6. Atmospheric Supply of Cadmium to the Baltic Sea in 2001

Cadmium depositions to the Baltic Sea sub-basins and catchments were computed for 2001 using MSC-E Eulerian Heavy Metal transport model MSCE-HM (Ilyin et al., 2003). Modelling was carried out for the EMEP domain with horizontal resolution 50x50 km^2 based on the latest available cadmium emission data. In this chapter a short description of emissions and computed annual depositions of cadmium along with their seasonal variations and contributions of HELCOM countries to the depositions over the Baltic Sea sub-basins and catchments. Obtained results were compared with available monitoring data of cadmium concentrations in air and precipitation for the Baltic Sea region.

6.1 Cadmium emissions

For modelling of cadmium atmospheric input to the Baltic Sea and its catchment area three categories of emissions were used: direct anthropogenic emissions, natural emissions and re-emission. Direct anthropogenic emissions of cadmium in HELCOM countries were based on officially submitted data (Vestreng, 2003).

Official data on cadmium emissions from anthropogenic sources for 2001 was reported to the UN ECE Secretariat by most of the HELCOM countries. Official information on cadmium emissions in 2001 was missing for Germany and Russian Federation. Germany submitted cadmium emission data for 1995 and projection of emission for 2010. Emissions for other years from 1995 to 2001 were estimated by linear interpolation. Cadmium emission of Russian Federation was available for 2000 and previous years therefore the value for 2000 was applied in computations for 2001.

Total annual emissions of HELCOM countries in 2001 as well as total cadmium emission within the EMEP region are summarized in the table 6.1. Total emission of HELCOM countries in 2001 accounts for 120 tonnes. The contribution of HELCOM countries emissions to cadmium anthropogenic emission within the whole EMEP region is approximately 40%. The highest emissions within the HELCOM region are reported by Poland (52.5 tonnes), the Russian Federation (50.5 tonnes), and Germany (11 tonnes). For the comparison emissions for 2000 are also presented in the table. It should be noted that some of these figures differ with those given in the previous joint report of EMEP Centres (Bartnicki *et al.,* 2002).These differences are due to updates of emission data for the previous years recently made by the countries. Spatial distribution of cadmium anthropogenic emission for 2001 is presented in Figure 6.1.

Table 6.1. Annual emissions of cadmium in HELCOM countries and 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 forth column as the difference between 2001 and 2000 in tonnes

Country	2000	2001	Change
Denmark	0.70	0.72	+0.02
Estonia	0.68	0.62	-0.06
Finland	1.35	1.65	+0.3
Germany	11	11	0
Latvia	0.59	0.56	-0.03
Lithuania	1.35	1.17	-0.18
Poland	50.43	52.50	+2.07
Russian Federation	50.5	50.5	0
Sweden	0.93	1.11	+0.18
TOTAL – HELCOM countries	**117.5**	**119.8**	**+2.3**
TOTAL - EMEP	**286.2**	**290.2**	**+4**

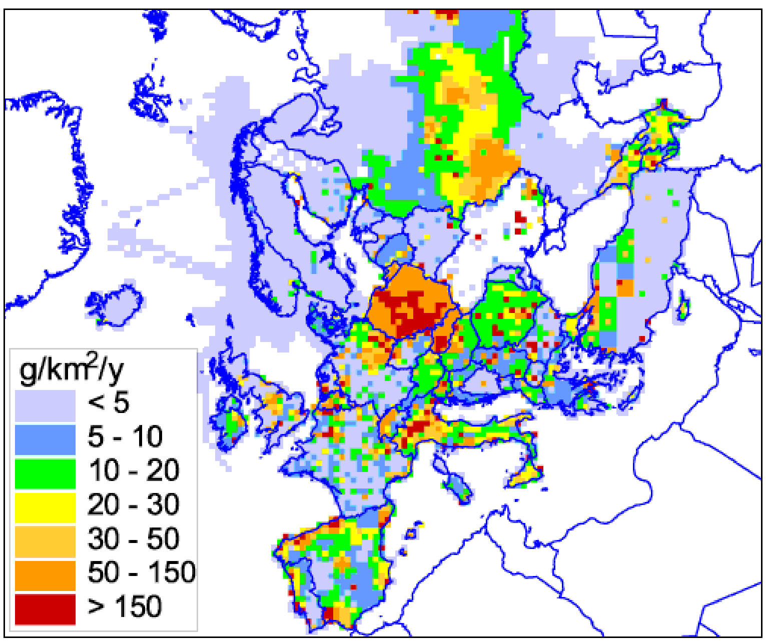


Figure 6.1. Spatial distribution of cadmium anthropogenic emission within the EMEP region in 2001 with resolution 50x50 km^2. Units: g/km^2/year

The input from re-emission and natural emissions sources of cadmium within the EMEP region for 2001 is estimated as much as approximately 150 tonnes. The description of parameterization of cadmium natural emission and re-emission used in the MSCE-HM model is given in (Ilyin *et al*., 2002).

6.2 Annual deposition of cadmium

Annual and monthly depositions of cadmium were computed for six sub-basins and six catchments of the Baltic Sea. Total depositions of cadmium to the Baltic Sea and its catchment area in 2001 amount to 8.3 tonnes and 75 tonnes, respectively. Corresponding values for 2000 were 9.3 tonnes and 76 tonnes indicating some decrease of cadmium deposition to the Baltic Sea by 10% and nearly the same level of depositions to the catchment area. Spatial distribution of cadmium total deposition flux tot the Baltic Sea region in 2001 is given in Figure 6.2.

