5. Atmospheric Supply of Lead to the Baltic Sea in 2002

This chapter presents a short description of model evaluation of lead atmospheric input to the Baltic Sea, its sub-basins and catchment area in 2002. Modelling of lead atmospheric transport and depositions was carried out using MSC-E Eulerian Heavy Metal transport model MSCE-HM (Ilyin et al., 2004). Latest available official information on lead emission from HELCOM countries and other European countries was used in computations. Based on these data levels of annual and monthly lead depositions to the Baltic Sea region have been obtained and contributions of HELCOM countries emission sources to the depositions over the Baltic Sea and its catchment area are estimated. Model results were compared with observed levels of lead concentrations in air and precipitation measured at monitoring sites around the Baltic Sea.

5.1 Lead emissions

To evaluate lead atmospheric load to the Baltic Sea the following three categories of emission data were used: direct anthropogenic emissions, natural emissions and re-emission. As the direct anthropogenic emission of lead of HELCOM countries in 2002 the officially submitted information on lead emissions to the UN ECE Secretariat were used (EB.AIR/GE.1/2004/10). For Germany and Poland official information on emissions in 2002 was missing. The value of total annual lead emission of Germany in 2002 was estimated using linear interpolation between submitted data for 1995 and projection for 2010 (EB.AIR/GE.1/2003/6). Total annual lead emission of Poland in 2002 was assumed equal to the value of 2001.

The information on total annual lead emissions of HELCOM countries in 2002 as well as total emission within the EMEP region is summarized in the Table 5.1. Along with the data for 2002, the emissions for 2001 are also given in the table. Total lead emission of HELCOM countries in 2002 accounts for 3320 tonnes that is lower than in 2000 by 258 tonnes (7%). The contribution of HELCOM countries emissions to lead anthropogenic emission within the whole EMEP region is approximately 40%, which is higher than in previous year by 10%. The latter is connected with the more significant reduction of lead emissions outside the HELCOM region. Reduction of lead emissions within the whole EMEP region is accounted for 26%.

The highest emissions within the HELCOM region were reported by the Russian Federation (2118 tonnes), Poland (610 tonnes), and Germany (474 tonnes). Spatial distribution of lead anthropogenic emission for 2002 is presented in Figure 5.1.

Table 5.1. Annual emissions of lead in HELCOM countries and in entire EMEP region, used in computations for 2001 and 2002. Units: tonnes per year. The change of emissions between 2001 and 2002 is shown in third column as the difference in tonnes

Country	2001	2002	Change
Denmark	6.1	5.3	-0.8
Estonia	37	36.7	-0.3
Finland	37.5	39.6	2.1
Germany	497	474.3	-22.7
Latvia	8.5	8.9	0.4
Lithuania	14.7	14.9	0.2
Poland	610	610	0
Russian Federation	2352	2118	-234
Sweden	15	12.6	-2.4
TOTAL – HELCOM countries	**3578**	**3320**	**-258**
TOTAL – EMEP	**10774**	**7998**	**-2776**

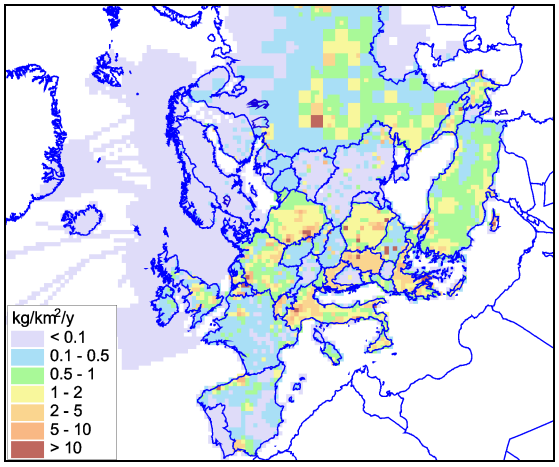


Figure 5.1. Spatial distribution of lead anthropogenic emission within the EMEP region in 2002 with resolution 50x50 km^2. Units: kg/km^2/year

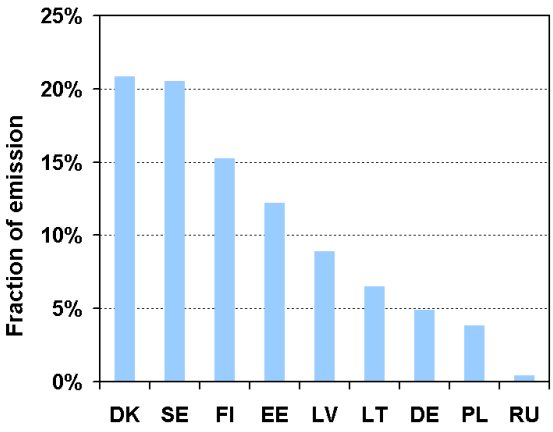


Figure 5.2. Fractions of lead anthropogenic emissions of HELCOM countries in 2002 deposited to the Baltic Sea.

It should be noted that the emission of Russian Federation in the Table 5.1 is related to its whole European territory. However only a small part of this emission is actually reaching the

Baltic Sea. Estimated fractions of lead anthropogenic emissions of HELCOM countries deposited to the Baltic Sea in 2002 are shown in Figure 5.2.

The input of lead re-emission and natural emission sources of European territory for 2002 is estimated to about 1 ktonnes. The description of parameterization of lead natural emission and re-emission used in the MSCE-HM model can be found in (Ilyin et al., 2002).

