SIMULATION AND COMPARISON OF MEAN FLOW, TURBULENCE AND DISPERSION IN COMPLEX TERRAIN

S.Alessandrini[1], E.Ferrero[2,3], S. Trini Castelli[3], D.Anfossi[3]

[1]CESI, Milano, Italy
[2]Dipartimento di Scienze e Tecnologie Avanzate,Universita' del Piemonte Orientale, Alessandria, Italy
[3]ISAC-CNR, Torino, Italy

INDEX

- Description of the modelling system
- Closure schemes
- “TRACT” experiment for the models comparison
- Comparison between computed and measured data
- Analysis of the different closure schemes performances
- Conclusion and future development

INTRODUCTION

- The integrated modelling system **RMS** (RAMS-MIRS-SPRAY) is used to simulate a tracer experiment carried out during the TRACT campaign (**TRA**sport of air Pollutants over **C**omplex **T**errain)
- RMS is based on a combination of: the meteorological model **RAMS** (Regional Atmospheric Modelling System), the interface code MIRS, the Lagrangian particle model SPRAY
- The influence of different closure schemes on turbulence fields and on dispersion is analysed

MODELLIG SYSTEM:RAMS-MIRS-SPRAY

Atmospheric circulation model: **RAMS**

- -WIND FIELD
- -T.K.E.
- -TEMPERATURE
- -TOPOGRAPHY
- -SURFACE FLUXES
- -DIFFUSION COEFFICIENT

Boundary layer parameterisation interfacing code: **MIRS**

- -PBL HEIGHT/S.L. PARAMETERS
- -STANDARD DEVIATIONS
- -SKEWNESS / KURTOSIS
- -LAGRANGIAN TIME SCALES

Lagrangian particle dispersion model: **SPRAY**

- -PARTICLE TRAJECTORY
- -CONCENTRATION

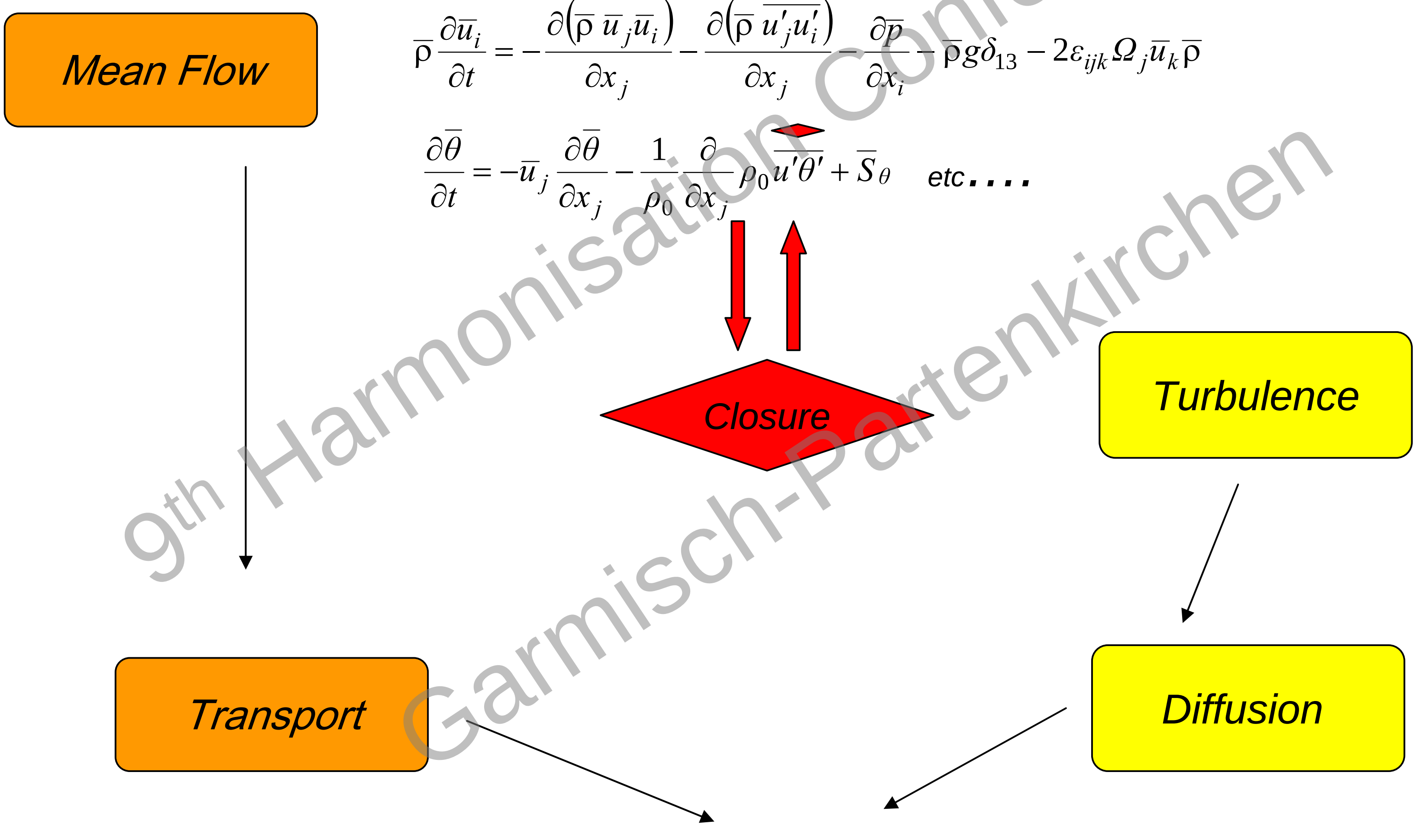
MODELLIG SYSTEM:RAMS-MIRS-SPRAY

METEOROLOGICAL MODEL

$$\bar{\rho}\frac{\partial \bar{u}_i}{\partial t} = -\frac{\partial\left(\bar{\rho}\,\bar{u}_j\bar{u}_i\right)}{\partial x_j} - \frac{\partial\left(\bar{\rho}\,\overline{u'_j u'_i}\right)}{\partial x_j} - \frac{\partial \bar{p}}{\partial x_i} - \bar{\rho} g \delta_{13} - 2\varepsilon_{ijk}\Omega_j \bar{u}_k \bar{\rho}$$

$$\frac{\partial \bar{\theta}}{\partial t} = -\bar{u}_j\frac{\partial \bar{\theta}}{\partial x_j} - \frac{1}{\rho_0}\frac{\partial}{\partial x_j}\rho_0\overline{u'\theta'} + \bar{S}_\theta$$

etc....



DISPERSION MODEL

CLOSURE SCHEMES: MELLOR and YAMADA

In RAMS

$$\frac{dE}{dt} = \frac{\partial}{\partial z} K_E \frac{\partial E}{\partial z} + P - \varepsilon$$

Level 2.5: B.L approximation, horizontal homogeneity

$$P = K_m \left[\left(\frac{\partial \overline{u}}{\partial z} \right)^2 + \left(\frac{\partial \overline{v}}{\partial z} \right)^2 \right] - \frac{g}{\theta_0} K_h \frac{\partial \overline{\theta}}{\partial z} \qquad \varepsilon = \frac{(2E)^{3/2}}{\Lambda_1}$$

$$K_m = S_m l (2E)^{1/2} \qquad K_h = S_h l (2E)^{1/2} \qquad K_E = S_E l (2E)^{1/2}$$

$$(l_1, \Lambda_1, l_2, \Lambda_2) = l(A_1, B_1, A_2, B_2) \qquad l = \frac{kz}{1 + kz/l_\infty} \qquad l_\infty = 0.1 \frac{\int z\sqrt{E}dz}{\int \sqrt{E}dz}$$

$$S_m, S_h, S_E = f\left(\frac{\partial u}{\partial z}, \frac{\partial u}{\partial z}, \frac{\partial \theta}{\partial z}, E, l, A_1, A_2, B_1, B_2, C \right)$$

