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Parameterization of near-source atmospheric diffusion in eulerian models: comparative analysis

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The Abdus Salam International Centre for Theoretical Physics
Arpa, FVG
Trieste, Italy

Parameterization of Near-Source Atmospheric Diffusion in Eulerian Models: Comparative Analysis

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УкрНДГМІ

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Outline

- Introduction
- Parameterizations of the vertical eddy diffusivity
- Numerical simulation
- Comparison of the results
- Conclusion

Introduction

● K-theory is used. We consider only diffusion of plume

● "Near-source area": up to 10 km (approximately) down along direction of regular transport

● Limitations of K-theory: $\Delta t >> T^L$, $l >> l_{max}$. In near-source area both are not satisfied

● The condition $\Delta t < T^L$ means that memory effects play important role in diffusion processes

● According to Taylor's theorem the eddy diffusivity has to grow with time (or with distance from the source in our case)

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Parameterizations of the vertical eddy diffusivity

- Arya, S.P. (1995) *Journal of Applied Meteorology* , 34, 1112–1122

$$K_z = \sigma_w^2 T_w^L \left(\frac{cx}{c\,l + x} \right) \qquad (1)$$

- Sharan, M. at al. (1996) *Atmospheric Environment*, 30, 1137-1145

$$K_z = \sigma_w^2 T_w^L \frac{x}{l} \qquad (2)$$

- Voloshchuk, V. at al. (2002) *Proceeding of UHMI*, 250, 7-18

$$K_z = \sigma_w^2 T_w^L \left(1 - e^{-\frac{x}{l}} \right) \qquad (3)$$

- Degrazia, G.A. at al. (2001) *Journal of Applied Meteorology* , 40 1233–1240

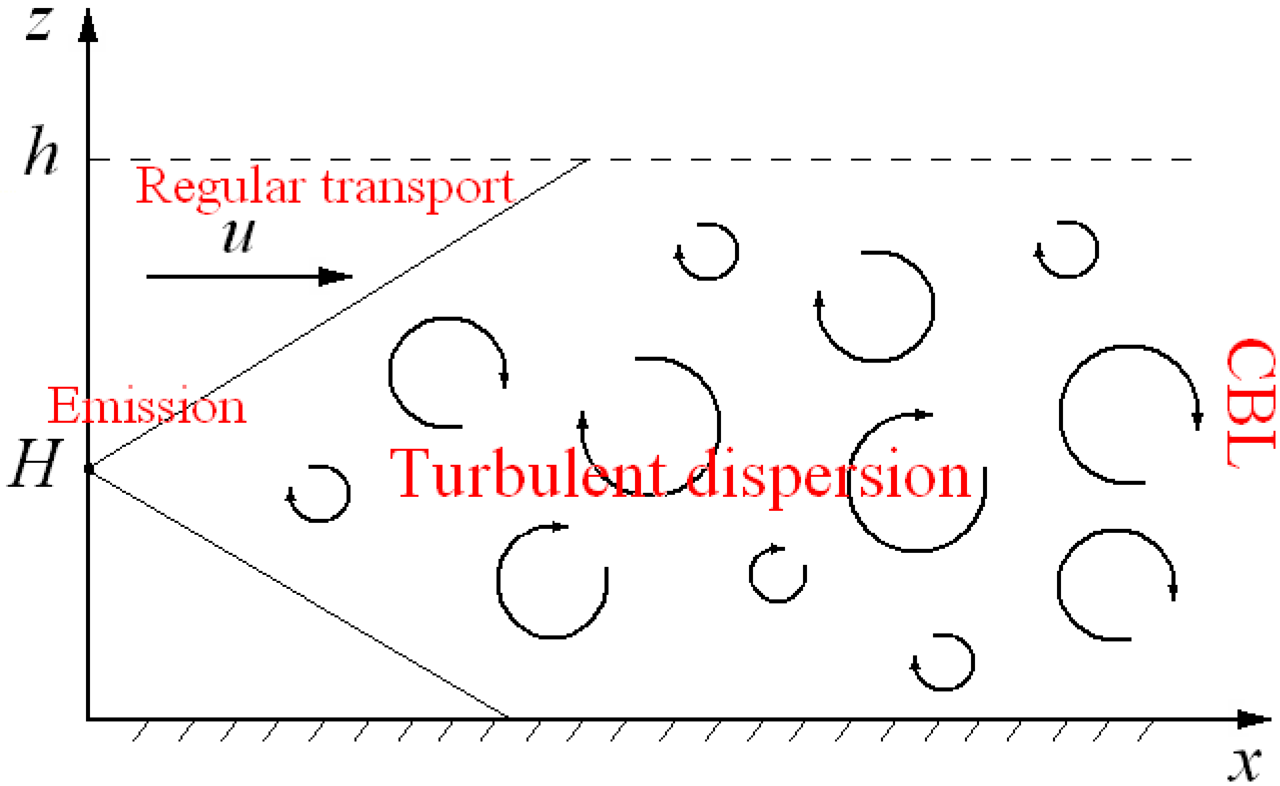
$$K_z = 0.12 w_* h \psi^{\frac{1}{3}} \left[1 - e^{-\frac{4z}{h}} - 0.0003 e^{\frac{8z}{h}} \right]^{\frac{4}{3}} \times$$

