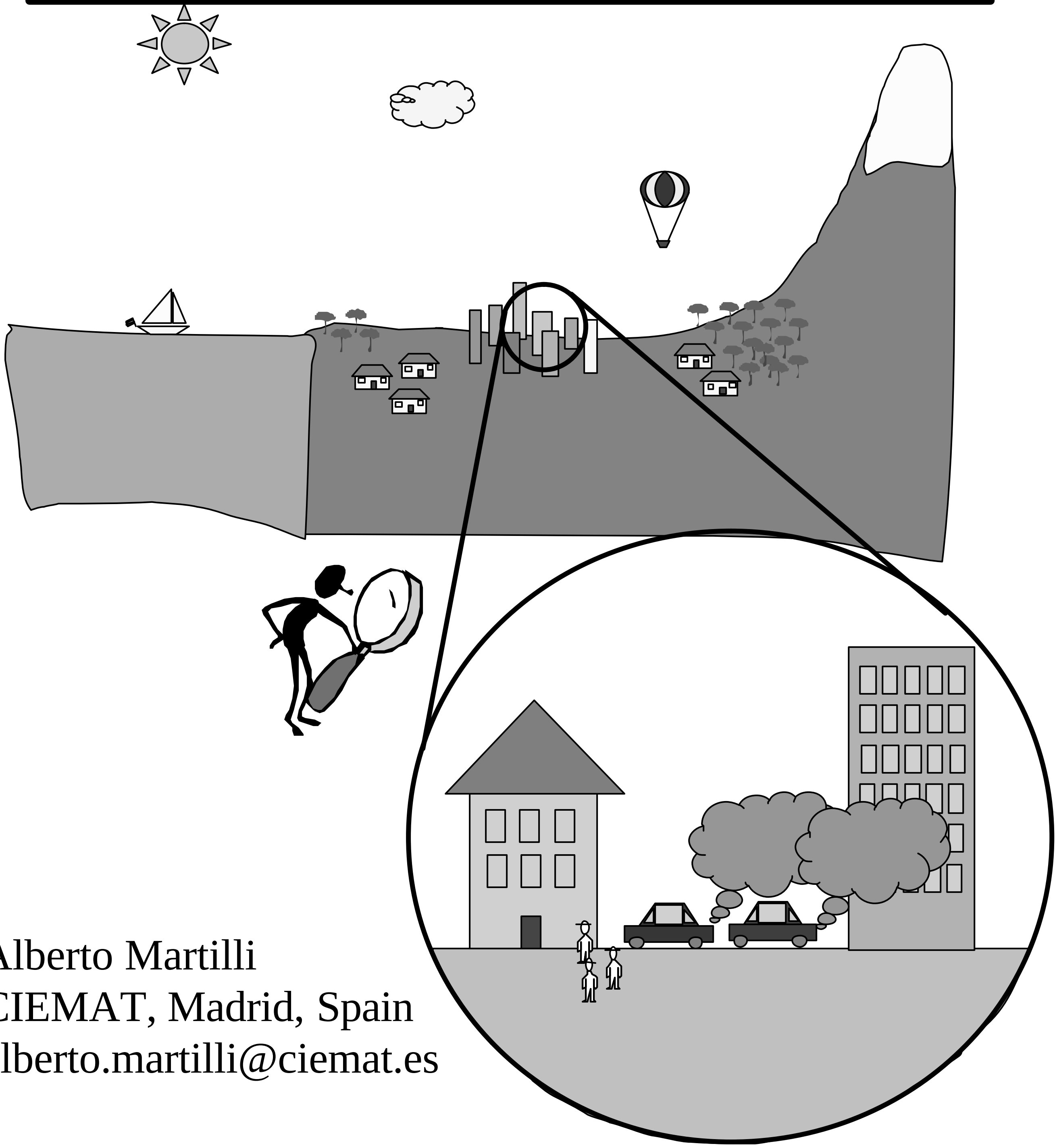
State of the art of urban mesoscale modelling and possible use of the Helsinki testbed data



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Since the origin of mesoscale meteorological modeling, urban areas have been investigated.

Bornstein 1975

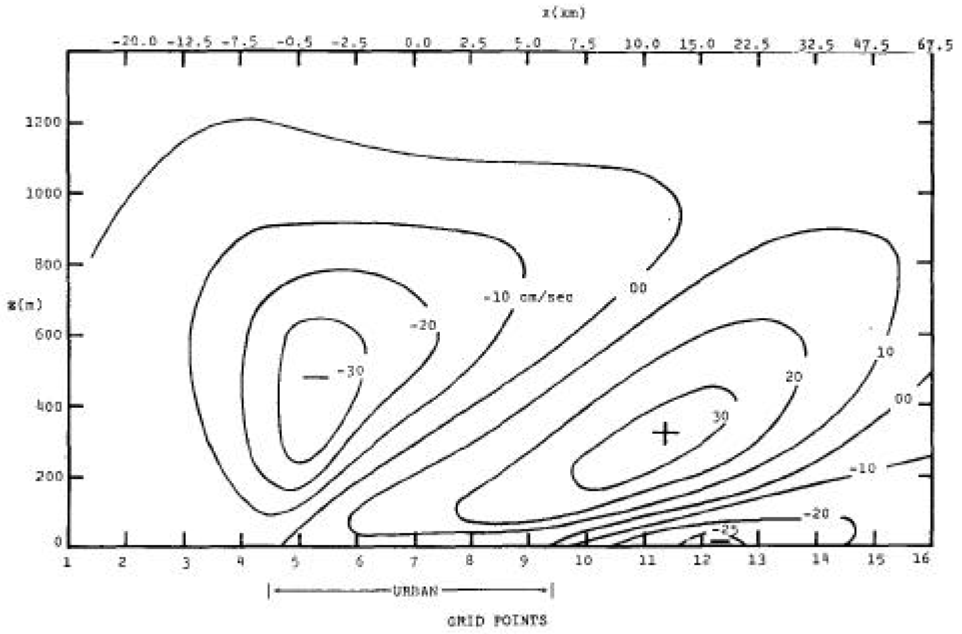
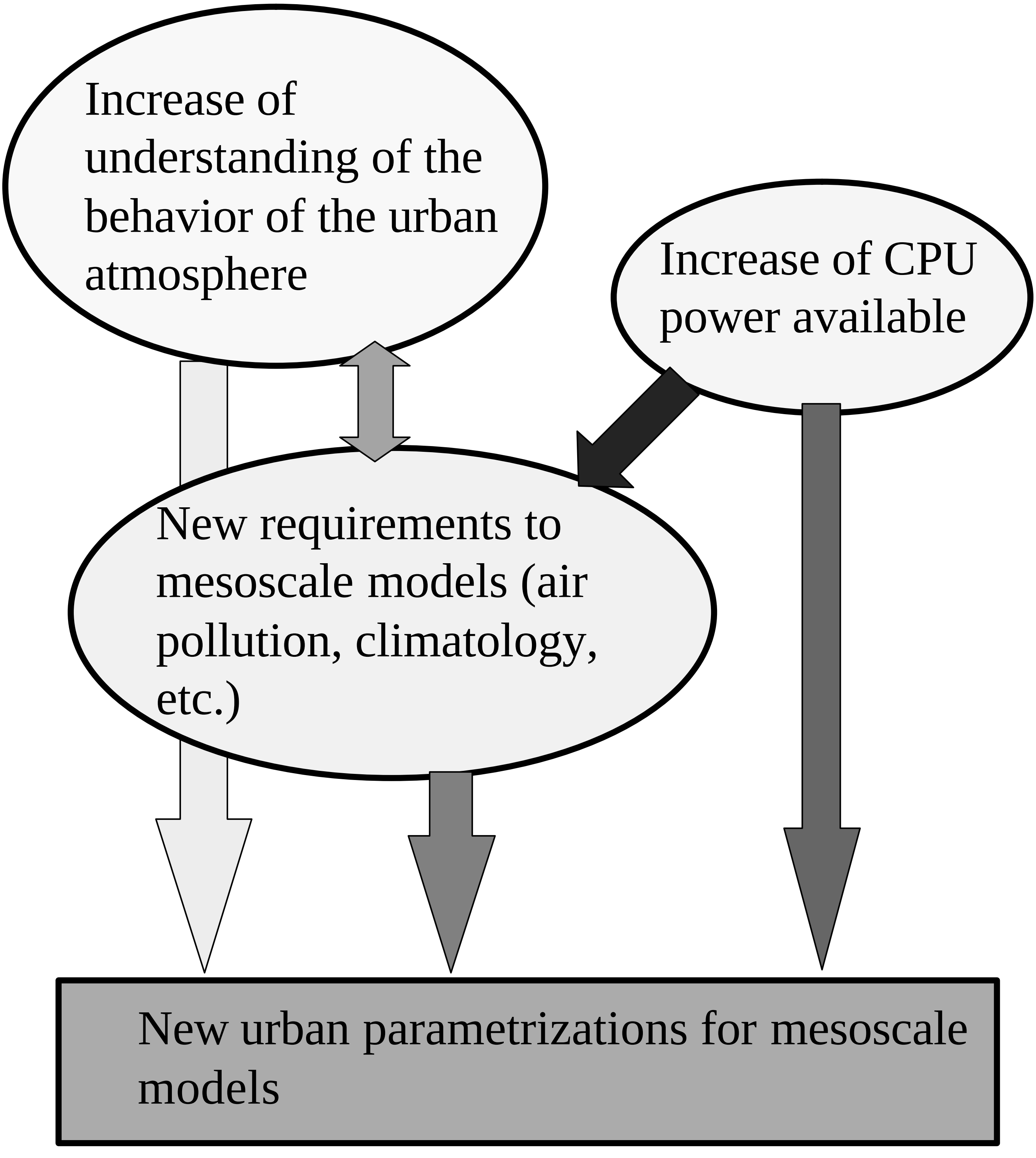


