Developing an Integrated Urban Modeling System in WRF: Current Status and Future Plan

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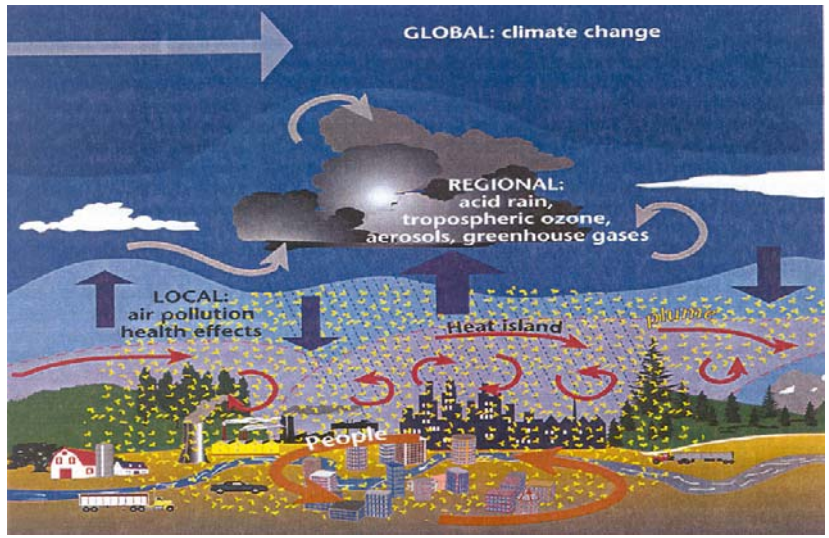
Outline

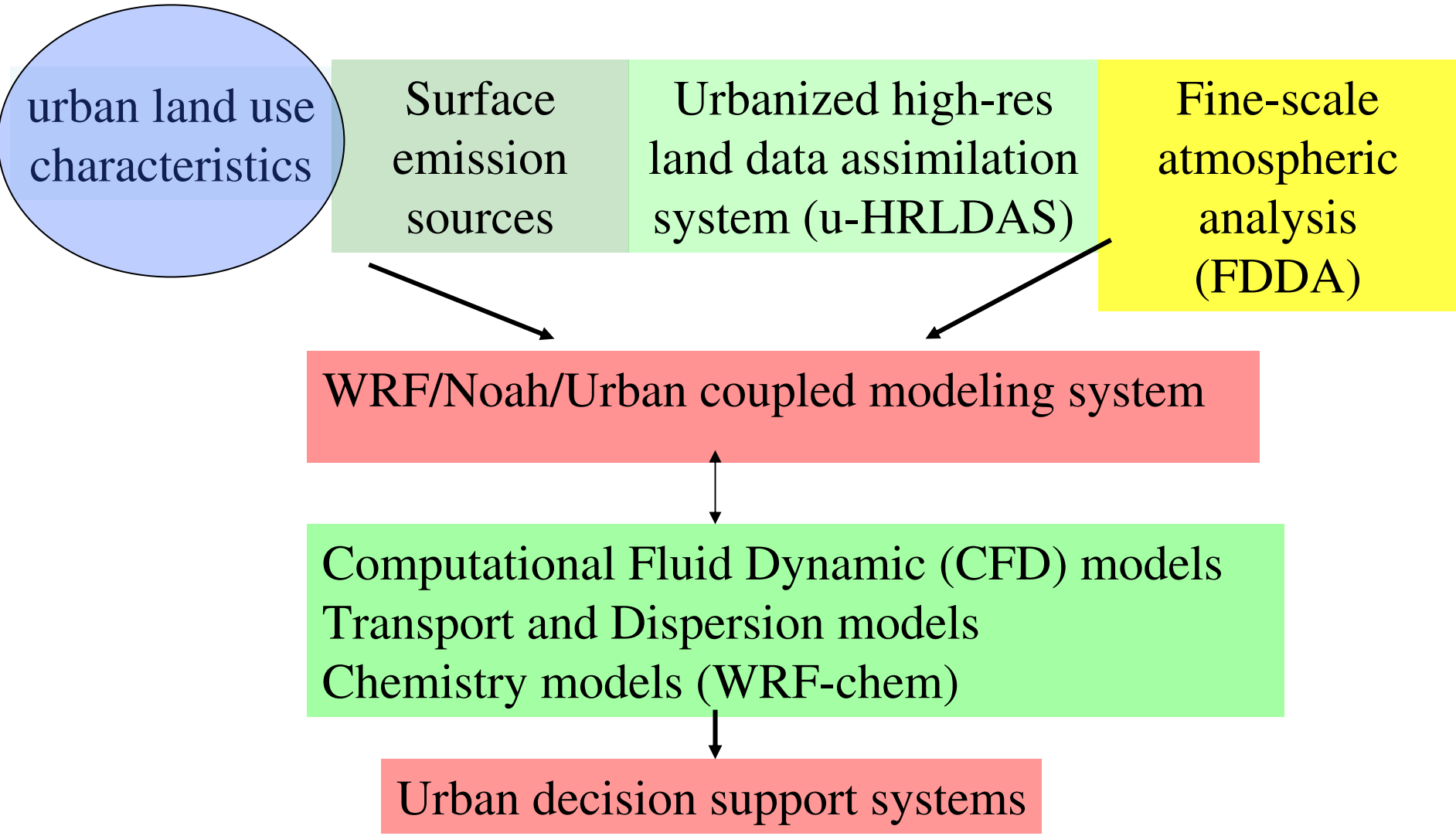
Overview of an urban modeling framework
Examples of applying this modeling system
Future work