(A_1, A_2, B_1, B_2, C)=(0.92, 16.6, 0.74, 10.1, 0.08)

From MIRS to SPRAY

$$\sigma_u^2 = (1 - 2\gamma) q^2 \qquad \sigma_v^2 = \gamma q^2 \qquad \sigma_w^2 = \gamma q^2 \qquad T_{Li} = \frac{K_m}{\sigma_i^2} \qquad q^2 = 2E$$

$$\overline{w^3} = -0.6 \frac{w^{*3}}{k} \frac{z}{L} + 0.1 \sigma_w^3$$

From Chiba (1978)

$$\gamma \equiv \frac{1}{3} - 2 \frac{A_1}{B_1}$$

CLOSURE SCHEMES: E-l isotropic

In RAMS

$$\frac{dE}{dt} = \frac{\partial}{\partial x_j} K_E \frac{\partial E}{\partial x_j} + P - \varepsilon$$

$$P = -\overline{u'_i u'_j} \frac{\partial \overline{u}_i}{\partial x_j} + \delta_{i,3} g \alpha \overline{u'_i \theta'} \qquad \varepsilon = \frac{c_\varepsilon E^{3/2}}{l}$$

$$\overline{u'_i u'_j} = -K_m \left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i} \right) + \frac{2}{3} E \delta_{ij} \qquad \overline{u'_i \theta'} = -K_h \frac{\partial \overline{\theta}}{\partial x_i}$$

(K-theory)

$$l = \frac{k\mathrm{z}}{1 + {k\mathrm{z}}/{l_\infty}} \qquad l_\infty = 0.1 \frac{\int \mathrm{z}\sqrt{\mathrm{E}}\mathrm{dz}}{\int \sqrt{\mathrm{E}}\mathrm{dz}}$$

$$K_m = c_\mu E^{1/2} l \qquad K_h = \alpha_h K_m \qquad K_E = \alpha_E K_m$$

From MIRS to SPRAY

$$\sigma_{u_i}^2 = -2K_m \frac{\partial \overline{u_i}}{\partial x_i} + \frac{2}{3} E \qquad T_{Lu_i} = \frac{K_m}{\sigma_{u_i}^2}$$

$$\overline{w^3} = -0.6 \frac{w^{*3}}{k} \frac{z}{L} + 0.1 \sigma_w^3$$

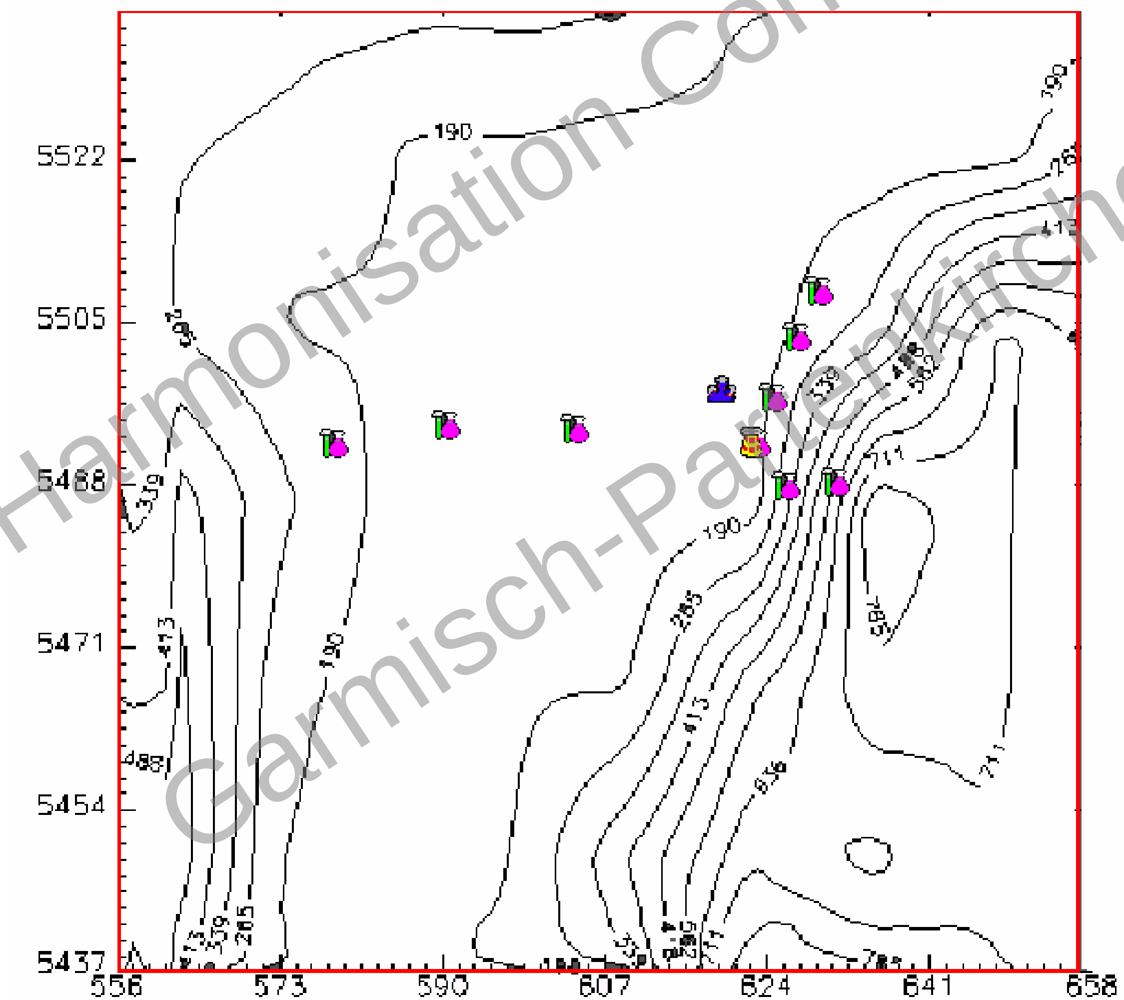
From Chiba (1978)

TRACT EXPERIMENT

- Experiment performed during 7-23 September 1992
- Investigation area was about 300 x 300 km^2
- The tracer was released at a height of 8 m in Sasbach in the Rhine Valley for a period of about 3 hours (from 5:02 until 7:58 of 16 September)
- Ground network: 20 stations collected 224 g.l.c samples of 30 min
- Meteorological measures with a sodar station located near the source
- 16 September was a sunny day with 25 C° in the valley and westerly winds

