Atmospheric transport and deposition of coarse solid particles: relations with PBL (and underlying terrain)

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Basic: turbulent dispersion depending on PBL stability

Flux of a passive admixture to the surface:

$$J = \overline{w'C'}$$

Or in gradient-transfer theory formulation:

$$J = -K_{(h)}\,\partial C / \partial z$$

Often taken the same *K* as for heat:

$$H = -K_h \rho c_p\, \partial \overline{\theta} / \partial z \quad \text{or} \quad H = \rho c_p\, \overline{w'\theta'}$$

Briggs' dispersion parameters:

"Old stuff", but still useful in many cases.

For idealised Gaussian dispersion $\sigma_i=(2K_i t)^{1/2}$ for plume

$$C = \frac{Q}{2\pi\sigma_z\sigma_y u}\exp\left[-\frac{y^2}{2\sigma_y{}^2}-\frac{(z-H)^2}{2\sigma_z{}^2}\right],$$

but real stratification makes certain correctives and therefore Briggs (1970's) proposed on experimental basis, e.g. for open country for small releases (0.1 < x < 10 km):

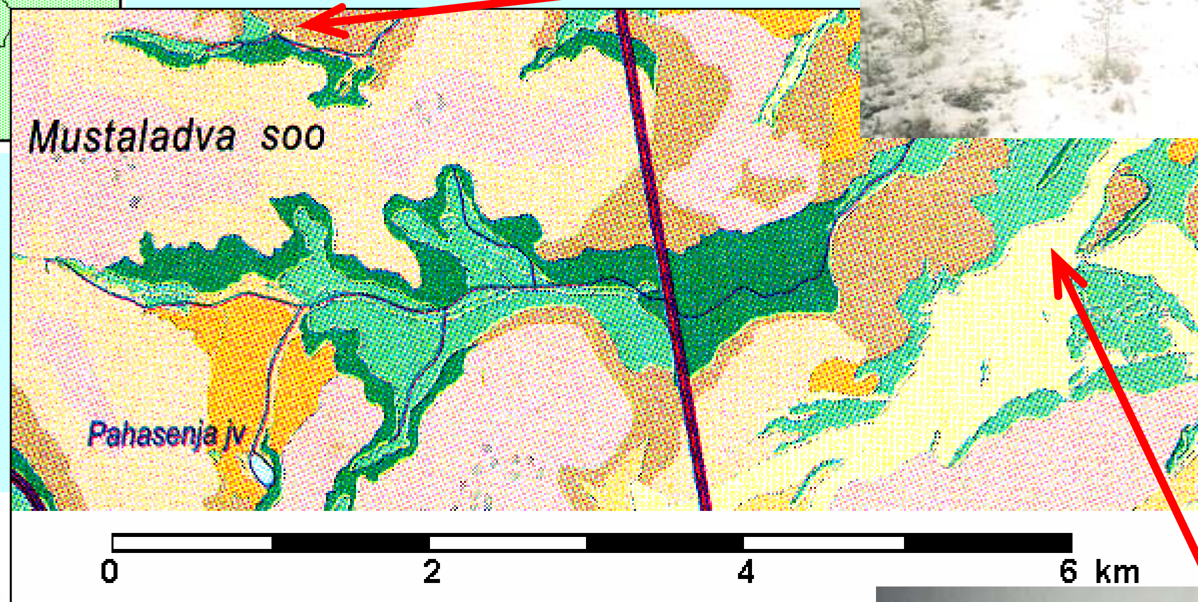
$\sigma_z = 0.06x(1+1.5x)^{-1/2}$ Pasquill stability "D"

$\sigma_z = 0.03x(1+0.3x)^{-1}$ Pasquill stability "E"

$\sigma_z = 0.016x(1+0.3x)^{-1}$ Pasquill stability "F"

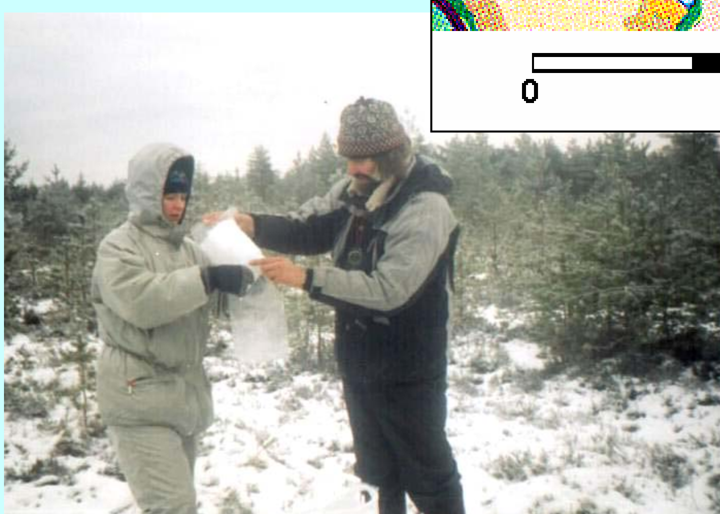
Research area and method, December 2 – 14, 2002

