5. Atmospheric Supply of Lead to the Baltic Sea in 2001

Model evaluation of lead atmospheric input to six sub-basins and six catchments of the Baltic Sea for 2001, was carried out using MSC-E Eulerian Heavy Metal transport model MSCE-HM (Ilyin *et al*., 2003). Model computations were made for the EMEP domain with horizontal resolution 50x50 km^2 using the latest available lead emission data for HELCOM countries and other European countries. This chapter presents a short description of lead emissions and computed annual depositions of lead to the Baltic Sea region along with their seasonal variations. Besides the contributions of HELCOM countries to the depositions over the Baltic Sea sub-basins and catchments are given. Obtained results were compared with available monitoring data of lead concentrations in air and precipitation for the Baltic Sea region.

5.1 Lead emissions

Evaluation of lead atmospheric load to the Baltic Sea was based on emission data of the following three categories: direct anthropogenic emissions, natural emissions and re-emission. Direct anthropogenic emissions of lead in HELCOM countries were based on officially submitted data (Vestreng, 2003). Most of the HELCOM countries officially submitted information on anthropogenic emission of lead for 2001 to the UN ECE Secretariat. For Germany and Russian Federation official information on emissions in 2001 was missing. The emission data on lead for Russian Federation was available up to 2000 therefore this value was applied in computations for 2001. Germany submitted lead emission data for 1995 and projection of emission for 2010. Emission for 2001 was estimated by linear interpolation.

Total annual lead emissions of HELCOM countries in 2001 as well as total lead emission within the EMEP region are summarized in the Table 5.1. Along with the data for 2001 emissions for 2000 are also given in the table. It should be noted that some of these figures differ from those given in the previous joint report of EMEP Centres (Bartnicki *et al*., 2002). These differences are due to updates of emission data for previous years recently made by the countries. Total lead emission from HELCOM countries in 2001 accounts for 3578 tonnes, which is lower than in 2000 by 66 tonnes. The contribution of HELCOM countries emissions to lead anthropogenic emission within the whole EMEP region is approximately 30%. The highest emissions within the HELCOM region were reported by the Russian Federation (2352 tonnes), Poland (610 tonnes), and Germany (497 tonnes). Spatial distribution of lead anthropogenic emission for 2001 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 2000 and 2001. Units: tonnes per year. The change of emissions between 2001 and 2000 is shown in third column as the difference between 2001 and 2000 in tonnes

Country	2000	2001	Change
Denmark	7	6.1	-0.9
Estonia	40.7	37	-3.7
Finland	37.5	37.5	0
Germany	519.3	497	-22.3
Latvia	8.4	8.5	+0.1
Lithuania	15.9	14.7	-1.2
Poland	647.5	609.8	-37.7
Russian Federation	2352	2352	0
Sweden	15.4	15	-0.4
TOTAL – HELCOM countries	**3644**	**3578**	**-66**
TOTAL – EMEP	**11193**	**10774**	**-419**

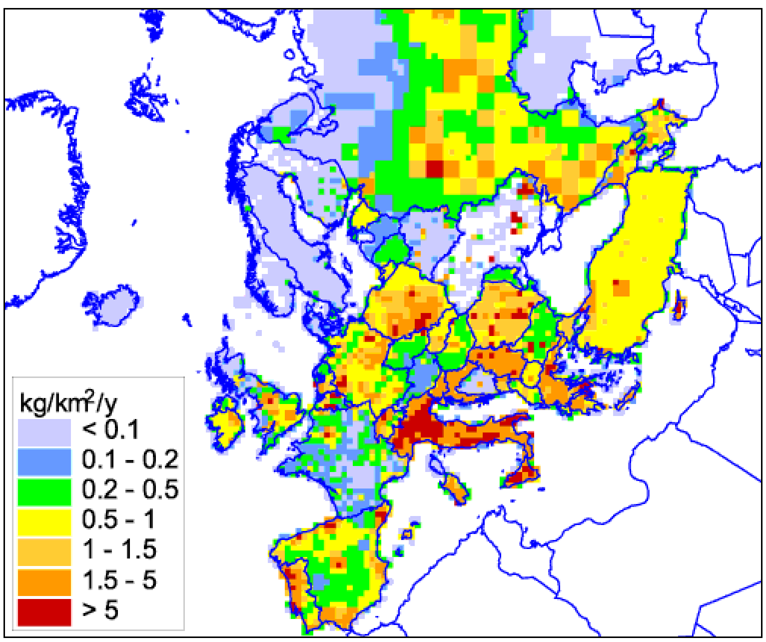

Figure 5.1. Spatial distribution of lead anthropogenic emission within the EMEP region in 2001 with resolution 50x50 km^2. Units: $kg/km^2/year$

The input of lead re-emission and natural emission sources within the EMEP region for 2001 is estimated to about 3000 tonnes. 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 2001 amounts to 143 tonnes and to its catchment area – about 1260 tonnes. Computed atmospheric depositions for 2000 were higher by 12% for the Baltic Sea and by 9% for its catchment area, accounting to 162 tonnes and 1380 tonnes, respectively. Spatial distribution of lead total deposition flux in 2001 is given in Figure 5.2.

