EMEP Status Report 2/2008

June 2008

Heavy Metals:
Transboundary Pollution of the Environment

METEOROLOGICAL SYNTHESIZING CENTRE - EAST

I. Ilyin, O. Rozovskaya, O. Travnikov

CHEMICAL CO-ORDINATING CENTRE

W. Aas

COORDINATION CENTRE FOR EFFECTS

J.P.Hettelingh, G.J. Reinds

ccc

Norwegian Institute for Air Research (NILU)
P.O.Box 100
N-2027 Kjeller
Norway
Phone: +47 63 89 81 58
Fax: +47 63 89 81 58
E-mail: kjetil.torseth@nilu.no
Internet: www.nilu.no

msc-e

Meteorological Synthesizing Centre - East
Krasina pereulok, 16/1
123056 Moscow
Russia
Tel.: +7 495 981 15 66
Fax: +7 495 981 15 67
E-mail: msce@msceast.org
Internet: www.msceast.org

msc-w

Norwegian Meteorological Institute (met.no)
Postboks 43 Blindren
N-01313 Oslo
Norway
Phone: +47 22 96 30 00
Fax: +47 22 96 30 50
E-mail: emep.mscw@met.no
Internet: www.emep.int

CCE

Coordination Centre for Effects
c/o PBL, Bilthoven-office
postback 24
P.O.Box 303
NL-3720 AH Bilthoven
Phone: +31 30 274 30 48
Fax: +31 30 274 44 33
E-mail: J.P.Hettelingh@mnp.nl
Internet: www.mnp.nl/cce

EXECUTIVE SUMMARY

In 2008 Meteorological Synthesizing Centre – East (MSC-E) and Chemical Co-ordinating Centre (CCC) continued the collaborative work on the assessment of heavy metal atmospheric pollution in the EMEP region. The main directions of this work were formulated in the EMEP Workplan for 2008 [*ECE/EB.AIR/ 2007/8*]. Primary goal of this activity is to assess regional-scale pollution levels of lead, cadmium and mercury in the EMEP by means of monitoring and atmospheric modelling. In order to include territories of the Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) the EMEP domain was extended eastward. The assessment of pollution levels described in this report comprises both Europe and Central Asia. Furthermore, significant attention was paid to the development of global modelling framework in cooperation with MSC-W. Besides, MSC-E continued its work on implementation of recommendations of TFMM aimed at improvements of MSC-E heavy metal model. In addition to this, MSC-E cooperated with WGE, TFHM, TFHTAP as well as various international organizations. The report summarizes the results of scientific work achieved by MSC-E and CCC in 2008.

Information on the observed concentrations in air and in precipitation of heavy metals was reported from 65 monitoring stations. There were 29 stations which measured concentrations of lead and cadmium in both media, and 16 stations where at least one form of mercury was observed. However, southern, eastern and south-eastern regions of Europe still suffer from unsatisfactory spatial coverage by measurement stations.

The lowest concentrations of lead, cadmium and mercury were observed in the northern part of Scandinavia. The concentrations tend to increase southward. The highest concentrations of the measured species are noted for Slovakia, Hungary and the Czech Republic. National laboratories demonstrated marked improvements in quality of EMEP measurements since 1995. However, results of intercomparison of analytical methods demonstrated by some laboratories do not match data quality objectives.

The emission data on lead, cadmium and mercury in 2008 were officially reported by 31 EMEP countries for 2006 reporting year. Information on gridded emissions was presented by 26 countries at least for one year in the period 1990-2006. In addition to this, emission sector data were presented by 31 countries. Besides, 21 countries changed emission data previously reported for the period 1990–2005. Because of these re-calculations the changes of the emission estimates in some countries exceed 100%. The main contributor to lead and cadmium emission is the source category “Manufacturing Industries and Construction”, providing 36% of lead and 38% of cadmium emissions. As for mercury, the main contributor is “Public Electricity and Heat Production” (34%).

Following the recommendations of the EMEP Steering Body Bureau MSC-W and MSC-E have started work on gradual development of the common EMEP global modelling system. According to the

adopted workplan the Centres at the current stage concentrated their efforts on collection and evaluation of various input data (meteorological data, emissions, land-cover etc.) for the global modelling system and testing the available atmospheric transport modules.

In 2008 MSC-E continued to work on implementation of recommendations of TFMM aiming at further improvement of MSCE-HM atmospheric transport model. Transition from NCEP/DOE re-analyses to ECMWF analysis as driving input for preparation of meteorological data has been completed. To analyse quality of meteorological data based on the two driving datasets the generated meteorological parameters were compared against observations. Besides, pollution levels calculated with the use of the two meteorological datasets were also evaluated. The model sensitivity to refining the vertical model structure by inclusion of lowest shallow layer was investigated. The numerical experiments has shown that reduction of the lowest model layer does not lead to evident improvement of the model performance.

Model assessment of depositions, concentrations and transboundary fluxes of lead, cadmium and mercury in 2006 was fulfilled over the extended EMEP domain including Europe and the Central Asia. According to the modelling results concentrations and depositions of lead, cadmium and mercury in 2006 varied significantly over Europe and Central Asia. The highest pollution levels were obtained for regions of central, eastern and south-eastern Europe, some regions of western Europe and some areas of Central Asia.

Contribution of wind re-suspension to depositions of lead and cadmium in the European and Central Asian countries is comparable with that from the anthropogenic sources, and in case of lead, even exceeds it. However, wind re-suspension scheme is under development and present calculations of wind re-suspension flux are subject to significant uncertainty. In case of mercury the contribution of anthropogenic depositions is comparable with the contribution of sources located outside the EMEP domain.

The influence of the transboundary transport on heavy metal depositions in Europe and Central Asia is significant. Contribution of transboundary transport to depositions from anthropogenic sources exceeds 50% in 37, 35 and 27 countries for lead, cadmium and mercury, respectively. On the other hand, fraction of national emissions contributing to the transboundary transport in Europe and Central Asia varies from 60% to 90% for lead and cadmium. In case of mercury, this fraction is commonly higher than 70%.

Contribution of wind re-suspension and non-EMEP sources is comparable with or even exceeds that of anthropogenic sources in the Central Asian countries (Kazakhstan, Kyrgyzstan, Uzbekistan, Turkmenistan and Tajikistan). As for mercury, the major contribution to depositions is made by non-EMEP sources. The most important contributors to anthropogenic depositions of lead in the Central Asian countries are Kazakhstan and Uzbekistan.

Evaluation of modelling results via comparison with measurements demonstrates that spatial variability of pollution levels (air concentrations, concentrations in precipitation, wet deposition fluxes) was reproduced reasonably well. On average, the modelled levels of lead underestimate the observed values by 20-30%. Cadmium air concentrations were underestimated by 20%, and concentrations in precipitation and wet deposition fluxes – by 50%. Mercury calculated levels were slightly (by 20%) lower than the measured ones. The most significant underestimation of the observed concentrations of lead and cadmium was identified for stations locating in Scandinavia and Central Europe. On the base of numerical experiments it was shown that the underestimation can be explained by uncertainties of spatial distribution of emission sources, and possible influence of local emissions.

Critical loads of lead, cadmium and mercury were evaluated by Coordinating Centre for Effects (CCE) of the Working Group on Effects (WGE) over Europe and Central Asia. Besides, on the base of deposition data exceedances of these metals were calculated. The new CCE background database formed a proper basis for computing critical loads for lead, cadmium and mercury. Results obtained in this study are in good agreement with previously published heavy metal critical loads maps for Europe. Sources of critical load uncertainties were indicated.

Intercomparison of mercury transport models has been performed on a global scale under conditions of the TF HTAP. Obtained results have shown that variation of elemental mercury concentrations simulated by different models does not exceed 15%. The difference between the simulated mercury depositions is much higher and can reach a factor of two. The largest contribution to the deposition uncertainty is made by dry deposition. In spite of significant discrepancies in simulated mercury deposition levels the models in general agree quantifying relative deposition response to emission

The EMEP Centres were also involved in cooperation with subsidiary bodies to the Convention (TFMM, TFHM, TF HTAP, WGE) as well as international organizations and national programmes (European Commission, HELCOM, OSPAR, UNEP, AMAP). In line with EMEP priorities, a particular attention of MSC-E activity in the field of heavy metal transboundary pollution was paid to EECCA countries.

CONTENTS

INTRODUCTION

A number of heavy metals, such as lead, cadmium and mercury, are know for their toxicity. They can cause adverse effects on humans and biota. Besides, they can be accumulated in the environmental compartments and/or tissues of living organisms increasing the risk of the harmful effects in future. The problems regarding the environmental pollution by heavy metals are studied both at national and at international level. In order to take control over the atmospheric emissions of heavy metals 36 Parties to the Convention on Long-Range Transboundary Air Pollution (CLRTAP, hereinafter the Convention) signed the Protocol on Heavy Metals. Heavy metals targeted by the Protocol are lead (Pb), cadmium (Cd) and mercury (Hg).

According to the Protocol, Cooperative Programme for Monitoring and Evaluation of Long-range Transmission of Air Pollutants in Europe (EMEP) provides the Executive Body for the Convention with information on depositions, and transboundary transport of heavy metals within the geographical scope of EMEP. 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 Meteorological Synthesizing Centre – East (MSC-E) performs the model assessment of depositions and air concentrations of heavy metals over the EMEP region as well as the transboundary fluxes between countries of the EMEP region. The aim of this report is to overview the results of the EMEP activities in 2008 in the field of heavy metal pollution.

