Earth Systems Models and Sub-models

by

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Types

- Evolution of global patterns of climate – Earth Systems Models (AOGCMs)
- Models dealing with components of climate and sub-climate scales

    synoptic scale

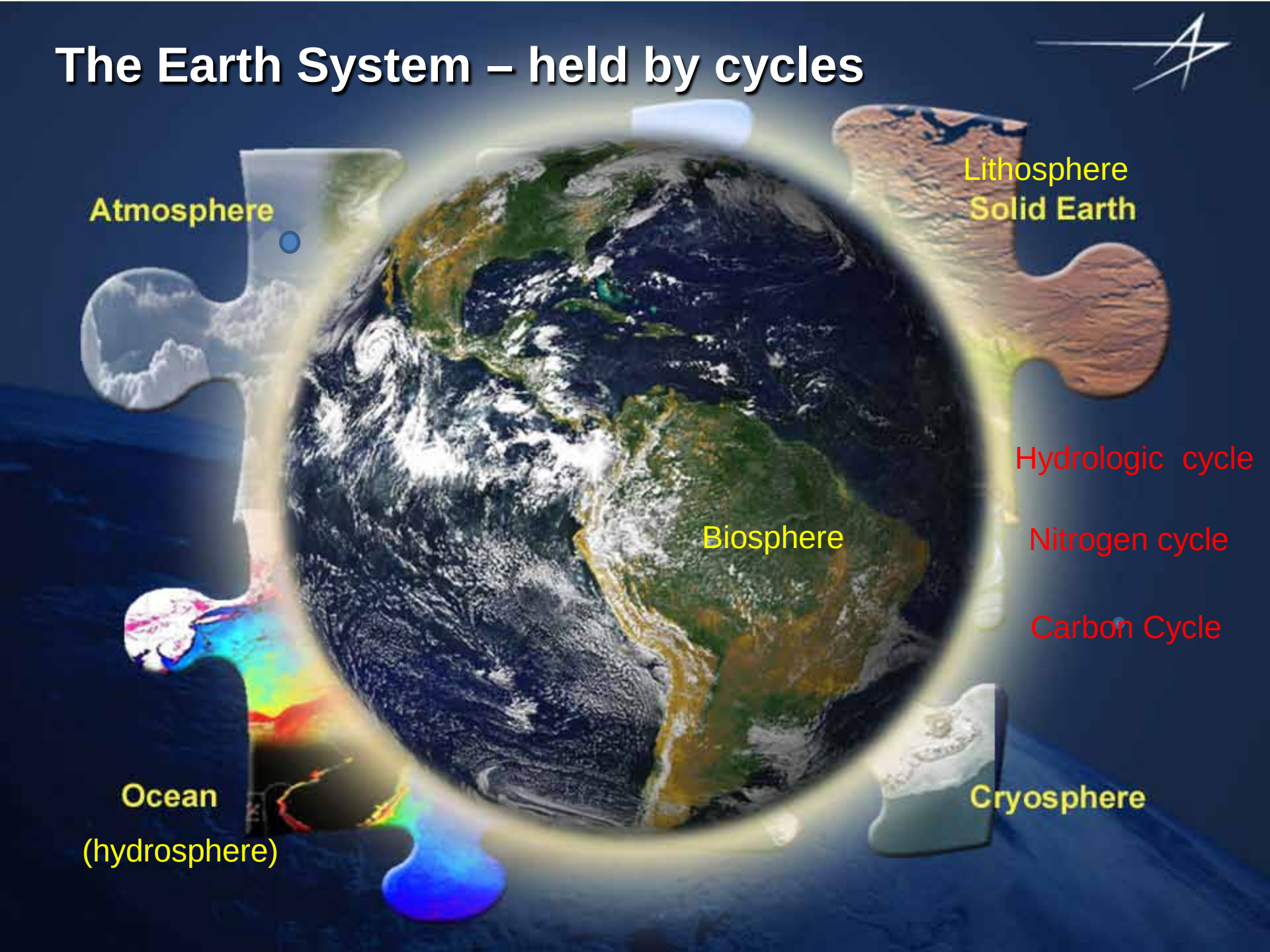
    meso-scale

    micro-scale

System and the components

Mouse Moral: Seeing a part makes a fine tale.
Wisdom comes, however, from seeing the whole.
(From Nature, Nov. 2000).