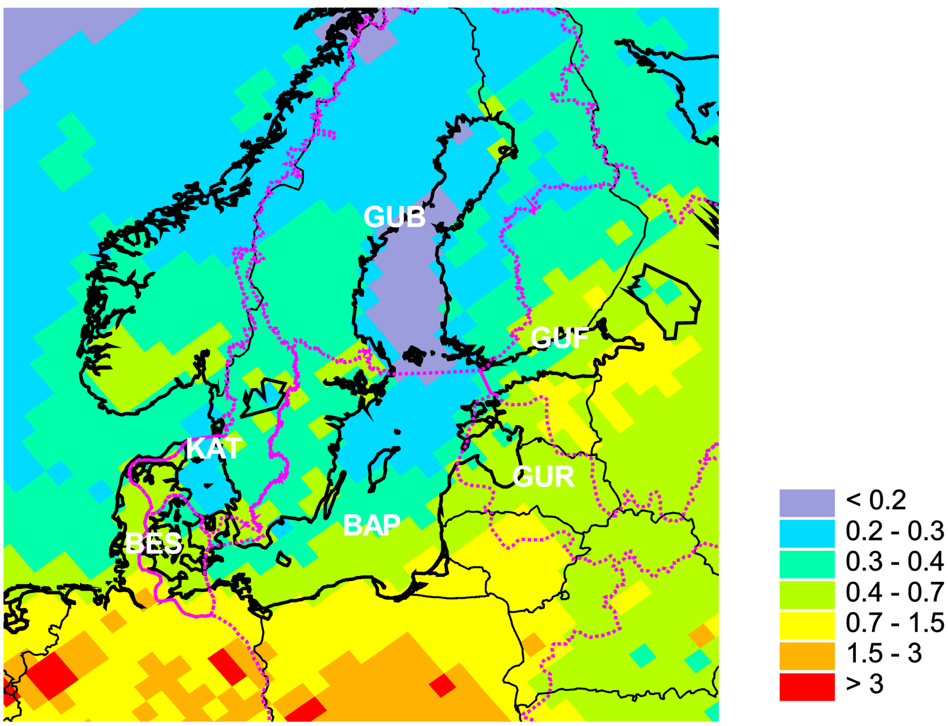

Figure 5.2. Spatial distribution of total lead deposition flux in the Baltic Sea region in 2001 with resolution 50**x**50 km^2. Units: kg/km^2/year

Elevated values of 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). Over the Baltic Sea catchment area the highest deposition fluxes of lead are obtained for the Baltic Proper catchment (BAP), in particular, over the territory of Poland.

Annual dry, wet, and total lead depositions in 2001 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 depositions to the Baltic Sea sub-basins are obtained for the Baltic Proper sub-basin (BAP). Over the catchment area maximum depositions can be noted for the Baltic Proper catchment (BAP).

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 2001

Deposition	GUB	GUF	GUR	BAP	BES	KAT	Baltic Sea
Dry	1.8	0.7	0.3	3.8	0.3	0.3	7.2
Wet	22.6	13.9	7.8	76.6	8.9	6.3	136.2
Total	24.4	14.6	8.1	80.4	9.3	6.7	143.4
Flux	0.21	0.49	0.44	0.38	0.45	0.28	0.34

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 2001

Deposition	GUB	GUF	GUR	BAP	BES	KAT	Catchment area
Dry	49	73	19	178	3	10	335
Wet	95	157	63	580	12	22	928
Total	144	230	83	757	16	32	1262
Flux	0.29	0.55	0.60	1.36	0.14	0.38	0.73

5.3 Monthly depositions of lead

Monthly variations of total lead depositions to the Baltic Sea and its catchment area are presented in Figure 5.3.

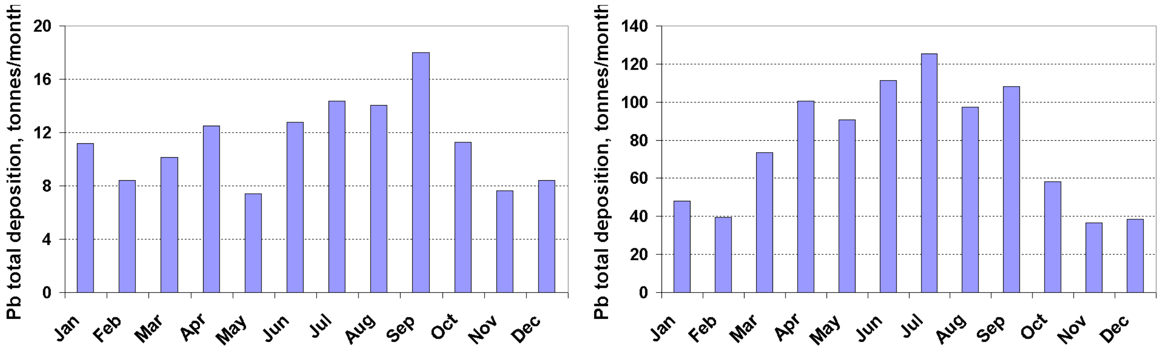

Figure 5.3. Monthly variations of lead total depositions to the Baltic Sea (a) and its catchment area (b) in 2001. Units: tonnes/month

Total monthly lead depositions to the Baltic Sea sub-basins and catchments undergo pronounced variations throughout the year. Relatively high monthly depositions over the Baltic Sea basin are obtained for summer months and September. Maximum depositions of lead follow to elevated levels of precipitation since wet deposition is the dominating pathway of lead removal from the atmosphere. Lower depositions are obtained for February, November, and December with minimum in May. Over the catchment area maximum lead depositions also take place in summer months and minimum in winter period.