Concentrations, depositions and their long-term tendencies are evaluated by means of monitoring and modelling. Measurements of lead, cadmium and mercury concentrations in air, in precipitation and wet deposition fluxes is carried out at EMEP background monitoring network supervised by CCC. In 2006 the measurement information is available from 65 stations. These stations cover limited territory of the EMEP region concentrated mainly in the northern, central and western parts of Europe. Besides, the means of monitoring can hardly supply detailed information of transboundary aspect of the pollution levels. In order to provide information on pollution levels over the entire EMEP domain, and to establish source-receptor relationships, numerical modelling is used.

For model assessment of atmospheric transport and depositions of heavy metals the MSCE-HM atmospheric transport model is used. The model was thoroughly reviewed at the workshop held in October, 2005 under supervision of the EMEP Task Force of Measurements and Modelling (TFMM). It was concluded that “MSC-E model is suitable for the evaluation of long-range transboundary transport and depositions of HMs in Europe” [*ECE/EB.AIR/GE.1/2006/4*]. The TFMM recommended a number of activities aimed at the further improvement of the model. The progress in the implementation of these recommendations is reflected in this report.

Inline with EMEP priorities, a particular attention of MSC-E activity in the field of heavy metal transboundary pollution was paid to EECCA countries. In 2008 territories of Kazakhstan and Kyrgyzstan as well as Tajikistan, Turkmenistan and Uzbekistan that are going to join the Convention in the nearest future were fully covered by the extended EMEP domain. Pilot calculations of lead transport and depositions over the extended EMEP domain were carried out in 2007. This year for the first time the model assessment was carried out over the extended domain for the all three priority metals – lead, cadmium and mercury.

Main directions of EMEP activity in 2008 concerning heavy metals are outlined in the EMEP Workplan [*ECE/EB.AIR/2007/8*]. Following this workplan, MSC-E performed model assessment of concentrations, depositions and transboundary transport of lead, cadmium and mercury in the EMEP region and over the Northern Hemisphere. The calculated pollution levels were evaluated via comparison with measurement data from the EMEP monitoring network. The progress in the field of heavy metals, achieved by the EMEP Centres is summarized in this status report. Content of the report is briefly described below.

Chapter 1 is devoted to the EMEP monitoring activities regarding heavy metals. Magnitudes and spatial gradients of measured concentrations of lead, cadmium and mercury, and spatial coverage of measurement data are characterized. Quality of measurement data was overviewed and the most doubtful measured values were identified. The results of the most recent laboratory intercomparison study are presented.

Chapter 2 overviews the emission data of lead, cadmium and mercury within the extended EMEP region. The chapter presents the information on official reporting of the emission data, on emission trends, re-calculations of previously reported estimates and analysis of the emissions by source categories. Besides, the emission data prepared for modelling purposes are described.

Chapter 3 is focused on the development of modelling tools. In particular, the progress in development of global modelling framework is described. Furthermore, the sensitivity of modelling results to changes in meteorological input data is characterized and effect of refining the vertical model structure is analysed.

Chapter 4 is devoted to model assessment of pollution levels in the extended EMEP domain. Concentrations and depositions of lead, cadmium and mercury in countries of Europe and Central Asia are described, and a role of the transboundary transport information of pollution levels is assessed. Calculated concentrations and depositions are evaluated against measurements. Results of the intercomparison of mercury transport models on a global scale are also described.

Chapter 5 presents contribution of Coordinating Centre for Effects (CCE) of the Working Group on Effects (WGE). The contribution is focused on the evaluation of critical loads of lead, cadmium and mercury and the calculations of critical load exceedances of these metals in countries of Europe and Central Asia in 2006.

Chapter 6 is focused on cooperation of MSC-E with subsidiary bodies to the Convention, national and international organizations. In particular, MSC-E contribution to the Task Force of Measurements and Modelling, the Task Force on Heavy Metals and Task Force on Hemispheric Transport of Air Pollution is overviewed. Cooperation of the Centre with HELCOM, OSPAR, UNEP, AMAP and the European Commission is described.

The main outcomes of EMEP activities concerning heavy metals are summarized in *Conclusions*. Important supplementary information is given in the *Annexes*.

1. MONITORING OF HEAVY METALS IN EMEP

1.1. Measurement network

Heavy metals were included in EMEP's monitoring program in 1999. However, earlier data have 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 AMAP, HELCOM, and OSPAR.

The locations of the measurement sites, which have delivered data on heavy metals for 2006, are found in Fig. 1.1. 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*, 2008]. 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 2006 it was 29 sites measuring heavy metals (Pb and Cd) in both compartments, and altogether it was 65 measurement sites. It was 16 sites measuring at least one form of mercury.

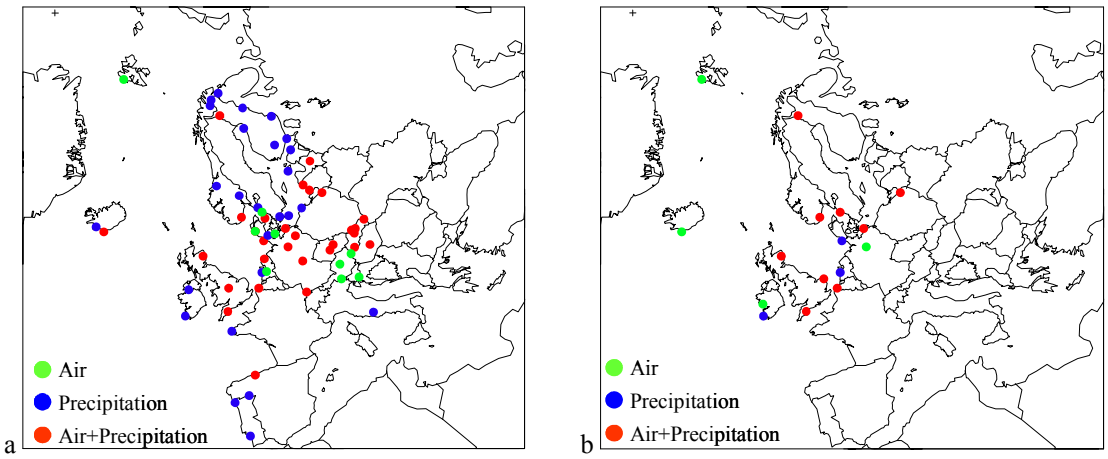


Fig. 1.1. *Measurement network of lead, cadmium (a) and mercury (b) in 2006*

From Fig.1.1 one can see that the spatial in east and southern Europe is unsatisfactory, especially for mercury. In addition, it is too few sites measuring both in air and precipitation. The adopted EMEP monitoring strategy for 2004-2009 (EB.AIR/GE.1/2004/5) and the EUs daughter directive on heavy metals and PAH will expectantly improve this situation.

1.2. Monitoring of Pb, Cd and Hg in 2006

Annual averages of Pb, Cd and Hg concentrations in precipitation and in air in 2006 are presented in Fig. 1.2-1.7. 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 concentrations of heavy metals are in Hungary, Slovakia and the Czech Republic. Elevated levels are also in Poland, Lithuania, and in the Benelux countries. There are only a few stations measuring mercury in Europe, and most of them are related to the OSPAR program CAMP. The concentrations of mercury at the different sites are decreasing from north to south.

