

Impacts of urban/rural LU/LC changes on
MM5 simulated UHI-conditions in the
Houston-Galveston region

by

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- D. Nowak, USFS
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OUTLINE

- PROJECT GOALS
- uMM5 CONFIGURATION
- SYNOPTICS: 700 MB & SFC
- DOMAIN 1: MM5* VS NWS WINDS
 - *MESO CONVENTION:
 - FULL BARB = 1 M/S; FLAG = 5 M/S
- UHIs and FLOWs: current vs. re-forested
- ONGOING EFFORTS

Project Summary:

- **Overall:** Evaluate impacts of de- & re-forestation on Houston O₃ levels (**Nowak**)
- **O₃ SIP:** Aug-Sept Texas2000, Houston (**Byun**)
- **Met Model:** EPA uMM5 (**Martilli, Dupont, Ching**)
- **Improved uMM5 input:** (**Burian, Stetson, Taha**)
- **CPU:** SJSU 96 cluster (**Balmori**)
- **Programming and graphics:** (**Noble**)
- **Evaluation:** (**Taha**):
 - uMM5 vs. MM5 performance
 - uMM5 sensitivity to LU/LC changes

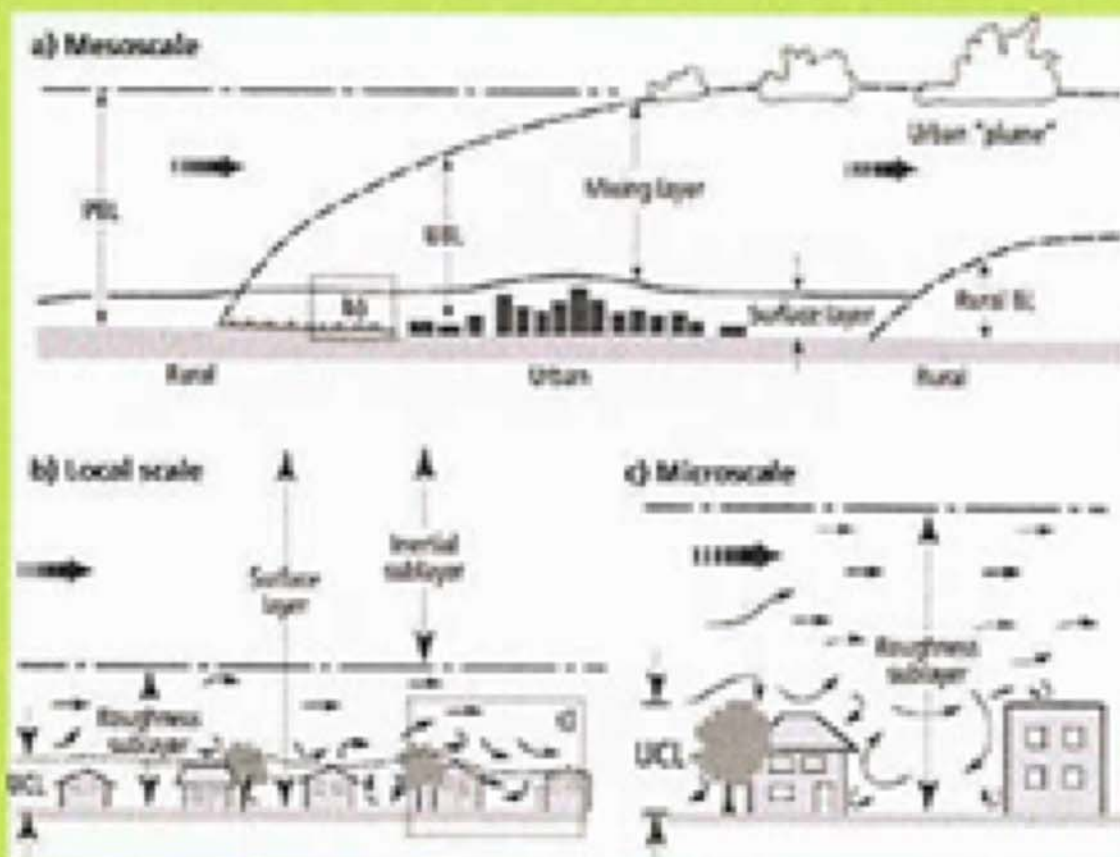


Figure 1. Schematic of climatic scales and vertical layers found in urban areas.

Urbanization Techniques

- **Urbanize**: surface, SBL, & PBL momentum, thermo, & TKE Eqs
- Allows prediction *within* UCL
- From vegetation canopy-model of Yamada (1982)
- Veg parameters *replaced* with urban (GIS/RS) terms
 - Brown and Williams 1998
 - Masson 2000
 - Sievers 2001
 - Martilli et al. 2001 (in TVM)
 - Dupont et al. 2003 (in MM5)
 - LLNL 2004

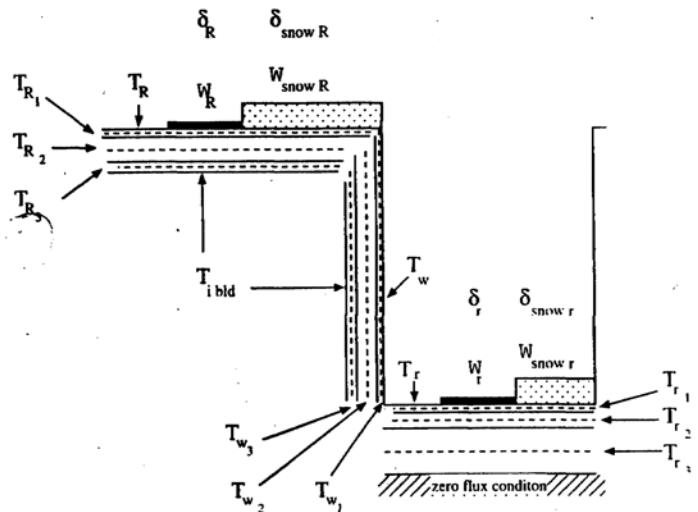
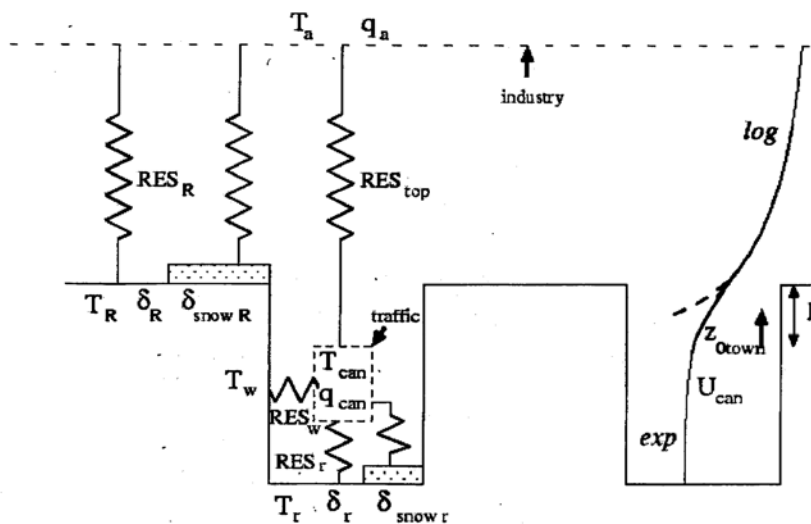


Figure 1. Discretization of the surfaces (roof, wall, road) and prognostic variables: layer temperatures T_{s_k} ($s = R, w, r$; here three layers are displayed for each surface, so $k = 1, 2, 3$), surface water content W_s ($s = R, r$), surface snow content W_{snow_s} ($s = R, r$). The layer temperatures are representative of the middle of each layer (dotted lines). The surface temperatures are assumed to be equal to the surface-layer temperature: $T_s = T_{s1}$. The internal building temperature T_{ibld} is prescribed. Fractions of water or snow (δ_s and δ_{snow_s} , respectively) are computed from the water and snow contents (see text). Snow density, albedo and temperature are computed independently for roof and road by a snow mantle scheme (in this paper, a one-layer scheme was chosen).



Aerodynamical resistances

wind profile

Figure 15.3: Energy fluxes between the artificial surfaces and the atmosphere.

Urban Parameterization for Mesoscale Models:

Martilli et al. (2000)

Momentum

Three terms are added to the horizontal momentum equations to account for walls, roofs, and streets.

Street

$$M_{S_i} = -\rho u_{*S}^2 \frac{U_i}{\sqrt{u^2 + v^2}} \left[\frac{S_S}{V - V_b} \right]$$

Roof

$$M_{R_i} = -\rho u_{*R}^2 \frac{U_i}{\sqrt{u^2 + v^2}} \left[\frac{S_R}{V} \right]$$

Wall

$$M_{W_i} = -\rho C_{drag} U_{ort} U_i \left[\frac{S_W}{V - V_b} \right]$$

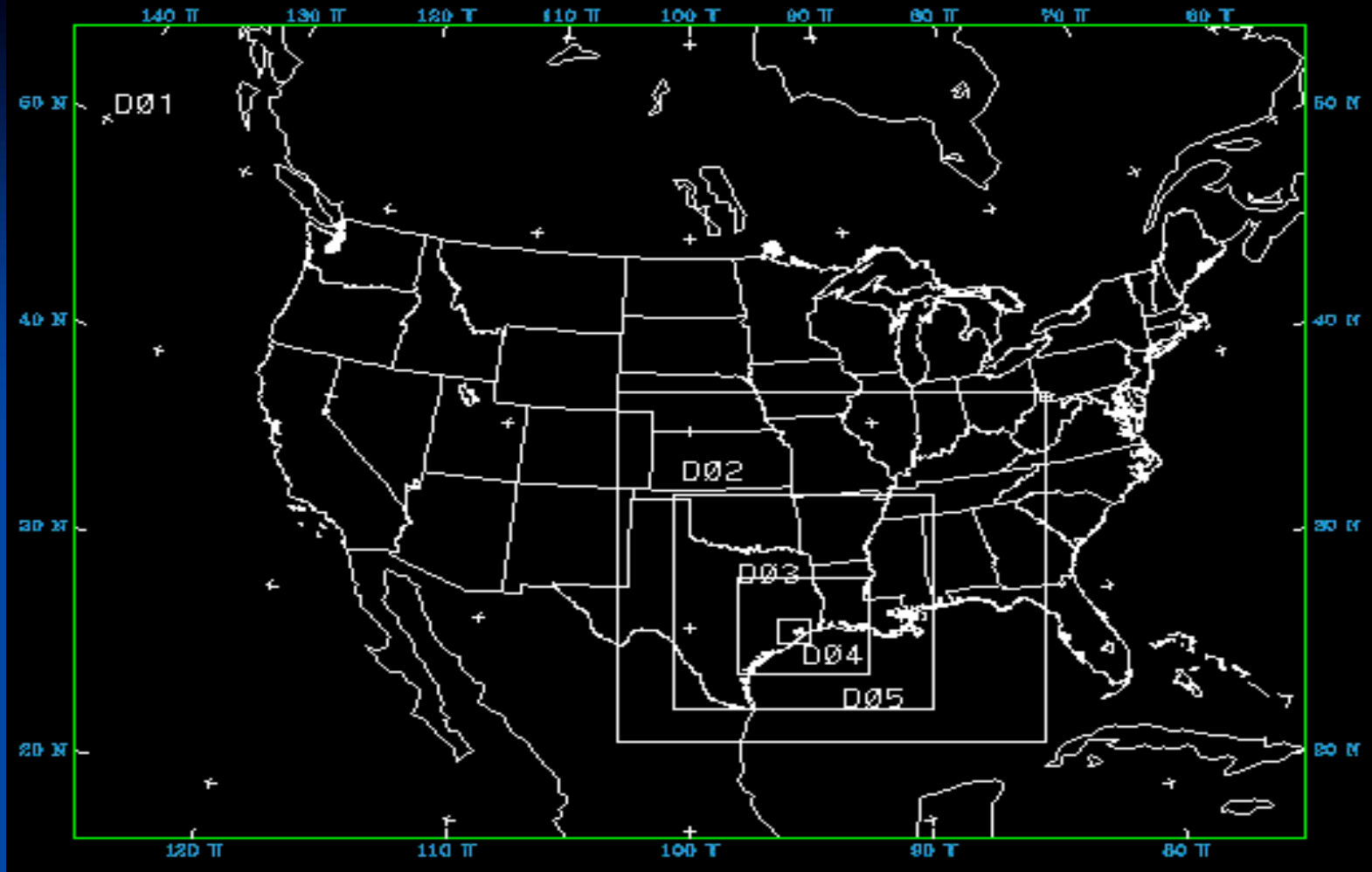
Where S = sfc area

V = vol

← From Masson (2000)

uMM5 input + as $f(x, y)$ in D-05 (from Burian, Stetson, USFS)

