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Prairie grass experiment

10.2.e , 2017-03-23

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1 Abstract

This report presents test runs for the prairie grass experiment, where measurements were taken in the plume of a low emission source. Calibration factors, used in the parameterisation of K_z and in for representative heights at which to compute wind speed and K_z, are identified in section 3. In section 4, the vertical dispersion length is plotted for the prairie grass experiments and problems for very stable situations are discussed.
In section 5, test results of runs for the prairie grass experiment are presented. We concluded in section 5.3 that in unstable, neutral and stable conditions, the K_z-model is able to represent observed crosswind integrated concentrations, but the performance for very stable situations ($1/L > 0.075$ m^{-1}) is unsatisfactory.
In section 5.6, we used an optimisation algorithm of MATLAB to find an optimal set of calibration parameters for the Gaussian plume model, by minimising the Gaussian model error (difference between Gaussian model and measurements), see Table 4; very stable situations were excluded from the optimisation procedure.
In sections 5.7 and 5.8, we investigated the effect of using a receptor height of 10 m, instead of the standard height of 1.5 m.

2 Introduction

Quoted from Olesen et al. (2007):
"The Prairie Grass experiment is a classic experiment conducted in July-August 1956. A release took place from a point source close to ground level (46 cm height). SO_2 was used as a tracer, and concentrations were measured on arcs at distances of 50 m, 100 m, 200 m, 400 m and 800 m. The duration of each of the 68 sampling periods was 10 minutes. The original data were published in a paper report (Barad, 1958). There is no official, digital version of the data. The wind speed was measured at heights of 0.25, 0.5, 1, 2, 4, 8 and 16 m above the ground. Use of the velocity profile to estimate a roughness length for each run gives quite consistent results, except for 4 runs. Generally, a roughness length of approximately 6 mm is estimated. However, for runs 3, 4, 13 and 14 the estimated roughness length is considerably larger (around 10 cm). For the runs in question the wind speed profile is not well-behaved. It is characteristic for these runs that the wind speed is very low – less than 1 m/s (at a height of 1 m)."

Runs 3, 4, 13, 14 are cases where we have very stable atmosphere; the estimated mixing height z_i = 800 u_* = 8, 32, 32, 24 m resp.

3 NUMDIF-model, calibration

The NUMDIF-model is described in van Jaarsveld et al. (2000) and in a test report 10.2.e . There is test module implemented in NUMDIF that simulates the prairie grass experiment with either the numerical K_z-model or the Gaussian plume model.

In the OPS-model, as well as in the NUMDIF model, several calibration parameters are used. In the NUMDIF-version, calibrations take place in subroutine *kzair*:

$$K_z = a \frac{\kappa u_* z}{\varphi_h(z/L)}$$, for $L > 0$ (Businger, 1973)

$$K_z = a \frac{\kappa u_* z}{\varphi_h(z/L)} \left(1 - \frac{z}{z_i}\right)^{1.5b}$$, for $L \le 0$ (Brost and Wyngaard, 1978),

where $\varphi_h(z/L)$ is the non-dimensional temperature gradient:

$\varphi_h(z/L) = 0.74\ (1 - 9\ z/L)^{-1/2}$ for $L \leq 0$,
$\varphi_h(z/L) = 0.74 + 4.7\ z/L$ for $L > 0$

and calibration factors a, b (in the exponent, for $L \leq 0$).

Table 1: Values of calibration factors a and b for parameterisation of K_z for OPS-ST and OPS-LT.

	ST		LT		names	
range for 1/L	***a***	***b***	***a***	***b***	***a***	***b***
$1/L < 0$	0.87	2	1	1	*calpar%kz_a_unstable*	*calpar%kz_b_unstable*
$0 \leq 1/L \leq 0.033$	1	-	1.2	-	*calpar%kz_a_neutral*	-
$0.033 < 1/L$	1	-	2.4	-	*calpar%kz_a_stable*	-

Subroutine *ops_surface6* (test routine) computes an analytical expression of the centre of mass z_c of the plume and computes 'representative heights' z_u and z_w, such that $u(z_u)$ and $K_z(z_w)$ are representative for the whole plume. These heights are a factor times the centre line of the plume z_c:

Table 2: Calibration factors α and β for representative heights z_u and z_w as a factor times centre of mass z_c.

range for 1/L	$z_u = \alpha\ z_c$		$z_w = \beta\ z_c$	
$1/L < 0$	α_U	*calpar%zu_ol_unstable*	β_U	*calpar%zw_ol_unstable*
$0 \leq 1/L \leq 0.1$	α_N	*calpar%zu_ol_other*	β_N	*calpar%zw_ol_other*
$0.1 < 1/L$	α_S	*calpar%zu_ol_verystable*	β_S	*calpar%zw_ol_verystable*

FS → grenzen $1/L$ gelijktrekken?

4 Vertical dispersion length

The vertical dispersion length σ_z is a crucial parameter in the computation of the Gaussian plume. In NUMDIF, it is computed in the subroutine *ops_surface6*. For the 68 data points of the prairie grass experiment, we plotted the computed σ_z as function of $1/L$, the inverse of the Obukhov length. No calibration was used in *ops_surface6*.

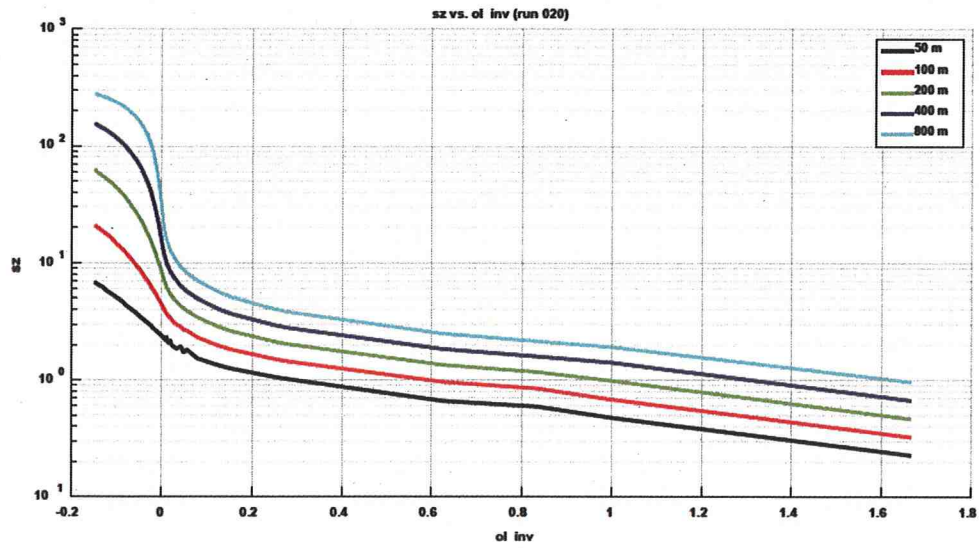

Figure 1: Vertical dispersion length σ_z (m) as function of *ol_inv* = $1/L$, the inverse Obukhov length (1/m) at different distances of the source; log scale. Data from Prairie grass experiment; σ_z from subroutine *ops_surface6* (uncalibrated).

