University of Alabama in Huntsville / Minerals Management Service
Cooperative Study

Satellite Data Assimilation into Meteorological / Air Quality Models

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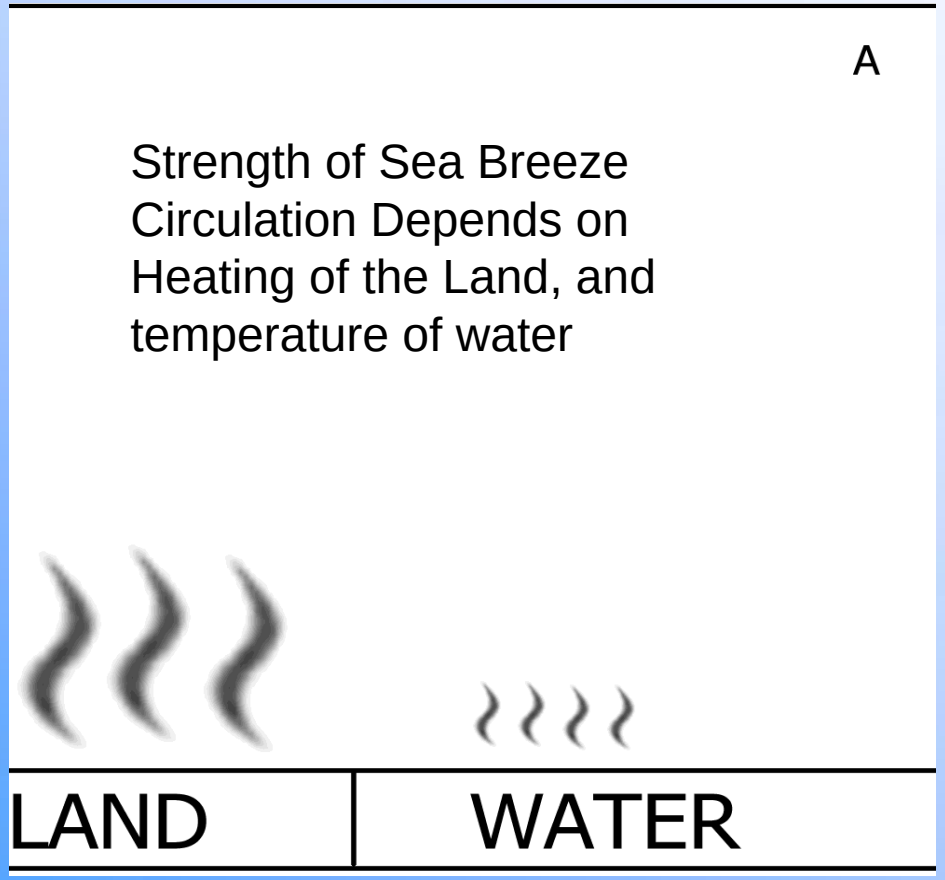
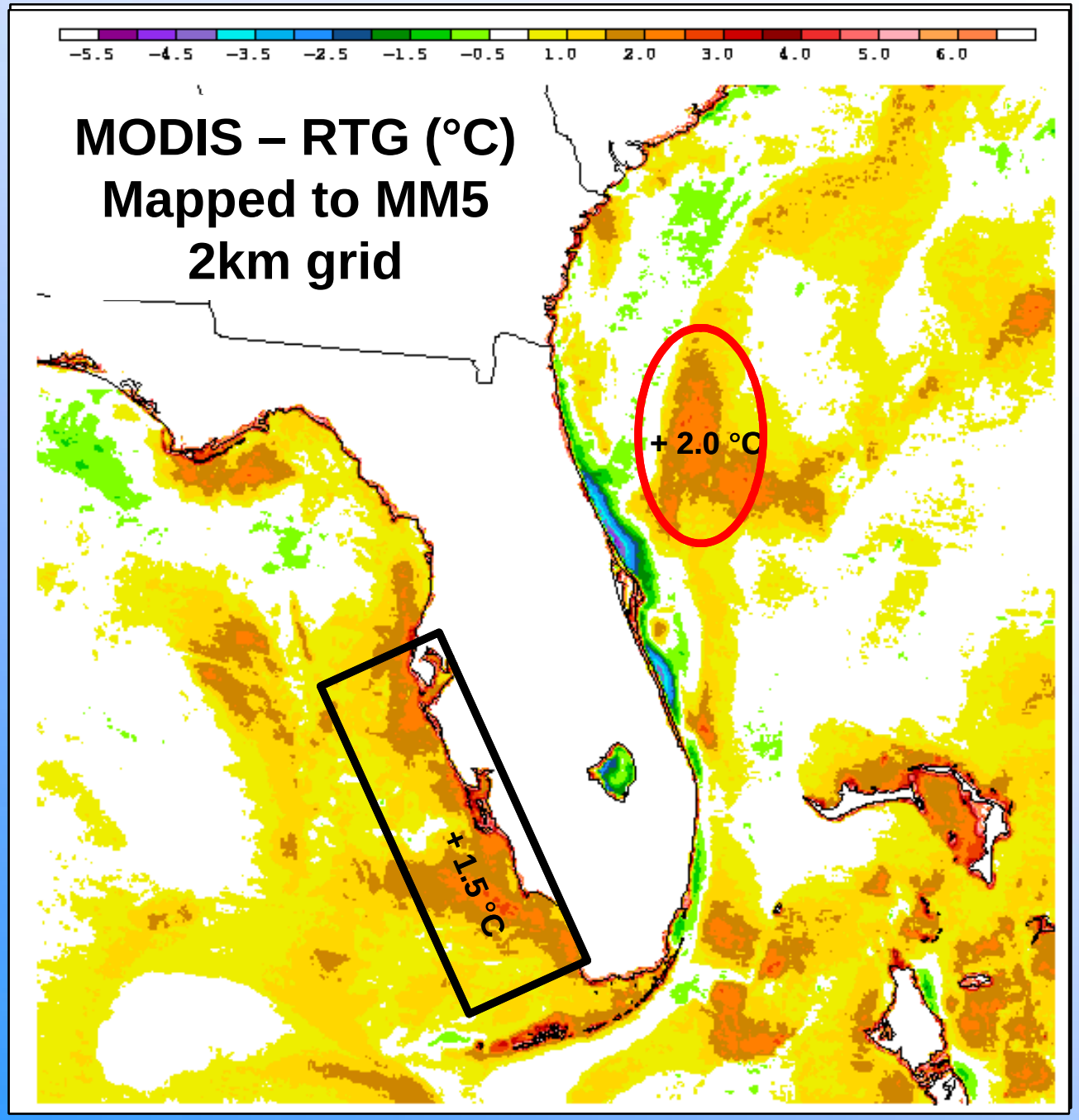
The Sea Breeze Is Critically Important in Air Quality in Coastal Areas

For example, in Houston high concentrations are associated with wind reversals related to the land/sea breeze system.

50 – 2000 m



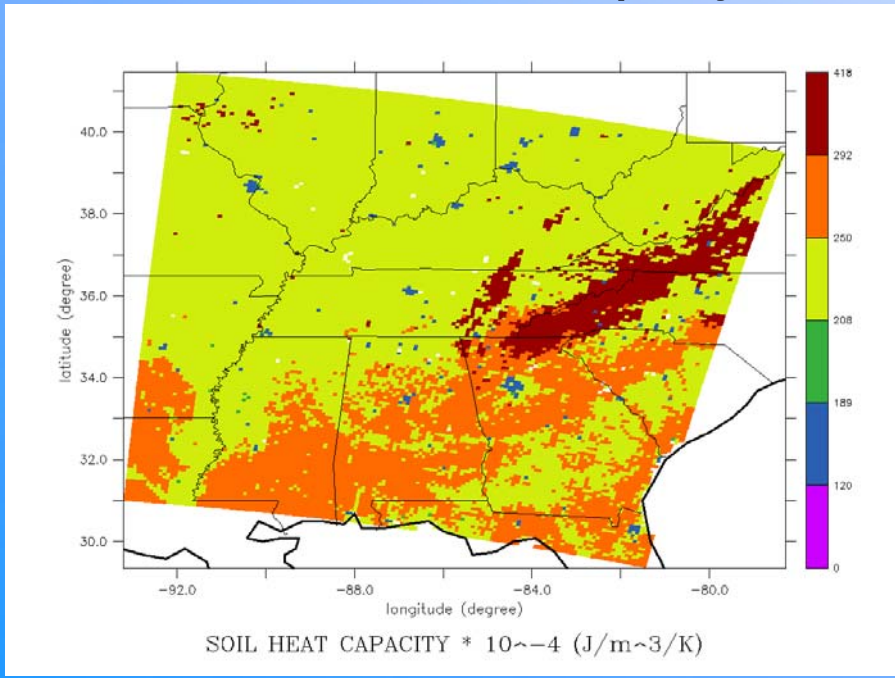
10 to 100km


-5.5 -4.5 -3.5 -2.5 -1.5 -0.5 1.0 2.0 3.0 4.0 5.0 6.0
MODIS – RTG (°C)
Mapped to MM5
2km grid
+ 2.0 °C
+ 1.5 °C

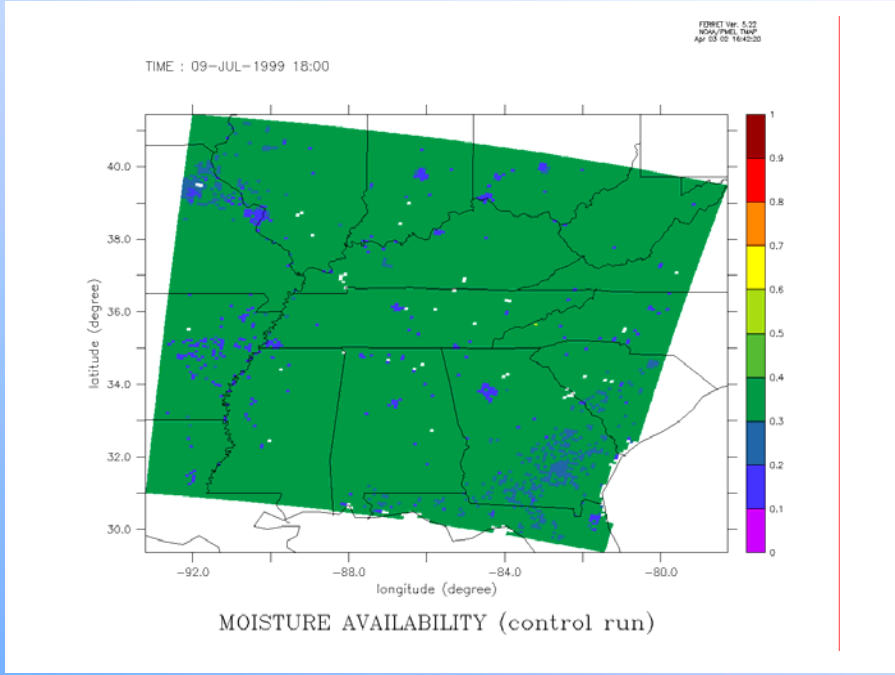
The rate at which the land surface heats up in the morning and cools down in the evening is related to surface characteristics such as **heat capacity, surface moisture and incoming solar radiation**.

However, these parameters are ill-defined and not directly observable on fine scales from standard networks.

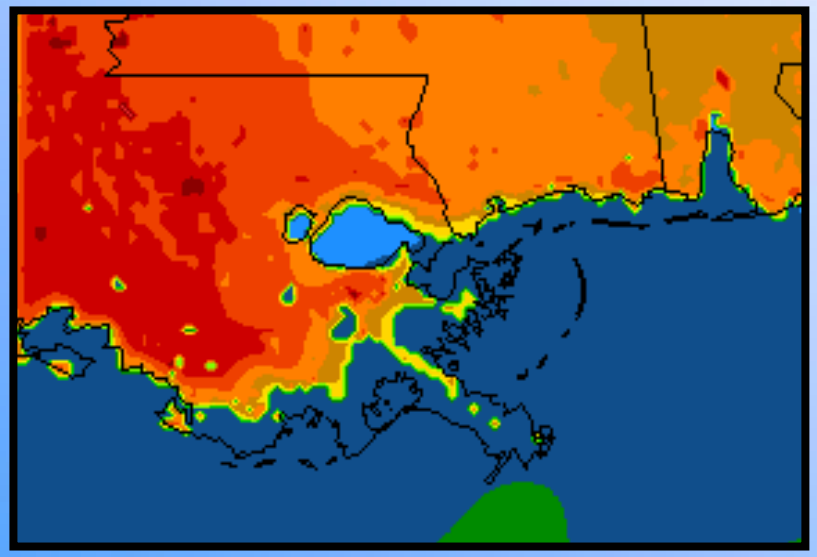
MM5 Landuse Heat Capacity



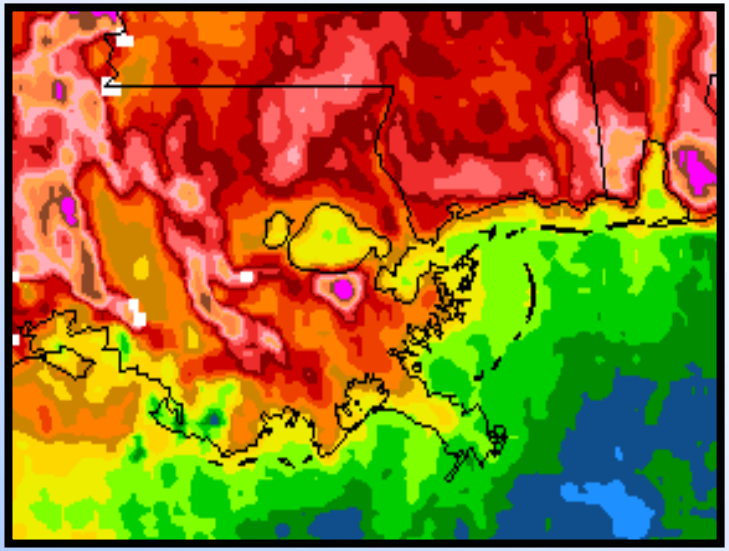
MM5 Landuse Moisture Availability



Specification of land-water boundaries can be difficult in complex coastlines and at marshy boundaries.



