Modelling of fly ash deposition in Estonian oil shale processing region and validation based on deposition in snow cover

Riinu Ots *and* ***Ardi Loot,***

University of Tartu, Estonia

Aim

- Until now SILAM has been developed (and tested) as a meso-scale model
- Using SILAM for local-to-regional scale computations
- Validating results against deposited particulate matter measured in snow samples
- Oil shale based power plants and chemical industries in NE Estonia

Thermal plume rise

- Thermal plume rise has to be considered when trying to describe dispersion near the pollution sources
- Used Briggs' formulas for buoyant plumes
- Buoyancy flux:

$$F = \frac{g w_s D^2 (T_s - T)}{4 T_s}$$

Plume rise algorithm

- Thermal rise
  - For stable stratification

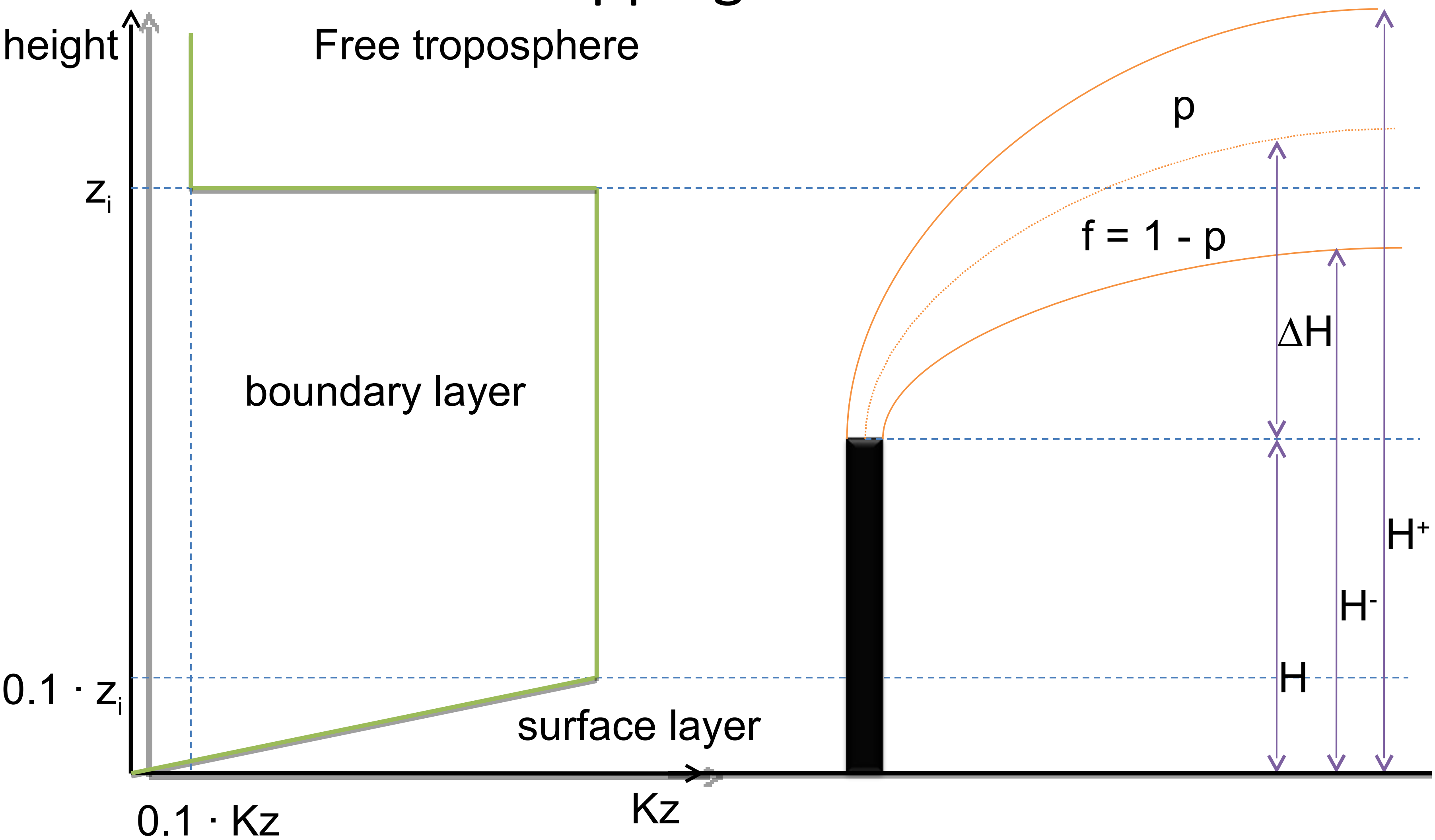
$$\Delta H = 2.6\left(\frac{F}{Vs}\right)^{1/3}$$

$$s = \frac{g}{\Theta}\frac{\partial \Theta}{\partial z} = N^2$$

  - For unstable stratification (Modified by Kaasik, 2000):

$$\Delta H = \frac{40[\ln(1+F)]^2}{(1+160/F)^{1/2}V}$$

Stack plume rise and penetration through the capping inversion



- Penetration out of the atmospheric boundary layer. Fraction *f* remained in the ABL:

$$f = \begin{cases} 0, & z_i - H < 0.5\Delta H \\ 1, & z_i - H > 1.5\Delta H \\ \dfrac{z_i - H}{\Delta H} - 0.5, & 0.5\Delta H < z_i - H < 1.5\Delta H \end{cases}$$