For very stable situations ($1/L > 1$), the value of σ_z, 800 m from the source, is very low ($\sigma_z \approx 1$ m). For an emission height of 0.46 m and a σ_z of 1 m, the computed concentration at receptor height 1.5 m is still high; the measured concentration is much lower.

→ wind speed is also very low; is steady state reached within measuring period? e.g. u = 0.1 m/s, t= 8000 s ~ 2.2 hour. Olesen: measured velocity profile is not 'well-behaved'.

5 Test results

In the next figures, we present the results of different test runs as graphs of C_{cross} = crosswind integrated concentration in g/m², measured at 50, 100, 200, 400 and 800 m from the source. Source strength Q = 10000 g/s. Most figures show two panels: a left panel where all 68 prairie grass runs have been plotted and a right panel, where we left out 4 runs (3,4,13,14) with 'not well-behaved' velocity profiles (4 runs x 5 observations = 20 points).

5.1 Run 036: Gauss-model, original subroutine *surface*

In this run, we used the original NUMDIF-routine *surface.f*, which is based on the *surface*-routine in OPS-ST. This includes the calibration factors for K_z: a = 0.87, b = 2.0 for $L \leq 0$, but uses no calibration for $L > 0$.

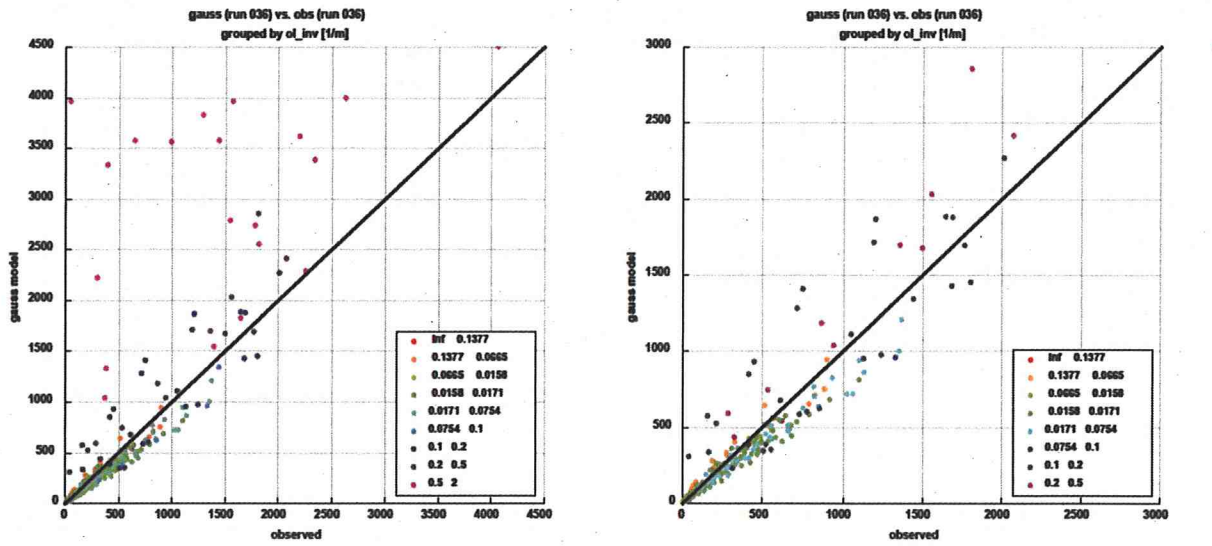

Figure 2: C_{cross} [g/m^2] for prairie grass experiment, Gauss-model vs. observations, receptor height = 1.5 m, coloured according to classes of $1/L$ (L = Obukhov length). Left panel: all runs; right panel: runs 3,4,13,14 left out. The boundaries of the colour classes are defined by Pasquill-Golder classes for z_0 = 0.006 m: red = strongly unstable, orange = unstable, light green = weakly unstable, green = neutral, cyan = stable, blue - magenta = strongly stable. Original *surface.f* from OPS-ST.

5.2 Run 037: Gauss-model, original subroutine ops_surface

In this run, we used the original NUMDIF-routine *ops_surface.f*, which is based on the *surface*-routine in OPS-LT. This uses no calibration for K_z for $L \leq 0$, and calibration factor a = 1.2 for $L > 30$, a = 2.4 for $0 < L < 30$.