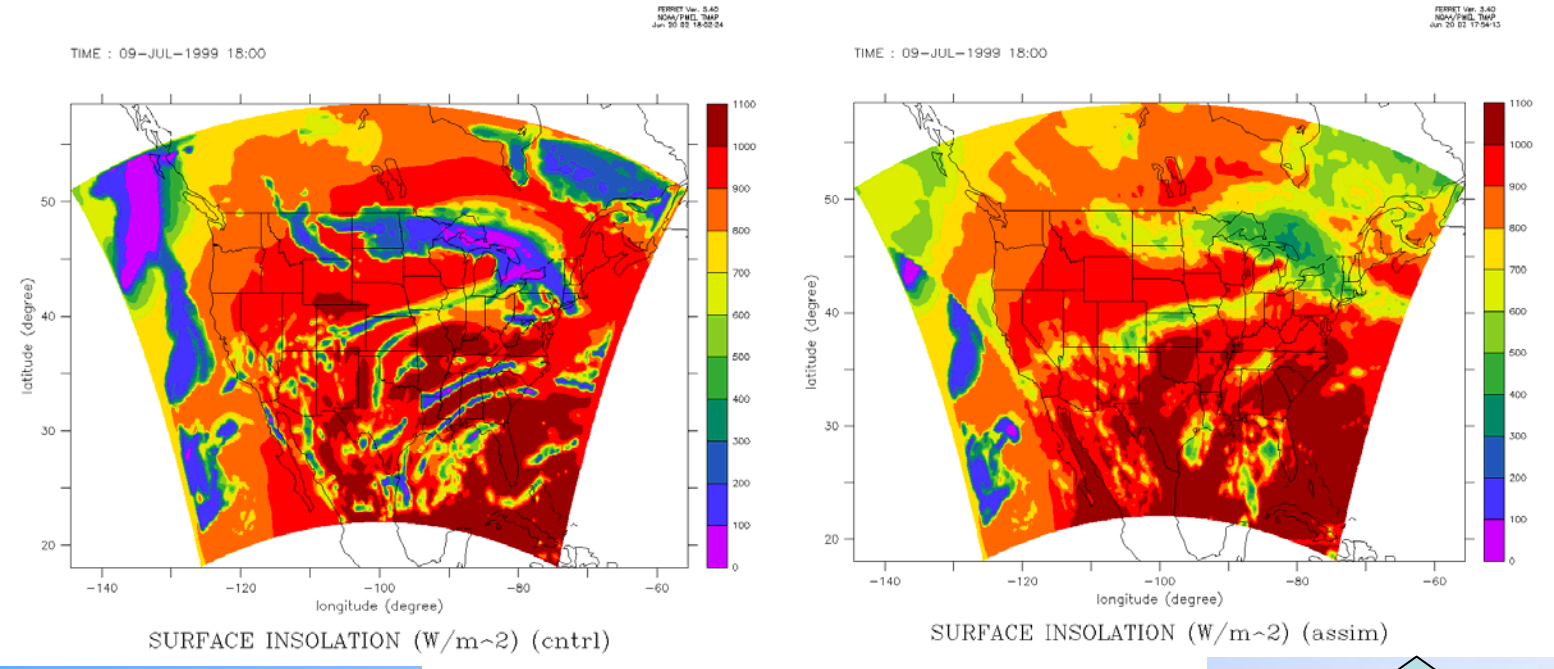
MM5 Skin Temperatures



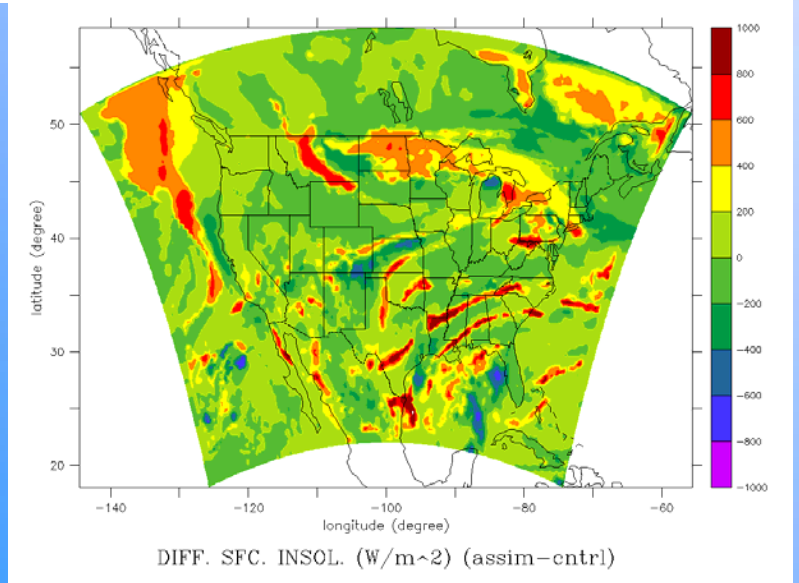
Satellite Skin Temperatures

Use satellite data to naturally determine heat capacity and moisture fraction of grids.

Clouds at Wrong Place, Wrong Time, and Too Opaque



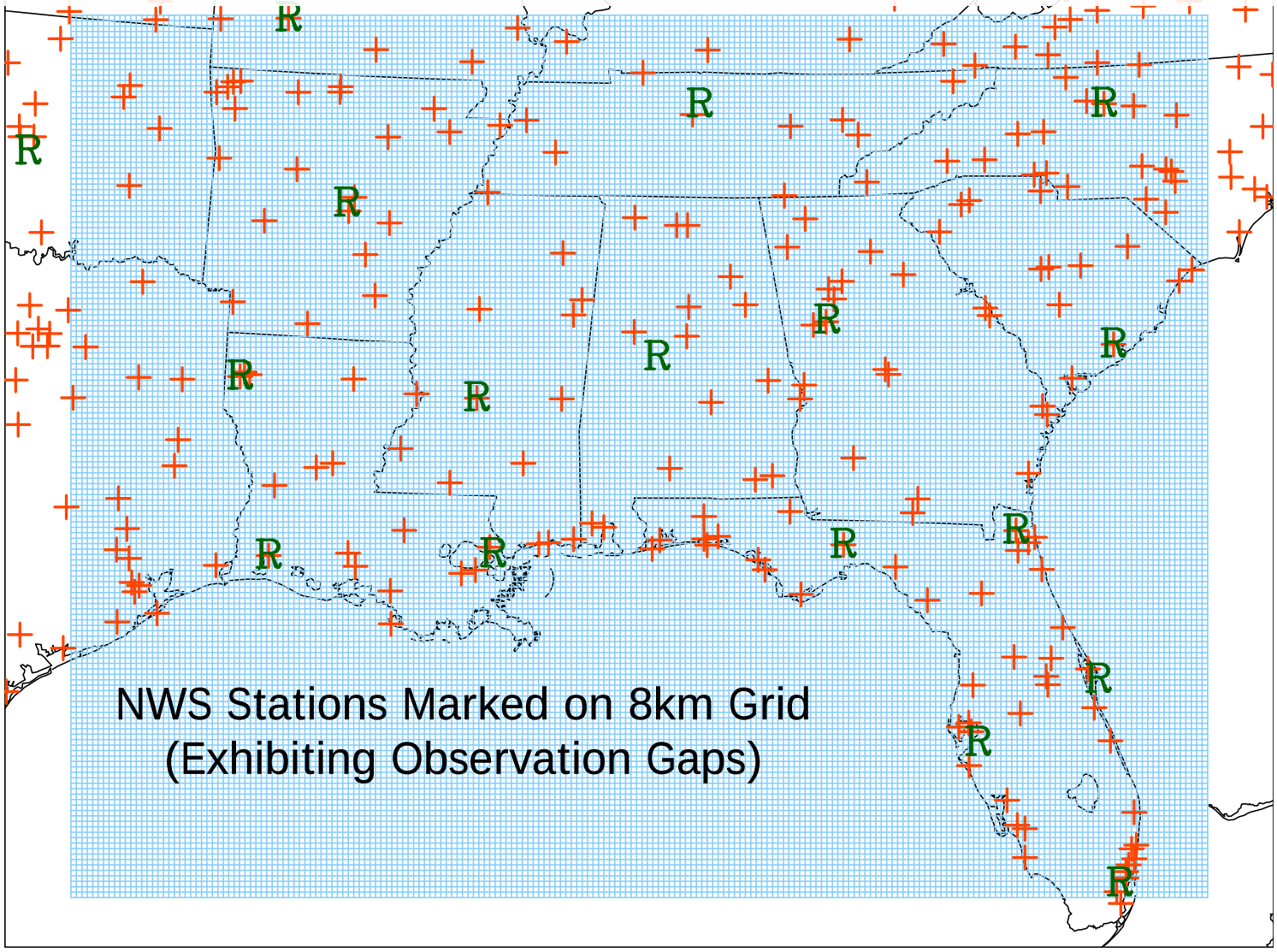
Model

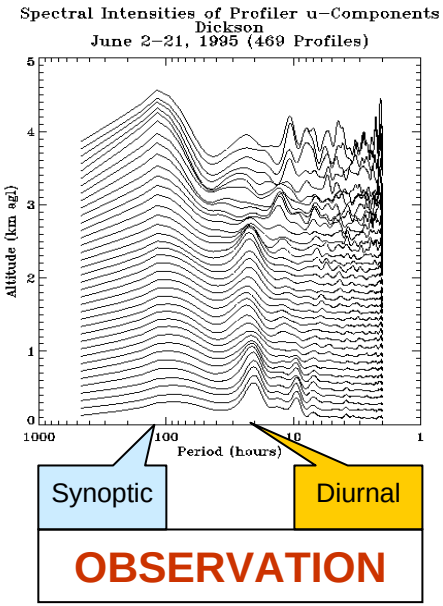


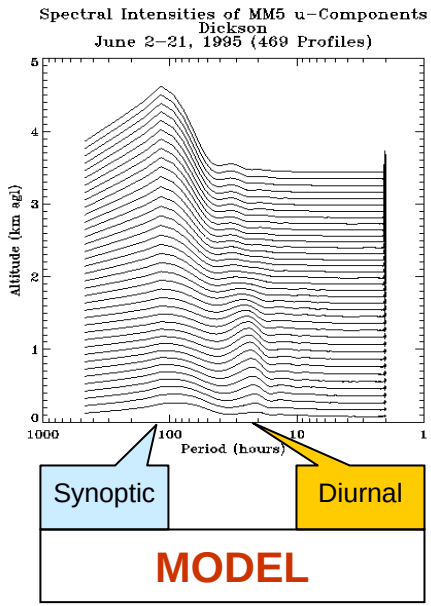
Satellite

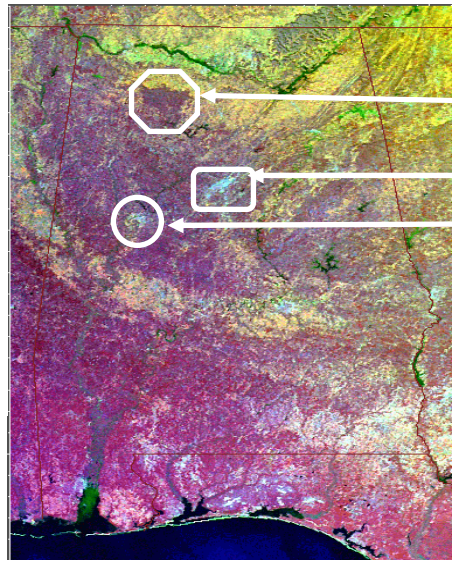
Difference

NWS stations are too sparse for model spatial resolution and not representative of the grid averaged quantity.

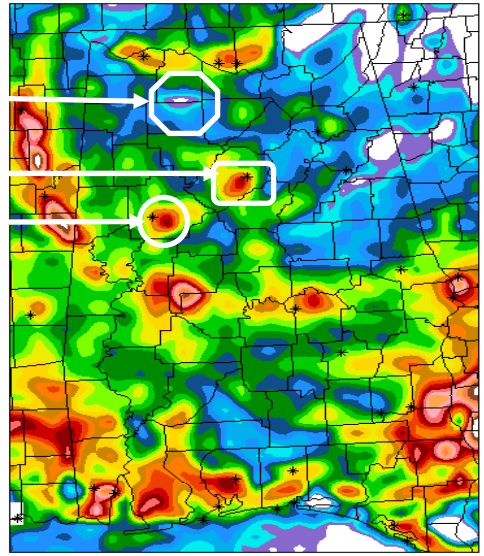








AVHRR



GOES-8 Skin Temperature
19 May 1999 3:00 PM CDT

Models do not maintain as much energy at higher frequencies as observations indicate. This can severely hinder short term forecasting efforts.

Satellite data can be utilized to fill the diurnal energy gap and to improve the model performance with respect to short term forecasts.

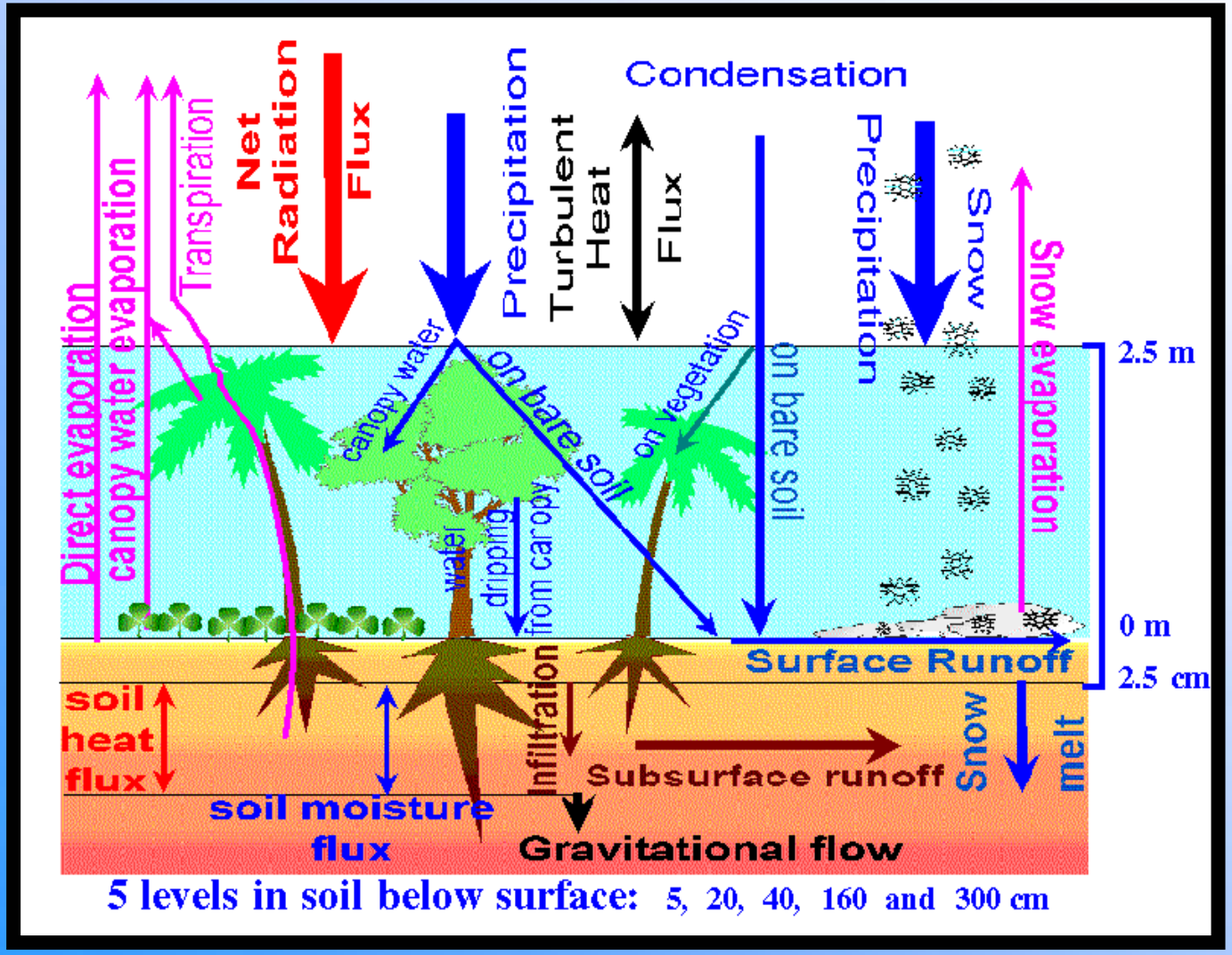
Appealing attributes of GOES data:

- High sampling frequency
- High spatial resolution
- Pixels provide an integral quantity

TARGETS FOR ASSIMILATION

1. Surface energy budget
    - Insolation
    - Albedo
    - Moisture availability
    - Bulk heat capacity
2. Vertical motion and clouds
3. Photolysis rates

Typical Schemes Used to Infer Moisture Availability



Surface Energy Budget

Three Uncertain Parameters

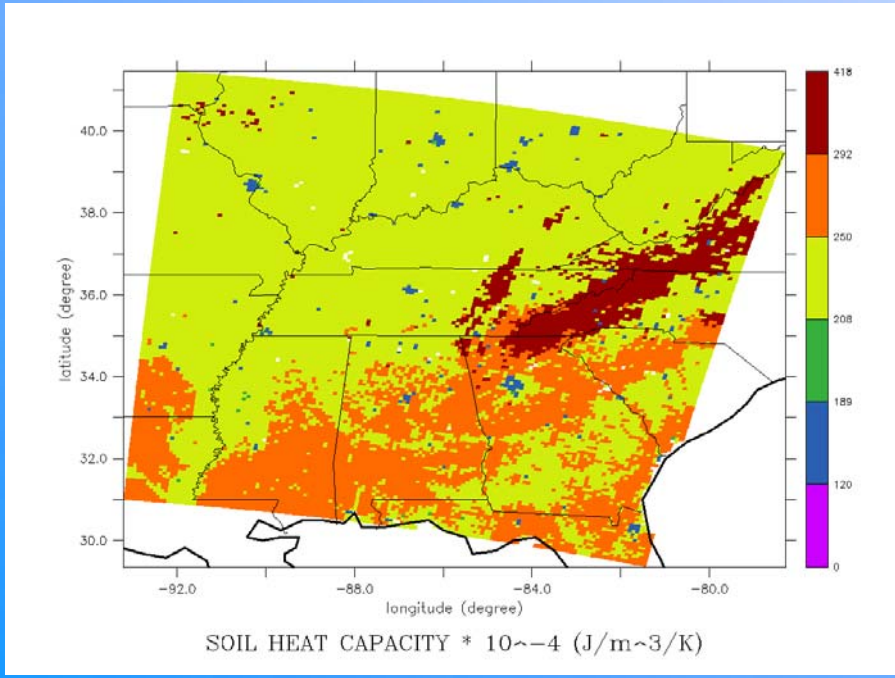
$$C_b\left(\frac{dT_G}{dt}\right) = \left(R_N + H + G\right) + E$$

Bulk Heat Capacity

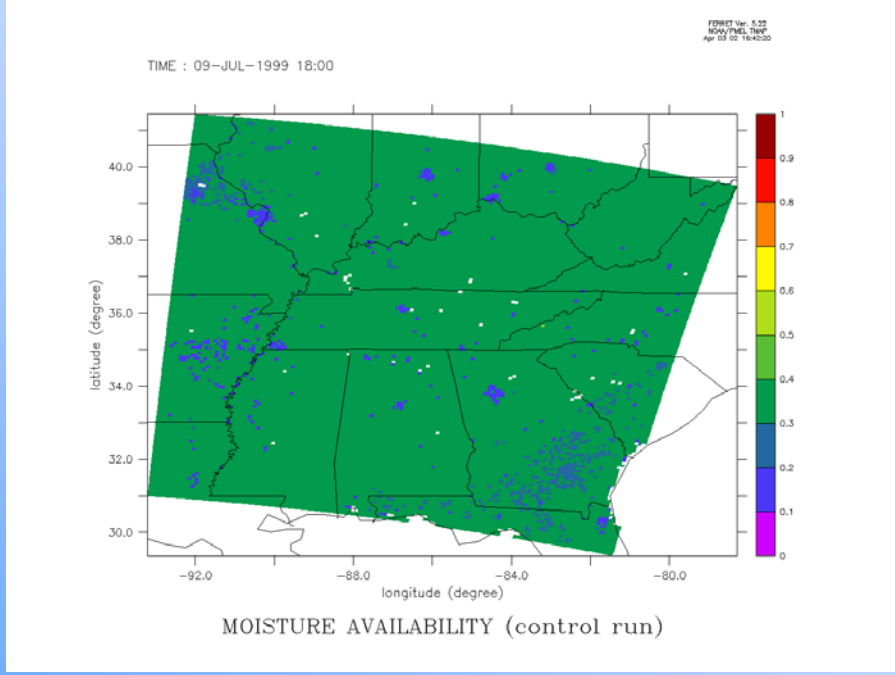
Net Short-wave Radiation Obtained from Satellite

Evaporative Heat Flux

MM5 Landuse Heat Capacity

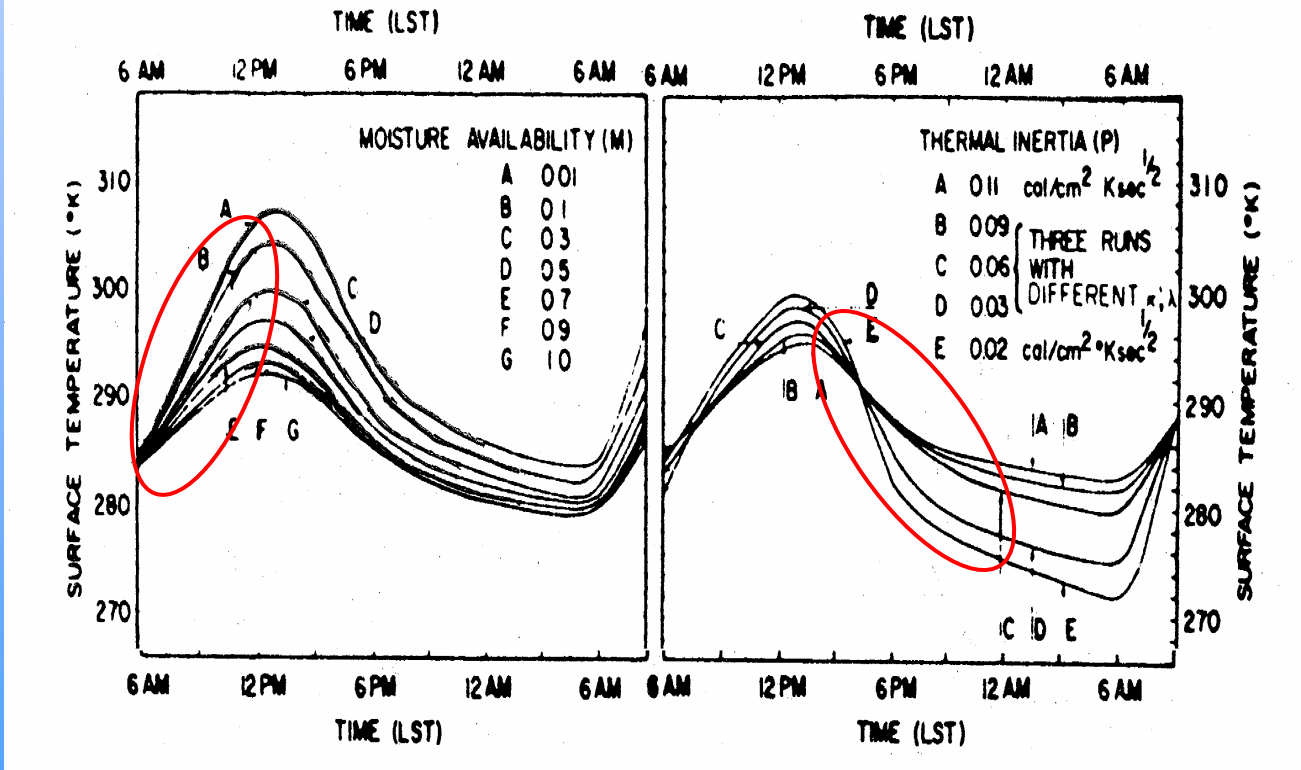


MM5 Landuse Moisture Availability



Sensitivity of Surface Energy Budget to Various Parameters

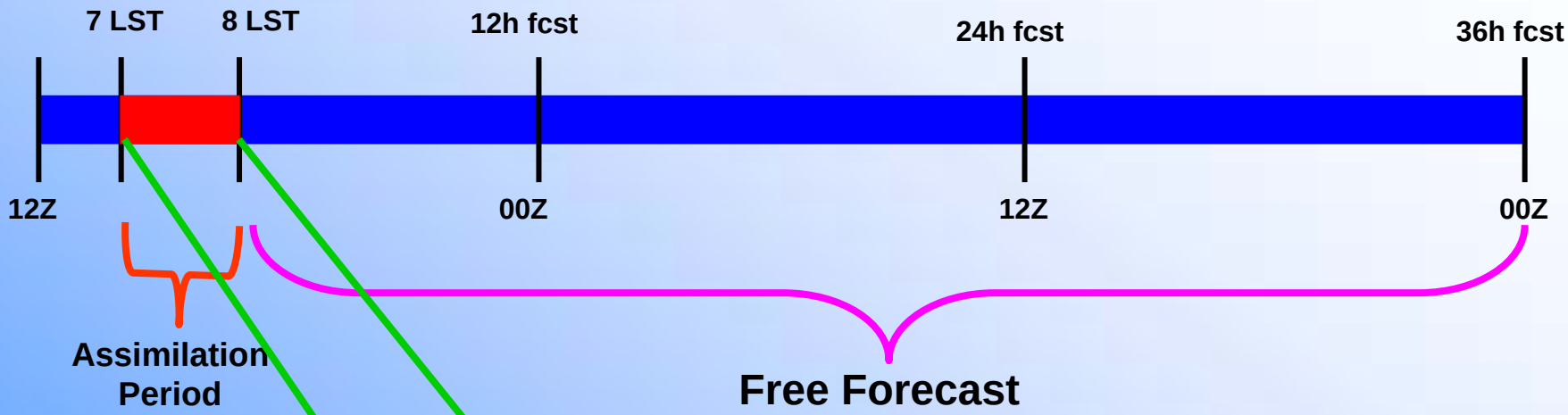
Moisture Availability

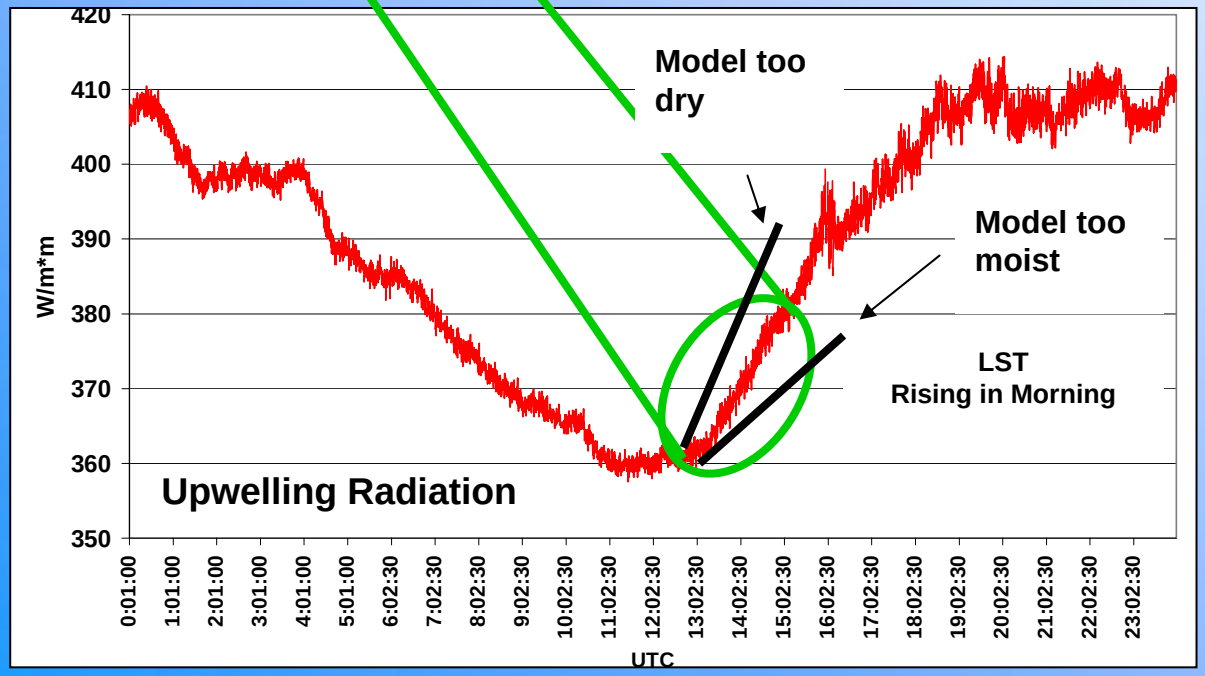


Thermal Inertia

Taken from Carlson (1986) to demonstrate the sensitivity of the surface energy budget model. Each panel represents the sensitivity of the simulated LST to uncertainty in a given parameter.

