Convention on Long-Range Transboundary Air Pollution

emep

Co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe

STATUS REPORT
2/2005 June 2005

Heavy Metals: Transboundary Pollution of the Environment

Status Report 2/2005

msc-e & ccc

EXECUTIVE SUMMARY

In accordance with the 2005 Work-plan for the Implementation of the Convention [ECE/EB.AIR/83/Add.2] the Meteorological Synthesizing Centre – East (MSC-E) and the Chemical Coordinating Centre (CCC) continue research activities in the field of heavy metal atmospheric pollution assessment. The main objective of the work is to evaluate lead, cadmium and mercury pollution levels in Europe on the basis of measurement data and modelling results. Particular attention is paid to cooperation with the effect community on development of the critical loads approach, to support of activities on the review of the Protocol on Heavy Metals, and to the evaluation of the MSC-E heavy metal transport model in the framework of preparation to the model review.

At present the EMEP monitoring network contains 64 stations measuring lead and cadmium, of which 23 stations measure concentrations of these metals both in air and precipitation. There are 15 stations where at least one mercury form is measured. The monitoring stations, however, are non-uniformly distributed over European territory: they are mainly located in Central and Northern Europe. Annual analytical intercomparison of national laboratories treating measurements of heavy metals indicate an essential improvement of data quality during the period of 1995-2003, but still there is need for improvement for some countries.

Measured concentrations of Pb and Cd in air and precipitation show a significant decrease at most of the sites with long time series, a reduction more than 60% for both the elements since 1989. The lowest concentrations of lead, cadmium and mercury in 2003 were observed in Northern Scandinavia. In general, concentration levels increase towards the southeast of Europe.

National data on lead, cadmium and mercury emissions were submitted to the UN ECE Secretariat by 33 countries at least for one year of the period 1990-2003. However, only 14 of them submitted data for the whole period, whereas 11 counties did not submit any national data. Completeness of data on annual total emissions for the whole period is about 60%. Analysis of national data consistency has shown that anthropogenic emissions data officially submitted to the Convention cannot explain observed levels of lead and cadmium wet depositions in Europe. Based on observations of these metals in the EMEP monitoring network one can expect 2-3-fold underestimation of emission data in Europe.

Following the TFMM work-plan MSC-E has started preparation for the EMEP/TFMM Workshop on the review of the MSC-E models. As a first step towards model review MSC-E presented a detailed description of the regional HM transport model, model sensitivity study, uncertainty analyses and results of the five-year programme of model intercomparison study for mercury. The model sensitivity study demonstrated that the modelling results for such heavy metals as lead and cadmium are the most sensitive to anthropogenic emissions, natural emission and re-emission and to removal parameters. Sensitivity of mercury modelling results is highest to boundary concentration of gaseous elemental mercury. The intrinsic model uncertainty of lead and cadmium concentration in air, concentration in precipitation and total deposition are estimated as 43%, 40% and 33% respectively; the appropriate uncertainties for mercury are 19%, 53% and 39%.

Model estimates of the environment pollution with heavy metals in Europe were performed using the adjusted emission scenarios. According to the modelling results decrease of heavy metal depositions over the European territory on the whole in the period from 1990 to 2003 constituted 2.3 times for lead

and cadmium and 1.6 times for mercury. Less essential decrease of depositions in comparison with the anthropogenic emission reduction is conditioned by the contribution of natural sources, re-emission as well as by global sources of heavy metals.

According to the modelling results deposition flux in different parts of Europe in 2003 can differ by more than an order of magnitude. High deposition levels are characteristic of Central and Southern Europe, the lowest levels – of Northern Europe. The transboundary transport plays an important role in pollution of most of European countries. Contribution of the external European anthropogenic sources to depositions ranges from 9 to 89% for lead, 7 – 83% for Cd and 2 – 55% for Hg. The contribution of the transboundary transport to depositions of heavy metals to the European Union varies from 3 to 10%.

Atmospheric depositions contribute significantly to heavy metal pollution of marginal seas. The highest mean deposition flux of lead and cadmium is obtained over the Black Sea, and of mercury – over the North and the Baltic Seas.

The MSC-E regional transport model used for the assessment of the pollution levels in Europe was evaluated against the available measurement data for the period 1990-2003. Modelling results based on the adjusted emission scenario were used in the model evaluation. The evaluation demonstrates satisfactory agreement with measurement data for all tree metals. A significant correlation of calculations with measurements was obtained for all metals and more 70% of modelling results differ from observations less than by 50% of the observed values.

The activities under the multi-stage project on the intercomparison of mercury transport models are complete. The third stage of the project was dedicated to the comparison of long-term modelling results with annual and monthly mean measurements of mercury concentration in the ambient air and atmospheric deposition fluxes. The comparison reveals that for the main calculated parameters both regional and hemispheric MSC-E models predict quite similar results. Both models do not occupy any extreme position among the other participating models.

In the framework of cooperation with the Working Group on Effects MSC-E performed calculations of relevant parameters of atmospheric inputs of heavy metals to ecosystems based both on official emission data and the adjusted emission scenario. Ecosystem-specific depositions of heavy metals in Europe were assessed and analysed.

Besides, the EMEP Centres were involved in cooperation with other subsidiary bodies to the Convention as well as international organizations and national programmes (European Commission, HELCOM). The main results were discussed at a number of scientific conferences, workshops and expert meetings.

CONTENTS

INTRODUCTION

Pollution of the environment by heavy metals is the subject of concern of a number of national and international bodies. In 1998 a number of Parties to the Convention on Long-Range Transboundary Air Pollution (hereinafter the Convention) signed the Protocol on Heavy Metals (Protocol). The aim of the Protocol was to control atmospheric emissions of toxic metals (lead, cadmium and mercury). In accordance with the Protocol the Co-operative Programme for Monitoring and Evaluation of Long-Range Transmission of Air Pollutants in Europe (EMEP) provides the assessment of pollution levels of heavy metals in the European region. Measurements of heavy metal concentrations in the air and precipitation are carried out at the EMEP monitoring network under the methodological guidance of the Chemical Coordinating Centre (CCC). Along with that the Meteorological Synthesizing Centre – East (MSC-E) performs the model assessment of depositions and air concentrations of heavy metals throughout the European region as well as the transboundary fluxes between the European countries.

For the practical use of the modelling results, e.g. for the development of optimal emission reduction, comparison with the critical values etc., the results should be reliable. Following the TFMM work-plan MSC-E has started preparation for the EMEP/TFMM Workshop on the review of the MSC-E models. As a first step towards model review, MSC-E presented at the 6th session of TFMM (Croatia, April 2005) a detailed description of the regional HM transport model, reported on model sensitivity study, uncertainty analyses and on the results of five-year programme of model intercomparisons for mercury. TFMM approved the plans for the Workshop on the review of the MSC-E models to be held in Moscow, Russia in October 2005 and drew attention of MSC-E to focus the Workshop on comparison with observations and model intercomparison.

In order to correlate the existing pollution levels with their effects on the environment and human health, they are compared with the scientifically sound critical values, developed by the Working Group on Effects (WGE). In the framework of the cooperation with WGE, MSC-E evaluated ecosystem-specific depositions of lead, cadmium and mercury for the European region.

The Status Report describes the progress in the study of air pollution by lead, cadmium and mercury in Europe. The presented results were obtained in studies made by CCC and MSC-E in 2005 according to the EMEP work-plan on heavy metals (Annex A).

Chapter 1 is focused on the monitoring activities in the field of heavy metals. The measurement network is described, and the measured pollution levels (concentrations in the air and precipitation) are presented. Special attention is devoted to the quality of measurement data. Reliable data were suggested for further use in the analysis of pollution levels and model validation. Results of the recent intercomparison of the analytical methods are outlined.

Chapter 2 summarizes available official emission data submitted by Parties to the Convention, characterises consistency of the data and briefly describes the approach applied to development of the adjusted emission scenario based on available measurements of these metals in air and precipitation within the EMEP monitoring network.

Chapter 3 contains a brief description of the model parameterisations, input data and the sensitivity study of the modelling results to input parameters. Besides, it considers application of hemispheric modelling for evaluation of global sources contribution to mercury pollution in Europe.

Chapter 4 describes the modelling assessment of the atmospheric transport of lead, cadmium and mercury in Europe in the period 1990-2003. Spatial distribution patterns of heavy metal deposition in the European region in 2003 is analysed and information on source-receptor relationships were evaluated. In addition to separate European countries, source-receptor relationships were determined for the European Union as a whole. Atmospheric loads of heavy metals to marginal seas were estimated. Much attention in the report was paid to the validation of the model. Modelled concentrations of lead, cadmium and mercury in air and precipitation were compared against the monitoring data.

Chapter 5 is devoted to cooperation between EMEP and other bodies to the Convention, international organizations, and national programmes. In cooperation with WGE EMEP evaluates ecosystem-dependent depositions of heavy metals based on different emission scenarios. Besides, the results of the cooperation of EMEP with HELCOM, European Commission and national programmes are described.

The main results of the EMEP work in the field of heavy metals are summarized in *Conclusions*. The EMEP work-plan on heavy metals for 2005 is described in Annex A. Matices of source-receptor relationships for European countries are presented in ANNEX B. Detailed information about CCC and MSC-E activities can be found at the EMEP website (*www.emep.int*).

1. MONITORING OF HEAVY METALS IN EMEP

Measurement network

Heavy metals were included in EMEP's monitoring program in 1999. However, earlier data has been available and collected, and the EMEP database thus also includes older data, even back to 1987 for a few sites. A number of countries have been reporting heavy metals within the EMEP area in connection with different national and international programmers such as HELCOM, AMAP and OSPARCOM.

The locations of the measurement sites, which have delivered data on heavy metals for 2003, are found in Fig. 1. Detailed information about the sites and the measurement methods are found in EMEP/CCC's data report on heavy metals and POPs [*Aas and Breivik,* 2005]. In the figure, the sites are divided in those measuring both concentrations in air and in precipitation, and those measuring only one of them. In 2003 it was 23 sites measuring heavy metals in both compartments, and altogether it was 64 measurement sites. It was 15 sites measuring at least one form of mercury.

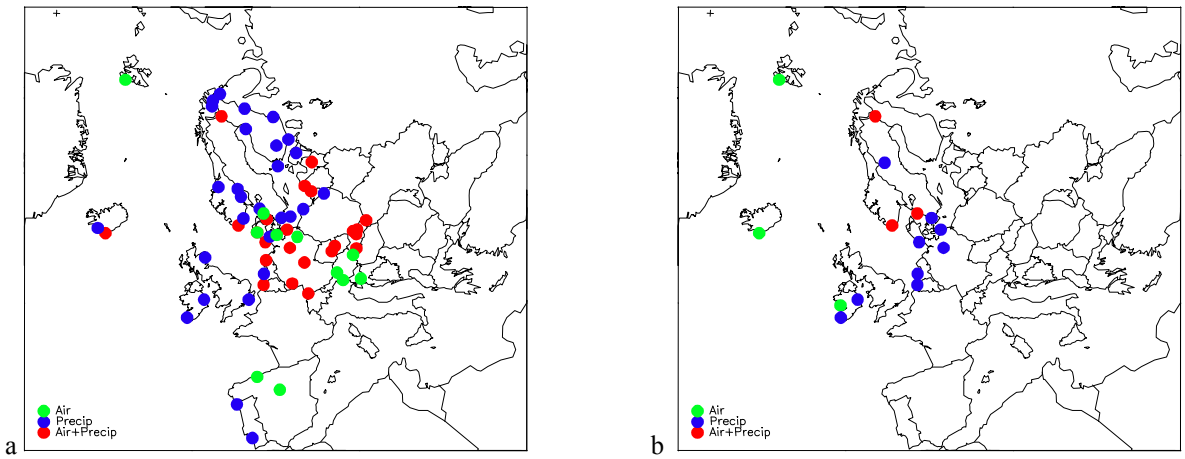


Fig. 1. *Measurement network of lead, cadmium (a) and mercury (b) in 2003*

From Fig.1 it is apparent that the spatial distribution of monitoring sites in Europe is unsatisfactory. There are hardly any sites that measure heavy metals in east of Europe, and in southern Europe at the Iberian Peninsula only. In addition, it is too few sites measuring both in air and precipitation. In the adopted EMEP monitoring strategy for 2004-2009 (EB.AIR/GE.1/2004/5), it states that all EMEP parties should measure heavy metals; this strategy will expectantly improve the situation.

Monitoring of Pb, Cd and Hg in 2003

Annual averages of Pb, Cd and Hg concentrations in precipitation and in air in 2003 are presented in Fig. 2-7. The lowest concentrations for all elements in air as well as precipitation are found in northern Scandinavia. An increasing gradient can in general be seen southeast, but the concentration levels are not evenly distributed, there are some “hotspots” for some elements.

The highest cadmium concentrations in precipitation are seen in Slovakia; in air the highest concentrations are observed in Slovakia as well as in Austria. Also for lead in precipitation, the highest concentrations are seen in Slovakia, but elevated levels are also seen in hotspots like e.g. the sites in northern Scandinavia, Lithuania, and in the Benelux countries. The concentrations in air show similar distribution.

There are only a few stations measuring mercury in Europe, and most of them are related to the OSPARCOM program CAMP. The concentrations of mercury at the different sites are decreasing from north to south, but these differences are quite small.

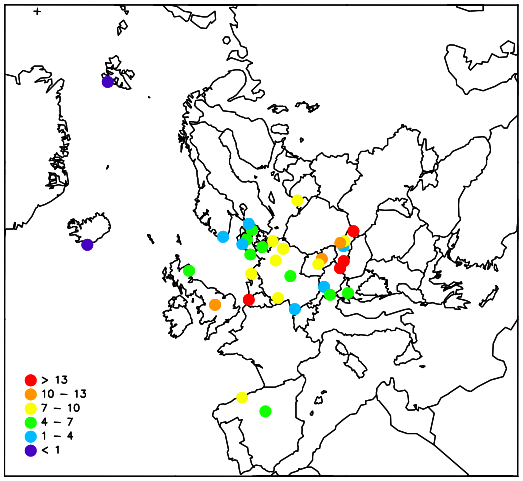


Fig. 2. *Lead in aerosol, ng/m^3*

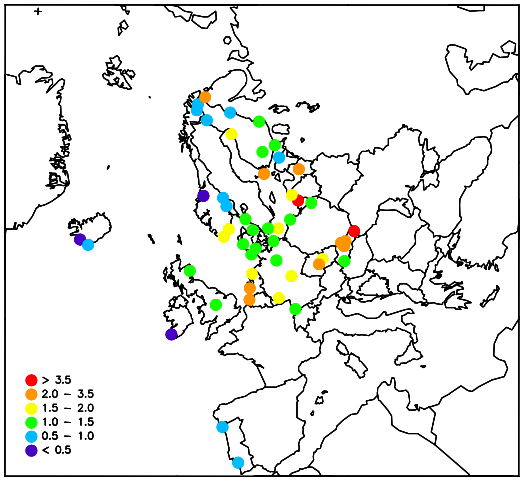


Fig. 3. *Lead in precipitation, µg/L*

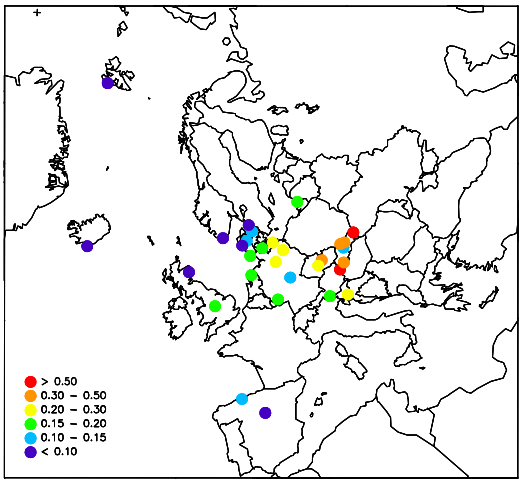


Fig. 4*. Cadmium in aerosol, ng/m^3*

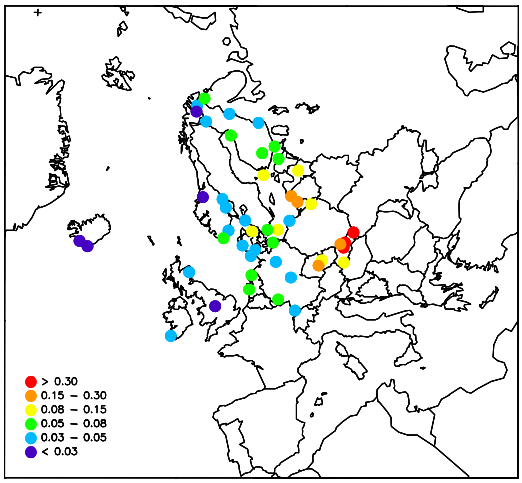


Fig. 5. *Cadmium in precipitation, µg/L*

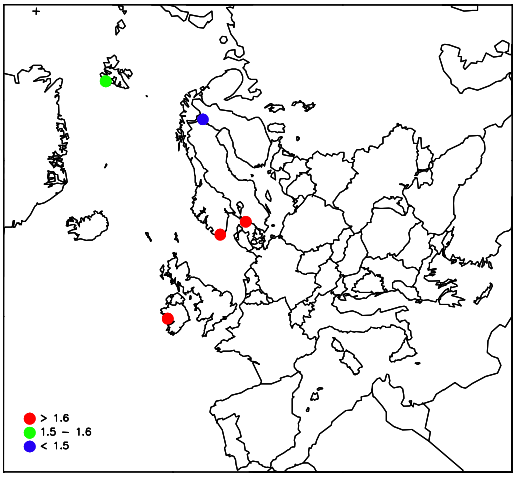


***Fig. 6**. Mercury in air, ng/m^3*

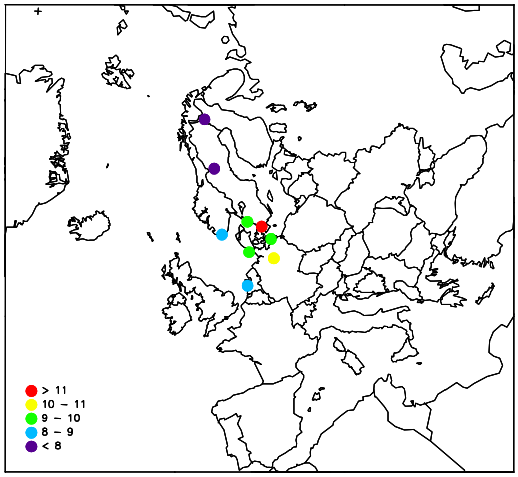


***Fig. 7.** Mercury in precipitation, ng/L*

Measured trends

Figure 8 shows temporal trends for Cd and Pb in atmospheric aerosols at a few selected stations for which there have been measurements for a longer period. The emissions of Cd and Pb have decreased in Europe and the concentration levels of both elements show a significant reduction at most EMEP sites. A Mann Kendall test has been run to calculate the Sen's slope estimate for the time period 1989-2003, Table 1. The highest reductions in absolute quantities for both elements are seen at the Slovakian site, but the percentage decrease in concentrations are relatively similar for all the sites except at NO99, 62-68% for cadmium and 71-84% for lead in aerosol. Similar reductions are also seen in the concentrations in precipitation, but these data series are somewhat more inconsistent with e.g. contamination problems in some of the years.

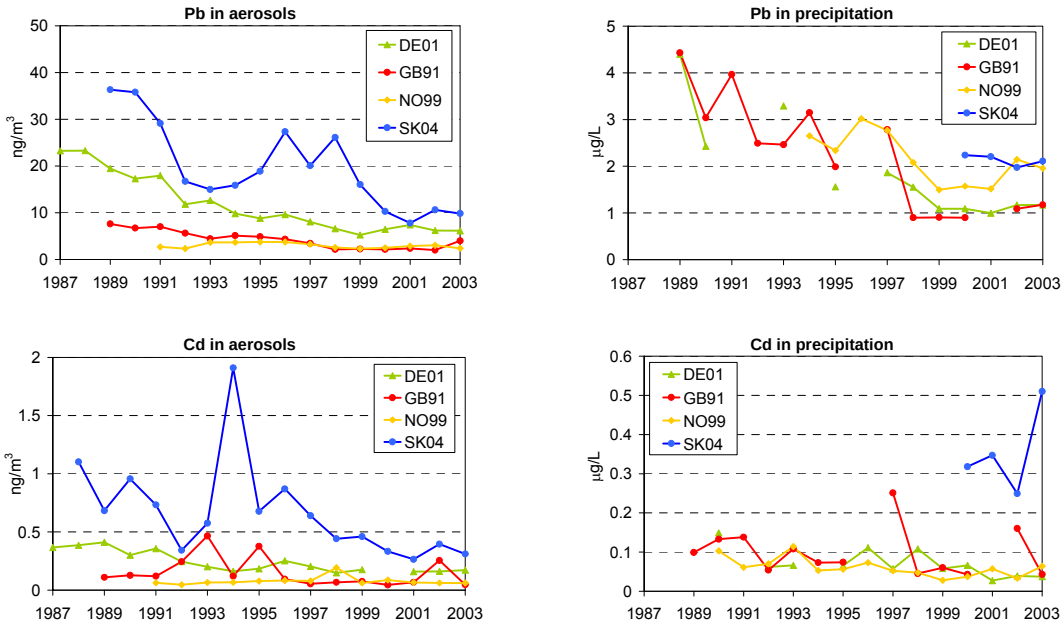


***Fig. 8**. Trends in cadmium and lead concentrations in air and precipitation at four EMEP sites*

Table 1. *Total percentage change for the annual changes in lead and cadmium air and precipitation at four selected EMEP sites, 1989-2003 (from 1990 for NO01) using the Sen's slope estimate. Changes are only given for sites with significant trend*

Site	Pb		Cd	
	precip	aerosol	precip	aerosol
DE01	69%	84%	58%	62%
GB91	94%	80%	-	63%
NO99	-	-	58%	-
SK04	-	71%	-	68%

Data quality

For precipitation the Belgium data is very uncertain. Both wet only and bulk precipitation is included and it is substantial difference between them both in precipitation amount and concentration. The bulk measurement is chosen, Cd is omitted because very detection limit. Also Portugal has very high detection limit for Cd so these data are not shown in Fig 4. Also the Portuguese Pb data as will as all the Irish data are all under the detection limit and these should be looked upon as max values. At IE02 the last 4 month is missing and these data are neither included in the figures. The data capture is otherwise above 90% for most of the precipitation measurements. For mercury, the precipitation data from Ireland has too high detection limits and are not useful. The data quality objectives (DQO) in EMEP states that the accuracy in the laboratory should be better than 15% and 25% for high and low concentrations of heavy metals, respectively. One important measure to check the data quality is laboratory ring test. There is a marked improvement in the laboratory performance for both lead and cadmium since the beginning of the laboratory comparison in 1995. The intercomparison completed last year is representative for the 2003 data. In Table 2, there is a summary of the results from this laboratory intercomparison. Sweden and Iceland were not participating because these measurements were analyzed in Norway. The measurements of high concentration samples are hardly any problems, but these samples are not very representative for many EMEP sites. For the priority compounds Pb and Cd, Denmark has some problems with both of these, while Czech Republic, Slovenia and Estonia need to check their Cd measurements. In addition, there are some countries reporting measurements data without participation in the laboratory intercomparison: Belgium, Ireland, Portugal, and Spain. Data from these countries are of unknown quality; and it is therefore strongly recommended that they take part in the annual laboratory intercomparison.

Table 2. *Average per cent error (absolute) in low and high concentration samples, results from the laboratory intercomparison. DQO is EMEPs data quality objectives*

	Cr		Ni		Cu		Zn		As		Cd		Pb	
	low	high	low	high	low	high	low	high	low	high	low	high	low	high
AT	1	1	1	2	4	3	2	4	1	4	0	1	0	1
CZ	5	6	46	2	3	1	1	2	7	1	41	3	3	1
DK	13	6	78	7	9	4	0	0	0	5	252	9	28	2
FI	7	5	6	4	16	5	14	15	9	7	8	7	8	14
FR	13	5	0	9	15	7	27	32	7	2	0	0	3	4
DE	0	1	2	3	1	1	4	1	1	1	2	1	3	3
NL	0	5	0	4	0	1	8	5	5	4	2	2	0	2
NO	2	1	2	1	0	1	9	0	5	2	4	0	1	1
PL	0	0	0	0	13	1	2	1	0	0	7	13	5	5
GB	6	9	7	3	6	2	2	5	8	1	13	12	7	4
SK	2	4	49	2	2	1	0	0	11	2	0	1	3	1
LT	1	2	7	1	7	4	62	0	51	19	13	2	10	3
LV	22	10	14	7	12	18	12	1	14	7	0	3	4	3
SI	10	1	78	7	45	4	26	4	3	0	50	3	0	3
EE	0	17	0	1	0	9	0	6	0	23	30	7	3	4
PL05	0	2	0	2	0	2	9	1	0	0	0	6	0	0

1/2 - 1 DQO 1 - 2 DQO > 2 DQO

2. EMISSIONS DATA OF HEAVY METALS IN EUROPE

Under the commitments taken in the framework of the Convention the Parties annually submit to the UN ECE Secretariat information on national anthropogenic emissions of heavy metals. Regular submission of national data became even more important after coming the Protocol on Heavy Metals into force in 2003.