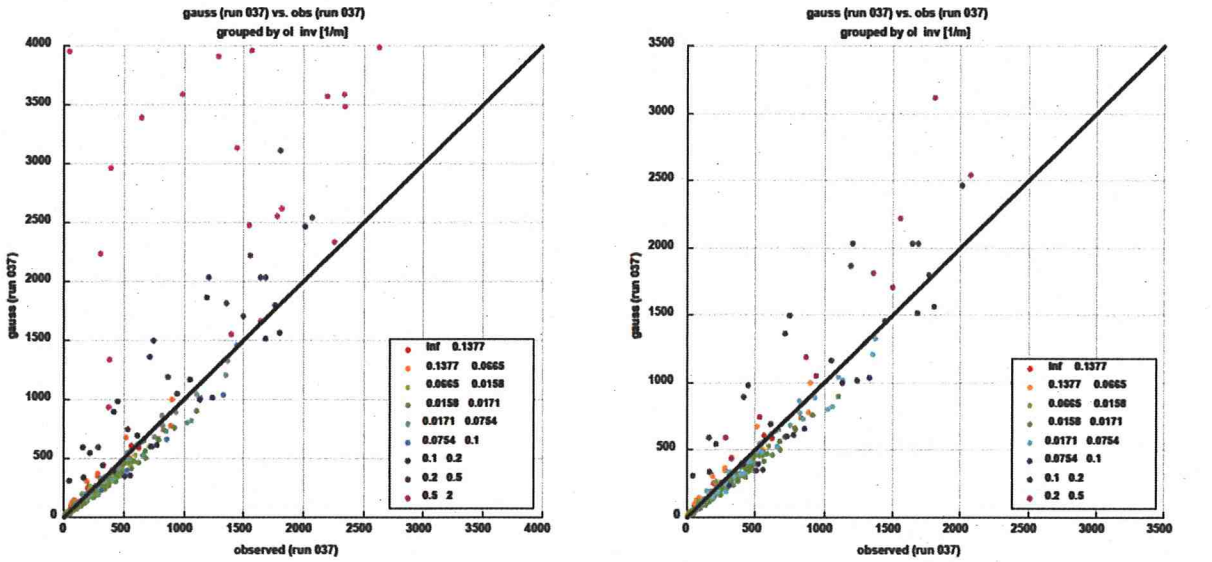

Figure 3: C_{cross} [g/m^2] for prairie grass experiment, Gauss-model vs. observations, receptor height = 1.5 m, coloured according to classes of $1/L$ (L = Obukhov length). Left panel: all runs; right panel: runs 3,4,13,14 left out. The boundaries of the colour classes are defined by Pasquill-Golder classes for z_0 = 0.006 m: red = strongly unstable, orange = unstable, light green = weakly unstable, green = neutral, cyan = stable, blue - magenta = strongly stable. *ops_surface.f* from OPS-LT.

5.3 Run 020: K_z-model, no calibration

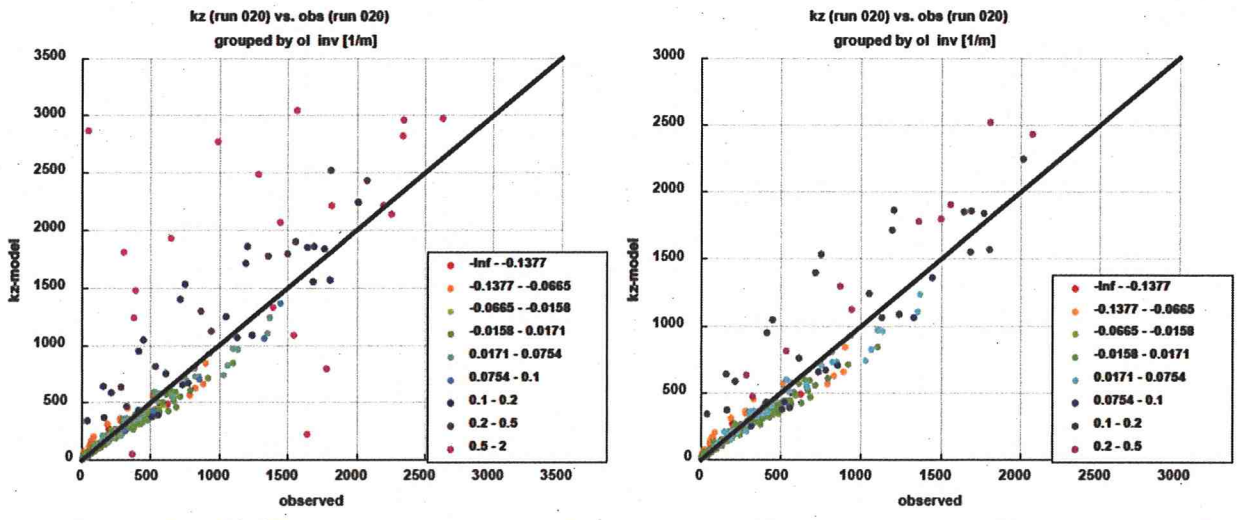

Figure 4: C_{cross} [g/m²] for prairie grass experiment, K_z-model vs. observations, receptor height = 1.5 m, coloured according to classes of $1/L$ (L = Obukhov length). Left panel: all runs; right panel: runs 3,4,13,14 left out. The boundaries of the colour classes are defined by Pasquill-Golder classes for z_0 = 0.006 m: red = strongly unstable, orange = unstable, light green = weakly unstable, green = neutral, cyan = stable, blue - magenta = strongly stable. Calibration factors a=1, b=1.

We may conclude that in unstable, neutral and stable conditions, the K_z-model is able to represent observed crosswind integrated concentrations. If we include runs 3,4,13,14 with a 'non well-behaved' velocity profile (left panel), the performance for very stable situations ($1/L > 0.075\ m^{-1}$) is unsatisfactory. If we leave out these runs (right panel), there is still a tendency to overestimate concentrations for very stable situations.

5.4 Run 020: Gauss-model, ops_surface6, no calibration

see also run 043 run 020 is corrupt ??

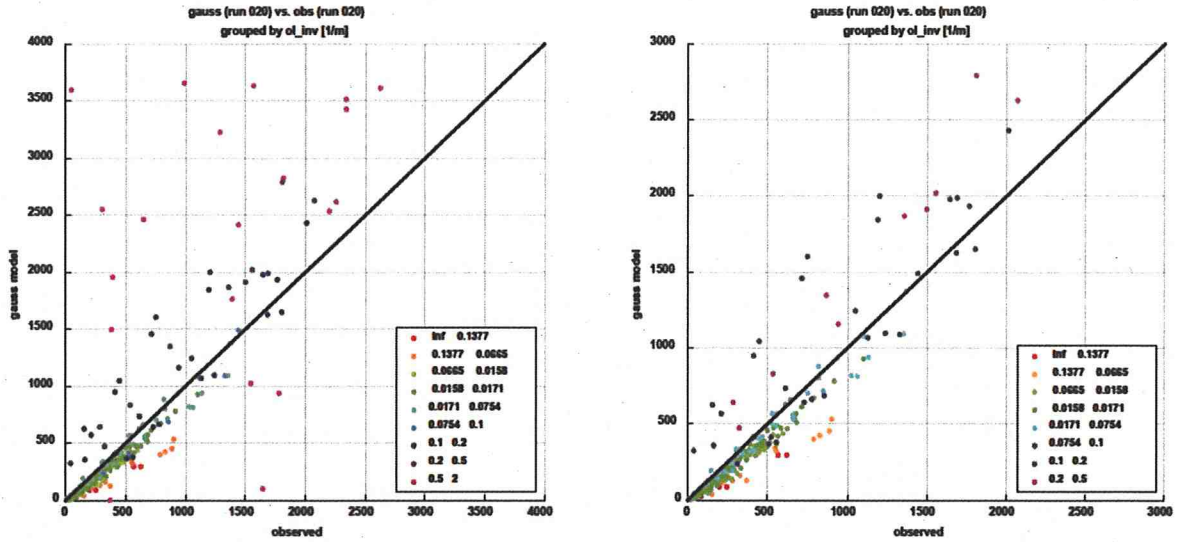

Figure 5: C_{cross} [g/m²] for prairie grass experiment, Gauss-model vs. observations, receptor height = 1.5 m, coloured according to classes of $1/L$ (L = Obukhov length). Left panel: all runs; right panel: runs 3,4,13,14 left out. The boundaries of the colour classes are defined by Pasquill-Golder classes for z_0 = 0.006 m: red = strongly unstable, orange = unstable, light green = weakly unstable, green = neutral, cyan = stable, blue - magenta = strongly stable. Calibration factors a=1, b=1.