Urbanization Issues

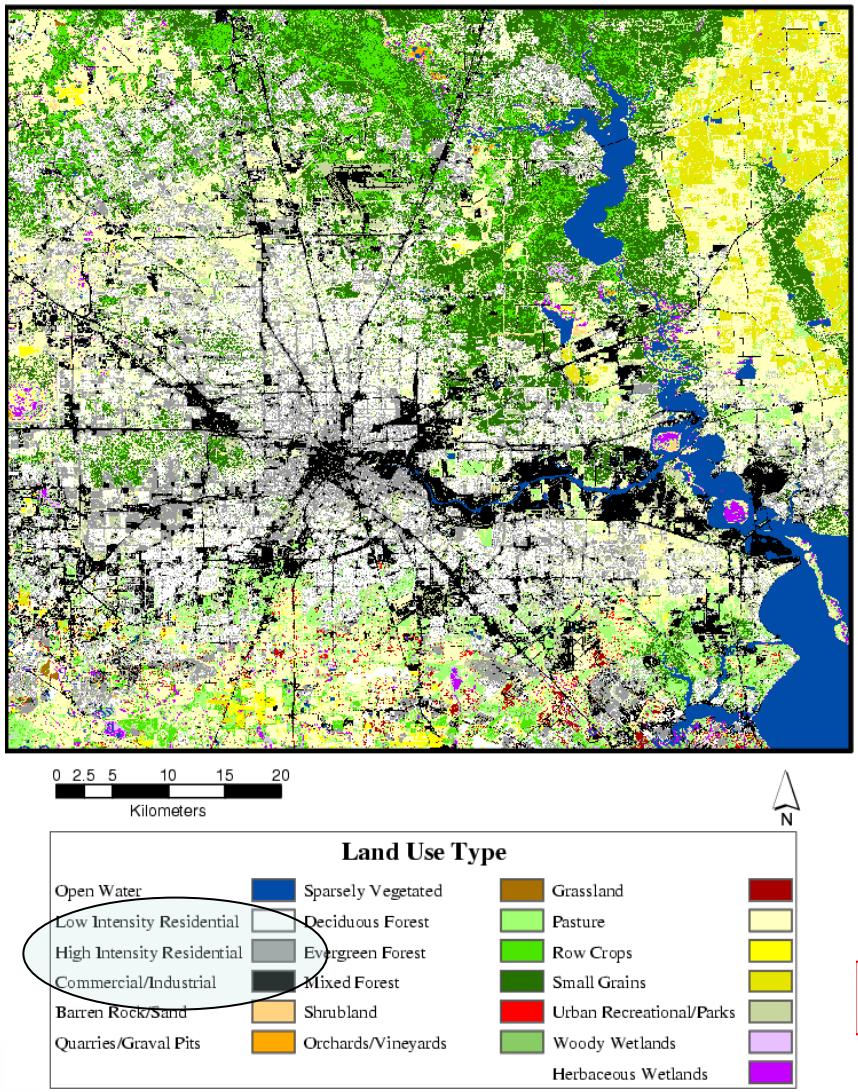
- Nearly 300 cities have a million or more inhabitants
- Impacts of urbanization
  - Urban heat (cool) island
  - Boundary layer structures
  - Deformation of synoptic system
  - Formation of convergence zone and thunderstorm
  - air quality, toxic contaminant dispersal, human health, damage to agriculture and ecosystems, water and energy supply/demand, climate (ozone and aerosol, greenhouse radiation budget)
- WRF is running routinely on 1-4 km grid spacing, need to capture these effects