By April 2005 national data on lead, cadmium and mercury emissions were submitted by 33 countries at least for one year of the period 1990-2003. However, only 14 of them submitted data for the whole period, whereas 11 countries did not submit any national data at all. The overall completeness of data on total annual emissions for the whole considered period is about 60%. Besides, 13 countries have revised previously submitted national data because of the improvement of statistical data, emission factors, calculation methods etc. National information on the spatial distribution of emission sources at least for one year is submitted by 18 countries.

In order to have a complete set of anthropogenic emissions data, for countries that have not submitted any national data or data for some years, a linear interpolation or expert estimates of anthropogenic emissions were used [*Berdowski et al.*, 1998]. For the countries not submitted information on spatial distribution of emission sources expert estimates [*Berdowski et al*., 1997] were used to distribute the total national emission over a country.

Analysis of national data consistency has shown [*Ilyin and Travnikov*, 2005] that anthropogenic emissions data officially submitted to the Convention cannot explain observed levels of lead and cadmium wet depositions in Europe. Particularly, Figures 9 and 10 illustrate comparison of total Pb and Cd wet deposition to EMEP countries based on measurement data with total official anthropogenic emissions in these countries. As seen from Fig. 9 total wet deposition of lead to territories of European countries exceeds total anthropogenic emissions. However, one should realize that significant mass of the pollutant is also deposited over marginal seas, due to dry uptake and is transported out the EMEP domain. Hence, one could expect that total annual lead depositions approximately twice exceed official anthropogenic emissions. This exceedance could be even higher in the case of cadmium (Fig. 10). This inconsistency can be explained by two reasons. The first one is underestimation of national anthropogenic emissions. The second possible reason is unaccounted natural emission or re-emission at least comparable with anthropogenic one. Available estimates of heavy metal emission from natural sources [*Nriagu*, 1989; *Richardson*, 2001] vary within two orders of magnitude. Taking into account uncertainty of such estimates it is difficult to prefer any of these reasons. It is most probable that both of them are correct to some extent.

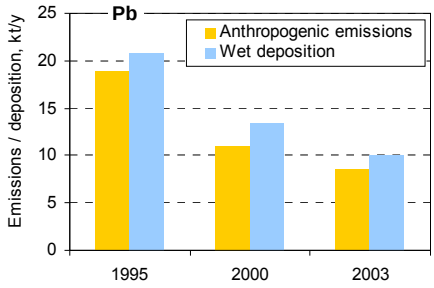


Fig. 9. *Comparison of total lead wet deposition to EMEP countries based on measurement data with total official anthropogenic emissions*

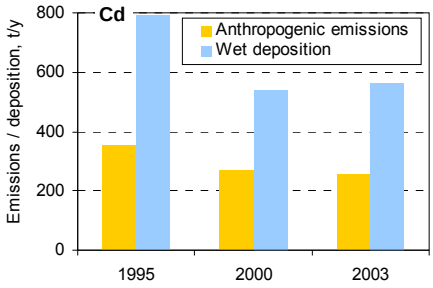


Fig. 10. *Comparison of total cadmium wet deposition to EMEP countries based on measurement data with total official anthropogenic emissions*

A tentative parameterisation of lead and cadmium non-anthropogenic emission is used in the current calculations. Non-anthropogenic emission from land is divided into direct natural flux and secondary emission of previously deposited mass (re-emission). The direct natural emission flux assumed to be uniformly distributed over the sea and over land surfaces, whereas the re-emission flux from land is distributed over the model domain proportionally to appropriate deposition field. The resulting emission fluxes was evaluated to fit the measured background concentrations in remote areas. The direct natural emission flux of lead and cadmium from land is 70 g/km^2/y and 8 g/km^2/y, respectively [*Nriagu*, 1989]. The re-emission flux from land varies from 150 to 600 g/km^2/y for lead and from 14 to 50 g/km^2/y for cadmium. The natural emissions of lead and cadmium from sea surface are 250 and 14 g/km^2/y, respectively. The direct natural emission and re-emission are assumed to be zero from surfaces covered with snow or ice.

In order to fit observed lead and cadmium pollution levels in Europe adjusted anthropogenic emission scenario was developed for the period 1990-2003 based on available measurements of these metals in air and precipitation and using described above assumptions on natural emission and re-emission [*Ilyin and Travnikov*, 2005]. These rough estimates should not be considered as an attempt to define actual anthropogenic emissions in each European country but rather present more or less consistent dataset for modelling of realistic pollution levels. Spatial distributions of anthropogenic emissions of lead and cadmium in Europe in 2000 are presented in Figs. 11 and 12 according to official data and the adjusted emission scenarios.

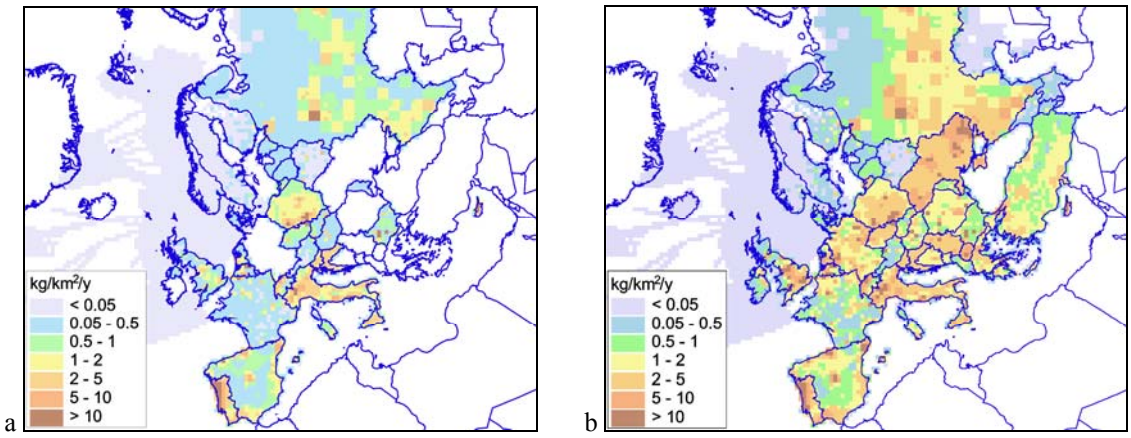


Fig. 11. *Spatial distribution of lead anthropogenic emission in Europe in 2000: (a) – official data; (b) – adjusted emission scenario*

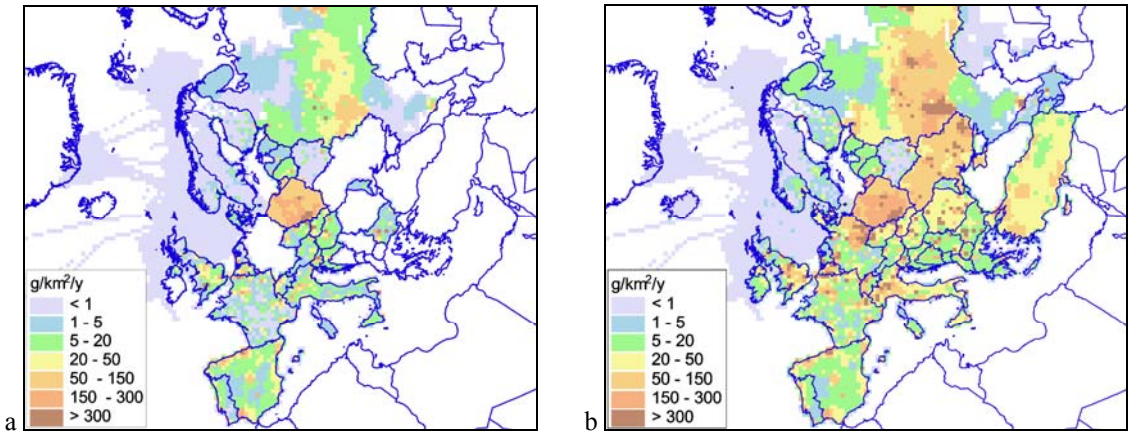


Fig. 12. *Spatial distribution of cadmium anthropogenic emission in Europe in 2000: (a) – official data; (b) – adjusted emission scenario*

It should be noted that division of lead and cadmium emissions into anthropogenic and natural (re-emission) in the described adjusted scenario is conditional to some extent taking into account high uncertainty of natural emission estimates. For example, estimates suggested in [*Richardson*, 2001] are two orders of magnitude higher than those from [*Nriagu*, 1989].

Mercury differs from lead and cadmium by complicated atmospheric chemistry to great extent effecting deposition of this pollutant and by significant influence of global sources on pollution levels in Europe. Besides, mercury monitoring network includes only few sites operating on regular base (see Chapter 1). Therefore it is difficult to evaluate mercury emissions data consistency based on available measurement data. That is why model estimates of mercury pollution levels in Europe were based on official anthropogenic emissions data.

To take into account natural emission of mercury we used global estimates by *C.H. Lamborg et al.* [2002]. According to this work global natural emission of mercury is estimated as much as 1000 t/y from land and 800 t/y from the ocean. Emission flux from land depends on temperature and type of the underlying surface and differs for ice-covered surfaces, background soils, geochemical mercuriferrous belts, and soil of mercury deposit areas. The emission from oceanic surface depends on organic carbon primary production. Detailed description of the approaches to parameterisation of mercury natural emission flux is presented in [*Travnikov and Ilyin*, 2005].

A tentative approach to assess mercury re-emission from European soils was applied basing on conjunction of the MSCE-HM model with a simple box model [*Ryaboshapko and Ilyin*, 2001]. The box model considered European soils as a single reservoir with two output fluxes – re-emission and hydrological leaching. The transport model calculated mercury depositions accumulated during last century. Estimated mercury re-emission by the end of 20^{th} century is around 50 t/y.

Finally, emissions data are probably the most important input parameter effecting modelling results. It was demonstrated in the sensitivity study (Chapter 3) that the model is the most sensitive to this parameter and emission uncertainty is critical for modelling results. It is evident that further consideration and improvement of emissions data (both anthropogenic and natural) are principally important for heavy metal modelling.

3. MODEL REVIEW AND DEVELOPMENT

In 2005 MSC-E made significant efforts for review and improvement of the regional MSCE-HM model of heavy metal airborne pollution in Europe used for operational calculations within EMEP. Details of the model formulation were considered at 6th Task Force on Measurement and Modelling (Zagreb, April 2005). This chapter of the report contains a brief description of the model parameterisations, input data and the sensitivity study of the modelling results to input parameters. Besides, it considers application of hemispheric modelling for evaluation of global sources contribution to mercury pollution in Europe. All these aspects in more details are available in EMEP/MSC-E Technical Report [*Travnikov and Ilyin*, 2005].

3.1. Brief description of the model

MSCE-HM is a three-dimensional Eulerian-type chemical transport model driven by off-line meteorological data. It is developed to evaluate atmospheric transport and deposition of such heavy metals as Pb, Cd and Hg. Besides, pilot parameterisations for some other toxic metals and metalloids like Cr, Ni and As are included. The model domain covers EMEP region (Europe, part of Northern Africa and Middle East, the north-eastern Atlantic and part of the Arctic) with spatial resolution 50×50 km^2.

The vertical structure of the model is formulated in the sigma-pressure (σ-p) coordinate system. The model domain consists of 15 irregular σ-layers and has a top at pressure level equal to 100 hPa. The layers are confined by surfaces of constant σ and do not intersect the ground topography. The vertical grid structure of the model domain is shown schematically in Fig. 13. The midlevel of the lowest σ-layer approximately corresponds to 37 m. The top of the model domain can be roughly estimated at 15 km.

The model takes into account key processes governing behaviour of heavy metals in the atmosphere and their deposition to the ground. They include anthropogenic and natural emissions, advective transport, turbulent mixing, wet and dry removal, mercury chemical transformations both in gaseous and aqueous phases. Schematically these processes are depicted in Fig. 14.

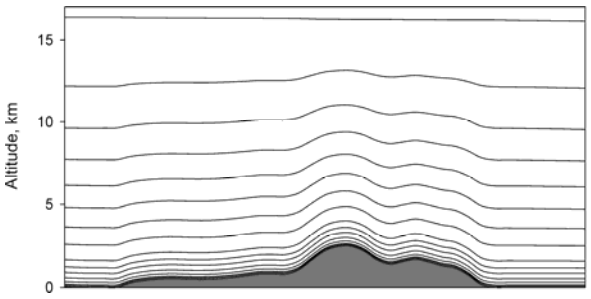


Fig. 13. *Vertical grid structure of the model domain. The curves show boundaries of σ-layers*

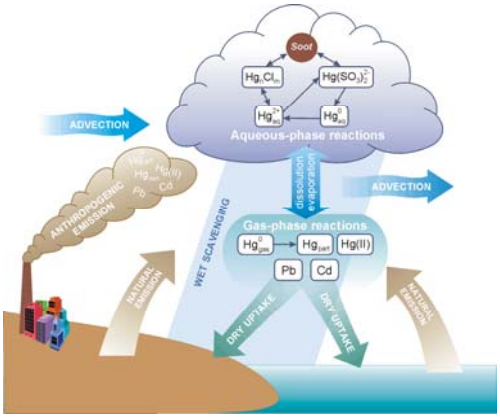


Fig 14. *The model scheme of heavy metal behaviour in the atmosphere*

Advective and vertical transport is evaluated by Bott scheme [*Bott*, 1989a; 1989b, 1992]. Turbulent mixing is approximated by second-order implicit numerical scheme. Lead and cadmium are assumed to be transported in the atmosphere only as a part of aerosol particles. Besides, chemical transformations of these metals do not change removal properties of their particles-carriers. Physical and chemical transformations of mercury include dissolution of gaseous elemental Hg in cloud droplets, gas-phase and aqueous-phase oxidation by ozone and chlorine, aqueous-phase formation of chloride complexes, reactions of mercury ion reduction through the decomposition of sulphite complex, and adsorption by soot particles in droplet water. Dry deposition scheme is based on resistance-analogy approach. Modelled dry deposition velocity depends on surface type (forests, arable lands, water etc.) and atmospheric conditions (atmospheric stability, wind velocity etc). At present the model is capable of calculating dry deposition fluxes to 18 categories of land cover. The model distinguishes in-cloud and sub-cloud wet scavenging. Boundary concentrations of heavy metals are set along outer boundaries of EMEP region and updated once a month. Mercury concentrations at the domain boundaries are derived by means of hemispheric-scale modelling. The concentrations of lead and cadmium are based on monitoring data.

3.2. Input data to the model

The model requires a number of gridded input parameters. These parameters are meteorological data, emissions, geophysical information and concentrations of chemical reactants.

Meteorological data. Meteorological data for the off-line MSCE-HM model are produced by the pre-processing system based of PSU/NCAR mesoscale model MM5 [*Grell et al*., 1995; *http://www.mmm.ucar.edu/mm5/overview.html*]. This system has a number of advantages. First of all, it can work with different sets of initial meteorological data. It allows selecting and adjusting appropriate parameterisations of physical atmospheric processes (boundary layer, precipitation, radiation transfer etc.). Finally, this system is worldwide spread and tested for different geographical and climatic conditions. Input data used to run MM5 are NCEP/DOE re-analysis data. At present a set of meteorological data with 6-hour resolution is available for the period from 1990 to 2003. List of meteorological parameters derived from MM5 and utilized by the model is given in Table 3.

Table 3. *Meteorological parameters and their usage in MSCE-HM model*

Parameter	Dimension	Usage
Surface pressure	2D	Air density, atmospheric transport
Components of wind velocity	3D	Atmospheric transport
Air temperature	3D	Air density, atmospheric chemistry, dry deposition
Water vapour mixing ratio	3D	Air density, dry deposition
Liquid water mixing ratio	3D	Atmospheric chemistry, in-cloud scavenging
Ice mixing ratio	3D	In-cloud scavenging
Stratiform precipitation	3D	Wet removal
Convective precipitation	3D	Wet removal
Eddy diffusion coefficient	3D	Vertical eddy diffusion
Monin-Obukhov length	2D	Stability, dry deposition
Surface temperature	2D	Natural emission and re-emission
Snow cover height	2D	Natural emission and re-emission

***Land cover*.** Land cover data is mostly required for evaluation of the dry deposition velocities and assessment of ecosystem-specific depositions. Currently a preliminary land cover dataset developed by the Coordinating Centre for Effects (CCE) is used in the model. The dataset consider 17 landuse/landcover categories listed in Table 4 (in the calculations we divide the water surface category into the ocean and inland waters).

Table 4. *Land cover categories of CCE dataset used in the model*

1. Temperate coniferous forest	10. Semi-natural
2. Temperate deciduous forest	11. Mediterranean scrub
3. Mediterranean needleleaf forest	12. Wetlands
4. Mediterranean broadleaf forest	13. Tundra
5. Temperate crops	14. Desert/Barren
6. Mediterranean crops	15. Inland water
7. Root crops	16. Ice
8. Grasslands	17. Urban
9. Wheat	18. Ocean

The dataset is partly based on the database developed in the framework of EC Programme on Coordination of Information on the Environment (CORINE) [*dataservice.eea.eu.int*]. The information was contributed to this database by European countries. Since the CORINE Land Cover data do not cover entire EMEP area, Stockholm Environment Institute (SEI) database was used to fill the gaps [*http://www.york.ac.uk/inst/sei/APS/projects.html*]. In order to unify the CORINE and SEI inventories ecosystem classification EUNIS (European Nature Information System) was adopted.

***Chemical reactants*.** Atmospheric mercury undergoes chemical transformations both in the gaseous and aqueous phase. Description of the chemical processes involving mercury needs data on spatial and temporal distribution of reactants concentration (ozone, sulfur dioxide, and hydroxyl radical) in the atmosphere.

Global monthly mean data on O3 and SO2 concentration in the atmosphere calculated by the MOZART model were used. The original data with spatial resolution 2.8°×2.8° were interpolated to the EMEP grid. For hydroxyl radical in the atmosphere we used modelled monthly mean concentrations from [*Spivakovsky et al.*, 2000]. The original data were interpolated to the EMEP grid. In order to take into account diurnal cycle of OH radical we assume zero concentration at night and concentrations proportional to the cosine of the solar zenith angle during daytime. Besides, air concentrations of OH were decreased by a factor of 10 in the cloud environment and below clouds to account for reduction of its photochemical activity [*Seigneur et al*., 2001]. The model chemistry also considers oxidation of elemental mercury by chlorine both in gaseous and aqueous phase. Following *C.Seigneur et al.* [2001] we adopt air concentration of molecular chlorine in the lowest model layer over the ocean to be 100 ppt at night and 10 ppt during daytime and zero concentration over land.

3.3. Sensitivity study and uncertainty analysis

Analysis of the model sensitivity and uncertainty has been performed to define the most critical elements of the model formulation, to uncertainties introduced by individual model parameters and to estimate of the model uncertainty. Lead and cadmium exemplify characteristics of particle-bound heavy metals, whereas mercury is characterized by long-lived gaseous form, chemical transformations and principally differs form other metals. The main model output variables considered

in the analysis are heavy metal concentration in the ambient air, concentration in precipitation and total deposition flux. Sensitivity of these output parameters was analysed with regard to multi-annual meteorological variability, emission values, wet and dry removal parameters. In addition to this, the sensitivity due to chemical processes and mercury depletion events was studied. This section contains basic results of the sensitivity analysis, more detailed information is available in [*Travnikov and Ilyin*, 2005].

Sensitivity to multi-annual meteorological variability. The model sensitivity to the variability of meteorological parameters (wind speed, surface pressure, cloudiness, precipitation etc.) was analysed as a separate case since these parameters are adjusted by the meteorological pre-processor and cannot be considered independently. For example, changes in wind velocities and directions should lead to changes in advection of heat and moisture. This, in its turn, can change pattern and magnitude of precipitation. To assess the model uncertainty due to the variability of meteorological parameters a multi-year (1990-2002) calculation was performed with the same emissions data, initial and boundary concentrations. The obtained mean annual fields of the output parameters were compared between each other and with the average value. On average, changes of output values of lead modelling due to multi-annual variability of meteorological parameters are around 30%. The changes of total gaseous mercury (TGM) concentrations are around 10%, of concentrations in precipitation – 30% and of total depositions of mercury – about 25%.

Model sensitivity to input parameters. The model sensitivity to different input parameters and to the model processes formulation was estimated by variation of the parameter or switching off the appropriate process. The obtained mean annual fields of the pollutant concentration in air and in precipitation as well as total deposition flux were compared with the base case.

Sensitivity of the main model outputs to uncertainty of input parameters is illustrated in Fig. 15 for lead and cadmium and in Fig. 16 for mercury. The error bars in the figure show the 90% confidence interval of the sensitivity coefficient variation over the model domain. As seen from the figure the model is the most sensitive to anthropogenic, natural emissions along with re-emission (at current calculations natural emission and re-emission make up roughly a half of anthropogenic ones). Among other important parameters are the wet deposition coefficient and the dry deposition velocity, which in its turn is influenced by the aerosol mass median diameter. On the other hand, the model is only weakly sensitive to such parameters as boundary concentrations and the liquid water content.

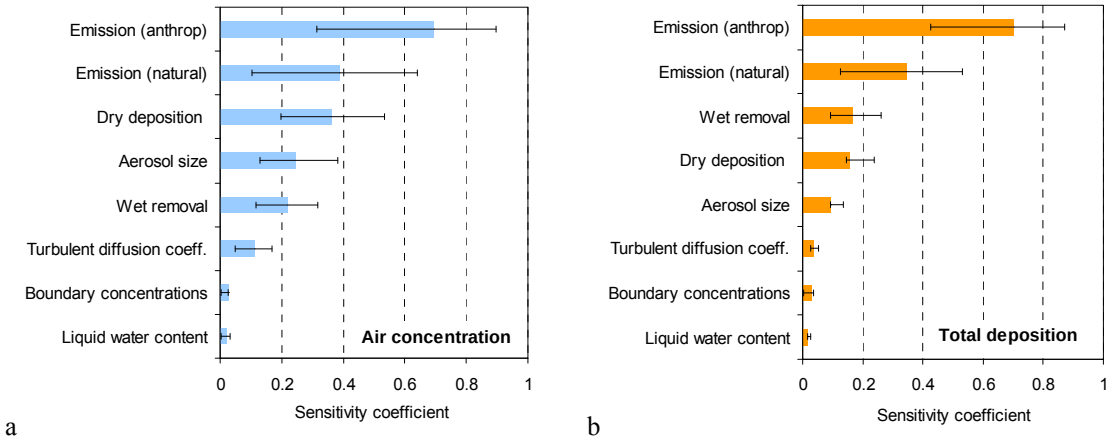


Fig. 15. *Coefficients of the model sensitivity to the main input parameters for lead and cadmium concentration in air (a) and for total deposition flux (b). The error bars show 90% confidence interval*

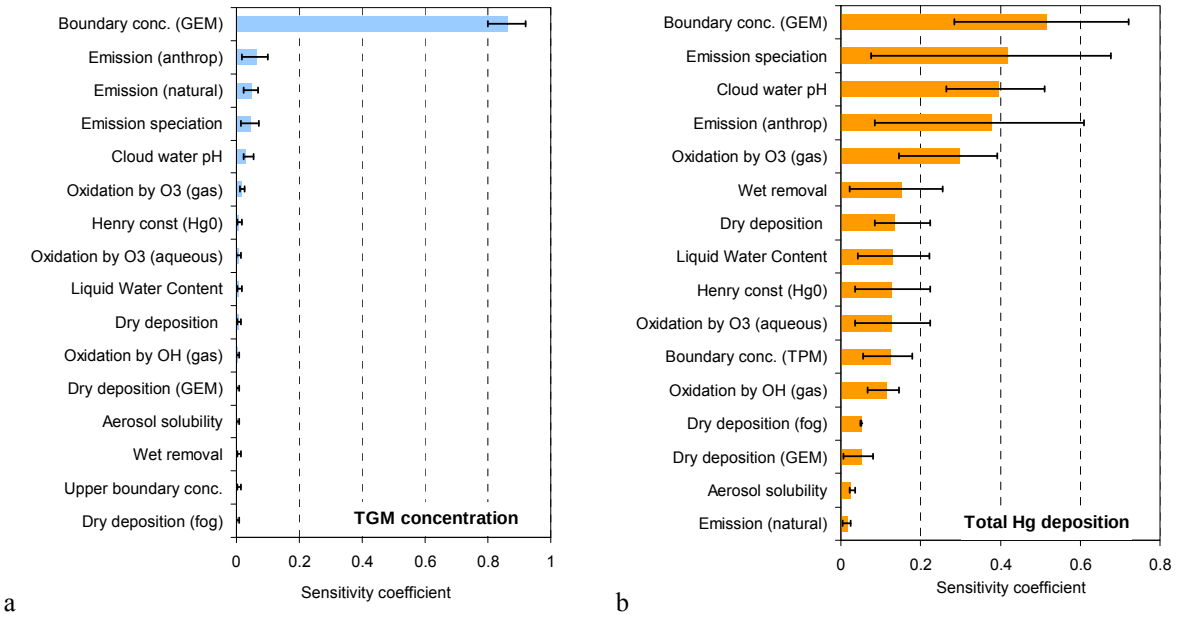


Fig. 16. *Coefficients of the model sensitivity to the main input parameters for TGM concentration (a) and for total mercury deposition flux (b). The error bars show 90% confidence interval*

The character of the mercury model sensitivity is principally different form that described above. The main reason for that is long residence time of the bulk mercury form in the atmosphere – gaseous elemental mercury (GEM) – and chemical transformations in gaseous and aqueous phases governing mercury removal from the atmosphere. The sensitivity of TGM concentration is dominated by boundary concentration of GEM. The contribution of GEM in total gaseous mercury makes up to 99%. Taking into account very long residence time of GEM in the free troposphere (an order of year) it is obvious that this major mercury form can easily reach the centre of Europe or even cross the model domain. Sensitivity of TGM concentration to other parameters is significantly lower. The GEM boundary concentration is the most important parameter for Hg concentration in precipitation and total deposition flux as well. However, since these output variables are mostly defined by oxidized mercury forms, they are also quite sensitive to other parameters responsible for emissions, oxidation and removal processes.