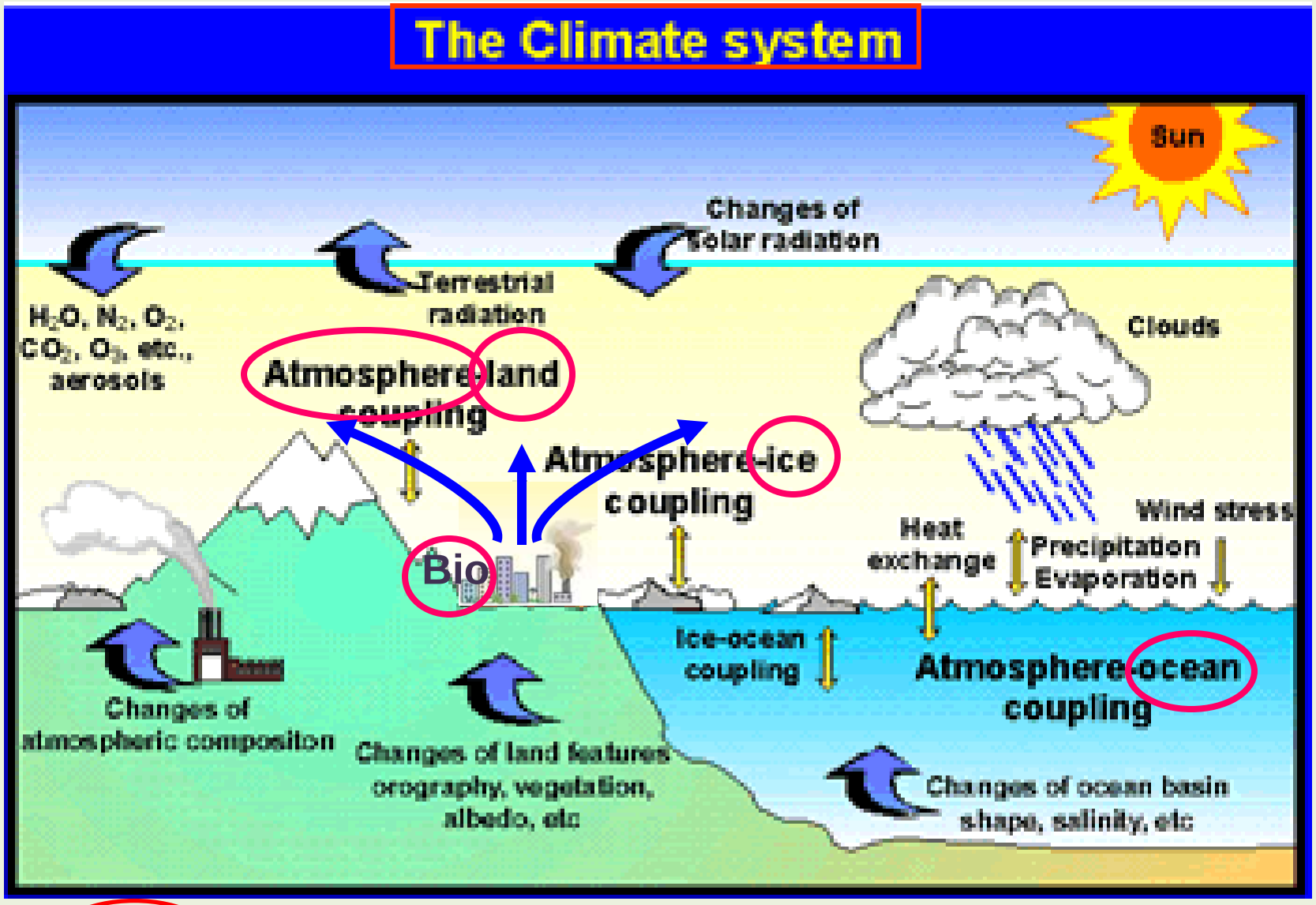
The Earth System – held by cycles



Hydrologic cycle

Nitrogen cycle

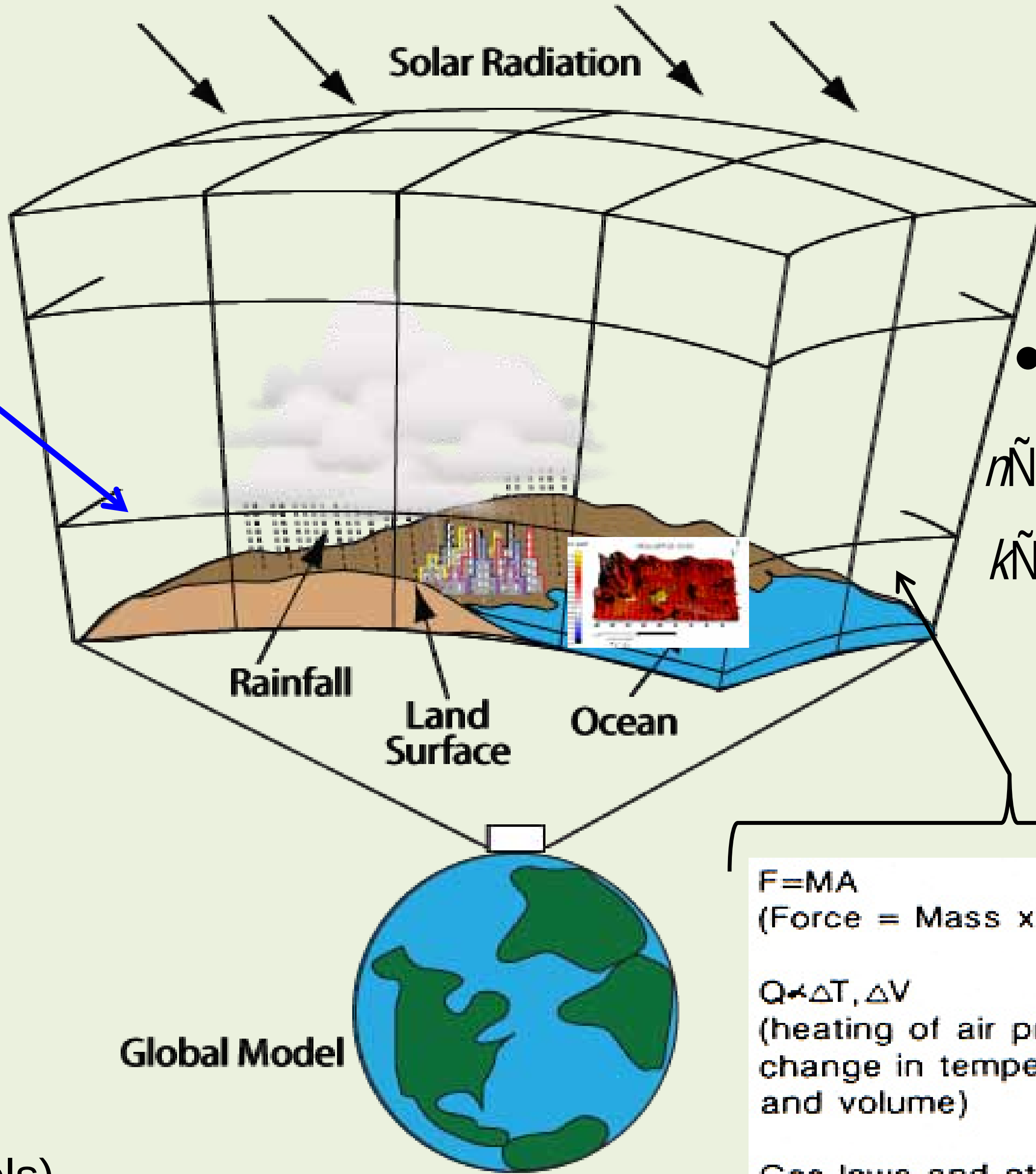
Carbon Cycle



City

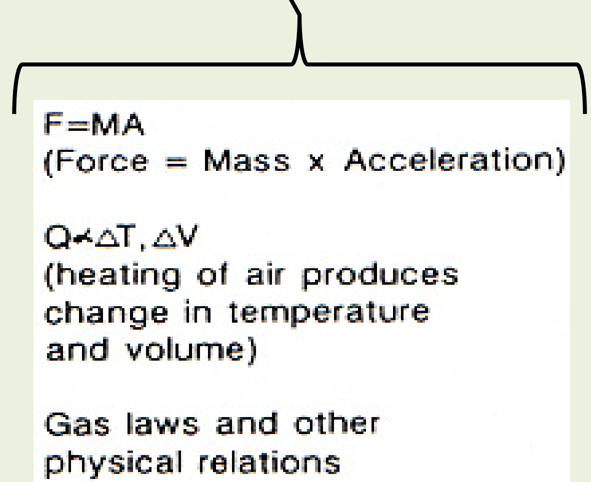
"Pollution" – anthropogenic stressors

100km



- GCMs

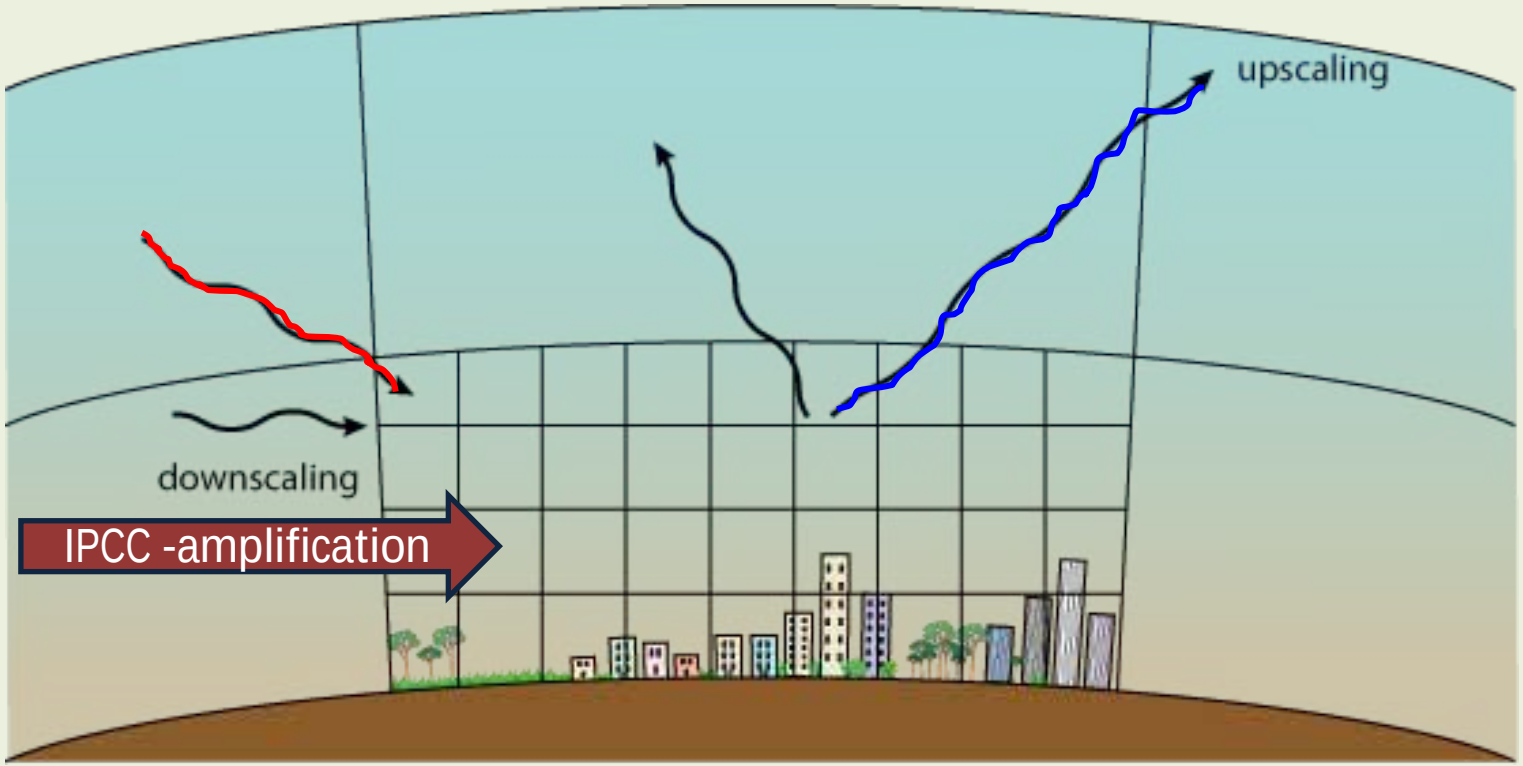
$$\left.\begin{matrix} n\nabla^2 u \\ k\nabla^2 c \end{matrix}\right\} \Rightarrow A_x \frac{\partial^2}{\partial x^2} + A_y \frac{\partial^2}{\partial y^2}$$



Earth Systems Modeling

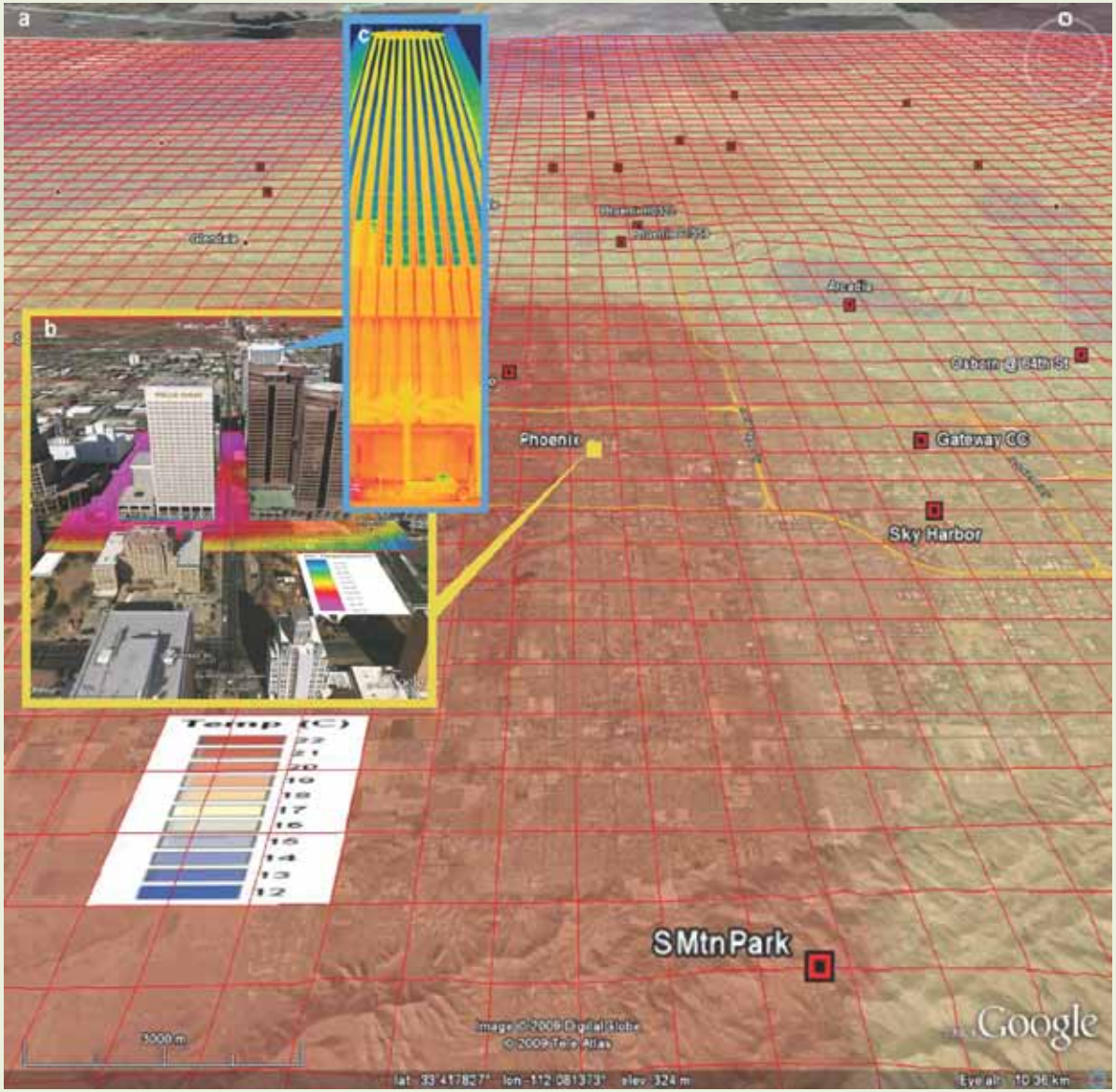
(Atmosphere Ocean General Circulation Models)