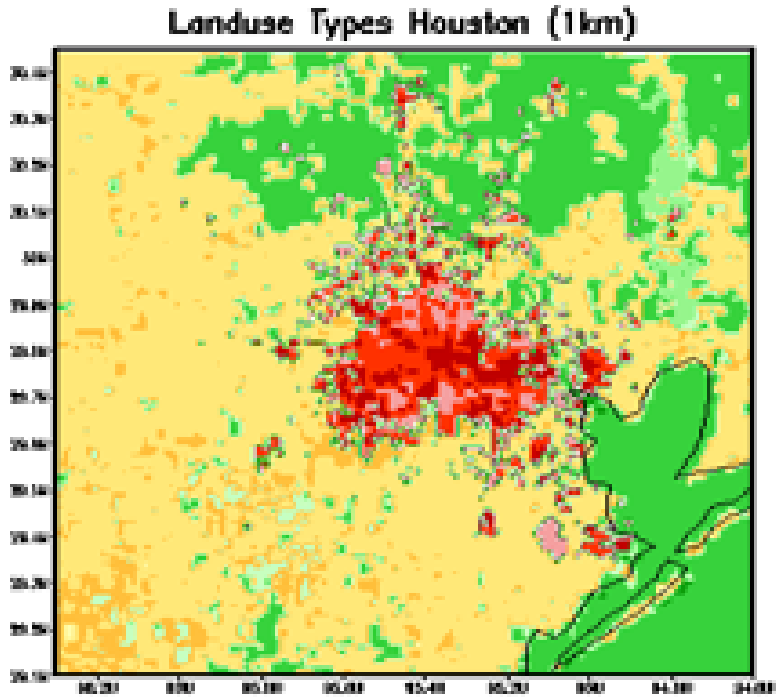


Integrated WRF Urban Modeling Framework



Enhance WRF/UCM global land-use data with high-resolution detailed urban data





Aggregated to WRF 1-km domain

30-m Landsat land-cover Houston

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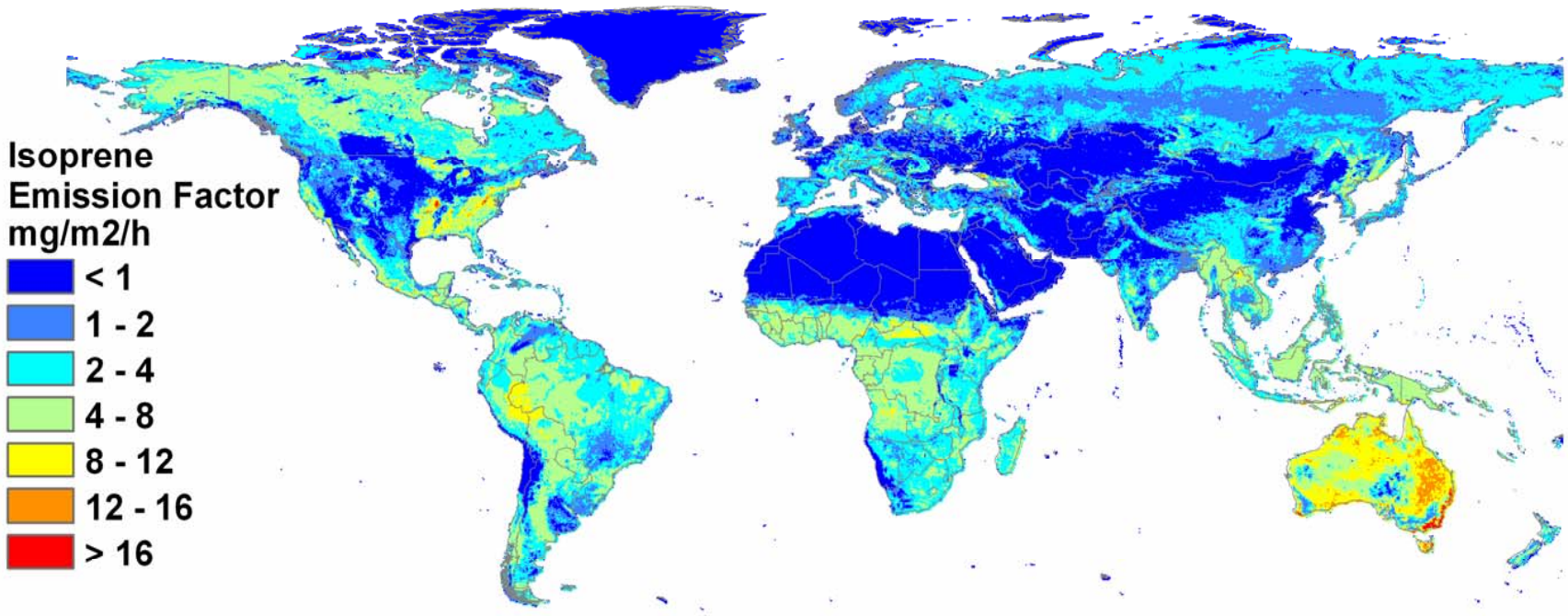
Integrate Surface Emission Model

MEGAN: Model of Emissions of Gases and Aerosols from Nature (Guenther 2006)

- Global biogenic emissions model
  - 1 km^2 spatial resolution
  - Predicts emissions of > 50 BVOC (Biogenic Volatile Organic Compounds)

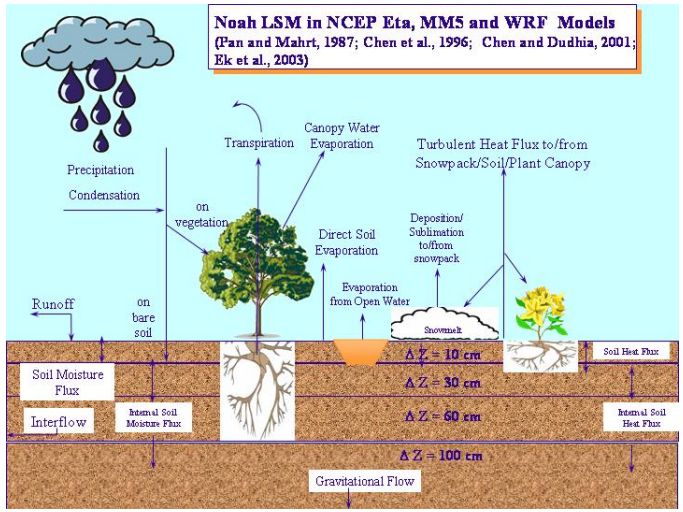


$$Emission_i = AEF_i * MEA * WEA * HEA$$

The Noah Land Surface Model

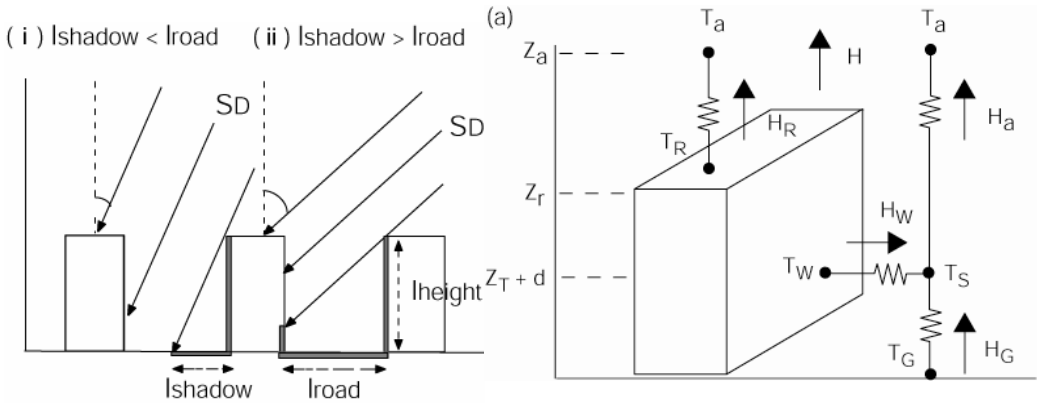
- Noah LSM primarily for NWP, air pollution, and regional hydrology applications
- Noah in operational models
  - NCEP WRF-NMM (June 2006)
  - AFWA: WRF-ARW (July 2006)
- Single layer urban-canopy model (UCM, based on Kusaka 2001)
  - 2-D urban geometry
  - Street canyons
  - Shadowing from buildings and reflection of radiation
  - Multi-layer roof, wall and road models
- Noah/UCM was released in WRF V2.2 (Dec. 2006)