TRACT EXPERIMENT

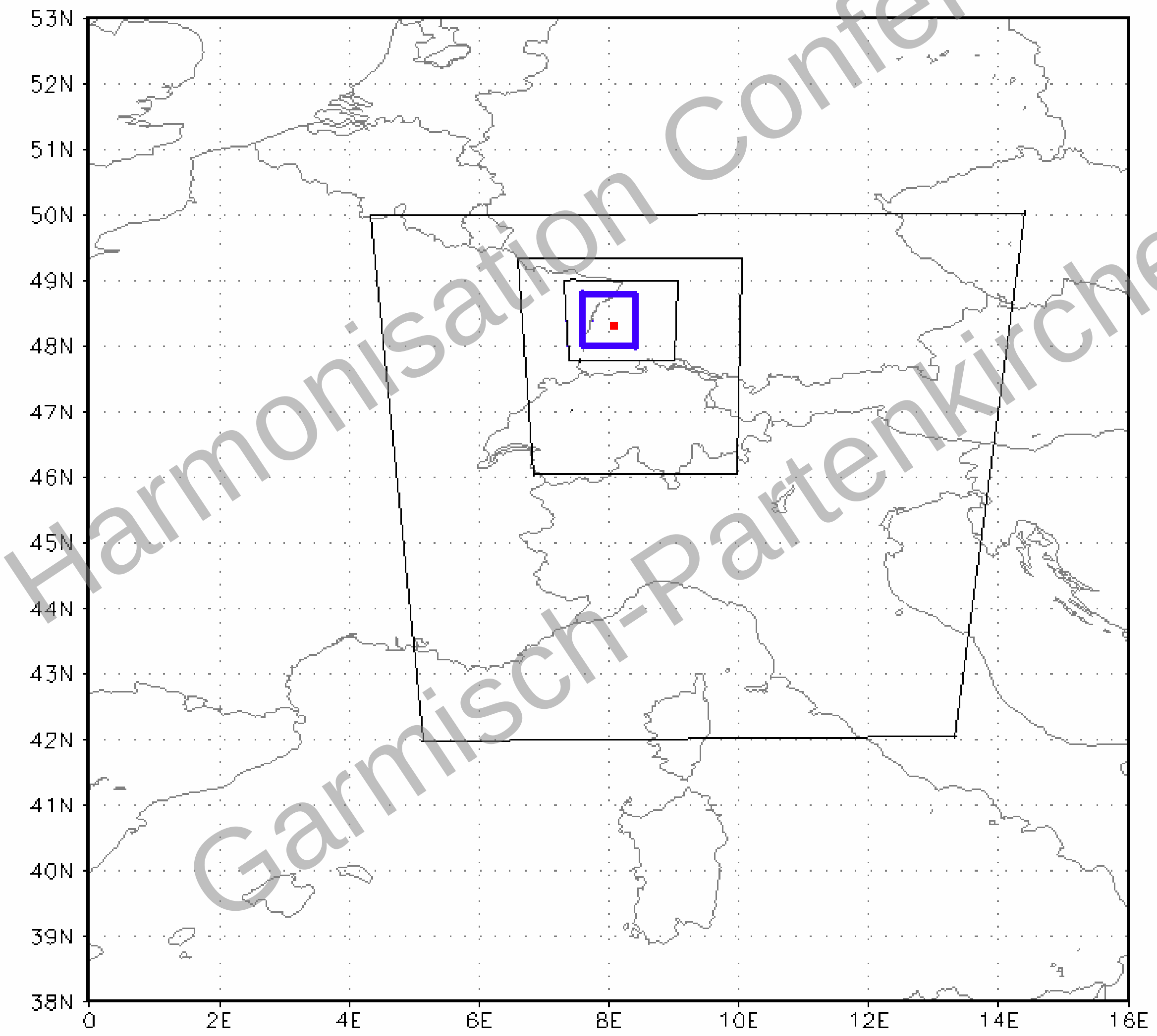
⌘ Topography, samplers, sodar and source



RAMS CONFIGURATION

- 4 nested grids with $\Delta x = \Delta y$=60, 15, 5, 1.6 km , Δz=50-500 m
- Horizontal Grid extensions 13x17, 18x18, 29x29, 62x62 points
- Stretched vertical grid extensions: 30 points up to 10000 m
- Time step Δt =60, 20, 6.6, 2.2 sec
- Numerical scheme: Leapfrog time differencing
- Simulation period 48 hours from 15 September 00 UTC until 17 September 00 UTC
- Initialisation from ECMWF analysis fields
- Nudging from ECMWF analysis fields every 6 hours

RAMS MIRS configuration : 4 grids locations



RAMS-MIRS simulations descriptions

- 4 simulations with different turbulence schemes:

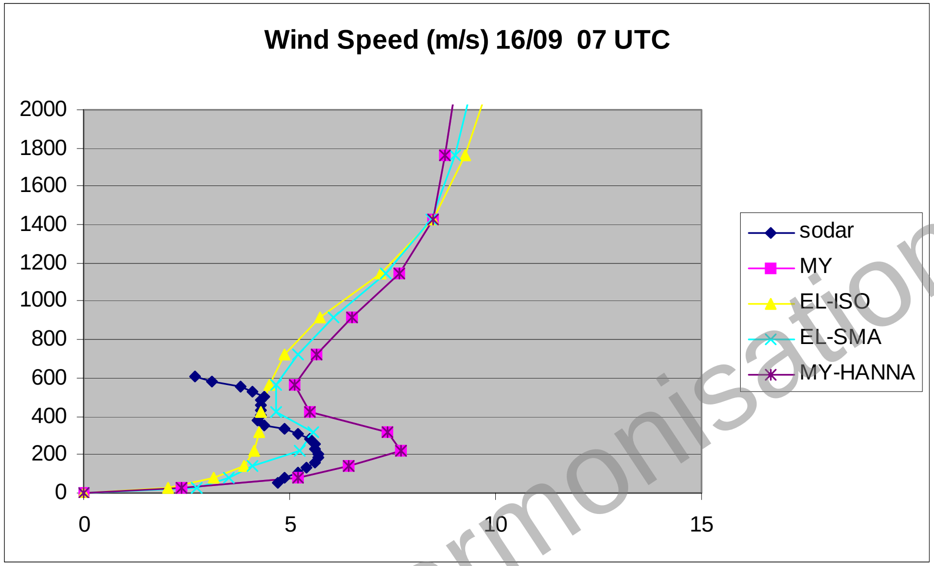
    -Mellor and Yamada (MY)

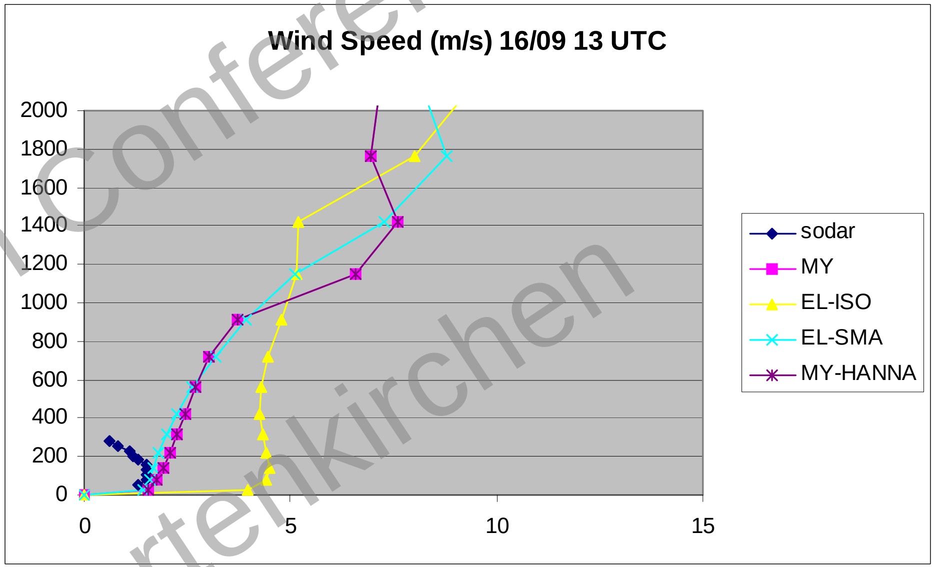
    -E-l isotropic (EL-ISO)