Climate to Local Scales

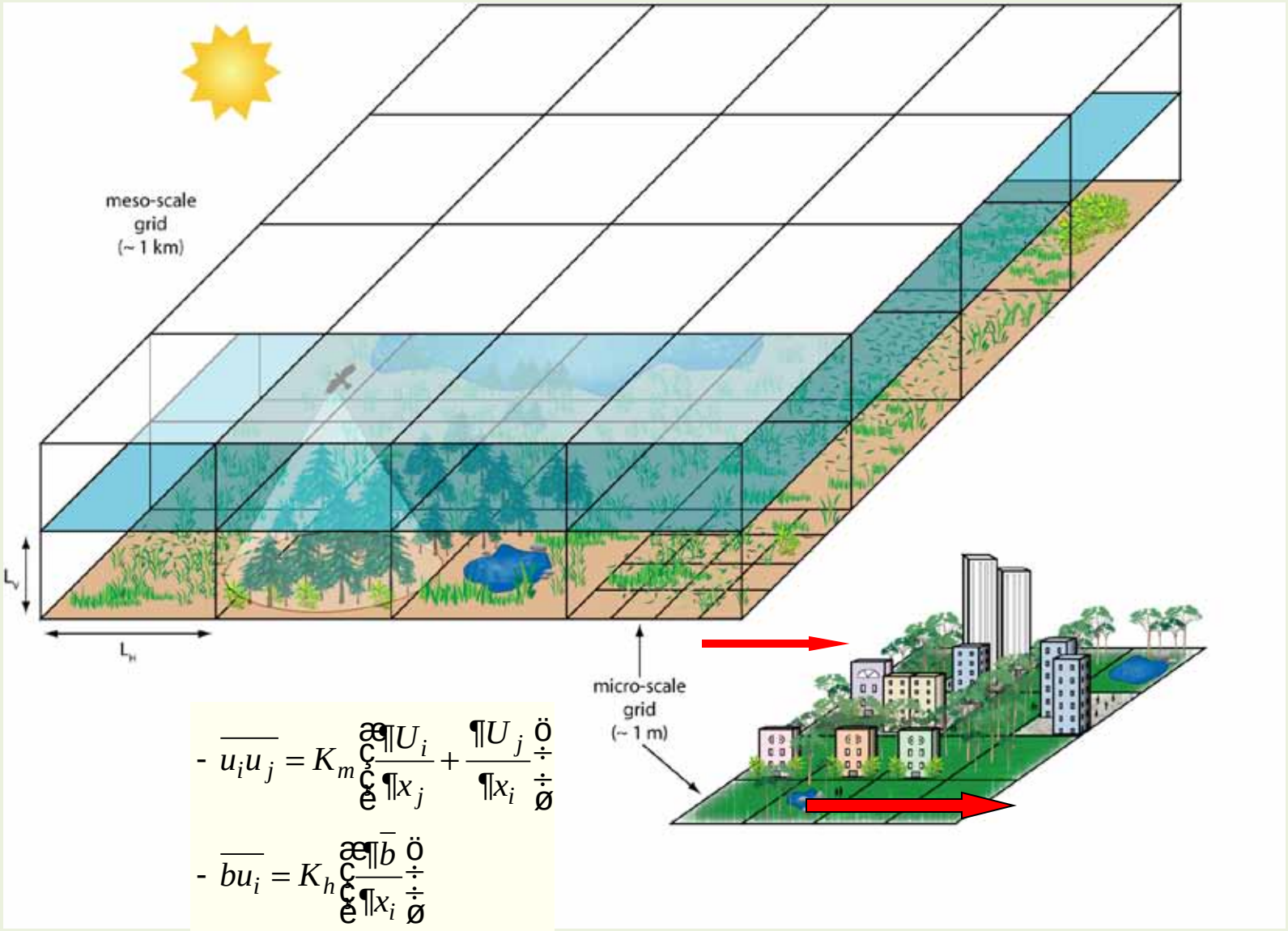


Meso-scale to sub-urban scales

- Canyons
- Building canopies (DT, separations)
- Anthropogenic emissions
- Land use inhomogeneities
- Tree canopies
- Roadways



Need for Eddy Diffusion Parameterizations



$$-\overline{u_i u_j} = K_m \left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i} \right)$$

$$-\overline{b u_i} = K_h \frac{\partial \bar{b}}{\partial x_i}$$

Diffusion Coefficients

MRF (Medium Range Forecast model)

MRF is a vertical diffusion non-local scheme in which is taken into account that the transport of mass, momentum and heat is mostly accomplished by large eddies (Troen and Mahrt 1986, Hong and Pan 1996).

The turbulence diffusion equation for prognostic variable is:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[K_c\left(\frac{\partial C}{\partial z} - g_c\right)\right]$$

Below the PBL:

$$K_{zm} = k w_s z\left(1 - \frac{z}{h}\right)^p \qquad \frac{K_{zm}}{K_{zh}} = Pr$$

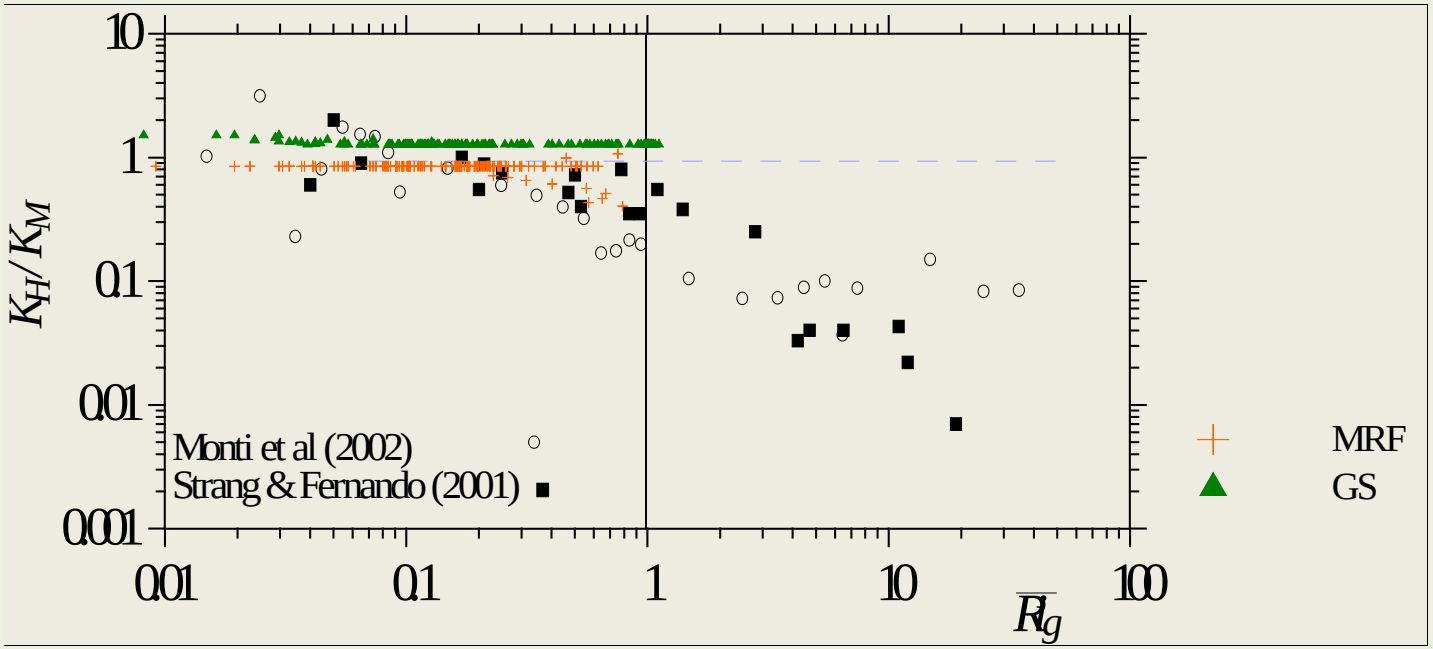
-Regime 1 ========== è Nighttime Stable conditions **(BR>0.2)**

-Regime 2 ========== è Dumped mechanical turbulence **(0<BR<0.2)**

-Regime 3 ========== è Forced Convection conditions **(BR=0)**

-Regime 4 ========== è Free Convection conditions **(BR<0)**

Eddy Diffusivity Ratio



Inverse Prandtl Number

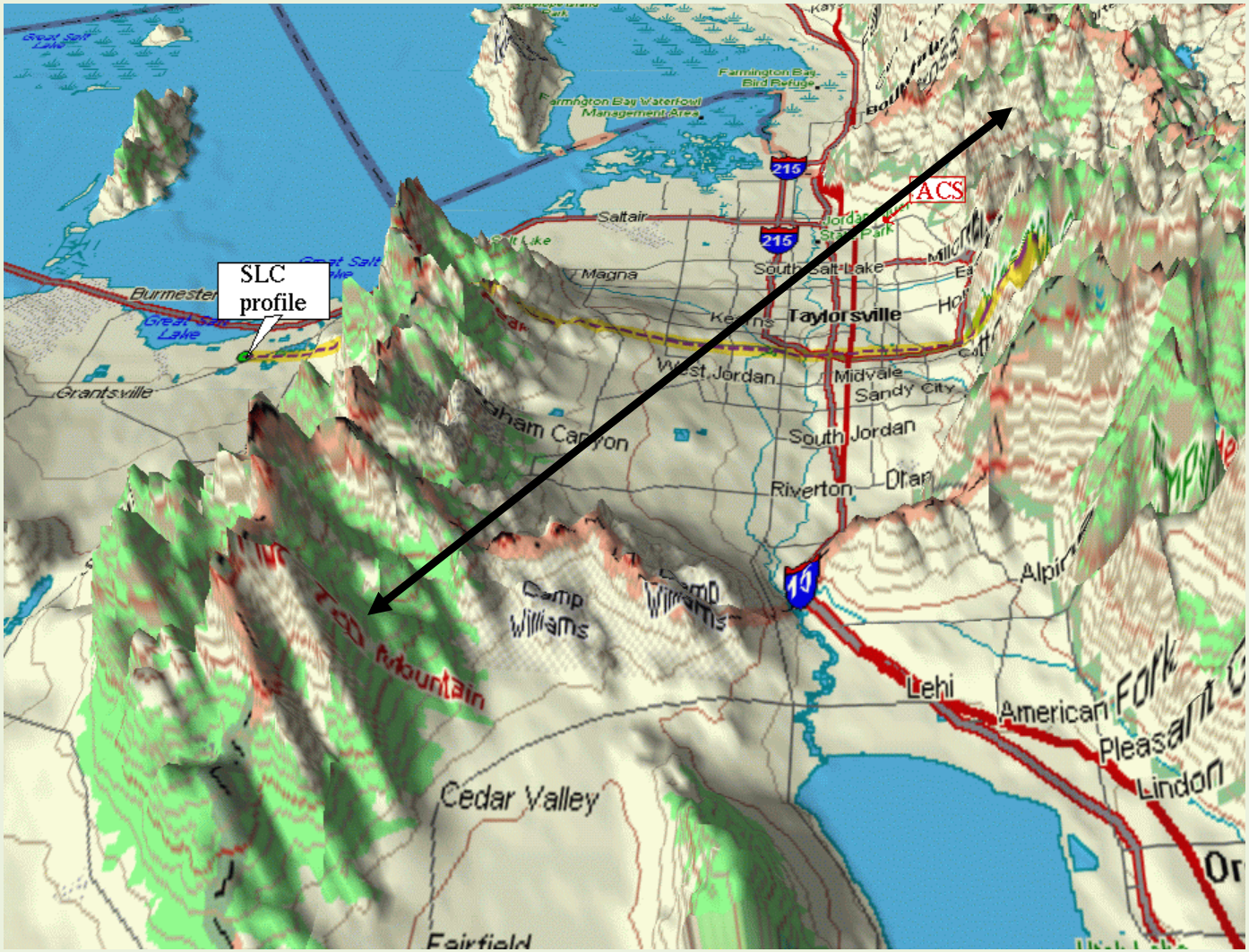
- J. Physical Oceanography 2001
- Boundary layer Meteor. 2006

