Trees and Heat Island Modeling for the Houston-Galveston Region: Land Use, Meteorology, Air Quality Study (Preliminary Progress Report)

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Research Team

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Project support

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USDA, EPA (Eva Wong, Brian Timin, J. Edwards, S.T. Rao)

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**
- **Improve meteorological simulations by applying better physics**
- **Incorporate most up-to-dated detailed land use and land cover data**

Most Recent TAMU Base Simulation Uses "5-layer" slab model with Satellite Skin Temperature Assimilation

1. Ground heat budget model with multiple soil layers (5) 1, 2, 4, 8, 16cm thick
2. Improved version of a 2-layer force-restore surface energy balance model
3. Couples surface momentum, heat, and moisture fluxes
4. But, no treatment of evapotranspiration
5. No moisture diffusion in the soil layer
6. Requires good prescription of soil moisture
7. Satellite skin temperature assimilation is a good way to overcome items 4, 5, and 6.

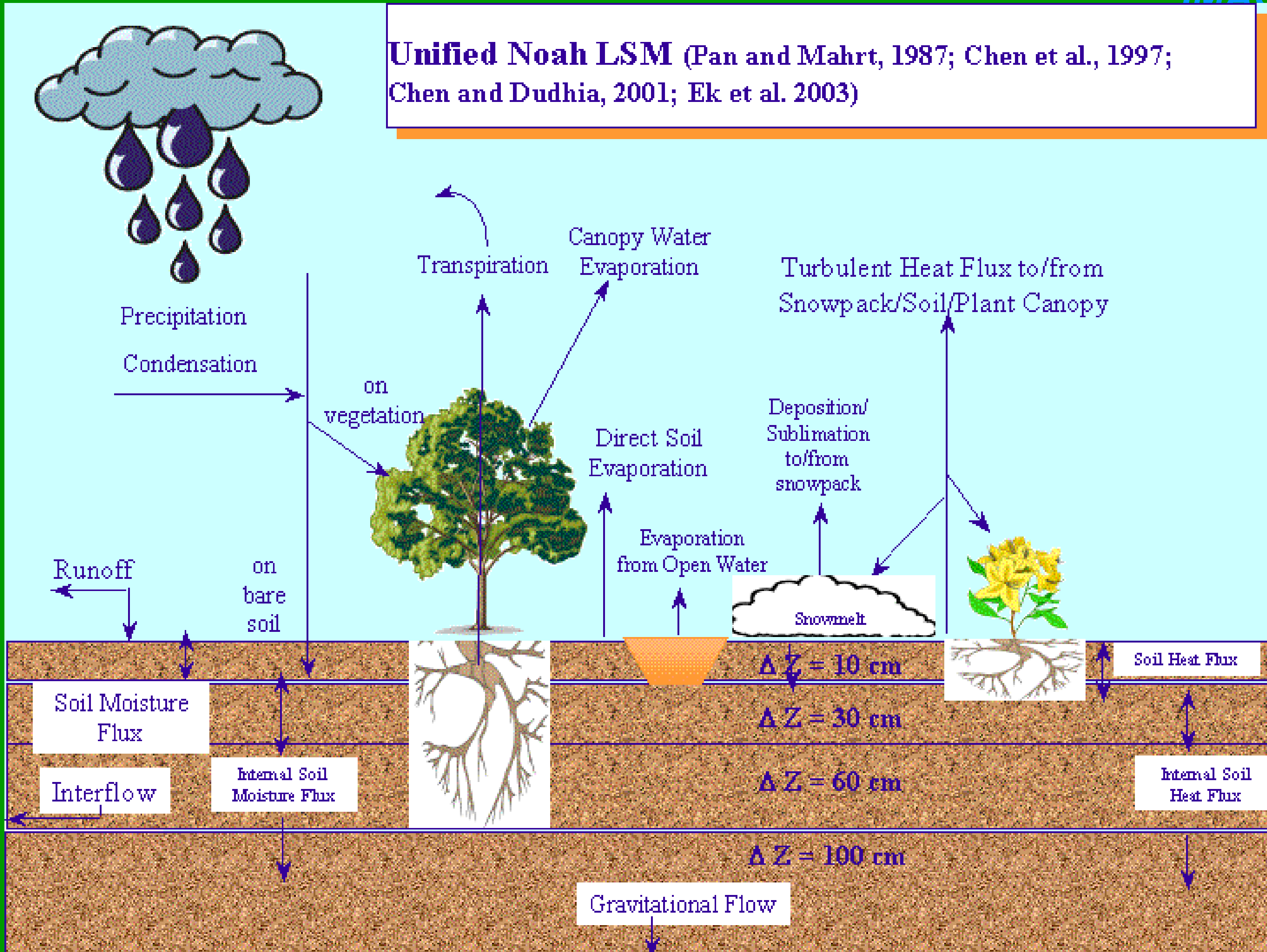
To study the effects of land use change on meteorology and air quality…

- **Standard LU/LC data used in MM5 simulation: USGS ~1-km resolution, aggregated up to 4-km.**
- **Higher resolution of LU/LC data available from Texas Forest Service**
- **MM5/slab with satellite data assimilation cannot reflect the effects of changes in the land use because it bypasses physical simulation of land-surface processes**
- **Test MM5/slab requires precise prescription of soil moisture**

How to study the land use change effects in MM5?

- 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)



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.**
5. **Initially, we thought it were soil moisture problem, but …?**

- Question: How to treat the evapotranspiration from 20% tree/vegetation coverage when the current dominant category of USGS 25-LU/LC is used?

- Experiment S3: We added new anthropogenic canopy water source in the urban area in the NOAH LSM to reflect Houston's 20% urban vegetation and thus reduce the daytime temperature bias.

Design of Meteorological Simulation

	S1 (TAMU)	S2	S3
LSM	SLAB	NOAH	NOAH
Treatment of Soil Moisture	Increase SM in urban area; Decrease SM in rural area; (Dr. Nielsen-Gammon, J. W., 2002)		Add canopy moisture (CM) in urban area

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**

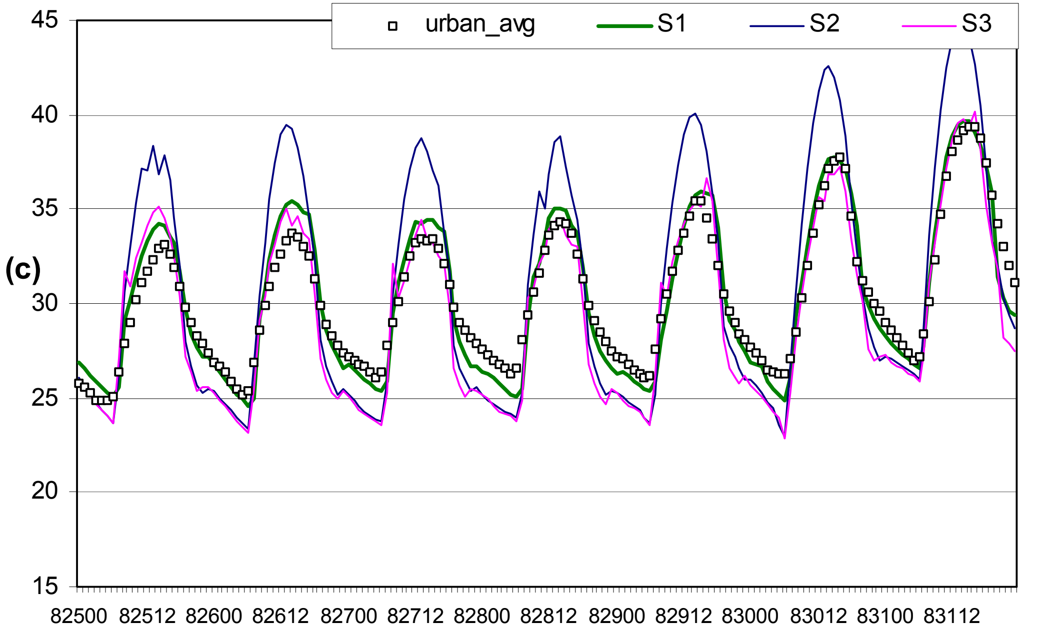
E_c **canopy evaporation**

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

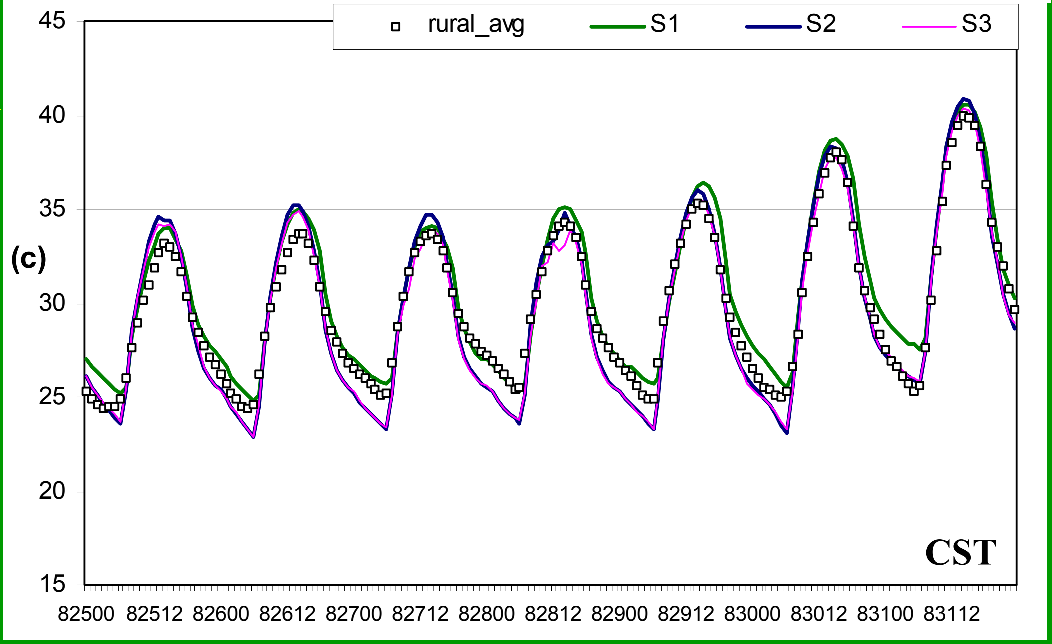
E_u **is the anthropogenic contribution to the canopy water content. A reasonable value 3×10^{-6} (meter of available water per second) was picked for the simulation (* need to be justified).**

Surface (2-m) Temp Analysis

Urban



Rural



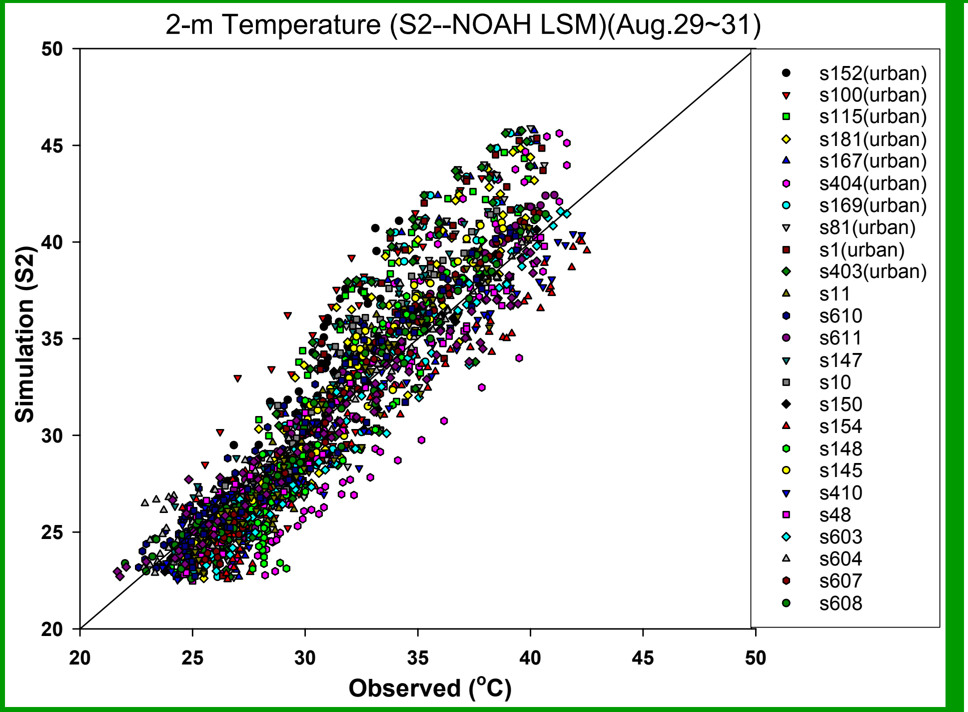
- Now, temperature simulations at urban areas improved, not much change in rural sites.

- Minimum temperature problem still exists

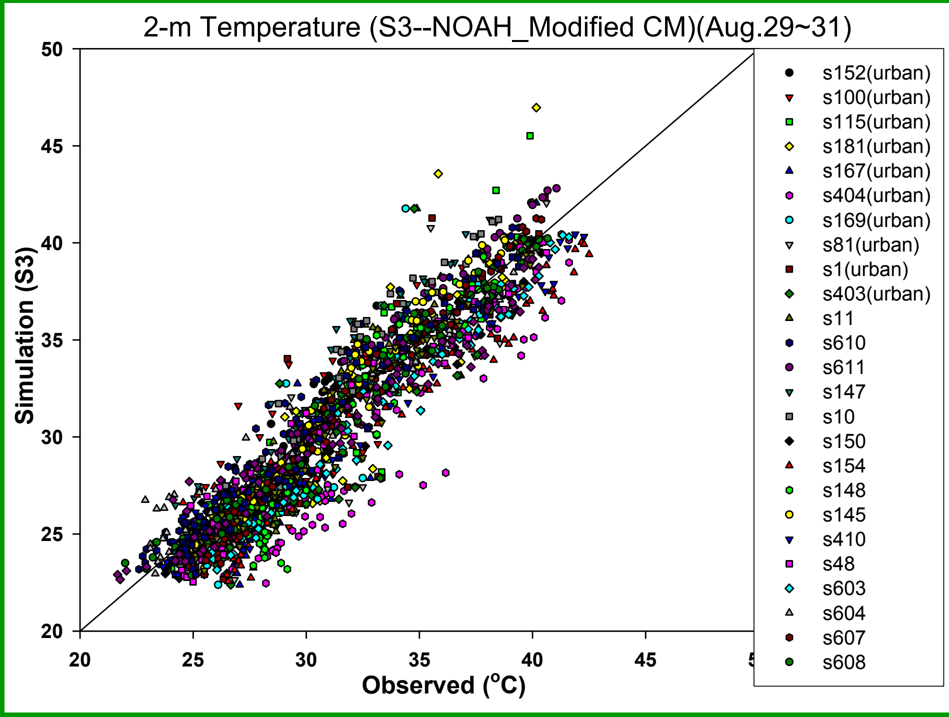
- S3A ; fixed min. temperature problems by adding LU/LC dependent emissivity,…but

Scattered Diagram of 2-m Temp

(a)



(b)



Scattered diagram of 2-m temperature with (a) S2; (b) S3 simulations.