$$\int_0^{\infty} \frac{\sin\left(3.17 \left[1 - e^{-\frac{4z}{h}} - 0.0003 e^{\frac{8z}{h}} \right]^{-\frac{2}{3}} \psi^{\frac{1}{3}} X n \right)}{(1+n)^{\frac{5}{3}}} \frac{dn}{n} \qquad (4)$$

$$\psi^{\frac{1}{3}} = \left[\left(1 - \frac{z}{h} \right)^2 \left(\frac{z}{-L} \right)^{-\frac{2}{3}} + 0.75 \right]^{\frac{1}{2}}$$

The diffusion problem

- Physical formulation (scheme)



The diffusion problem

- Mathematical formulation

$$u\frac{\partial c}{\partial x}=\frac{\partial}{\partial z}K_z\frac{\partial c}{\partial z}$$

$$c=c(x,z) \qquad (x>0,\ 0<z<h) \qquad (5)$$

$$uc=Q\delta(z-H) \quad \text{at} \quad x=0$$

$$K_z\frac{\partial c}{\partial z}=0 \quad \text{at} \quad z=0,h$$

$$u=u(z) \qquad K_z=K_z(x,z)$$

- Parameterization of vertical profiles of turbulent parameters

$$u = \begin{cases} \frac{u_*}{\kappa}\left\{ \ln(z/z_0) - \psi_m(z/L) + \psi_m(z_0/L) \right\}, & z < z_b \\ u(z_b), & z \geq z_b \end{cases} \quad (6)$$

