HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt

Environmental Modelling for RAdiation Safety II – Working group 9

Comparison between test field data and Gaussian plume model

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AG Radioecological Modelling and Retrospective Dosimetry(REM)

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HELMHOLTZ
GEMEINSCHAFT

Simulation program for determination of population exposure to high doses after the explosion of an RDD device

1) Gaussian model with known metereological parameters
2) With at least 3 TLD measurements the free parameters can be inversely determined
3) Mathematical approach for inverse modelling: *Levenberg-Marquardt Algorithm*

Two calculated examples:
A) Synthetic data produced with HOTSPOT 2.07

National project: Retrospective dosimetry for the population in emergency situations Contract No 3607S04560

Bundesamt für Strahlenschutz (BfS)
Federal Ministry for the environment, Nature Conservation and Nuclear Safety (BMBF)

Equations from SSK report No. 37 pp. 29-30-31

Gaussian dispersion model

$$\chi(x,y,z;H) = \underbrace{\frac{1}{2\pi\sigma_y(x)\sigma_z(x)u(x)}}_{1} \underbrace{\exp^{-\frac{y^2}{2\sigma_y(x)^2}}}_{2} \underbrace{\left(e^{-\frac{(z-H)^2}{2\sigma_z(x)^2}} + e^{-\frac{(z+H)^2}{2\sigma_z(x)^2}}\right)}_{3}$$

Dispersion coefficients a,b,c depend on stability class (from HOTSPOT guide 2.07)

$$\sigma_{y,z}(x) = \frac{ax}{(1+bx)^c}$$

Depletion factor (from HOTSPOT guide 2.07))

$$DF(x) = \left[exp(\int_0^x \frac{1}{exp(-\frac{H^2}{2\sigma_z^2(x')}\sigma_z(x'))} dx'\right]^{-\frac{v_d}{u}\sqrt{\frac{2}{\pi}}}$$

Wet deposition

$$W(x) = \frac{\Lambda}{\sqrt{2\pi}\sigma_y(x)u(x)} e^{-\frac{y^2}{2\sigma_y^2(x)}}$$

Ground deposition

$$B_r(x,y) = Q_r(v_d\ DF(x)\ \chi(x,y,0) + W(x))e^{-\lambda_r\ t}$$

Dose conversion factors: submersion $g_{w,r}$, inhalation $g_{h,r}$, deposition $g_{b,r}$

submersion dose

$$H_{wr}(x,y,z) = Q_r\chi(x,y,z)g_{wr}$$

inhalation dose

$$H_{hr}(x,y,0) = Q_r\chi(x,y,z)g_{hr}3.34\cdot 10^{-4}$$

deposition dose

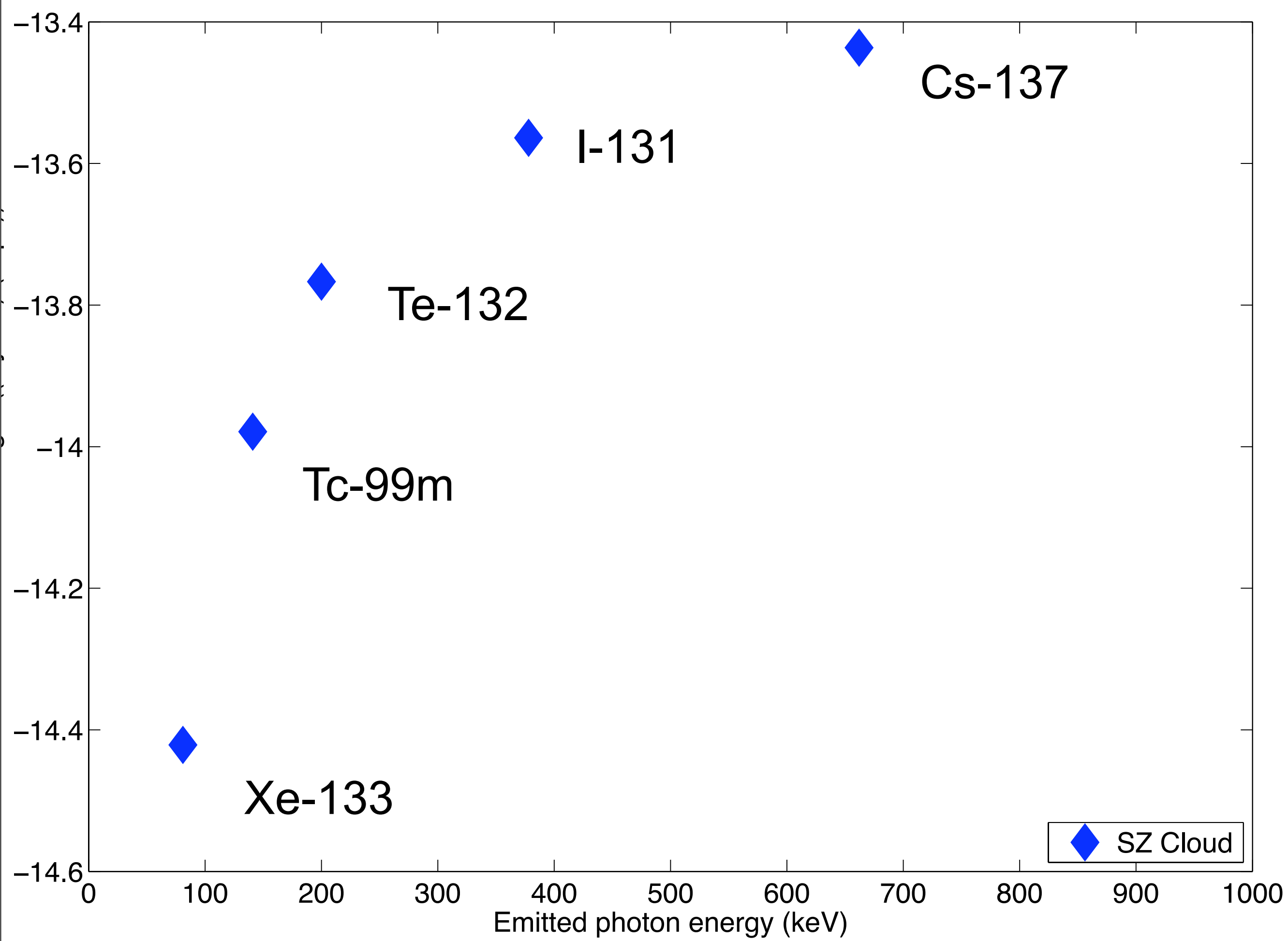
$$H_{br}(x,y,0) = Q_r(\chi(x,y,0)v_d DF(x) + W(x))b\ g_{br}K_{br}$$