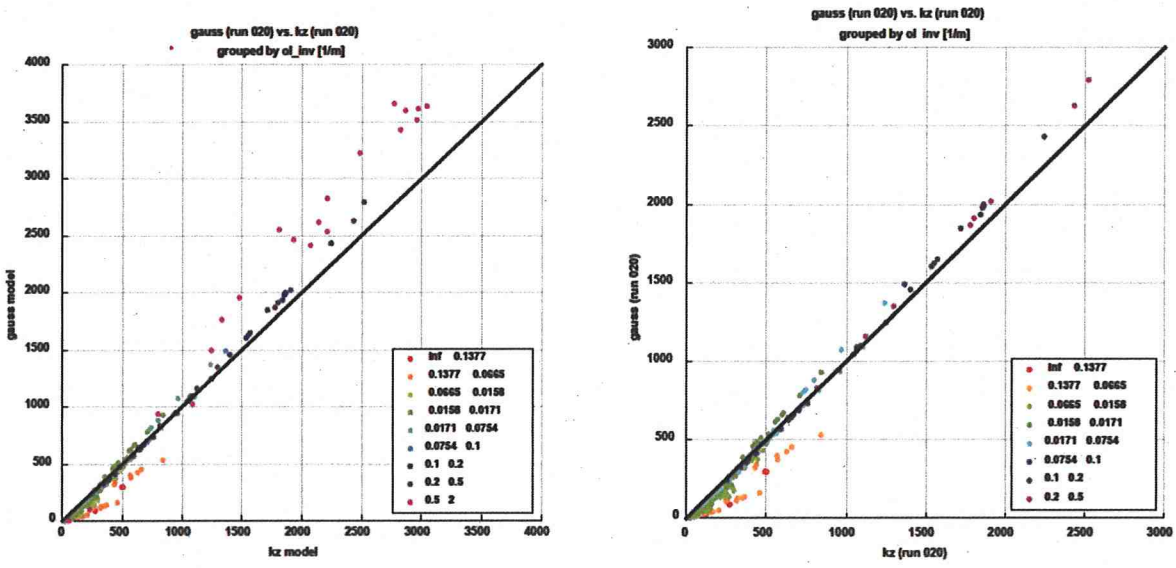

Figure 6: C_{cross} [g/m^2] for prairie grass experiment, Gauss-model vs. K_z-model, receptor height = 1.5 m, coloured according to classes of $1/L$ (L = Obukhov length). Left panel: all runs; right panel: runs 3,4,13,14 left out. The boundaries of the colour classes are defined by Pasquill-Golder classes for z_0 = 0.006 m: red = strongly unstable, orange = unstable, light green = weakly unstable, green = neutral, cyan = stable, blue - magenta = strongly stable. Calibration factors a=1, b=1.

The Gauss-model performs roughly the same as the K_z-model, but for some underestimation for unstable cases (orange). For very stable situations, overestimation is even larger than for the K_z-model.

5.5 Run 018: Gauss-model, calibration of 6 parameters α and β

In this run, we tried to calibrate the 6 values of α and β. A MATLAB function was constructed that uses a non-linear optimisation procedure (*lsqnonlin*) to search for an optimal combination of calibration parameters that minimises the root mean square error of Gauss-model results compared to observations. For each function call of the optimisation function, the OPS-model was run with a different set of calibration parameters. After ~20 steps, the optimisation procedure converged. Different initial settings have been tried in order to check for local minima. Prairie grass-runs 3,4,13,14 have been excluded from the optimization process, but are still present in the left panels of the graphs below. We show the scatter plot of Gauss-model with optimal set of calibration parameters against the observations.

Table 3: Optimal set of calibration factors for z_u and z_w, no calibration for Kz.

range for $1/L$	$z_u = \alpha\, z_c$		$z_w = \beta\, z_c$	
$1/L < 0$	1.35	*calpar%zu_ol_unstable*	0.71	*calpar%zw_ol_unstable*
$0 \le 1/L \le 0.1$	0.84	*calpar%zu_ol_other*	0.87	*calpar%zw_ol_other*
$0.1 < 1/L$	2.86	*calpar%zu_ol_verystable*	2.22	*calpar%zw_ol_verystable*

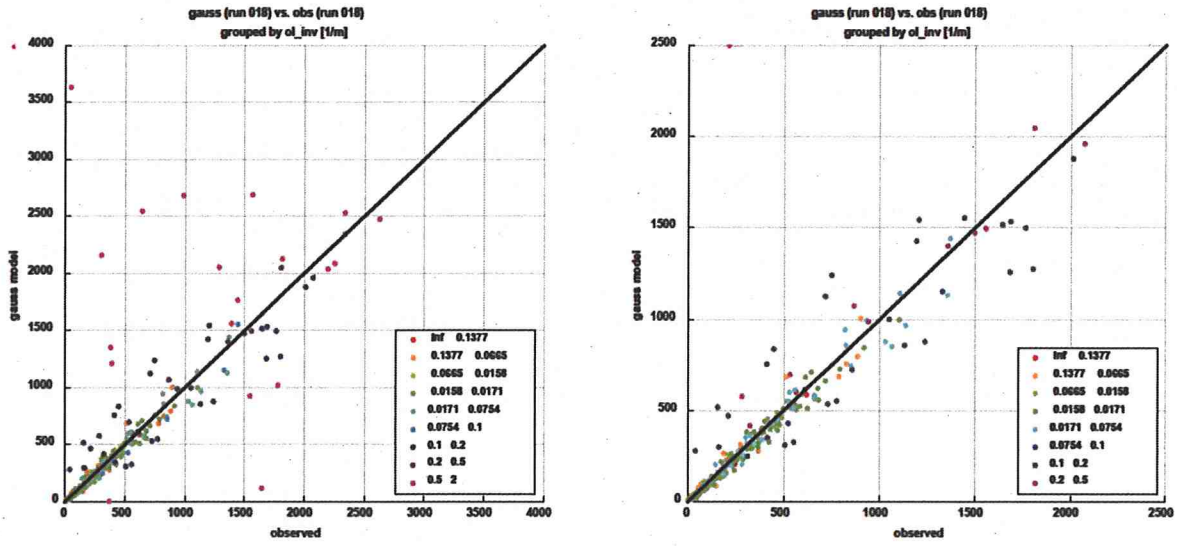

Figure 7: C_{cross} [g/m²] for prairie grass experiment, Gauss-model vs. observations, receptor height = 1.5 m, coloured according to classes of $1/L$ (L = Obukhov length). Left panel: all runs; right panel: runs 3,4,13,14 left out. The boundaries of the colour classes are defined by Pasquill-Golder classes for z_0 = 0.006 m: red = strongly unstable, orange = unstable, light green = weakly unstable, green = neutral, cyan = stable, blue - magenta = strongly stable. Calibration factors see Table 3.