- land use (38 categories)
- roughness elements
- anthropogenic heat as $f(t)$
- vegetation and building heights
- paved surface fractions
- drag-force coefficients for buildings & vegy
- building height-to-width, wall-to-plan,
& impervious-area ratios
- building frontal [as $f(dd)$], building plan, & and rooftop
area-densities
- vegetation top- and area-densities
- ϵ , c_p , α , etc. of walls and roofs



5-domain configuration, D5 is “urbanized”

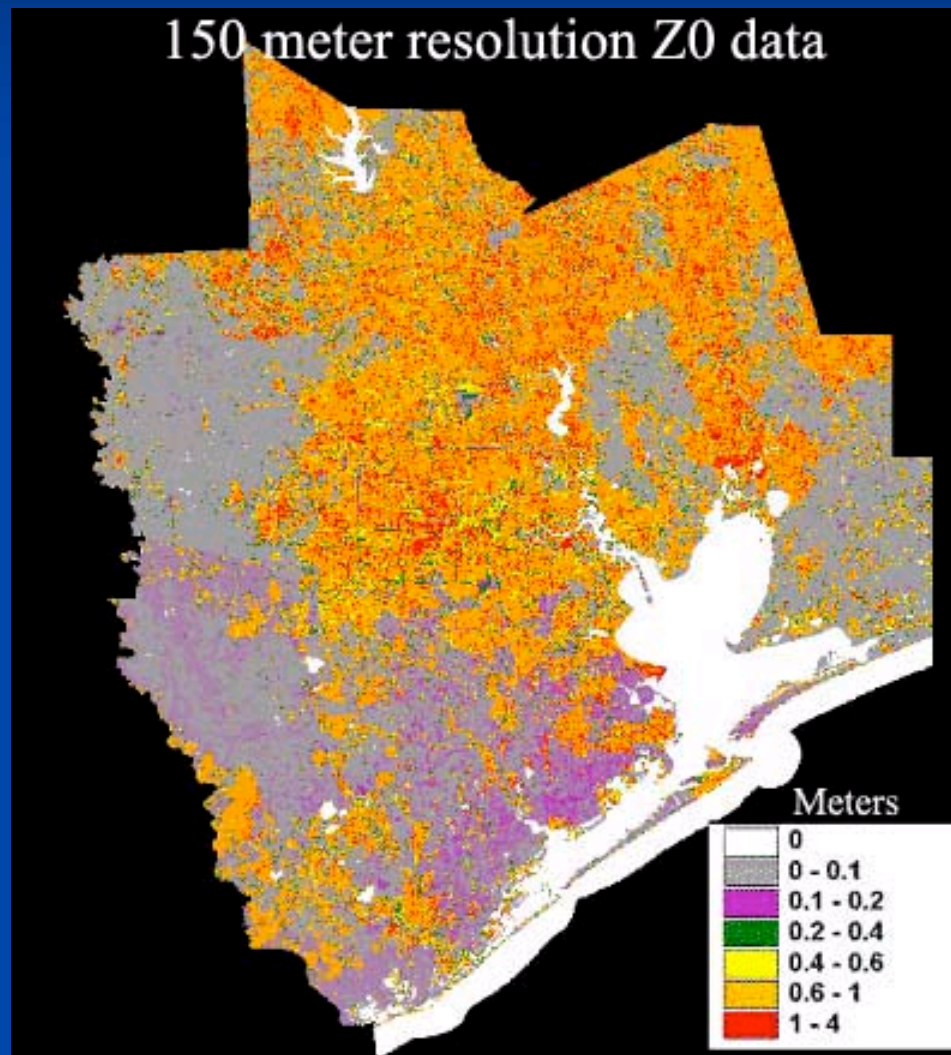
Resolution: 108, 36, 12, 4, 1 km

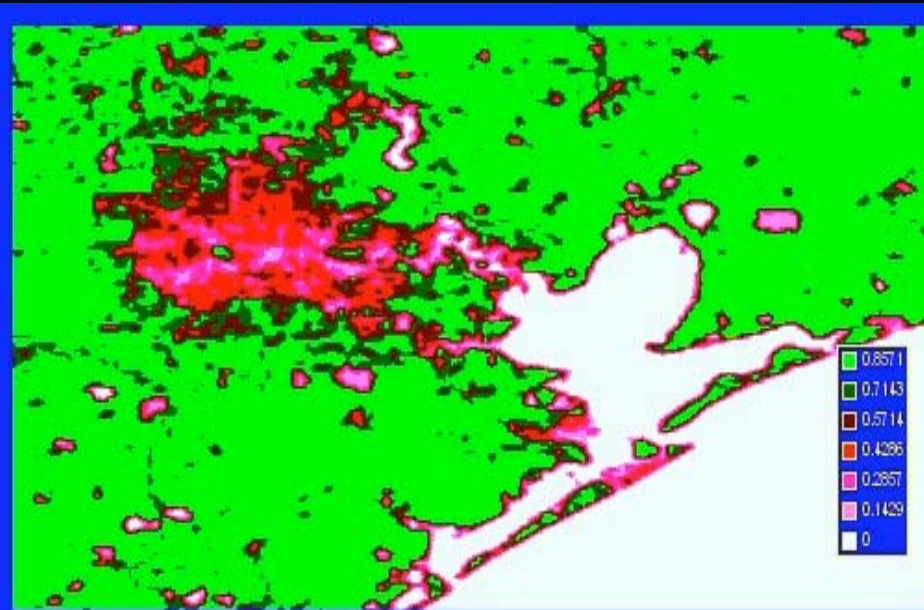
Grid dimensions (excluding surface):

43×53×28, 55×55×28, 100×100×28,

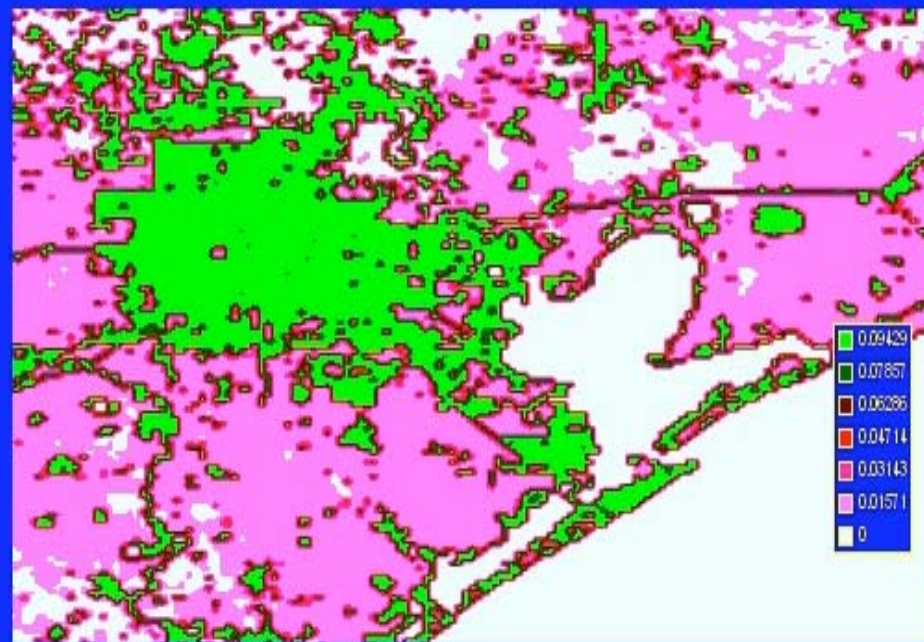
136×151×28, **133×141×48.**

From Stetson: high- resolution Houston z_0 data



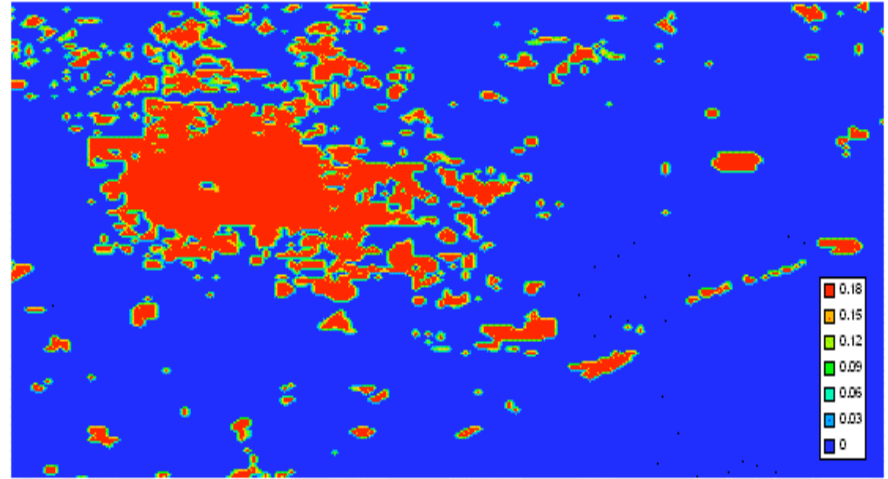
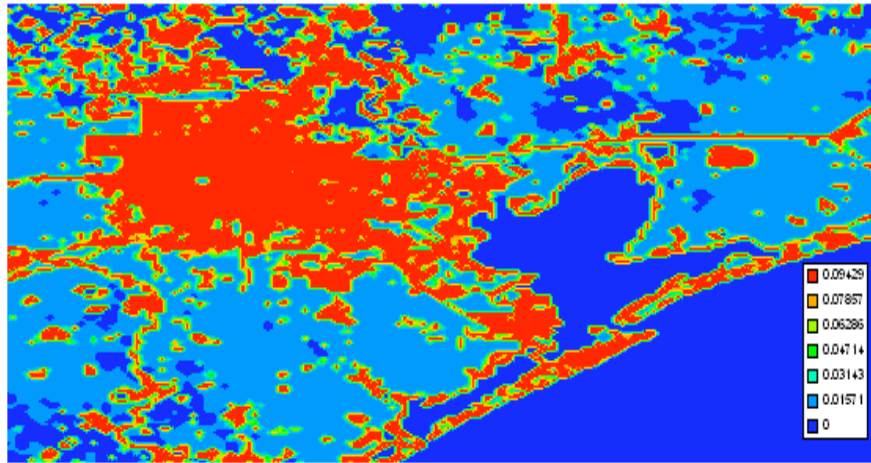


Base-case (current)
vegetation cover (urban
min)



Modeled **increases** in
vegetation cover (urban
max); values are **0.1** of
those above

Soil moisture increase for: Run 12 (entire area, left) and Run 13 (urban area only, right)



MM5 vs. uMM5: Preview of Results

- **uMM5 takes longer than MM5**
 - with 1-CPU: 8 times longer
 - with 96-CPU: only 3 times longer
 - each-day of our uMM5 simulation took
 - 16 days with 1-CPU
 - 4.5 hours with 96-CPU
- **uMM5 gives better:**
TKE, UHIs, & winds

Synoptic Preview

■ Pre-episode day

- **700 hPa:** flow NE of Houston was from SE
- **Sfc:** Sea-breeze frontal formation

