An Improved Model for the Turbulent Atmospheric Boundary Layer with Parameterization of the Urban Roughness

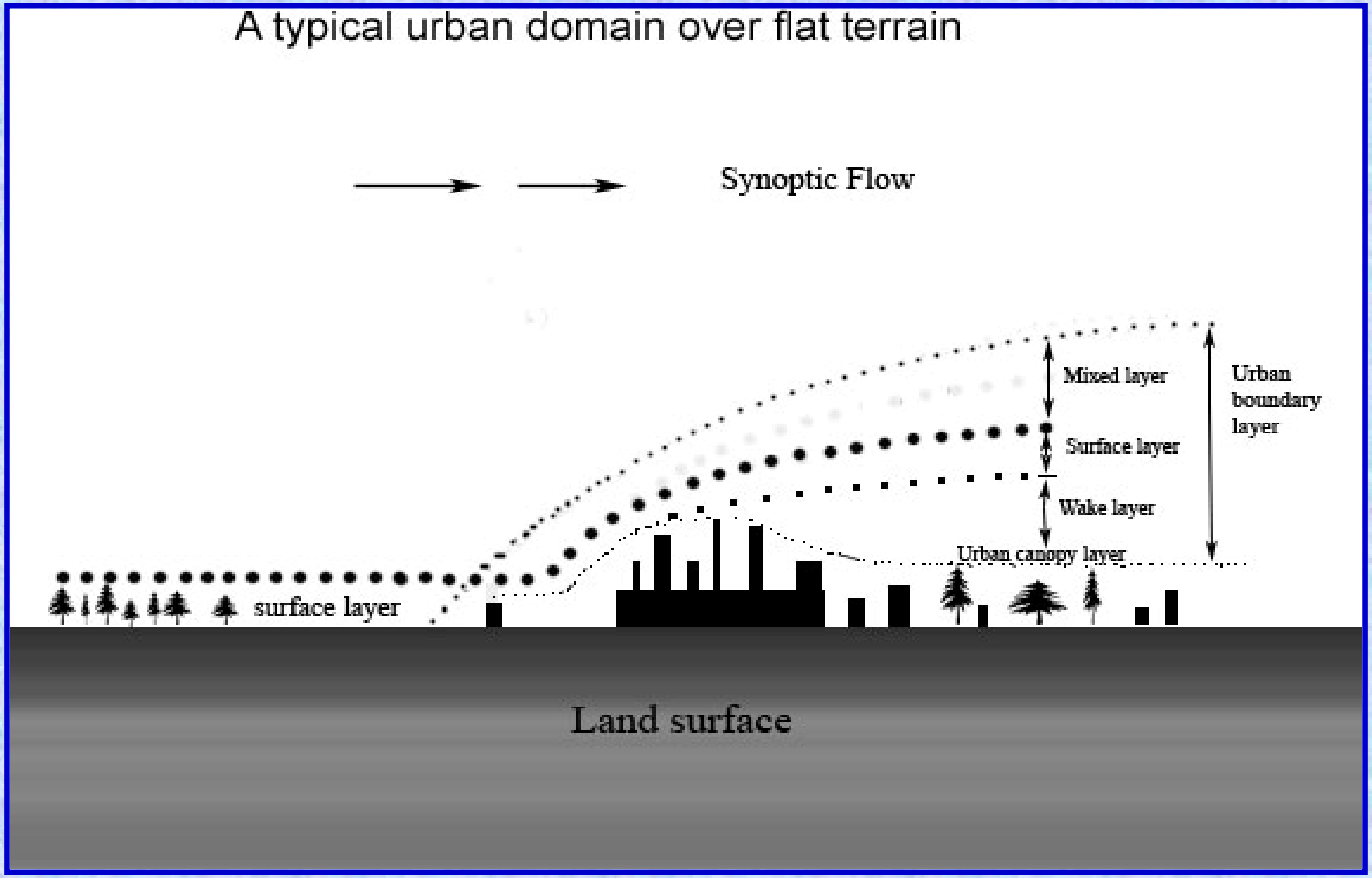
Kurbatskiy A. F., Lonchakov A. V., Kurbatskaya L. I.

Institute of Theoretical and Applied Mechanics of SB RAS,
Institute of Computational Mathematics
and Mathematical Geophysics of SB RAS, Novosibirsk, Russia

O U T L I N E:

- Objectives
- Introduction
- Improved Model for the Turbulent ABL
- Urban Heat Island in a Calm and Stably Stratified Environment
- Impact of the UHI and the UCL on the ABL Structure
- Dispersion of Passive Tracer in the UBL
- Conclusions

Objectives



In lecture results of development of the improved turbulence model for the urban boundary layer and its verification are stated.

Introduction

- Complexity of simulation of urban air quality problems consists in the necessary of resolution the variety spatial-temporal scales over which the phenomena originate.
- The two most important scales include:

Æ an 'urban' scale of a few tens kilometers (a typical scale of city) where large amounts of contaminants are emitted, and

Æ a 'мesо' scale of a few hundreds of kilometers where secondary pollutants are formed and dispersed.

Introduction

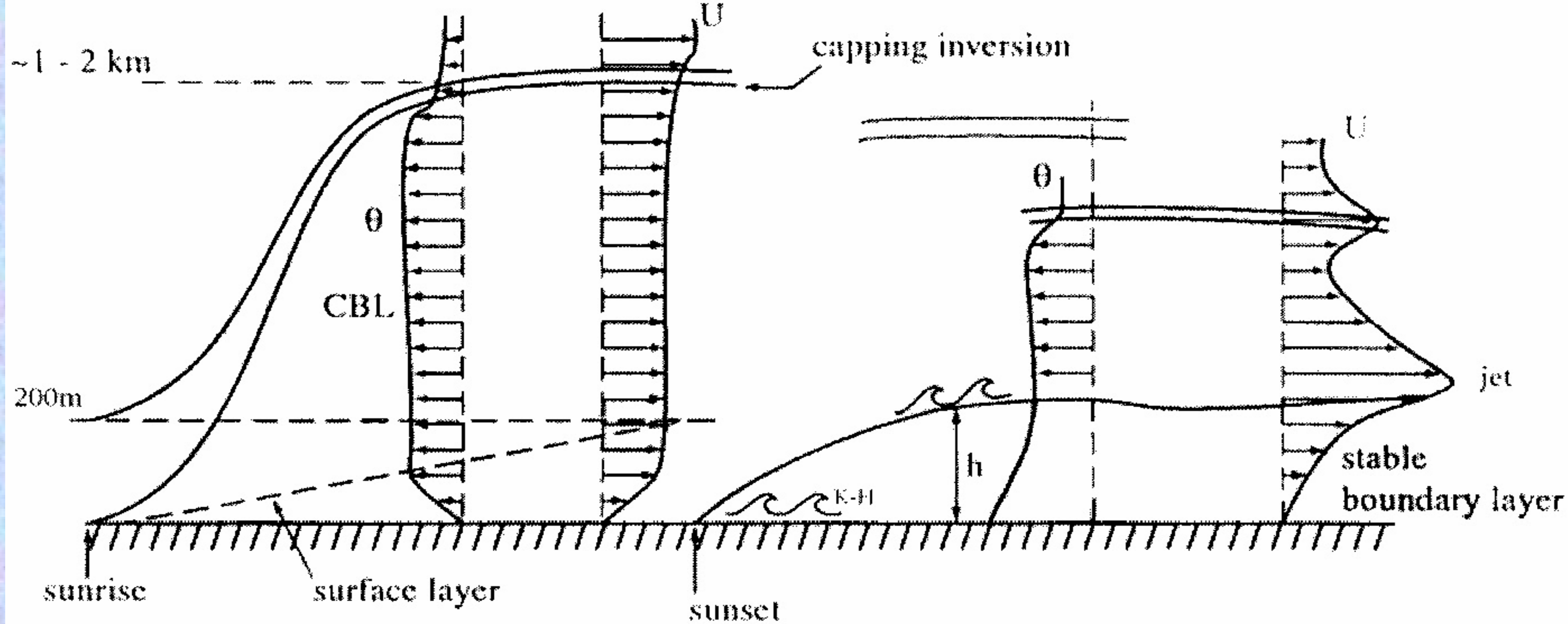
- In order to compute the mean and turbulent transport and the chemical transformations of pollutants, several meteorological variables, such as wind, turbulent fluxes, temperature etc., it is necessary to known as more as possible precisely.

  These meteorological variables can be calculated by an improved model for the turbulent ABL.

Introduction

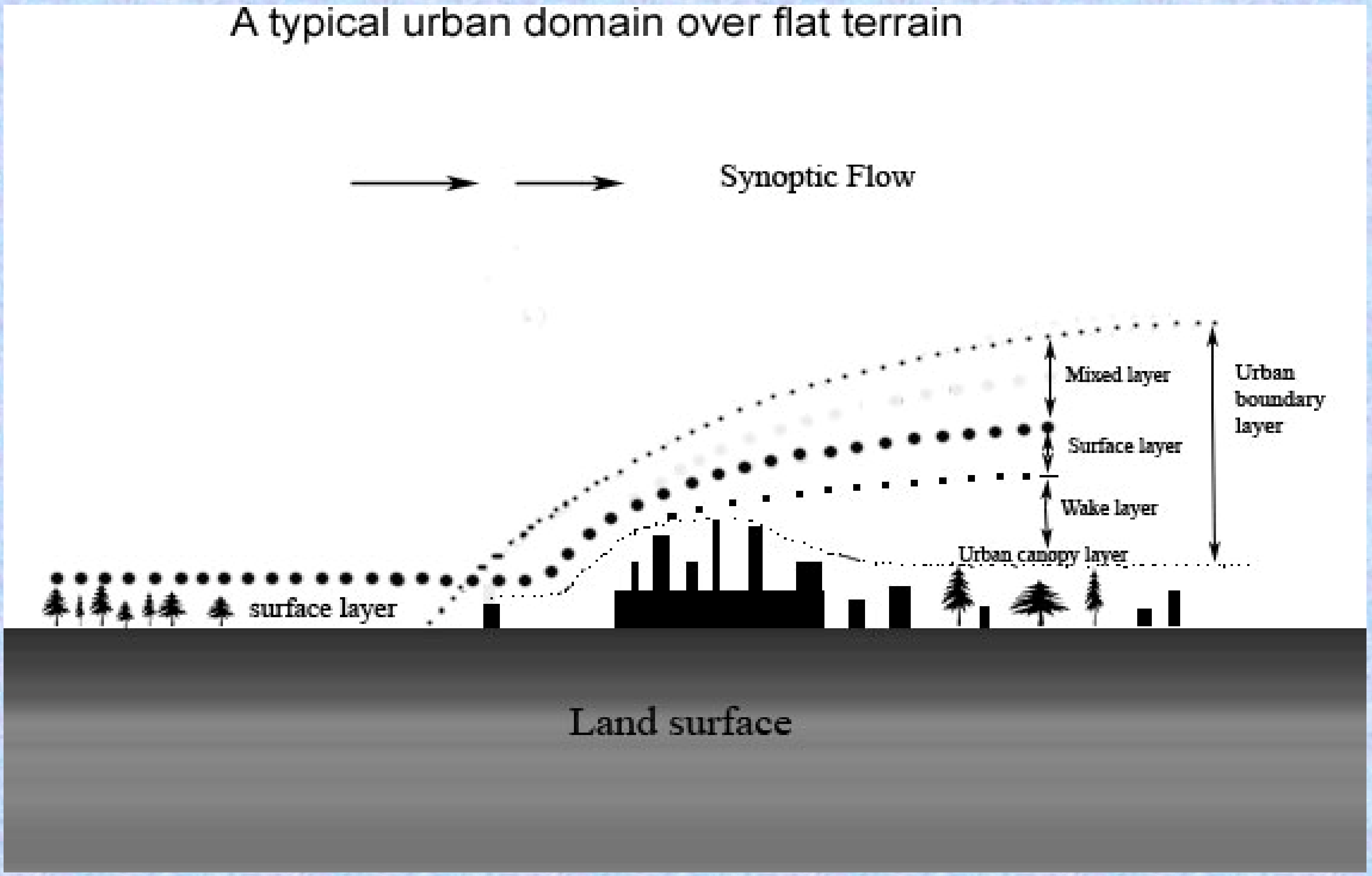
- The two most important effects of the urbanized surface have an influence on the air flow structure**:**
  -] **Differential heating/**cooling **of the urbanized surfaces which can generate the so-called urban heat island effect**
  -] **Drag due to buildings**
- **UHI effect** may produce major temporal and spatial alterations to circulation of the urban ABL.

The development of ABL over flat terrain



The potential temperature θ and wind velocity U are shown for the convective and stable boundary layers.

Urban Boundary Layer



GOVERNING EQUATIONS FOR TURBULENT PBL

$$\frac{DU_i}{Dt} = -\frac{\partial}{\partial x_j}\tau_{ij} - g_i - \frac{1}{\rho}\frac{\partial P}{\partial x_i} - 2\varepsilon_{ijk}\Omega_j U_k;$$

$$\frac{D\Theta}{Dt} = -\frac{\partial}{\partial x_j} h_j, \qquad \frac{DC}{Dt} = -\frac{\partial}{\partial x_j} m_j,$$

$\boldsymbol{\tau_{ij}} \equiv \langle u_i u_j \rangle$ are the turbulent momentum fluxes

$h_i \equiv \langle u_i \theta \rangle$ are the turbulent heat fluxes

$m_i \equiv \langle u_i c \rangle$ are the turbulent mass fluxes

Turbulence equations

- Reynolds stresses, $\tau_{ij} \equiv \langle u_i u_j \rangle$

$$\frac{D}{Dt}\tau_{ij} + D_{ij} = P_{ij} + \beta_i h_j + \beta_j h_i - \Pi_{ij} - \varepsilon_{ij}$$

$$P_{ij} = -\left(\tau_{ik} \frac{\partial U_j}{\partial x_k} + \tau_{jk} \frac{\partial U_i}{\partial x_k} \right) \quad \Pi_{ij} = \langle u_i \frac{\partial p}{\partial x_j} \rangle + \langle u_j \frac{\partial p}{\partial x_i} \rangle - \frac{2}{3}\delta_{ij} \frac{\partial}{\partial x_k} \langle p u_k \rangle$$

$$D_{ij} \equiv \frac{\partial}{\partial x_k}\left(\langle u_i u_j u_k \rangle + \frac{2}{3}\delta_{ij} \langle p u_k \rangle \right) \qquad \varepsilon_{ij} = 2\nu \langle \frac{\partial u_i}{\partial x_k} \frac{\partial u_j}{\partial x_k} \rangle = \frac{2}{3}\delta_{ij}\varepsilon \qquad \beta_i \equiv \beta g_i$$

- Heat flux, $h_i \equiv \langle u_i \theta \rangle$

$$\frac{Dh_i}{Dt} + D_i^h = -h_j \frac{\partial U_i}{\partial x_j} - \tau_{ij} \frac{\partial \Theta}{\partial x_j} + \beta_i \langle \theta^2 \rangle - \Pi_{i\theta},$$

$$\Pi_{i\theta} \equiv \langle \theta \frac{\partial p}{\partial x_i} \rangle, \quad D_i^h = \frac{\partial}{\partial x_j} \langle u_i u_j \theta \rangle$$

An updated expressions for the pressure-strain Π_{ij} (= $\Pi_{ij}^{(1)}$+ $\Pi_{ij}^{(2)}$+ $\Pi_{ij}^{(3)}$) and the pressure-temperature $\Pi_{i\theta}$ (= $\Pi_{i\theta}^{(1)}$+ $\Pi_{i\theta}^{(2)}$+ $\Pi_{i\theta}^{(3)}$) correlations

– **Mellor-Yamada model 1982, Mellor,1973:**

$\Pi_{ij}^{(1)}=C\tau^{-1}b_{ij}$

$\Pi_{ij}^{(2)}\sim -ES_{ij}$ Å most of rapid terms are neglected

$\mathbf{\Pi_{ij}^{(3)}=0}$ Å no buoyancy effects are included

$\Pi_{i\theta}^{(1)}=C_{1\theta}h_i$, $\mathbf{\Pi_{i\theta}^{(2)}=0}$, $\Pi_{i\theta}^{(3)}=C_{3\theta}\beta\langle\theta^2\rangle$,

($E=1/2\langle u_iu_i\rangle$ is TKE; $S_{ij}=(U_{i,j}+U_{j,i})/2$)