Background site

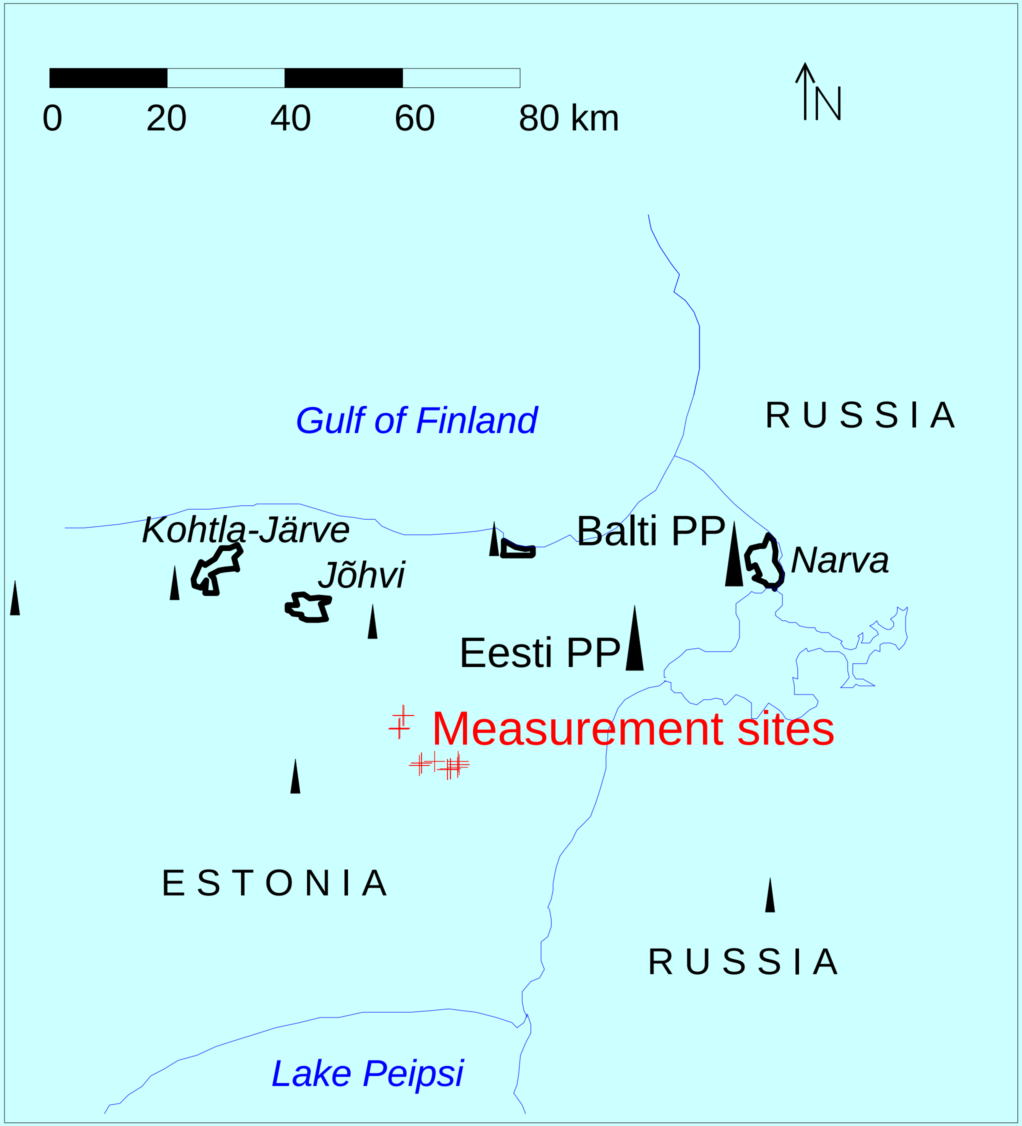


Bog with sparse trees ☞

Open bog ☞



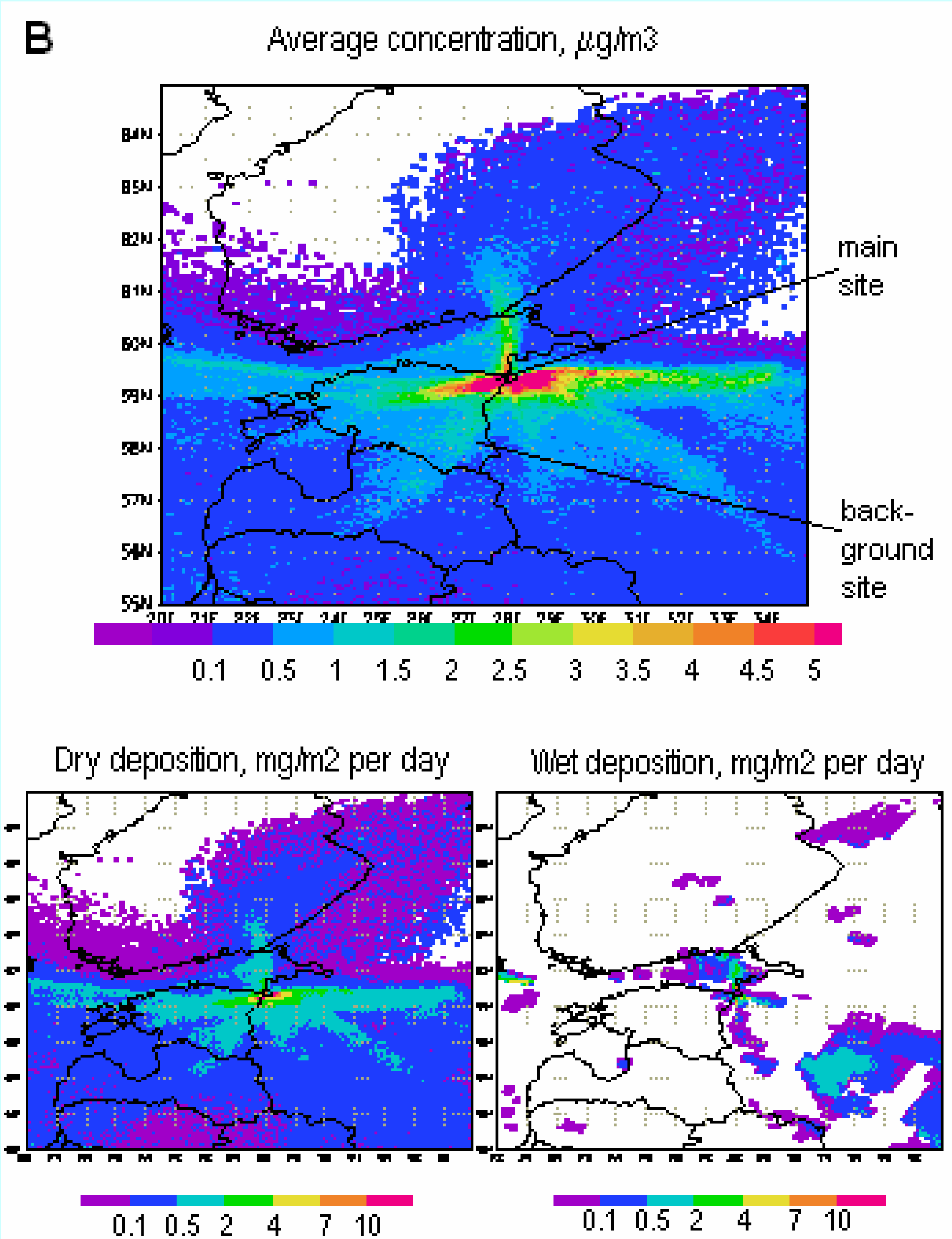
☜ Snow sampling



Location of snow sampling sites, Narva power plants (PP-s) and minor industrial sources

Deposition fluxes (average and standard deviation) of fly ash estimated from measurements and computed applying SILAM, December 2 – 14, 2002. Number of samples is indicated in brackets.

