Effects of Land Cover Changes on the Air Quality in the Houston-Galveston Area

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Objectives: **Study of the effects of land use and land cover modification on the urban heat island development and on the air quality in the Houston-Galveston metropolitan area.**

Methods: **Conduct meteorological, emissions, and air quality sensitivity modeling using …**

- **Improve land surface parameterizations with better physics**
- **Incorporate most up-to-dated detailed land use & land cover data for biogenic emissions estimates and meteorological simulations**
- **Perform sensitivity air quality simulations with different emissions & meteorology inputs**

Urbanization modeling

- Effects of Land use and Land Cover (LU/LC) changes
- Urban Heat Island (UHI)
- Neighborhood Scale Meteorology
- Air Quality

How Does the Land Use/Land Cover Change Affect Local Weather/Climate?

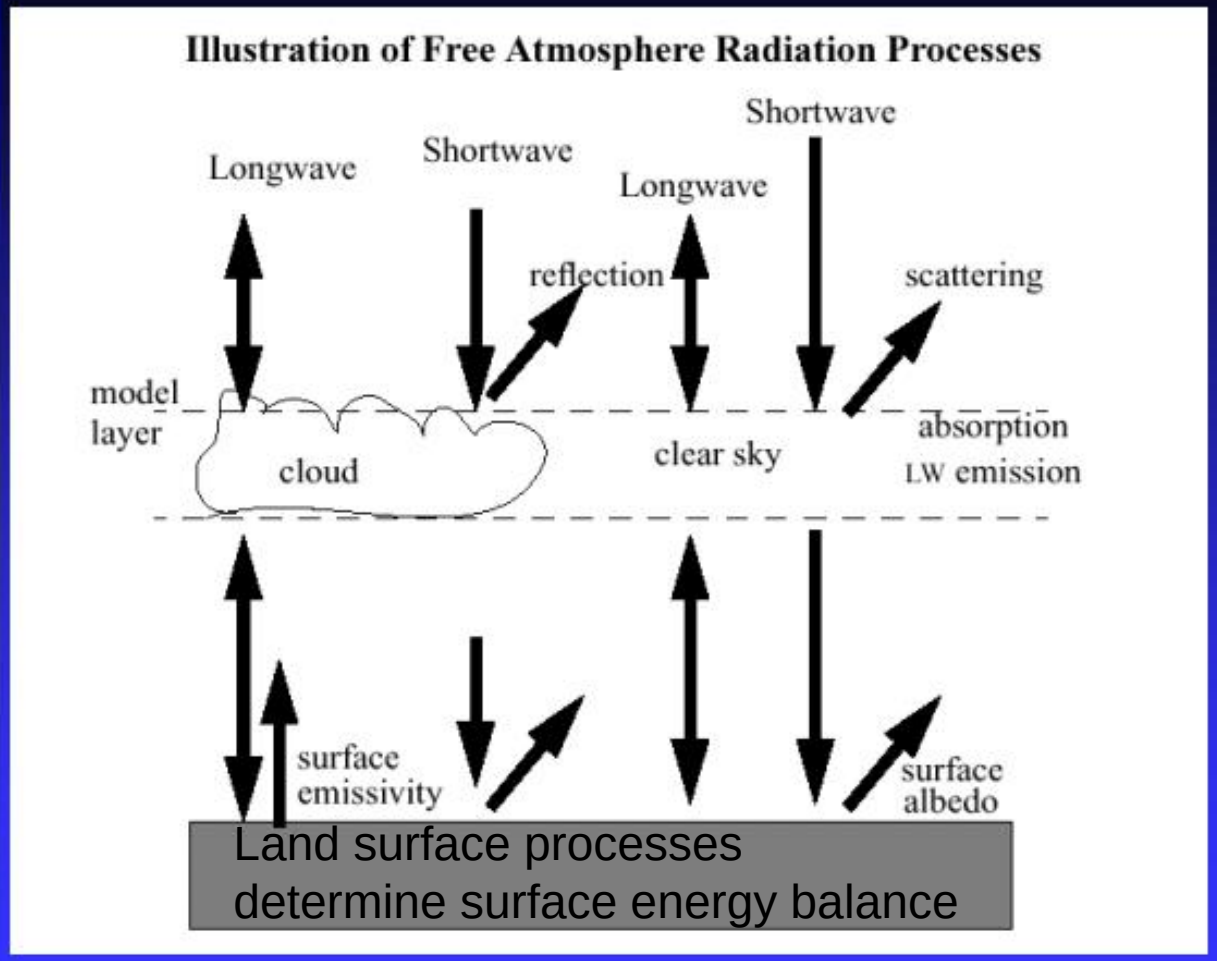
- Climate is a cumulative state of local weather
- There are synoptic changes in the weather due to the changes in land surface processes
- More importantly, mesoscale (of the scale 100s – 1000s km) and neighborhood scale (of the scale 1s – 10s km) meteorology is dependent on the changes in the local energy budget and surface characteristics more closely

How does the Land Use/Land Cover Change Affect Local Weather/Climate?

- Land surface changes affect the thermal and radiative characteristics of the energy balance

- The diurnal evolution of heat (temp.) and momentum (winds) in the planetary boundary layer (PBL) is strongly affected by the energy balance and moisture budget.

Radiation Balance



Land surface processes
determine surface energy balance

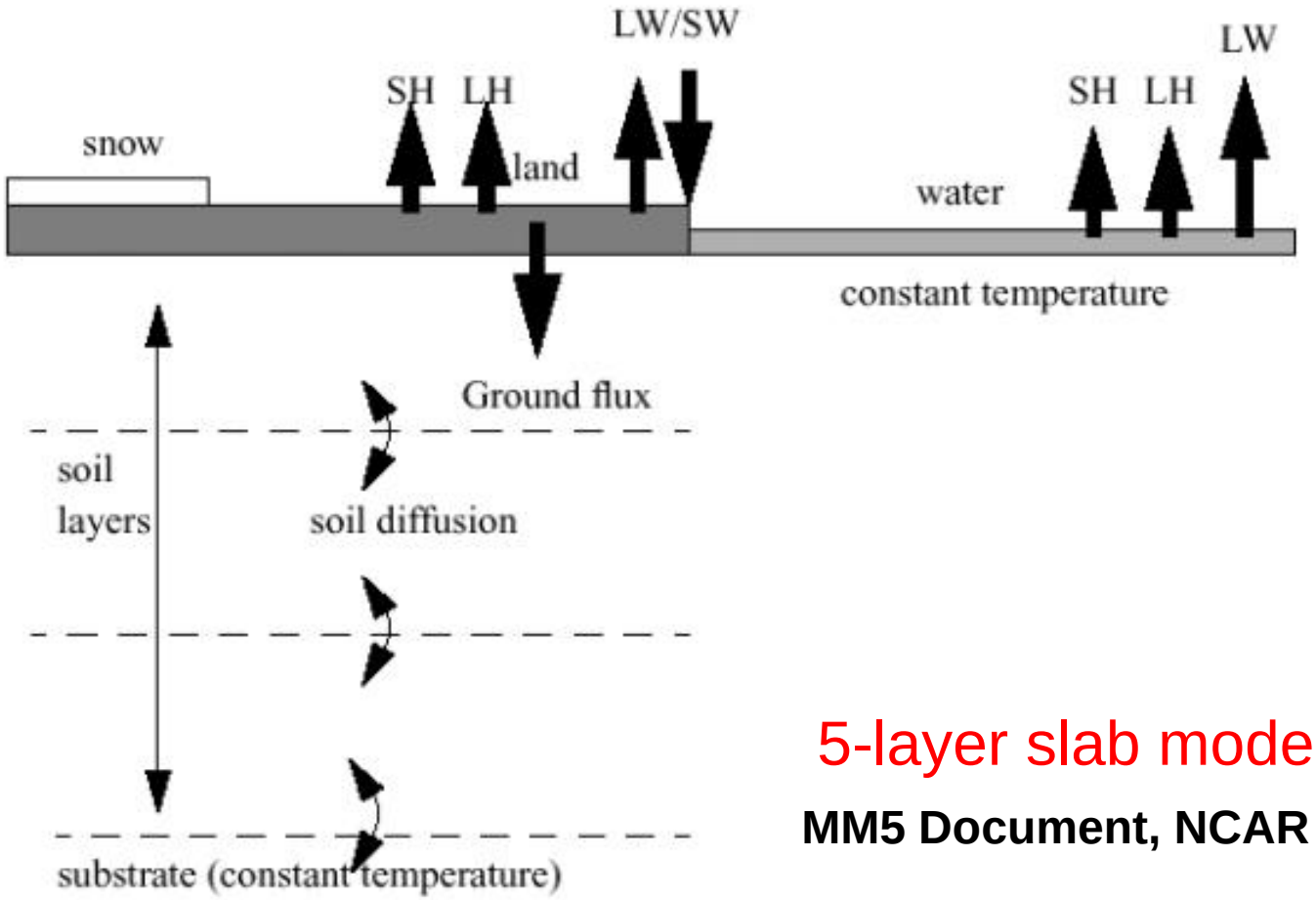
MM5 Document, NCAR

Current TCEQ's TAMU Base Simulation Uses Simple "5-layer" slab model, with GOES Satellite Skin Temp. Assimilation

- Ground heat budget model with multiple layers (5)
- Improved version of a 2-layer force-restore surface energy balance model
- Couples surface momentum, heat, and moisture fluxes
- But, no treatment of evapotranspiration
- No moisture diffusion in the soil layer
- Uses satellite temperature to modulate soil moisture daily/hourly

Predict temperature at 5-soil layers.

1, 2, 4, 8, 16 cm thick



5-layer slab model

MM5 Document, NCAR

Phase 1: Improve Modeling of Land Surface Processes in MM5

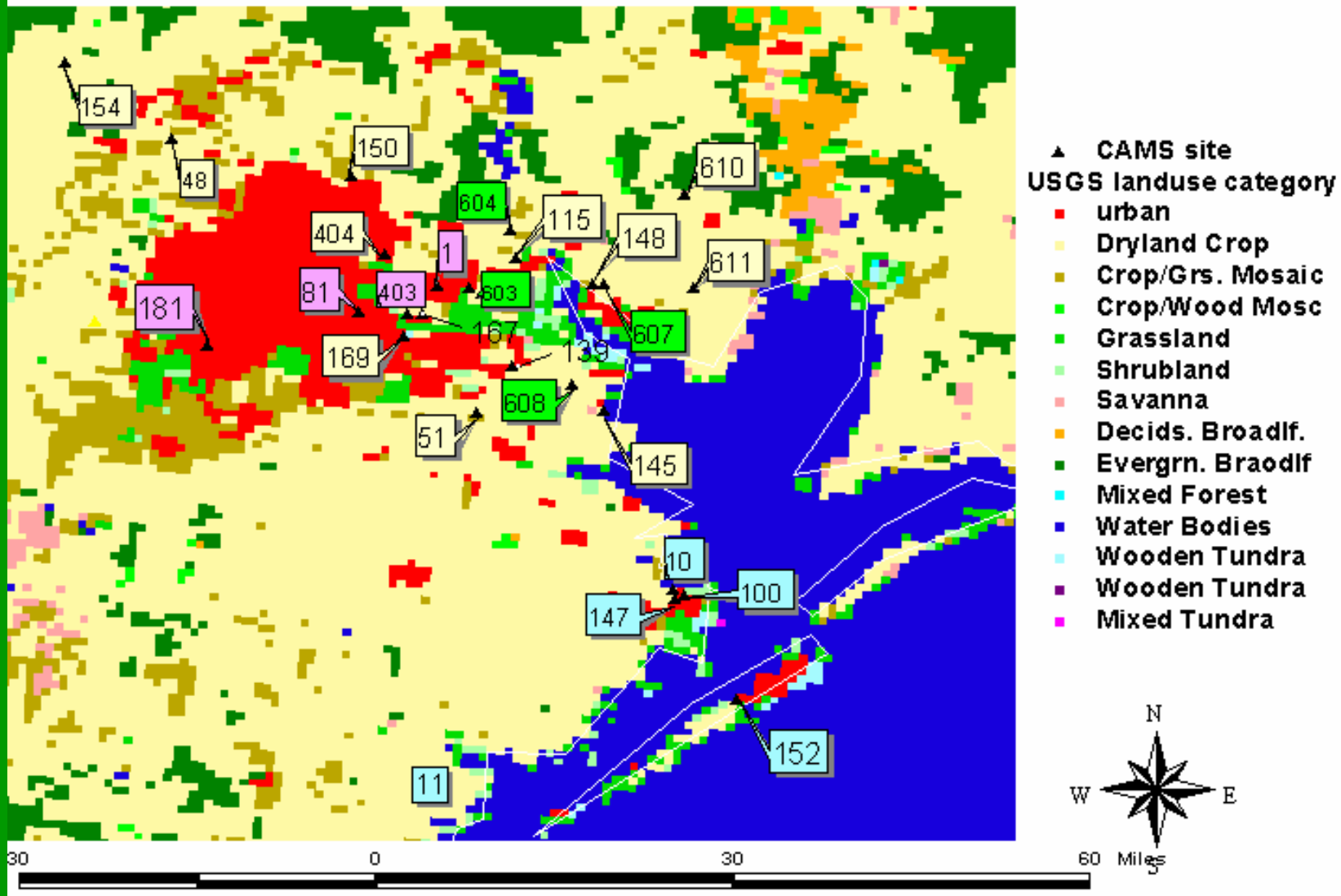
Motivation

- **LU/LC data used in MM5 simulations: USGS ~1-km resolution.**
- **Higher resolution of LU/LC data now available**
- **Dominant LU/LC algorithm used in MM5 does not allow mosaic LU/LC land-surface processes (unless the code is modified)**
- **The question is how to make best MM5 land-surface simulations if our LU/LC data is limited by the current data**

dominant landuse data used in MM5

Urban : 10 sites **Rural : 18 sites**

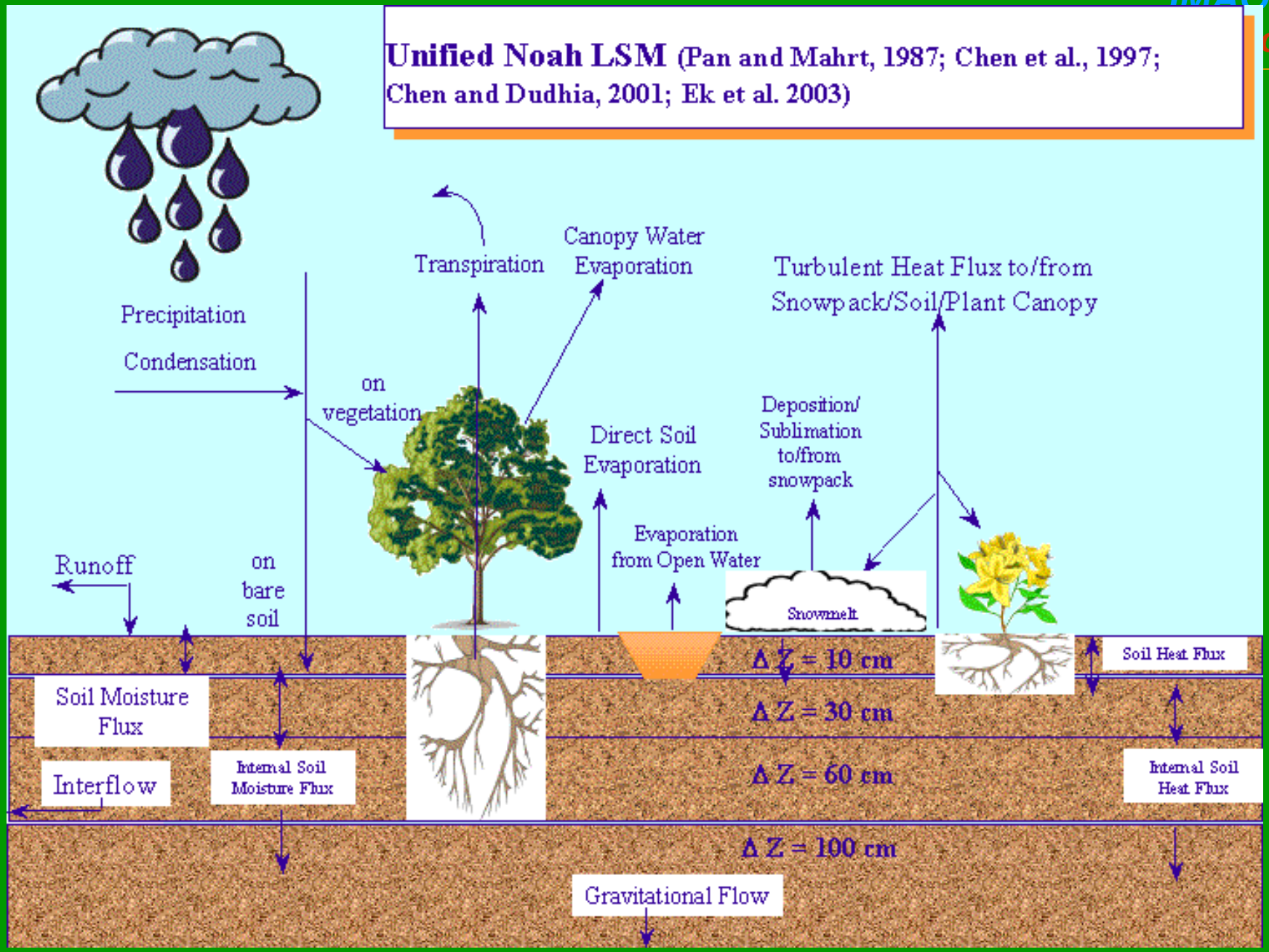
CAMS Site/Landuse Distribution



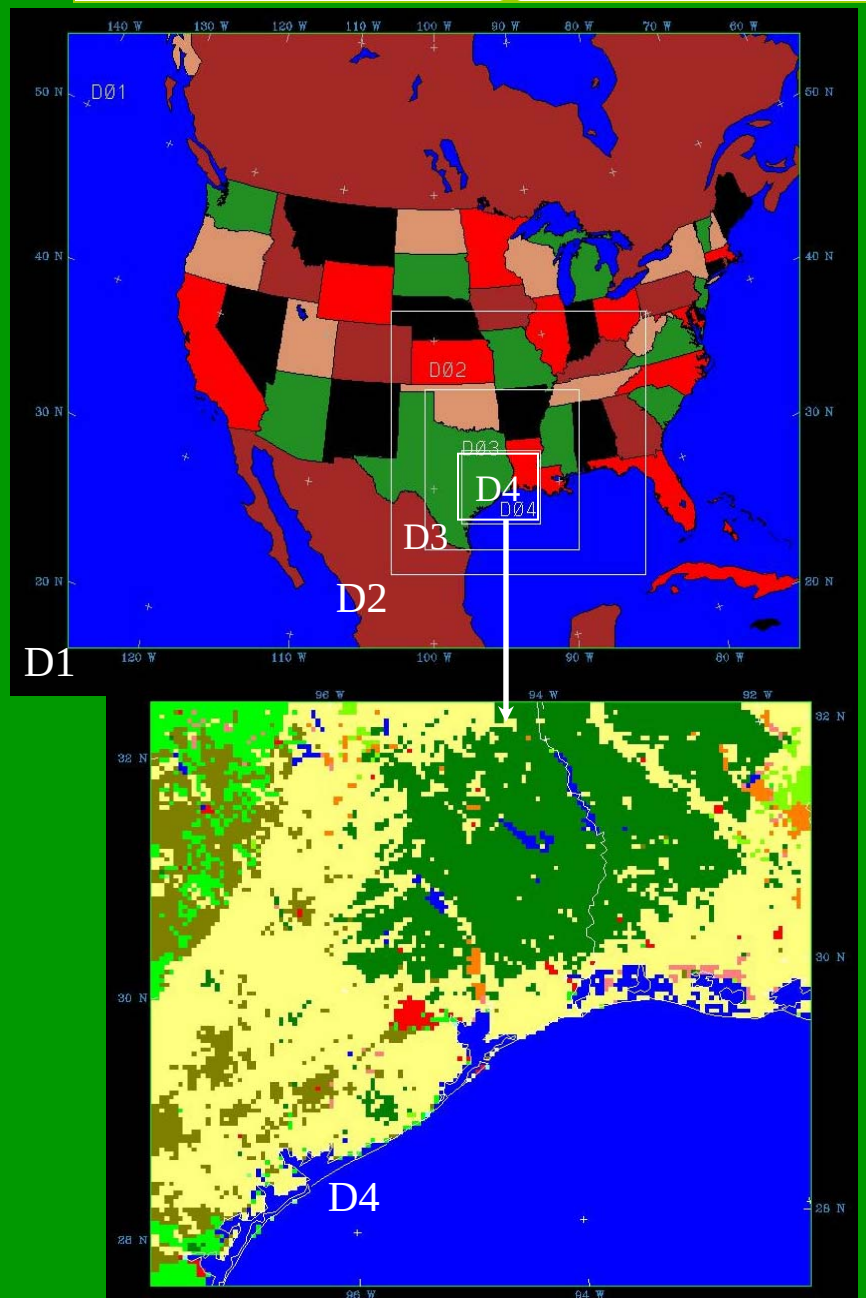
How to better model the land-surface processes?