5.2 Annual deposition of lead

Total annual deposition of lead to the Baltic Sea in 2002 amounts to 149 tonnes and to its catchment area – about 932 tonnes. Atmospheric depositions over the Baltic Sea computed for 2001 were slightly lower (143 tonnes) whereas over its catchment area they were higher, accounting to 1260 tonnes. Comparing the results for these two years it can be seen that total annual depositions of lead to the Baltic Sea did not change significantly. At the same time, depositions of lead to the Baltic Sea catchment area in 2002 have decreased by 26%.

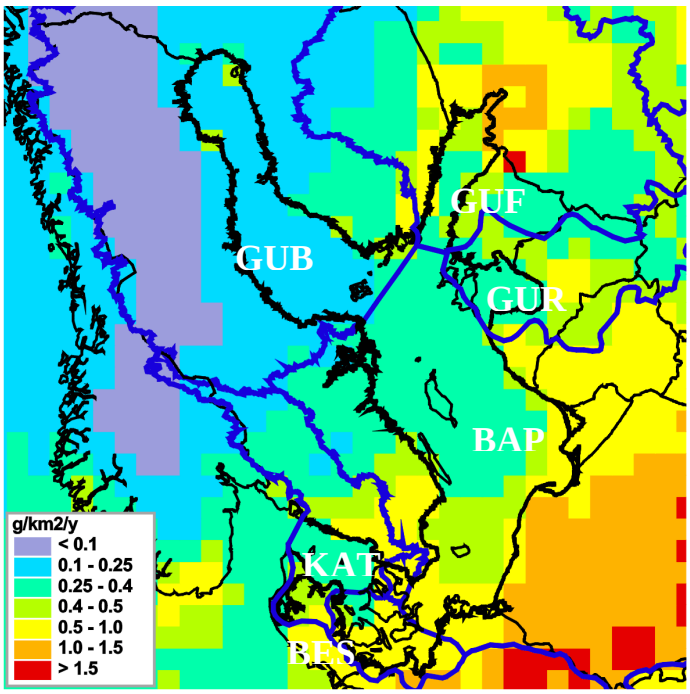


Figure 5.3. Spatial distribution of total lead deposition flux in the Baltic Sea region in 2002 with resolution 50x50 km^2. Units: kg/km^2/year

Spatial distribution of lead total deposition flux in 2002 is given in Figure 5.3. The pattern of depositions is similar to that of the previous year 2001. Elevated lead deposition flux can be noted in the southern part of the Baltic Proper sub-basin (BAP) and in the Gulf of Riga (GUR) and Gulf of Finland (GUF) sub-basins. Lowest deposition rates are the characteristic of the Gulf of Bothnia sub-basin (GUB).

Annual dry, wet, and total lead depositions in 2002 are presented in Table 5.2 for the sub-basins of the Baltic Sea and in Table 5.3 for its catchment area. The most significant contribution to the total depositions of lead belongs to wet deposition for all sub-basins and catchments. The highest lead deposition fluxes to the Baltic Sea sub-basins are obtained for the Belt Sea sub-basin (BES) and the Gulf of Finland (GUF). Over the catchment area highest deposition fluxes can be noted for the catchments of the Baltic Proper (BAP) and Belt Sea sub-basins.

Table 5.2. Annual dry, wet, and total depositions (tonnes/year) and total deposition fluxes (kg/km^2/year) of lead to the Baltic Sea sub-basins in 2002

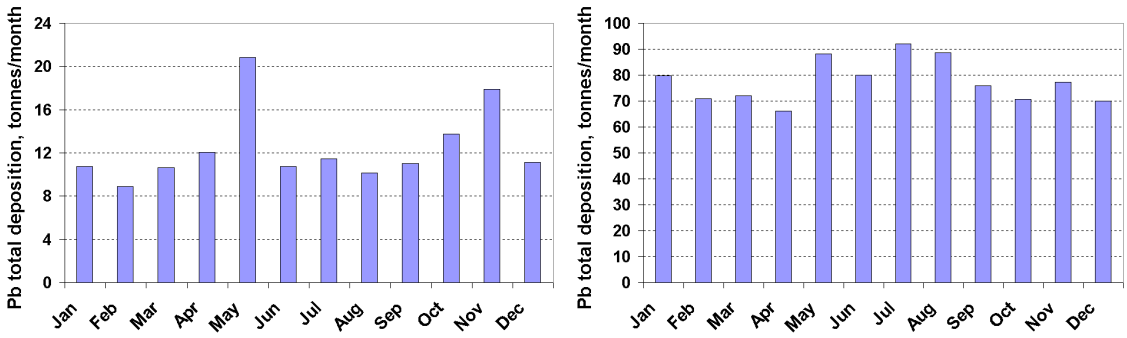
Deposition	GUB	GUF	GUR	BAP	BES	KAT	Baltic Sea
Dry	2.0	2.8	0.8	8.1	1.5	0.7	15.9
Wet	23.3	11.6	4.9	75.9	10.0	7.8	133.4
Total	25.3	14.4	5.7	84.0	11.4	8.4	149.3
Flux	0.22	0.48	0.31	0.40	0.56	0.36	0.35

Table 5.3. Annual dry, wet, and total depositions (tonnes/year) and total deposition fluxes (kg/km^2/year) of lead to the Baltic Sea catchments in 2002

Deposition	GUB	GUF	GUR	BAP	BES	KAT	Catchment area
Dry	13	60	18	216	4	6	318
Wet	54	123	40	357	14	24	614
Total	68	184	58	573	18	31	932
Flux	0.14	0.44	0.42	1.03	0.70	0.36	0.54

5.3 Monthly depositions of lead

Monthly variations of total lead depositions to the Baltic Sea and its catchment area in 2002 are presented in Figure 5.4.