* Assimilation Performed Between 1300–1400 UTC





Assimilate:

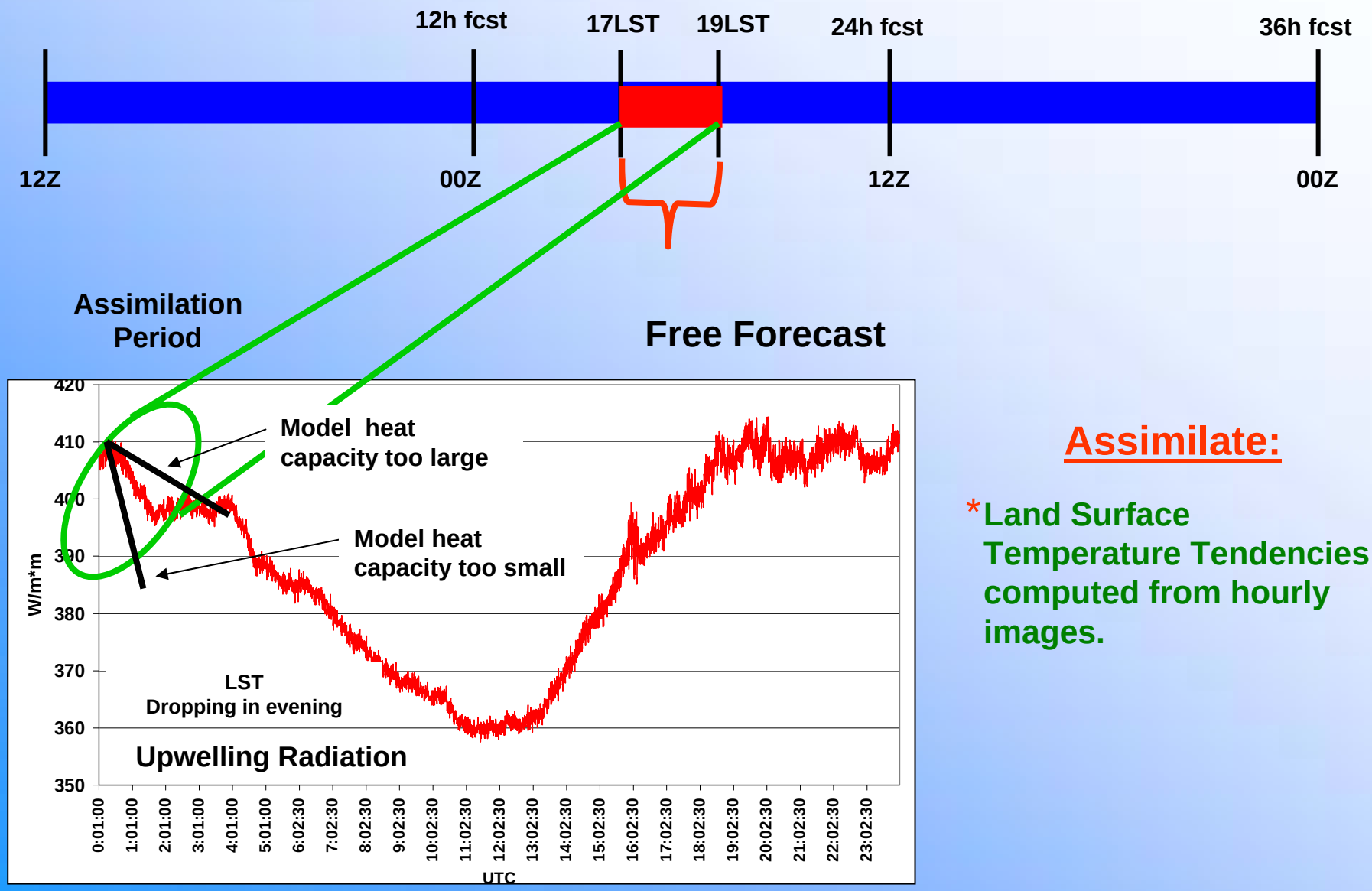
- *Land Surface Temperature Tendencies computed from hourly images.
- *Solar insolation

Grid scale heat capacity very difficult to define

Grid box made up of soil, trees, buildings, grass, water etc.

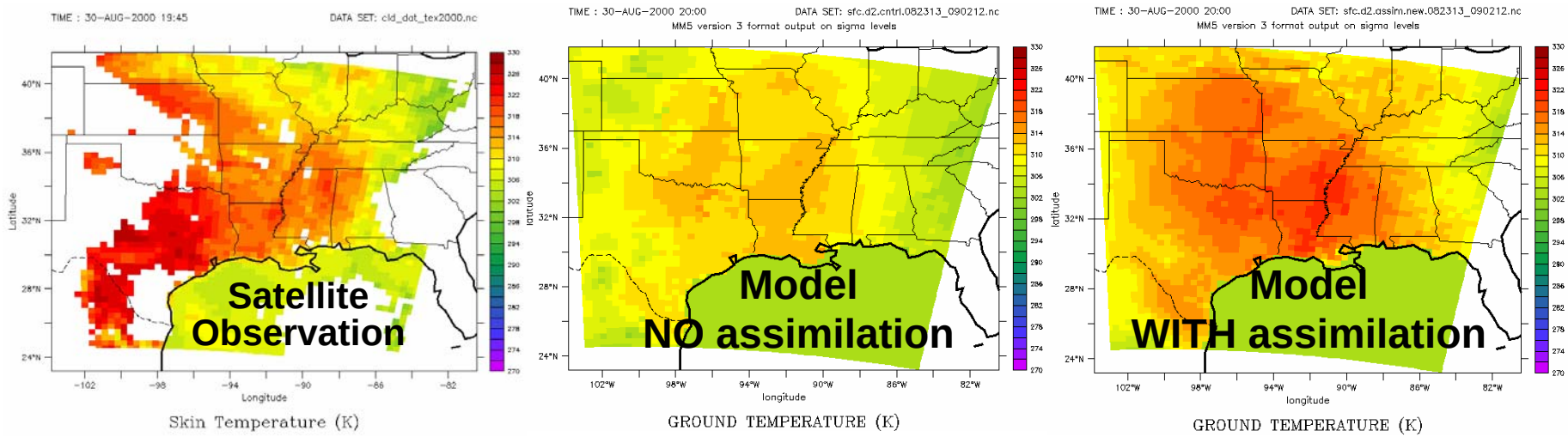
Model heat capacity not well defined fundamentally.

* Assimilation Performed in Early Evening

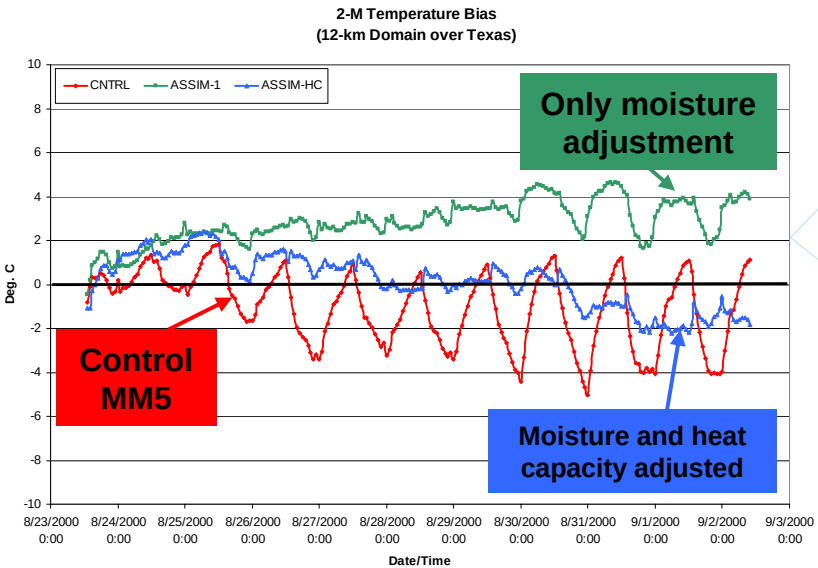


Assimilate:

* Land Surface Temperature Tendencies computed from hourly images.

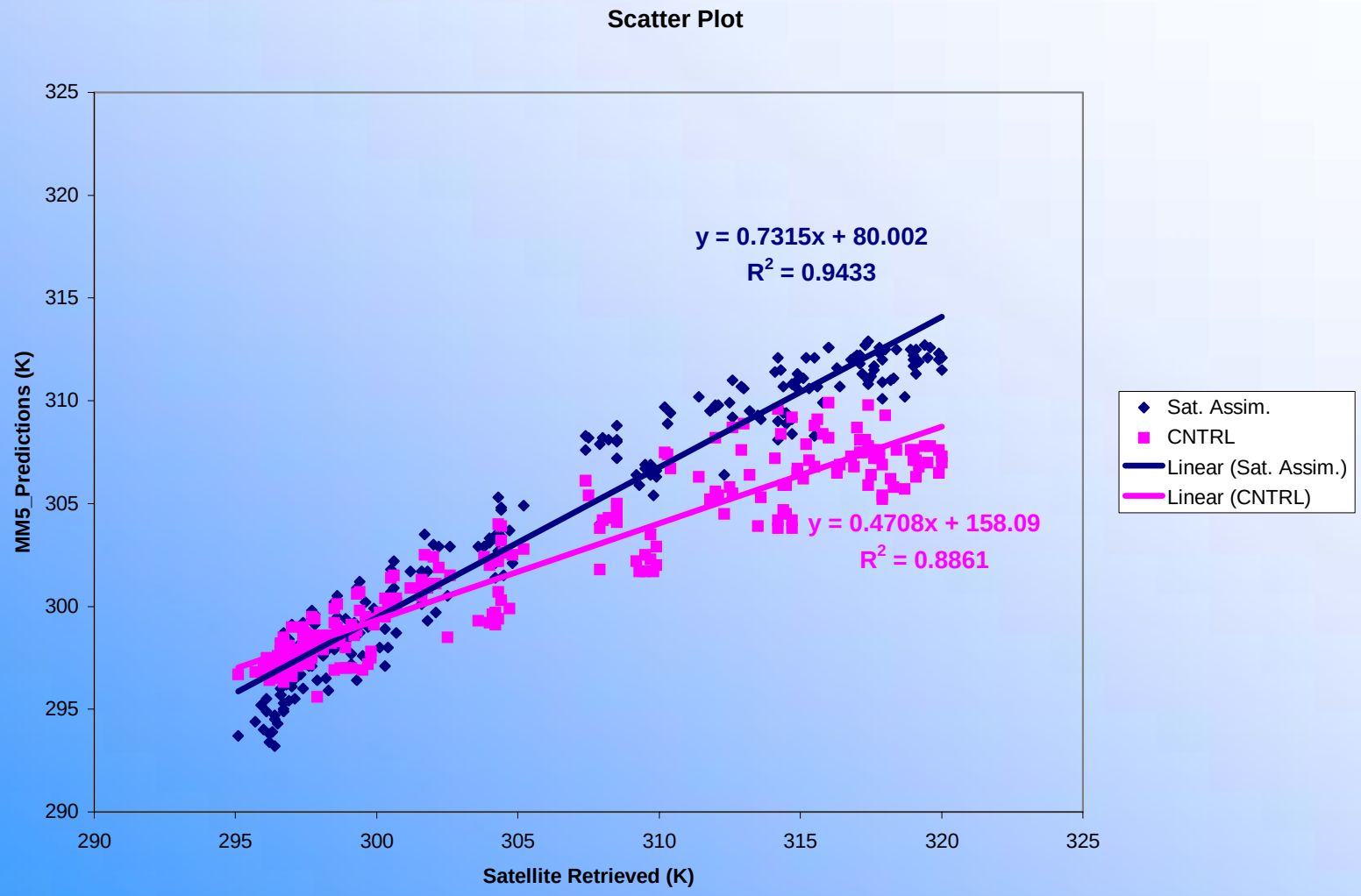


Satellite assimilation technique for surface properties has shown that the surface/air temperature predictions can greatly be improved.



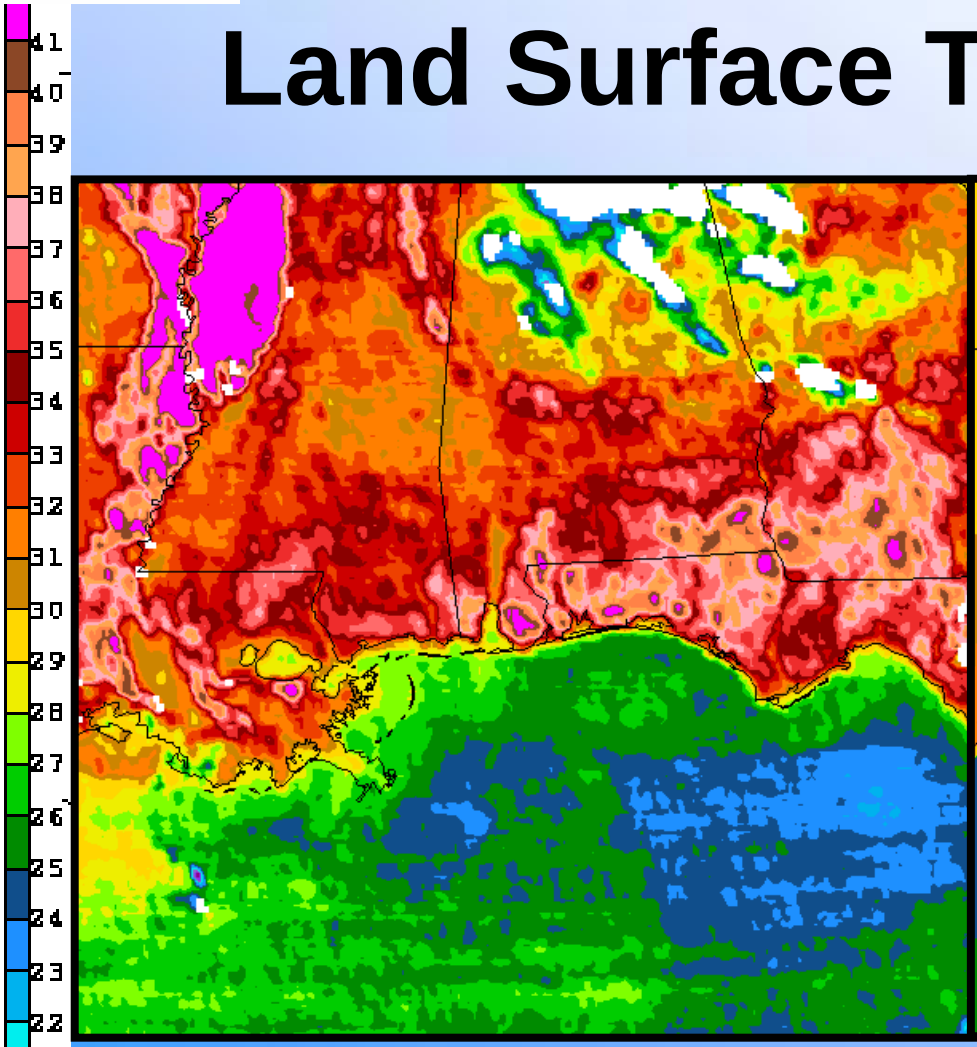
Comparing model 2-M temperature predictions to the observed temperatures from National Weather Service stations shows that the satellite assimilation technique **(blue line)** reduces the forecast bias in the model (warm bias at night and cold bias during the day).