- Use comprehensive land-surface model
- NOAH LSM (N:National Center for Environmental Prediction; O: Oregon State University; A: Air Force; H: Hydrological Research Lab.) (Ek *et al.*, 2001).
- 4-layers (10, 30, 60, and 100 cm thick)
- Predicts soil temperature, soil water, canopy water, and snow/ice

Unified Noah LSM (Pan and Mahrt, 1987; Chen et al., 1997; Chen and Dudhia, 2001; Ek et al. 2003)



Configuration of MM5 simulations



Simulation time: Aug. 22~Sep.02, 2000			
Domain	X (km)	Y (km)	Z
1	108	108	43
2	36	36	43
3	12	12	43
4	4	4	43

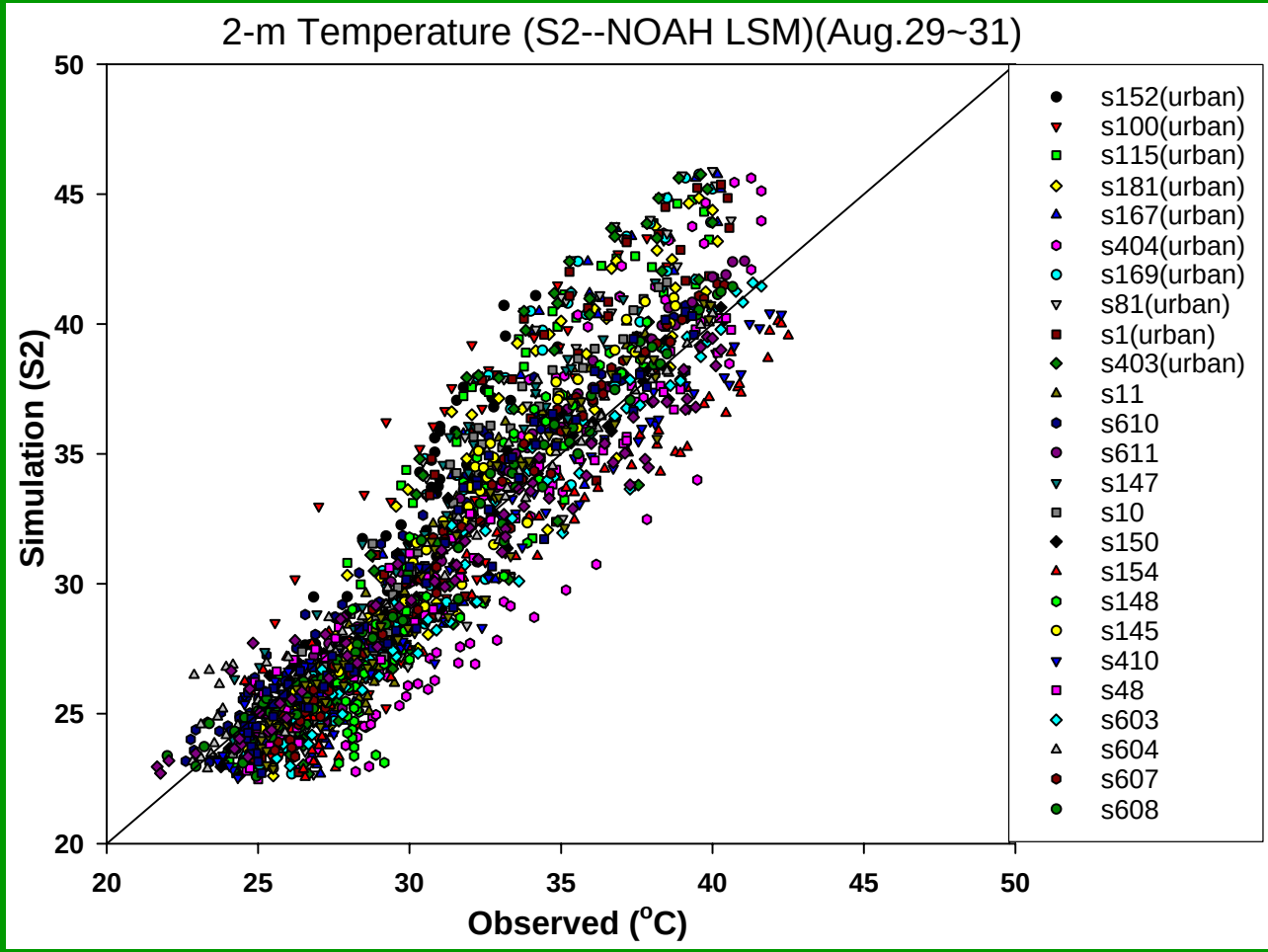
- Analysis nudging for d1,d2,d3; observation nudging(wind vector)for d4
- d1, d2 2way nesting;
  d3,d4 continuous one-way nesting
- MRF PBL Parameterization
- Dudhia explicit moisture scheme
- RRTM radiation scheme
- Slab land-surface model (LSM)

Design of Meteorological Simulation: *S2(NOAH)*

- Experiment #2: Use the recently developed NOAH Land Surface Model (NOAH LSM) (EK, 2001) with identical inputs and model configurations as in S1 case except using different land-surface parameterizations (***S2).***

	S1 (TAMU/GOES)	S2
LSM	SLAB	NOAH
Treatment of Soil Moisture (SM)	Increased SM in urban area GOES skin temperature assimilation to modify SM	SM is updated with the recent precipitation and runoff processes

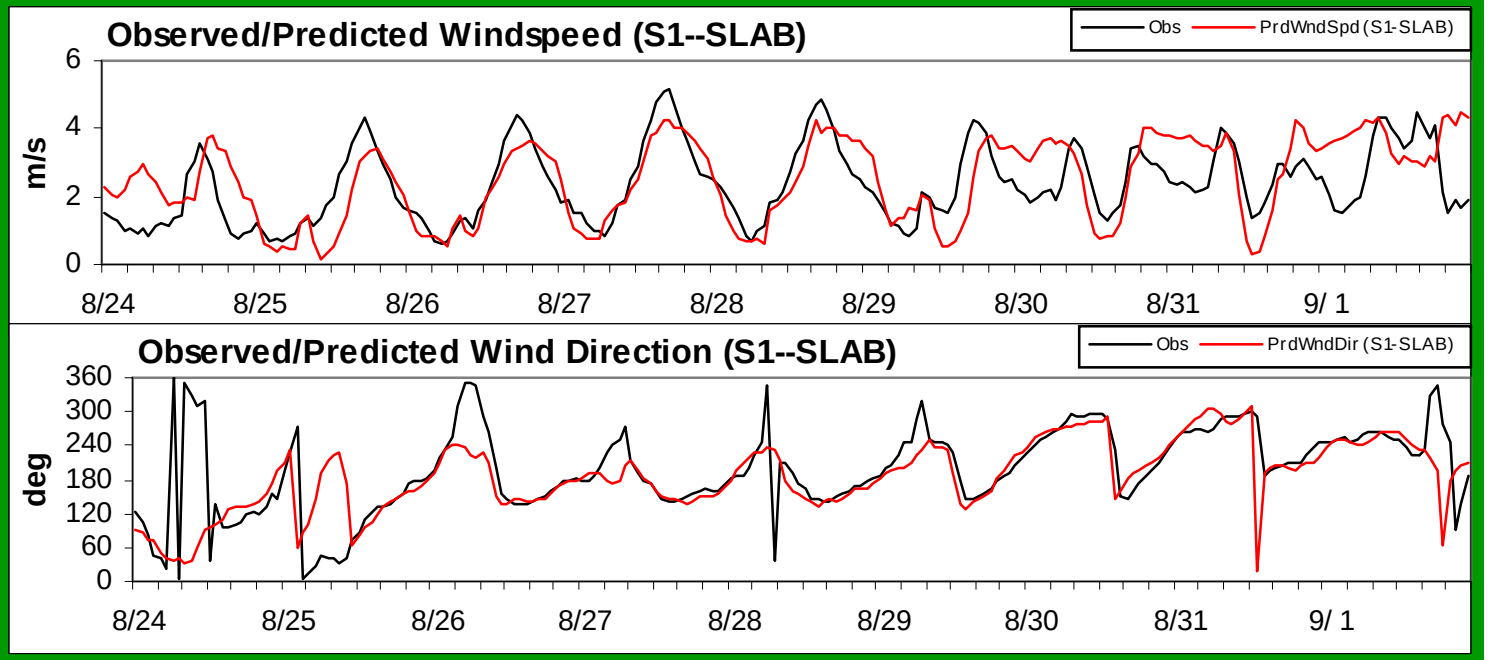
Scattered Diagram of 2-m Temp

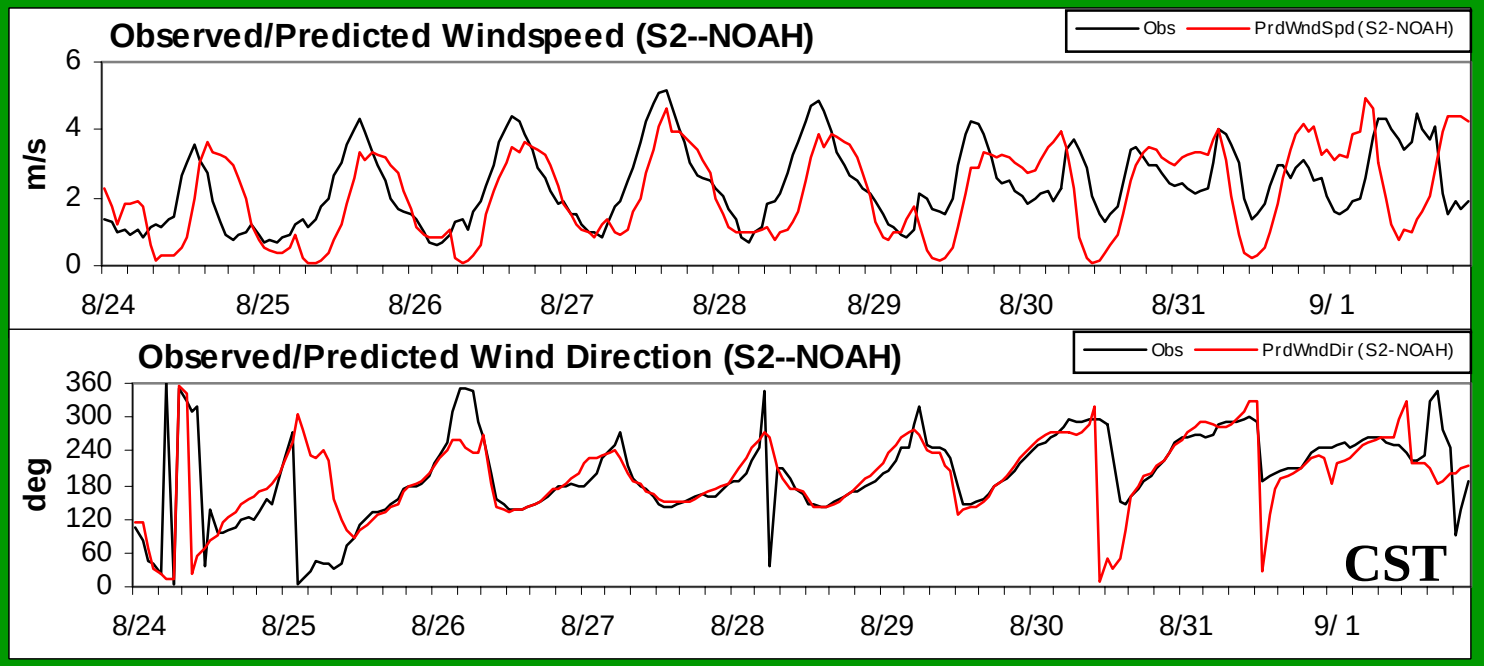


Scattered diagram of 2-m temperature with MM5/NOAH simulations.

10m WS,WD from metstat program (Emery, 2001)

Averaged over the CAMS sites





Summary of problems with the MM5/NOAH simulation with default parameters.

1. **Simulated daytime temperature too high, and nighttime temperature too low at urban sites.**
2. **The urban area was treated as if totally covered with impervious surfaces. Therefore, we have large diurnal variations in temp and very low latent/sensible heat flux ratio.**
3. **At rural sites, we have no daytime temperature bias, but serious nighttime temperature bias.**
4. **Serious delays in the development of diurnal wind speed build up – related to #3.**

Vegetation Parameters in LSM

Vegetation Parameters

USGS

Parameters that determine evapotranspiration

27,1,	'ALBEDO	Z0	SHDFAC	NROOT	RS	RGL	HS	SNUP	LAI	MAXALB'	
1,	.15,	1.00,	.10,	1,	200.,	999.,	999.0,	0.04,	4.0,	40.,	'Urban'
2,	.19,	.07,	.80,	3,	40.,	100.,	36.25,	0.04,	4.0,	64.,	Dryland Cropland
3,	.15,	.07,	.80,	3,	40.,	100.,	36.25,	0.04,	4.0,	64.,	'Irrigated Cropland
4,	.17,	.07,	.80,	3,	40.,	100.,	36.25,	0.04,	4.0,	64.,	Dryland/Irrigated'
5,	.19,	.07,	.80,	3,	40.,	100.,	36.25,	0.04,	4.0,	64.,	'Cropland/Grassland
6,	.19,	.15,	.80,	3,	70.,	65.,	44.14,	0.04,	4.0,	60.,	'Cropland/Woodland'
7,	.19,	.08,	.80,	3,	40.,	100.,	36.35,	0.04,	4.0,	64.,	'Grassland'
8,	.25,	.03,	.70,	3,	300.,	100.,	42.00,	0.03,	4.0,	69.,	'Shrubland'
9,	.23,	.05,	.70,	3,	170.,	100.,	39.18,	0.035,	4.0,	67.,	'Shrubland/Grass'
10,	.20,	.86,	.50,	3,	70.,	65.,	54.53,	0.04,	4.0,	45.,	'Savanna'
11,	.12,	.80,	.80,	4,	100.,	30.,	54.53,	0.08,	4.0,	58.,	'Broadleaf Forest'
12,	.11,	.85,	.70,	4,	150.,	30.,	47.35,	0.08,	4.0,	54.,	'Needleleaf Forest'
13,	.11,	2.65,	.95,	4,	150.,	30.,	41.69,	0.08,	4.0,	32.,	'Broadleaf Forest'
14,	.10,	1.09,	.70,	4,	125.,	30.,	47.35,	0.08,	4.0,	52.,	'Needleleaf Forest'
15,	.12,	.80,	.80,	4,	125.,	30.,	51.93,	0.08,	4.0,	53.,	'Mixed Forest'
:	:	:	:	:	:	:	:	:	:	:	:
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Addition of Canopy Moisture

$$\frac{\partial W_c}{\partial t} = \sigma_f P - D - E_c + E_u$$

W_c is intercepted canopy water content

σ_f is green vegetation fraction

P is input total precipitation

E_c canopy evaporation

If W_c exceeds S (maximum canopy capacity: 0.5 mm), the excess precipitation or drip, D reaches the ground.

E_u is the anthropogenic contribution to the canopy water content. A reasonable value 3×10^{-6} (meter of available water per second) was picked for the simulation (* need to be justified).

MM5 sensitivity test continued to correct minimum temperature problem

a. Add canopy water into urban area

b. Test emissivity value for different LU categories

(original emissivity in NOAH =1.0)

$$L\uparrow = a_{surface}\ \sigma\ T^4$$

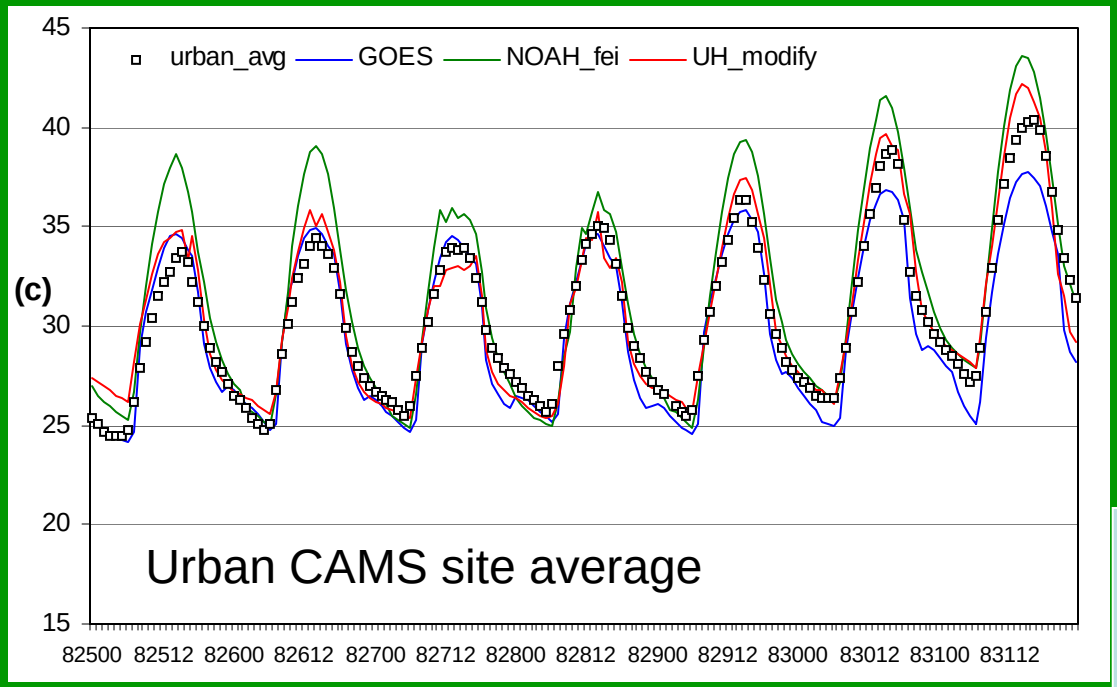
a : *emissivity of the surface*

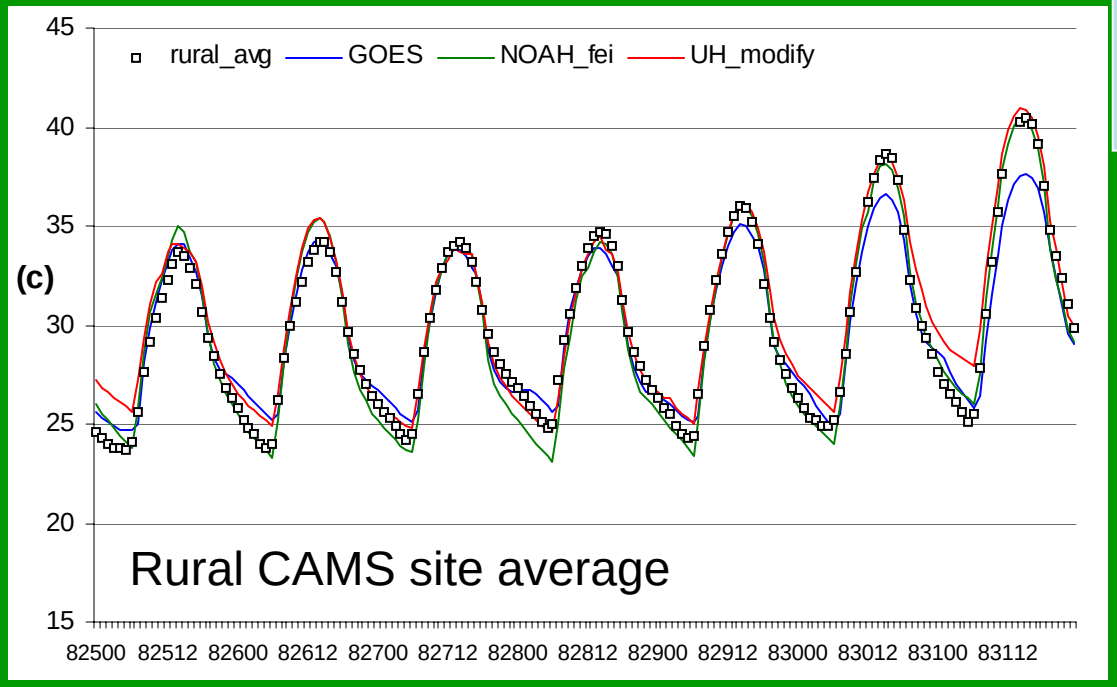
σ : *Stefan – Boltzmann constant*

T : *average daily air temperature*

Name	Category	Emissivity
Urban	1	0.90
Dryland	2	0.98
Cropland	5	0.95
Grassland	7	0.95
Evergreen forest	14	0.95

2-m temperature





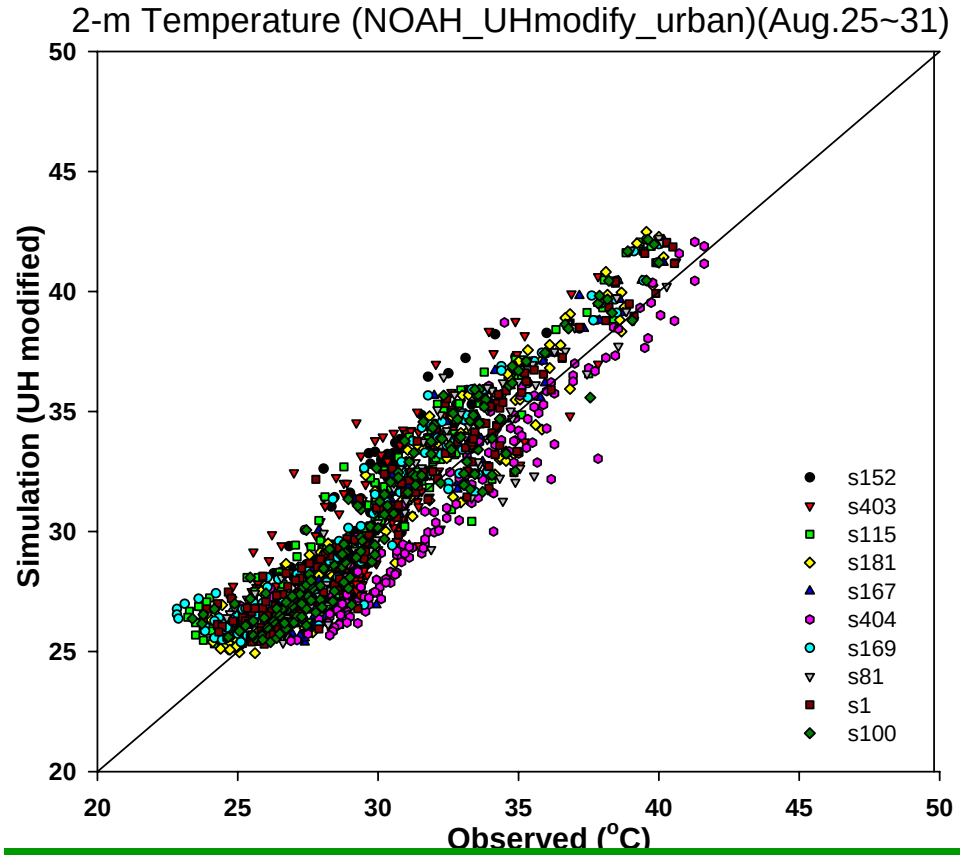
UH_modify

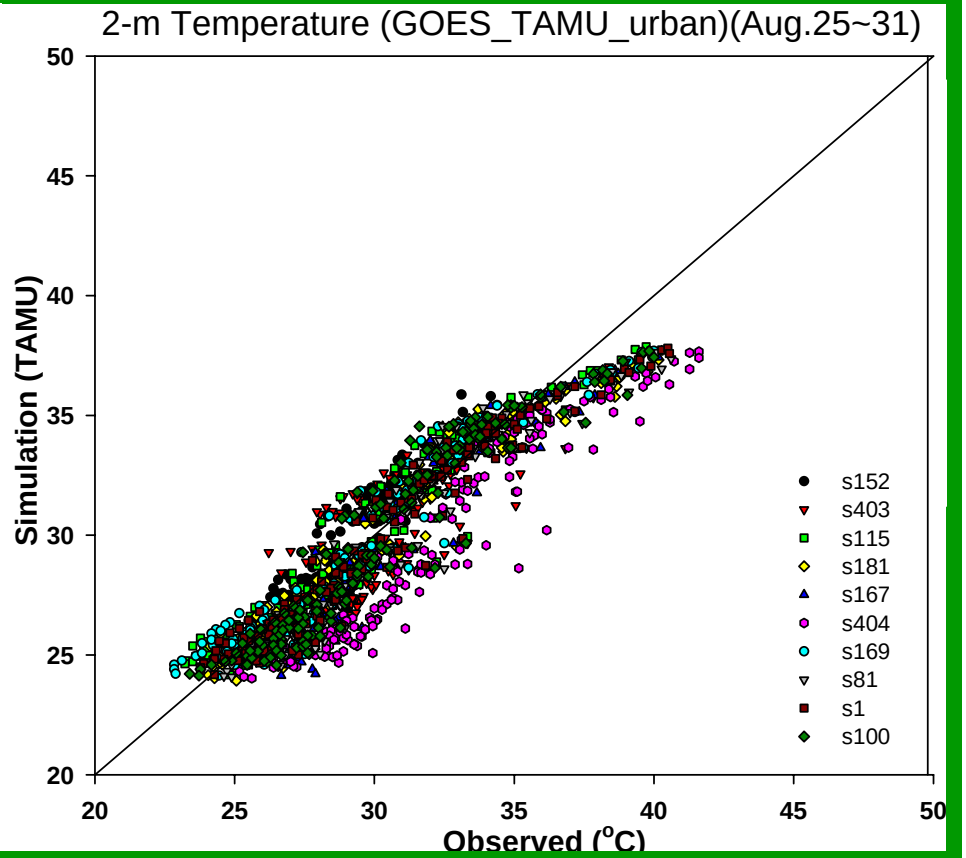
+ modify thermal conductivity in urba
+ adding canopy moisture into urban
+ modify emissivity in urban
+ modify emissivity in rural

Scattered diagram of 2-m temperature the urban sites

UH_modify

+ modify thermal conductivity in urban
+ adding canopy moisture into urban
+ modify emissivity in urban
+ modify emissivity in rural