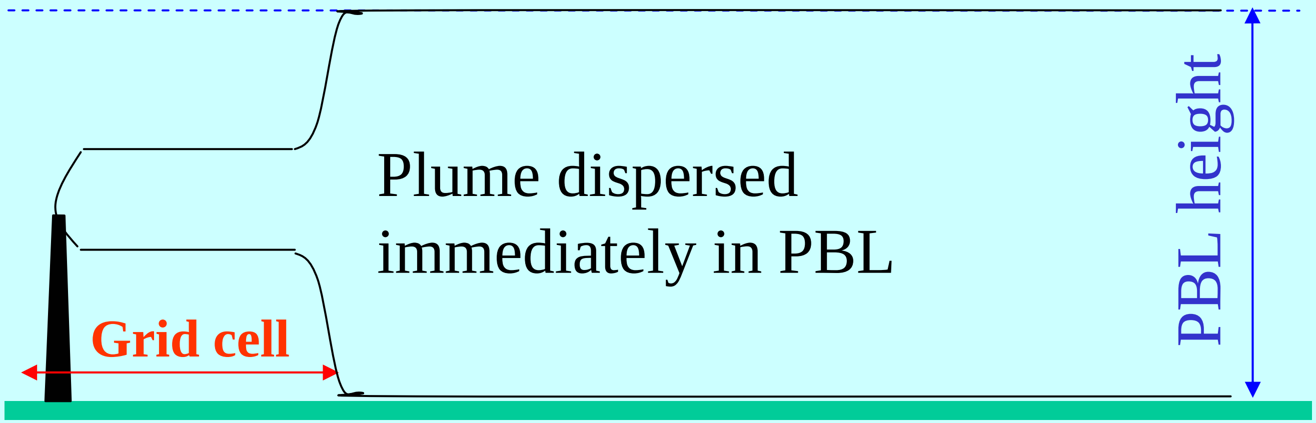
Site type (number of samples)	Measured deposition flux, mg/m^2 per day, based on:						SILAM:			
	Ca^{2+}		spheroidal particles		total mass		deposition flux, mg/m^2 per day		concen-tration, $\mu g/m^3$	
Woodland (6)	29.0	±4.5	30.2	±5.4	25.6	±2.2	3.7	±0.3	6.0	±0.5
Open land (5)	28.3	±3.6	38.5	±4.1	26.5	±1.7	3.7	±0.3	6.0	±0.5



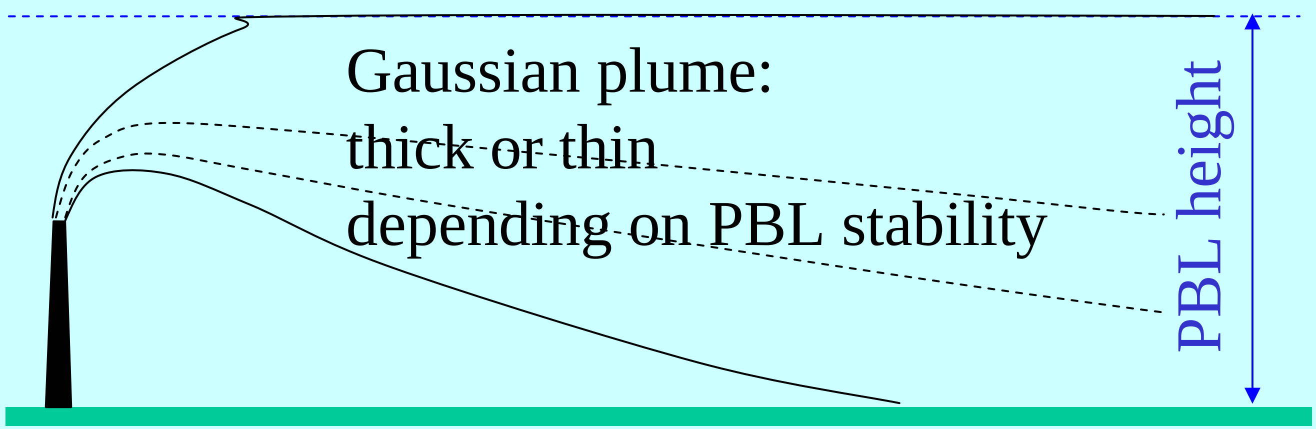
SILAM dispersion and deposition, HIRLAM meteo