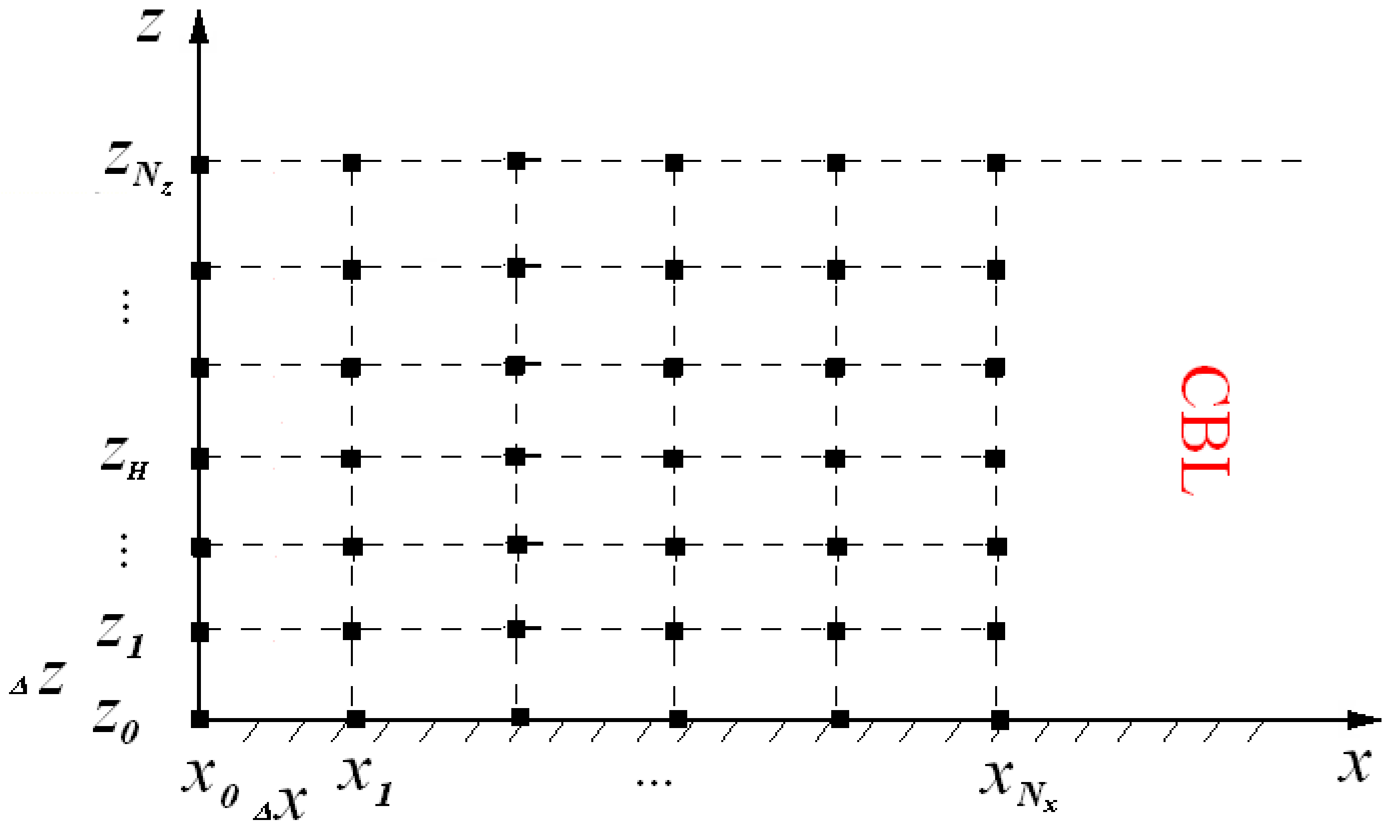
$$\sigma_w^2 = 1.44 w_*^2 \left\{ \left(\frac{z}{h}\right)^{\frac{2}{3}} \left(1 - 0.7\frac{z}{h}\right)^2 + \frac{10}{9}\frac{u_*^2}{w_*^2} \right\} \quad (7)$$

$$T_w^L = \begin{cases} 0.59\frac{z}{\sigma_w}, & \frac{z}{h} < 0.1 \\ 0.15\frac{h}{\sigma_w}\left\{ 1 - e^{-\frac{4z}{h}} - 0.0003 e^{\frac{8z}{h}} \right\}, & \frac{z}{h} > 0.1 \end{cases} \quad (8)$$

- Input variables for the diffusion problem (turbulent scales)

$$z_0, \quad L, \quad h, \quad u_*$$

Numerical solution of the diffusion problem



$N_z = 200$; $\Delta x = 0.1\ s$;