An updated expressions for the pressure-strain Π_{ij} (= $\Pi_{ij}^{(1)} + \Pi_{ij}^{(2)} + \Pi_{ij}^{(3)}$) and the pressure-temperature $\Pi_{i\theta}$ (= $\Pi_{i\theta}^{(1)} + \Pi_{i\theta}^{(2)} + \Pi_{i\theta}^{(3)}$) correlations

Launder's model (1975)

È

Present model (2001)

$\Pi_{ij}^{(1)} = C_1 \tau^{-1} b_{ij}$

$\Pi_{ij}^{(2)} = -4/3 C_2 E S_{ij} - C_2(Z_{ij} + \Sigma_{ij})$

$\boldsymbol{\Pi_{ij}^{(3)} = C_3 B_{ij}}$

$\Pi_{i\theta}^{(1)} = C_{1\theta}\, \tau^{-1} h_i$,

$\boldsymbol{\Pi_{i\theta}^{(2)} = -C_{2\theta} h_j U_{i,j}}$,

$\Pi_{i\theta}^{(3)} = C_{3\theta} \beta_i \langle\theta^2\rangle$

$\Sigma_{ij} = b_{ik} S_{ij} + S_{ik} b_{kj} - 2/3 \delta_{ij} b_{km} S_{mk};$

È

The model constants of Π_{ij} are

C_1, C_2, C_3, $C_{1\theta}$, $C_{2\theta} = C_{3\theta}$

Zeman and Lumley model (1979)

È

Canuto et al. model (2002)

$\Pi_{ij}^{(1)} = C_1 \tau^{-1} b_{ij}$

$\Pi_{ij}^{(2)} = -4/5 E S_{ij} - \alpha_1 \Sigma_{ij} - \alpha_2 Z_{ij}$

$\Pi_{ij}^{(3)} = (1-\beta_5) B_{ij}$

$\Pi_{i\theta}^{(1)} = C_{1\theta}\, \tau^{-1} h_i$,

$\Pi_{i\theta}^{(2)} = -3/4 \alpha_3 (S_{ij} + 5/3 R_{ij}) h_j$,

$\Pi_{i\theta}^{(3)} = \gamma_1 \beta_i \langle\theta^2\rangle$

$Z_{ij} = R_{ik} b_{kj} - b_{ik} R_{kj}$; $B_{ij} = \beta_i h_j + \beta_j h_i - 2/3 \delta_{ij} \beta_k h_k$

Transport equations for heat and mass fluxes

$$\frac{D\langle u_i\theta\rangle}{Dt} - D^t_{\theta u} = -\langle u_i u_j\rangle \frac{\partial \Theta}{\partial x_j} - \langle u_j\theta\rangle \frac{\partial U_i}{\partial x_j} - c_{1\theta}\frac{\varepsilon}{E}\langle u_i\theta\rangle$$

$$+ c_{2\theta}\langle u_j\theta\rangle \frac{\partial U_i}{\partial x_j} - (1 - c_{2\theta})\cdot g_i\beta\langle\theta^2\rangle$$

$$\frac{D\langle u_i c\rangle}{Dt} - D^t_{cu} = -\langle u_i u_j\rangle \frac{\partial C}{\partial x_j} - \langle u_j c\rangle \frac{\partial U_i}{\partial x_j} - \alpha_{1c}\frac{\varepsilon}{E}\langle u_i c\rangle$$

$$+ \alpha_{2c}\langle u_j c\rangle \frac{\partial U_i}{\partial x_j} - (1 - \alpha_{2c})\cdot g_i\beta\langle c\theta\rangle$$

Anisotropic Algebraic Models for Reynolds Stresses and Heat Fluxes

$$\frac{D}{Dt} b_{ij} + D_{ij} = 0 = -\frac{4}{3} E S_{ij} - \left(S_{ij} + Z_{ij} \right) + B_{ij} - \Pi_{ij}$$

$$\frac{Dh_i}{Dt} + D_i^h = 0 = -h_j \frac{\partial U_i}{\partial x_j} - \tau_{ij} \frac{\partial \Theta}{\partial x_j} + \beta_i \langle \theta^2 \rangle - \Pi_{i\theta},$$

$\Downarrow$

Coupled algebraic system equations for $\langle u_i u_j \rangle$ and $h_i \equiv \langle u_i q \rangle$:

- $b_{ij} = -\alpha_1 E \tau S_{ij} - \alpha_2 \left(\Sigma_{ij} + Z_{ij} \right) + \alpha_3 B_{ij}$
- $A_{ij} h_j = -\tau \left(b_{ij} + \frac{2}{3} \delta_{ij} E \right) \frac{\partial \Theta}{\partial x_j} + \alpha_4 \tau \beta g \delta_{i3} \langle \theta^2 \rangle$

Algebraic equations system of turbulent fluxes for the Planetary Boundary Layer : 2D Case

$$<u^2> = \frac{2}{3}E - \frac{t}{3}\left(4a_2\frac{\partial U}{\partial z}<uw> - 2a_2\frac{\partial V}{\partial z}<vw> + 2a_3 b\, g <wq>\right)$$

$$<v^2> = \frac{2}{3}E - \frac{t}{3}\left(4a_2\frac{\partial V}{\partial z}<vw> - 2a_2\frac{\partial U}{\partial z}<uw> + 2a_3 b\, g <wq>\right)$$

$$<w^2> = \frac{2}{3}E + \frac{t}{3}\left(2a_2\frac{\partial U}{\partial z}<uw> + 2a_2\frac{\partial V}{\partial z}<vw> + 4a_3 b\, g <wq>\right)$$

$$<uw> = -\frac{t}{2}\frac{\partial U}{\partial z}2a_2 <w^2> + a_3 t\, b\, g <uq>$$

$$<vw> = -\frac{t}{2}\frac{\partial V}{\partial z}2a_2 <w^2> + a_3 t\, b\, g <vq>$$

$$<uv> = -t\, a_2\left(\frac{\partial V}{\partial z}<uw> + \frac{\partial U}{\partial z}<vw>\right)$$

$$<uq> = -\frac{t}{a_5}\left(\frac{\partial \Theta}{\partial z}<uw> + a_4\frac{\partial U}{\partial z}<wq>\right)$$

$$<vq> = -\frac{t}{a_5}\left(\frac{\partial \Theta}{\partial z}<vw> + a_4\frac{\partial V}{\partial z}<wq>\right)$$

$$<wq> = -\frac{t}{a_5}\left(\frac{\partial \Theta}{\partial z}<w^2> - a_4 b\, g <q^2>\right)$$

Full Explicit Algebraic Models for Reynolds Stresses and Heat Fluxes

$$\left(<uw>,<vw>\right) = -K_M\left(\frac{\partial U}{\partial z},\frac{\partial V}{\partial z}\right)$$

$$\langle w\theta\rangle = -K_H\frac{\partial \Theta}{\partial z} + \gamma_c$$

$$\gamma_c = \frac{1}{D}\left\{1+\frac{2}{3}\alpha_2^2 G_M + s_6 G_H\right\}\alpha_5(\tau\beta g)\langle\theta^2\rangle$$

this is the countergradient term

$$K_M = E\tau S_M$$

$$K_H = E\tau S_H$$

$$\tau = \frac{E}{\varepsilon}$$

$$G_H \equiv (\tau N)^2$$

$$G_M \equiv (\tau S)^2$$

$$N^2 = \beta g(\partial\Theta/\partial z)$$

$$S^2 \equiv \left(\frac{\partial U}{\partial z}\right)^2 + \left(\frac{\partial V}{\partial z}\right)^2$$

$$S_M = \frac{1}{D}\left\{\begin{array}{l} s_0\left[1+s_1 G_H\left(s_2 - s_3 G_H\right)\right] + s_4 s_5 \times \\ \times\left(1+s_6 G_H\right)(\tau\beta g)^2\langle\theta^2\rangle / E \end{array}\right\}$$

$$S_H = \frac{1}{D}\left\{\frac{2}{3}\frac{1}{c_{1q}}\left(1+s_6 G_H\right)\right\}$$

$$D = 1 + d_1 G_M + d_2 G_H + d_3 G_M G_H + d_4 G_H^2 + (d_5 G_H^2 - d_6 G_M G_H) G_H$$

Three-parametric turbulence model

- TKE, $E = (1/2)\langle u_i u_i \rangle$

$$\frac{DE}{Dt} + \frac{1}{2} D_{ii} = -\tau_{ij} \frac{\partial U_i}{\partial x_j} + \beta_i \eta_i - \varepsilon,$$

$$\frac{1}{2} D_{ii} = -\frac{\partial}{\partial x_i}\left(\frac{c_\mu}{\sigma_E} \frac{E^2}{\varepsilon} \frac{\partial E}{\partial x_i} \right)$$

- TKE dissipation, ε

$$\Psi = \psi_0 + \psi_1 \frac{b_{ij}}{\varepsilon} \frac{\partial U_i}{\partial x_j} + \psi_2 \frac{\beta_i}{\varepsilon} h_i + \psi_3 \beta_j \frac{2E}{\varepsilon} h_i \frac{\partial U_i}{\partial x_j},$$

$$\frac{D\varepsilon}{Dt} + D_\varepsilon = -\frac{\varepsilon^2}{E} \Psi,$$

- Temperature variance, $\langle \theta^2 \rangle$:

$$R = \frac{\tau_\theta}{\tau} = \frac{\langle \theta^2 \rangle}{2\varepsilon_\theta} \frac{\varepsilon}{E}$$

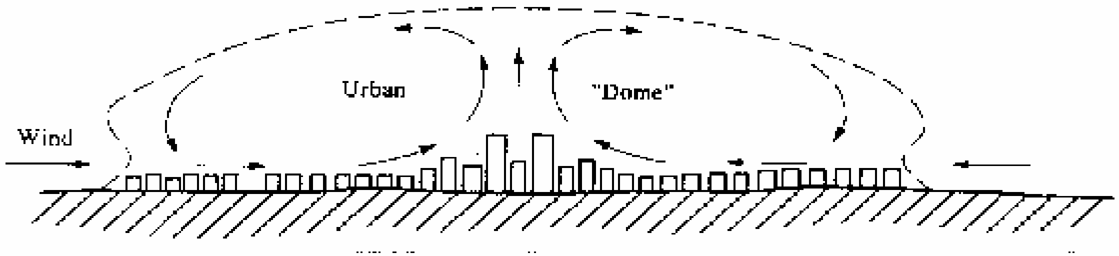
$$\frac{D\langle \theta^2 \rangle}{Dt} + D_{\theta^2} = -2\eta_i \frac{\partial \Theta}{\partial x_i} - 2\varepsilon_\theta,$$

$$D_a = -\frac{\partial}{\partial x_i}\left(\frac{c_\mu}{\sigma_a} \frac{E^2}{\varepsilon} \frac{\partial a}{\partial x_i} \right)$$

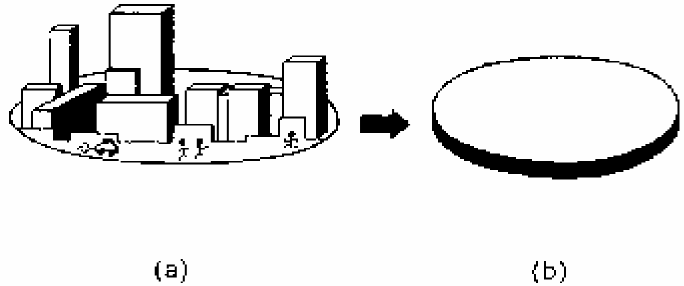
$$a = (\varepsilon, \langle \theta^2 \rangle)$$

■ Air Circulation and Passive Tracer Dispersion above an Urban Heat Island in a Calm and Stably Stratified Environment

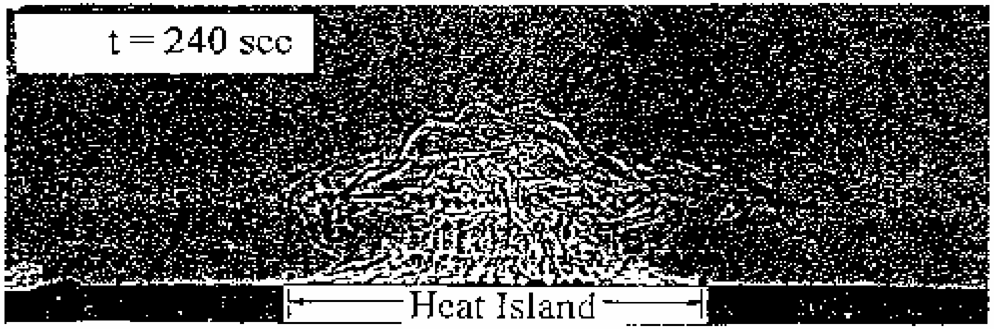
Air Circulation above an Urban Heat Island



