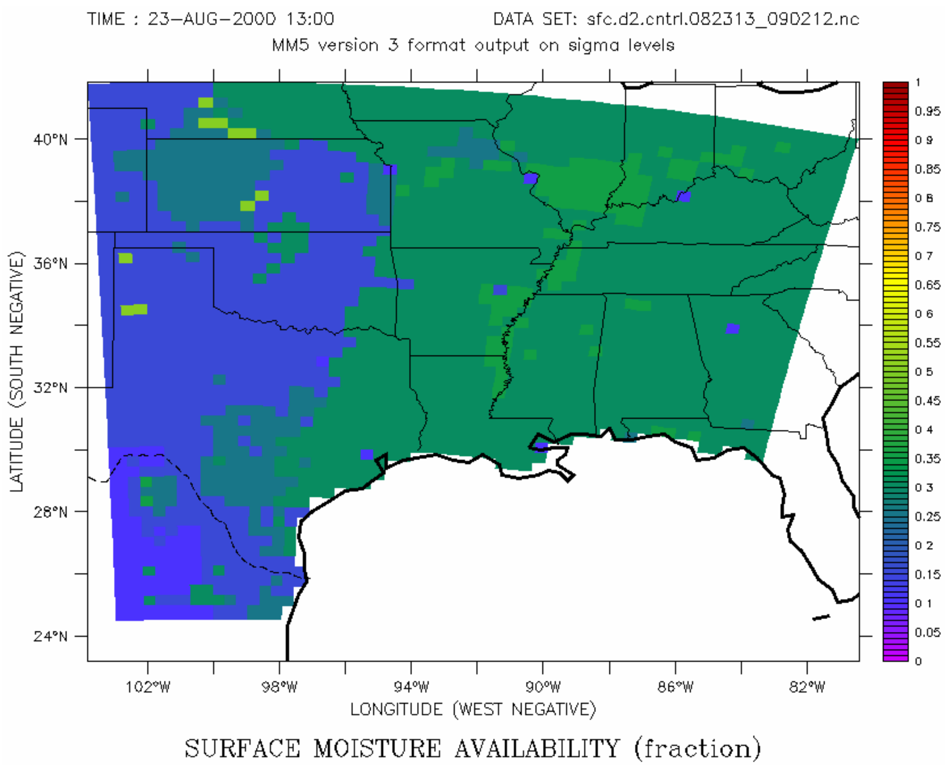

Satellite Observation
TIME : 30-AUG-2000 19:45
DATA SET: cld_dat_tex2000_d2.nc
Latitude
Longitude
TIME : 30-AUG-2000 20:00
DATA SET: sfc.d2.assim.new.082313_090212.nc
MM5 version 3 format output on sigma levels
latitude
longitude
Assimilation
GROUND TEMPERATURE (K)
TIME : 30-AUG-2000 20:00
DATA SET: sfc.d2.cntrl.082313_090212.nc
MM5 version 3 format output on sigma levels
latitude
longitude
Control
GROUND TEMPERATURE (K)

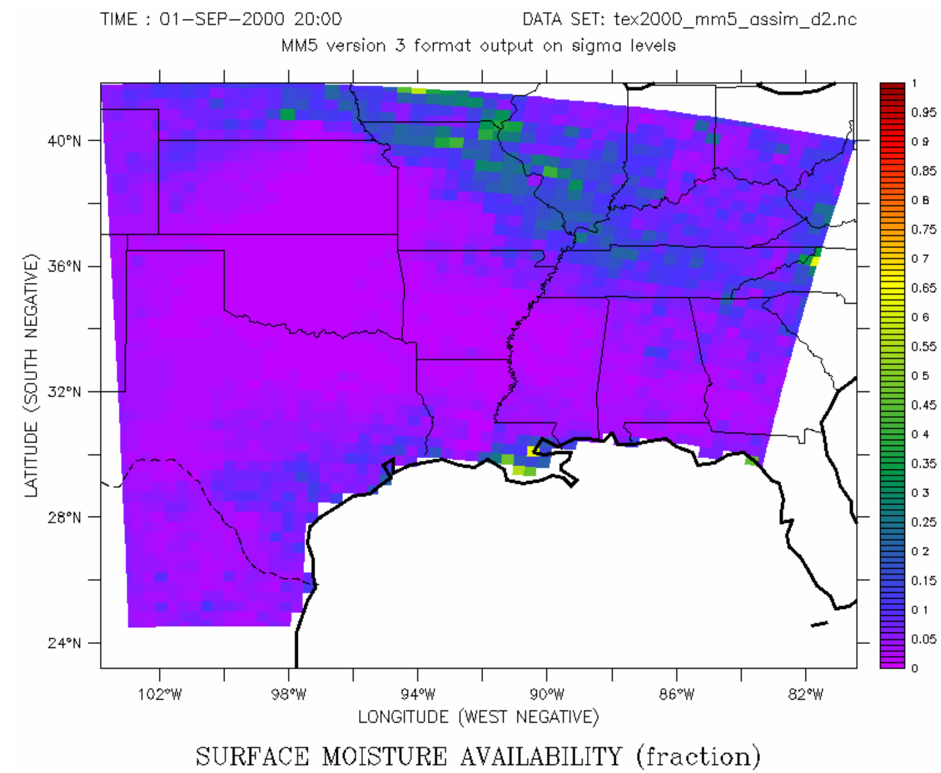
Photolysis Rates – Errors in photolysis rates can change response time of ozone production and change significantly levels at a given monitor