MM5 sensitivity test continued to correct minimum temperature problem: S3A

a. Add canopy water into urban area

b. Test emissivity value for different LU categories

(original emissivity in NOAH =1.0)

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

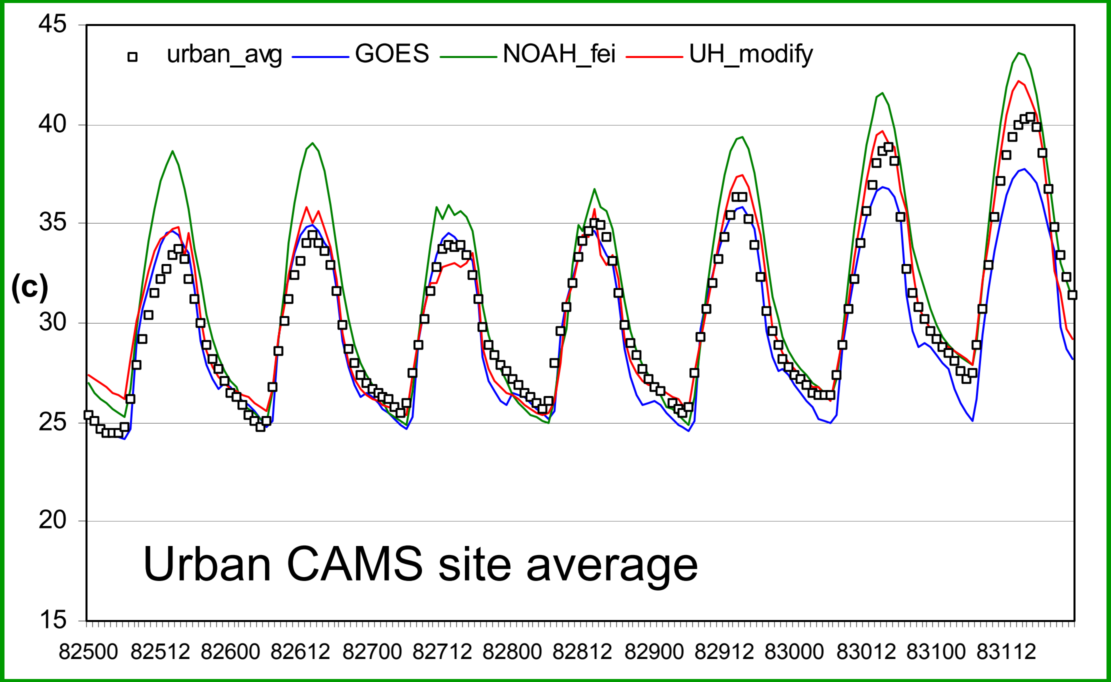
a : emissivity of the surface

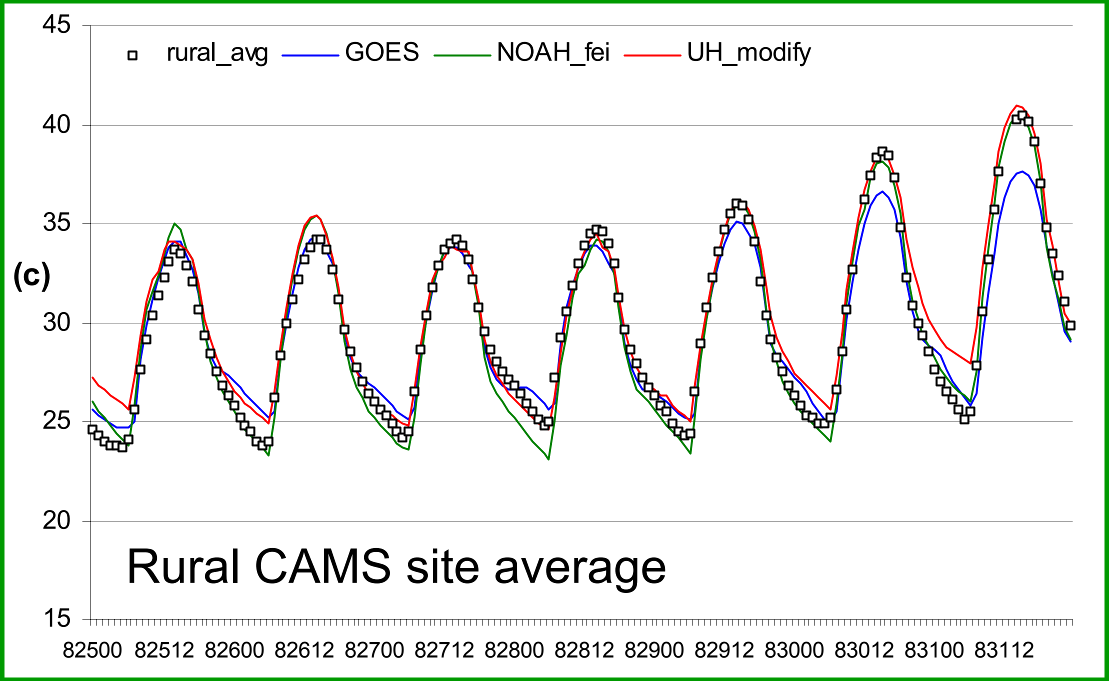
σ : Stefan – Boltzmann constant

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



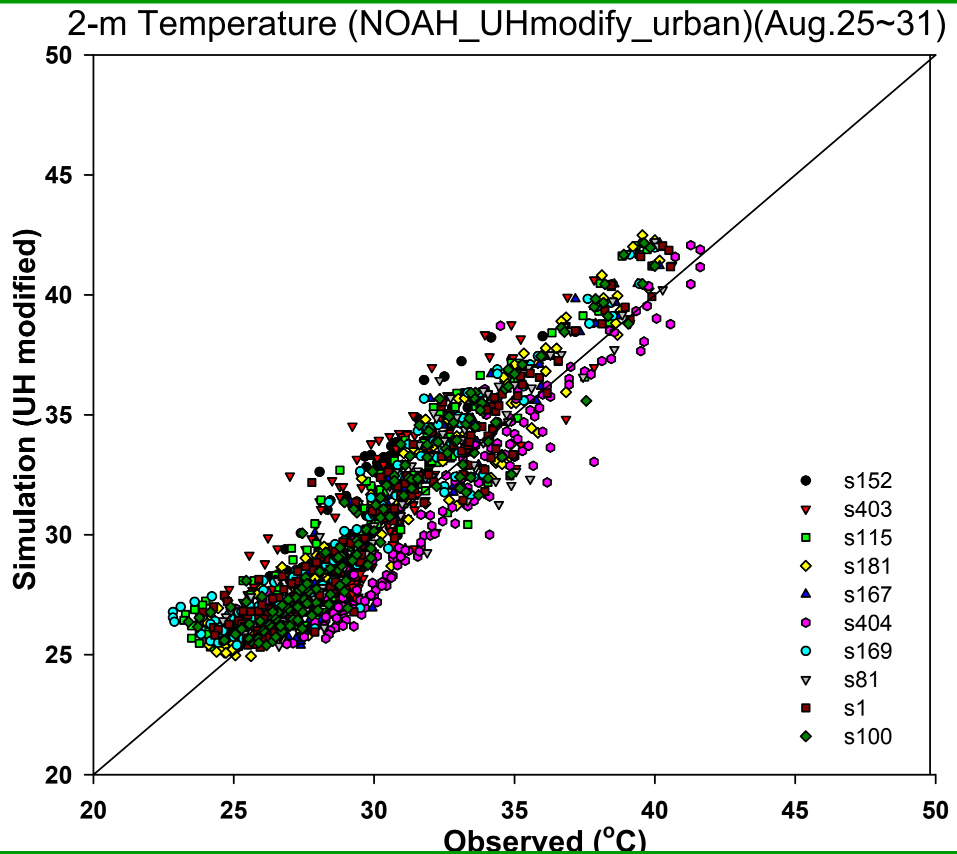


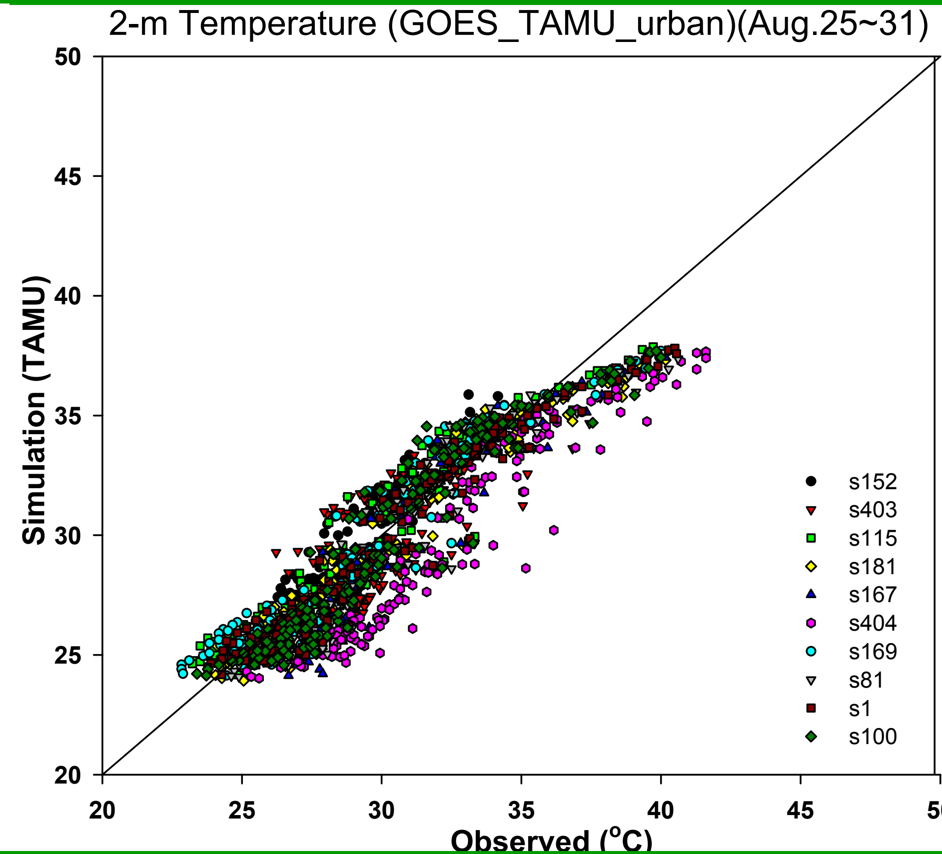
UH_mod

= (modified thermal conductivity + added canopy moisture + modified emissivity) for urban area
+ modified emissivity in rural LU/LC

Scattered diagram of 2-m temperature the urban sites

UH_mod
= (modified thermal conductivity + added canopy moisture + modified emissivity) for urban area
+ modified emissivity in rural LU/LC



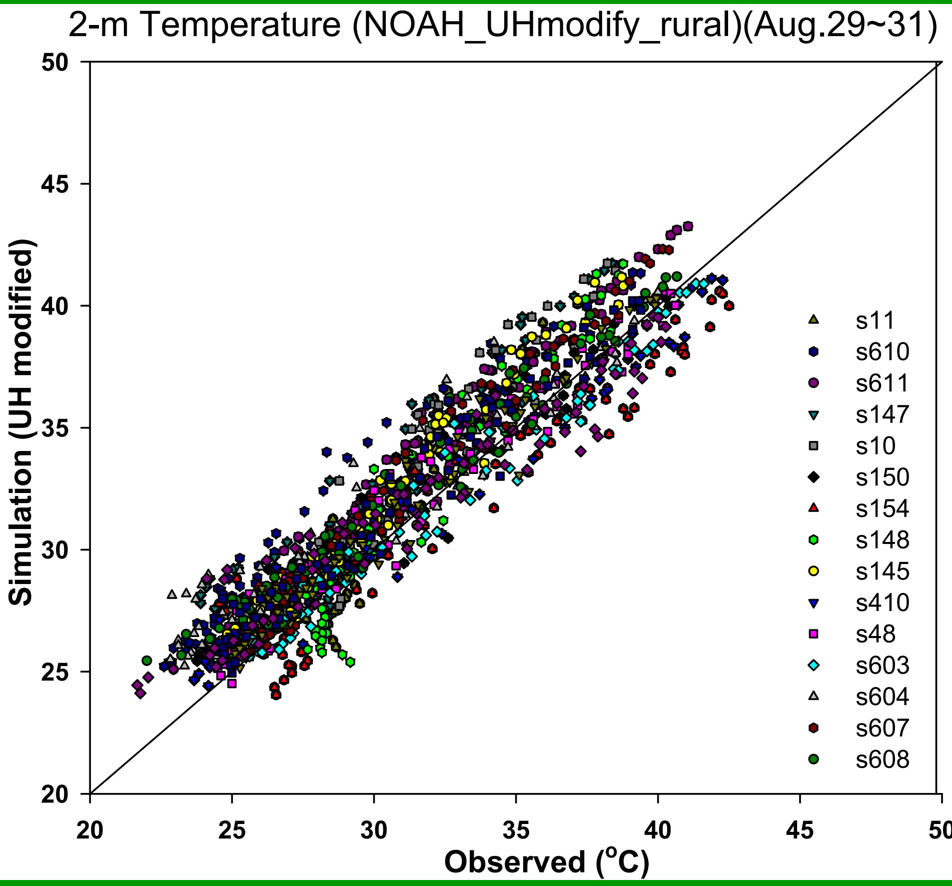


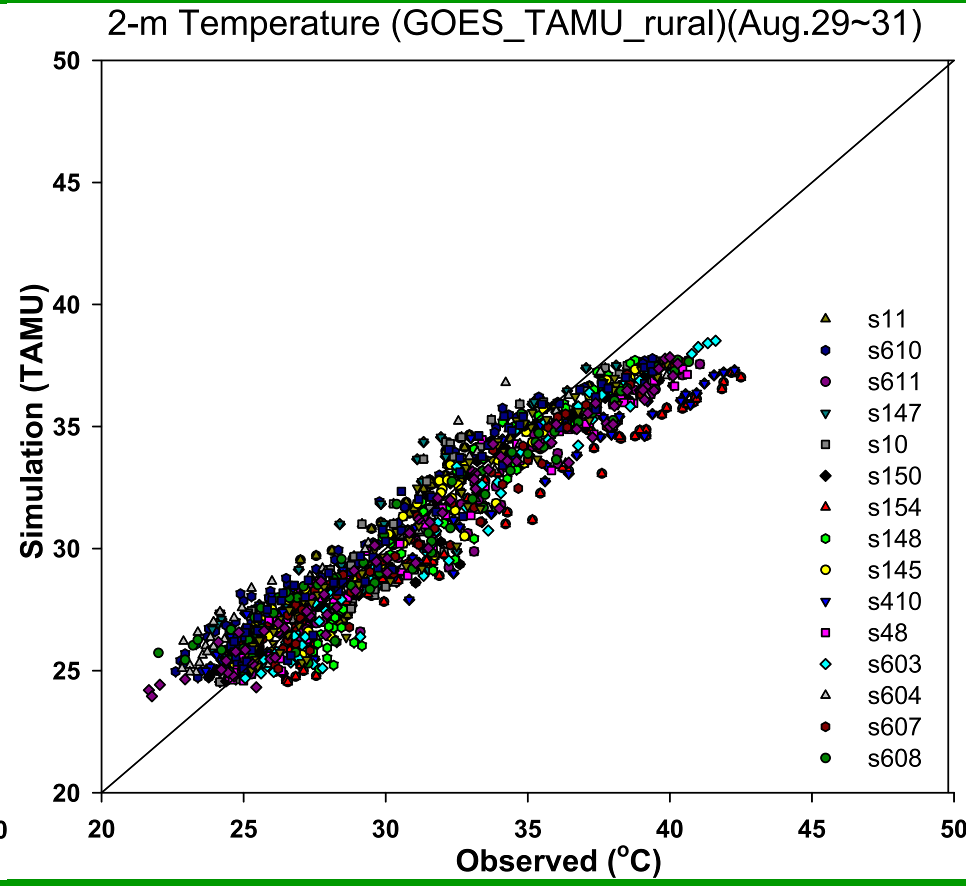
Scattered diagram of 2-m temperature the rural sites

UH_mod

= (modified thermal conductivity + added canopy moisture + modified emissivity) for urban area