Oke's model of a heat island in calm condition

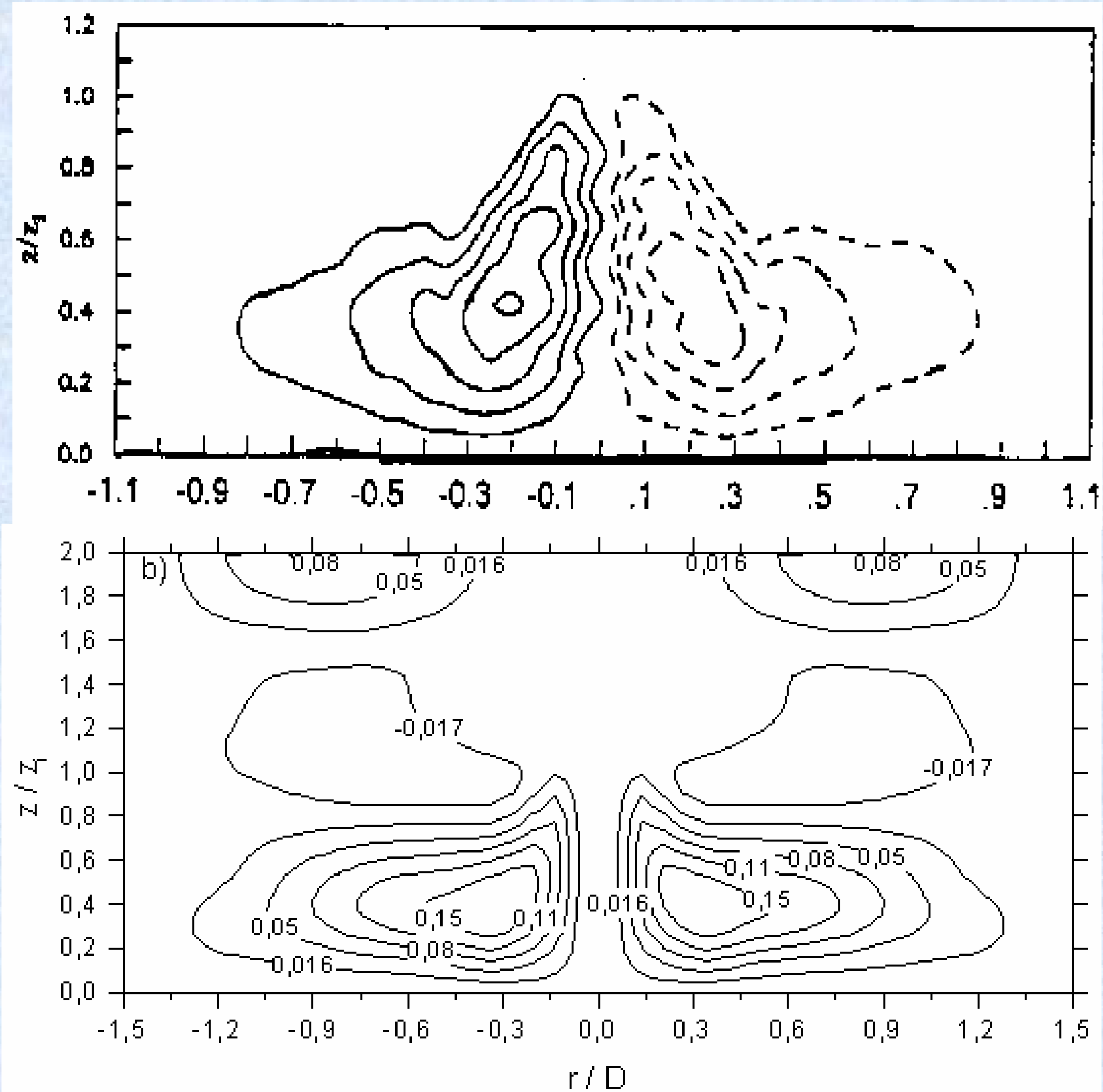


(a) real urban area (b) heated circular disc



Shadowgraph picture heat island above a heated circular disc

Thermal circulation above an urban heat island



Å **Experiment**

of **Lu et al.**

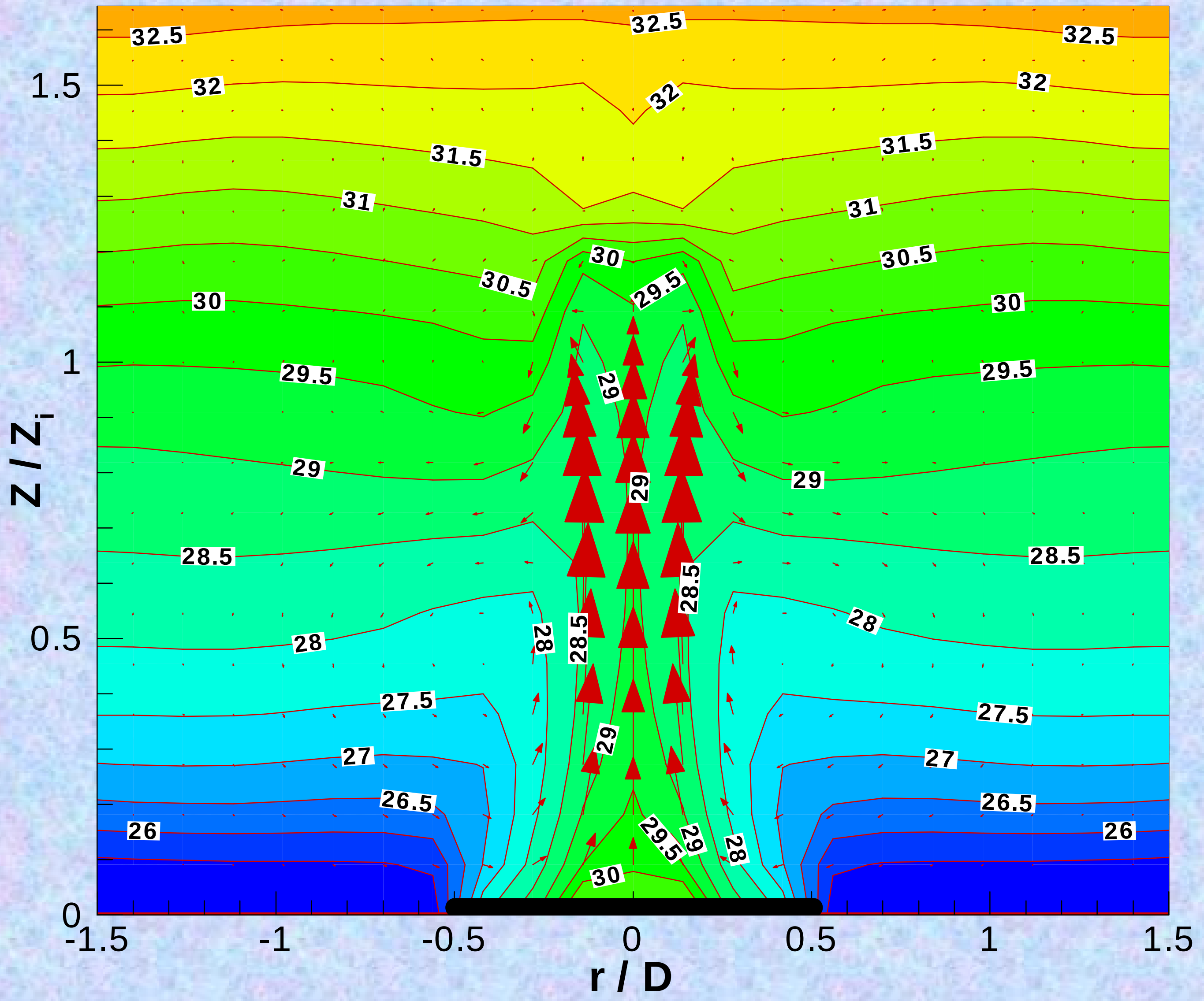
(**JAM.1997.V.36**)

Å **Computation** by

three-parametric

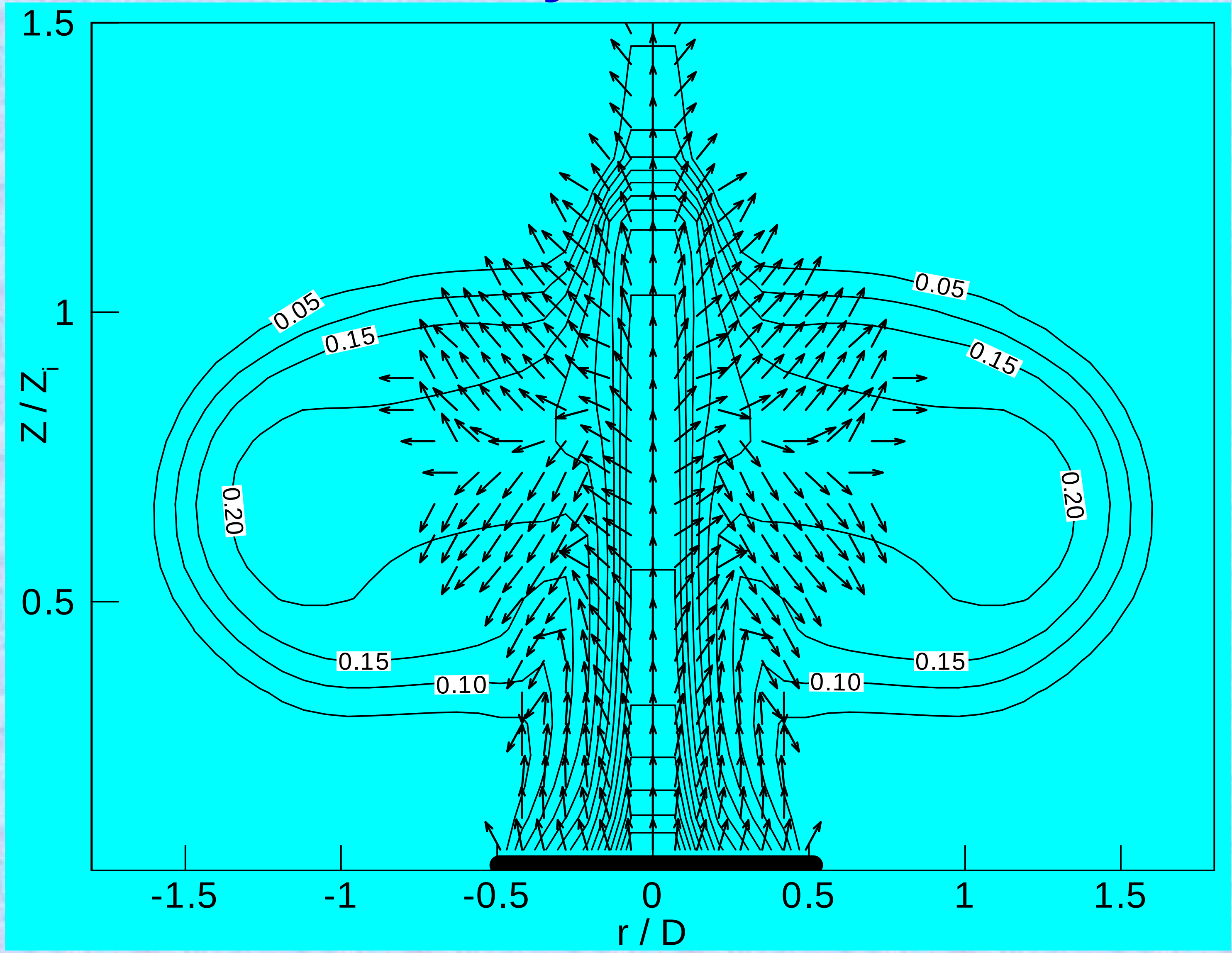
turbulence model

(**Kurbatskii A. JAM. 2001. V.40**)



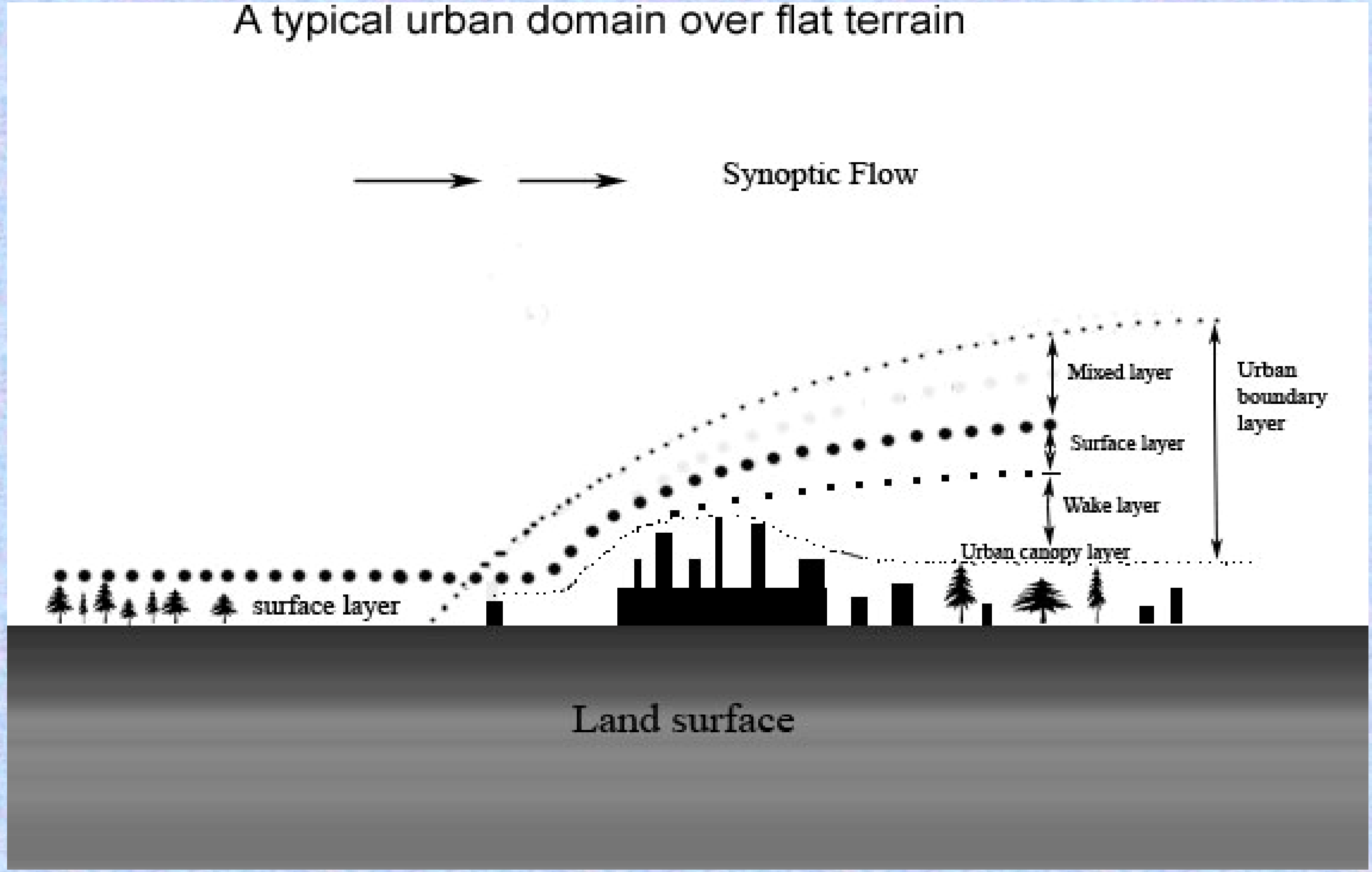
(A. F. Kurbatskii, J. Appl. Meteor. 2001. V. 40. №10)

Dispersion of passive tracer above UHI in a Calm and Stably Stratified Environment

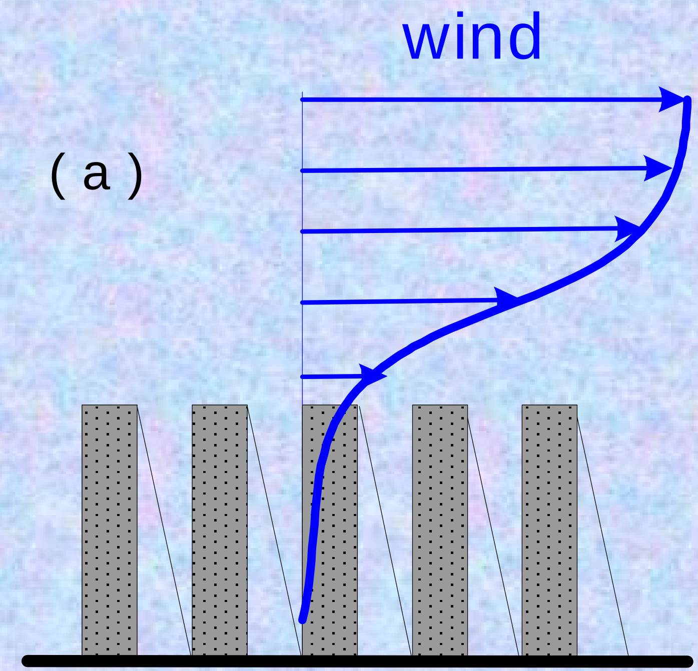


■ Impact of Urban Heat Island and Urban Canopy Layer on the ABL Structure

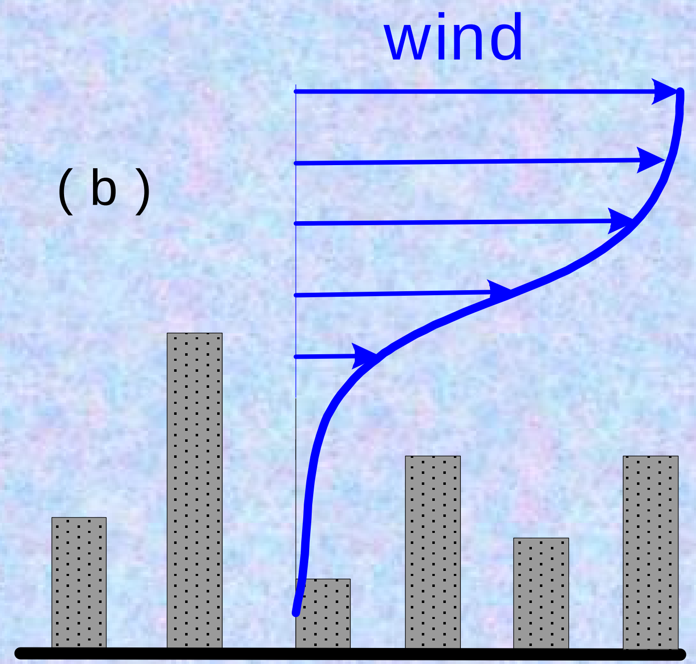
Typical Flat Urban Modeling Domain



Parameterization of Urban Roughness



Scheme of the numerical grid in the urban area by Kondo et al. (1998)



Scheme of the numerical grid in the urban area by Martilli (2002)

The concept of incorporation of urban canopy model

Governing Equations for UBL

2D case:

$$U_x + W_z = 0,$$

$$U_t + UU_x + WU_z = -\frac{1}{\rho}P_x - \langle wu \rangle_z + fV + \mathbf{D_u},$$

$$V_t + UV_x + WV_z = -\langle wv \rangle_z - fU + \mathbf{D_v},$$

$$W_t + UW_x + WW_z = -\frac{1}{\rho_0}P_z - \langle w^2 \rangle_z + \beta\Theta g,$$

$$\Theta_t + U\Theta_x + W\Theta_z = -\boxed{\langle u\theta \rangle_x} - \langle w\theta \rangle_z + \mathbf{D_\theta}.$$

Parameterization of Effects of Urban Surfaces on the Airflow

[Raupach et al.(1991), Raupach (1992), Vu et al.(2002), Martilli (2002)]

The extra terms D_A in the Governing Equations are:

D_U = **turbulent momentum flux (roofs and canyon floors) + drag (vertical walls)**

D_θ = **turbulent fluxes of sensible heat from roofs and the canyon floor + the temperature fluxes from the walls**

D_E = **increasing of conversion of mean kinetic energy into the TKE**

[by as, for example, Raupach and Shaw (1982)]

$$D_\varepsilon = c_{p\varepsilon} \frac{E^{1/2}}{L} \varepsilon \quad (c_{p\varepsilon} = 0.7)$$

[a] **a ‘second’ dissipation induced by buildings**

Turbulent fluxes

$$\left(\langle uw\rangle,\langle vw\rangle\right)=-K_M\left(\frac{\partial U}{\partial z},\frac{\partial V}{\partial z}\right)$$

$$\langle w\,\theta\rangle=-\;K_H\frac{\partial \Theta}{\partial z}+g_C$$

$$K_M = E\,t\,S_M \qquad K_H = E\,t\,S_H$$

$$g_c = \frac{1}{\mathbf{D}}\left\{1+\frac{2}{3}a_2^2\mathbf{G_M}+\mathbf{s}_6\mathbf{G_H}\right\}a_5(\tau\beta\mathbf{g})\langle q^2\rangle$$ **is the countergradient term**

$$S_M=\frac{1}{D}\left\{s_0\left[1+s_1G_H\left(s_2-s_3G_H\right)\right]+s_4s_5\left(1+s_6G_H\right)(\tau\beta g)^2\frac{\langle\theta^2\rangle}{E}\right\}$$

$$S_H=\frac{1}{D}\left\{\frac{2}{3}\frac{1}{c_{1\theta}}\left(1+s_6G_H\right)\right\}$$

$$G_H\equiv(\tau N)^2,\; G_M\equiv(\tau S)^2,\; \tau=E/\varepsilon$$

$$N^2=\beta g\frac{\partial\Theta}{\partial z}, \qquad S^2\equiv\left(\frac{\partial U}{\partial z}\right)^2+\left(\frac{\partial V}{\partial z}\right)^2$$

$$D=1+d_1G_M+d_2G_H+d_3G_MG_H+d_4G_H^2+\left[d_5G_H^2-d_6G_MG_H\right]G_H$$

$d_i, s_i\,(i=1,\ldots,6)$ are the functions of $(c_1,c_2,c_3,c_{1\theta},c_{2\theta})$

Three-parametric turbulence model

$$E,_t + \left[(c_\mu / \sigma_E)(E^2/\varepsilon)E,_i \right],_i = -\langle u_i u_j \rangle,_i U_{i,j} + \beta_i \langle u_i \theta \rangle - \varepsilon + \mathbf{D_E}$$

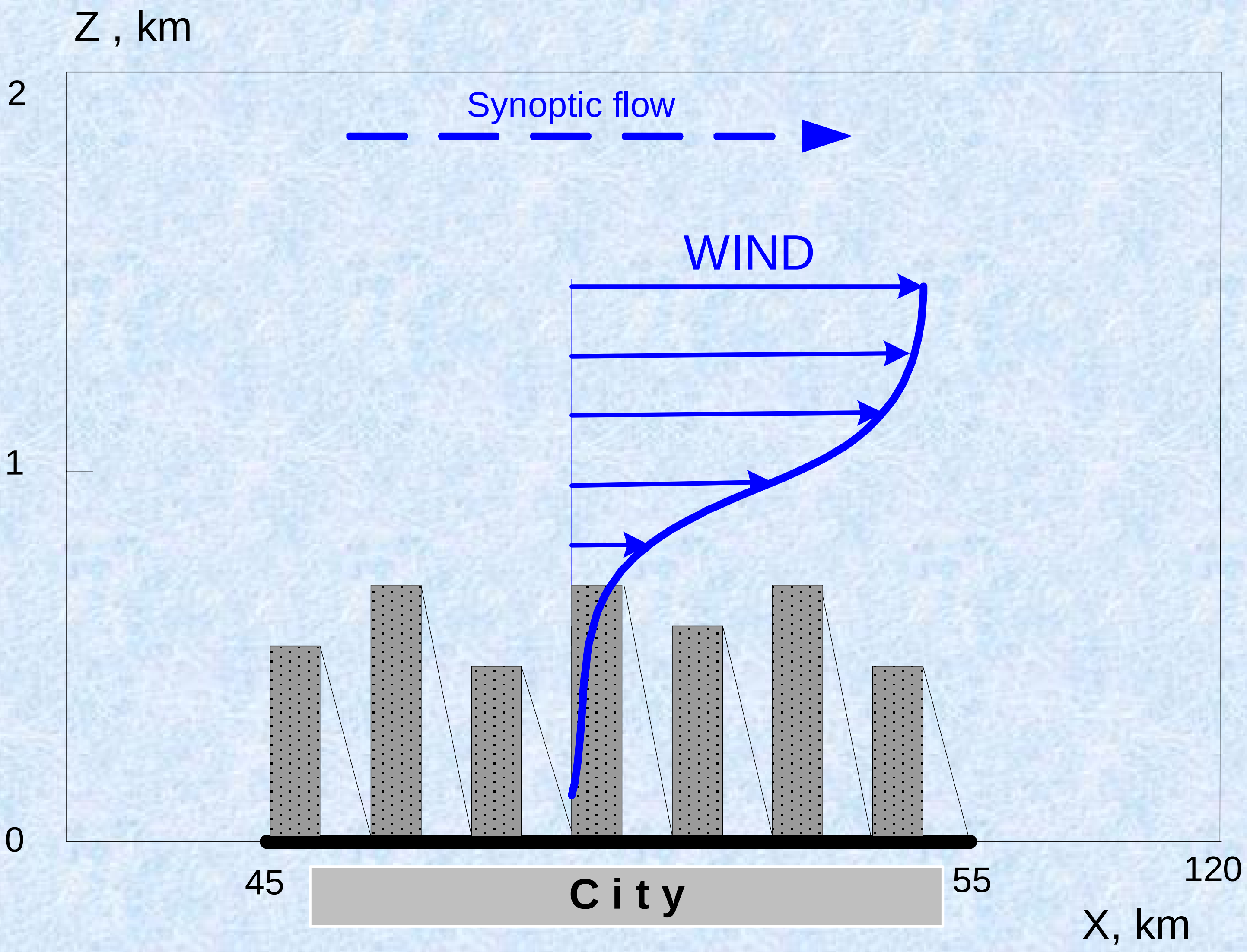
$$\varepsilon,_t + \left[(c_\mu / \sigma_E)(E^2 / \varepsilon)\varepsilon,_i \right],_i = -\frac{\varepsilon^2}{E}\Psi + D_\varepsilon$$

$$(\Psi = \psi_0 + \psi_1 \frac{b_{ij}}{\varepsilon}\frac{\partial U_i}{\partial x_j} + \psi_2 \frac{\beta_i}{\varepsilon}\langle \theta u_i \rangle + \psi_3 \beta_j \frac{2E}{\varepsilon}\langle \theta u_i \rangle \frac{\partial U_i}{\partial x_j})$$

$$\langle \theta^2 \rangle,_t + \left[(c_\mu / \sigma_E)(E^2 / \varepsilon)\langle \theta^2 \rangle,_i \right],_i = -2\langle u_i \theta \rangle \Theta,_i - 2\varepsilon_\theta,$$

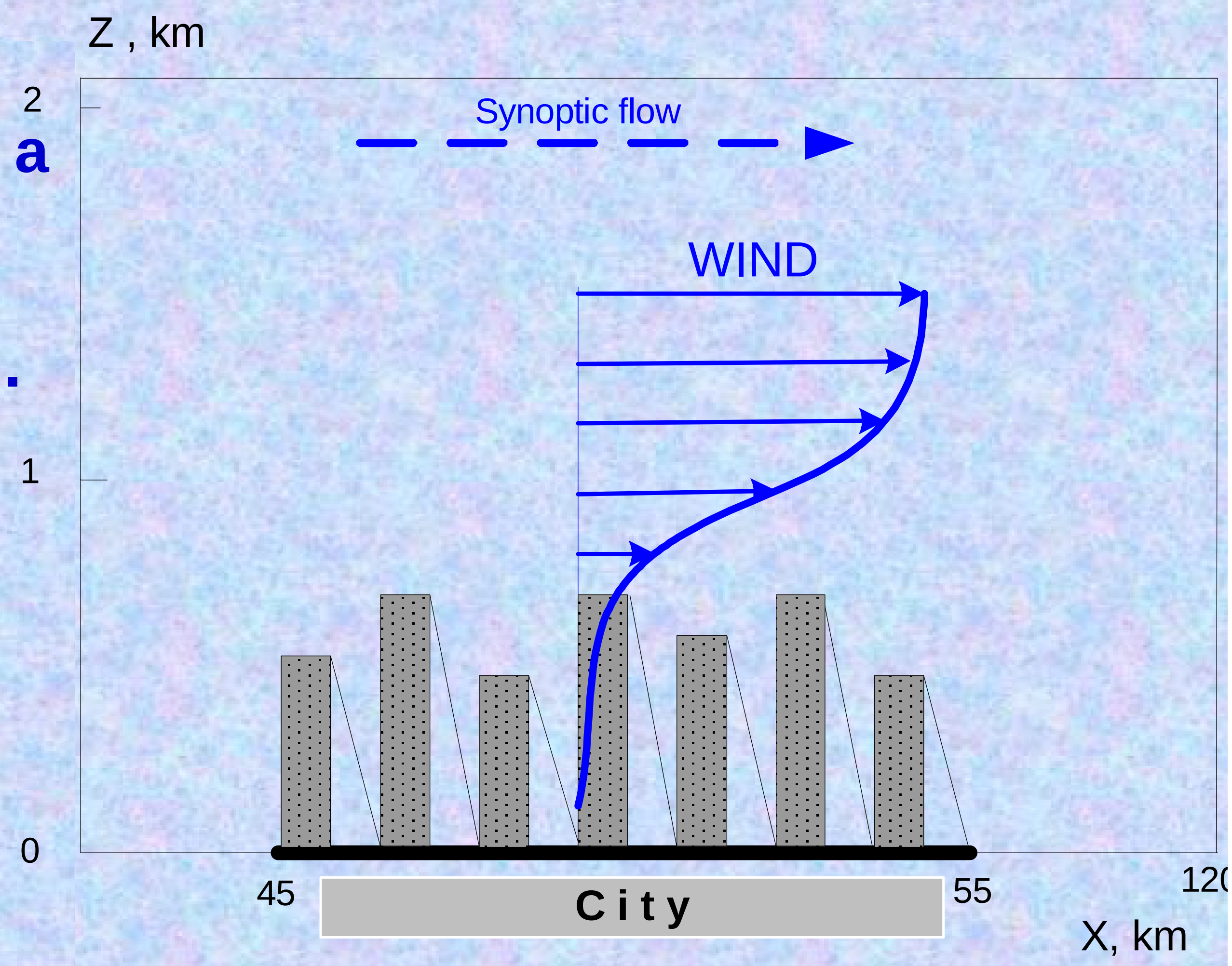
$\mathbf{D_A}$ $(A = U_i, \Theta, E, \varepsilon)$ are the extra terms in urban areas.

2D computational test



Computational Test

- The horizontal extension of domain is 120 km with a resolution of 1 km.
- In a vertical direction the stretching of grid is used.
- The geostrophic wind speed = 3 and 5 m/s.
- The atmospheric thermal stratification equal to 3.5 K/km in potential temperature.



The Urban Heat Island Effect

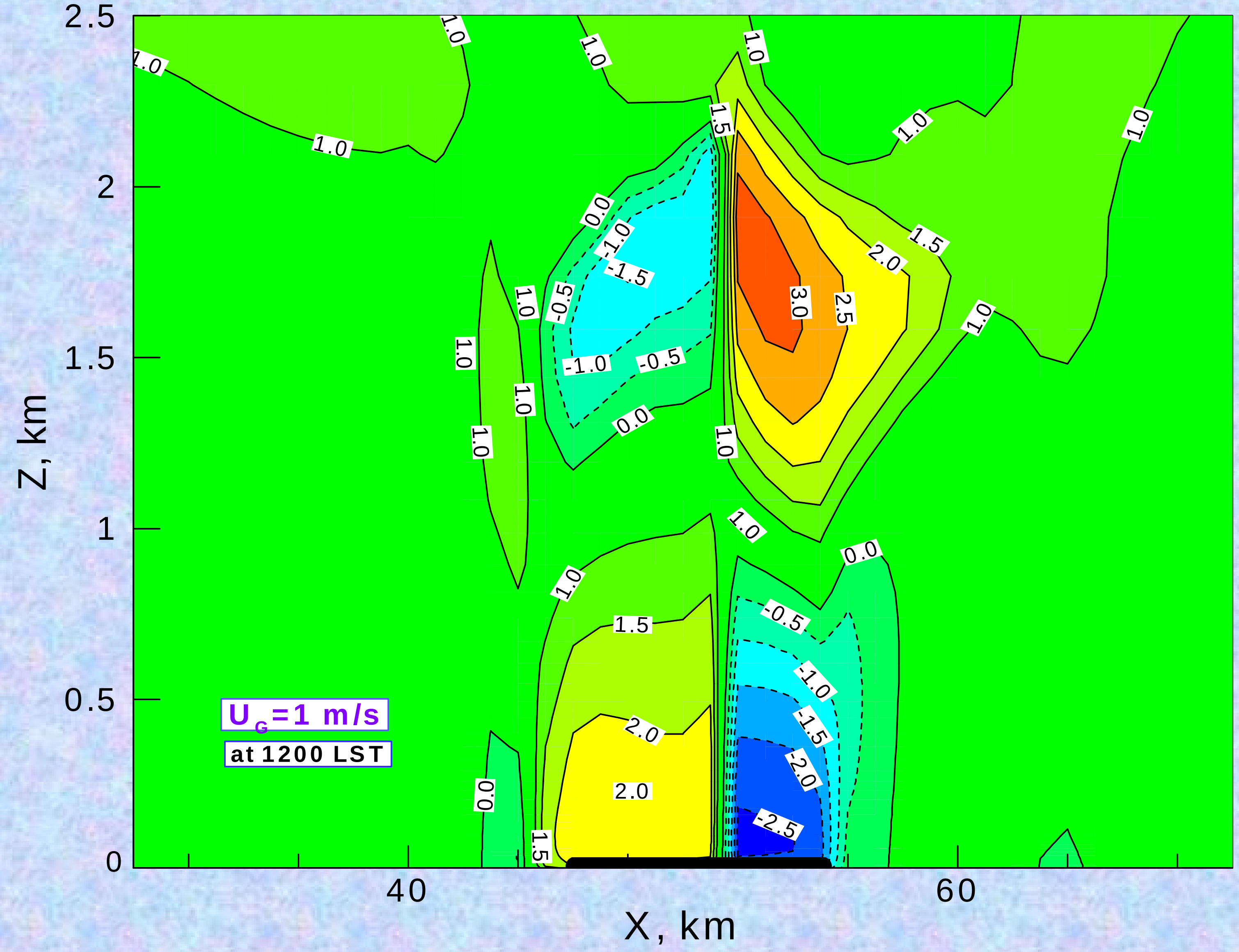
- In this modeling, the UHI effect was specified by an urban-rural temperature difference.
- The ground temperature was specified as