December 2 – 14, 2002

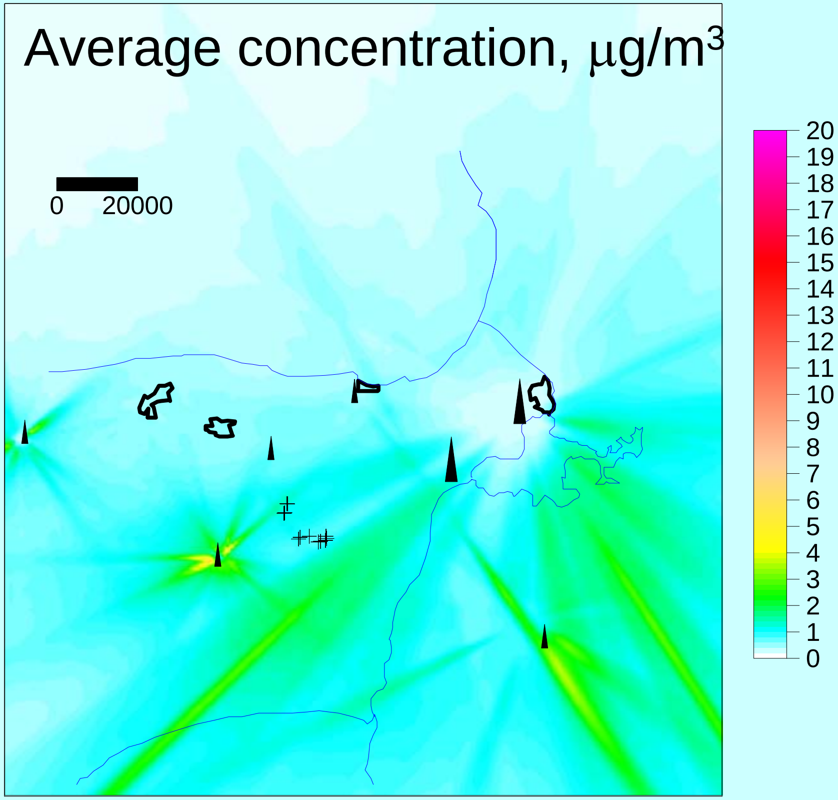
Vertical dispersion

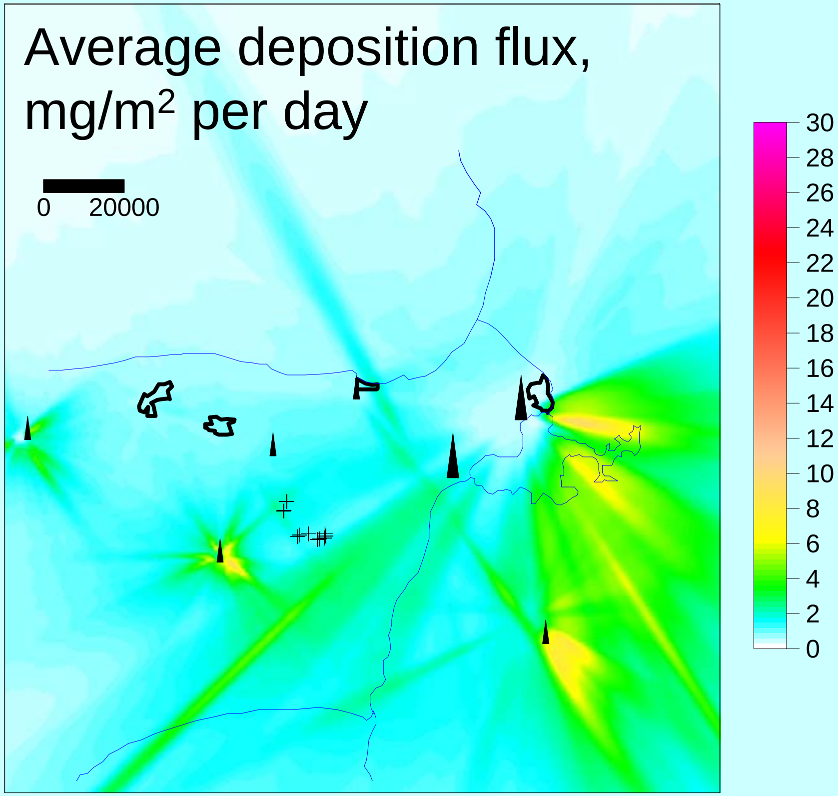


SILAM (FMI, Finland)



AEROPOL (Tartu Observatory, Estonia)