Uncertainty of modelling results. Model uncertainty was estimated in two steps. Firstly, uncertainty of the model output parameters due to uncertainty of the individual parameters are estimated. Secondly, overall model uncertainty was calculated. It was shown that the greatest source of the uncertainty of lead air concentration and deposition is caused by emission data. Significant contribution to the model uncertainty is also caused by variability of meteorological data and parameters of wet and dry depositions. Uncertainty of gaseous elemental mercury (GEM) concentrations is mainly determined by the uncertainty of boundary concentrations of GEM. The influence of other input parameters on GEM concentrations seems to be much less important. As for total deposition, the main contributors to its uncertainty are multi-annual meteorological variability, emission magnitude and speciation, and gas-phase oxidation process. Detailed description of the results of the uncertainty analysis is available in [*Travnikov and Ilyin*, 2005].

An attempt to estimate the model uncertainty was made based on the uncertainties due to individual parameters. Two types of the model uncertainty were distinguished: the intrinsic model uncertainty, which includes contribution of all model parameters except anthropogenic, natural emissions and re-emission; and the overall uncertainty including contribution all parameters. However, only the

stochastic component of anthropogenic emissions uncertainty is considered. A possible influence of the systematic error (underestimation) is not included. It should be noticed that the results of this analysis to significant extent depend on the uncertainties of input parameters and should be considered as tentative.

Estimated uncertainties of the main model parameters for lead, cadmium and mercury are presented in Table 5. The range indicates 90% confidence interval of the uncertainty variation over the model domain. The intrinsic model uncertainty of lead concentration in air, concentration in precipitation and total deposition varies from 20% to 65% over the domain with average values 43%, 40% and 33% respectively. The overall uncertainties reach 60% on average (the range 30-97%). The intrinsic model uncertainty of mercury differs for different outputs. It does not exceed 20% on average for TGM concentration (the range 16-22%) but reaches 40% for total deposition and 50% for concentration in precipitation (the ranges 20-57% and 29-74% respectively). The overall uncertainty for mercury only slightly exceeds the intrinsic one indicating limited effect of emissions uncertainty on the model results.

Table 5. *Model intrinsic and the overall uncertainties of the main model output parameters*

Output parameter	Intrinsic		Overall *	
	Uncertainty, %	Range, %	Uncertainty, %	Range, %
Lead and cadmium				
Air concentration	43	22 – 64	65	39 – 97
Concentration in precipitation	40	20 – 57	61	32 – 85
Total deposition	33	19 – 49	58	31 – 81
Mercury				
TGM concentration	19	16 – 22	20	16 – 23
Concentration in precipitation	53	29 – 74	56	29 – 80
Total deposition	39	20 – 57	46	20 – 70

** - Only stochastic component of anthropogenic emissions uncertainty is considered. The systematic component (underestimation) is not included*

3.4. Mercury transport from global sources

The mercury intercontinental transport was evaluated to take into account the effect of sources located outside the EMEP region on mercury pollution in Europe. According to the modelling results contribution of the intercontinental transport to deposition of mercury in Europe is comparable (up to 40%) with contribution of regional sources (see Fig. 17). Therefore, setting the proper boundary concentrations of mercury species at the domain boundaries is principally important for the assessment of realistic pollution levels. Besides, it was demonstrated in the sensitivity analysis that boundary conditions are among the most important parameters determining results of mercury modelling. Available measurement data are too sparse to supply concentrations of mercury along the whole model boundary.

In order to set up the boundary conditions adequately we performed hemispheric modelling of mercury atmospheric transport with the MSCE-HM-Hem model. Fig.18 shows spatial distribution of total gaseous mercury in the Northern Hemisphere. As seen air concentration of this bulk mercury species varies insignificantly in the Northern Hemisphere due to its long residence time in the atmosphere. On the other hand mercury atmospheric depositions are mostly determined by short-lived mercury species such as particulate mercury or reactive gaseous mercury.

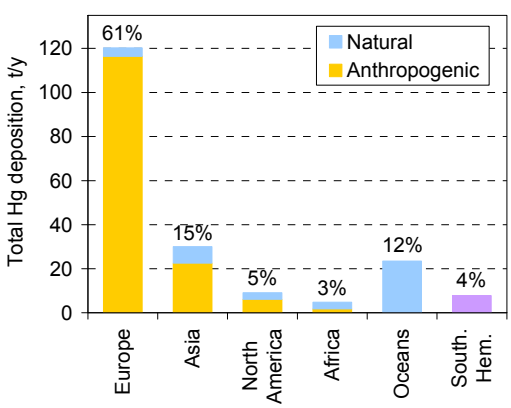


Fig. 17. *Contribution of different continents of the Northern Hemisphere to total mercury deposition in Europe*

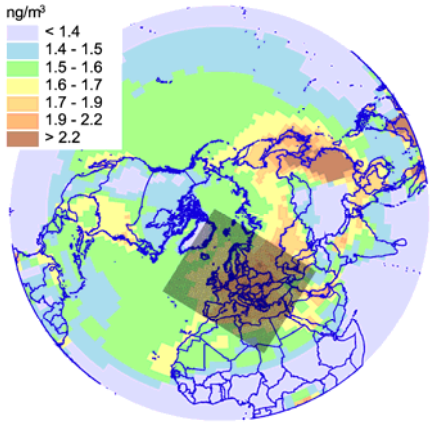


Fig. 18. *Spatial Distribution of total gaseous mercury in the Northern Hemisphere. Rectangular shows the EMEP domain*

Both hemispheric and regional models have similar vertical structures, advection schemes and the same scheme of chemical transformations. Therefore mercury concentrations obtained from the hemispheric modelling can be directly used for the boundary conditions of the regional model. Monthly mean concentrations of three atmospheric mercury forms – gaseous elemental mercury (GEM), total particular mercury (TPM), and reactive gaseous mercury (RGM) – calculated at the EMEP domain boundaries were applied as the boundary conditions. Fig. 19 illustrates annual mean distribution of three mercury forms concentration in the ambient air along the boundary of the model domain.

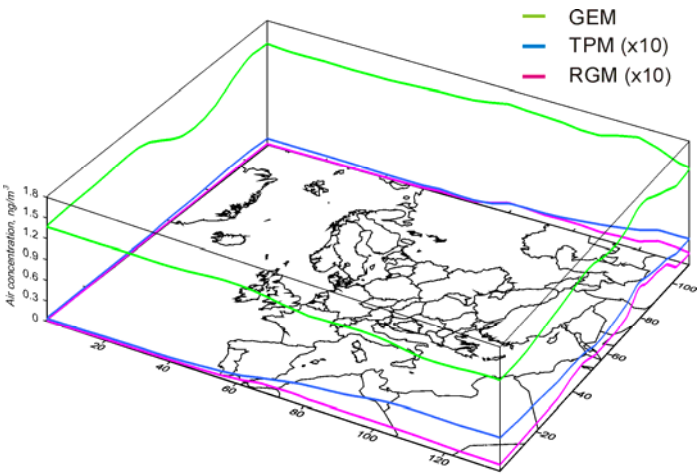


Fig. 19. *Distribution of three mercury forms (GEM, TPM, RGM) concentration in the near surface air along the boundary of the model domain*

4. MODEL ASSESSMENT OF HEAVY METAL POLLUTION IN EUROPE

This Chapter is devoted to the model assessment of the long-range transport of heavy metals in the atmosphere of Europe. The first section contains the trends analysis of lead, cadmium and mercury pollution of Europe during the period 1990–2003, description spatial distribution of heavy metal pollution levels in Europe in 2003, information on transboundary fluxes between European countries, and heavy metal atmospheric loads to the regional seas. All modelling results presented in this Chapter were performed using the adjusted emission scenarios, except mercury ones which are based on official emissions data (see Chapter 2). Therefore presented results should be considered rather as tentative to describe measured pollution levels in Europe. In the second section performance of the MSC-E heavy metal model is briefly characterised in comparison with measurement data. Detailed information on source-receptor relationships for European countries is presented in Annex B.

4.1. Pollution levels in Europe

Lead

According to the modelling results lead depositions in Europe declined 2.3 times during the 1990–2003 period. Fig. 20 illustrates trend of total lead depositions in Europe. Total depositions over the entire European territory decreased monotonely during the whole period. Nevertheless, the character of lead deposition changes differs considerably in different European countries.

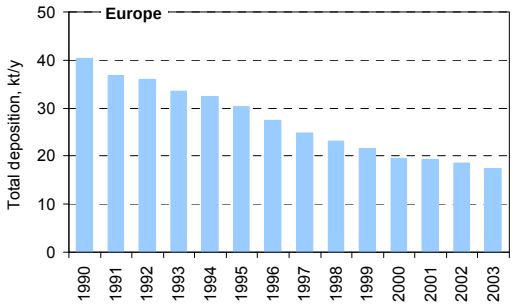
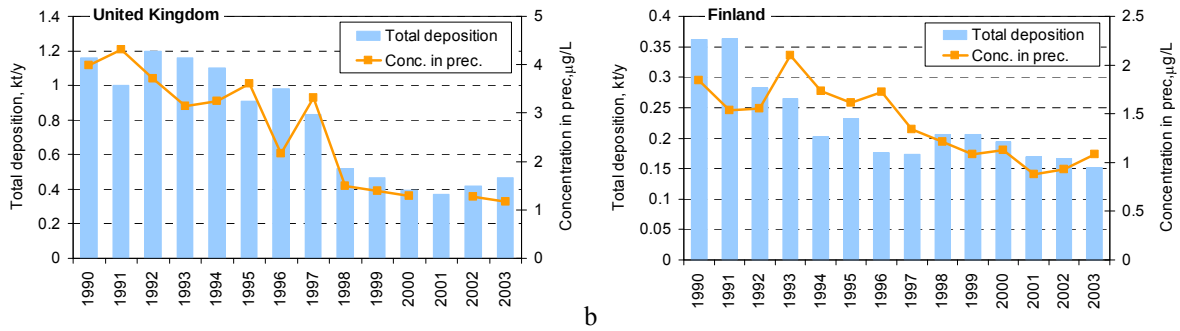


Fig. 20. *Trend of lead total deposition in Europe in the period of 1990-2003*

Fig. 21 shows changes of lead depositions in the United Kingdom and Finland. Measured lead concentrations in precipitation are also presented. Both modelling results and measurements demonstrate more significant decrease of pollution levels in the United Kingdom (3 times) in comparison with Finland (about 2 times). It could be explained by more significant role of the transboundary transport from other European countries and considerable relative contribution of permanent natural sources.



a b

Fig. 21. *Trends of lead total deposition in the United Kingdom (a) and in Finland (b). Symbols indicate measured lead concentration in precipitation (3 stations in the UK and 2 stations in Finland)*

Total deposition to European countries in 2003 was 17.5 kt, most part of which came from European anthropogenic sources (87%), and the rest (13%) – from re-emission, natural emission and from sources located outside the EMEP region.

Distribution of lead depositions over the EMEP region is highly inhomogeneous (Fig. 22). In general, averaged deposition fluxes ranges from 0.3 to 4 kg/km^2/y. In the most pollution loaded areas of such countries as Germany, Belgium, Portugal, Russia, Poland, Ukraine deposition fluxes often exceed 4 kg/km^2/y. In the northern part of Europe (Iceland, north of Scandinavia Peninsula) deposition fluxes of lead are typically less then 0.3 kg/km^2/y.

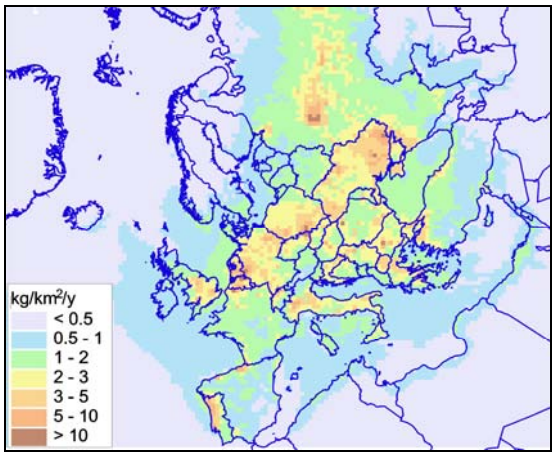


Fig. 22. *Spatial distribution of lead depositions in Europe in 2003*

Deposition fluxes averaged over territory of a country are summarized in Fig. 23 for all EMEP countries. Almost in a half of countries the average deposition flux exceeds 2 kg/km^2/y. High deposition fluxes are determined both by own emission sources in such countries as Belgium, the Netherlands, Ukraine, Poland, Czech Republic etc. and by the transboundary transport from other European countries.

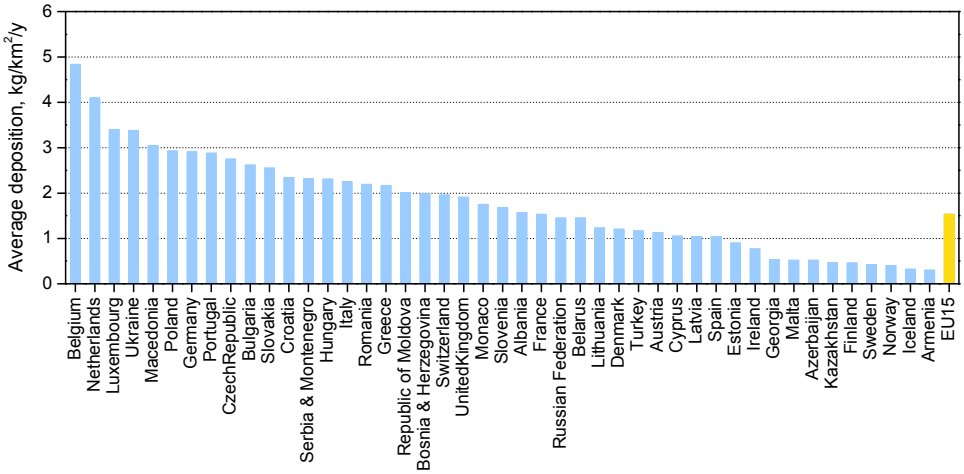


Fig. 23. *Average lead anthropogenic deposition flux in European countries in 2003*

Indeed, contribution of the transboundary transport from anthropogenic European sources to depositions in Republic of Moldova, Luxemburg, Monaco and Belarus exceeds 80% (Fig. 24). In twenty countries this contribution exceeds 50%. Contribution of the transboundary transport to depositions is relatively low for countries which are characterized by high emission, and hence, high depositions from national sources (e.g., Germany, Italy), or countries remote from main anthropogenic sources (e.g., Iceland), or where both factors seems to be significant (e.g. the United Kingdom, Spain). For the EU15[1] the contribution of the transboundary transport is insignificant (around 8%).

[1] Here and after we imply the European Union of 15 member states (EU15) before its expansion in 2004

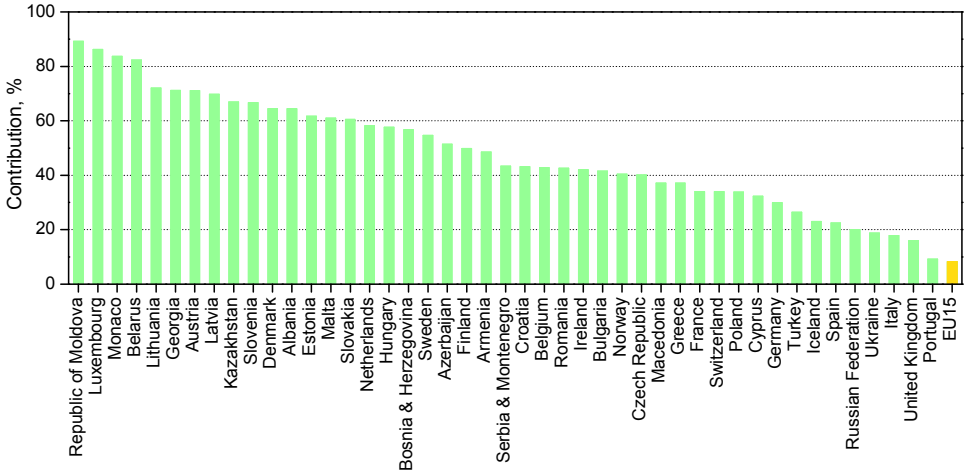


Fig. 24. *Relative contribution of external anthropogenic sources to lead depositions in European countries in 2003*

Cadmium

During the period of 1990–2003 total depositions of cadmium in Europe as a whole decreased 2.3 times – from 1300 to 560 t/y (Fig. 25). Deposition changes vary in different parts of Europe. Fig.26 illustrates variation of cadmium deposition from 1990 to 2003 in Germany and in Finland along with observed concentrations of this pollutant in precipitation.

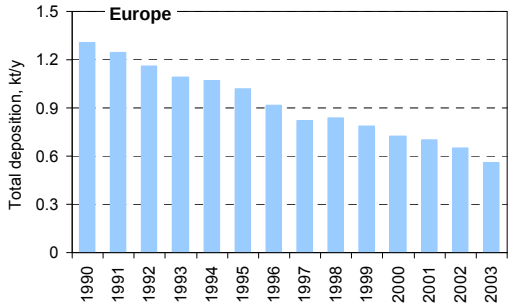


Fig. 25. *Trend of cadmium total deposition in Europe in the period of 1990-2003*

As seen depositions changes in such large country as Germany more or less reflect common tendency of depositions reduction in Europe since pollution of its territory to significant extent is determined by own emission sources. On the other hand, cadmium depositions decrease is not so pronounced in Finland, since relative contribution of its own emission sources is not so significant in comparison with that of the transboundary transport and natural sources.

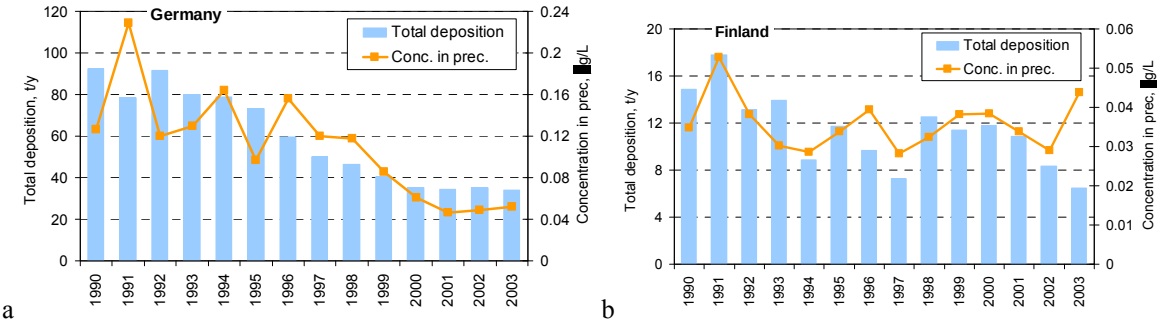


Fig. 26. *Trends of cadmium total deposition in the Germany (a) and in Finland (b). Symbols indicate measured lead concentration in precipitation (2 stations in Germany and 2 stations in Finland)*

Total deposition to EMEP countries in 2003 was about 560 t/y from which 78% came from European anthropogenic sources and 22% from re-emission, natural emission and from external sources.

Spatial distribution of cadmium deposition in Europe is shown in Fig. 27. The areas with relatively high depositions are in such countries as Poland Germany, Belgium, Ukraine, Russia, and in the south-east of Europe. Deposition fluxes in these regions can exceed 100 g/km^2/y. In the northern part of Europe deposition fluxes are below 30 g/km^2/y.

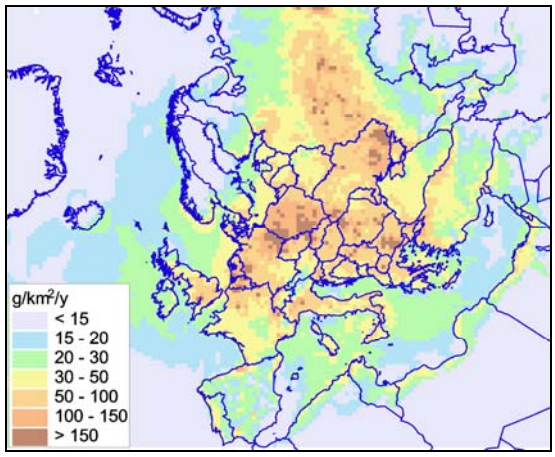


Fig. 27. *Spatial distribution of cadmium depositions in Europe in 2003*

The spatial pattern of national emissions and atmospheric transport from neighbouring countries causes high variability in depositions to different countries (Fig. 28). The highest deposition flux of cadmium averaged over the country area is obtained for Poland (135 g/km^2/y), followed by Belgium, Slovakia, and Bulgaria. Average deposition flux over EU15 countries is about 45 g/km^2/y.

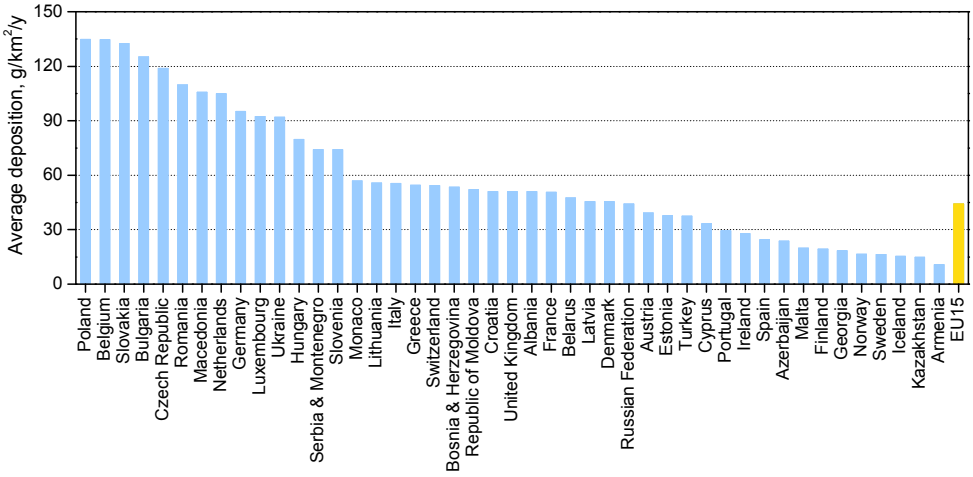


Fig. 28. *Average cadmium anthropogenic deposition flux in European countries in 2003*

The contribution of the external European anthropogenic sources to cadmium depositions in Europe in 2003 varies from 7 to 83% (Fig. 29). In 16 countries it exceeded 50%. The countries most affected by the transboundary transport of cadmium are Republic of Moldova, Belarus, Lithuania, Luxemburg and Latvia. The lowest contributions are estimated for remote countries as Spain and Iceland. The contribution of the transboundary transport to pollution of the European Union with cadmium is about 10%.