$$\Theta(x,0,t) = 6 \cdot \sin(\pi t/43200)$$

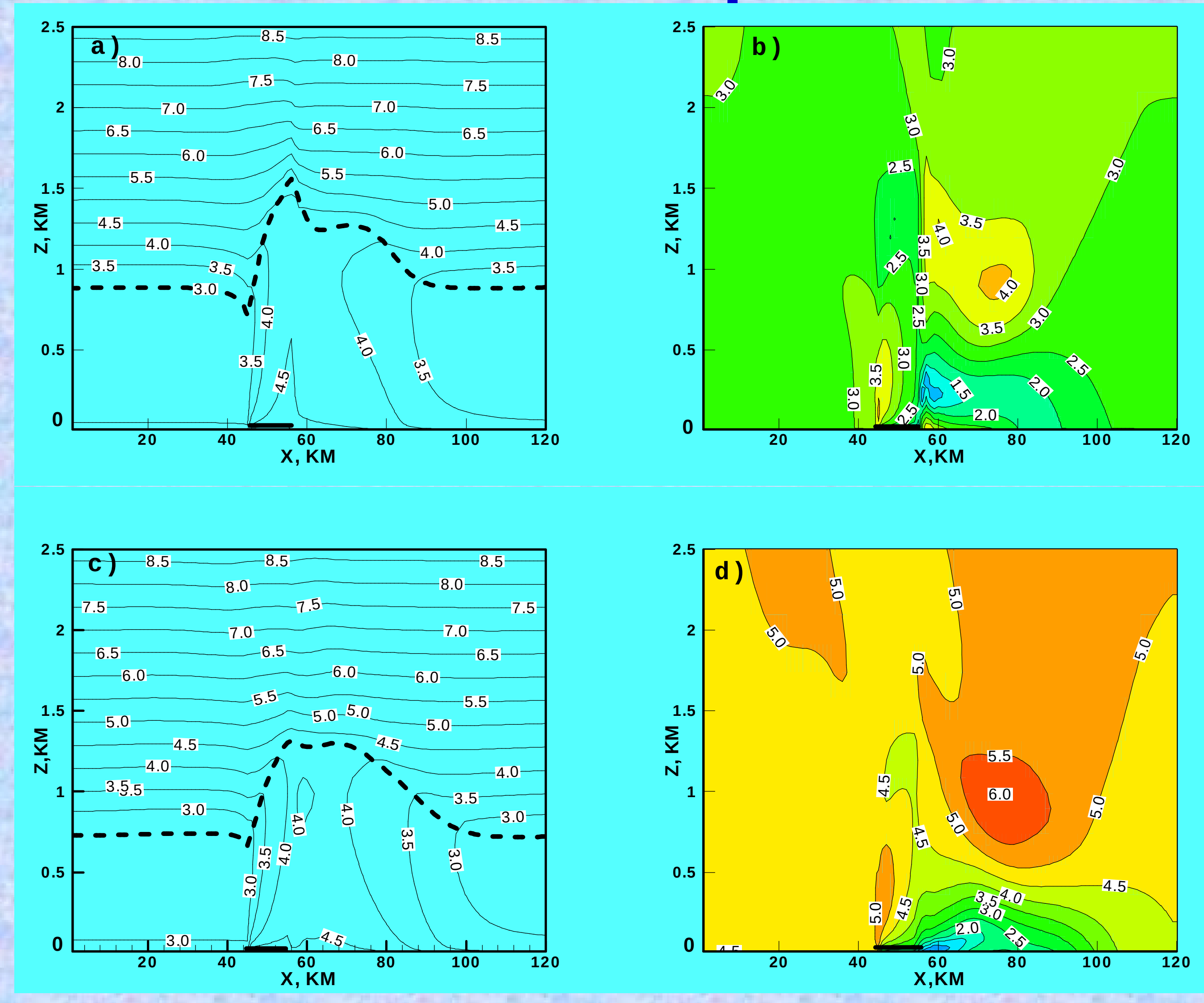
This is the only nonstationary boundary condition of the problem, which models the 24-hour cycle of solar heating of the Earth's surface.

Main Results of Simulation

Vertical section of horizontal wind speed (U_G=1ms^{-1})



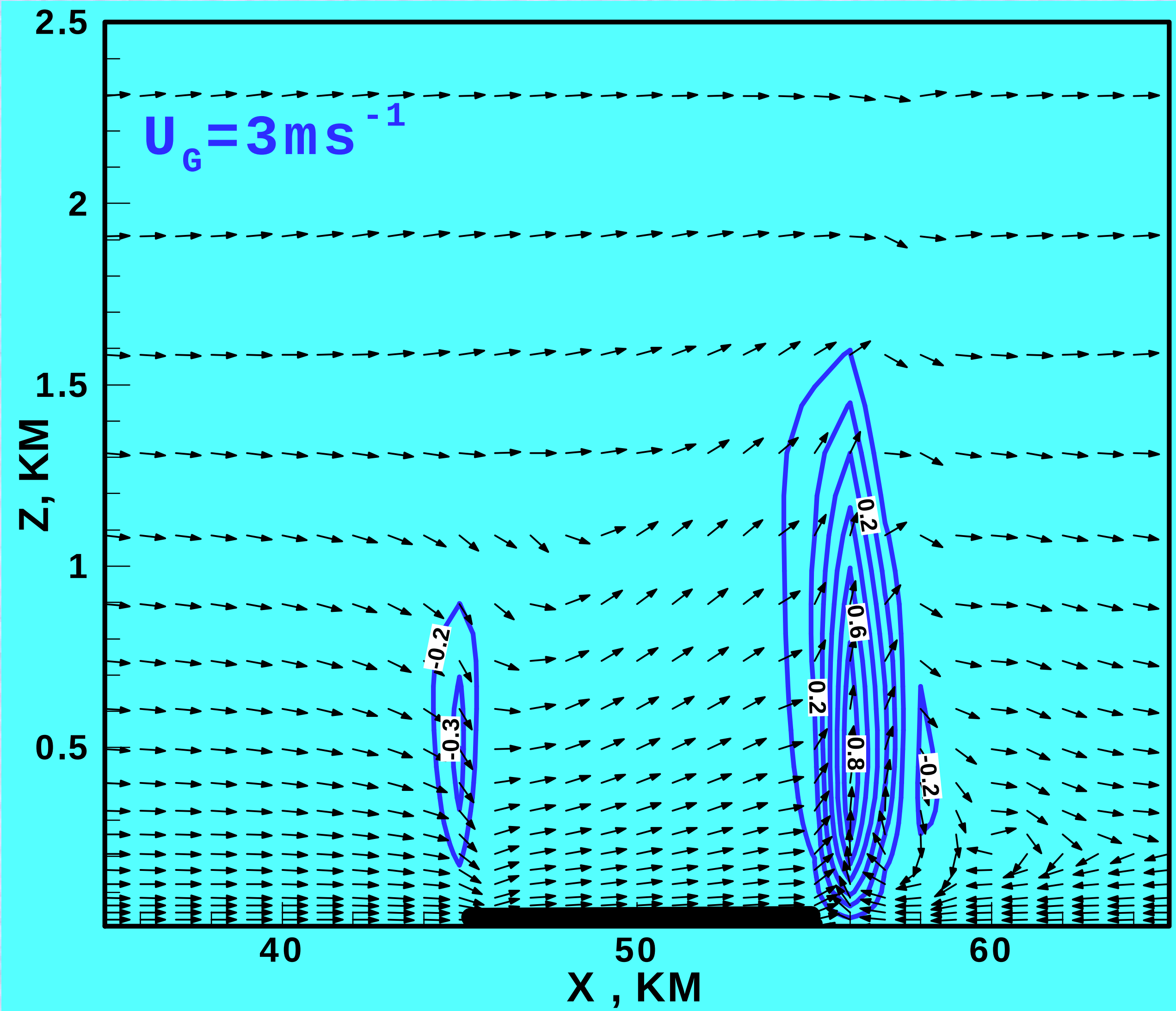
Vertical section of potential temperature and horizontal wind speed at 12:00 LST



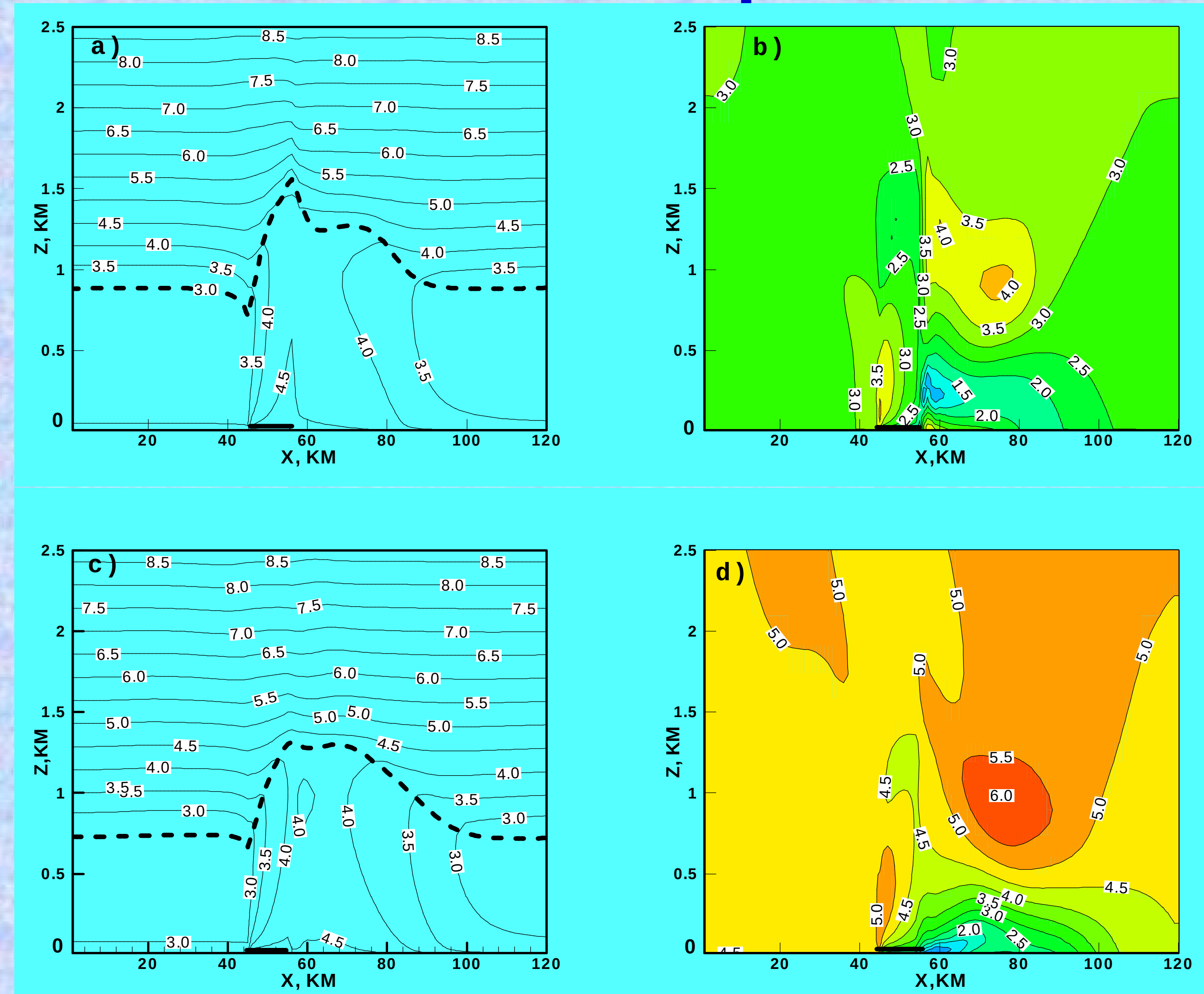
Å U_G=3 ms^{-1}

Å U_G=5 ms^{-1}

Vector field of horizontal wind speed and isotachs of vertical velocity for 12:00 LST



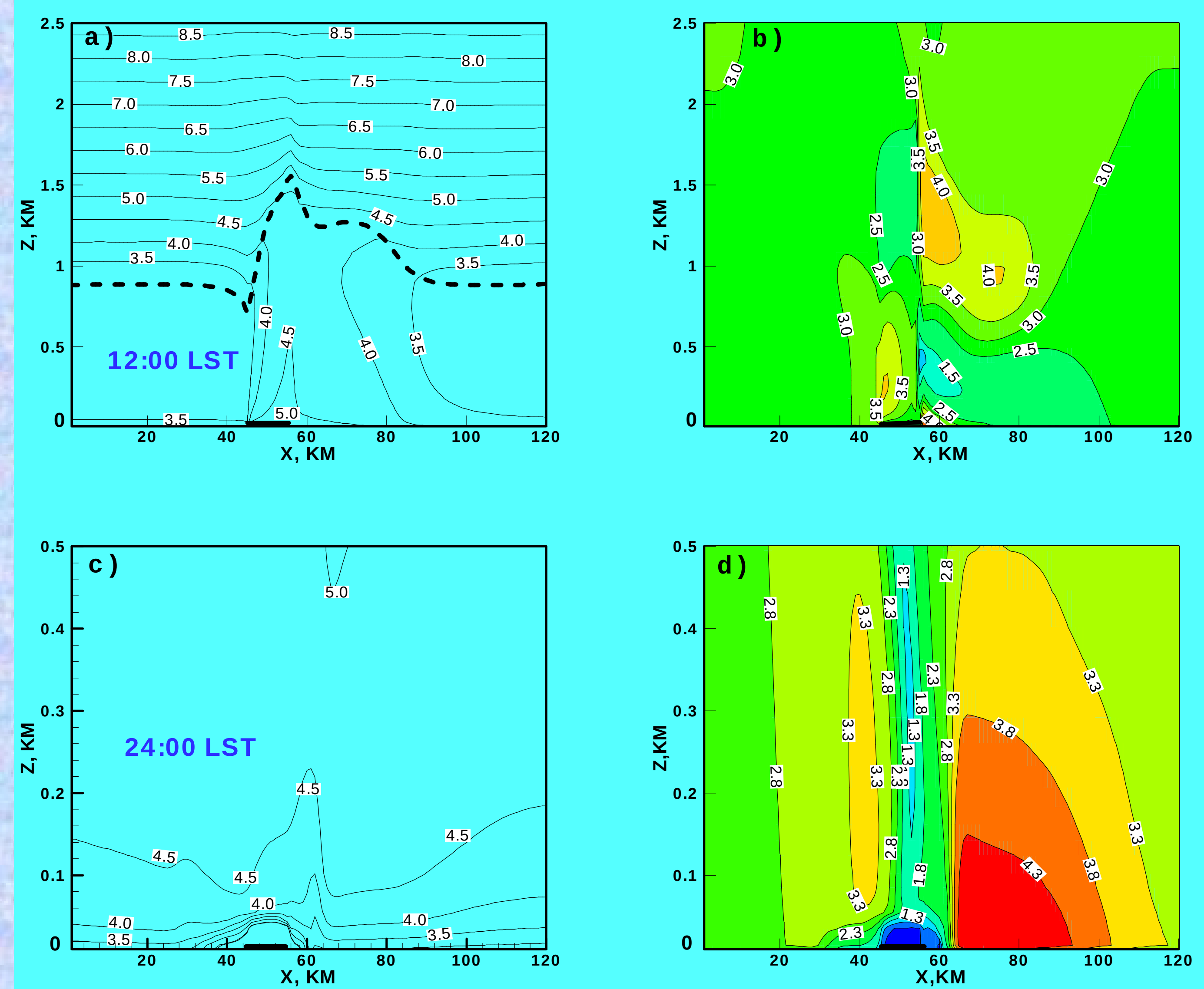
Vertical section of potential temperature and horizontal wind speed at 1200 LST