Natural surface



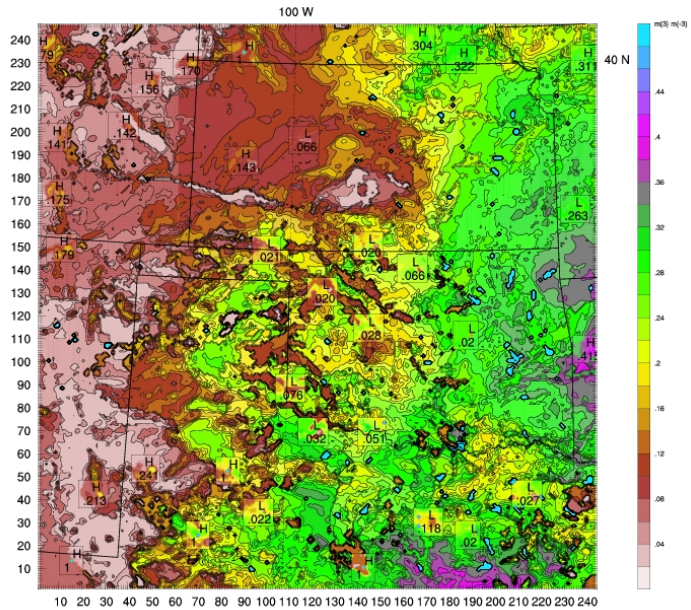
Coupled through 'urban fraction'

Man-made surface



Urbanized high-resolution land data assimilation system (u-HRLDAS)

- No routine high-resolution soil and urban observation for initializing WRF/UCM
- HRLDAS: Using observations to drive LSMs in uncoupled mode
  - long term evolution of multi-layer soil moisture, soil temperature, roof/wall/road temperature, surface fluxes, and runoff

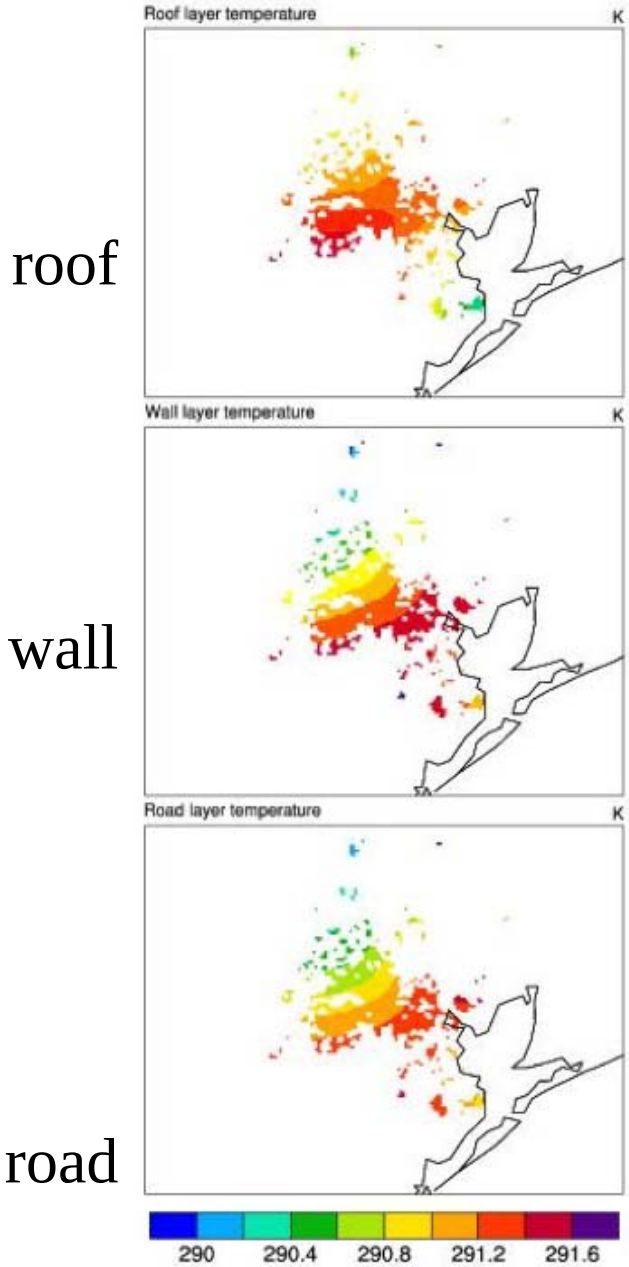


4-km HRLDAS surface soil moisture in IHOP domain 12 Z May 29 2002. Chen et al. 2007, J. Appli. Met. Clim.

Example of u-HRLDAS

U-HRLDAS simulated spatial distribution of roof, wall, and road surface temperature valid at 1 January 2006 for Houston

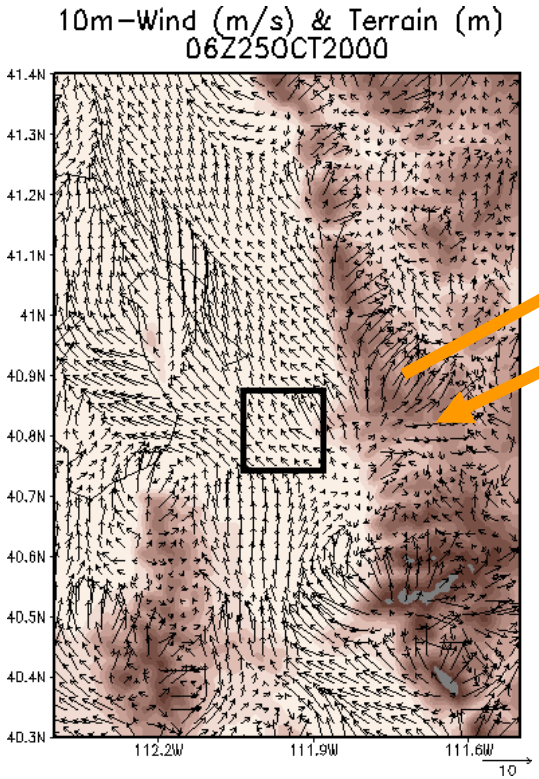
- Highly dependent on urban types
- Reflecting strong heterogeneity in urban environments