(a) (b)

Figure 5.4. Monthly variations of lead total depositions to the Baltic Sea (a) and its catchment area (b) in 2002. Units: tonnes/month

Total monthly lead depositions to the Baltic Sea sub-basins and catchments undergo pronounced variations throughout the year with maxima in May and November. Over the catchment area lead depositions in summer time are slightly higher comparing to other periods of the year.

5.4 Source allocation of lead deposition

The contributions of HELCOM countries sources to the depositions of lead to the Baltic Sea sub-basins and catchments as well as contributions of other European countries were estimated using the computations of lead transboundary fluxes over European region (Ilyin et al., 2004). Figures 5.5 and 5.6 present estimated values of lead depositions to the Baltic Sea and its catchment area along with contributions of each HELCOM country.

Anthropogenic sources of HELCOM countries contribute 48% to lead depositions over the Baltic Sea among which main contributions belong to Poland (16%), Germany (16%), and Russia (6%). The sources of other HELCOM countries contribute about 11% and contribution of European countries outside the Baltic Sea region amounts to 21%. The contribution of re-emission and natural sources accounts for 31%.

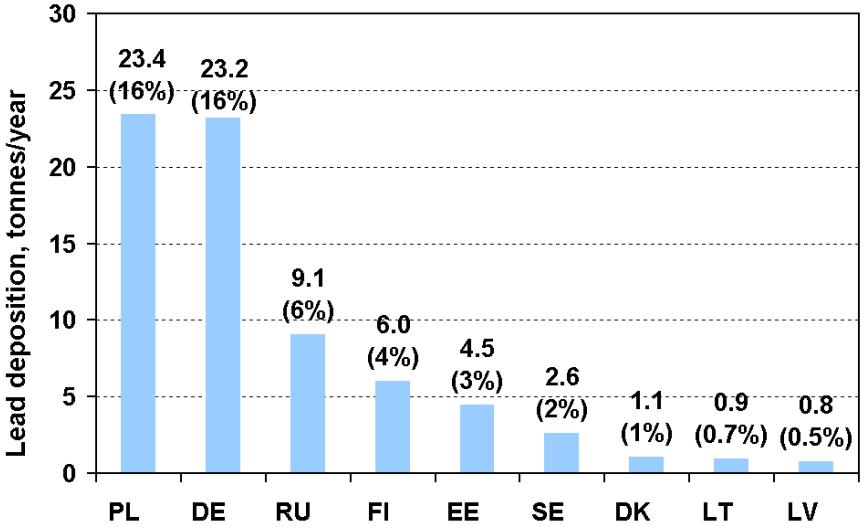


Figure 5.5. Contributions of HELCOM countries emissions from anthropogenic sources to total lead depositions to the Baltic Sea in 2002, tonnes/year

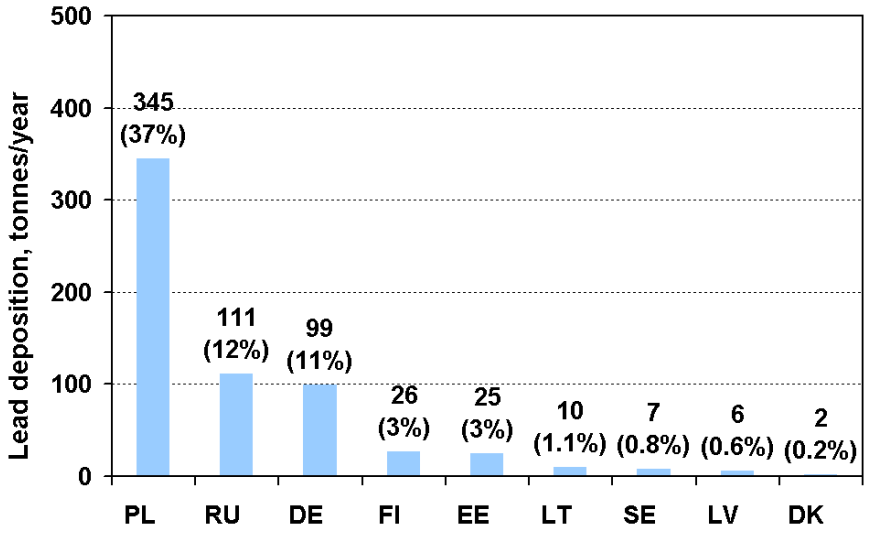


Figure 5.6. Contributions of HELCOM countries emissions from anthropogenic sources to total lead depositions to the Baltic Sea catchment area in 2002, tonnes/year

The share of lead depositions to the catchment area from anthropogenic sources of HELCOM countries is accounted for 68%. Main contributions to depositions among the HELCOM countries belong to Poland (37%), Russia (12%), and Germany (11%). Anthropogenic sources of other HELCOM countries contribute about 8%. Contribution of re-emission and natural sources amounts to 16% and of European countries outside the Baltic Sea region to 16%.

Tables 5.4 and 5.5 present atmospheric input of two most important contributors among the HELCOM countries to lead depositions in the six sub-basins and six catchments of the Baltic Sea in 2001 and in 2002.

Table 5.4. Comparison of main contributors to lead depositions in six sub-basins of the Baltic Sea in 2001 and 2002. BAS means the whole Baltic Sea basin. Units: percent of total depositions

Sub-basin	2001					2002				
	Country	%	Country	%	*, %	Country	%	Country	%	*, %
GUB	FI	9	RU	5	65	FI	16	PL	10	38
GUF	RU	24	EE	16	41	EE	23	RU	22	23
GUR	PL	12	EE	8	53	PL	15	DE	14	37
BAP	PL	18	DE	13	50	PL	20	DE	19	30
BES	DE	29	GB	5	48	DE	29	PL	10	28
KAT	DE	9	GB	6	65	DE	15	PL	9	39
BAS	PL	12	DE	11	53	PL	16	DE	16	31

* - contribution in percent of re-emission and natural sources.