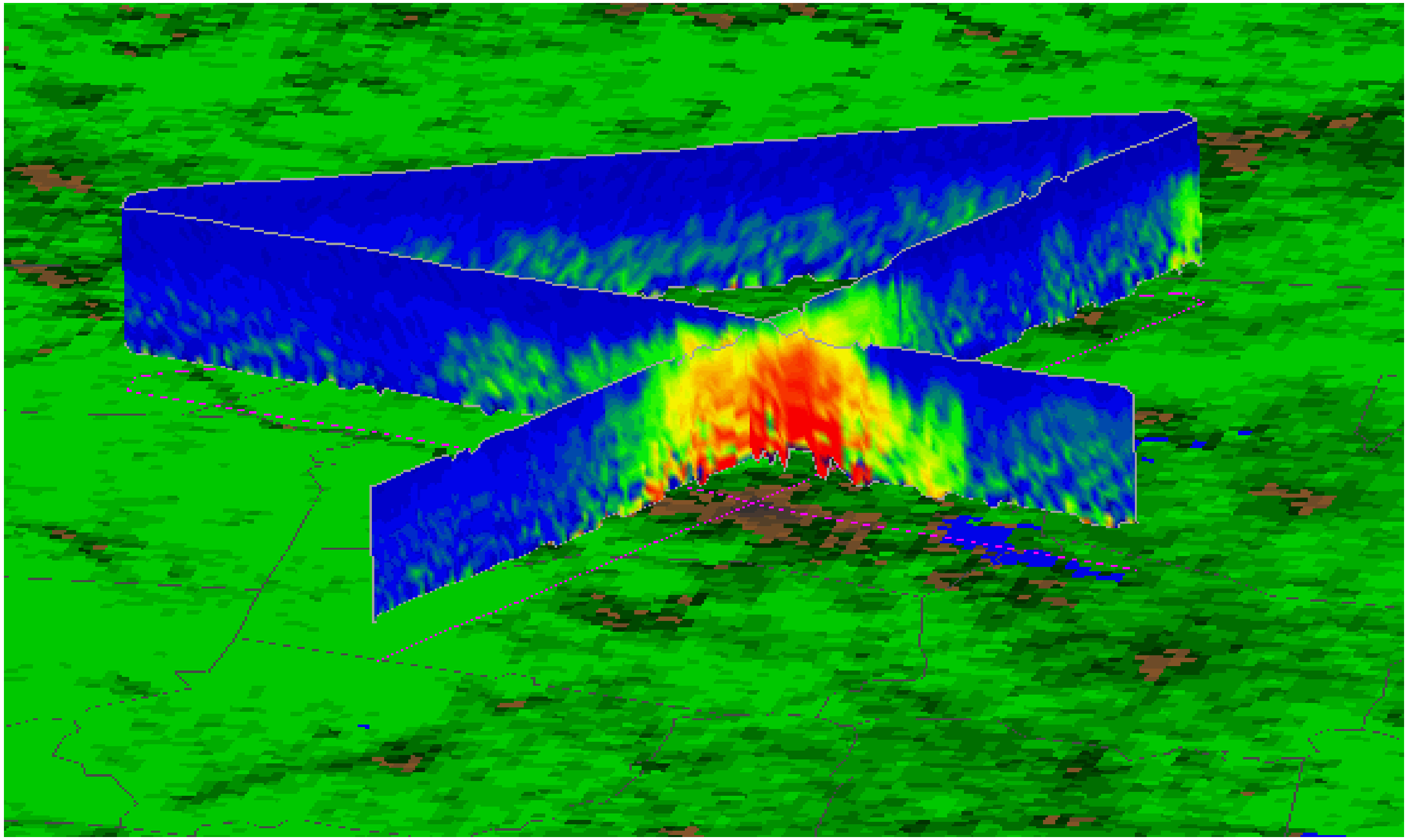
Max abs. diff in O3 concentration

Moisture – Pollutant uptake by plants is directly related to photosynthesis and transpiration. Under-estimation of moisture and associated surface loss can overestimate the role of long range transport in local air pollution levels.



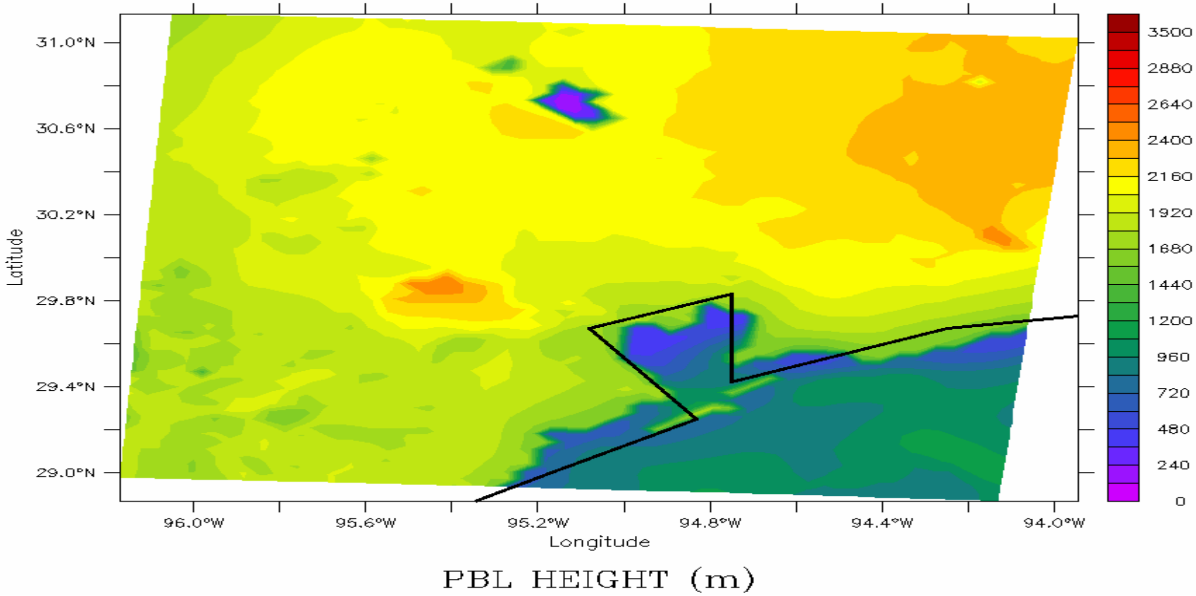


Mixing Heights – Underestimate of mixing heights can cause an over-estimate of the sensitivity of controls. Emission reductions confined to a smaller volume cause a larger reduction in pollutants. A 30% error in mixing heights can produce 30% error in emission change impacts