Two-way coupling WRF/CFD through MCEL (Model Coupling Environmental Library)

(Bill Coirier, CFDRC; John Michalakes, NCAR)

WRF-Noah/UCM coupled model forecast 0.5 -1 km

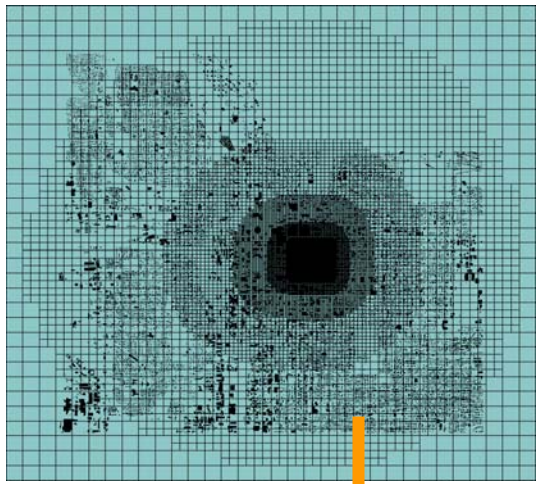


Coupling through MCEL

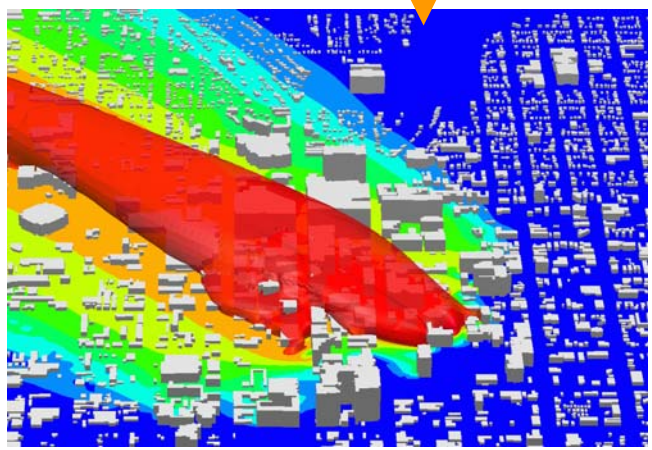
Down-Scale

Up-Scale

CFD-Urban: Hi-Res Urban Mode (1-3 m)

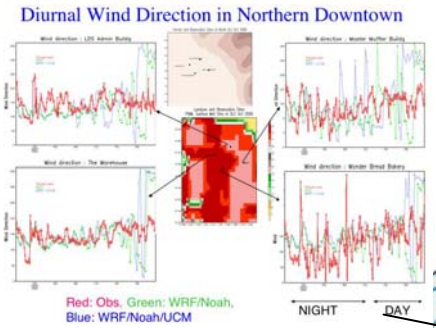


CFD-Urban: T&D

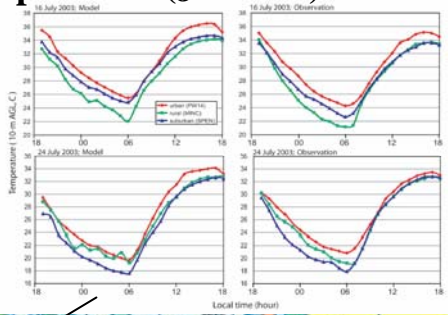


Application of Coupled MM5/WRF Urban Models

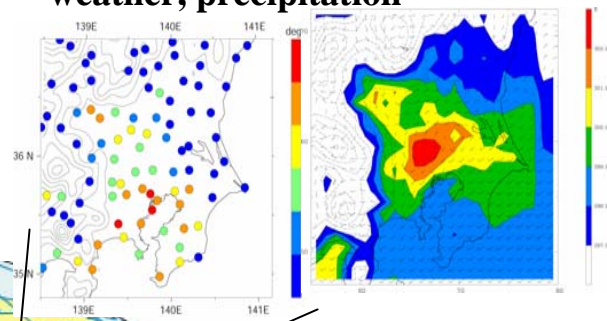
Salt Lake City: **Diurnal wind direction (URBAN-2000)**



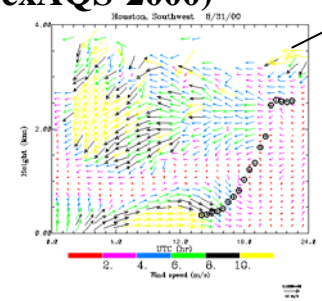
Oklahoma City: **2-m temperature (JU-2003)**



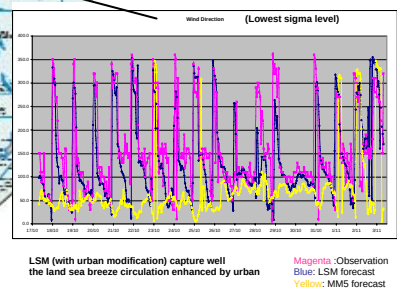
Beijing and Tokyo: **surface weather, precipitation**



Houston: **Diurnal cycle of wind profile (TexAQS-2000)**



Hong Kong: **10-day surface wind**



LSM (with urban modification) capture well the land sea breeze circulation enhanced by urban