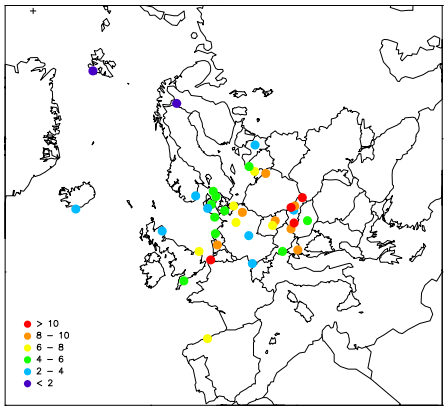


Fig. 1.2. *Pb in aerosol, ng/m^3*

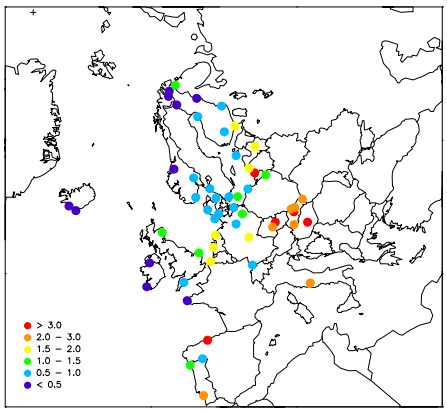


Fig. 1.3 *Pb in precipitation, µg/L*

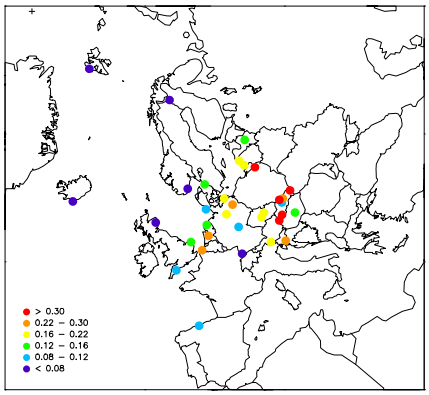


Fig. 1.4*. Cd in aerosol, ng/m^3*

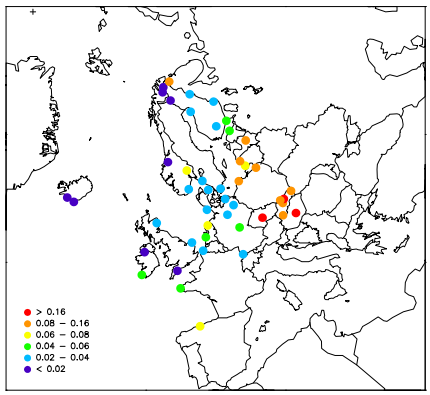


Fig. 1.5. *Cd in precipitation, µg/L*

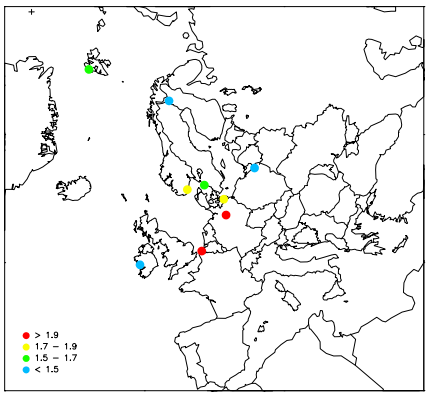


Fig. 1.6*. Hg in air, ng/m^3*

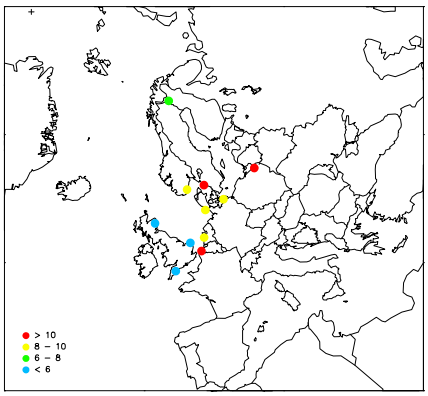


Fig. 1.7. *Hg in precipitation, ng/L*

1.3. Data quality

Portugal has very high detection limit for Cd so these data are not shown in Fig. 1.4. This is also the case for the mercury measurements in precipitation in Ireland, not included in Fig 1.7. Much of the Portuguese, Slovenian, Irish and Estonian data are under the detection limit and these concentration levels should be looked upon as max values. The data capture is above 90% for most of the precipitation measurements. For air measurement data capture is commonly lower due to less frequent sampling, i.e one day per week at several sites.

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 [*Aas and Breivik*, 2007] is representative for the 2006 data. In Table 1.1, there is a summary of the results from this laboratory intercomparison. There are some countries/laboratories reporting measurements data without participation in the laboratory intercomparison: France, 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. Sweden and Iceland were not participating because these measurements were analysed in Norway. As can be seen from the table, Estonia, Hungary and Italy have too high detection limits for many of the metals, and Denmark has some analytical problems. Otherwise, the performance for most elements and labs are satisfactory especially for lead and cadmium which are the priority metals.

Table 1.1. *Average per cent error (absolute) in low and high concentration samples, results from the laboratory intercomparison. DQO is EMEPs data quality objectives*

	As		Cd		Cr		Cu		Pb		Ni		Zn	
	low	high	low	high	low	high	low	high	low	high	low	high	low	high
AT	4	2	<DL	4	3	6	0	4	0	3	<DL	5	<DL	11
BE	12	4	8	3	26	2	22	10	1	5	16	14	16	12
CZ	15	1	13	7	7	12	25	14	5	0	20	4	0	1
DK	25	11	146	11	<DL	26	100	34	15	21	<DL	31	<DL	<DL
FI	21	20	13	12	28	11	7	8	9	11	6	8	10	11
DE	11	8	12	3	1	0	5	0	3	0	<DL	0	6	0
DE	1	0	2	2	3	2	1	3	3	6	1	5	1	2
HU	<DL	<DL	17	2	<DL	<DL	<DL	<DL	25	8	<DL	<DL	<DL	<DL
IT	<DL	<DL	16	4	<DL	<DL	10	4	51	10	<DL	<DL	11	865
NL	5	2	7	2	49	3	3	3	1	2	6	1	4	3
NO	1	3	2	1	2	0	1	1	6	2	6	2	11	3
PL	<DL	<DL	0	0	0	0	4	0	9	3	12	0	0	4
PL05	<DL	0	<DL	0	0	1	6	3	6	5	<DL	0	<DL	0
UK	8	6	18	2	20	6	5	4	2	3	2	1	4	7
LT	4	3	23	5	10	13	21	3	19	4	11	5	6	5
LV	41	8	15	1	9	10	3	3	4	6	9	18	9	9
SI	1	1	5	4	7	2	1	1	10	10	11	2	1	7
EE	<DL	5	<DL	12	<DL	3	<DL	7	21	3	<DL	9	<DL	90

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

2. EMISSIONS OF HEAVY METALS IN EUROPE

This Chapter provides information on heavy metal official emission data submitted by Parties to the LRTAP Convention by May 2008. Particularly, trends of anthropogenic emission reduction of lead, cadmium and mercury in the EMEP region are presented for the period 1990-2006 along with information on emission reduction in individual countries and specification of emission data by source categories. Emission changes caused by backward recalculations of emission data are also analyzed. In order to include the Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) into routine calculations of heavy metal transboundary pollution gridded emissions data for the modelling purposes have been prepared for the extended EMEP domain.

2.1. Official submissions of emission data

In 2008, national totals on lead, cadmium and mercury emissions for 2006 reporting year were submitted to the UNECE Secretariat by 31 European countries. These countries are Austria, Belarus, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Malta, Monaco, the Netherlands, Poland, Portugal, Republic of Moldova, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, the Ukraine and the United Kingdom. Among them 21 countries recalculated previously reported emission data on Pb, Cd and Hg for all or for selected years from the period of 1990-2005. It should be pointed out that six EECCA countries have submitted emission data for the period from 1990 to 2006 (at least for one year). These countries are Armenia (only for lead), Belarus, Republic of Moldova, the Russian Federation and the Ukraine. Besides, national experts from Kazakhstan have unofficially presented preliminary emission data on lead for 2002-2006.

Emission trends in the EMEP region (1990-2006)

Changes of Pb, Cd and Hg anthropogenic emissions in the EMEP region (without Central Asian region) in the period 1990-2006 are shown in Fig. 2.1. Emission trends were assessed on the base of the reported emission data. In the absence of official emission data non-official estimates [*Berdowski et al.,* 1997; *Denier van der Gon et al.,* 2005] were used. Between 1990 and 2006 total anthropogenic emissions in the EMEP region decreased for all the three metals: for lead by about 88%, for cadmium by about 50% and for mercury by about 46%.

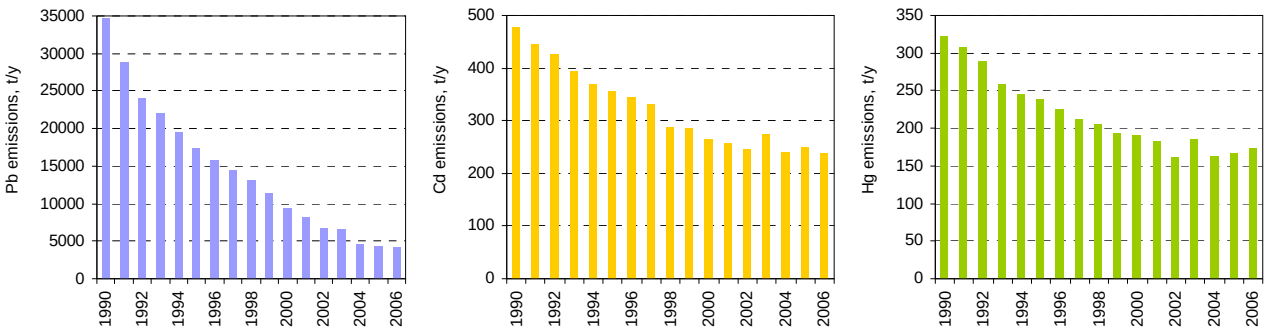


Fig. 2.1. *Total anthropogenic emissions of lead, cadmium and mercury in the EMEP region in the period 1990-2006 according to the official data combined with non-official estimates*

Emission reductions from 1990 to 2006 in individual countries

The extent of emission reductions varies significantly from country to country. The relative emission reduction was estimated as $100*(E_{1990}-E_{2005})/E_{1990}$ (%), where E_{1990} and E_{2005} are emissions in 1990 and 2006, respectively. Figure 2.2 shows the relative reductions of lead, cadmium and mercury emissions between 1990 and 2006 in the 28 countries of the EMEP region, which reported their emissions both for 1990 and 2006. Emissions of lead decreased in all the countries varying from about 15% (Latvia) to 99% (Monaco). The lowest reduction of cadmium is in Slovenia (9%), the highest – in Republic of Moldova (93%). In Portugal and Belarus cadmium emissions have increased by about 2% and 18% respectively. In Cyprus, emissions of cadmium have increased about 2 times. The reductions of mercury emissions vary from about 9% (Italy) to 94% (Republic of Moldova). In Cyprus, emissions of mercury have increased by a factor of two, and in Lithuania – almost 23 times.