New Eddy Diffusivities

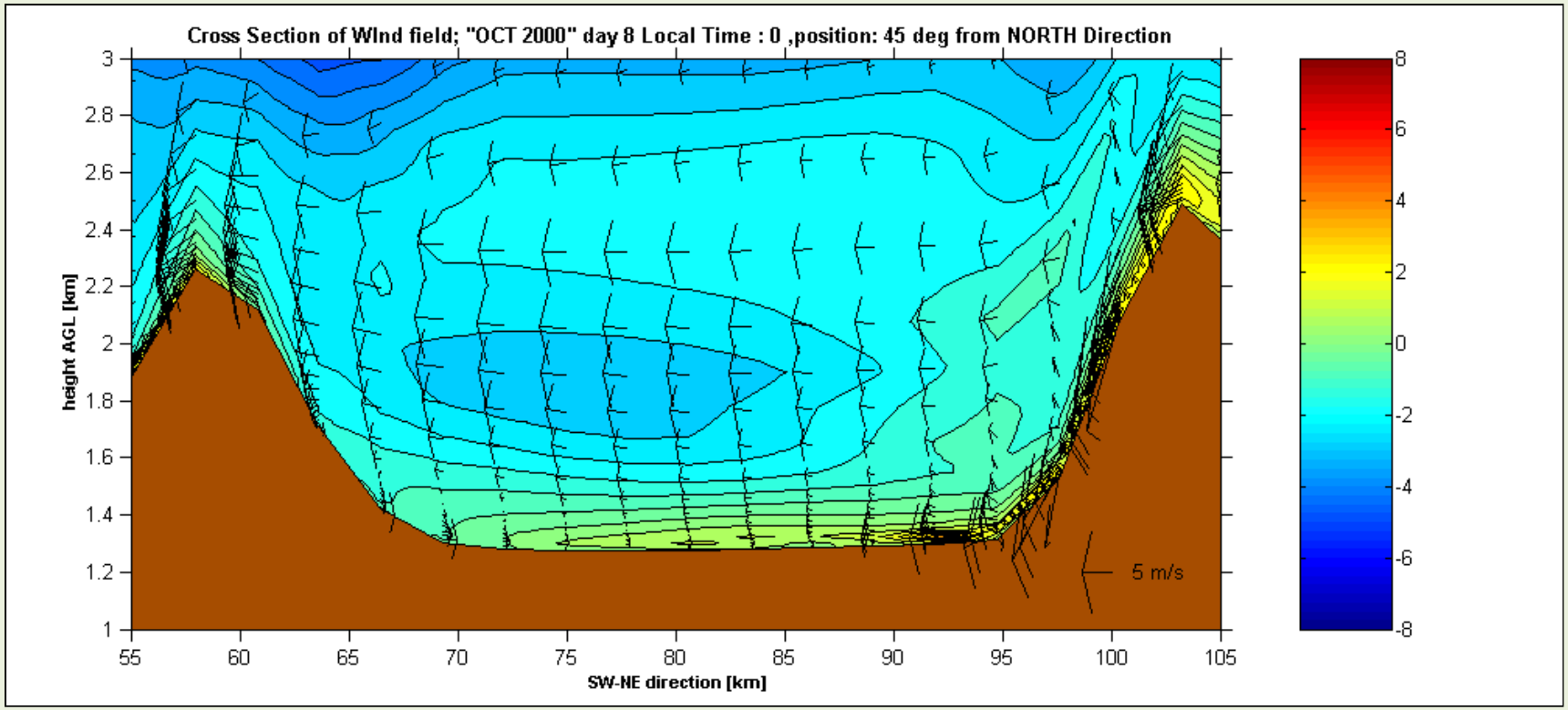
$$\frac{K_m}{\sigma_w^2 / \left| d\tilde{V} / dz \right|} = (0.34)\overline{Ri_g}^{-0.02} \approx 0.34$$

$$\frac{K_h}{\sigma_w^2 / \left| d\tilde{V} / dz \right|} = (0.08)\overline{Ri_g}^{-0.49} \approx (0.08)\overline{Ri_g}^{-0.5}$$

Salt Lake City – VTMX



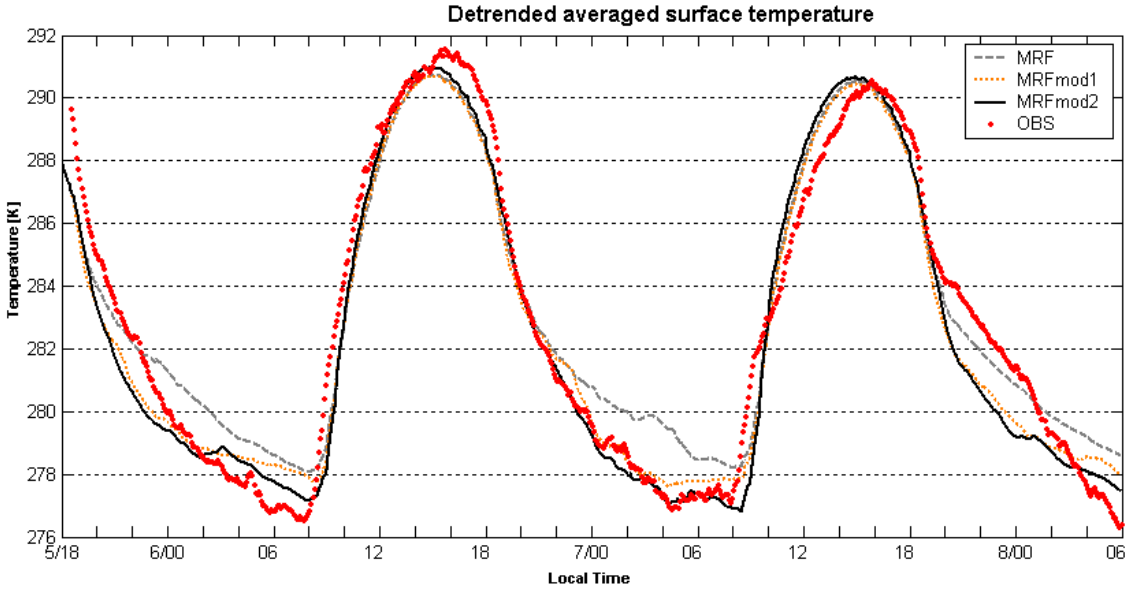
CROSS SECTION SW-NE 45 deg.

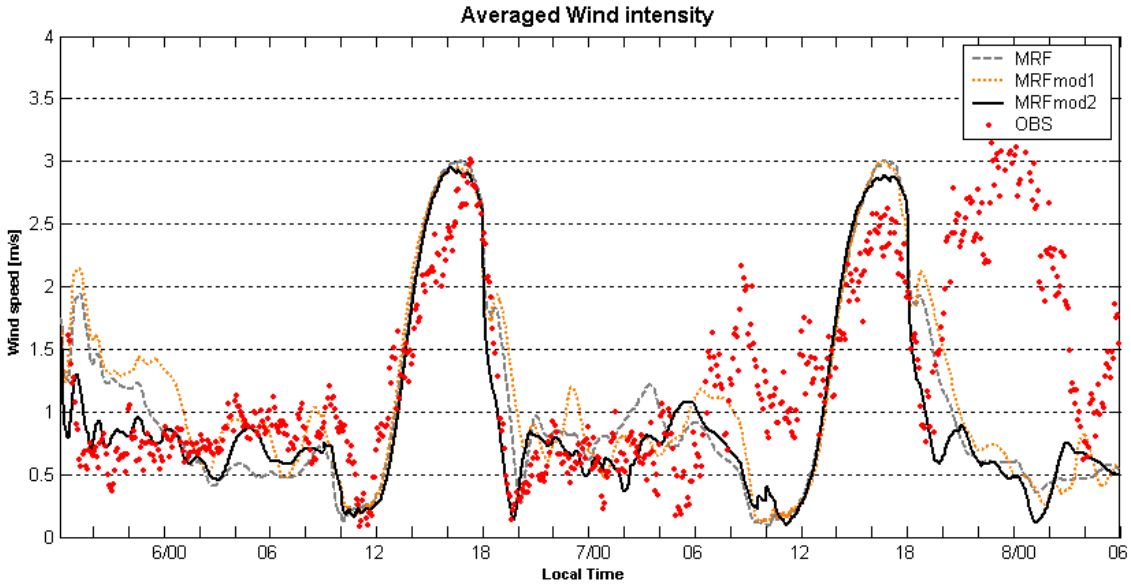


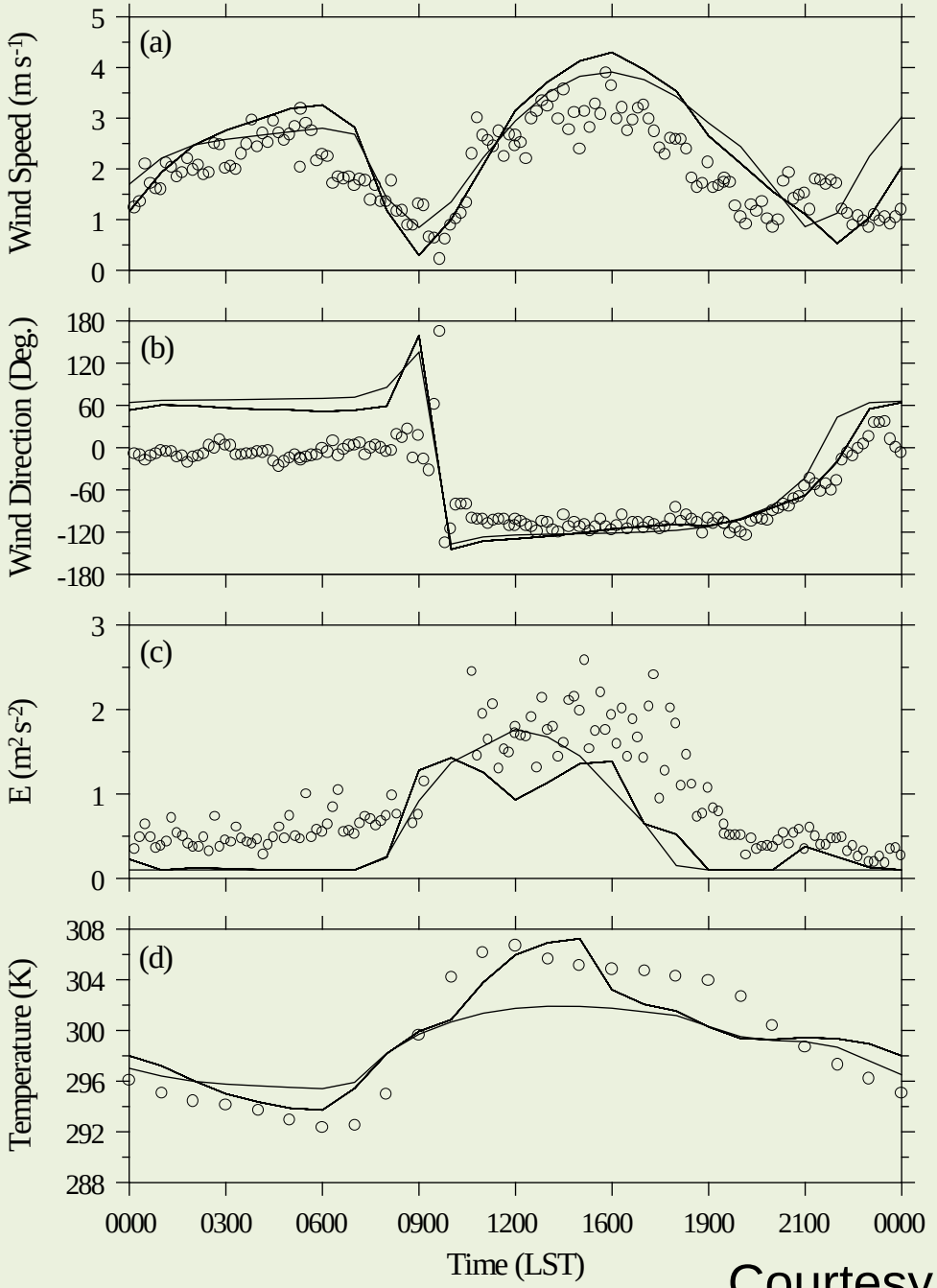
Lee et al. Boundary Layer Meteorology, 119, 2006

Temperature & Wind comparison

• Lee et. al. *Boundary Layer Meteorology, 119, 2006*







(averaged over 1-h, at 10 km)