Magenta: Observation
Blue: LSM forecast
Yellow: MM5 forecast

Liu, Chen, Warner, and Basara: 2006, J Appli. Meteorol.
Lo, Lau, Chen, and Fung, 2007: J. Appli. Meteorol.
Lo, Lau, Fung, and Chen, 2007: J Geophys. Res.
Zhang, Chen, and Miao 2006: J Geophys. Res., in revision.
Miao and Chen, 2007: Geophy. Res. Let., submitted

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Daunting Challenge: Specify fine-scale urban parameters

- Urban fraction
- building height, ZR
- roughness for momentum above the urban canopy layer, Z0C
- roughness for heat above the urban canopy layer Z0HC
- zero-displacement height above the urban canopy layer, ZDC
- percentage of urban canopy, PUC
- sky view factor, SVF
- building coverage ratio (roof area ratio), R
- normalized building height, HGT
- drag coefficient by buildings, CDS
- buildings volumetric parameter, AS
- anthropogenic heat, AH
- heat capacity of the roof, wall, and road
- heat conductivity of the roof, wall, and road
- albedo of the roof, wall, and road
- emissivity of the roof, wall, and road
- roughness length for momentum of the roof, wall, and road
- roughness length for heat of the roof, wall, and road

Example of defining urban parameters for Beijing

Gridded UCM parameters

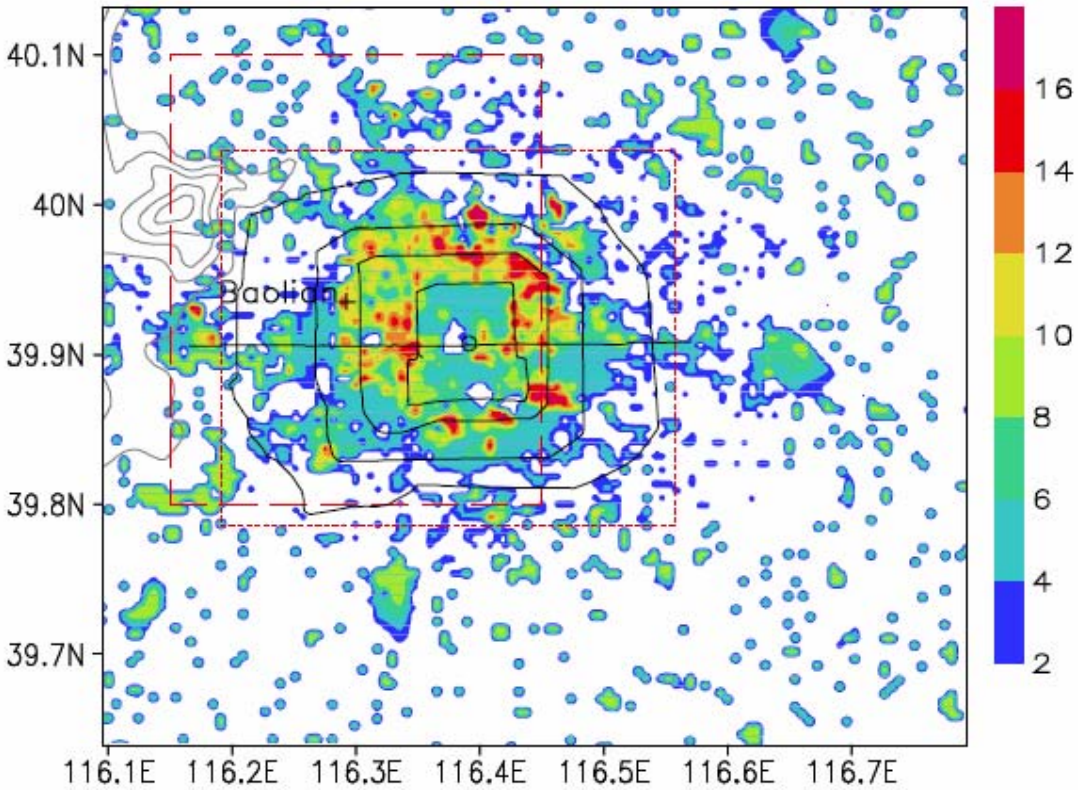
1, *ZR*
2, *Z0C, Z0HC, ZDC*
3, *FRC_URB*
4, *R, RW*
5, *HGT*
6, *SVF*
7, *AS*
8, *AH: AHB and AHC*

UCM parameters assigned from table (urban_param.tbl)

CDS, BETR, BETB, BETG
CAPR, CAPB, CAPG
AKSR, AKSB, AKSG
ALBR, ALBB, ALBG
EPSR, EPSB, EPSG
Z0R, Z0B, Z0G, Z0HR, Z0HB, Z0HG

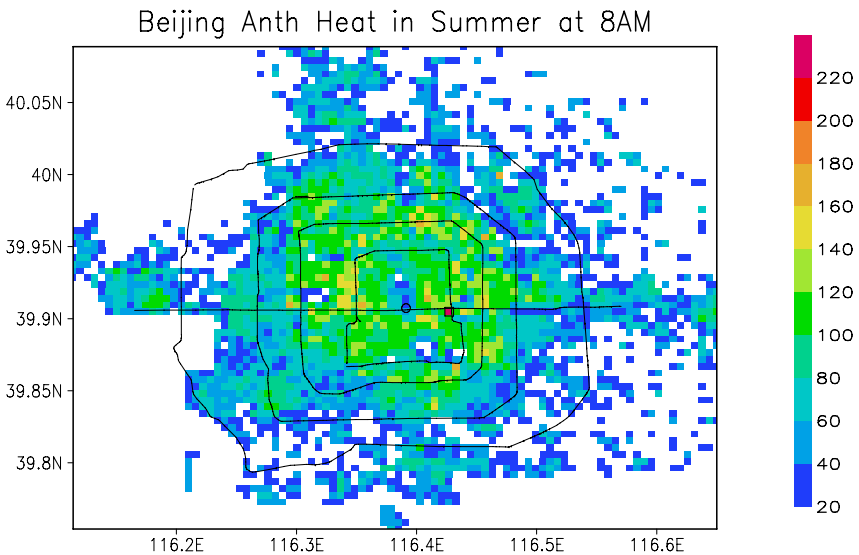
WRF/Noah/UCM Model Using Building Morphological Date for Beijing Study