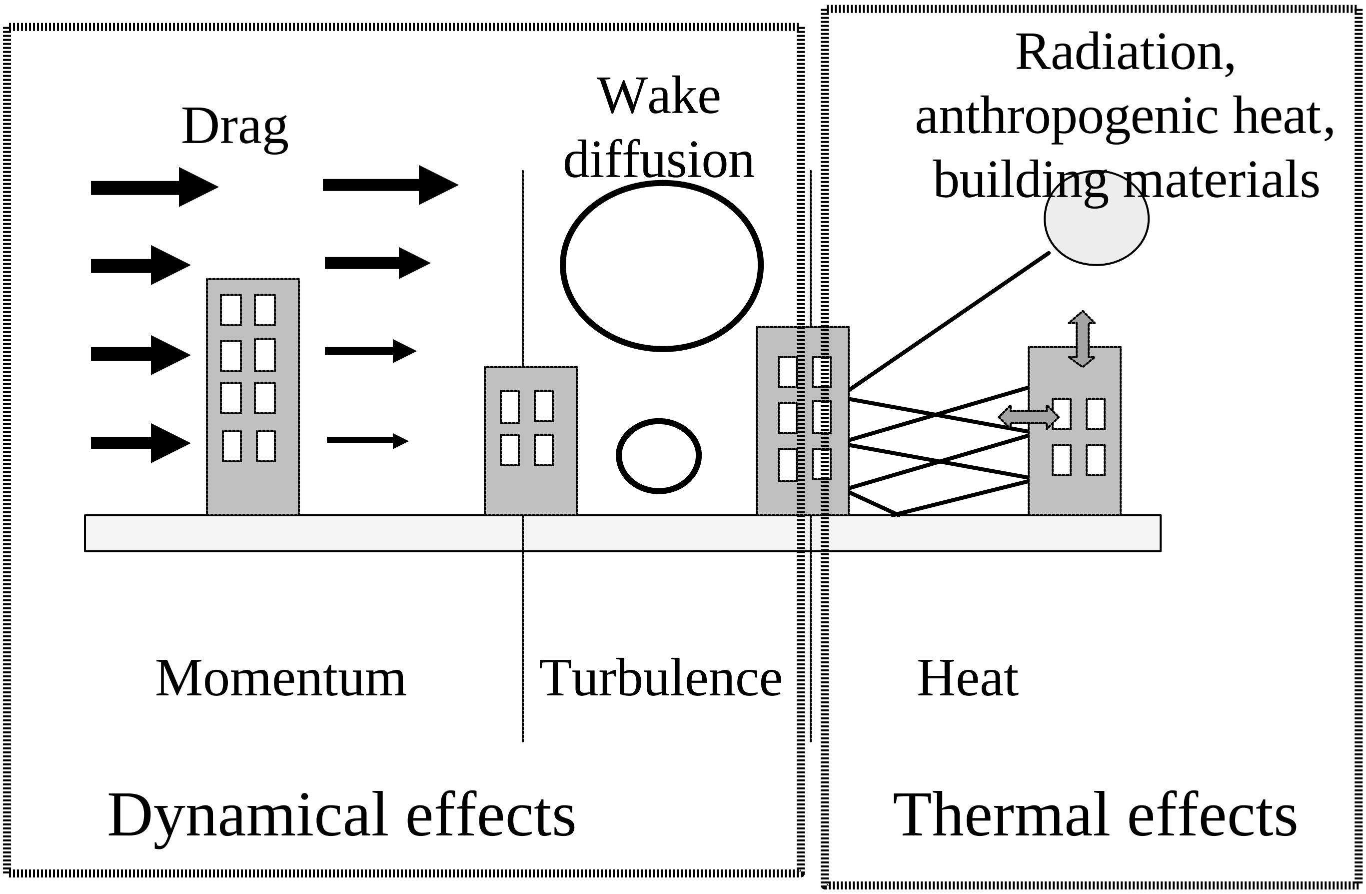
FIG. 7. Distribution of horizontal wind speed (cm s^{-1}) after 6 h of simulated time, i.e., 2400 LST, for the flow over a rough, warm city. Values represent the deviation from values at the upwind boundary. The geostrophic wind speed is 3 m s^{-1}, and the urban and rural roughnesses are 3 and 0.5 m, respectively.

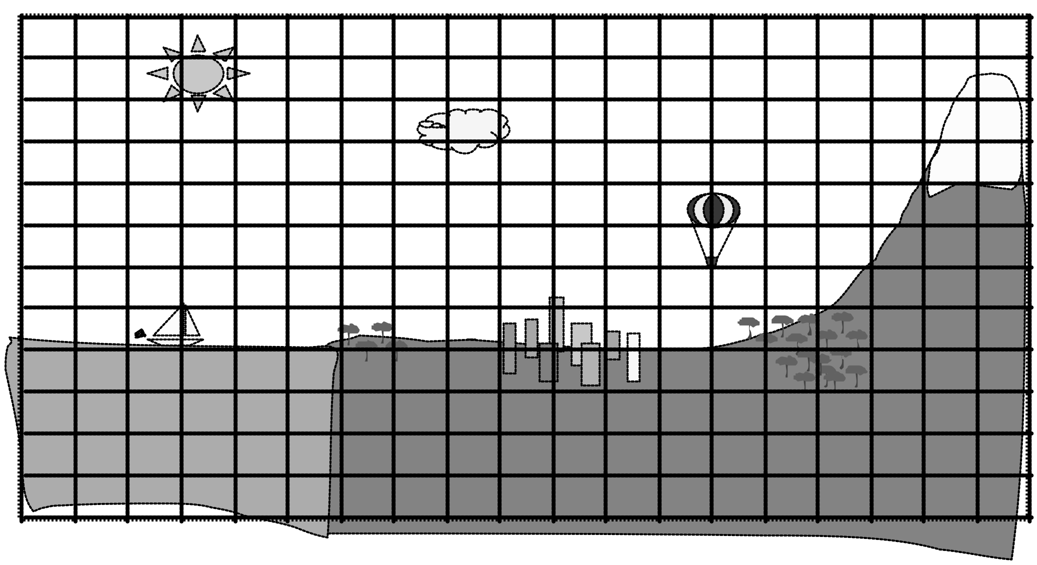
However, city was represented in a crude way (strong roughness and heat flux)