Table 5.5. Comparison of main contributors to lead deposition in six catchments of the Baltic Sea in 2001 and 2002. CAT means the whole Baltic Sea catchment area. Units: percent of total depositions

Sub-basin	2001					2002				
	Country	%	Country	%	*, %	Country	%	Country	%	*, %
GUB	RU	6	FI	6	74	FI	17	RU	8	36
GUF	RU	34	EE	6	42	RU	42	EE	12	18
GUR	RU	16	PL	10	44	PL	19	RU	17	23
BAP	PL	53	DE	6	21	PL	55	DE	13	11
BES	DE	35	GB	4	44	DE	34	PL	10	26
KAT	DE	7	PL	5	66	DE	13	PL	8	39
CAT	PL	34	RU	9	34	PL	37	RU	12	16

* - contribution in percent of re-emission and natural sources.

Comparison of inputs to lead depositions, both over the Baltic Sea and over its catchment area, shows that in general the contribution of re-emission, natural and remote sources for 2002 is lower than for 2001 whereas the contributions of HELCOM countries are somewhat higher. This can be explained by interannual variability of meteorological data however their influence was not thoroughly investigated.

Finland, Poland, Estonia, and Russia are the most important contributors to lead depositions for the Gulf of Bothnia (GUB) and the Gulf of Finland (GUF). For other sub-basins, in particular, the Gulf of Riga (GUR), the Baltic Proper (BAP), the Belt Sea (BES), and the Kattegat (KAT), the most important contributors are Poland and Germany. Significant contribution to lead depositions over the Baltic Sea sub-basins belongs to re-emission and natural sources of lead.

On the whole for the Baltic Sea basin the main contributors to lead depositions in both years are Poland and Germany. For the catchment area two most important contributors to lead depositions are Poland and Russia.

5.5 Comparison of model results with measurements

Comparison of modelling results for lead was made with available measurements from HELCOM stations in 2002. Data on lead concentrations for 2002 were reported by Zingst (DE09), Keldsnor (DK5), Anholt (DK8), Pedersker (DK20), Lahemaa (EE09), Vilsandy (EE11), FI09 (Uto), Virolahti II (FI17), Hailuoto (FI53), Utö (FI9), Preila (LT15), Rucava (LV10), Zoseni (LV16), Leba (PL04), Bredkälen (SE05), Råö (SE14), and Arup (SE51). However the data of FI09, FI53, EE9, EE11, and LT15 were not included in the comparison. The precipitation amounts measured at FI09 and FI53 differed more than 1.5 times from that used in the model. Information on lead concentrations in precipitation of Estonian sites EE9 and EE11 was considered by CCC as unreliable because of high uncertainty of the measurements and low data capture. Data of LT15 for lead in precipitation were also recommended to exclude by CCC due to too high values. Table 5.6 presents results of the comparison of mean annual calculated and measured lead concentrations in air and precipitation for 2002. Comparison of monthly variations of calculated and measured lead concentrations at stations listed above is presented in Figures 5.7 – 5.22.

On average computed concentrations of lead are 2.5 times lower than concentrations in air and 2.7 times than concentrations in precipitation observed at HELCOM sites in 2002. At the same time the correlation of modeled and measured concentrations is rather high. Highest discrepancies between model results and measurements are obtained for SE05 and DK08 both for concentrations in air and in precipitation. The most likely reason of the underestimation of observed level of concentrations can be connected with the uncertainties in lead emissions and their seasonal variations. Additional input of atmospheric lead within the Baltic Sea region can be expected from the ship traffic. However the inventory of these heavy metals emissions is not currently available for modelling. Taking into account results of the comparison with measurements the actual atmospheric load of lead to the Baltic Sea in 2002 can be approximately two times higher than model estimates presented in this chapter.

Table 5.6. Comparison of calculated and measured mean annual lead concentrations in air and precipitation for 2002.

Station code	Station name	Observed	Calculated	Obs / Calc
Pb concentrations in air (ng/m^3)				
DE09	Zingst	6.9	4.0	1.7
DK05	Keldsnor	6.0	2.7	2.3
DK08	Anholt	3.6	1.1	3.3
LT15	Preila	6.9	3.9	1.8
LV10	Rucava	5.6	2.3	2.4
LV16	Zoseni	3.1	1.6	2.0
SE05	Bredkälen	0.6	0.1	4.2
SE14	Råö	2.9	1.1	2.6
Pb concentrations in precipitation (μg/l)				
DE09	Zingst	1.2	0.7	1.7
DK08	Anholt	1.6	0.3	5.5
DK20	Pedersker	1.5	0.6	2.5
FI17	Virolahti II	1.6	0.8	2.1
LV10	Rucava	1.3	0.6	2.2
LV16	Zoseni	1.0	0.4	2.4
PL04	Leba	1.0	0.5	1.8
SE05	Bredkälen	0.5	0.1	4.5
SE51	Arup	1.7	0.5	3.5

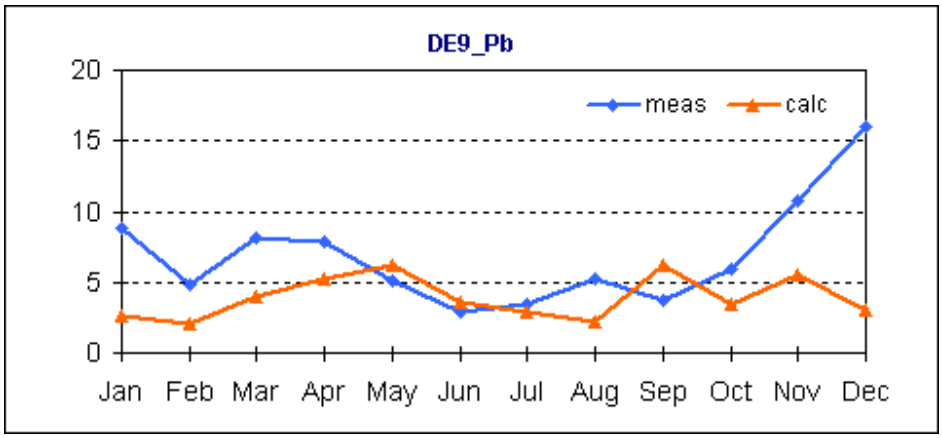


Figure 5.7. Comparison of calculated mean monthly lead concentrations in air with measured at station Zingst (DE09). Units: ng / m^3.