- Half-depth of a plume

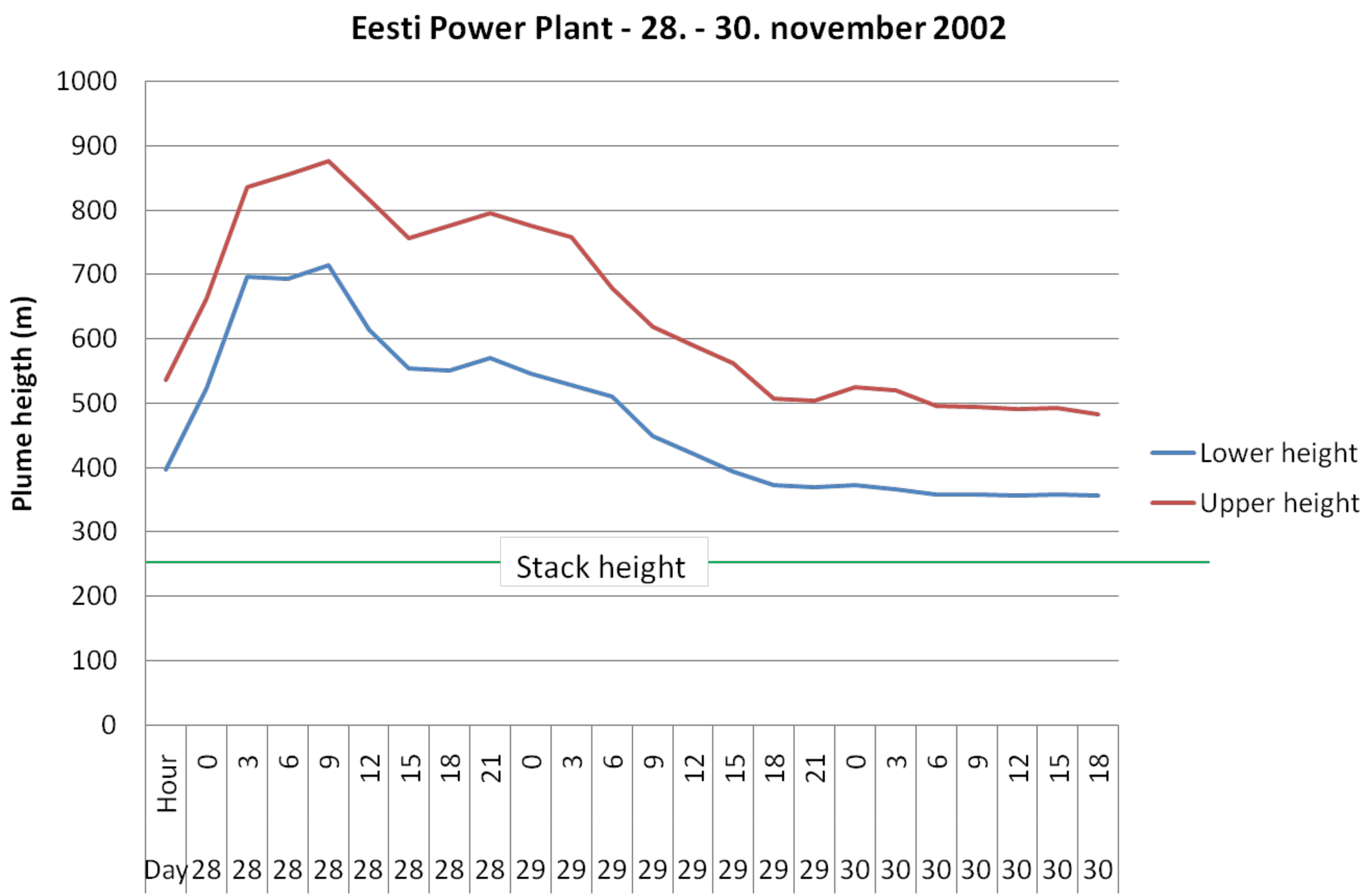
$$r = \frac{0.6}{\sqrt{\pi}}\Delta H$$

(Briggs, 1975)