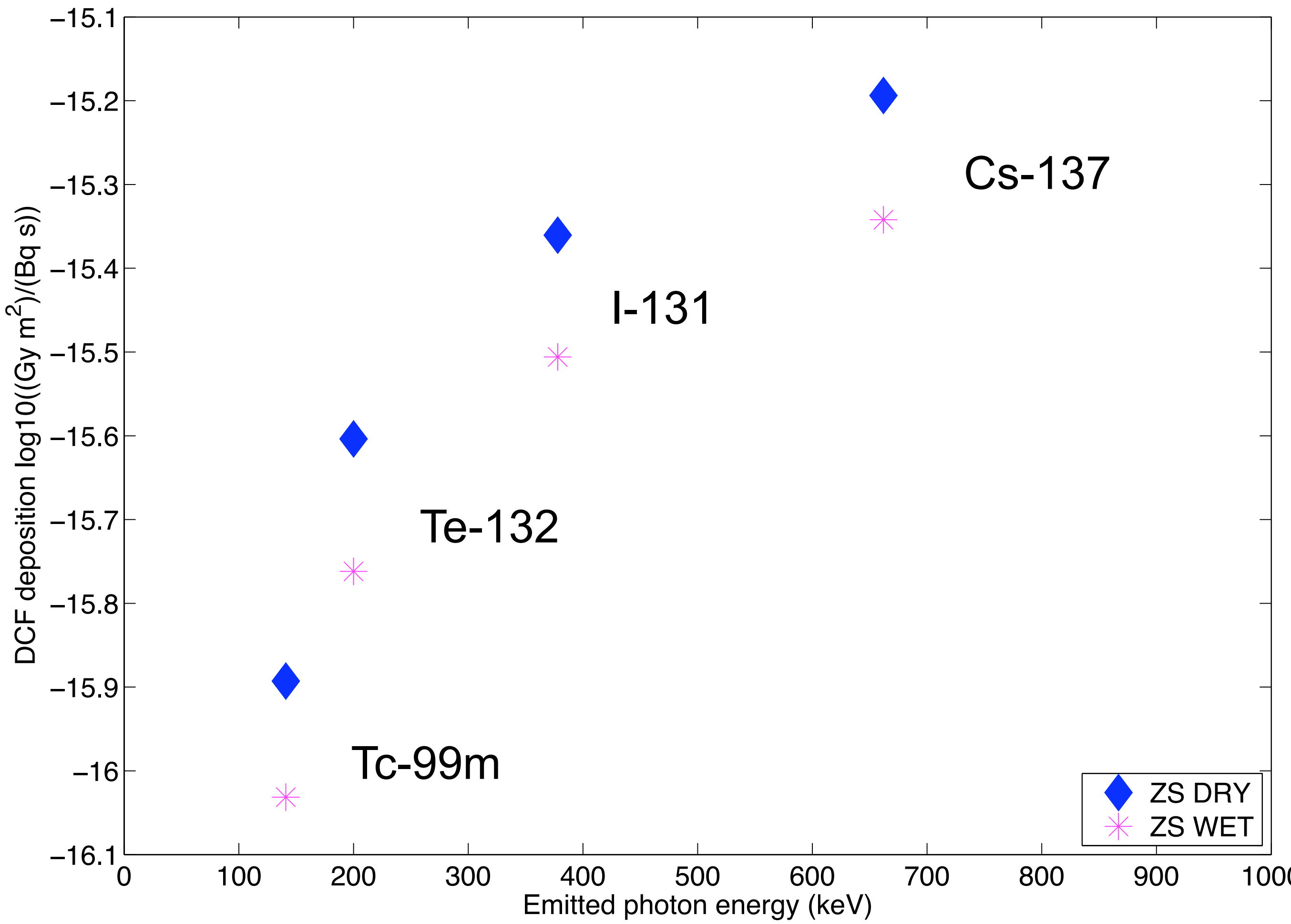
External dose

$$H_{tot}(x,y,z) = H_{wr}(x,y,z) + H_{br}(x,y,0)$$

Dose conversion factors (Zähringer-Sempau BfS-IAR-2/97)

submersion $g_{w,r}$ (Gy s / Bq m^3) TABLE A.3, deposition $g_{b,r}$ (Gy s / Bq m^2) TABLE A.2





Source homogeneously distributed in the air

Source exponentially distributed in the soil with relaxation mass per unit area β

DRY = 0.1 g/cm^2
WET = 1 g/cm^2

CODE: OPTLMDOSE.f90

MAIN PROGRAM
SUBROUTINE FCN.f90 calculates objective function as
$\log_{10}(\text{Dosedata}) - \log_{10}(\text{Dose})$
SUBROUTINE LMDIF from MINPACK runs optimisation
SUBROUTINE COVAR calculates covariance matrix for error estimation
cartesian axis: wind direction is x-axis

INPUT data

namelist:

&global_para rnuclide='Tc-99m' wind_ref=3.3d0 theta= 0.0d0
stability_class = 'A' H= 2.5d0 vd= 0.1d0 h_ref=2.0d0
dep_model="DRY"
I_rain = 0.0d0 eq_model='EXPONENTIALX' xdata0=1.0d0 Dt_plot=60.0d0
Qr = 5.8D8/

filename_read: x (km), y(km), Dose(Sv), Surface activity (kBq/m^2), Dt(s)
Radionuclide implemented are: Cs-137, I-131, Xe-133, Te-132, Tc-99m

OUTPUT data

filename_save:
info 1 M 23 N 1 opt_value 436806916.322 NORM 0.216464 unbiased
sigmaX 9533334.244

+ other output files to produce plots

CODE: LEVENBERG-MARQUARDT ALGORITHM in MINPACK

$F = \log_{10}(\text{Dosedata}) - \log_{10}(\text{Dose})$

If x_{sol} is a solution of a non-linear least square problem then x solves: $$\sum_{i=1}^{m} f_i(x) \nabla f_i(x) = 0$$

and orthogonality condition is valid $$F'(x_{sol})^T F(x_{sol}) = 0$$

The algorithm looks for a correction p such that $F(x+p) \leqslant F(x)$

To find appropriate p, the algorithm solves the problem: $\min\{ ||f=J \cdot p ||: ||D \cdot p|| \leqslant \Delta\}$

where D is diagonal scaling matrix and Δ is a step bound

LMDIF runs various convergency tests between approximation x and the solution x_{sol}

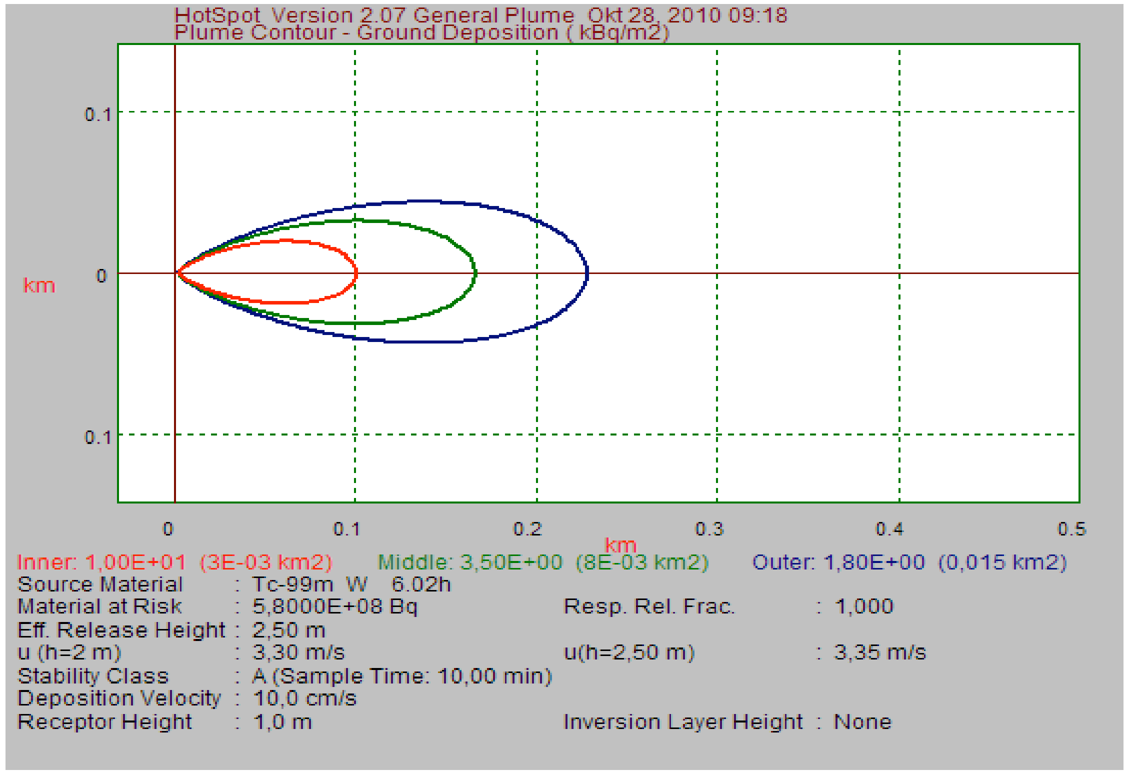
INFO 1: if the final norm of the residual has K significant decimal digits compared to initial one (the assumed tolerance 10^{-K} is set to square root of machine precision)

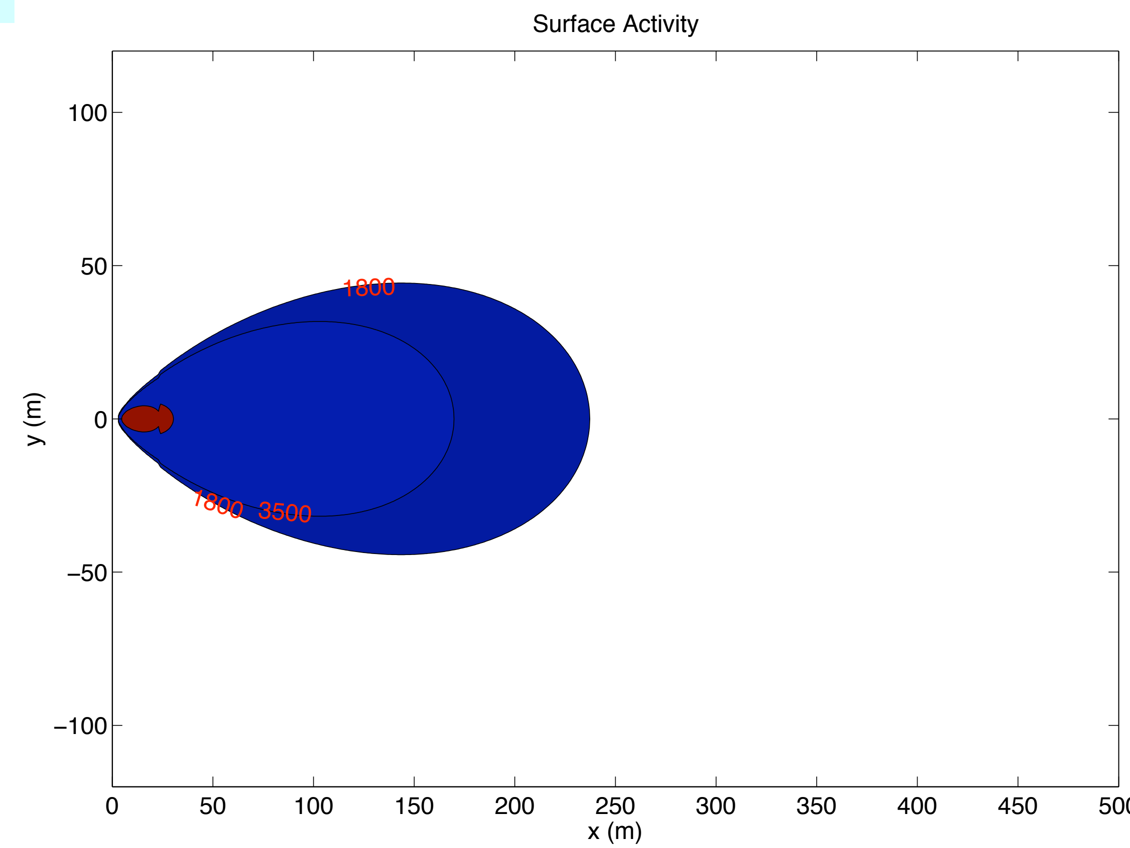
INFO 2: the larger components of $(D \cdot x)$ have K significant digits compared to initial ones