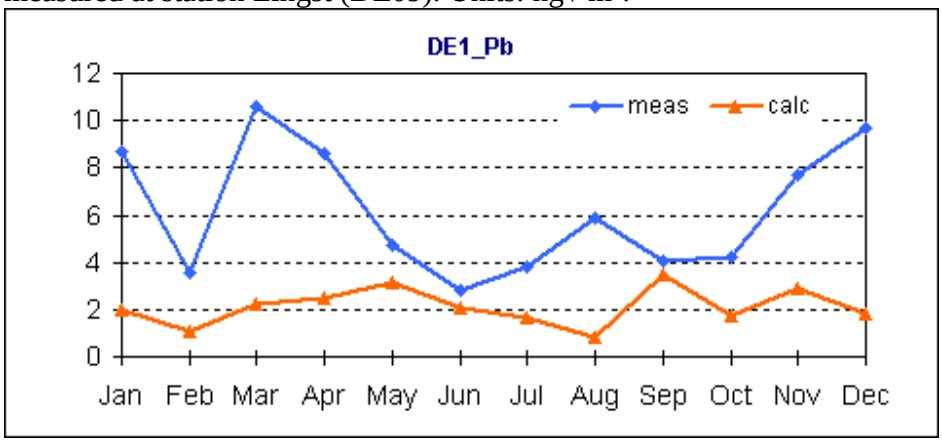


Figure 5.8. Comparison of calculated mean monthly lead concentrations in air with measured at station Keldsnor (DK05). Units: ng / m^3.

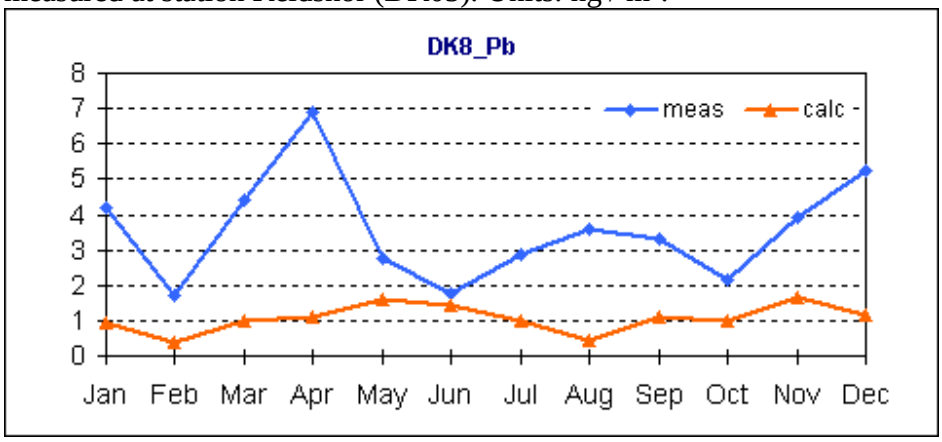


Figure 5.9. Comparison of calculated mean monthly lead concentrations in air with measured at station Anholt (DK08). Units: ng / m^3.

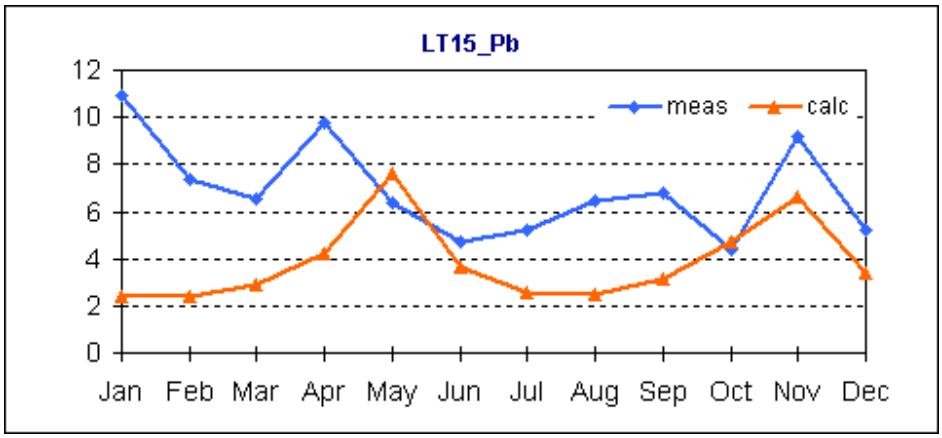


Figure 5.10. Comparison of calculated mean monthly lead concentrations in air with measured at station Preila (LT15). Units: ng / m^3.