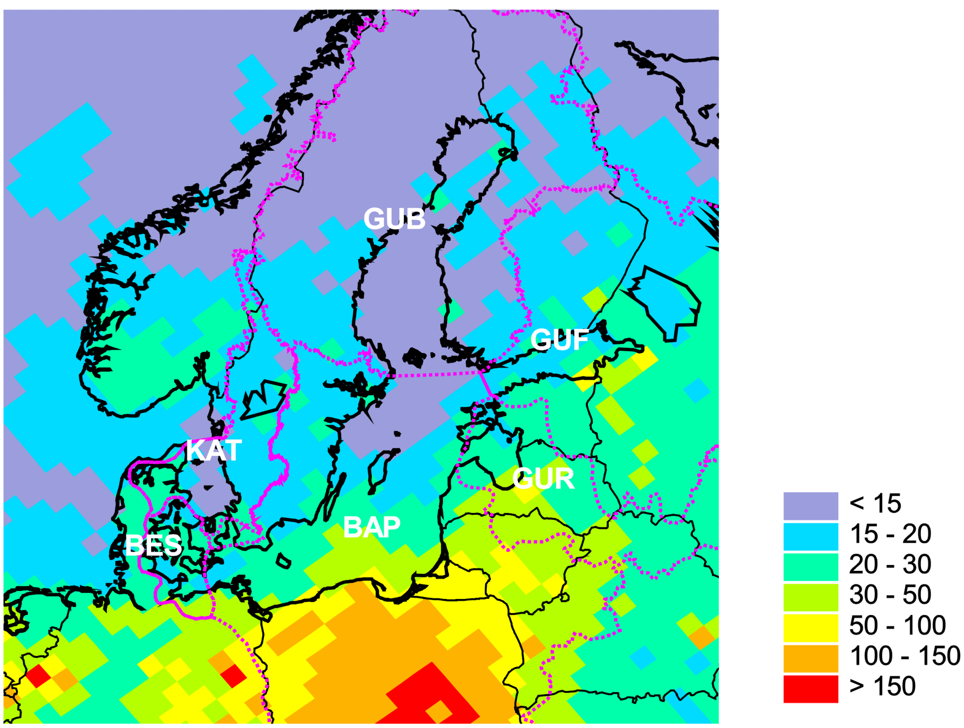


Fig. 6.2. Spatial distribution of total cadmium deposition flux in the Baltic Sea region for 2001 with resolution 50**x**50 km^2. Units: g/km^2/year

It can be seen that cadmium depositions to the Baltic Sea gradually decrease from its southern part to northern one. Elevated deposition fluxes are found in the southern part of the Baltic Proper sub-basin (BAP) and in the Gulf of Riga sub-basin (GUR). Lowest values of deposition fluxes are characteristic of the Gulf of Bothnia sub-basin (GUB). Over the

Baltic Sea catchment area the highest deposition fluxes of cadmium are obtained for the Baltic Proper catchment (BAP).

Distribution of annual cadmium depositions in 2001 is presented in Table 6.2 for the sub-basins of the Baltic Sea and in Table 6.3 for its catchment area. Contribution of wet deposition to total cadmium deposition significantly higher than the one of dry deposition for all sub-basins and catchments. The highest cadmium depositions to the Baltic Sea sub-basins are obtained for the Baltic Proper (BAP) sub-basin and over the catchment area to the Baltic Proper catchment (BAP).

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 2001

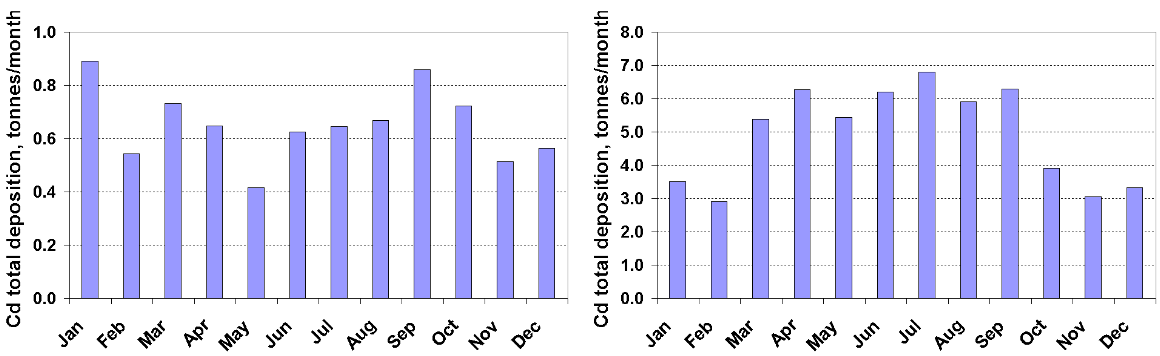
Deposition	GUB	GUF	GUR	BAP	BES	KAT	Baltic Sea
Dry	0.12	0.03	0.01	0.30	0.02	0.02	0.51
Wet	1.36	0.59	0.43	4.71	0.41	0.33	7.83
Total	1.48	0.62	0.44	5.01	0.43	0.36	8.34
Flux	12.7	20.8	24.0	23.7	20.9	15.3	19.8

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 2001

Deposition	GUB	GUF	GUR	BAP	BES	KAT	Catchment area
Dry	1.91	2.27	0.68	10.30	0.13	0.42	15.74
Wet	5.00	6.91	3.33	42.11	0.54	1.18	59.02
Total	6.91	9.17	4.01	52.41	0.66	1.59	74.76
Flux	14.0	21.8	29.0	93.9	5.9	18.6	43.4

6.3 Monthly depositions of cadmium

Total monthly depositions of cadmium to the Baltic Sea sub-basins and catchments in 2001 are presented in Figure 6.3. Maximum of depositions to the catchment area take place in summer following elevated level of precipitation. The variation of depositions over the Baltic Sea basin is less pronounced. Relatively high depositions are obtained for January and September. Lower deposition values are obtained for February, May, November, and December with minimum in May. The variation of monthly cadmium depositions is mainly caused by the variation of precipitation amount and atmospheric transport pathways carrying pollutants from different regions.