Å U_G=3 ms^{-1}

Å U_G=5 ms^{-1}

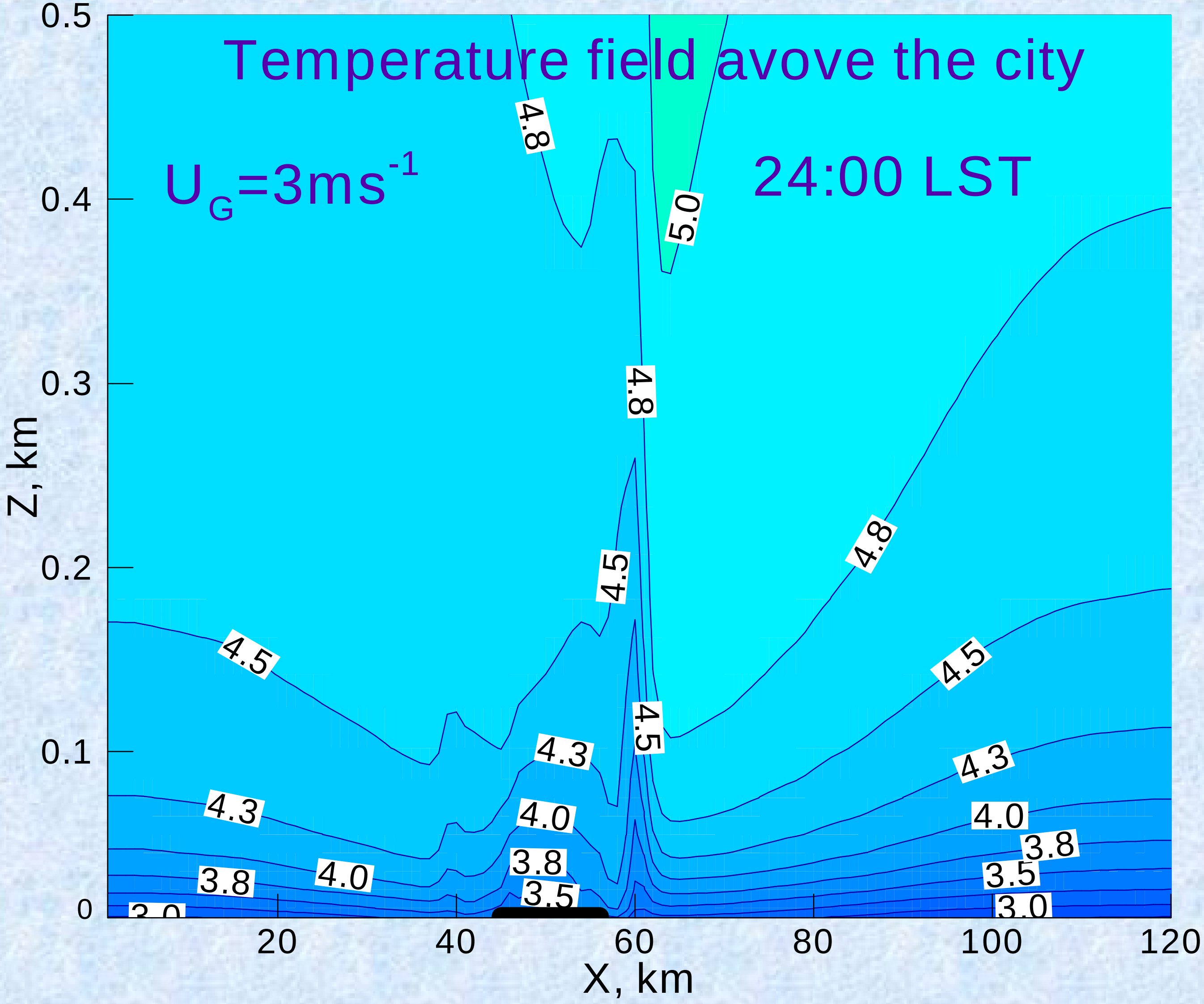
Vertical section of potential temperature and horizontal wind speed



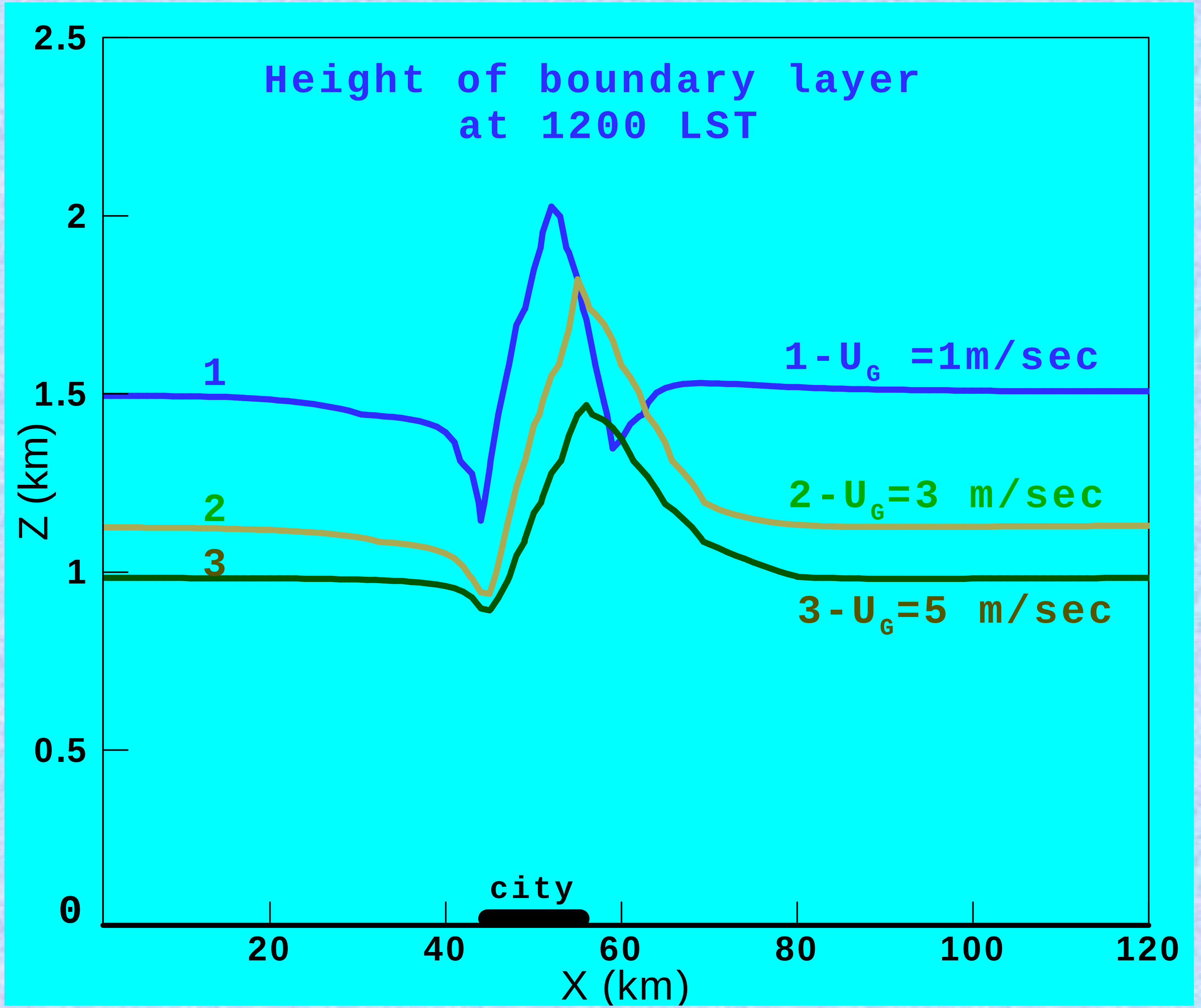
ÅU_G=3 ms^{-1}

ÅU_G=3 ms^{-1}

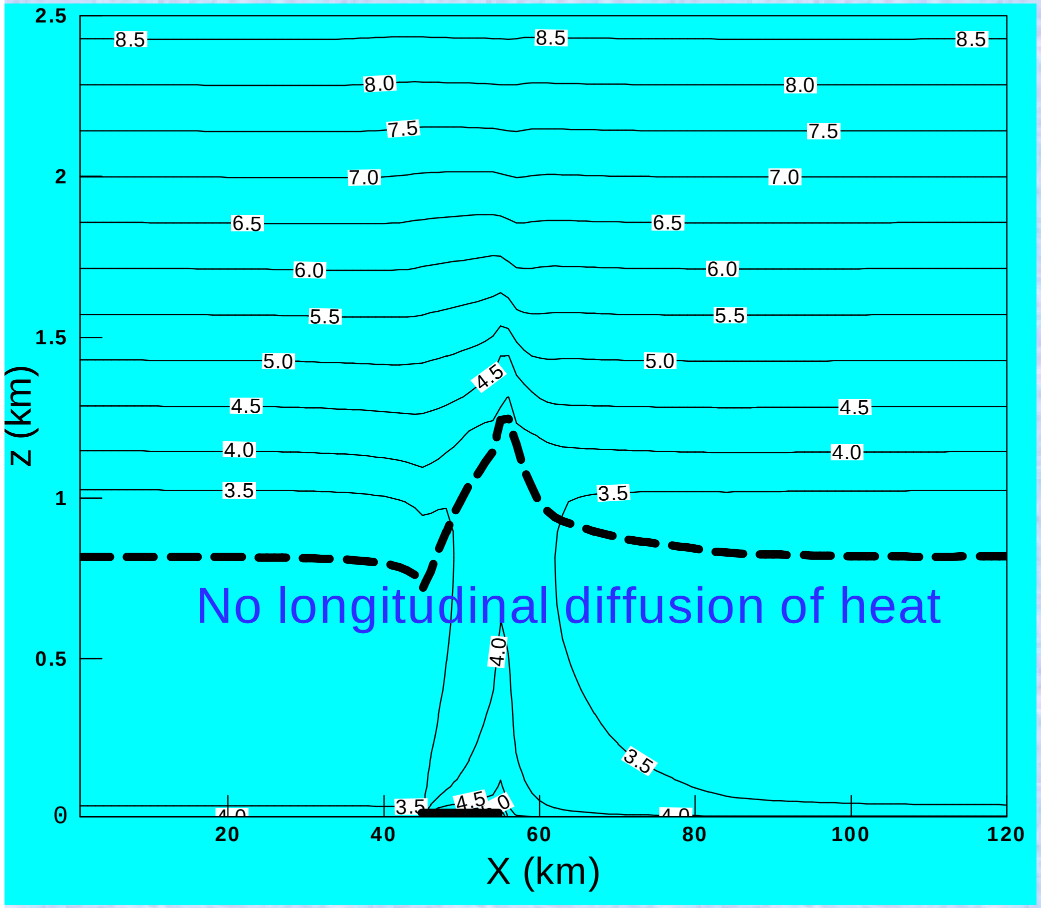
Temperature field above the city

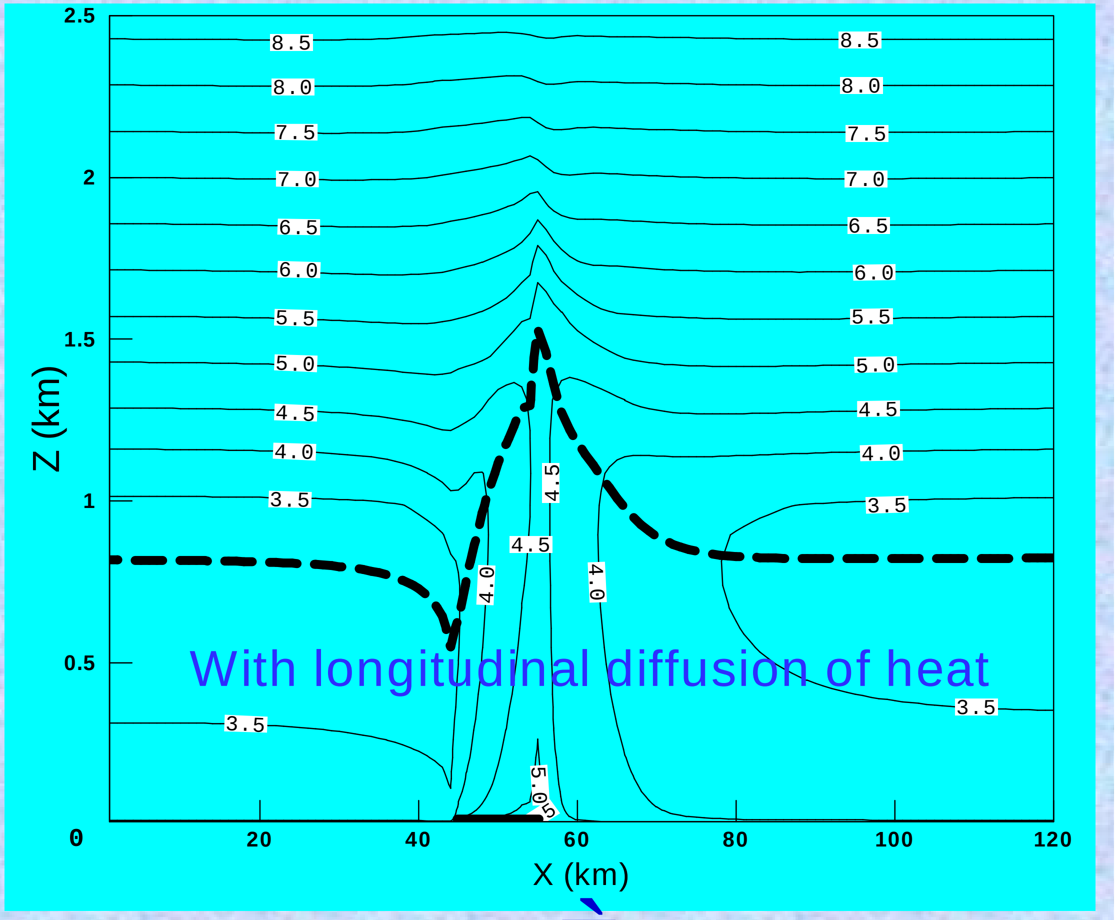


Height of boundary layer



Height of boundary layer

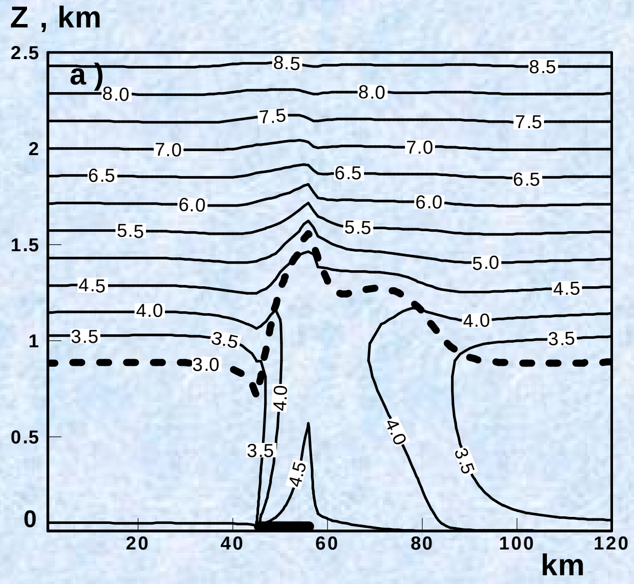


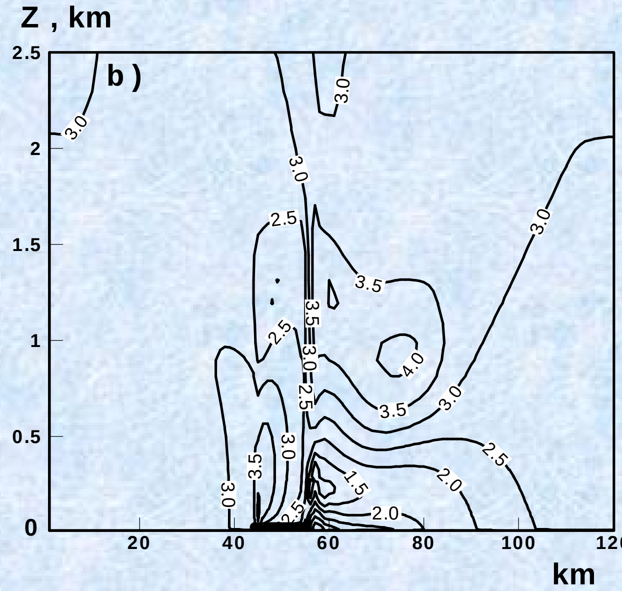


È

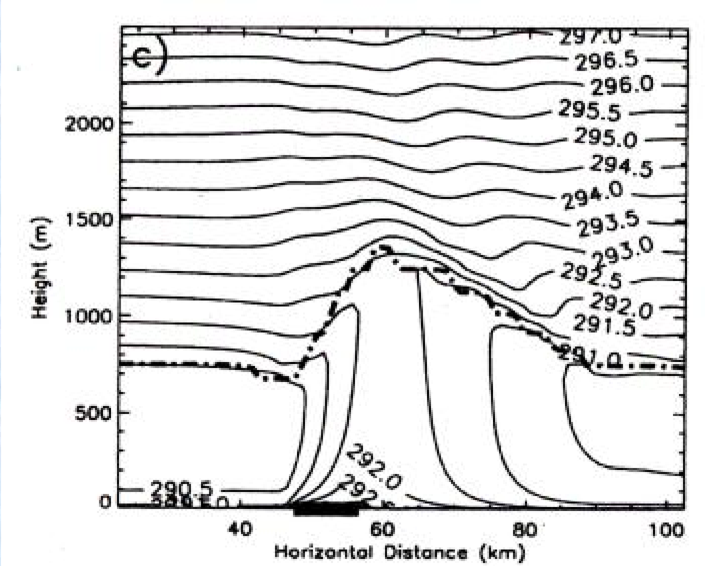
$$\frac{\partial \Theta}{\partial t} + U\frac{\partial \Theta}{\partial x} + W\frac{\partial \Theta}{\partial z} = -\frac{\partial}{\partial z}\langle w\theta \rangle - \frac{\partial}{\partial x} <uq>$$