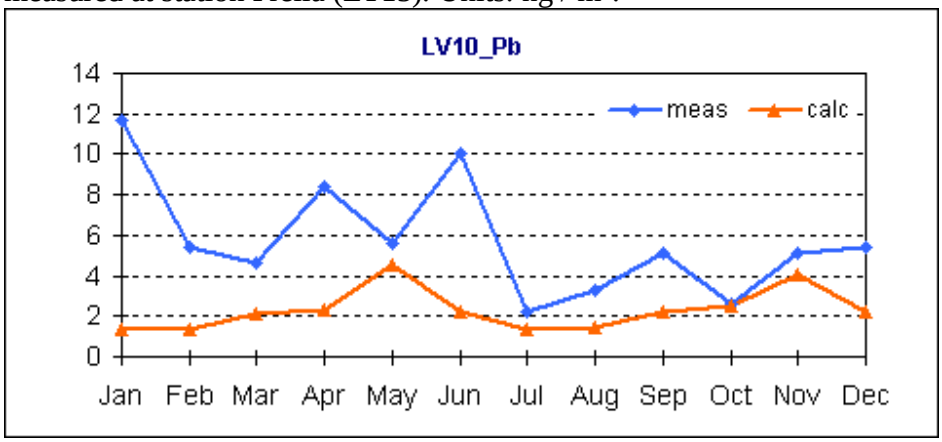


Figure 5.11. Comparison of calculated mean monthly lead concentrations in air with measured at station Rucava (LV10). Units: ng / m^3.

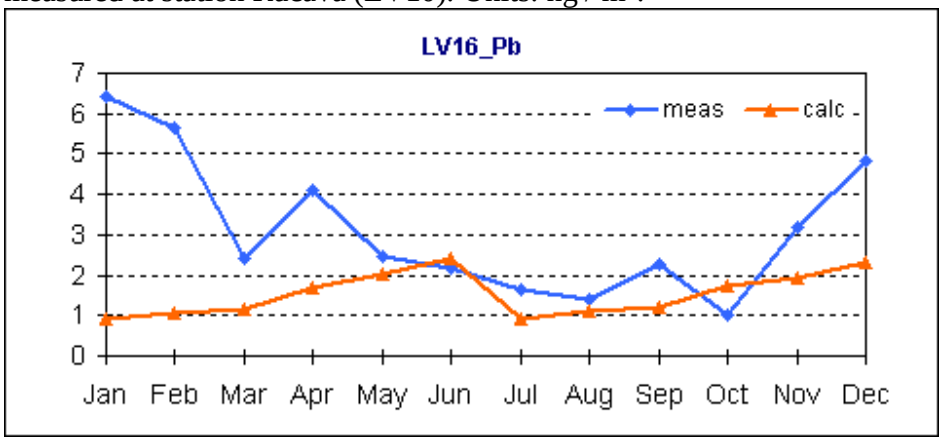


Figure 5.12. Comparison of calculated mean monthly lead concentrations in air with measured at station Zoseni (LV16). Units: ng / m^3.

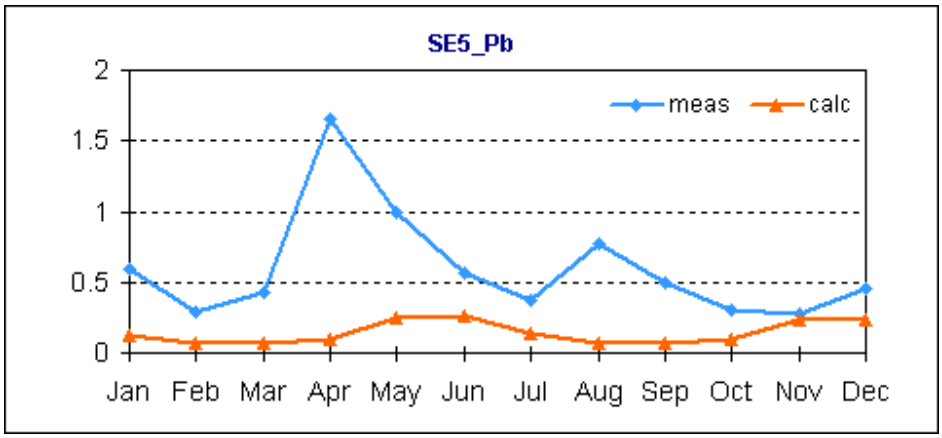


Figure 5.13. Comparison of calculated mean monthly lead concentrations in air with measured at station Bredkälen (SE05). Units: ng / m^3.

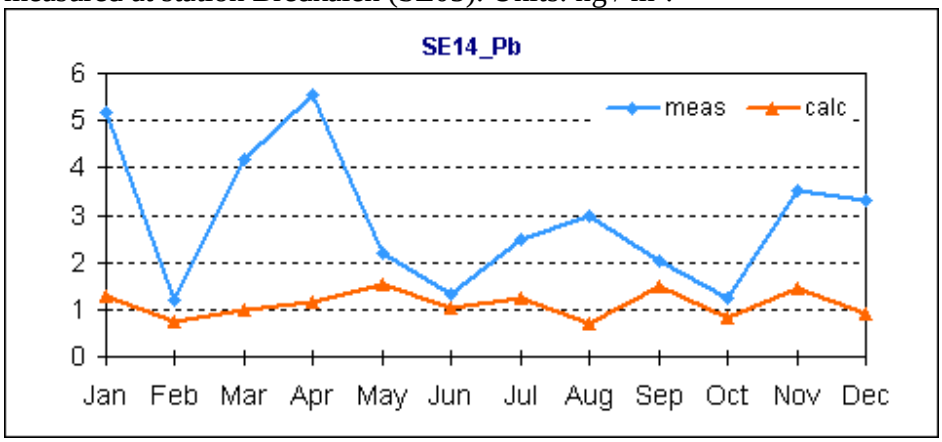


Figure 5.14. Comparison of calculated mean monthly lead concentrations in air with measured at station Räo (SE14). Units: ng / m^3.