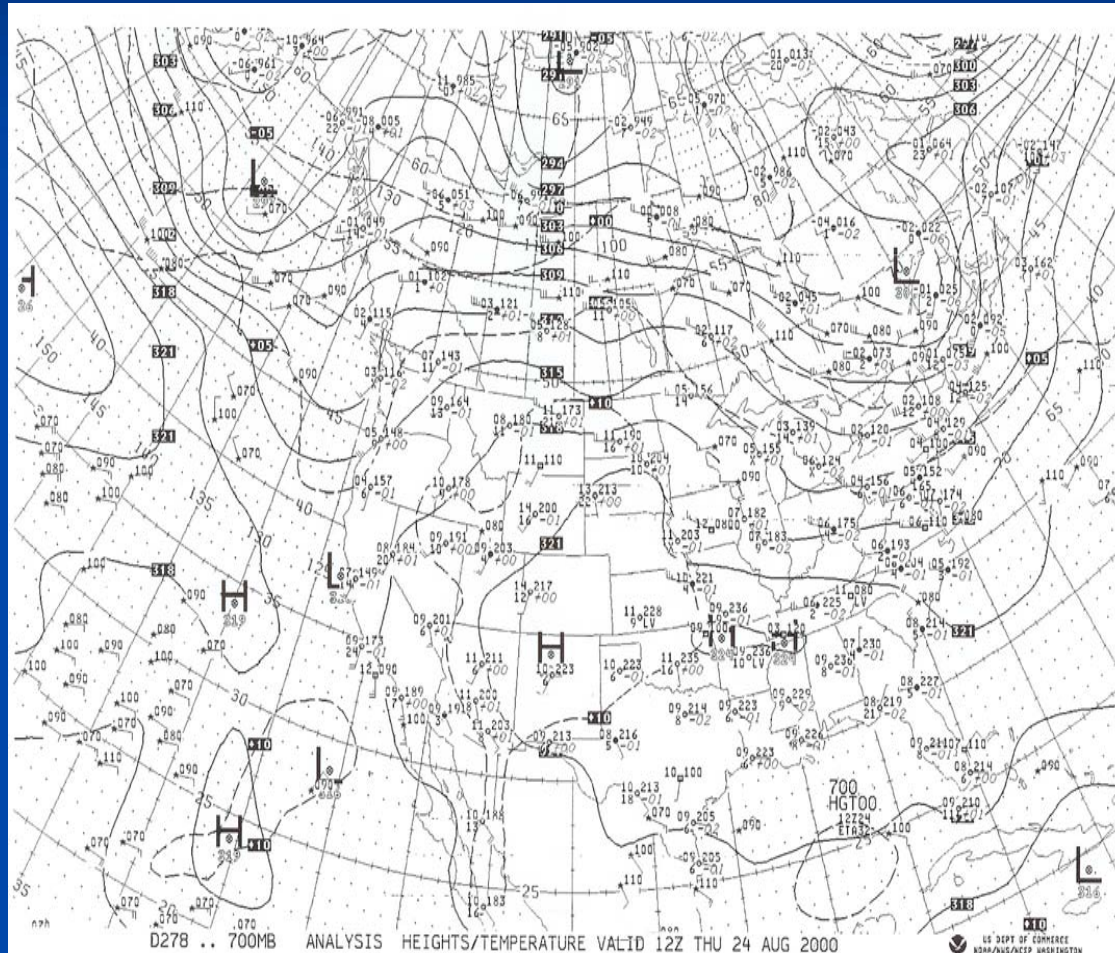
■ Episode day

- **700 hPa:** flow now from NE →
opposition to onshore sea-breeze flow
- **Sfc:** offshore cold-core low forms →
along-shore (NE to SW) coastal-flow →
ozone episode

■ NWS vs. MM5

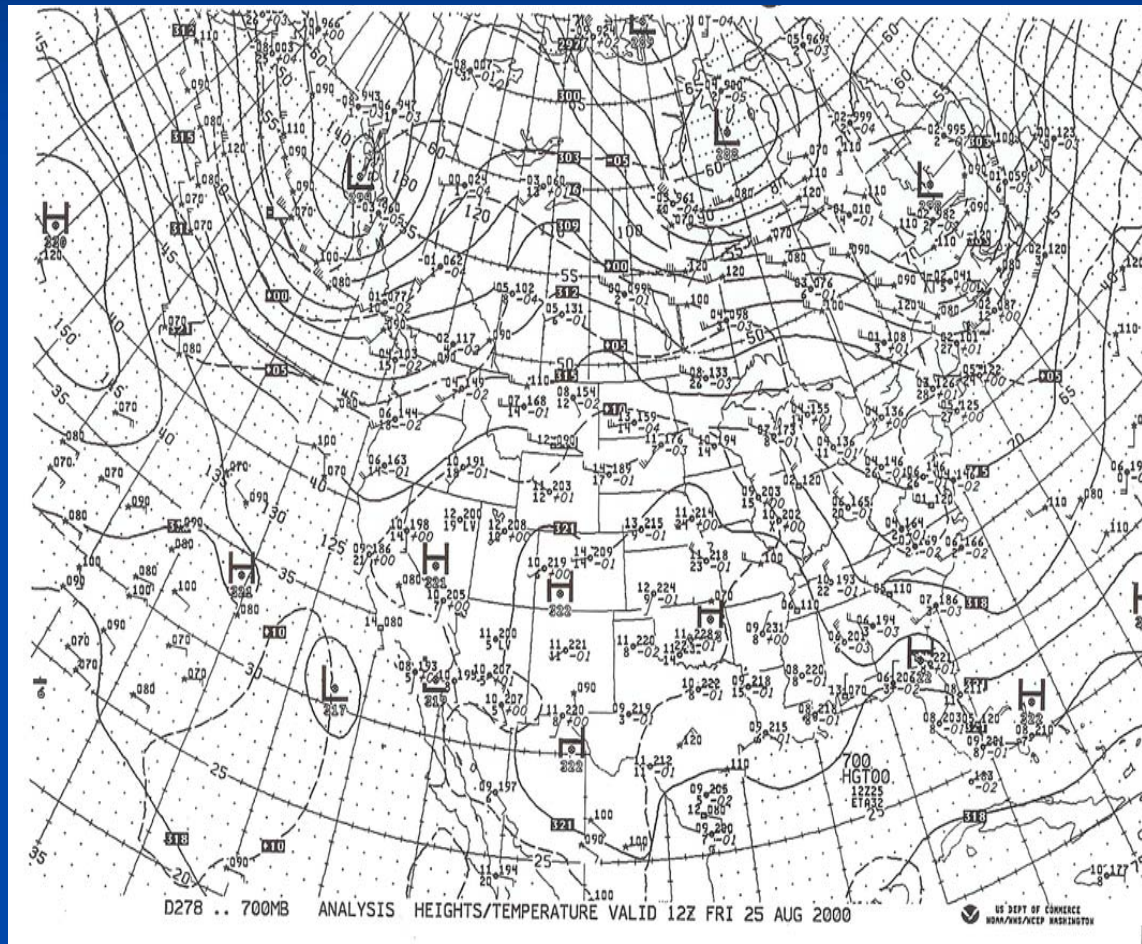
- **NWS** charts show only subtle changes
- **MM5** provides the more details (in inner grids)

1200 UTC (0700 DST) 24 AUG



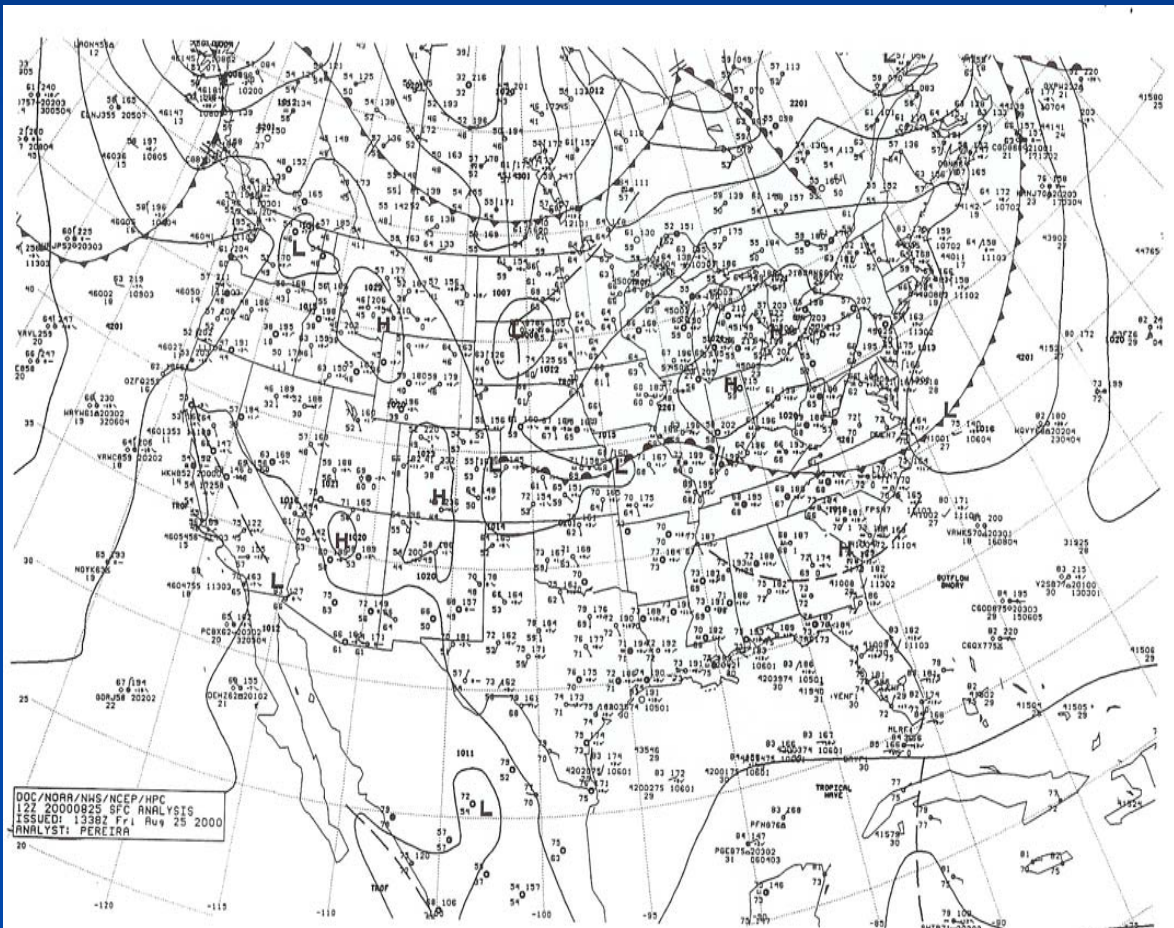
- 700 mb
- Pre-episode AM
- SE flow NE of Houston

1200 UTC (0700 DST) 25 AUG



- 700 mb
- Episode AM
- Opposing NE flow NE of Houston
- Will cause con with sfc SB V

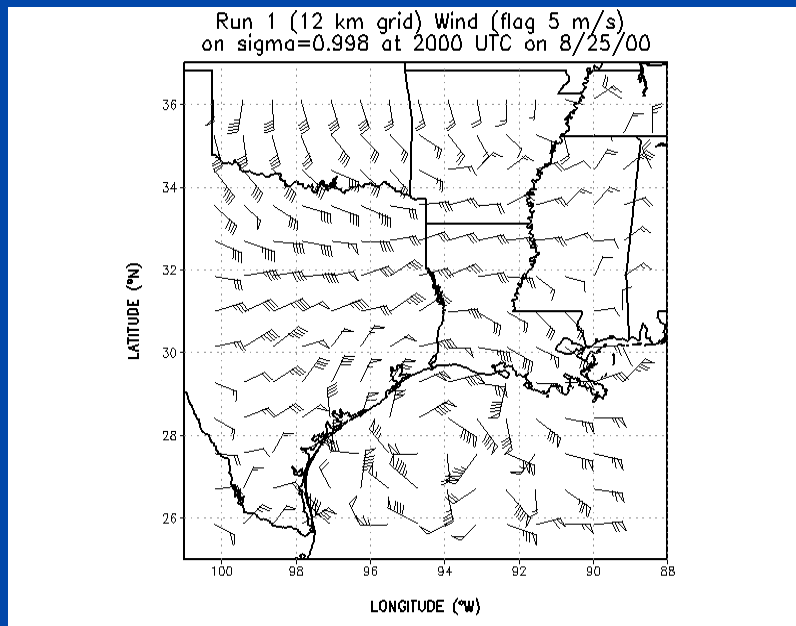
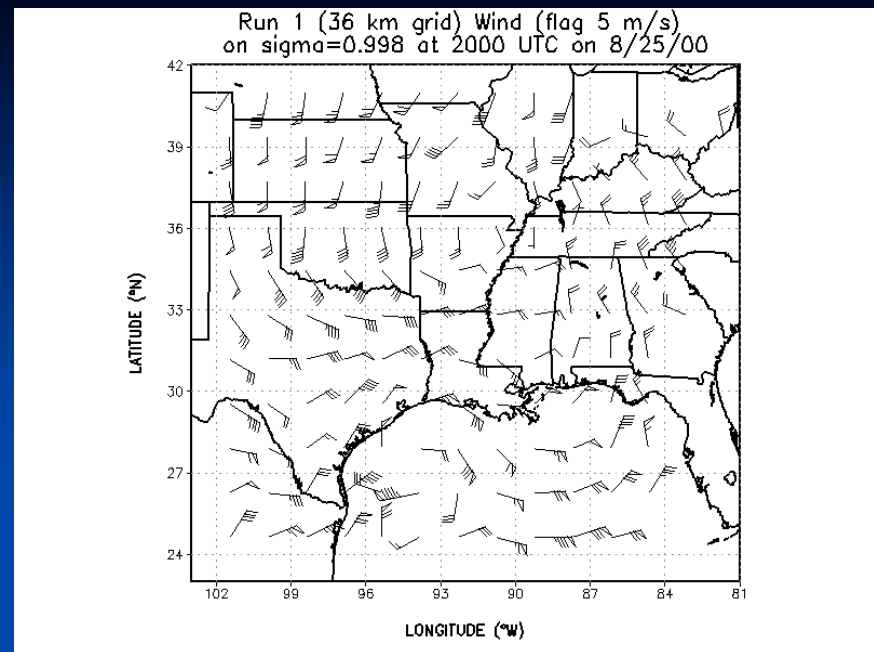
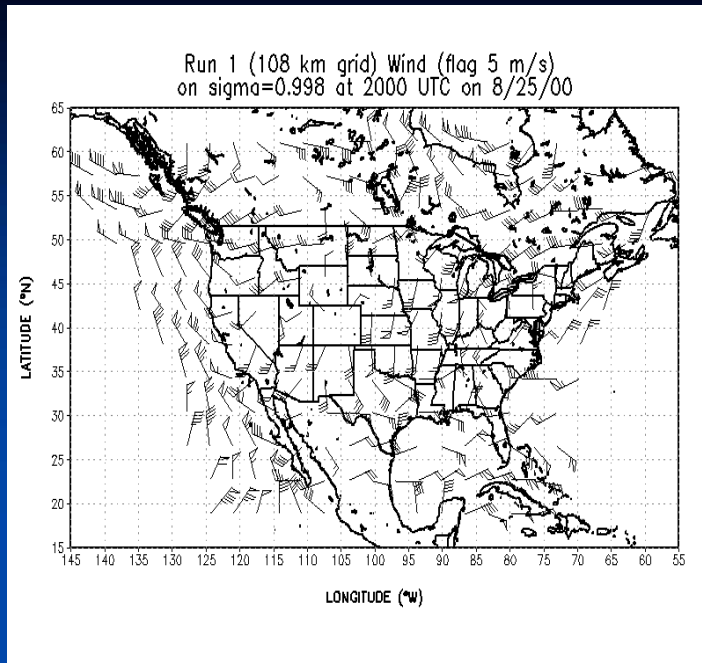
1200 UTC (0700 DST) 25 AUG