From Table 3, we may conclude that the optimisation process tries to increase the wind speed by taking unrealistically high values of calibration factors for z_u and z_w for very stable situations. Unfortunately, this does not lead to an improved modelling of the cases 3,4,13,14.

5.6 Run 025: Gauss=model, calibration of 4 parameters (no calibration for very stable situations)

Because the modelling of very stable situations is apparently beyond the capabilities of the current parameterisations, a new optimal set was computed where the calibrations factors for very stable situations were fixed at 1. With this calibration, there is better agreement with observations and with the K_z-model.

Table 4: Optimal set of calibration factors for z_u and z_w, no calibration very stable situations, no calibration for Kz.

range for $1/L$	$z_u = \alpha z_c$		$z_w = \beta z_c$	
$1/L < 0$	0.88	*calpar%zu_ol_unstable*	0.72	*calpar%zw_ol_unstable*
$0 \le 1/L \le 0.1$	0.79	*calpar%zu_ol_other*	0.88	*calpar%zw_ol_other*
$0.1 < 1/L$	1	*calpar%zu_ol_verystable*	1	*calpar%zw_ol_verystable*

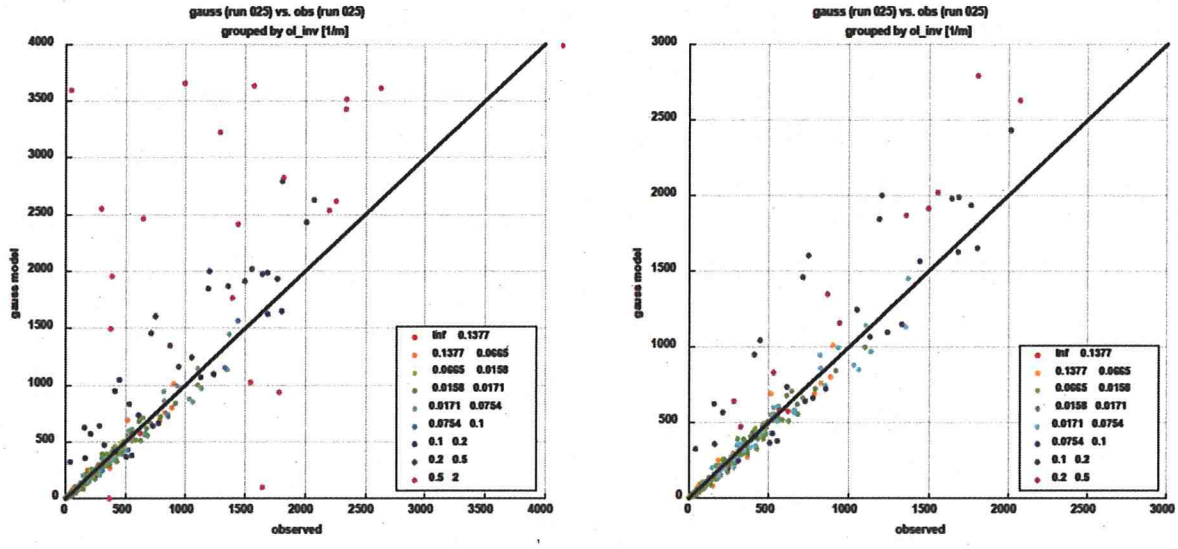

Figure 8: C_{cross} [g/m²] for prairie grass experiment, Gauss-model vs. observations, receptor height = 1.5 m, coloured according to classes of $1/L$ (L = Obukhov length). Left panel: all runs; right panel: runs 3,4,13,14 left out. The boundaries of the colour classes are defined by Pasquill-Golder classes for z_0 = 0.006 m: red = strongly unstable, orange = unstable, light green = weakly unstable, green = neutral, cyan = stable, blue - magenta = strongly stable. Calibration factors see Table 4.

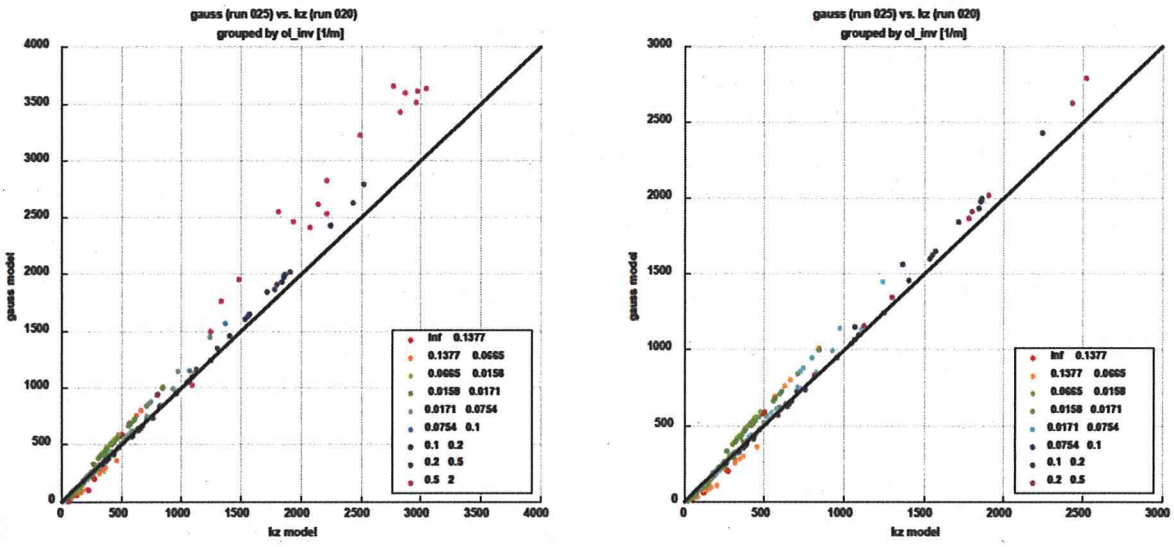

Figure 9: C_{cross} [g/m²] for prairie grass experiment, Gauss-model vs. K_z-model, receptor height = 1.5 m, coloured according to classes of $1/L$ (L = Obukhov length). Left panel: all runs; right panel: runs 3,4,13,14 left out. The boundaries of the colour classes are defined by Pasquill-Golder classes for z_0 = 0.006 m: red = strongly unstable, orange = unstable, light green = weakly unstable, green = neutral, cyan = stable, blue - magenta = strongly stable. Calibration factors see Table 4.