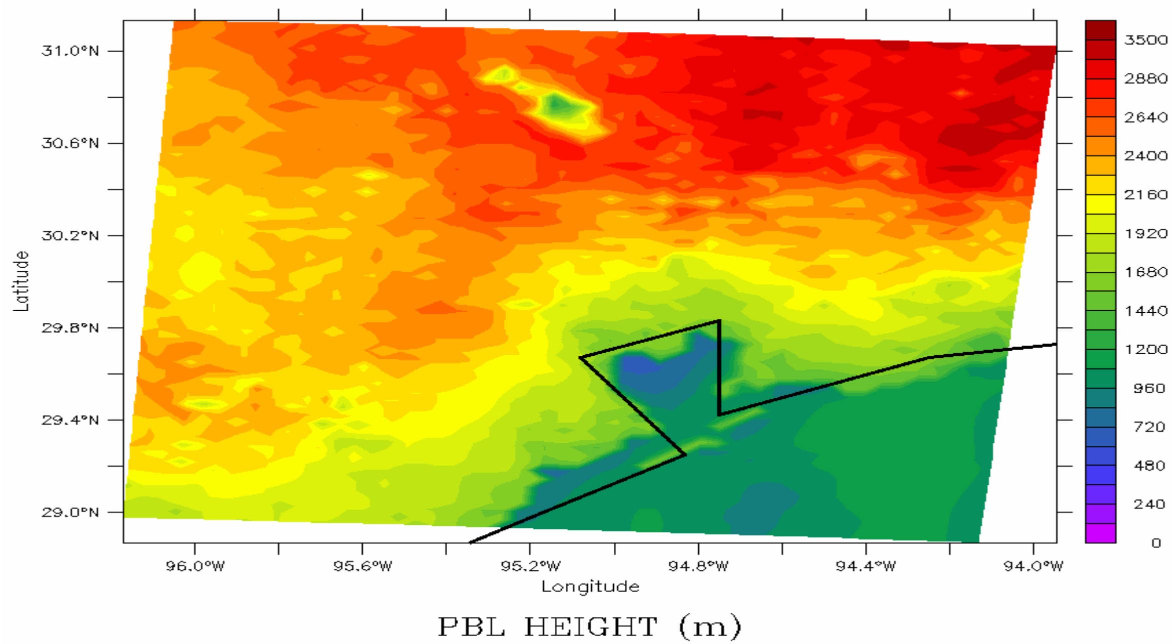


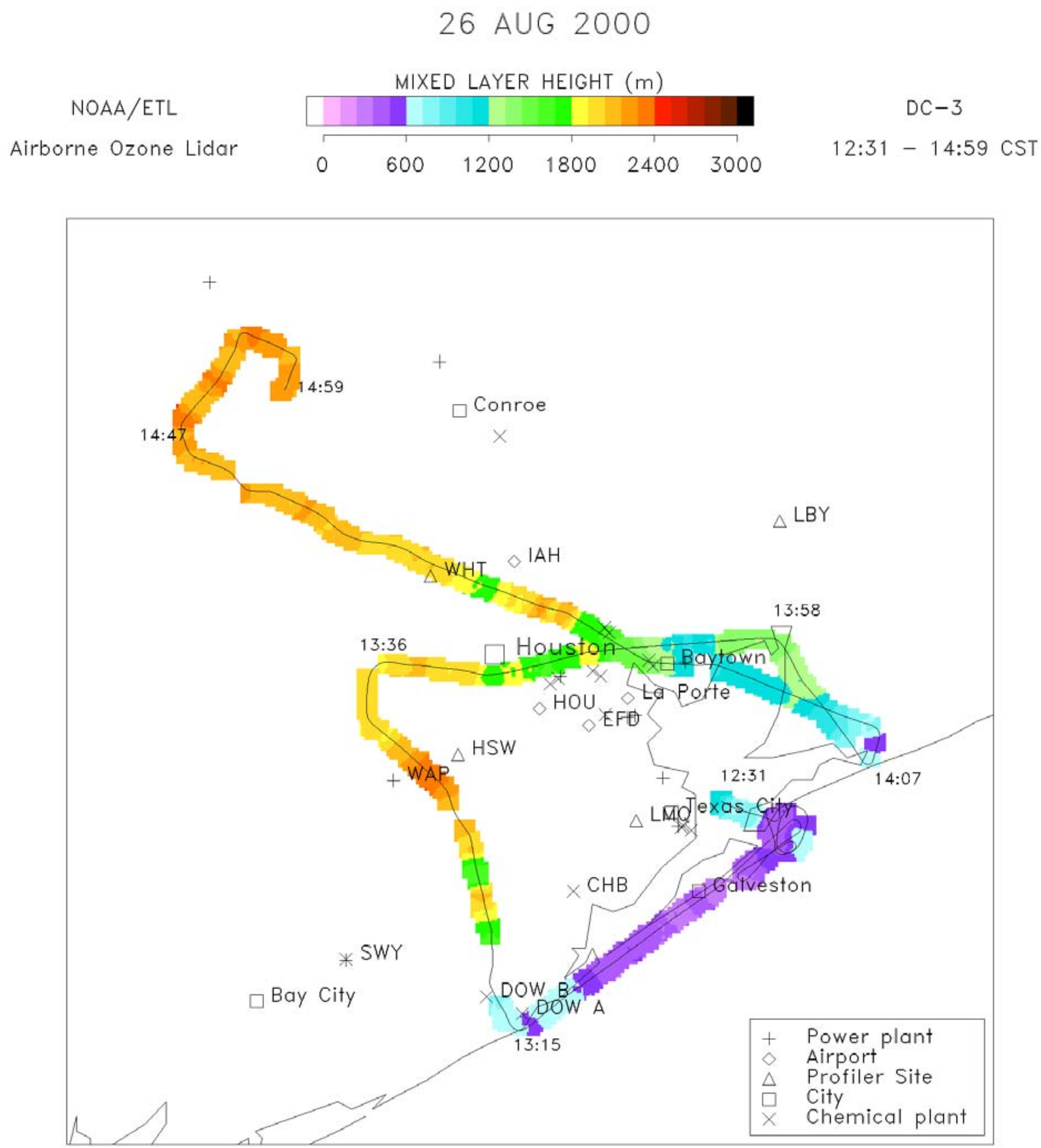
NASA NOAA EPA NSSTC UAH

Model BL Heights (CNTRL)



Model BL Heights (assimilated)





26 AUG 2000
MIXED LAYER HEIGHT (m)
NOAA/ETL
Airborne Ozone Lidar
0
600
1200
1800
2400
3000
DC-3
12:31 – 14:59 CST
14:59
14:47
Conroe
LBY
IAH
WHT
13:58
13:36
Houston
Baytown
HOU
La Porte
EFD
HSW
WAP
12:31
14:07
LMO
Texas City
CHB
Galveston
SWY
Bay City
DOW B
DOW A
13:15
Power plant
Airport
Profiler Site
City
Chemical plant

Wind speed – In the southeast the under-prediction of wind speed can bias control strategies toward VOC sensitivity as local VOC emissions dominate over transport of biogenic emissions into the city.

Major Tasks

1. Benchmark satellite improvements in MM5/CMAQ
2. Develop model/data distribution system to serve federal/states/cities/private consultants carrying out SIP modeling.
3. Partners - EPA NERL/AMD / NOAA Air Resources Laboratory

Benchmarking

Current Benchmarking Plan

1. Compare control MM5/CMAQ versus satellite assimilation MM5/CMAQ for TEXAQS 2000 and TEXAQS2006 against observed in situ data.
2. Compare control MM5 versus satellite assimilation MM5 for test cases against MODIS/GOES skin temperature data

AQ MODELING COMPONENTS IMPROVED BY THE UTILIZATION OF SATELLITE DATA

Data assimilation will improve the representation of physical atmosphere in the AQ modeling system by impacting:

1. Surface energy budget (MM5, WRF)
    - Assimilating Insolation
    - Assimilating surface albedo
    - Recovering moisture availability
    - Recovering bulk heat capacity
2. Photolysis rates (CMAQ)
3. Vertical motion and clouds (MM5, WRF)

Surface Energy Budget (MM5, WRF)

Three Uncertain Parameters

Bulk Heat Capacity →

$$C_b\left(\frac{dT_G}{dt}\right) = \left(R_N + H + G\right) + E$$

← Evaporative Heat Flux

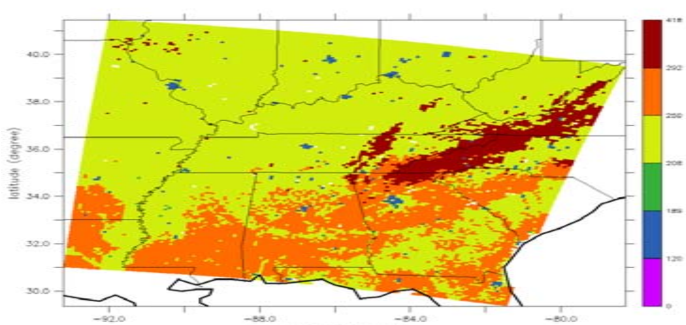
$$\left(C_g\right)_{sat} = \left(C_g\right)_m \left(\frac{dT_G}{dt}\right)_m \Bigg/ \left(\frac{dT_G}{dt}\right)_{sat}$$

Net Short-wave radiation obtained from Satellite

$$h = \frac{C_g}{E_m}\left[\left(\frac{dT_G}{dt}\right)_m - \left(\frac{dT_G}{dt}\right)_s\right]$$

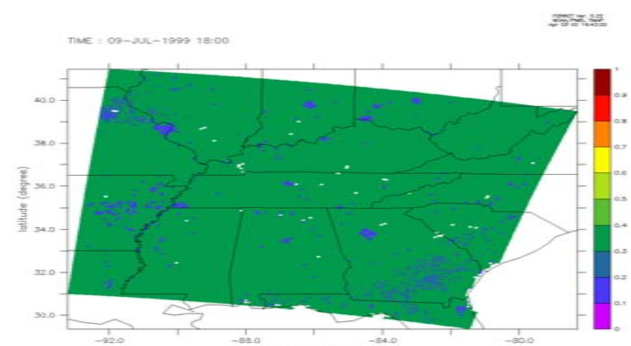
$$M_s = \left(1 + \delta(h)\right) M_m$$