- Final upper and lower boundaries of a plume

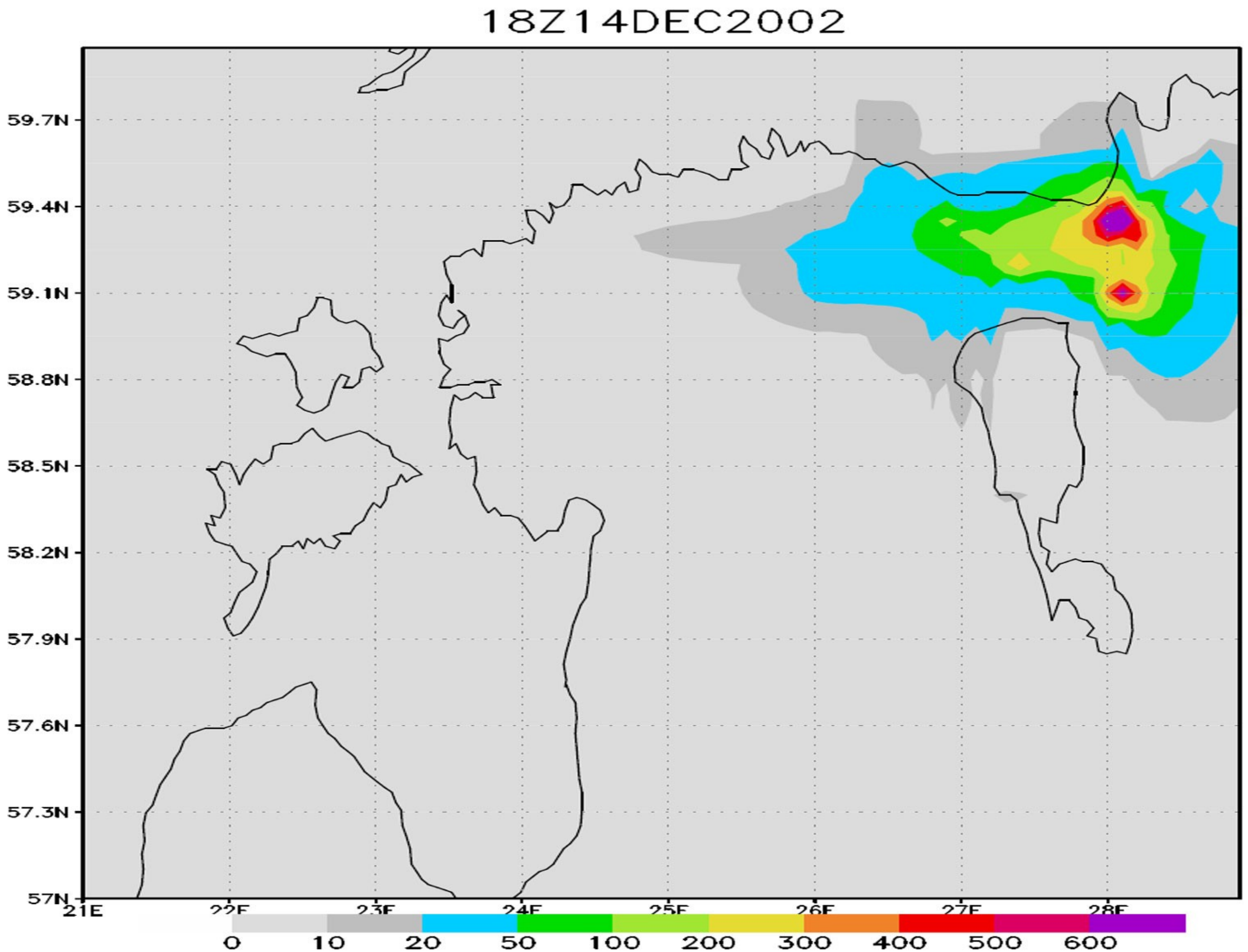
$$H_+ = H_f + \mathrm{r} \qquad H_- = H_f - \mathrm{r}$$

- H_f - final plume rise (corrected, considering partial penetration).