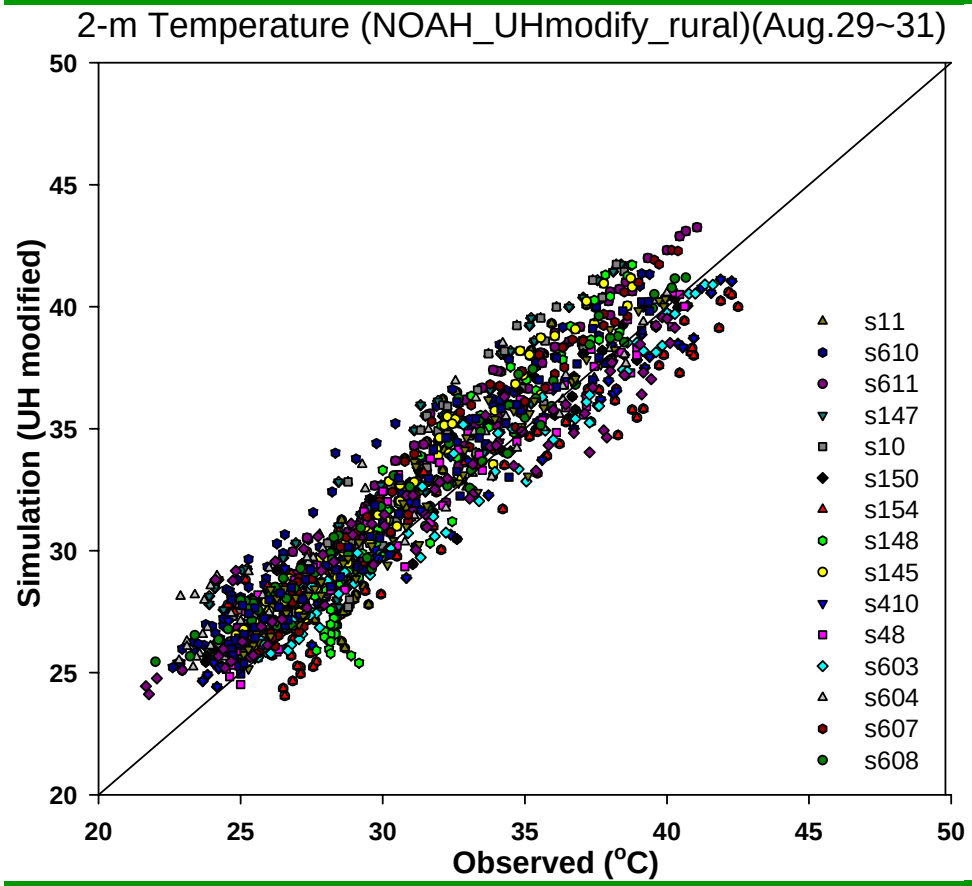


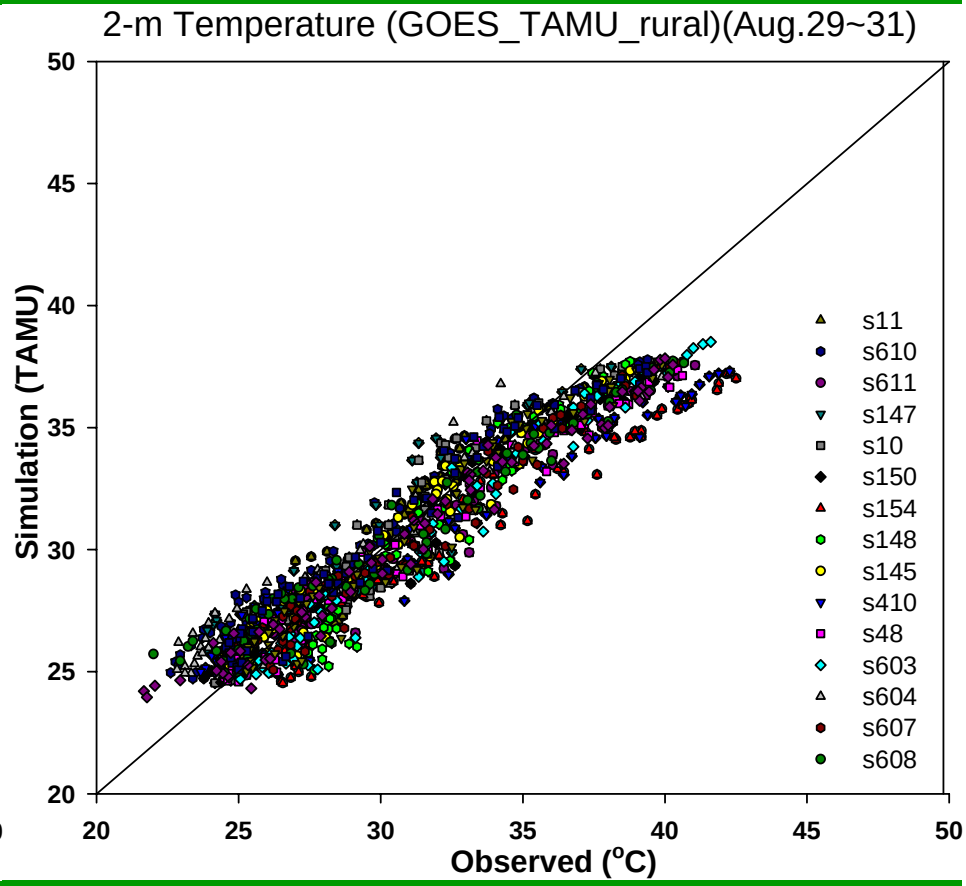


Scattered diagram of 2-m temperature the rural sites

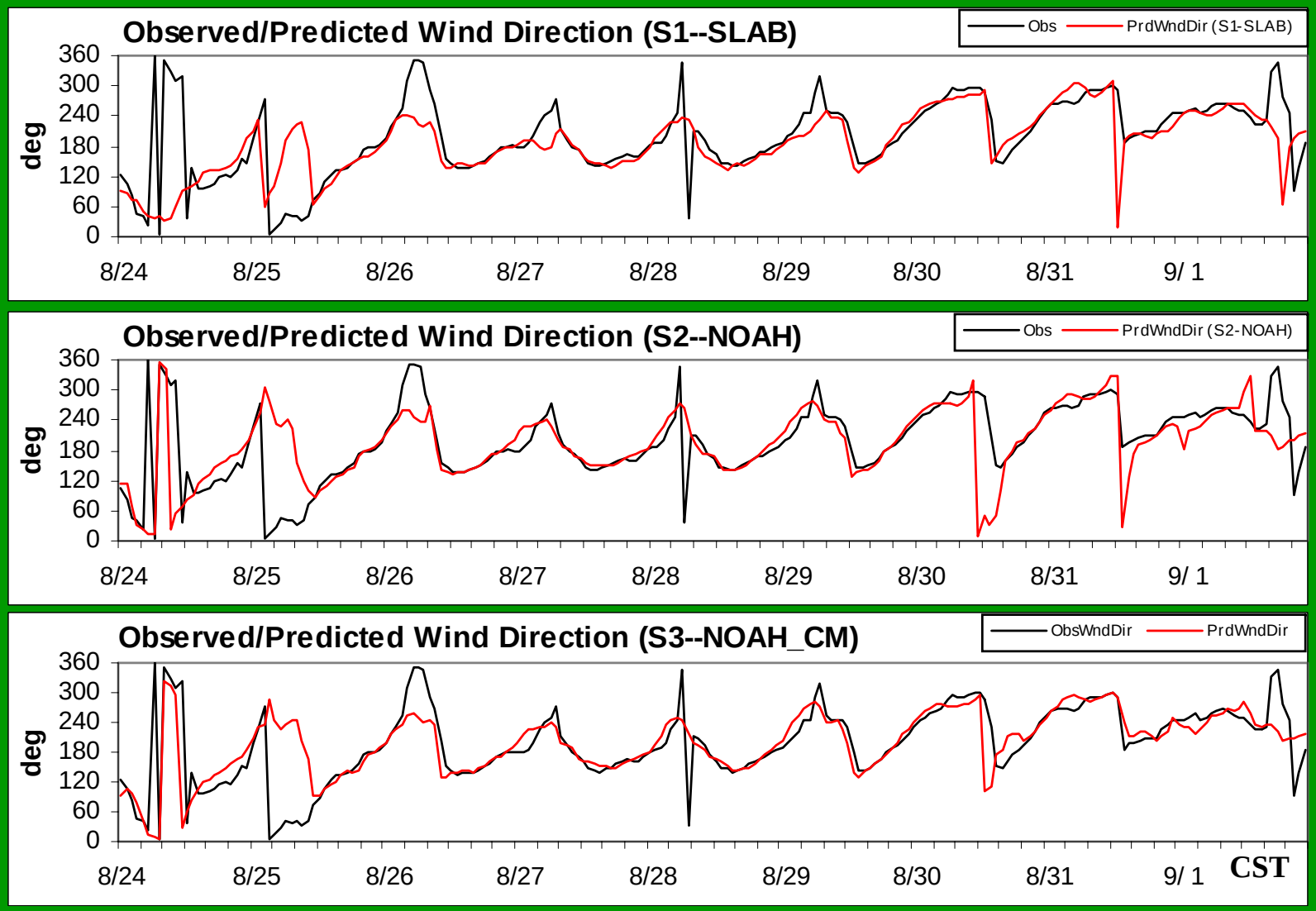
UH_modify

+ modify thermal conductivity in urban
+ adding canopy moisture into urban
+ modify emissivity in urban
+ modify emissivity in rural

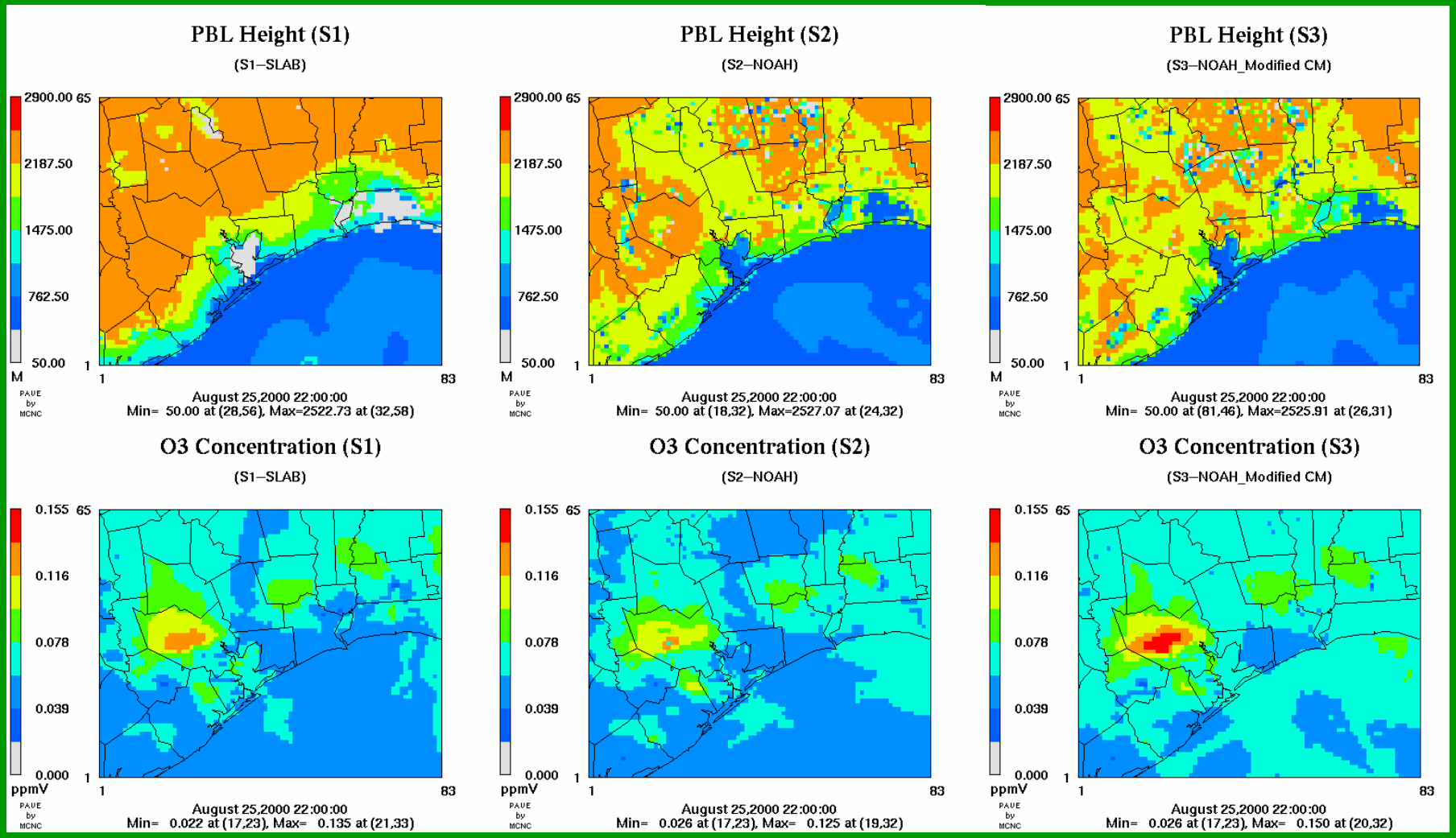




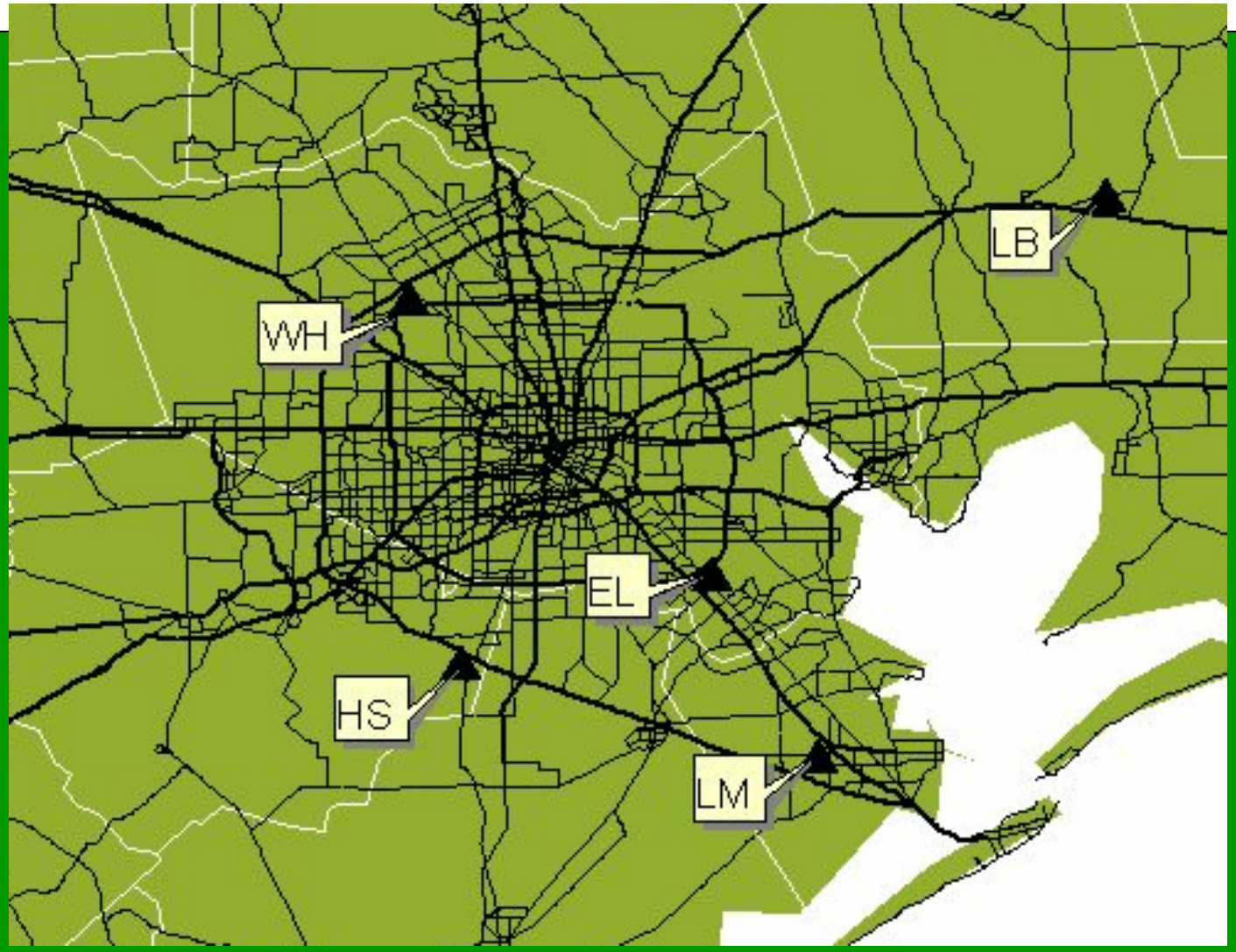
10m Wind Direction from S1, S2 and S3 simulations:

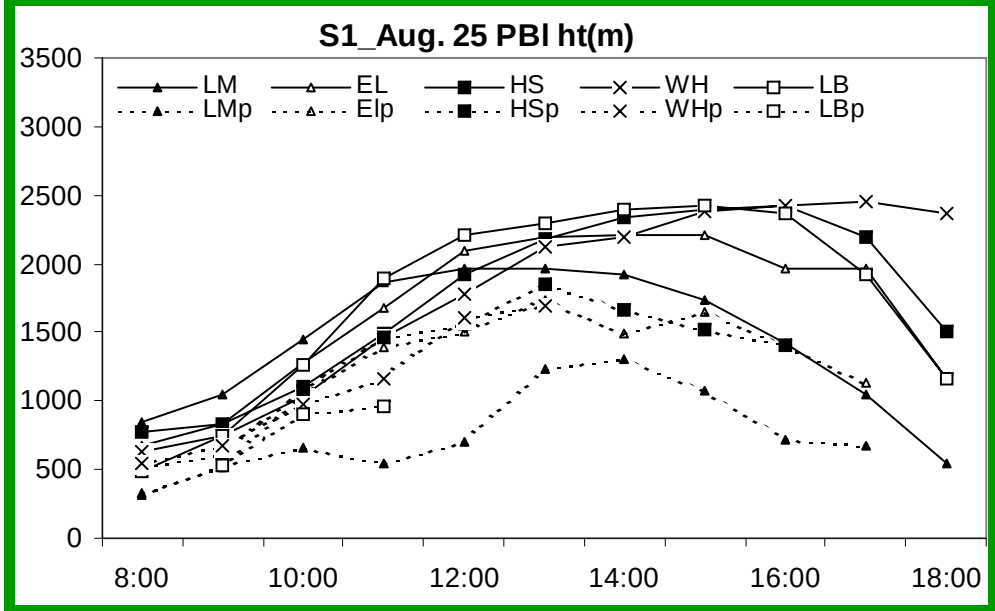


PBL heights & O_3 on Aug. 25

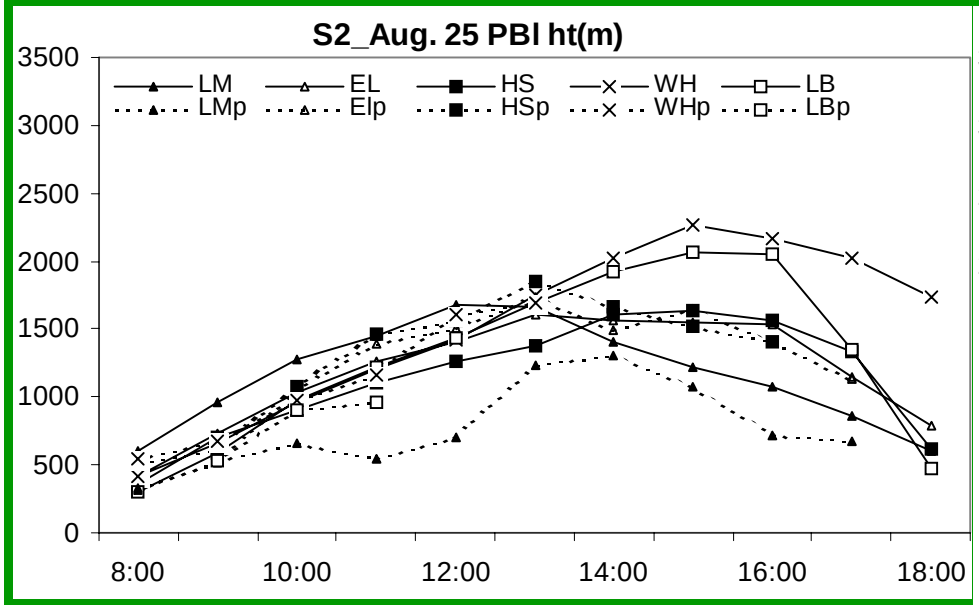


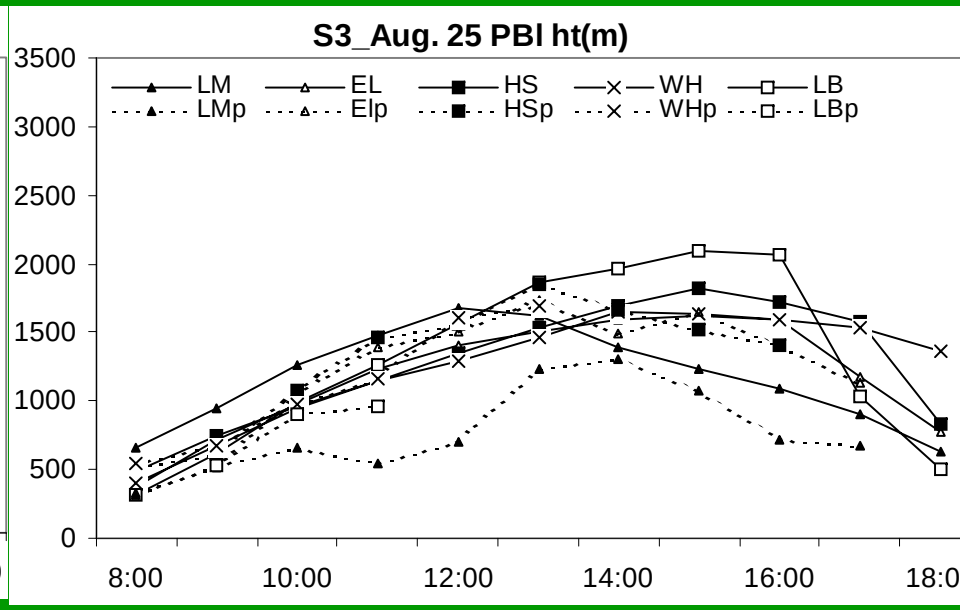
Wind Profiler Sites (TexAQS-2000)





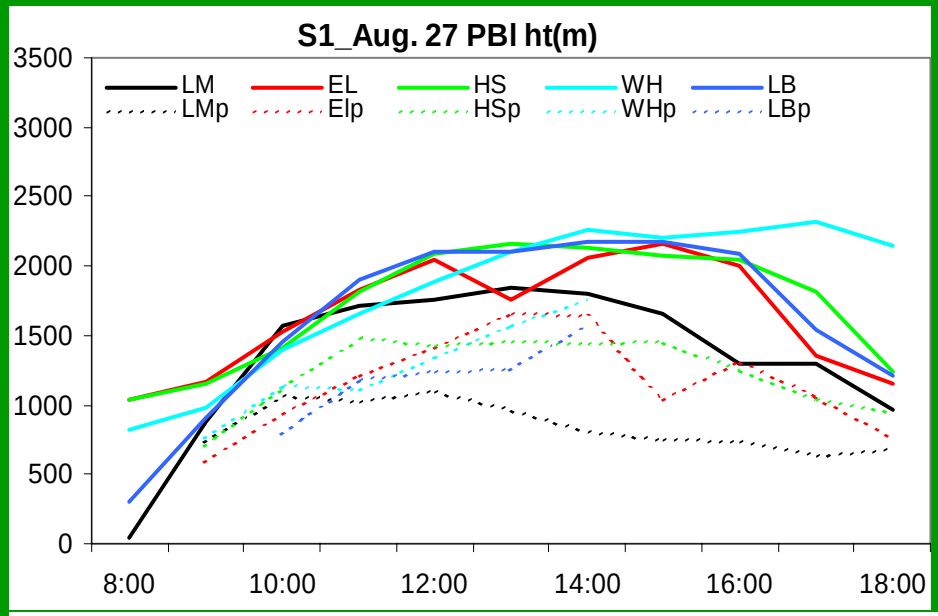
PBL Height Analysis from S1, S2 and S3 simulations on Aug. 25 Profiler PBL ht. from NOAA/FSL