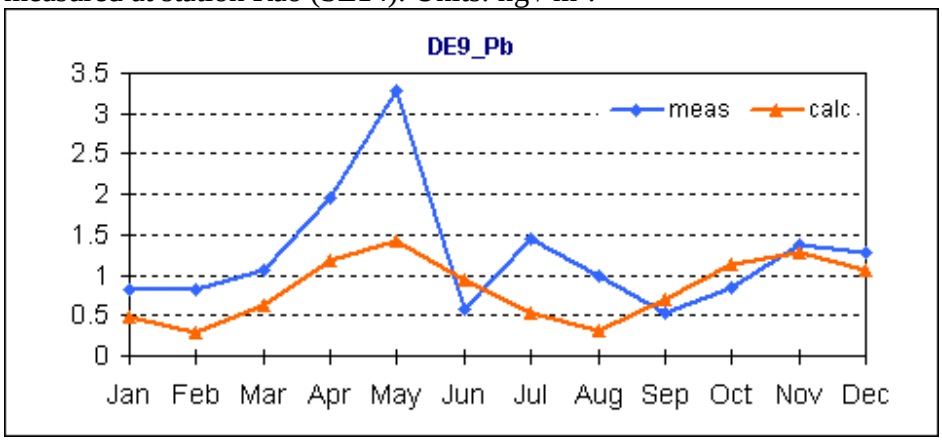


Figure 5.15. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Zingst (DE09). Units: µg / l.

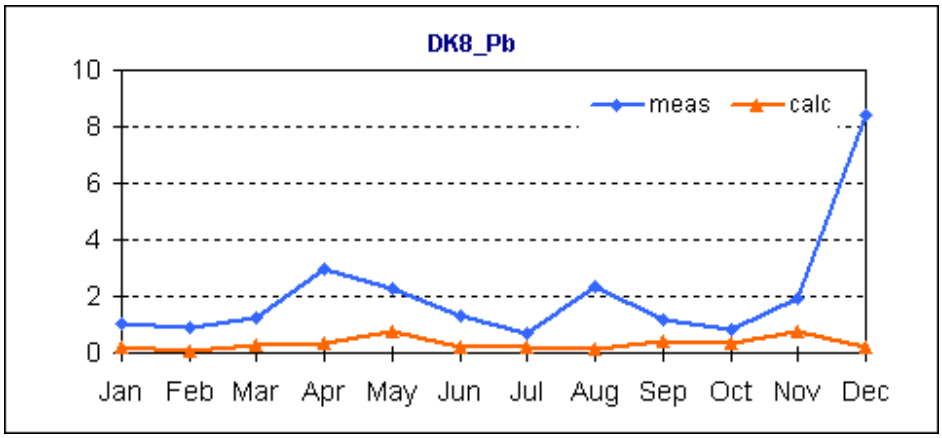


Figure 5.16. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Anholt (DK08). Units: µg / l.

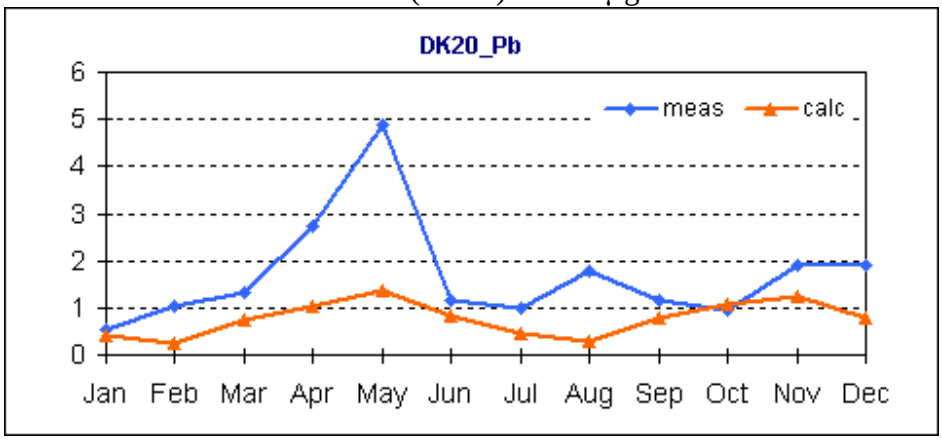


Figure 5.17. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Pedersker (DK20). Units: µg / l.

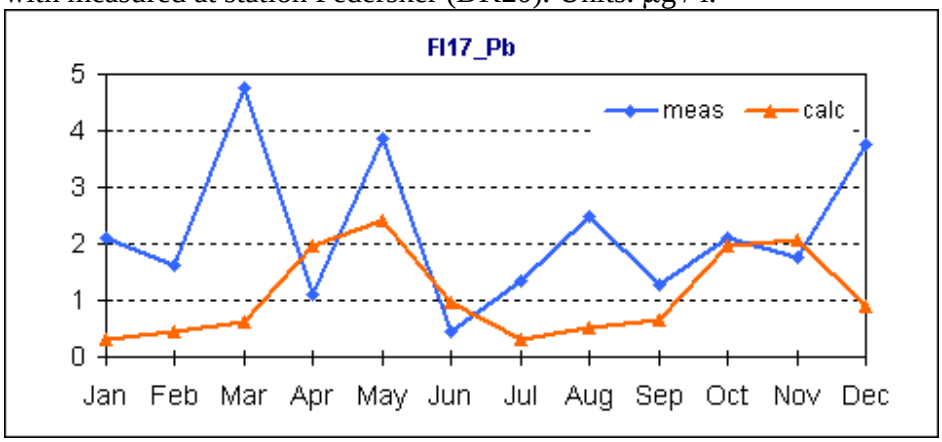


Figure 5.18. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Virolahti II (FI17). Units: µg / l.