MM5 Landuse Heat Capacity



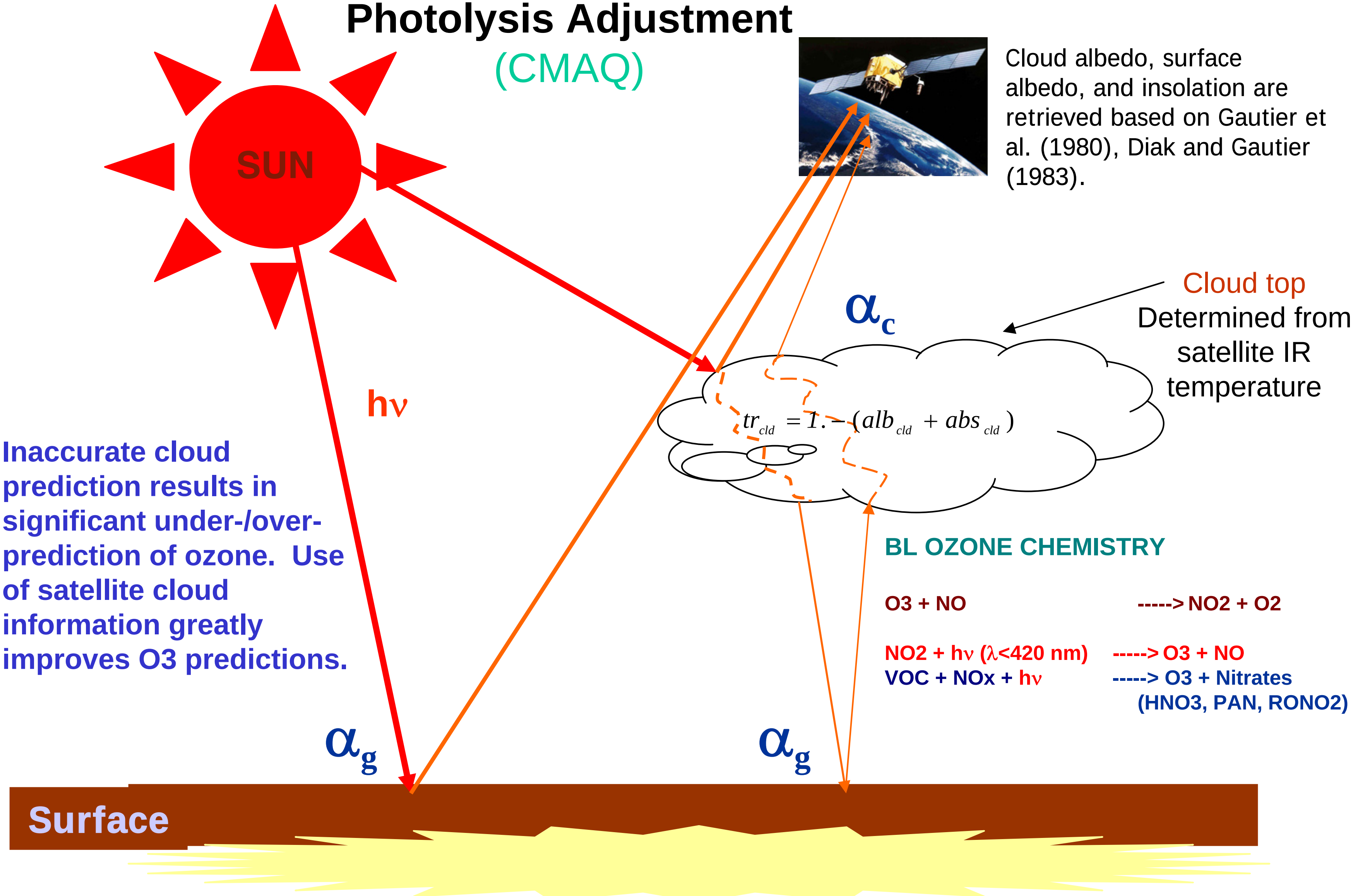
SOIL HEAT CAPACITY * 10^-4 (J/m^3/K)

MM5 Landuse Moisture Availability



MOISTURE AVAILABILITY (control run)

Photolysis Adjustment (CMAQ)



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

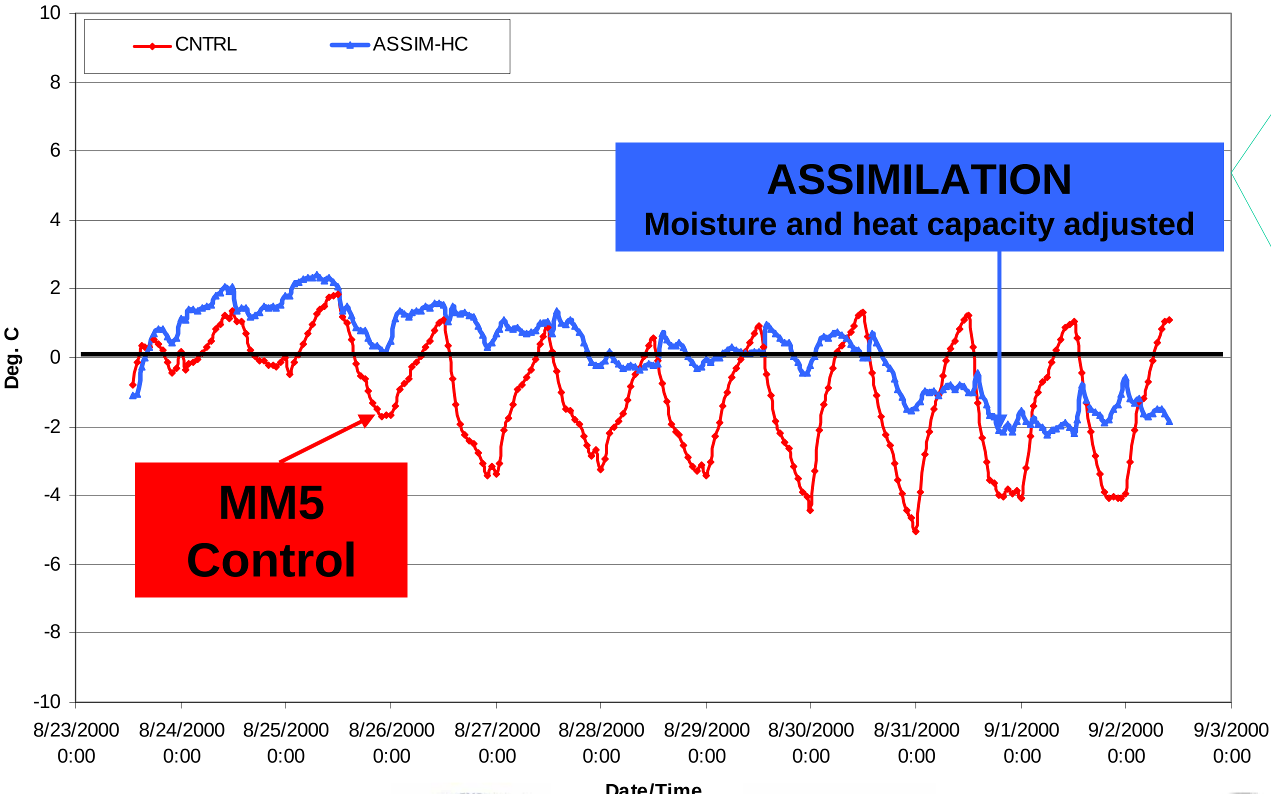
State, Local & Private Sector Users

PROJECT VALIDATION ACTIVITY

Satellite assimilation technique for surface properties has shown that the surface/air temperature predictions can greatly be improved.