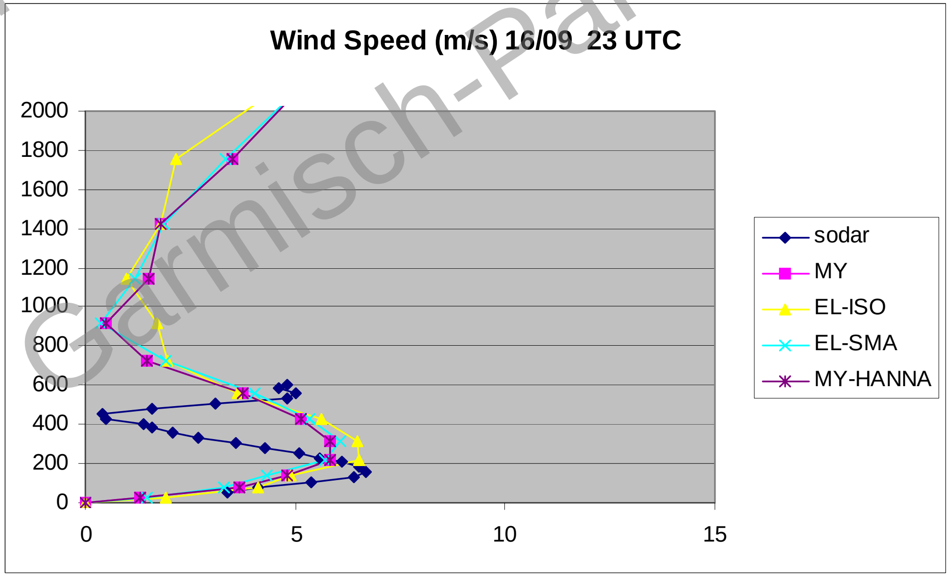
    -E-l for vertical direction and Smagorisky-type deformational scheme in horizontal (EL-SMA)

    -Mellor and Yamada closure model with the Hanna (1982) parameterisation for wind velocity fluctuation standard deviations and Lagrangian Time (MY-HANNA)

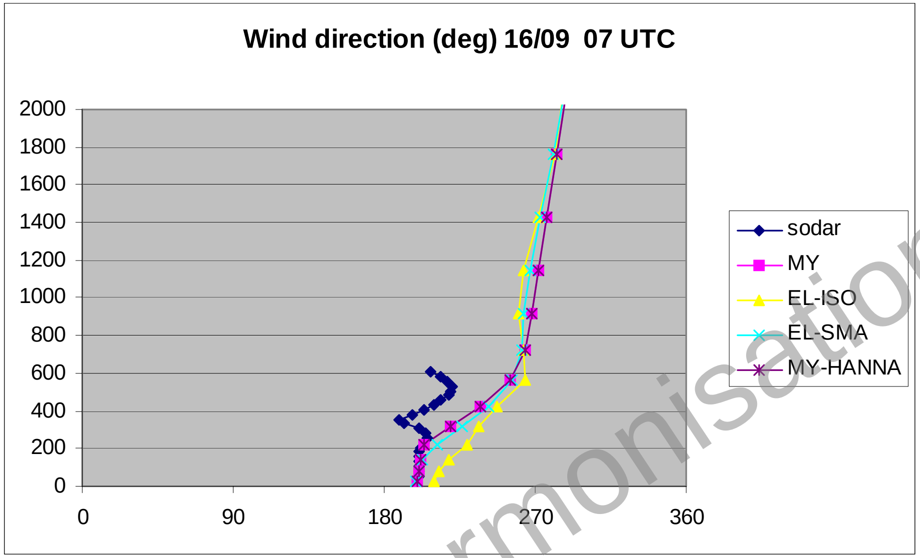
RAMS-MIRS comparison between different schemes and sodar data

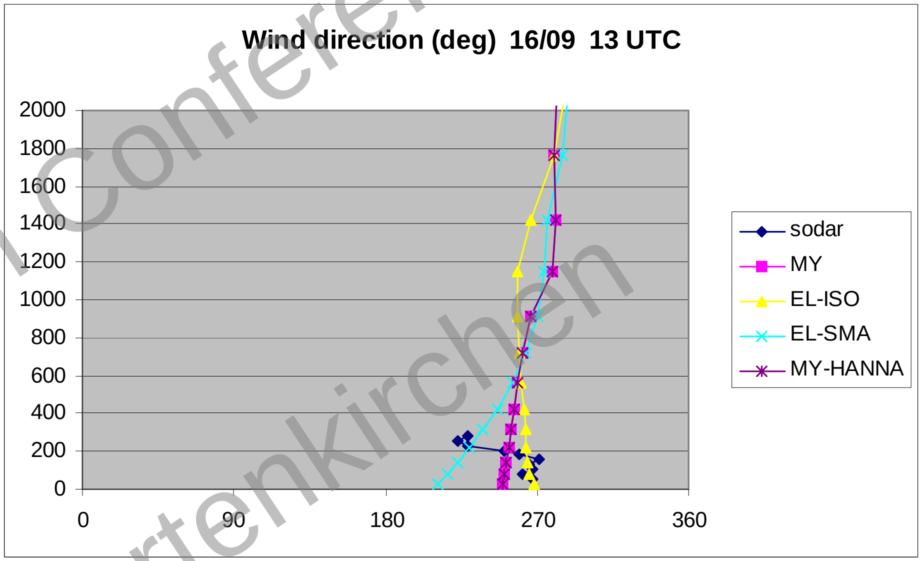


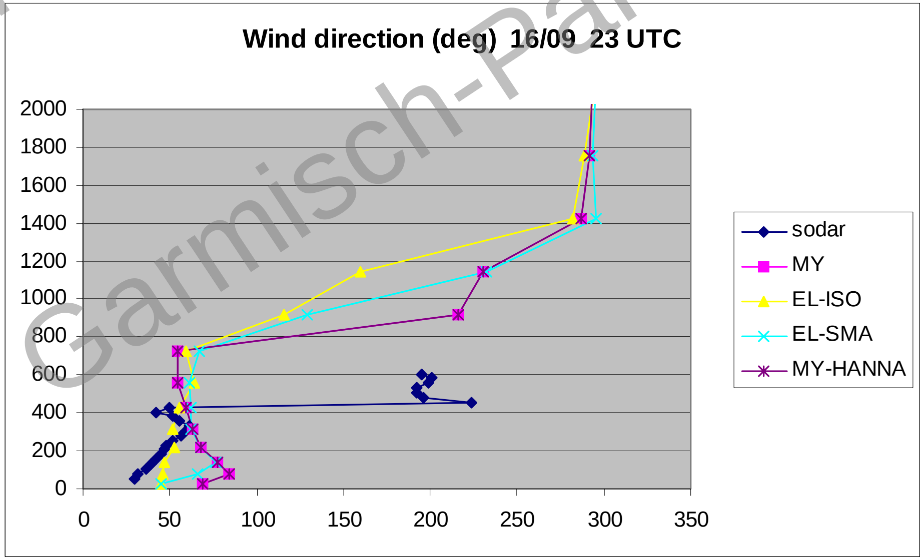




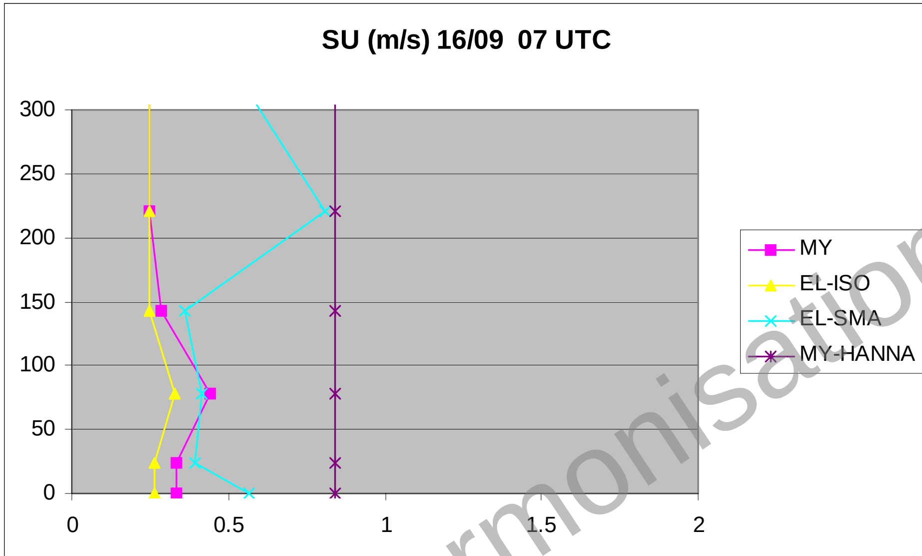
RAMS-MIRS comparison between different schemes and sodar data