12-km Domain

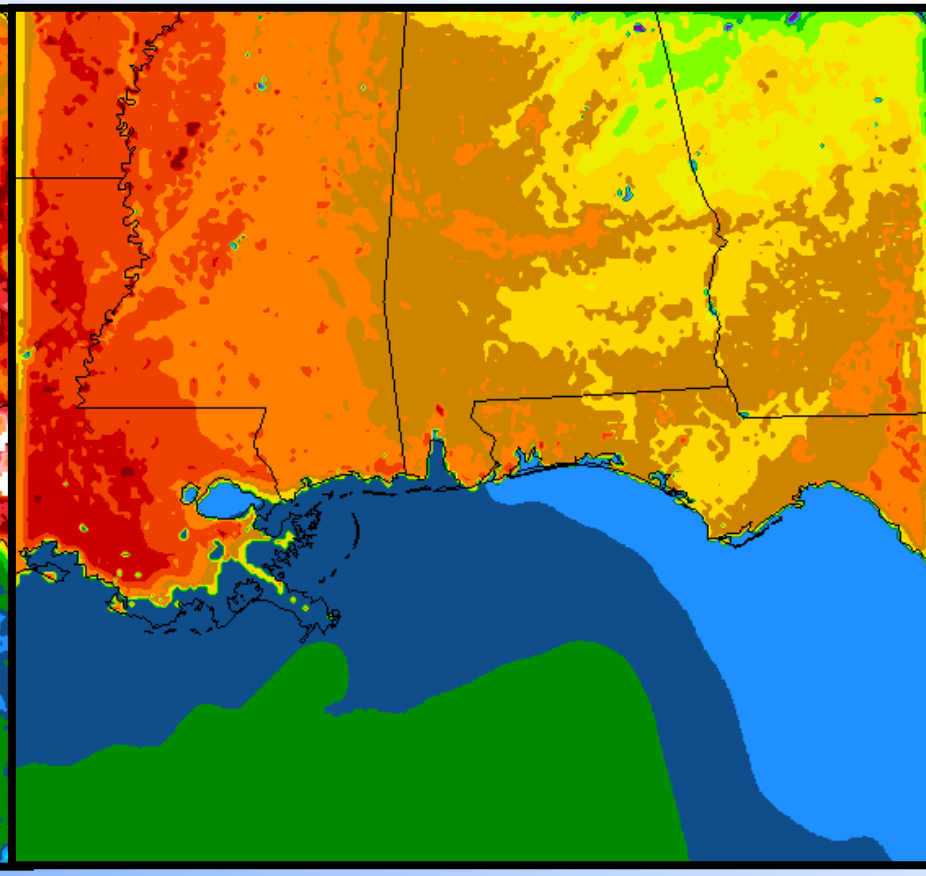


Scatter plot from a simulation (12-km) in which moisture availability was only adjusted periodically.