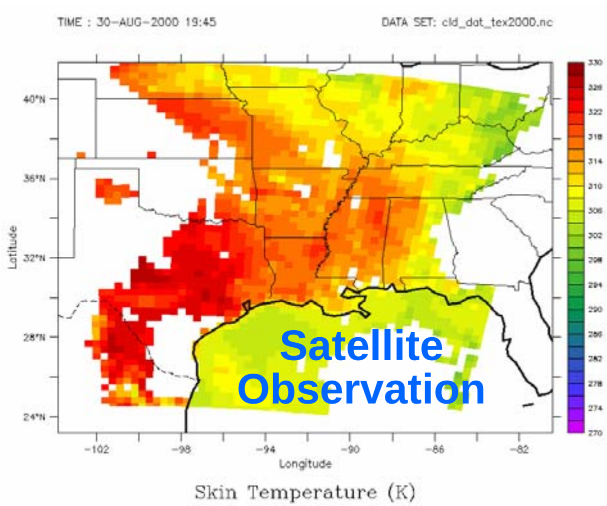
2-m Temperature Bias

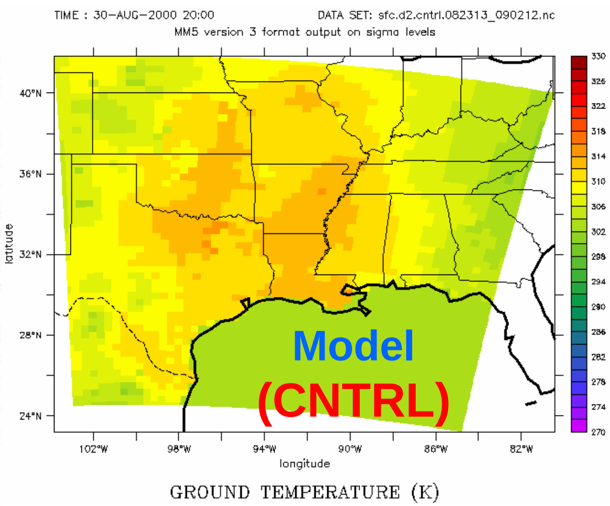
(12-km domain, TexAQS2000)

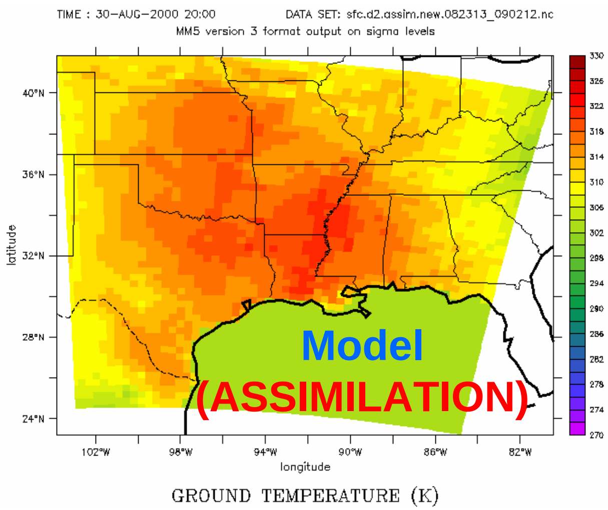


Comparing model 2-M temperature predictions to the observed temperatures from National Weather Service stations shows that the satellite assimilation technique **(blue line)** reduces the model bias in the model (warm bias at night and cold bias during the day).

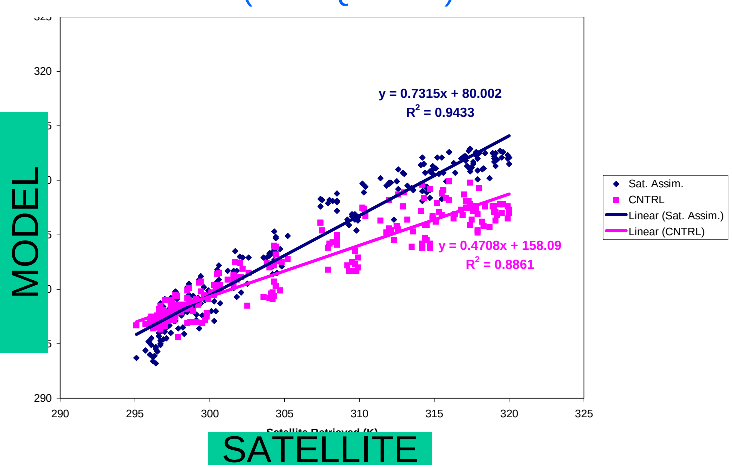
Utilizing Satellite Observed Temperature for Model Evaluation

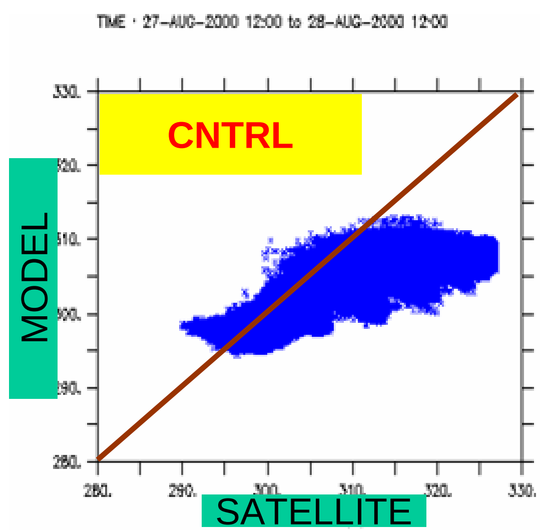


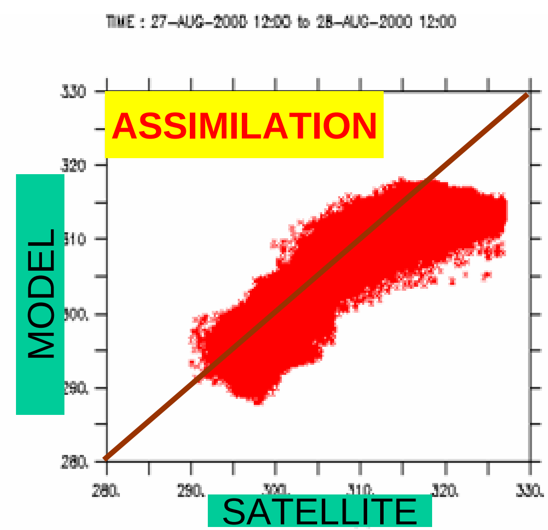




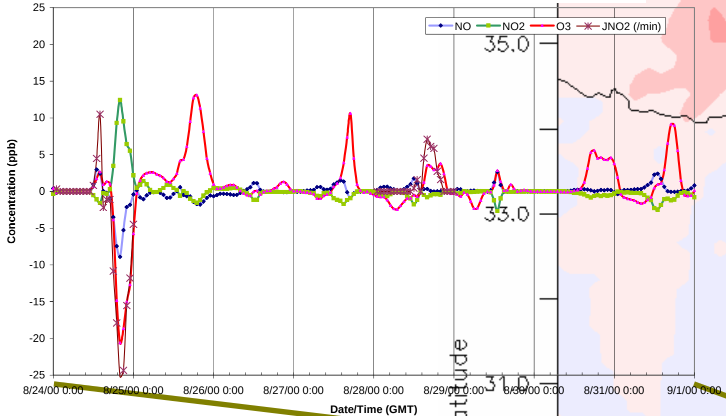
Averaged Skin T scatter plot for 12-km domain (TexAQS2000).



