6. Atmospheric Supply of Cadmium to the Baltic Sea in 2002

This chapter presents a short description of model evaluation of cadmium atmospheric input to the Baltic Sea, its sub-basins and catchment area in 2002. Modelling of cadmium 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 cadmium emission from HELCOM countries and other European countries was used in computations. Based on these data levels of annual and monthly cadmium 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 cadmium concentrations in air and precipitation measured at monitoring sites around the Baltic Sea.

6.1 Cadmium emissions

Three categories of emission data were used for evaluation of cadmium atmospheric load to the Baltic Sea: direct anthropogenic emissions, natural emissions and re-emission. Direct anthropogenic emission of HELCOM countries in 2002 were based on officially submitted information on cadmium emissions to the UN ECE Secretariat (EB.AIR/GE.1/2004/10). For Germany and Poland official information on emissions in 2002 was missing. The value of total annual cadmium 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 cadmium emission of Poland in 2002 was assumed to be equal to the value of 2001.

The information on total annual cadmium emissions of HELCOM countries in 2002 as well as total emission within the EMEP region is summarized in the Table 6.1. Along with the data for 2002 the emissions for 2001 are also given in the table. Total cadmium emission of HELCOM countries in 2002 is practically on the same level as in 2001 (120 tonnes). The contribution of HELCOM countries emissions to cadmium anthropogenic emission within the whole EMEP region is approximately 47% which is slightly higher than in previous year. The changes in cadmium emissions outside the HELCOM region are more significant. Total cadmium emissions within the whole EMEP in 2002 are lower than in 2001 by 33%.

The highest cadmium emissions within the HELCOM region were reported by the Poland (52.5 tonnes), Russian Federation (51.5 tonnes), and Germany (11 tonnes). Spatial distribution of cadmium anthropogenic emission for 2002 is presented in Figure 6.1.

Table 6.1. Annual emissions of cadmium in HELCOM countries and 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 forth in tonnes

Country	2001	2002	Change
Denmark	0.72	0.66	-0.06
Estonia	0.62	0.62	0
Finland	1.65	1.27	-0.38
Germany	11	11	0
Latvia	0.56	0.54	-0.02
Lithuania	1.17	1.01	-0.16
Poland	52.5	52.5	0
Russian Federation	50.5	51.5	1.00
Sweden	1.11	0.52	-0.59
TOTAL – HELCOM countries	**120**	**120**	**0**
TOTAL - EMEP	**290**	**257**	**-33**

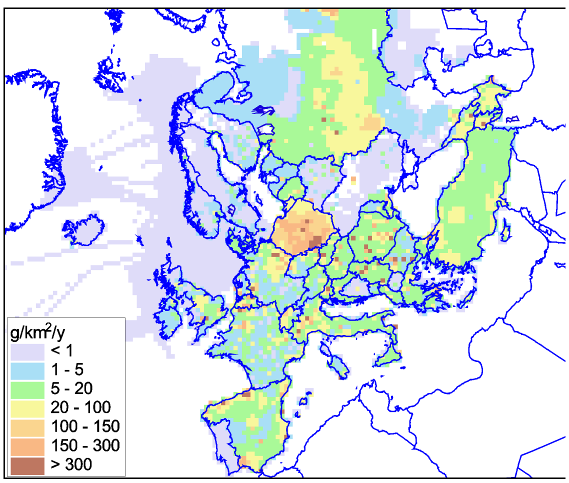


Figure 6.1. Spatial distribution of cadmium anthropogenic emission within the EMEP region in 2002 with resolution 50x50 km^2. Units: g/km^2/year

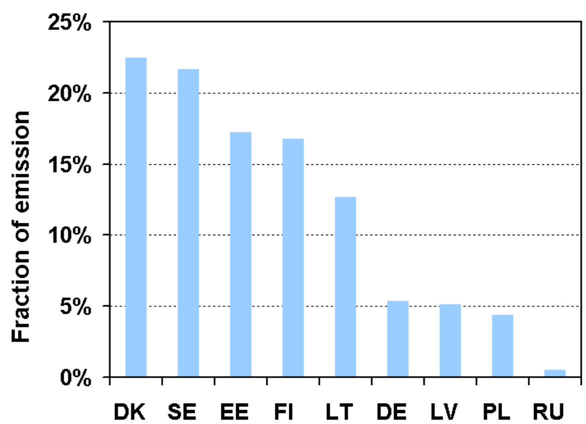


Figure 6.2. Fractions of cadmium anthropogenic emissions of HELCOM countries in 2002 deposited to the Baltic Sea.

It should be noted that the emission of Russian Federation in the Table 6.1 is related to its whole European territory. However only a small part of this emission is actually reaching the Baltic Sea. Estimated fractions of cadmium anthropogenic emissions of HELCOM countries deposited to the Baltic Sea in 2002 are shown in Figure 6.2.

The input of cadmium re-emission and natural emission sources of European territory for 2002 is estimated to about 55 tonnes. The description of parameterization of cadmium natural emission and re-emission used in the MSCE-HM model can be found in (Ilyin et al., 2002).