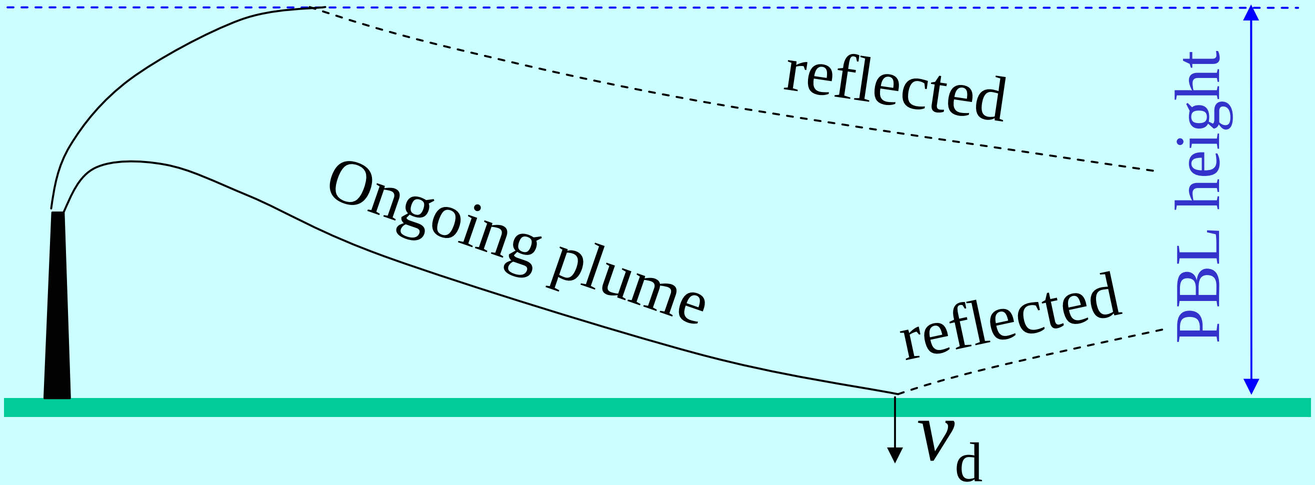




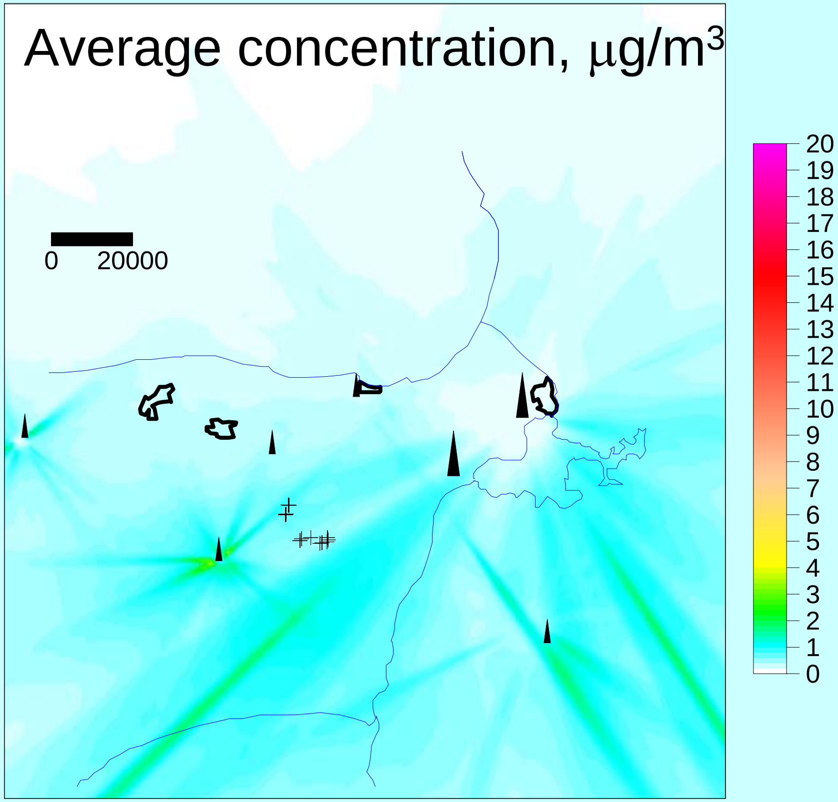
AEROPOL:

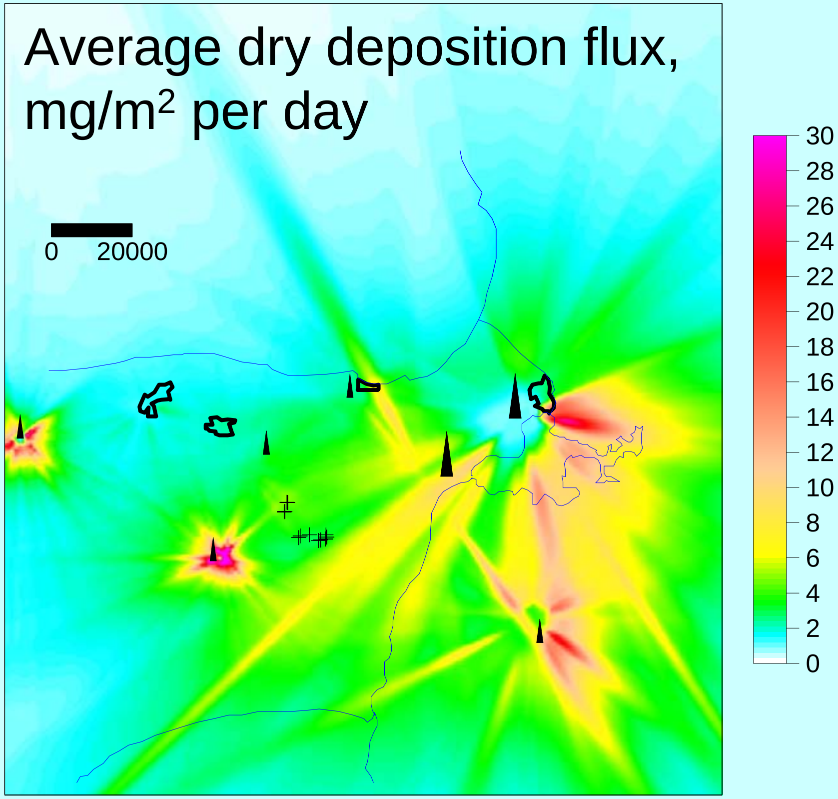
HIRLAM meteo, Gaussian reflection with gravitational sedimentation only, 8.15 μm ash particles (ρ = 2800 kg/m^3).

Reflection, partial or complete adsorption?



$$\left[K_z \frac{\partial C}{\partial z} + v_d C \right]_{z=0} = 0$$





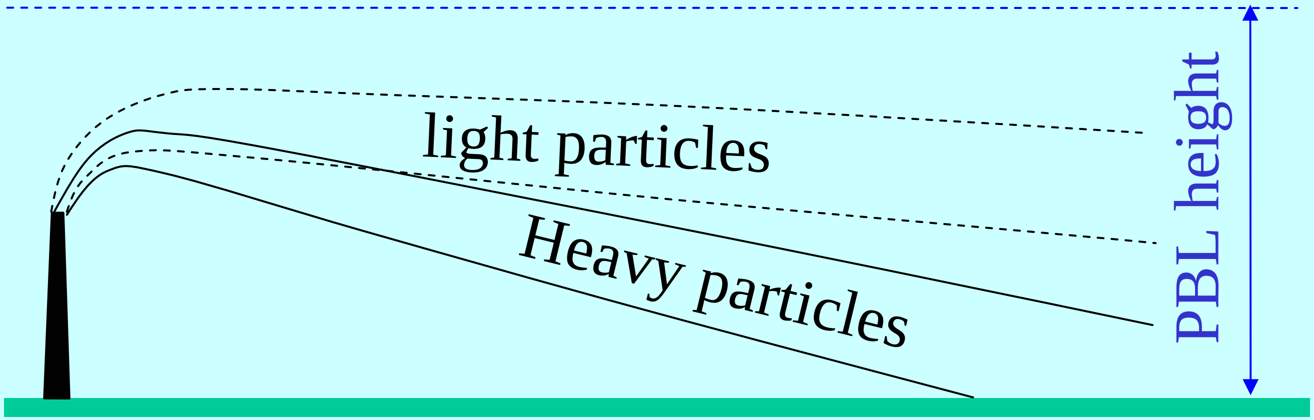
AEROPOL:

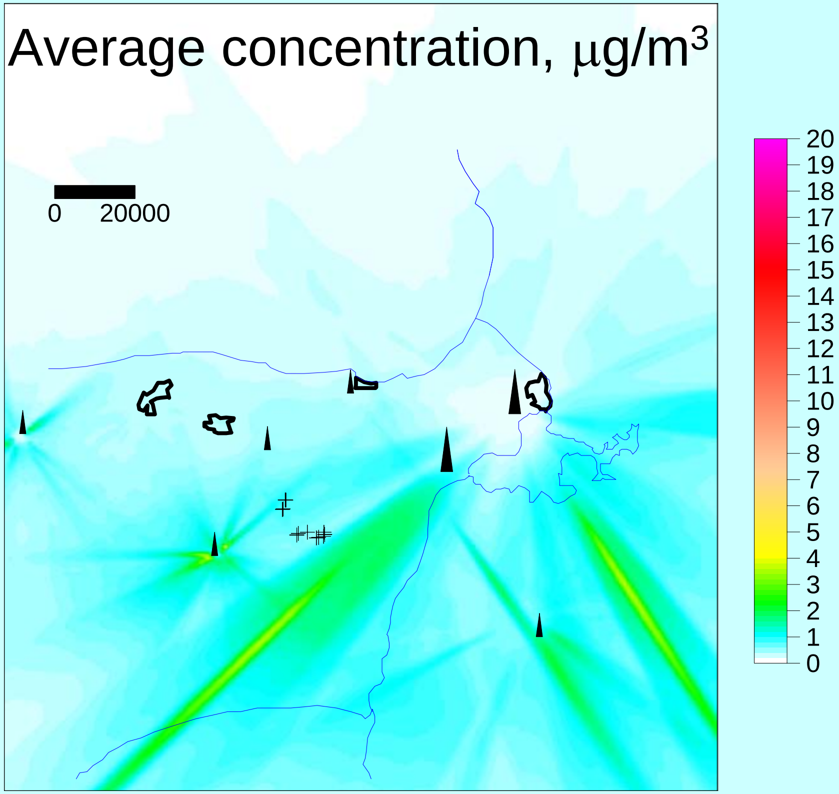
HIRLAM meteo, complete Gaussian adsorption, gravitational sedimentation and vertical flow, 8.15 μm ash particles (ρ = 2800 kg/m^3).

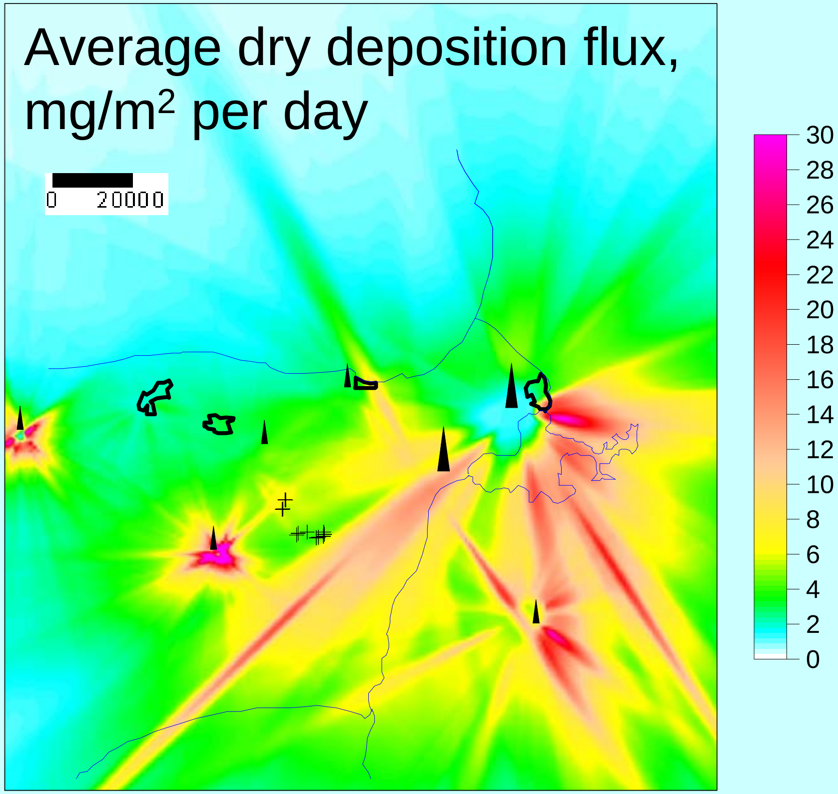
What a kind of particles?

The main admixture in flue gases is water vapour – about 60 g/m^3 or 30 times more than fly ash.

Cooling rapidly from +300 ºC down to -10…-20 ºC that water most likely gets frozen onto the particles making them much larger. v_d must increase.