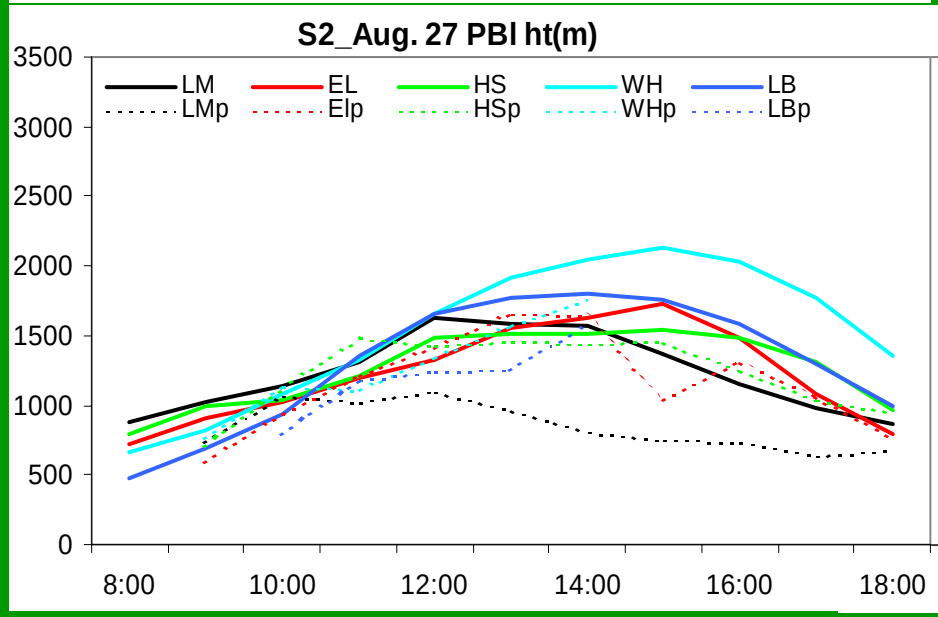


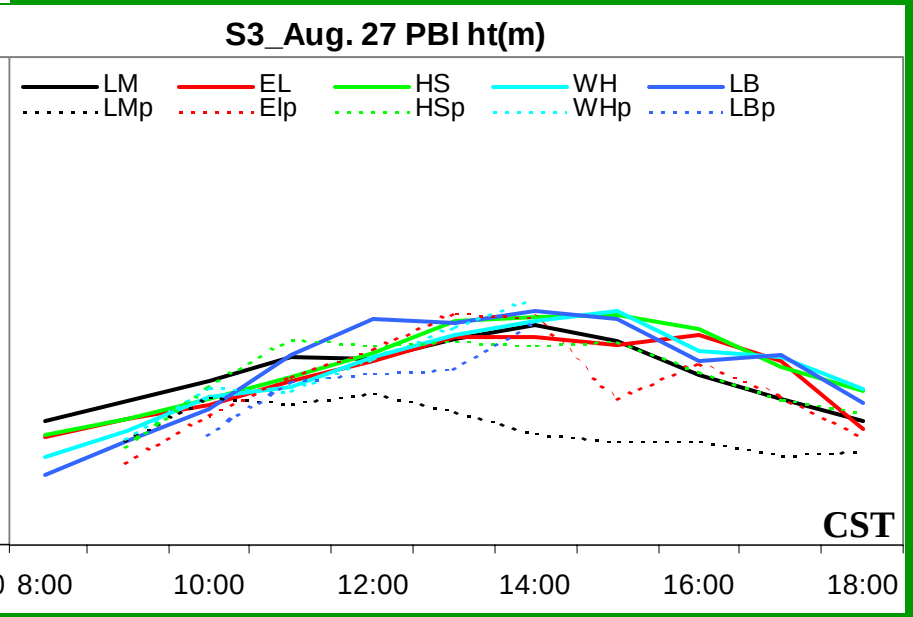


CST

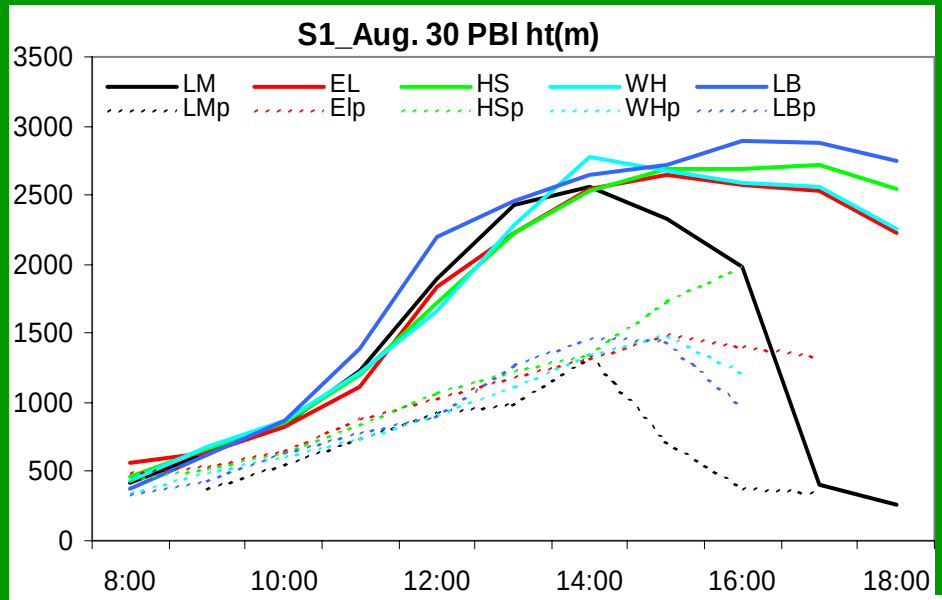
PBL Height Analysis from S1, S2 and S3 simulations on Aug. 27

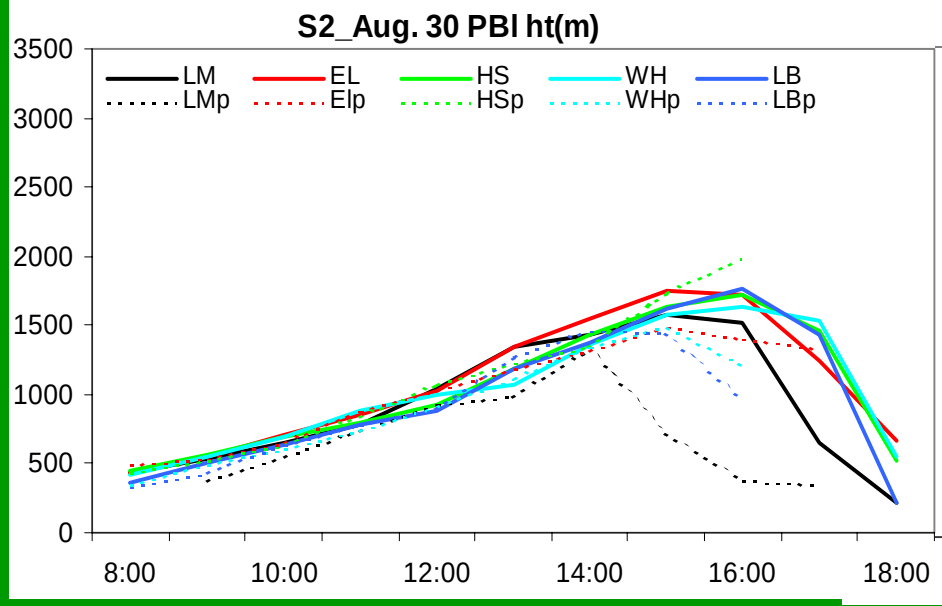


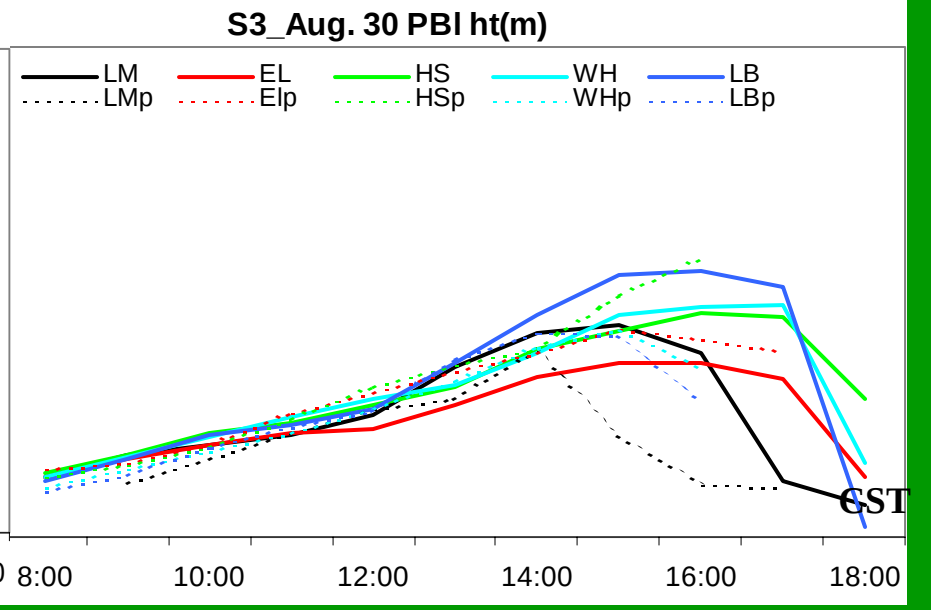




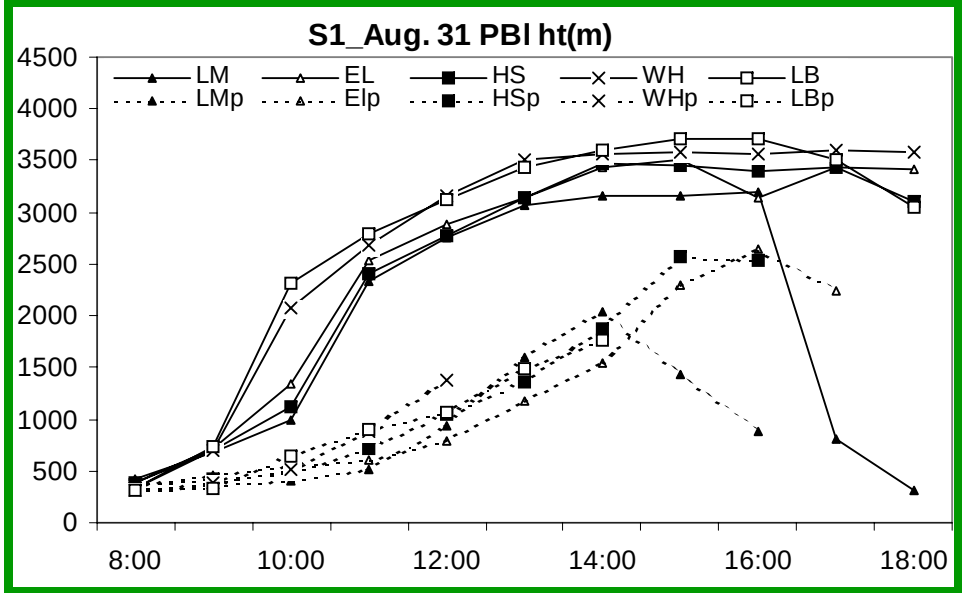
PBL Height Analysis from S1, S2 and S3 simulations on Aug. 30

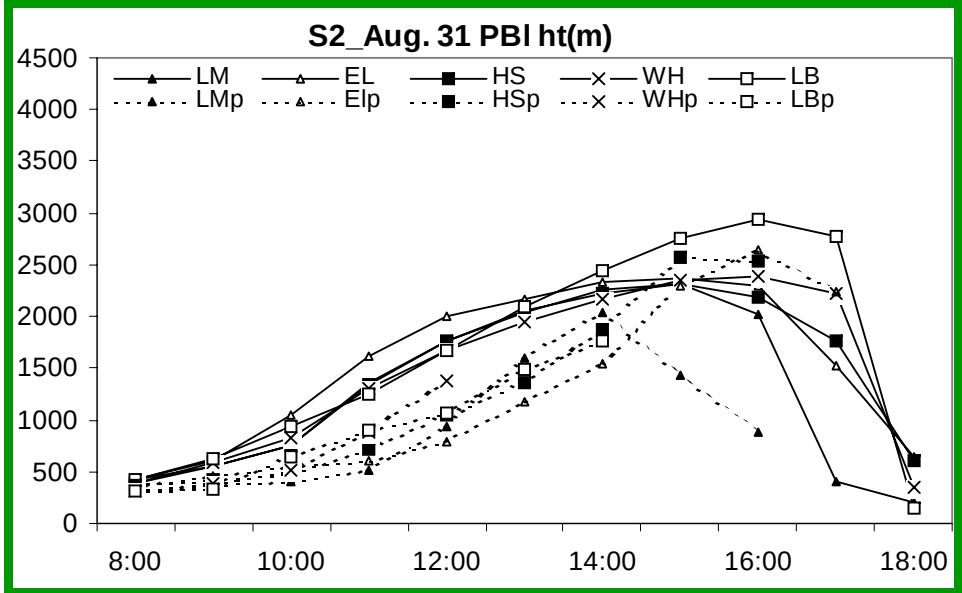


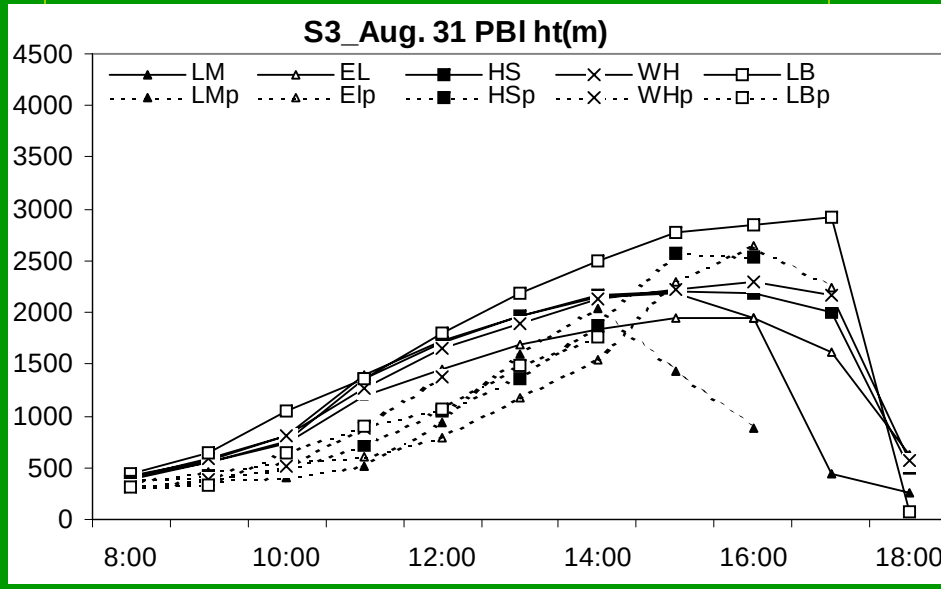




PBL Height Analysis from S1, S2 and S3 simulations on Aug. 31







CST

Summary of Phase 1 MM5/NOAH simulation with

1. Urban area was treated as if it were totally covered with impervious surface. Therefore, we have large diurnal variations in temp and very low latent/sensible heat flux ratio in urban areas.
2. Bias in daytime temperature fixed with added canopy water.
3. The nighttime min. temperature bias was minimized by introducing LU/LC dependent emissivity
4. Still there are serious delays in the development of daytime wind speed build up.

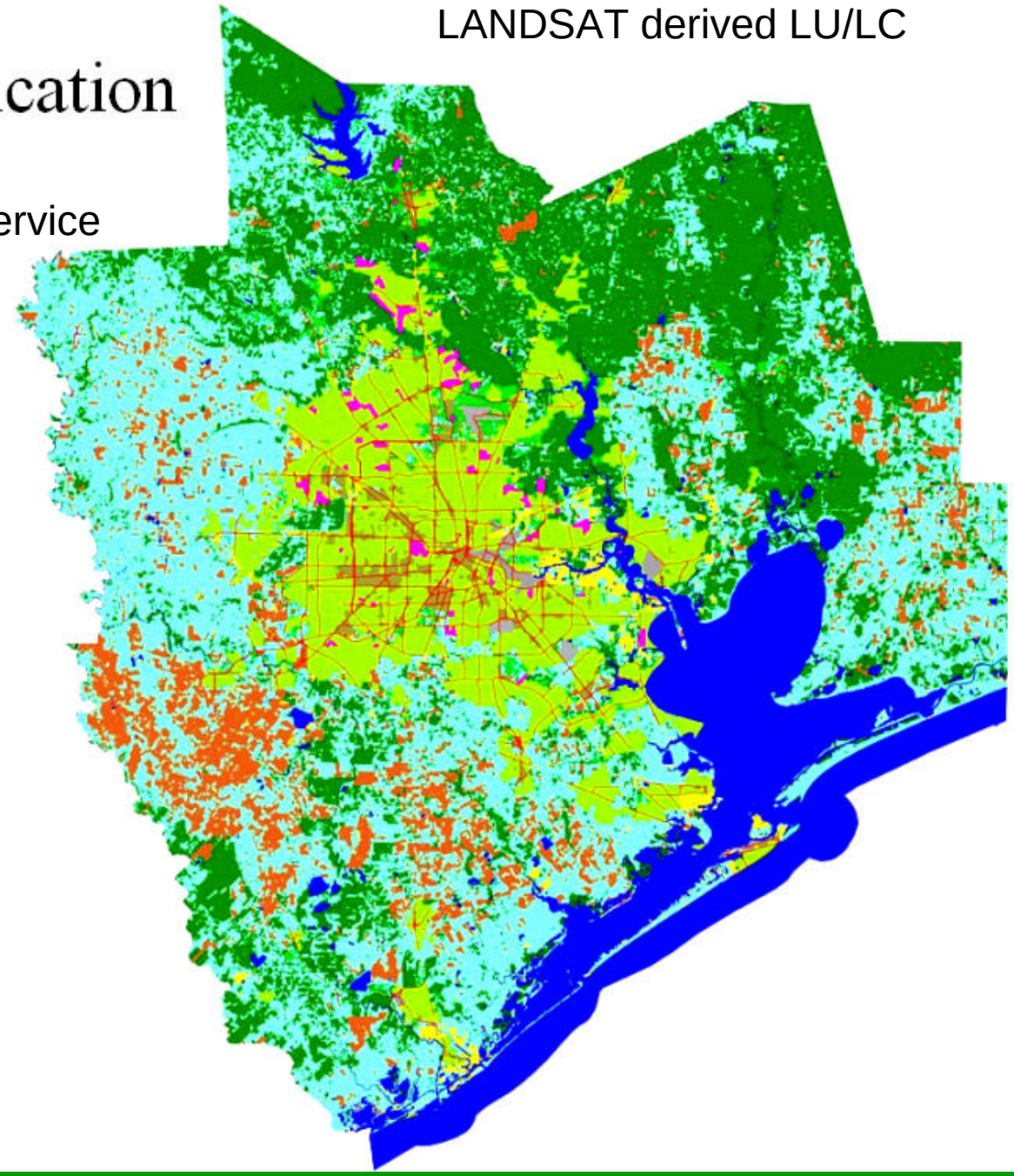
Phase 2: MM5 simulations with LANDSAT derived high-resolution LU/LC

- **Continue to test MM5/NOAH with new LANDSAT derived land use and land cover data**
- **Estimate biogenic emissions with LC and meteorology data**
- **Study effects on air quality**

Land Use Classification

Stephen Stetson, GEM
Pete Smith, Texas Forest Service

LANDSAT derived LU/LC

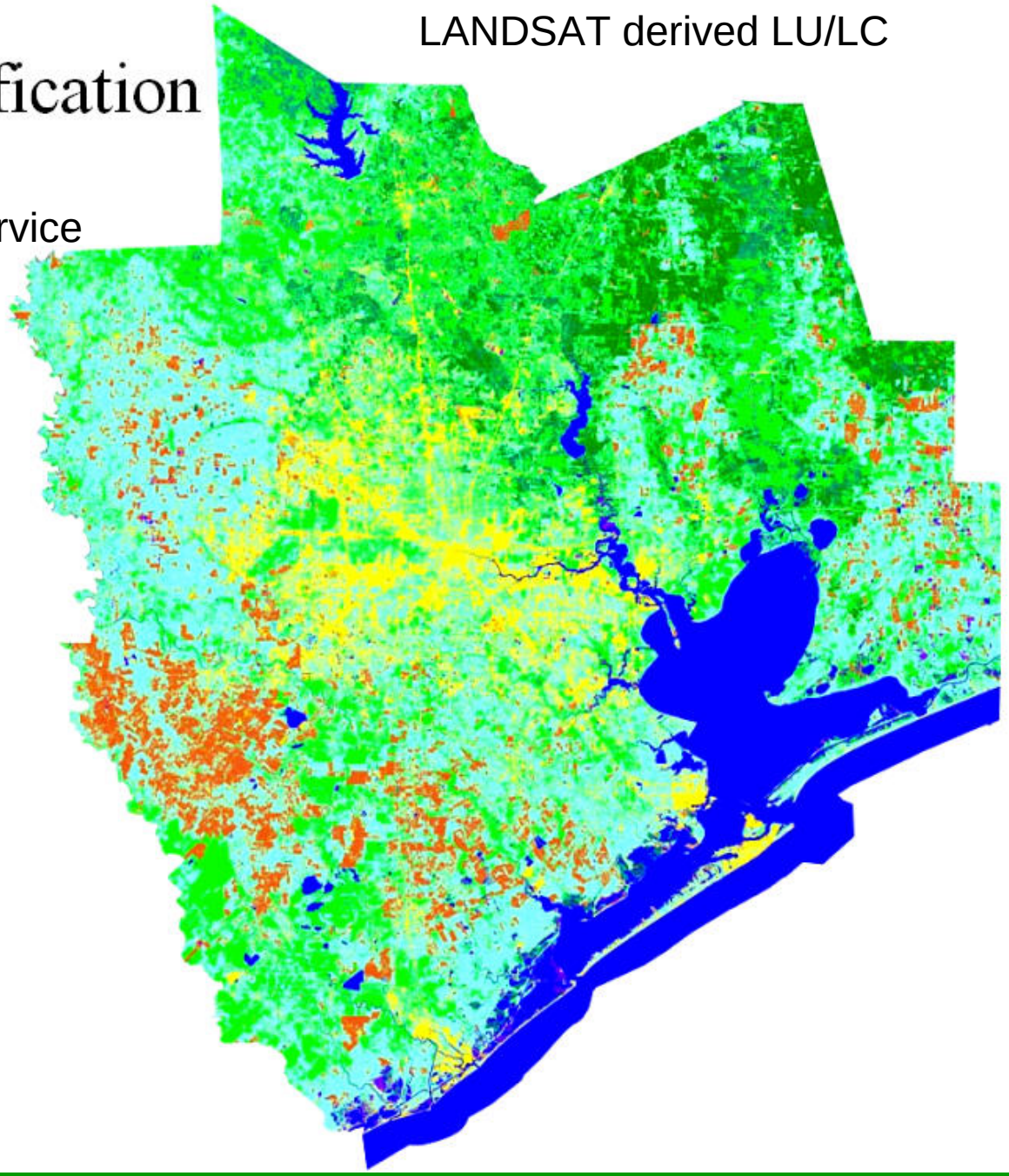


- Forest
- Range
- Agriculture
- Residential
- Commercial
- Industrial
- Parks
- Transportation Corridors
- Urban Forest
- Urban Grass
- Urban Barren
- Urban Impervious
- Rural Impervious
- Urban Airports
- Water