+ modified emissivity in rural LU/LC





dominant landuse data used in MM5

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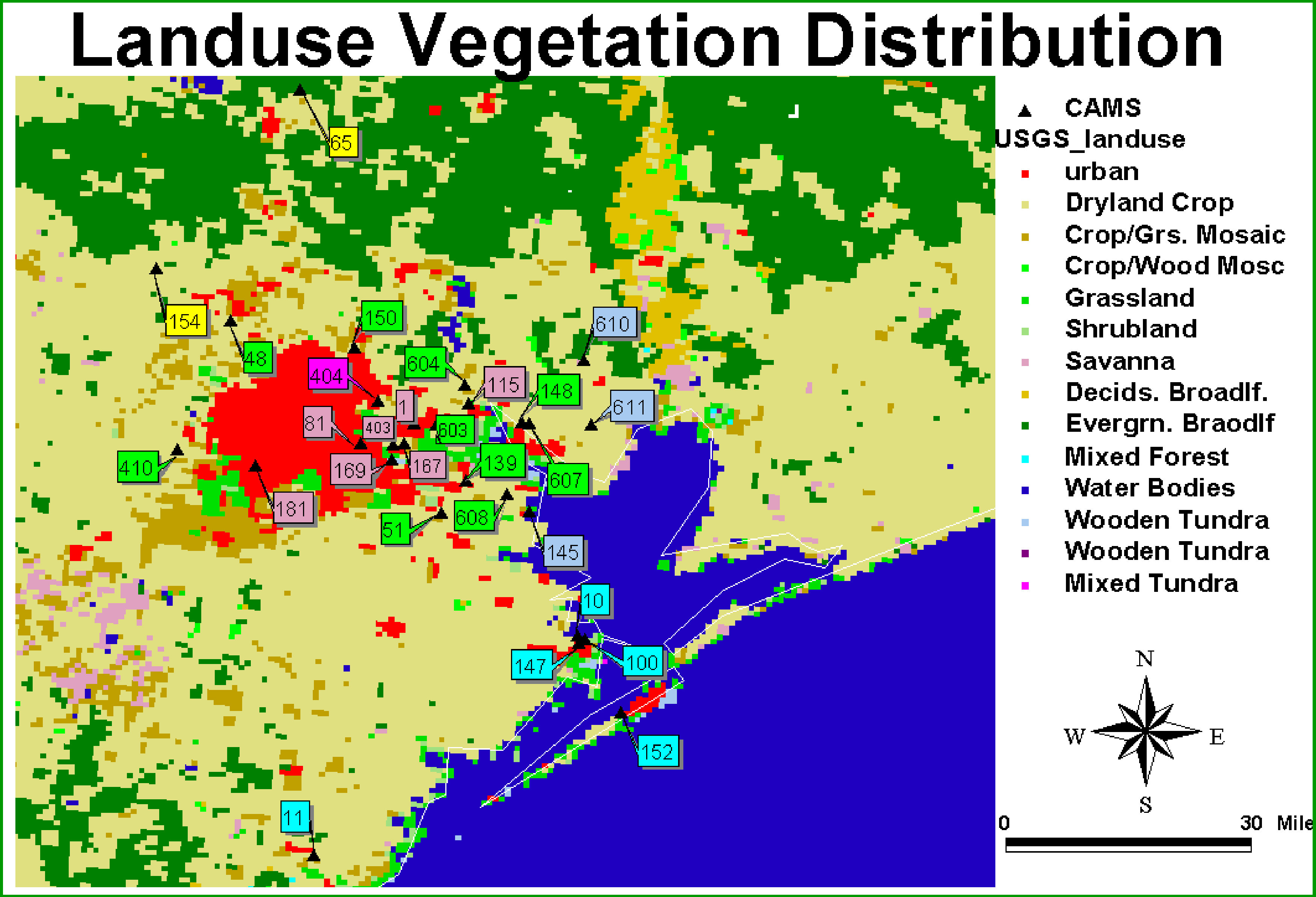
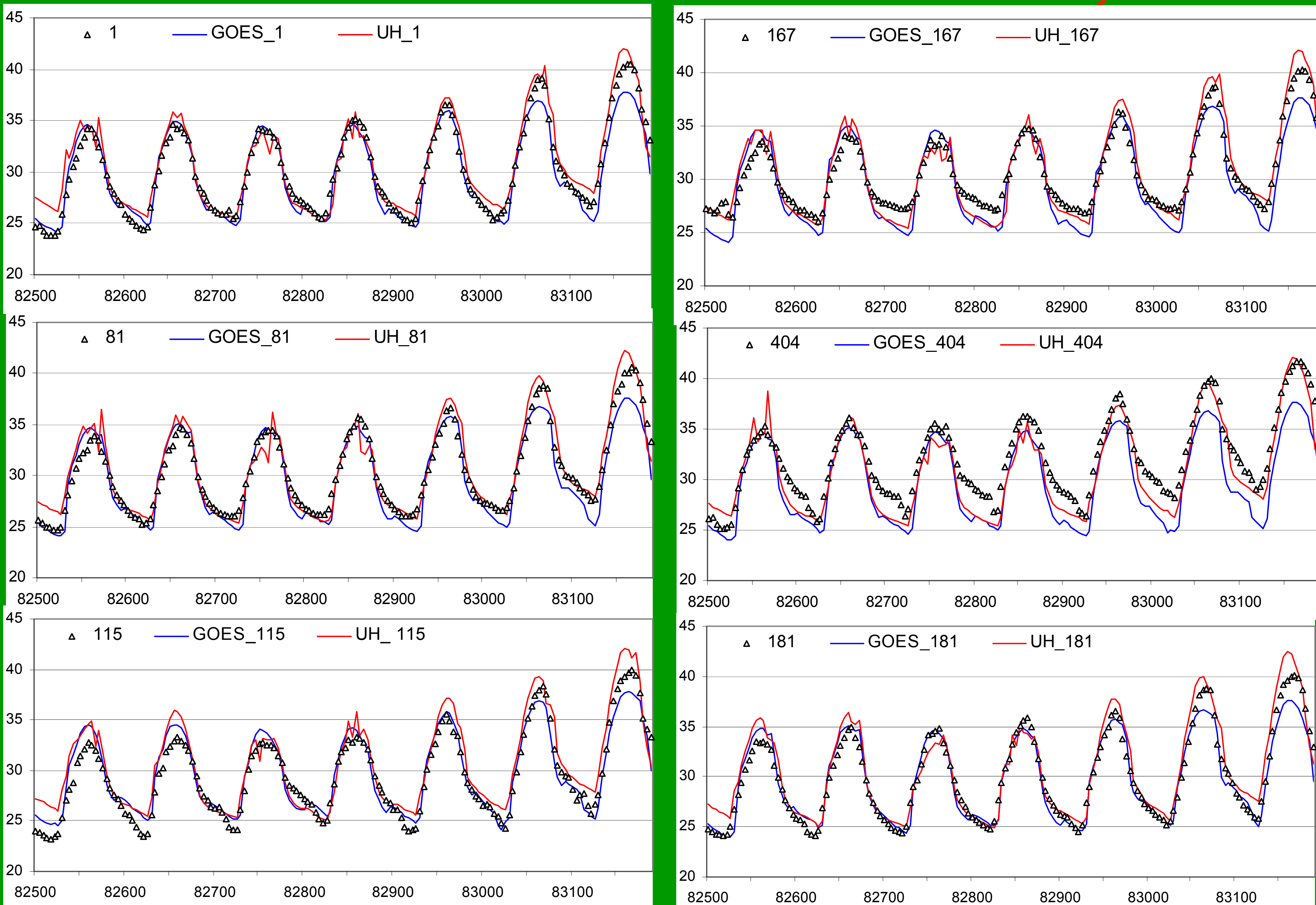
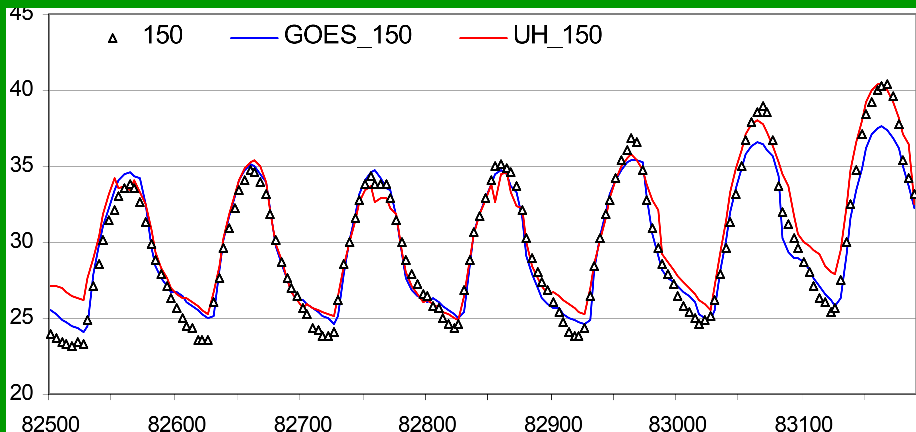
Urban : 10 sites   Rural : 18 sites