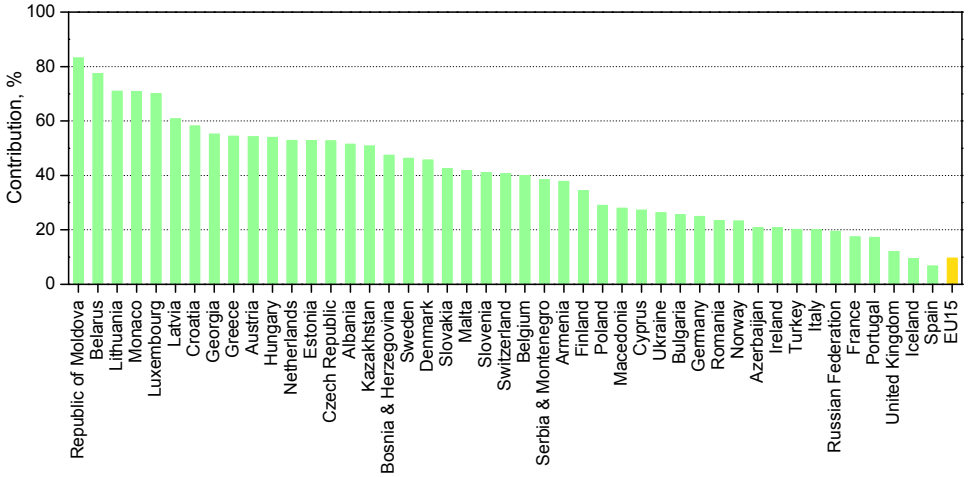


Fig. 29. *Relative contribution of external anthropogenic sources to cadmium depositions in European countries in 2003*

Mercury

Assessment of mercury pollution levels and its transboundary transport were performed on the base of officially submitted emissions for 2003. Expert estimates of the emissions were applied only for countries for which the official data were not available. Total mercury deposition on the territory of Europe reduced only 1.6 times from 1990 to 2003 (Fig. 30). It came about due to the impact of global sources as well as natural component of emissions and mercury re-emission assumed to be unchanged during this period. In contrast to lead and cadmium, mercury is a global pollutant and can be transported in the atmosphere all around the globe. Therefore mercury emission sources located on other continents have a significant impact on pollution of Europe. Apart from that, natural emission sources and re-emission contribute significantly to mercury input to the atmosphere.

Fig. 31 shows mercury deposition changes in two countries from different parts of Europe. In Germany, where contribution of own anthropogenic sources to mercury depositions is large, reduction of depositions is significant. Whereas in Norway there is no pronounced deposition trend due to considerable relative contribution of global and natural sources.

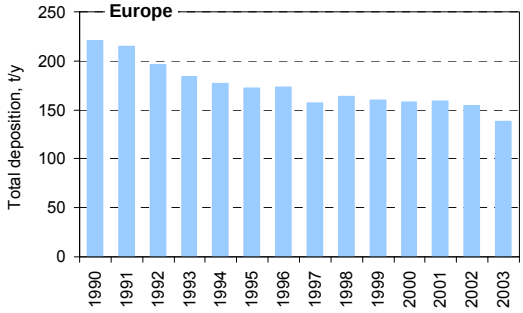


Fig. 30. *Trend of mercury total deposition in Europe in the period of 1990-2003*

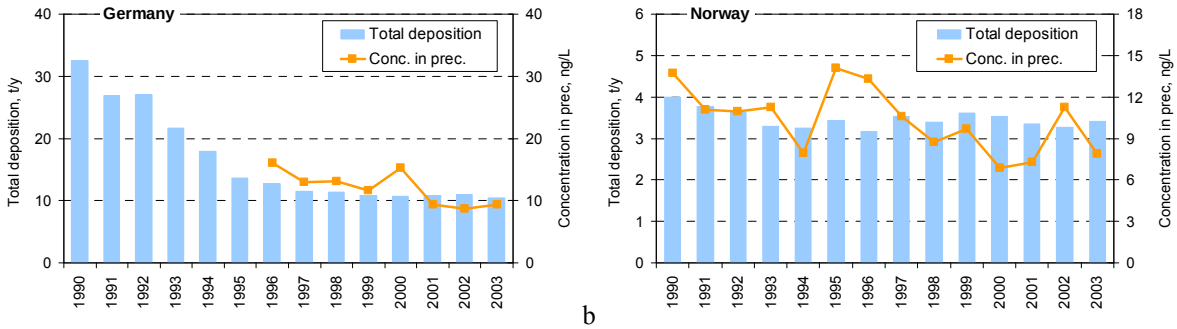


Fig. 31. *Trends of mercury total deposition in the Germany (a) and in Norway (b). Symbols indicate measured lead concentration in precipitation (DE9 in Germany and NO99 in Norway)*

Total deposition of mercury to EMEP countries in 2003 made up about 140 t/y, from which 45% came from European anthropogenic sources, and the rest 65% – from natural sources, re-emission and global sources located outside EMEP region. The contribution of these sources to depositions of mercury to Europe is much higher than those of lead or cadmium because of global character of mercury atmospheric transport.

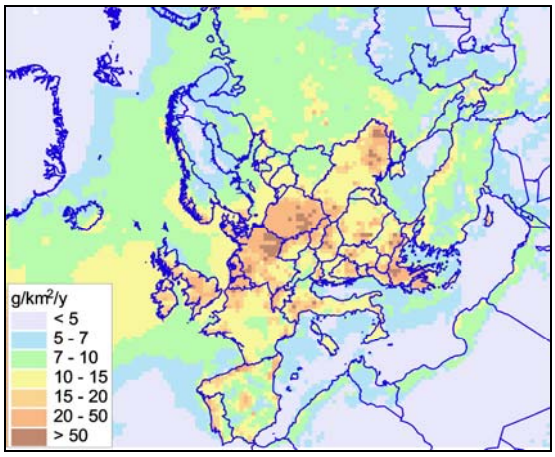


Fig. 32. *Spatial distribution of mercury depositions in Europe in 2003*

Generally, mercury depositions in Europe were higher then 5 g/km^2/y but rarely exceeded 50 g/km^2/y (Fig. 32). The highest deposition fluxes took place in eastern part of Germany, Poland, eastern Ukraine, Romania and Greece. Over central parts of Scandinavia Peninsula and the Artic the depositions did not exceed 10 g/km^2/y. Average mercury deposition fluxes in European countries are compared in Fig 33. It is seen in 23 European countries the average flux exceed 15 g/km^2/y. This value is also characteristics of average mercury depositions in EU countries.

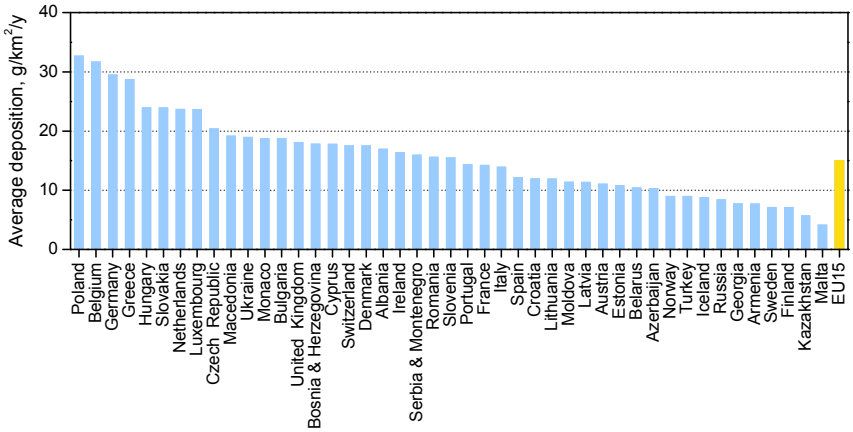


Fig. 33. *Average mercury anthropogenic deposition flux in European countries in 2003*

The role of the transboundary transport in mercury pollution in Europe varies greatly from country to country (Fig. 34). The highest contribution of external European anthropogenic sources to mercury deposition took place in Czech republic and Moldova (around 50%). Similar to lead and cadmium, the highest input from external anthropogenic sources is typical for countries, located close to major emission sources. For example, for Austria, Denmark and the Netherlands the main transboundary source of mercury is Germany, for Slovenia and Malta – Italy. As a rule, low contribution of external European sources is typical for countries located far from main anthropogenic sources (Iceland, Norway, Cyprus). Iceland is characterized by the lowest (2%) contribution. The contribution of the transboundary transport to European Union pollution is about 3%. Relatively low contribution to EU as whole is explained by the fact that EU incorporates most of countries with high emissions. Therefore, depositions from these countries to EU territory are considered as depositions from “own” sources.

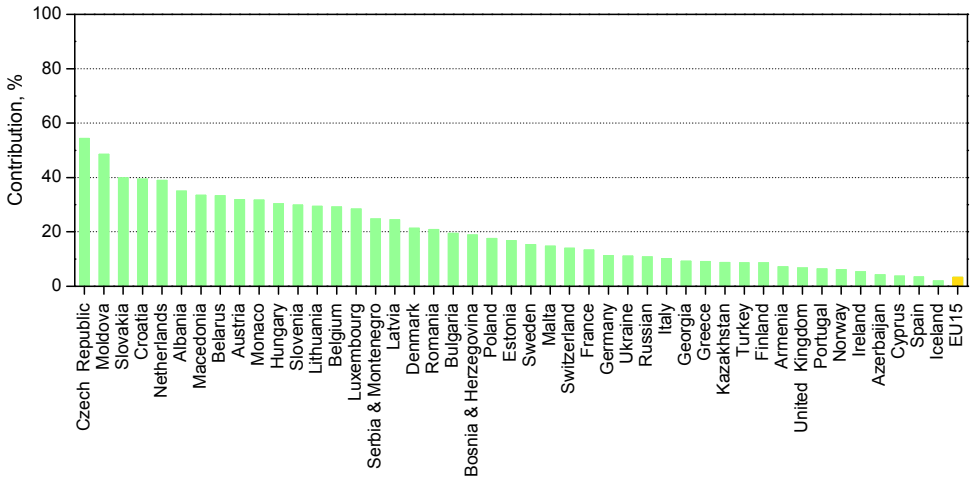


Fig. 34. *Relative contribution of external anthropogenic sources to mercury depositions in European countries in 2003*

Depositions to regional seas

Atmospheric loads to seas surrounding Europe are computed by MSC-E operationally. In 2003 the highest average deposition flux of lead and cadmium was obtained for the Black and Azov Seas (Fig. 35). This is caused by atmospheric transport from the countries with significant emission sources located nearby. The lowest depositions are to the Caspian Sea since it is located far from the major European sources. The most significant depositions of mercury occur over the North and the Baltic Seas, the lowest – over the Black and Azov Seas.

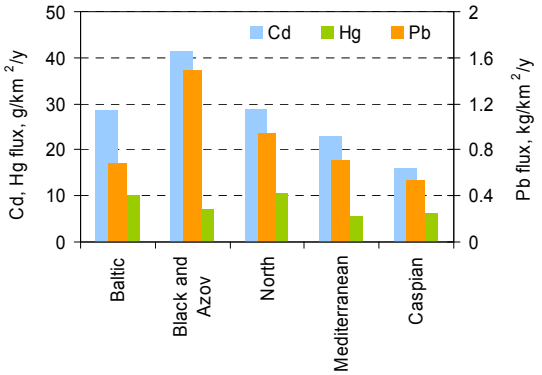


Fig. 35. *Averaged deposition fluxes of lead, cadmium and mercury to regional seas in 2003*

4.2. Model validation against measurements

For validation of the model performance computed concentrations in air and in precipitation were compared with monitoring data. Monitoring data were collected in the framework of national monitoring programmes of EMEP countries under scientific and methodological supervision of Chemical Coordinating Centre of EMEP. Description of the available monitoring data from the EMEP network and evaluation of their quality is presented in Chapter 1 of this report. This section contains brief conclusions of the model validation for the period 1990 – 2003. More detailed information is available in MSC-E Technical Report 8/2005 [*Ilyin and Travnikov*, 2005]

For the period from 1990 to 2003 as much as 88 stations have been carrying out measurements of lead and cadmium in air or/and in precipitation at least for one year within the period. Among these 14 stations measured only concentrations in air, 44 – only concentrations in precipitation and 30 - in both media at least for one year. Most of the stations are located in the northern, western and central parts of Europe, and only few EMEP stations measure heavy metals in the southern and eastern parts of Europe. Mercury in air or/and in precipitation has been measured at least in one year of the period

1990 – 2003 at 19 stations. Among these stations, 5 measured concentrations in air, 6 – in precipitation and 8 – both in air and in precipitation. Mercury measurement data are available only from the northern or north-western part of Europe.

The model evaluation against measurements was performed using modelling results based on the adjusted emission scenario. Fig. 36 shows comparison of modelled and measured lead concentrations in air and precipitation for 1990–2003. Modelled lead concentrations in air well agree with measurements: slope of the regression line close to unity and correlation coefficient is 0.89. In more that 87% of cases difference between modelled and measured concentrations in air does not exceed 50%. High correlation coefficient indicates that the model managed to catch spatial gradients of the pollution levels. Concentrations in precipitation in 2003 are slightly underestimated by the model – the regression slope is 0.8. The correlation coefficient is quite significant – 0.74. About 71% of model/observation pairs are within 50%-difference range. Weaker model results for concentrations in precipitation, compared to the results for concentrations in air, can be explained by additional uncertainty, caused by difference in precipitation amounts measured at monitoring stations and used in the model.

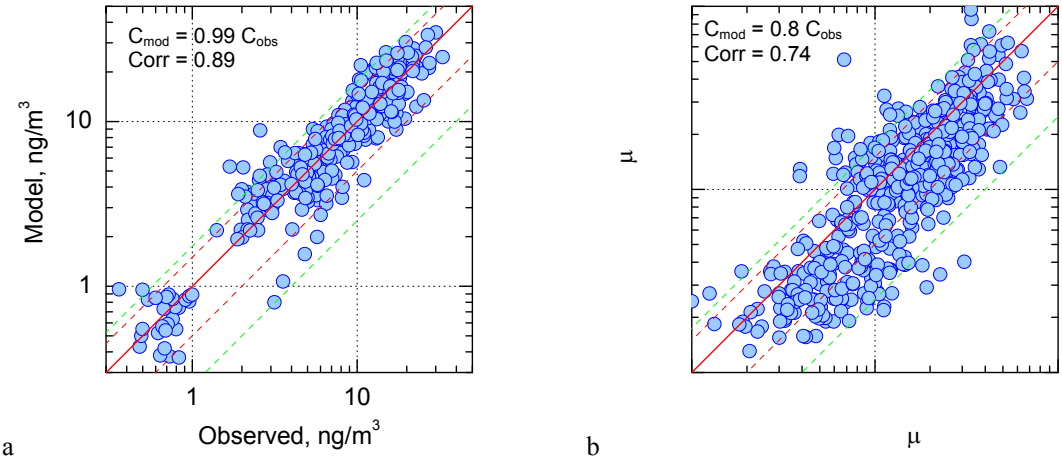


Fig. 36. *Comparison of annual mean modelled and measured concentrations of lead in air (a) and in precipitation (b) for 1990–2003. Solid red line depicts 1:1 ratio; dashed lines: deviation ±50% (red) and ±75% (green)*

Comparison of modelled results for cadmium with measured data illustrated in Fig. 37. Cadmium concentrations in air also well correspond to observations. Slope of the regression line is equal to unity and the correlation coefficient is 0.78. More then 74% of modelled results do not differ from the measurements more than by 50%. Some underestimation of measurement data is still obtained for cadmium in precipitation (slope of the regression line is 0.6). One of possible reasons of the underestimation is imperfection of the adjusted emission scenario based of national emission totals, which is not able to take into account actual spatial distribution of emission sources. Another reason is very low cadmium concentration in precipitation at many sites, which are close to the detection limit. Potentially this situation can lead to some artificial increase of measured concentrations due to inaccuracy of measurements. However still 76% of model/measurement pairs are within 50%-difference interval.

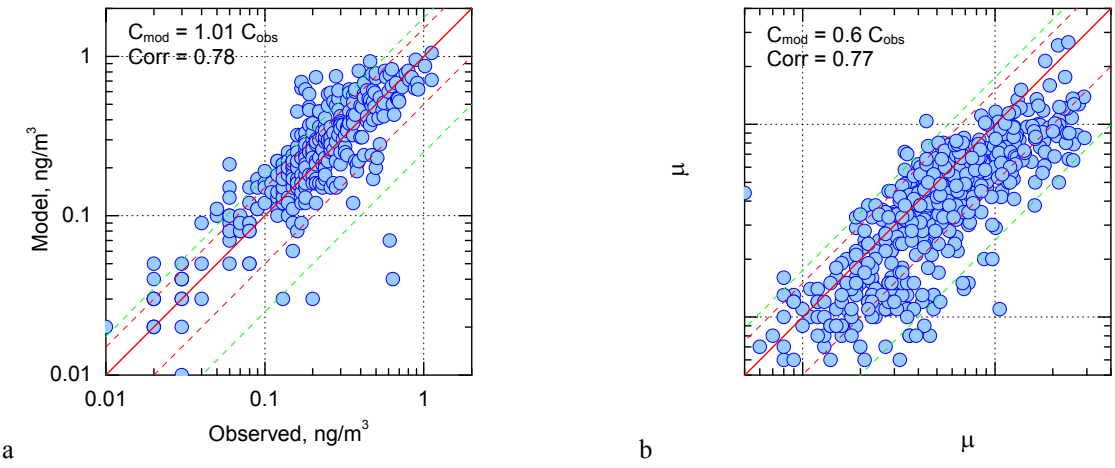


Fig. 37. *Comparison of annual mean modelled and measured concentrations of cadmium in air (left) and in precipitation (right) for 1990–2003. Solid red line depicts 1:1 ratio; dashed lines: deviation ±50% (red) and ±75% (green)*

Comparison of measured and modelled mercury concentrations in air and precipitation is presented in Fig. 38. Total gaseous mercury concentration is characterised by very low variability around the background value 1.5 ng/m^3 caused by significant mixing of this long-lived pollutant in the global atmosphere. Therefore correlation of modelling results with measurements is not high – 0.38. However, the model well reproduces concentration levels – slope of the regression line is close to unity and in 96% of cases difference between model and measurements does not exceed 30%. Correlation of mercury concentration in precipitation is better – 0.5, the regression line slope is equal to unity and about 79% of model/observation pairs are within 50%-difference range.

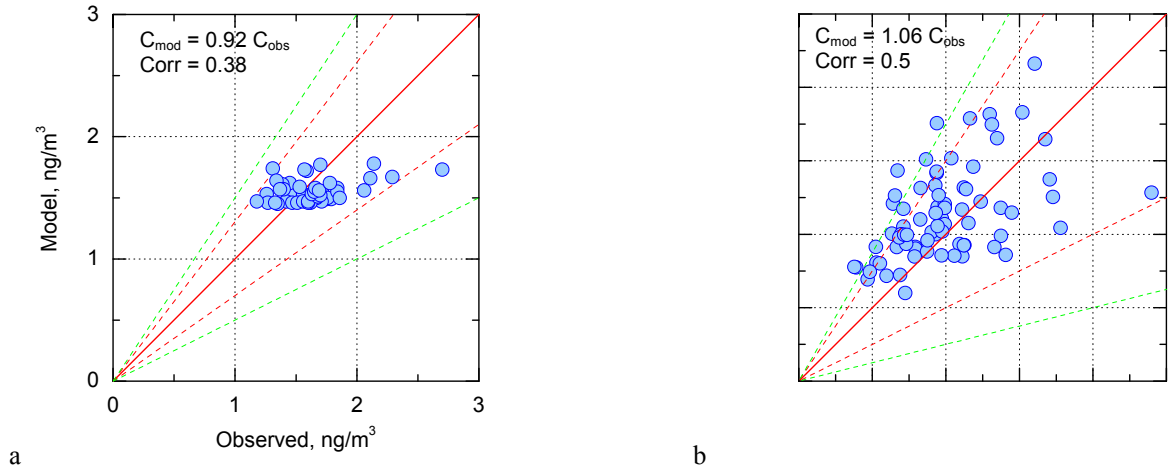


Fig. 38. *Comparison of annual mean modelled and measured total gaseous mercury concentration in air (a) and total mercury concentration in precipitation (b) for 1990–2003. Solid line depicts 1:1 ratio, dashed lines: (a) – deviation ±30% (red) and ±50% (green), (b) – deviation ±50% (red) and ±75% (green)*

5. CO-OPERATION

Investigations of the environmental pollution by heavy metals are carried out by the EMEP Centres in co-operation with the Task Force on Measurements and Modelling, with subsidiary bodies to the Convention: the Working Group on Effects (WGE), the Working Group on Strategies and Review (WGSR); with national experts of Parties to the Convention within the Mercury Intercomparison Study; with Helsinki Commission (HELCOM) and European Commission (EC).

5.1. Task Force on Measurements and Modelling

Following the TFMM work-plan [EB.AIR/GE.1/2004/3] MSC-E has started preparation for the EMEP/TFMM Workshop on the review of the MSC-E models. The main goal of the Workshop is to establish whether MSCE-HM and MSCE-POP models are state-of-the-art and fit for purpose of evaluating contribution of long-range transport to the environmental impacts caused by heavy metals and persistent organic pollutants. As a first step towards model review, MSC-E presented at the 6th session of TFMM (Croatia, April 2005) a detailed description of the regional HM transport model, reported on model sensitivity study, uncertainty analyses and on the results of five-year programme of model intercomparisons for mercury. It also gave information on available input data for models: emissions, land cover, and chemical reactants. MSC-E provided members of the TFMM with the background material on the model parameterizations and the model sensitivities. They are available in the Technical report [*Travnikov and Ilyin*, 2005] on the MSC-E website (*www.msceast.org/events/review.html*).

TFMM appreciated the recent modelling work on heavy metals and presentations on the above-mentioned topics. It recognized the work on analysis of HM emission uncertainties and their effects on modelling results, and took note that emission data were incomplete and to fill the gaps in the data, expert estimates should be used. Taking into account that modelling of Pb and Cd deposition fields on the basis of emission expert estimates were in a good agreement with measurements, TFMM recommended MSC-E to produce two types of deposition maps for Cd and Pb for the evaluation of exceedance of critical loads. One deposition field should be calculated on the basis of official emission data and another one using available emission expert estimates.

TFMM approved the plans for the Workshop on the review of the MSC-E models to be held in Moscow, Russia from 13 to 14 October 2005 and drew attention of MSC-E to focus the Workshop on comparison with observations and model intercomparison. It also encouraged the full support and attendance from national experts.

5.2. Working Group on Effects

Working Group on Effects (WGE) is one of important consumers of heavy metal modelling information produced by MSC-E. According to the critical loads approach developed in WGE estimated pollution levels should be compared with some threshold values, e.g. so-called critical loads, in order to assess the degree of harmful impact caused by atmospheric pollution. At the recent joint meeting of Bureaux of the EMEP Steering Body and the WGE it was recommended to continue collaboration between CCE and MSC-E. This collaboration was focused on modelling of ecosystem-specific depositions and

concentrations in precipitation of lead, cadmium and mercury in 1990 and 2000 and calculation of critical loads exceedances over Europe. Preliminary results were published in joint CCE/MCS-E report [*Slootweg et al*., 2005]. In this section recent calculations are presented based on the more detailed adjusted emission scenario.

Depositions were evaluated based both on emission data officially submitted by European countries and on the adjusted emission scenario. Depositions were calculated to all land cover types considered in the model such as forests, crops, grassland etc. Examples of lead depositions to coniferous forests in 2000 are presented in Fig. 39. As seen from the figures modelling results based on the adjusted emission scenario predict significantly higher deposition fluxes than those based on official emission data. Taking into account that modelling results based on the estimated emissions much better agreed with measurement data (see Section 4.4), they more realistically reproduce actual pollution level. Thus, deposition flux to coniferous forests over most part of Europe lies in the range from 1 to 15 kg/km^2/y (Fig 39b). In the northern part of Europe this flux mostly does not exceed 2 kg/km^2/y.