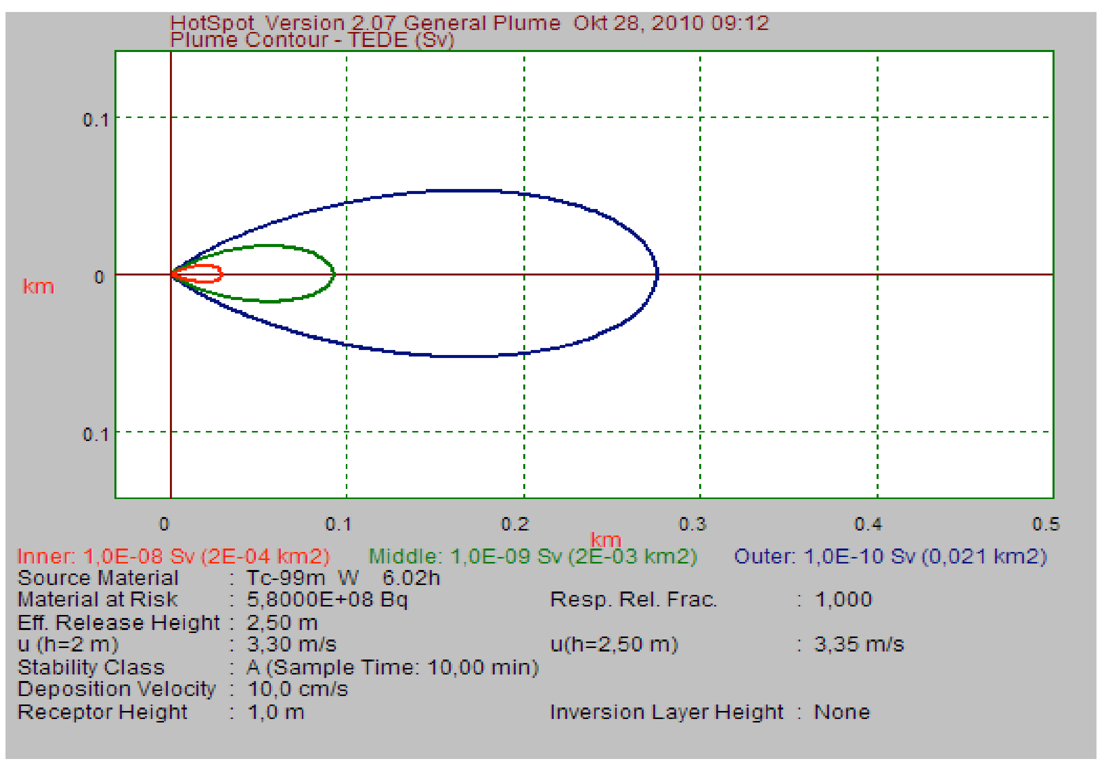
INFO 3: if both 1 and 2 are fulfilled

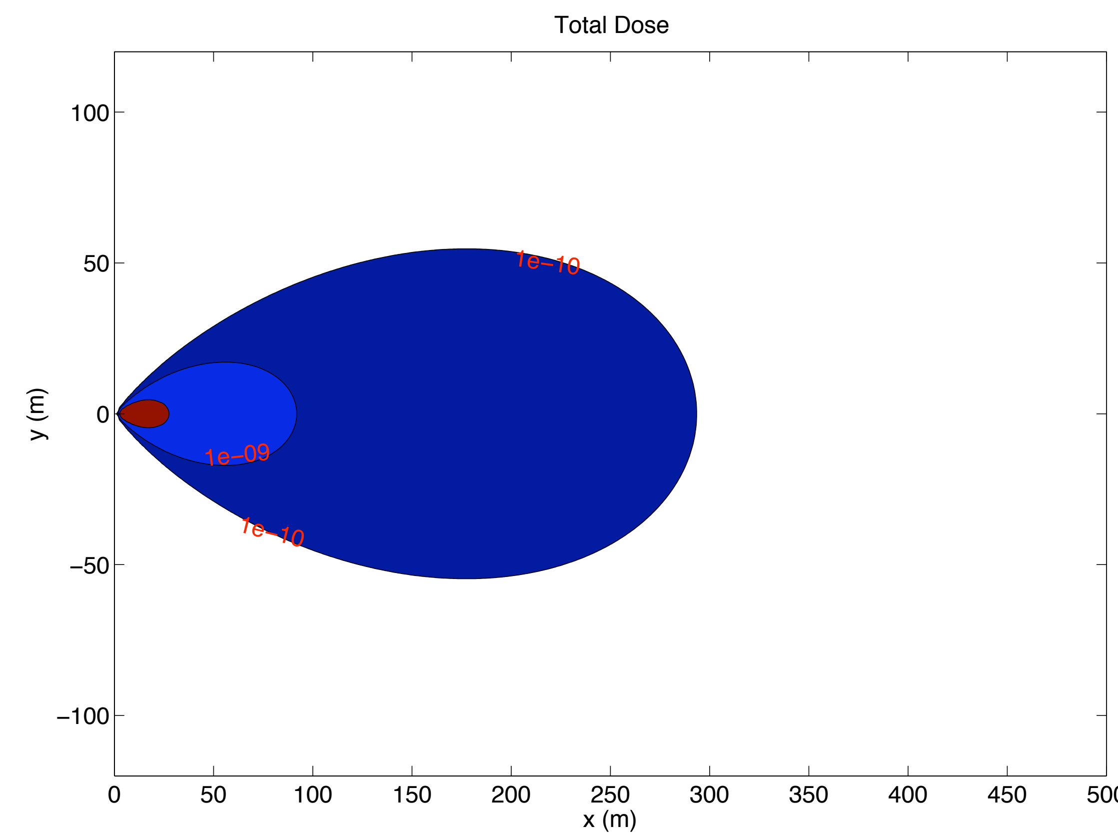
INFO 4: if the norm of the residuals is orthogonal to the Jacobian matrix.This should be examined further: could be $F(x)=0$, some local minimum and accuracy is not implicit