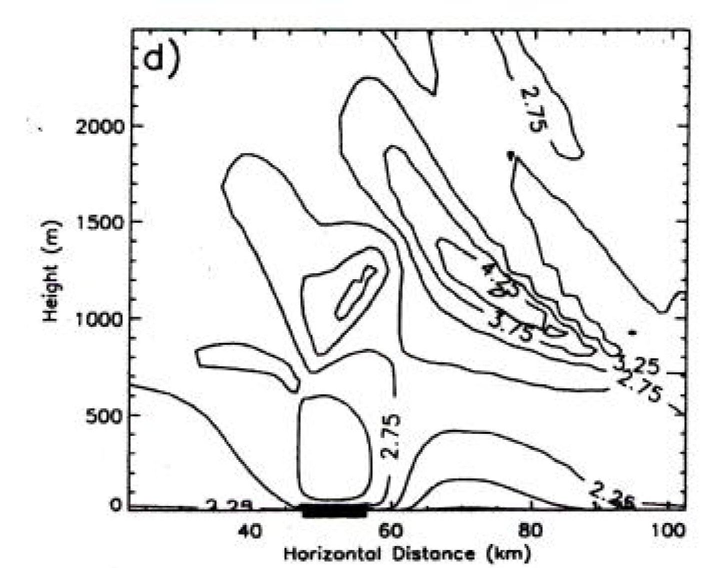
Vertical section of potential temperature and horizontal wind speed ($3\ ms^{-1}$) for simulation at 1200 LST





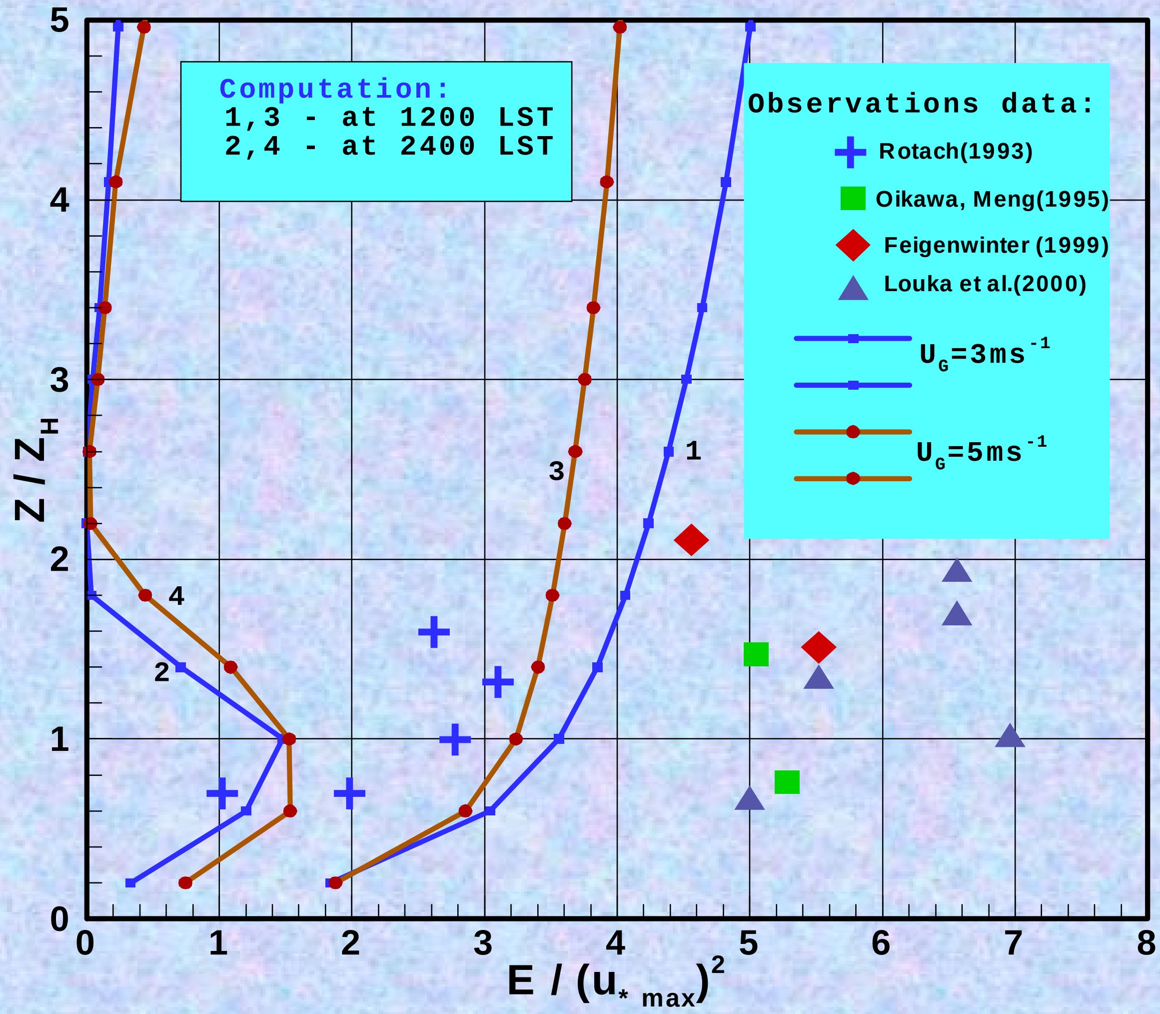
- Å **Present computation**





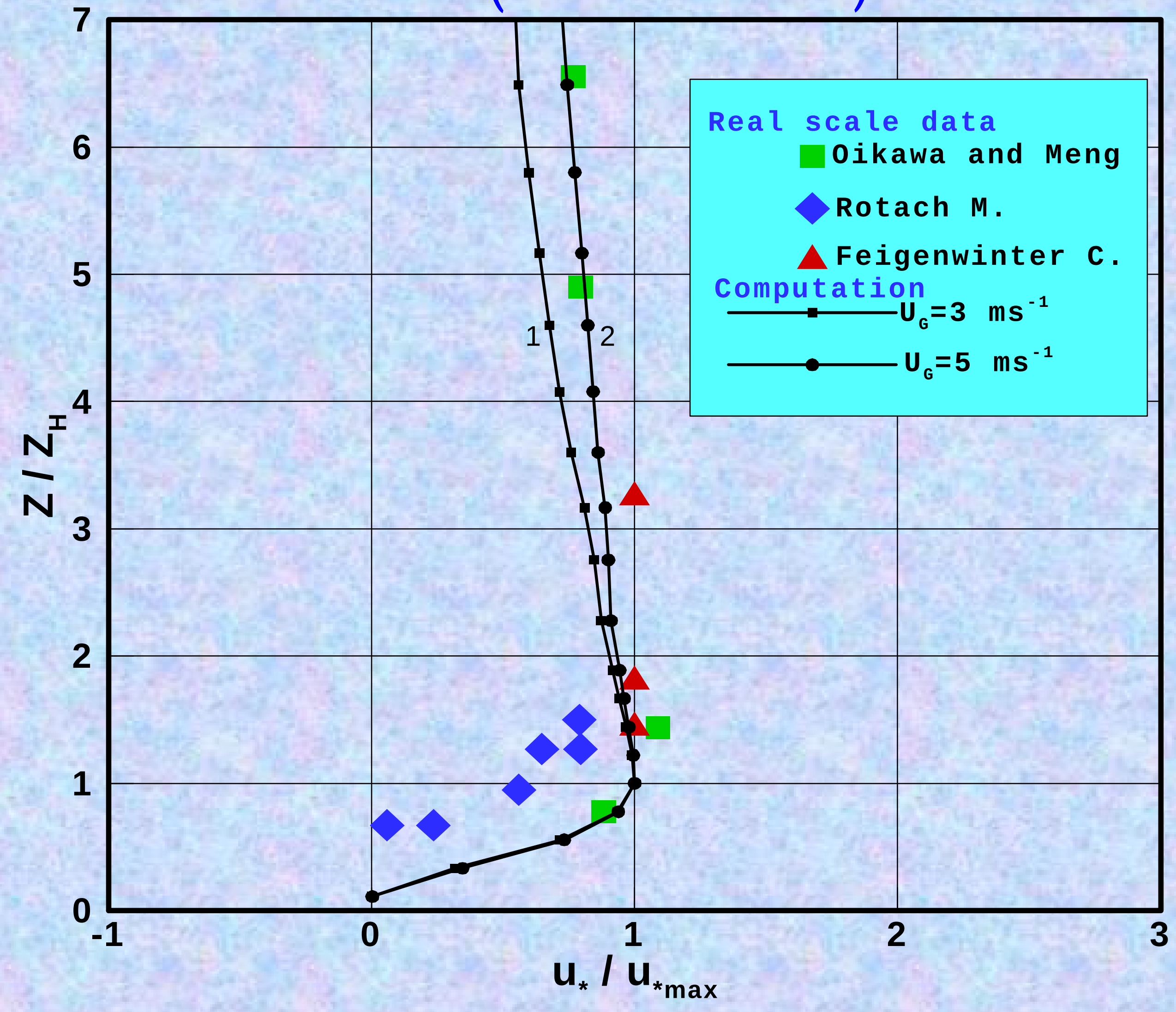
- Å **Computation of Martilli (JAM,2002,V.41,1 247-1266)**

Vertical profiles of TKE in the centre city

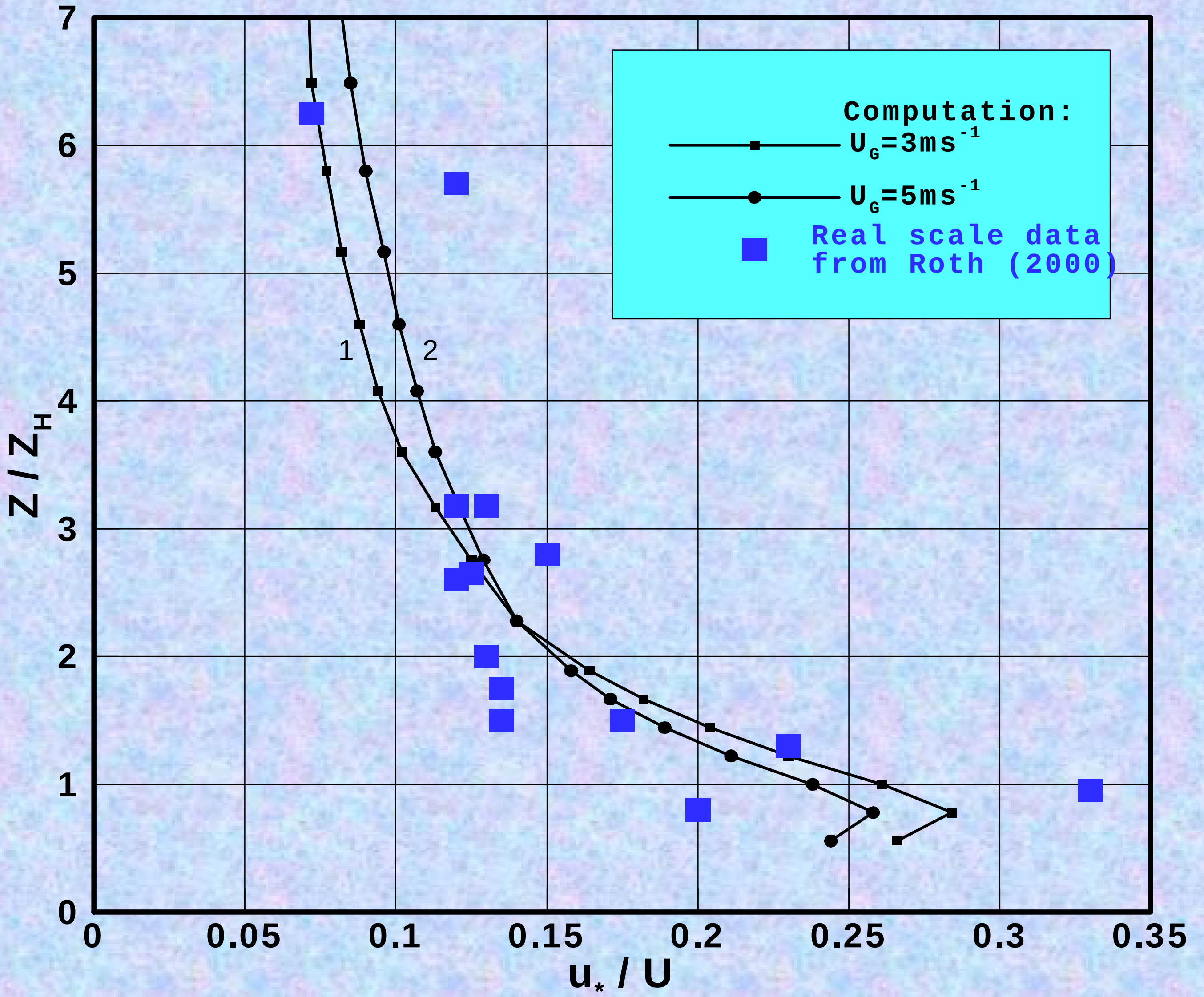


Vertical profiles of 'local' friction velocity

$$u_* = \left(\overline{uw}^2 + \overline{vw}^2 \right)^{1/4}$$



Verticals profiles of ratio u_*/U



■ Impact on the Dispersion of a Passive Tracer

Turbulent Diffusion Model

Weak- equilibrium assumption

$$A_{ij}\cdot m_j = -\frac{E}{\varepsilon}\left(b_{ij}+\frac{2}{3}E\delta_{ij}\right)\frac{\partial C}{\partial x_j}+(1-\alpha_{2C})\beta g\delta_{i3}\frac{E}{\varepsilon}\langle c\theta\rangle$$

$$\langle c\theta\rangle = -\frac{1}{\alpha_{3C}}\frac{E}{\varepsilon}\left(\langle u_j c\rangle\frac{\partial \Theta}{\partial x_j}+\langle u_j\theta\rangle\frac{\partial C}{\partial x_j}\right)$$

$$\mathbf{A_{ij}}\cdot \mathbf{m_j} = -\frac{\mathbf{E}}{\varepsilon}\left\{\left(\mathbf{b_{ij}}+\frac{2}{3}\mathbf{E}\delta_{\mathbf{ij}}\right)+\frac{(1-\alpha_{2\mathbf{C}})}{\alpha_{3\mathbf{C}}}\beta\mathbf{g}\delta_{\mathbf{i}3}\frac{\mathbf{E}}{\varepsilon}\mathbf{h_j}\right\}\frac{\partial \mathbf{C}}{\partial \mathbf{x_j}}$$

$$A_{ij} = \alpha_{1C}\delta_{ij}+\frac{E}{\varepsilon}\frac{\partial U_i}{\partial x_j}+\left(\frac{E}{\varepsilon}\right)^2\frac{(1-\alpha_{2C})}{\alpha_{3C}}\beta g\delta_{i3}\frac{\partial \Theta}{\partial x_j}$$

Turbulent fluxes of pollutant

$$-\langle wc\rangle = \frac{1}{D}\left(\alpha_{1C}\frac{E}{\varepsilon}\left[\langle w^2\rangle + \alpha^*\lambda_1\langle w\theta\rangle\right]\right)\frac{\partial C}{\partial z} + $$
$$+\frac{1}{D}\left(\alpha_{1C}\frac{E}{\varepsilon}\left[\langle uw\rangle + \alpha^*\lambda_1\langle u\theta\rangle\right]\right)\frac{\partial C}{\partial x}$$

$$-\langle uc\rangle = \frac{1}{D}\left(\frac{E}{\varepsilon}\left[\langle u^2\rangle\lambda_2 + \frac{E}{\varepsilon}\frac{\partial U}{\partial z}\left(\langle uw\rangle + \alpha^*\lambda_1\langle u\theta\rangle\right)\right]\right)\frac{\partial C}{\partial x} + $$
$$+\frac{1}{D}\left(\frac{E}{\varepsilon}\left[\langle uw\rangle\lambda_2 + \frac{E}{\varepsilon}\frac{\partial U}{\partial z}\left(\langle w^2\rangle + \alpha^*\lambda_1\langle w\theta\rangle\right)\right]\right)\frac{\partial C}{\partial z}$$