- Sfc chart
- Episode AM
- Not much detail
- Similar to day b/f & after

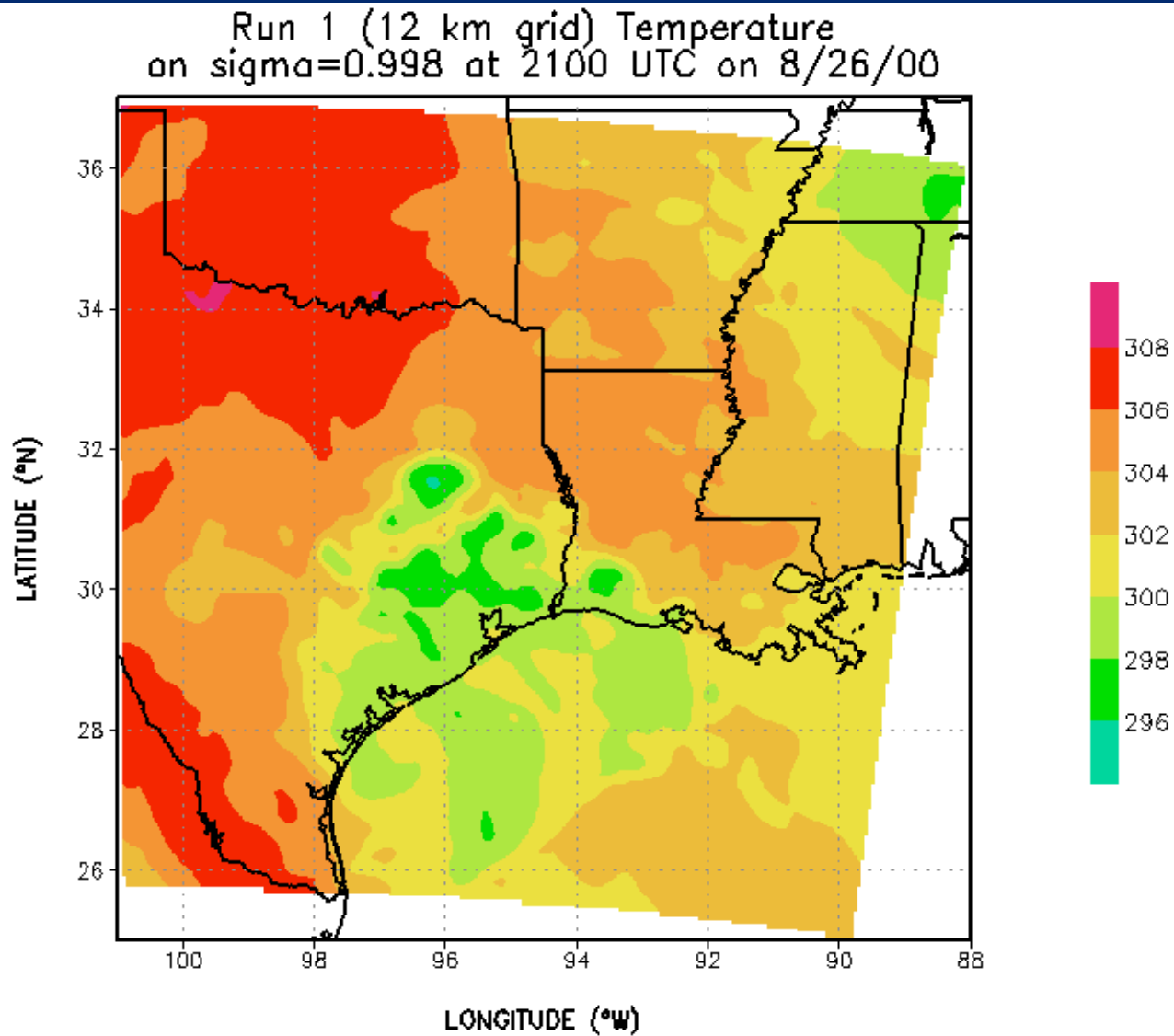
MM5 results: Preview

- Domain 1:
 - Captures NWS synoptic features (change in 700 hPa flow-direction NE of Houston)
 - Indicates off-shore feature (cold-core L) not on NWS charts
- Domains 2-4: shows details of off-shore L
- Domain: 5: shows UHI effects



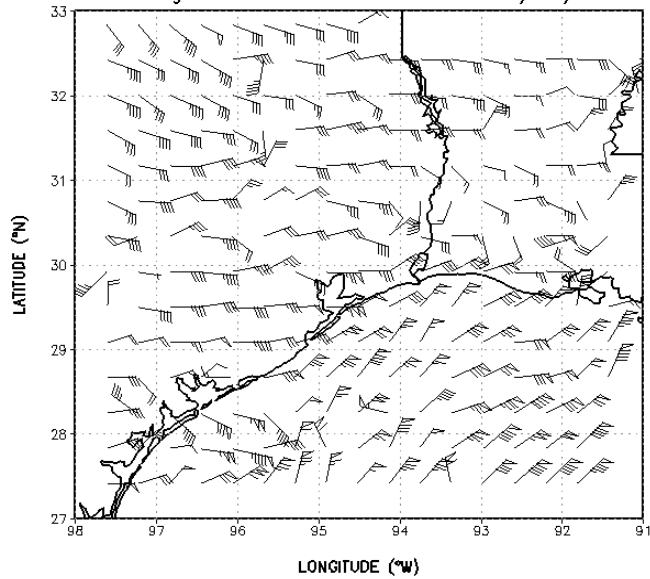
Coastal Cold-Core L Episode day 3 PM Domains 1-3

Domain 3 (12 km) 4 PM: cold-core L (from where?)

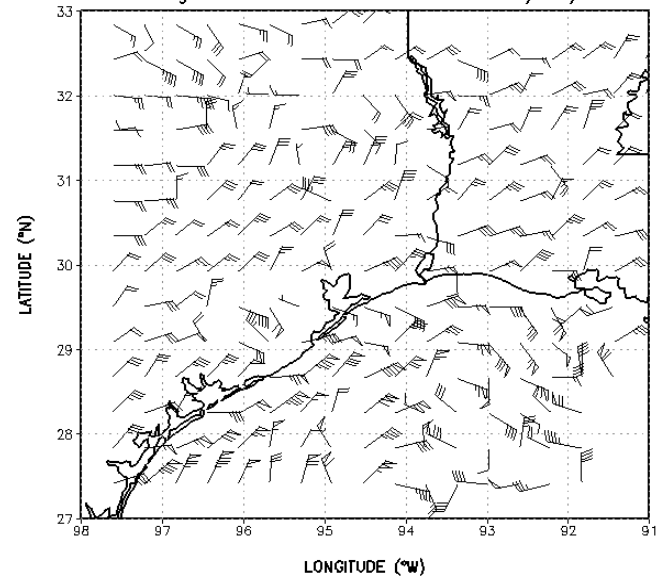


Domain 4 (3 PM) : Note cold-core L off of Houston on O₃ day (25th)

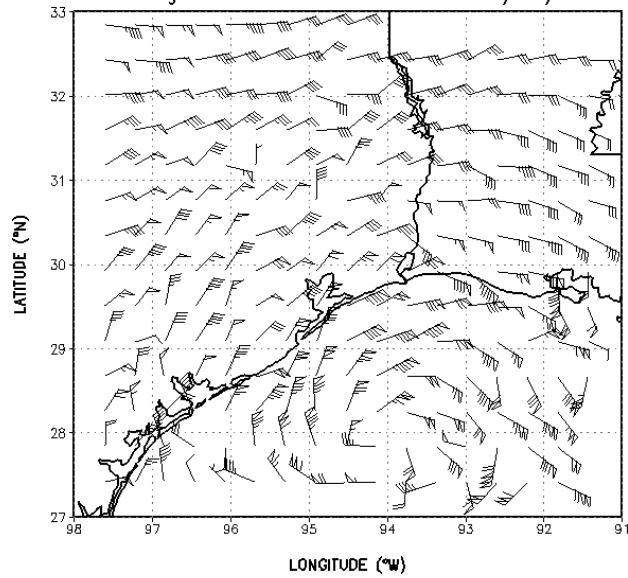
Run 1 (4 km grid) Wind (flag 5 m/s)
on sigma=0.998 at 2000 UTC on 8/23/00



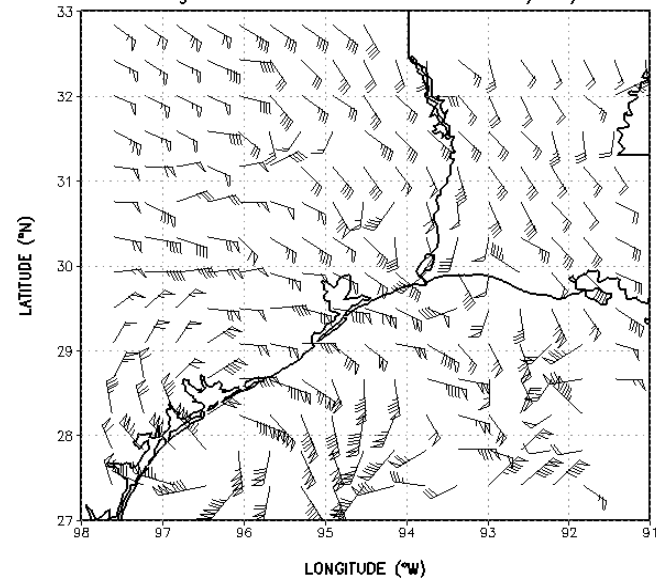
Run 1 (4 km grid) Wind (flag 5 m/s)
on sigma=0.998 at 2000 UTC on 8/24/00