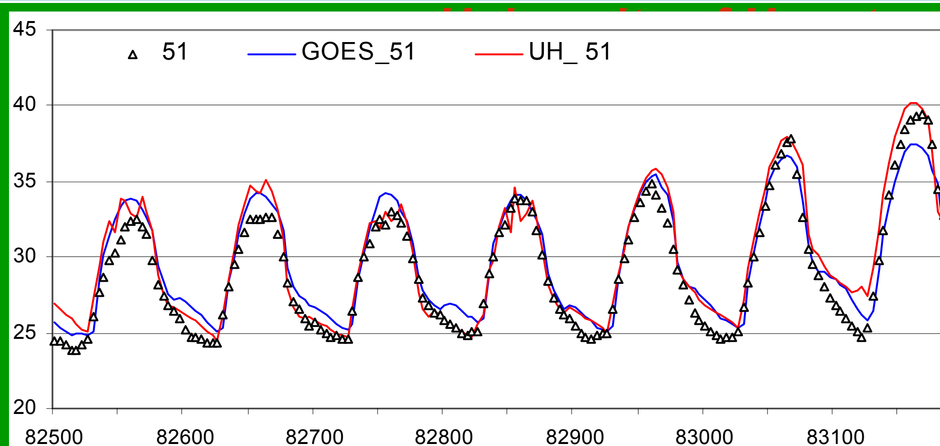


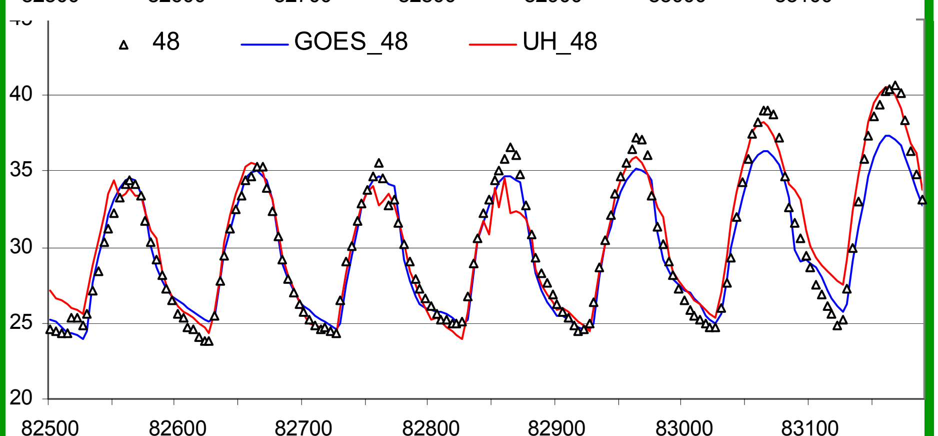
2-m temperature in the urban sites

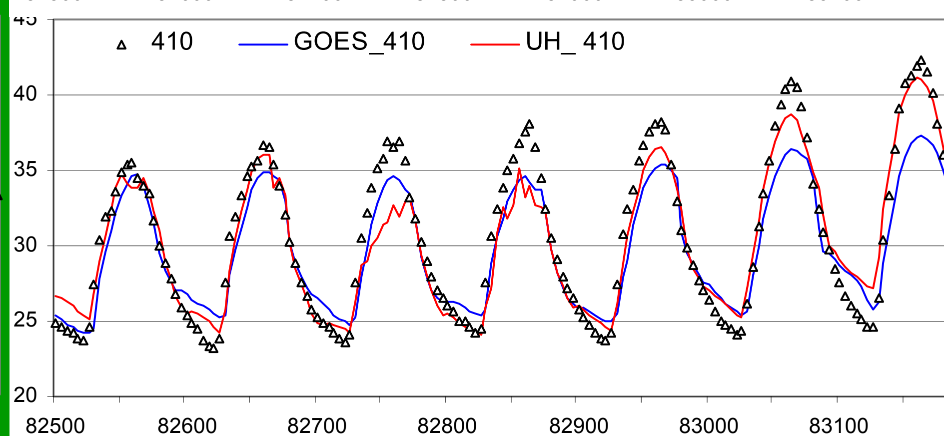


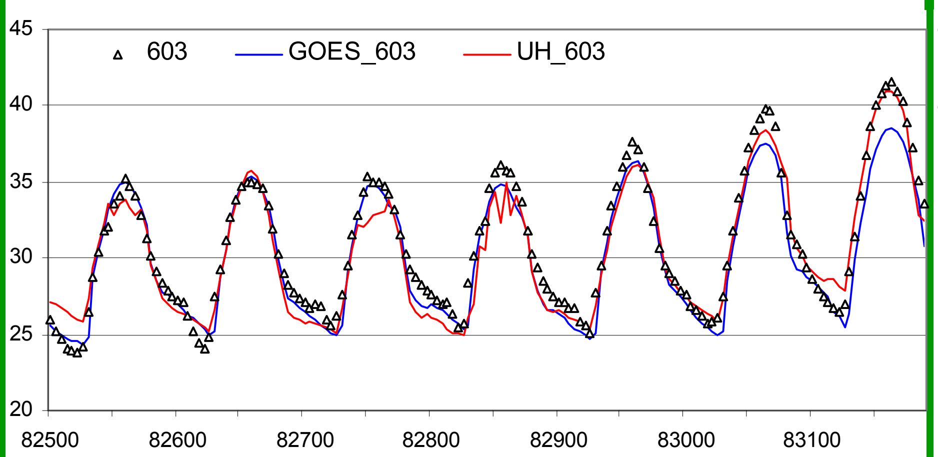
2-m temperature in the rural sites

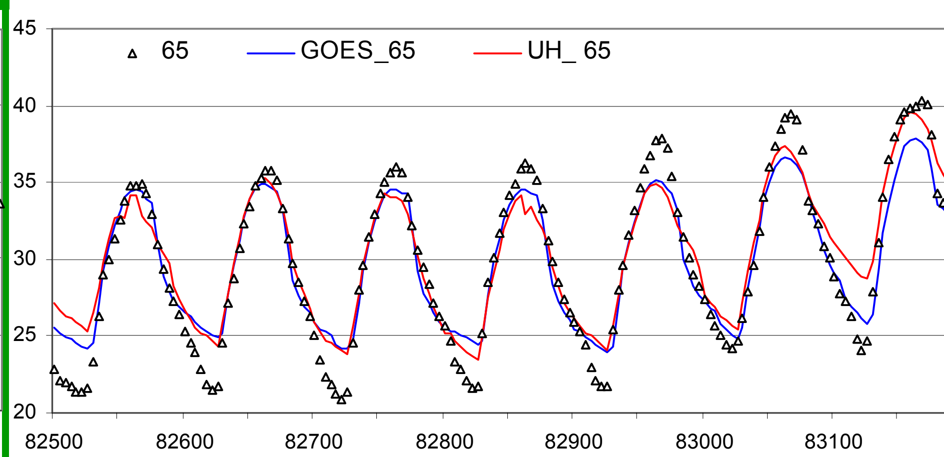




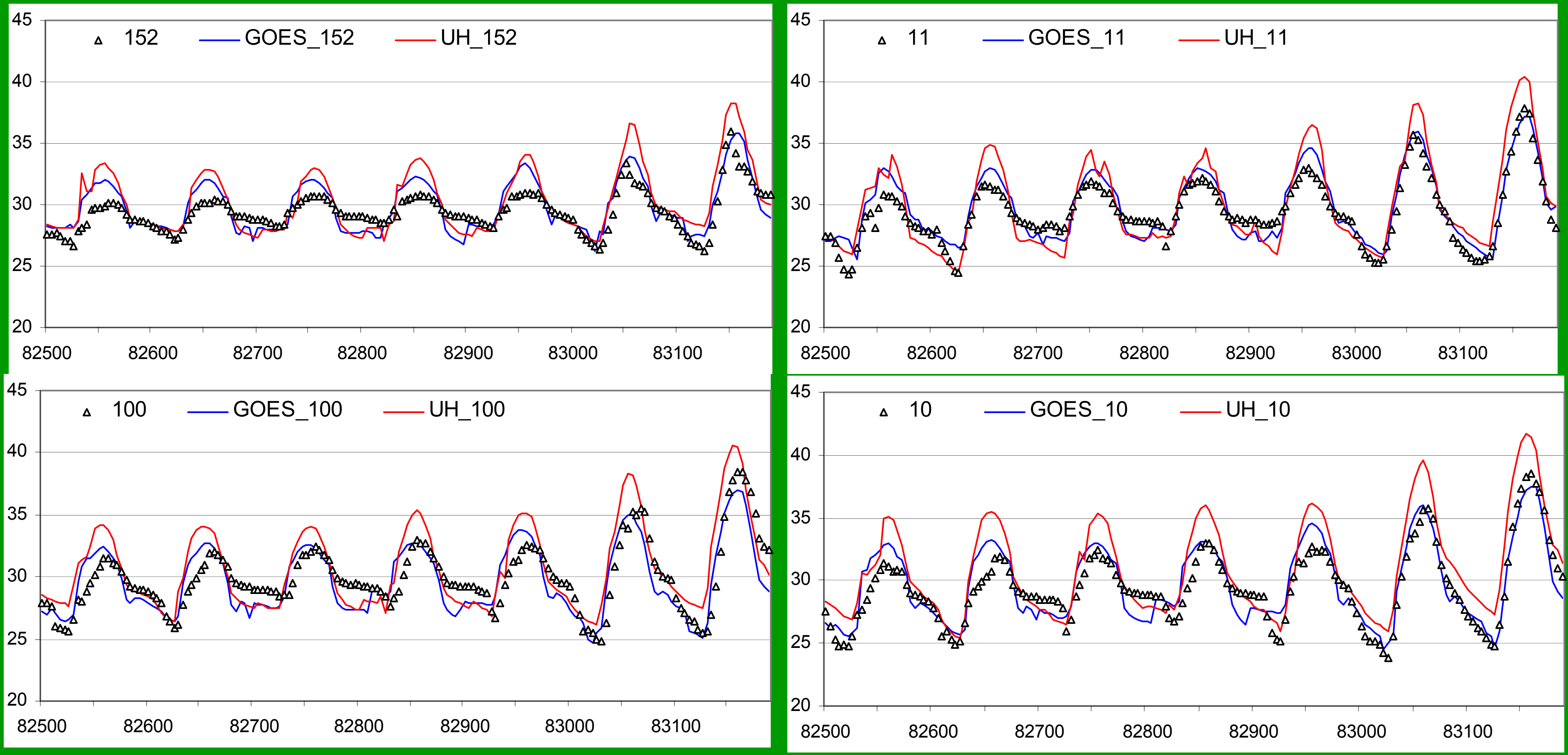




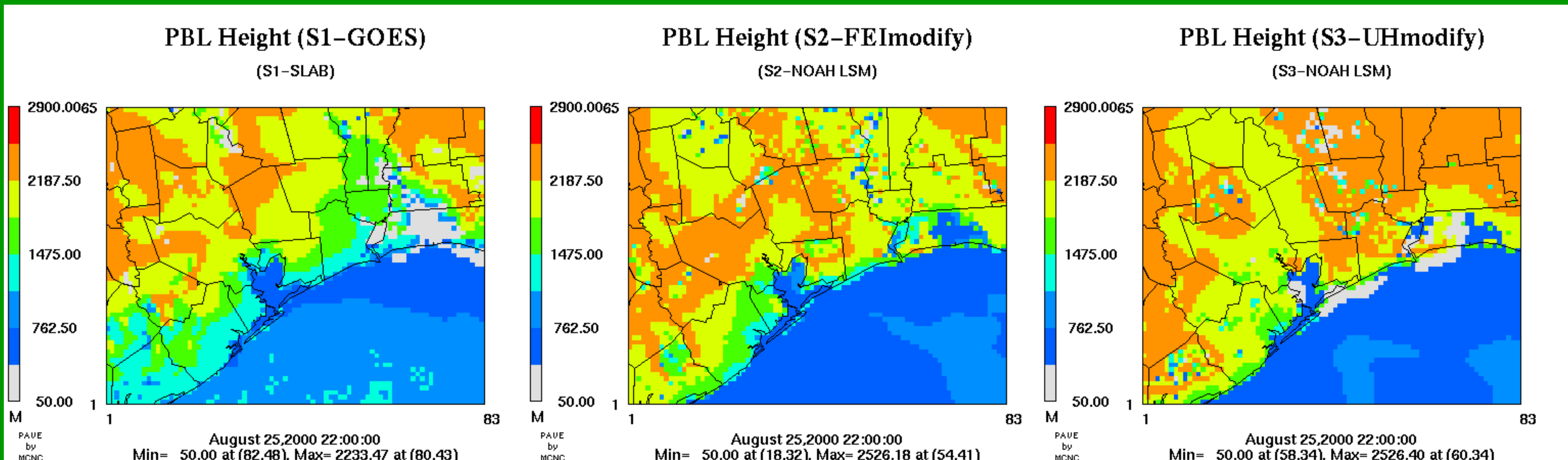


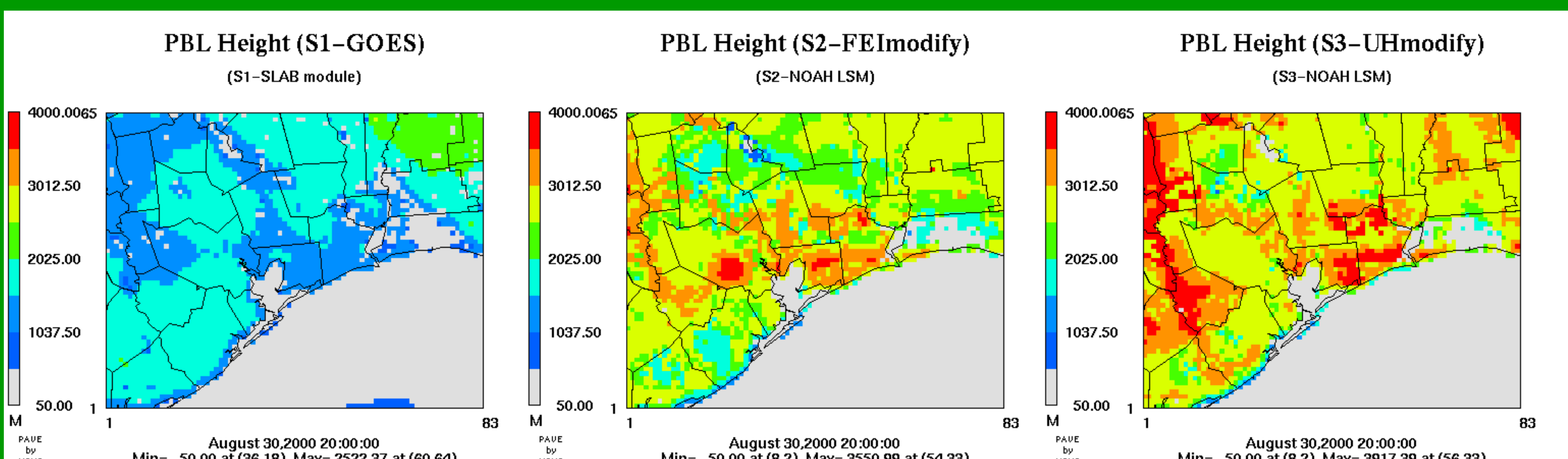


2-m temperature in the coast sites



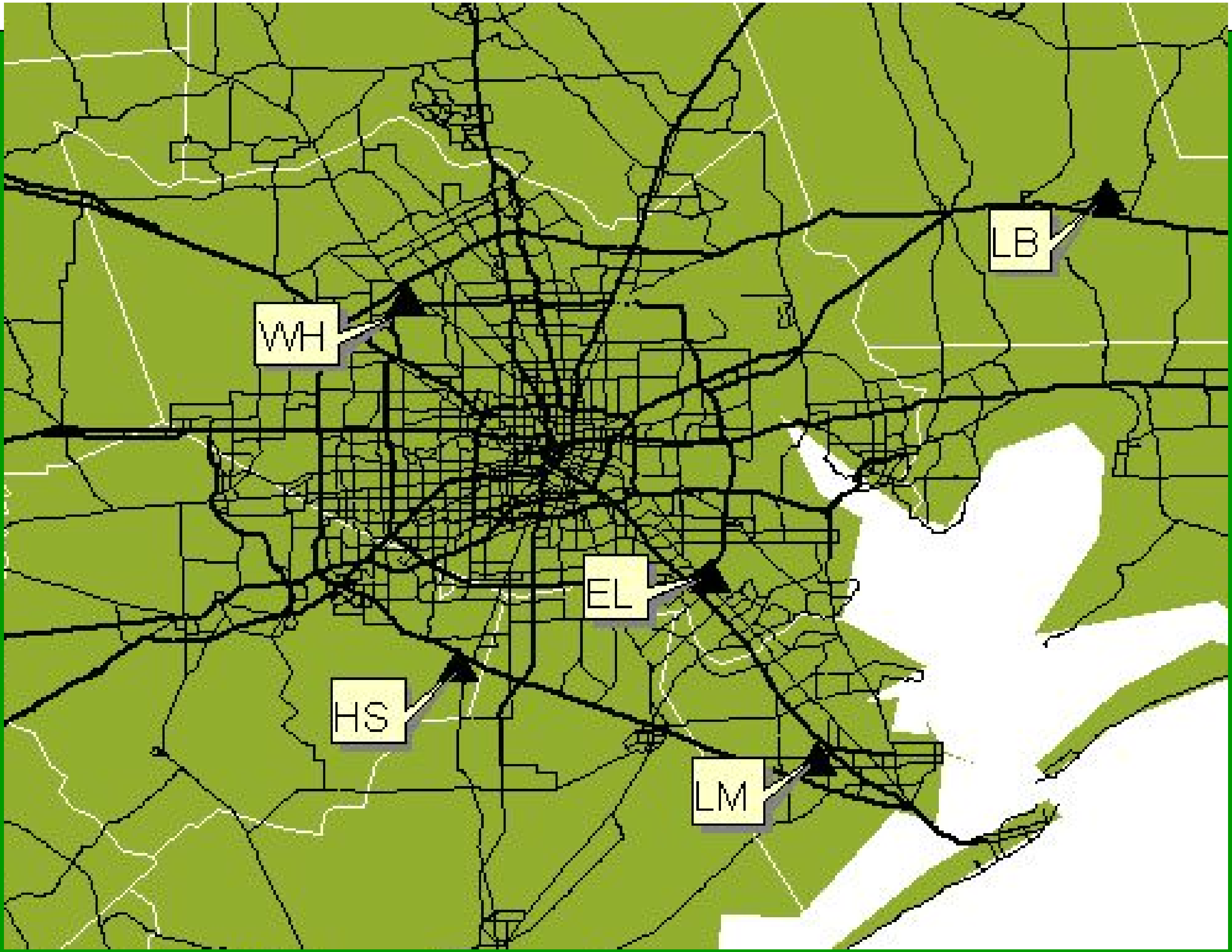
PBL Height


PBL Height (S1-GOES)
(S1-SLAB)
PBL Height (S2-FEImodify)
(S2-NOAH LSM)
PBL Height (S3-UHmodify)
(S3-NOAH LSM)
2900.0065
2187.50
1475.00
762.50
50.00
M
1
83
PAVE by MCNC
August 25,2000 22:00:00
Min= 50.00 at (82,48), Max= 2233.47 at (80,43)
August 25,2000 22:00:00
Min= 50.00 at (18,32), Max= 2526.18 at (54,41)
August 25,2000 22:00:00
Min= 50.00 at (58,34), Max= 2526.40 at (60,34)

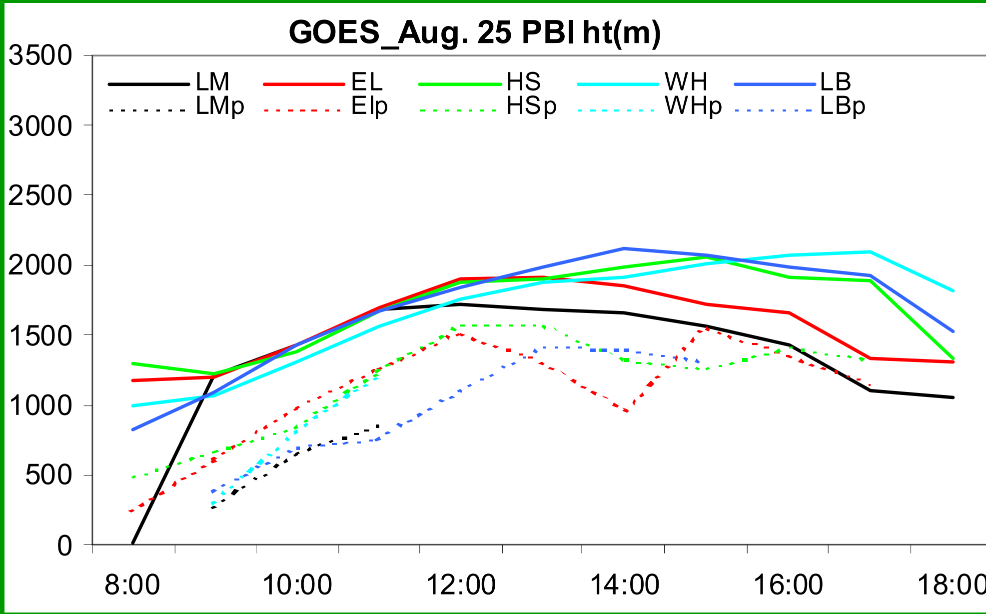

PBL Height (S1-GOES)
(S1-SLAB module)
PBL Height (S2-FEImodify)
(S2-NOAH LSM)
PBL Height (S3-UHmodify)
(S3-NOAH LSM)
4000.0065
3012.50
2025.00
1037.50
50.00
M
1
83
PAVE by MCNC
August 30,2000 20:00:00
Min= 50.00 at (36,18), Max= 2522.37 at (60,64)
August 30,2000 20:00:00
Min= 50.00 at (8,2), Max= 3550.99 at (54,33)
August 30,2000 20:00:00
Min= 50.00 at (8,2), Max= 3917.39 at (56,33)

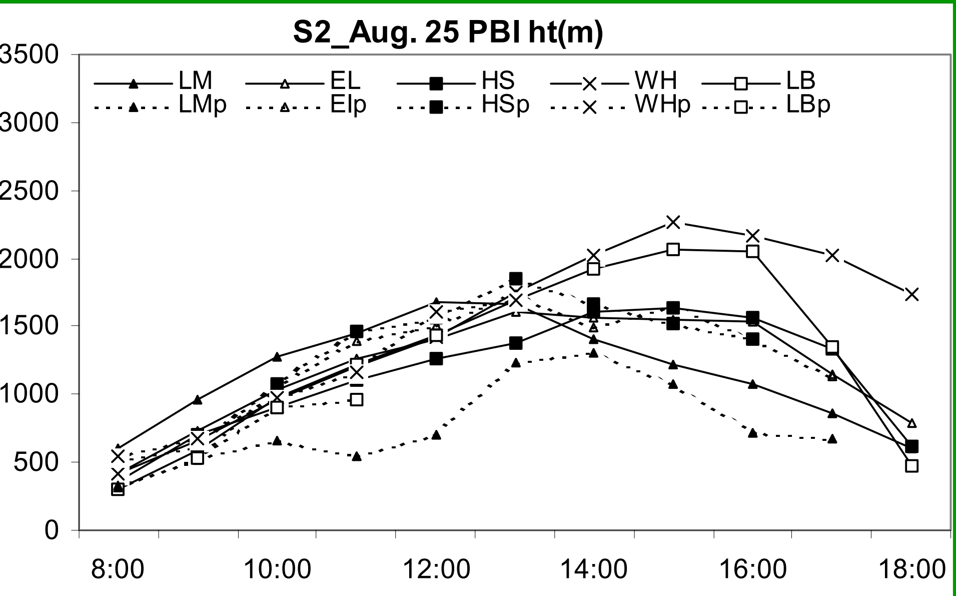
Wind Profiler Sites (TexAQS-2000)

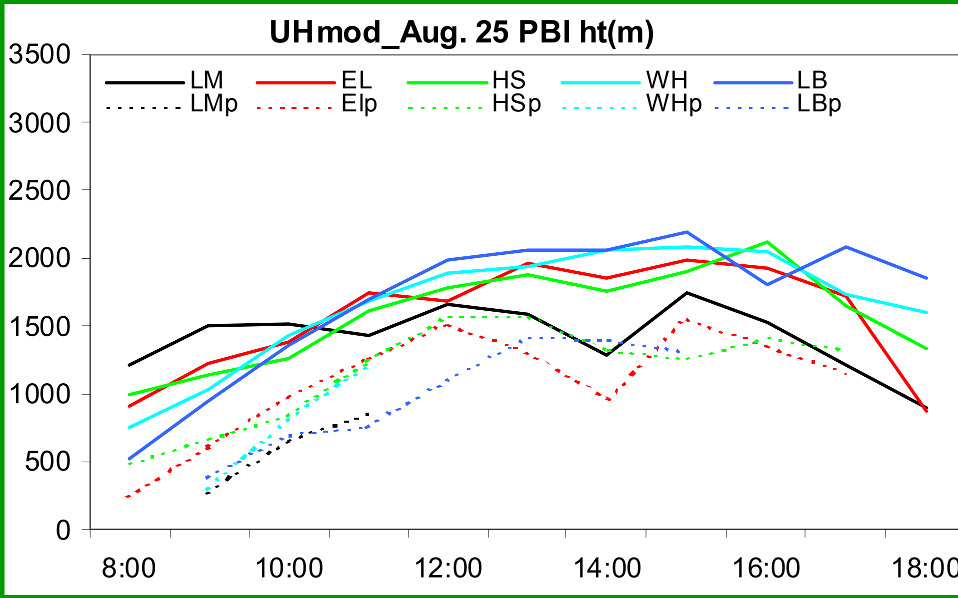
Mostly on rural LU/LC



PBL Height Analysis with slab/satellite data assimilation, S2 and S3A on Aug. 25, 2000