Since then, urban mesoscale modeling evolved due to



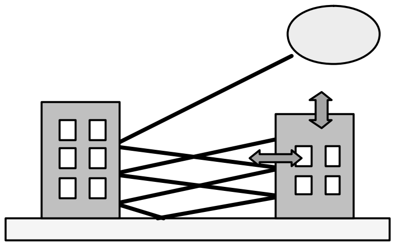
The most important urban effects are



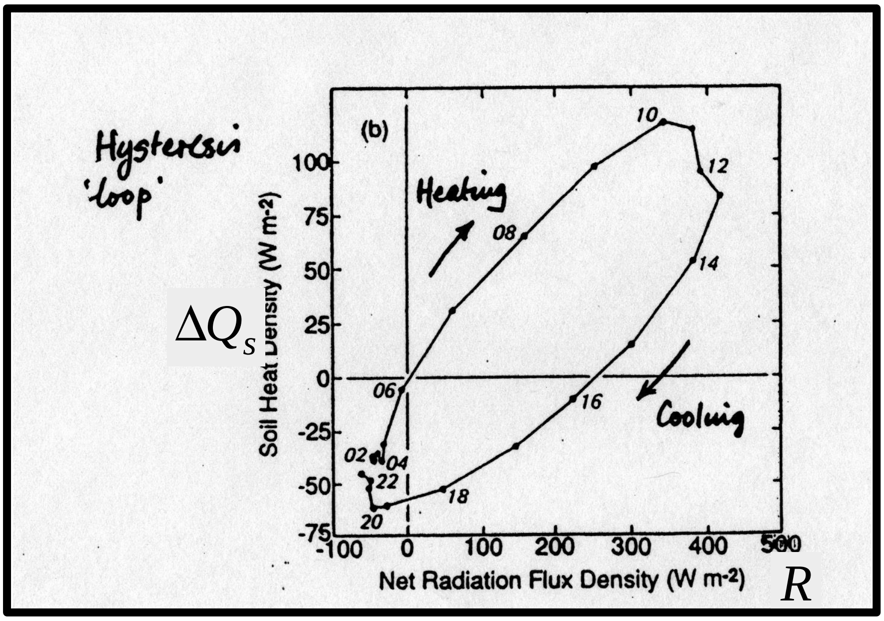


Thermal effects

Semi-empirical approach



Objective Hysteresis Model (OHM Grimmond et al., 1991). Reasonable expectation that ΔQ_S (storage) is a fraction of R (net all-wave radiation). A daily plot of ΔQ_S vs R results in a hysteresis loop



H. Taha (1999) implemented OHM in a mesoscale model

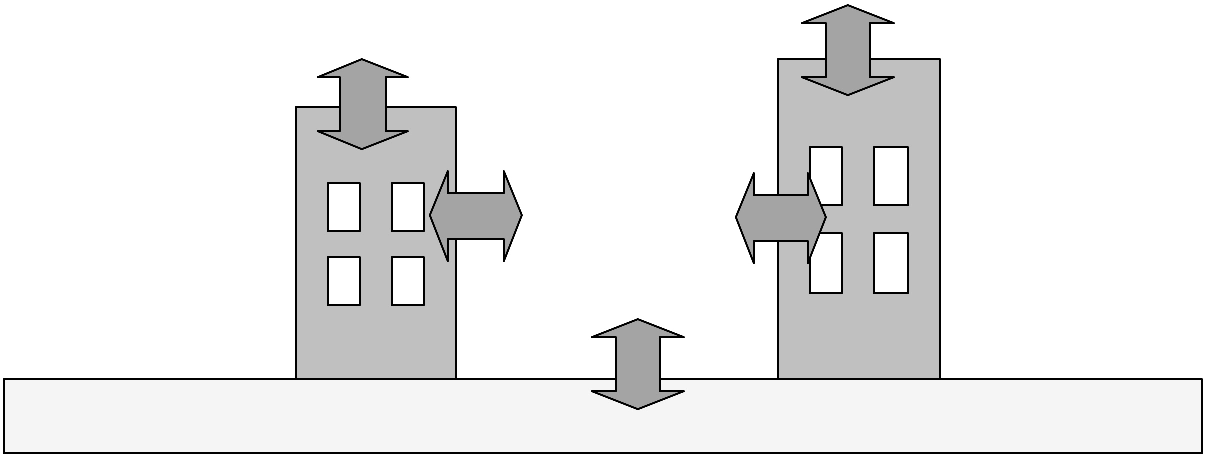
Changing the coefficents, it can work for any surface.

$$\Delta Q_s = \sum_{i=1,n} \left(a_{1i} R + a_{2i} \frac{\partial R}{\partial t} + a_{3i} \right)$$

Problem: a long series of data is needed to find the parameters a_1, a_2, a_3.

Physically based approaches

Weigthed average of fluxes from different urban surfaces (road, wall, roof) (Masson 2000, Kusaka et al. 2001, Martilli et al.2002).



$$H_{r,w,s} = -C_{r,w,s}\left(T_{air} - T_{r,w,s}\right)$$

$$H_{r,w,s} = heat\ \ flux$$

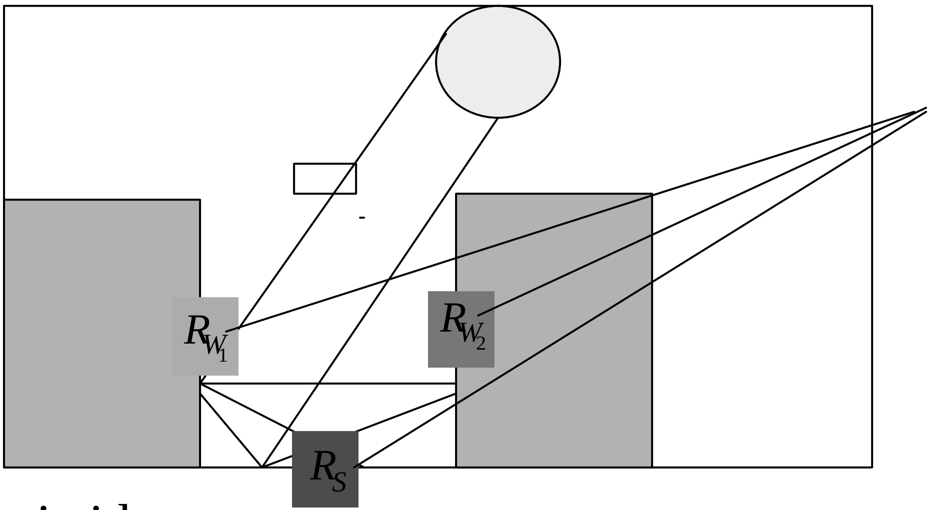
r=roof,
s=street
w=wall

$C_{r,w,s}$ is a coefficient function of wind speed and surface roughness.

Surface temperatures are estimated through an energy budget.

Radiation is composed by short (solar), and long (infrared) waves. For walls and street radiation trapping must be considered.

Solar



Short wave radiation reaching the surface

Isotropic reflection

Basic idea

$$R_{W_1} = R_{WD_1} + a_S \Psi_{SW} R_S + a_W \Psi_{WW} R_{W_2}$$

$$R_{W_2} = R_{WD_2} + a_S \Psi_{SW} R_S + a_W \Psi_{WW} R_{W_1}$$

$$R_S = R_{SD} + a_W \Psi_{WS} R_{W_1} + a_W \Psi_{WS} R_{W_2}$$

3 equations
3 unknonwn

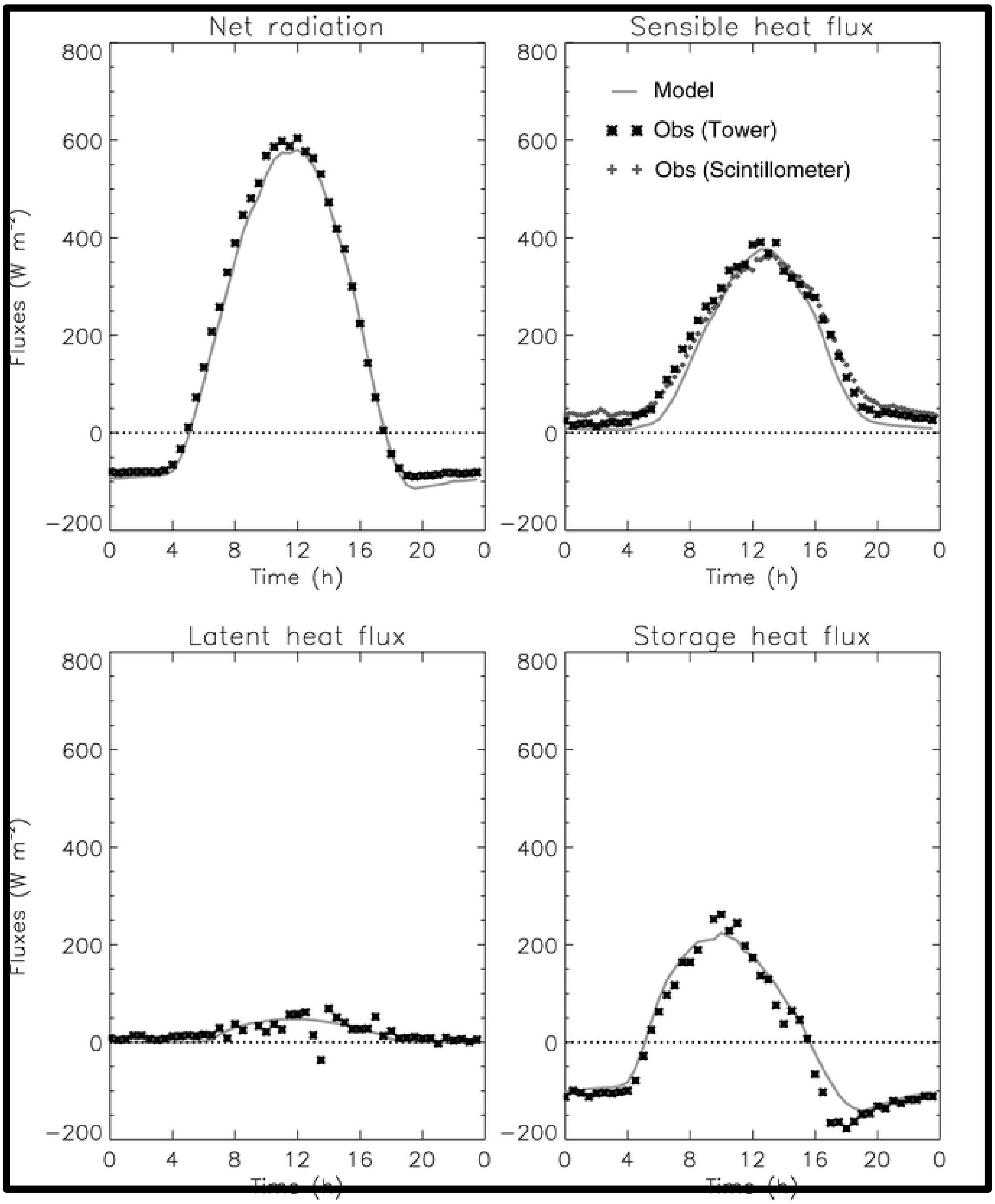
$R_{WD_1}, R_{WD_2}, R_{SD} =$ Incident radiation at walls and street function of the solar zenith angle and street orientation.