Test data from HOTSPOT





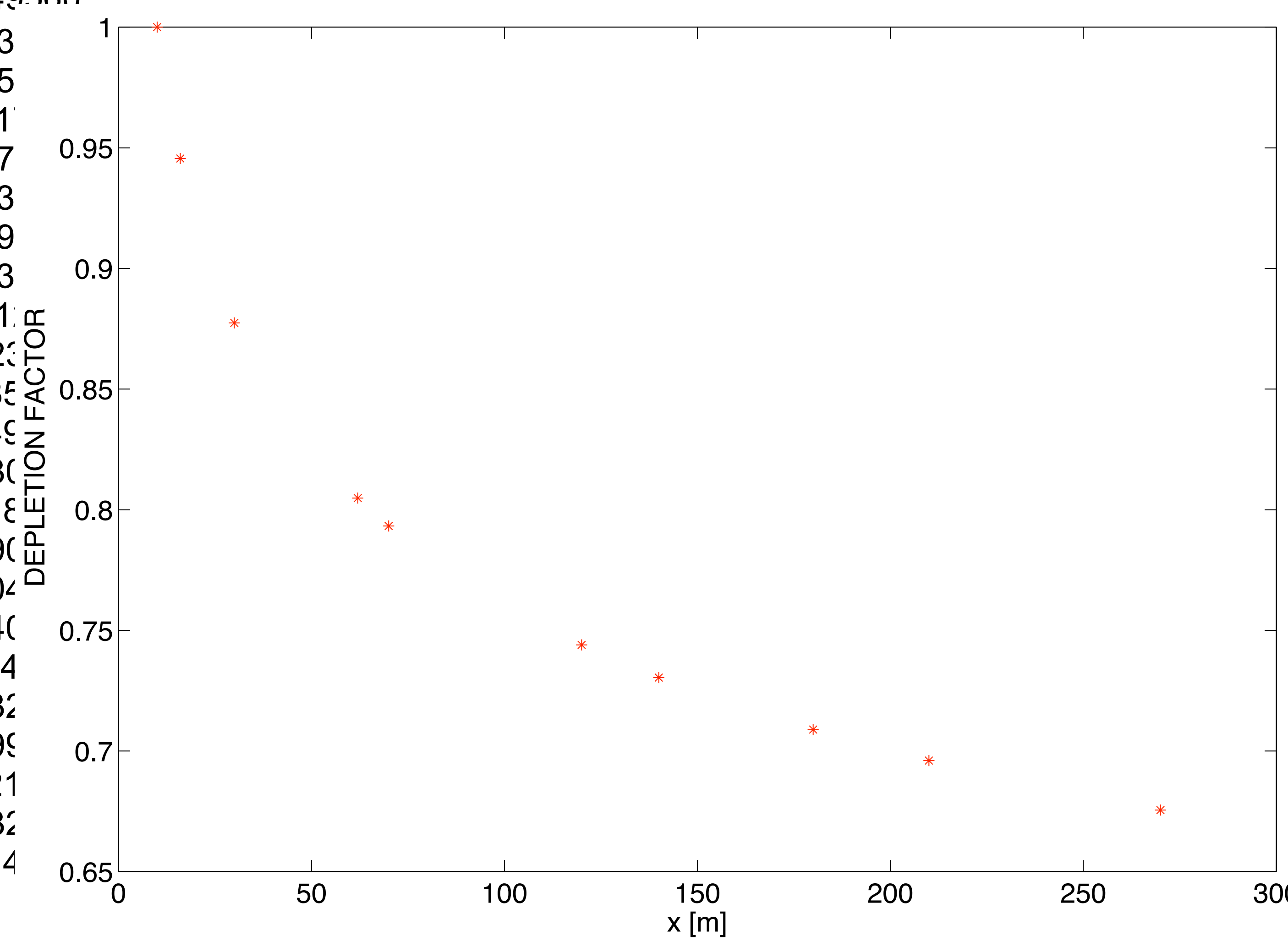




Test data from HOTSPOT

- In principle with identical input values and initial guess, initial value for surface activity and dose should be the same as test data. BUT there is a difference of about 4-5% between the two

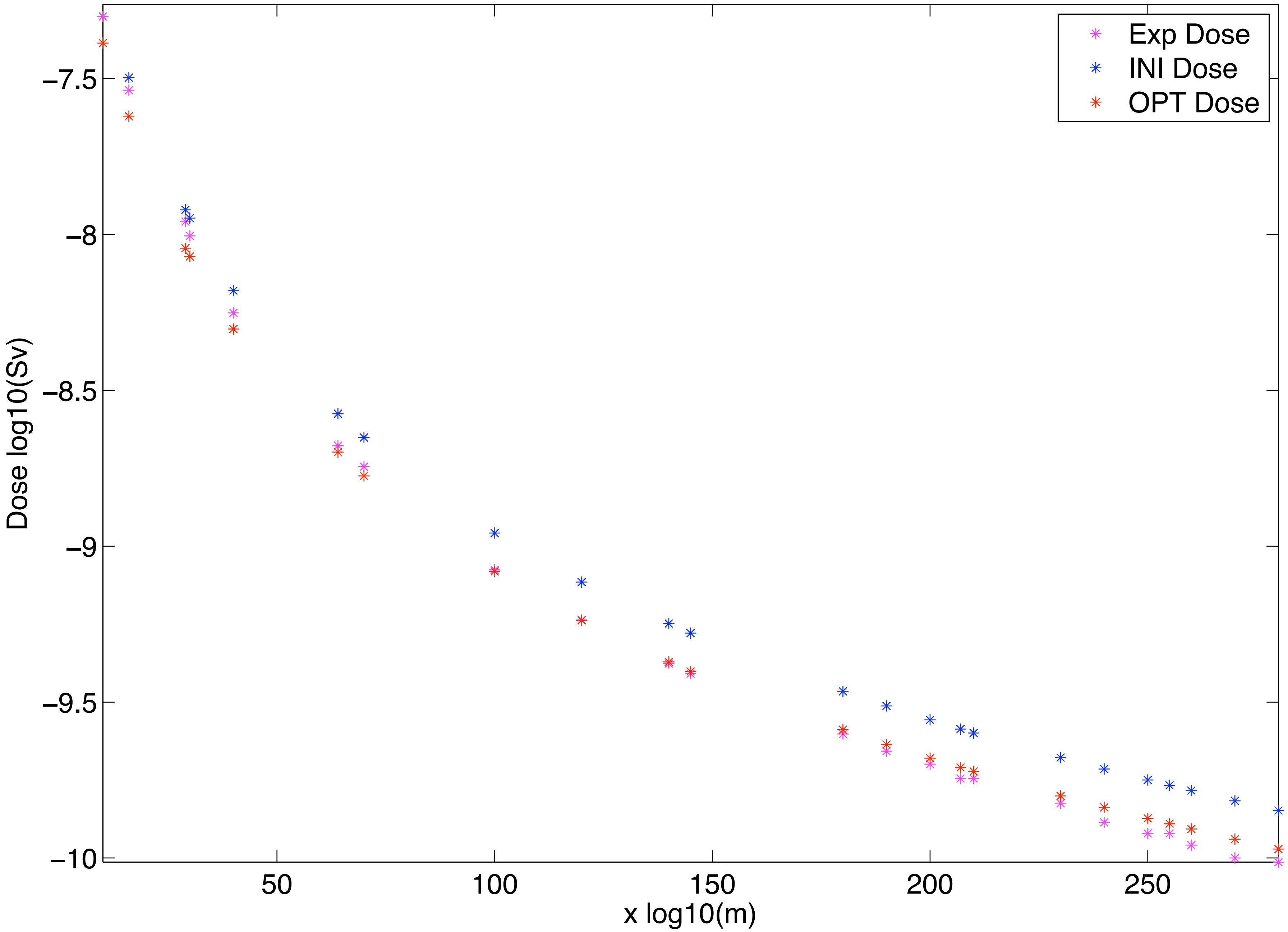
1	573338.11800501496	570000.00000000000	-3338.1180050149560
2	348971.81045471644	350000.00000000000	1028.189545283
3	123771.53738900440	130000.00000000000	6228.462610995
4	115940.33859631824	120000.00000000000	4059.661403681
5	65610.549861342719	68000.000000000000	2389.450138657
6	24991.867137796769	26000.000000000000	1008.132862203
7	20742.875084625062	21000.000000000000	257.1249153749
8	9829.3327847436140	10000.000000000000	170.6672152563
9	6700.8849740578798	6900.0000000000000	199.115025942
10	4844.4895649776836	5000.0000000000000	155.510435022
11	4499.5026392314594	4700.0000000000000	200.497360768
12	2852.9649621150870	3000.0000000000000	147.035037884
13	2545.7964861216942	2600.0000000000000	54.203513878
14	2285.0045575781460	2400.0000000000000	114.995442421
15	2125.2379080010996	2200.0000000000000	74.762091998
16	2061.7740325329546	2100.0000000000000	38.225967467
17	1702.1308755155908	1800.0000000000000	97.869124484
18	1556.1511190830588	1600.0000000000000	43.84888091694
19	1427.9172252346712	1500.0000000000000	72.082774765
20	1369.5773037010044	1400.0000000000000	30.422696298
21	1314.6877891197842	1400.0000000000000	85.31221088021
22	1214.2254259686752	1300.0000000000000	85.774574031
23	1124.6957174068584	1200.0000000000000	75.304282593