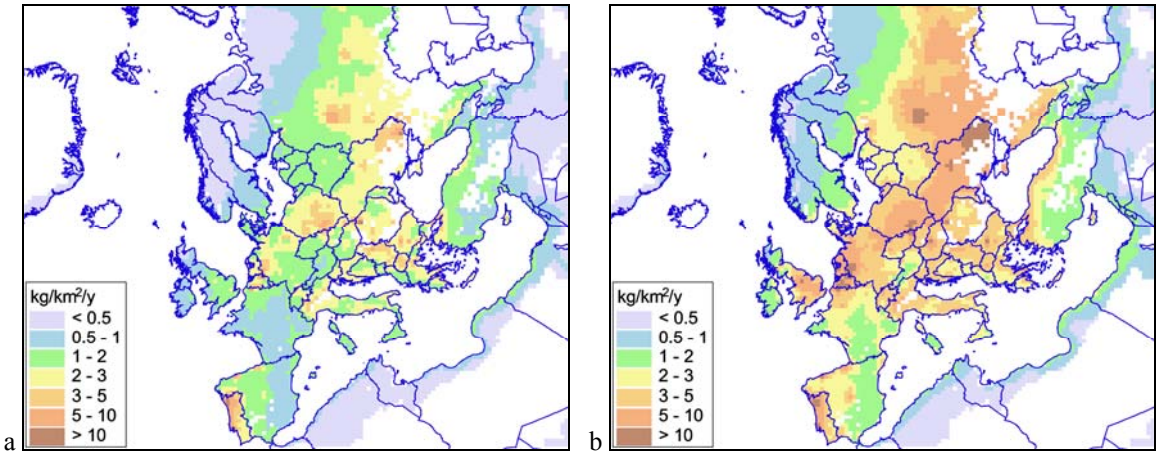


Fig. 39. *Deposition flux of lead to coniferous forests in 2000 according to official emission data (a) and the adjusted emission scenario (b)*

Calculation of the critical loads exceedances for mercury differs from those for lead and cadmium. In the case of mercury the key parameter defining critical loads is not only deposition, but also concentration in precipitation. Mercury atmospheric pollution modelling was performed based on the official emission data. Fig. 40 illustrates spatial distribution of mercury concentration in precipitation in Europe in 2000. The concentrations in precipitation in central Europe were typically 10–40 ng/L. Over Scandinavia and some remote areas of Western Europe the concentrations are below 10 ng/L.

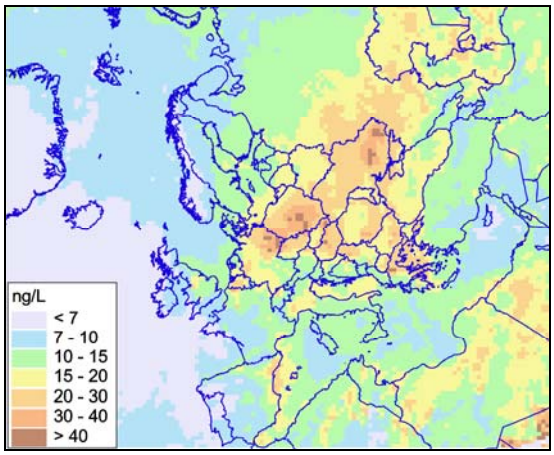


Fig 40. *Total mercury concentrations in precipitation in Europe in 2000*

5.3. Task Force on Heavy Metals

To support the Working Group on Strategies and Review in its preparatory work for the review of the Protocol on Heavy Metals MSC-E took part in the second meeting of the Task Force on Heavy Metals (Geneva, June 2005). MSC-E made a presentation on the results of recent work by EMEP on emission inventories, monitoring of heavy metals, dispersion modelling and transboundary fluxes.

TF on HMs requested MSC-E to contribute to the preparation for the following elements of the sufficiency and effectiveness review of the Protocol on HMs:

- Atmospheric transport, ambient concentrations and deposition of heavy metals
- Results of modelling and mapping of critical loads of Pb, Cd, Hg and critical concentrations of mercury in precipitation and their exceedances for Europe

The Task Force also invited MSC-E to prepare a synthesis document on the best available emission data, including 1990 and more recent years and evaluate existing trends. The overview of emissions would address the three heavy metals listed in Annex I of the Protocol and possibly second priority heavy metals.

5.4. Expert Group on Particles

In 2005 MSC-E participated in the first meeting of the Expert Group on Particulate Matter (Berlin, 2005). The problems of airborne particulate matter pollution and of such pollutants as heavy metals and POPs are connected very tightly. On one hand, the particulate matter carriers of most part of this pollutants in the atmosphere. Hence, physical and chemical properties of the particles determine atmospheric behaviour of heavy metals and POPs. On the other hand, in many cases just occurrence of micro-pollutants in particulate matter can determine degree of toxicity of the airborne particulate matter.

At the EG meeting MSC-E presented information on concentrations of heavy metals and POPs in primary PM10 and suggested to use an approach to assess levels of integral pollution of particulate matter. This approach is based on calculations of hazard quotients for individual pollutants and summing these hazard quotients to evaluate the Integral Hazard Index of particulate matter [*US EPA*, 2003]:

$$HI = \sum_{j=1}^{m} \frac{\sum_{i=1}^{n} \frac{C_{i,j} * \varphi_{i,j}}{T_{i,j}}}{COV_j} ,$$

where $C_{i,j}$ is concentration of the i^{th} pollutant in the j^{th} class of the pollutants; $T_{i,j}$ is the threshold of the i^{th} pollutant in the j^{th} class of the pollutants; $\varphi_{i,j}$ is the share of the i^{th} pollutant of the j^{th} class in the particulate phase; COV_j – coverage factor, which reflect contribution of toxicity of calculated pollutants to the total toxicity of the j^{th} class of the pollutants.

To illustrate the approach possibility five individual pollutants were considered to estimate spatial distribution of the Hazard Indexes of particular matter over Europe in 2002 (Fig. 41). The figure demonstrates that over large territory of Central Europe the values of the Hazard Index of particulate matter exceed unity. The US EPA mentioned [*US EPA*, 2003]: “If there is an exceedance, it may be advisable to consider this aspect of the risk assessment further”.

In the strict sense, there is no common opinion among the human health experts about additivity of the effects caused by particulate matter and different pollutant within the particulate matter. More generally, the total health effect (ΣE) can be expressed by the following formula:

$$\sum E = E_{PM} + \alpha * A + \beta * B + ... + \sigma * X$$

where E_{PM} is the effect caused by particulate matter *per se*; A, B, … , X are concentrations of different pollutants within particulate matter; α, β, … σ are coefficients, which should take into consideration effects of synergism or antagonism of the corresponding pollutants.

In further, quantitative values of the coefficients can be assessed by human health experts, while the concentrations can be modelled by MSC-E.

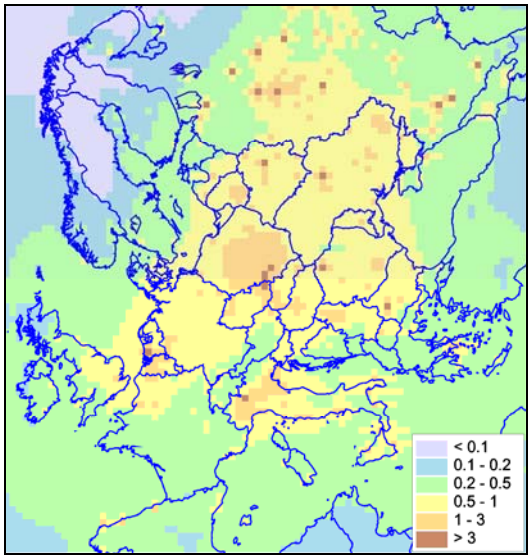


Fig. 41. *Spatial distribution of hazard indexes for particulate matter over Europe in 2002*

5.5. Mercury intercomparison study

MSC-E continued its activity in the field of mercury intercomparison study. The aim of this study was to compare results of different regional-scale and global-scale models with each other and with available measurement data. This comparison should reveal abilities of modern models to reproduce observed mercury pollution levels, indicate knowledge gaps and suggest ways of further model improvement.

The final stage of the study was aimed at comparisons of modelling results with long-term (months-year) observations. Particularly, the third stage was focused on the comparison of integrated items of mercury atmospheric balances for individual countries. National experts in the fields of emissions, monitoring and modelling from Bulgaria, Denmark, Germany, Norway, Sweden and the USA took part in this stage along with MSC-E. The comparison involved seven models of regional and hemispherical scales (Table 6). MSC-E participated with results of two versions of its mercury transport model: regional-scale MSCE-HM and hemispheric MSCE-HM-Hem. This section briefly summarizes the most important outcomes of the study, more detailed description can be found in MSC-E Technical Report 1/2005 [*Ryaboshapko et al*., 2005].

Table 6. *Models participating in the third stage of mercury intercomparison study*

Model	Country	Scale
CMAQ	USA	Regional
ADOM	Germany	Regional
EMAP	Bulgaria	Regional
HYSPLIT	USA	Regional
DEHM	Denmark	Hemispheric
MSCE-HM	EMEP/MSC-E	Regional
MSCE-HM-Hem	EMEP/MSC-E	Hemispheric

Measurements of mercury concentrations in air and in precipitation from the EMEP monitoring network were used in the study. The monitoring stations were collected into three groups in accordance with their location in Europe: “polluted”, “regional” and “background”. Example of comparison of mercury wet deposition flux in February in 1999 at these three groups of stations is demonstrated in Fig. 42. Wet deposition fluxes observed at the “regional” stations are higher those at “polluted” stations because of difference in precipitation amounts. As seen from the figure, models of MSC-E predicted wet deposition fluxes with reasonable accuracy (within 50% for polluted areas and within factor 2 for regional and background stations). Compared to other participating models, MSC-E models mostly occupy middle positions, not predicting extreme values of wet deposition fluxes.

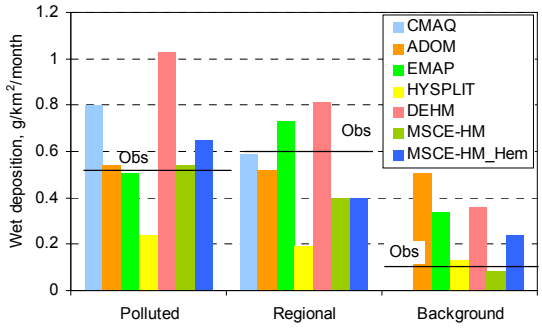


Fig. 42. *Comparison of modelled mercury wet deposition fluxes with observations at three groups of monitoring stations in Europe in February 1999*

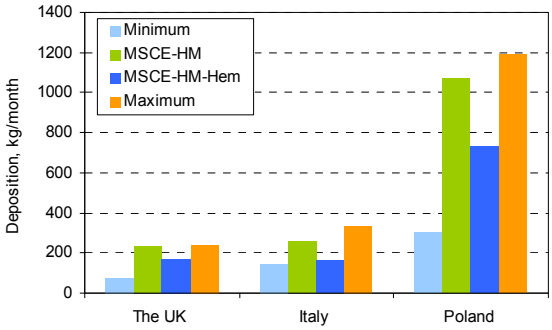


Fig. 43. *Total mercury depositions to three selected countries in February 1999*

One of the EMEP tasks is providing countries with information on transboundary pollution. In this connection special attention was paid to the comparison of budget components of long-range transport, computed by the models for three countries: the United Kingdom, Italy and Poland. Total mercury depositions to these countries in February, 1999 are shown in Fig. 43. “Maximum” and “Minimum” in this figure illustrate the highest and the lowest values of the depositions among results of all participating models. As seen, results of both regional and hemispheric MSC-E models lie between maximum and minimum values.

Basic conclusions of Stage III of the itercomparison study:

- Calculations of elemental mercury concentrations in air show that the concentration levels over Europe are mainly determined by the "hemispheric background". For most of the monitoring stations the models can predict the observations of elemental mercury with accuracy within a factor of 1.2.

- Comparison of calculated and measured data on deposition with precipitation on the annual basis shows that for the "polluted" and "regional" stations (Germany, The Netherlands, Southern Scandinavia) the modelled values are in agreement with the observations within a factor of 1.5. However, for the "background" stations the factor exceeds 2. Model-to-model variations for annual values are small: from 13% to 40%.

- The participating models can predict monthly values of items of mercury atmospheric budgets for individual countries with accuracy on the level of a factor of 2.5. As to yearly atmospheric budgets, such accuracy can be expressed by a factor of 2 or better.

- Most of the models predict that all the countries are net sources of mercury for the global atmosphere. The fraction of mercury mass transported outside the country is about 90% for the United Kingdom and Italy and 70% for Poland regarding to national anthropogenic emission.

- The comparison reveals that for the main calculated parameters both versions of MSC-E models predict quite similar results. The agreement between them is as a rule better than a factor of 1.5. Both models do not occupy any extreme position among the other participating models. It is possible to conclude that both EMEP models are acceptable to comply with demands of Heavy Metal Protocol to the Convention. At the same time The Parties of the Convention should keep in mind that accuracy of modern mercury modelling cannot exceed a factor of two.

5.6. Helsinki Commission

In 2004 within the framework of co-operation between EMEP Centres and Helsinki Commission MSC-E had contributed to the preparation of joint annual report for HELCOM devoted to the evaluation of airborne pollution load to the Baltic Sea in 2002 [*Bartnicki et al*., 2004]. The Centre has prepared the information on atmospheric transport and depositions of lead, cadmium, and mercury to the Baltic Sea as well as contributions to depositions of particular HELCOM countries on the basis of officially submitted emission data.

In addition to this MSC-E has provided updated environmental indicator reports with regard to temporal variations of heavy metals emissions to the atmosphere and their depositions to the Baltic Sea in period 1990-2002. These reports can be found in the Internet at the web site of Helsinki Commission (www.helcom.fi).

According to official data annual emissions of heavy metals from HELCOM countries have decreased during the period 1990-2002 by 46% for cadmium, 62% for mercury, and 61% for lead (Fig. 44). For individual countries, the most significant drop of cadmium and mercury emissions can be noted for Latvia (75% and 86%). In case of lead emission, the most significant decrease can be seen for Sweden (97%).

The reduction in heavy metal emissions to the atmosphere is a consequence of increased use of lead-free fuels, use of cleaner production technologies as well as of economic contraction and industrial restructuring in Poland, Estonia, Latvia, Lithuania, and Russia in early 1990s.

Total annual atmospheric depositions of heavy metals to the surface of the Baltic Sea have substantially decreased in period 1990-2002 (Fig. 45). The most significant drop in depositions over the Baltic Sea is obtained for lead (67%). The decrease of cadmium and mercury depositions is amounted to 38% and 40%, respectively. On the level of individual sub-basins the most significant drop in cadmium and lead depositions can be noted for the Kattegat, by 79% and 50%, respectively. Largest decrease in mercury depositions is obtained for the Belt Sea (63%).

Among the HELCOM countries the most significant contributions to depositions over the Baltic Sea belong to Poland, Germany, and Russia. In spatial distribution of heavy metals depositions on the Baltic Sea the highest levels can be noted for the southern-western part of the Baltic Sea (the Belt Sea and the Baltic Proper). Significant levels of lead and cadmium depositions can also be noted for the Gulf of Riga (Fig. 46).

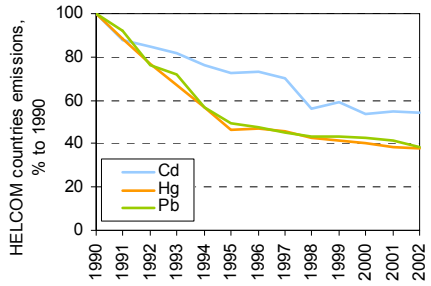


Fig. 44. *Trend of anthropogenic emissions of cadmium, mercury, and lead from HELCOM countries in 1990-2002 according to official emissions data*

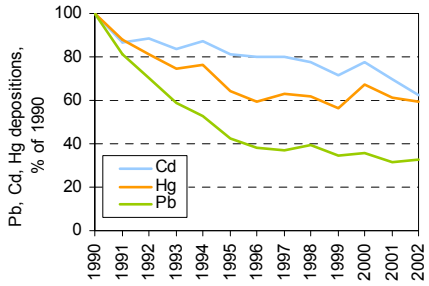


Fig. 45. *Temporal variations of cadmium, mercury, and lead depositions to the Baltic Sea in 1990-2002*

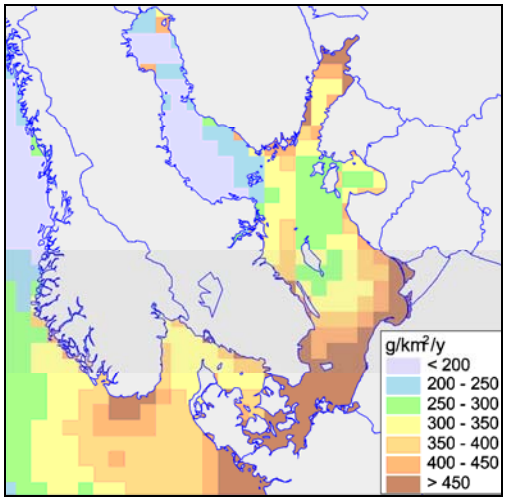


Fig. 46. *Total annual lead depositions to the Baltic Sea in 2002*

5.7. European Commission

MSC-E in 2005 participated in the EU ESPREME project (SSPI-CT-2003-502527) launched in 2004. The project aims to develop methods and tools to support European environmental policy making in the specific case of reducing the harmful impacts of heavy metals in a harmonised way across Europe. The role of MSC-E in the project is to assess by means of its chemical transport models the atmospheric dispersion of selected heavy metals (Hg, Pb, Cd, As, Ni and Cr) and their deposition to water and soil.

The main activities carried out by MSC-E during the last year were connected with review and improvement of available Heavy Metal Chemical Transport Models (regional and hemispheric) as well as preparation of input information required for the modelling. The following parts of the models were improved or revised:

- Dry and wet deposition schemes
- Chemical scheme of mercury transformation in the atmosphere
- Model parameterization of Cr, Ni and As atmospheric dispersion

Dry and wet deposition modules were improved in order to refine deposition of heavy metals to different types of land cover (arable lands, pastures, forests etc.) as well as to describe more adequate sub-cloud and in-cloud precipitation scavenging of the pollutants from the atmosphere. Revision of the mercury chemical scheme was performed to bring the model parameterization to the state-of-the-art including new oxidation reactions and updated chemical reaction constants. Parameterization of heavy metals not included to the model previously (Cr, Ni and As) was developed. It comprises aerosol characteristics, physical properties and removal parameters. The input information prepared for the modelling include:

- Meteorological data
- Land cover data
- Boundary conditions

A new preprocessor for preparation of the input meteorological data required for the modelling was developed based on the PSU/NCAR Mesoscale Model (MM5). A full dataset of meteorological parameters for the year 2000 has been calculated using NCEP/NCAR reanalysis data. The land cover data was harmonized with other the project work-packages to ensure correct description of heavy metals fluxes between the atmosphere and other environmental compartments (such as soil, vegetation etc.) and adequate link between atmospheric dispersion and water/soil models. Boundary conditions for modelling atmospheric transport of mercury, which is characterized by global scale dispersion, were evaluated using the hemispheric scale model. It allows taking into account contribution of global sources to regional mercury pollution.

CONCLUSIONS

The EMEP Centres' activities in the field of monitoring and modelling of heavy metals in 2005 were aimed at investigation of the pollution of the European region in the period 1990-2003. Besides, a particular attention was paid to review and development of the regional MSC-E heavy metal model. The main conclusions of the studies are formulated below.

Monitoring of heavy metals

1. Measurements of heavy metal pollution levels in 2003 showed that the lowest concentrations of lead, cadmium and mercury were observed in Northern Scandinavia. In general, concentration levels increase towards the southeast of Europe.

2. At present the EMEP monitoring network contains 64 stations measuring lead and cadmium, of which 23 stations measure concentrations of these metals both in air and precipitation. There are 15 stations where at least one mercury form is measured. The monitoring stations, however, are non-uniformly distributed over European territory: they are mainly located in Central and Northern Europe.

3. Annual analytical intercomparison of national laboratories treating measurements of heavy metals indicate an essential improvement of data quality during the period of 1995-2003, but still there is need for improvement for some countries.

4. Measured concentrations of Pb and Cd in air and precipitation show a significant decrease at most of the sites with long data series, a reduction more than 60% for both the elements since 1989.

Emissions data

1. National data on lead, cadmium and mercury emissions were submitted by 33 countries at least for one year of the period 1990-2003. However, only 14 of them submitted data for the whole period, whereas 11 counties did not submit any national data. Completeness of data on annual total emissions for the whole period is about 60%.

2. Analysis of national data consistency has shown that anthropogenic emissions data officially submitted to the Convention cannot explain observed levels of lead and cadmium wet depositions in Europe. Based on observations of these metals in the EMEP monitoring network one can expect 2-3-fold underestimation of emission data in Europe.

3. In order to fit observed lead and cadmium pollution levels in Europe the adjusted emission scenario were developed for the period 1990-2003 based on available measurements of these metals in air and precipitation within the EMEP monitoring network.

Model review and evaluation

1. Following the TFMM work-plan MSC-E has started preparation for the EMEP/TFMM Workshop on the review of the MSC-E models. As a first step towards model review MSC-E presented a detailed description of the regional HM transport model, model sensitivity study, uncertainty analyses and results of the five-year programme of model intercomparison study for mercury. It also gave information on available input data for models: emissions, land cover, and chemical reactants.

2. The model sensitivity study demonstrated that the modelling results for such heavy metals as lead and cadmium are the most sensitive to anthropogenic emissions, natural emission and re-emission and to removal parameters. Sensitivity of the mercury model outputs is highest to boundary concentration of gaseous elemental mercury and, to lower extent, to anthropogenic emissions, removal characteristics and oxidation parameters by ozone

3. The intrinsic model uncertainty of lead and cadmium concentration in air, concentration in precipitation and total deposition are estimated as 43%, 40% and 33% respectively; the appropriate uncertainties for mercury are 19%, 53% and 39%.

4. The MSC-E regional transport model used for the assessment of the pollution levels in Europe was evaluated against the available measurement data for the period 1990-2003. Modelling results based on the adjusted emission scenario were used in the model evaluation. The evaluation demonstrates satisfactory agreement with measurement data for all tree metals. A significant correlation of calculations with measurements was obtained for all metals and more 70% of modelling results differ from observations less than by 50% of the observed values.

5. The activities under the multi-stage project on the intercomparison of mercury transport models are complete. The third stage of the project was dedicated to the comparison of long-term modelling results with annual and monthly mean measurements of mercury concentration in the ambient air and atmospheric deposition fluxes. The comparison reveals that for the main calculated parameters both regional and hemispheric MSC-E models predict quite similar results. Both models do not occupy any extreme position among the other participating models.

Model assessment of pollution levels

1. According to the modelling results based on the adjusted emission scenario decrease of heavy metal depositions over the European territory on the whole in the period from 1990 to 2003 constituted 2.3 times for lead and cadmium and 1.6 times for mercury. Less essential decrease of depositions in comparison with the anthropogenic emission reduction is conditioned by the contribution of natural sources, re-emission as well as by global sources of heavy metals.

2. The spatial distribution of environmental pollution levels of heavy metals in 2003 was highly non-uniform. The deposition flux in different parts of Europe can differ by more than an order of magnitude. High deposition levels are characteristic of Central and Southern Europe, the lowest levels – of Northern Europe.

3. The transboundary transport plays an important role in pollution of most of European countries. Contribution of the external European anthropogenic sources to depositions ranges from 9 to 89% for lead, 7 – 83% for Cd and 2 – 55% for Hg. The contribution of the transboundary transport to depositions of heavy metals to the European Union varies from 3 to 10%.

4. Atmospheric depositions contribute significantly to heavy metal pollution of marginal seas. The highest mean deposition flux of lead and cadmium is obtained over the Black Sea, and of mercury – over the North and the Baltic Seas.

Co-operation

1. In the framework of cooperation with the Working Group on Effects MSC-E performed calculations of relevant parameters of atmospheric inputs of heavy metals to ecosystems based both on official emission data and the adjusted emission scenario. Ecosystem-specific depositions of heavy metals in Europe were assessed and analysed.

2. The EMEP Centres were also involved in cooperation with other subsidiary bodies to the Convention as well as international organizations and national programmes (HELCOM, EC).

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Annex A

EMEP WORK-PLAN FOR 2005

2005 Work-plan for the Implementation of the Convention [ECE/EB.AIR/83/Add.2]

Description/objectives

Provide monitoring and modelling data on concentrations, depositions and transboundary fluxes of cadmium (Cd), lead (Pb) and mercury (Hg). Develop further the Pb, Cd and Hg transport models in parallel with the development of heavy metal critical limits under the Working Group on Effects. Develop reliable emission data for Cd, Pb and Hg, as well as a preliminary data set for other metals. Support preparatory work for the review of the Protocol on Heavy Metals, in particular the work of the Expert Group on Heavy Metals.