6.2 Annual deposition of cadmium

Total annual deposition of cadmium to the Baltic Sea in 2002 amounts to 3.8 tonnes and to its catchment area – about 40 tonnes. Atmospheric depositions over the Baltic Sea computed for 2001 were slightly lower (3.6 tonnes) whereas over its catchment area they were higher, accounting to 46 tonnes. Comparing the results for these two years it can be seen that total annual depositions of cadmium to the Baltic Sea did not change significantly. At the same time depositions of cadmium to the Baltic Sea catchment area in 2002 have decreased by 14%.

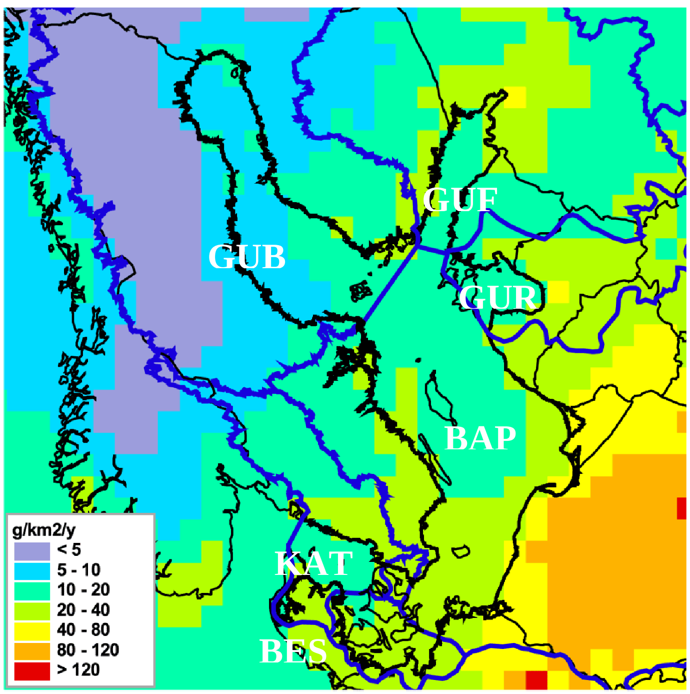


Fig. 6.3. Spatial distribution of total cadmium deposition flux in the Baltic Sea region for 2002 with resolution 50x50 km^2. Units: g/km^2/year

Spatial distribution of cadmium total deposition flux in 2002 is given in Figure 6.3. Cadmium depositions over the Baltic Sea gradually decrease from its southern part to northern one. Higher levels of deposition fluxes can be found in the Belt Sea sub-basin

(BES) and southern part of the Baltic Proper sub-basin (BAP). Lowest values of deposition fluxes are found in the Gulf of Bothnia sub-basin (GUB). Over the Baltic Sea catchment area the highest deposition fluxes of cadmium as for the previous year are obtained for the Baltic Proper catchment (BAP).

Annual dry, wet, and total cadmium depositions in 2002 are presented in Table 6.2 for the sub-basins of the Baltic Sea and in Table 6.3 for its catchment area. The most significant contribution to the total depositions of cadmium belongs to wet deposition for all sub-basins and catchments.

Table 6.2. Annual dry, wet, and total depositions (tonnes/year) and total deposition fluxes (g/km^2/year) of cadmium to the Baltic Sea sub-basins in 2002

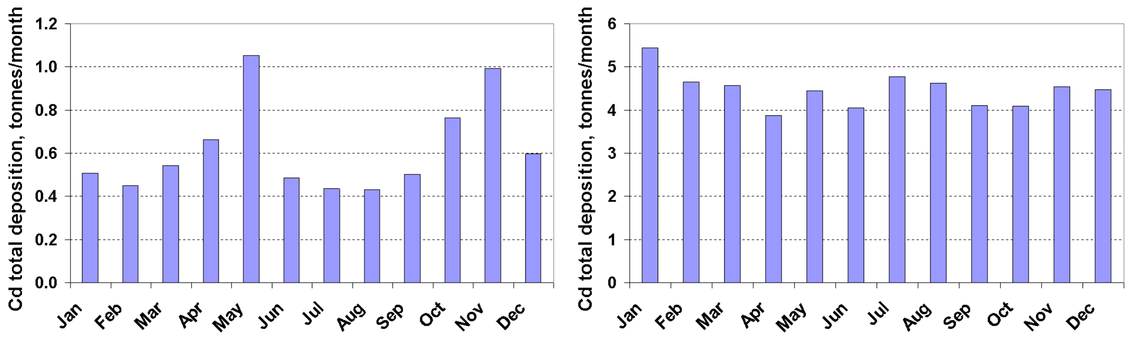
Deposition	GUB	GUF	GUR	BAP	BES	KAT	Baltic Sea
Dry	0.08	0.08	0.04	0.45	0.07	0.03	0.75
Wet	1.16	0.46	0.26	3.99	0.43	0.37	6.68
Total	1.24	0.54	0.30	4.44	0.50	0.40	7.43
Flux	11	18	16	21	24	17	18

Table 6.3. Annual dry, wet, and total depositions (tonnes/year) and total deposition fluxes (g/km^2/year) of cadmium to the Baltic Sea catchment area in 2002

Deposition	GUB	GUF	GUR	BAP	BES	KAT	Catchment area
Dry	0.5	1.7	0.8	13.2	0.2	0.3	16.7
Wet	2.4	4.8	2.2	25.7	0.6	1.1	37.0
Total	2.9	6.5	3.0	38.9	0.8	1.4	53.6
Flux	6	16	22	70	29	17	31

6.3 Monthly depositions of cadmium

Monthly variations of total cadmium depositions to the Baltic Sea and its catchment area in 2002 are presented in Figure 6.4. As for lead monthly depositions the highest cadmium deposition fluxes take place in May and November. Variation of depositions over the catchment area is less pronounced. Maximum of depositions takes place in January. The rest of the year the values of depositions are more or less the same about 4 tonnes per month.