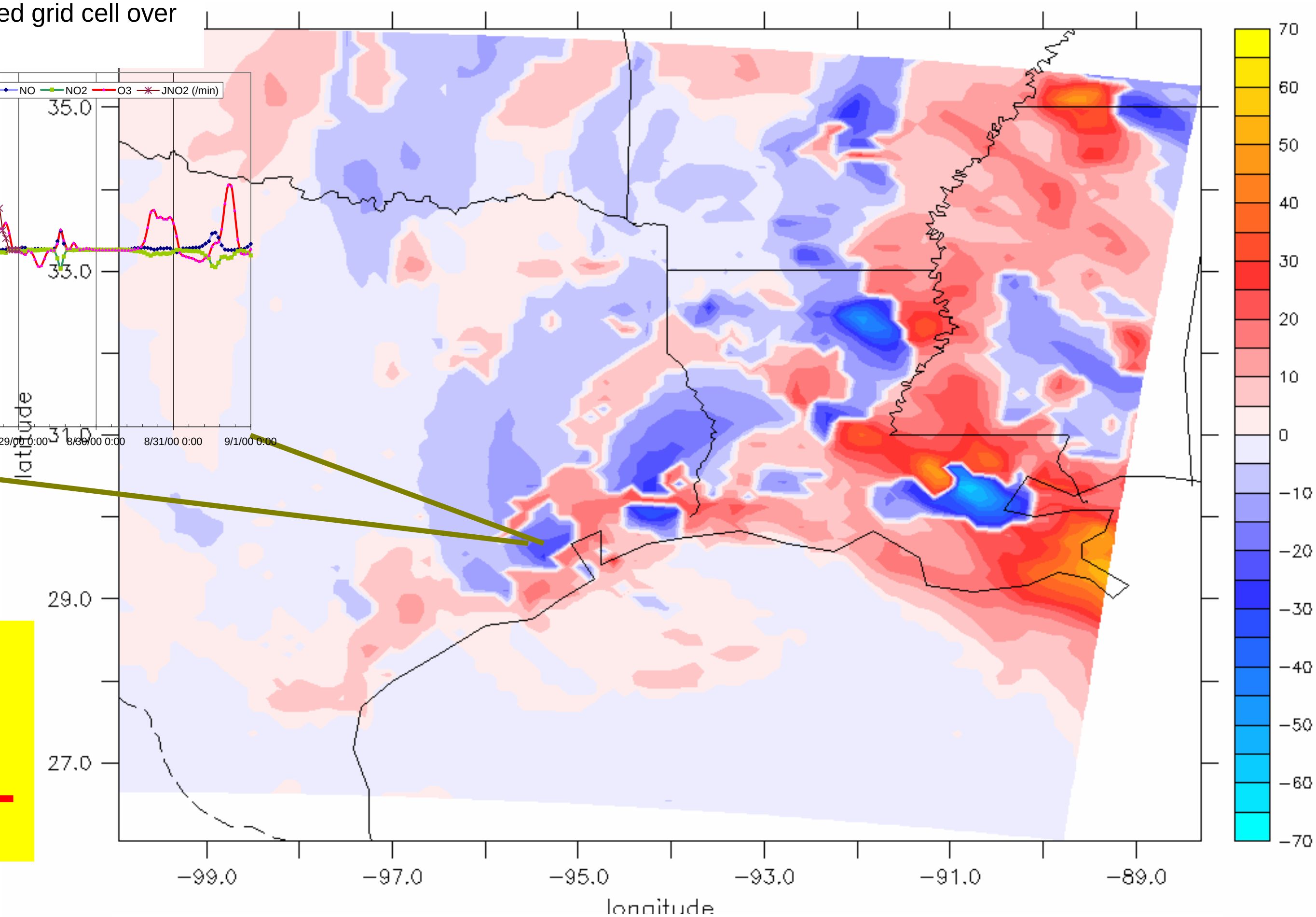




The differences between NO, NO2, O3 (ppb) and JNO2 from satellite cloud assimilation and control simulations for a selected grid cell over Houston-Galveston area.



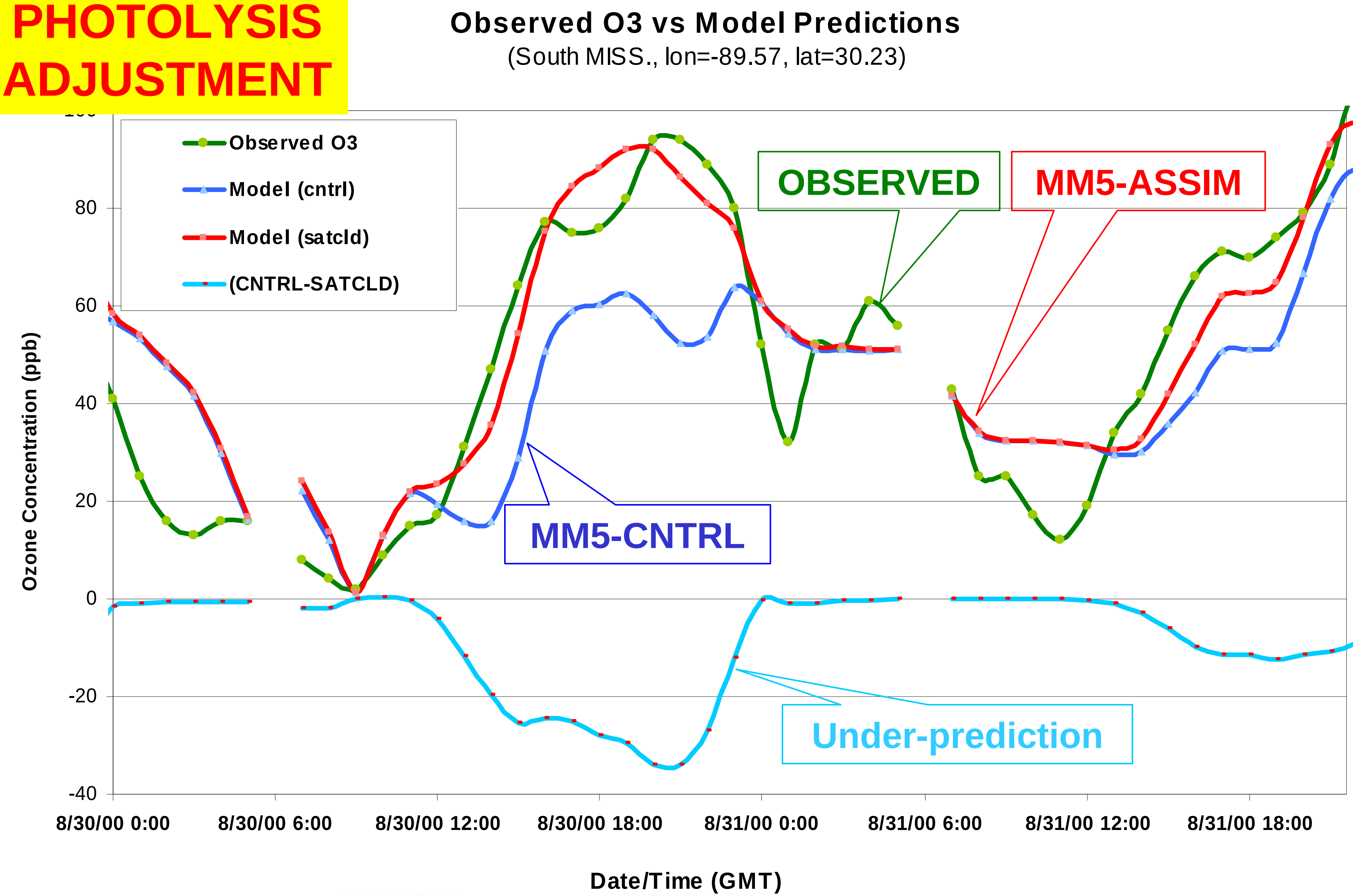
Largest changes in O3 concentration due to use of observed clouds for the period of August 24, 2000, to September 1, 2000.
($O3_b$-$O3_a$, b=Sat. Observed Cloud, a=Control)