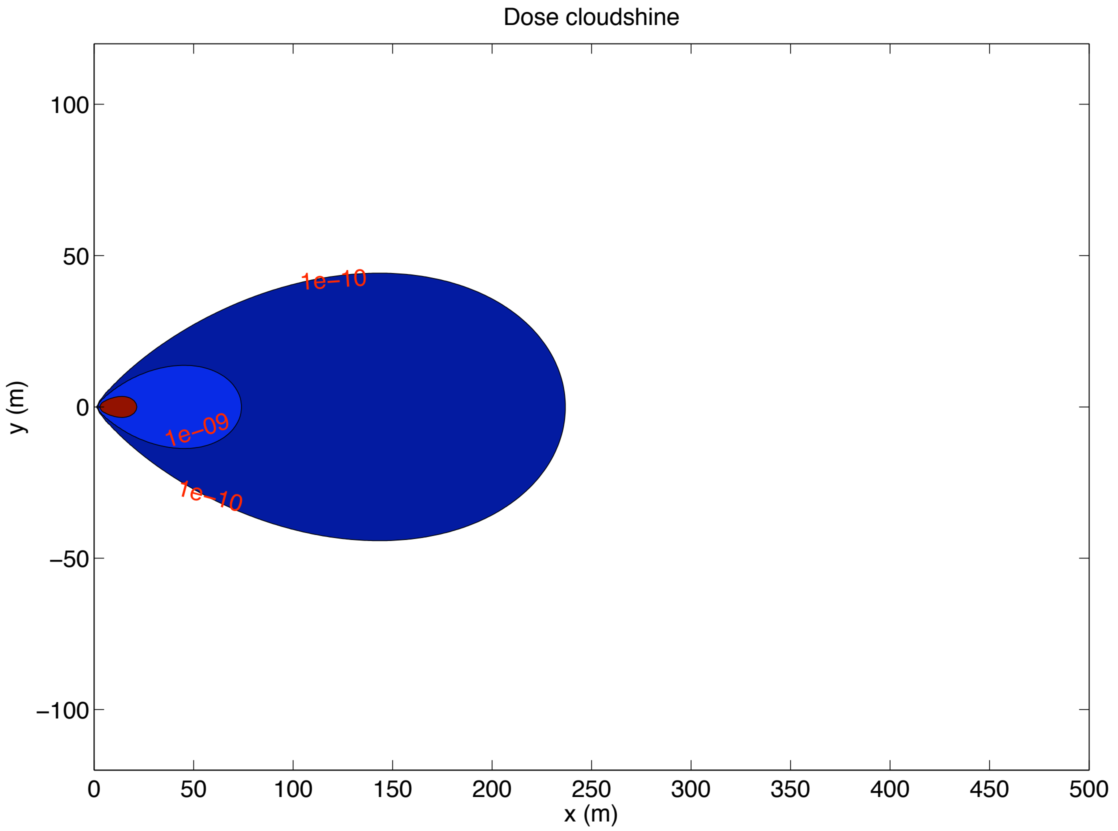
- HOTSPOT CODE and OP_LM_BfS almost identical: the only difference is integration for Depletion factor!
- In OPT_LM_BfS GAUSS integration is used to increase the number of steps during integration. HOSPOT uses trapezoidal rule but no possibility to check it

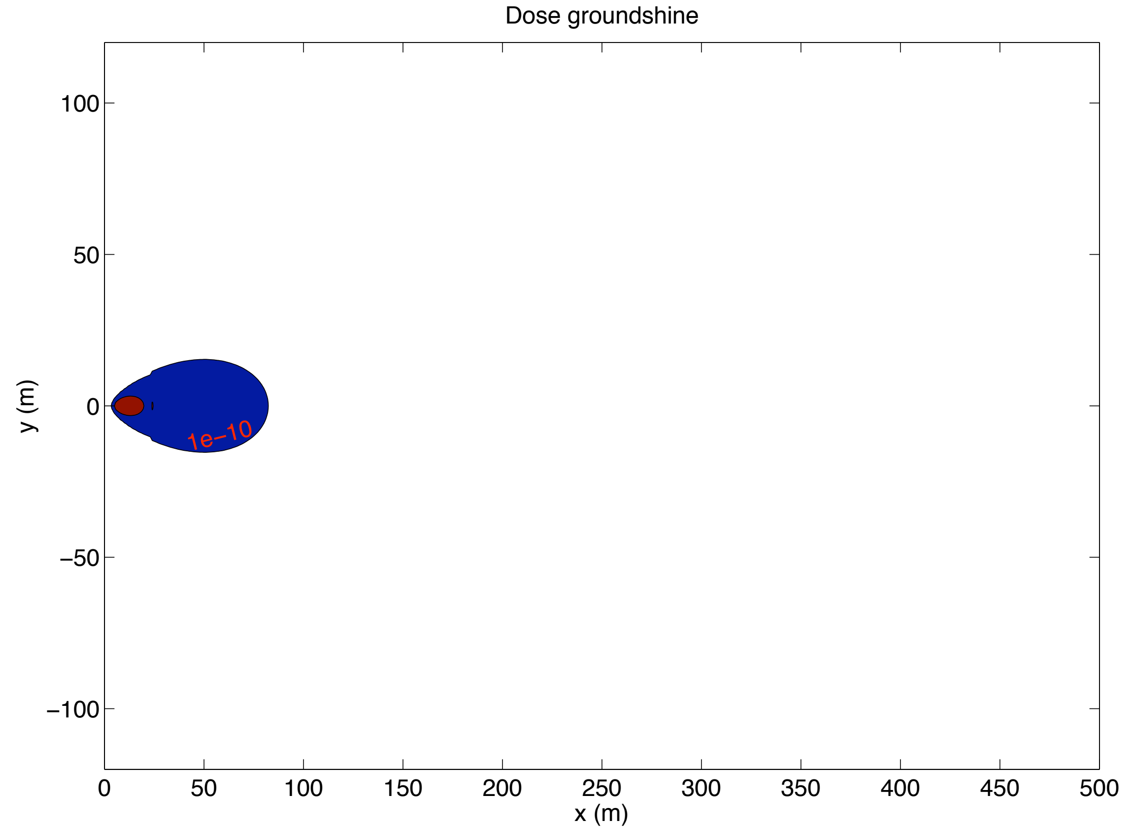
Test data from HOTSPOT: result

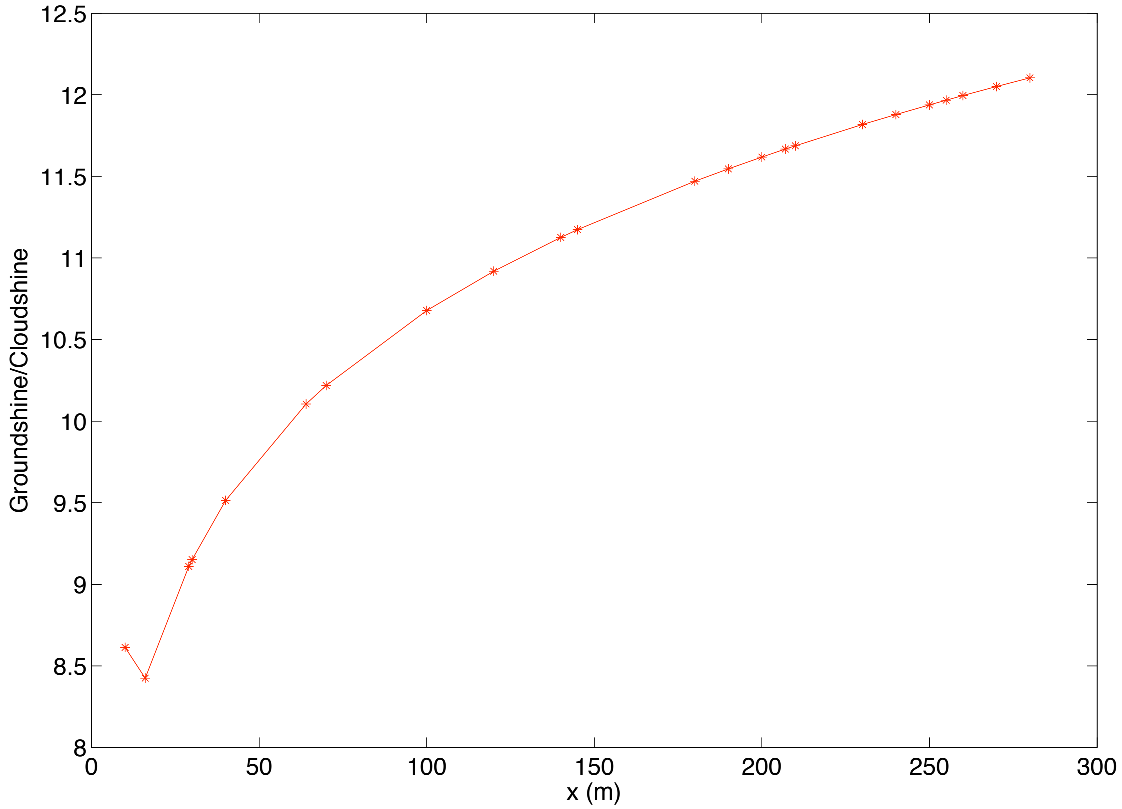
info 1 M 23 N 1 opt_value 436806916.322   NORM   0.216464   unbiased sigmaX 20804118.71 (sigmaX divided by M-N)
convergence achieved after 9 iterations



