NEAR SOURCE DEPOSITION OF DIOXINS DURING A SNOW STORM

Guido Cosemans[1], Pierre Geuzens[1], Martine Blondeel[2], Koen Mergaert[2] and Robert Baert[2]

[1]VITO, Mol, Belgium

[2]Environmental Inspectorate Division of the Flemish Government, Brussels, Belgium

Introduction

In late autumn 2008, an extremely high dioxin deposition was measured in the neighbourhood of a sintering plant.

Of the three deposition gauges located near the sintering plant (Figure 1), monthly deposition of dioxins was

- 19 and 29 pg TEQ/m².day at two gauges
- 485 pg TEQ/m².day at the third gauge.

Past dioxin deposition values in the vicinity of this plant were usually between 3 and 26 pg TEQ/m².day.

The Environmental Inspectorate Division (EID) was alerted to quickly find the source and the cause of the extremely high deposition value at the third gauge.

A quick initial investigation of

- data on stack emission concentrations of the sintering plant and meteorological data (Figure 2)
- congener profiles of dioxins in emission and deposition (Figure 3)

led to questions more than answers.

The problem

The Environmental Inspectorate Division asked VITO whether they could give a plausible science based explanation for this high deposition value.

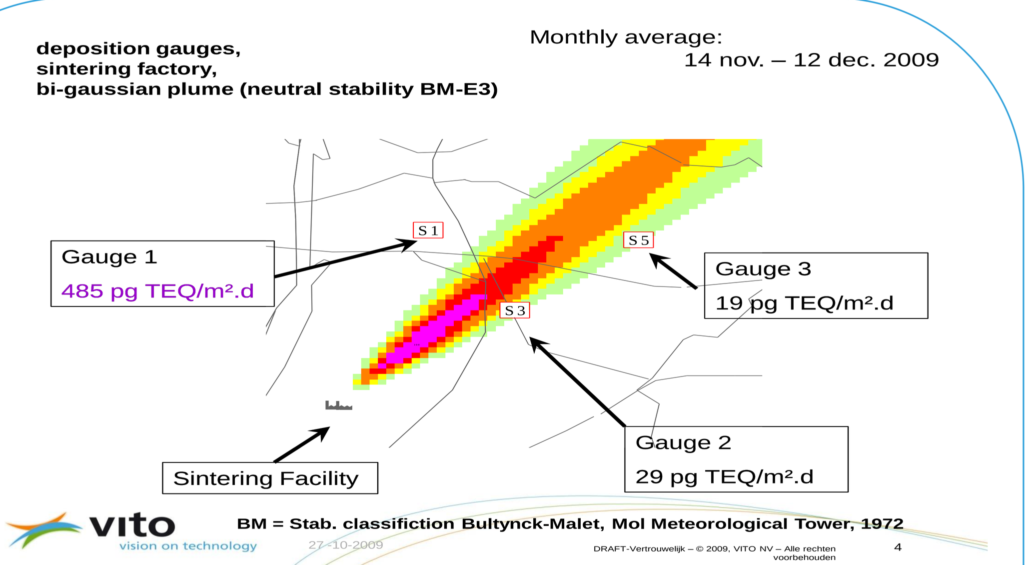


Figure 1

Sintering plant, measured dioxins deposition in gauges S1, S2 and S3 and ground-level concentration profile under the plume axis ± 3 horizontal standard deviation $\sigma_y(x)$ during the 23 November snow storm conditions.

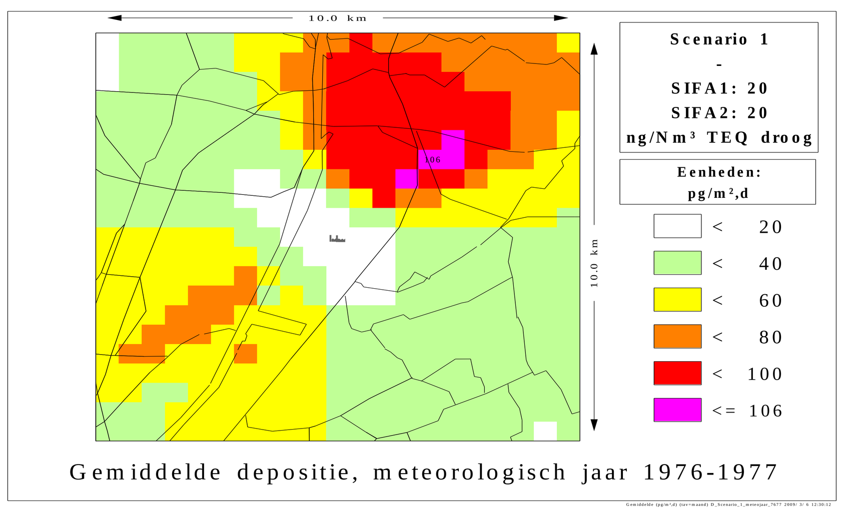


Figure 2

Monthly deposition if two sintering facilities worked all month long without flue gas cleaning.