5.7 Run 027: Receptor height 10 m, no calibration

Up till now, all runs have been done with a receptor height of 1.5 m. In this run, we want to compare the Gauss-model with the K_z-model for a receptor height of 10 m. Observations are not available for this height.

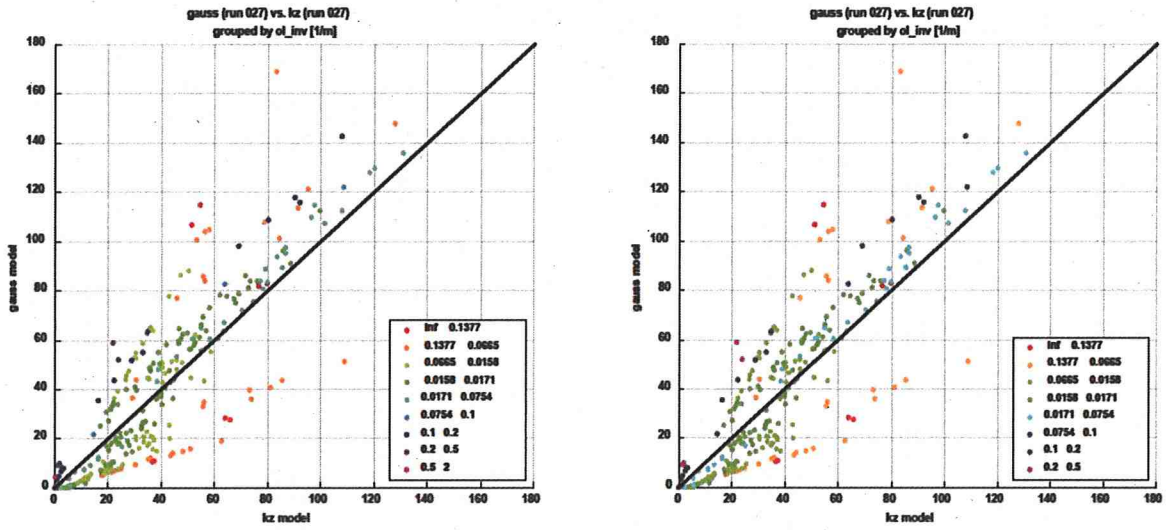

Figure 10: C_{cross} [g/m²] for prairie grass experiment, Gauss-model vs. K_z-model, receptor height = 10 m, coloured according to classes of $1/L$ (L = Obukhov length). Left panel: all runs; right panel: runs 3,4,13,14 left out. The boundaries of the colour classes are defined by Pasquill-Golder classes for z_0 = 0.006 m: red = strongly unstable, orange = unstable, light green = weakly unstable, green = neutral, cyan = stable, blue - magenta = strongly stable. No calibration.

5.8 Run 029: Receptor height 10 m, calibration factors of run 025 (receptor height = 1.5 m)

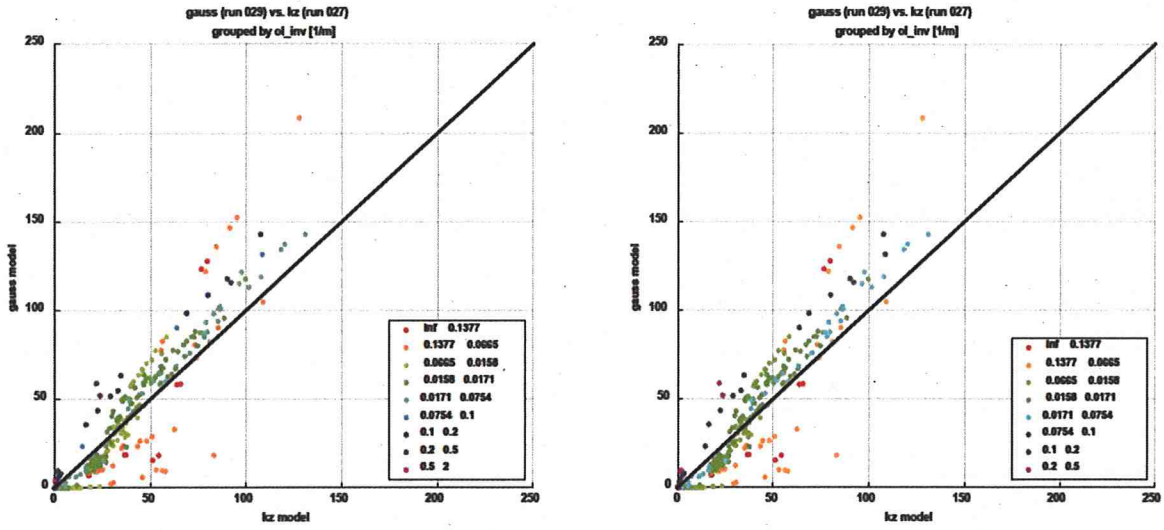

Figure 11: C_{cross} [g/m²] for prairie grass experiment, Gauss-model vs. K_z-model, receptor height = 10 m, coloured according to classes of $1/L$ (L = Obukhov length). Left panel: all runs; right panel: runs 3,4,13,14 left out. The boundaries of the colour classes are defined by Pasquill-Golder classes for z_0 = 0.006 m: red = strongly unstable, orange = unstable, light green = weakly unstable, green = neutral, cyan = stable, blue - magenta = strongly stable. Calibration factors see Table 4.

The agreement between Gauss- and K_z-model has deteriorated.

5.9 Run 032, 033: calibration of Gauss-model against K_z-model

In these runs, we calibrated the Gauss-model against the K_z-model results separately for receptor heights 1.5 m and 10 m. In the following set of graphs, we present results of these two calibrations and of combining a receptor height of 1.5 m with a set of calibration parameters derived from the 10 m concentrations and vice versa.