(a) (b)

Fig. 6.3. Monthly variations of cadmium total depositions to the Baltic Sea (a) and its catchment area (b) in 2001. Units: tonnes/month

6.4 Source allocation of cadmium deposition

Figures 6.4 and 6.5 present the source allocation budgets of cadmium depositions from HELCOM countries to the Baltic Sea and its catchment area. Source allocation budget of cadmium depositions to the Baltic Sea region was estimated on the basis of computations of cadmium transboundary fluxes over European region for 2001 (Ilyin *et al*., 2003).

Anthropogenic sources of cadmium emissions of HELCOM countries contribute to the deposition over the Baltic Sea about 43% among which main contributions belong to Poland (25%), and Germany (5%). Sources of other HELCOM countries contribute about 13%. Contribution of European countries outside the Baltic Sea region amounts to 6%. Significant contribution to cadmium depositions to the Baltic Sea belongs to the input from re-emission and natural sources (51%).

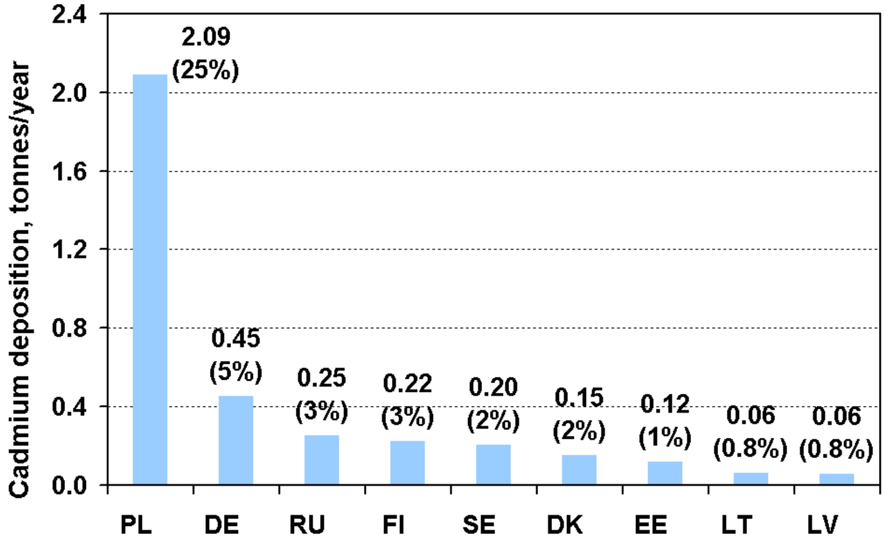


Figure 6.4. Contributions of HELCOM countries emissions to total cadmium depositions to the Baltic Sea in 2001 from anthropogenic sources, tonnes/year

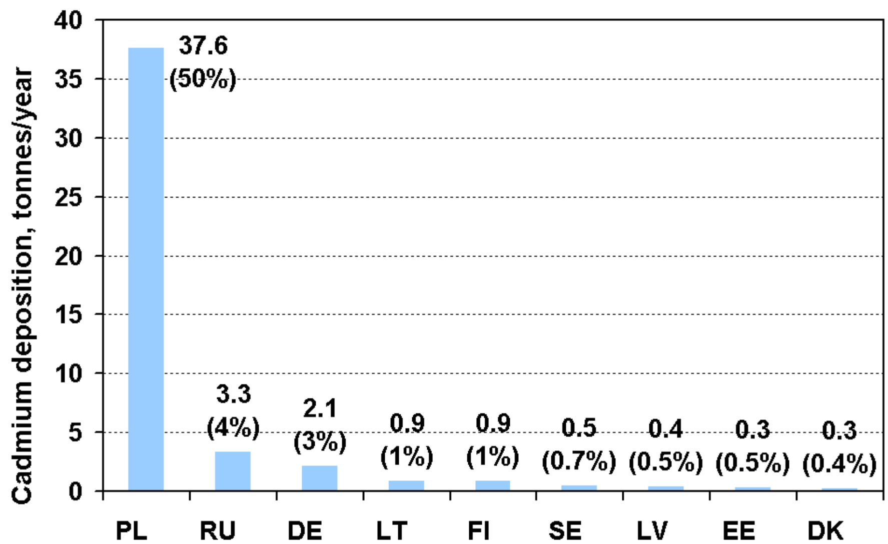


Figure 6.5. Contributions of HELCOM countries emissions to total cadmium depositions to the Baltic Sea catchment area in 2001 from anthropogenic sources, tonnes/year

The share of depositions to the catchment area from the sources of HELCOM countries amounts to 62%. Main contribution to cadmium depositions among the HELCOM countries belong to Poland (50%). Other HELCOM countries contribute about 12%. Significant contribution belongs to the input of re-emission and natural sources (30%). Contribution of European countries outside the Baltic Sea region accounts for 8%.