5.4 Source allocation of lead deposition

Source allocation budget of lead depositions to the Baltic Sea, its sub-basins and catchments was estimated using the computations of lead transboundary fluxes over European region for 2001 (Ilyin *et al*., 2003). The contributions of HELCOM countries to the depositions of lead to the Baltic Sea sub-basins and catchments as well as contributions of other European countries, re-emission and natural sources are presented. Figures 5.4 and 5.5 present the contributions of HELCOM countries to lead depositions over the Baltic Sea and its catchment area.

Anthropogenic sources of HELCOM countries contribute 37% to lead depositions over the Baltic Sea among which main contributions belong to Poland (12%), Germany (11%), and Russia (6%). The sources of other HELCOM countries contribute about 8% and contribution of European countries outside the Baltic Sea region amounts to 10%. It can be noted that significant contribution belongs to the input of re-emission and natural sources (53%).

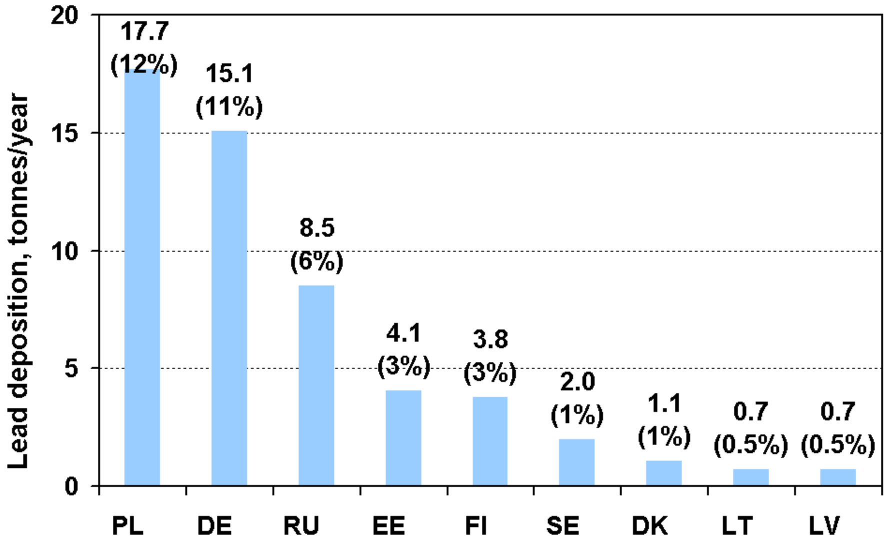

Figure 5.4. Contributions of HELCOM countries emissions to total lead depositions to the Baltic Sea in 2001 from anthropogenic sources, tonnes/year

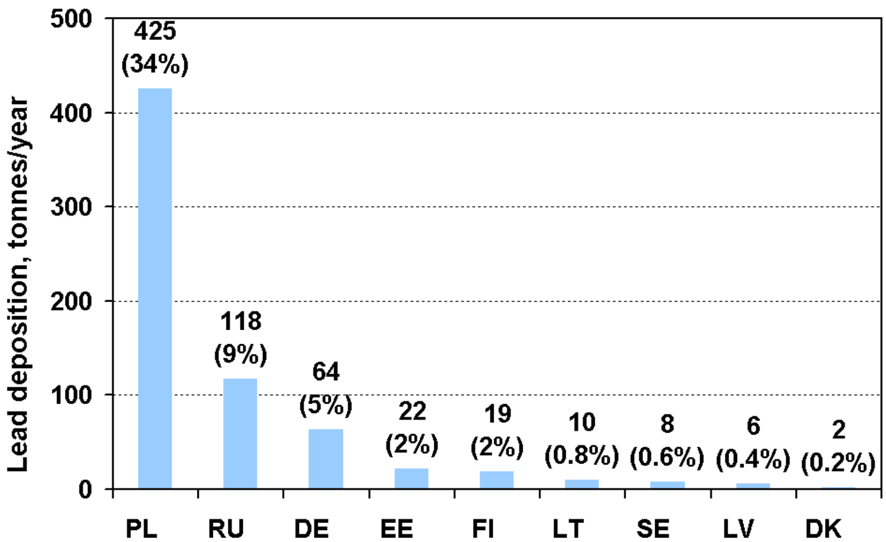

Figure 5.5. Contributions of HELCOM countries emissions to total lead depositions to the Baltic Sea catchment area in 2001 from anthropogenic sources, tonnes/year

The share of lead depositions to the catchment area from anthropogenic sources of HELCOM countries is accounted for 53%. Main contributions to depositions among the HELCOM countries belong to Poland (34%), Russia (9%), and Germany (5%). Anthropogenic sources of other HELCOM countries contribute about 5%. Contribution of re-emission and natural sources amounts to 34% and of European countries outside the Baltic Sea region to 13%.

Tables 5.4 and 5.5 present the 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 2000 and in 2001.

Table 5.4. Comparison of main contributors to lead depositions in six sub-basins of the Baltic Sea in 2000 and 2001. BAS means the whole Baltic Sea basin. Units: percent of total depositions

Sub-basin	2000					2001				
	Country	%	Country	%	*, %	Country	%	Country	%	*, %
GUB	FI	8	PL	7	55	FI	9	RU	5	65
GUF	RU	19	EE	15	38	RU	24	EE	16	41
GUR	PL	13	DE	8	46	PL	12	EE	8	53
BAP	PL	18	DE	14	42	PL	18	DE	13	50
BES	DE	26	GB	4	44	DE	29	GB	5	48
KAT	DE	16	PL	7	47	DE	9	GB	6	65
BAS	PL	12	DE	12	45	PL	12	DE	11	53

* - 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 2000 and 2001. CAT means the whole Baltic Sea catchment area. Units: percent of total depositions