Main activities and time schedule

(a) MSC-E will prepare information for 2003 for Pb, Cd and Hg on: deposition and air concentration fields in Europe with a resolution of 50 km x 50 km; country-to-country deposition matrices; and deposition to the regional seas. It will compare model results for concentrations in air and precipitation and deposition fluxes with measurements, and study model sensitivity and uncertainty. It will carry out trend analysis of Pb, Cd and Hg pollution (1990-2003) including longterm changes in total deposition to countries and air concentration and deposition fluxes at selected monitoring stations. It will present calculations for Hg dispersion at the hemispheric scale for evaluation of European pollution from global sources and boundary conditions for the regional EMEP modelling;

(b) For the model review, MSC-E will evaluate uncertainties in modelling, measurement and emission data, in cooperation with CCC and the Task Force on Emission Inventories and Projections;

(c) MSC-E will prepare a detailed description of its model and study the model sensitivity and evaluate uncertainties in modelling, measurement and emission data in collaboration with CCC and the Task Force on Emission Inventories and Projections. In close collaboration with CCC and experts from Parties, MCS-E will prepare an extensive evaluation of model performance against long-term measurements, for the model review;

(d) MSC-E will further develop its models and its input databases. It will work on meteorological data and, together with CCC, on the preparation of gridded anthropogenic emission data for regional modelling, based on official emissions and expert estimates, compilation of available data of natural emissions, and measurement data.

MSC-E activity in the field of heavy metals

Activity	Results
Modelling the transport of heavy metals	▪ Fields of deposition and air concentrations of Cd, Pb and Hg have been calculated with spatial resolution 50x50 km for 2003 ▪ Transboundary fluxes of Cd, Pb and Hg between European countries and fluxes to regional seas have been specified. ▪ Pollution trends of Cd, Pb and Hg air concentrations and depositions in European countries have been analyzed for the period 1990-2003. ▪ Deposition fluxes of Cd, Pb and Hg to different surface types have been computed for the assessment of critical load exceedance in different ecosystems. ▪ Hg airborne transport within the Northern Hemisphere has been calculated for evaluation of boundary conditions for the regional modelling.
Model review and evaluation	▪ Detailed description of the MSC-E regional model has been prepared for the model review. The model sensitivity study has been performed and uncertainty of the modelling results has been evaluated. ▪ An extensive evaluation of model performance against long-term measurements has been performed and presented. ▪ The intercomparison of Hg transport models has been completed. Final results of the third stage have been presented.
Development of model approaches	▪ Dry deposition scheme of the model has been significantly improved applying size-segregated approach for particles based on theoretical formulation and empirical data
Preparation of data for modelling	▪ Long-term dataset of meteorological data (1990-2003) has been prepared for the trend analysis. ▪ Data on Cd, Pb and Hg anthropogenic emission have been prepared on the basis of the submitted official data and expert estimates. ▪ The adjusted emission scenario has been developed for the period 1990-2003 based on available measurements of these metals in air and precipitation within the EMEP monitoring network.

Annex B

COUNTRY-TO-COUNTRY DEPOSITION MATRICES FOR 2003

(Based on the adjusted emission scenario)

Table B.1. *Codes of countries, regions and seas*

Country/Region/Sea	Code	Country/Region/Sea	Code
Albania	AL	Malta	MT
Armenia	AM	Monaco	MC
Austria	AT	Netherlands	NL
Azerbaijan	AZ	Norway	NO
Belarus	BY	Poland	PL
Belgium	BE	Portugal	PT
Bosnia and Herzegovina	BA	Republic of Moldova	MD
Bulgaria	BG	Romania	RO
Croatia	HR	Russian Federation (European part)	RU
Cyprus	CY	Serbia and Montenegro	CS
Czech Republic	CZ	Slovakia	SK
Denmark	DK	Slovenia	SI
Estonia	EE	Spain	ES
Finland	FI	Sweden	SE
France	FR	Switzerland	CH
Georgia	GE	The Former Yugoslav Republic of Macedonia	MK
Germany	DE	Turkey	TR
Greece	GR	Ukraine	UA
Hungary	HU	United Kingdom	GB
Iceland	IS		
Ireland	IE		
Italy	IT	Baltic Sea	BAS
Kazakhstan	KZ	Black Sea	BLS
Latvia	LV	Caspian Sea	CAS
Lithuania	LT	North Sea	NOS
Luxembourg	LU	Mediterranean Sea	MDT

***Table B.2**. Matrix of lead country-to-country depositions from anthropogenic sources in 2003, kg/y*

Receptors ↓ Emitters →

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CS	CY	CZ	DE	DK	EE	ES	
AL	5923	1.9	43	1.3	476	34	1659	7.7	189	4289	2.2	201	257	1.6	0.9	883	**AL**
AM	0.78	1484	0.8	141	3.3	1.5	14	2.4	3.2	8.0	16	13	18	0.5	0.4	7.4	**AM**
AT	15.2	1.0	11849	0.9	305	1175	140	23	7994	560	0.9	10232	16355	36	7.3	830	**AT**
AZ	2.7	471	4	2789	15	9.3	66	17	20	36	40	53	89	2.5	3.5	32	**AZ**
BA	224	2.6	388	1.7	29137	192	655	21	643	5569	2.1	2213	1913	14	3.6	935	**BA**
BE	1.2	0.04	21	0.05	6.0	71734	3.0	1.3	485	9.5	0.05	100	6182	22	1.4	1983	**BE**
BG	316	22.4	194	16	1307	173	133848	110	552	13142	36	1656	1671	17	12	685	**BG**
BY	77	7.3	439	7.2	709	799	2163	30785	1647	2049	2.0	7016	8457	220	506	1026	**BY**
CH	2.51	0.13	105	0.1	26	586	16	0.8	45483	30	0.1	134	3061	6.1	0.6	1338	**CH**
CS	1136	6	495	4.2	9312	268	8743	44	989	98943	3.5	3476	2956	21	7.0	1128	**CS**
CY	2.58	4.25	0.9	1.2	5.2	1.1	30	0.5	4.8	14	4090	4.5	7.8	0.1	0.1	29	**CY**
CZ	12.4	0.9	1971	0.9	291	1404	183	44	3541	687	0.6	111071	33939	88	13	650	**CZ**
DE	9.5	1.2	2508	1.2	110	57565	55	66	40014	196	1.7	18376	610415	1011	47	8941	**DE**
DK	0.6	0.1	50	0.1	15	2017	7.8	15	515	23	0.2	725	10507	4046	10	1087	**DK**
EE	3.6	0.8	58	0.9	41	323	102	329	294	107	0.4	905	2597	140	5209	238	**EE**
ES	17.5	0.2	51	0.2	97	339	75	2.8	737	122	0.2	226	895	5	1.0	284794	**ES**
FI	11.9	3.9	146	4.7	114	1252	338	518	890	303	3.3	1994	7275	438	2478	812	**FI**
FR	78.3	0.5	338	0.5	555	13375	306	10	16891	635	0.6	1320	22240	87	8.0	105536	**FR**
GB	4.1	0.4	50	0.5	28	6141	20	15	909	42	0.2	360	5911	80	4.5	9426	**GB**
GE	8.7	385	6.75	282	32	12	198	15	27	88	65	92	124	2.4	2.8	66	**GE**
GR	838	20	133	14	928	121	19287	66	461	4841	180	756	987	11	6.7	1680	**GR**
HR	195	2.3	799	1.6	5526	211	491	25	970	3921	2.0	3232	2293	13	4.5	1196	**HR**
HU	94	3.2	1557	2.3	2627	406	1705	65	1578	8051	2.2	9108	5239	27	11	838	**HU**
IE	0.91	0.05	11.3	0.1	5.8	603	4.4	2.6	221	8.6	0.04	56	699	8.1	0.6	2387	**IE**
IS	0.62	0.18	14.0	0.2	6.7	412	3.2	1.3	192	11	0.1	79	721	14	0.6	544	**IS**
IT	1107	10	1336	6.7	4898	676	2381	44	11566	5143	19	3529	5009	28	7.5	12745	**IT**
KZ	33	191	62	395	208	127	1081	242	294	613	73	583	960	20	59	339	**KZ**
LT	12	1.0	157	0.9	129	586	263	1984	696	322	0.4	2852	5498	239	184	503	**LT**
LU	0.1	0.01	4.1	0.01	0.6	708	0.3	0.1	97	0.7	0.01	16	1549	1.6	0.1	181	**LU**
LV	7.2	1.3	127	1.3	87	532	208	953	600	228	0.5	2061	4777	232	691	418	**LV**
MC	0.01	0.00	0.04	0.00	0.1	0.02	0.04	0.0	0.4	0.1	0.0	0.1	0.2	0.00	0.00	0.8	**MC**
MD	22	6.0	28	4.5	112	46	1177	147	87	419	1.4	393	459	9.0	14	89	**MD**
MK	705	2.1	51	1.5	455	37	6188	10	142	7062	4.3	326	335	2.6	1.1	302	**MK**
MT	1.2	0.01	0.2	0.005	2.0	0.2	3.9	0.0	1.4	4.8	0.02	1.0	1.4	0.01	0.004	8.7	**MT**
NL	0.8	0.1	24	0.1	5.2	25822	2.8	2.4	404	8.1	0.1	163	15878	47	2.1	1975	**NL**
NO	2.7	0.8	101	0.7	70	2772	43	52	896	99	1.1	1039	9825	919	36	2309	**NO**
PL	67	6	1665	5.4	952	4790	1192	1982	5484	2343	2.3	81398	98687	1318	223	2536	**PL**
PT	0.5	0.02	3.7	0.03	4.4	33	2.1	0.3	70	4.2	0.02	16	77	0.3	0.1	22580	**PT**
RO	396	27	705	20	4310	545	21784	359	1907	21269	10	5839	5714	56	41	1512	**RO**
RU	396	872	1723	1267	3467	4929	12664	16596	7890	8832	377	20040	37521	1330	20980	7110	**RU**
SE	10	2.0	238	1.7	129	3634	212	302	1547	282	2.7	3695	22146	3399	263	2068	**SE**
SI	17	0.5	766	0.4	354	76	96	8.6	525	438	0.5	1140	926	4.4	1.9	364	**SI**
SK	39	1.7	780	1.4	910	321	718	58	1067	2330	0.9	15837	4390	32	11	427	**SK**
TR	274	1217	152	336	708	256	9741	337	578	2536	3976	1486	2116	39	35	1870	**TR**
UA	281	106	876	98	2563	1114	11786	5123	2787	7687	58	11280	11990	226	336	2021	**UA**
BAS	14	3	477	3.2	222	5825	384	843	2728	526	2.7	7938	49006	4725	4201	3016	**BAS**
BLS	285	331	273	212	1239	370	15229	796	935	4543	349	2576	3457	60	108	1061	**BLS**
CAS	17	470	23	1885	84	74	467	130	116	250	175	279	530	15	40	192	**CAS**
MDT	6633	176	2152	85	14868	1923	32461	289	12794	23607	13367	8810	12841	112	43	115750	**MDT**
NOS	7	2	290	2.0	102	26927	55	89	3639	173	1.9	2973	51977	2391	49	19294	**NOS**
	AL	**AM**	**AT**	**AZ**	**BA**	**BE**	**BG**	**BY**	**CH**	**CS**	**CY**	**CZ**	**DE**	**DK**	**EE**	**ES**	

***Table B.2**. Matrix of lead country-to-country depositions from anthropogenic sources in 2003, kg/y (continued)*

Receptors ↓ Emitters →

	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KZ	LT	LU	LV	MC	
AL	0.9	475	76	1.9	4125	614	176	1.3	0.003	6998	0.9	2.9	0.3	1.2	0.1	**AL**
AM	0.4	5.8	5.3	100	24	5.4	3.5	0.1	0.00	28	5.3	0.7	0.01	0.4	0.001	**AM**
AT	10	4128	1310	0.9	121	1356	1482	14	0.04	8269	1.1	20	15	9.5	0.2	**AT**
AZ	3.0	33	29	270	76	25	13	0.5	0.002	130	58	4.6	0.1	2.8	0.004	**AZ**
BA	4.9	1105	287	2.4	448	18201	2872	4.3	0.01	10118	1.7	10	1.8	4.6	0.3	**BA**
BE	2.7	37245	10746	0.03	5.0	16	6.5	82	0.08	285	0.1	1.7	147	1.2	0.02	**BE**
BG	11	752	385	27	8419	1785	1390	5.9	0.01	4201	21	29	1.5	14	0.1	**BG**
BY	297	2362	1815	8.7	597	1657	1755	28	0.11	3934	29	3910	5.5	1295	0.1	**BY**
CH	0.9	9138	1592	0.1	16	138	35	18	0.03	9952	0.1	0.8	8.9	0.5	0.3	**CH**
CS	8.7	1422	441	6.5	2331	11543	6207	6.3	0.02	11046	4.2	22	2.6	10	0.3	**CS**
CY	0.1	11	3.1	1.7	184	8.2	2.8	0.1	0.00	87	0.2	0.1	0.01	0.1	0.002	**CY**
CZ	21	3619	1722	0.8	72	1051	2126	20	0.04	2099	1.6	39	14	18	0.1	**CZ**
DE	78	75093	37712	1.2	73	331	419	389	0.58	5960	2.4	84	513	49	0.3	**DE**
DK	17	3307	8107	0.1	4.5	37	41	103	0.20	212	0.3	22	7.8	10	0.01	**DK**
EE	922	716	1475	0.9	30	99	125	21	0.06	353	2.3	566	1.8	1388	0.01	**EE**
ES	1.4	6791	1189	0.2	96	343	85	46	0.09	4080	0.3	1.8	3.5	1.0	0.3	**ES**
FI	25773	2543	4844	3.6	110	278	313	77	0.47	1205	10	595	6.8	544	0.05	**FI**
FR	15	365115	33703	0.5	406	1872	421	556	0.46	30757	0.7	11	319	6.9	10	**FR**
GB	8.1	19701	302940	0.4	20	86	43	3479	1.45	1217	1.0	14	23	5.3	0.1	**GB**
GE	2.3	51	36	1180	267	47	29	0.7	0.003	270	11	4.2	0.1	2.3	0.01	**GE**
GR	6.0	908	286	23	133198	1270	559	4.5	0.01	7738	13	17	1.1	8	0.2	**GR**
HR	5.5	1509	300	2.0	433	57219	5187	4.4	0.01	15255	1.6	13	2.0	5.9	0.5	**HR**
HU	12	1797	565	3.0	403	13254	63437	7.5	0.02	9189	2.6	31	4.0	14	0.3	**HU**
IE	0.8	2616	8312	0.05	4.4	20	9.0	4599	0.36	308	0.2	2.2	3.1	0.8	0.02	**IE**
IS	1.2	1070	2328	0.2	2.2	22	13	94	62	289	0.2	1.4	2.0	0.6	0.02	**IS**
IT	10	14637	1263	10	5594	16764	2708	19	0.04	458418	5.0	21	7.9	9.2	7.8	**IT**
KZ	48	456	326	150	739	356	227	4.8	0.02	1321	5935	50	0.9	35	0.04	**KZ**
LT	147	1372	1562	1.0	85	343	406	24	0.07	922	2.9	11525	3.4	1059	0.03	**LT**
LU	0.2	4355	351	0.0	0.6	2.0	1.0	3.4	0.004	40	0.01	0.2	214	0.1	0.00	**LU**
LV	329	1206	1737	1.4	53	234	300	27	0.1	707	3.5	4083	3.0	7625	0.03	**LV**
MC	0.00	3.4	0.1	0.0	0.04	0.3	0.1	0.001	0.00	11.5	0.0	0.0	0.0	0.0	0.05	**MC**
MD	10	143	114	5.8	259	182	182	2.1	0.005	470	11	30	0.3	14	0.02	**MD**
MK	1.2	230	73	2.1	5258	549	288	1.1	0.003	1975	1.3	3.8	0.3	1.6	0.04	**MK**
MT	0.006	7.1	0.8	0.01	8.3	3.4	0.9	0.0	0.00	54	0.002	0.009	0.002	0.004	0.001	**MT**
NL	4.7	20819	16546	0.1	4.4	14	7.7	125	0.1	225	0.1	3.0	24	1.9	0.02	**NL**
NO	101	5159	22458	0.7	16	150	108	467	2.6	717	1.1	72	11	34	0.04	**NO**
PL	270	9604	8175	5.7	423	2943	4508	119	0.3	6072	13	1150	32	321	0.2	**PL**
PT	0	290	53	0.01	1.4	18	4.2	2.9	0.01	203	0.02	0.1	0.3	0.1	0.01	**PT**
RO	37	2467	1077	28	3639	6951	6684	17	0.03	11429	32	101	5.1	46	0.4	**RO**
RU	11818	13633	18031	1111	5781	6764	5509	294	1.9	20444	5998	5348	30	5453	0.7	**RU**
SE	1530	6615	15724	1.8	73	326	335	228	1.0	1454	3.8	501	17	253	0.1	**SE**
SI	2.4	612	104	0.4	68	5166	855	1.5	0.004	7612	0.6	5.5	0.8	2.5	0.2	**SI**
SK	14	1113	471	1.5	180	3079	8619	6.5	0.02	3689	2.0	34	2.9	15	0.1	**SK**
TR	30	1191	736	553	16482	1108	712	13	0.03	6468	119	78	1.9	38	0.2	**TR**
UA	228	3724	2516	131	3756	5319	6269	40	0.1	10509	298	837	8.4	351	0.3	**UA**
BAS	5741	9924	16767	3.1	111	636	799	228	0.6	2461	7.4	1792	29	1606	0.1	**BAS**
BLS	76	1424	1004	604	8201	1838	1212	19	0.1	6457	200	160	3.0	90	0.2	**BLS**
CAS	33	231	195	341	412	135	74	3.2	0.02	651	1178	31	0.4	22	0.0	**CAS**
MDT	47	58395	5644	151	165671	39562	6677	108	0.2	376908	56	96	21	47	12.6	**MDT**
NOS	98	70736	212781	2.1	39	289	254	2470	5.6	2958	3.4	117	82	53	0.2	**NOS**
	FI	**FR**	**GB**	**GE**	**GR**	**HR**	**HU**	**IE**	**IS**	**IT**	**KZ**	**LT**	**LU**	**LV**	**MC**	

***Table B.2**. Matrix of lead country-to-country depositions from anthropogenic sources in 2003, kg/y (continued)*

Receptors ↓ Emitters →

	MD	MK	NL	NO	PL	PT	RO	RU	SE	SI	SK	TR	UA	Total, t/y	
AL	6.9	4846	17	1.4	303	309	782	405	2.4	50	180	432	1164	34.9	**AL**
AM	1.5	4.2	1.5	0.5	41	5.4	35	1075	0.9	0.7	6.9	1998	745	5.8	**AM**
AT	2.1	76	506	21	4868	471	577	391	36	1132	3651	120	1298	79.4	**AT**
AZ	5.9	16	8.4	3.1	179	23	134	13744	5.1	3.4	25	2725	4618	25.8	**AZ**
BA	8	329	102	9.4	2627	347	2507	595	17	489	1904	289	2788	87.0	**BA**
BE	0.1	3.2	3598	12	126	1965	17	24	13	4.1	14	3.4	49	134.9	**BE**
BG	274	5331	116	15	2960	306	24740	8278	31	165	1461	8341	31558	254.4	**BG**
BY	250	482	595	220	38150	828	7619	37704	582	254	3323	1325	112892	277.8	**BY**
CH	0.3	8.4	163	4.4	117	672	60	37	4.0	61	44	20	106	73.0	**CH**
CS	36	6420	155	15	4571	440	12345	1616	30	469	3504	915	7163	198.3	**CS**
CY	0.5	14	0.7	0.1	10	12	23	122	0.2	1.0	3.3	2411	158	7.3	**CY**
CZ	2.7	67	837	38	23535	472	741	597	90	222	4671	68	1700	197.7	**CZ**
DE	3.4	31	30677	304	16671	8157	621	977	513	103	935	106	2179	921.3	**DE**
DK	0.6	2.8	2554	187	1796	2033	57	169	356	8.0	84	12	289	38.4	**DK**
EE	7.6	20	329	179	3837	358	378	5598	613	19	247	75	2989	30.7	**EE**
ES	0.5	54	113	6	276	100137	128	80	4.1	78	103	19	194	401.2	**ES**
FI	22	69	1096	1410	7396	1142	1099	21611	6664	55	551	330	7518	101.8	**FI**
FR	2.7	243	3033	62	1429	47638	739	268	61	412	513	108	883	650.0	**FR**
GB	0.7	13	4324	88	777	20399	157	220	45	21	87	17	648	377.3	**GB**
GE	11	57	9.0	2.7	261	35	330	10585	4.5	5.8	49	7254	5474	27.4	**GE**
GR	100	13314	74	8.9	1338	552	5311	5490	16	129	626	21953	15580	238.9	**GR**
HR	5.4	300	110	7.9	3374	437	1842	560	15	2653	2738	217	2646	113.7	**HR**
HU	11	608	233	16	10376	427	11464	1033	33	1310	29846	265	11008	186.7	**HU**
IE	0.1	3.2	336	7.4	114	6631	27	34	4.5	5.9	17	2.9	110	27.2	**IE**
IS	0.1	2.2	279	40	128	1035	29	40	9.0	6.7	22	5.4	87	7.6	**IS**
IT	22	2046	290	19	4343	4120	3838	1911	32	3418	2675	2196	6319	579.2	**IT**
KZ	59	236	92	33	1666	241	2007	124464	52	48	302	6375	47577	198.1	**KZ**
LT	21	59	521	177	17429	568	998	9339	555	64	828	142	7456	69.0	**LT**
LU	0.01	0.2	74	0.8	17	138	2.4	3.2	1.2	0.6	2.3	0.5	6.9	7.8	**LU**
LV	16	41	501	222	9949	542	768	7248	727	49	594	127	6260	54.3	**LV**
MC	0.0	0.0	0.01	0.001	0.1	0.2	0.1	0.1	0.001	0.1	0.1	0.02	0.2	0.02	**MC**
MD	2539	175	32	7.2	1806	55	6896	3555	17	21	296	1485	41590	62.9	**MD**
MK	10	40087	22	2.2	466	113	1235	499	3.8	44	279	590	1602	69.0	**MK**
MT	0.017	2.8	0.1	0.0	1.5	2.0	2.3	1.9	0.02	0.4	0.8	2.7	3.9	0.1	**MT**
NL	0.1	2.4	44445	29	222	2496	21	42	24	3.5	18	6.0	83	129.5	**NL**
NO	2.8	14	2928	14465	2917	4835	217	956	798	30	208	61	1011	75.9	**NO**
PL	51	340	3371	466	518312	2336	5903	9335	1339	557	11915	588	36179	827.0	**PL**
PT	0.0	1.4	11	0.5	21	196551	5.2	6.4	0.3	3.8	5.8	0.9	12	220.0	**PT**
RO	1202	3161	331	44	12964	753	236732	10704	91	643	7443	6695	80454	458.2	**RO**
RU	953	2665	4353	2824	71413	6421	32098	3971470	6168	1038	9457	45883	687492	5088.4	**RU**
SE	12	56	3689	5795	13318	3864	766	3343	24247	65	654	210	4248	125.3	**SE**
SI	1.4	51	37	2.9	1206	148	443	170	5.6	6091	800	50	728	28.9	**SI**
SK	6.2	236	197	18	19056	288	3761	729	41	482	37175	156	6275	112.6	**SK**
TR	373	1811	202	38	4277	866	11032	62118	71	137	1173	496697	107000	739.0	**TR**
UA	2665	2105	795	208	55661	1335	43366	150221	467	673	10728	18893	1556650	1936.1	**UA**
BAS	27	84	5430	1610	37371	4999	1539	17718	11222	130	1518	307	9742	211.7	**BAS**
BLS	1040	2318	252	61	7698	565	23446	129361	119	235	1862	79275	300091	599.4	**BLS**
CAS	34	116	52	22	981	142	810	92718	38	18	118	8101	33729	144.9	**CAS**
MDT	339	18734	949	90	12195	23807	23023	26977	136	4600	6499	166589	63975	1247.2	**MDT**
NOS	3.9	26	39369	3594	6524	33500	557	1190	1007	74	496	118	2495	486.8	**NOS**
	MD	**MK**	**NL**	**NO**	**PL**	**PT**	**RO**	**RU**	**SE**	**SI**	**SK**	**TR**	**UA**	**Total, t/y**	