$a_W, a_S =$ Albedo of wall and street

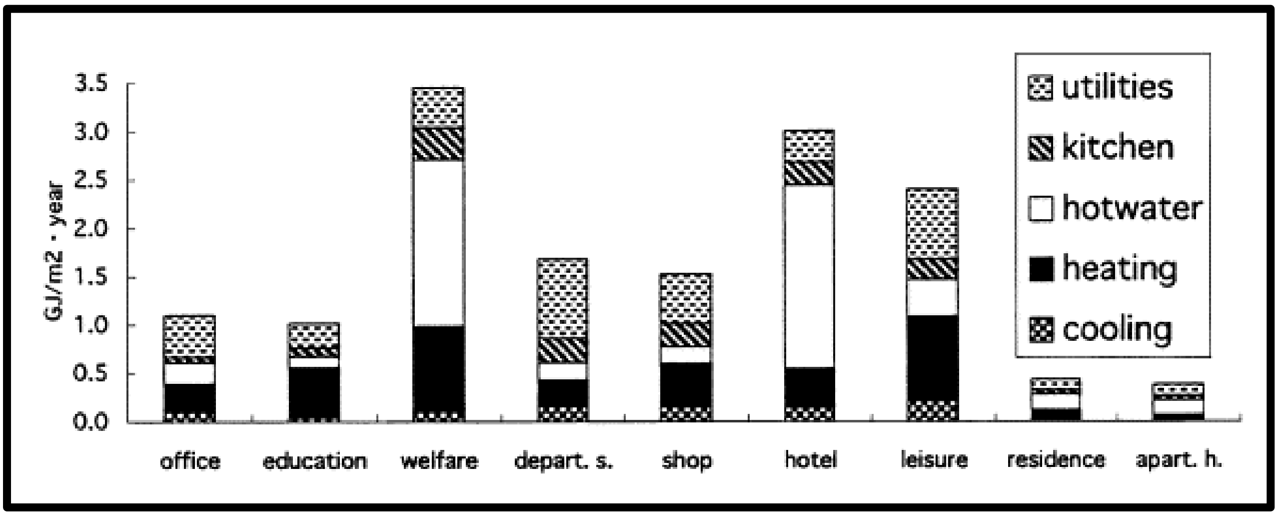
$\Psi_{SW}, \Psi_{WS}, \Psi_{WW} =$ View factors street-to-wall,wall-to-street,wall-to-wall. View factor from surface A to surface B, is defined as the fraction of radiative energy leaving surface A that reaches surface B

Validations

Masson 2000 over Marseille (from Lemonsu et al. 2004)



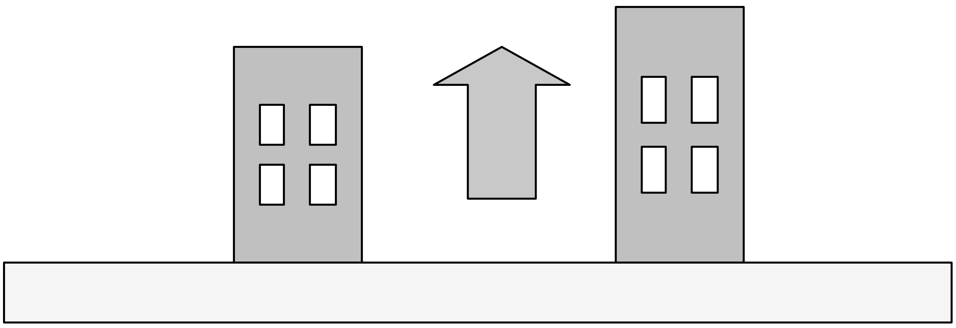
Moreover there are additional anthropogenic sources of heat.



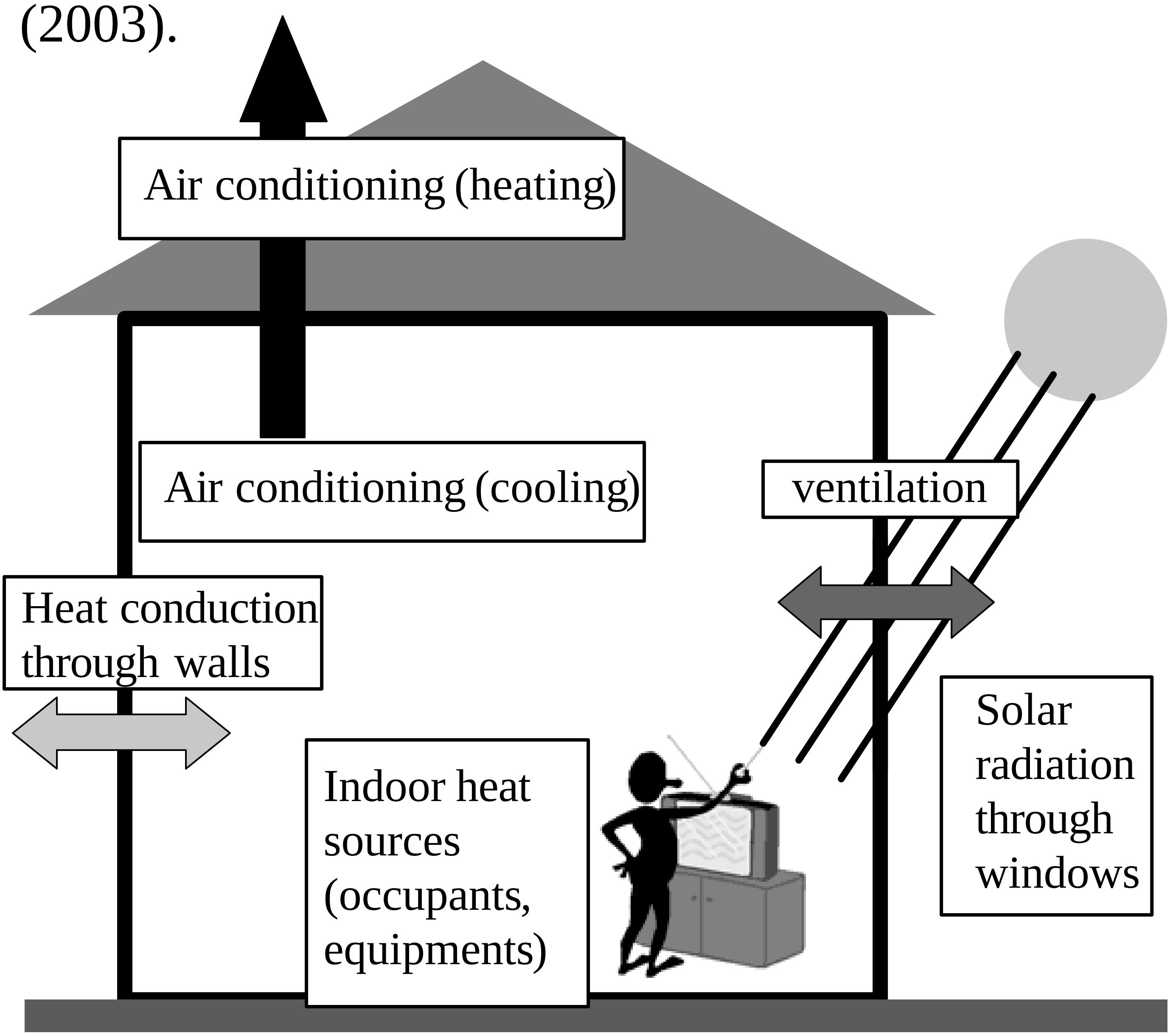
From Ichinose et al. 1999 for Tokyo

In limited areas, they can reach peaks of hundreds of W/m^2 . Of the same order of the the solar radiation.