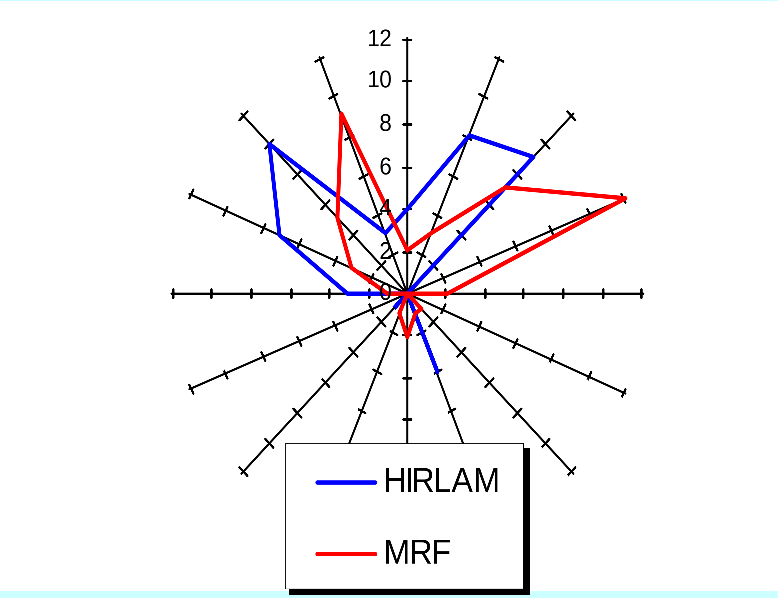


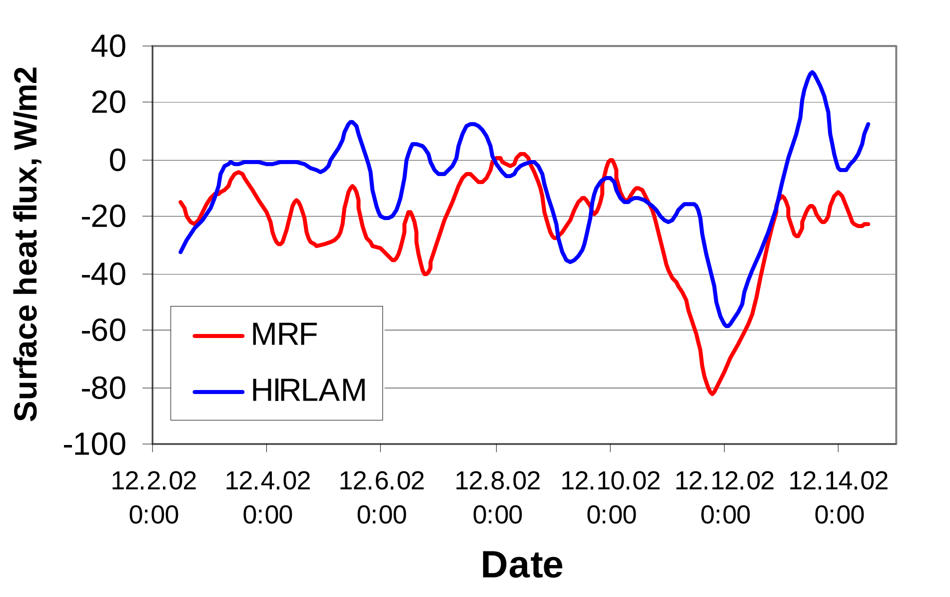




AEROPOL:
HIRLAM meteo, complete Gaussian adsorption, gravitational sedimentation and vertical flow, 25 μm ice/ash particles (ρ = 1000 kg/m^3).

Are HIRLAM met. data correct?