The input of two most important contributors among the HELCOM countries to cadmium depositions in 2000 and 2001 over sub-basins and catchments of the Baltic Sea 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 2000 and 2001. BAS means the whole Baltic Sea basin. Units: percent of total depositions

Sub-basin	2000					2001				
	Country	%	Country	%	*, %	Country	%	Country	%	*, %
GUB	PL	13	FI	7	57	FI	10	SE	9	63
GUF	EE	15	PL	12	47	EE	17	RU	10	52
GUR	PL	25	DE	5	46	PL	23	LV	6	53
BAP	PL	35	DE	8	41	PL	35	DE	7	45
BES	DE	14	PL	9	53	DE	13	DK	11	56
KAT	PL	13	DE	9	53	DK	11	PL	8	65
BAS	PL	25	DE	7	46	PL	25	DE	5	51

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

Table 6.5. Comparison of main contributors to cadmium deposition in sub-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	PL	9	FI	4	72	FI	5	PL	5	77
GUF	RU	19	PL	9	55	RU	21	PL	7	57
GUR	PL	22	RU	7	45	PL	19	RU	9	49
BAP	PL	65	DE	4	17	PL	68	DE	3	16
BES	DE	16	PL	10	51	DE	18	DK	10	54
KAT	PL	19	DE	6	55	PL	11	DK	5	66
CAT	PL	47	RU	4	31	PL	50	RU	4	30

* - 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 are Finland, Estonia, Sweden, and Russia. Other sub-basins - the Gulf of Riga

(GUR), the Baltic Proper (BAP), the Belt Sea (BES), and the Kattegat (KAT) - are mostly subject of the influence of Poland, Germany, and Denmark emissions. Significant contribution to cadmium depositions over the Baltic Sea sub-basins belongs to re-emission and natural sources. Due to the changes in emission and transport pathways the contributions to cadmium deposition over the Baltic Sea in 2001 differ from those obtained for 2000. While for the whole Baltic Sea main contributors to depositions are the same (Poland and Germany) the contributions on the level of individual sub-basins changed for most of them. In particular, drop of cadmium emission in Poland leads to decreasing of its contributions to depositions over the Gulf of Bothnia (GUB), the Gulf of Finland (GUF), the Belt Sea (BES), and the Kattegat (KAT) sub-basins.

For catchments of the Gulf of Bothnia (GUB) and the Gulf of Finland (GUF) the largest contribution belongs to re-emission and natural sources. The Gulf of Riga (GUR), the Baltic Proper (BAP), and the Kattegat (KAT) catchments are mostly influenced by emission sources of Poland, followed by Russia, Germany, and Denmark emissions. For the catchment of the Belt Sea significant contributions belong to Germany and Denmark. Comparing to 2000 the contributions of HELCOM countries emissions to cadmium depositions in 2001 are approximately the same. Changes in contributions of Finland and Poland for the Gulf of Bothnia (GUB) catchment can be noted as well as increased contribution of Denmark to depositions over the Belt Sea (BES) and the Kattegat (KAT).

6.5 Comparison of model results with measurements

To verify obtained modelling results computed cadmium concentrations were compared with available measurements made on HELCOM stations for 2001. Measured concentrations of cadmium 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). Information on cadmium concentrations in precipitation was also available for Utö (FI9) and Arup (SE51). However, precipitation amounts measured at these sites differed by more than a factor of 1.5 from that used in model computations. Therefore the comparison of concentrations in precipitations for these sites was considered incorrect. Table 6.6 presents results of the comparison of mean annual calculated and measured cadmium concentrations in air and precipitation for 2001.

Computed cadmium air concentrations for Zingst (DE9), Keldsnor (DK5), Anholt (DK8), and Preila (LT15) are within the factor of 2 in comparison to observed concentrations. Higher discrepancies are obtained for Rucava (LV10) and Zoseni (LV16). Computed cadmium concentrations in precipitation for Zingst (DE9), Anholt (DK8), Vilsandy (EE11), Hailuoto (FI53), Leba (PL04), and Bredkälen (SE05) are within the factor of 2 in comparison with observations. For Pedersker (DK20), Lahemaa (EE09), Virolahti II (FI17), Preila (LT15), Rucava (LV10), and Zoseni (LV16) measured levels are higher than computed ones more than factor of 2. Comparison of monthly variations of calculated and measured cadmium concentrations at stations listed above is presented in Figures 6.6 – 6.23.

Table 6.6. Comparison of calculated and measured mean annual cadmium concentrations in air and precipitation for 2001

Station code	Station name	Observed	Calculated	Obs / Calc
Cd concentrations in air (ng/m^3)				
DE09	Zingst	0.16	0.24	0.7
DK05	Keldsnor	0.17	0.16	1.1
DK08	Anholt	0.15	0.12	1.2
LT15	Preila	0.21	0.27	0.8
LV10	Rucava	0.48	0.17	2.9
LV16	Zoseni	0.22	0.11	2.0
Cd concentrations in precipitation (μg/l)				
DE09	Zingst	0.035	0.042	0.8
DK08	Anholt	0.056	0.044	1.3
DK20	Pedersker	0.09	0.042	2.1
EE09	Lahemaa	0.103	0.025	4.1
EE11	Vilsandy	0.047	0.024	2.0
FI17	Virolahti II	0.073	0.023	3.2
FI53	Hailuoto	0.039	0.039	1.0
LT15	Preila	0.107	0.037	2.9
LV10	Rucava	0.09	0.028	3.2
LV16	Zoseni	0.076	0.033	2.3
PL04	Leba	0.05	0.107	0.5
SE05	Bredkälen	0.022	0.014	1.6