Table 5: Optimal set of calibration factors for z_u and z_w, no calibration for very stable situations, no calibration for K_z, for runs 032 (height 10 m) and 033 (height 1.5 m)

	$z_u = \alpha\, z_c$			$z_w = \beta\, z_c$		
receptor height [m]	1.5	1.5	10	1.5	1.5	10
calibrated against	obs	K_z	K_z	obs	K_z	K_z
$1/L < 0$	0.88	2.91	1.96	0.72	0.73	0.94
$0 \le 1/L \le 0.1$	0.79	1.40	1.52	0.88	0.96	1.22
$0.1 < 1/L$	1	1	1	1	1	1

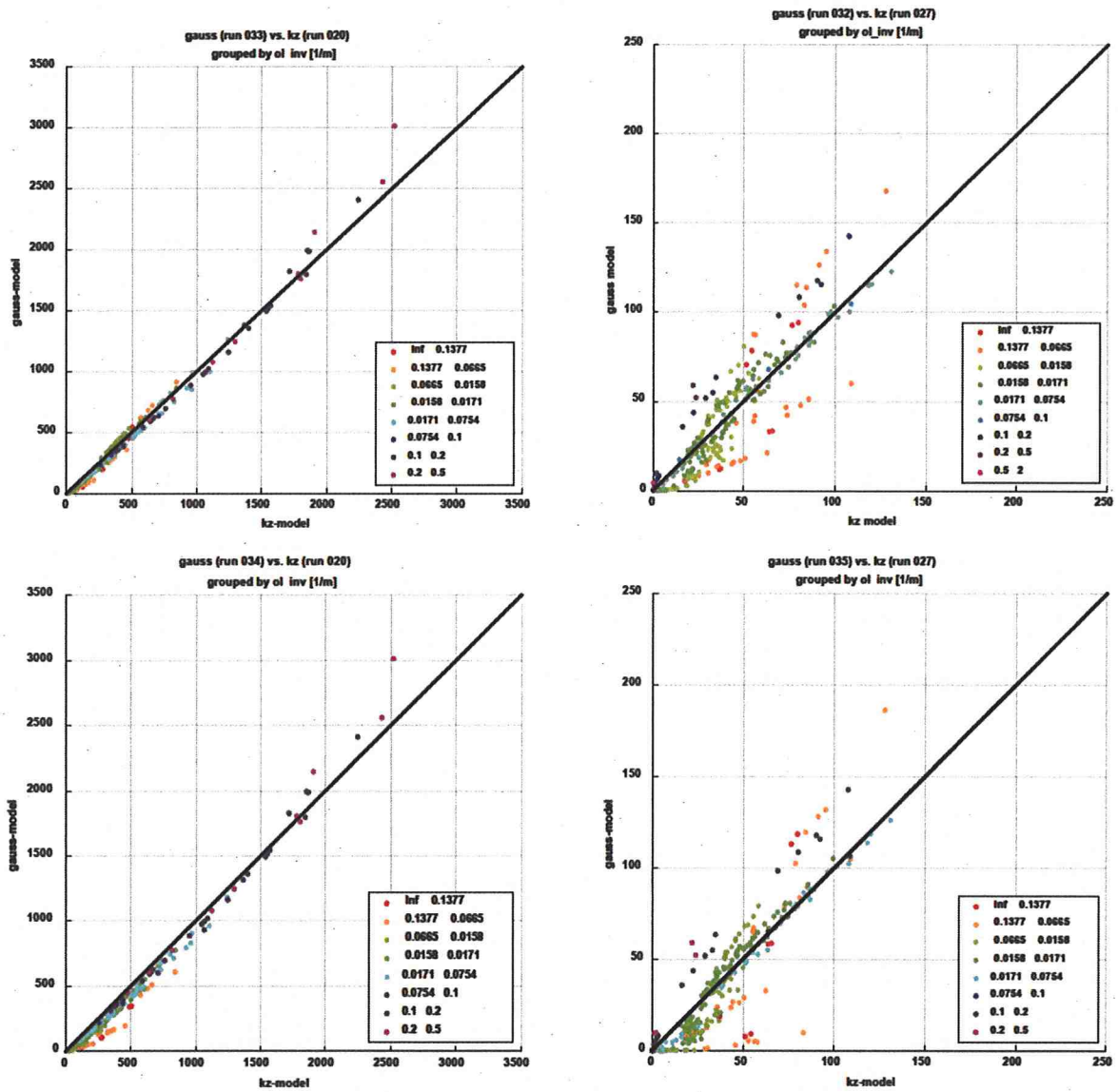

Figure 12: C_{cross} [g/m²] for prairie grass experiment, Gauss-model vs. K_z-model, receptor height/calibration factors = 1.5 m/1.5 m (upper left panel), 10 m/10 m (upper right panel), 1.5 m/10 m (lower left panel), 10 m/1.5 m (lower right panel), coloured according to classes of $1/L$ (L = Obukhov length). All prairie grass runs. The boundaries of the colour classes are defined by Pasquill-Golder classes for z_0 = 0.006 m: red = strongly unstable, orange = unstable, light green = weakly unstable, green = neutral, cyan = stable, blue - magenta = strongly stable. Calibration factors see Table 5.

For a receptor height of 1.5 m (left panels), calibration parameters are not very sensitive and both sets give good results. However, for a receptor height of 10 m, results are much worse. Calibration

for this specific height of 10 m does improve the comparison, compared to the 1.5 m calibration set, but differences with the K_z-model are much larger than for 1.5 m.

5.10 Deposition

The deposition velocity v_d shows large differences between the K_z-model and the Gauss-model. This is due to the fact that the Kz-model computes the deposition velocity at the centre of the first numerical layer at 12.8 cm (z_0 = 0.6 cm, top of first layer at 25 cm), whereas the Gauss-model computes the deposition velocity at the receptor height.