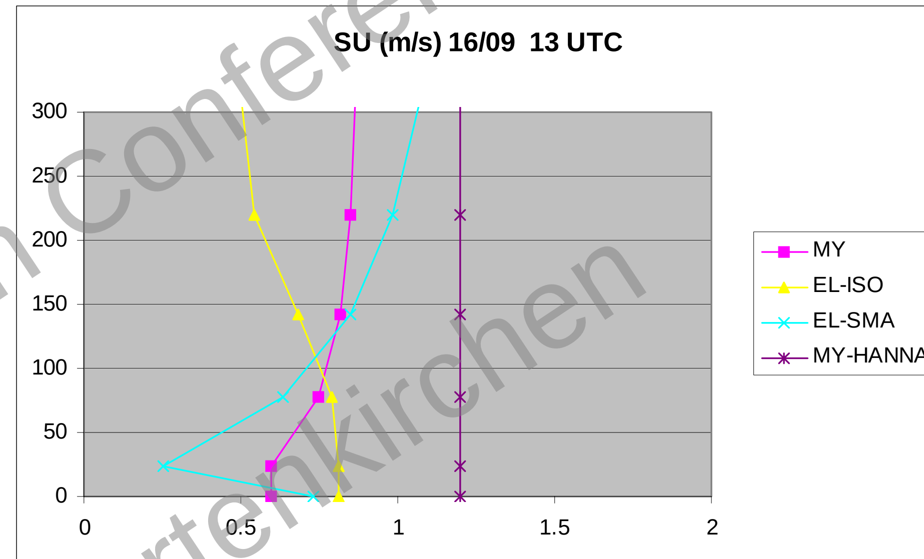


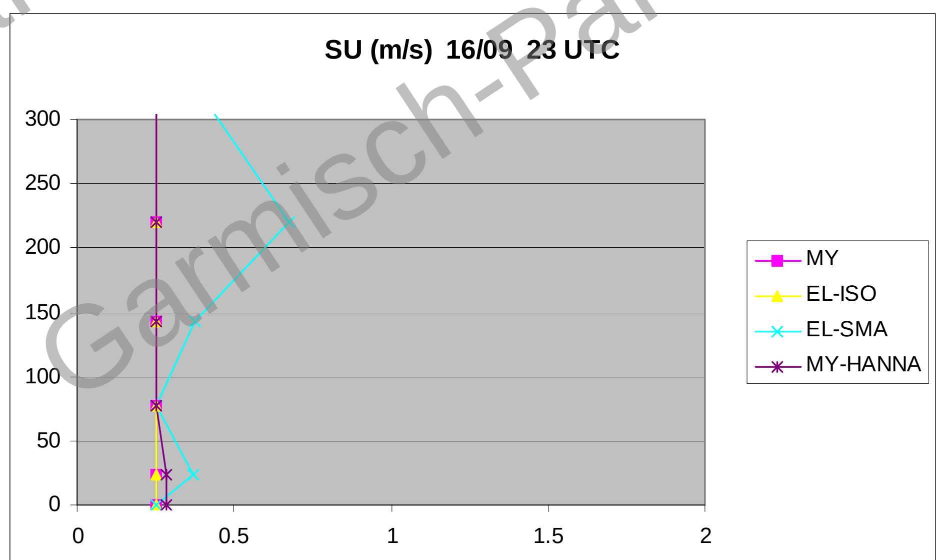




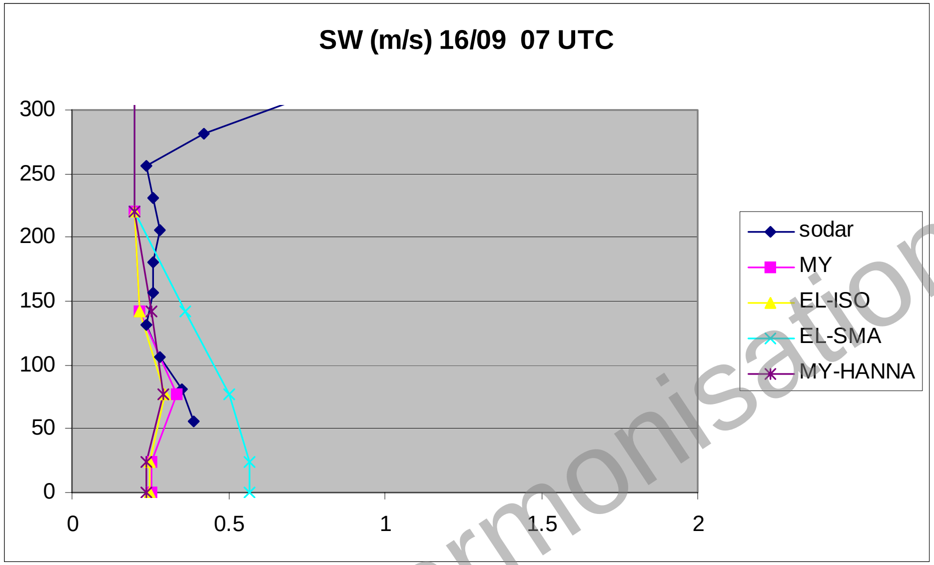
RAMS-MIRS comparison between different schemes and sodar data