The distribution of building height (shaded) and terrain height (gray contours from 100 m to 500 m with the interval of 100 m) in the 5th domain with the resolution of 500 m

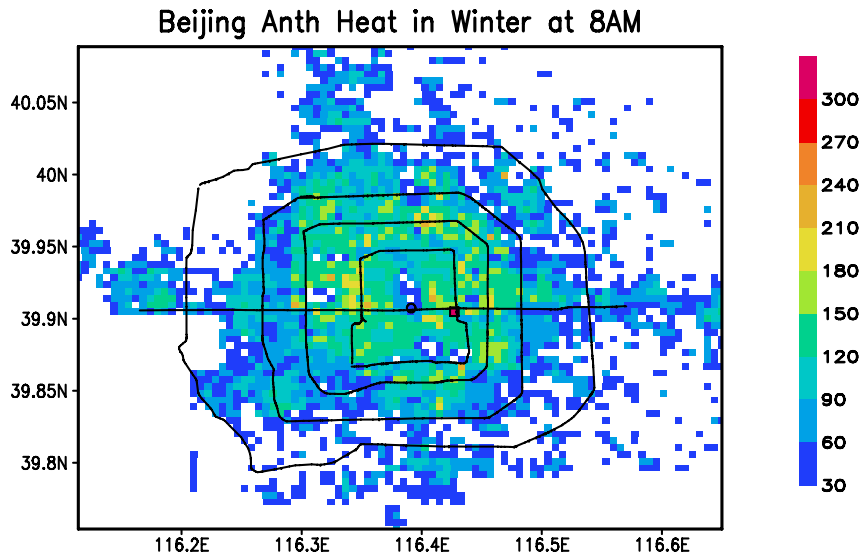


Anthropogenic heating (AH)