(a) (b)

Fig. 6.4. Monthly variations of cadmium total depositions to the Baltic Sea (a) and its catchment area (b) in 2002. Units: tonnes/month

6.4 Source allocation of cadmium deposition

The contributions of HELCOM countries sources to the depositions of cadmium to the Baltic Sea sub-basins and catchments as well as contributions of other European countries were estimated using the computations of cadmium transboundary fluxes over European region (Ilyin et al., 2004). Figures 6.5 and 6.6 present estimated values of cadmium depositions to the Baltic Sea and its catchment area and their contributions to the total depositions for each HELCOM country.

Anthropogenic sources of cadmium emissions of HELCOM countries contribute to the deposition over the Baltic Sea about 52% with main contributions from Poland (31%) and Germany (8%). Sources of other HELCOM countries contribute about 13%. Contribution of European countries outside the Baltic Sea region amounts to 15%. Contribution to cadmium depositions over the Baltic Sea from re-emission, natural and remote sources is accounted for 33%.

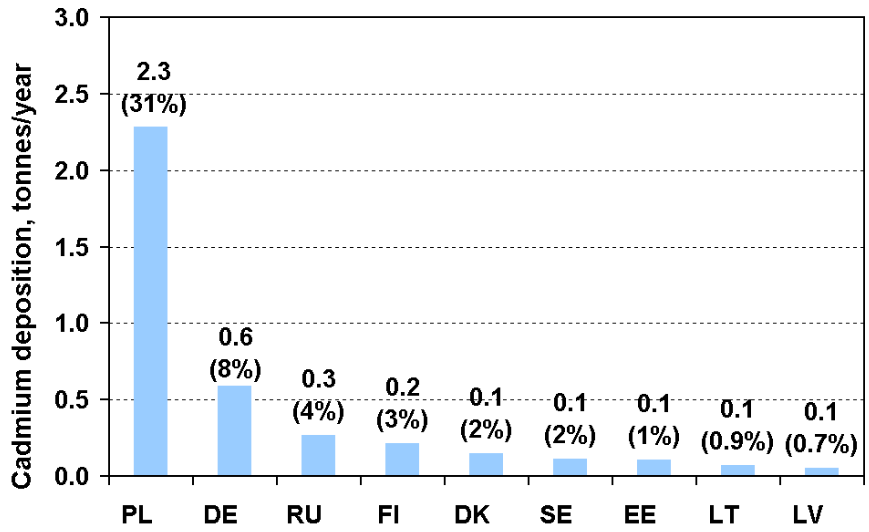


Figure 6.5. Contributions of HELCOM countries emissions to total cadmium depositions to the Baltic Sea in 2002 from anthropogenic sources, tonnes/year

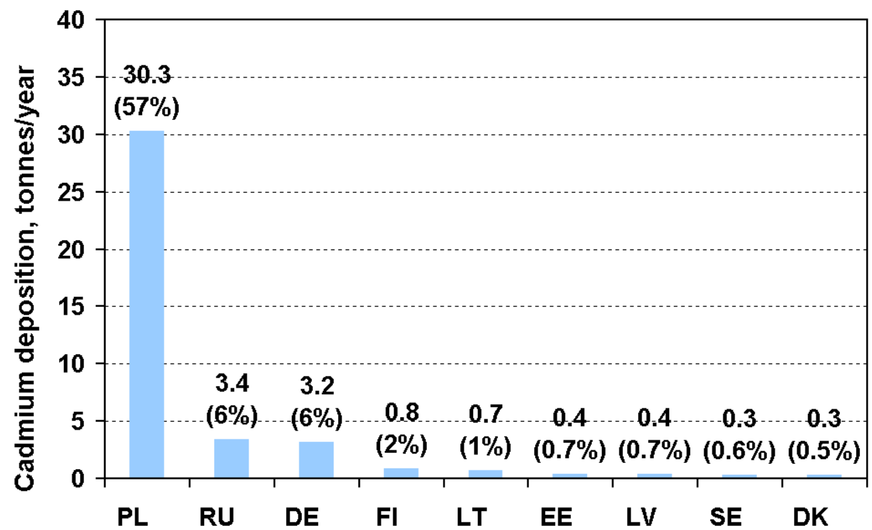


Figure 6.6. Contributions of HELCOM countries emissions to total cadmium depositions to the Baltic Sea catchment area in 2002 from anthropogenic sources, tonnes/year

The share of depositions to the catchment area from the sources of HELCOM countries amounts to 74% with main contribution from Poland (57%). Other HELCOM countries contribute about 18%. Contribution from re-emission, natural and remote sources is accounted for 15%. European countries outside the Baltic Sea region contribute 11% to the total cadmium depositions over the Baltic Sea catchment area.