Sub-basin	2000					2001				
	Country	%	Country	%	*, %	Country	%	Country	%	*, %
GUB	RU	5	FI	5	67	RU	6	FI	6	74
GUF	RU	31	EE	6	41	RU	34	EE	6	42
GUR	RU	14	PL	11	41	RU	16	PL	10	44
BAP	PL	50	DE	7	21	PL	53	DE	6	21
BES	DE	31	PL	5	40	DE	35	GB	4	44
KAT	DE	11	PL	10	52	DE	7	PL	5	66
CAT	PL	31	RU	8	33	PL	34	RU	9	34

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

For the Gulf of Bothnia (GUB) and the Gulf of Finland (GUF) the most important contributors to lead depositions are the neighboring countries – Finland, Estonia, and Russia. 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, Germany, and the United Kingdom. Significant contribution to lead depositions over the

Baltic Sea sub-basins belongs to re-emission and natural sources of lead. Due to year-to-year changes in emissions and transport pathways the contributions to lead deposition over the Baltic Sea in 2001 differ from those obtained for 2000. On the whole for the Baltic Sea basin the main contributors to lead depositions in both years are Poland and Germany. However contributions on the level of individual sub-basins changed for the Gulf of Riga (GUR) and the Kattegat (KAT) where second contributors were changed from Germany to Estonia and from Poland to the United Kingdom, respectively.

The most important contributors to lead depositions over the catchment area in 2000 and 2001 are nearly the same. For the catchments of the Gulf of Bothnia (GUB), the Gulf of Finland (GUF), and the Gulf of Riga (GUR) the most important contributor to lead depositions among the HELCOM countries is Russia. Significant contribution belongs to re-emission and natural sources. The Baltic Proper (BAP), the Belt Sea (BES), and the Kattegat (KAT) catchments are mostly influenced by emissions of Poland and Germany. At the same time for the Belt Sea in 2001 significant contribution belongs also to the United Kingdom lead emissions.

5.5 Comparison of model results with measurements

Modelling results for lead were compared with available measurements made on HELCOM stations in 2001. Measurements of lead concentrations for 2001 were reported by Zingst (DE09), Keldsnor (DK5), Anholt (DK8), Pedersker (DK20), Lahemaa (EE09), Vilsandy (EE11), Virolahti II (FI17), Hailuoto (FI53), Preila (LT15), Rucava (LV10), Zoseni (LV16), Leba (PL04), and Bredkälen (SE05). Lead concentrations in precipitation were also available for Utö (FI9) and Arup (SE51). However, precipitation amounts measured at these sites differed more than 1.5 times from that used in the model. For this reason the comparison of concentrations in precipitation for these sites was considered incorrect. Table 5.6 presents results of the comparison of mean annual calculated and measured lead concentrations in air and precipitation for 2001.

Most of computed lead air concentrations are within a factor of 2 in comparison to observed concentrations. The discrepancies higher than a factor of 2 are obtained for Rucava (LV10).

Lead concentrations in precipitation for Zingst (DE9), Pedersker (DK20), Lahemaa (EE09), Vilsandy (EE11), Hailuoto (FI53), and Bredkälen (SE05) computed by the model are within a factor of 2 in comparison to observations. For Anholt (DK8), Virolahti II (FI17), Preila (LT15), Rucava (LV10), Zoseni (LV16), and Leba (PL04) measured levels are underestimated by the model more than a factor of 2.

Comparison of monthly variations of calculated and measured lead concentrations at stations listed above is presented in Figures 5.6 – 5.23.

Table 5.6. Comparison of calculated and measured mean annual lead concentrations in air and precipitation for 2001.

Station code	Station name	Observed	Calculated	Obs / Calc
Pb concentrations in air (ng/m^3)				
DE09	Zingst	8.3	6.0	1.4
DK05	Keldsnor	6.7	4.0	1.7
DK08	Anholt	4.5	3.1	1.5
LT15	Preila	6.5	8.6	0.8
LV10	Rucava	8.2	3.7	2.2
LV16	Zoseni	2.9	2.9	1.0
Pb concentrations in precipitation (µg/l)				
DE09	Zingst	1.06	0.96	1.1
DK08	Anholt	1.44	0.52	2.8
DK20	Pedersker	1.31	0.78	1.7
EE09	Lahemaa	0.82	0.71	1.2
EE11	Vilsandy	0.67	0.42	1.6
FI17	Virolahti II	1.48	0.50	3.0
FI53	Hailuoto	1.22	0.87	1.4
LT15	Preila	3.70	0.87	4.3
LV10	Rucava	1.38	0.56	2.4
LV16	Zoseni	1.42	0.61	2.3
PL04	Leba	1.66	0.60	2.8
SE05	Bredkälen	0.56	0.28	2.0

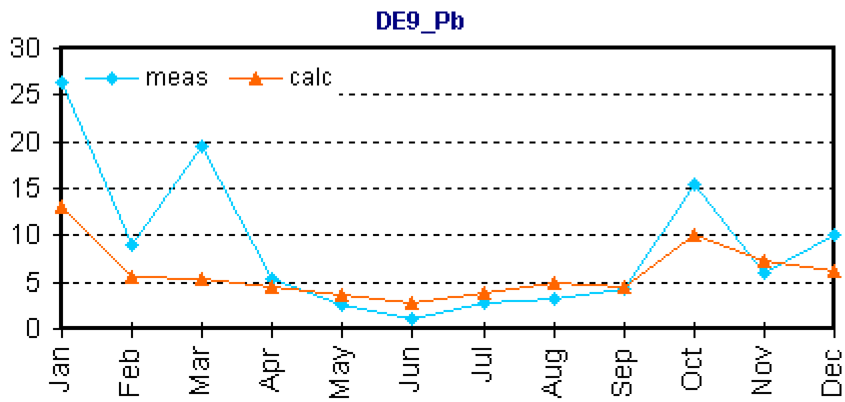

Figure 5.6. Comparison of calculated mean monthly lead concentrations in air with measured at station Zingst (DE09). Units: ng / m^3.