Dispersion of a passive tracer

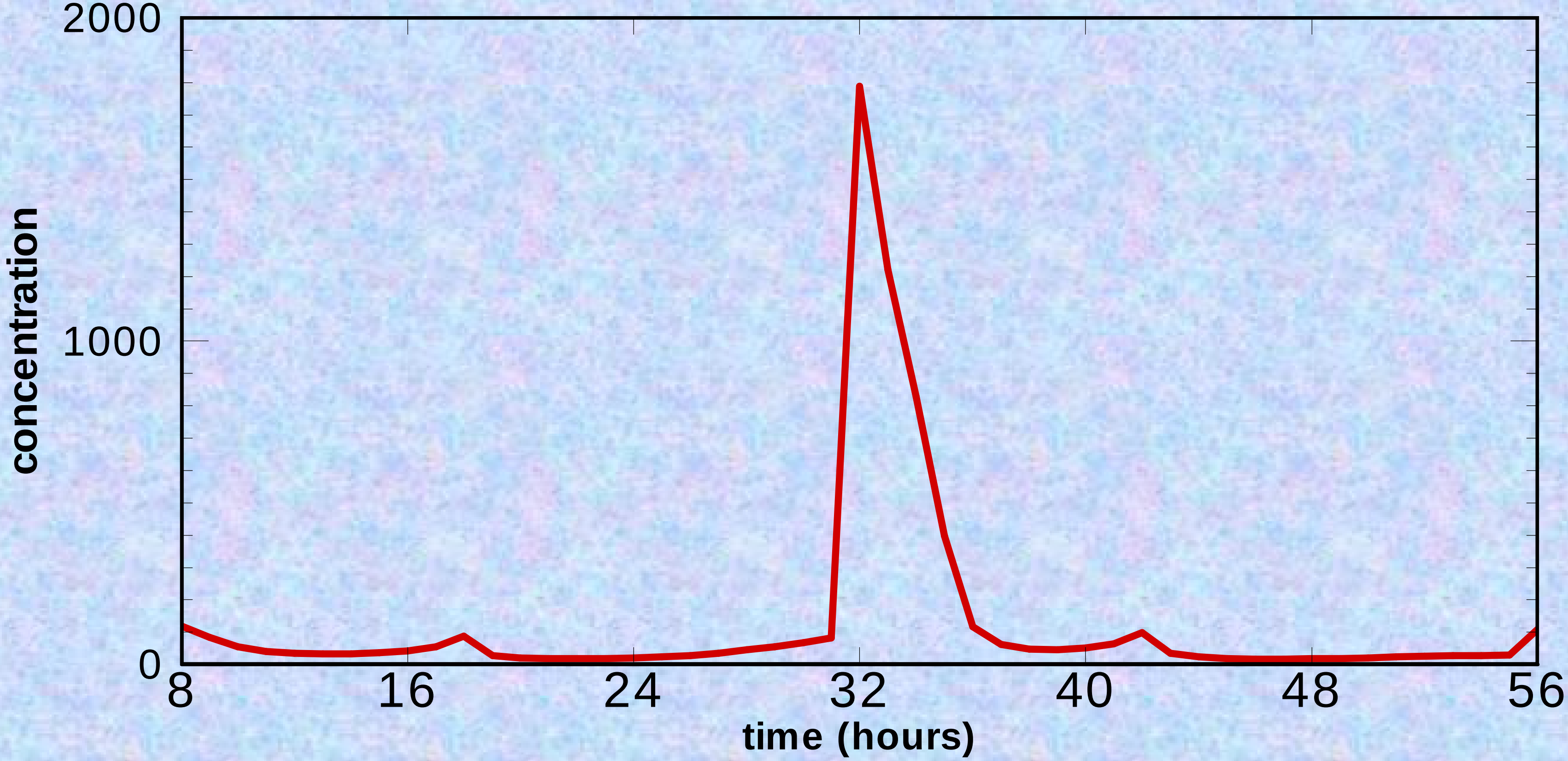
$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial x} + W\frac{\partial C}{\partial z} = \frac{\partial \langle uc \rangle}{\partial x} + \frac{\partial \langle wc \rangle}{\partial z}$$

The passive tracer is emitted in the city at ground level with a time variation typical of traffic emissions

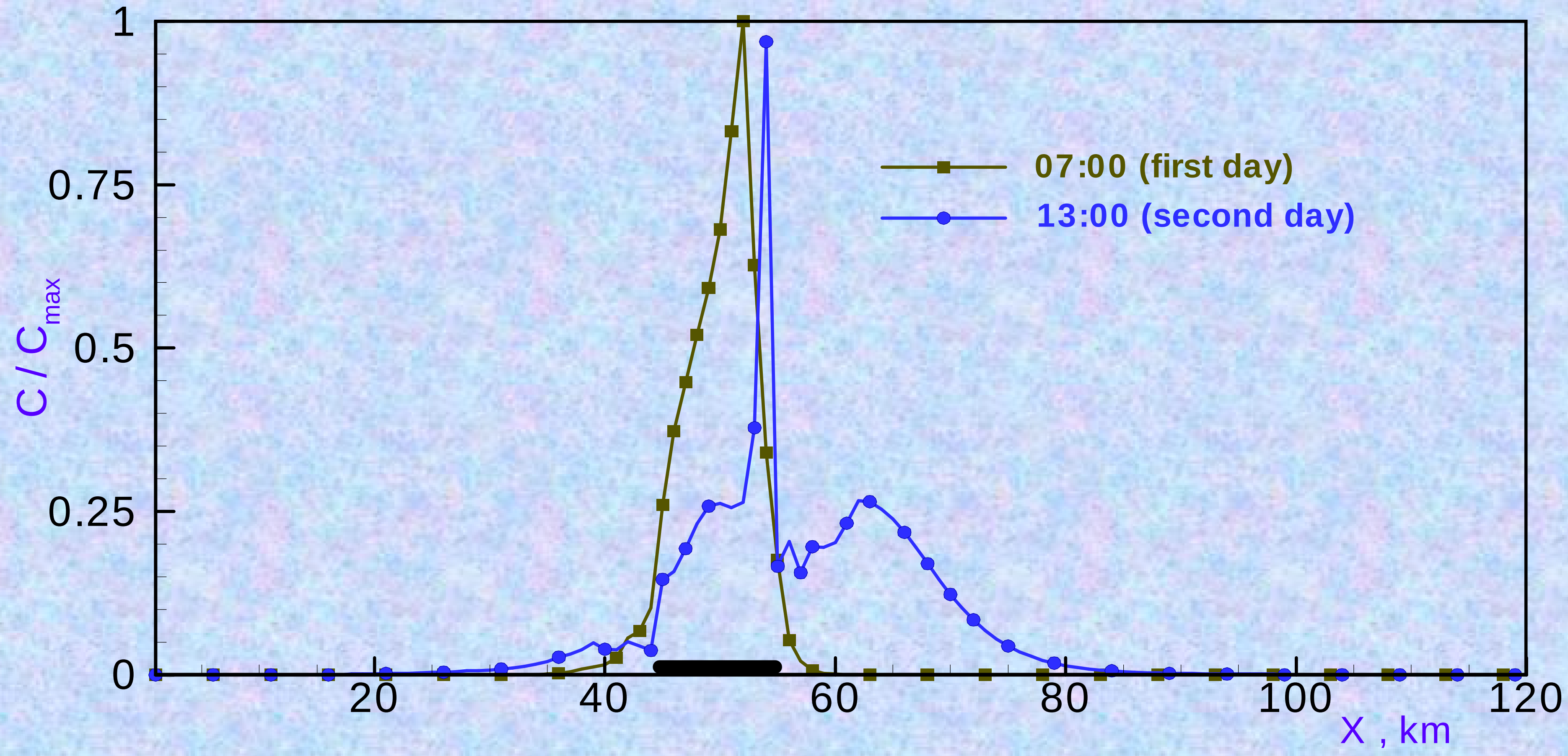
- ã high values during day
- ä low values during night

Time evolution of passive tracer surface concentration in the centre of the urban area

with 3m s^{-1} geostrophic wind

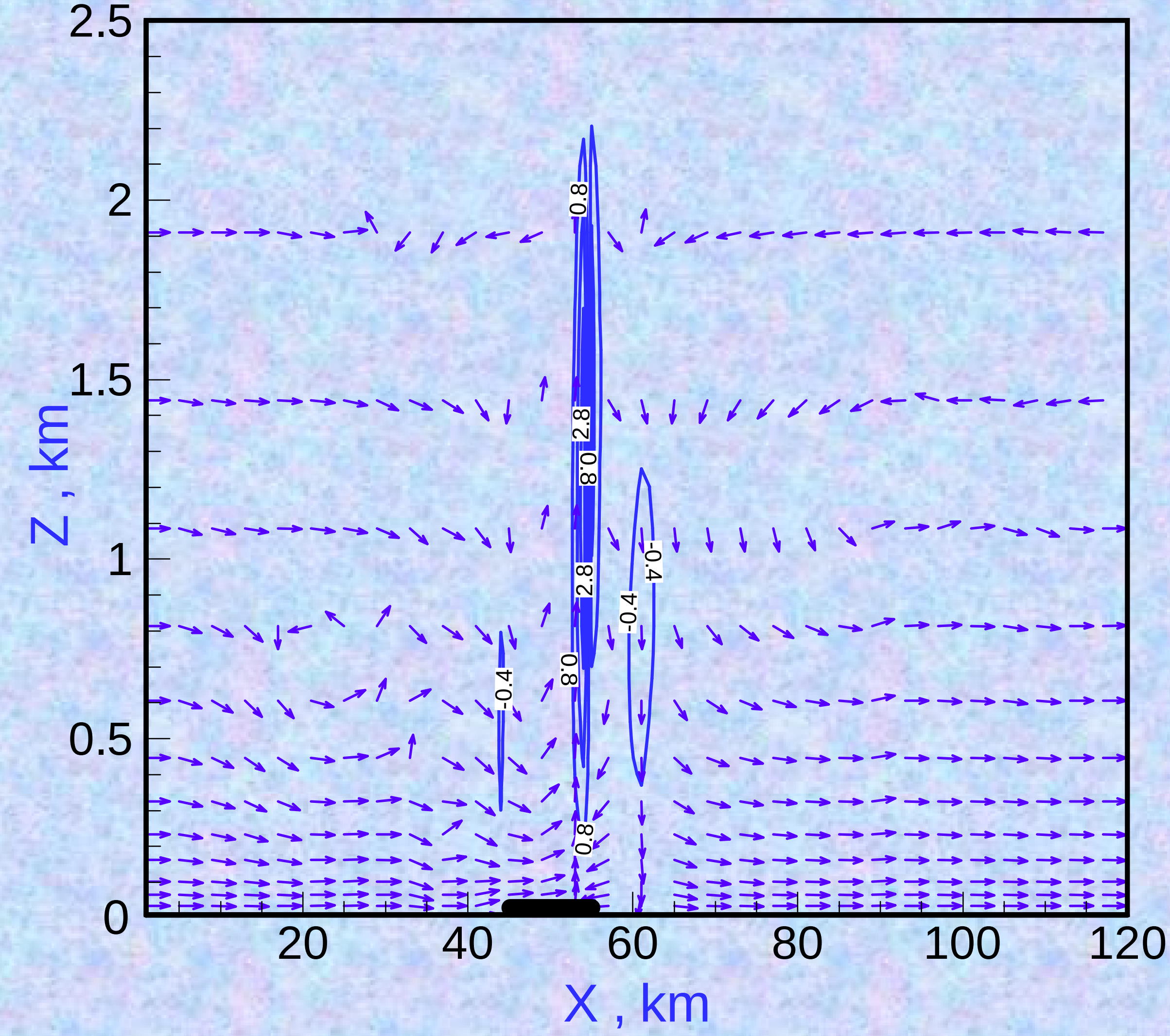


Impact on the dispersion of a passive tracer concentration at the lowest level for modeling with 3 m s^{-1} wind speed



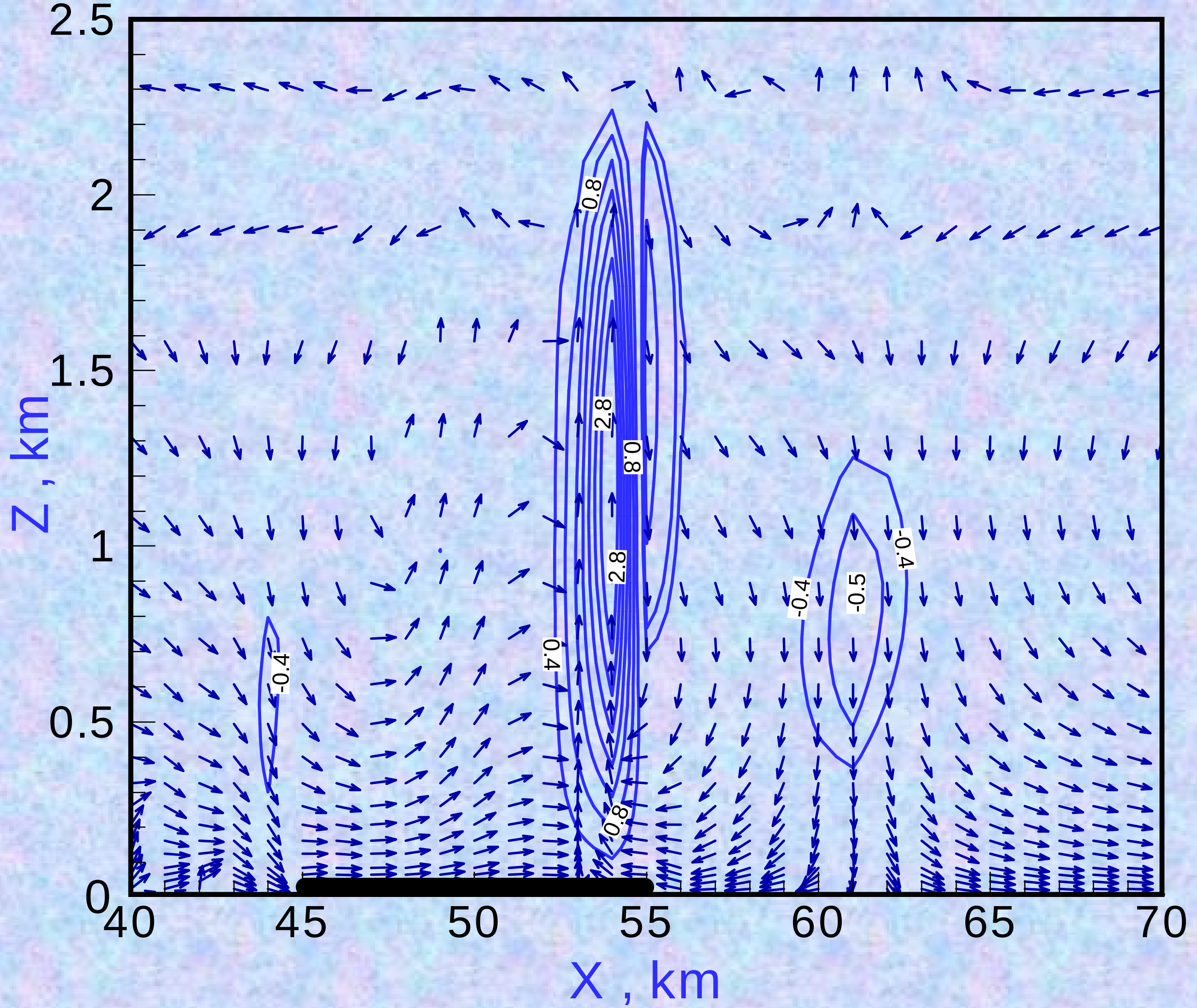
Impact on the dispersion of a passive tracer:

velocity vectors and isotachs for vertical velocity for 13:00 (second day)



Impact on the dispersion of a passive tracer:

velocity vectors and isotachs for vertical velocity for 13:00 (second day)



CONCLUSIONS

- Using the updated expressions for the pressure-strain and pressure-temperature correlations, we have derived an improved turbulence model to describe the Urban Boundary Layer.

- In simple 2D case are investigated the modifications in global structure of the ABL caused by the Urban Heat Island and the Urban Canopy Layer.

- The comparison between computed results and field observational data on various integrated turbulent characteristics reveals that the improved model can simulate the turbulent transport processes within and above the building canopy with satisfactory accuracy.