Run 1 (4 km grid) Wind (flag 5 m/s)
on sigma=0.998 at 2000 UTC on 8/25/00

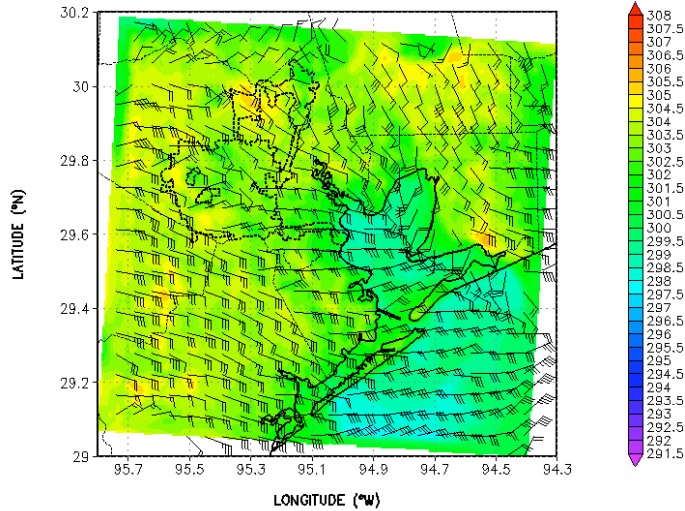


Run 1 (4 km grid) Wind (flag 5 m/s)
on sigma=0.998 at 2000 UTC on 8/26/00

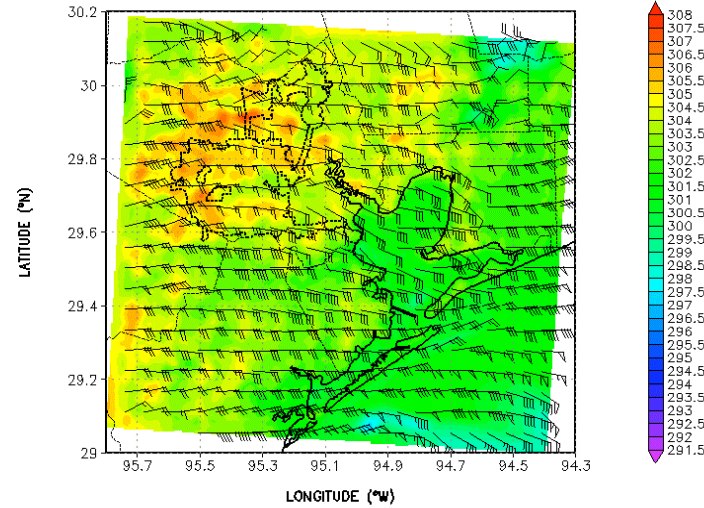


Urbanized Domain 5: near-sfc 3 PM winds

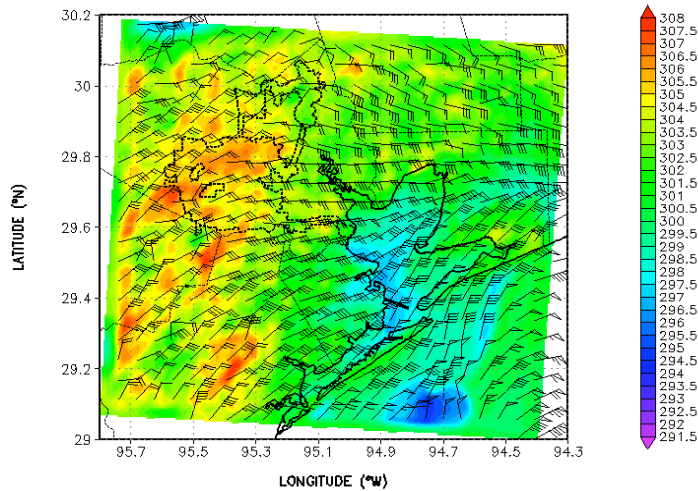
Run 12 (1 km) Temp (K) Wind (flag 5 m/s) Urbanized
on sigma=0.99975 at 2000 UTC on 08/22/10



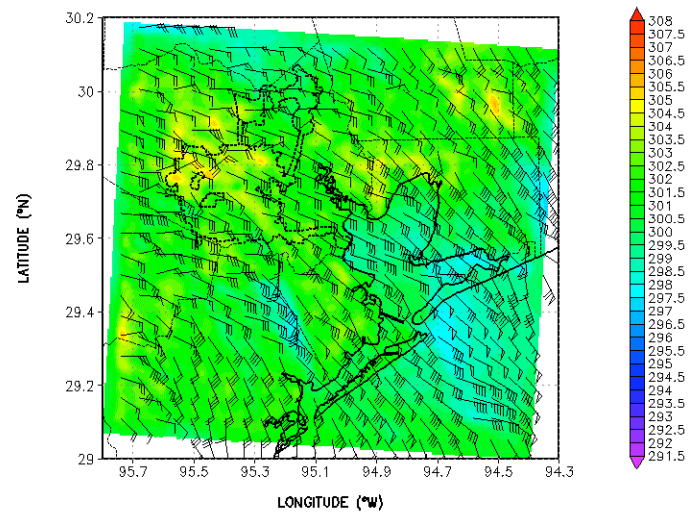
Run 12 (1 km) Temp (K) Wind (flag 5 m/s) Urbanized
on sigma=0.99975 at 2000 UTC on 08/23/10



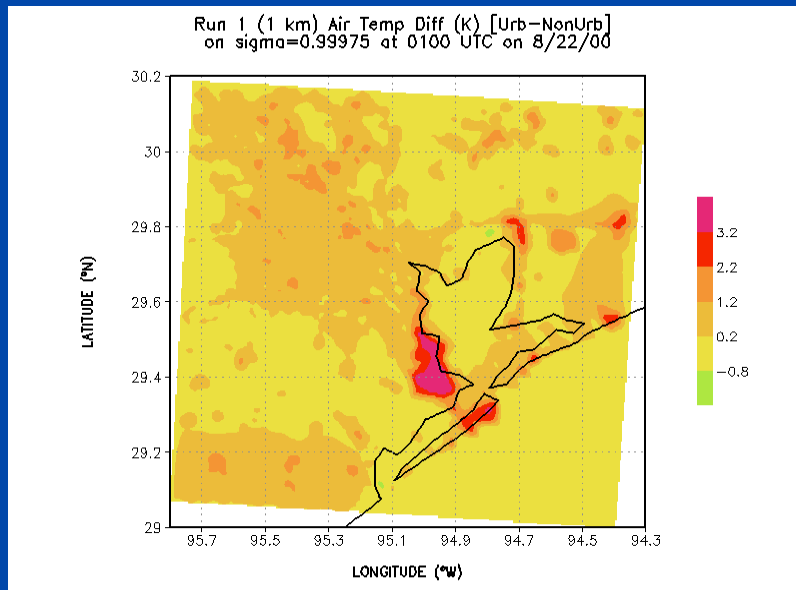
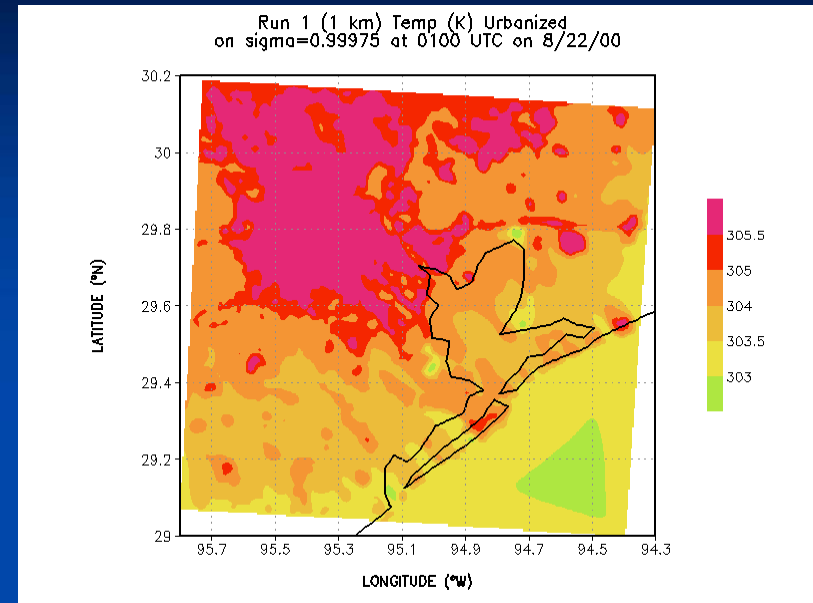
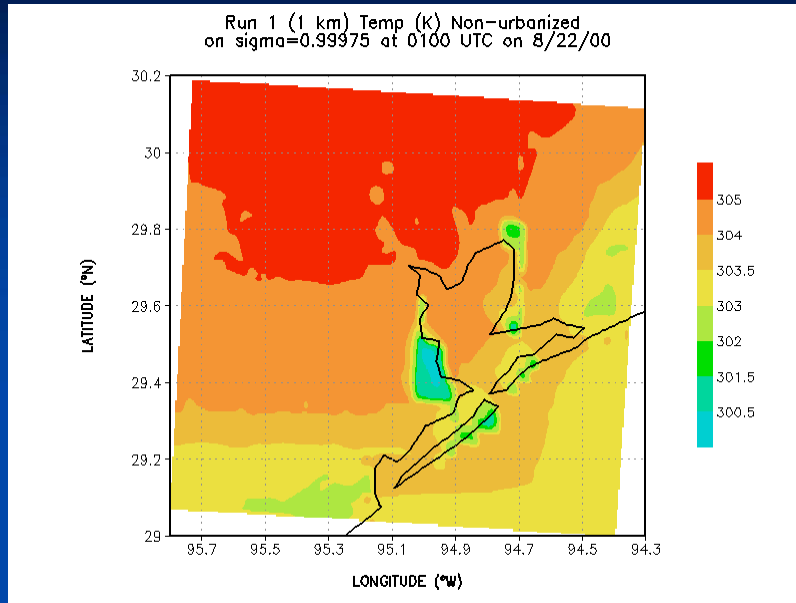
Run 12 (1 km) Temp (K) Wind (flag 5 m/s) Urbanized
on sigma=0.99975 at 2000 UTC on 08/25/10



Run 12 (1 km) Temp (K) Wind (flag 5 m/s) Urbanized
on sigma=0.99975 at 2000 UTC on 08/26/10



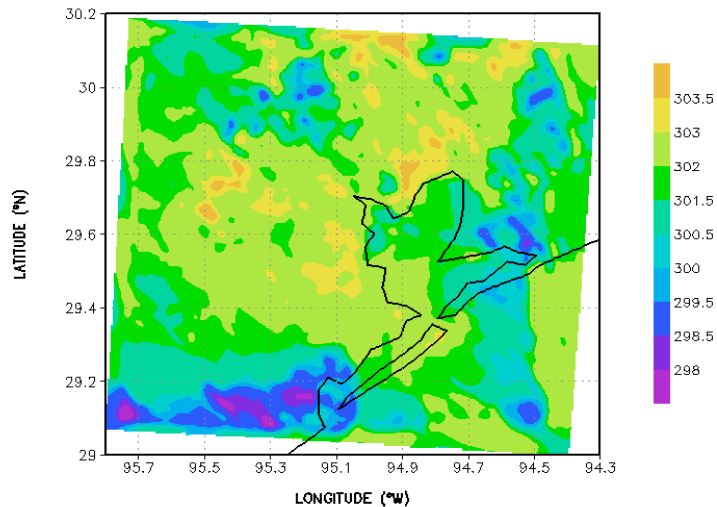
1 km Domain: end of daytime UHI (8 PM 21 Aug)



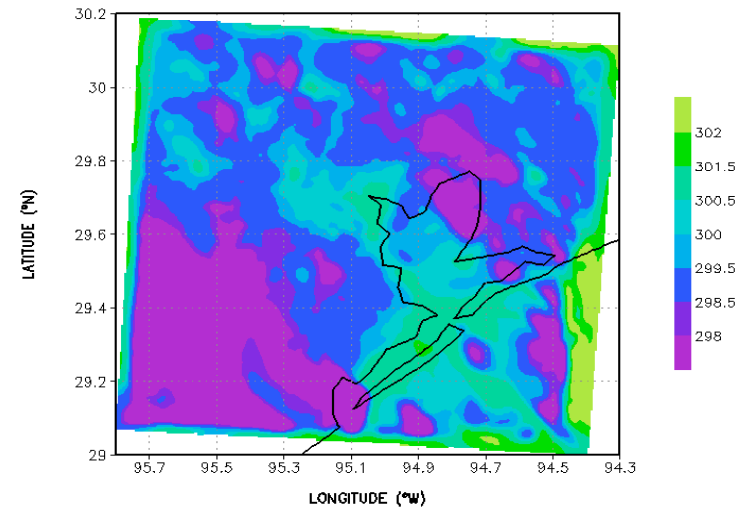
- Upper L: MM5
- Upper R: uMM5
- Lower L: uMM5-MM5
- uMM5 → 1.5 K warmer (stronger UHI)
- Blob is LU/LC error