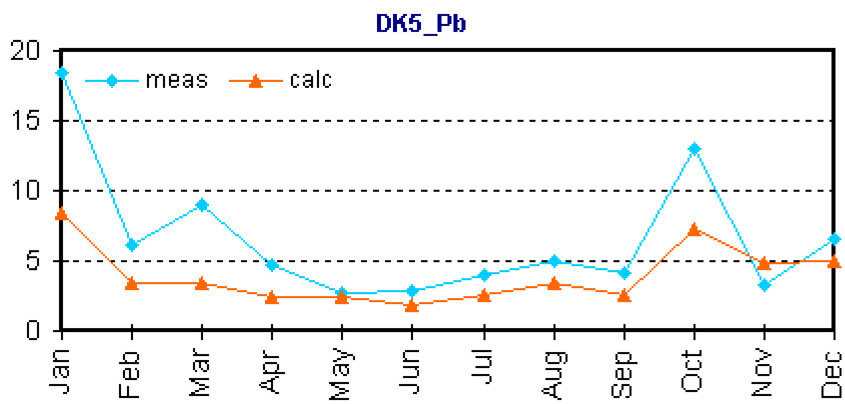

Figure 5.7. Comparison of calculated mean monthly lead concentrations in air with measured at station Keldsnor (DK05). Units: ng / m^3.

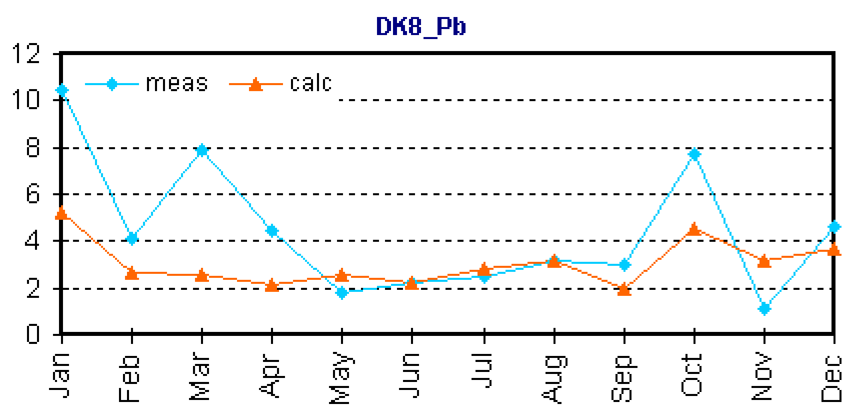

Figure 5.8. Comparison of calculated mean monthly lead concentrations in air with measured at station Anholt (DK08). Units: ng / m^3.

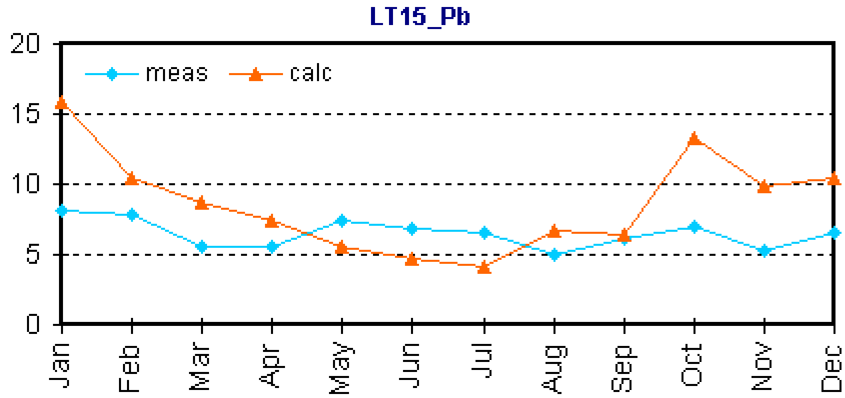

Figure 5.9. Comparison of calculated mean monthly lead concentrations in air with measured at station Preila (LT15). Units: ng / m^3.

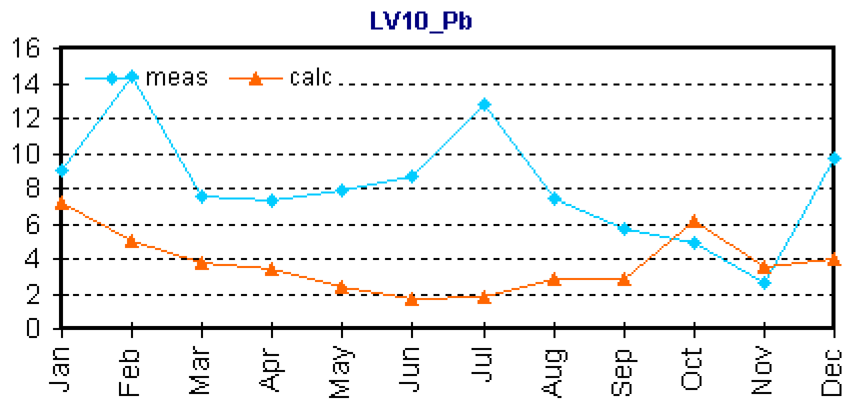

Figure 5.10. Comparison of calculated mean monthly lead concentrations in air with measured at station Rucava (LV10). Units: ng / m^3.