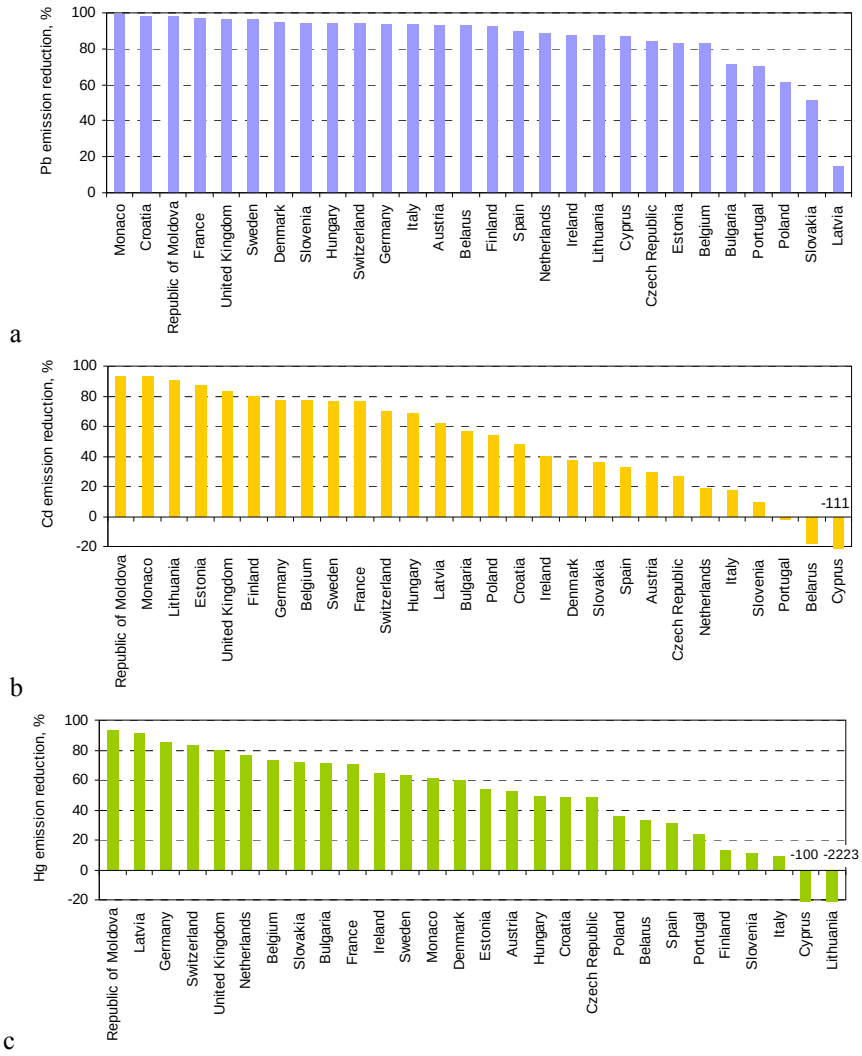


Fig. 2.2. *Reductions of lead (a), cadmium (b) and mercury (c) emissions in the 28 countries of the EMEP region for the period of 1990-2006 based on data reported for both 1990 and 2006*

Changes of national emission estimates

In 2008 changes of previously submitted data on Pb, Cd and Hg emissions for the period 1990-2005 were reported by 21 countries (Austria, Belarus, Belgium, Cyprus, Denmark, Finland, France, Germany, Ireland, Italy, Latvia, Malta, Monaco, the Netherlands, Portugal, Romania, Slovenia, Spain, Sweden, Switzerland and the United Kingdom). Relative changes of national estimates of total heavy metal emission in these countries for the period 1990-2005 are given in Annex B.

The changes of lead, cadmium and mercury emissions in each country are expressed as $100*(E_{curr} - E_{prev})/E_{prev}$ (%), where E_{curr} and E_{prev} are current and previous total emissions in the each particular year, respectively. Maximum changes are presented in Figs. 2.3 – 2.5. Negative values indicate decrease in emissions after the recalculations, whereas positive values illustrate increase in emissions.

Lead. For Austria, Belarus, Finland, France, Germany, Italy, Monaco, Spain and the United Kingdom the changes of emission estimates did not exceed ±10% (Fig. 2.3). For Ireland the changes were more than 100%: Lead emissions were increased about twice for 2005. The maximum emission decrease after the recalculation was 60% (Cyprus for 2001).

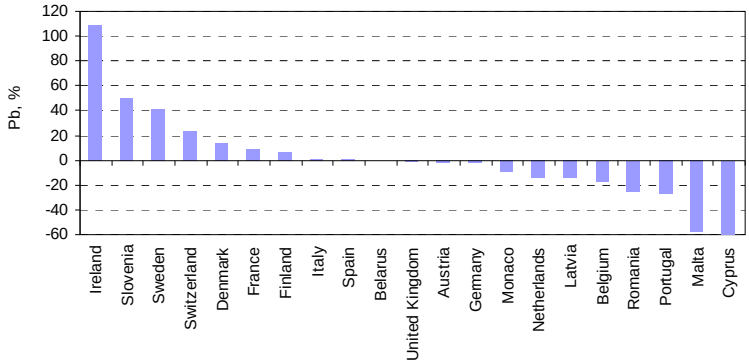


Fig. 2.3. *Maximum relative changes in lead official emissions after the recalculations*

Cadmium. For Austria, Belarus, Cyprus, Denmark, Germany, Italy, Ireland, Malta, Monaco, Portugal, Spain, Sweden, Switzerland and the United Kingdom the changes of emission estimates were less than ±10% (Fig. 2.4). In Romania the changes exceeded 100%. Cadmium emissions were increased about 3.7 times for 2005. The maximum emission decrease after the recalculation was 43% for the Netherlands in 1996.

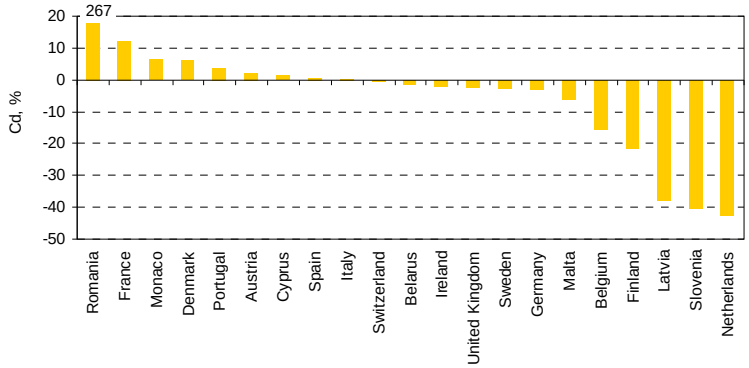


Fig. 2.4. *Maximum relative changes in cadmium official emissions after the recalculations*

Mercury. For Austria, Belarus, Denmark, France, Germany, Ireland, Italy, Malta, Monaco, Spain, Sweden, Switzerland and the United Kingdom the changes of emission estimates were less than ±10% (Fig. 2.5). For Finland and Romania the changes exceeded 100%. Finnish and Romanian emissions of mercury were increased about 3 times for 1999 and 2005, respectively. The highest decrease of emissions after recalculations was about 54% for Latvia in 2005.

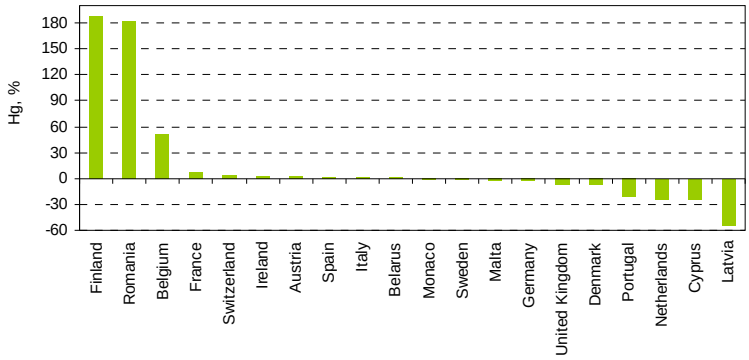


Fig. 2.5. *Maximum relative changes in mercury official emissions after the recalculations*

Emissions of heavy metals by source categories

Official data on heavy metals emissions by source categories in 2006 are available for 31 countries. Below the emission splitting by sectors was aggregated for Europe as a whole (based on the data from 31 countries).

Figure 2.6 shows relative contribution of different source categories to total emission of lead, cadmium and mercury from 31 European countries in 2006. *Manufacturing industries and construction* is the largest contributor (36%) to lead emissions in Europe (Fig. 2.6a). This sector is the largest source of lead for Belarus, Bulgaria, the Czech Republic, Finland, France, Hungary, Italy, Republic of Moldova, Poland, Slovakia, Spain and the United Kingdom. The next important emission sectors are *metal production* (26%) and *road transportation* (13%).

The largest contribution to the total cadmium emissions is also made by *manufacturing industries and construction* (38%; Fig. 2.6b). This sector is the most significant source of cadmium for Belarus, Bulgaria, Finland, France, Ireland, Italy, Republic of Moldova, Portugal, Slovakia, Spain, Switzerland and the United Kingdom. The second most important sector for cadmium emissions is *residential combustion* (18%) which is followed by *metal production* (13%).