Atmospheric input of two most important contributors among the HELCOM countries to cadmium depositions over sub-basins and catchments of the Baltic Sea in 2001 and 2002 is given in Tables 6.4 and 6.5.

Table 6.4. Comparison of main contributors to cadmium deposition in 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	10	SE	9	63	PL	21	FI	12	41
GUF	EE	17	RU	10	52	EE	16	PL	15	32
GUR	PL	23	LV	6	53	PL	28	DE	7	37
BAP	PL	35	DE	7	45	PL	38	DE	9	30
BES	DE	13	DK	11	56	PL	22	DE	14	34
KAT	DK	11	PL	8	65	PL	18	DK	9	41
BAS	PL	25	DE	5	51	PL	31	DE	8	33

* - contribution of re-emission, natural and remote sources.

Table 6.5. Comparison of main contributors to cadmium deposition in sub-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	FI	5	PL	5	77	PL	16	FI	13	40
GUF	RU	21	PL	7	57	RU	32	PL	15	25
GUR	PL	19	RU	9	49	PL	34	RU	11	23
BAP	PL	68	DE	3	16	PL	70	DE	7	9
BES	DE	18	DK	10	54	PL	22	DE	17	32
KAT	PL	11	DK	5	66	PL	16	DK	6	42
CAT	PL	50	RU	4	30	PL	57	RU	6	15

* - contribution of re-emission, natural and remote sources.

Comparing the inputs to cadmium depositions both over the Baltic Sea and its catchment area it can be seen that on the whole contribution of re-emission, natural and remote sources for 2002 is lower than for 2001 whereas the contributions of HELCOM countries are somewhat higher. There are also changes on the level of contributions of individual HELCOM countries. These differences are mainly conditioned by interannual variability of meteorological data, in particular, transport pathways and precipitation amount, however their influence was not thoroughly investigated in this work.

For the Gulf of Bothnia (GUB) and the Gulf of Finland (GUF) the most important contributors among the HELCOM countries are Poland, Finland, and Estonia. The input of Poland becomes more significant. For other sub-basins - 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 Denmark. Comparing to 2001 Poland becomes dominating contributor for these sub-basins in computations for 2002.

For the catchment area of the Gulf of Bothnia (GUB) and the Gulf of Finland (GUF) the largest contributions among the HELCOM countries belongs Poland, Finland, and Russian Federation. Catchment areas of other sub-basins - the Gulf of Riga (GUR), the Baltic Proper (BAP), and the Kattegat (KAT) - are mostly influenced by emission sources of Poland, Germany, and Denmark emissions. Comparing to 2001 the contribution of Poland to cadmium depositions over the catchment area in computations for 2002 is more significant.

6.5 Comparison of model results with measurements

Model results for cadmium were compared with available measurements made on HELCOM stations for 2002. Measurements of cadmium concentrations were reported by Zingst (DE09), Keldsnor (DK5), Anholt (DK8), Pedersker (DK20), Lahemaa (EE09), Vilsandy (EE11), Utö (FI09), Virolahti II (FI17), Hailuoto (FI53), Preila (LT15), Rucava (LV10), Zozeni (LV16), Leba (PL04), Bredkälen (SE05), Råö (SE14), and Arup (SE51). However the data of DK05 and DK08 on concentrations in air and precipitation data of FI09, FI53, EE11, LV10, LT15, and SE05 were not included in the comparison. The most part of the data on cadmium in air from DK05 and DK08 were below detection limit. The precipitation amounts measured at FI09 and FI53 differed more than 1.5 times from that used in the model. Information on cadmium concentrations in precipitation of EE11, LV10, and SE05 were excluded due to low data capture. Data of LT15 for cadmium in precipitation were also recommended to exclude by CCC due to too high values. Table 6.6 presents the results of the comparison of mean annual calculated and measured cadmium concentrations in air and precipitation for 2002. Comparison of monthly variations of calculated and measured cadmium concentrations at stations listed above is presented in Figures 6.7 – 6.22.

As it can be seen computed air concentrations of cadmium are 1.7 times lower than measured ones. The most significant discrepancies are obtained for LV16 and SE05. Computed concentrations in precipitation in comparison with observed values are lower in 2.6 times. The highest discrepancies are obtained for DK08, EE09, and LV16. The reason of the underestimation of observed level of concentrations is most likely connected with the underestimated level of cadmium emissions. For instance, cadmium emissions from the ship traffic which is not currently taken into account can also contribute to concentrations and depositions within the Baltic Sea region. Based on the results of the comparison with measurements the actual atmospheric load of cadmium to the Baltic Sea in 2002 can be approximately two times higher than model estimates presented in this chapter.