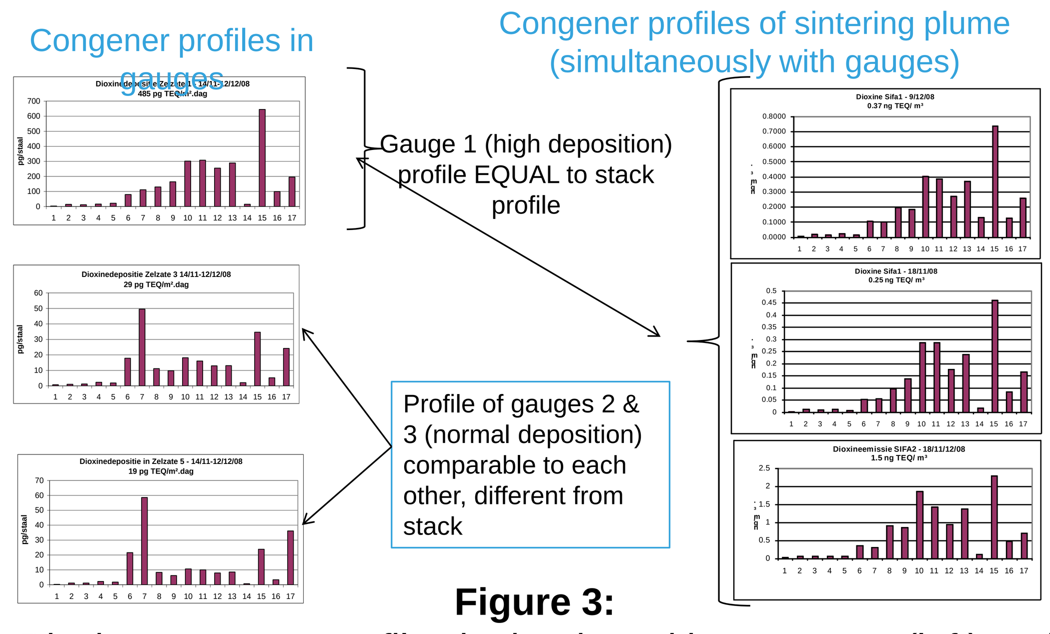


Figure 3:

Dioxins congener profiles in the depositions gauges (left) and in the stacks of the sintering facility (right)

1	2,3,7,8-TCDD	**7**	OCDD	**13**	2,3,4,6,7,8-HxCDF
2	1,2,3,7,8-PeCDD	**8**	2,3,7,8-TCDF	**14**	1,2,3,7,8,9-HxCDF
3	1,2,3,4,7,8-HxCDD	**9**	1,2,3,7,8-PeCDF	**15**	1,2,3,4,6,7,8-HpCDF
4	1,2,3,6,7,8-HxCDD	**10**	2,3,4,7,8-PeCDF	**16**	1,2,3,4,7,8,9-HpCDF
5	1,2,3,7,8,9-HxCDD	**11**	1,2,3,4,7,8-HxCDF	**17**	OCDF
6	1,2,3,4,6,7,8-HpCDD	**12**	1,2,3,6,7,8-HxCDF		

Given that:

1) 20 year of spring and autumn monthly deposition data =>

2) *the probability for such high deposition is less than 1 upon 10^{27}*

In other words:

3) the high deposition is not due to
   A) 'normal operations' and
   B) 'normal atmospheric transport & dispersion conditions'

4) As scientists, we can only verify whether **B** during the measurement period were 'normal' or not.

5) -> Exceptional 3 hour heavy snow storm in autumn 2008

6) during which the wind blew straight from the stack to the deposition gauge.

7) The snow storm lasting three hours, with winds (at 30 m) of 10 m/s which resulted in a blanket of snow 15 cm deep. During the snowfall, ambient temperature was 3 to 5 °C above zero, resulting in large snowflakes.

Question: what can we tell on the potential impact of snow on the deposition of dioxins ?