Land Surface Temperatures

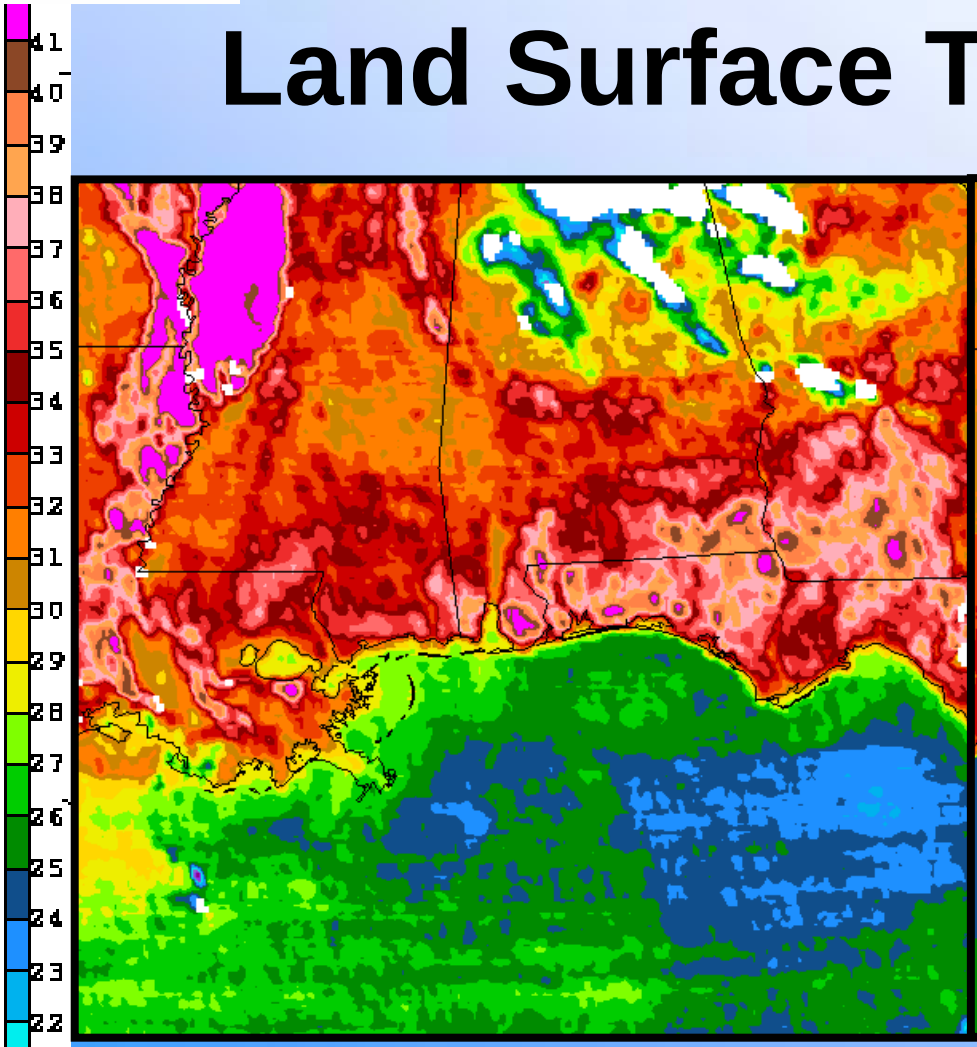


GOES LST (C) valid 1945 UTC

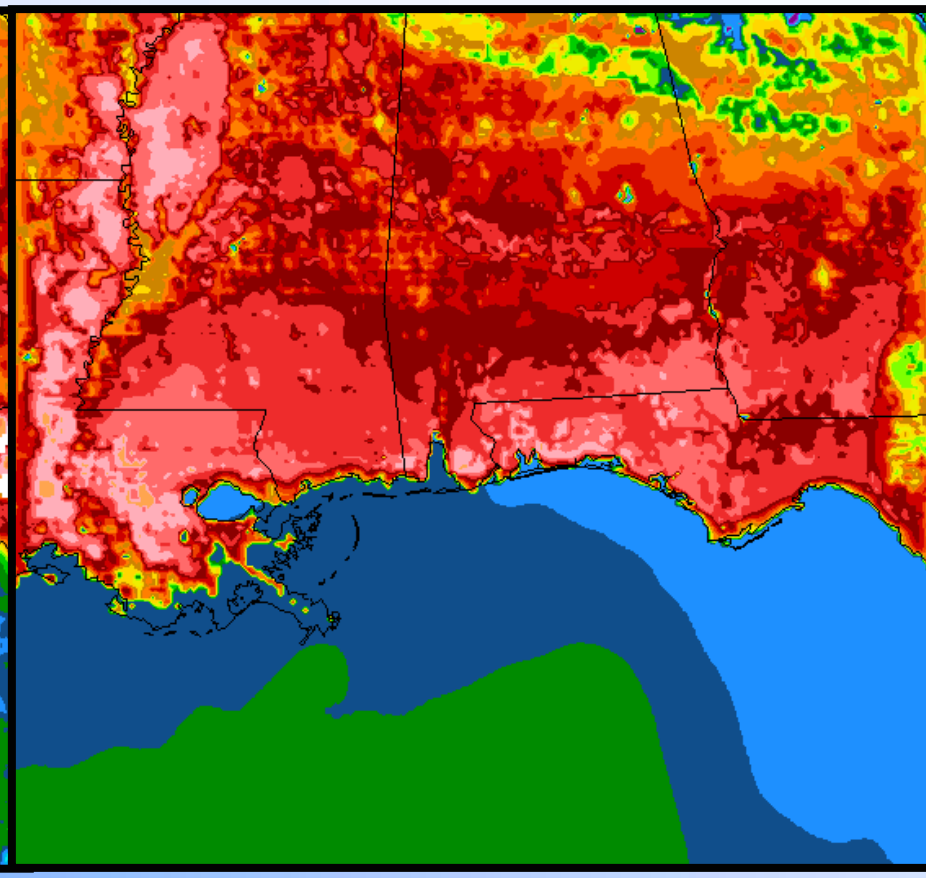


CTRL LST (C) valid 20 UTC

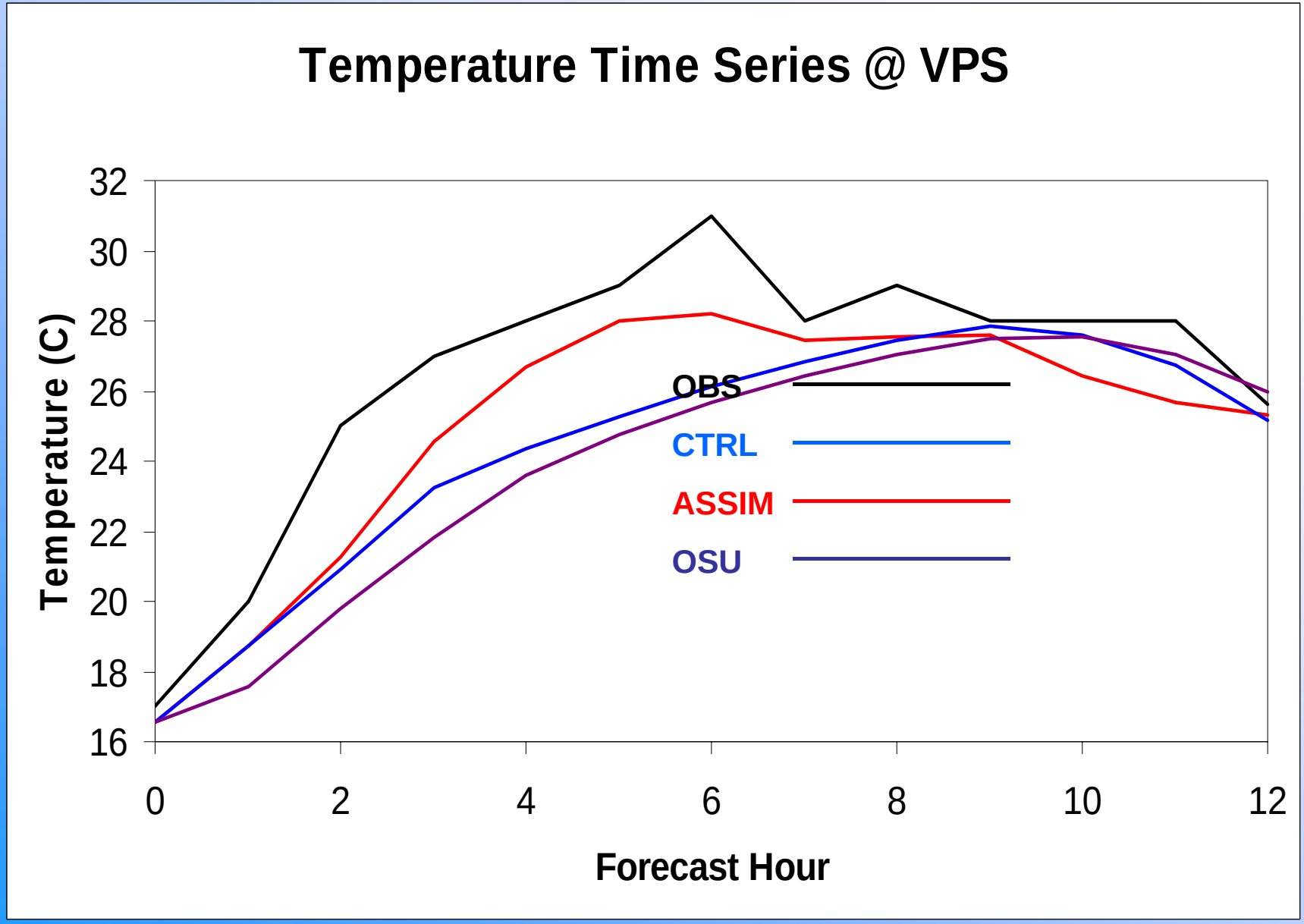
Land Surface Temperatures

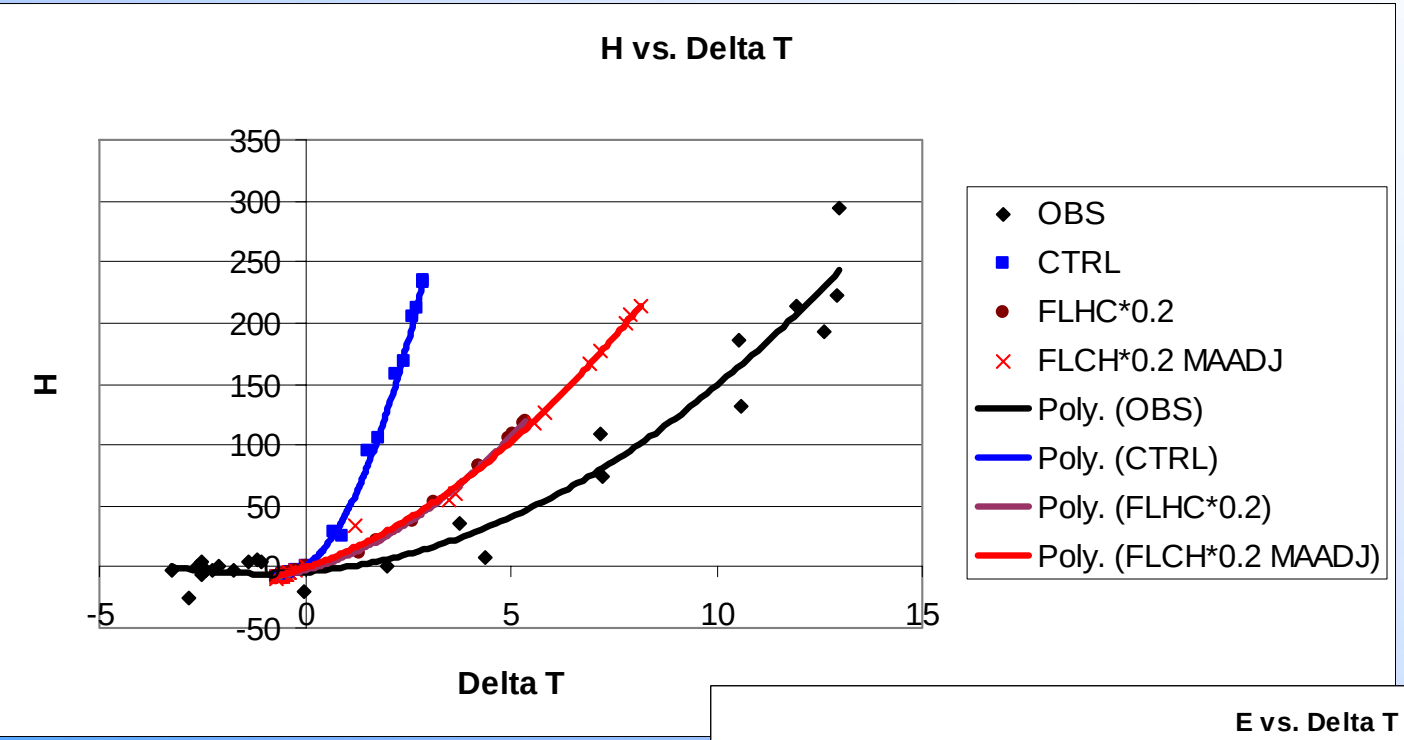


GOES LST (C) valid 1945 UTC

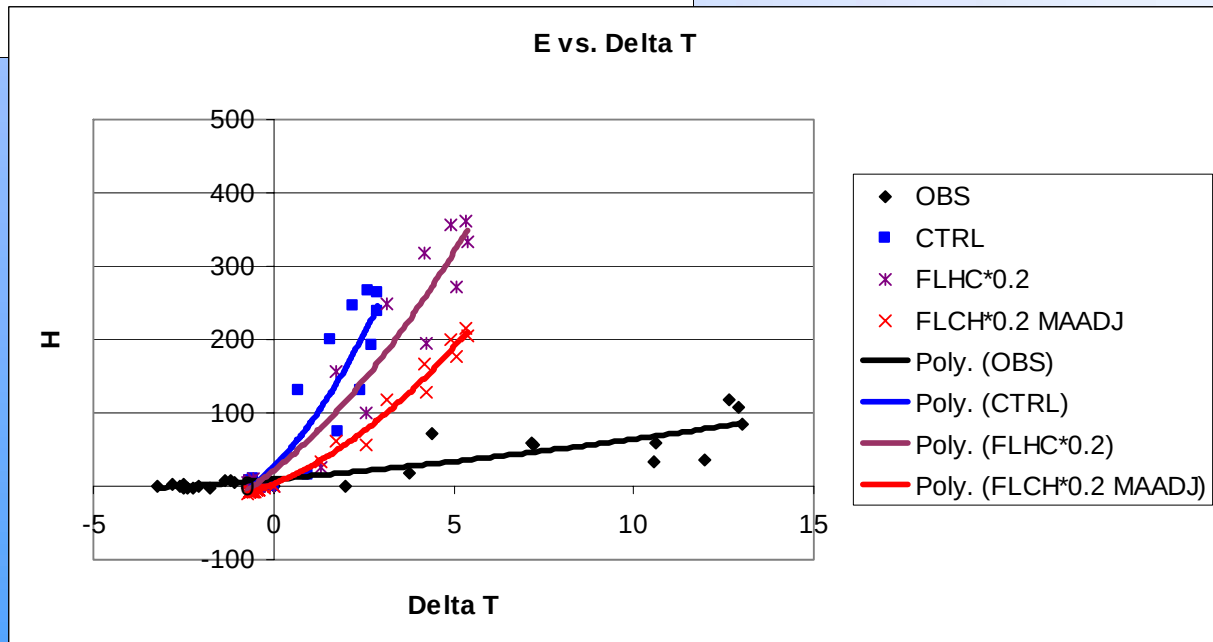


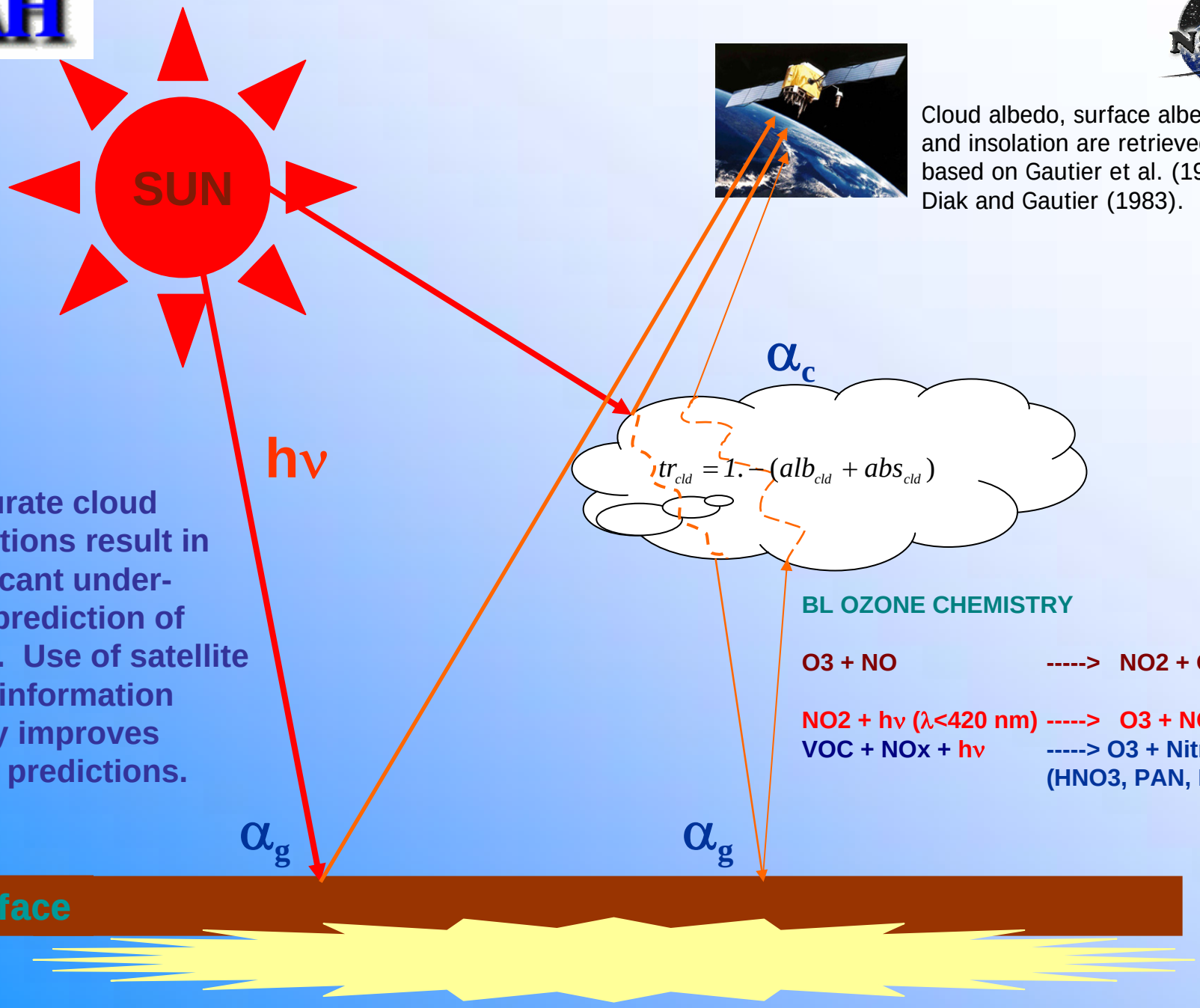
ASSIM LST (C) valid 20 UTC


Temperature Time Series @ VPS
Temperature (C)
32
30
28
26
24
22
20
18
16
0
2
4
6
8
10
12
Forecast Hour
OBS
CTRL
ASSIM
OSU



Model over-predicts surface fluxes as a function of temperature gradient.





Cloud albedo, surface albedo, and insolation are retrieved based on Gautier et al. (1980), Diak and Gautier (1983).

Inaccurate cloud predictions result in significant under-/over-prediction of ozone. Use of satellite cloud information greatly improves model predictions.

BL OZONE CHEMISTRY

O3 + NO -----> NO2 + O2

NO2 + hν (λ<420 nm) -----> O3 + NO

VOC + NOx + hν -----> O3 + Nitrates (HNO3, PAN, RONO2)

Satellite Method

Photolysis Rates

MM5 Method

Cloud top

Determined from satellite IR temperature

Cloud top

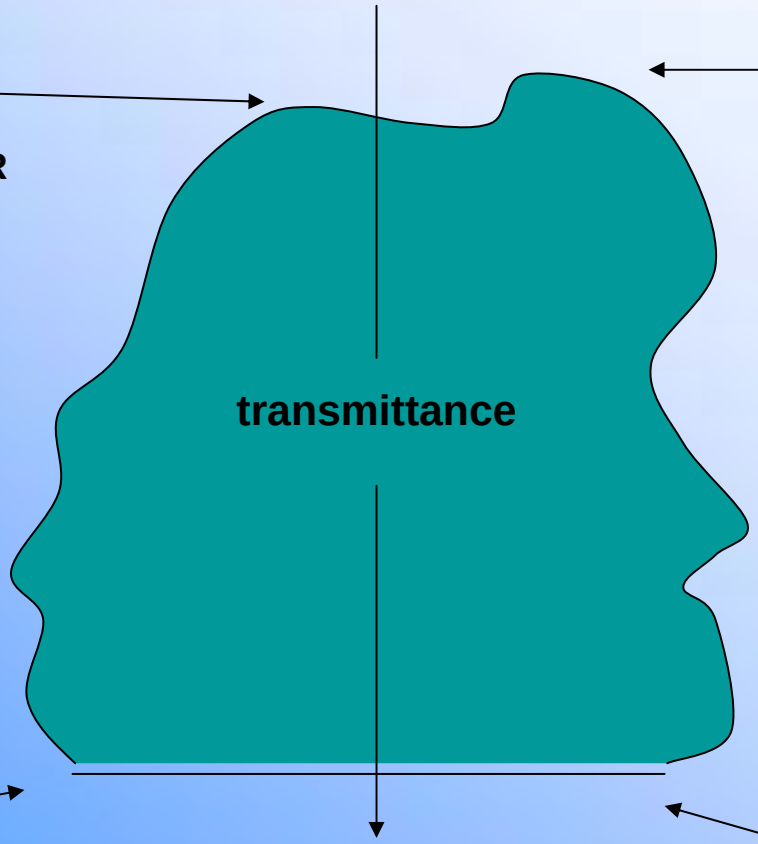
Determined from model LW = f(RH)

Transmittance =

1- reflectance - absorption

Observed by satellite

F(reflectance)



Transmittance

Determined from LW= f(RH) and assumed droplet size

Cloud Base

Determined from LCL

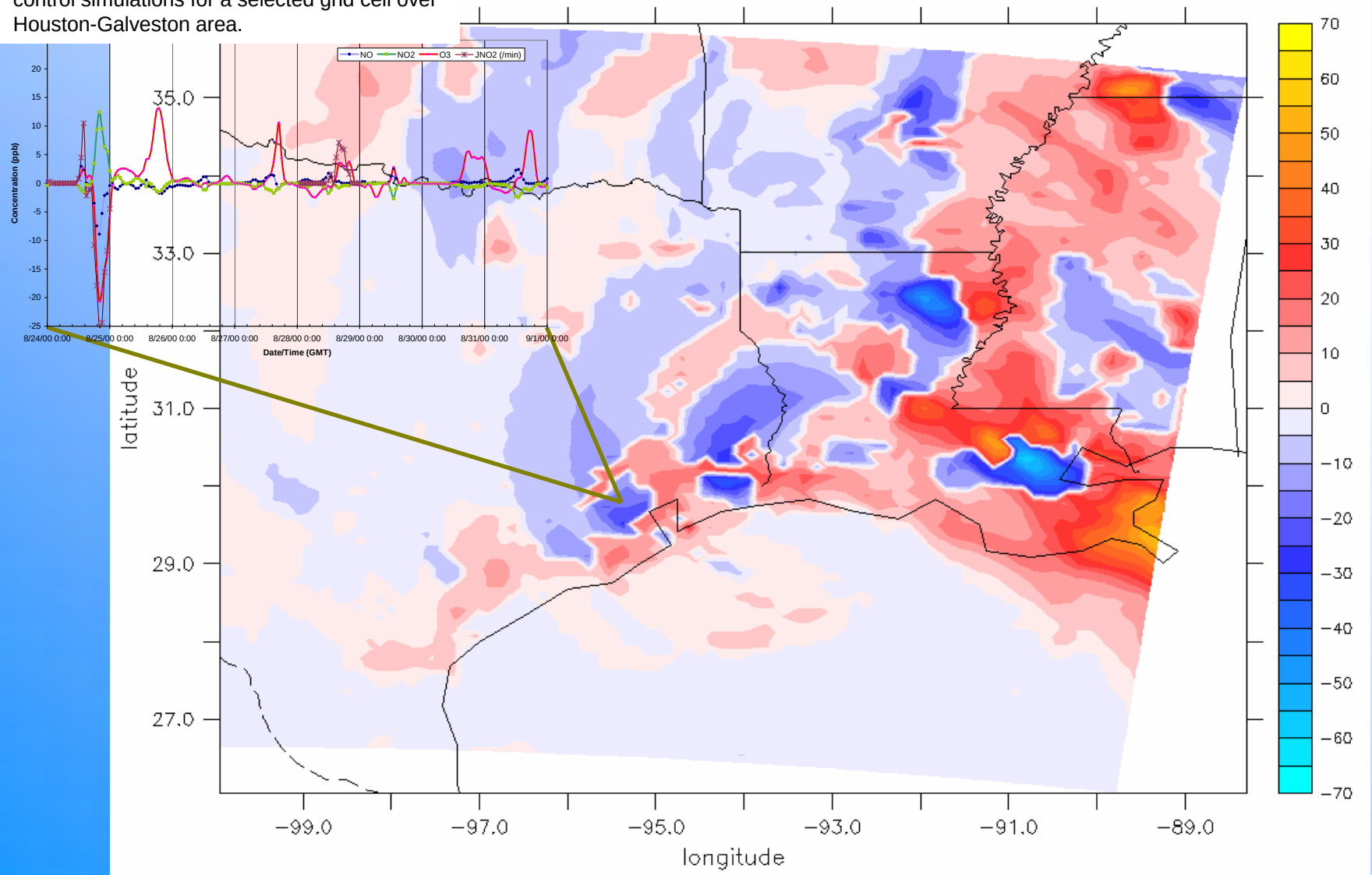
Cloud Base

Determined from model LW = f(RH)