Table 6.6. Comparison of calculated and measured mean annual cadmium concentrations in air and precipitation for 2002

Station code	Station name	Observed	Calculated	Obs / Calc
Cd concentrations in air (ng/m^3)				
DE09	Zingst	0.18	0.17	1.1
LT15	Preila	0.23	0.21	1.1
LV10	Rucava	0.22	0.12	1.9
LV16	Zoseni	0.30	0.07	4.1
SE05	Bredkälen	0.023	0.006	3.8
SE14	Råö	0.09	0.05	1.8
Cd concentrations in precipitation (µg/l)				
DE09	Zingst	0.04	0.03	1.4
DK08	Anholt	0.052	0.012	4.5
DK20	Pedersker	0.06	0.029	2.1
EE09	Lahemaa	0.10	0.023	4.4
FI17	Virolahti II	0.066	0.032	2.1
LV16	Zoseni	0.115	0.024	4.8
PL04	Leba	0.051	0.029	1.8
SE51	Arup	0.048	0.025	2.0

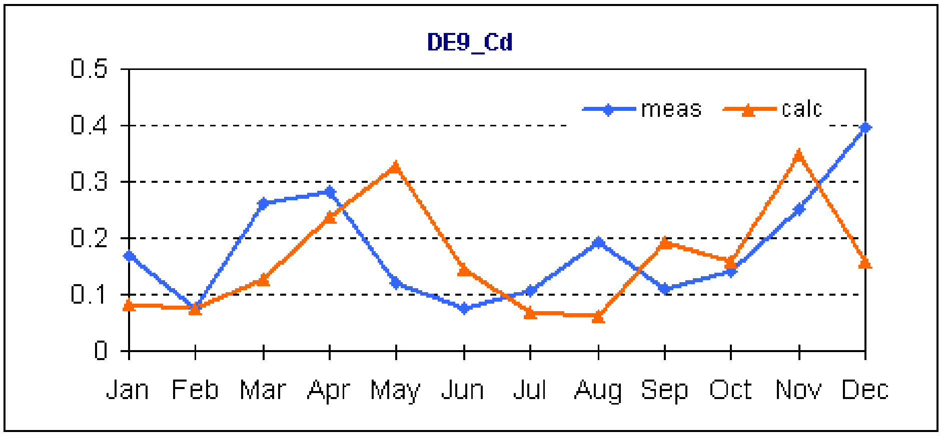


Figure 6.7. Comparison of calculated mean monthly cadmium concentrations in air with measured at station Zingst (DE09). Units: ng / m^3.

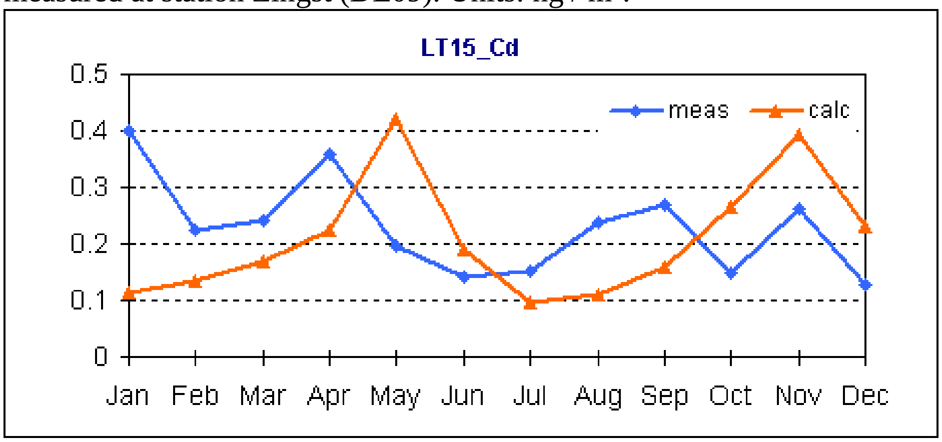


Figure 6.8. Comparison of calculated mean monthly cadmium concentrations in air with measured at station Preila (LT15). Units: ng / m^3.

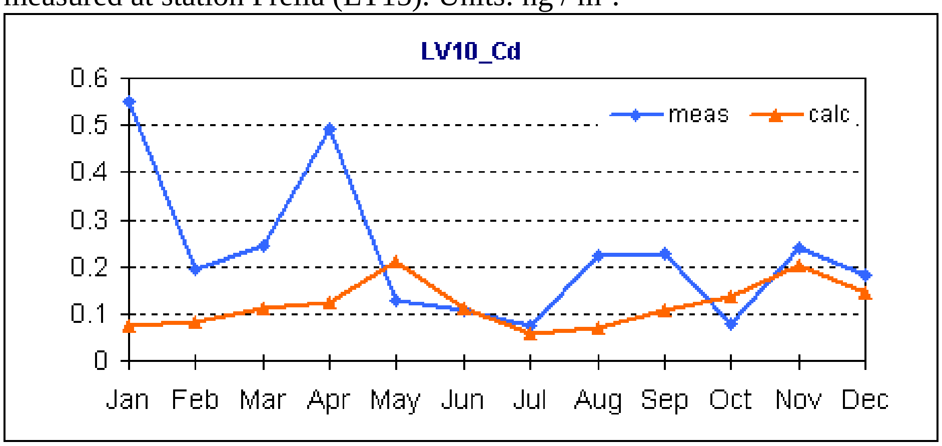


Figure 6.9. Comparison of calculated mean monthly cadmium concentrations in air with measured at station Rucava (LV10). Units: ng / m^3.