Test data from HOTSPOT: cloudshine and groundshine







Test data from HOTSPOT: results

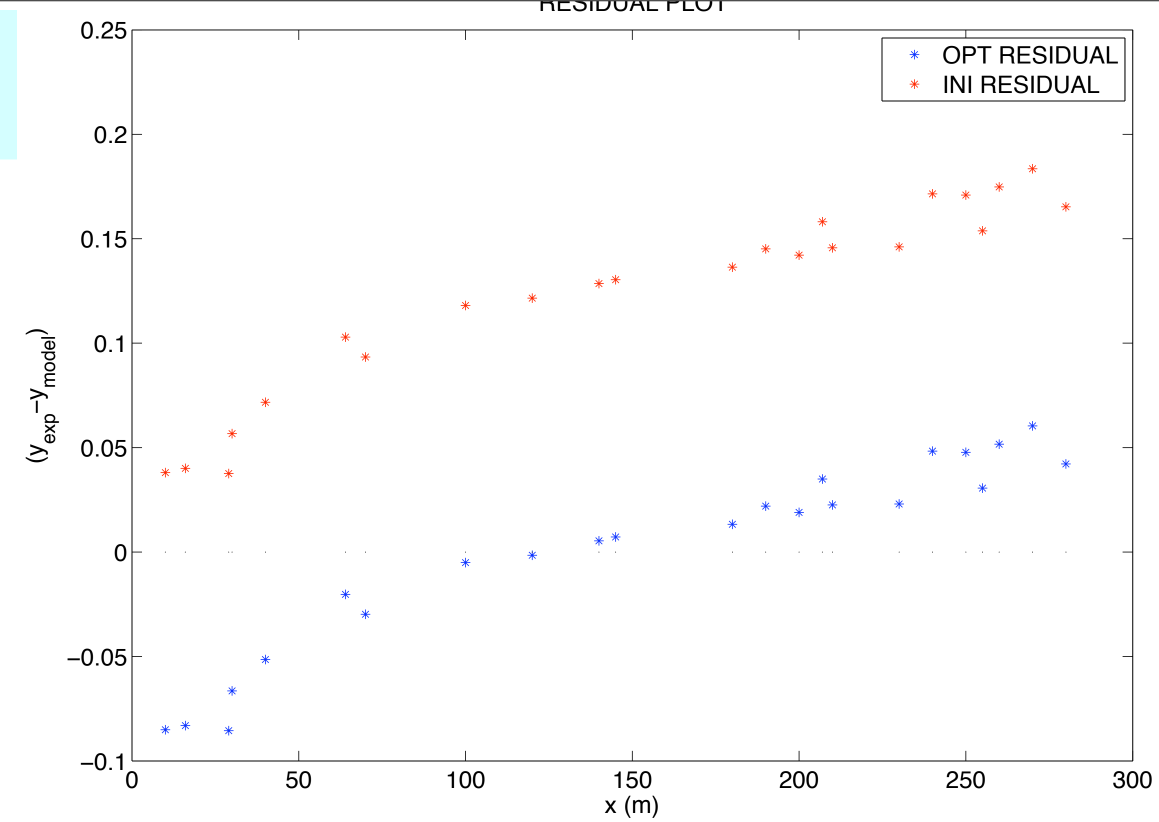
During optimisation, the residuals decrease and mean value goes to zero (1.7 10^{-11})

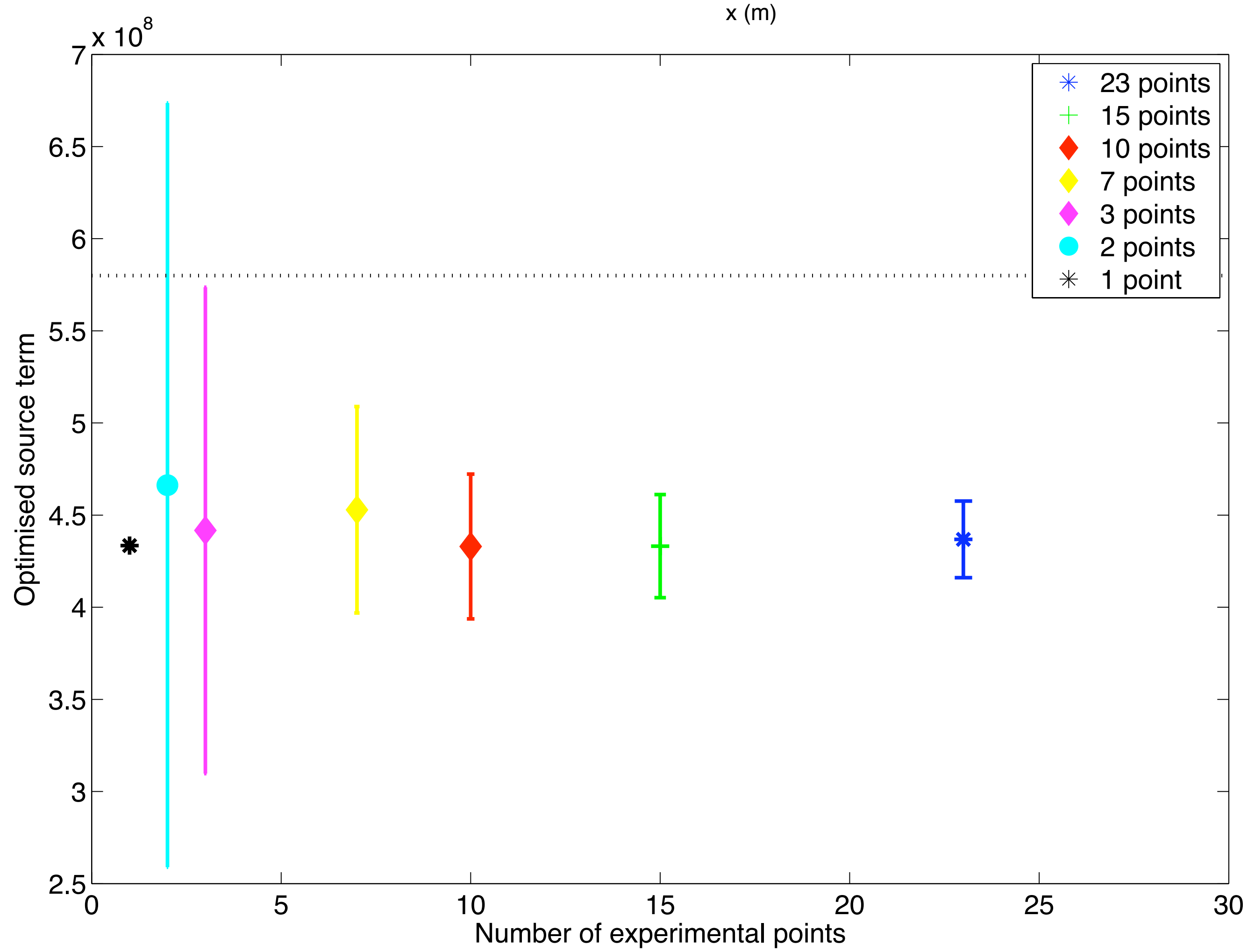
The norm of the residual decreases from 0.62 to 0.26

There is a clear trend in the residual plot - residual is not random!

Uncertainty on source term decreases with increasing the number of points

Small uncertainty in the result of the fit has to be expected as by fixing the meteorological data the ‘shape’ of the curve is fixed