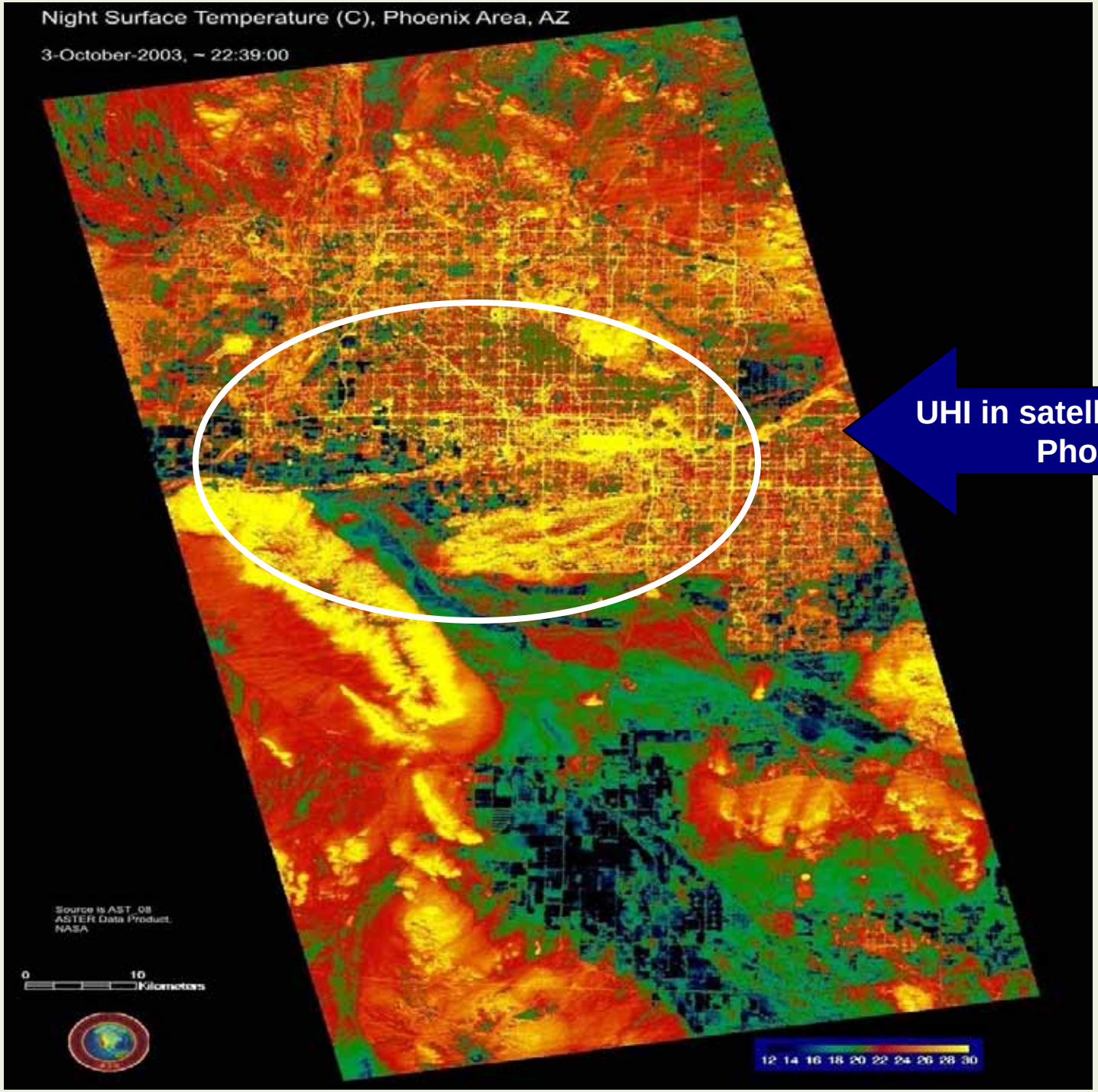
RAMS uses Therry and Lacarrere's (1983) parameterization

200x200 km domain, including Rome

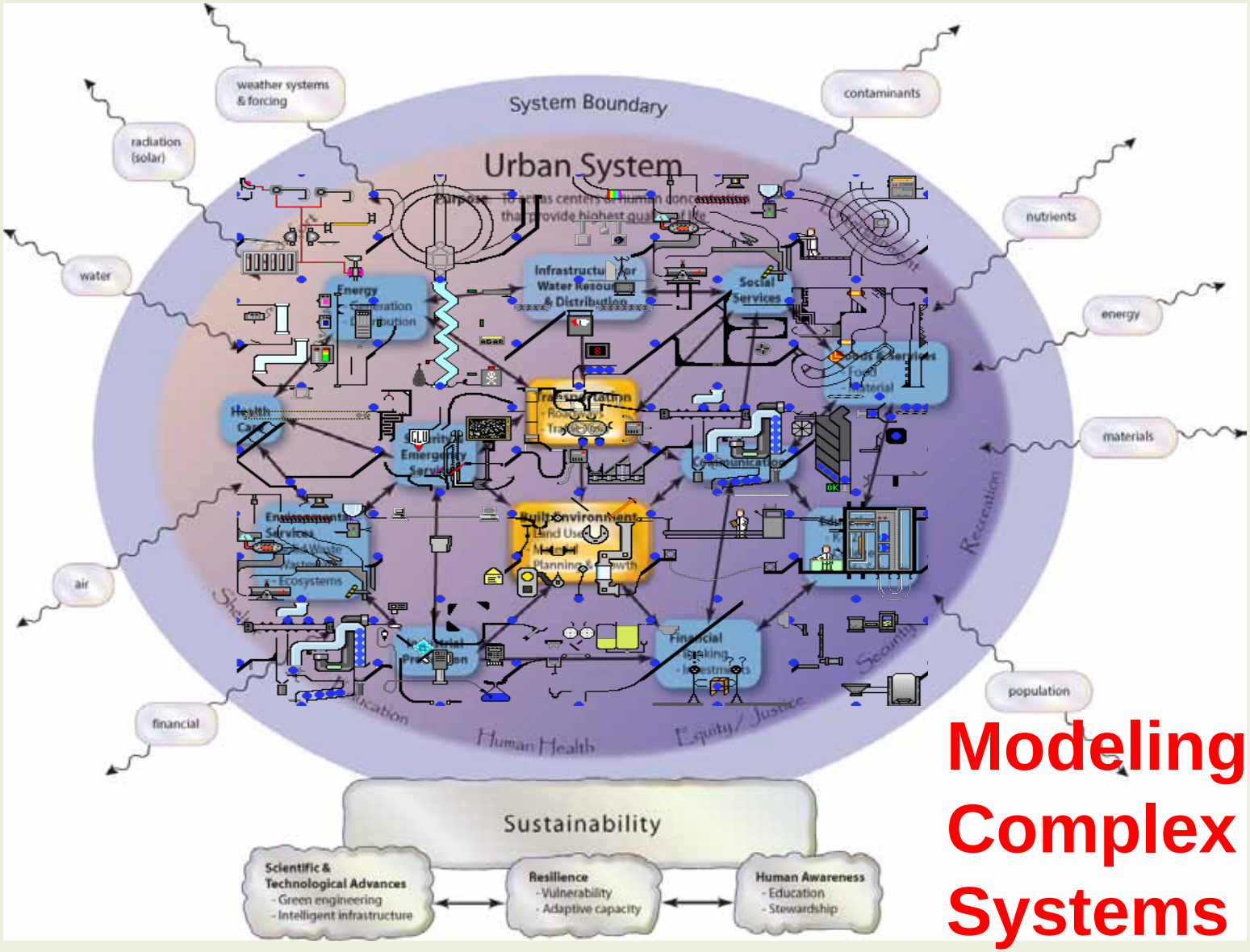
Courtesy: Paolo Monti, University of Rome

Urban Sales

Urban Heat Island – Not predicted well by the conventional meso-scale models

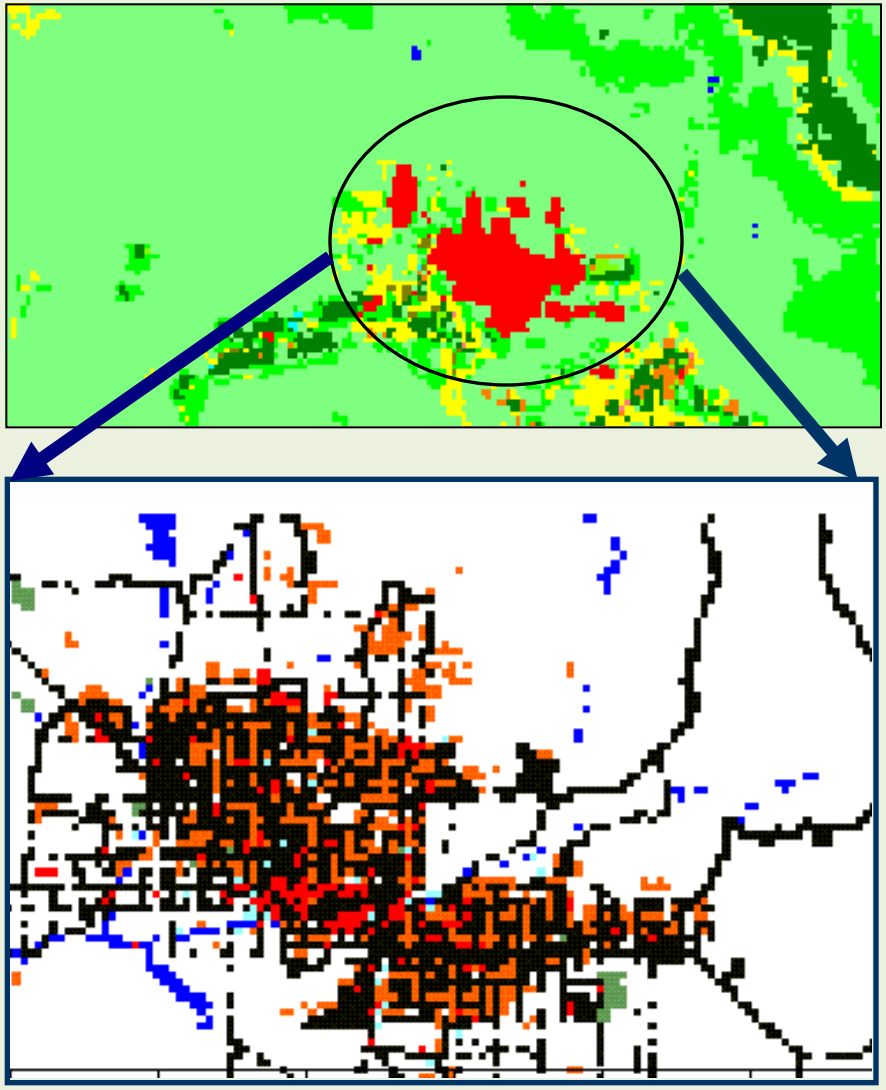


UHI in satellite image of Phoenix



Modeling of Complex Systems

Parameterization of Urban areas



Conventional MM5
Ø Urban is one category

Urban version of MM5
Ø Urban is one category

- Sub-Urban area/residential houses
- Low commercial/residential houses (2-3 level)
- Buildings less than 24-stories /low industrial
- Low commercial, administrative and cultural buildings
- Salt River
- Freeway and Road
- Commercial offices (high)