Injected as a source term in the atmosphere

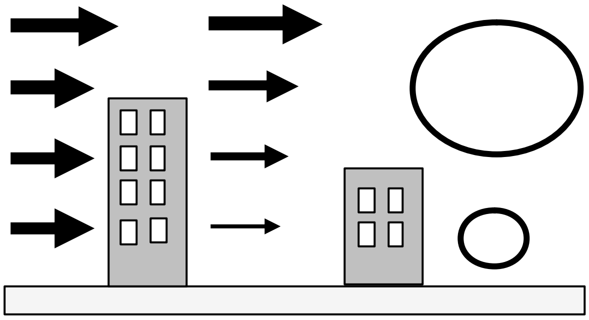


A step forward to evaluate energy fluxes in urban areas. Account for Building Energy. An example, inspired to Kikegawa et al. (2003).



Important in estimates of energy savings for UHI mitigation strategies.

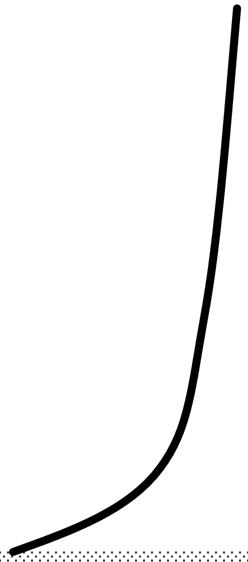
Dynamical effects

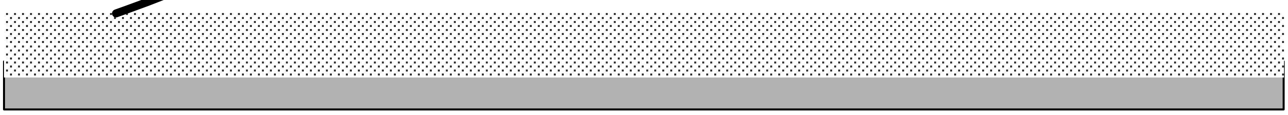


Traditional method.

Logarithmic profile

$$U(z) = \frac{u_*}{k} \ln\left(\frac{z}{z_o}\right)$$

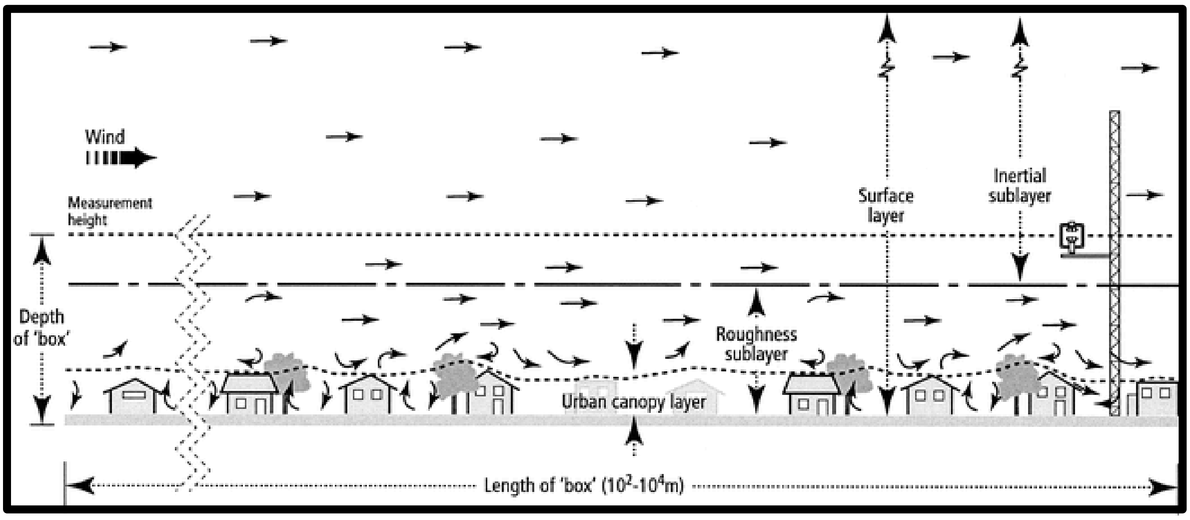


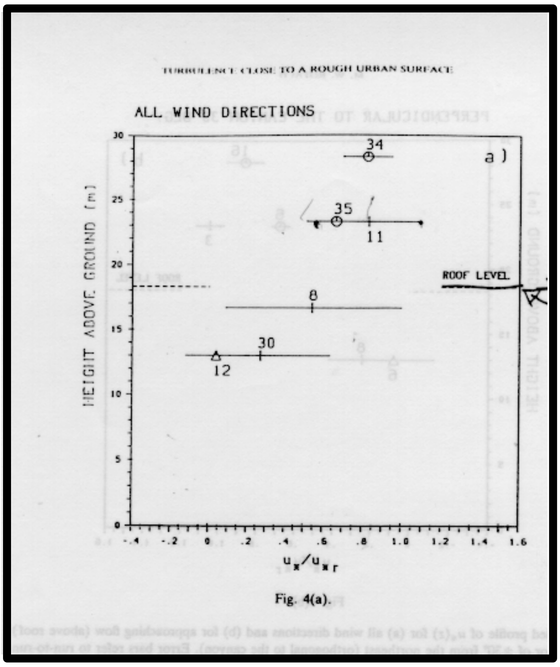


Roughness length (z0)~of 1-3 m,. Based on similarity theory that assumes that turbulent fluxes are constant with height in the surface layer.

However....

Turbulent fluxes are not constant with height (Rotach 1993) in the Urban Roughness Sublayer (1-3 times mean building heigth). The similarity theory cannot be applied.





Zurich, Switzerland

Rotach, 1993

Approaches to parameterize momentum drag are mutuated from vegetation canopy modelling. Small differences between the approaches.

i=1,2, e. g. the drag force is horizontal

Uno et al., 1989

$$\left\langle \frac{\partial \tilde{p}}{\partial x_i} \right\rangle = -rC_d h a(z) \langle u_i \rangle \left(\langle u_1 \rangle^2 + \langle u_2 \rangle^2 \right)^{1/2}$$

a(z)=building surface area density, η fraction of building area, C_d=0.1

Sievers, 1990

$$\left\langle \frac{\partial \tilde{p}}{\partial x_i} \right\rangle = -rC_d w_f \langle u_i \rangle \left| \langle \vec{u} \rangle \right|$$

w_f wall area density, C_d=0.2

Brown and Williams, 1998

$$\left\langle \frac{\partial \tilde{p}}{\partial x_i} \right\rangle = -r f_{roof} C_d a(z) \langle u_i \rangle \left| \langle u_i \rangle \right|$$

f_{roof}=horizontal fraction of model grid covered by buildings, a(z)building surface area density

Martilli et al. 2002,

$$\left\langle \frac{\partial \tilde{p}}{\partial x_i} \right\rangle = -rC_d \frac{S_w}{V_{air}} \langle u_i^{ort} \rangle \left| \langle u_i^{ort} \rangle \right|$$

S_w wall surface in the cell, V_{air}=air volume of the cell, u^{ort}= wind component ortogonal street direction, C_d=0.4

Coceal and Belcher 2004

$$\left\langle \frac{\partial \tilde{p}}{\partial x_i} \right\rangle = -rC_d \frac{l_f}{(1-b)} \langle u_i \rangle \left| \langle \vec{u} \rangle \right|$$

λf total frontal area per unit ground area, (1-β)=fractional volume of the cell occupied by air, C_d=1.

Usually a TKE budget is solved to estimate the turbulent exchange coefficients.