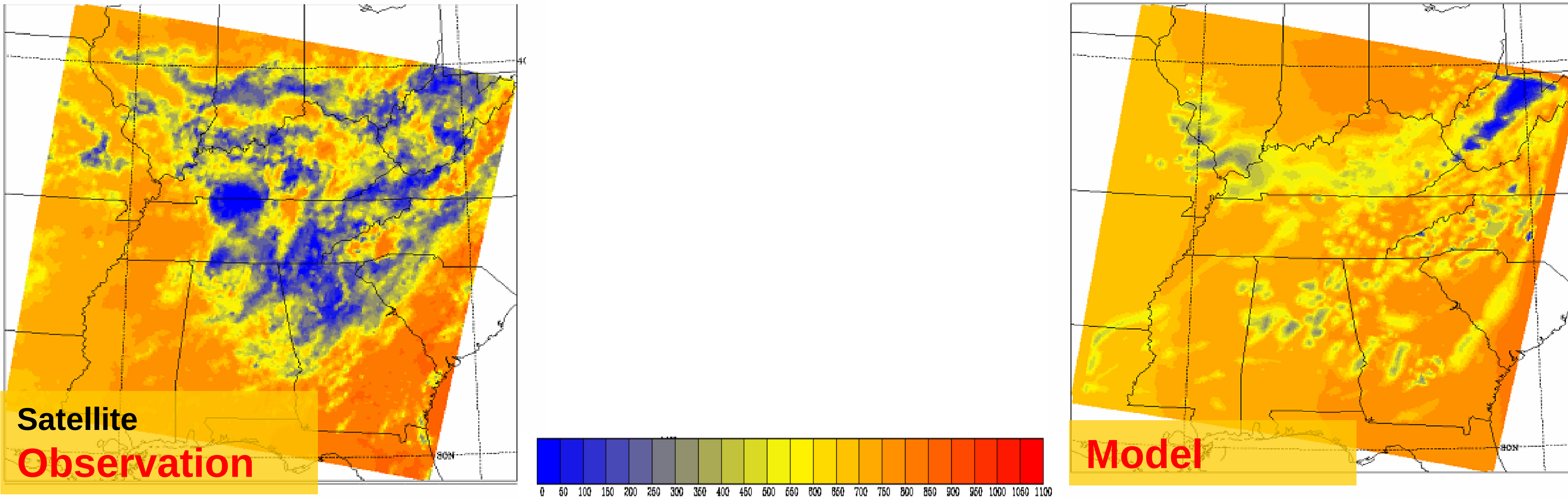
IMPACT OF PHOTOLYSIS ADJUSTMENT

Corrections of up to 70 ppb for Ozone

IMPACT OF PHOTOLYSIS ADJUSTMENT



Cloud Adjustment in (MM5)

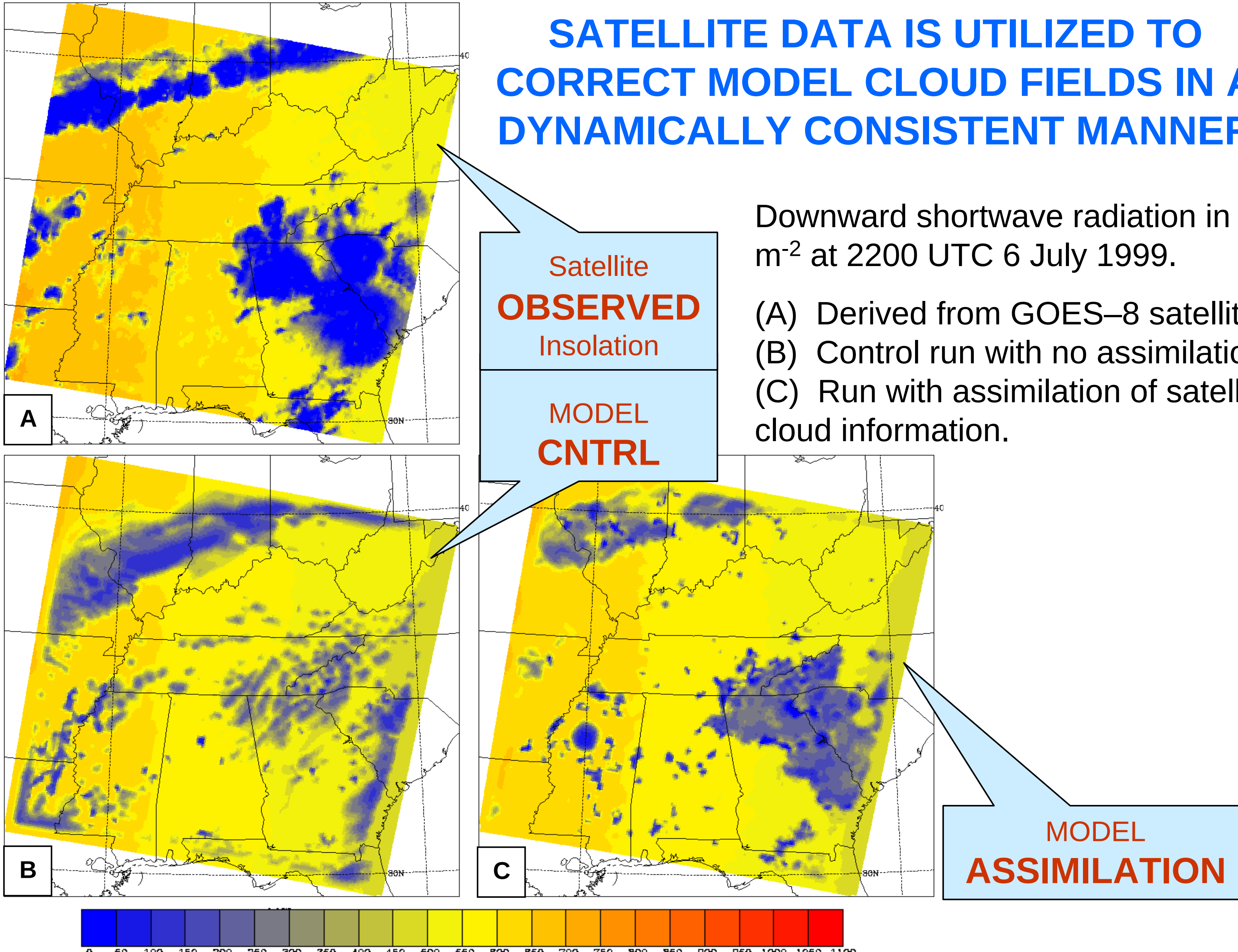


- Use satellite cloud top temperatures and cloud albedoes to determine a maximum vertical velocity (Wmax) in the cloud column (Multiple Linear Regression).
- Adjust divergence to comply with Wmax in a way similar to O'Brien (1970).
- Nudge MM5 winds toward new horizontal wind field to sustain the vertical motion.
- Remove erroneous model clouds by suppressing convective initiation.

SATELLITE DATA IS UTILIZED TO CORRECT MODEL CLOUD FIELDS IN A DYNAMICALLY CONSISTENT MANNER

Downward shortwave radiation in W m^{-2} at 2200 UTC 6 July 1999.

(A) Derived from GOES–8 satellite.
(B) Control run with no assimilation.
(C) Run with assimilation of satellite cloud information.