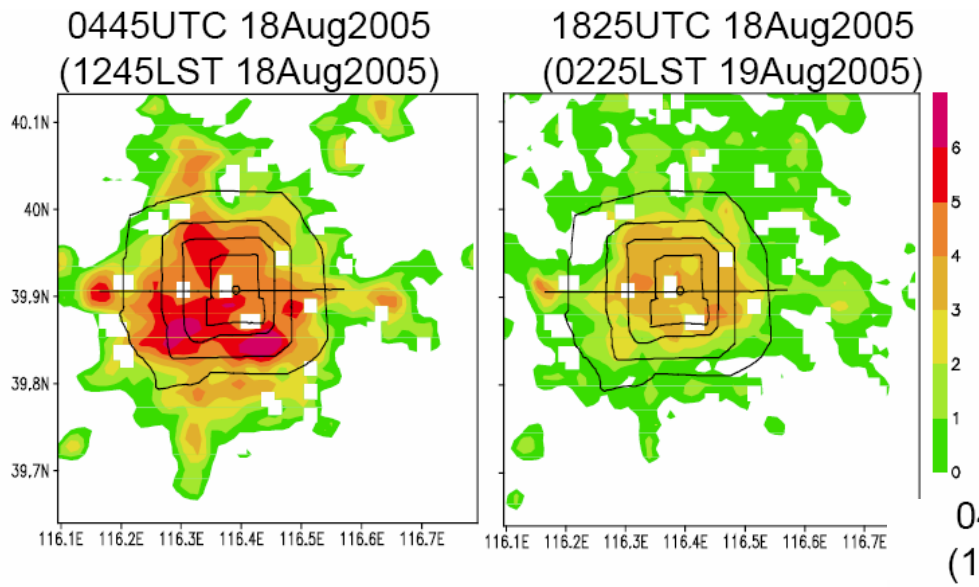
0800 LST Summer



0800 LST Winter

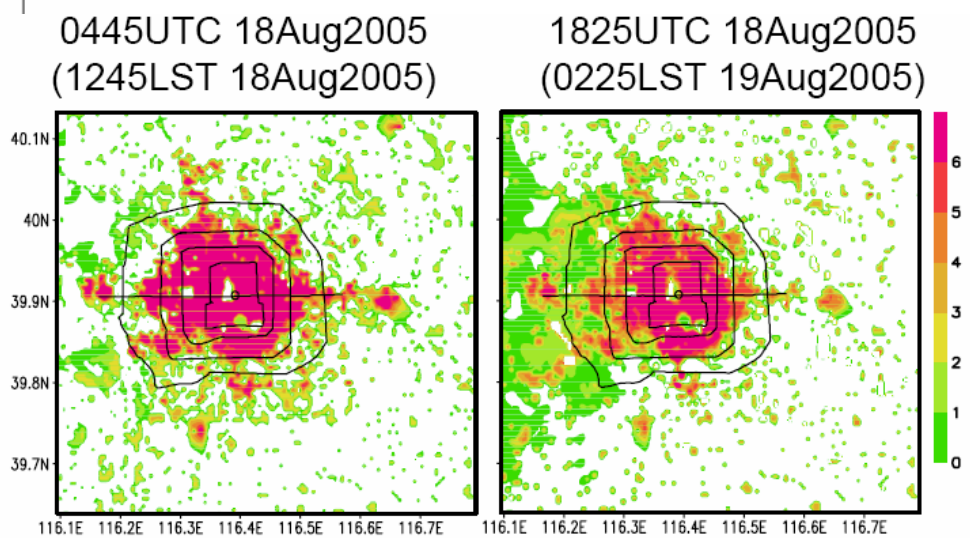


Spatial Variance of land surface temperature



MODIS Observations

WRF/Noah/UCM simulations



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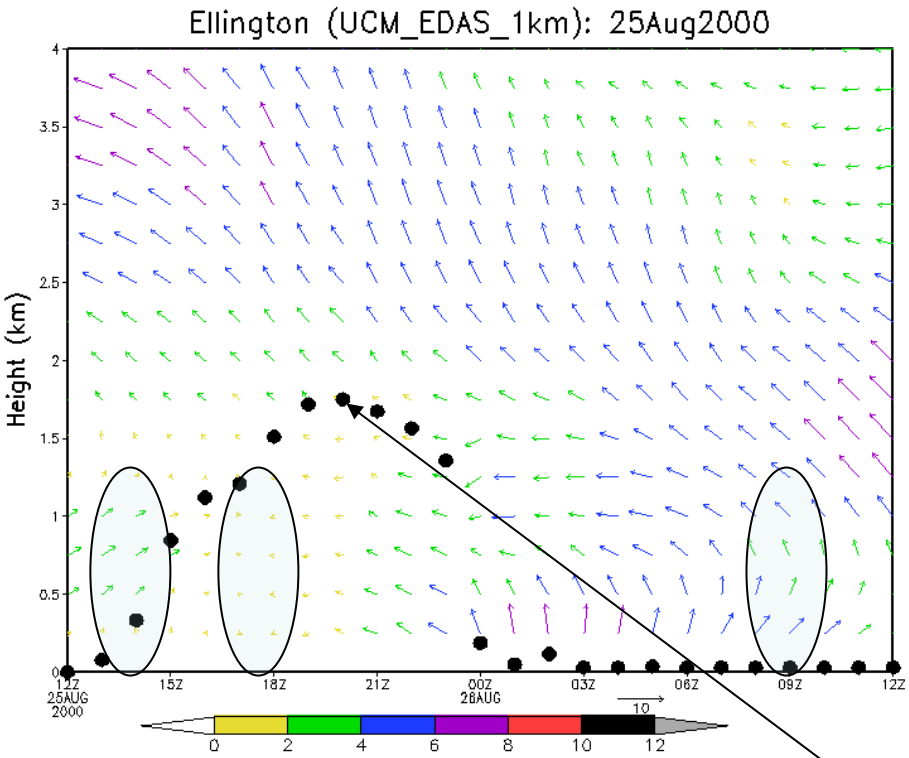
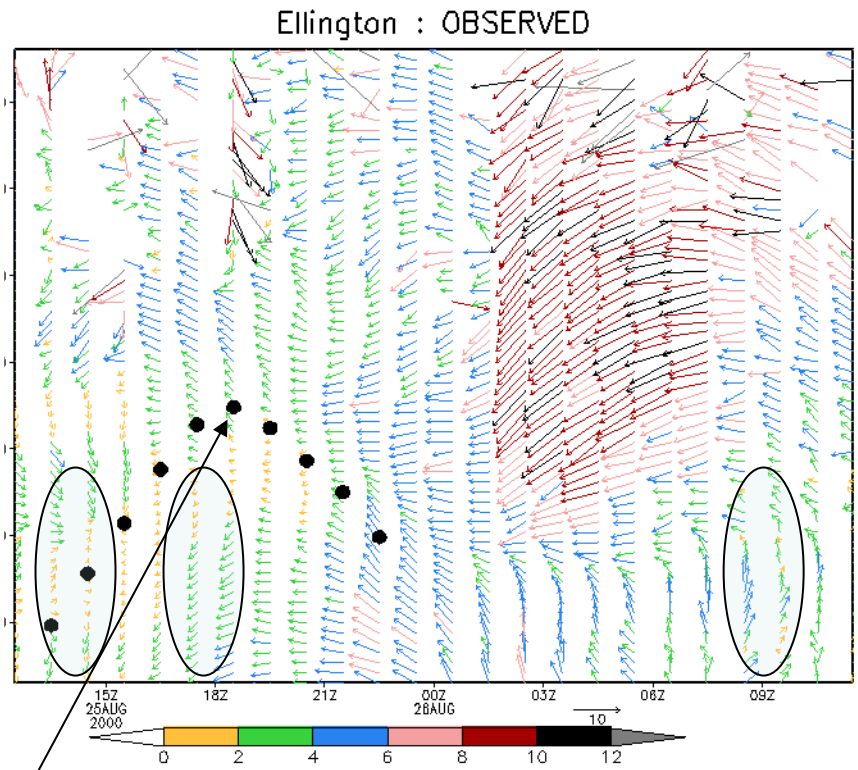
WRF/UCM simulation compared to obs from wind profiler at Ellington 25 Aug 2000





PBL depth

Summary

- The coupled WRF/Noah/UCM (single-layer) was released in WRF V2.2 (Dec 2006)
  - Documentation: http://rap.ucar.edu/research/land/technology/urban.php
  - Promising to capture fine-scale urban weather phenomena
- Integrating other components (new urban land-use data, surface BVOC emission model, u-HRLDAS, 2-way coupling with CFD model) are in progress.
- High-resolution land-use data and initialization systems (u-HRLDAS and FDDA) are important to improving WRF, T&D, and air quality models.

Future Work

- Improve urban land use data sets
- Test and evaluate multi-layer urban canopy model (Martilli-Dupont-EPA, Dupont et al. 2004)
- Test the two-way coupling of WRF/CFD with MCEL for Oklahoma City (JU-2003 field campaign)
- Collaborating with
  - Bob Bornstein: SJSU
  - Jason Ching: US EPA
  - Bill Coirier: CFDRC
  - Steve Burian: U. Utah