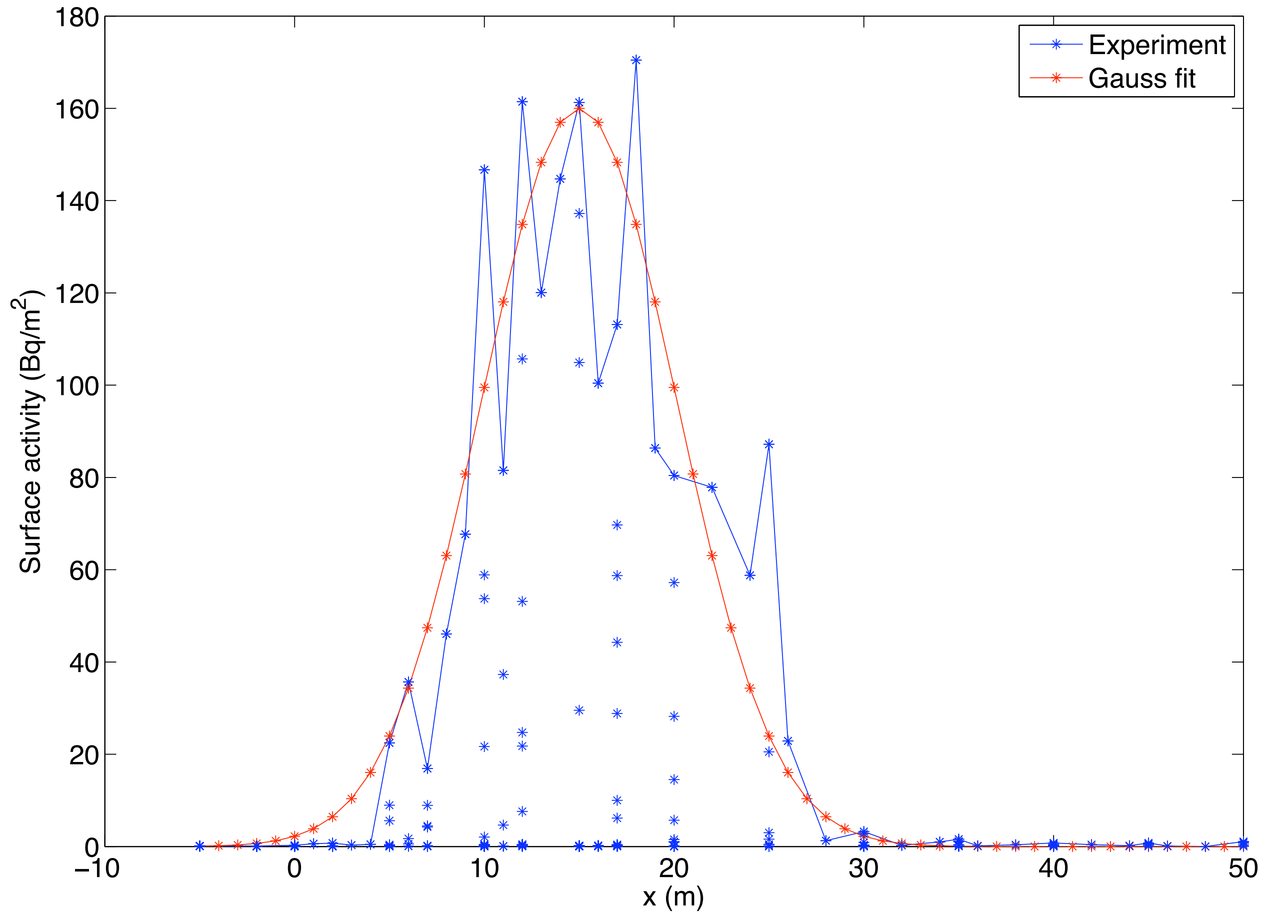


Experimental data from Prouza et al.

TEST 2: 221 measurements of surface activity

&global_para rnuclide='Tc-99m' wind_ref=1.10d0   theta= 0.00d0   stability_class ='B'
H= 5.0d0   vd= 0.01   h_ref=2.0d0 I_rain = 0.0d0 Dt=45.0d0 Qr = 9.10D4/

- large uncertainty on deposition velocity v_d
- Initial source term (measured) is 910 MBq
- Along x-direction, experimental profile of the plume is NOT an exponential
- --> slow wind and clear Gaussian profile suggest diffusive process also in X direction: possibility for users to choose!
- No source partitioning is included
- objective function which is minimised is $\log_{10}(Bdata+1) - \log_{10}(Br+1)$



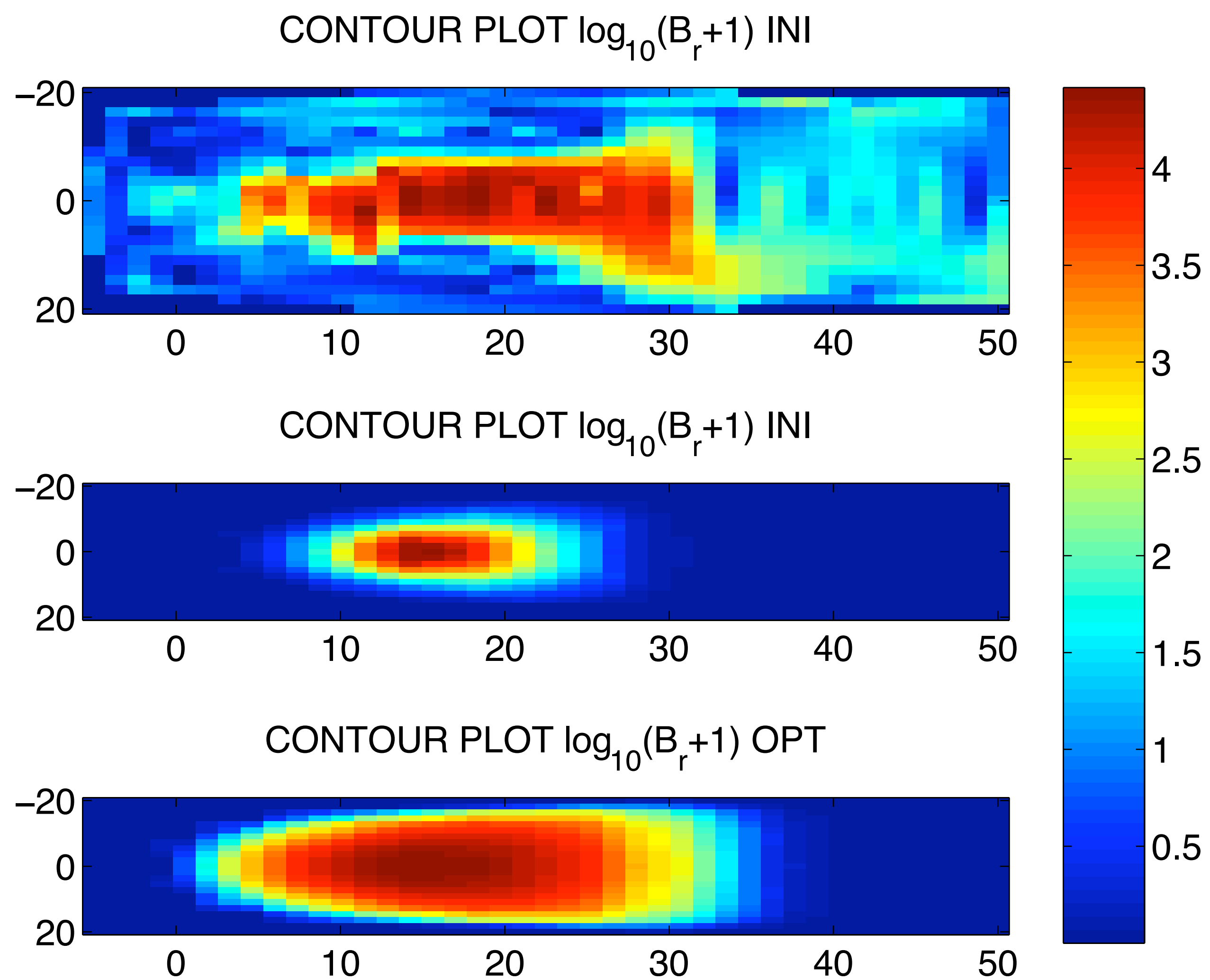
$$diffusivex(x) = e^{-(x-x_0)^2/(2\sigma_x^2)}$$

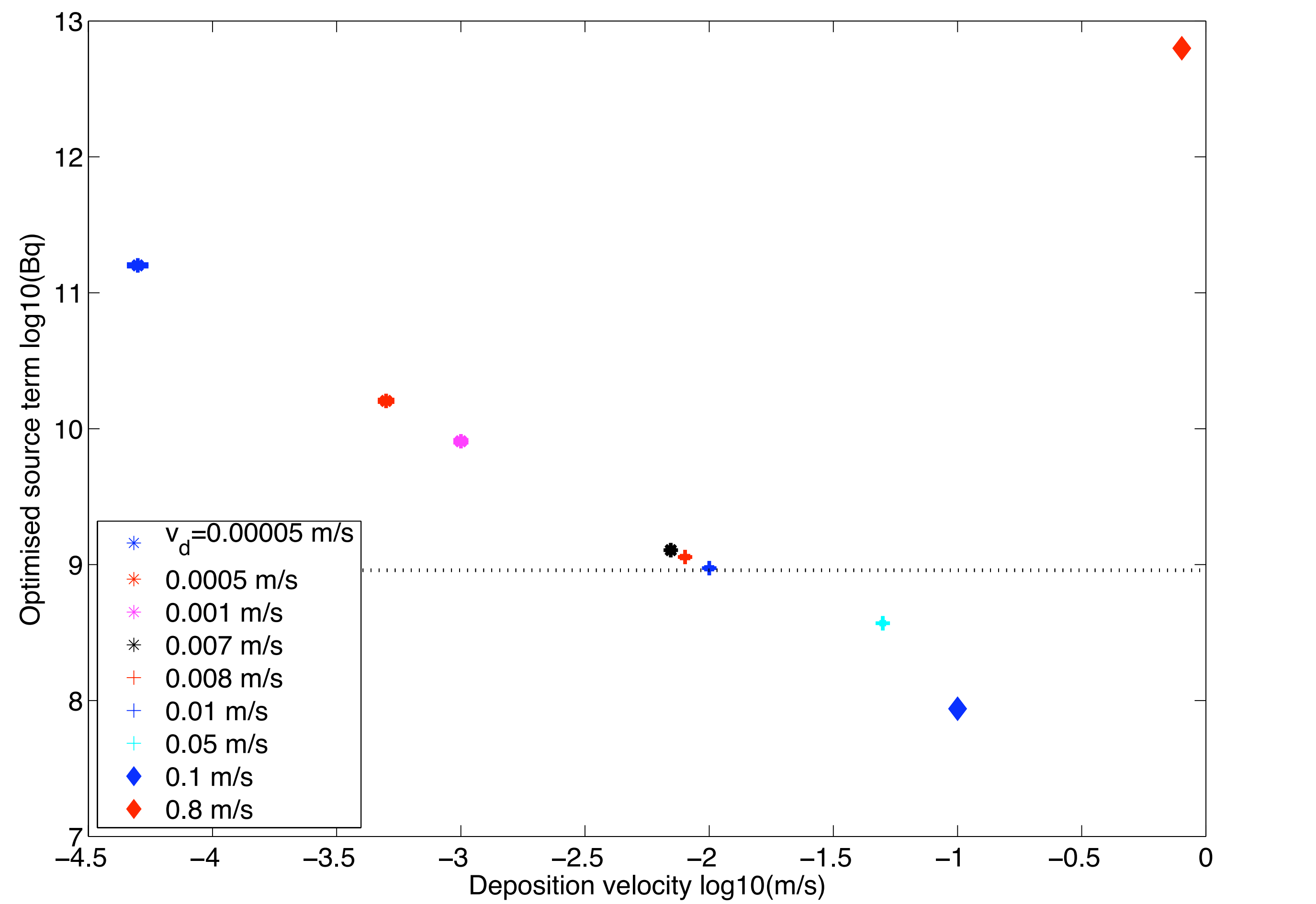
Fitted Gaussian profile
x_0=15 m, σ_x=5.13