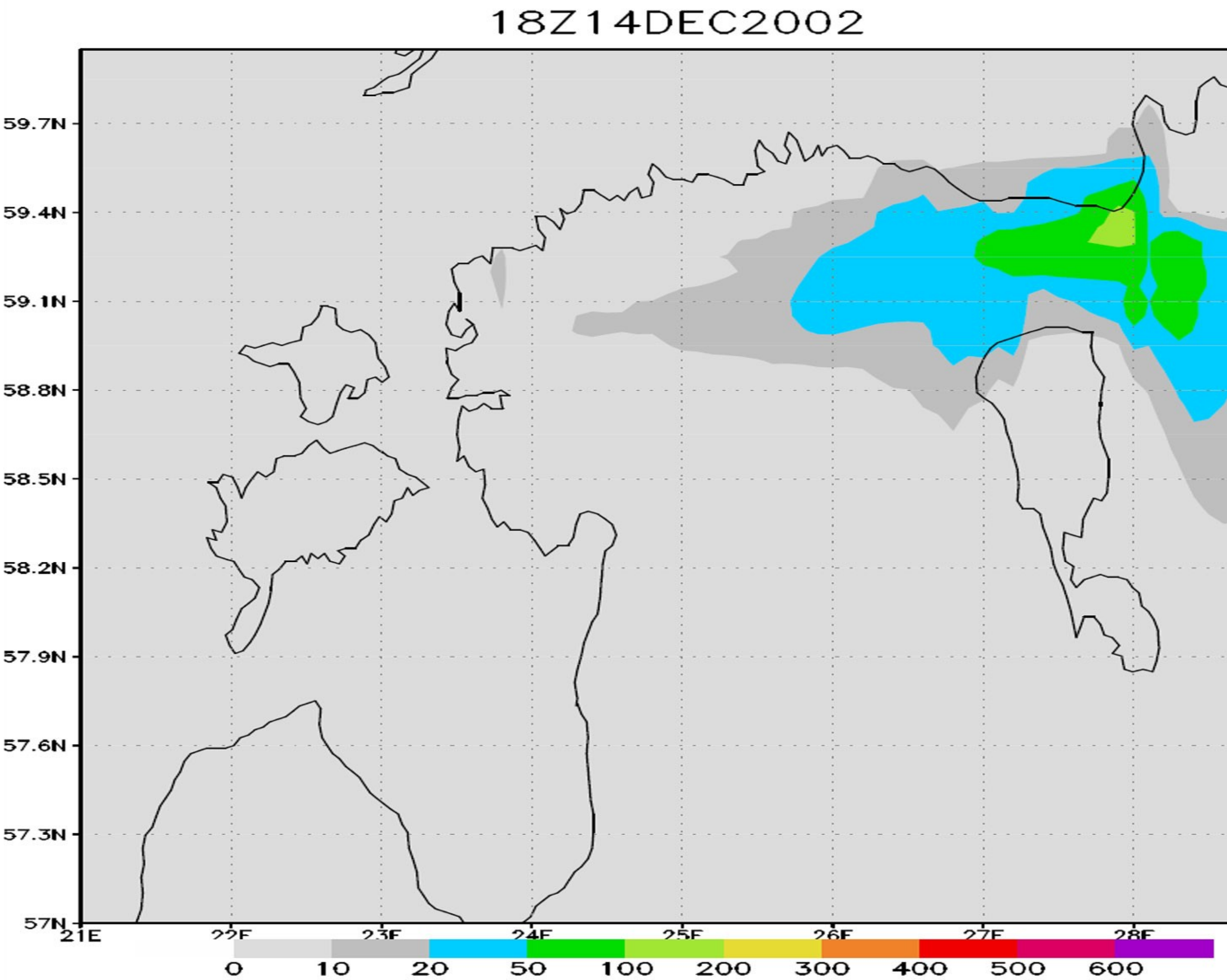


Eesti Power Plant - 28. - 30. november 2002
Plume heigth (m)
1000
900
800
700
600
500
400
300
200
100
0
Stack height
Lower height
Upper height
Hour 0 3 6 9 12 15 18 21 0 3 6 9 12 15 18 21 0 3 6 9 12 15 18
Day 28 28 28 28 28 28 28 28 29 29 29 29 29 29 29 29 30 30 30 30 30 30 30

No plume rise (stack height)



With plume rise



9 winters

Year	Begin	End	Duration (days)
1985	11.12	20.03	99
1987	18.12	22.03	94
1994	28.01	25.02	27
1996	11.12	20.02	69
1999	07.01	13.03	66
2001	20.12	28.02	68
2002	28.11	14.12	16
2008	16.03	28.03	12
2009	08.02	20.03	42

Configuration

- SILAM, Eulerian kernel
- Timestep: 3 min
- Grid 119x103, resolution 3 km
- 7 layers: 30, 50, 100, 250, 500, 1000, 1500m
- Meteorological fields:

  <u>1985 -2002 </u>BaltAN65+ (reanalysis around Baltic sea – an Estonian national project), res. 11 km

  <u>2008, 2009 </u>ETB HIRLAM – resolution 3.3 km.

Emitted substances

Name	Density kg/m^3	Fraction	Diameter (µm)		
			Minimum	**Average**	**Maximum**
Ice-bricks	1000	1.0	20.0	25.0	30.0
Ash	2800	0.35	1.0	2.0	2.5
		0.60	2.5	6.0	10.0
		0.05	10.0	12.0	15.0
Sulphate	1000	1.0	0.01	0.35	1.0

"Ice-bricks" – as stack plume contains 20 – 50 times more water vapour than fly ash and condensation starts from temperature about +40 °C, we expect that water condensates and freezes on ash particles in winter, making them much bigger (affecting gravitational settling) – however, process depends highly on ambient conditions. Thus, we investigate two alternatives: genuine ash particles and ice-bricks.