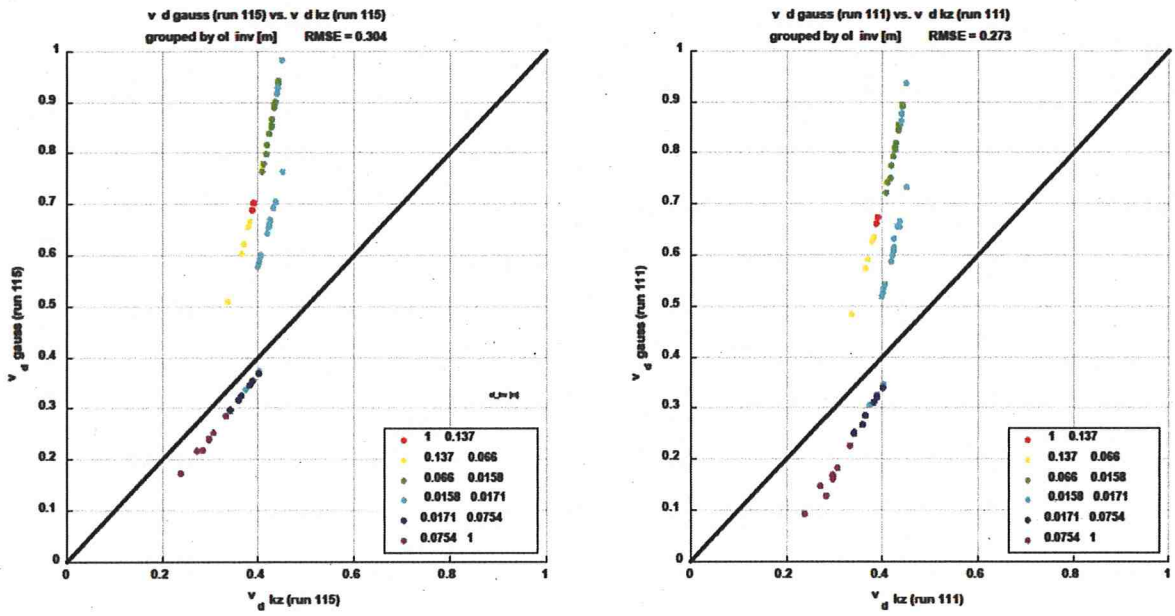

Figure 13. Deposition velocity v_d [cm/s] for run 115 (receptor height = 1.5 m) and run 111 (receptor height 10 m). The x-axis is the K_z-model (v_d at 12.8 cm), the y-axis the Gauss model (v_d at receptor height). Prairie grass runs 3,4,13,14 left out. Coloured according to classes of $1/L$ (L = Obukhov length). The boundaries of the colour classes are defined by Pasquill-Golder classes for z_0 = 0.006 m: red = strongly unstable, orange = unstable, light green = weakly unstable, green = neutral, cyan = stable, blue - magenta = strongly stable.

In the following figure, we show the concentration loss due to deposition (subtracting the concentration of runs excluding and including deposition). Because the Gauss model computes the deposition at receptor height instead of at the surface and because the concentration at 10 m is much lower than at the surface, the deposition is underestimated by the Gauss model.

→ compute source depletion at surface
→ compute local deposition at surface

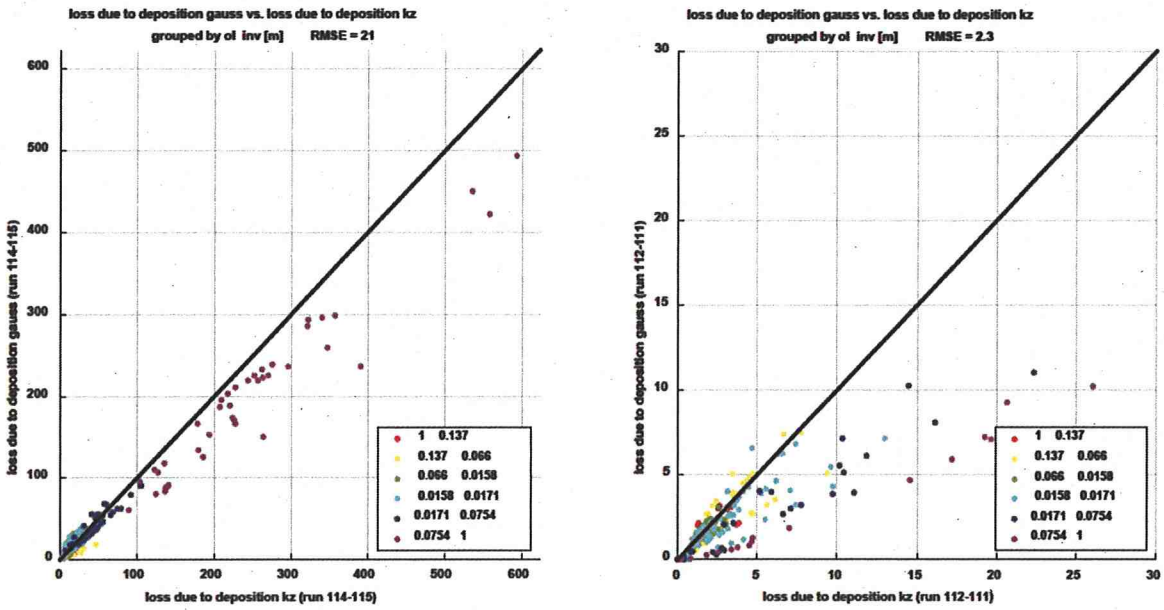

Figure 14. Loss due to deposition [g/m²], x-axis K_z-model, y-axis Gauss model. Receptor height = 1.5 m (left panel) or 10 m (right panel). Prairie grass runs 3,4,13,14 left out. Coloured according to classes of $1/L$ (L = Obukhov length). The boundaries of the colour classes are defined by Pasquill-Golder classes for z_0 = 0.006 m: red = strongly unstable, orange = unstable, light green = weakly unstable, green = neutral, cyan = stable, blue - magenta = strongly stable.

5.11 Other test runs

Other test runs are described here in short:

- run 044/046: yes (044) or no (046) interpolation of u_h and K_z in x-direction does not give much difference. We choose to keep the interpolation, because for larger distances it may be of significant influence.
- Runs 117-128: tests with an iterative procedure in subroutine *vertdisp_it*, where the scaling region is chosen, based on a representative plume height (in case of iteration) instead of emission height only (no iteration). The iterative procedure showed 'flip-flop' behaviour for the values of z_u and σ_z (between *surface* and *convec/neutral* scaling regions), so convergence was not always achieved. Furthermore, the effect of the iteration on test results for prairie grass data was not very large. Therefore it is advised to use *maxit_vertdisp* = 1 (no iteration).
- Run 130-138: different options for subroutine surface; no obvious 'winner', but ops_surface6 (iopt_sz_ST = 8) is one of the best and relatively simple too understand.

FS xxx
run 028: K_z-model, calibration factor a = 1.2, a = 2.4.

run xxx: effect of threshold *u_min*
- The cut-off threshold for low wind speeds is 0.75 m/s (if $u < 0.75 \rightarrow u = 0.75$). If the threshold is not used, OPS overestimates concentrations for very stable situations even more than now.

- bug effvd?

zrcp = 5 m
run 021: Gauss vs. K_z-model
run 026: Gauss with calibration factors of run 025

6 References

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