***Table B.3**. Matrix of cadmium country-to-country depositions from anthropogenic sources in 2003, kg/y*

Receptors ↓ Emitters →

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CS	CY	CZ	DE	DK	EE	ES	
AL	128	0.0	2.5	0.2	10.8	0.9	101	0.3	3.7	97.3	0.04	5.9	7.3	0.1	0.03	15.7	**AL**
AM	0.02	23.3	0.0	17.9	0.1	0.04	0.9	0.1	0.1	0.2	0.3	0.3	0.7	0.03	0.02	0.1	**AM**
AT	0.39	0.02	558	0.2	5.9	28.9	7.0	0.8	159	16.8	0.02	227	273	2.4	0.2	12.7	**AT**
AZ	0.06	8.0	0.2	517	0.3	0.2	4.3	0.8	0.4	1.1	0.7	1.4	3.4	0.2	0.1	0.5	**AZ**
BA	6.72	0.04	21.6	0.3	607	4.5	36.2	0.7	12.5	150	0.04	56.8	60.1	0.9	0.1	14.7	**BA**
BE	0.03	0.0	1.0	0.01	0.1	1752	0.1	0.05	9.9	0.2	0.001	3.7	152	1.5	0.04	30.0	**BE**
BG	7.70	0.3	11.0	3.0	28.1	4.3	8205	4.7	10.8	543	0.6	43.9	51.7	1.1	0.4	11.1	**BG**
BY	1.80	0.1	22.2	1.4	13.1	17.8	116	1008	29.4	56.1	0.03	177.9	306	14.7	19.7	14.5	**BY**
CH	0.07	0.00	6.8	0.01	0.5	15.6	0.9	0.03	882	0.8	0.002	3.8	28.7	0.4	0.02	21.1	**CH**
CS	28.18	0.1	27.4	0.7	196	6.1	352	1.6	18.4	2806	0.1	86.7	88.0	1.3	0.2	17.6	**CS**
CY	0.06	0.1	0.0	0.2	0.1	0.0	2.1	0.02	0.1	0.3	78	0.1	0.2	0.01	0.002	0.5	**CY**
CZ	0.32	0.02	101	0.2	5.8	34.2	9.2	1.7	64.0	21.0	0.01	3278	1365	6.3	0.5	9.3	**CZ**
DE	0.23	0.02	117	0.2	2.1	1394	2.9	2.3	758	5.5	0.03	986	18889	75.9	1.6	130	**DE**
DK	0.02	0.002	2.6	0.02	0.3	48.2	0.4	0.6	9.6	0.7	0.003	32.5	357	269	0.4	16.6	**DK**
EE	0.09	0.01	3.0	0.2	0.8	7.5	5.6	11.1	5.4	2.9	0.01	26.6	93.9	9.3	191	3.4	**EE**
ES	0.45	0.003	2.6	0.04	1.7	8.7	4.0	0.1	14.7	2.7	0.003	5.7	17.8	0.3	0.03	5148	**ES**
FI	0.27	0.1	7.5	1.0	2.0	28.9	17.9	18.8	17.4	8.0	0.1	61.6	253	28.7	87.2	12.0	**FI**
FR	1.85	0.01	17.6	0.1	9.3	407	15.6	0.3	343	13.5	0.01	40.8	477	5.9	0.2	1627	**FR**
GB	0.09	0.01	2.4	0.1	0.5	168	1.0	0.5	18.1	0.9	0.004	12.4	159	5.5	0.1	157	**GB**
GE	0.20	7.0	0.3	61.1	0.6	0.3	12.4	0.7	0.5	2.5	1.1	2.4	4.6	0.2	0.1	1.1	**GE**
GR	18.88	0.3	7.3	2.5	19.6	3.0	1575	2.9	8.8	118	3.0	20.6	28.2	0.7	0.2	28.7	**GR**
HR	5.56	0.04	46.6	0.3	76.0	4.9	24.1	0.9	18.5	97.9	0.04	80.2	66.2	0.8	0.2	18.4	**HR**
HU	2.25	0.1	101	0.4	47.8	9.6	82.2	2.6	29.6	211	0.04	237	163	1.8	0.4	12.6	**HU**
IE	0.02	0.001	0.5	0.01	0.1	15.9	0.2	0.1	4.5	0.2	0.001	1.7	15.6	0.5	0.0	41.9	**IE**
IS	0.01	0.003	0.6	0.02	0.1	9.4	0.1	0.04	3.5	0.3	0.001	2.2	16.6	0.9	0.0	8.6	**IS**
IT	30.87	0.2	81.4	1.2	89.1	16.9	134	1.6	226	120	0.3	89.5	119.3	1.8	0.3	223	**IT**
KZ	0.72	3.0	3.1	84.7	3.9	2.8	62.9	11.5	5.4	17.6	1.2	14.9	29.3	1.3	2.2	5.2	**KZ**
LT	0.28	0.0	8.3	0.2	2.4	13.8	14.0	50.0	12.7	8.9	0.01	82.7	211.2	16.1	6.8	7.1	**LT**
LU	0.00	0.0	0.2	0.0	0.01	25.5	0.02	0.01	1.9	0.0	0.0	0.6	44.3	0.1	0.004	2.6	**LU**
LV	0.17	0.0	6.5	0.3	1.6	12.5	11.4	28.1	11.0	6.2	0.01	59.5	181.2	15.7	27.2	6.0	**LV**
MC	0.00	0.0	0.0	0.0	0.001	0.0	0.0	0.0	0.01	0.002	0.0	0.003	0.0	0.0	0.0	0.014	**MC**
MD	0.51	0.1	1.4	0.8	2.2	1.0	63.9	6.3	1.6	12.4	0.02	9.6	15.7	0.5	0.5	1.4	**MD**
MK	15.86	0.0	2.9	0.3	9.8	0.9	292	0.4	2.8	128	0.1	9.1	10.2	0.2	0.04	5.0	**MK**
MT	0.03	0.0	0.01	0.0	0.04	0.00	0.2	0.001	0.03	0.1	0.0	0.03	0.03	0.001	0.0	0.2	**MT**
NL	0.02	0.0	1.1	0.01	0.1	575	0.1	0.1	7.4	0.2	0.002	6.8	419	3.4	0.1	29.4	**NL**
NO	0.07	0.0	5.1	0.1	1.4	66.6	2.3	1.7	17.4	2.9	0.02	38.1	315	60.3	1.2	36.4	**NO**
PL	1.64	0.1	92.2	1.0	18.5	115	63.4	77.4	103	69.2	0.04	2192	5198	92.8	7.9	37.1	**PL**
PT	0.01	0.0	0.2	0.0	0.1	0.9	0.1	0.01	1.4	0.1	0.0	0.4	1.5	0.0	0.003	424	**PT**
RO	9.89	0.4	40.2	3.7	91.0	13.5	1079	14.9	37.8	738	0.2	163	182	3.8	1.4	24.3	**RO**
RU	9.46	14.0	86.2	245	65.2	109	740	768	145	249	6.3	525	1221	84.2	794	103	**RU**
SE	0.24	0.0	12.3	0.3	2.4	87.0	12.2	10.5	30.2	7.6	0.05	130	813	227	8.7	31.5	**SE**
SI	0.46	0.0	53.5	0.1	6.5	2.2	4.7	0.3	11.3	14.0	0.01	30.0	25.9	0.3	0.1	5.9	**SI**
SK	0.93	0.0	49.4	0.3	17.2	8.4	36.1	2.5	21.2	68.0	0.02	431	166	2.3	0.4	6.6	**SK**
TR	6.12	20.1	8.2	58.1	14.2	6.4	540	15.5	11.2	78.3	69.6	39.8	72.7	2.6	1.2	30.9	**TR**
UA	6.82	1.6	47.1	18.9	51.5	25.9	664	236	52.5	236	0.9	283	422	14.4	12.3	30.5	**UA**
BAS	0.34	0.1	24.3	0.6	4.0	134	20.4	30.7	50.8	14.1	0.05	264	1813	334	150	43.6	**BAS**
BLS	6.51	5.1	13.5	38.4	23.8	7.8	865	34.2	17.0	135	5.8	63.9	104.5	3.7	3.5	16.6	**BLS**
CAS	0.37	7.4	1.1	435	1.6	1.6	27.5	5.6	2.1	6.8	2.9	7.0	17.4	0.9	1.4	2.9	**CAS**
MDT	180	2.6	112	13.9	268	43.3	2118	11.1	238	516	241	207	304	6.5	1.3	2279	**MDT**
NOS	0.16	0.0	12.7	0.3	1.7	680	2.6	2.8	65.3	4.4	0.0	107.4	1466	161	1.5	300	**NOS**
	AL	**AM**	**AT**	**AZ**	**BA**	**BE**	**BG**	**BY**	**CH**	**CS**	**CY**	**CZ**	**DE**	**DK**	**EE**	**ES**	

***Table B.3**. Matrix of cadmium country-to-country depositions from anthropogenic sources in 2003, kg/y (continued)*

Receptors ↓ Emitters →

	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KZ	LT	LU	LV	MC	
AL	0.04	17.1	1.4	0.1	22.7	2.7	5.9	0.0	0.001	169	0.02	0.1	0.02	0.1	0.01	**AL**
AM	0.02	0.3	0.1	3.5	0.1	0.0	0.1	0.0	0.0	0.6	0.1	0.0	0.001	0.02	0.0	**AM**
AT	0.5	176	23.7	0.0	0.7	7.3	41.9	0.4	0.02	156	0.0	0.8	1.1	0.5	0.03	**AT**
AZ	0.1	1.4	0.5	10.3	0.5	0.1	0.4	0.0	0.001	2.8	1.1	0.2	0.0	0.1	0.0	**AZ**
BA	0.2	45.0	5.2	0.1	2.3	78.8	79.6	0.1	0.01	184	0.03	0.4	0.1	0.2	0.04	**BA**
BE	0.1	1131	204	0.001	0.02	0.1	0.2	2.3	0.04	6.9	0.0	0.1	9.2	0.1	0.003	**BE**
BG	0.5	30.8	7.0	0.8	43.2	8.0	42.9	0.2	0.0	87.8	0.4	1.2	0.1	0.7	0.02	**BG**
BY	13.4	87.7	31.7	0.2	3.1	7.4	52.5	0.7	0.1	74.7	0.6	164	0.4	57.8	0.02	**BY**
CH	0.04	600	29.1	0.004	0.1	0.9	1.0	0.5	0.01	177	0.002	0.03	0.7	0.0	0.04	**CH**
CS	0.4	56.9	7.6	0.2	12.7	40.4	173	0.2	0.01	210	0.1	0.9	0.2	0.5	0.04	**CS**
CY	0.003	0.4	0.1	0.05	1.1	0.04	0.1	0.002	0.0	2.2	0.003	0.01	0.0	0.0	0.0	**CY**
CZ	1.0	136	32.0	0.03	0.4	5.2	66.0	0.5	0.02	41.6	0.03	1.6	1.0	1.1	0.01	**CZ**
DE	3.9	2525	677	0.04	0.4	1.6	11.9	10.2	0.3	113	0.04	3.4	35.2	2.6	0.04	**DE**
DK	0.9	100	149	0.004	0.03	0.2	1.2	2.7	0.1	4.0	0.004	0.9	0.5	0.6	0.002	**DK**
EE	41.0	24.2	26.1	0.03	0.2	0.5	3.8	0.5	0.03	6.8	0.04	22.7	0.1	65.5	0.002	**EE**
ES	0.1	193	25.7	0.005	0.5	1.7	2.2	1.6	0.05	109	0.004	0.1	0.2	0.0	0.04	**ES**
FI	1195	86.6	84.5	0.1	0.5	1.2	9.1	1.9	0.2	23.2	0.2	23.5	0.4	29.3	0.01	**FI**
FR	0.7	12321	687	0.02	2.0	9.1	10.9	16.7	0.2	659	0.01	0.4	25.3	0.3	1.4	**FR**
GB	0.3	599	6189	0.01	0.1	0.4	1.2	90.1	0.7	24.1	0.01	0.5	1.6	0.3	0.01	**GB**
GE	0.1	2.0	0.6	35.0	1.6	0.2	0.9	0.0	0.001	5.8	0.2	0.2	0.0	0.1	0.001	**GE**
GR	0.3	34.7	5.1	0.6	744	5.6	17.1	0.1	0.005	211	0.2	0.7	0.1	0.4	0.02	**GR**
HR	0.3	63.5	5.3	0.1	2.1	260	150	0.1	0.005	282	0.03	0.5	0.1	0.3	0.1	**HR**
HU	0.6	76.0	10.1	0.1	2.0	59.5	1809	0.2	0.01	182	0.05	1.3	0.3	0.8	0.04	**HU**
IE	0.03	80.8	187	0.002	0.02	0.1	0.3	131	0.2	6.0	0.002	0.1	0.2	0.0	0.002	**IE**
IS	0.05	33.4	42.0	0.004	0.01	0.1	0.3	2.4	30.7	5.0	0.002	0.05	0.1	0.03	0.002	**IS**
IT	0.5	794	23.5	0.3	29.4	85.3	77.0	0.5	0.02	8083	0.1	0.8	0.6	0.5	1.0	**IT**
KZ	2.2	16.8	5.6	4.8	4.1	1.5	6.2	0.1	0.01	25.4	113	2.0	0.1	1.8	0.005	**KZ**
LT	7.1	48.1	27.8	0.0	0.4	1.6	12.5	0.6	0.03	17.4	0.1	428	0.2	53.3	0.004	**LT**
LU	0.0	79.8	6.9	0.0	0.003	0.01	0.03	0.1	0.002	0.8	0.0	0.0	14.7	0.01	0.0	**LU**
LV	15.7	42.5	31.2	0.04	0.3	1.1	9.0	0.7	0.04	13.4	0.1	163	0.2	414	0.003	**LV**
MC	0.0	0.1	0.001	0.0	0.0	0.002	0.002	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.01	**MC**
MD	0.4	5.2	1.9	0.2	1.4	0.8	5.4	0.1	0.002	9.1	0.2	1.2	0.02	0.7	0.002	**MD**
MK	0.1	9.1	1.3	0.1	27.5	2.4	9.0	0.03	0.001	41.8	0.02	0.2	0.03	0.1	0.006	**MK**
MT	0.0	0.2	0.02	0.00	0.05	0.01	0.02	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	**MT**
NL	0.2	598	298	0.002	0.02	0.1	0.2	3.3	0.1	4.5	0.001	0.1	1.5	0.1	0.002	**NL**
NO	4.9	160	396	0.02	0.1	0.8	3.2	11.7	1.2	13.6	0.02	2.9	0.7	1.9	0.005	**NO**
PL	13.4	349	149	0.2	2.2	14.3	144	3.1	0.1	120	0.2	47.0	2.2	18.4	0.03	**PL**
PT	0.01	9.6	1.1	0.0	0.01	0.1	0.1	0.1	0.01	4.6	0.0	0.01	0.02	0.004	0.002	**PT**
RO	1.7	106	20.2	0.8	20.5	31.4	223	0.5	0.02	227	0.5	4.2	0.4	2.4	0.05	**RO**
RU	551	490	303	34.0	32.6	30.3	163	7.1	0.9	396	136	196	1.9	247	0.1	**RU**
SE	71.2	213	286	0.1	0.4	1.5	9.9	5.9	0.5	28.0	0.1	20.2	1.1	14.5	0.01	**SE**
SI	0.1	30.8	2.2	0.02	0.4	32.7	27.1	0.05	0.002	173	0.01	0.2	0.1	0.1	0.03	**SI**
SK	0.7	48.3	9.4	0.1	0.9	14.6	269	0.2	0.01	72.5	0.04	1.4	0.2	0.9	0.01	**SK**
TR	1.4	45.1	12.7	15.1	101	4.9	22.5	0.3	0.01	155	2.1	3.4	0.1	2.0	0.02	**TR**
UA	10.2	147	43.3	3.6	20.7	25.5	211	1.0	0.1	211	5.2	34.8	0.6	17.9	0.04	**UA**
BAS	304	315	297	0.1	0.6	2.9	23.7	5.8	0.3	46.6	0.1	72.6	1.8	90.7	0.01	**BAS**
BLS	3.1	53.8	16.6	15.4	46.7	7.7	34.5	0.5	0.02	126	3.1	6.2	0.2	4.2	0.03	**BLS**
CAS	1.4	8.2	3.2	11.2	2.3	0.6	2.0	0.1	0.01	13.3	19.4	1.2	0.0	1.0	0.003	**CAS**
MDT	1.9	1939	101	4.0	1047	173	172	2.8	0.1	9819	0.9	3.5	1.4	2.1	1.6	**MDT**
NOS	4.5	2050	3708	0.1	0.2	1.3	6.5	62.8	2.7	53.4	0.0	4.3	5.2	2.6	0.0	**NOS**
	FI	**FR**	**GB**	**GE**	**GR**	**HR**	**HU**	**IE**	**IS**	**IT**	**KZ**	**LT**	**LU**	**LV**	**MC**	

***Table B.3**. Matrix of cadmium country-to-country depositions from anthropogenic sources in 2003, kg/y (continued)*

Receptors ↓ Emitters →

	MD	MK	NL	NO	PL	PT	RO	RU	SE	SI	SK	TR	UA	Total, kg/y	
AL	0.1	151	0.3	0.1	15.5	1.3	55.4	7.1	0.1	4.0	10.7	12.3	27.5	878	**AL**
AM	0.02	0.1	0.0	0.0	1.8	0.0	1.9	16.3	0.0	0.0	0.3	54.2	19.7	143	**AM**
AT	0.0	2.2	9.0	0.9	193	1.8	56.4	12.8	0.8	81.2	250	3.1	24.8	2337	**AT**
AZ	0.1	0.5	0.2	0.1	8.2	0.1	7.5	166	0.1	0.2	1.3	72.3	128	941	**AZ**
BA	0.1	9.4	1.8	0.4	109	1.2	208	12.8	0.3	33.2	111	7.6	49.2	1912	**BA**
BE	0.0	0.1	72.1	0.5	5.5	7.3	1.4	0.8	0.3	0.3	1.4	0.1	0.9	3395	**BE**
BG	3.1	110	2.1	0.6	133	1.1	1163	139	0.6	13.5	83.7	219	728	11747	**BG**
BY	2.5	12.3	10.4	9.4	1966	2.8	514	1458	13.4	19.4	183	31.4	2101	8617	**BY**
CH	0.003	0.3	3.2	0.2	4.6	2.5	4.7	0.7	0.1	4.4	3.6	0.5	1.9	1797	**CH**
CS	0.4	135	2.6	0.5	192	1.6	735	29.3	0.6	34.7	185	23.1	137	5610	**CS**
CY	0.01	0.4	0.0	0.0	0.5	0.04	1.3	1.4	0.004	0.1	0.2	67.9	4.0	162	**CY**
CZ	0.03	1.9	15.6	1.7	1027	1.7	73.7	21.7	1.9	19.8	1805	1.9	32.6	8188	**CZ**
DE	0.04	0.9	520	13.5	771	29.2	58.4	34.1	10.6	7.2	102	2.8	39.8	27339	**DE**
DK	0.01	0.1	46.3	8.9	90.1	7.1	5.3	7.4	7.8	0.6	9.3	0.3	5.4	1187	**DK**
EE	0.1	0.5	5.8	7.9	198	1.3	28.7	204	18.3	1.5	21.4	1.8	58.7	1100	**EE**
ES	0.005	1.5	2.2	0.3	9.7	379	8.8	1.9	0.1	5.3	6.7	0.5	3.5	5961	**ES**
FI	0.2	1.7	19.5	47.4	374	4.2	77.1	558	132	4.1	45.4	8.1	148	3420	**FI**
FR	0.02	6.8	65.5	2.7	55.4	173.5	54.0	7.6	1.2	28.3	35.3	2.7	14.4	17141	**FR**
GB	0.01	0.3	96.2	3.9	34.4	77.2	14.7	5.6	1.0	1.4	7.3	0.5	12.0	7687	**GB**
GE	0.1	1.8	0.2	0.1	11.5	0.1	18.6	229	0.1	0.4	2.6	191	144	741	**GE**
GR	1.1	378	1.4	0.4	61.4	2.0	281	93.4	0.3	10.0	35.5	564	355	4641	**GR**
HR	0.1	8.0	1.9	0.3	143	1.5	161	14.3	0.3	151.4	183	5.6	48.0	1923	**HR**
HU	0.1	14.8	4.1	0.6	469	1.5	1137	29.8	0.7	102.6	816	6.9	176	5802	**HU**
IE	0.001	0.1	7.0	0.3	4.9	25.0	2.6	0.9	0.1	0.4	1.4	0.1	1.9	532	**IE**
IS	0.001	0.1	5.1	1.4	5.1	3.8	2.2	0.7	0.2	0.4	1.6	0.1	1.5	179	**IS**
IT	0.2	62.0	5.3	0.8	186	15.8	301	39.8	0.6	228	175.5	53.7	121	11422	**IT**
KZ	0.7	7.0	1.6	1.2	75.6	0.8	114	2601	1.1	3.5	16.3	157	1282	4695	**KZ**
LT	0.2	1.4	9.4	7.8	967	2.0	76.0	676	12.4	5.1	69.8	3.3	125	2987	**LT**
LU	0.0	0.01	1.5	0.0	0.7	0.5	0.2	0.1	0.02	0.04	0.2	0.01	0.1	181	**LU**
LV	0.1	1.0	9.1	10.1	522	1.9	56.8	341	19.0	3.8	49.7	3.1	115	2191	**LV**
MC	0.0	0.0	0.0	0.0	0.01	0.001	0.01	0.001	0.0	0.01	0.01	0.0	0.004	0.39	**MC**
MD	29.3	5.1	0.5	0.3	82.0	0.2	251	91.9	0.3	1.5	12.3	36.2	827	1482	**MD**
MK	0.1	1441	0.4	0.1	21.9	0.4	78.6	8.6	0.1	3.6	16.9	15.7	35.8	2192	**MK**
MT	0.0	0.1	0.0	0.0	0.1	0.01	0.2	0.03	0.0	0.02	0.05	0.1	0.1	3.2	**MT**
NL	0.001	0.1	875.8	1.3	10.0	9.0	1.9	1.3	0.5	0.2	2.0	0.2	1.6	2853	**NL**
NO	0.03	0.4	54.0	609	138	17.7	18.3	29.9	18.7	2.3	17.8	1.6	17.8	2071	**NO**
PL	0.5	8.6	61.9	20.1	24222	8.6	575	580	27.0	47.3	1259	14.5	590	36347	**PL**
PT	0.0	0.04	0.2	0.0	0.7	728	0.4	0.2	0.01	0.3	0.5	0.02	0.2	1175	**PT**
RO	12.5	89.7	6.3	1.8	616	2.9	16232	238	1.9	52.5	327	171	1532	22325	**RO**
RU	10.6	79.4	73.5	93.0	3388	22.9	2060	111149	127	77.8	542	1135	17500	144011	**RU**
SE	0.1	1.5	67.2	206	680	13.9	59.2	144	474	4.9	70.0	5.4	79.7	3831	**SE**
SI	0.02	1.4	0.8	0.1	54.7	0.6	45.2	6.1	0.1	570	72.6	1.4	14.9	1190	**SI**
SK	0.1	5.7	3.9	0.8	943	1.1	389	27.5	0.9	40.5	2945	4.1	101.5	5692	**SK**
TR	4.5	56.1	3.7	1.5	203	3.0	562	883	1.5	10.4	55.4	13283	2779	19187	**TR**
UA	29.8	61.1	13.9	8.4	2756	4.8	3227	4511	9.9	55.3	393	463	36112	50481	**UA**
BAS	0.3	2.2	94.6	69.3	1973	17.3	120	677	251	10.0	153	7.7	182	7603	**BAS**
BLS	12.2	72.8	4.2	2.3	332	2.0	1066	1531	2.4	17.0	84.9	2032	7492	14313	**BLS**
CAS	0.4	3.3	0.9	0.8	42.5	0.5	42.4	1179	0.8	1.2	6.5	198	895	2957	**CAS**
MDT	3.4	537	16.0	3.3	475	92.7	1286	420	2.5	297.4	364	4251	1345	28904	**MDT**
NOS	0.0	0.7	755	164	284	120	45.5	36.4	23.6	4.8	43.2	2.9	43.4	10231	**NOS**
	MD	**MK**	**NL**	**NO**	**PL**	**PT**	**RO**	**RU**	**SE**	**SI**	**SK**	**TR**	**UA**	**Total, kg/y**	