Land Cover Classification

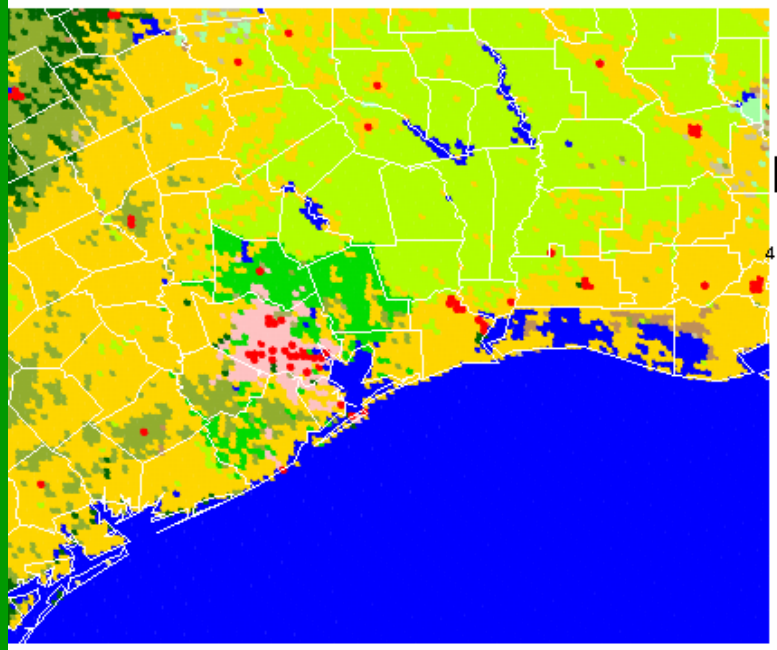
LANDSAT derived LU/LC

Stephen Stetson, GEM
Pete Smith, Texas Forest Service



- Forest Broadleaf
- Forest Coniferous
- Forest Mixed
- Grass
- Barren
- Beach
- Impervious
- Roads
- Wetland
- Water

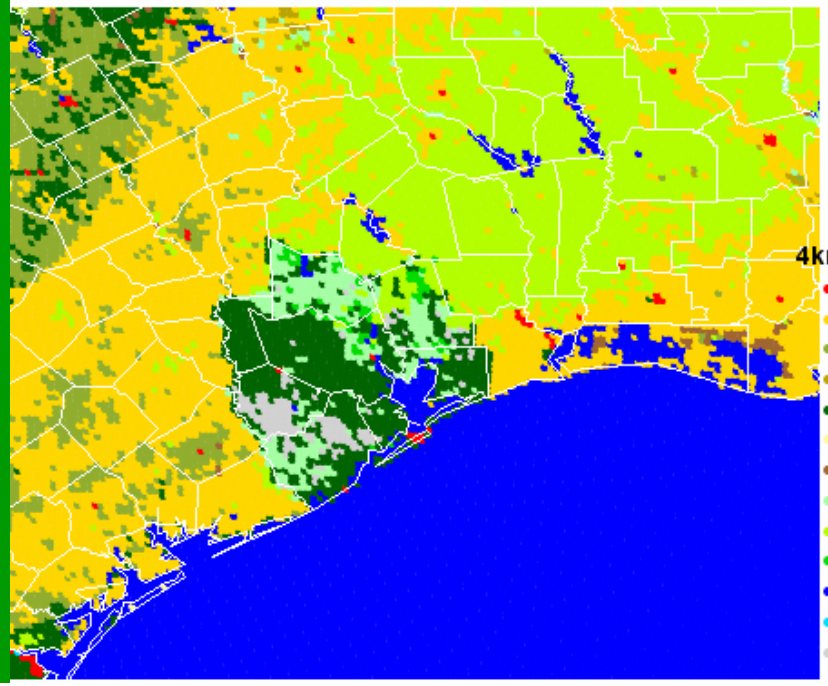
IMAQS
University of Houston



LANDSAT Land Use Data

4km land use type
- 1_urban
- 2_dryland/cropland
- 3_irrigated cropland and pasture
- 5_cropland/grassland
- 6_cropland/woodland
- 7_grassland
- 8_shrubland
- 9_sshrubland/grassland
- 10_savanna
- 11_deciduous broadleaf forest
- 14_evergreen needleleaf forest
- 15_mixed forest
- 16_water
- 18_wooded wetland
- 22_residential

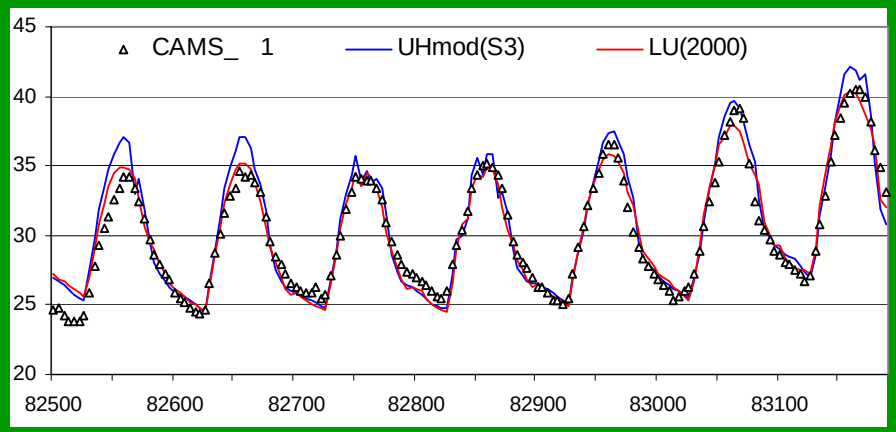
Digitized for MM5 4-km domain

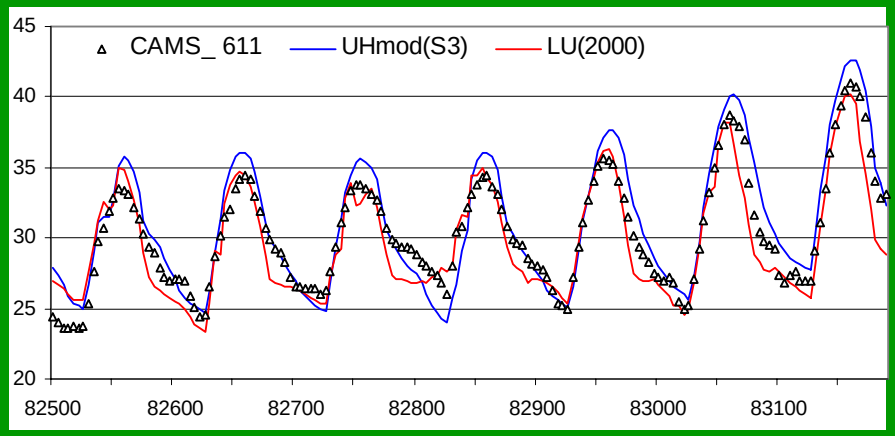


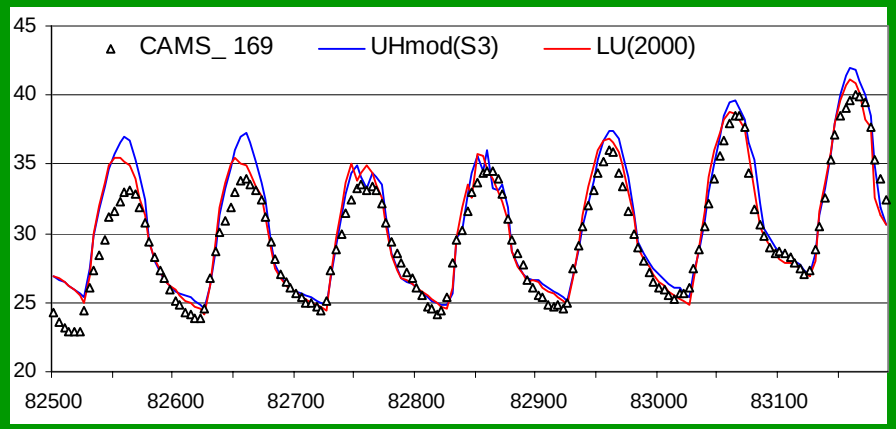
LANDSAT Land Cover

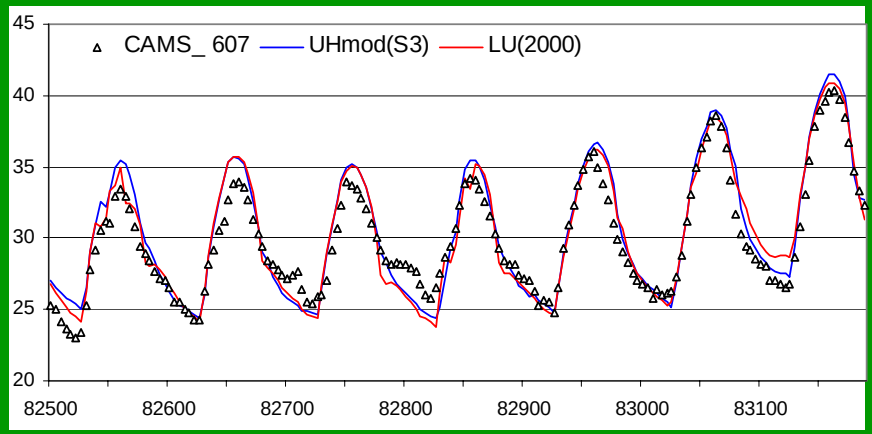
4km land cover type
- 1_urban
- 2_dryland/cropland
- 5_cropland/grassland
- 6_cropland/woodland
- 7_grassland
- 8_shrubland
- 10_savanna
- 11_deciduous broadleaf forest
- 14_evergreen needleaf forest
- 15_mixed forest
- 16_water
- 18_wooded wetland
- 19_bare soil

Modified LU/LC table in MM5 and re-simulated MM5
With high res. data

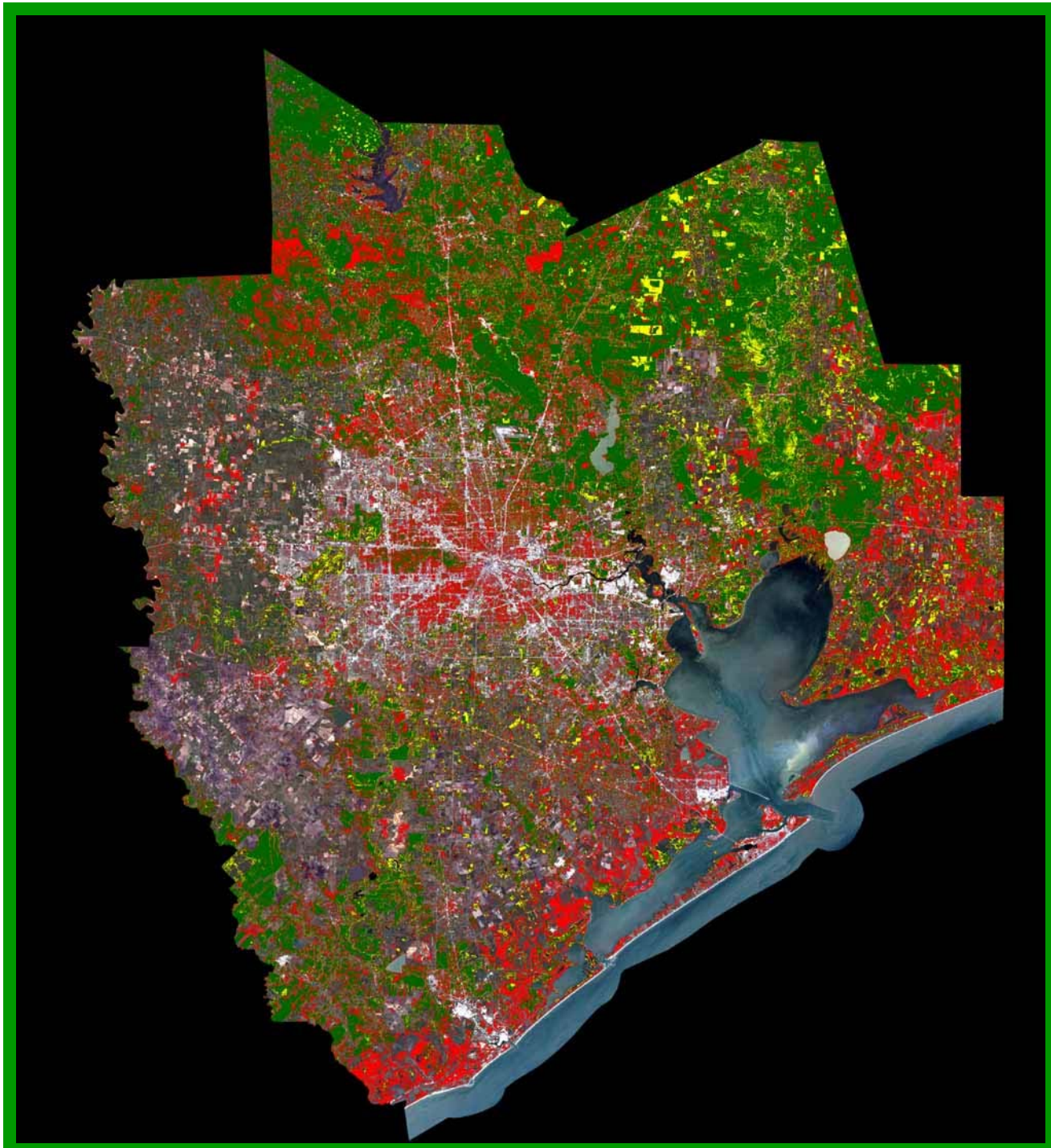








Time Series of 2-m temperature at selected CAMS locations



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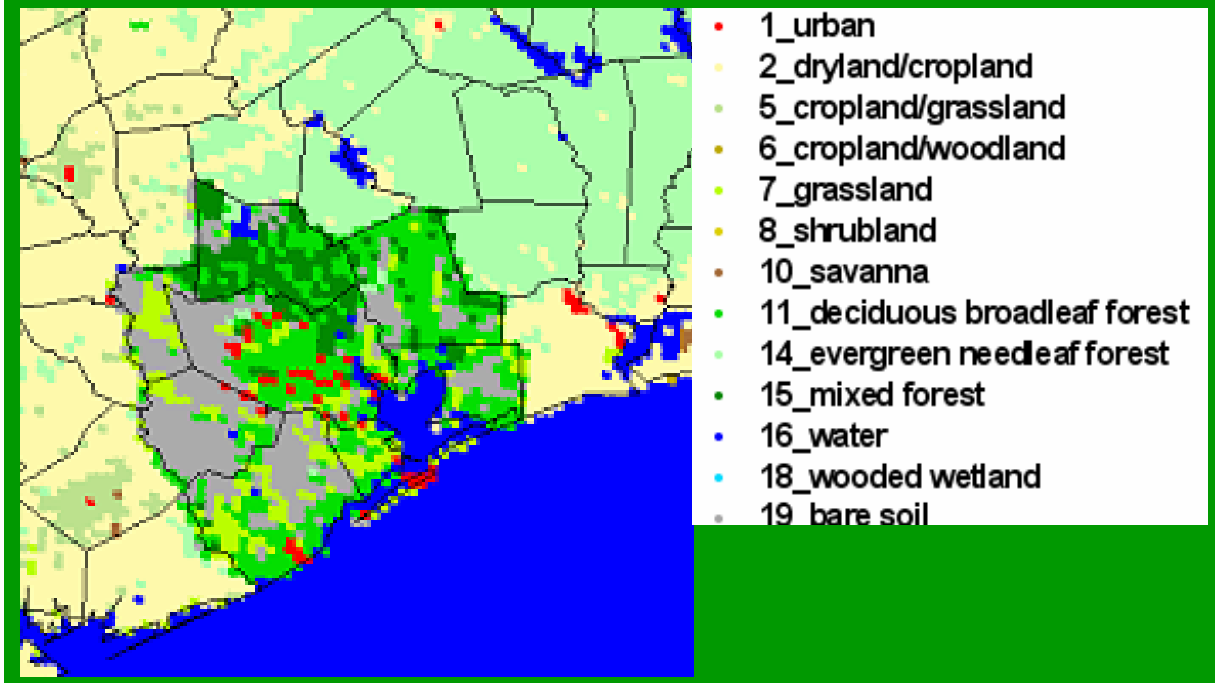
Land cover changes from 1990 overlaid on LADNSAT (Stephen Stetson)

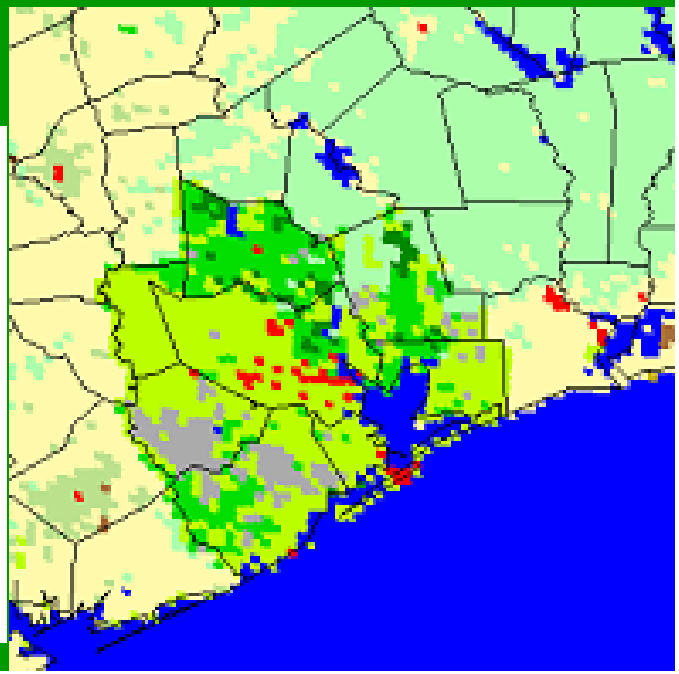
Study effects of land use change on air quality

Land Cover Modification: 1990 versus 2000



1990

2000



Comparison of MM5 simulated L1 temperature

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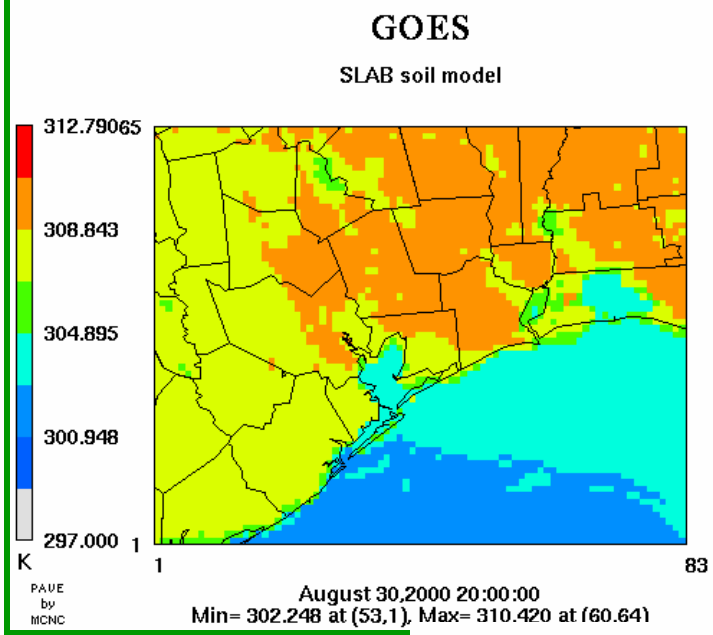