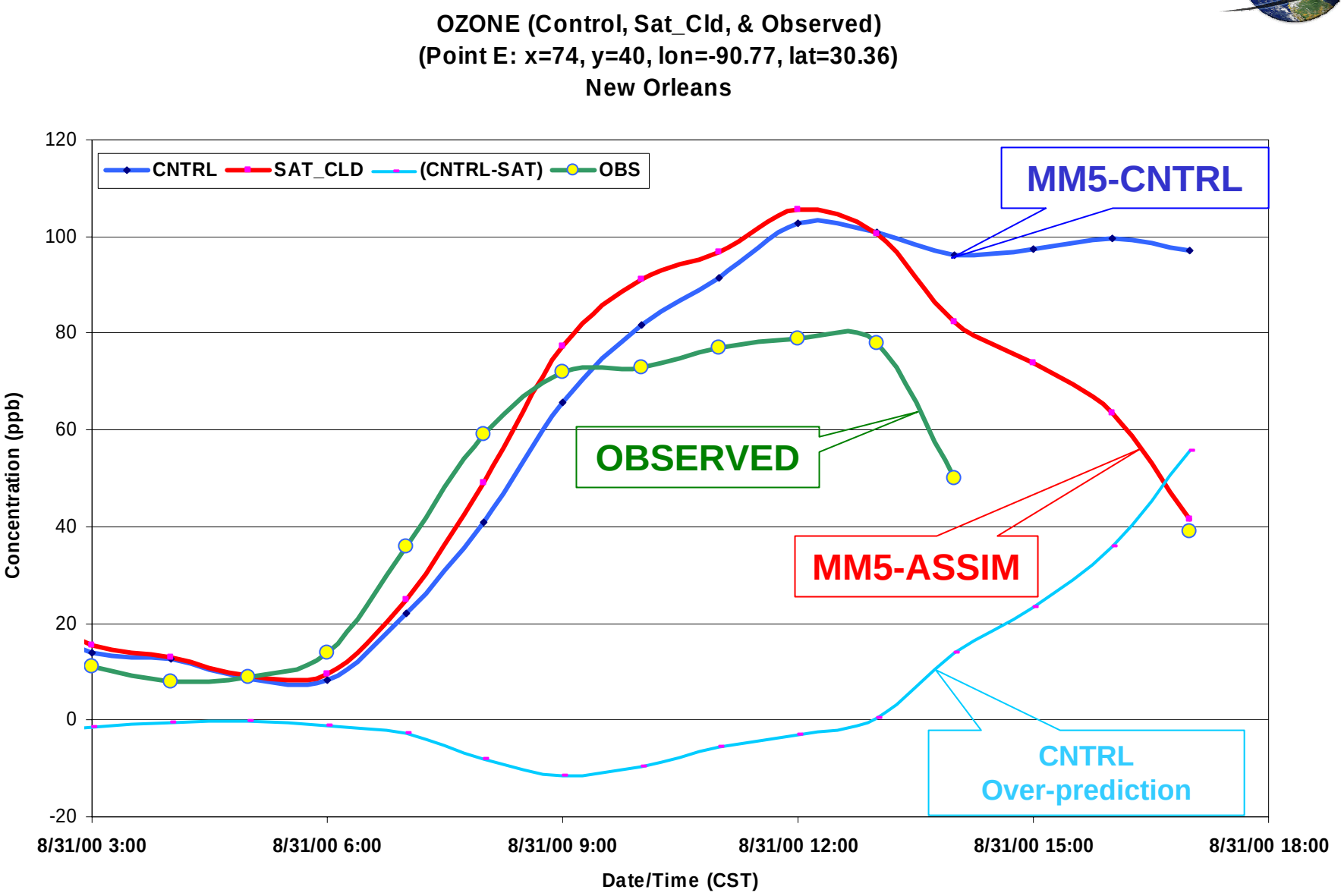
Largest changes in O3 concentration due to use of observed clouds for the entire period of study covering 24 August to 1 September 2000.

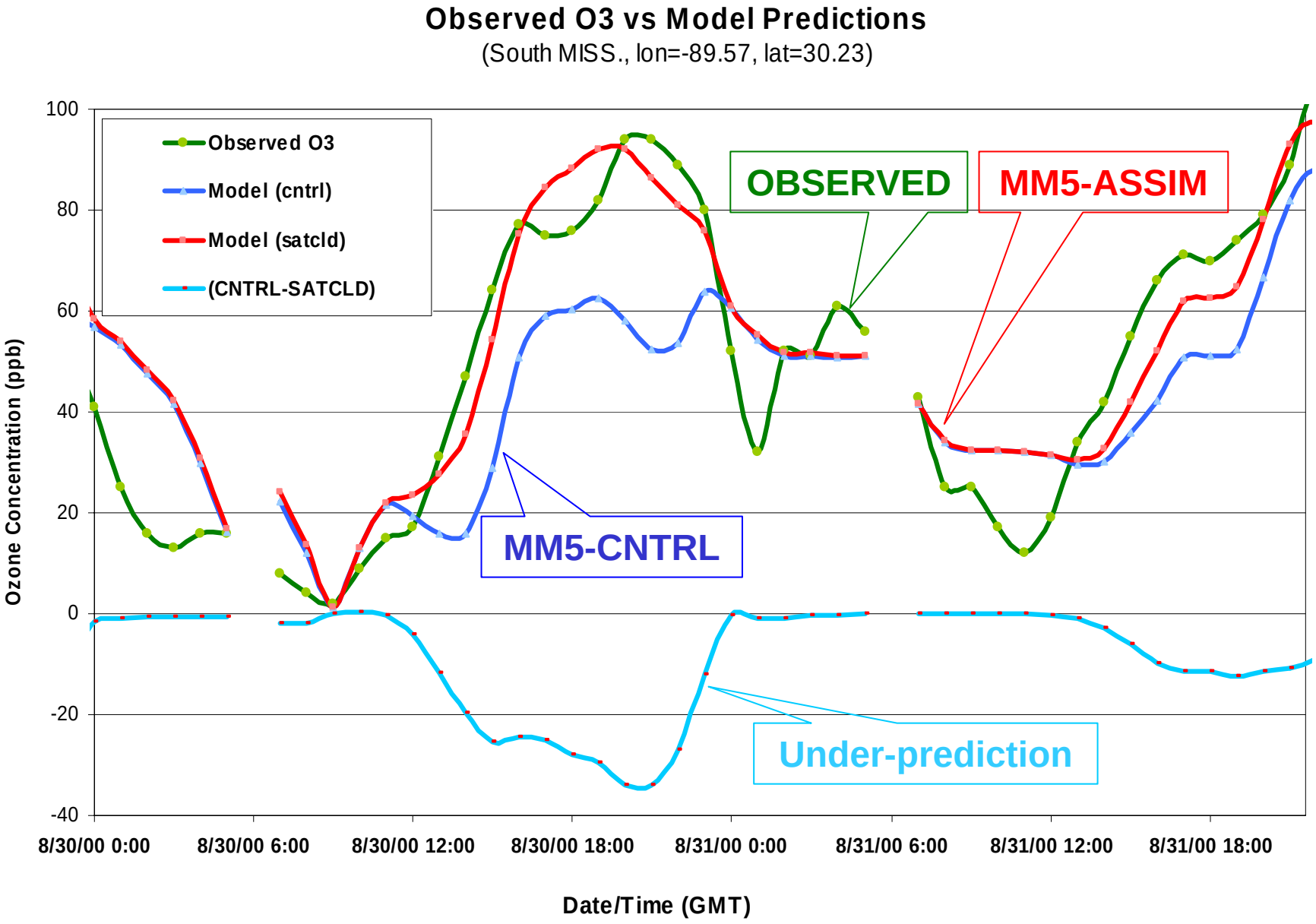
The differences between NO, NO2, O3 (ppb) and JNO2 from satellite cloud assimilation and control simulations for a selected grid cell over Houston-Galveston area.

($O3_b$-$O3_a$, b=Sat. Observed Cloud, a=Control)



Max abs. diff in O3 concentration


OZONE (Control, Sat_Cld, & Observed)
(Point E: x=74, y=40, lon=-90.77, lat=30.36)
New Orleans
CNTRL
SAT_CLD
(CNTRL-SAT)
OBS
MM5-CNTRL
OBSERVED
MM5-ASSIM
CNTRL
Over-prediction
Concentration (ppb)
120
100
80
60
40
20
0
-20
8/31/00 3:00
8/31/00 6:00
8/31/00 9:00
8/31/00 12:00
8/31/00 15:00
8/31/00 18:00
Date/Time (CST)


Observed O3 vs Model Predictions
(South MISS., lon=-89.57, lat=30.23)
Observed O3
Model (cntrl)
Model (satcld)
(CNTRL-SATCLD)
OBSERVED
MM5-ASSIM
MM5-CNTRL
Under-prediction
Ozone Concentration (ppb)
100
80
60
40
20
0
-20
-40
8/30/00 0:00
8/30/00 6:00
8/30/00 12:00
8/30/00 18:00
8/31/00 0:00
8/31/00 6:00
8/31/00 12:00
8/31/00 18:00
Date/Time (GMT)

ASSIMILATION OF GOES-DERIVED CLOUD PRODUCTS IN MM5

Initial Basic Approach

- Use GOES cloud top temperatures and/or cloud albedoes to determine a maximum vertical velocity (Wmax) in the cloud column.
- Adjust divergence to comply with Wmax in a way similar to O'Brien (1970).
- Calculate new horizontal divergent wind components.
- Nudge MM5 winds toward new horizontal wind field.
- Determine a way to remove erroneous model clouds.

Satellite Products

- Cloud albedo
- Cloud top pressure / brightness temperature
- Short wave radiation
- Surface albedo
- Skin temperature

Simulation History

- Texas 2000 AQS, 36-km grid, Grell scheme
- SOS 1999, 8-km grid, Kain-Fritsch scheme