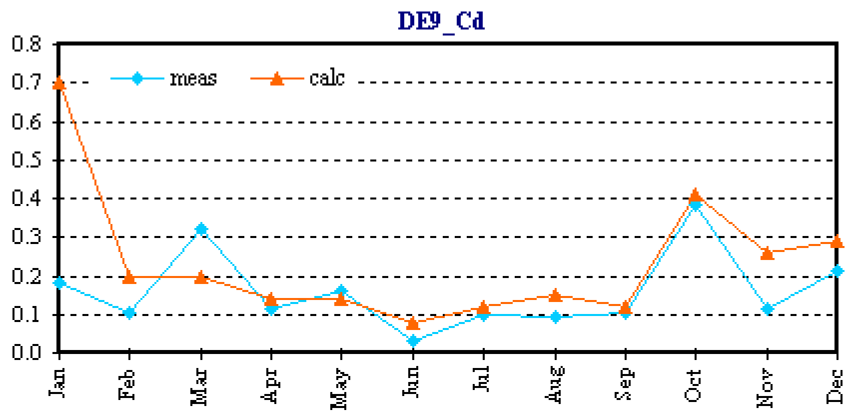


Figure 6.6. Comparison of calculated mean monthly cadmium concentrations in air with measured at station Zingst (DE09). Units: ng / m^3.

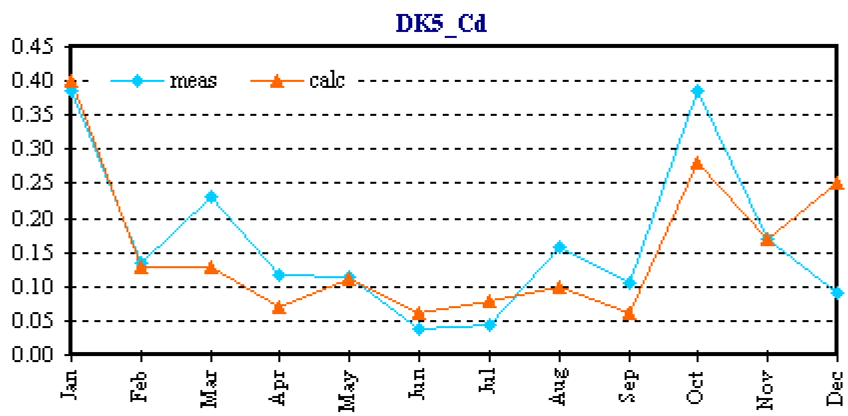


Figure 6.7. Comparison of calculated mean monthly cadmium concentrations in air with measured at station Keldsnor (DK05). Units: ng / m^3.

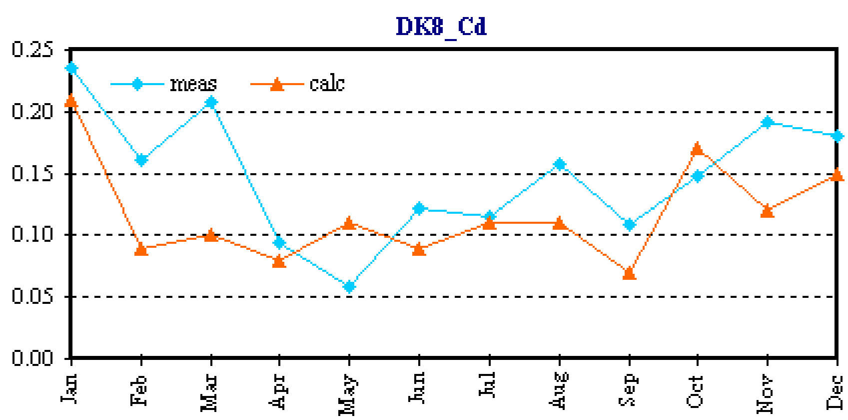


Figure 6.8. Comparison of calculated mean monthly cadmium concentrations in air with measured at station Anholt (DK08). Units: ng / m^3.

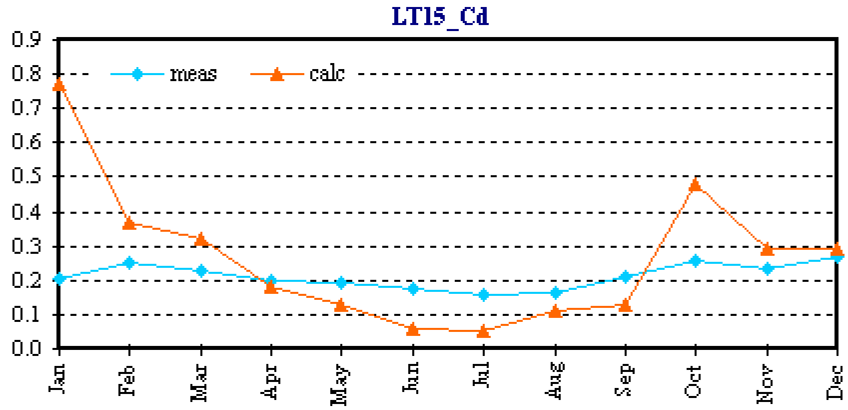


Figure 6.9. Comparison of calculated mean monthly cadmium concentrations in air with measured at station Preila (LT15). Units: ng / m^3.

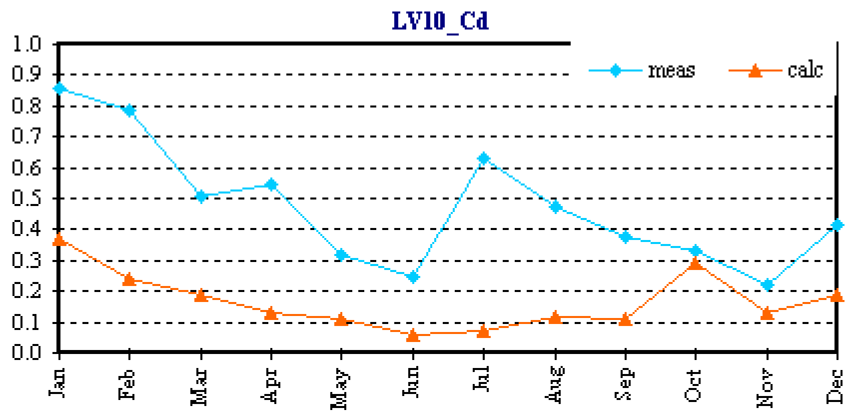


Figure 6.10. Comparison of calculated mean monthly cadmium concentrations in air with measured at station Rucava (LV10). Units: ng / m^3.