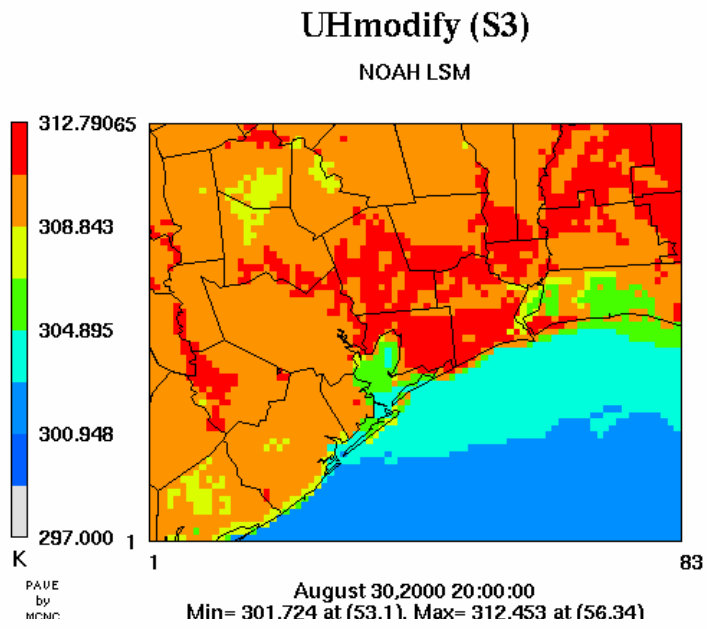

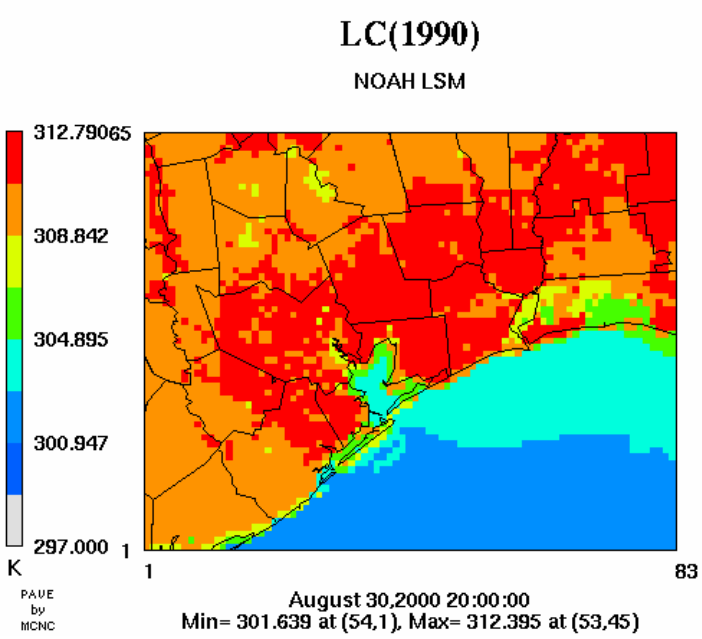

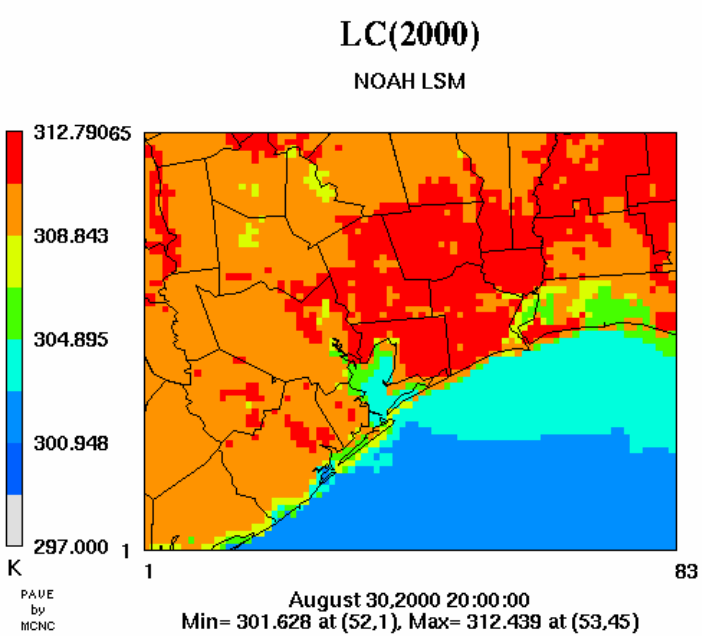

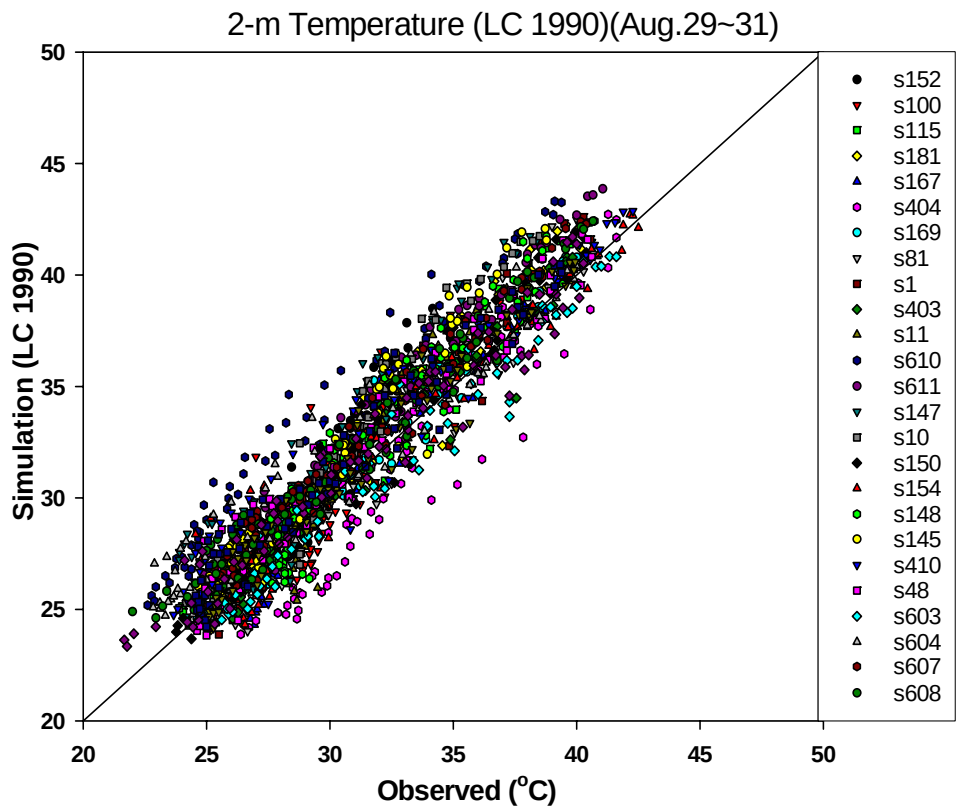

1990

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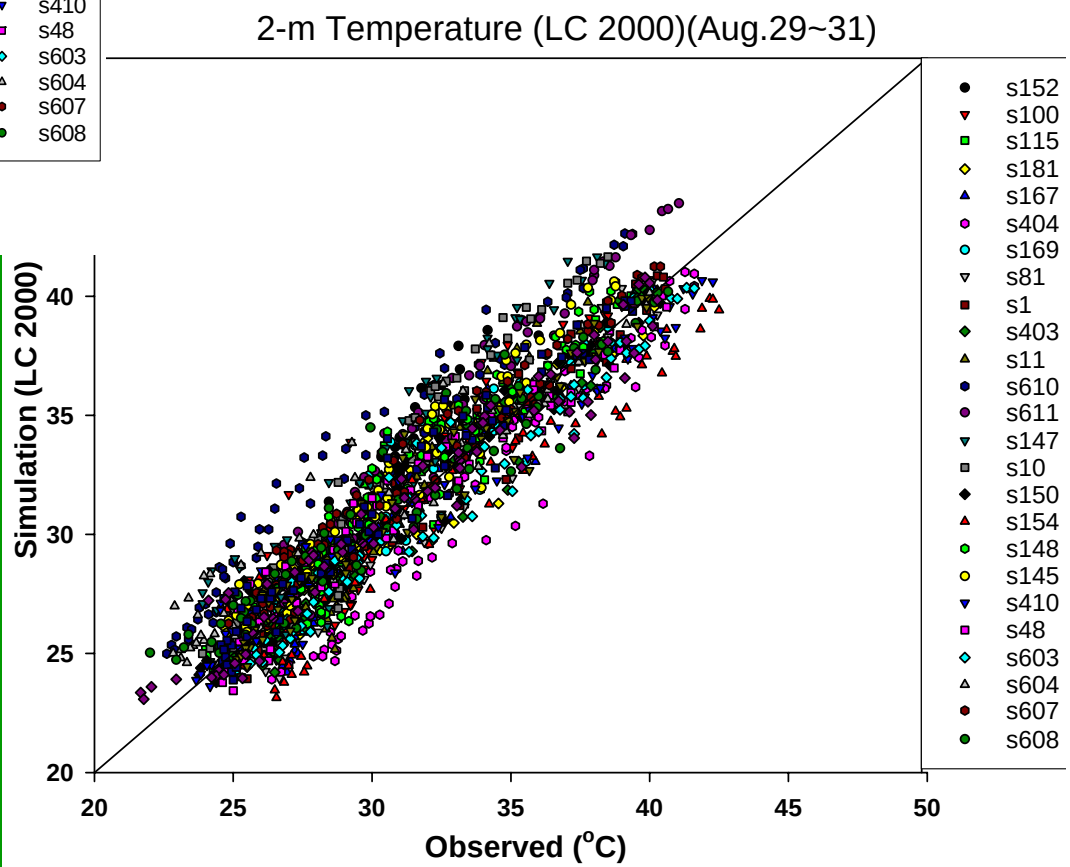
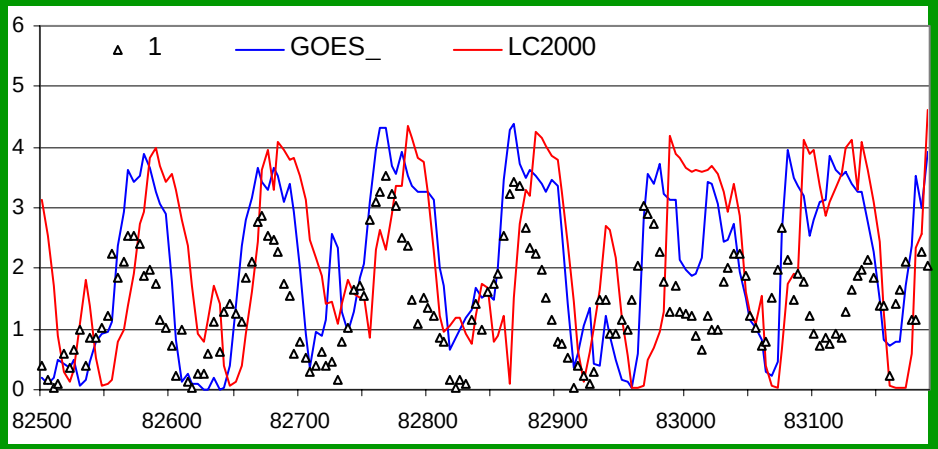
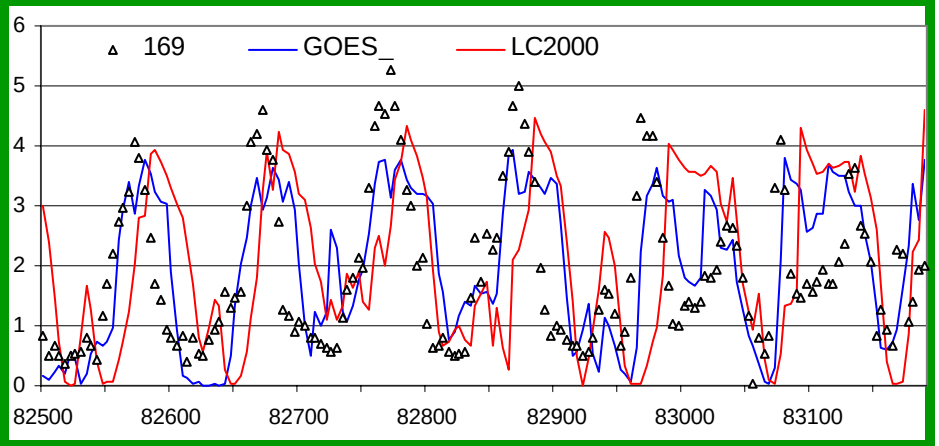
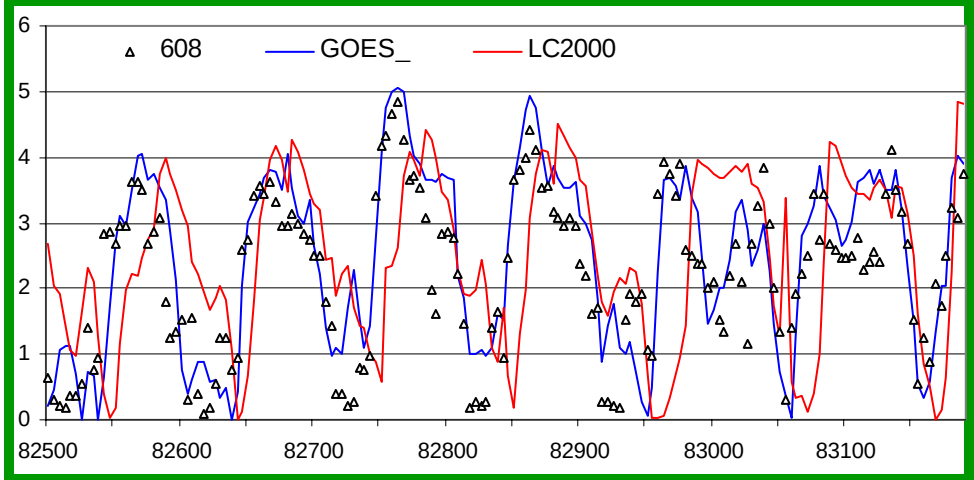
Simulated air temperature compared between 1990 and 2000 LU/LC data

2000









Still some problems with wind simulations

Air Quality Simulation

Biogenic Emissions Estimates

Data:

1. Use the same PASR as base case
2. Use 2000 LU canopy temperature using MM5/NOAH
3. Use 1990 LU canopy temperature using MM5/NOAH
4. 2000 Leaf mass density data from Nowak

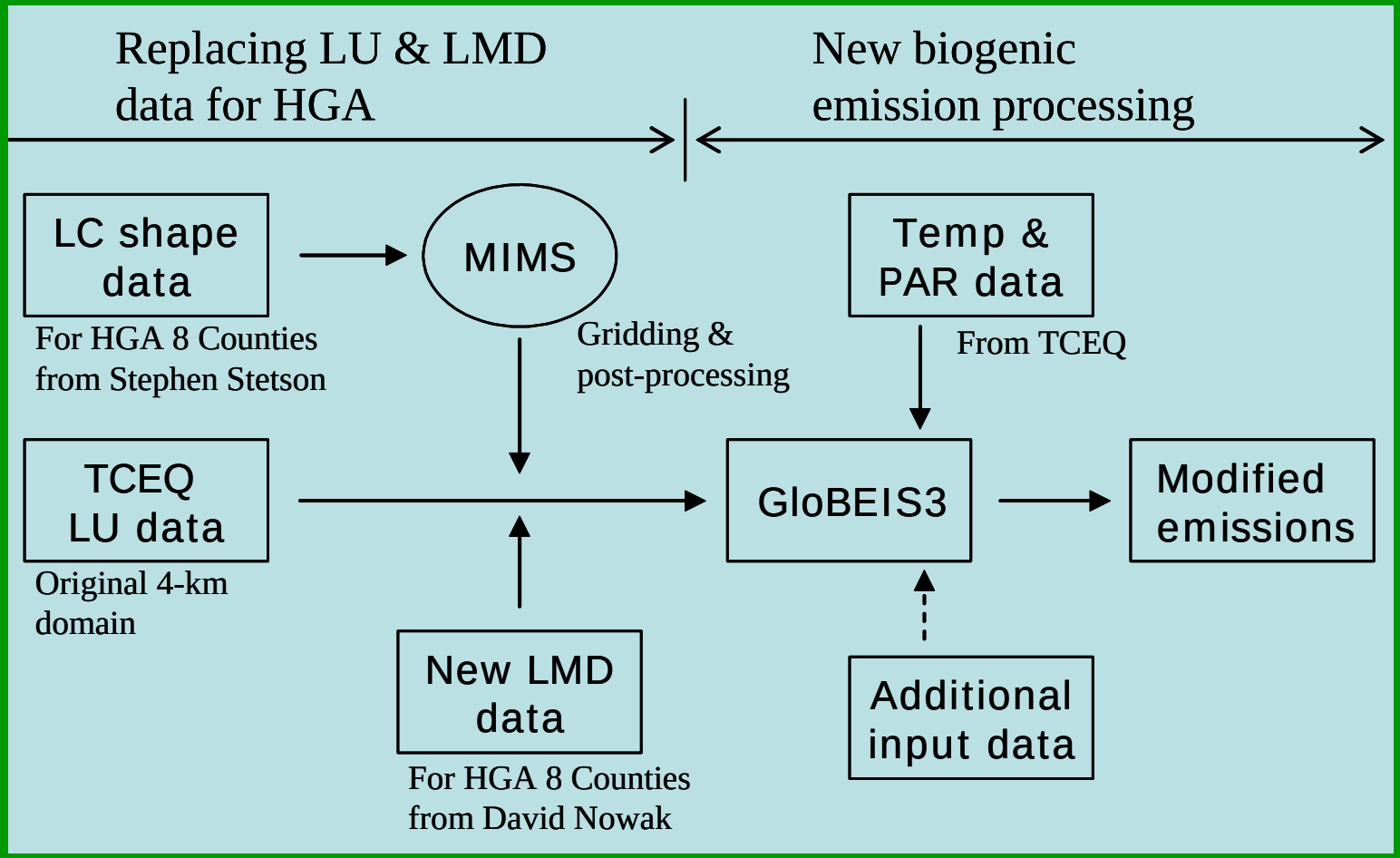
Table 2. LC classes and the mapping LC codes for GloBEIS3 processing

No.	Land Cover class [1)]	LC code [2)]	Description [3)]
1	Barren/Urban impervious	13590	Urban built
2	Forest Broadleaf	37590	Northern broadleaf
3	Forest Coniferous	37591	Northern coniferous
4	Forest Mixed	37592	Northern mixed
5	Grass	22590 22591	Northern agriculture/range - Chambers, Harris, Liberty, Montgomery and Waller Southern agriculture/range – Brazoria, Ft. Bend and Galveston
6	Impervious	13590	Urban built
7	Water	40000	Water

Note) [1)] LC classes are from Stephen Stetson's data. [2) & 3)] LC codes and descriptions area from David Nowak's table (refer to Appendix for the detailed LMD data).

Table 3. Biogenic NO emission factors and canopy type assigned

LU code	LU description	NO emission factors ($\mu g\ m^{-2}\ hr^{-1}$)	Canopy type
11590	urban residential	7.0	4
13590	urban built	4.5	4
16590	urban green	4.8	4
22590	Northern agriculture/range	100.0	4
22591	Southern agriculture/range	100.0	4
37590	Northern broadleaf	4.5	1
37591	Northern coniferous	4.5	3
37592	Northern mixed	4.5	2
37593	Southern forest	6.2	2



Modified estimation of GloBIES3 biogenic emissions utilizing new land use (LU), land cover (LC), and leaf mass density (LMD) data for the Houston-Galveston Airshed (HGA).

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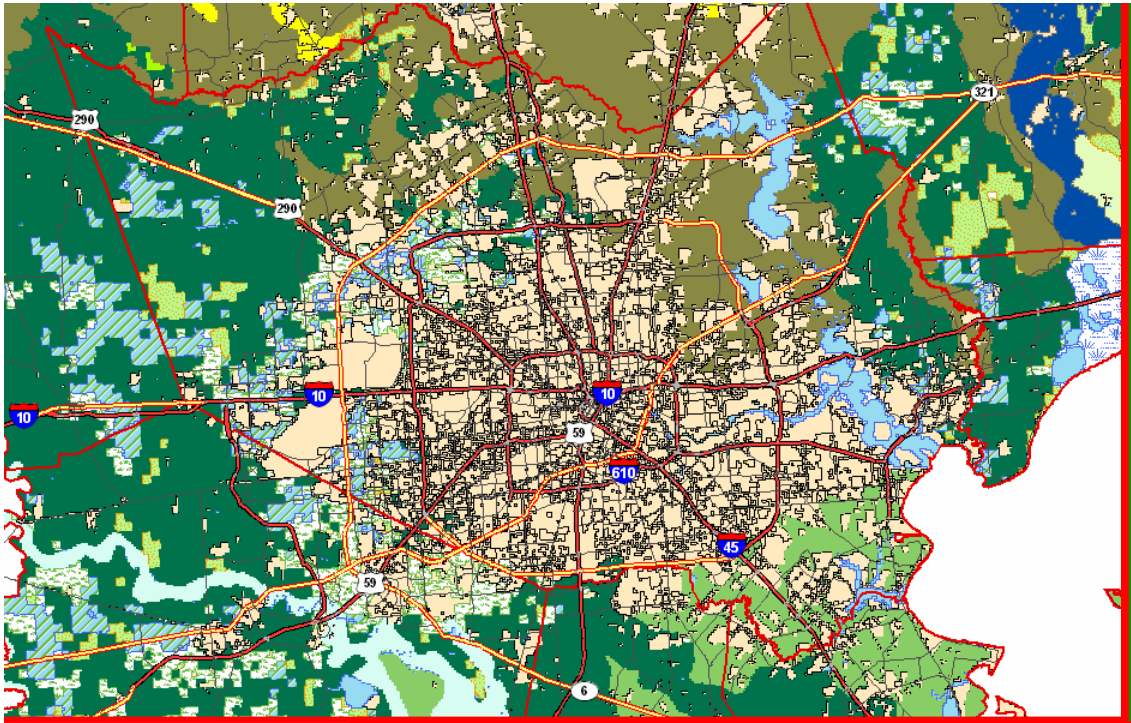
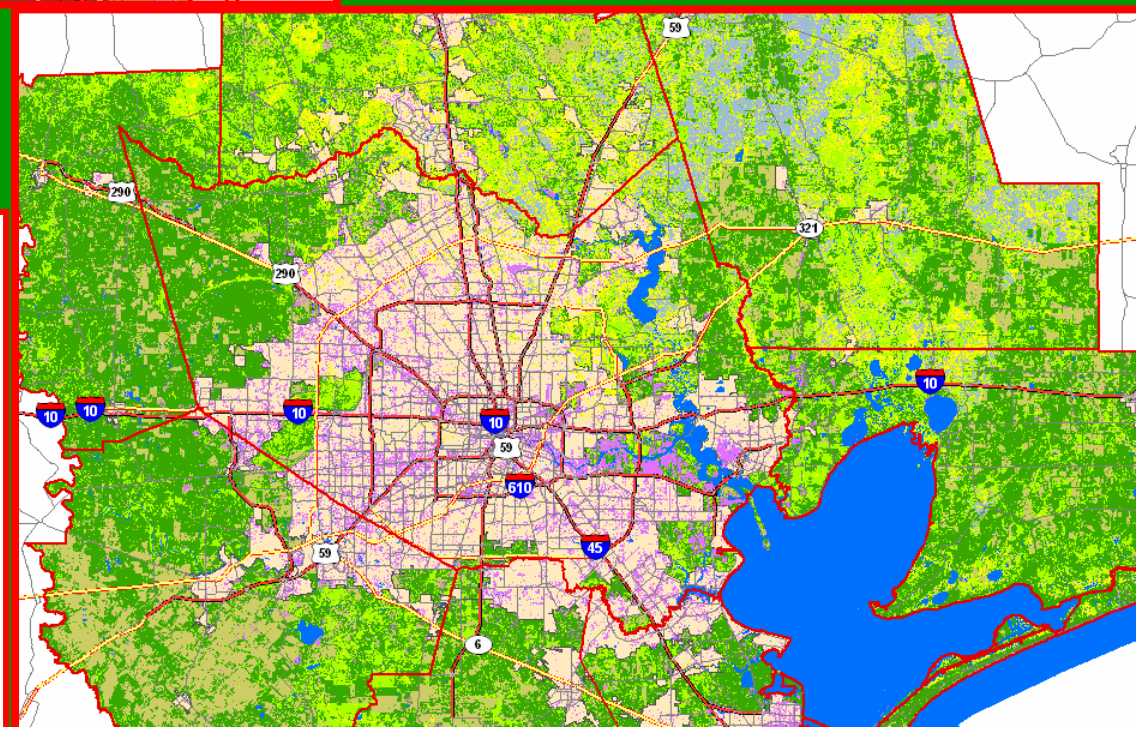


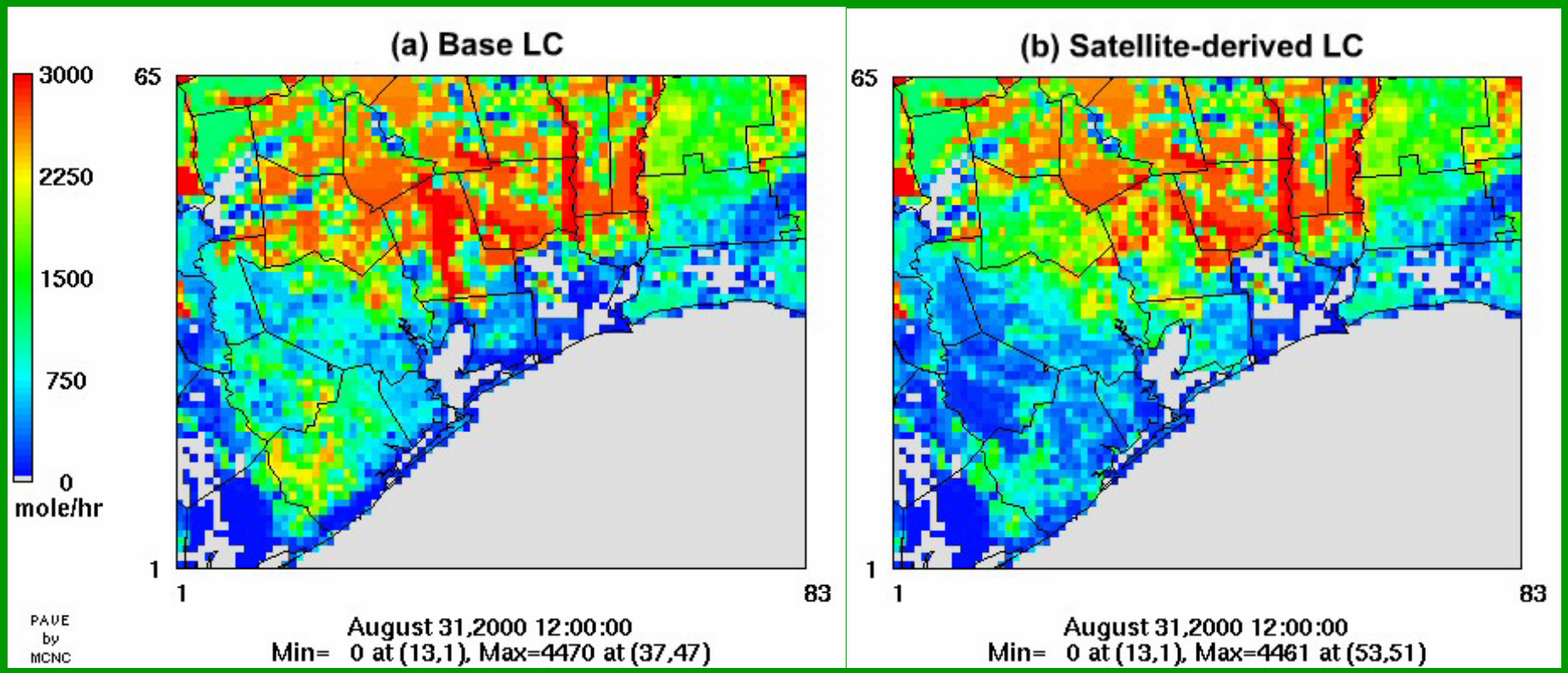
TCEQ Bio.
LU/LC

Crops w/ Grassland
Crops w/ Wetlands
Crops w/ Woodlands
Bald Cypress Water Tupelo Swa
Bluestem Grassland
LCC Woods
Evergreen Forest with Hardwoo
Grasslands and Young Forest
Marsh Barrier
Pecan Elm Forest
Pine, Hardwood Forest
Urban
Water
Willow Oak, Water Oak, Blackgu