To do this, an extra term must be added in the TKE eqn.

$$\frac{\P r\ E}{\P t} = -\frac{\P r\ U_i E}{\P x_i} - \frac{\P r\ \overline{ew}}{\P z} + r K_z \left[\left(\frac{\P U_x}{\P z} \right)^2 + \left(\frac{\P U_y}{\P z} \right)^2 \right] - \frac{g}{q_o} r K_z \frac{\P q}{\P z}$$

$$- e + D_E$$

$$\langle \overline{u'w'} \rangle = -K_z \frac{\partial U}{\partial z}$$

$$K_z = C_k l_k E^{1/2}$$

$$e = C_e \frac{E^{3/2}}{l_e}$$

Uno et al., 1989

$$r C_d h a(z) \left(\left| \langle u_1 \rangle \right|^3 + \left| \langle u_2 \rangle \right|^3 \right)$$

Brown and Williams, 1998

$$D_E = r f_{roof} C_d a(z) \sum_i \left| \langle u_i \rangle \right|^3$$

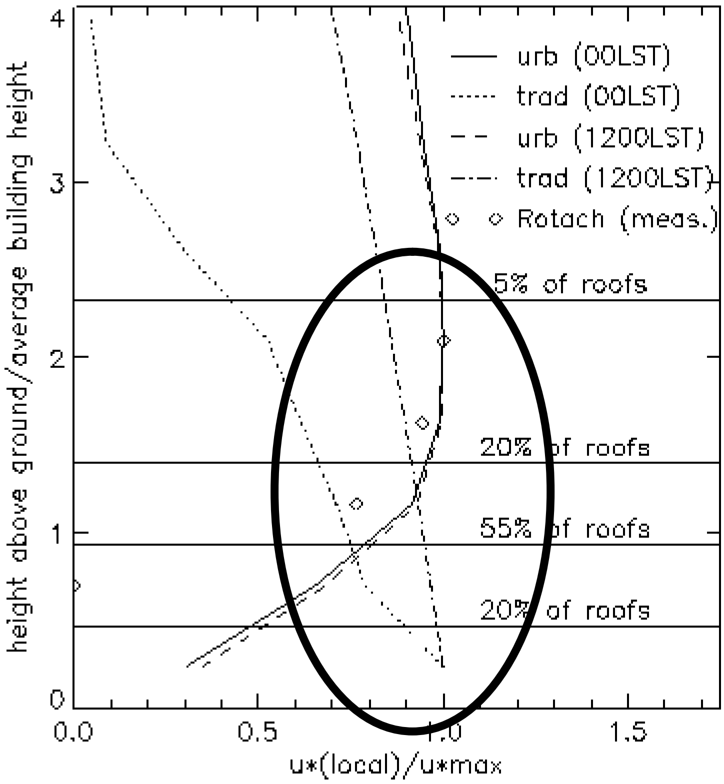
Martilli et al. 2002,

$$D_E = r C_{drag} \left| U_{IU}^{ort} \right|^3 \frac{S^V{}_{IU}}{V_{IU} - V_{IUbuild}}$$

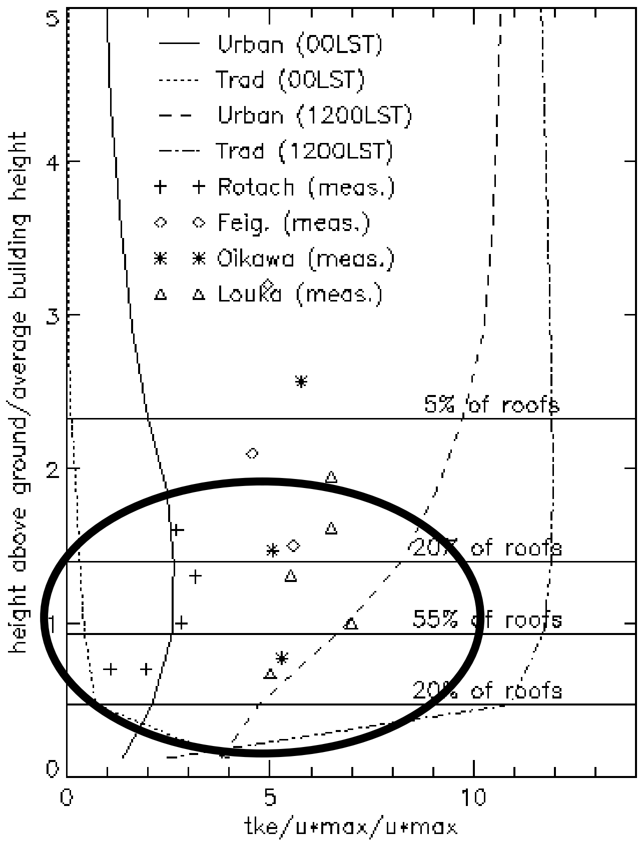
Length scales are modified to account for eddies generated by buildings

Reynolds Stress

From Martilli et al. 2002

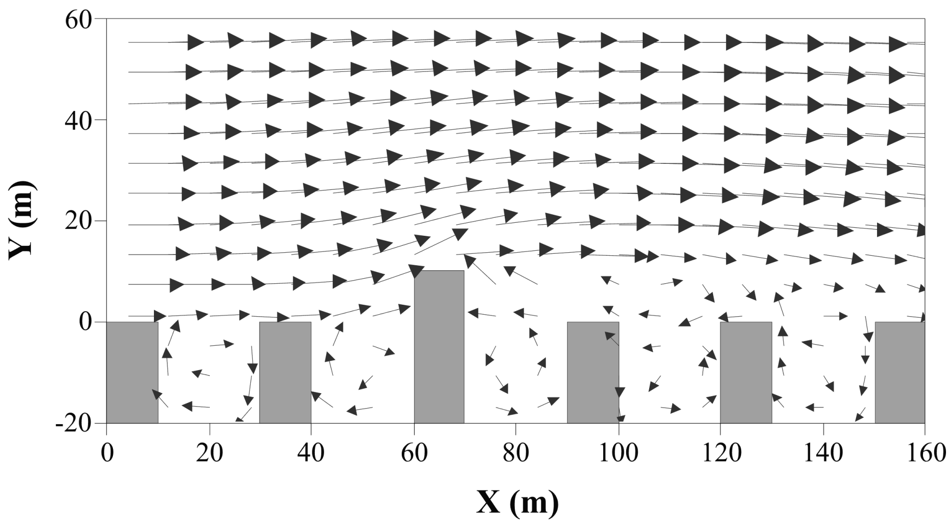


TKE

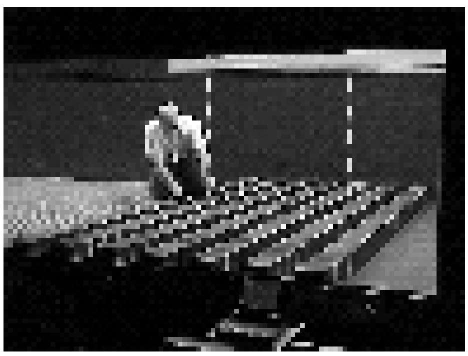


How to improve ?

Use street canyon CFD models to derive properties of the mean flow and parameterizations for mesoscale models.



Buildings are explicitly resolved. Simulation at high resolution, but for very small domain.



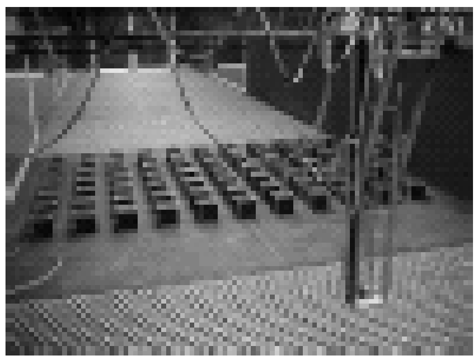
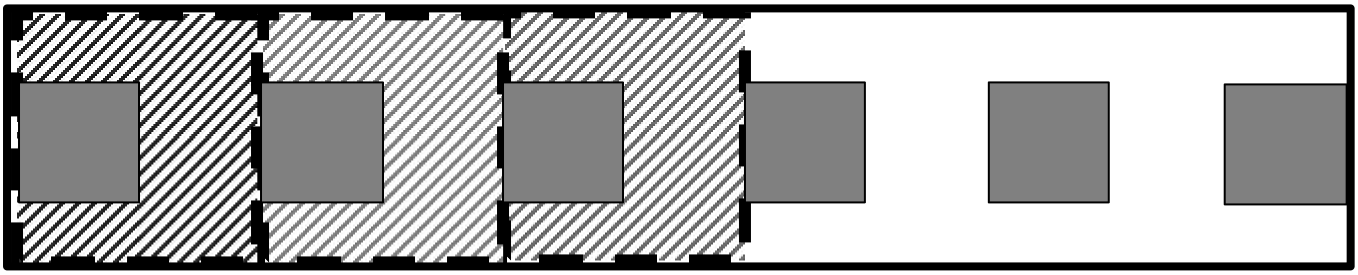