Methodology of UCP for Phoenix

- UCP(Urban Canopy parameterization) is adopted to MM5

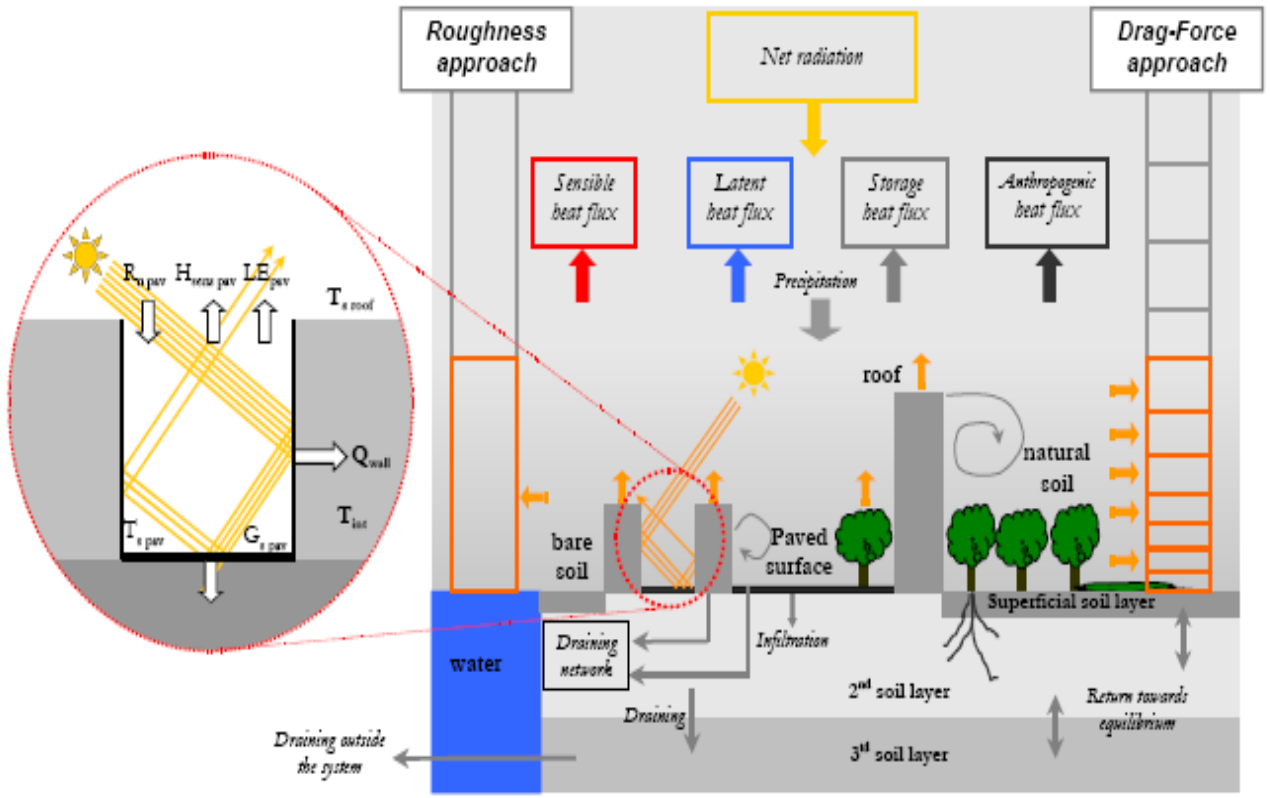
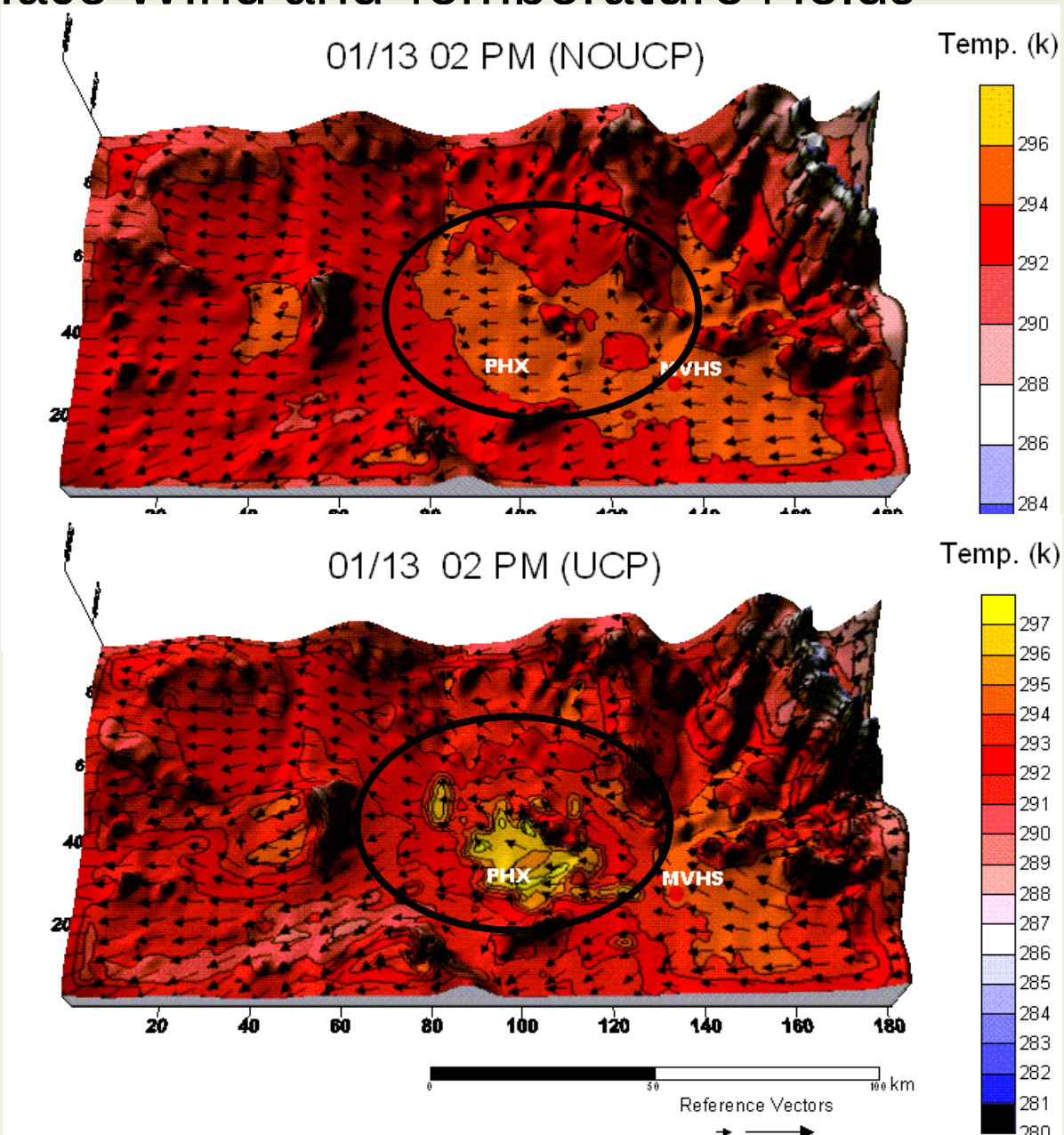


Figure 1. Scheme of the new MM5 canopy parameterization, DA-SM2-U, using the drag-force approach with the soil model SM2-U(3D), compared with the roughness approach. (from Dupont et al. ,2004)