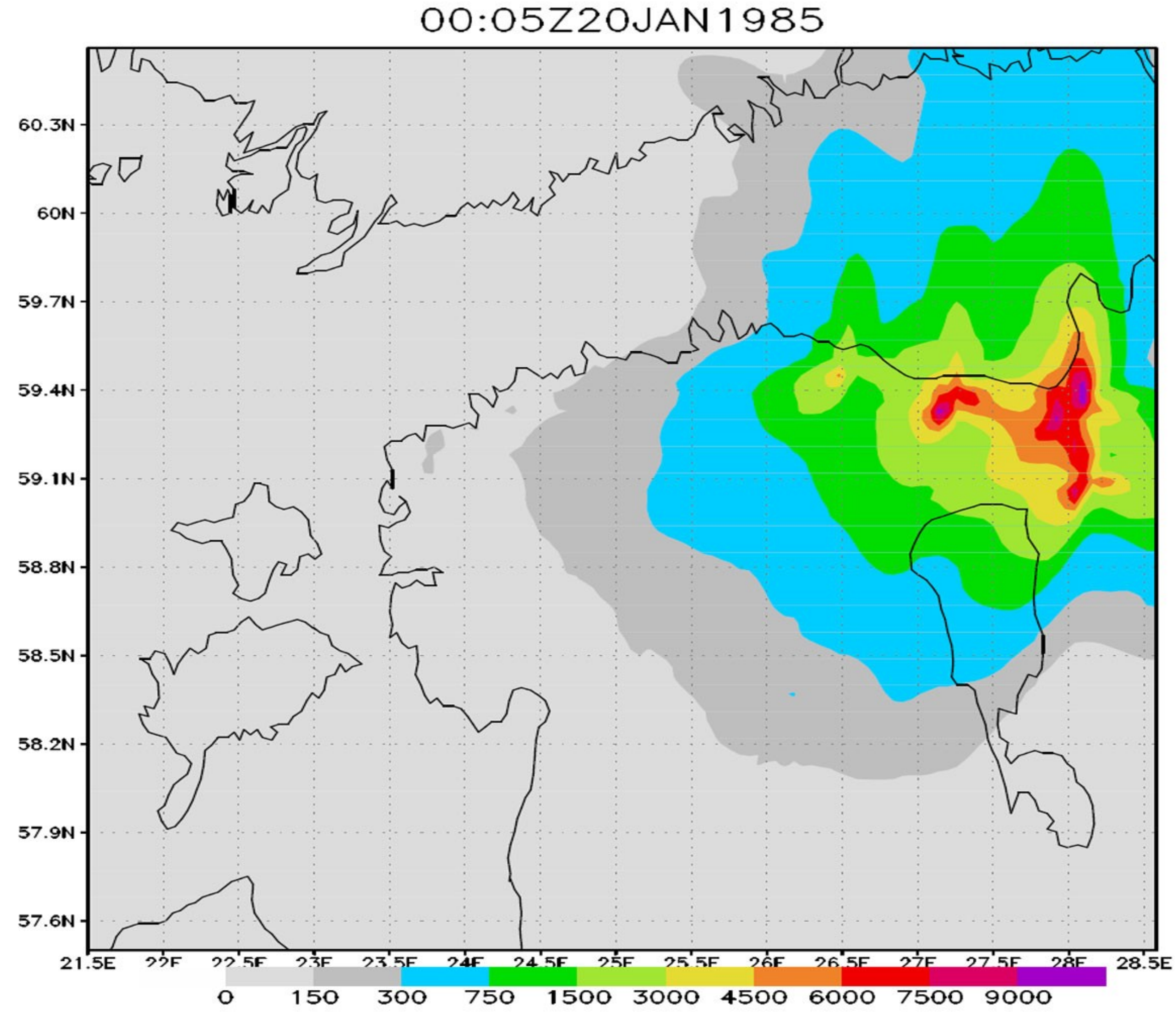
Output

Dry and wet deposition of

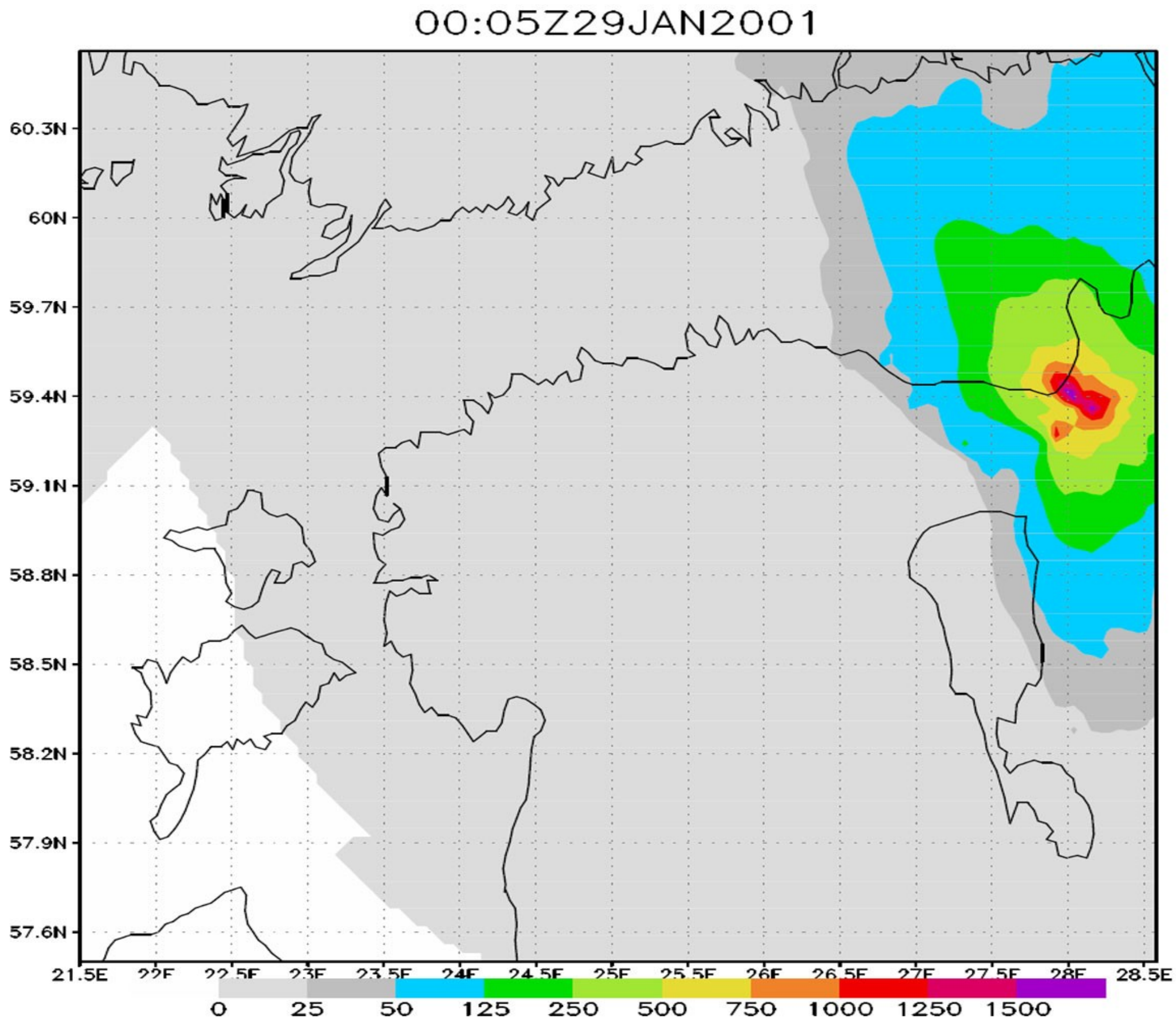
- Ice-bricks
- Ash
- SO_2
- SO_4

- SILAM assumes rigidly that 80% of sulphur is emitted as SO_2 and 20% as SO_4;
- calculates SO_2 to SO_4 conversion;
- It is assumed that deposited SO_2 is converted to SO_4.