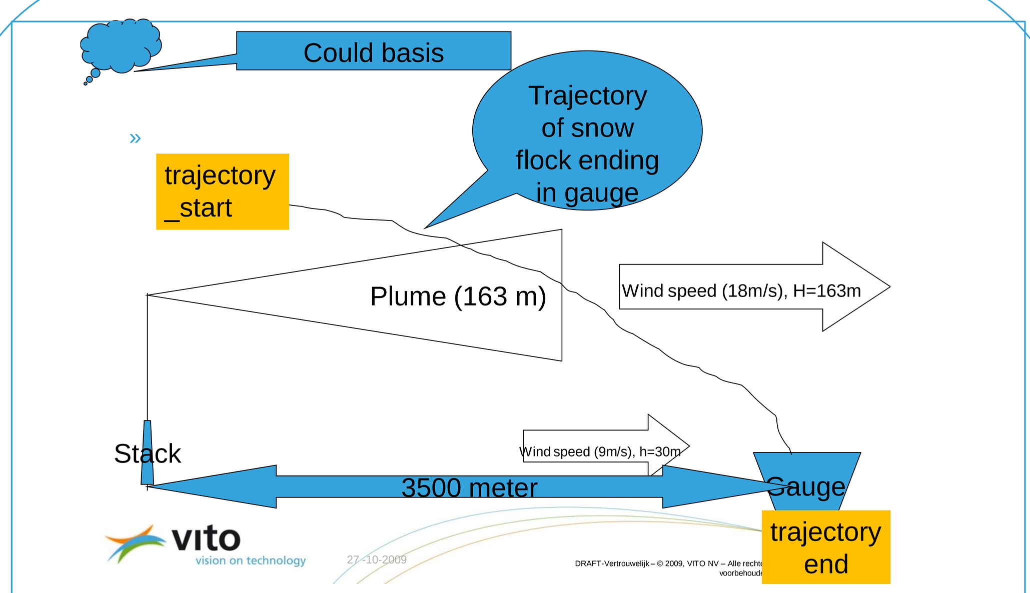
Idea: let's try to treat each falling snow flock as an fractal area upon which dry deposition of dioxins takes place

Something about snow

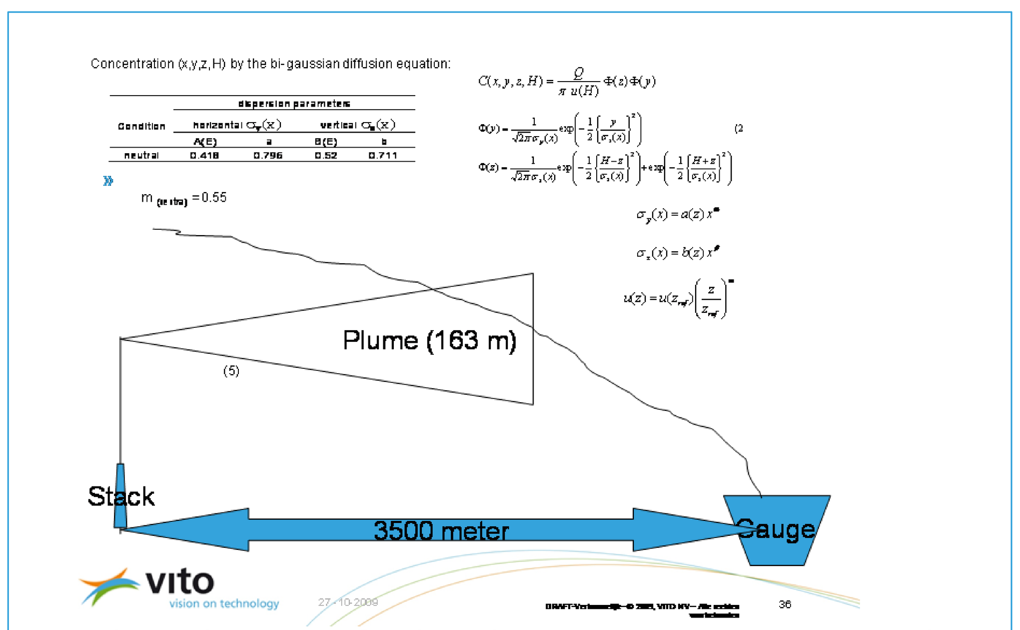
Quantifying the number and the area of snow flakes fallen

1. The snow cover after the storm was 15 cm. This is 5 cm per hour, and corresponds to 0.05 m³ fallen snow per square meter.
2. The density of falling snow is one tenth of that of fallen snow. Consequently, snowflakes have carried down 0.5 m³ of air, most of it while falling from cloud basis to the ground.
3. Cloud basis for subsequent calculations is taken to be **224 m**. The terminal fall speed of large snowflakes is **1 m/s**.
4. So, exposure time of a snowflake to the material in the plume between cloud basis and ground is **224 seconds**;
5. Pluviometers reported a precipitation of 12.5 litre for the snow storm. Hence snow fall was equivalent to 4100 g H_2O/m².h.
6. Assuming that the snowflakes were cubes with sides of 2 cm, their volume is 8 cm³.
7. The density of falling snowflakes this large is between 0.01 g/cm³ and 0.005 g/cm³.
8. Using a density of 0.005 g/cm³, the weight of a single snowflake is 0.04 g.
9. A cube has six sides, 4 cm² each. So a single snowflake has an area of 24 cm² or **0.0024 m²**.
10. In order to have an hourly precipitation of 4100 g/m², it takes 102 500 snowflakes of 0.04 g each to fall.
11. The sum of the areas of these 102 500 snowflakes then is 246 m².