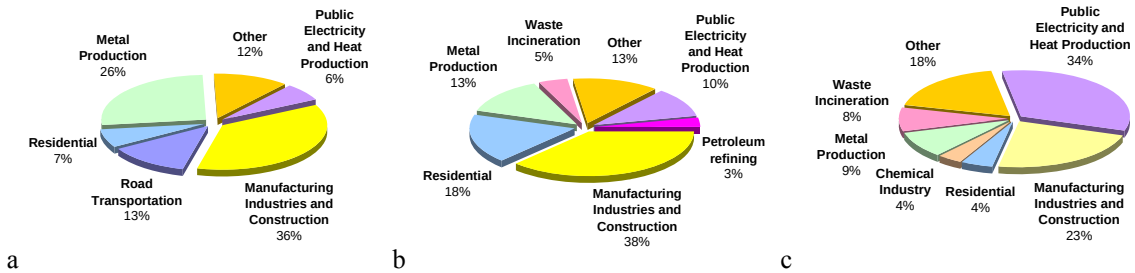


Fig. 2.6. *Relative contribution of source categories to total emission of lead (a), cadmium (b) and mercury (c) from European countries in 2006*

Public electricity and heat production the most significantly contribute (34%) to the total mercury emissions in Europe (Fig. 2.6c). This sector is the most important for Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, France, Germany, Lithuania, Malta, Monaco, the Netherlands, Poland, Romania, Slovenia, Spain, Sweden and the United Kingdom. The second contributor is *manufacturing industries and construction* (23%). This sector is the largest source of mercury in Belarus, Croatia, Ireland, Italy, Portugal and Slovakia.

2.2. Input emission data for modelling

In order to provide European countries with data on depositions, concentrations and source-receptor relationships, MSC-E needs emission data from all EMEP countries. The emission data used for modelling of 2006 were based on officially reported information from the EMEP Centre on Emission Inventories and Projections (CEIP) [http://www.emep-emissions.at/ceip/]. For countries, which official data are not available, emission totals for 2006 were estimated by interpolation between 2000 and 2010 of non-official estimates and projections made by the Dutch TNO institution [*Denier van der Gon et al.,* 2005]. Total emissions of lead, cadmium and mercury for 2006, derived through this combination of official data and non-official estimates were around 4860, 290 and 240 t/y, respectively.

The information about spatial distribution of heavy metals emissions at least for one year of the period 1990-2006 was provided by 26 countries (Austria, Belarus, Belgium, Bulgaria, Croatia, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Monaco, the Netherlands, Norway, Poland, Portugal, the Russian Federation, Slovakia, Spain, Sweden, Switzerland, the United Kingdom). Among them 20 countries (underlined) have submitted gridded emission data by sectors. For the first time, the gridded emission data have been reported by Croatia and Portugal. Denmark, Norway and Sweden presented information on spatial distribution of heavy metals emissions from sea transport.

Cooperation with EECCA countries, in particular, the Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) is one of the priority tasks under the CLRTAP. Due to the extension of the EMEP domain eastward territories of the Central Asian countries are entirely covered by the model grid (Fig. 2.7). Besides, significant part of the Asian part of Russia were also included into the EMEP domain. Pilot calculations of lead over the extended EMEP grid were carried out in 2007 [*Ilyin et al*., 2007]. This year the calculations of transboundary pollution over the new EMEP domain include all three priority heavy metals (Pb, Cd and Hg).

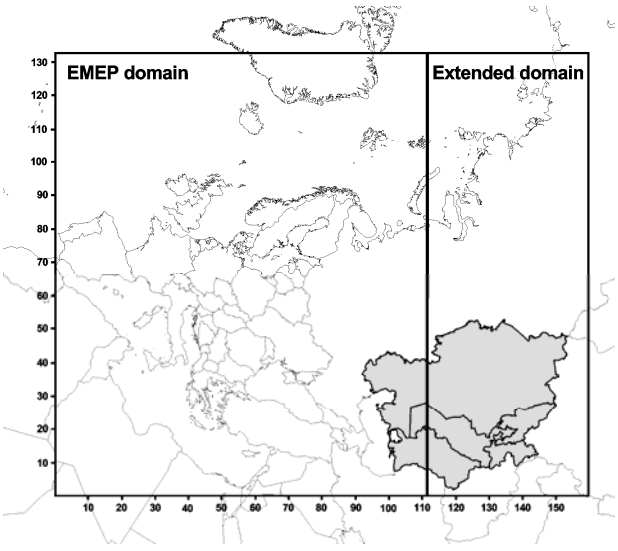


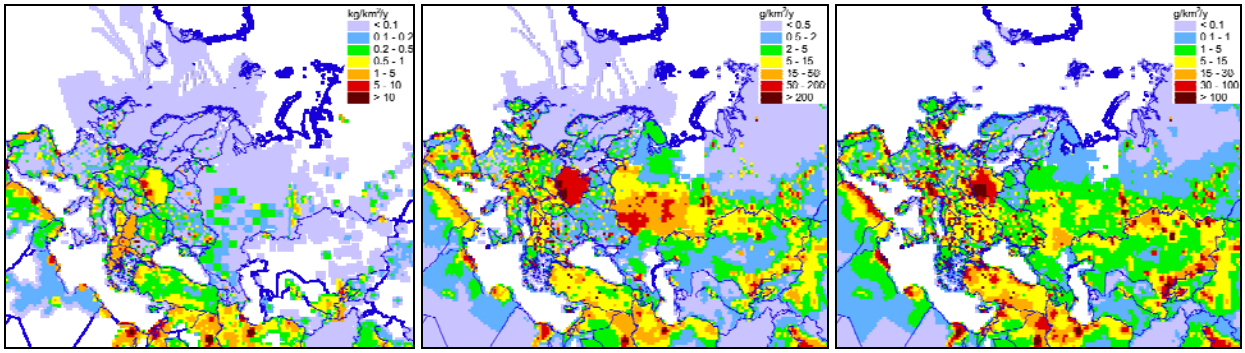
Fig. 2.7. *Extension of the model domain*

In order to fill in the extended part of the EMEP domain with emission data for modelling purposes, non-official estimates by TNO [*Denier van der Gon et al*., 2005], global lead emission inventory [*Pacyna et al*., 1995; http://www.ortech.ca/cgeic/index.html] and global mercury emission inventory [*Pacyna et al*., 2006; http://amap.no/Resources/ HgEmissions/] were used. Particularly, lead emission totals for Kyrgyzstan for 2006 are based on the TNO emission data using the interpolation between

2000 and 2010. Lead emissions in Kazakhstan are derived from the information, unofficially provided by national experts. Lead emissions in Turkmenistan, Tajikistan and Uzbekistan for 2006 were derived from the global inventory for 1990 expecting the same emission reduction in these countries between 1990 and 2006 as in the Russian Federation according to the EMEP official data. Emissions of lead from the Asian part of Russia was assessed using official emission data for the European part of the country and keeping ratio between the European and Asian parts derived from the global lead inventory. Besides, the global emissions data were also used for the other Asian and African countries, falling partly or fully into the modelling domain, assuming the same emission reduction between 1990 and 2006 as for Turkey. Turkey was selected for this purpose because it is the only country located in Asia, for which TNO estimates of lead emission changes are available. Spatial distribution of lead emissions from all these countries was obtained by interpolation of the global gridded emissions with 1°×1° spatial resolution into the model grid.

Mercury emissions for Turkmenistan, Tajikistan, Uzbekistan, Kazakhstan, Kyrgyzstan, the Asian part of Russia, and Asian and African countries were derived from global mercury inventory for 2000 [*Pacyna et al.*, 2006]. It was assumed that the emissions were constant between 2000 and 2006. Because of the absence of any global emissions inventory for cadmium, emissions data for this heavy metal in non-EMEP countries were derived from the global mercury inventory as the most recent heavy metal emission dataset. For this purpose, cadmium emission was assumed to be proportional to emission of mercury with a coefficient depending on a region: $E_{Cd} = \alpha \cdot E_{Hg}$. For eastern part of Russia the proportionality coefficient (α) was taken the same as for the European part (1.14). The coefficient for the three Central Asian countries was assumed to be the same as that for Kyrgyzstan (0.56). For other Asian countries and Africa the coefficient was taken equal to that for Turkey (0.91). Keeping in mind high uncertainty of this approach the derived emissions data can be considered as a pilot dataset for research purposes. To improve quality of emissions data in the Central Asian region close co-operation with national experts is required.

Spatial distributions of lead, cadmium and mercury emissions used in the modelling are shown in Fig. 2.8. Temporal and vertical distribution of the emission data and speciation of mercury emissions, employed in the MSCE-HM model, are described in [*Travnikov and Ilyin*, 2005].



a b c

Fig. 2.8. *Spatial distribution of lead (a), cadmium (b) and mercury (c) emissions over the extended EMEP domain in 2006*

3. MODEL DEVELOPMENT

This Chapter is focused on MSC-E activities in the field of development and improvement of regional and global scale atmospheric transport models. Significant efforts this year were undertaken on development of common EMEP global modelling system in close collaboration with MSC-W. Along with this, MSC-E performed a number of improvements of the regional heavy metal model in accordance with recommendations of the TFMM [*ECE/EB.AIR/GE.1/2006/4*]. Particularly, the Centre has completed transition from NCEP/DOE to the ECMWF data as meteorological input for the regional modelling. A short analysis of the modelling results sensitivity to different sets of meteorological data is presented below. Besides, preliminary analysis of the model sensitivity to refining the vertical grid structure was also performed.

3.1. Development of EMEP global modelling framework

A number of tasks under the scope of the LRTAP Convention cannot be solved within the regional bounds and requires consideration on a global scale. Particularly, it was recognized that specially for ozone, mercury, and some POPs, there is a clear need to consider their transport globally. For long-lived components, like mercury and POPs, global dispersion of pollution in the atmosphere is substantial and even for ozone, episodic intercontinental transport as well as convection in the Tropics becomes relevant process to take into account for an accurate description of the pollution levels in the free troposphere. Even application of hemispheric modelling approach leads to the uncertainties in the description of pollution levels near the equator due to necessity of definition of boundary conditions. This is particularly important for the Southeast Asia which growing economic development and increase of emission levels in recent years makes it an important source of pollution for other regions of the globe.