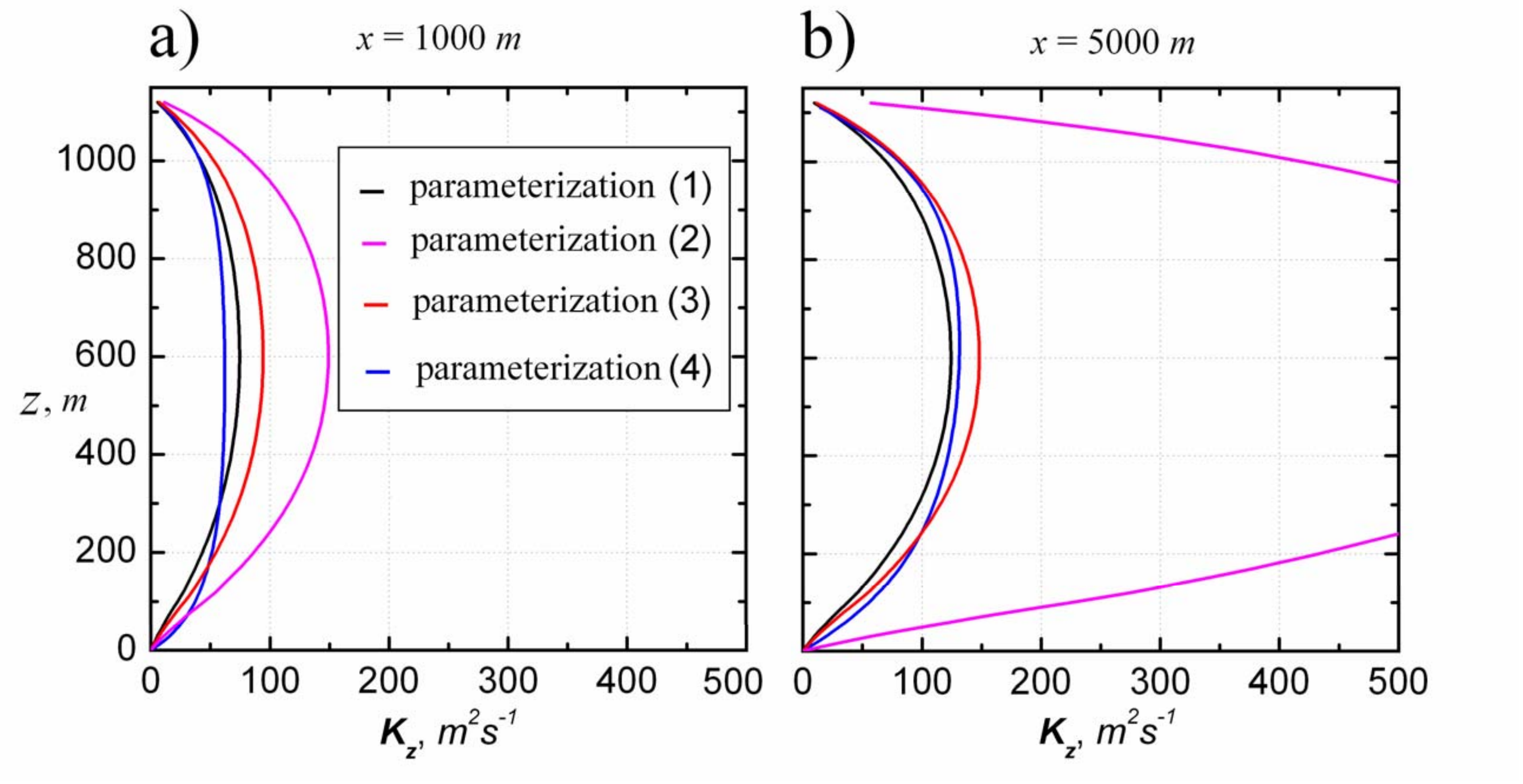
Comparative analysis of the results

- Some details of the Copenhagen diffusion experiment and numerical simulation

Number of experiment	Date	*L*, *m*	*h*, *m*	u_*, $m\ s^{-1}$	$u(115)$, $m\ s^{-1}$		$\sigma_w(115)$, $m\ s^{-1}$	
					measured	modeled	measured	modeled
1	20.09.78	-46	1980	0.37	3.4	3.9	0.83	0.91
2	26.09.78	-384	1920	0.74	10.6	8.6	1.07	1.21
3	19.10.78	-108	1120	0.39	5.0	4.1	0.68	0.77
4	03.11.78	-173	390	0.39	4.6	4.7	0.47	0.66
5	09.11.78	-577	820	0.46	6.7	5.6	0.71	0.70
6	30.04.79	-569	1300	1.07	13.2	12.8	1.33	1.65
7	27.06.79	-136	1850	0.65	7.6	6.9	0.87	1.26
Remark: $z_0 = 0.6\ m$					$r_u = 0.98$		$r_\sigma = 0.94$	