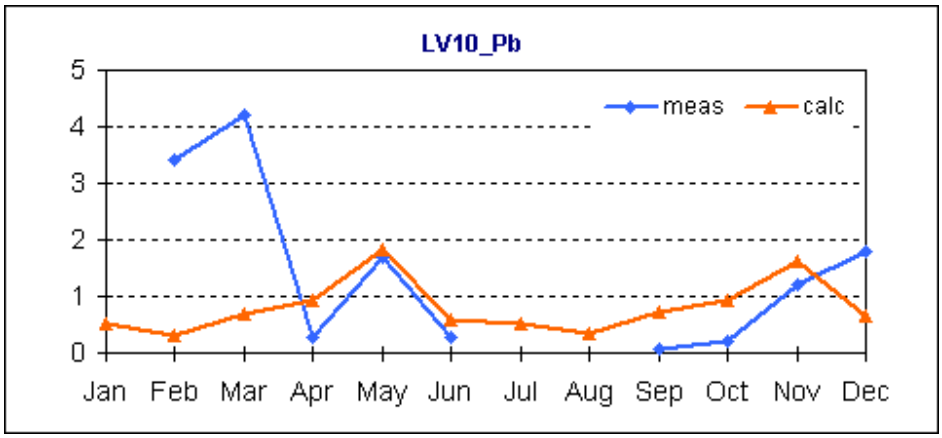


Figure 5.19. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Lahemaa (LV10). Units: µg / l.

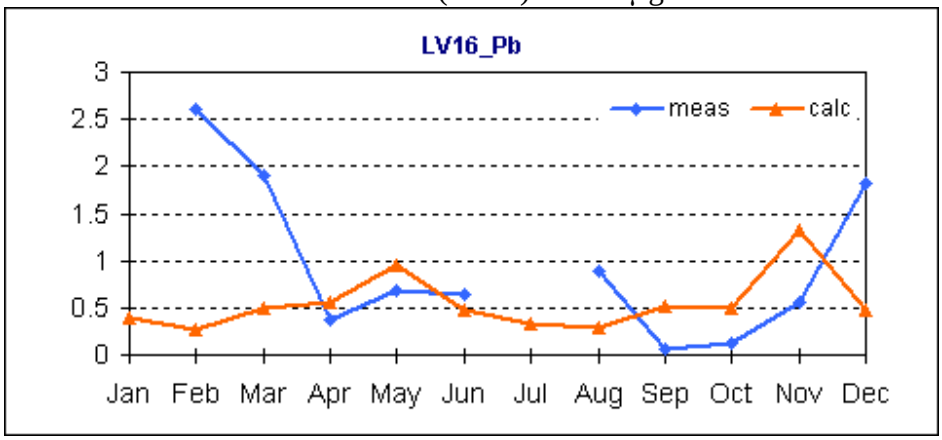


Figure 5.20. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Zoseni (LV16). Units: µg / l.

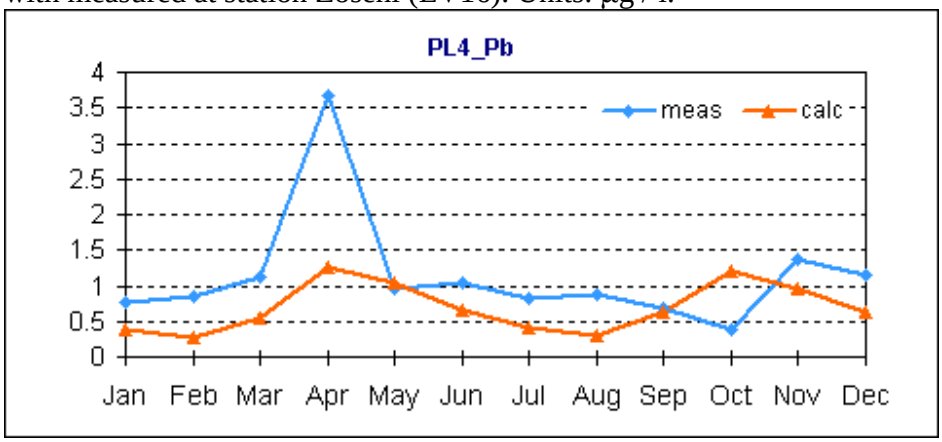


Figure 5.21. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Leba (PL04). Units: µg / l.

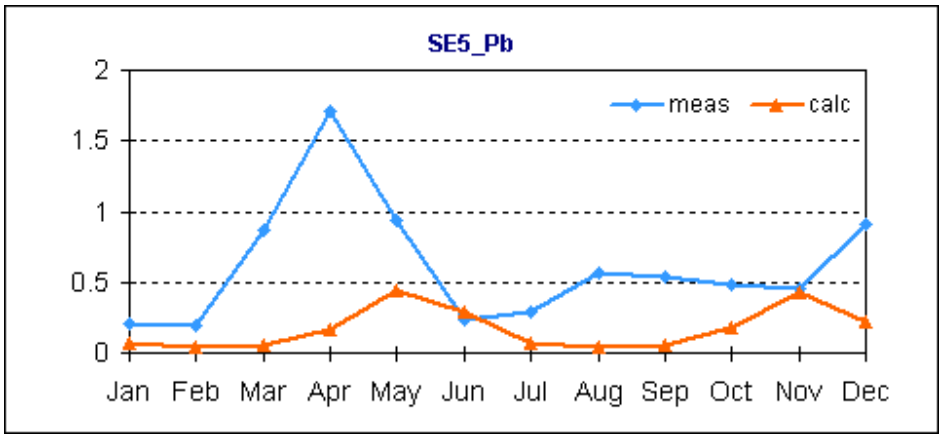


Figure 5.22. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Bredkälen (SE05). Units: µg / l.