Another aspect requiring development of a global approach is connected with extension of the EMEP domain in order to include all EECCA countries into routine calculations. As it is known some of these countries (particularly, Central Asian countries) are located partly or completely outside the boundaries of the traditional EMEP domain. An interim solution of this problem developed and implemented this year consists of extension of the standard EMEP 50x50 km grid eastward in the polar stereographic projection to cover the Central Asian countries. However, this quick interim solution has a number of drawbacks. First of all, the considered countries of Central Asia are contiguous with other Asian countries (China, India, Pakistan, Iran etc.) significantly affecting pollution levels over their territories. Besides, even the extended EMEP domain only partly covers territory of one of the EMEP countries – the Russian Federation. Elimination of these drawbacks requires further extension of the scope to the pan-Eurasian continental scale that should be done more properly with the global modelling approach. Therefore, development of a common EMEP global modelling system appears to be highly motivated.

Following recommendations of the EMEP Bureau [*ECE/EB.AIR/GE.1/2007/9*] MSC-W and MSC-E have started work on gradual development of the common EMEP global modelling system. According to the adopted workplan the Centres at the current stage concentrated their efforts on collection and evaluation of various input data (meteorological data, emissions, land-cover etc.) for the global modelling system and testing the available atmospheric transport modules within the framework of Task Force on Hemispheric Transport of Air Pollution (TF HTAP). Details of the Centres work on development of the EMEP global modelling framework is described in a joint MSC-W and MSC-E Technical report [*Tarrason and Gusev*, 2008]. A short summary of MSC-E activity in this field is presented below.

General overview of the global modelling framework

A significant challenge to development of a common EMEP global modelling system is connected with necessity to cover different pollutants under consideration within the CLRTAP such as sulphur and nitrogen compounds, ozone, PM, heavy metals and POPs. These pollutants are characterized by distinctive physical and chemical properties and different behaviour in the atmosphere and other environmental media. Therefore, the modelling system should provide appropriate means for simulation of different pollutants taking into account their peculiar properties. For instance, modelling sulphur and nitrogen compounds as well as ozone should take into account their extensive atmospheric chemistry, PM modelling requires detailed consideration of aerosol dynamics, whereas simulation of mercury and POPs cycle in the environment should include various media (atmosphere, soil, seawater etc.)

Taking into account wide variety of possible applications the global modelling system is to be flexible in definition of the model domain and spatial resolution. Simulations of the global pollutant dispersion and the intercontinental transport require the global coverage, whereas for regional or local applications the model domain can be restricted by the area of interest with higher spatial resolution with possible nesting procedure. On the other hand, long-term calculations of some pollutants (e.g. POPs, mercury) accumulation in the environment can be performed with relatively low spatial resolution because of lack of detailed historical input data.

As it was mentioned above, model simulation of current pollution levels and temporal trends of some of the considered pollutants (mercury and POPs) should include their cycling and accumulation in various environmental media: atmosphere, soil, ground water, vegetation, seawater. Along with atmospheric dispersion long-range transport of these substances should also include dispersion with sea currents in the ocean.

The modelling system should be efficient enough from the computational point of view to be applicable for calculations of long term trends and source-receptor relationships of the pollution both on regional and global scales. In practice, it implies efficient architecture of the model code and application of the parallel computation technique.

Variety of the model applications and considered pollutants could lead to unreasonable complexity of the modelling system and inconvenience of its usage and development. On the other hand, some functionality of the system can be unutilized or redundant in particular applications. For example, use of multi-media approach can be unnecessary for modelling atmospheric transport of particular matter, whereas detailed ozone chemistry or aerosol dynamics can be excessive for long-term simulations of POPs accumulation in the environment. To avoid this excessive functionality the modelling system should be flexible enough to include or exclude certain processes for particular model application.

Taking into account all aspects mentioned above, general requirements to the EMEP global modelling system can be formulated as follows:

- Multi-pollutant modelling system providing appropriate means for simulation of substances with different properties
- Variable model domain and spatial resolution
- Applicability of the multi-media approach
- Computational efficiency
- Flexible model structure

Practically, the mentioned above flexibility can be realized in the form of the *modelling framework* with easily connected functional modules. The modules should be as much isolated as possible and contain well specified interfaces to provide simple means for their disconnection or replacement. In particular, it will allow opportunity to have several versions of some modules with different levels of complexity and select the most appropriate ones for particular scientific tasks. On the other hand, this flexibility does not contradict the requirement to have a standard version of the modelling system for regular EMEP calculations.

Meteorological driver

Preparation of the meteorological input data necessary for evaluation of pollution levels at global scale is an essential part of the work plan on the development of the EMEP global modelling framework. It was agreed that the preparation of the required set of meteorological data should be based on the appropriate meteorological driver generating a set of the parameters consistent in space and time. The requirements for the selected meteorological drivers are as follows:

- capability to provide a consistent set of required meteorological parameters on a global scale;
- flexibility in usage of different driving meteorological input data (e.g. ECMWF, NCEP/DOE etc.);
- possibility to generate meteorological information with different spatial resolution.

Along with that additional features like possibility of data assimilation, spatial nesting, availability of source code and support, possibility of selection of different parameterizations of physical processes are also of importance. Above all, the meteorological data should be easily accessible for both Centers. It was planned to perform the testing of several currently available global scale meteorological models, in particular, GEM of the Environment Canada, PUM of the UK Met Office, ECMWF IFS, and WRF of the US EPA. For the driving meteorological input it was agreed to use meteorological analyses of ECMWF.

Following the work plan the MSC-E performed evaluation and testing of the Canadian forecasting and assimilation system GEM. In accordance with the evaluation procedure modelling results of the GEM for 2001 were compared with available measurements of selected meteorological parameters. Surface observations of daily precipitation amount from the Global Climate Observing System (GCOS) Surface Network [GSN; www.gosic.org/gcos/GSN-data-access.htm] were used to evaluate the precipitation fields. Upper-air observations from Radiosonde Database (RAOB; http://raob.fsl.noaa.gov) were used for the comparison of computed and observed data on pressure levels. Precipitation amount calculated by the GEM model was also compared with the combined precipitation dataset for 2001 prepared by the GPCP project and based on the blending of rain gauge observations and satellite data [*Rudolf et al.,* 1994; http://cics.umd.edu/~yin/GPCP]. Along with the comparison with measurements the spatial distribution of selected parameters was analyzed using the data of meteorological re-analyses ECMWF ERA-40 and NCEP/DOE.

Annual precipitation amount simulated by GEM for 2001 is presented in Fig. 3.1 in comparison with the GPCP data. It can be seen that general pattern of annual precipitation amount looks rather similar. At the same time there are some differences. In particular, GEM simulates considerably more precipitation in the tropics over the Indian Ocean and the South China Sea. On the other hand, GEM predict lower precipitation amount over South America. It should be noted that the difference between the two datasets is more significant over the oceans where the GPCP dataset is merely based on satellite remote sensing data and, therefore, is of less value of confidence.

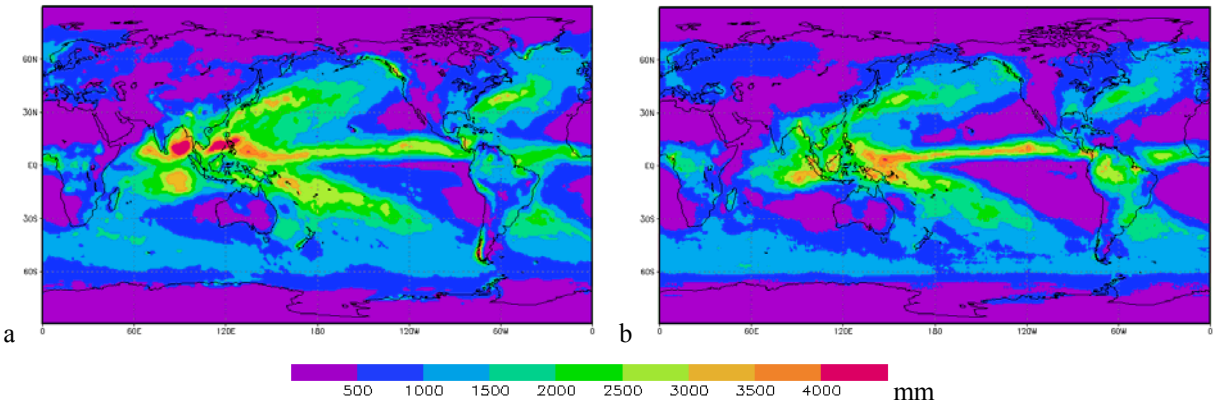


Fig. 3.1. *Spatial distribution of annual precipitation amount in 2001 simulated by GEM model (a), and from the GPCP dataset based on direct measurements and satellite data (b).*

Figure 3.2 presents scatter plots of the comparison of precipitation amount, surface air temperature and near-surface wind speed simulated by GEM and measured at GSN and RAOB sites. As seen GEM reasonably described global scale distribution of annual precipitation amount (Fig. 3.2a). The spatial correlation of observed and calculated precipitation is estimated at 0.88. There is a slight overestimation of observed precipitation amount by the modelling results. The calculated surface air temperature well agree with the observed values (Fig. 3.2b). In particular, the difference between the mean values of air temperature calculated by the model and observed at the RAOB sites is rather small and the spatial coefficient is as high as 0.97. On the other hand, correlation between the modelled and observed near-surface wind speed values is somewhat lower (correlation coefficient is 0.64). On average, the model tends to underestimate the measured wind speed by approximately 25% (Fig. 3.2c). The most significant underestimation takes place for the sites located in low and mid latitudes (North and South America, Northern Africa, and South Asia). The values of wind speed calculated for the Europe and East Asia are slightly overestimated.