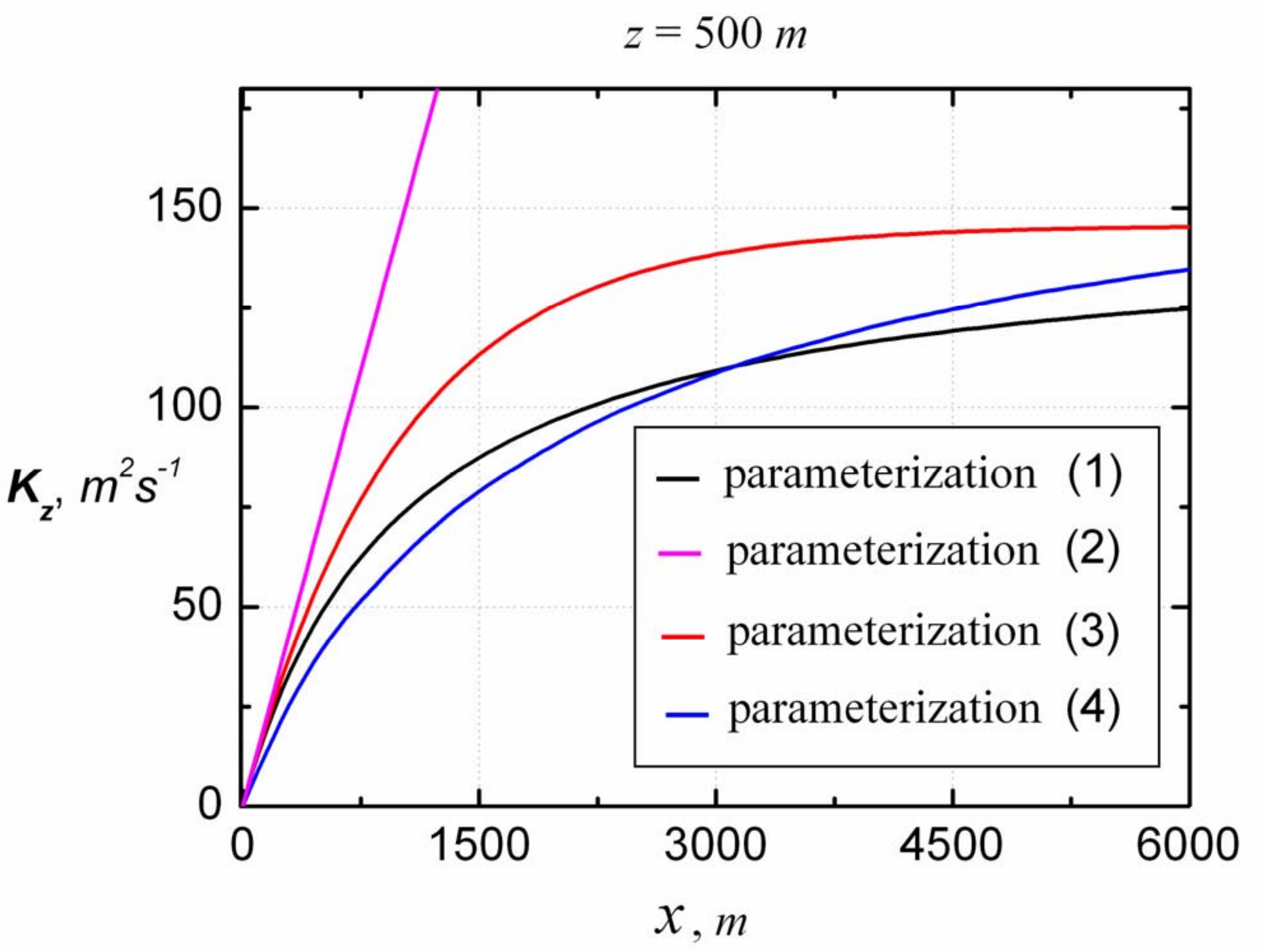
Comparison of vertical eddy diffusivities

- Vertical profiles (experiment 3)