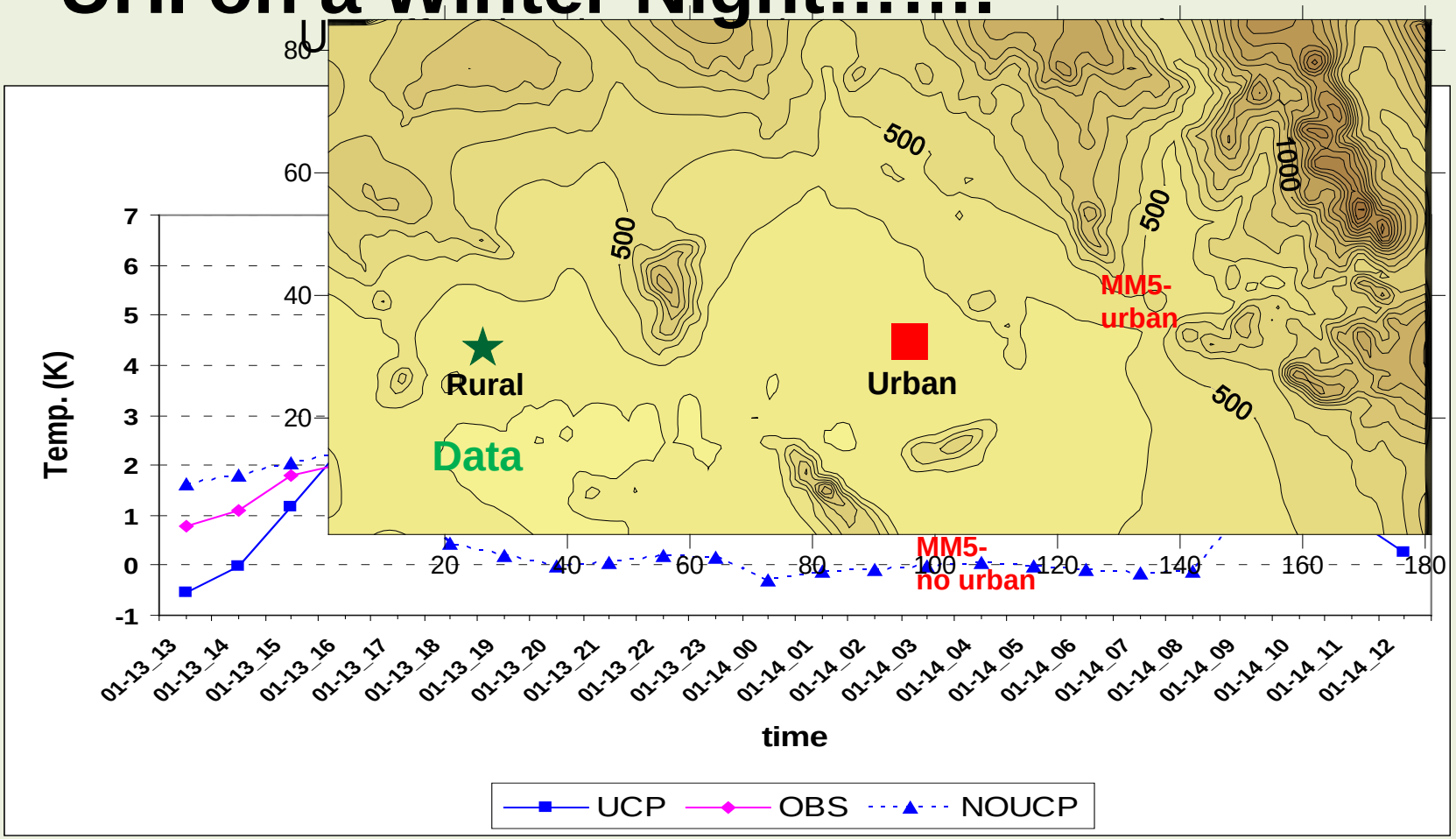
Surface Wind and Temperature Fields

NoUCP

UCP



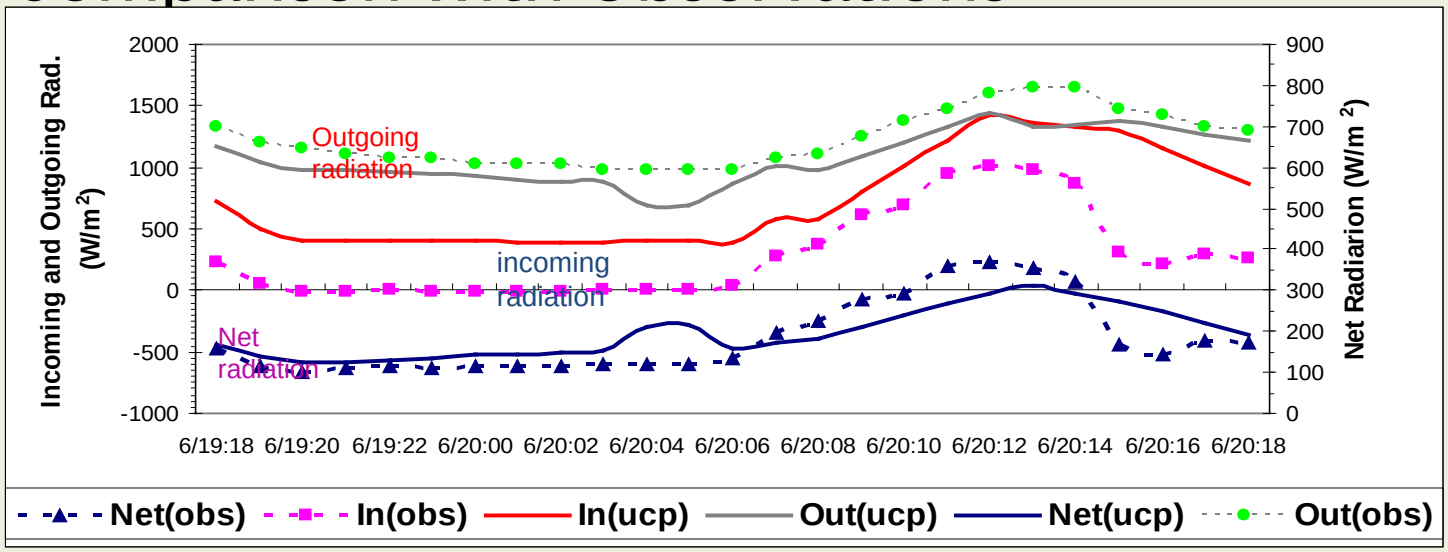
UHI on a Winter Night…….



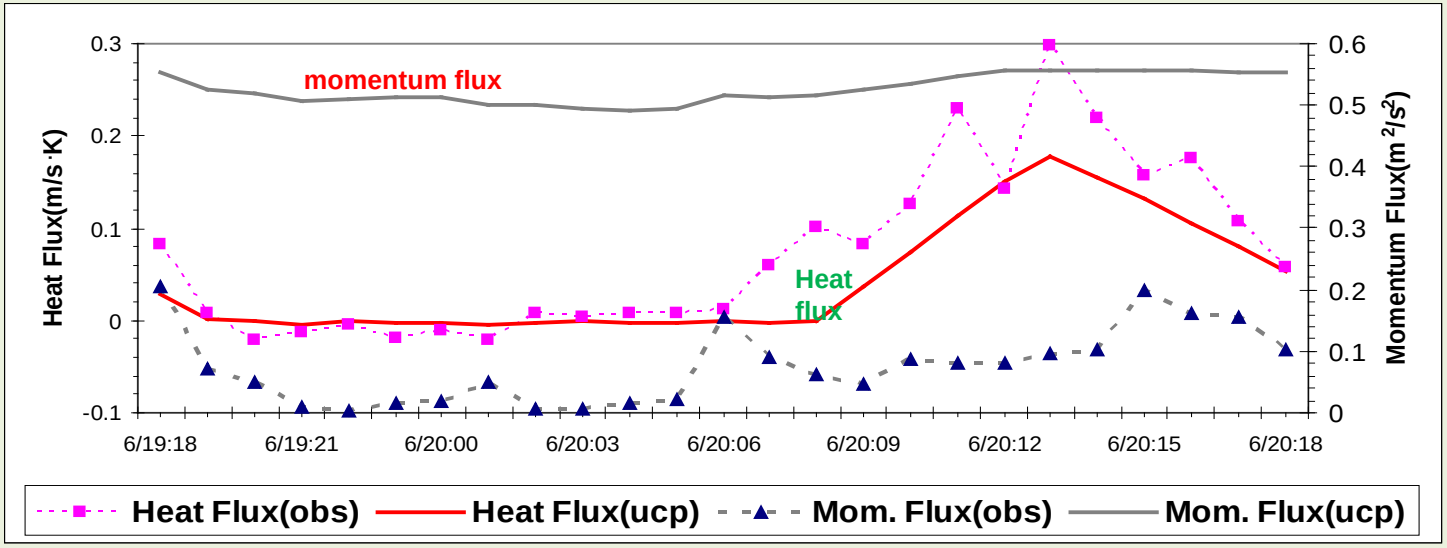
- Observations: (Urban – Rural) is about 6°
- Simulations:
  - 7° by MM5/UCP(ASU-Version);
  - No UHI by the conventional No-UCP version