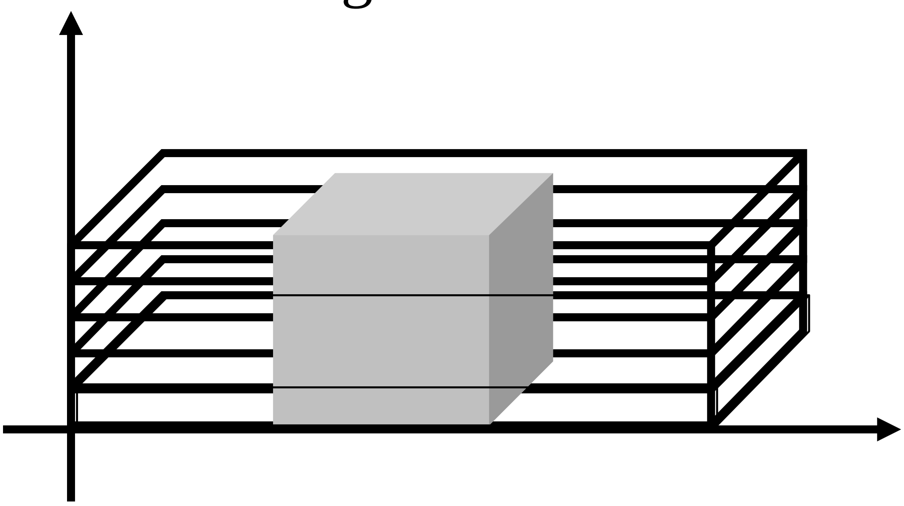
Figure 1. 2D and 3D building arrays in the USEPA meteorological wind tunnel.

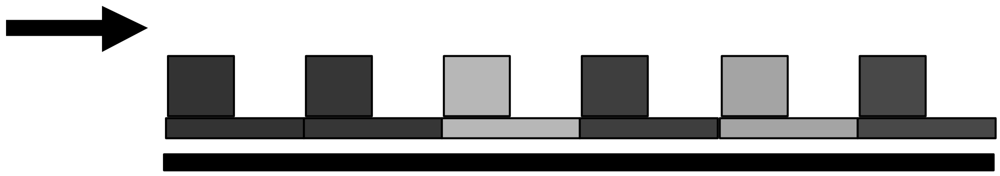
CFD models validated against wind tunnel data.

CFD simulation with model FLUENT of flow over an array of obstacles (made by Jose Luis Santiago). Reproduction of wind tunnel experiment of M. Brown at U.S. EPA.



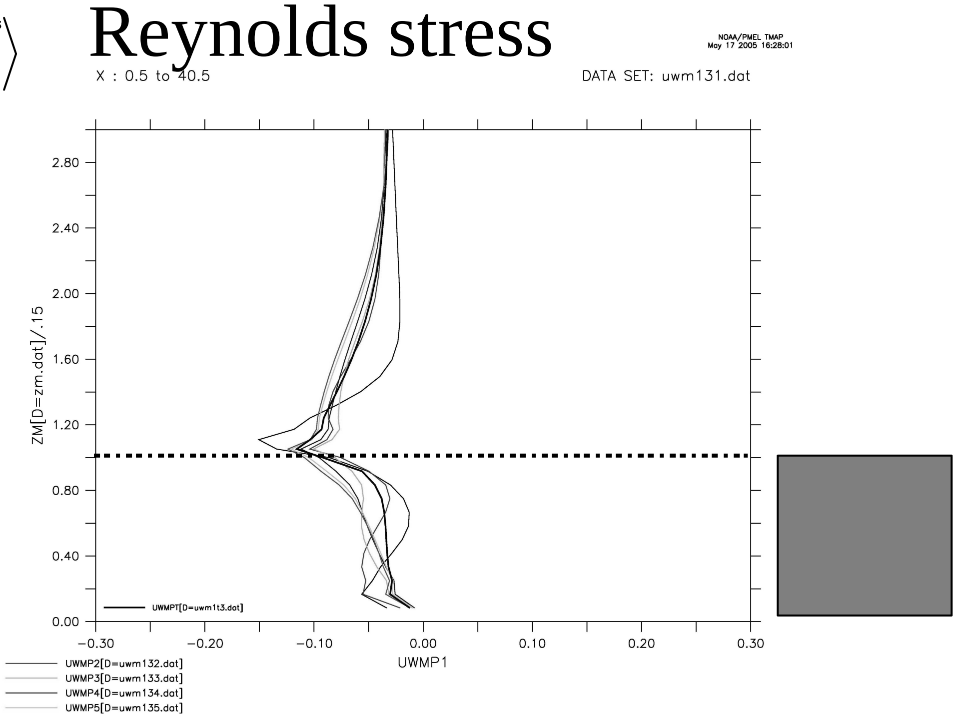
Spatial average of the results over thin slices of building-canyon units, and over the whole array. These is the closest to the average needed for mesoscale models.





$\langle \overline{u'w'} \rangle$ Reynolds stress

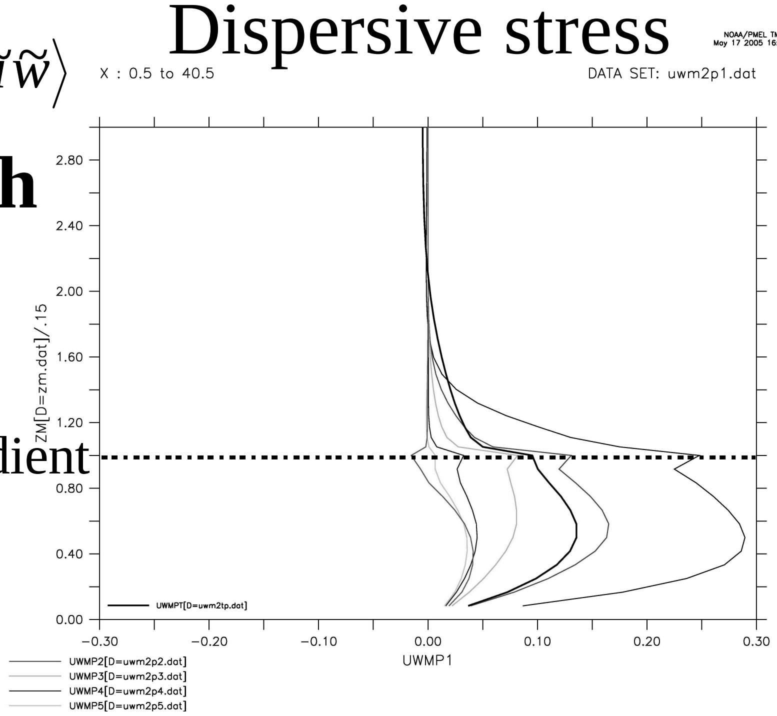
z/h



$\langle \tilde{u}\tilde{w} \rangle$ Dispersive stress

z/h

countergradient



Dispersive stress in the canopy is comparable, in magnitude, and opposite in sign to the Reynolds stress.

More important at city boundaries, less inside.

Athens

Night

Urban

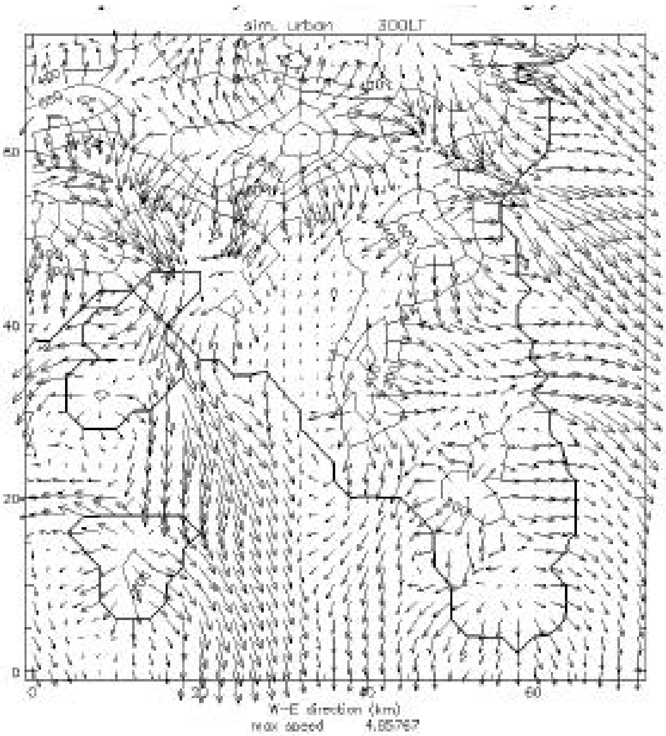


Fig. 7a)