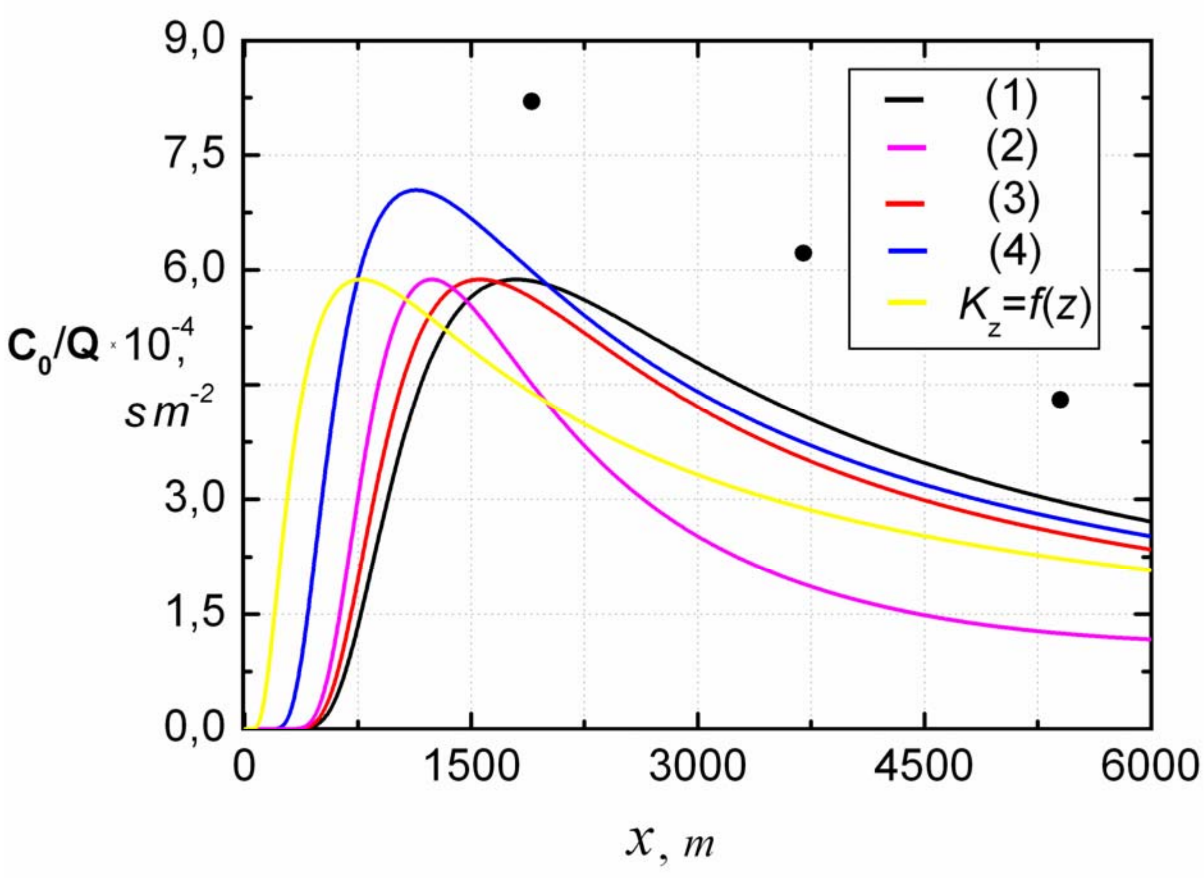
Comparison of vertical eddy diffusivities

- Horizontal profiles (experiment 3)