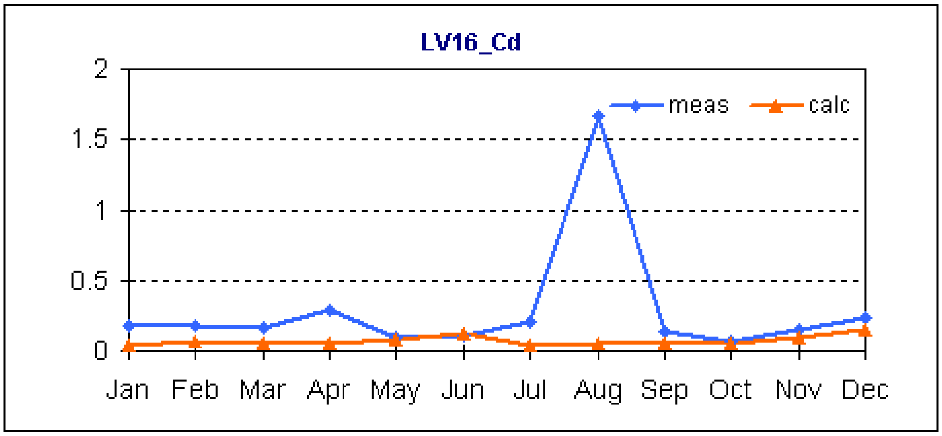


Figure 6.10. Comparison of calculated mean monthly cadmium concentrations in air with measured at station Zoseni (LV16). Units: ng / m^3.

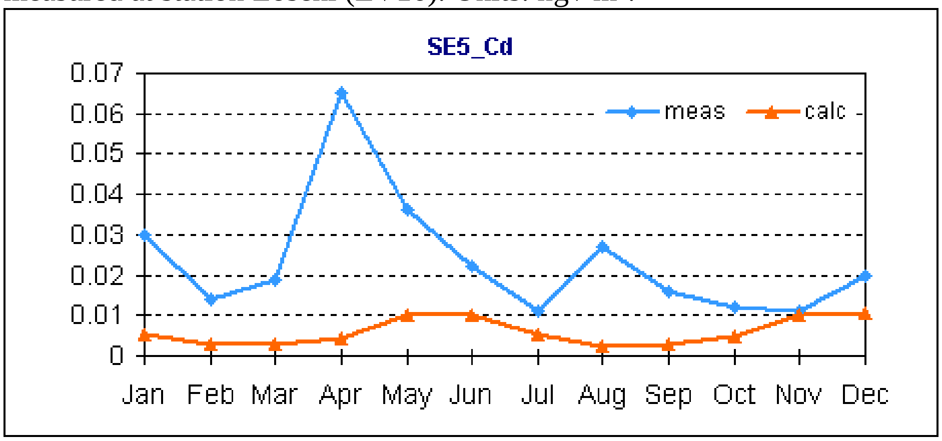


Figure 6.11. Comparison of calculated mean monthly cadmium concentrations in air with measured at station Bredkälen (SE05). Units: ng / m^3.

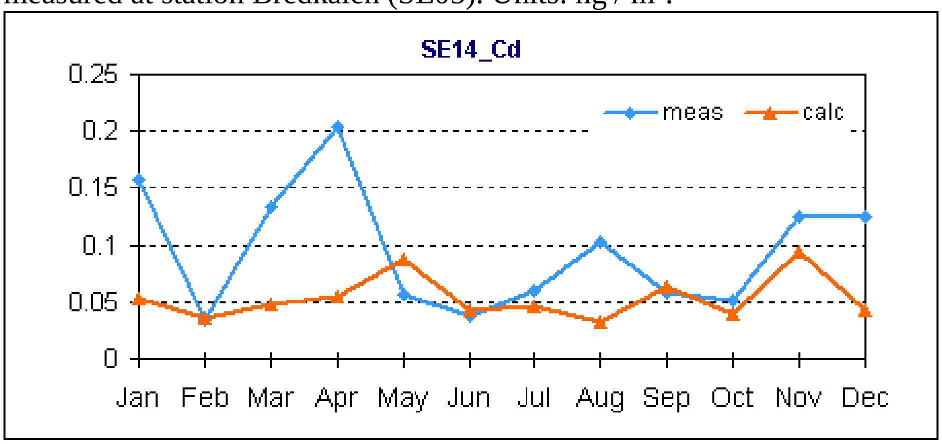


Figure 6.12. Comparison of calculated mean monthly cadmium concentrations in air with measured at station Råö (SE14). Units: ng / m^3.

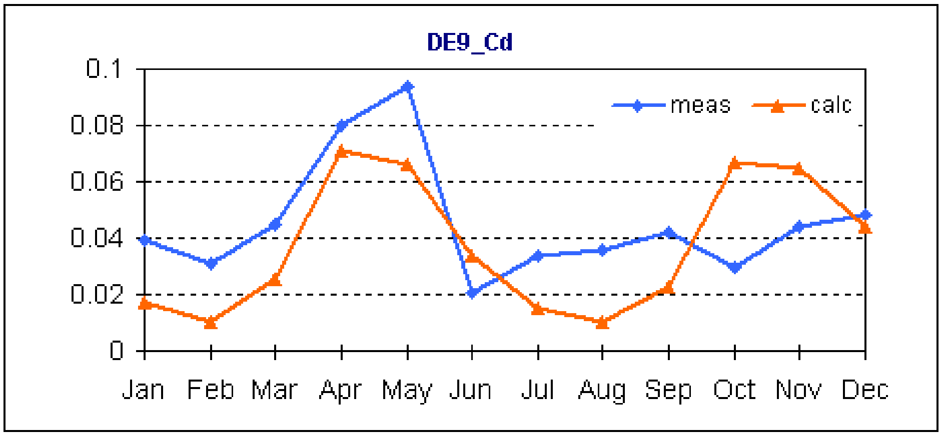


Figure 6.13. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Zingst (DE09). Units: µg / l.