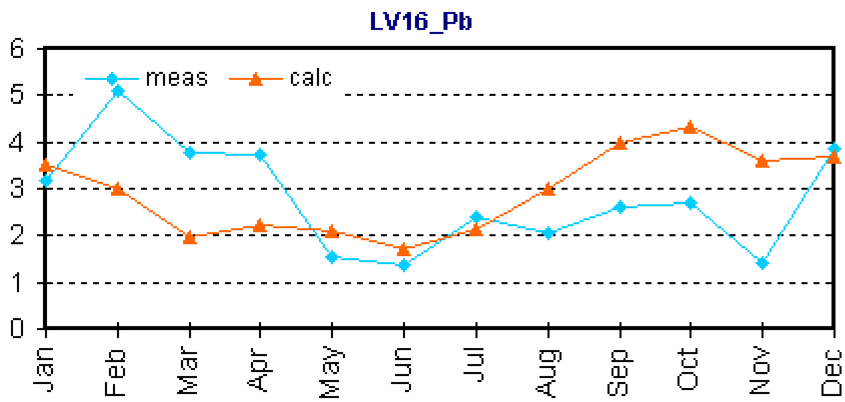

Figure 5.11. Comparison of calculated mean monthly lead concentrations in air with measured at station Zoseni (LV16). Units: ng / m^3.

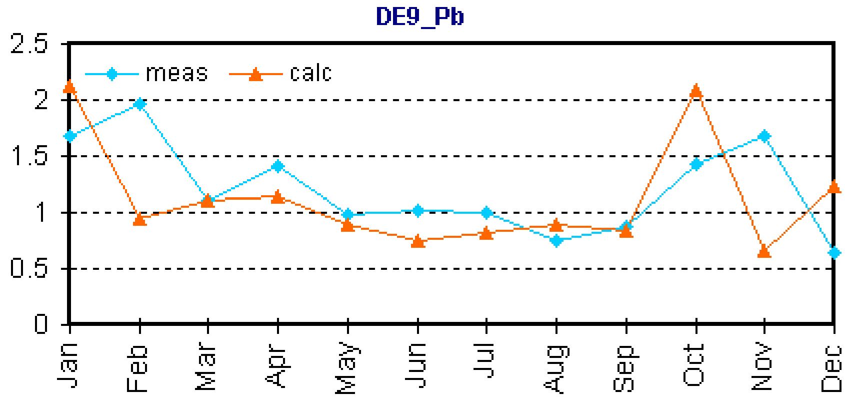

Figure 5.12. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Zingst (DE09). Units: µg / l.

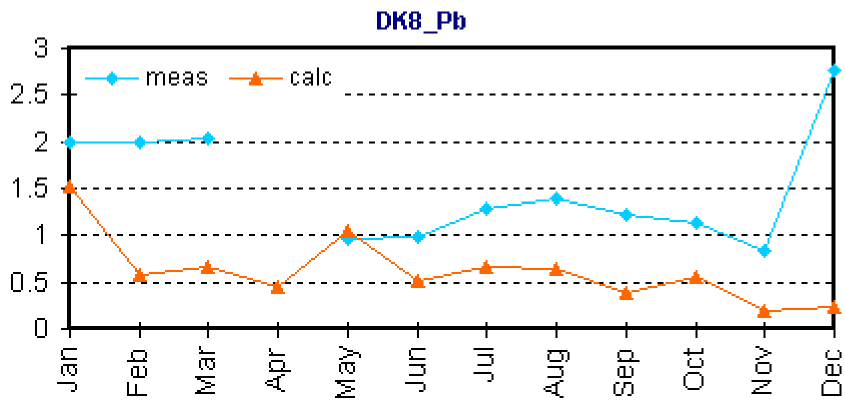

Figure 5.13. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Anholt (DK08). Units: µg / l.

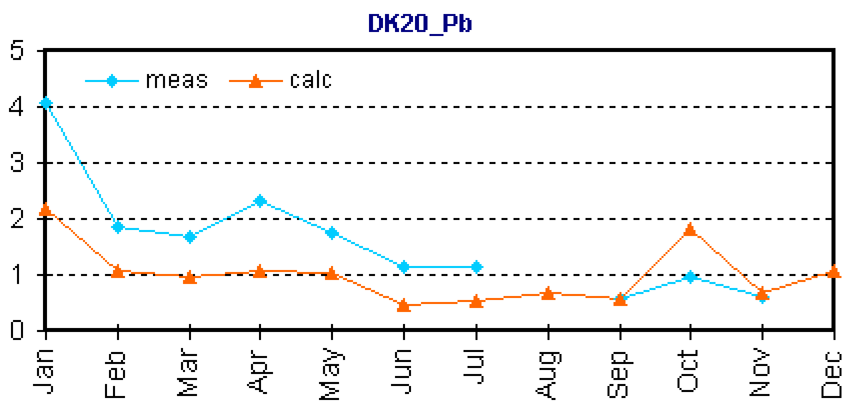

Figure 5.14. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Pedersker (DK20). Units: µg / l.