***Table B.4**. Matrix of mercury country-to-country depositions from anthropogenic sources in 2003, kg/y*

Receptors ↓ Emitters →

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CS	CY	CZ	DE	DK	EE	ES	
AL	66.2	0.01	0.4	0.03	3.5	0.1	7.0	0.03	0.6	24.3	0.02	0.3	1.7	0.04	0.01	3.2	**AL**
AM	0.01	25.8	0.01	5.6	0.0	0.01	0.1	0.01	0.04	0.04	0.2	0.02	0.2	0.01	0.00	0.1	**AM**
AT	0.1	0.01	170	0.03	2.0	3.0	0.4	0.1	44.2	1.9	0.0	21.3	92.9	0.7	0.04	4.2	**AT**
AZ	0.02	5.0	0.1	148	0.1	0.1	0.3	0.1	0.1	0.1	0.3	0.1	1.0	0.1	0.02	0.4	**AZ**
BA	1.5	0.01	3.5	0.04	382	0.4	1.9	0.1	2.3	25.6	0.02	2.9	11.1	0.2	0.02	4.2	**BA**
BE	0.003	0.0	0.1	0.001	0.02	382	0.01	0.01	2.5	0.02	0.001	0.2	28.6	0.5	0.005	6.4	**BE**
BG	2.1	0.1	1.5	0.2	7.5	0.4	1037	0.3	1.7	44.0	0.2	1.8	8.8	0.2	0.1	3.2	**BG**
BY	0.4	0.04	3.5	0.1	3.4	1.6	6.2	141	5.5	6.5	0.01	9.8	55.7	4.3	2.7	4.7	**BY**
CH	0.02	0.001	1.3	0.004	0.2	1.9	0.1	0.004	337	0.1	0.001	0.2	8.6	0.1	0.004	6.5	**CH**
CS	9.9	0.0	3.9	0.1	71.4	0.5	28.3	0.1	3.0	639	0.02	4.2	14.2	0.3	0.03	5.0	**CS**
CY	0.01	0.02	0.0	0.03	0.03	0.0	0.1	0.002	0.02	0.0	111	0.01	0.1	0.004	0.001	0.1	**CY**
CZ	0.1	0.01	20.6	0.02	1.5	3.4	0.4	0.2	14.1	1.9	0.01	344	453	1.7	0.1	2.4	**CZ**
DE	0.1	0.01	26.0	0.03	0.6	144	0.2	0.2	220	0.5	0.01	73.0	6833	28.4	0.2	29.0	**DE**
DK	0.005	0.001	0.4	0.004	0.1	4.9	0.0	0.1	2.1	0.1	0.002	2.0	92.2	173	0.0	3.5	**DK**
EE	0.02	0.01	0.5	0.03	0.2	0.7	0.4	1.0	1.0	0.3	0.003	1.3	16.1	2.9	38	0.9	**EE**
ES	0.04	0.002	0.3	0.01	0.2	0.9	0.1	0.0	3.1	0.2	0.004	0.2	2.8	0.1	0.01	2748	**ES**
FI	0.1	0.03	1.2	0.1	0.6	2.7	1.3	1.5	3.3	1.0	0.02	3.0	42.8	7.7	13	4.0	**FI**
FR	0.2	0.01	2.5	0.02	2.0	75.6	0.7	0.05	103	1.3	0.01	1.9	82.9	1.7	0.04	450	**FR**
GB	0.01	0.003	0.4	0.02	0.1	22.2	0.1	0.04	4.5	0.1	0.005	0.6	22.1	1.4	0.01	36.4	**GB**
GE	0.1	3.9	0.1	13.4	0.2	0.1	0.8	0.04	0.2	0.2	0.5	0.1	1.0	0.1	0.02	0.6	**GE**
GR	8.6	0.1	1.1	0.2	5.7	0.4	153	0.2	1.7	15.5	1.1	1.1	6.9	0.2	0.04	6.6	**GR**
HR	1.1	0.01	7.8	0.03	28.4	0.4	1.1	0.1	2.7	15.2	0.0	4.1	12.8	0.2	0.02	4.8	**HR**
HU	0.4	0.01	19.0	0.04	16.4	0.9	3.3	0.2	4.8	32.5	0.0	14.8	33.2	0.4	0.1	3.7	**HU**
IE	0.004	0.001	0.1	0.004	0.03	1.6	0.02	0.01	1.0	0.03	0.0	0.1	2.0	0.1	0.003	10.3	**IE**
IS	0.004	0.001	0.1	0.005	0.05	0.7	0.02	0.01	0.5	0.05	0.0	0.1	2.2	0.2	0.003	2.0	**IS**
IT	7.4	0.04	12.2	0.1	25.0	1.6	5.7	0.1	55.3	14.0	0.1	4.2	23.9	0.5	0.05	57.0	**IT**
KZ	0.2	1.2	0.7	15.1	1.4	0.5	4.5	0.9	1.5	2.0	0.6	1.1	9.2	0.5	0.4	3.2	**KZ**
LT	0.1	0.01	1.2	0.0	0.6	1.2	0.8	7.3	2.3	1.1	0.004	4.2	37.2	5.2	1.0	2.0	**LT**
LU	0.0	0.0	0.03	0.0	0.003	3.9	0.0	0.001	0.5	0.002	0.000	0.03	3.4	0.03	0.0	0.5	**LU**
LV	0.0	0.01	1.0	0.04	0.4	1.1	0.7	2.7	1.9	0.8	0.01	3.0	31.3	5.2	3.5	1.7	**LV**
MC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.002	0.0	0.0	0.0	0.001	0.0	0.0	0.005	**MC**
MD	0.1	0.0	0.2	0.1	0.5	0.1	3.8	0.4	0.3	1.1	0.01	0.5	3.0	0.1	0.1	0.5	**MD**
MK	7.2	0.01	0.3	0.02	2.6	0.1	25.6	0.03	0.5	26.8	0.03	0.4	1.8	0.0	0.01	1.3	**MK**
MT	0.005	0.0	0.001	0.0	0.005	0.0	0.005	0.0	0.003	0.007	0.0	0.001	0.006	0.0	0.0	0.027	**MT**
NL	0.003	0.0	0.2	0.002	0.02	97.7	0.01	0.01	1.6	0.0	0.001	0.4	86.2	1.3	0.0	5.8	**NL**
NO	0.02	0.01	0.8	0.02	0.5	6.0	0.2	0.2	3.5	0.4	0.01	1.9	50.2	18.5	0.2	8.9	**NO**
PL	0.4	0.03	14.5	0.1	5.2	10.1	3.5	13	18.9	8.8	0.02	187	1145	29.7	1.0	8.9	**PL**
PT	0.001	0.0	0.02	0.001	0.01	0.1	0.01	0.001	0.2	0.01	0.0	0.02	0.3	0.01	0.001	79.3	**PT**
RO	2.0	0.1	5.9	0.3	23.4	1.3	74.5	1.1	5.7	84.3	0.1	8.8	35.3	0.9	0.2	7.1	**RO**
RU	2.4	5.9	14.8	40.9	19.8	12.6	44.0	86	29.4	25.8	2.8	29.8	257	24.1	171	44.8	**RU**
SE	0.1	0.01	1.8	0.05	0.8	7.5	0.8	1.0	5.8	1.0	0.02	6.2	148	97.2	0.9	8.0	**SE**
SI	0.1	0.003	13.9	0.01	1.7	0.2	0.2	0.0	1.7	1.6	0.004	1.9	6.5	0.1	0.01	1.6	**SI**
SK	0.2	0.01	9.1	0.03	5.5	0.7	1.3	0.2	3.6	8.7	0.01	32.9	32.4	0.6	0.1	1.7	**SK**
TR	1.5	11.9	1.5	8.4	4.0	1.1	53.3	0.9	2.8	6.2	40.4	2.1	18.3	0.8	0.2	12.1	**TR**
UA	1.3	0.4	6.9	1.8	11.9	2.6	36.3	18	8.9	22.7	0.4	14.8	78.8	3.7	1.7	10.0	**UA**
BAS	0.1	0.0	3.9	0.1	1.2	12.7	1.4	3.6	10.6	1.9	0.02	15.0	497	178	40	11.0	**BAS**
BLS	1.3	1.4	1.5	3.9	4.8	0.8	72.8	1.9	2.4	8.5	2.2	2.5	17.3	0.9	0.4	5.5	**BLS**
CAS	0.1	2.8	0.3	99.5	0.6	0.3	1.9	0.4	0.7	0.8	1.2	0.5	5.1	0.3	0.2	1.9	**CAS**
MDT	42.9	0.5	12.6	1.2	58.5	3.5	125	0.7	30.0	44.6	170	8.1	49.9	1.5	0.2	836	**MDT**
NOS	0.03	0.01	2.1	0.1	0.5	93.2	0.2	0.3	14.7	0.4	0.0	5.8	293	63.5	0.1	65.6	**NOS**
	AL	**AM**	**AT**	**AZ**	**BA**	**BE**	**BG**	**BY**	**CH**	**CS**	**CY**	**CZ**	**DE**	**DK**	**EE**	**ES**	

***Table B.4**. Matrix of mercury country-to-country depositions from anthropogenic sources in 2003, kg/y (continued)*

Receptors ↓ Emitters →

	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KZ	LT	LU	LV	MC	
AL	0.01	1.1	0.2	0.02	77.1	0.4	1.9	0.04	0.0	12.4	0.001	0.02	0.02	0.004	0.031	**AL**
AM	0.003	0.1	0.04	2.5	0.3	0.01	0.04	0.01	0.0	0.1	0.01	0.004	0.002	0.001	0.001	**AM**
AT	0.04	15.1	3.3	0.0	0.8	1.1	14.2	0.3	0.002	25.0	0.001	0.1	0.8	0.02	0.115	**AT**
AZ	0.02	0.2	0.2	7.3	0.7	0.02	0.1	0.03	0.001	0.3	0.1	0.02	0.01	0.01	0.002	**AZ**
BA	0.02	2.9	0.6	0.02	3.8	17	29.6	0.1	0.001	19.8	0.002	0.04	0.1	0.01	0.102	**BA**
BE	0.01	183	33.1	0.001	0.04	0.01	0.1	2.0	0.001	0.4	0.0	0.01	14.2	0.003	0.006	**BE**
BG	0.04	2.0	0.9	0.1	79.0	0.9	11.2	0.1	0.002	7.3	0.01	0.1	0.1	0.03	0.040	**BG**
BY	0.9	5.9	4.3	0.1	4.7	0.8	13.7	0.6	0.01	7.8	0.02	20.0	0.3	3.9	0.057	**BY**
CH	0.01	43.4	3.9	0.003	0.2	0.1	0.3	0.4	0.0	30.7	0.0	0.003	0.5	0.001	0.150	**CH**
CS	0.03	3.4	0.9	0.0	20.1	7.8	62.2	0.1	0.002	20.0	0.004	0.1	0.2	0.02	0.100	**CS**
CY	0.001	0.04	0.02	0.02	0.6	0.005	0.03	0.004	0.0	0.1	0.000	0.001	0.001	0.0	0.001	**CY**
CZ	0.1	10.9	4.1	0.01	0.5	0.5	18.9	0.4	0.0	3.8	0.002	0.2	0.9	0.1	0.026	**CZ**
DE	0.2	276	101	0.02	0.7	0.2	3.2	8.8	0.01	8.9	0.002	0.3	40.8	0.1	0.085	**DE**
DK	0.1	9.4	25.9	0.002	0.1	0.02	0.4	2.5	0.002	0.4	0.0	0.1	0.4	0.02	0.004	**DK**
EE	3.3	1.8	3.5	0.01	0.3	0.1	1.0	0.5	0.003	0.8	0.002	2.3	0.1	4.3	0.005	**EE**
ES	0.01	16.5	3.4	0.003	0.5	0.1	0.3	1.6	0.002	5.1	0.0	0.0	0.2	0.002	0.085	**ES**
FI	117	6.8	11.1	0.1	1.0	0.2	2.5	1.6	0.01	2.8	0.01	1.8	0.4	1.1	0.019	**FI**
FR	0.1	2008	103	0.01	2.4	0.9	2.5	15.7	0.01	75.4	0.001	0.0	31.5	0.02	7.582	**FR**
GB	0.0	73.2	1530	0.01	0.1	0.03	0.4	99.0	0.01	1.6	0.0	0.0	1.3	0.01	0.019	**GB**
GE	0.01	0.2	0.2	34.0	2.4	0.03	0.2	0.03	0.001	0.6	0.01	0.02	0.01	0.01	0.004	**GE**
GR	0.03	2.4	1.0	0.2	2430	0.7	5.2	0.1	0.002	13.4	0.01	0.1	0.1	0.02	0.052	**GR**
HR	0.02	3.5	0.6	0.0	2.7	64	58.8	0.1	0.0	45.3	0.0	0.0	0.1	0.0	0.179	**HR**
HU	0.04	4.5	1.2	0.02	2.1	11	1096	0.1	0.002	20.7	0.003	0.1	0.2	0.04	0.131	**HU**
IE	0.005	8.2	28.3	0.001	0.04	0.01	0.1	236	0.003	0.4	0.0	0.01	0.1	0.002	0.005	**IE**
IS	0.01	2.1	4.0	0.002	0.04	0.01	0.1	2.1	0.026	0.4	0.0	0.01	0.1	0.002	0.005	**IS**
IT	0.1	40.2	3.0	0.1	33.0	11	17.7	0.5	0.004	1651	0.01	0.1	0.5	0.02	4.645	**IT**
KZ	0.3	2.0	1.4	2.1	7.4	0.2	2.2	0.2	0.005	2.7	16.5	0.2	0.1	0.1	0.016	**KZ**
LT	0.4	3.3	3.8	0.01	0.8	0.2	3.2	0.5	0.003	1.9	0.003	80.5	0.2	4.3	0.012	**LT**
LU	0.001	7.2	1.1	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.001	22.6	0.0	0.001	**LU**
LV	1.0	3.0	4.5	0.02	0.6	0.1	2.3	0.6	0.003	1.5	0.003	21.6	0.1	35.2	0.011	**LV**
MC	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04	0.0	0.0	0.0	0.0	0.006	**MC**
MD	0.03	0.4	0.3	0.04	1.8	0.1	1.3	0.04	0.001	0.9	0.01	0.1	0.02	0.04	0.015	**MD**
MK	0.01	0.6	0.2	0.02	72.8	0.3	2.3	0.03	0.0	3.8	0.001	0.02	0.02	0.004	0.000	**MK**
MT	0.0	0.01	0.001	0.0	0.04	0.0	0.003	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.004	**MT**
NL	0.02	80.8	45.8	0.0	0.04	0.01	0.1	2.8	0.002	0.3	0.0	0.01	1.4	0.005	0.017	**NL**
NO	0.3	13.4	60.7	0.01	0.2	0.1	1.0	10.2	0.02	1.7	0.002	0.2	0.6	0.1	0.078	**NO**
PL	0.8	25.3	19.2	0.1	3.7	1.6	41.4	2.4	0.01	13.1	0.01	5.8	1.7	1.0	0.004	**PL**
PT	0.002	0.7	0.2	0.0	0.01	0.005	0.02	0.1	0.0	0.3	0.00	0.0	0.0	0.0	0.141	**PT**
RO	0.1	6.3	2.4	0.2	26.5	3.5	74.6	0.3	0.005	22.6	0.03	0.4	0.3	0.1	0.292	**RO**
RU	38.4	41.3	46.6	15.9	53.8	3.6	45.1	7.3	0.1	41.4	13.9	20.4	1.6	13.3	0.026	**RU**
SE	0.04	16.6	40.9	0.02	0.7	0.2	2.7	5.0	0.02	3.2	0.004	1.5	0.8	0.5	0.112	**SE**
SI	0.01	1.6	0.3	0.01	0.4	5.3	8.6	0.04	0.0	30.2	0.001	0.02	0.1	0.01	0.044	**SI**
SK	3.9	3.0	1.0	0.01	0.9	2.0	149	0.1	0.001	7.9	0.002	0.2	0.2	0.05	0.058	**SK**
TR	0.2	4.6	3.0	5.8	118	0.6	5.8	0.5	0.0	10.4	0.1	0.3	0.1	0.1	0.122	**TR**
UA	0.8	10.0	5.9	1.1	26.2	2.5	53.4	0.8	0.01	19.8	0.3	3.7	0.5	1.0	0.043	**UA**
BAS	32.9	26.8	47.9	0.05	1.1	0.3	6.6	5.4	0.02	5.6	0.01	9.2	1.4	6.4	0.057	**BAS**
BLS	0.2	3.3	2.2	6.4	60.6	0.7	6.7	0.4	0.01	8.6	0.1	0.5	0.1	0.2	0.009	**BLS**
CAS	0.1	1.0	0.9	4.8	3.8	0.1	0.8	0.1	0.003	1.4	2.1	0.1	0.0	0.1	4.930	**CAS**
MDT	0.2	151	10.3	0.9	1237	22	32.1	2.0	0.01	770.2	0.03	0.2	0.7	0.1	0.056	**MDT**
NOS	0.3	253	681	0.0	0.4	0.1	1.8	56.0	0.03	4.8	0.003	0.3	4.1	0.1	0.031	**NOS**
	FI	**FR**	**GB**	**GE**	**GR**	**HR**	**HU**	**IE**	**IS**	**IT**	**KZ**	**LT**	**LU**	**LV**	**MC**	

***Table B.4**. Matrix of mercury country-to-country depositions from anthropogenic sources in 2003, kg/y (continued)*

Receptors ↓ Emitters →

	MD	MK	NL	NO	PL	PT	RO	RU	SE	SI	SK	TR	UA	Total, kg/y	
AL	0.1	21.3	0.03	0.01	3.0	0.3	5.9	0.2	0.01	0.4	1.5	0.6	2.3	236	**AL**
AM	0.01	0.02	0.003	0.01	0.3	0.02	0.1	0.5	0.01	0.01	0.05	4.2	1.6	42	**AM**
AT	0.02	0.1	0.7	0.1	29.2	0.6	2.5	0.3	0.1	10.3	15.5	0.1	2.9	464	**AT**
AZ	0.1	0.04	0.02	0.03	1.5	0.1	0.5	5.1	0.03	0.02	0.2	3.4	9.5	185	**AZ**
BA	0.1	0.7	0.1	0.04	14.6	0.4	9.4	0.3	0.04	3.3	10.6	0.3	4.9	555	**BA**
BE	0.001	0.003	8.0	0.1	0.7	1.7	0.1	0.01	0.03	0.02	0.1	0.004	0.1	664	**BE**
BG	2.2	9.5	0.1	0.1	15.6	0.4	142	2.4	0.1	1.1	8.1	7.5	42.5	1442	**BG**
BY	1.7	0.7	0.7	0.9	265	1.1	21.0	30.1	1.3	1.7	18.2	1.0	203	855	**BY**
CH	0.003	0.025	0.3	0.02	0.7	0.8	0.3	0.02	0.01	0.5	0.3	0.03	0.2	438	**CH**
CS	0.2	13	0.2	0.1	27.9	0.5	64.6	0.7	0.1	3.5	22.2	0.9	11.2	1040	**CS**
CY	0.005	0.018	0.001	0.001	0.1	0.01	0.1	0.05	0.001	0.005	0.02	4.3	0.3	118	**CY**
CZ	0.03	0.1	1.1	0.2	287	0.5	2.4	0.4	0.2	1.6	30.8	0.1	3.6	1213	**CZ**
DE	0.03	0.01	86.2	1.1	119	7.5	2.0	0.5	1.1	0.4	4.3	0.1	3.7	8021	**DE**
DK	0.01	0.01	3.2	1.1	12.1	1.8	0.2	0.1	1.5	0.05	0.5	0.02	0.7	339	**DK**
EE	0.1	0.04	0.3	0.8	23.6	0.4	1.1	3.8	1.5	0.1	1.5	0.1	5.7	120	**EE**
ES	0.05	0.1	0.1	0.02	1.0	171.6	0.3	0.04	0.01	0.2	0.3	0.02	0.3	2958	**ES**
FI	0.2	0.1	1.1	5.0	38.0	1.6	3.5	9.8	16.5	0.4	2.8	0.3	13.6	321	**FI**
FR	0.02	0.03	5.3	0.3	7.7	50.8	2.4	0.2	0.2	2.3	2.5	0.1	1.6	3043	**FR**
GB	0.01	0.02	7.0	0.3	3.8	20.3	0.5	0.1	0.1	0.1	0.5	0.03	1.0	1828	**GB**
GE	0.1	0.1	0.01	0.02	1.5	0.1	0.9	3.3	0.02	0.04	0.2	10.2	8.1	83	**GE**
GR	0.6	46.4	0.1	0.04	8.0	0.6	20.9	1.4	0.04	0.8	3.6	21.3	17.0	2777	**GR**
HR	0.0	0.5	0.1	0.0	18.4	0.5	6.7	0.3	0.0	24.9	16.3	0.2	4.9	327	**HR**
HU	0.1	0.9	0.3	0.1	70.8	0.5	41.9	0.6	0.1	11.2	353.8	0.3	24.3	1771	**HU**
IE	0.001	0.01	0.4	0.03	0.6	6.8	0.1	0.02	0.01	0.03	0.1	0.01	0.2	297	**IE**
IS	0.002	0.01	0.2	0.1	0.7	1.1	0.1	0.03	0.02	0.04	0.1	0.01	0.2	17	**IS**
IT	0.1	3.8	0.4	0.1	25.6	4.0	13.4	0.9	0.1	28.9	14.8	1.6	9.8	2072	**IT**
KZ	0.5	0.6	0.1	0.2	12.8	0.6	6.8	110	0.3	0.3	1.8	6.1	100	319	**KZ**
LT	0.1	0.1	0.6	0.7	110	0.6	2.7	9.2	1.1	0.4	5.0	0.1	12.8	307	**LT**
LU	0.0	0.001	0.2	0.004	0.1	0.1	0.01	0.002	0.003	0.003	0.01	0.001	0.01	40	**LU**
LV	0.1	0.1	0.5	0.9	63.1	0.6	2.0	5.2	1.6	0.3	3.5	0.1	10.6	213	**LV**
MC	0.0	0.0	0.0	0.0	0.001	0.0	0.001	0.0	0.0	0.001	0.0	0.0	0.0	0.1	**MC**
MD	59.0	0.2	0.0	0.03	13.7	0.1	41.9	1.7	0.05	0.1	2.1	1.2	109	244	**MD**
MK	0.1	154.5	0.0	0.01	3.4	0.1	7.2	0.2	0.01	0.3	1.8	0.6	2.6	318	**MK**
MT	0.0	0.003	0.0	0.0	0.004	0.001	0.004	0.0	0.0	0.001	0.002	0.001	0.002	0.2	**MT**
NL	0.001	0.003	119	0.1	1.2	2.2	0.1	0.0	0.1	0.0	0.1	0.01	0.2	447	**NL**
NO	0.03	0.04	3.1	95.2	14.2	4.5	0.8	0.5	2.6	0.2	1.1	0.1	2.4	305	**NO**
PL	0.4	0.6	4.9	2.1	6469	2.8	17.6	9.2	3.2	4.3	91.9	0.7	86.4	8254	**PL**
PT	0.0	0.002	0.0	0.0	0.1	491.9	0.02	0.01	0.002	0.01	0.02	0.002	0.04	573	**PT**
RO	15.3	5.3	0.5	0.2	97.8	1.2	1656	5.2	0.3	4.9	68.8	5.9	176	2425	**RO**
RU	7.1	5.2	4.3	9.9	436	10.7	96.9	3838	14.9	6.4	50.0	47.8	1612	7294	**RU**
SE	0.1	0.4	3.7	27.1	74.5	3.8	2.6	1.8	101	0.4	3.4	0.2	8.4	583	**SE**
SI	0.01	0.1	0.1	0.01	8.0	0.2	2.2	0.1	0.02	99.4	5.5	0.1	1.7	193	**SI**
SK	0.1	0.1	0.3	0.1	167	0.3	12.3	0.6	0.1	4.2	445.0	0.2	16.3	909	**SK**
TR	2.9	3.4	0.3	0.2	27.5	1.4	36.8	23.1	0.3	0.8	6.7	994	185	1597	**TR**
UA	40.2	3.2	1.1	1.0	483	2.1	146	125	1.3	4.5	82.4	17.1	7233	8487	**UA**
BAS	0.2	0.2	6.6	8.7	296	4.9	5.7	13.3	46.2	0.9	9.9	0.4	23.5	1336	**BAS**
BLS	12.7	3.7	0.3	0.3	37.5	0.8	78.8	58.2	0.3	0.9	8.2	103	710	1234	**BLS**
CAS	0.3	0.3	0.1	0.1	7.5	0.4	3.0	47.8	0.1	0.1	0.9	7.6	73.0	273	**CAS**
MDT	1.4	25.7	0.8	0.3	46.6	16.4	55.4	5.9	0.3	24.1	23.2	186	58.3	4061	**MDT**
NOS	0.0	0.1	62.1	19.3	30.8	28.0	1.6	0.6	3.5	0.4	2.4	0.2	4.5	1695	**NOS**
	MD	**MK**	**NL**	**NO**	**PL**	**PT**	**RO**	**RU**	**SE**	**SI**	**SK**	**TR**	**UA**	**Total, kg/y**	