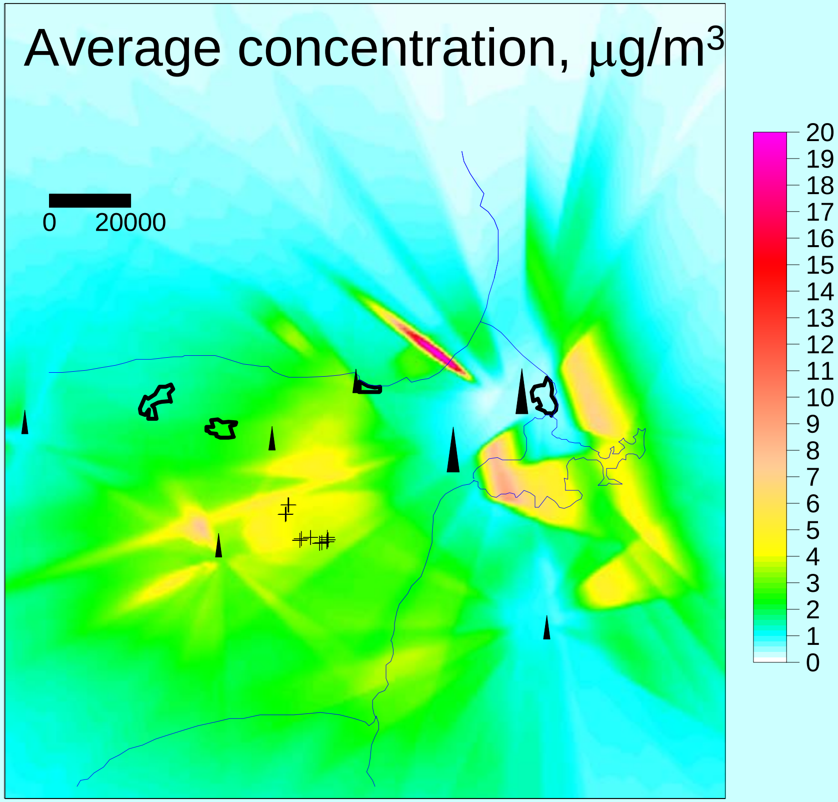


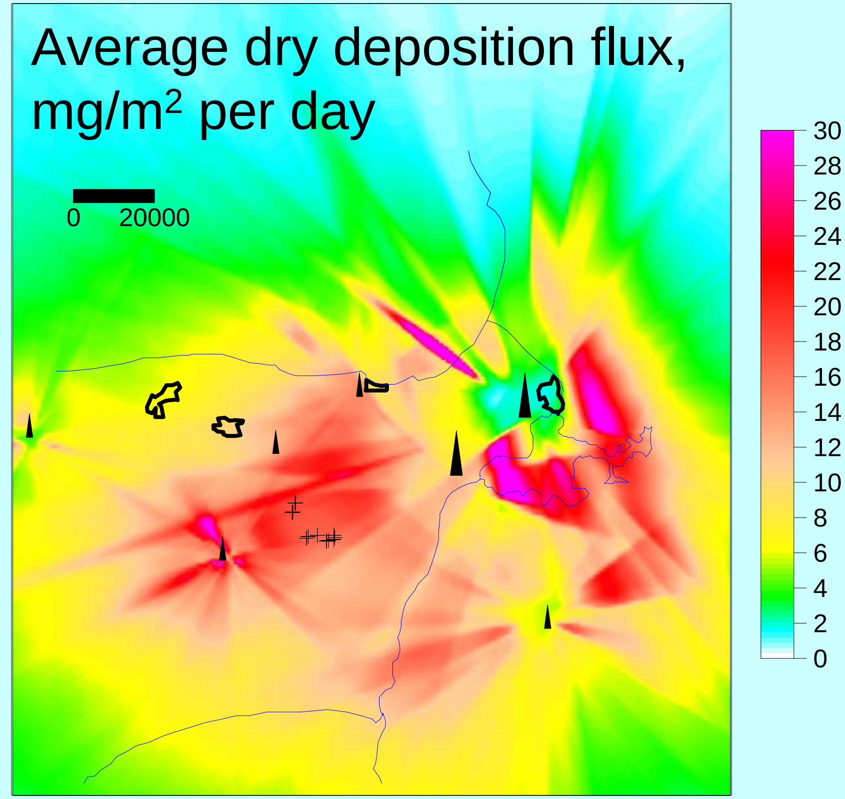
Wind roses

Surface heat fluxes

(MRF - http://www.arl.noaa.gov/ready)

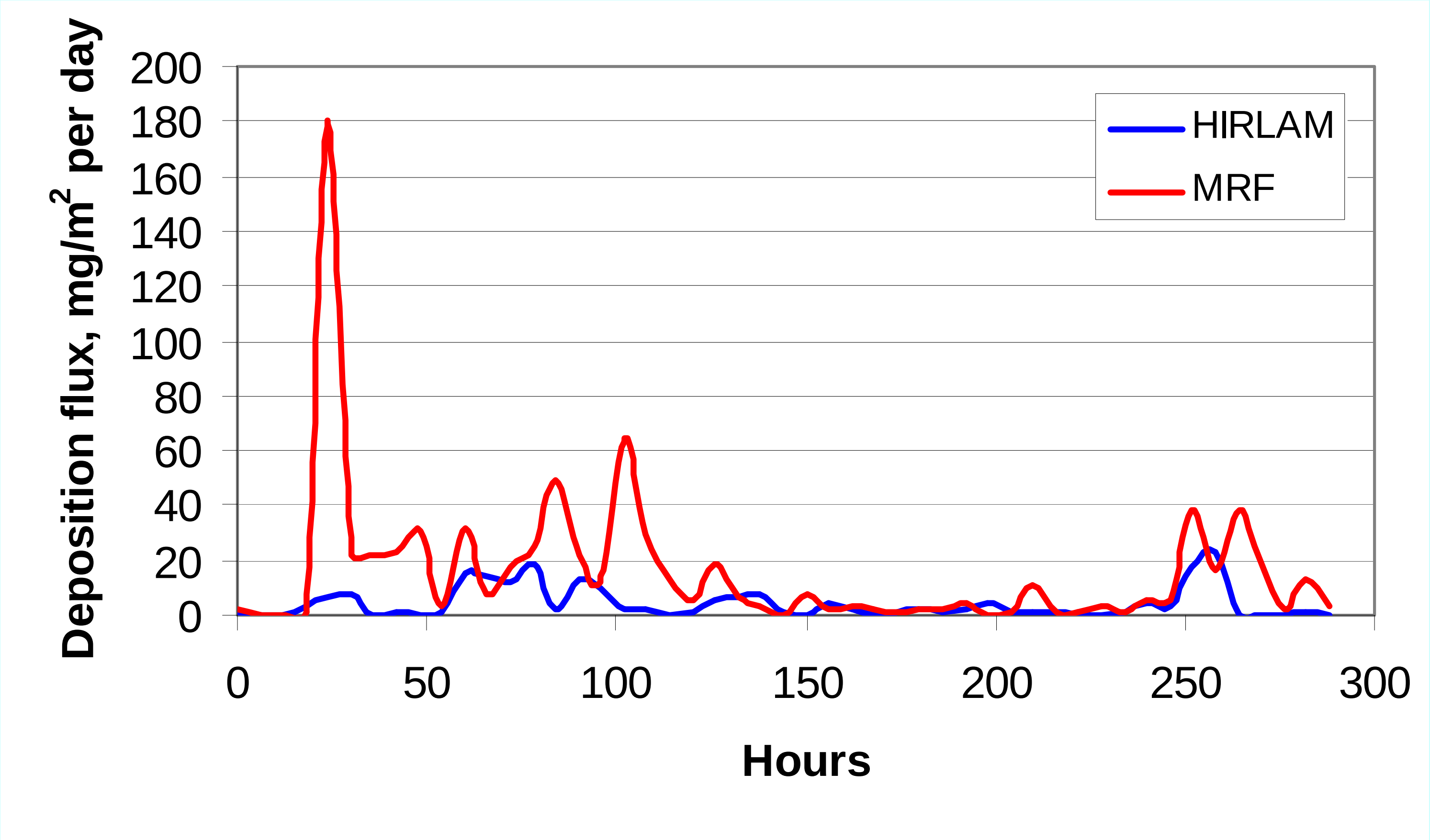
HIRLAM → mainly Pasquill stability "D"
MRF → often Pasquill stability "E" or "F"





AEROPOL:

MRF meteo, complete Gaussian adsorption, gravitational sedimentation and vertical flow, 25 μm ice/ash particles (ρ = 1000 kg/m³).



Deposition flux, computed for measurement point No. 1 (AEROPOL, 25 μm particles)

Deposition fluxes: HIRLAM *vs*. MRF met. data, different options (AEROPOL)

met. data / options	HIRLAM	MRF
Reflection, 8.15 μm particles	**1.4**	**3.9**
Adsorption, 8.15 μm particles	**3.5**	**5.3**
Adsorption, 25 μm particles	**4.9**	**17.0**
Measured	Ca-based: **28.7** Sph.-particles-based **34.0** Total mass-based **26.0**	

Conclusions

- So large deposition fluxes are not possible otherwise than particles must be concentrated into a thin (compared to the stack height) near-surface layer.
- Thus, forced mixing of plume within PBL is not always justified in a lower meso-scale model, but vertical dispersion must be treated carefully!
- More complex measurements and modelling exercises are needed.

Acknowledgements

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