1km Domain: end of night UHI: 9 AM 22 Aug

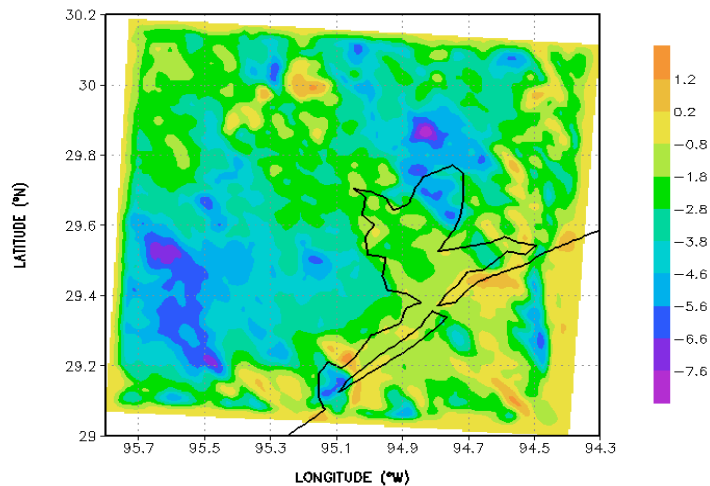
Run 1 (1 km) Temp (K) Non-urbanized
on sigma=0.99975 at 1400 UTC on 8/22/00



Run 1 (1 km) Temp (K) Urbanized
on sigma=0.99975 at 1400 UTC on 8/22/00



Run 1 (1 km) Air Temp Diff (K) [Urb-NonUrb]
on sigma=0.99975 at 1400 UTC on 8/22/00



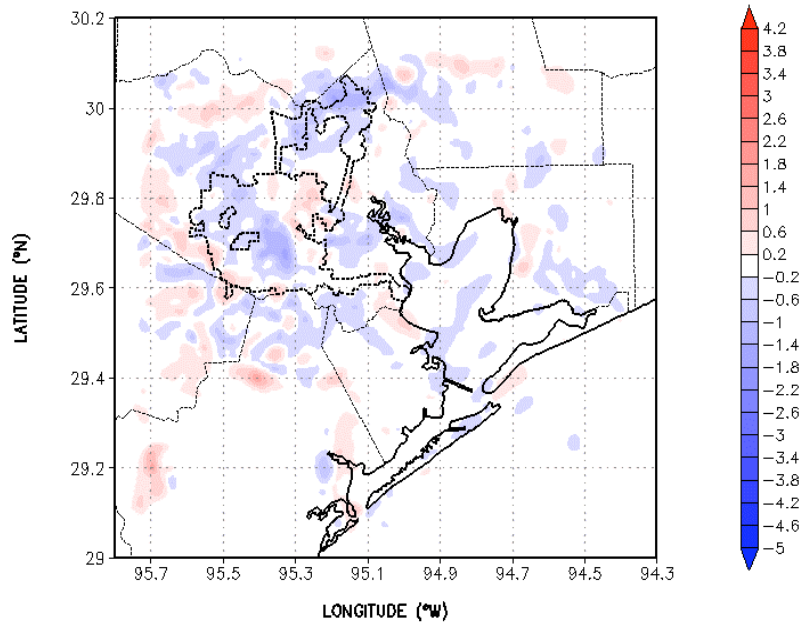
- Upper L: MM5
- Upper R: uMM5
- Lower L: MM5-uMM5
- uMM5 → 1.5 K cooler
(weaker UHI)

Explanation of uMM5 UHI & UCI

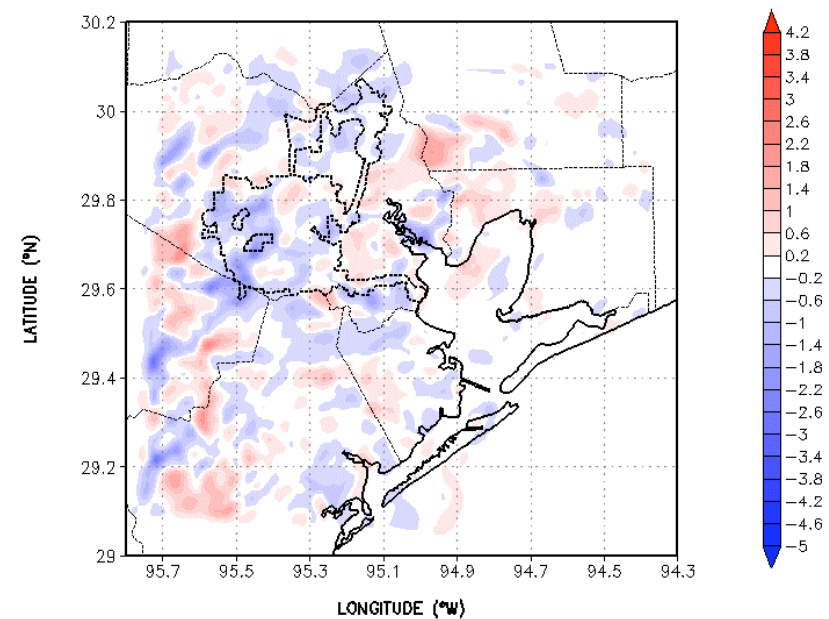
- Wet soil TI > urban TI > dry soil TI
- Urban an area surrounded by wet soil thus has
 - Daytime UHI (as urban area warms faster than soil)
 - Nighttime UCI (as urban area cools faster than soil)
- Reverse true with dry rural soil
- Current results thus consistent with wet rural soil (as expected) around Houston, as uMM5 produced daytime warming & nighttime cooling over urban Houston

Run 12 (urban-max reforestation) minus
Run 10 (base case): **near-sfc ΔT at 4 PM**
reforested central urban-area cools &
surrounding deforested rural-area warms

Run 12 - Run 10 (1 km) Sfc Temp Diff (K) Urbanized
on sigma=0.99975 at 2100 UTC, 08/23/10 - 08/23/00



Run 12 - Run 10 (1 km) Sfc Temp Diff (K) Urbanized
on sigma=0.99975 at 2100 UTC, 08/26/10 - 08/26/00

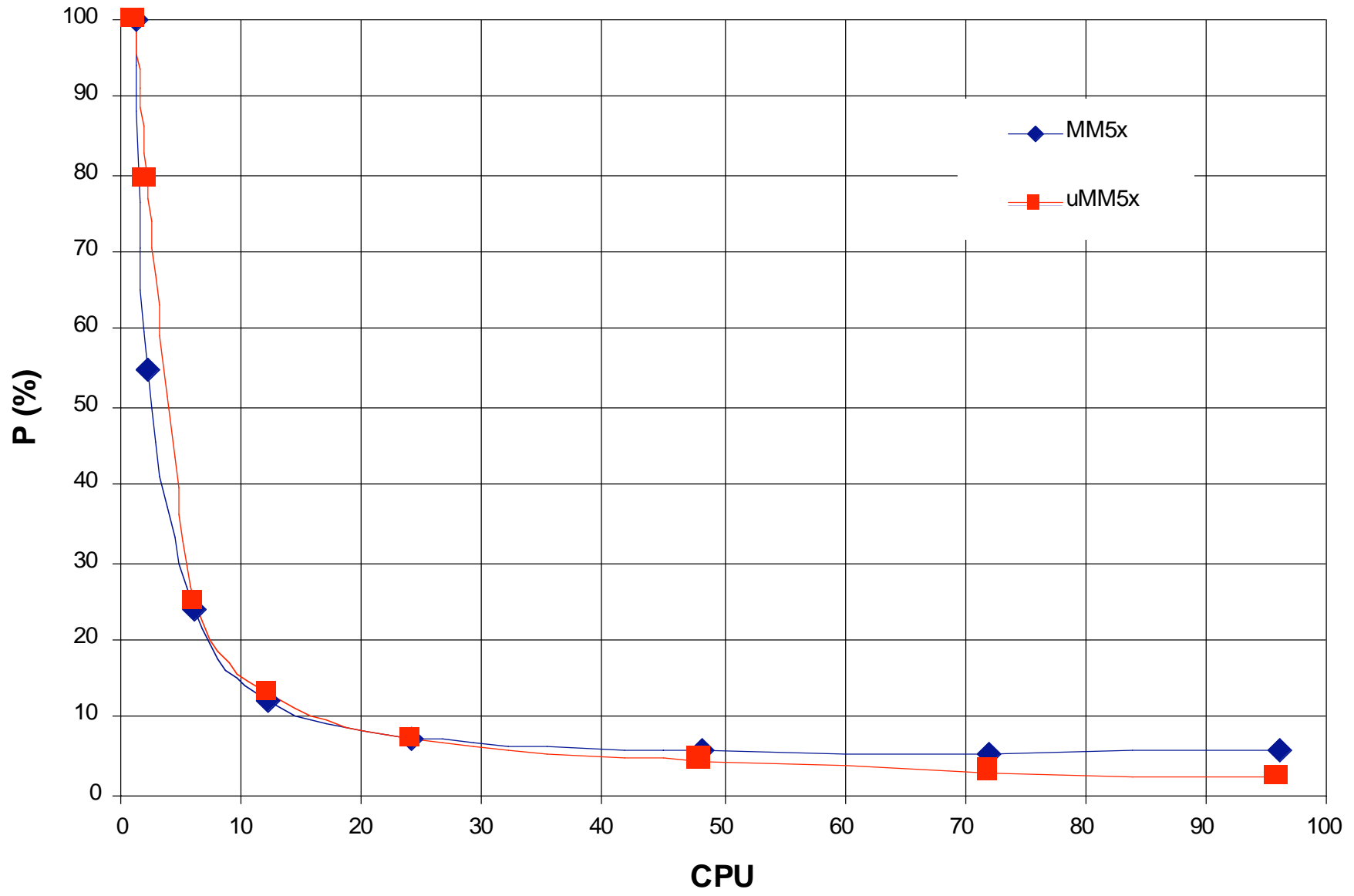


Ongoing efforts

- Additional analysis of current results
- Additional simulations on new 106 CPU cluster
- Use of GIS/RS gridded urban sfc parameters
- Run CMAQ ozone model:
reduced UHI → lower ozone →
emission-reduction credits
- Link urban CFD- & meso-models for:
NYC ER applications