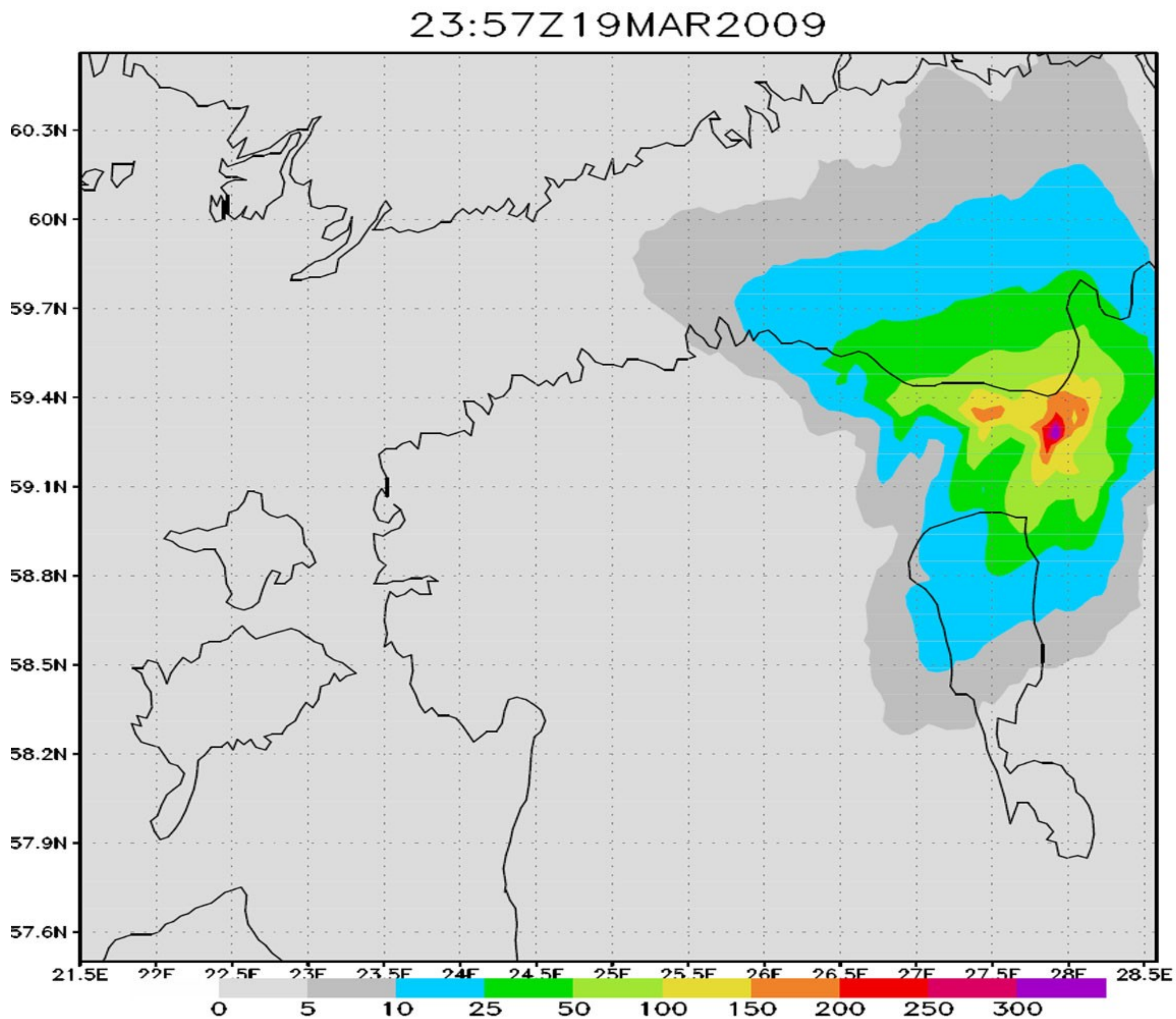
1985 ice-bricks, 42 days

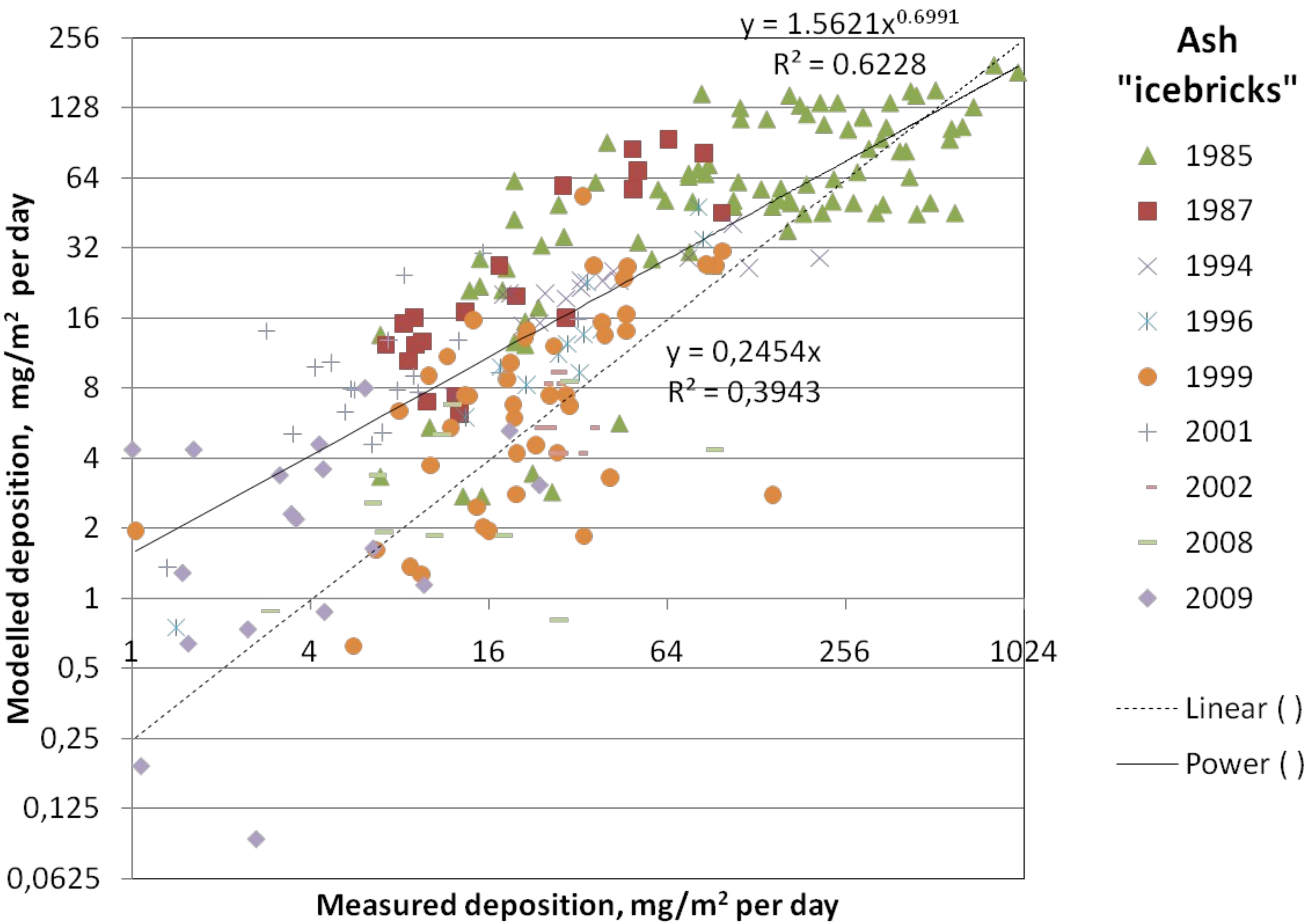


2001 ice-bricks, 42 days

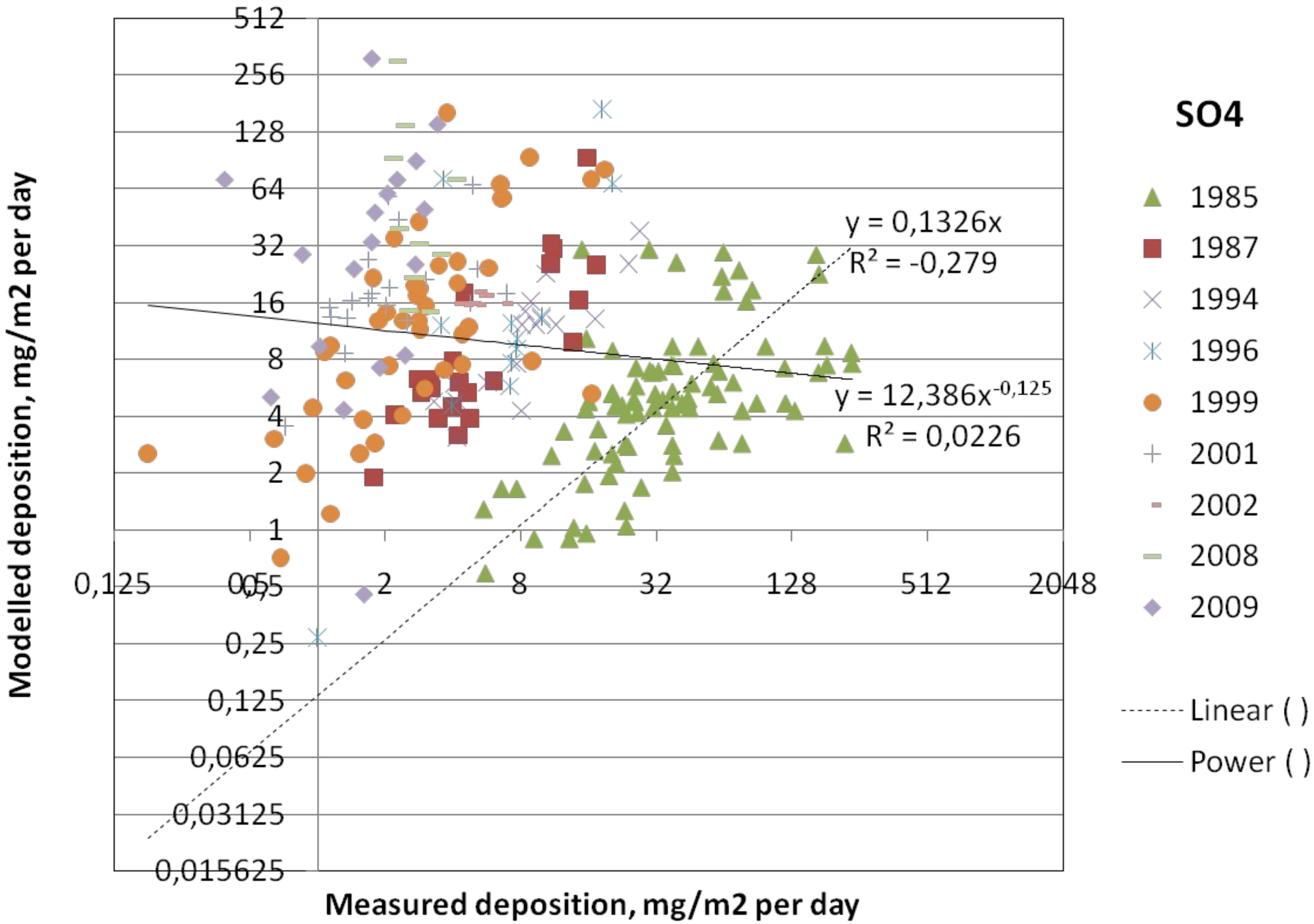


2009 ice-bricks, 42 days

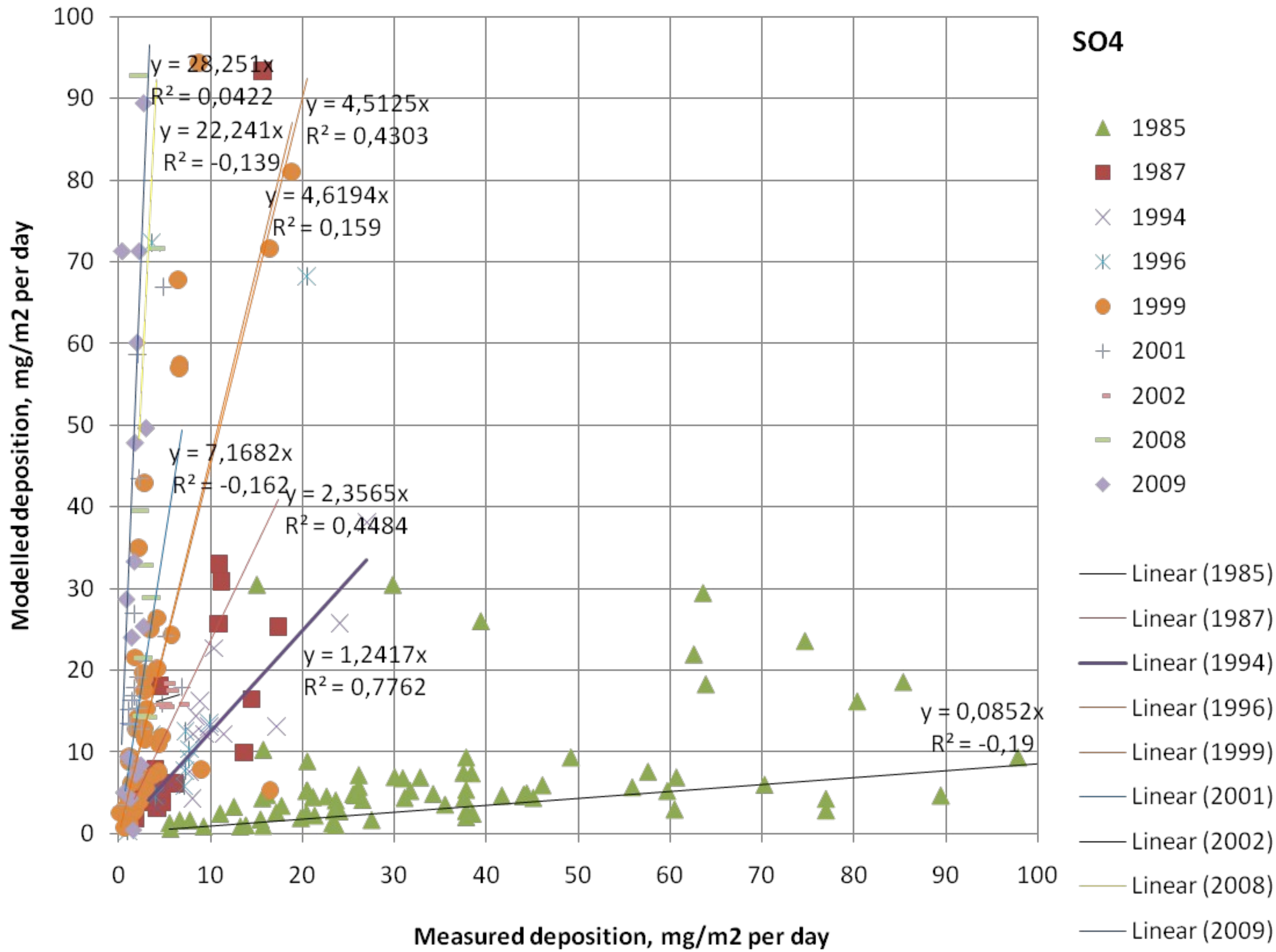




Ash (ice-bricks) deposition modelled *vs.* measured:
linear regression suggests four-fold underestimation;
power law regression: power ~2/3, i.e. more underestimated at larger values (closer to the stacks and earlier years).



Sulphate deposition modelled *vs.* measured: **a disaster!**



Sulphate deposition modelled *vs.* measured, winters separately: different slopes from severe underestimation to high overestimation; recent years are much more overestimated.

Conclusions

- Deposition on average: fly ash underestimated, sulphate overestimated.
- Sulphur over-estimations can be caused by changes in combustion technologies?
- Local-scale modelling effects?

  Good agreement of SILAM with EMEP stations in routine European-scale runs is reported by FMI.
- We have to validate with two closest EMEP stations – Lahemaa (EST) and Virolahti (FIN).

Thank you for listening!