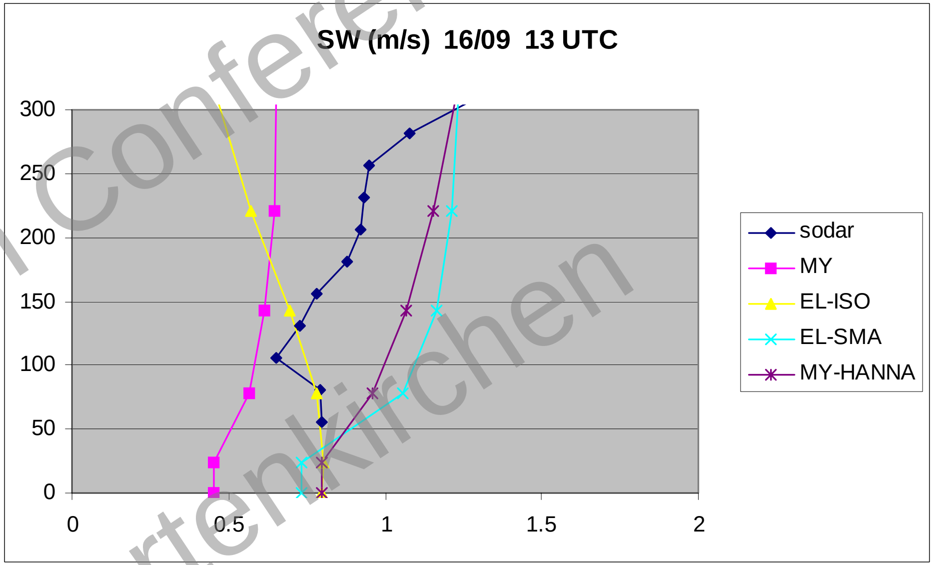


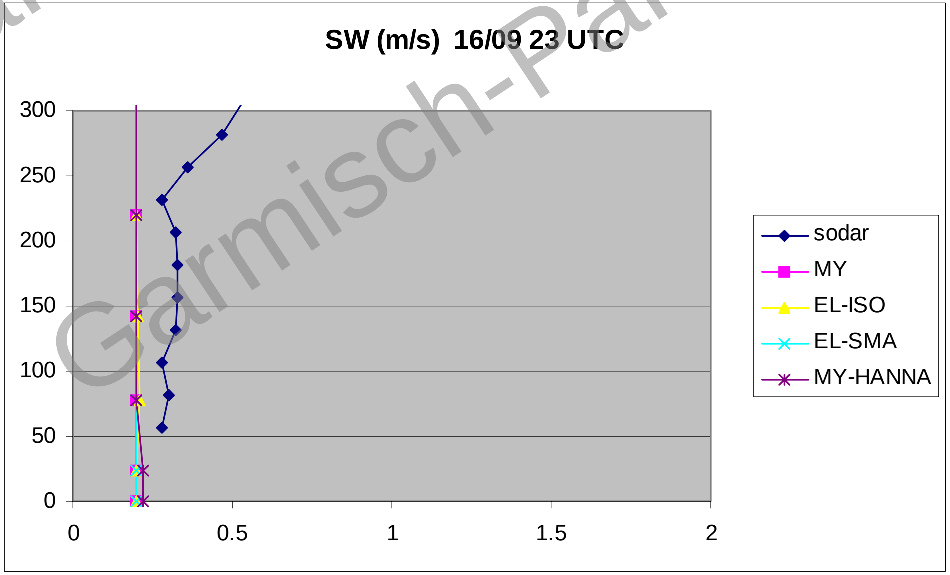




RAMS-MIRS comparison between different schemes and sodar data







SPRAY description

SPRAY

(Tinarelli et al., 2000, Ferrero and Anfossi, 1998) is a Lagrangian stochastic particle model for complex terrain based on three Langevin equations for the random velocities (Thomson, 1987):

$$du = a(\mathrm{x},\mathrm{u})dt + b(\mathrm{x},\mathrm{u})dW(t)$$

and

$$d\mathrm{x} = (\mathrm{U} + \mathrm{u})dt \text{ ,}$$

where,

U is the mean wind velocity,

$a(\mathrm{x},\mathrm{u})dt$

is a deterministic term depending on P_E(x,u),

$b(\mathrm{x},\mathrm{u})dW(t)$

is a stochastic term

$dW(t)$

is the incremental Wiener process.

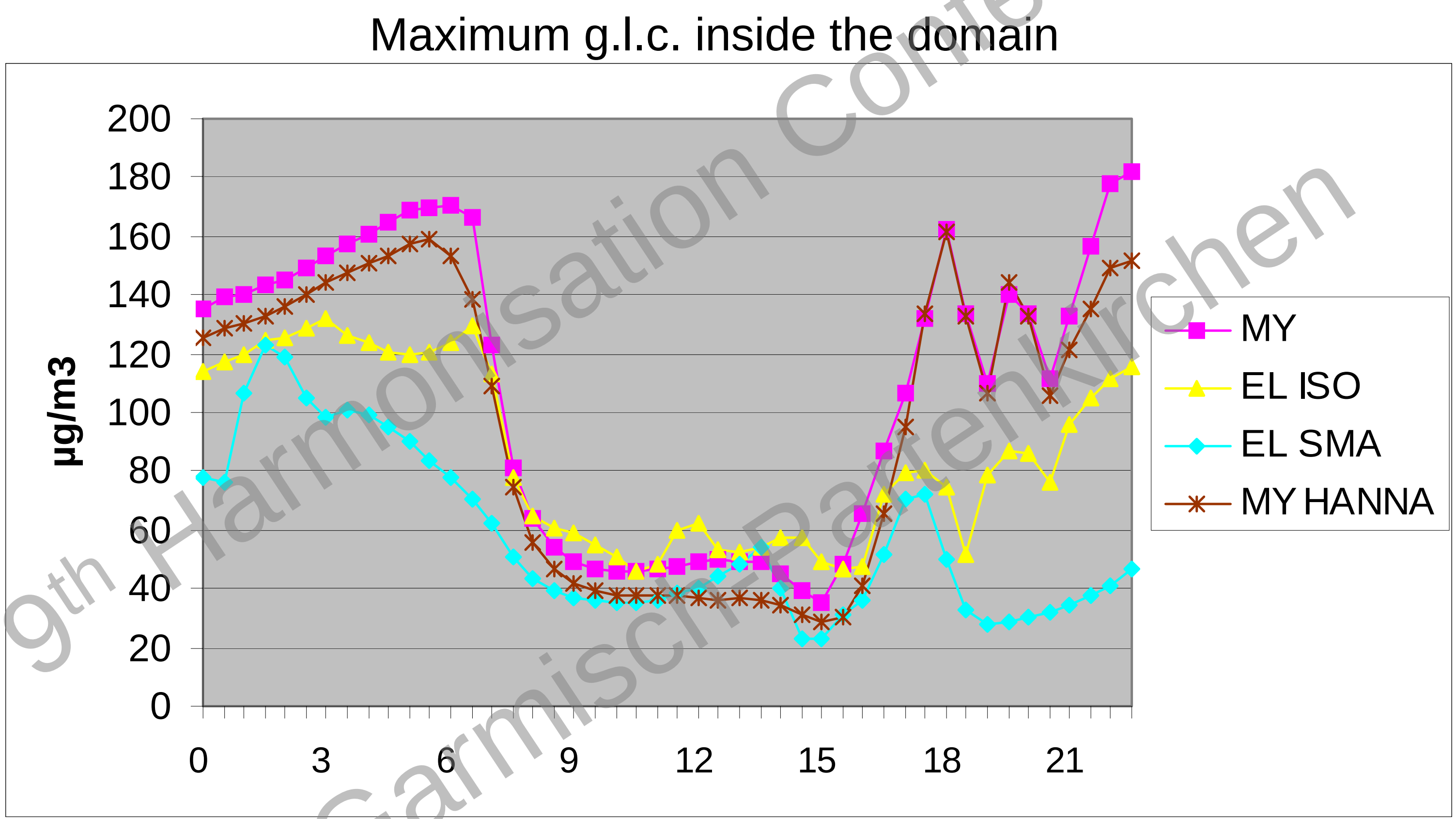
In the horizontal directions the PDF is assumed to be Gaussian. In the vertical direction the PDF is assumed to be non-Gaussian (to deal with non-uniform turbulent conditions and/or convection).

SPRAY configuration

- Domain extension (4th RAMS-MIRS grid): horizontal 62x62 points $\Delta x = \Delta y = 1.6$ Km, vertical 30 points between 0 m and 10000 m
- 100 particles released every 5 sec
- Ground level concentrations computed every 30 min. with cells of 500 x 500 x 50 m^3
- 2 simulations for every turbulence scheme (8 simulations): one with a constant emission period 24 hours long, one with the same emission period of the experiment