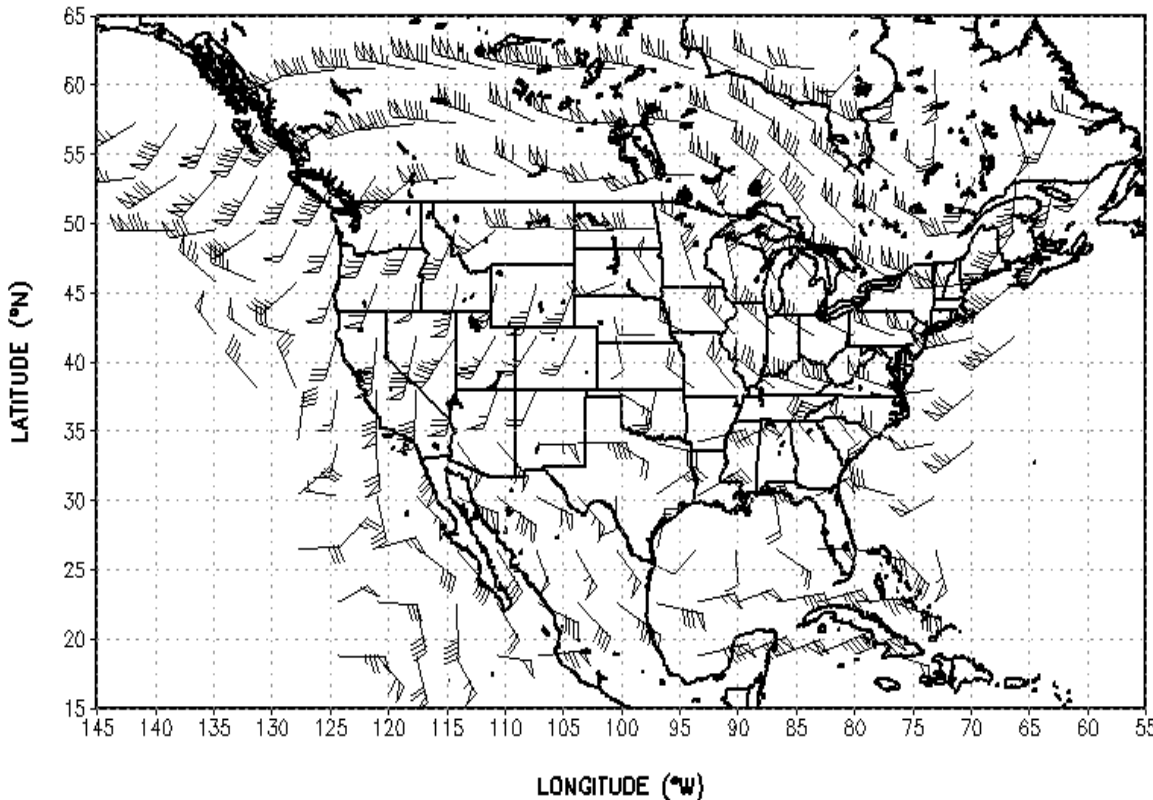
THE END

Performance for 18 hour prediction



Domain 1: 7 AM 24 AUG

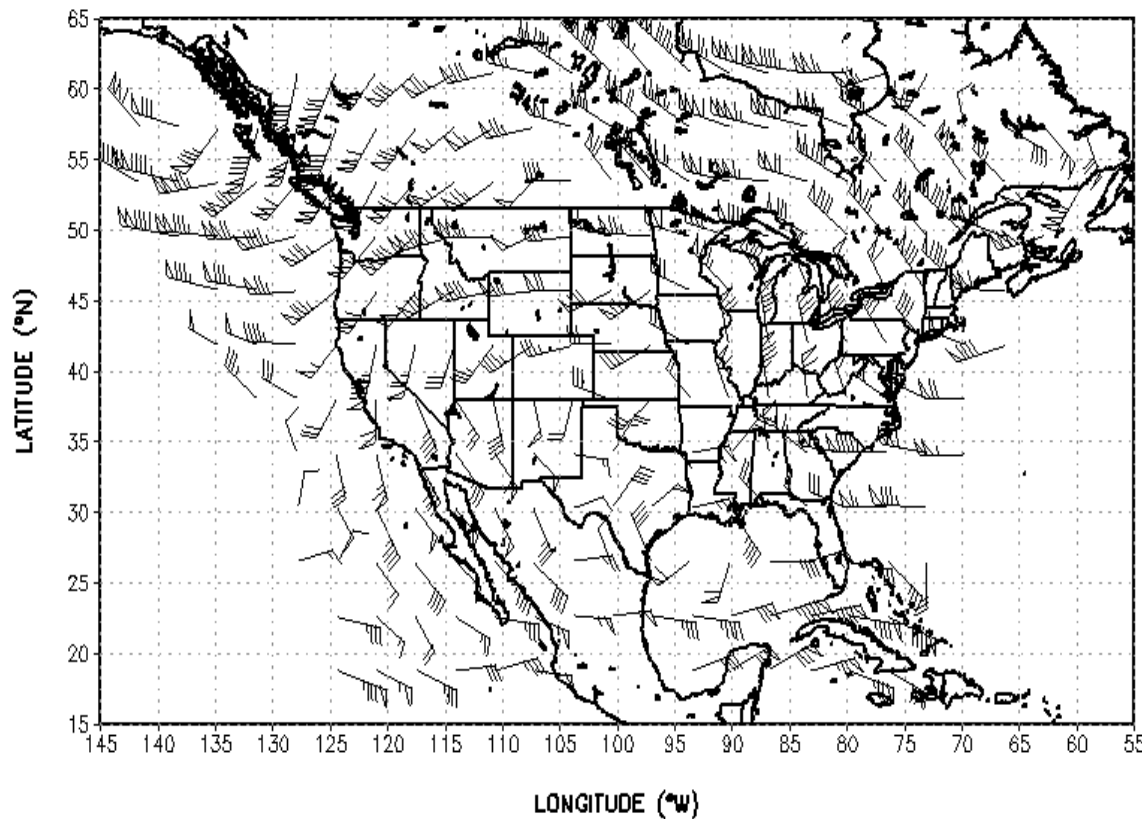
Run 1 (108 km grid) Wind
on sigma=0.675 at 1200 UTC on 8/24/00



- 700 mb
- Pre-episode
- Weak off-shore L (not in NWS)
- Weak NE flow NE of city

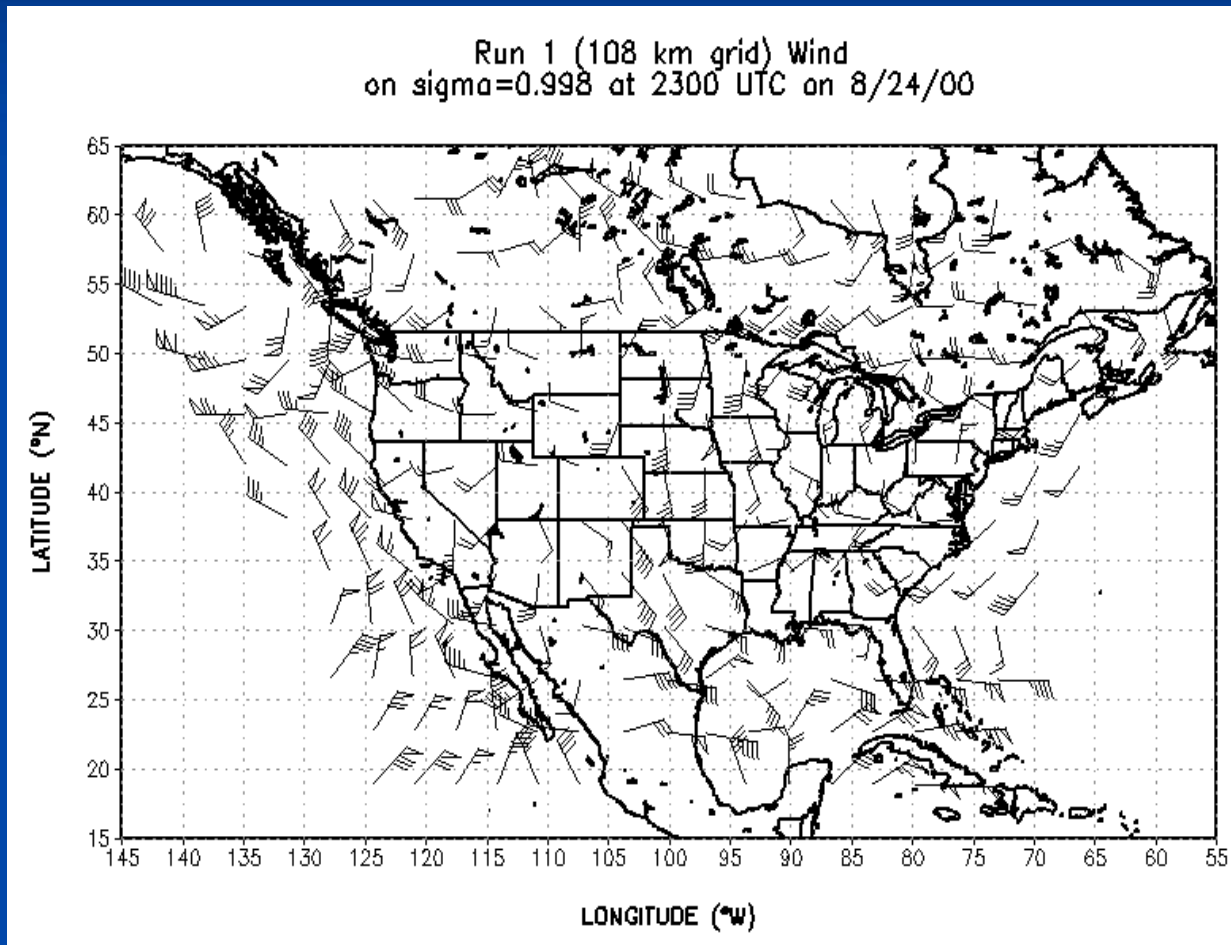
Domain 1: 0700 DST 25 AUG

Run 1 (108 km grid) Wind
on sigma=0.675 at 1200 UTC on 8/25/00



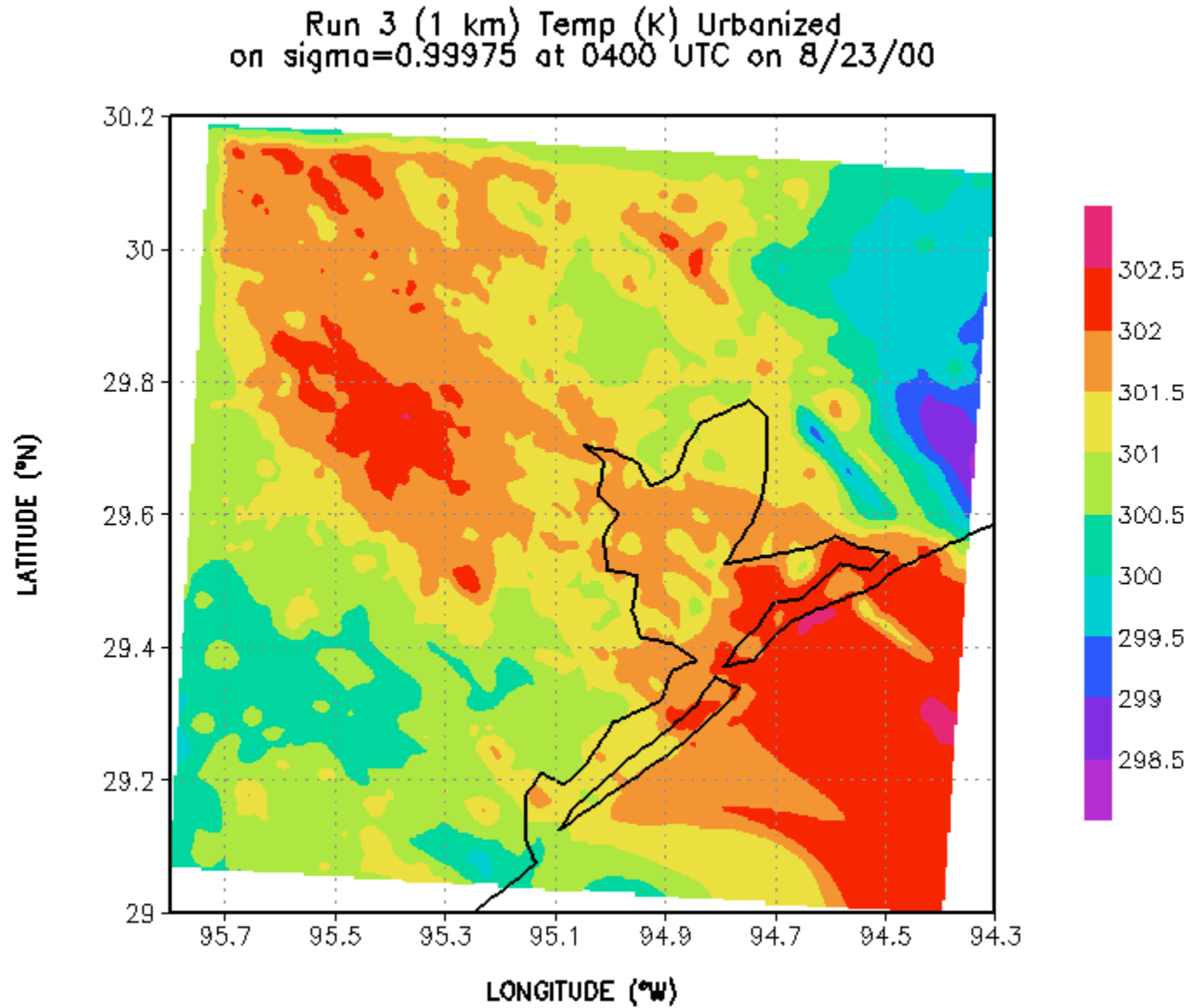
- 700 mb
- Episode AM
- Stronger off-shore L
- Stronger NE ff NE of city
- Will cause con with SB ff