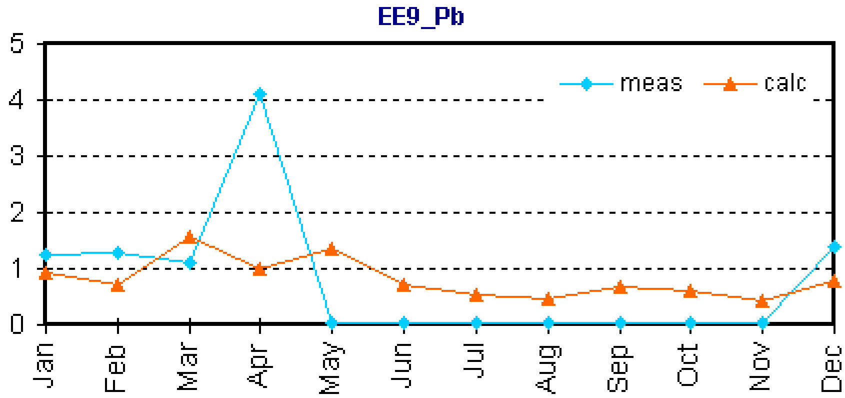

Figure 5.15. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Lahemaa (EE09). Units: µg / l.

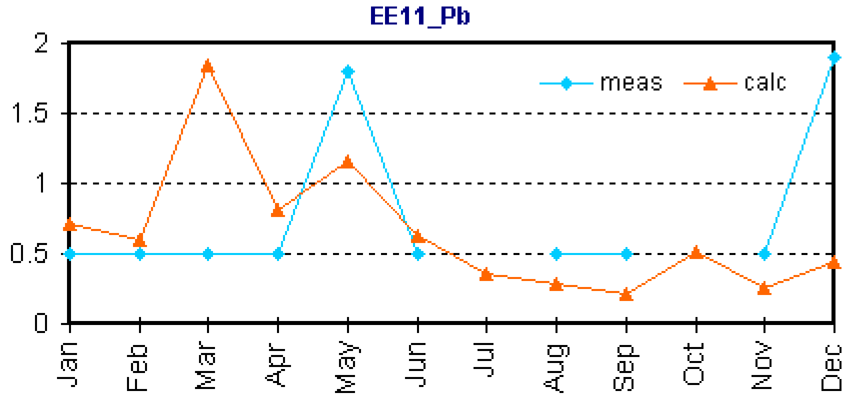

Figure 5.16. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Vilsandy (EE11). Units: µg / l.

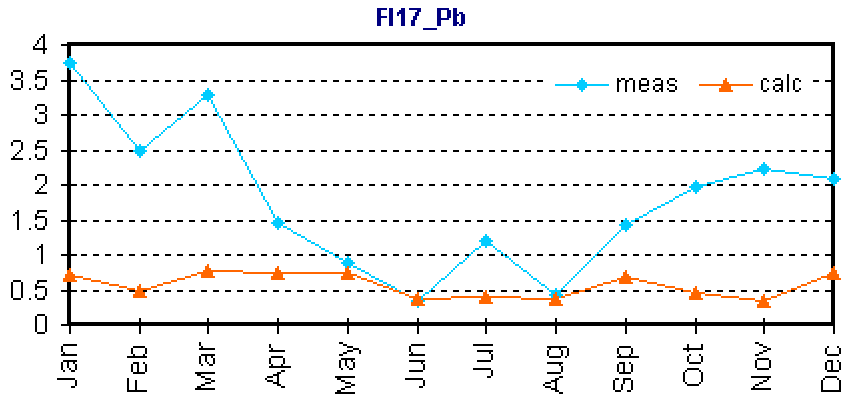

Figure 5.17. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Virolahti II (FI17). Units: µg / l.

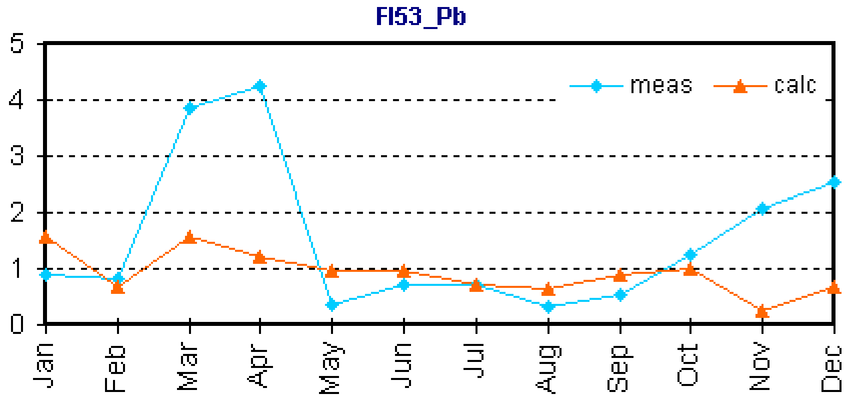

Figure 5.18. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Hailuoto (FI53). Units: µg / l.

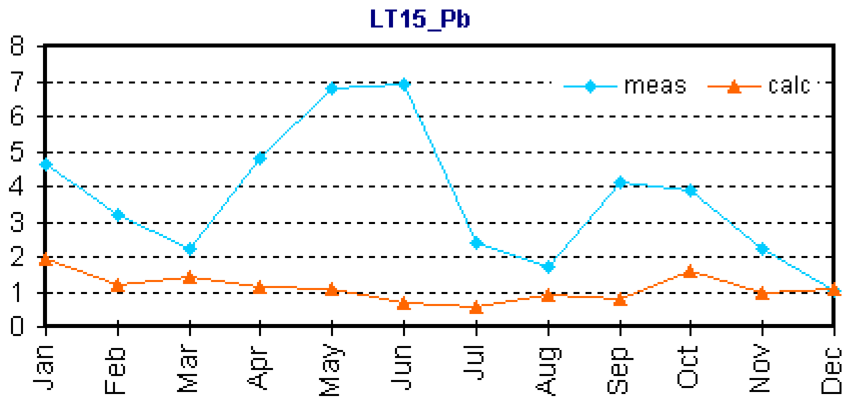

Figure 5.19. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Preila (LT15). Units: µg / l.