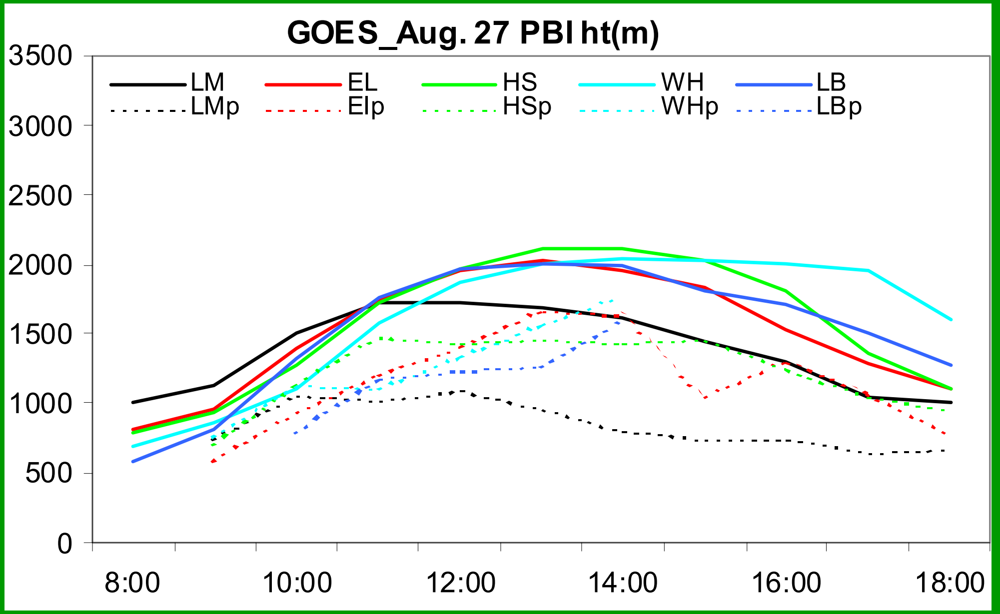


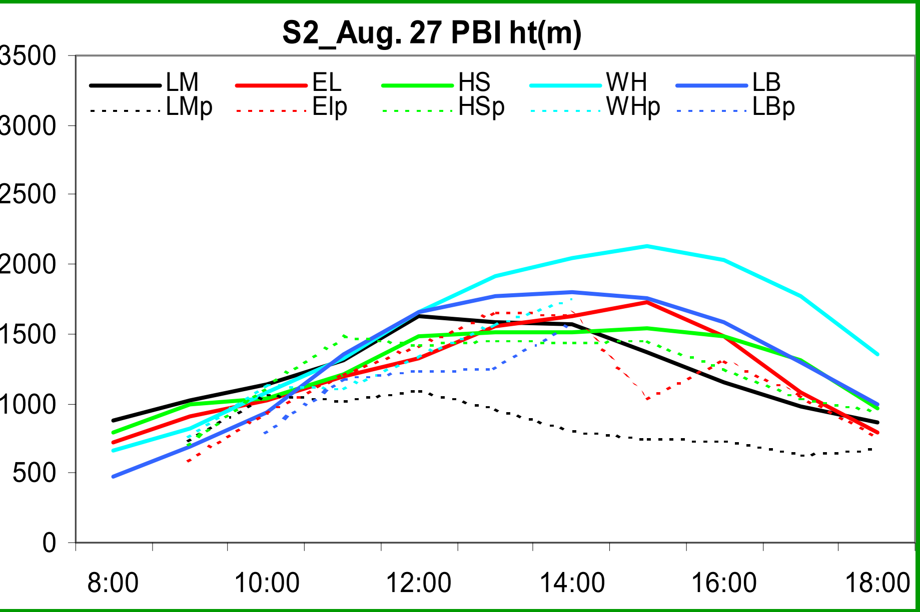


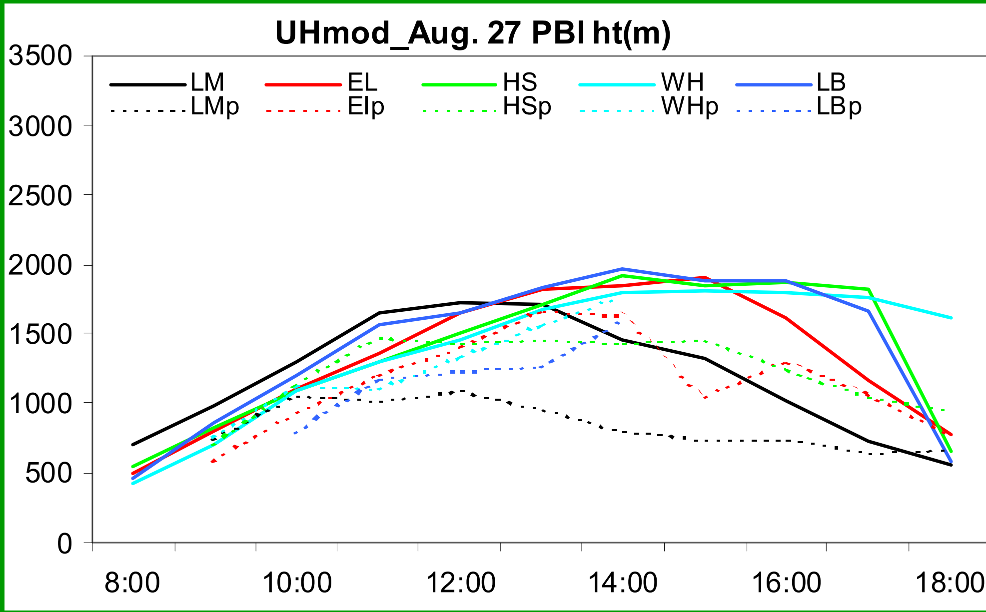


CST

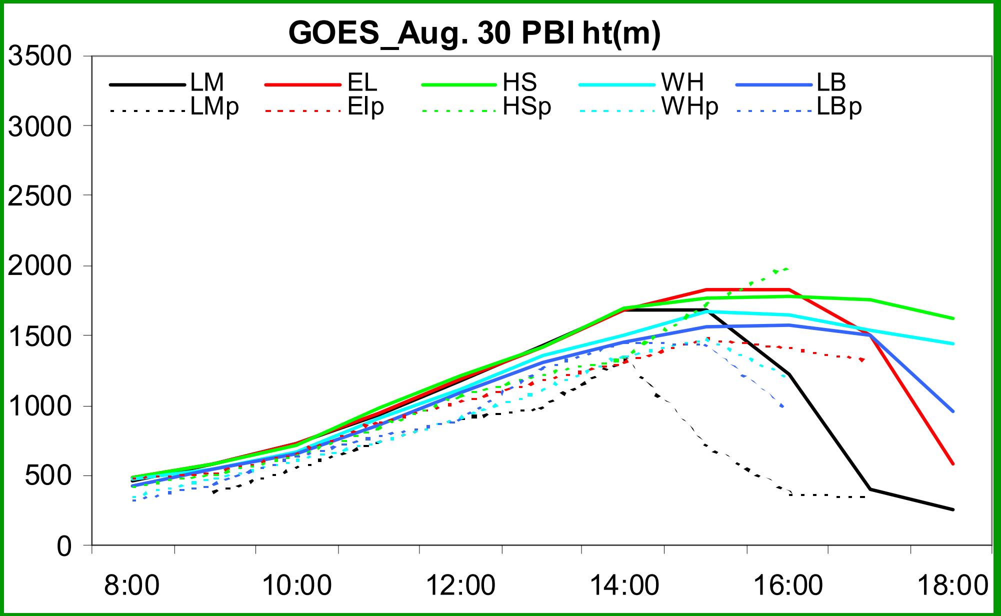
PBL Height Analysis with slab/satellite data assimilation, S2 and S3A on Aug. 27, 2000

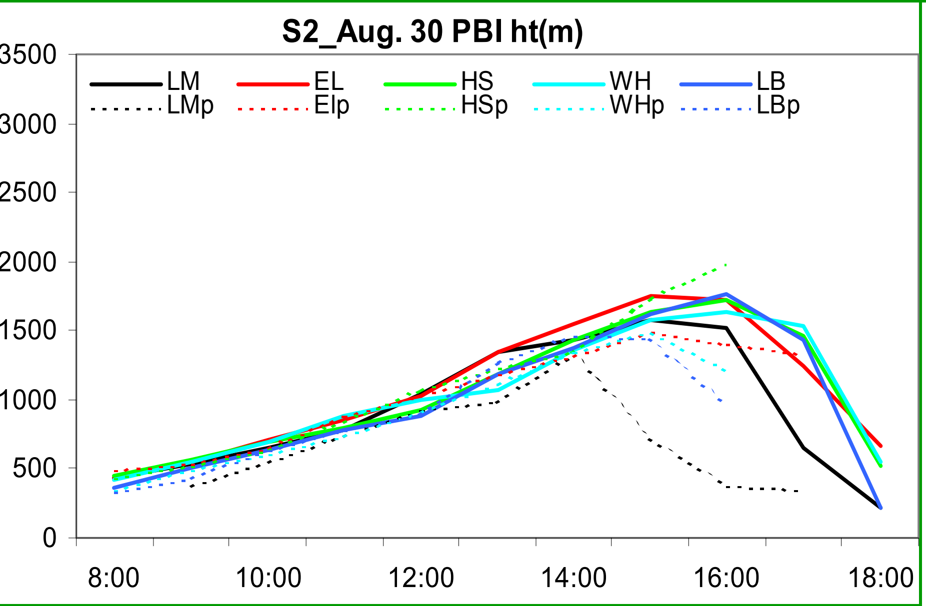


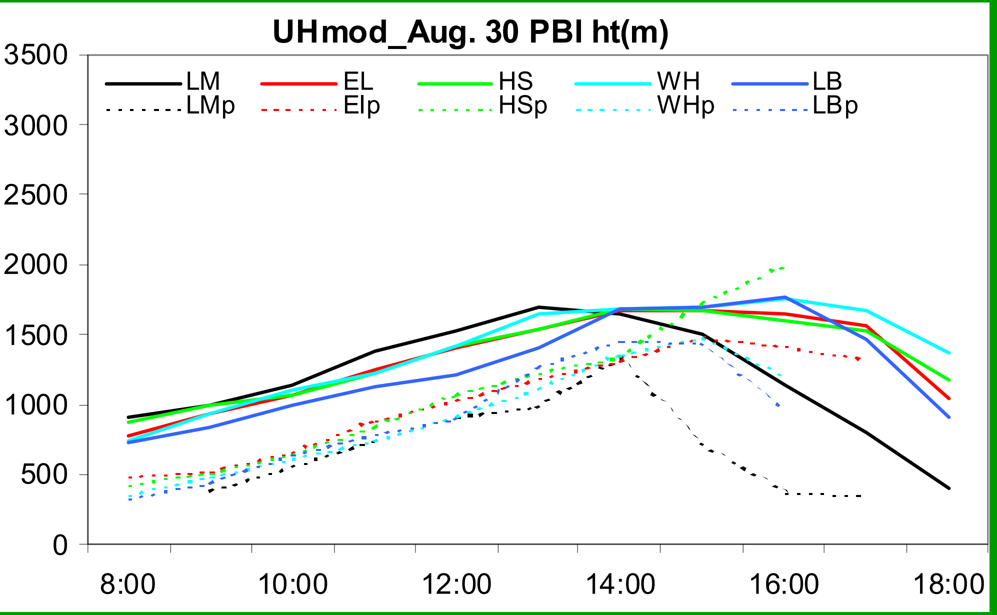




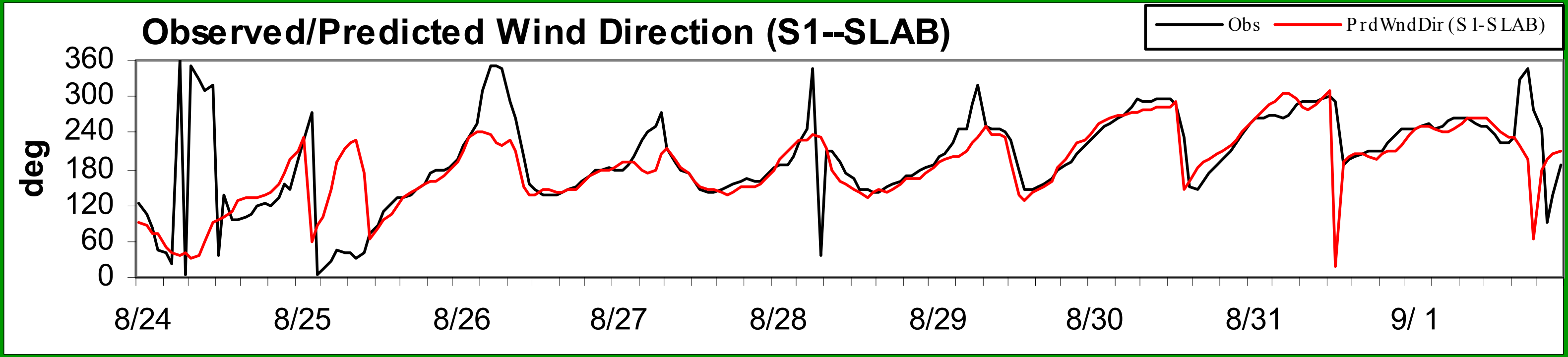
PBL Height Analysis with slab/satellite data assimilation, S2 and S3A on Aug. 30, 2000

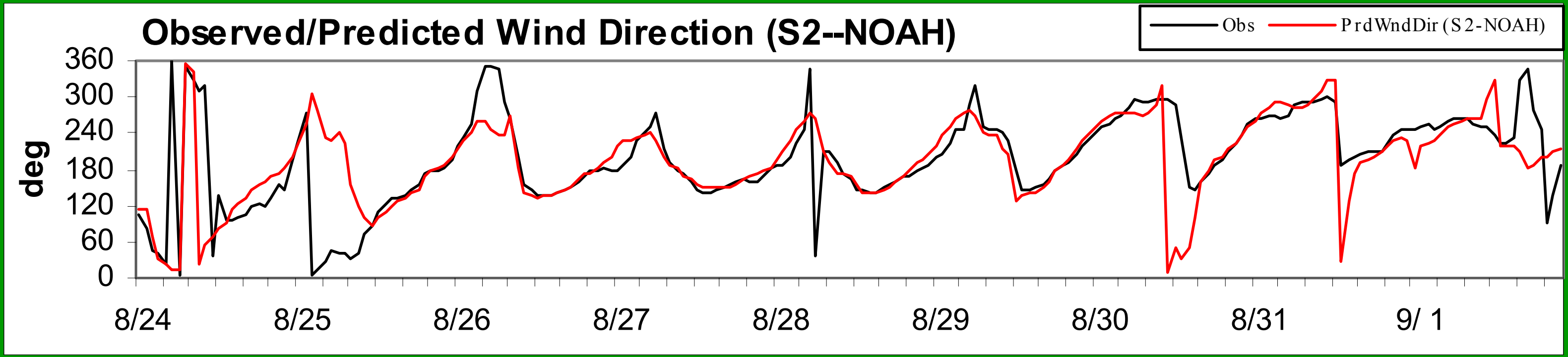


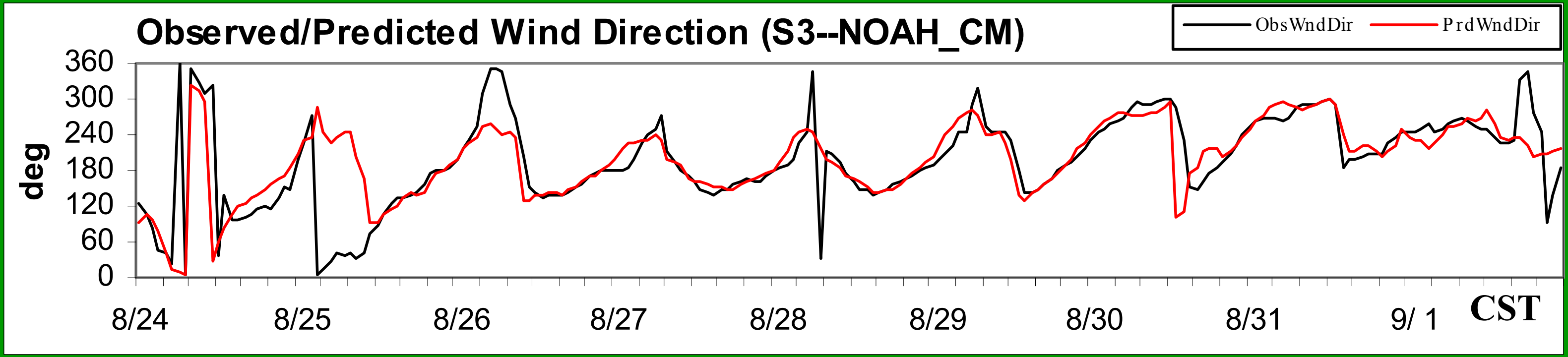




10m Wind Direction from S1, S2 and S3 simulations:

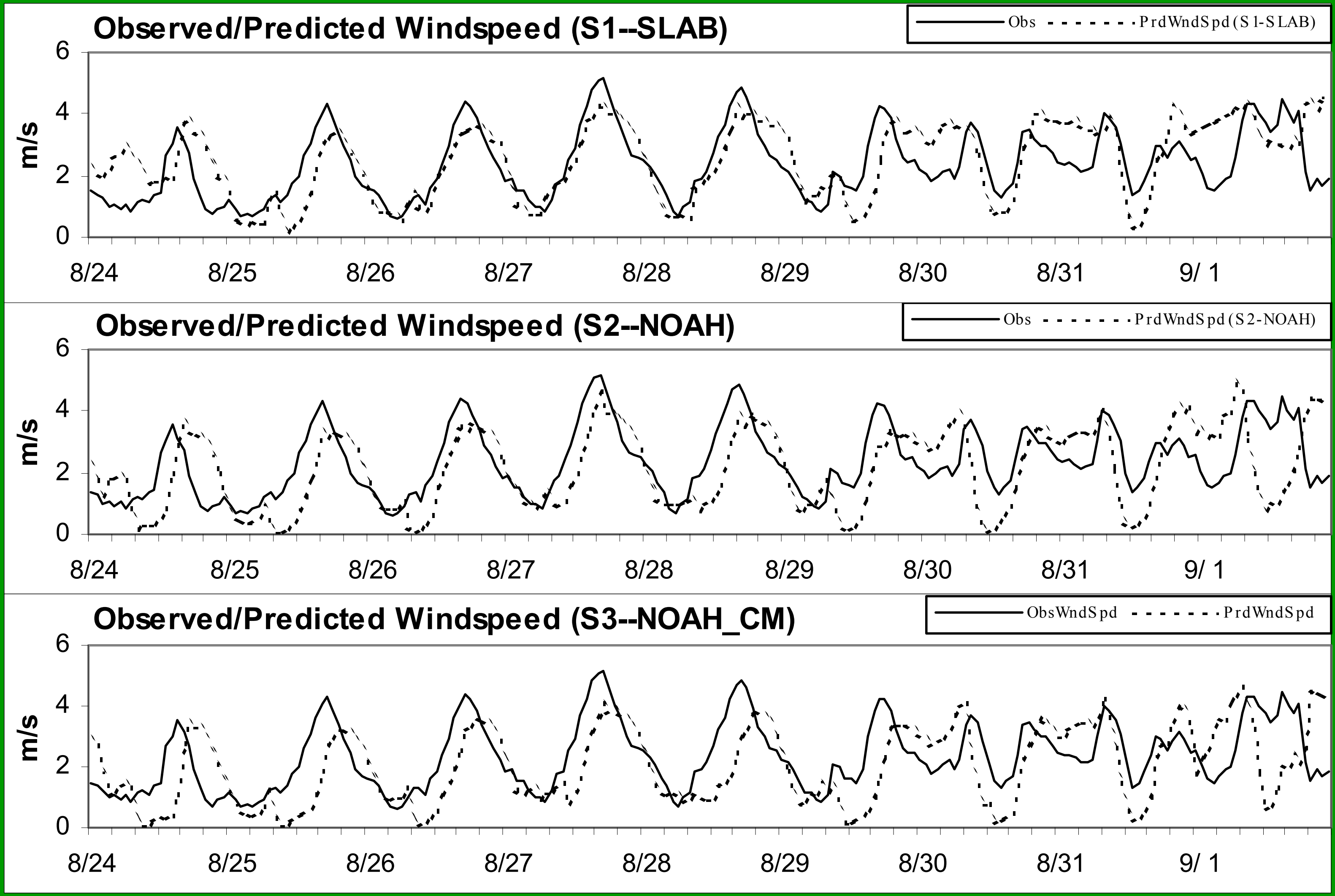






10m Wind Direction from S1, S2 and S3 simulations:

Shows 2-hr delay in wind speed development during day time!