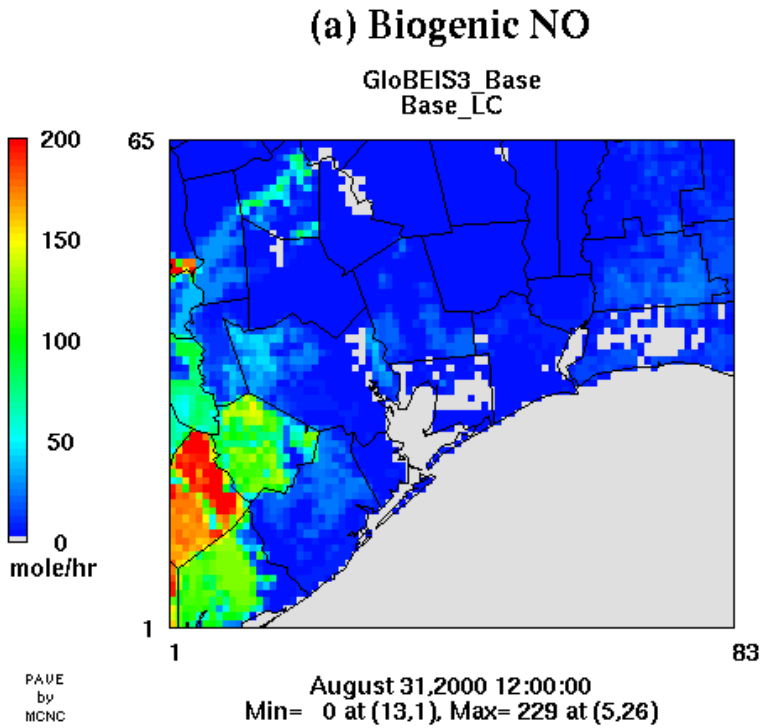
TFS LANDSAT based
Land Cover

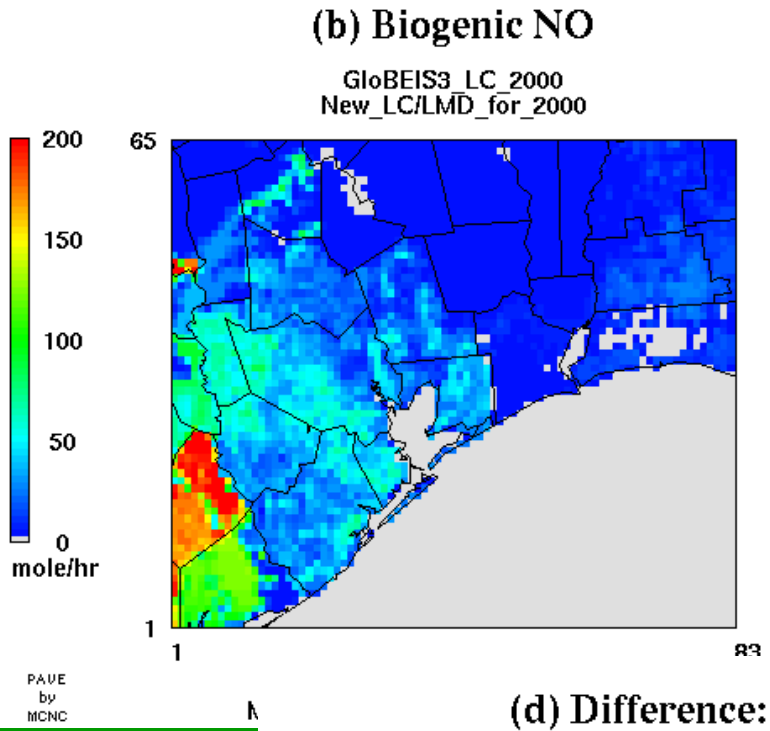
Water
Impervious
Forest_Mixed
Forest_coniferous
Urban_Areas
Forest_Broadleaf
Bare_fields_barren
Grass_Range



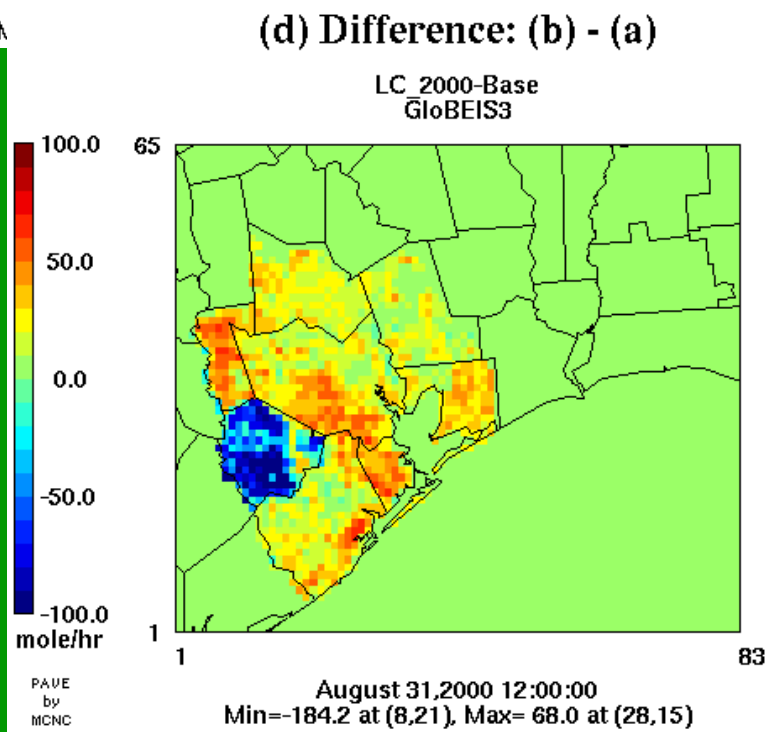


Effects of using different LU/LC data
Difference – spatial distribution
TCEQ-bio LU/LC vs. TFS LANDSAT LC





IMAQS
Houston



Effects of using different LU/LC data
Difference – spatial distribution
TCEQ-bio LU/LC vs. TFS LANDSAT LC

Base case O3 & Difference between LANSAT LC & TCEQ Biogenic emissions

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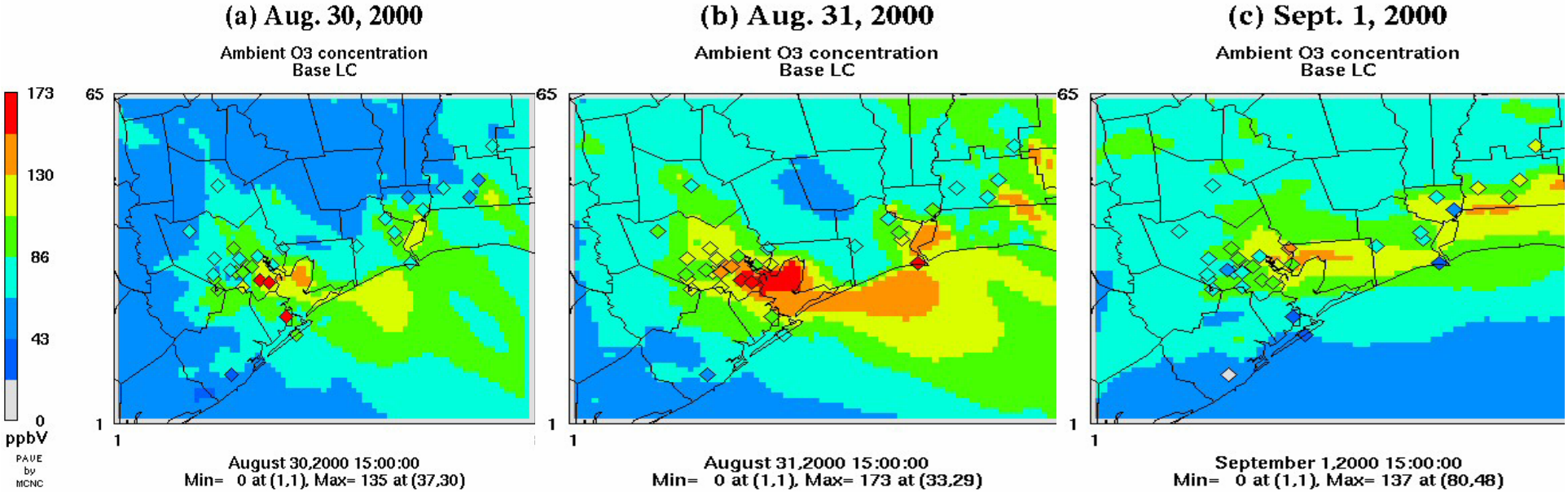
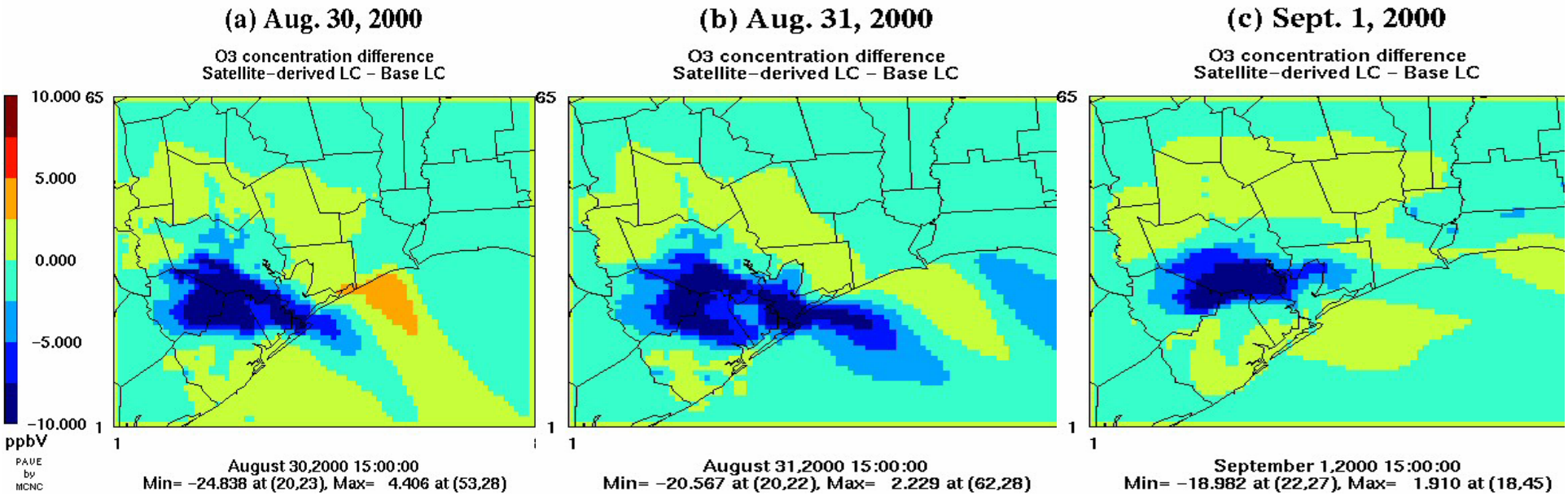
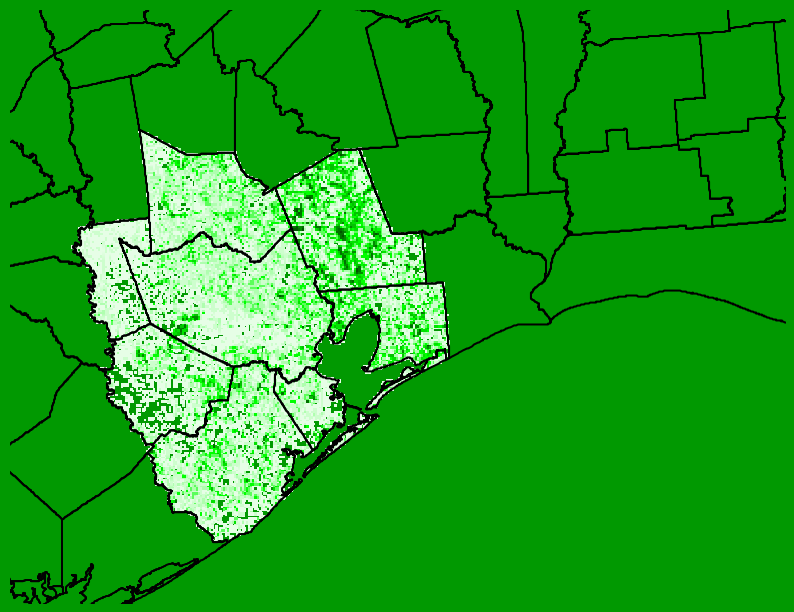
University of Houston



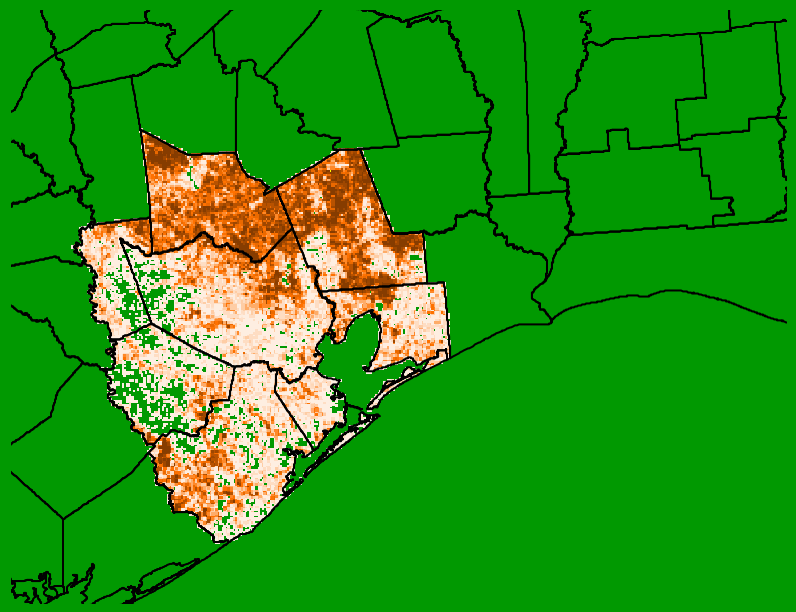


Study changes in tree cover



Between 1990 and 2000 LC data

New forest areas. The darker the green color scale, the larger the new forest areas in the cell (1 km x 1 km grid)



Areas of no change in forest areas. The darker the brown color scale, the smaller the changes in the forest areas in the cell (1 km x 1 km grid)

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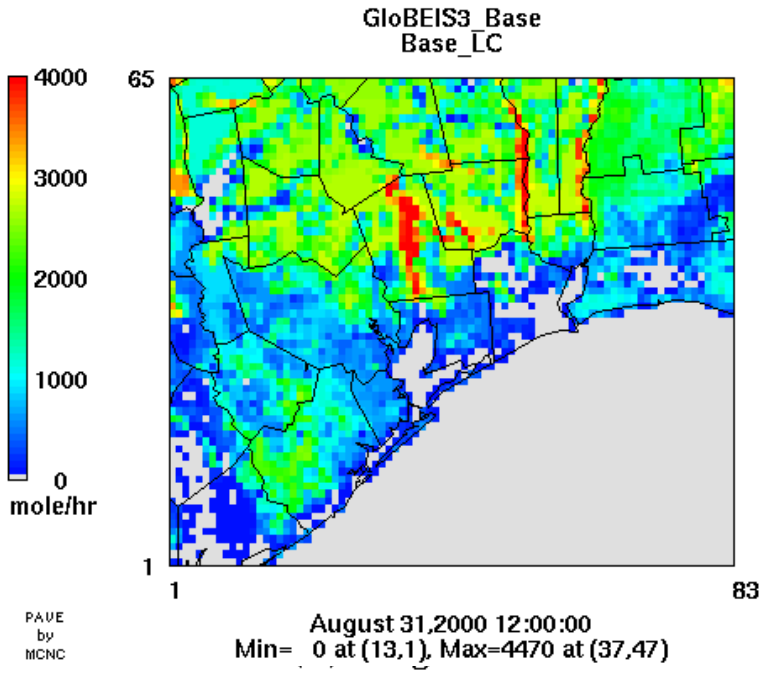
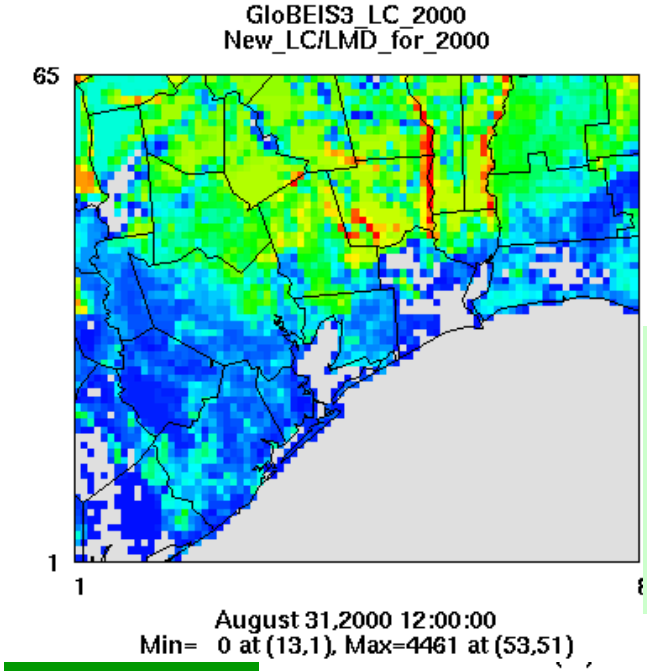
Effects of using different LU/LC data. LMD, & temp fields TCEQ-bio LU/LC vs. TFS LANDSAT LC 2000 & 1990