Ground level concentrations:different schemes comparisons

16 September: constant emission period of 24 hours

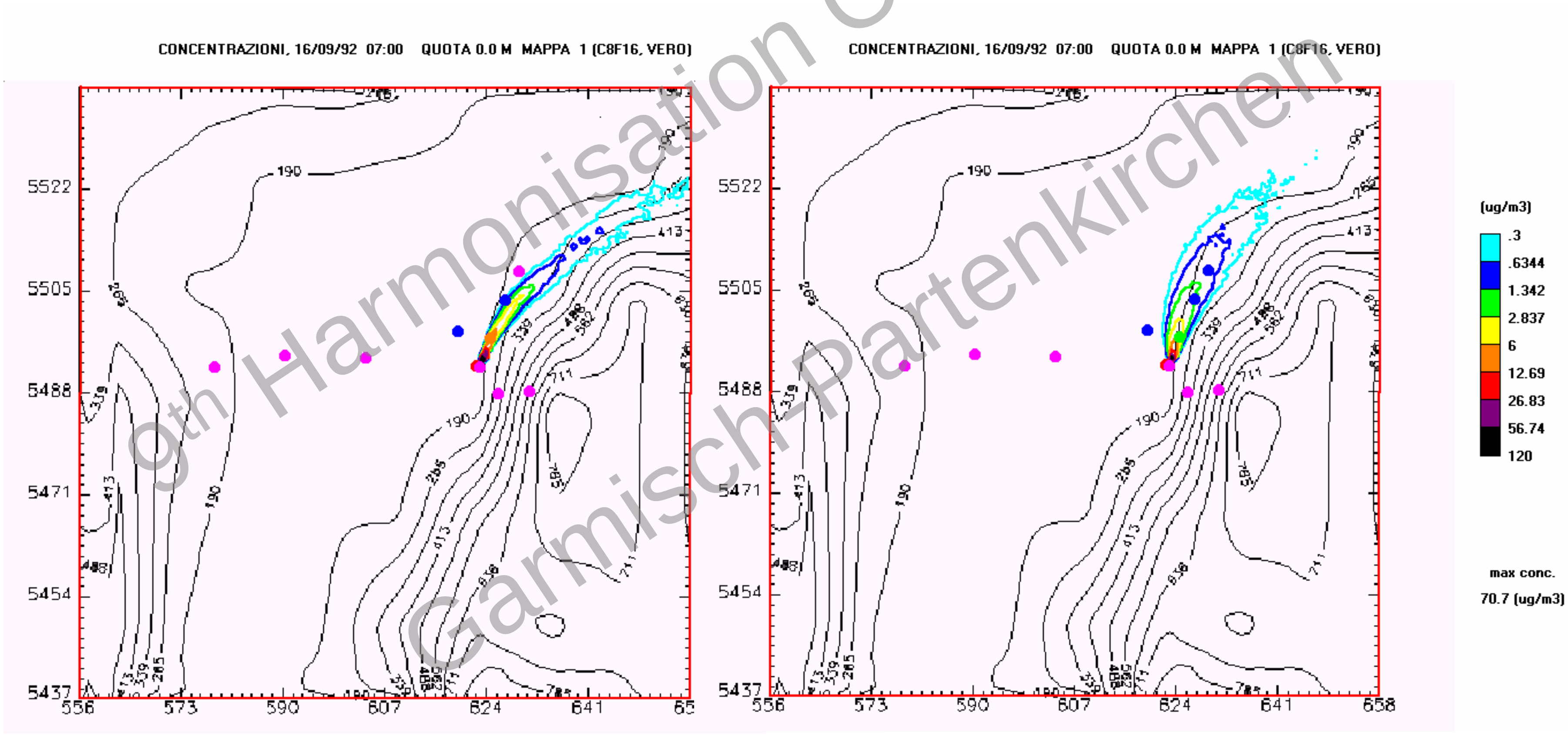


Ground level concentrations:different schemes comparisons

16 September 7 UTC: constant emission period of 24 hours

EL-ISO

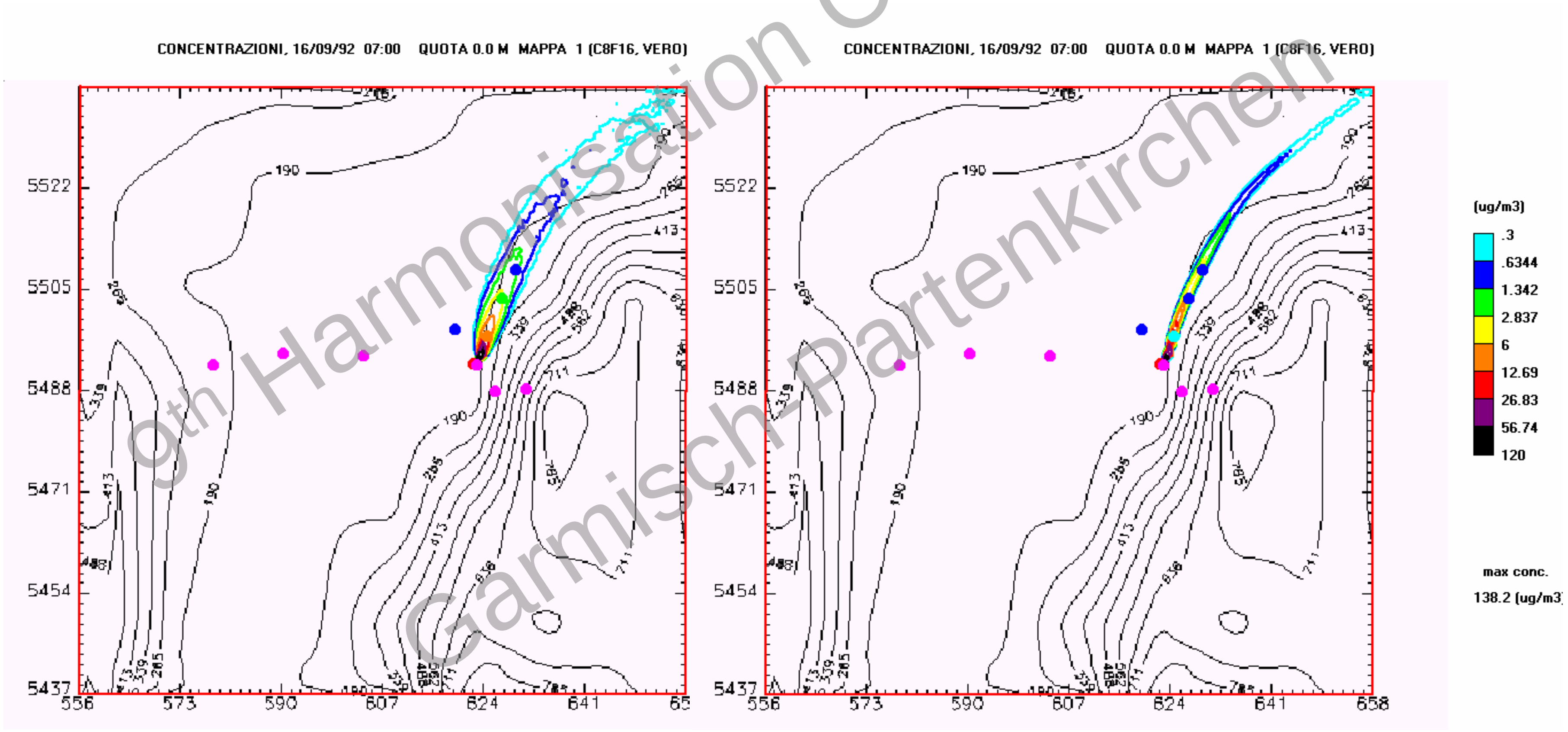
EL-SMA



Ground level concentrations:different schemes comparisons

16 September 7 UTC: constant emission period of 24 hours

MY   MY-Hanna

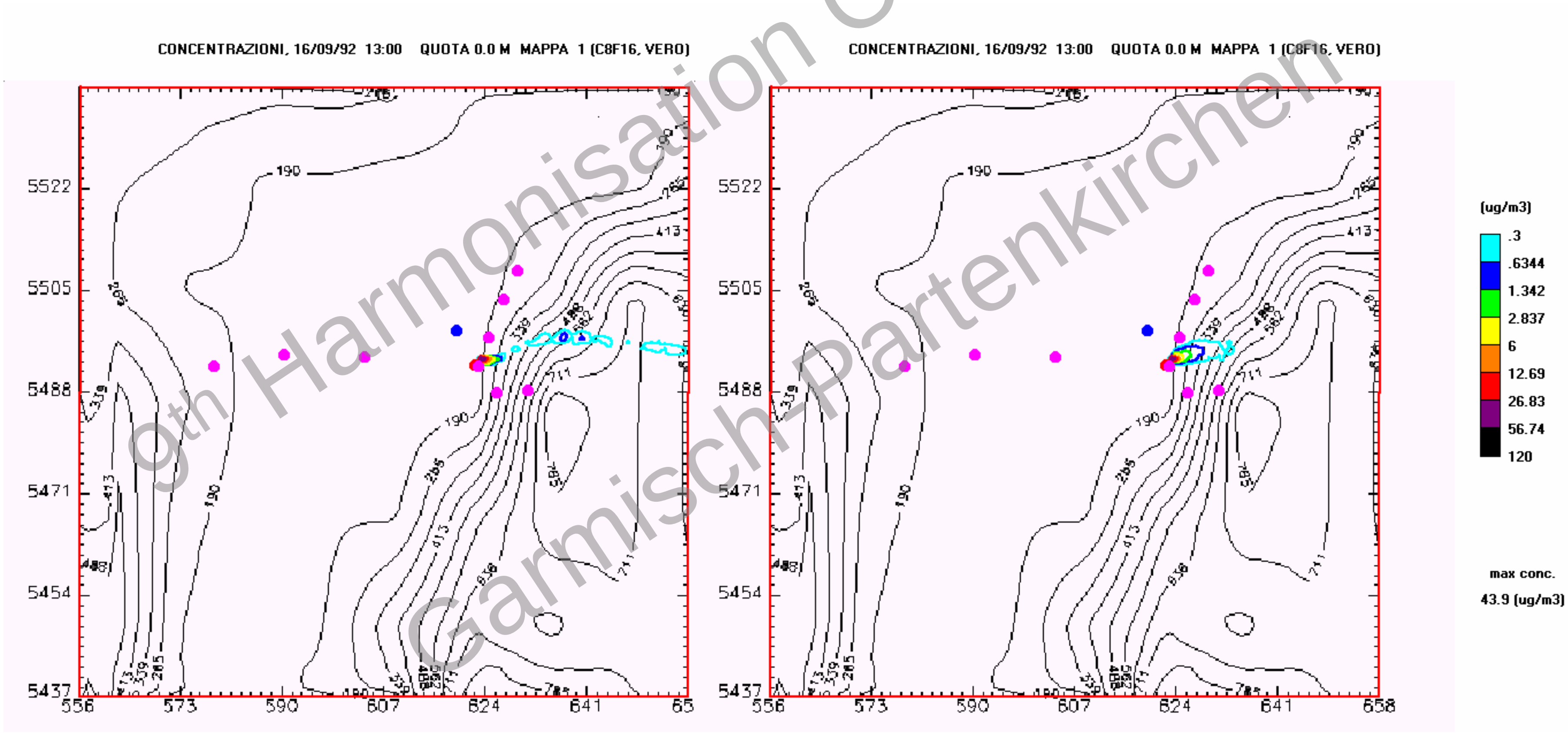


Ground level concentrations:different schemes comparisons

16 September 13 UTC: constant emission period of 24 hours

EL-ISO

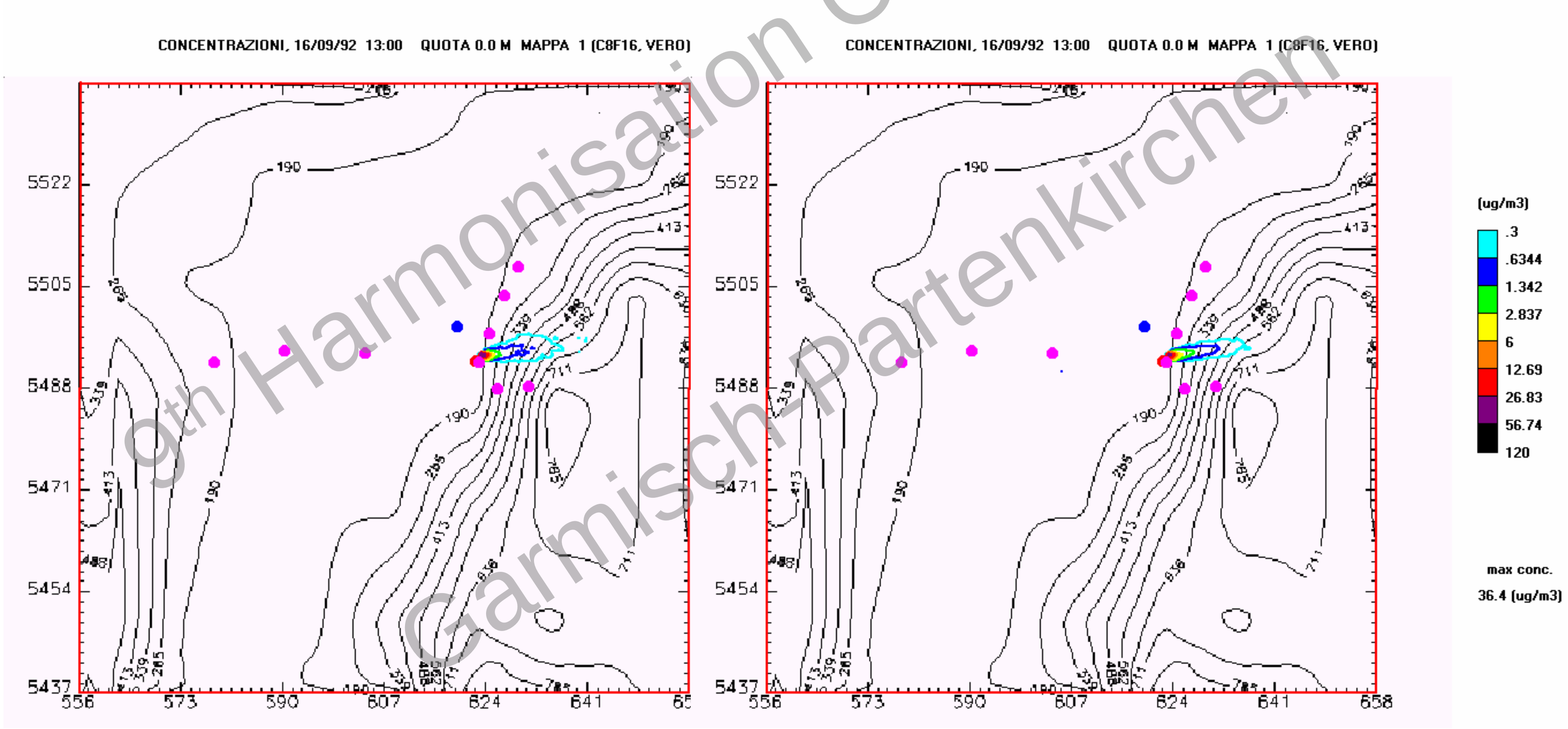
EL-SMA



Ground level concentrations:different schemes comparisons

16 September 13 UTC: constant emission period of 24 hours

MY | MY-Hanna



Ground level concentrations:comparison with measured data

- A better performance is obtained with the E-l model, both in the isotropic and non isotropic cases
- the analysis has been performed on 7 available measurements

Model	Mean	sigma	bias	nmse	cor	fa2	fb	fs
Observed	0.6	1.1	0.0	0.0	1.0	1.0	0.0	0.0
E-l SMA	0.8	0.7	-0.2	2.0	0.4	0.1	-0.3	0.5
E-l ISO	1.2	1.7	-0.6	2.9	0.6	0.3	-0.6	-0.4
M&Y Hanna	0.5	0.5	0.2	5.2	-0.03	0.1	0.4	0.7
M&Y	1.6	1.7	-1.0	4.1	0.2	0.0	-0.9	-0.5

CONCLUDING REMARKS

- The choice of the turbulence scheme influences both the mean field and dispersion parameters
- In unstable conditions all the models predict comparable maximum g.l.c values and the horizontal plume dispersion
- In stable conditions there are significant differences in maximum g.l.c. computed and in the horizontal plume dispersion
- The E-l schemes show slightly better performance in forecasting measured g.l.c.