Urban-rural

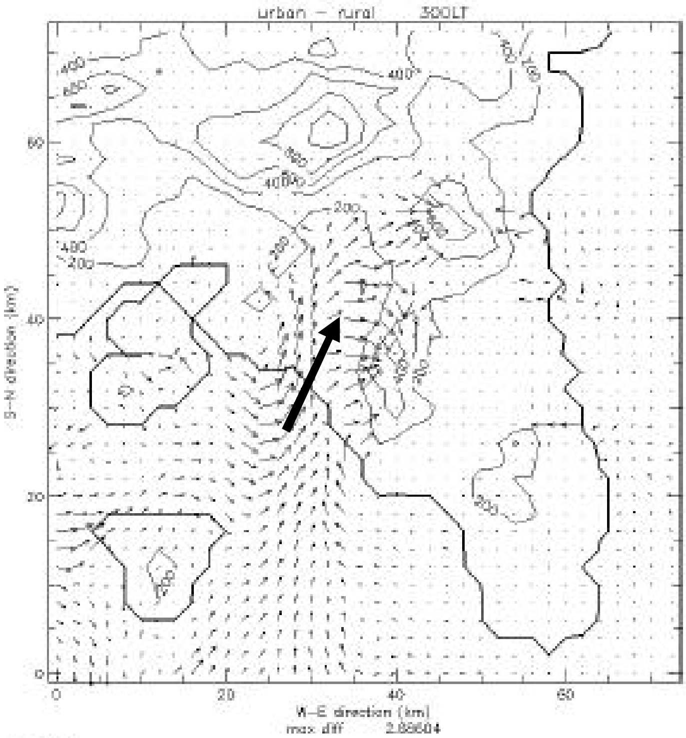


Fig. 7b)

Athens

Day

Urban

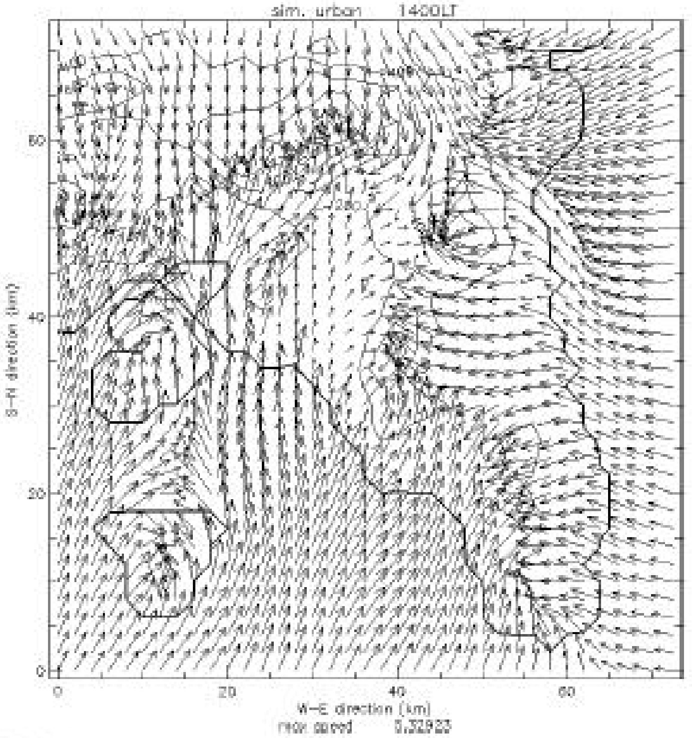
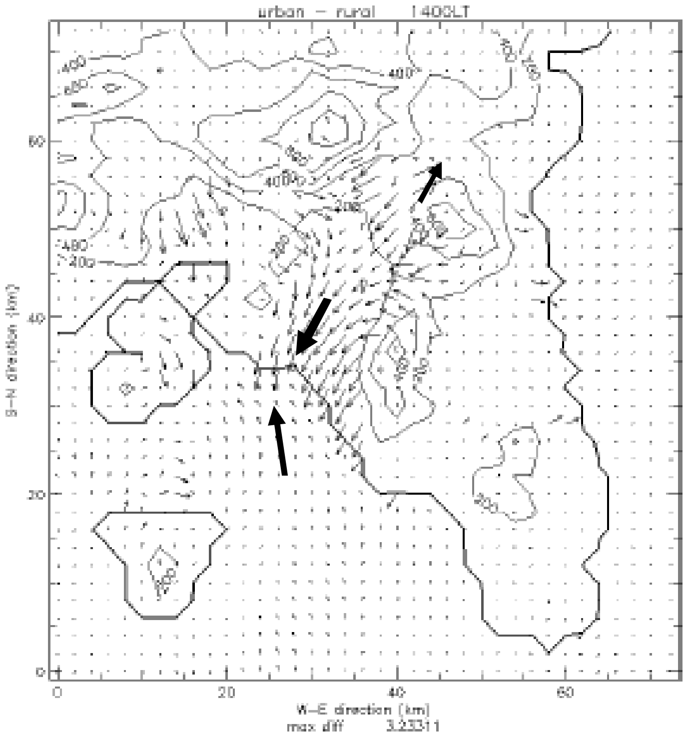


Fig. 8a)

Urban-rural



Athens

Ozone

Urban

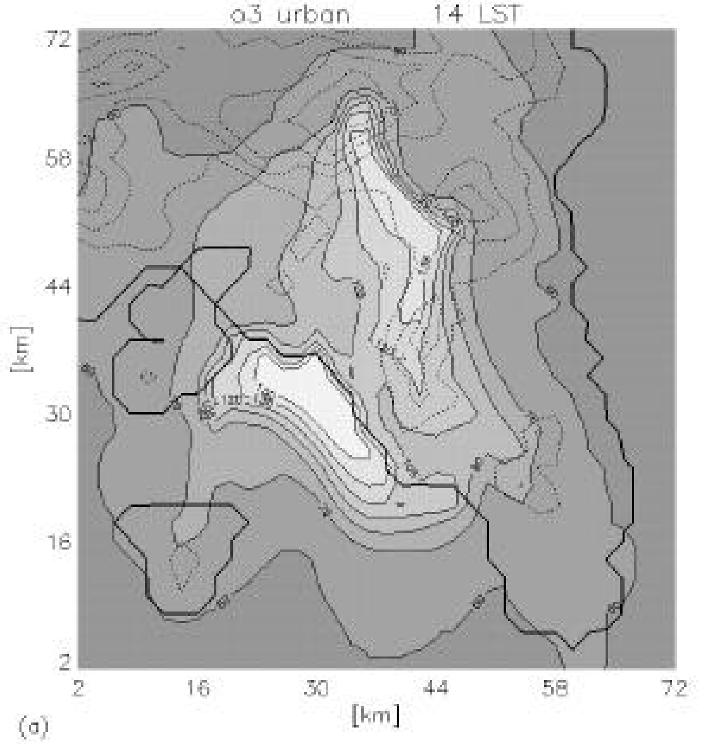


Fig. 14a)

Urban-rural

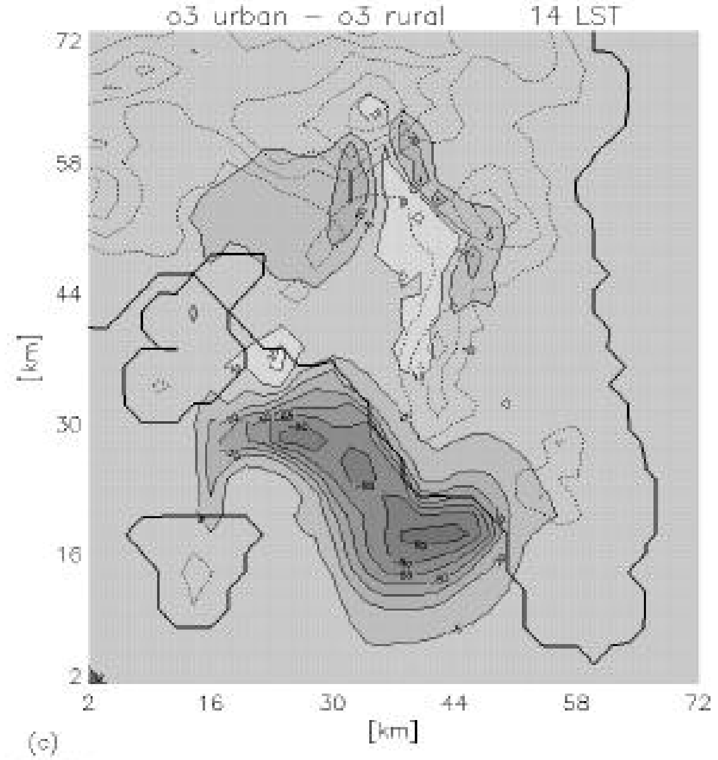


Fig. 14c)

Possible use of the Helsinki testbed data

- Urban schemes have never been tested for nordic climate.
- Interactions between sea breeze and urban areas.
- Impact of city on urban boundary layer (in particular for stable stratification)
- Urban vegetation (parks)
- Influence of city on weather (fog, precipitation, etc.)