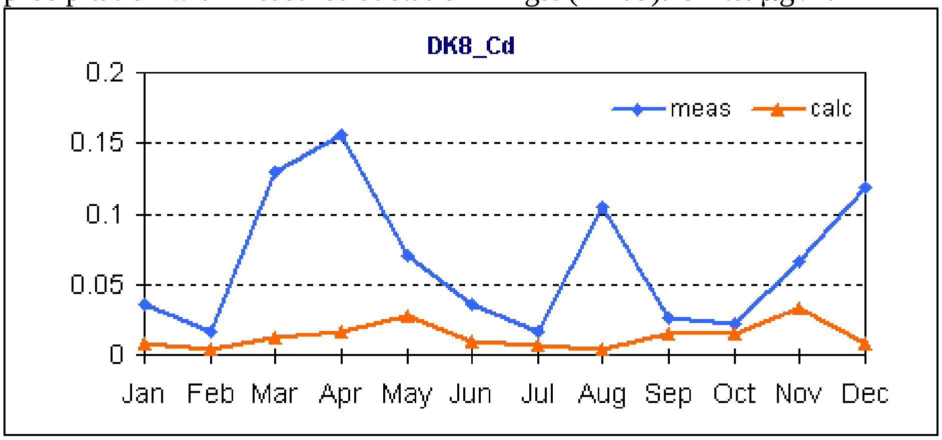


Figure 6.14. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Anholt (DK08). Units: µg / l.

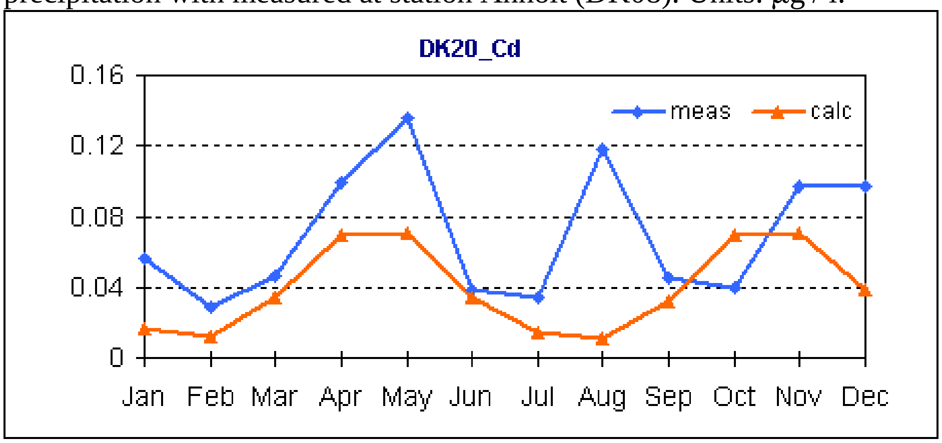


Figure 6.15. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Pedersker (DK20). Units: µg / l.

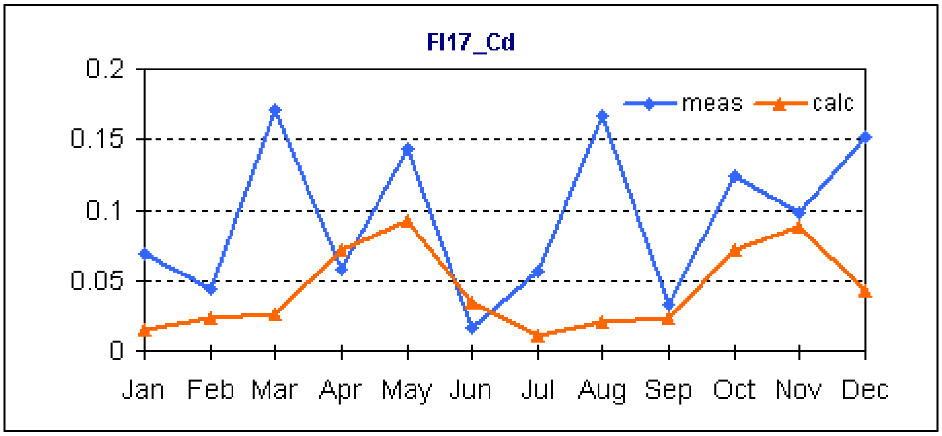


Figure 6.16. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Virolahti II (FI17). Units: µg / l.