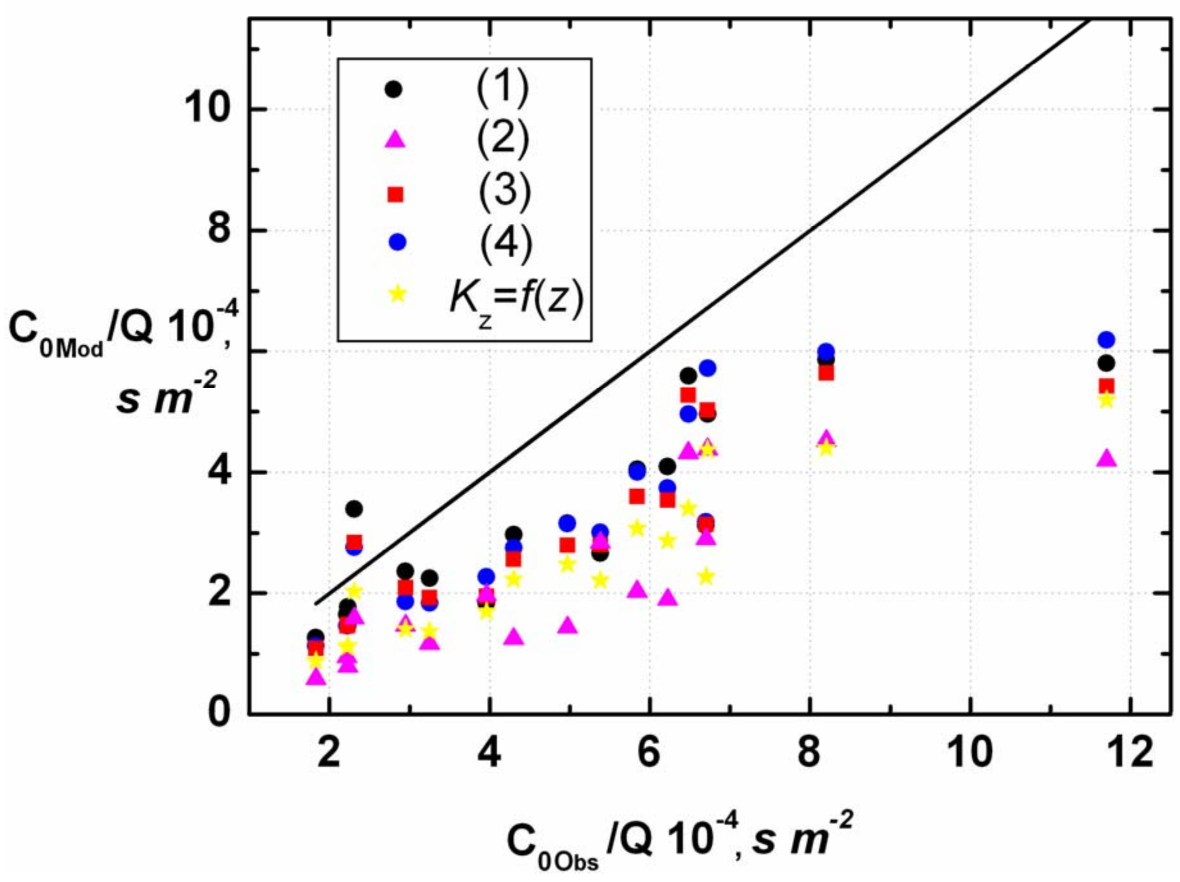
Comparison of concentrations

- Horizontal profiles of concentration at the ground (experiment 3)



Comparison of concentrations

- C – C plot between the observed and the modelled concentrations



- Observed and computed crosswind-integrated concentrations

N exper.	Parameters of numerical scheme			Distance from the source, *m*	$C_0/Q \times 10^{-4}$, *s m*$^{-2}$					
					Observed	Modeled				
	N_z	Δz, *m*	Δx, *m*			Par. (1)	Par. (2)	Par. (3)	Par. (4)	$K_z=f(z)$
1	200	9.8	0.1	1900	6.48	5.59	4.32	5.27	4.96	3.40
1	200	9.8	0.1	3700	2.31	3.39	1.59	2.84	2.76	2.03
2	200	9.5	0.1	2100	5.38	2.66	2.84	2.80	3.01	2.21
2	200	9.5	0.1	4200	2.95	2.36	1.47	2.09	1.86	1.41
3	200	5.6	0.1	1900	8.20	5.86	4.52	5.64	5.99	4.40
3	200	5.6	0.1	3700	6.22	4.09	1.90	3.54	3.74	2.87
3	200	5.6	0.1	5400	4.30	2.97	1.25	2.56	2.75	2.23
4	200	1.9	0.1	4000	11.70	5.80	4.20	5.42	6.19	5.19
5	200	4.1	0.1	2100	6.72	4.96	4.38	5.02	5.72	4.37
5	200	4.1	0.1	4200	5.84	4.05	2.03	3.60	4.00	3.07
5	200	4.1	0.1	6100	4.97	3.16	1.44	2.79	3.15	2.48
6	200	6.5	0.1	2000	3.96	1.84	1.97	1.95	2.27	1.70
6	200	6.5	0.1	4200	2.22	1.65	0.95	1.46	1.46	1.11
6	200	6.5	0.1	5900	1.83	1.27	0.59	1.09	1.13	0.88
7	200	9.2	0.1	2000	6.70	3.12	2.90	3.14	3.18	2.27
7	200	9.2	0.1	4100	3.25	2.25	1.17	1.93	1.84	1.37
$NMSE = \langle (C_{Obs}-C_{Mod})^2 \rangle / (\langle C_{obs} \rangle \langle C_{Mod} \rangle)$						**0.30**	**0.90**	**0.37**	**0.29**	**0.69**

Conclusion

● The memory effects in near-source area are very important

● The best parameterization is (4) (Degrazia, 2000): *NMSE* = 0.29. Complex!

● Simpler parameterizations (1) (Arya, 1995) and (3) (Voloshchuk, 2002) work well: *NMSE* = 0.30 and 0.37

● The additional factors (*) and (**) for K_z can easily be used to take memory effects into account

$$\left(\frac{cx}{cl+x}\right) \quad (*) \qquad\qquad \left(1-e^{-\frac{x}{l}}\right) \quad (**)$$