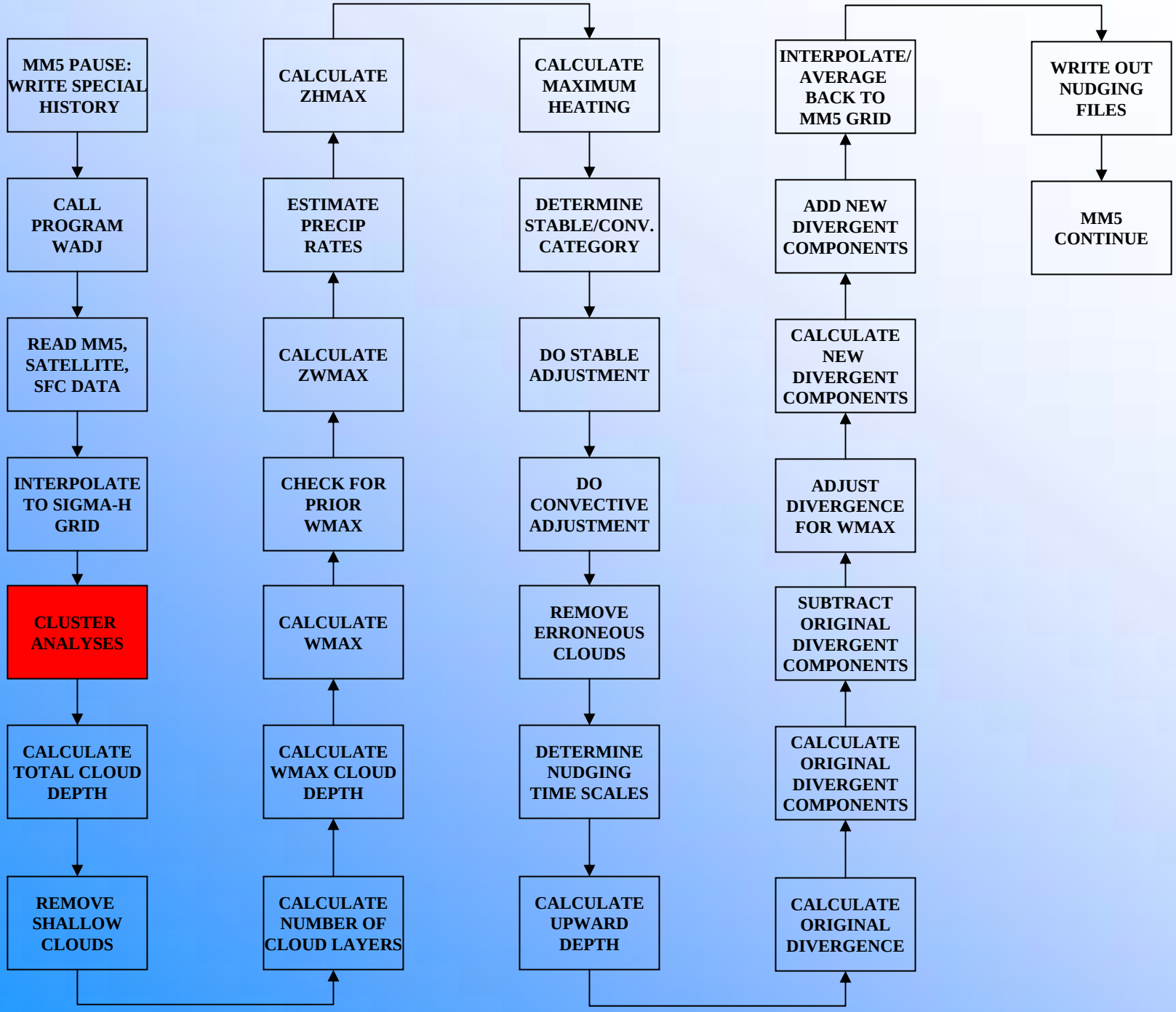
Multiple Linear Regression Variables

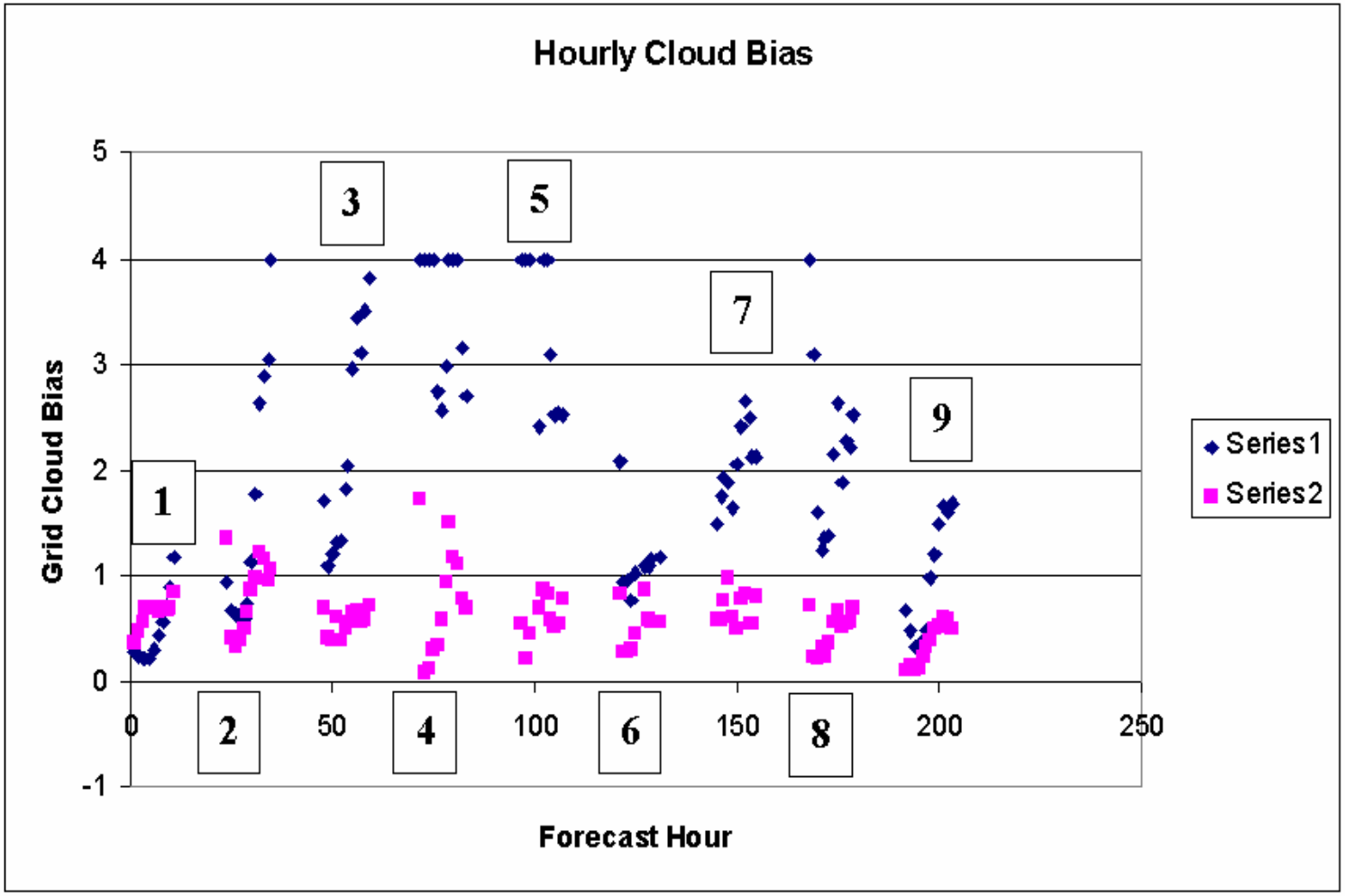
- Total Cloud Depth
- Number of Cloud Layers
- Depth Wmax Layer
- Wmax
- Height of Wmax
- Est. 1-h stable precip.
- Est. 1-h convective precip.
- Height of Max. Diabatic Heating
- Magnitude of Maximum Diabatic Heating
- Layer with Upward Motion

Steps in Regression Analysis

(1) Develop the needed regression equations using strictly MM5 control runs.

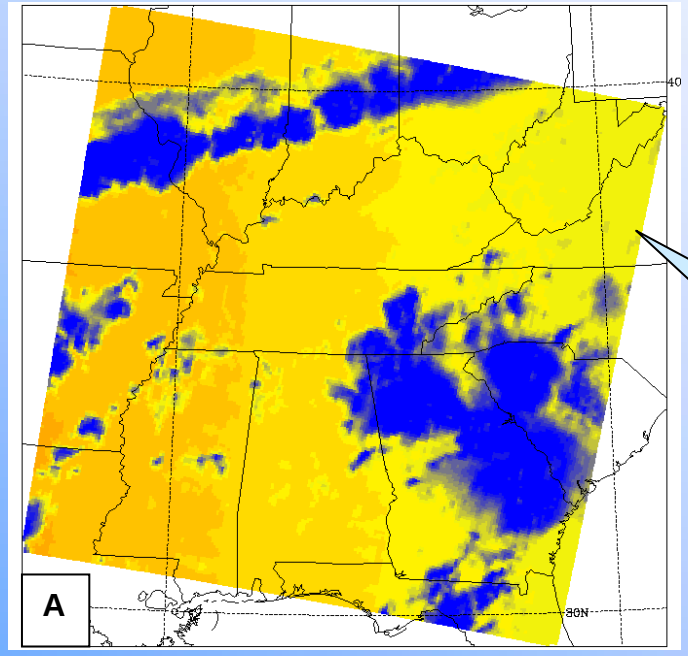
(2) Apply the regression equations in MM5 assimilation run utilizing satellite data as much as possible. We also define the cloud geometry by performing cluster analysis.


MM5 PAUSE: WRITE SPECIAL HISTORY
CALL PROGRAM WADJ
READ MM5, SATELLITE, SFC DATA
INTERPOLATE TO SIGMA-H GRID
CLUSTER ANALYSES
CALCULATE TOTAL CLOUD DEPTH
REMOVE SHALLOW CLOUDS
CALCULATE NUMBER OF CLOUD LAYERS
CALCULATE WMAX CLOUD DEPTH
CALCULATE WMAX
CHECK FOR PRIOR WMAX
CALCULATE ZWMAX
ESTIMATE PRECIP RATES
CALCULATE ZHMAX
CALCULATE UPWARD DEPTH
DETERMINE NUDGING TIME SCALES
REMOVE ERRONEOUS CLOUDS
DO CONVECTIVE ADJUSTMENT
DO STABLE ADJUSTMENT
DETERMINE STABLE/CONV. CATEGORY
CALCULATE MAXIMUM HEATING
CALCULATE ORIGINAL DIVERGENCE
CALCULATE ORIGINAL DIVERGENT COMPONENTS
SUBTRACT ORIGINAL DIVERGENT COMPONENTS
ADJUST DIVERGENCE FOR WMAX
CALCULATE NEW DIVERGENT COMPONENTS
ADD NEW DIVERGENT COMPONENTS
INTERPOLATE/ AVERAGE BACK TO MM5 GRID
WRITE OUT NUDGING FILES
MM5 CONTINUE



BIAS = (Total model predicted cloud) / (Total observed cloud)

Satellite Data Is Utilized to Correct Model Cloud Fields in a Dynamically Consistent Manner

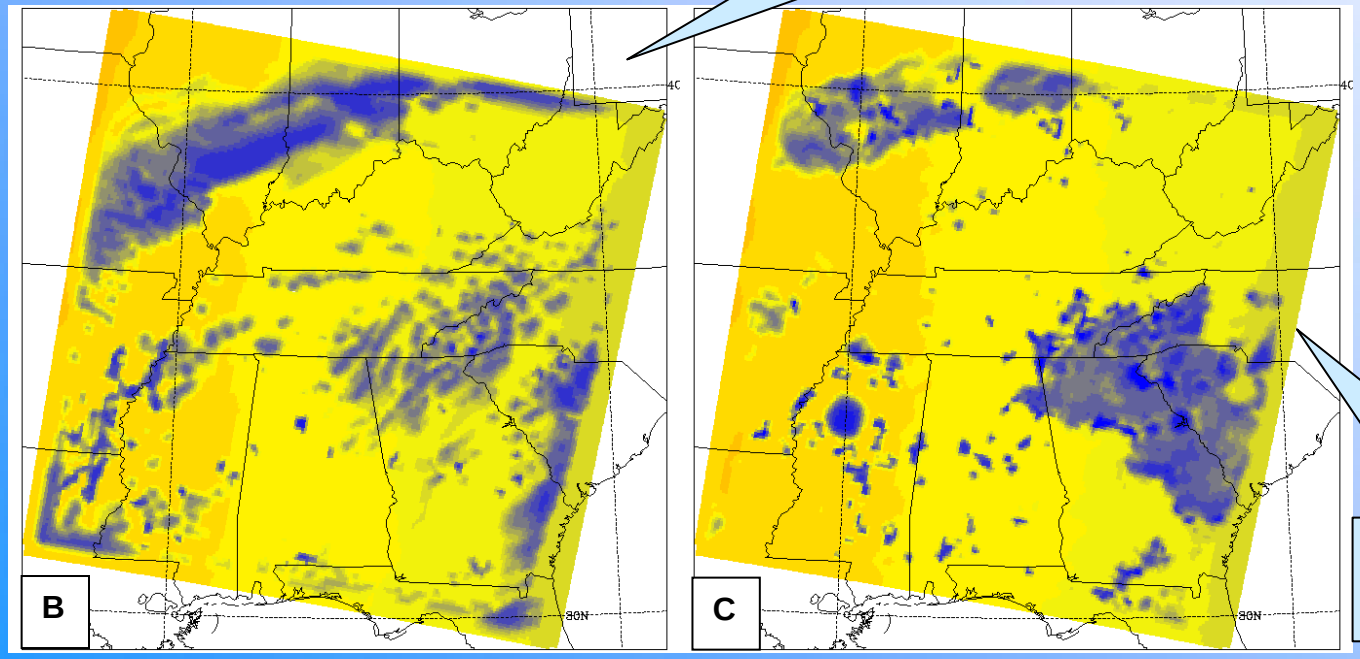


GOES
OBSERVED
Insolation

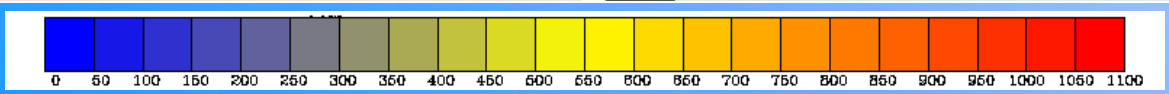
MODEL
NO assimilation

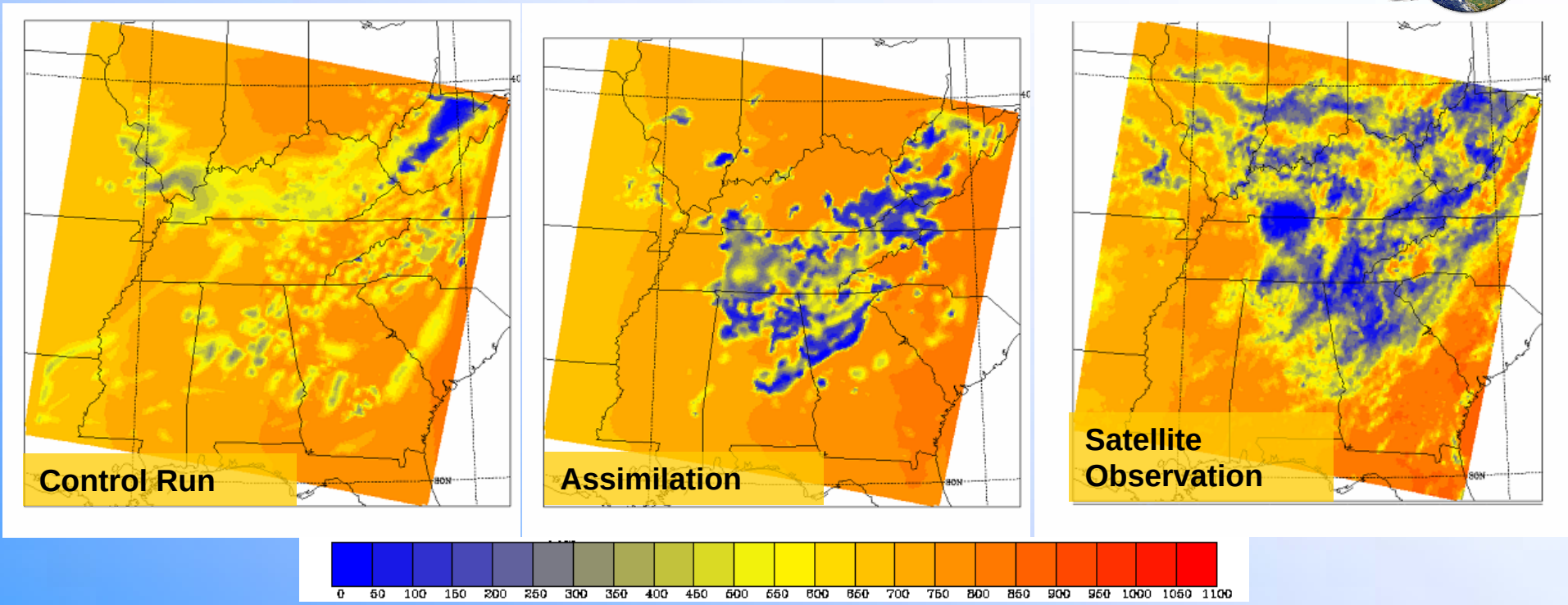
Downward shortwave radiation in W m^{-2} at 2200 UTC 6 July 1999.

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



MODEL
WITH assimilation





Surface incident shortwave radiation in W m^{-2} for 2 July 1999. Assimilation and satellite observation plots are @ 14:45 UTC, and the control run is @ 15:00 UTC.

Control: Control run with no assimilation.

Assimilation: Run with assimilation of satellite cloud information.

Satellite Observation: Derived from GOES–8 satellite.

Concluding Remarks

- The cause of dry bias in the assimilation technique is still unknown.
- Transition into WRF modeling system is under way.
- Preliminary results from MM5 cloud assimilation work are promising, but still need improvement.
- We would like to thank MMS for supporting this research.

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