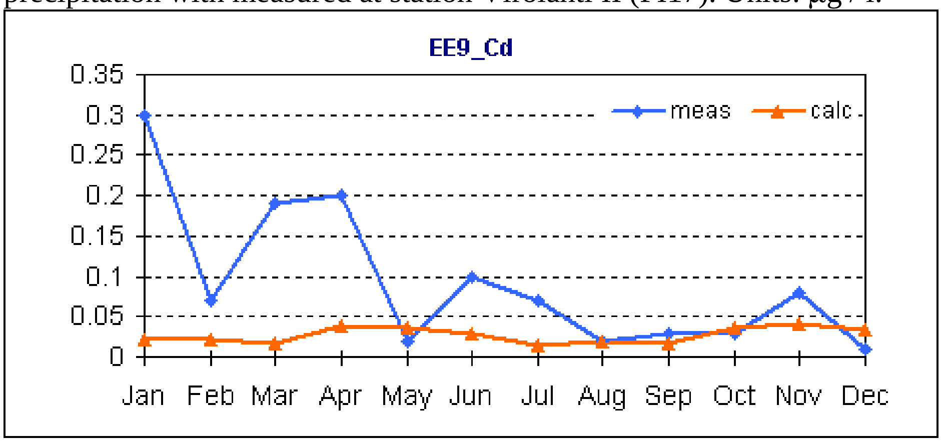


Figure 6.17. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Lahemaa (EE09). Units: µg / l.

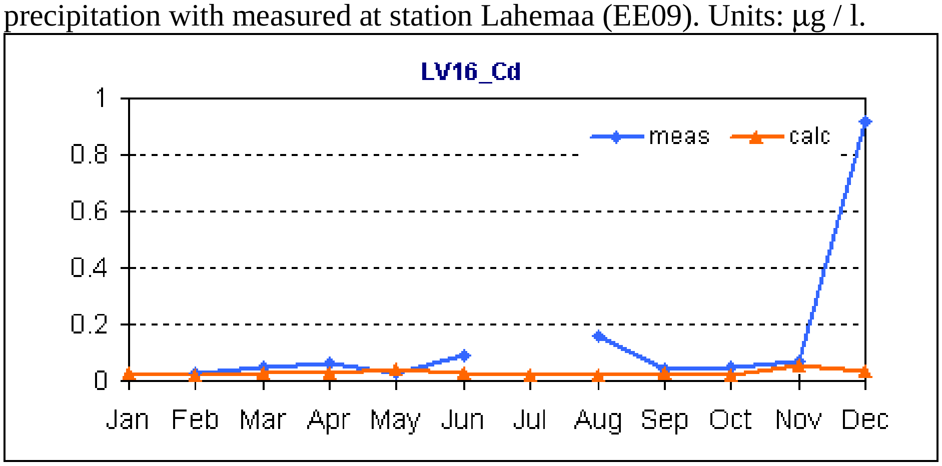


Figure 6.18. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Zozeni (LV16). Units: µg / l.

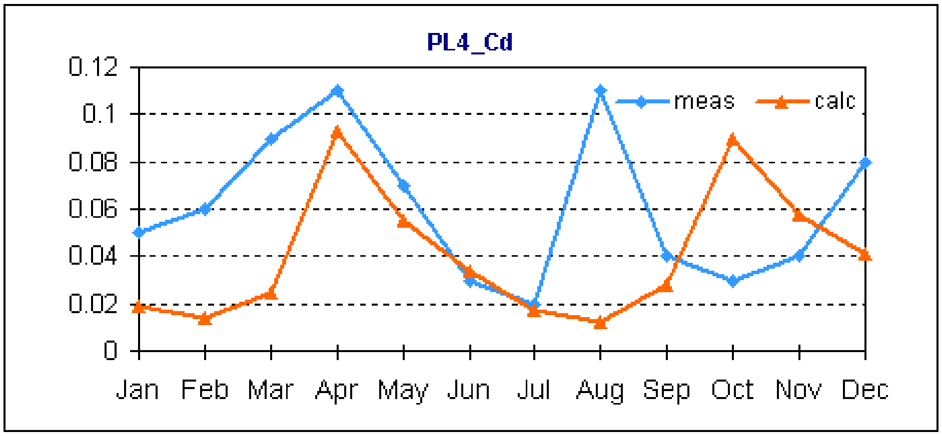


Figure 6.19. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Leba (PL04). Units: µg / l.

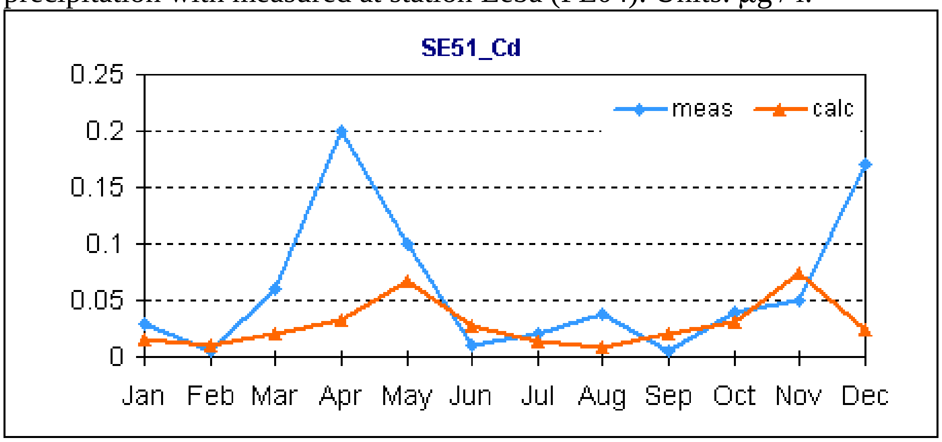


Figure 6.20. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Arup (SE51). Units: µg / l.