Summary of UH MM5/NOAH simulation with standard USGS LU/LC input

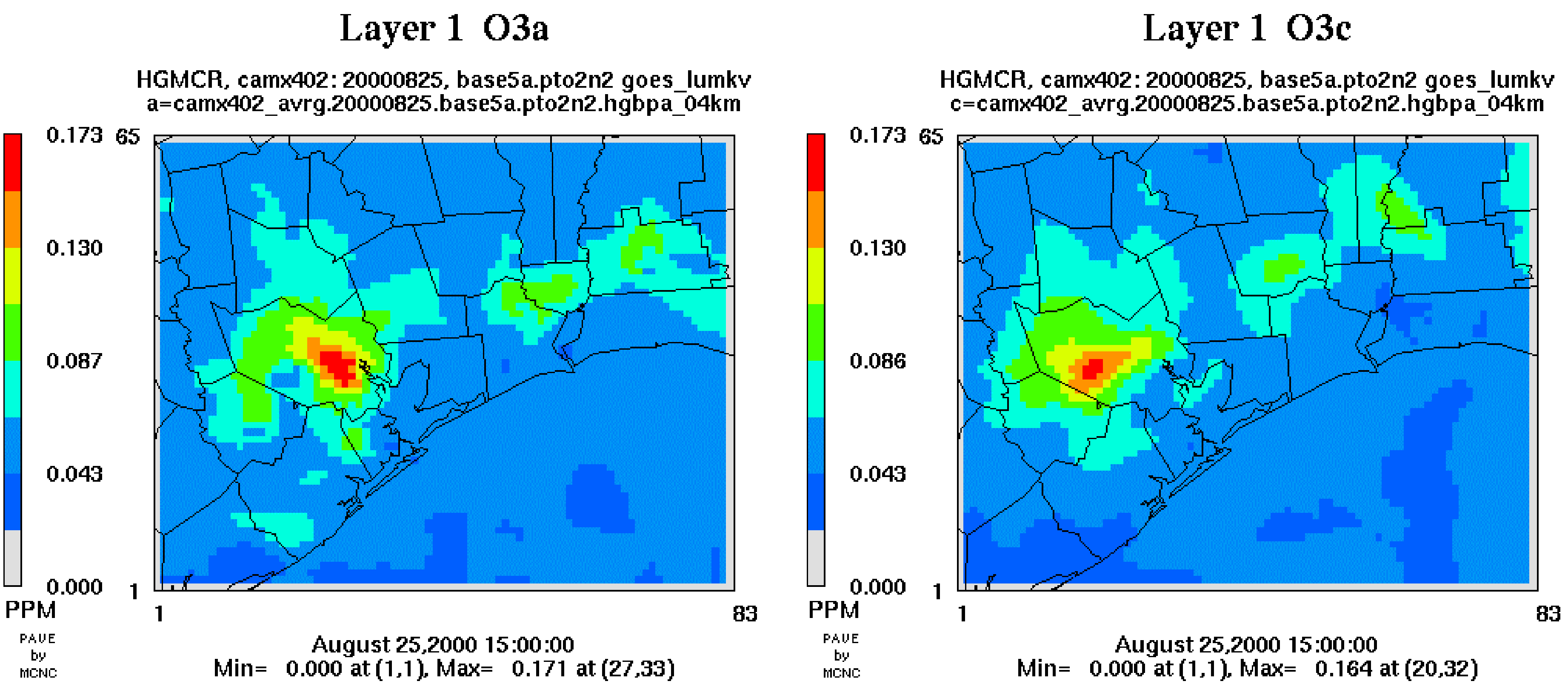
1. Bias in daytime temperature fixed with added canopy moisture in NOAH.
2. Still there are serious delays in the development of daytime wind speed build up.
3. Nighttime min. temperature bias issues addressed by applying the LU/LC dependent emissivity in NOAH
4. But, this DID NOT SOLVE the wind problem and made PBL height prediction somewhat worse
5. Started detailed land use and land cover data

   - developed methods to incorporate TFS LU/LC effects

   - estimate biogenic emissions for the new LU/LC data

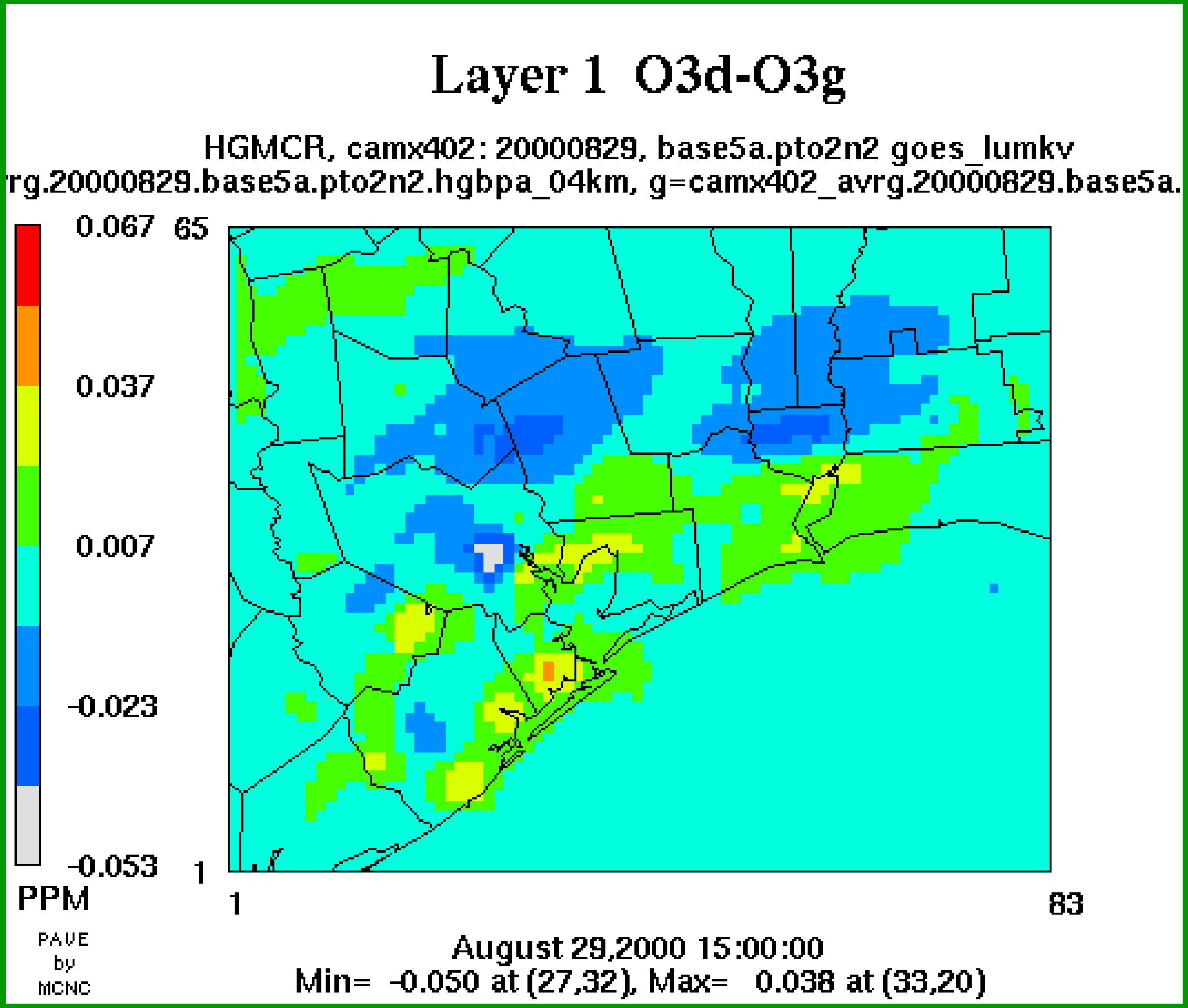
Preliminary Simulation of CAMx 4.02 using TAMU-Satellite assimilation and UH-S3A

UH MET TAMU MET



UH met case shows higher ozone in east Harris County.

UH met – TAMU met



Differences were higher later in the afternoon in this case.

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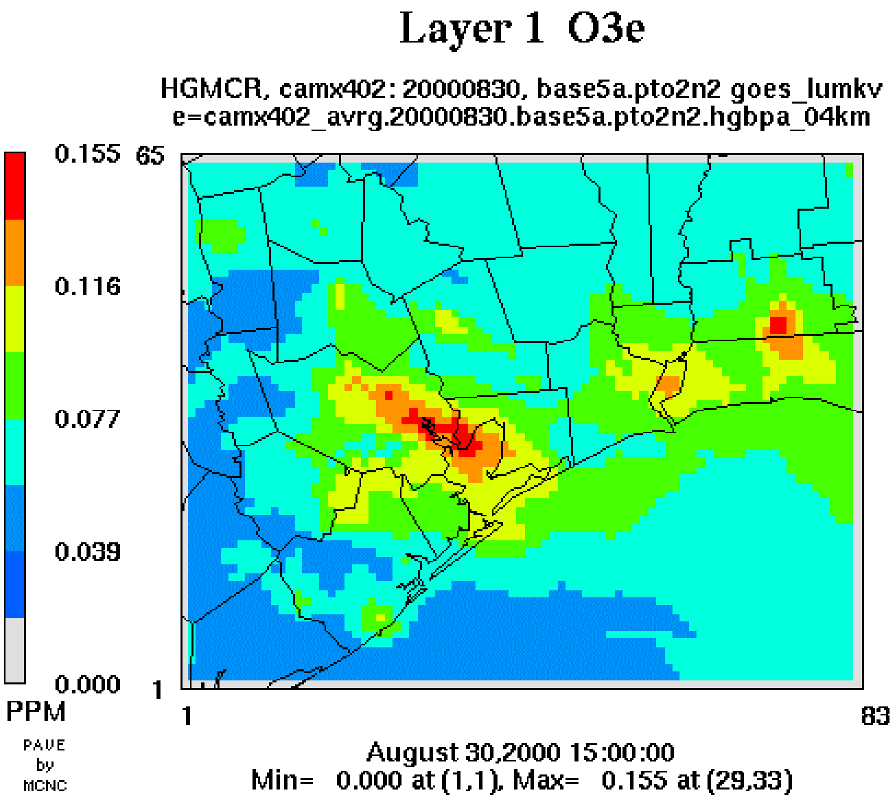
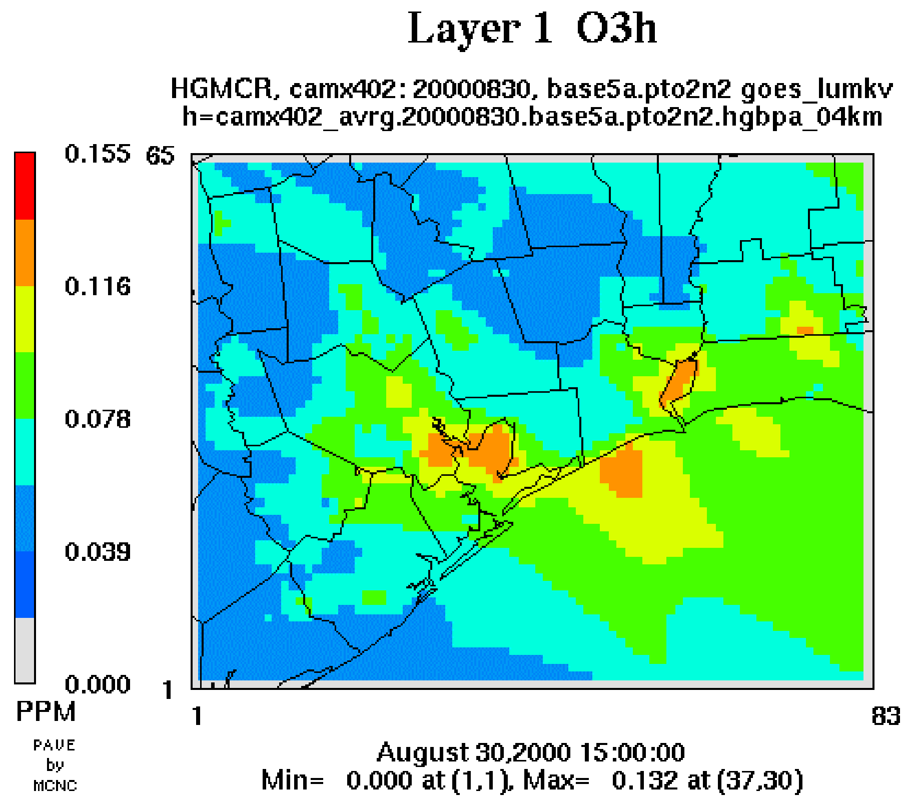
UH MET

TAMU MET





Higher ozone is observed closer to the source areas in the UH met case.

UH met – TAMU met

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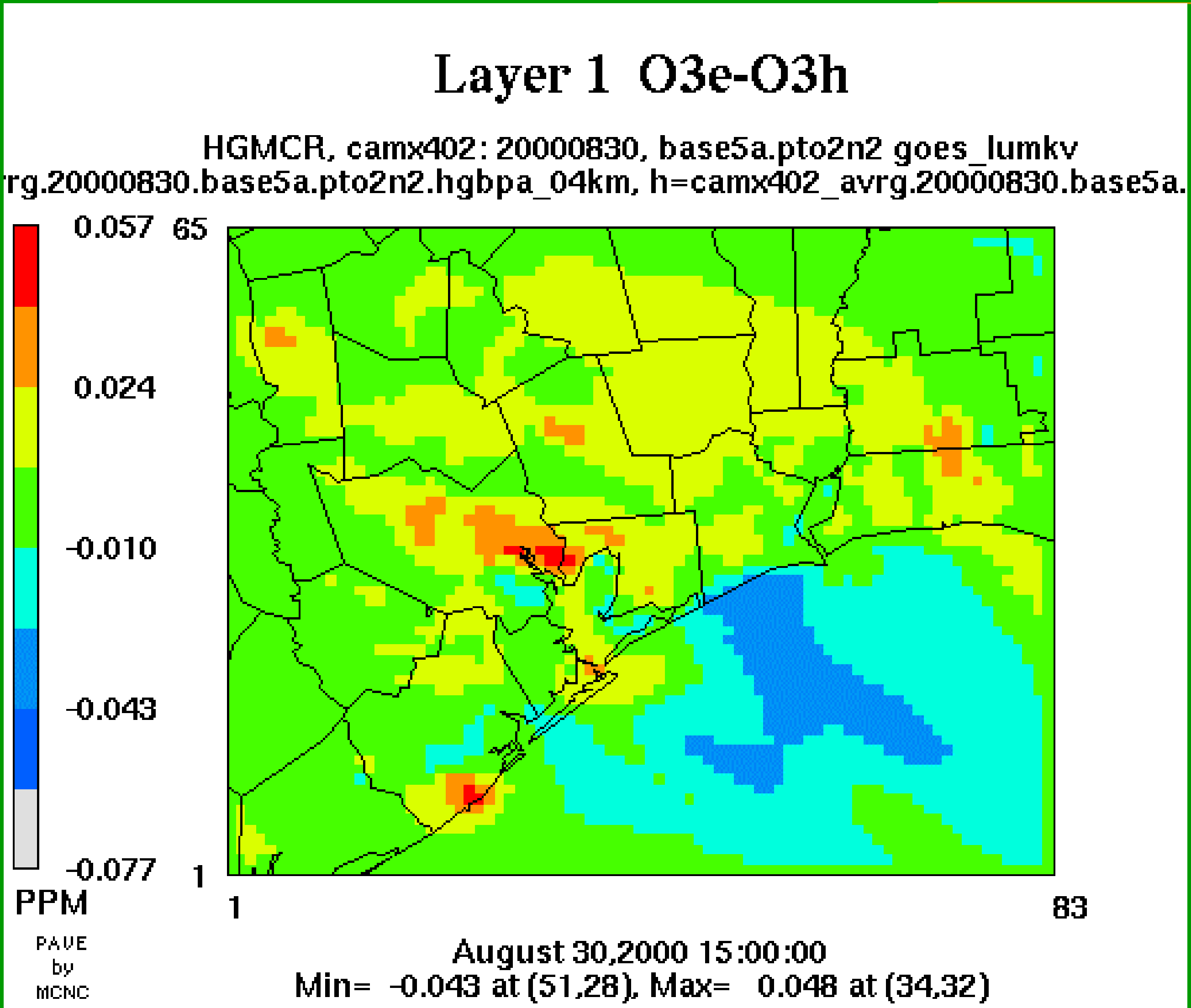