TRANSITIONING & STATUS OF THE PROJECT

The approach for transitioning is to

1) provide the satellite data to the users through a web based delivery system

2) transfer the modeling components to EPA so that they will become part of the standard release of Decision Support Tools.

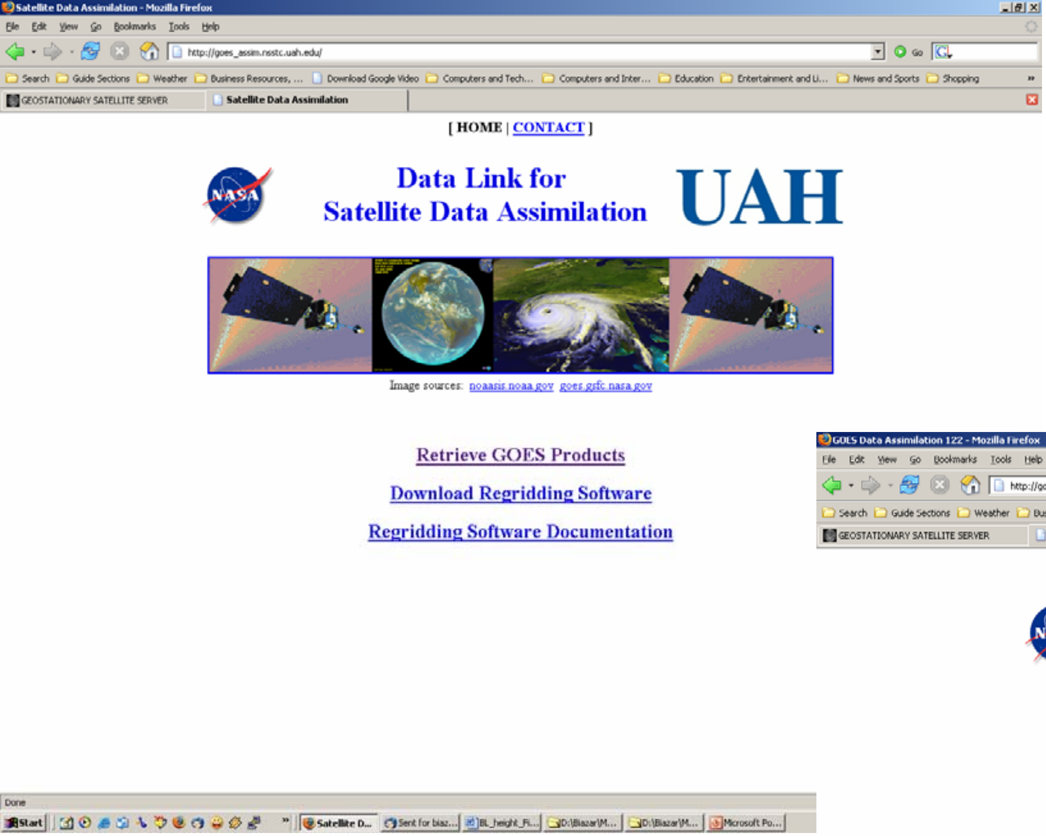
STATUS OF THE PROJECT:

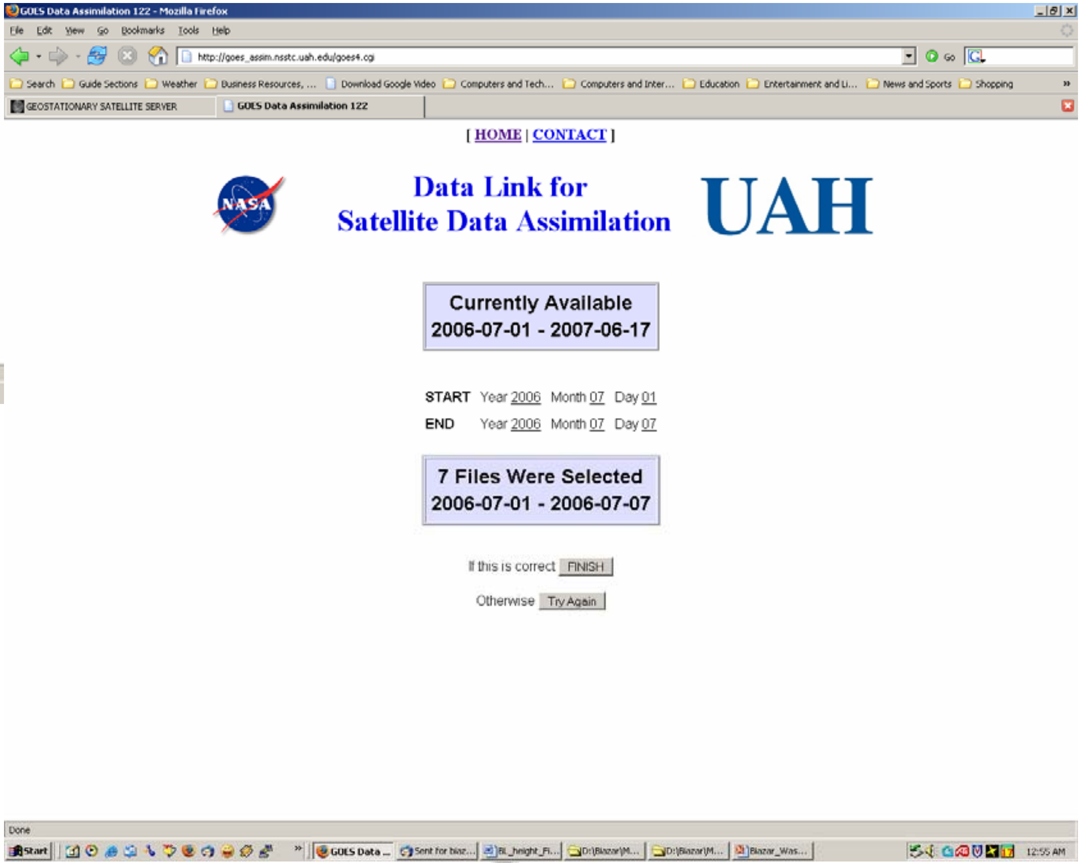
- Developed Web Based Delivery System
  - Processing & archiving current data
  - Processing & archiving old data
  - Developed Regridding Software

TRANSITIONING & STATUS OF THE PROJECT (cont.)

- Transfer of code to EPA/AMD
  - MM5 code for satellite assimilation and the preprocessors were delivered to EPA
  - CMAQ code for satellite assimilation and the preprocessors were delivered to EPA
  - Satellite data for TexAQS2000 was delivered to EPA
  - Worked (and continue to work) with EPA to implement the modifications for their in-house models.
- Collaborating with EPA/AMD on benchmark activities
  - TexAQS2000 and TexAQSII periods are considered for benchmarking.
  - EPA/AMD has already performed simulations for TexAQS2000
- Collaborating with EPA for transitioning to WRF modeling system

Web Based Delivery System





sat_assim.nsstc.uah.edu

Username: levl

Password: sparkx

SCHEDULE FOR THE REST OF THE PROJECT

- Complete the benchmarking activity
- Complete transition to WRF
- Turn over the web site to DAAC (GHRC)
- Continue to work with EPA/AMD to implement other model components for satellite assimilation.

WHERE DO WE GO FROM HERE

- Cloud adjustment within MM5 needs to be completed
- The inconsistency due to photolysis adjustment and insolation needs to be addressed
- Photolysis adjustment can take advantage of the new satellite observations of ozone.
- Calipso lidar can be used in certain situations to evaluate mixing heights