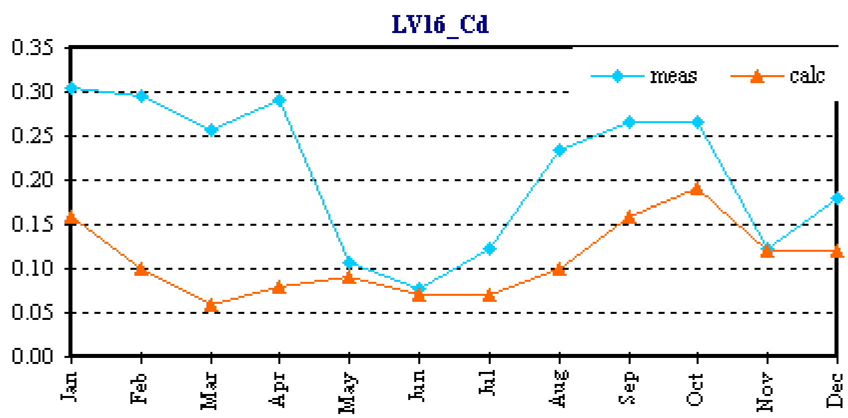


Figure 6.11. Comparison of calculated mean monthly cadmium concentrations in air with measured at station Zoseni (LV16). Units: ng / m^3.

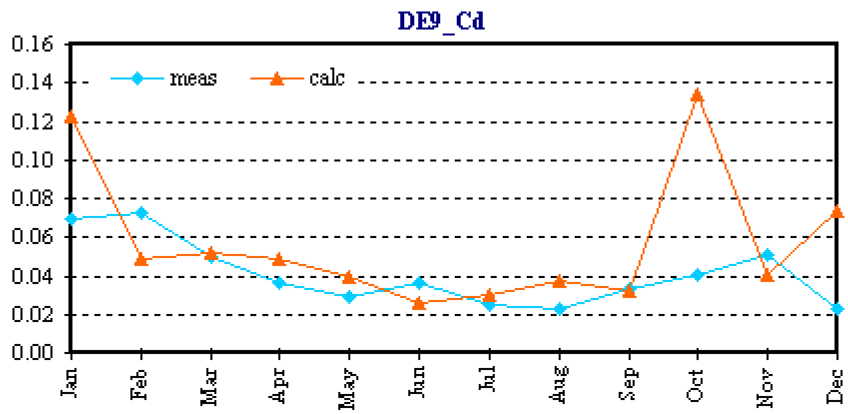


Figure 6.12. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Zingst (DE09). Units: µg / l.

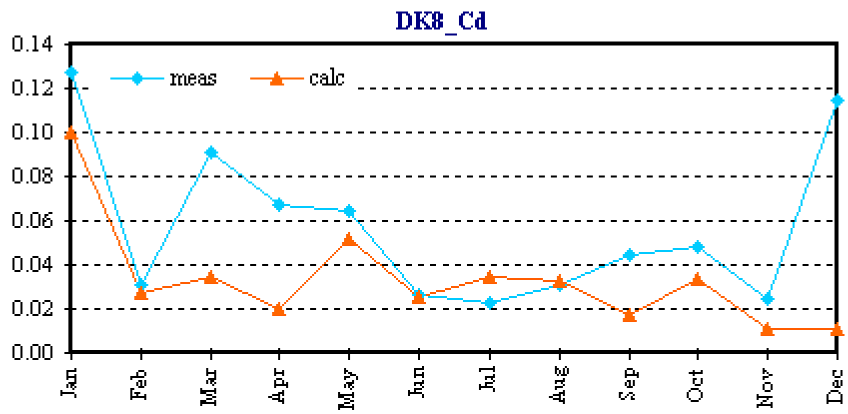


Figure 6.13. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Anholt (DK08). Units: µg / l.

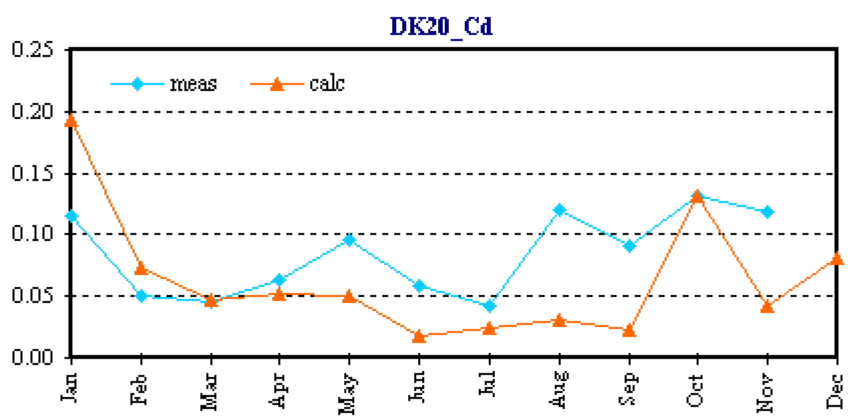


Figure 6.14. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Pedersker (DK20). Units: µg / l.