Comparison with Observations

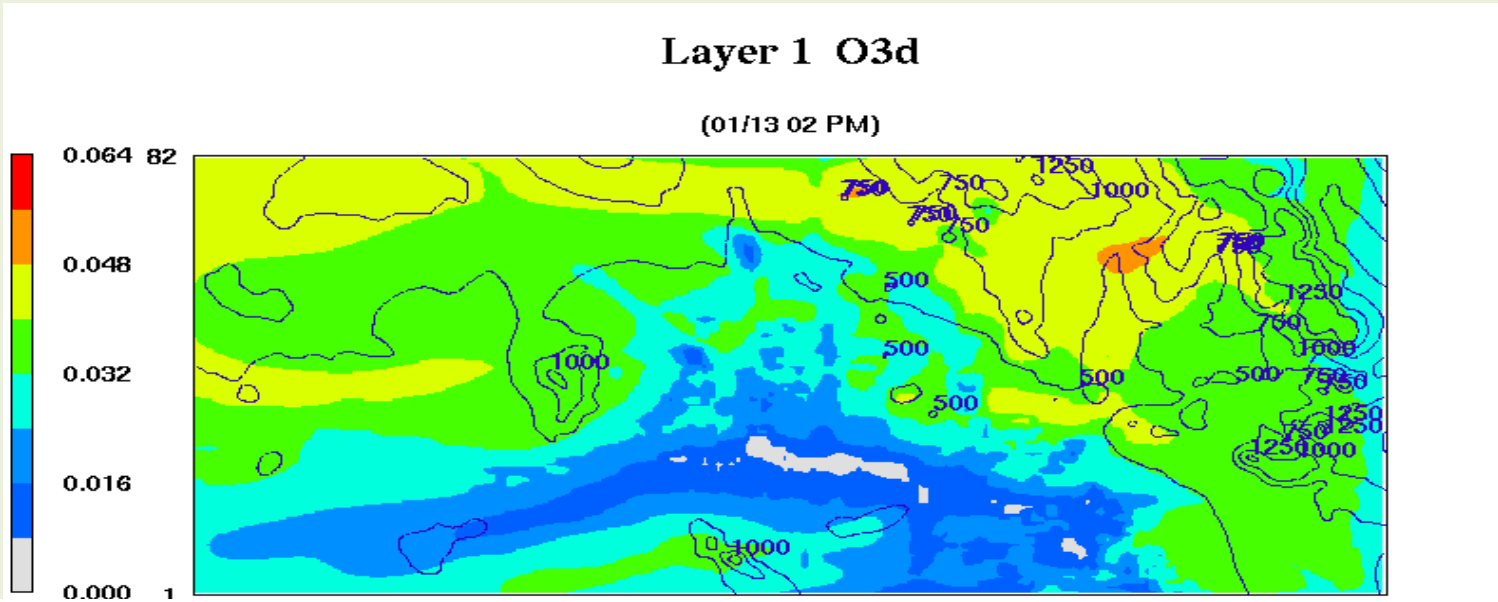
Radiation Budget



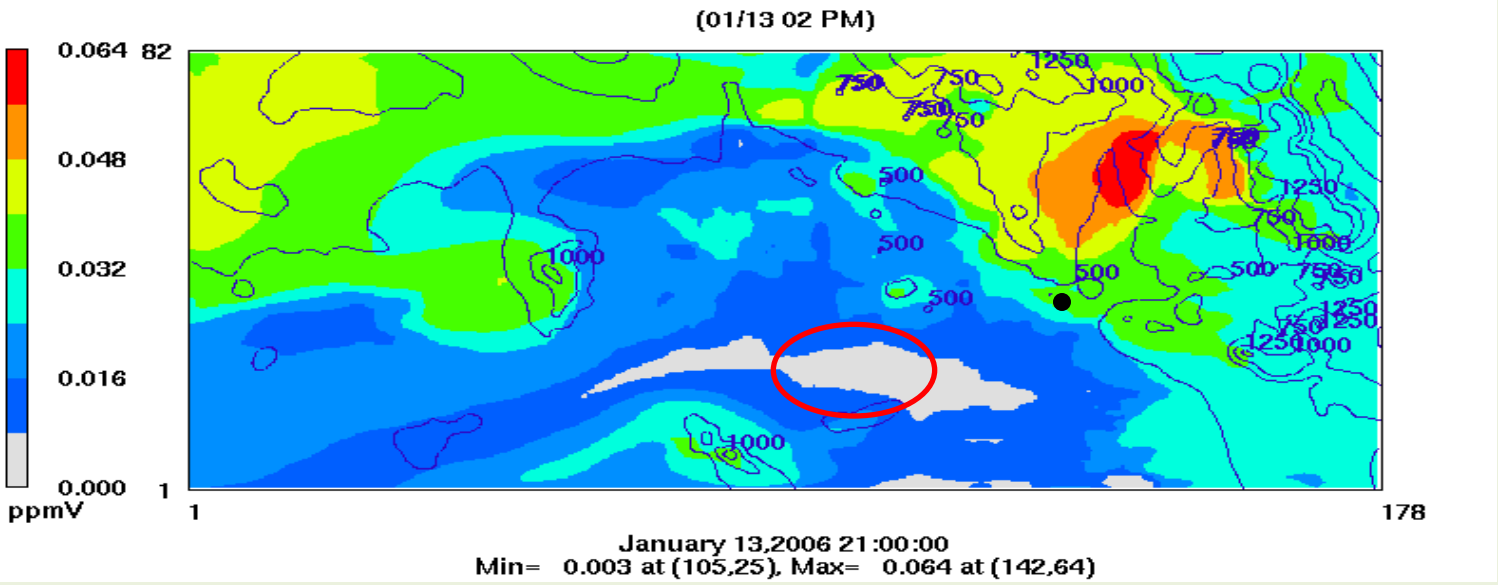
Heat / Momentum Flux



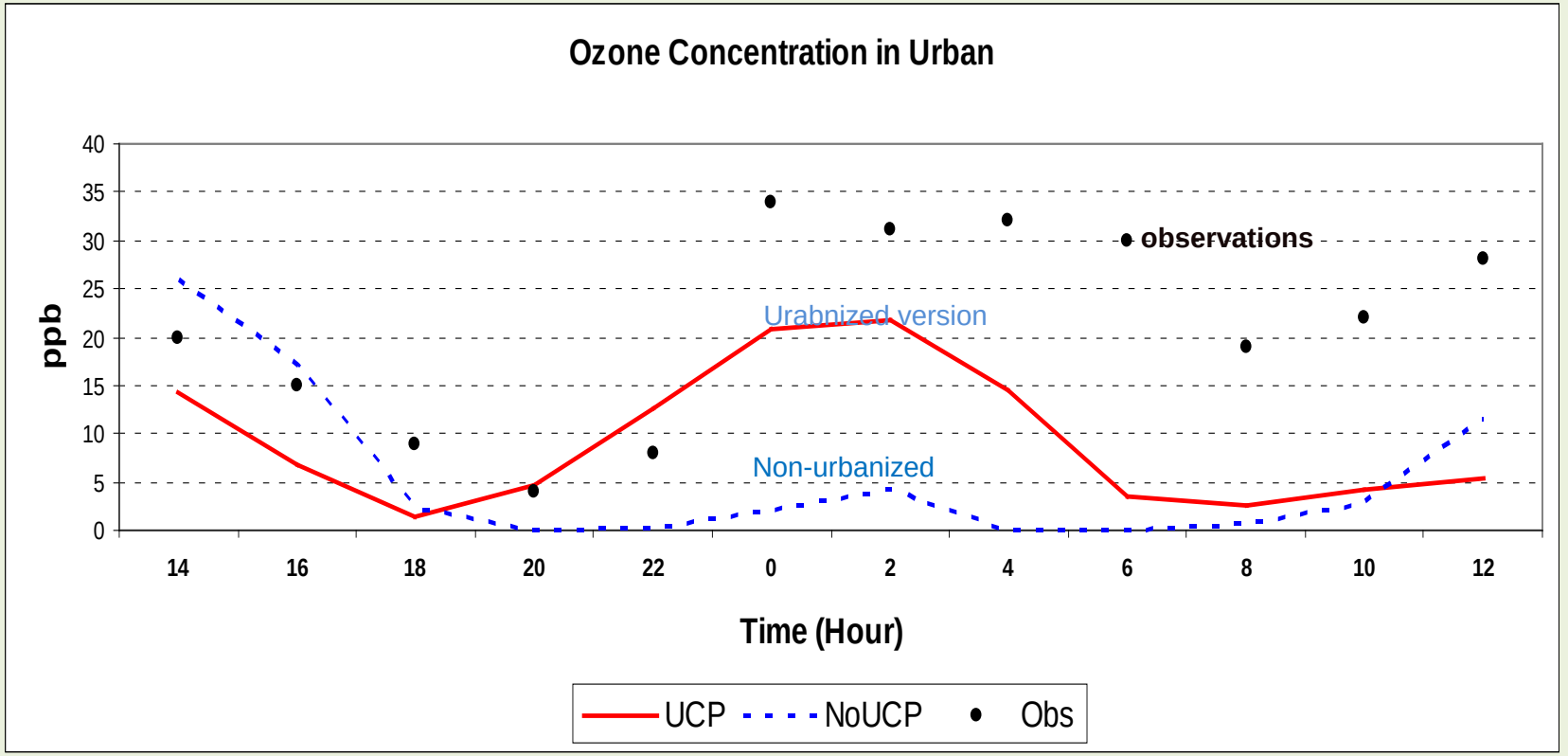
No Urbanization



Urbanized



Maximum Concentration of Ozone



Ø The maximum concentration of O3 in the northeastern urban area by UCP case is higher than the NoUCP in the night, because the developed local down-slope flow could be simulated by UCP version.

Integrated Air Quality – Health Warning System

PM10 continuous data:
MC - Maricopa County Air Quality Department; ADEQ

Health data:
ADHS;
CHIR-ASU

Monitoring

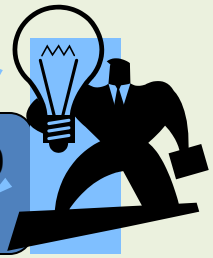
Emission data collection

Western Regional Air Partnership Inventory (WRAP)

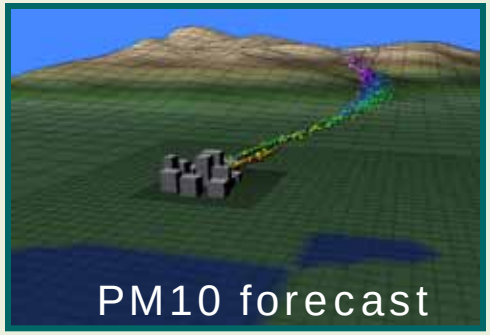
High resolution interpolation:
ØInverse Distance Weighting (IDW)
ØOrdinary Kriging

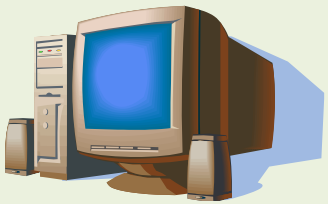
Data

Asthma/PM10 correlation



Better spatial estimation



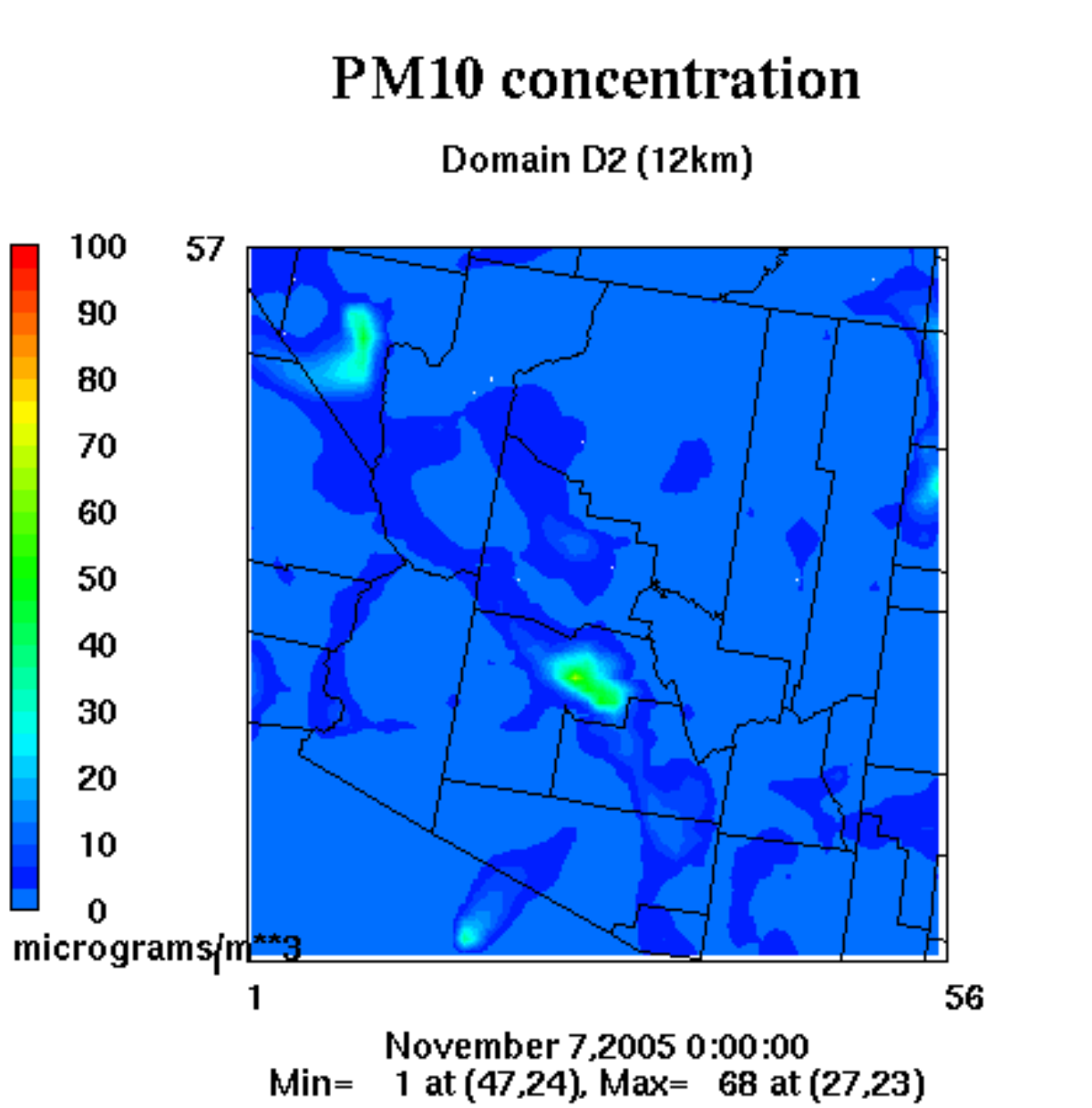


User interface
Graphics; GIS

Warning system

Modeling:
ØDeterministic – MM5/SMOKE/CMAQ
ØStatistical – EnviNNet neural network

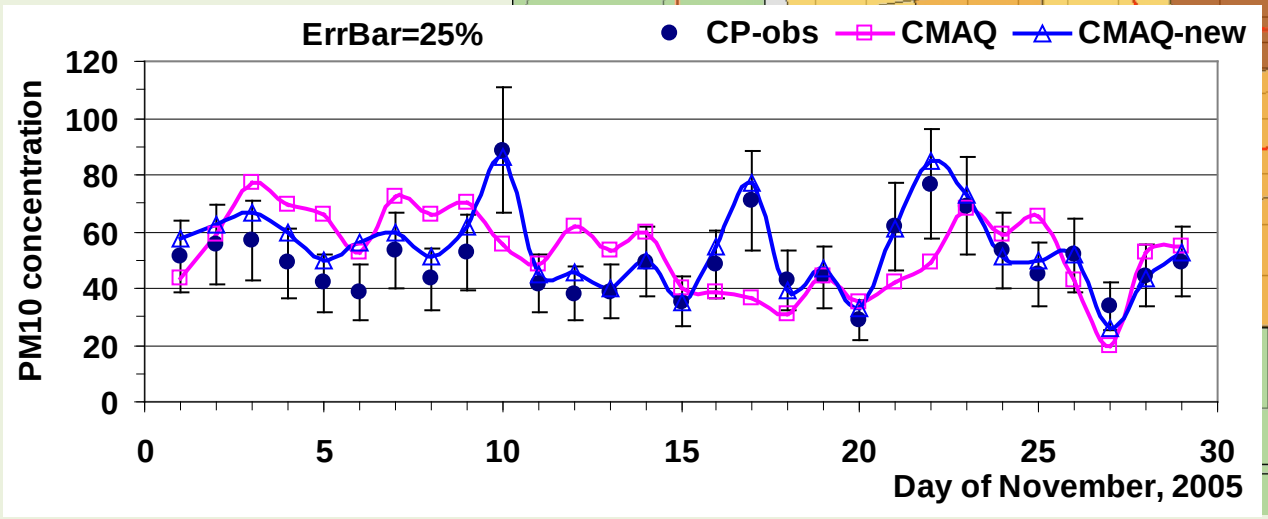
CMAQ modeling domain - Arizona State



CMAQ: outcomes improvement

MB between CMAQ and IDW surfaces

One possible solution to improve the numerical predictions - combine CMAQ and IDW surfaces



Comparison of calculated 24-hour PM_{10} with observations at CP site: violet - direct CMAQ; blue - “CMAQ-new” is combined with IDW surfaces