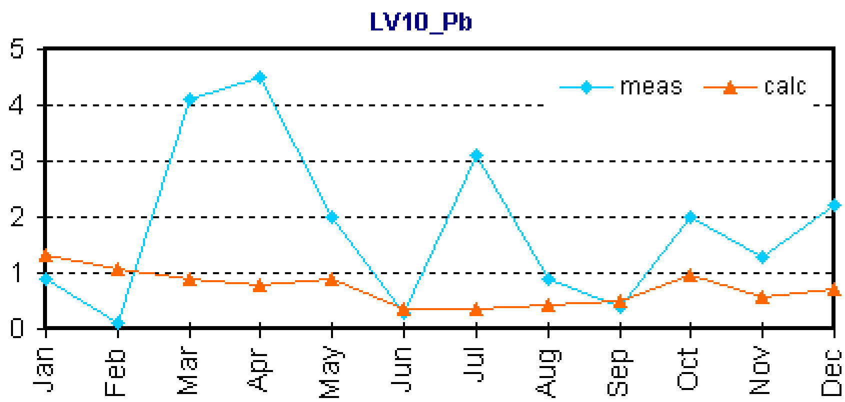

Figure 5.20. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Lahemaa (LV10). Units: µg / l.

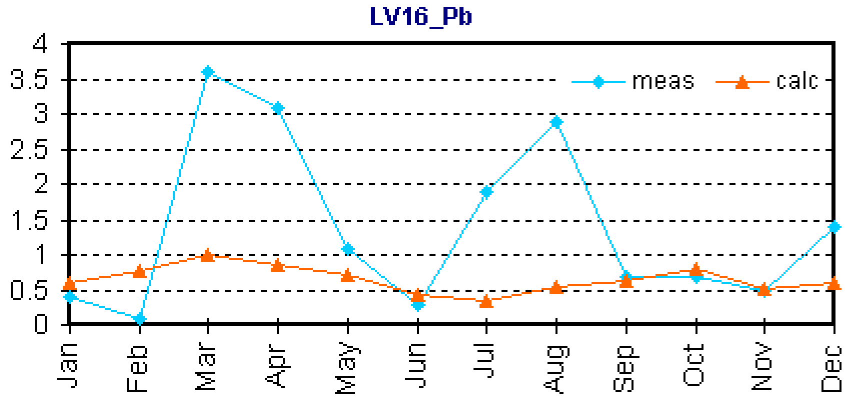

Figure 5.21. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Zoseni (LV16). Units: µg / l.

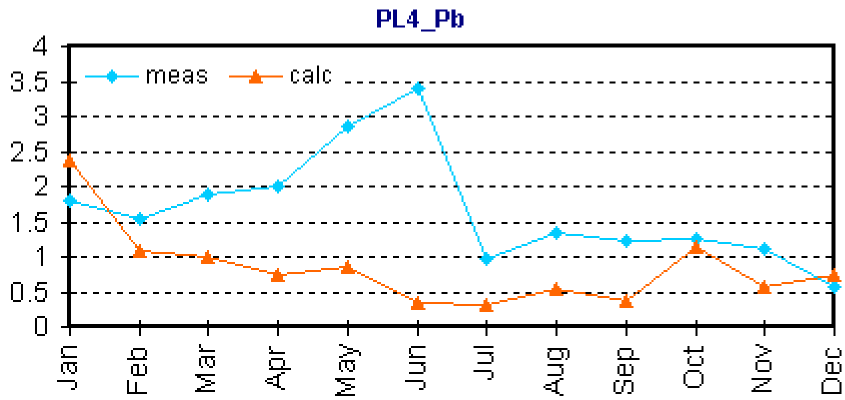

Figure 5.22. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Leba (PL04). Units: µg / l.

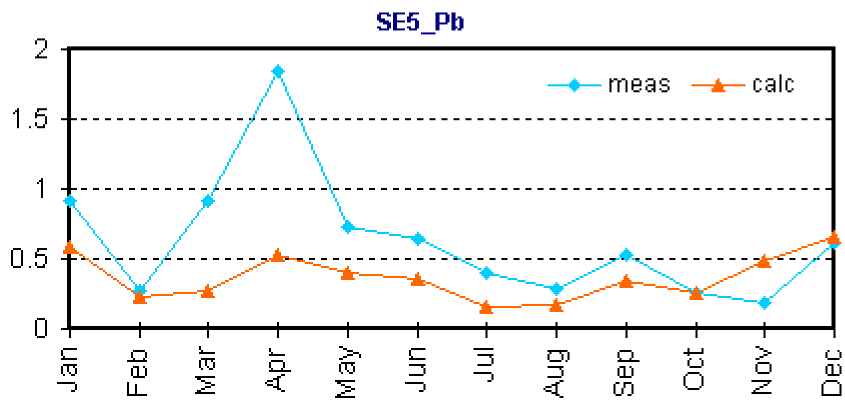

Figure 5.23. Comparison of calculated mean monthly lead concentrations in precipitation with measured at station Bredkälen (SE05). Units: µg / l.