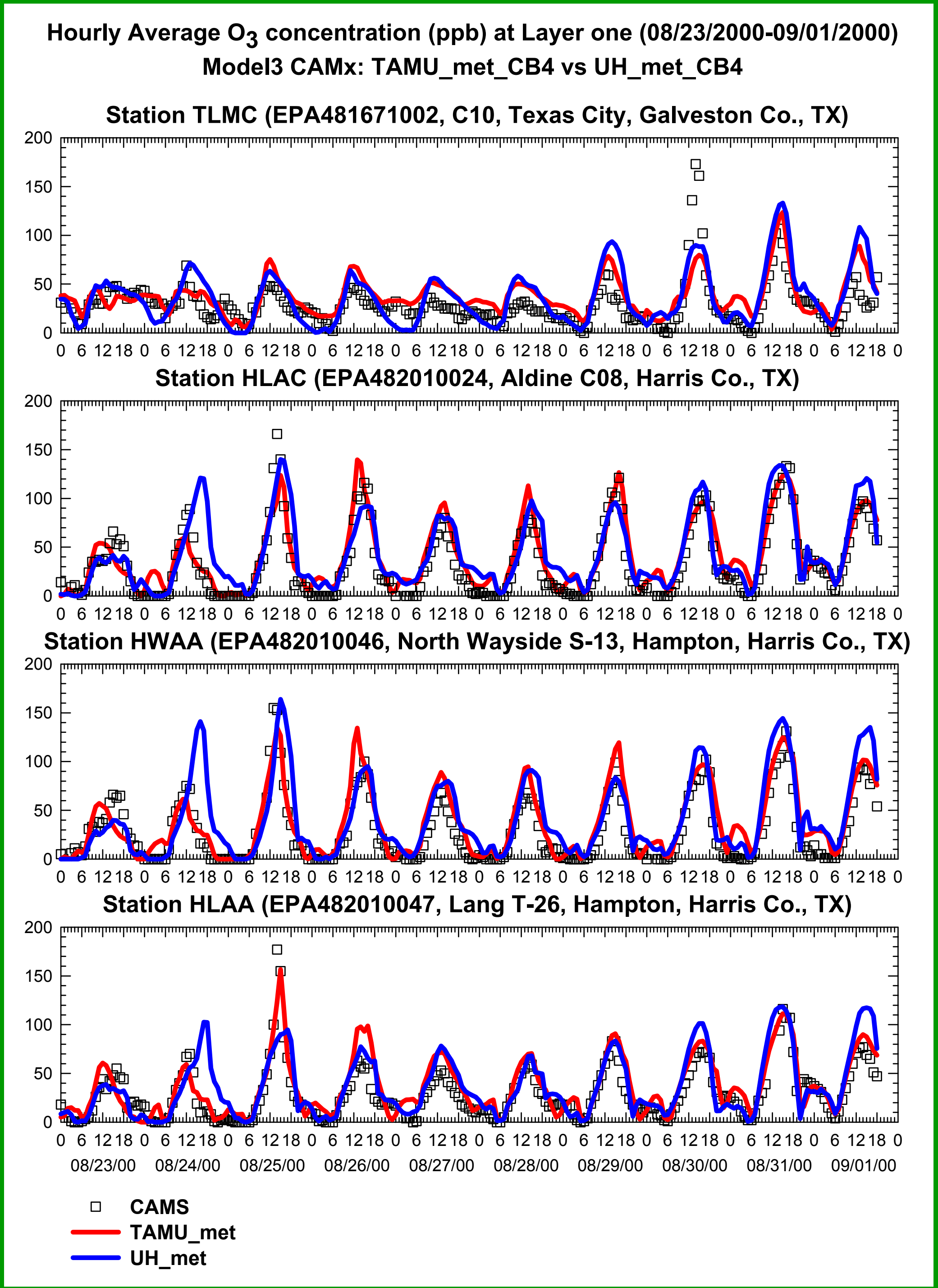

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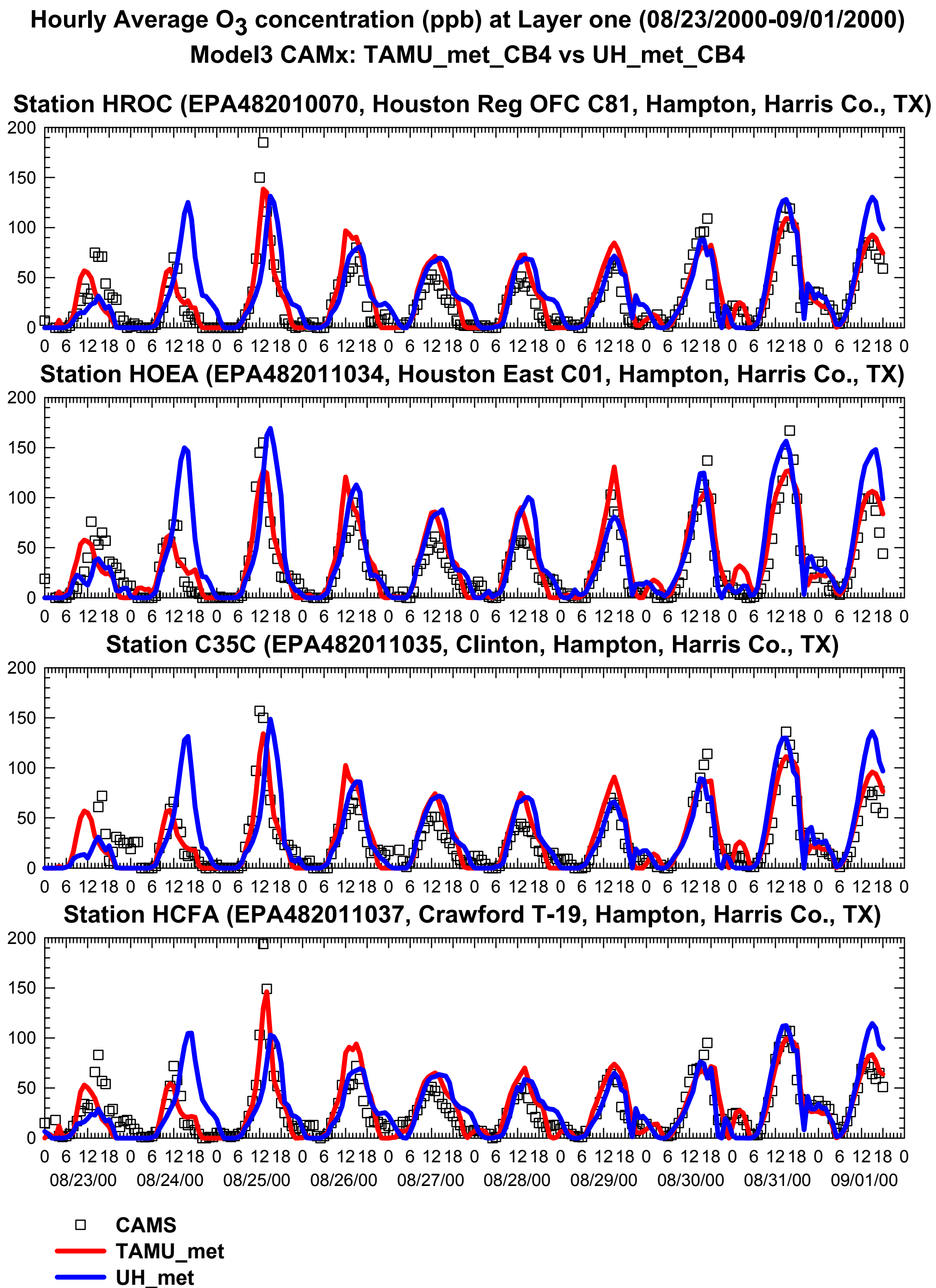


Discussion

Simulated wind appears to lag in the UH met, giving higher ozone concentrations closer to the source.

Peak ozone values are similar (sometimes UH met is higher, sometimes TAMU met is higher). UH met shows higher ozone values overall.

Ozone variations (differences observed in specific locations) are very high due to the placement of the ozone plume.

Current Other Efforts to Improve MM5 Simulations

AMS Conference, Seattle, January 10-15, 2004

1. Liu et al. – Different efinition of convective velocity, linkage with LSM, new PBL height algorithms; $U_c{}^2 = U^2 + aW^{*2}$

   (MRF's parameterized one vs. standard CBL similarity)

   $$W^* = C(\theta_{vg} - \theta_{va})^{0.5} \quad \text{vs.} \quad W^* = \left[\frac{gh}{T} \overline{w'\theta_v'} \right]^{1/3}$$

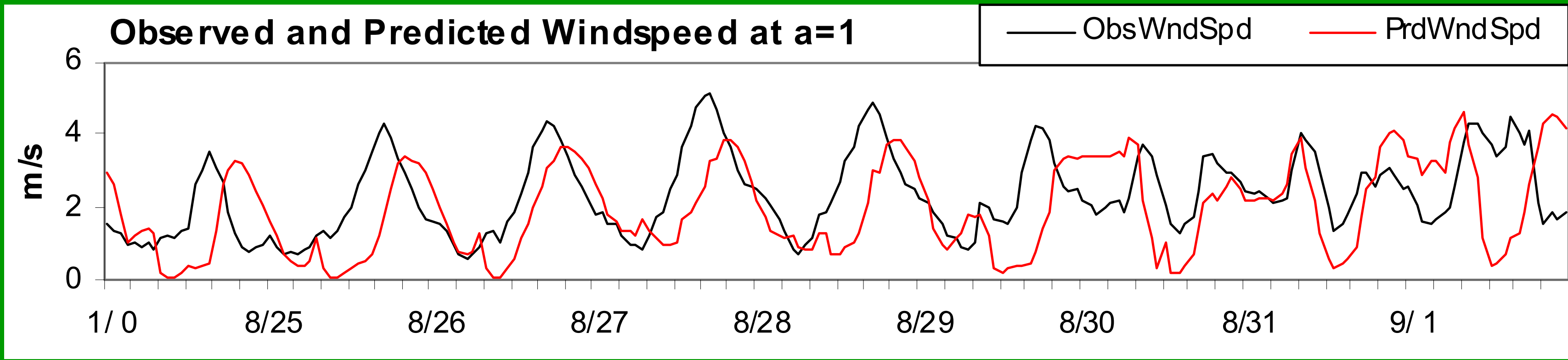
2. Lee et al. – Application of different parameterizations for momentum and heat diffusivity to improve nighttime and morning transition time (Monti et al, 2002)

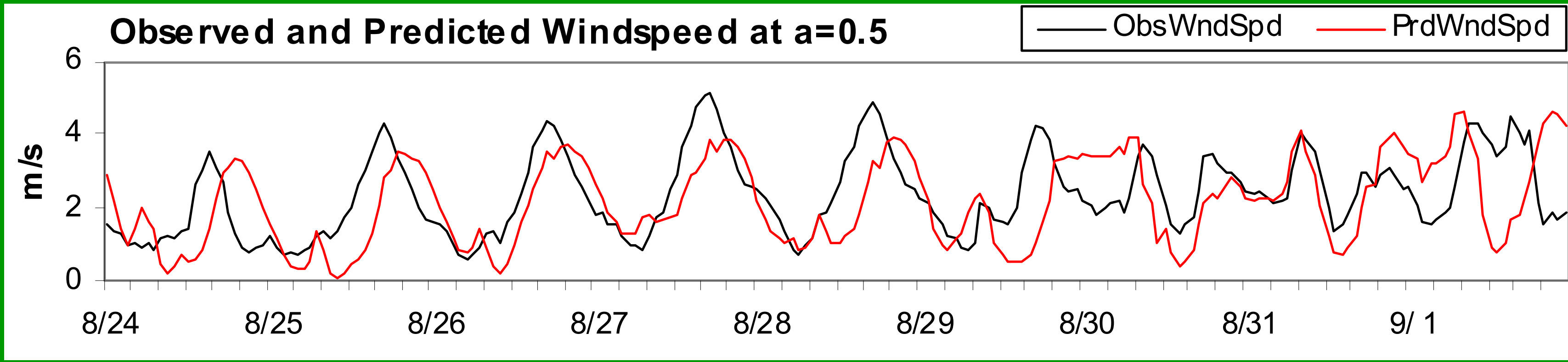
   $$\frac{K_m}{\sigma_w^2 / |dV/dz|} = (0.34) Ri_g^{-0.02} \qquad \frac{K_h}{\sigma_w^2 / |dV/dz|} = (0.08) Ri_g^{-0.49}$$

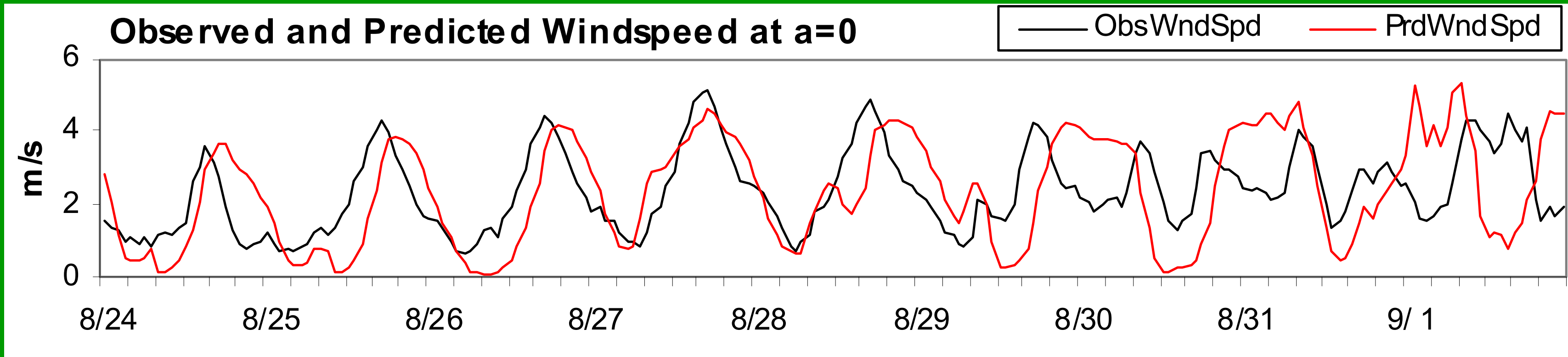
3. Da-lin Zhang – Diurnal variation in surface temperature and wind generated by various boundary layer schemes

Additional UH-MM5 Sensitivity Study with different a (similar to Craig Trembeck's experiment)

$$U_c^{\ 2} = U^2 + aW^{*2}$$







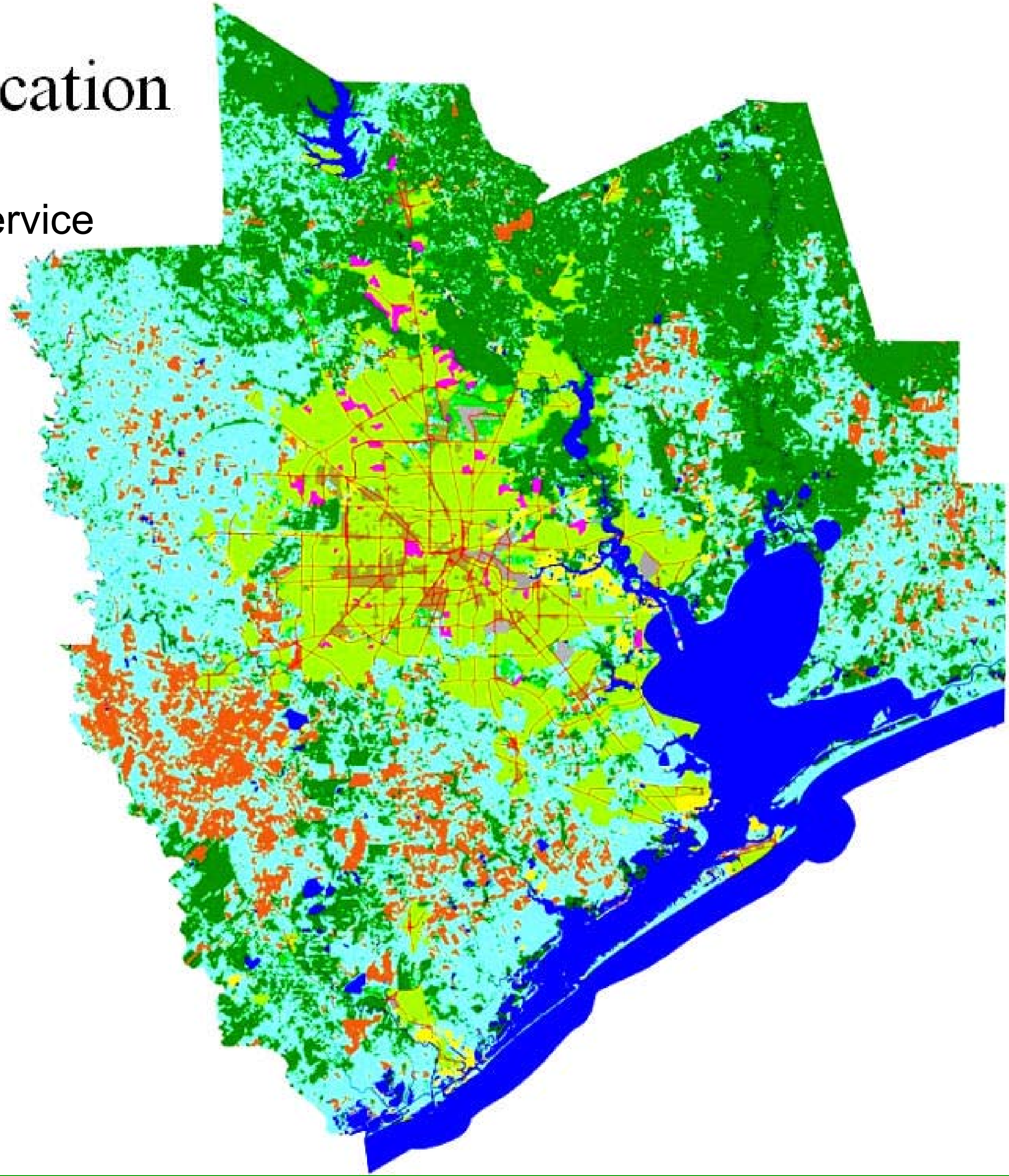
Use of new LU/LC data

Replace current USGS 25-category LU data with new LU datasets for the 8 counties in the Houston-Galveston area.

1. Change land use data definition inside TERRAIN output.
2. Using newly-generated TERRAIN file which contains newer land use definition to create initial condition for MM5.
3. Increase the LANDUSE table definition from original 25-category to 42-category.
4. Modify the code of MM5 modeling system to be able to compatible with the added LU categories.
5. Modify the code of MM5 modeling system to be able to feed in the grid-based emissivity, albedo and roughness parameters.