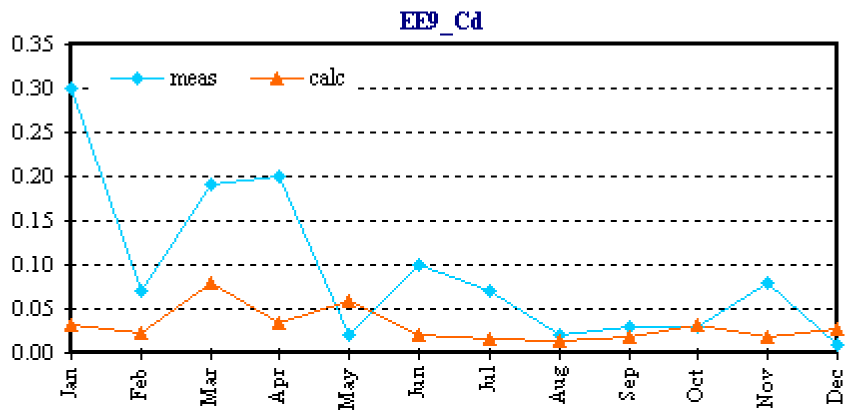


Figure 6.15. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Lahemaa (EE09). Units: µg / l.

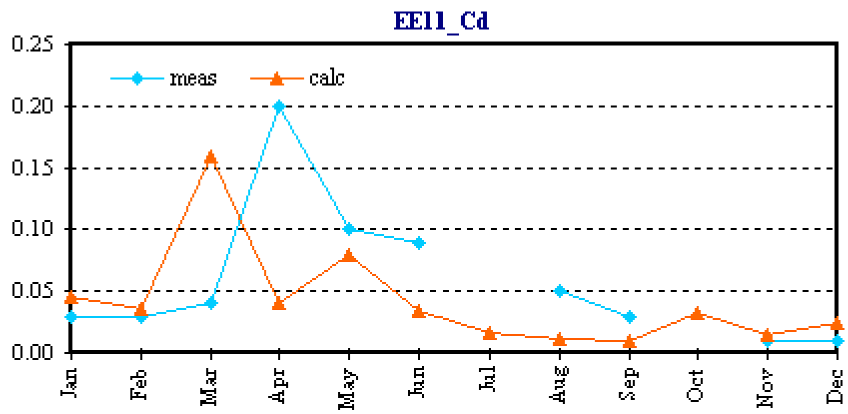


Figure 6.16. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Vilsandy (EE11). Units: µg / l.

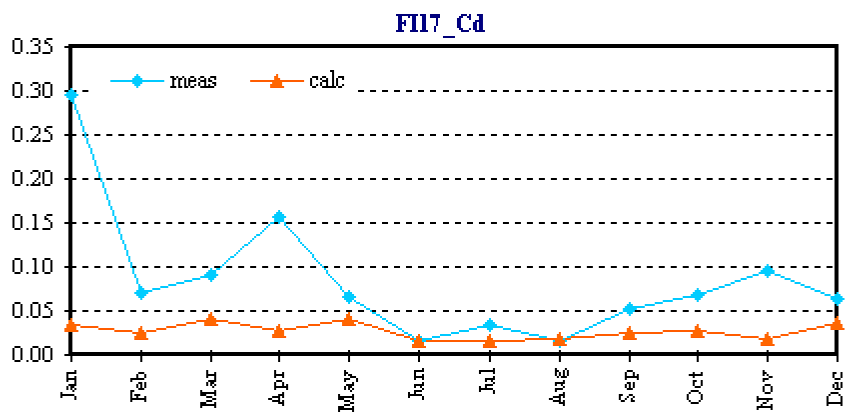


Figure 6.17. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Virolahti II (FI17). Units: µg / l.

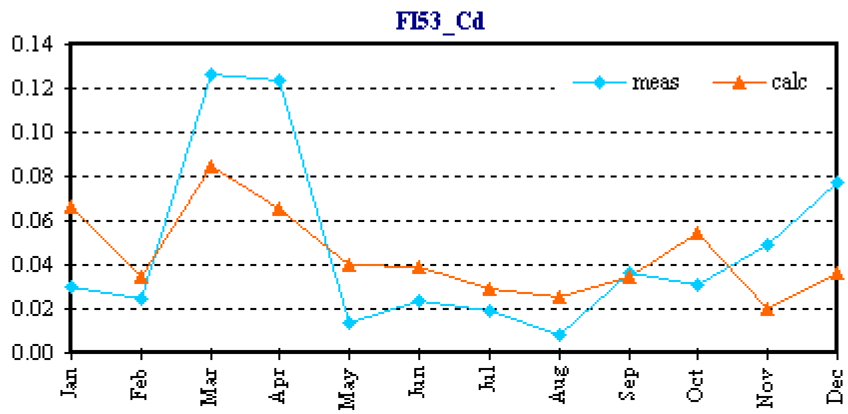


Figure 6.18. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Hailuoto (FI53). Units: µg / l.

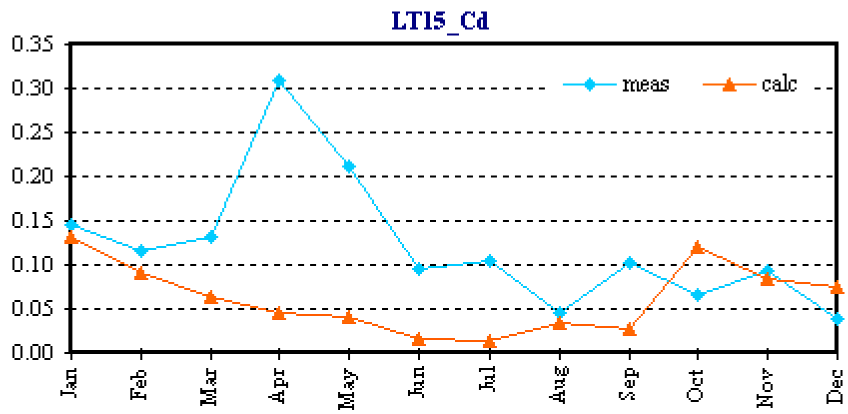


Figure 6.19. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Preila (LT15). Units: µg / l.