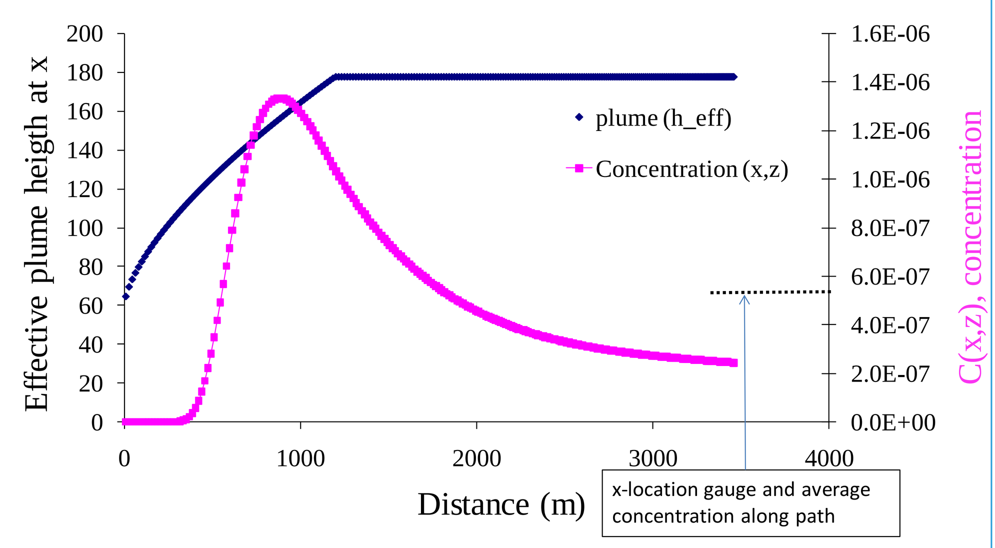
Deposition on falling snow flocks



Given the vertical wind speed profile, the trajectory of the snowflakes that fall into the gauge can be constructed on condition that the falling speed is known. (It is 1 cm/s.)



Given the snow flock trajectory, we can calculate the concentration of dioxin along each point of that path. (IFDM-model)



the average concentration along the path of such a snow flake is **357 fg TEQ/m³**.

The amount of dioxins, collected by a single snowflake during its fall from 224m high to the ground , is given by:

time_of_fall [s] * area_of_snowflake [m²/flake] * dry_deposition_speed [m/s] * average concentration [fg TEQ/m³] =

224 [s] * **0.0024 [m²/flake]** * 0.01 [m/s] * **357 [fg TEQ/m³]** = 1.92 fg TEQ

So, in one hour, with 102 500 snowflakes falling per square meter, this gives 196.7 pg TEQ/m².hour. This deposition was assumed to take place on the sides of a 2x2x2cm cubic snowflake.

However, snowflakes have a fractal area

In order to obtain the required hourly deposition of 4850 pg TEQ/m².hour, a fractal surface (suitable for dry deposition) that is 25 times larger than the smooth surface of a mathematical cube is required. This seems to be OK.

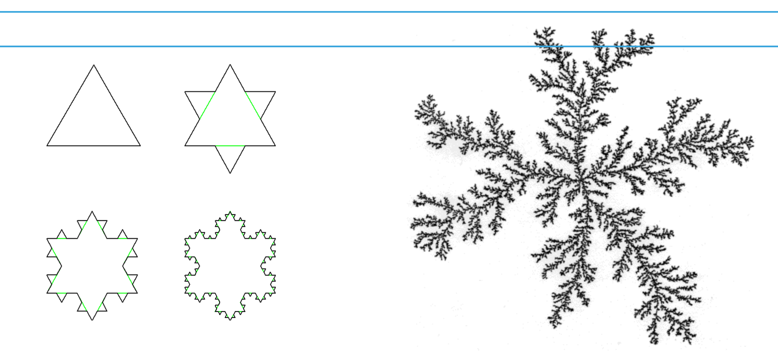


Figure 4: Left: first 4 iterations of the Koch snowflake curve. After N iterations , the length of this curve is $(4/3)^N$

Right: Diffusion limited aggregation snow/fern like structure.

VITO NV
Boeretang 200 – 2400 MOL – BELGIUM – Tel. + 32 14 33 55 11 – Fax + 32 14 33 55 99 – vito@vito.be – www.vito.be