Land Use Classification

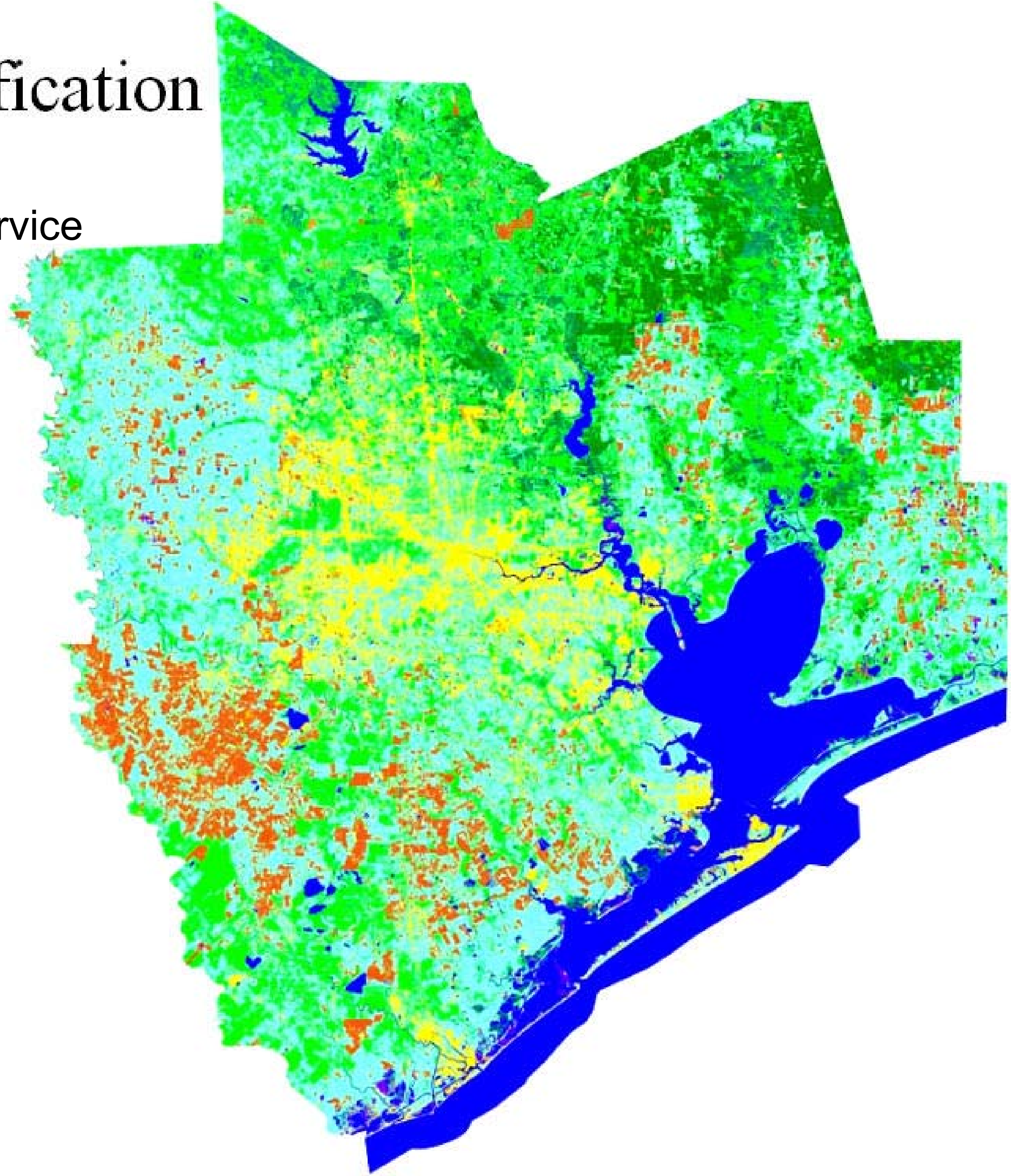
Stephen Stetsen, GEM
Pete Smith, Texas Forest Service



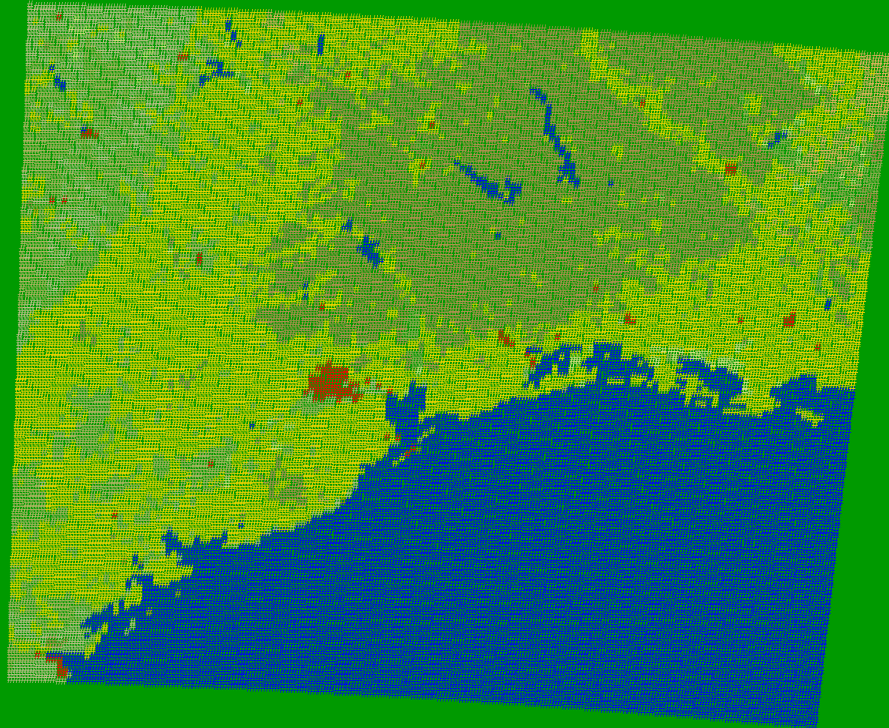
- Forest
- Range
- Agriculture
- Residential
- Commercial
- Industrial
- Parks
- Transportation Corridors
- Urban Forest
- Urban Grass
- Urban Barren
- Urban Impervious
- Rural Impervious
- Urban Airports
- Water

Land Cover Classification

Stephen Stetsen, GEM
Pete Smith, Texas Forest Service

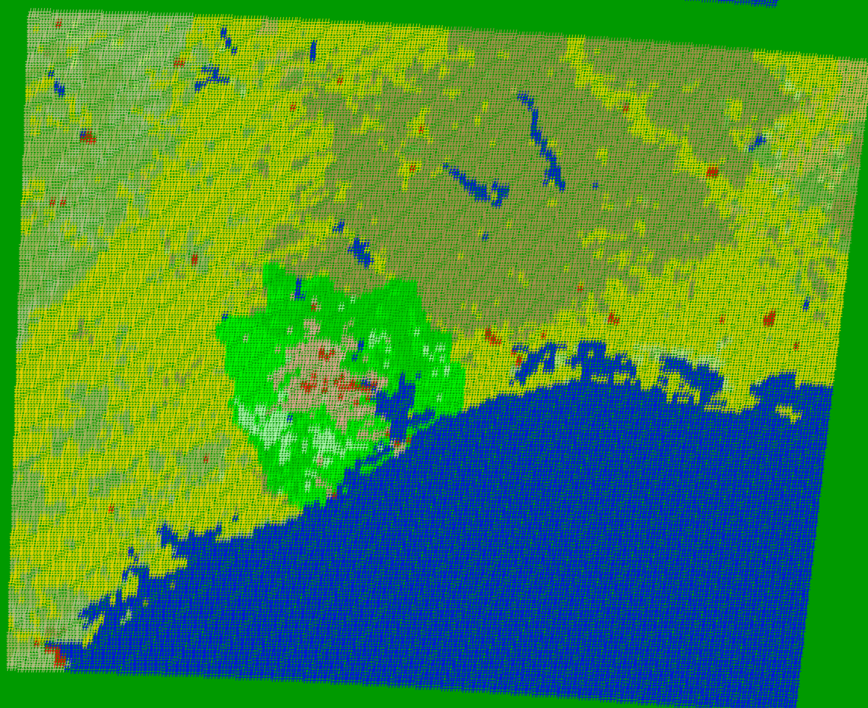


Forest Broadleaf
Forest Coniferous
Forest Mixed
Grass
Barren
Beach
Impervious
Roads
Wetland
Water



4km_USGS LU data

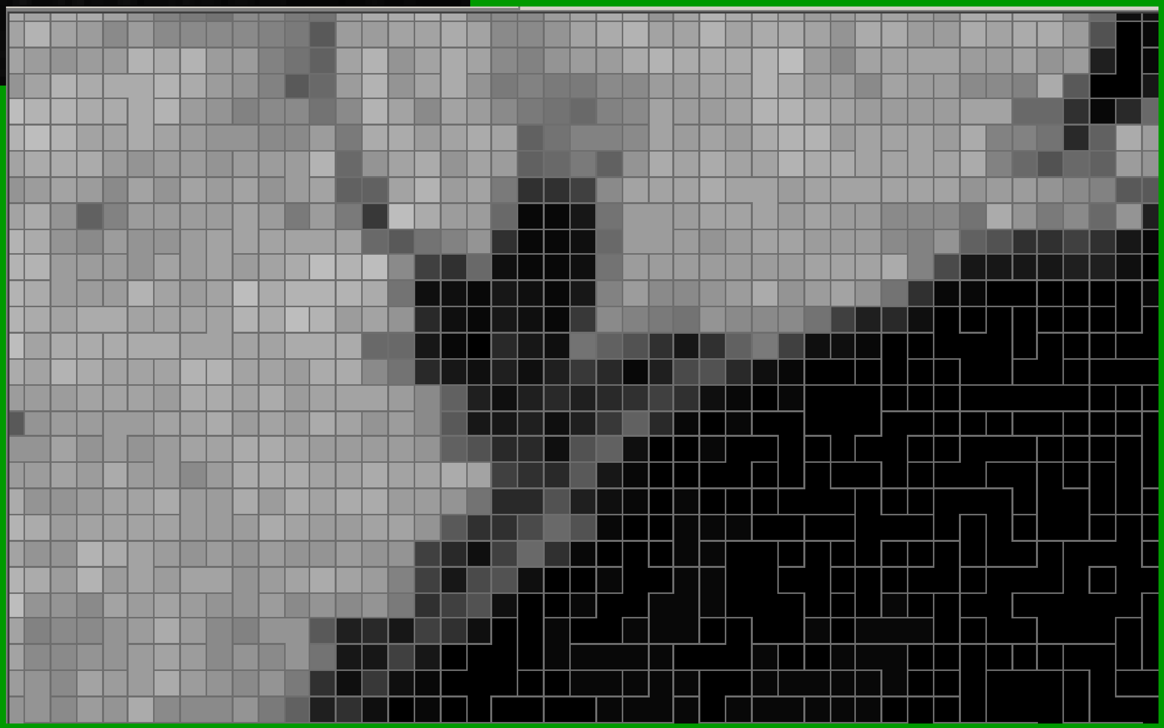
- Urban
- Dryland Cropland
- Cropland/Grassland
- Cropland/Woodland
- Grassland
- Shrubland
- Savanna
- Deciduous Broadleaf
- Evergreen Needleleaf Forest
- Water Bodies
- Wooded Wetland



4km_ New lu data

- Urban
- Dryland Cropland
- Cropland/Grassland
- Cropland/Woodland
- Grassland
- Shrubland
- Savanna
- Deciduous Broadleaf
- Evergreen Needleleaf Forest
- Water Bodies
- Wooded Wetland
- agriculture bare
- airports_urban
- forests
- parks
- rangeland
- residential
- rural impervious
- urban commercial
- urban forest
- urban grass
- urban industrial
- water

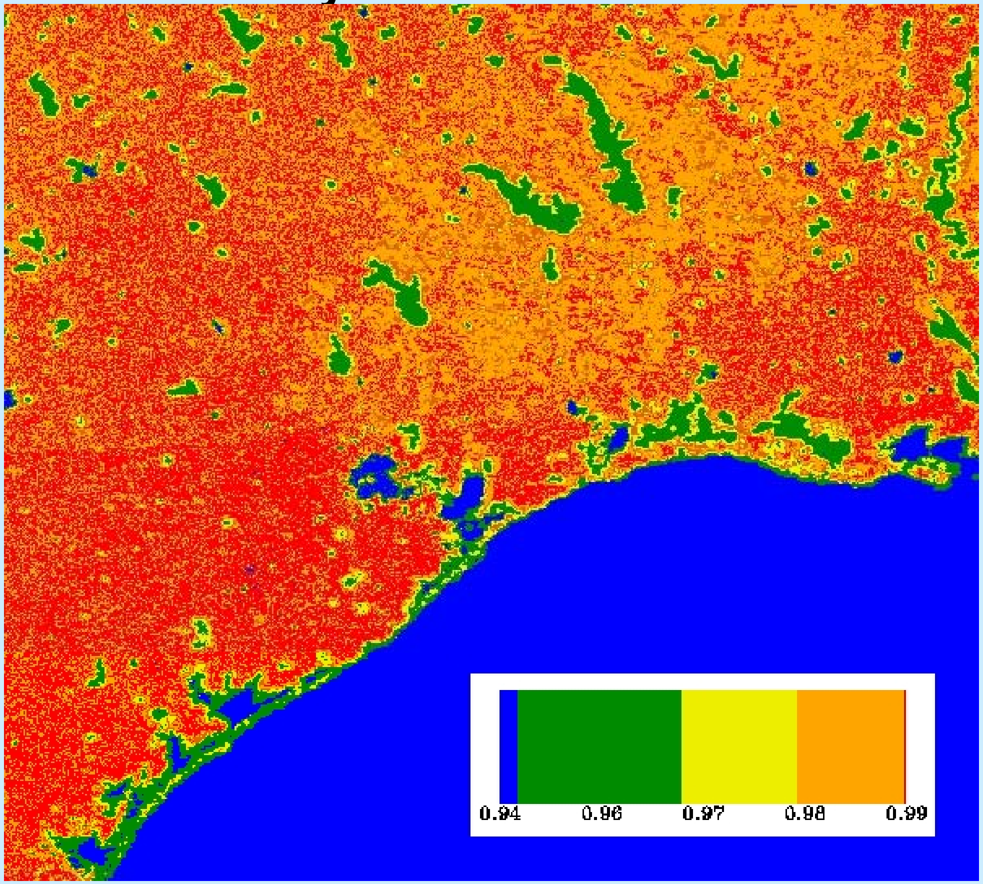
I-km resolution albedo estimated from LANDSAT data

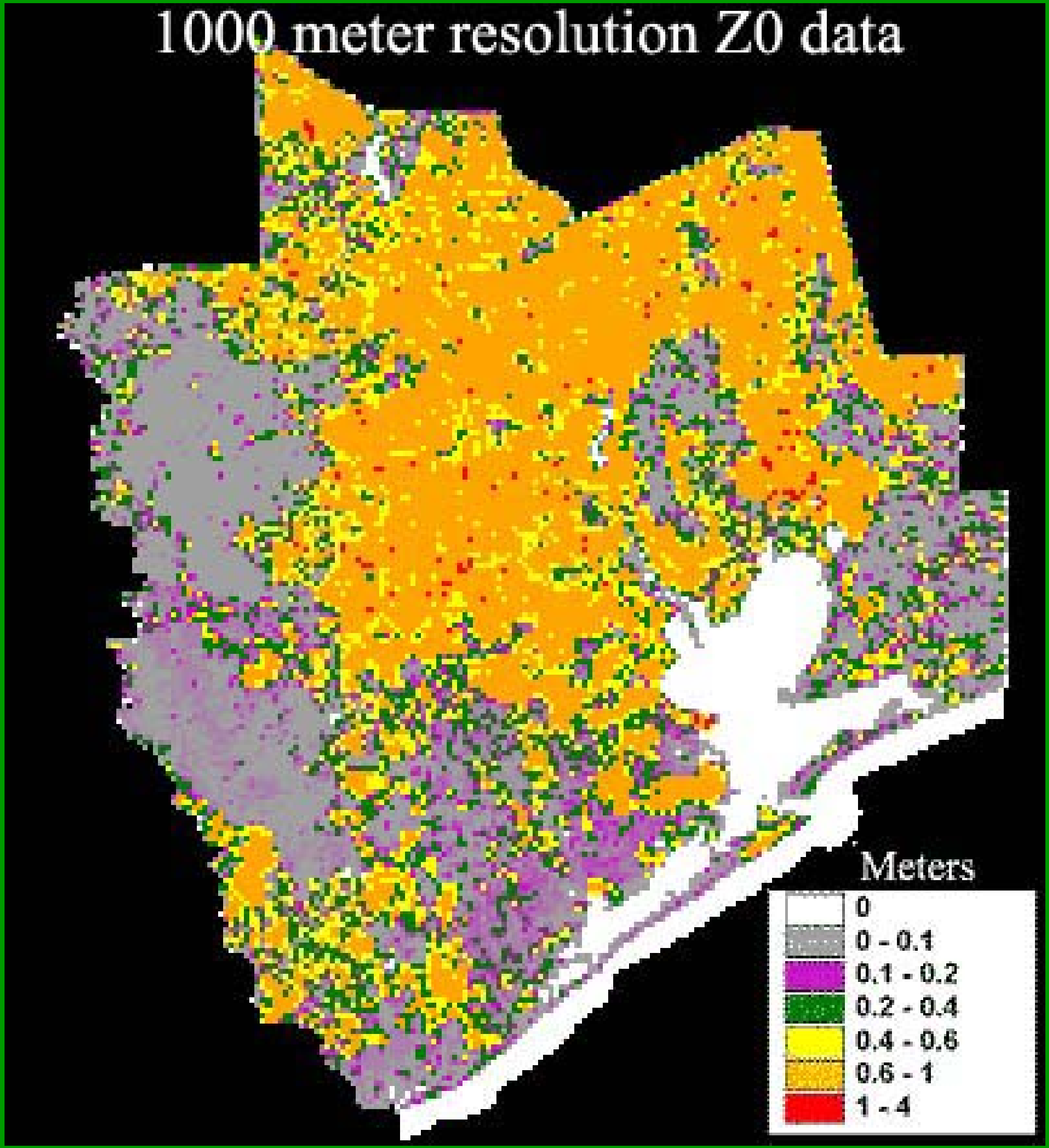


4-km resolution digitized albedo to be used with MM5 modeling

I-km resolution emissivity estimated from LANDSAT data

Estimation of Emissivity





I-km resolution roughness length estimated from LANDSAT data