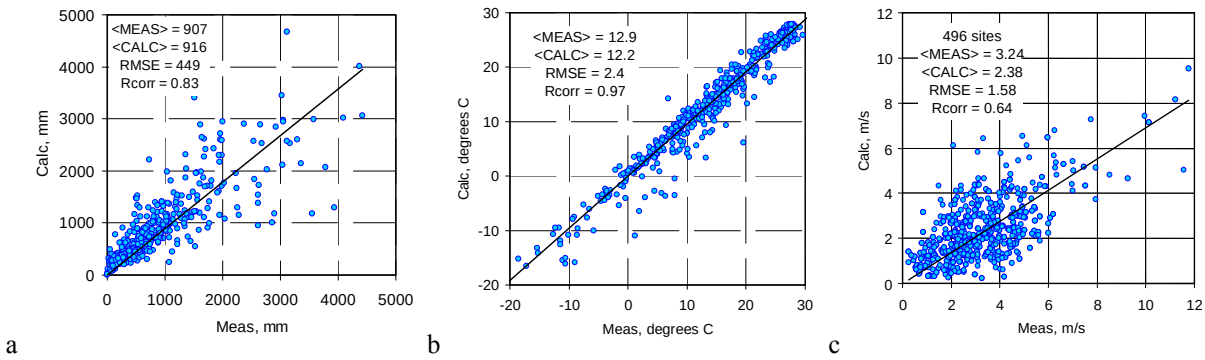


Fig. 3.2*. Scatter plots of comparison of simulated with GEM and measured annual precipitation amount (a), annual mean surface air temperature at 2 m height (b) and annual mean wind speed at 10 m height (c) in 2001*

An example of the comparison of vertical profiles of calculated annual mean magnitudes of wind speed produced by GEM with measurements at RAOB sites for 2001 is shown in Fig. 3.3. The first diagram presents the averaged vertical distribution of wind speed measured at the RAOB sites and calculated by GEM. Additional diagrams of the figure contain the vertical distributions of the statistical parameters calculated on the basis of model results and measurements. It can be seen that GEM simulation results are rather close to the measurements up to the height of 300 hPa. Some underestimation (up to 1.5 m/s) of the observed values by the model takes place at the heights 200-

300 hPa and above 50 hPa, while near the ground and close to the tropopause the bias becomes negligible. The correlation coefficients is the minimum in the surface layer (down to 0.6), whereas in the free atmosphere it does not fall below 0.8.

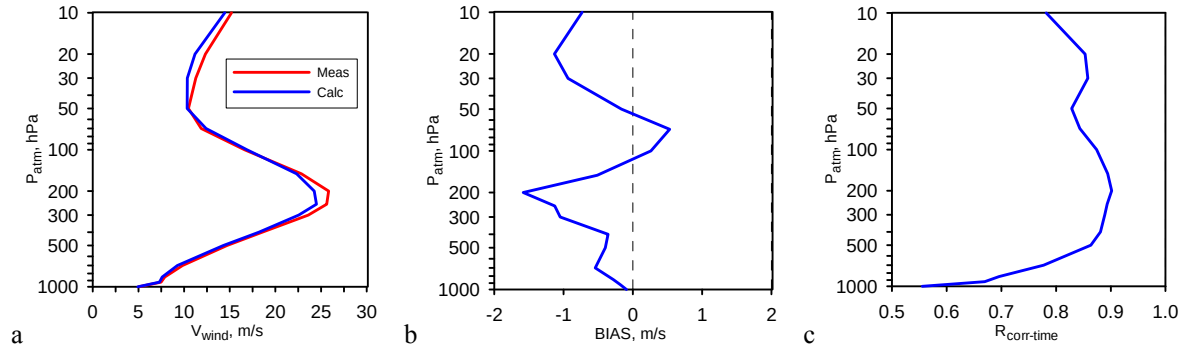


Fig. 3.3*. Comparison of annual mean wind speed profiles for 2001 calculated by GEM with measurements from the RAOB database: (a) – average vertical profile over all sites; (b) – vertical distribution of the absolute bias; (c) – temporal correlation coefficient*

Figure 3.4 presents an example of comparison of measured and modelled meteorological parameters at one of measurement sites (#2836) located in Finland. As seen from the figure the predicted variations of the surface air temperature are in good agreement with measured ones. The model well reproduces both the seasonal and in many cases the diurnal temperature variation. However, in winter the model tends to overestimate extremely low values of the temperature. Correlation between the calculated and observed 12-hour values is rather high (0.94). Computed daily variations of precipitation amount also reasonably agree with measured values. At the same time, the correlation coefficient between the modelling results and observations in this case is lower (0.5). Wind speed components computed for this site by GEM also satisfactory reproduce the observed values. The values of the bias and the root mean square error are quite low. Besides, the correlation coefficient in this case is also quite significant (0.73 for the zonal and 0.86 for the meridional components, respectively).

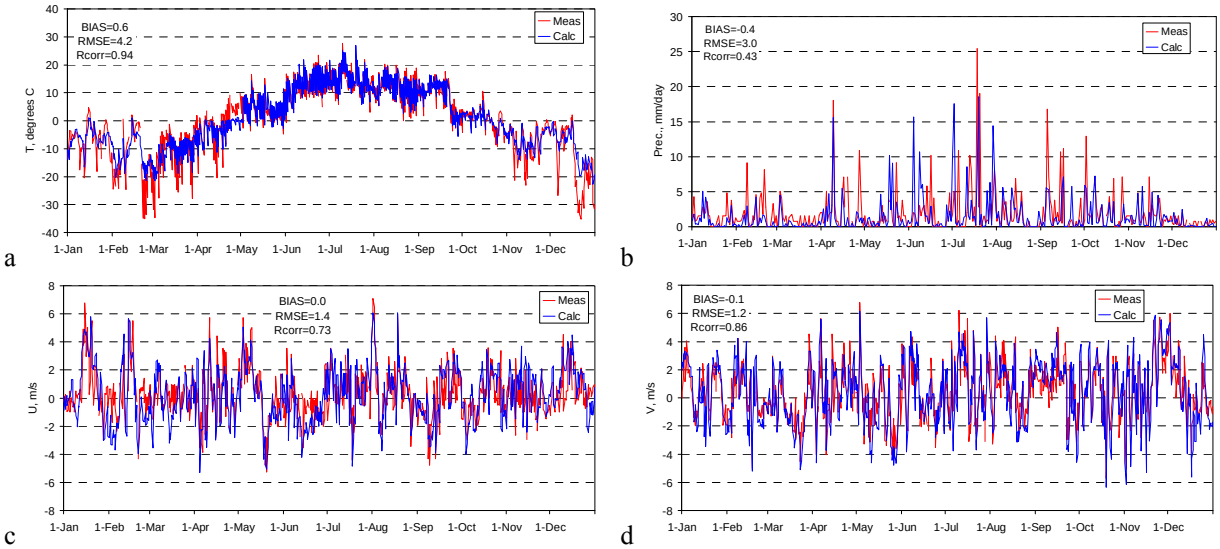


Fig. 3.4*. Comparison of air temperature at 2 m (a), precipitation amount (b), zonal (c) and meridional (d) components of wind calculated by the GEM model with measurements at the meteorological site #2836 (Finland) in 2001*

The MSC-E has also started evaluation of the recently developed global version of the WRF meteorological model of the US EPA. However, since the evaluation and testing of this model performance is at the very preliminary stage, results of the analysis and comparison with other selected models will be reported later.

Geophysical data

The geophysical information is important part of model input data required in many model parameterizations. These data include information on land use and land cover (LU/LC), leaf area index (LAI), surface temperature and wetness, and soil properties. Surface characteristics and vegetation cover significantly affect the air-surface interaction of air pollutants and their atmospheric transport. Thus the use of accurate and detailed information on underlying surface properties is of importance for modelling of air pollution transport on global and regional scales.

At the current stage of data compilation four land cover datasets were selected: UMD, USGS GLCC, GLC2000, and MODIS Land Cover products. These datasets differ in several aspects. The UMD and USGS GLCC land cover data are based on the satellite measurements obtained using AVHRR instruments. MODIS land cover products and GLC 2000 were prepared on the basis of information from more efficient instruments. The actual measurements were performed in the different time periods. Some differences can also be connected with the use of different methods which were applied for the processing and classification of satellite data.

To compare the selected datasets their land cover classes were aggregated into three groups: (1) forests of all types, (2) cropland areas, (3) urban and built-up areas. Aggregated information was correlated between the selected datasets. In addition the areas covered by these three aggregated groups of land cover types were compared. Figure 3.5 illustrates spatial distribution of the fraction of 1°x1° grid cells covered by forests in accordance with the selected datasets. In general, the distribution of forests in four datasets looks quite similar. Spatial correlation between different datasets is significant (correlation coefficient for each pair is about 0.85). At the same time some differences can be seen in north-eastern part of Russia, in India, and in central Africa, especially between the MODIS database and others.