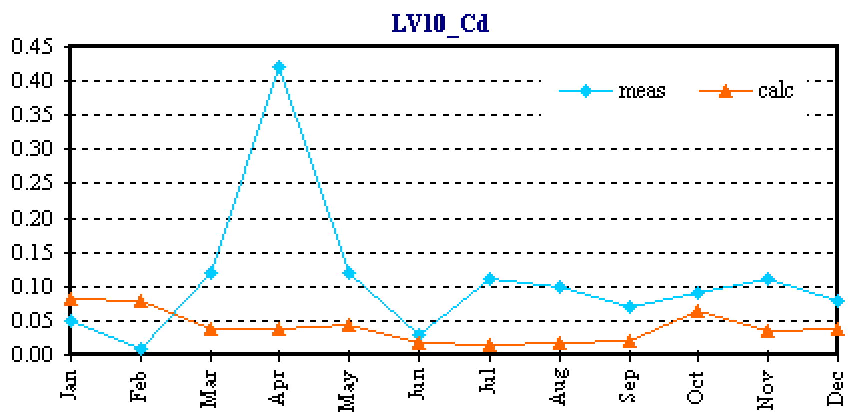


Figure 6.20. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Lahemaa (LV10). Units: µg / l.

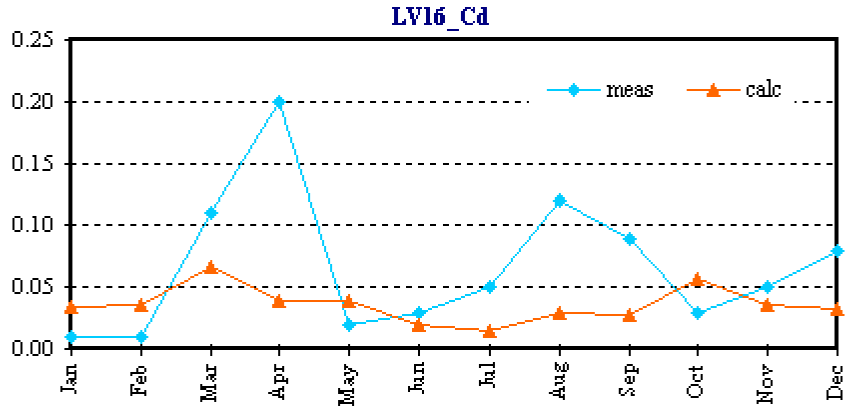


Figure 6.21. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Zoseni (LV16). Units: µg / l.

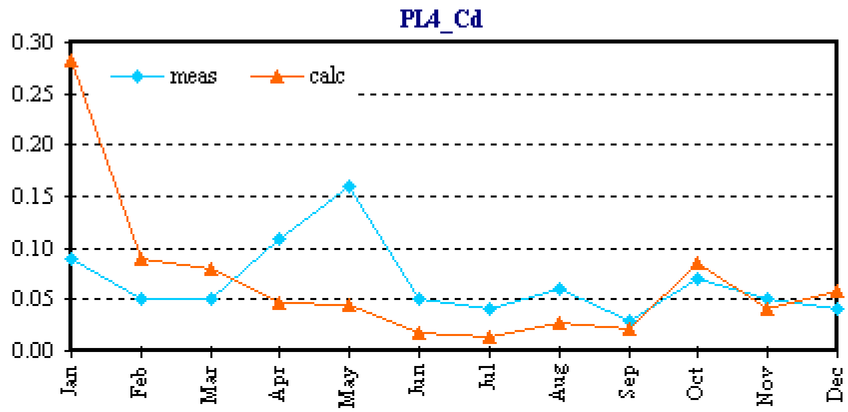


Figure 6.22. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Leba (PL04). Units: µg / l.

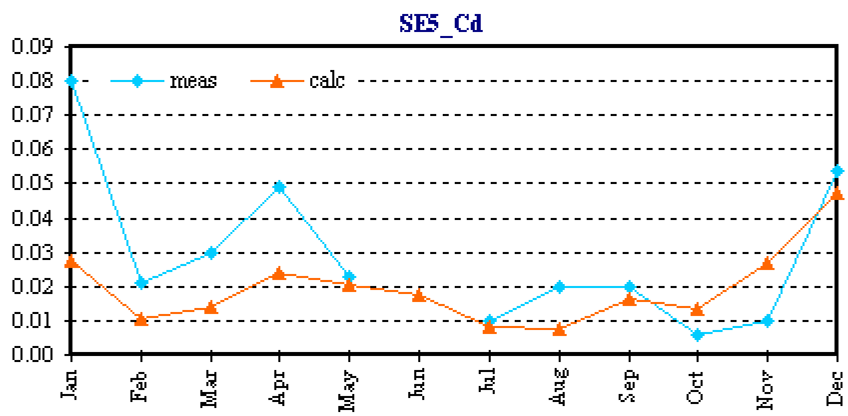


Figure 6.23. Comparison of calculated mean monthly cadmium concentrations in precipitation with measured at station Bredkälen (SE05). Units: µg / l.