Experimental data from Prouza et al.   TEST 2: results

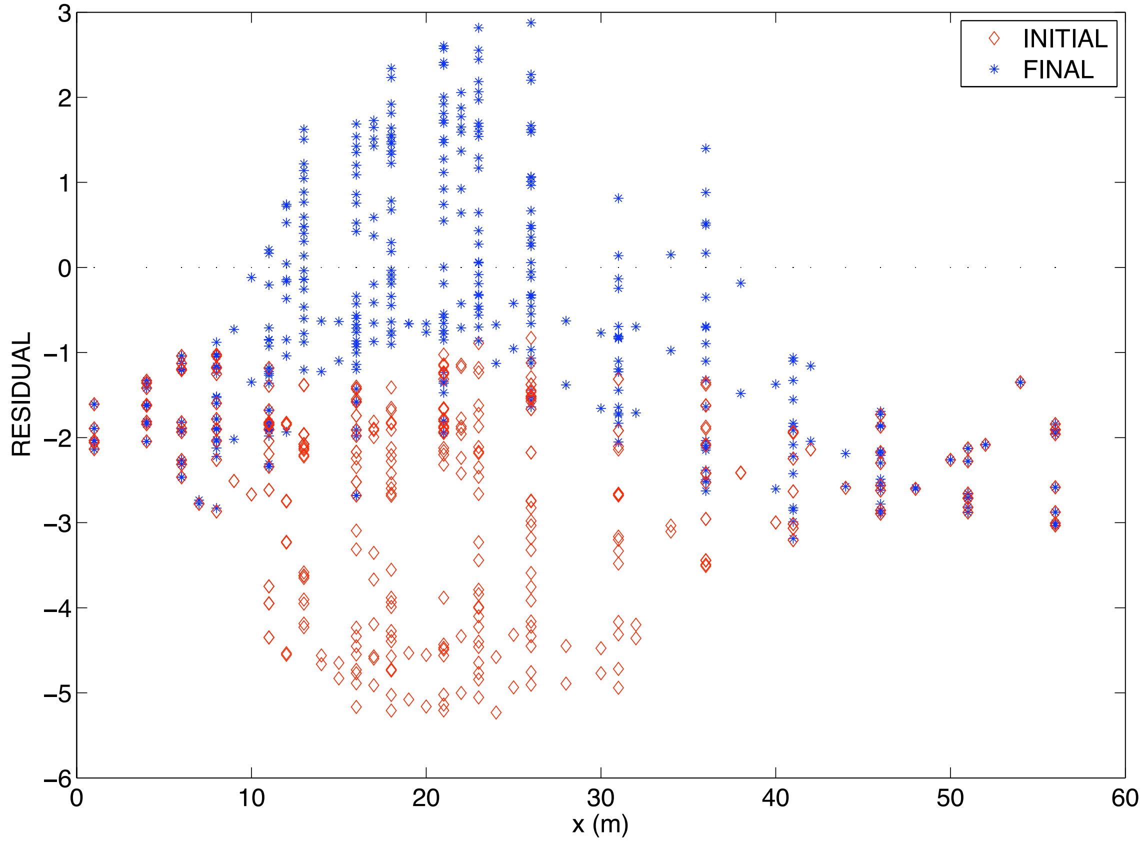
info 1 M 221 N 1
opt_value   941237240.30
unbiased sigmaX 20418567.41

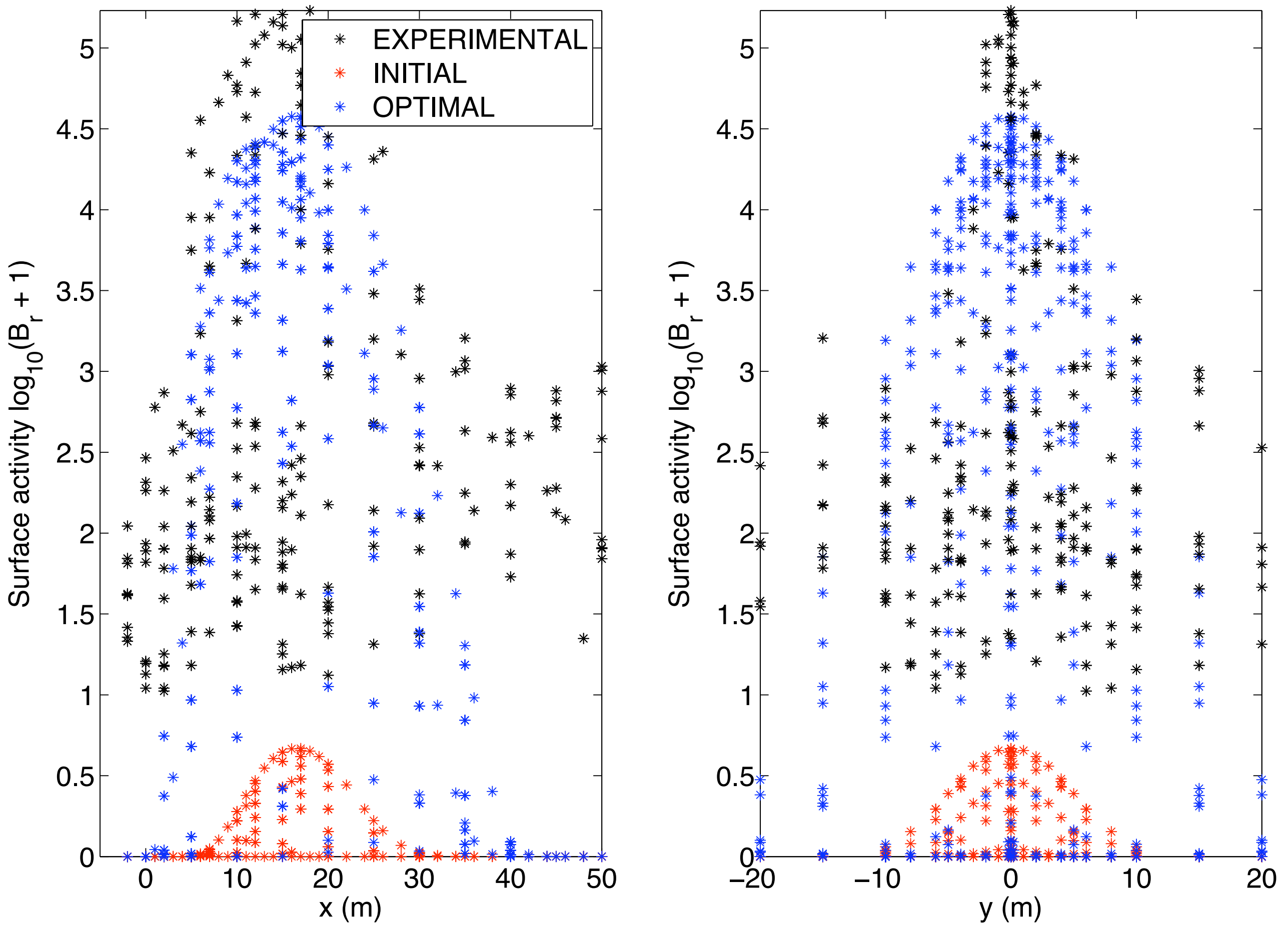
Result strongly depends on deposition velocity
for v_d = 0.8 m/s result is not physical anymore ?





Experimental data from Prouza et al.
TEST 2





The norm of the residual decreases from 40 to 23

The residual clearly follows a trend and is not random but around zero

The standard deviation is very small
....again by fixing meteorological data the form of the curve underlying the fit is fixed!