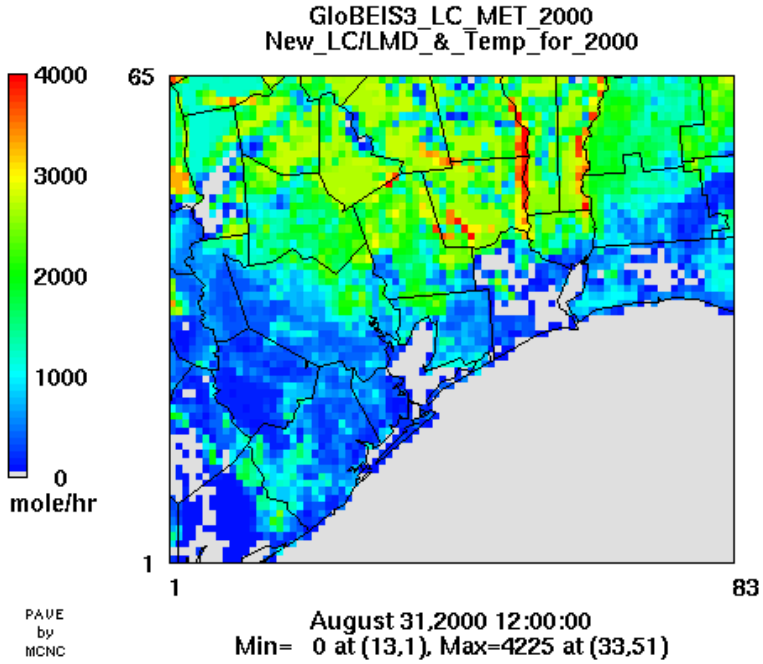
(a) Biogenic ISOP

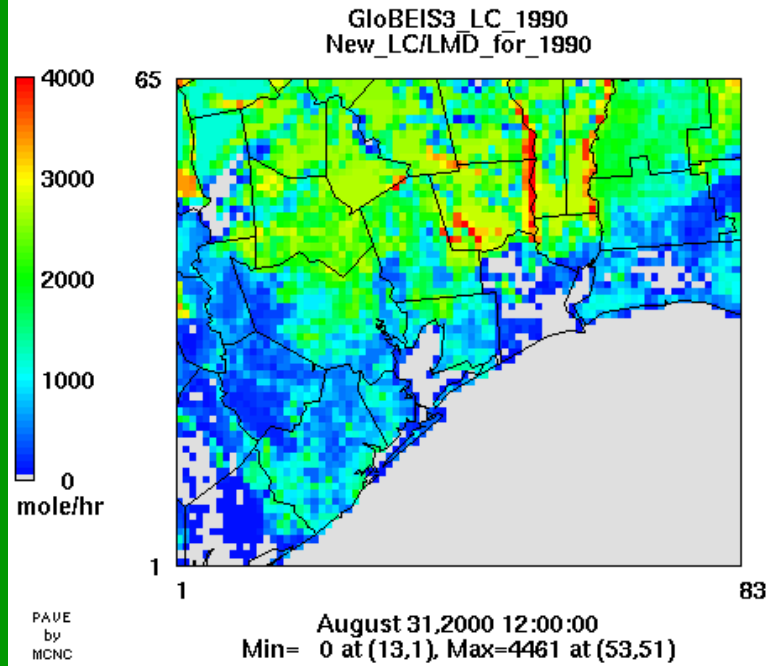


(b) Biogenic ISOP



c ISOP





Biogenic emissions with Different met & lu/lc data

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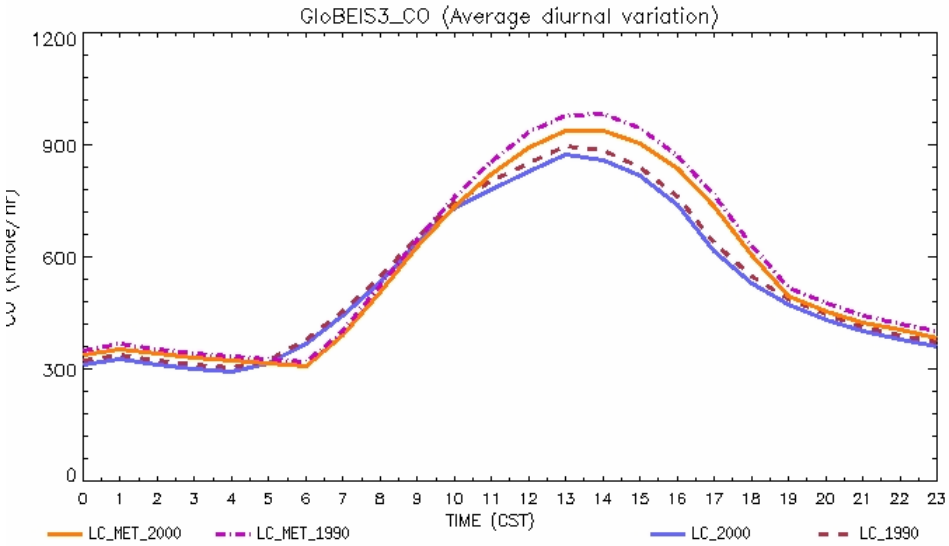
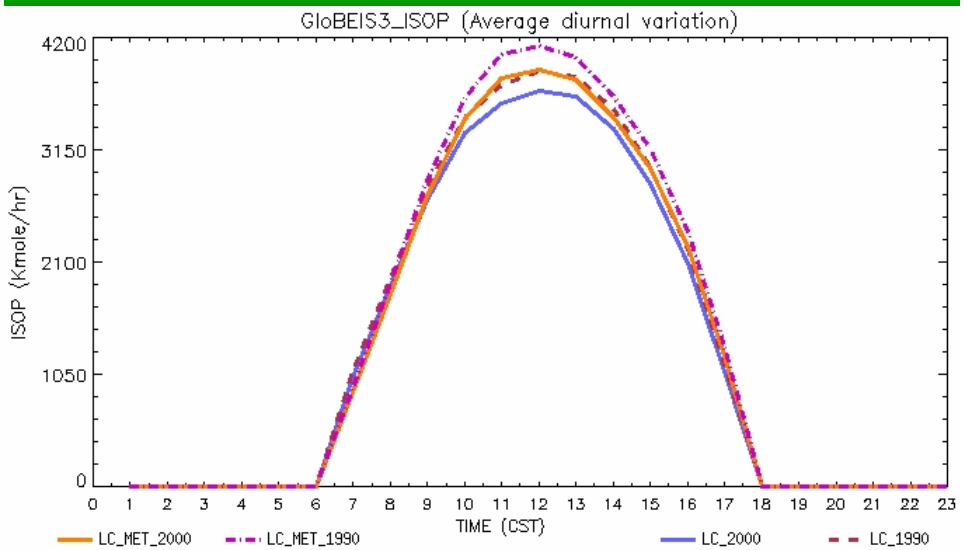
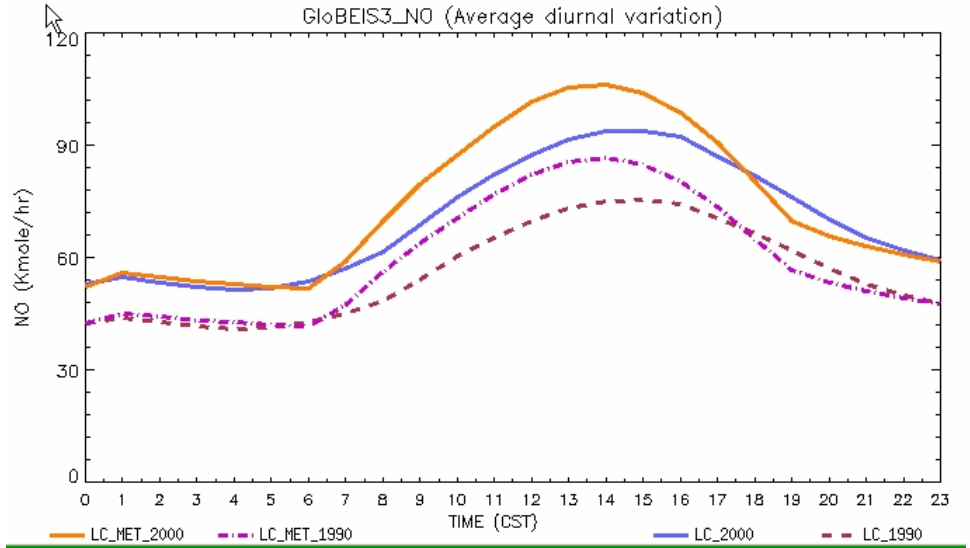
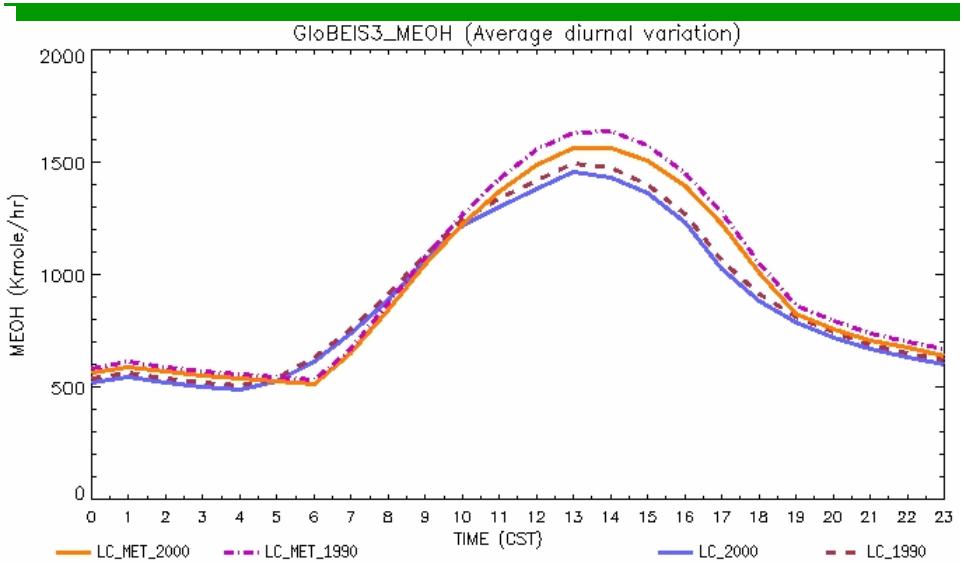


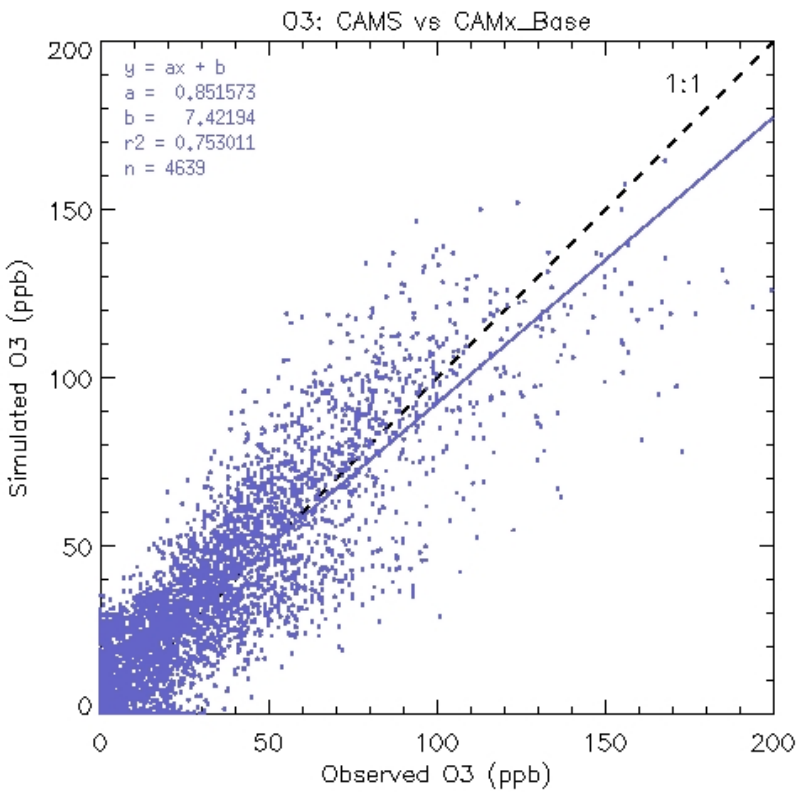




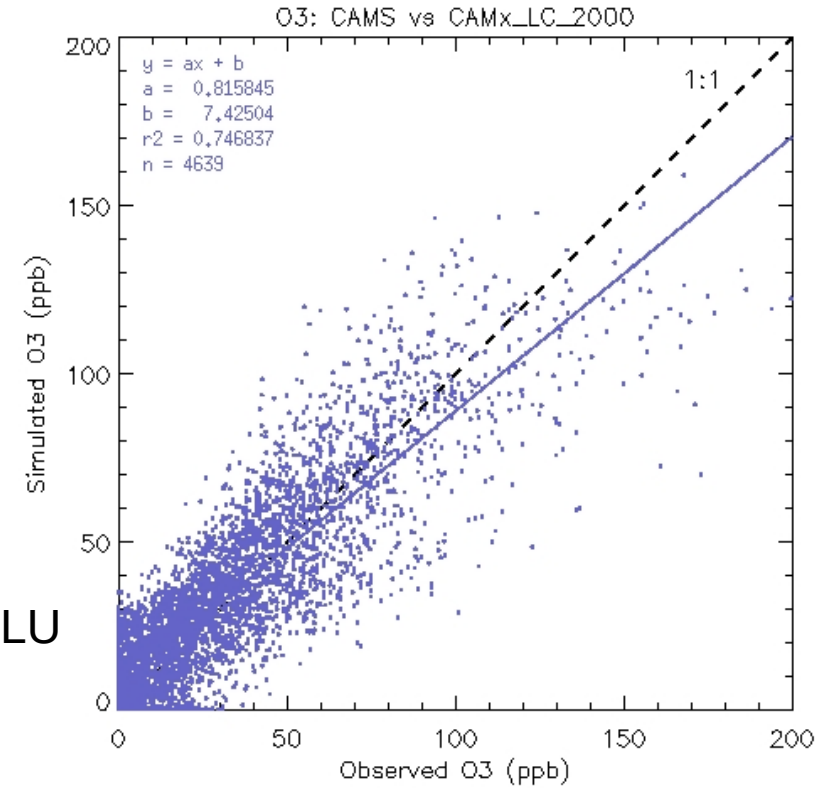


Air Quality Simulations
Reflect changes biogenic emissions by different LU & LMD data only (no met. Change)

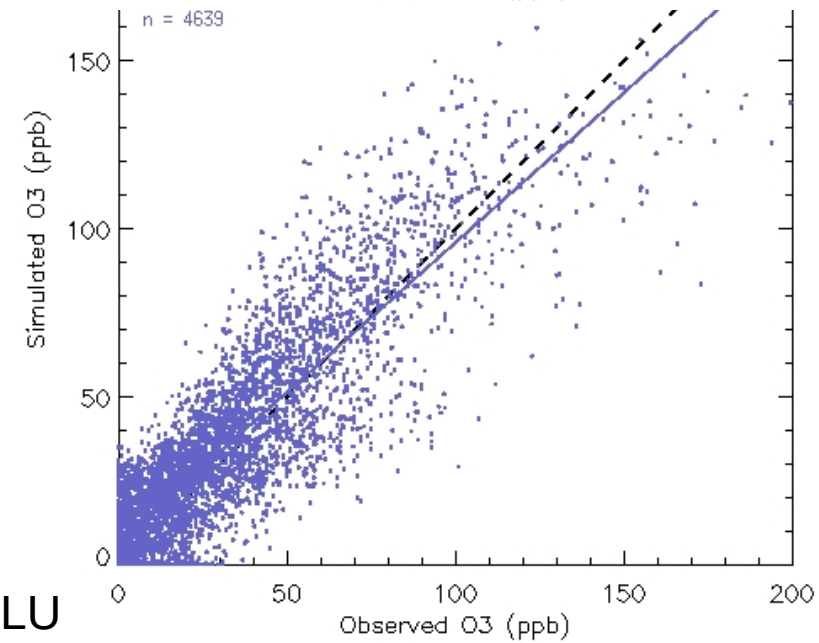
TCEQ Base



2000 LU



1990 LU



Air Quality Simulations: Reflect changes biogenic emissions by different LU & LMD data only (no met. Change)

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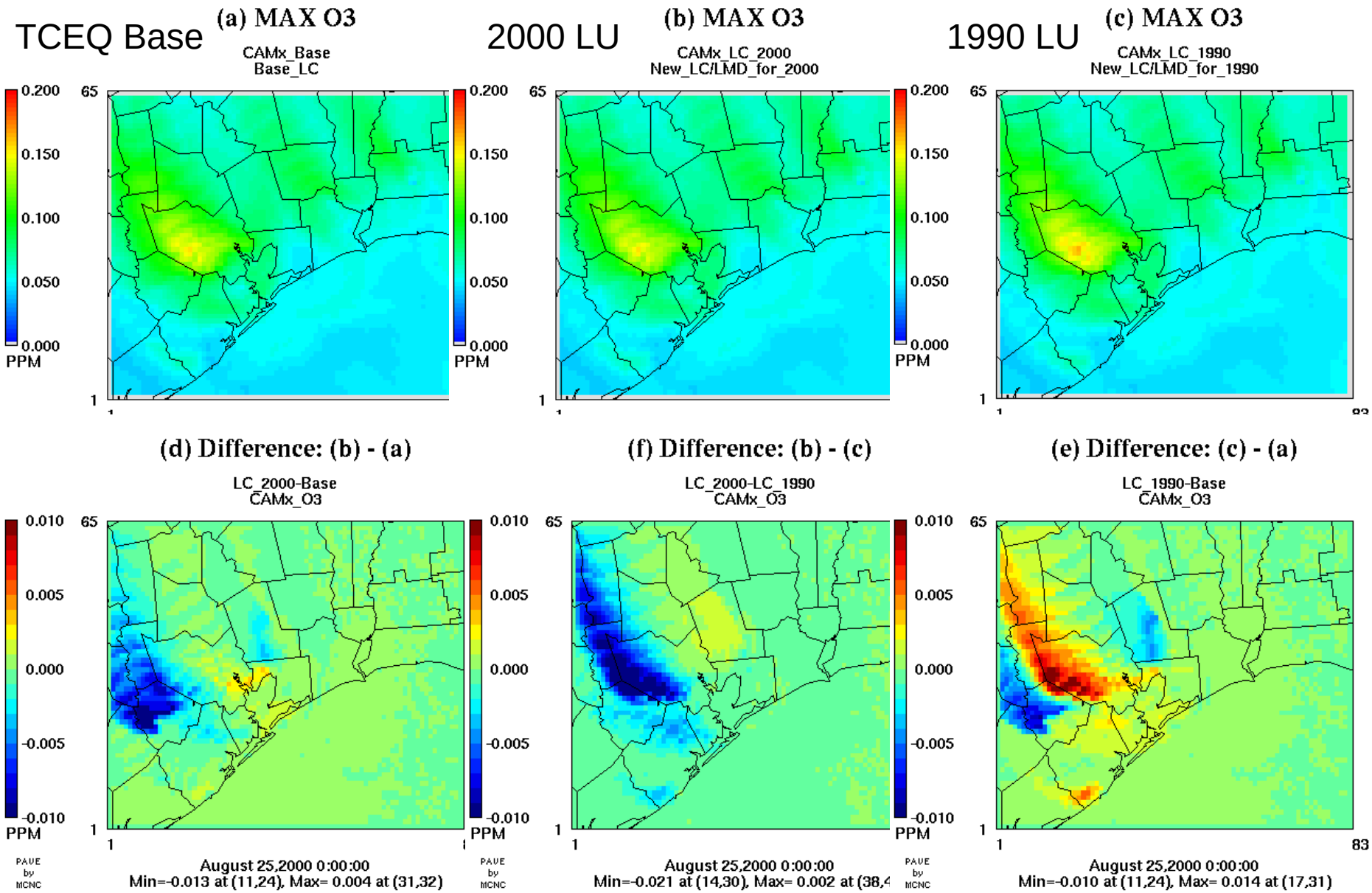
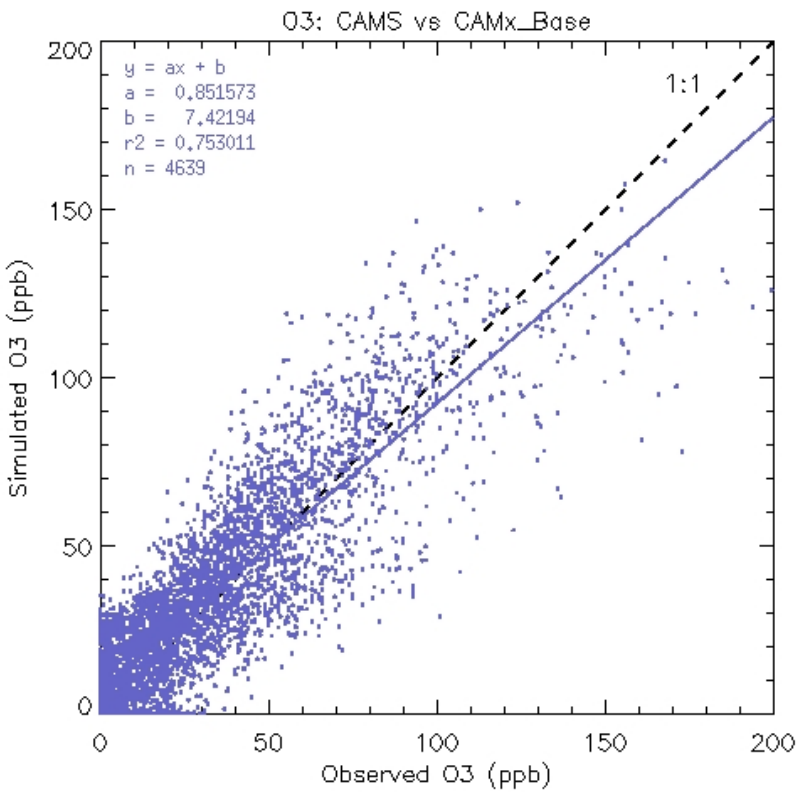
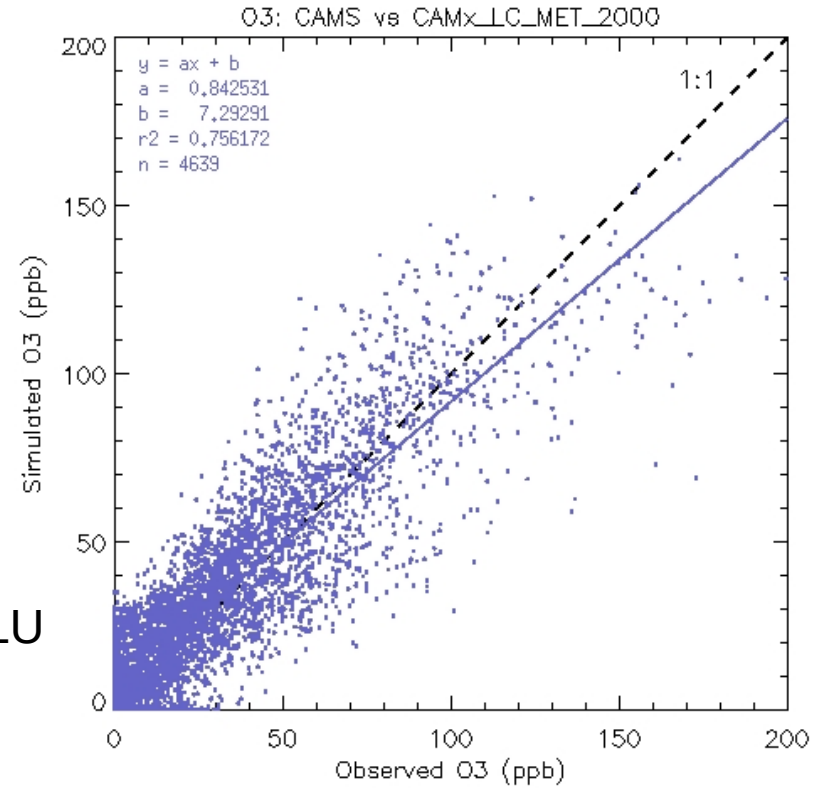


Air Quality Simulations
Reflect changes biogenic emissions by different LU & LMD data & temp (no wind & PBL Change)

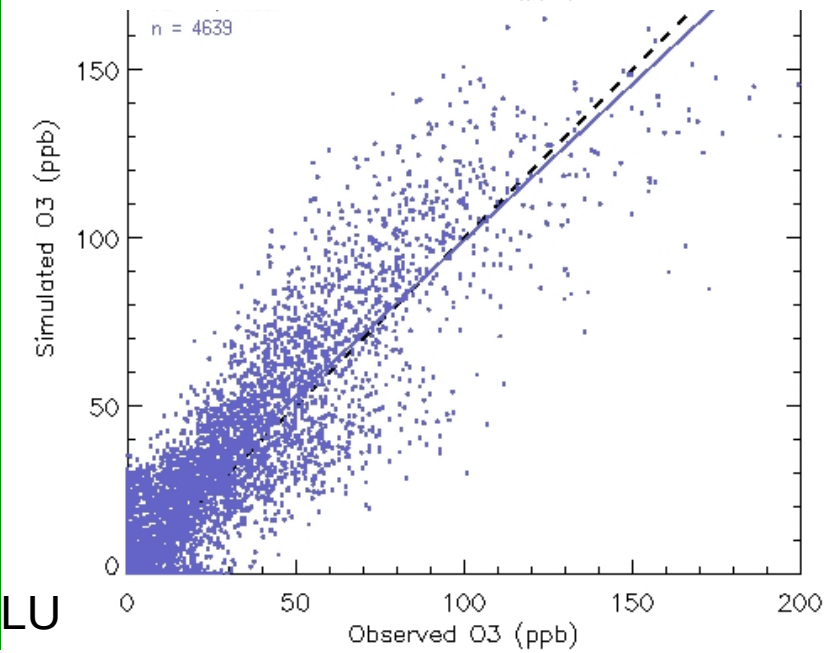
TCEQ Base



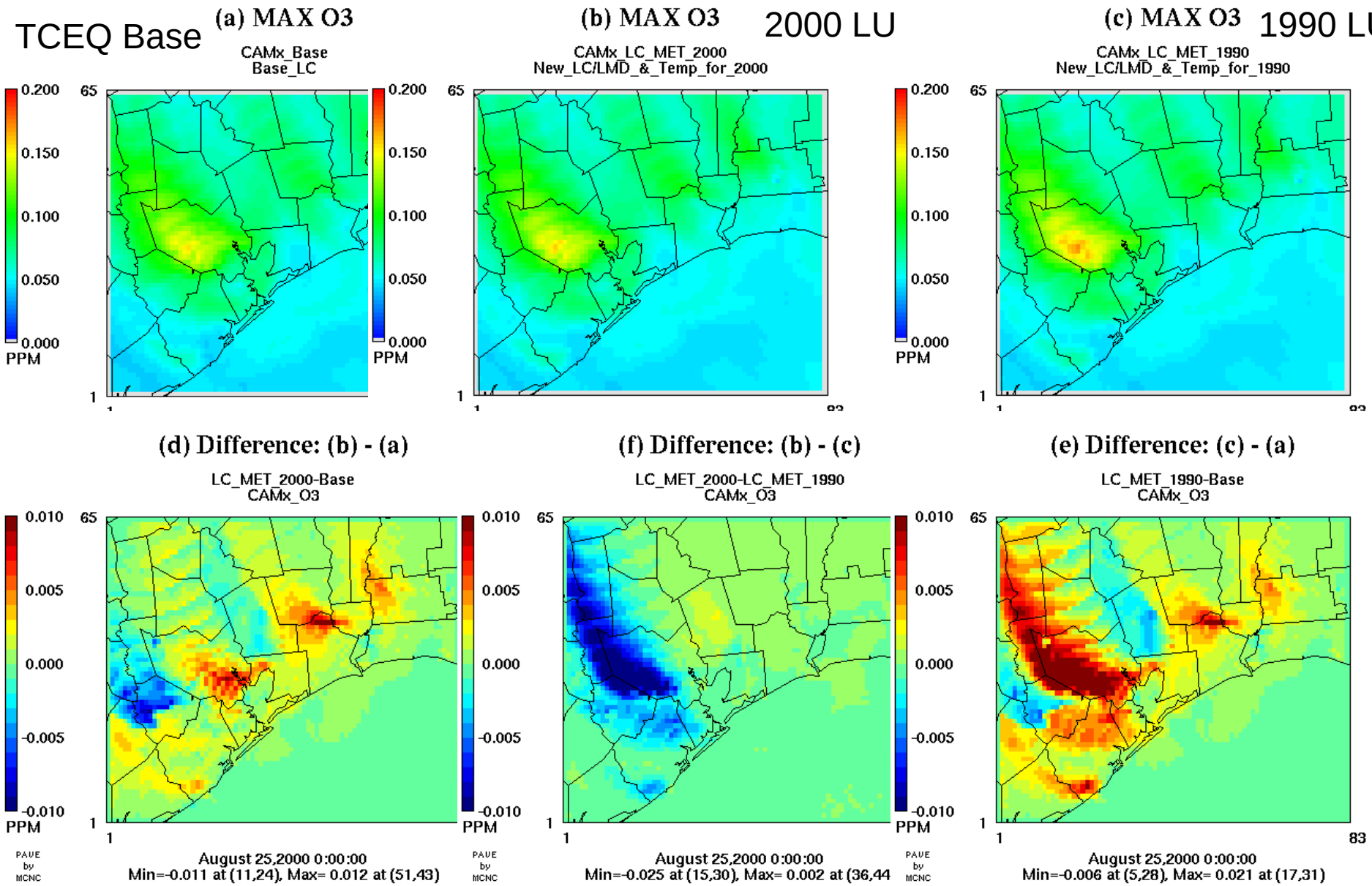
2000 LU



1990 LU



Air Quality Simulations: Reflect changes in biogenic emissions by different LU & LMD data + temp change (no wind. & PBL Change)

IMAQS
University of Houston

TCEQ Base