Domain 1: 1800 DST 23 AUG



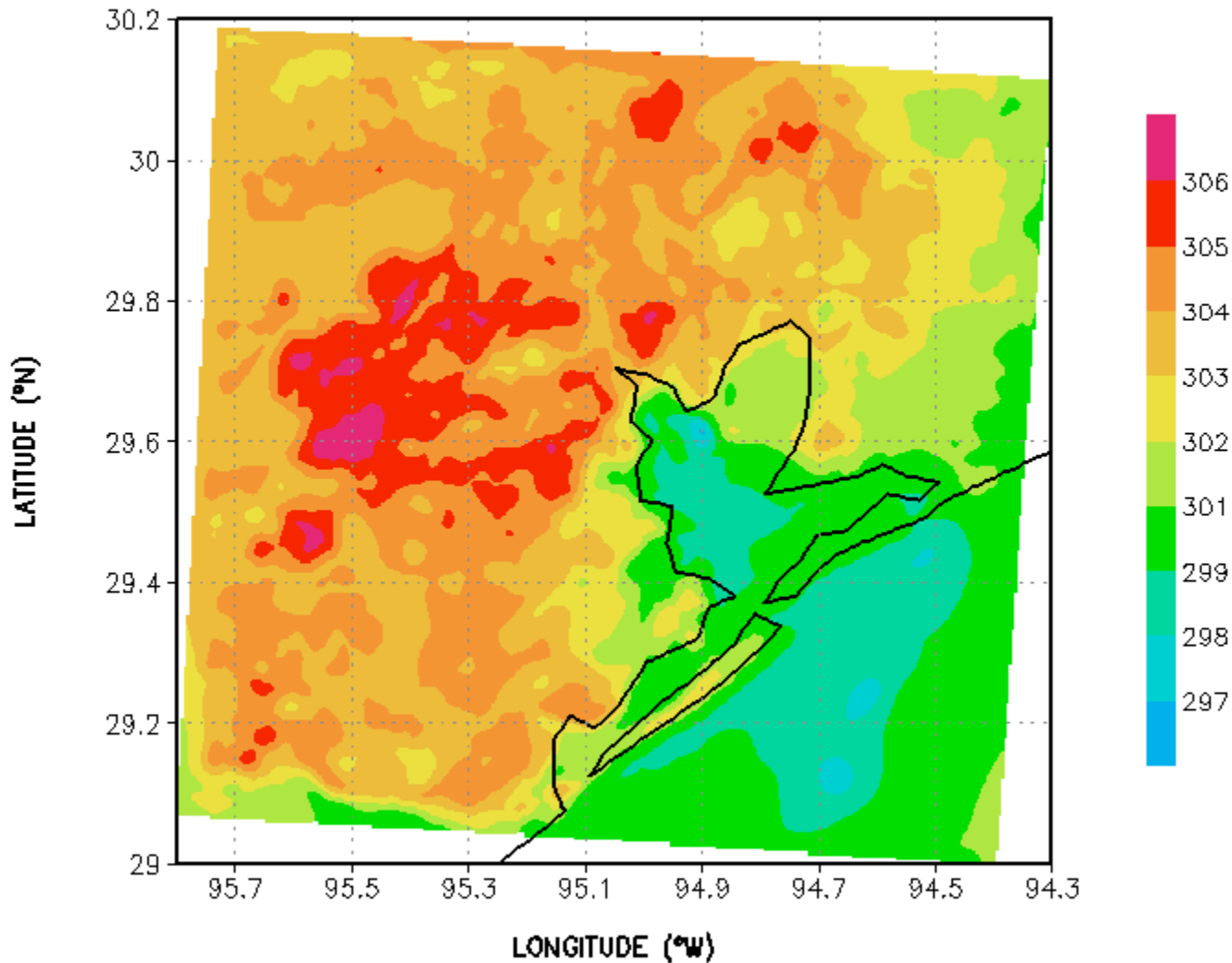
- Sfc chart
- Pre-episode
- On-shore SB
- Not much difference at same time on next 2 days
- Need to see inner domains

1 km uMM5 11 PM: nocturnal UHI



1 km uMM5 3 PM: daytime UHI

Run 3 (1 km) Temp (K) Urbanized
on sigma=0.99975 at 2000 UTC on 8/23/00



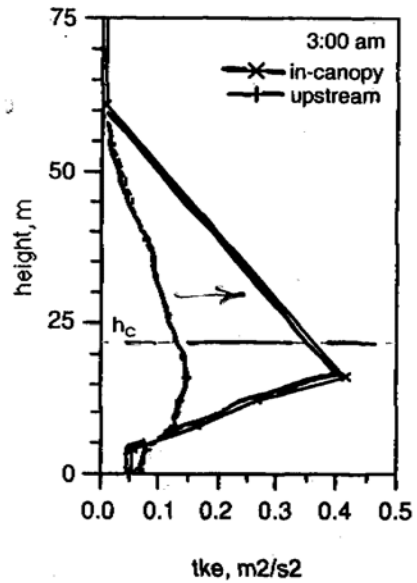
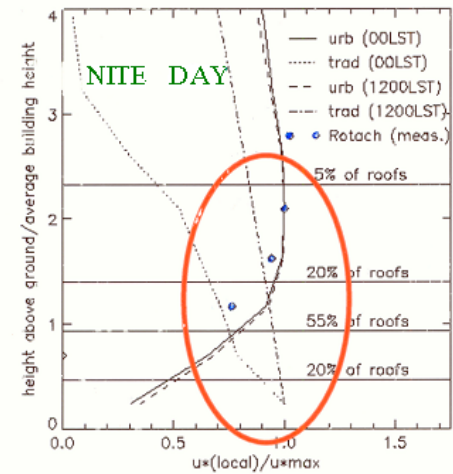
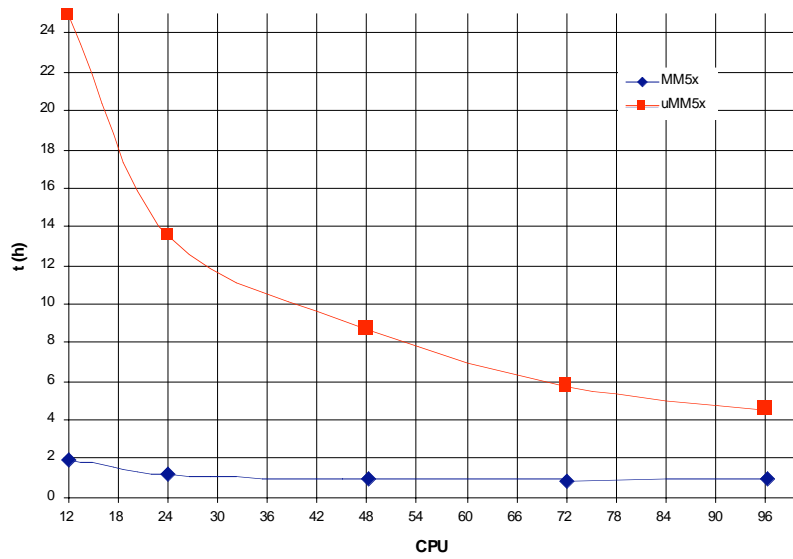


Figure 23: Comparison of t_{ke} profiles computed within and upstream of urban canopy (Brown and Williams [62]).

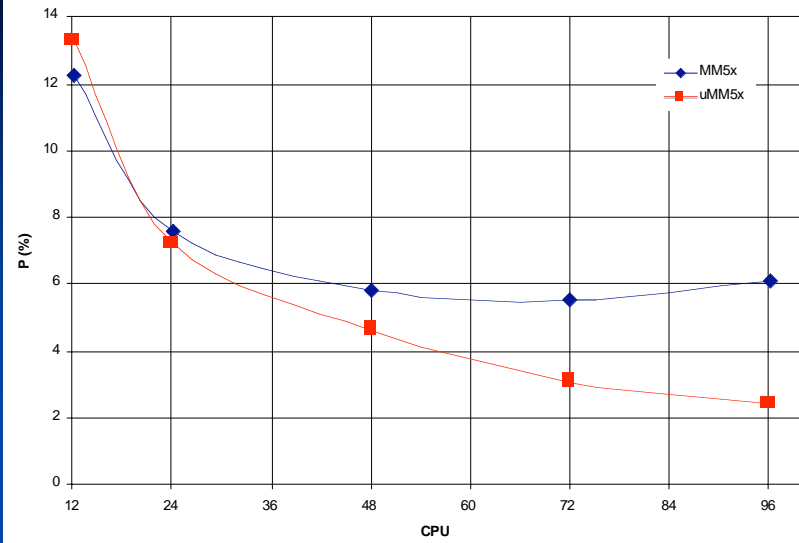
Reynolds Stress



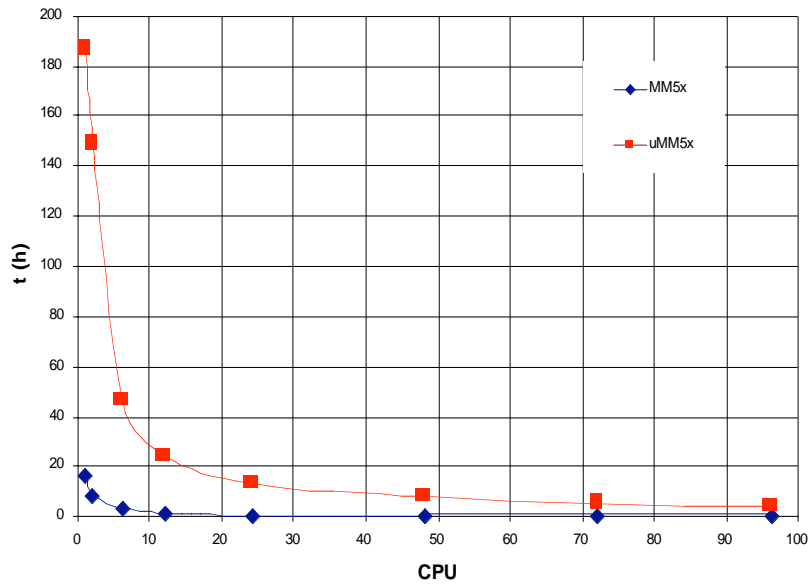
Performance for 18 hour prediction using 12 to 96 cpus



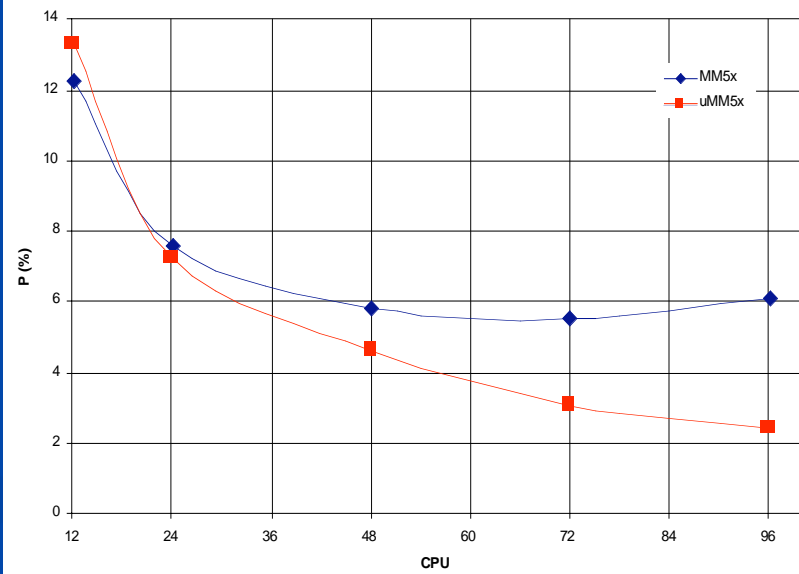
Performance for 18 hour prediction using 12 to 96 cpus



Performance for 18 hour prediction

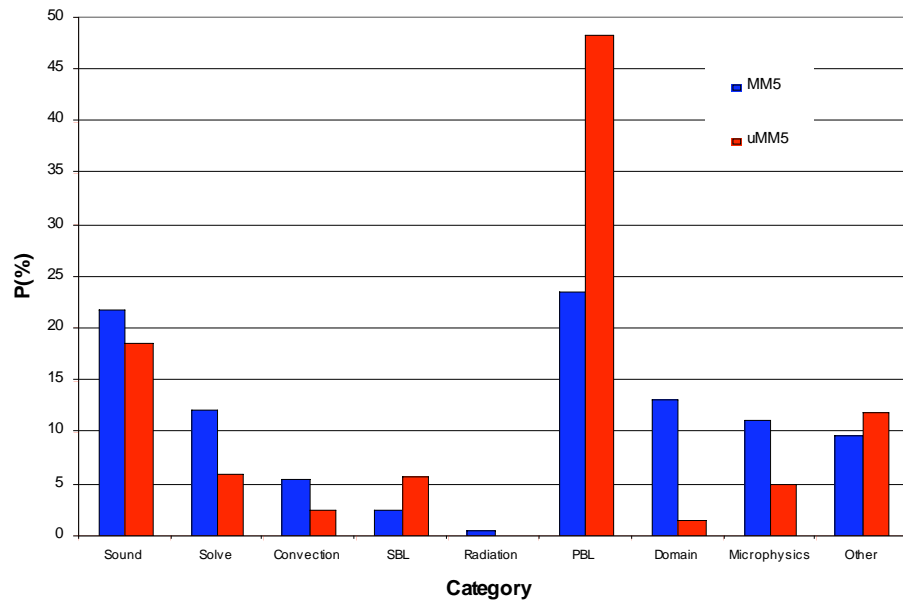


Performance for 18 hour prediction using 12 to 96 cpus



Performance by physics

Performance by category



Performance (real time) by category