Figure 3.6 shows total area covered by the three aggregated groups of land cover (forests, croplands, and urban and built-up areas). As seen from the figure the area covered by forests is more or less similar in all selected datasets: the difference does not exceed 40%. However, the areas covered by croplands and urban and built-up categories are essentially different. According to the GLC 2000 and USGS GLCC the area covered by croplands is as much as twice higher than the one of the UMD land cover. In case of urban and built-up LC type the area covered by this category in the MODIS dataset exceeds more than twice appropriate values in other datasets. The explanation of these differences requires further analysis and possibly will be included in following reports on the EMEP global model development.

The summary of the properties and peculiarities of the considered four global land cover datasets is presented in Table 3.1. All of considered datasets have their advantages and disadvantages which are reflected in the table.

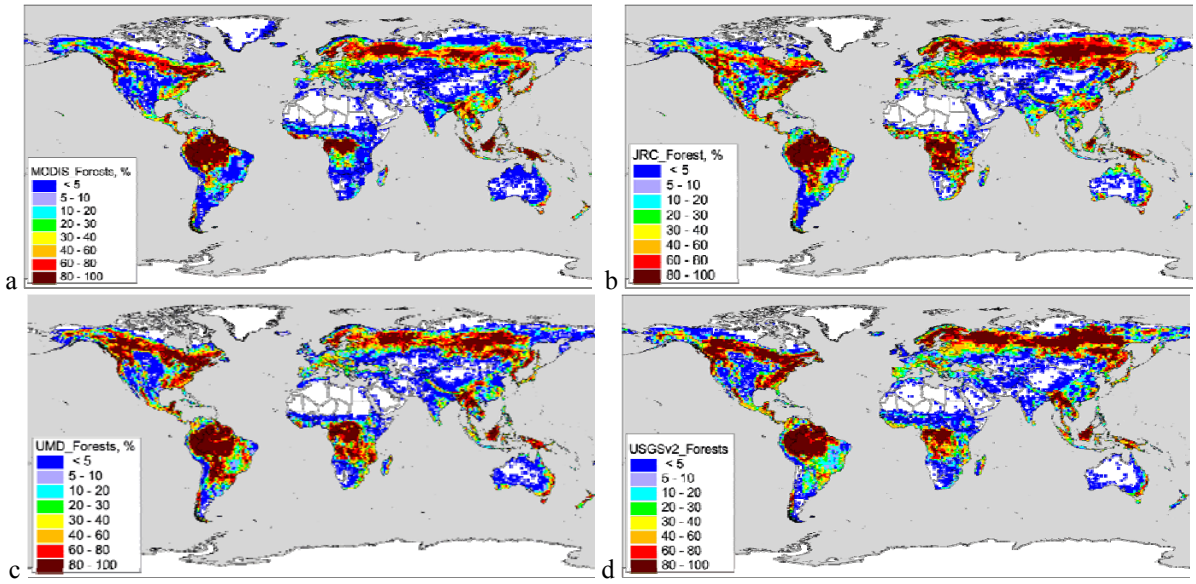


Fig. 3.5. *Spatial distribution of area fraction covered by forests of all types in 1°x1° grid according to the selected LC datasets: MODIS (a), GLC 2000 (b), UMD (c), and USGS GLCC(d)*

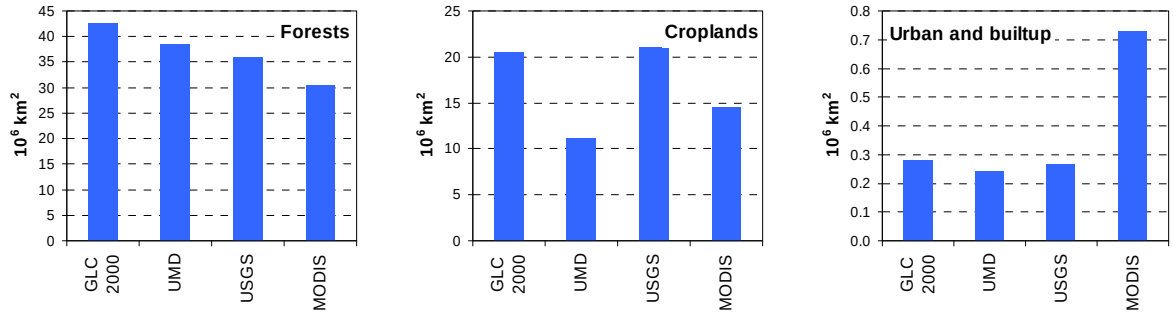


Fig. 3.6. *The area covered by aggregated categories in the selected LC datasets*

Table 3.1. *Summary of information on the considered four global land cover datasets (advantages and disadvantages of particular LC datasets are marked by plus and minus signs).*

LC dataset	Novelty	LAI included	Inclusion of mosaic classes	Different classifications	Peculiarities
MODIS	+	+	+	+	LC dynamics
GLC 2000	+	-	+	-	Lack of urban area in Eastern Asia
UMD	-	-	-	-	Lack of urban area in South America
USGS GLCC	-	+	+	+	Applied in WRF

It can be noted that MODIS Land Cover and GLC 2000 are the contemporary datasets produced on the basis of more efficient instruments and using more sophisticated methods of the analysis and classification of satellite measurements. MODIS Land Cover and USGS GLCC provide the possibility to use land cover information in several alternative classifications and contain spatial distribution of LAI. It can be noted that although providing another level of detail, the presence of mosaic classes in the land cover classification can potentially create some problems in interpreting the land cover type and subsequently necessary parameters for modelling.

The collection and preliminary analysis of Leaf Area Index (LAI) information is carried out in parallel with the work on land cover datasets. The leaf area index implies the ratio between the area of plant leaves (one-sided or projected) and the area of underlying surface. For modelling purposes it is important to use the geographically resolved LAI data. In addition the seasonal variations of vegetation cover should also be taken into account. At the current stage several sources of LAI information are considered including MODIS Land Cover, USGS GLCC, MEGAN, and NCAR CLM.

Emissions data

Heavy metals under consideration of environmental protection activity significantly differ in their properties and ability to long-range atmospheric transport. In particular, mercury is well known as a global scale pollutant with distinct ability to intercontinental transport. On the other hand, such particle bound heavy metals as lead and cadmium are mostly transported regionally. Therefore, mercury has the first priority for modelling on a global scale and requires global emissions data. Nevertheless, in many cases modelling other heavy metals also requires emissions data covering territories wider than the region of the primary interest. For example, lead and cadmium pollution levels in the EMEP countries and, in particular, in the EECCA countries can be affected by emission sources located in neighbouring non-EMEP countries of Northern Africa, Meddle East, Eastern and Southern Asia.

Although, there are detailed heavy metal anthropogenic emissions inventories developed for a number of regions (e.g. Europe, North America), global emission datasets are quite rare. Table 3.2 contains characteristics of available global emission datasets and inventories for some heavy metals. Global spatially resolved data on mercury emission are available for a number of years (1990, 1995, and 2000) and new dataset for 2005 is under development at the moment. The only gridded emission dataset for lead relates to 1990. The lead emissions inventory has been updated for mid-nineties but these data has no spatial distribution. Only aggregated emission estimates without spatial distribution of emission sources are available for cadmium and relate to mid-nineties.

Table 3.2. *Available data on heavy metals anthropogenic emissions on a global scale*

Chemical	Period of time	Global emissions, t/y	Spatial resolution	Dataset location	Reference
Mercury	1990	2 144	1º×1º	CGEIC [(a)]	CGEIC website
	1995	2 317	0.5º×0.5º	AMAP [(b)]	*Pacyna et al.* [2003]
	2000	2 190	0.5º×0.5º	AMAP [(b)]	*Pacyna et al.* [2006]
	2005	in progress			
Lead	1989	167 889 – 206 435	1º×1º	CGEIC [(a)]	*Pacyna et al.* [1995]
	1995	119 259	n/a	n/a	*Pacyna and Pacyna* [2001]
Cadmium	1995	2 983	n/a	n/a	*Pacyna and Pacyna* [2001]

[(a)] http://www.ortech.ca/cgeic/index.html
[(b)] http://amap.no/Resources/HgEmissions/

Testing the atmospheric transport module

Taking into account evident limitations of the hemispheric approach for the atmospheric transport modelling of such long-lived pollutants as mercury and POPs and following the recommendations of the EMEP Bureau [*ECE/EB.AIR/GE.1/2007/9*] MSC-E has performed extension of the existing hemispheric model MSCE-HM-Hem on a global scale. The new global model is named as the Global EMEP Multi-Media Modelling System (GLEMOS). In spite of the fact that the new global model is

largely based on parameterisations of the well developed and tested hemispheric model, a number of principal modifications have been done to follow the general requirements to the global modelling system mentioned above. First of all, the model domain has been extended upward up to 10 hPa (ca. 30 km). Extension of the vertical coverage is required for modelling of atmospheric dispersion of long-lived substances on a global scale in order to avoid the need of setting boundary conditions at the upper boundary as well as to take into account possible stratosphere-troposphere exchange. Secondly, the spatial resolution of the model grid was refined down to 1°×1°. Configuration of the global model grid and vertical structure of the model domain is shown in Fig. 3.7. This global model or some parts of it are planed to be used for the developed common EMEP global modelling system.

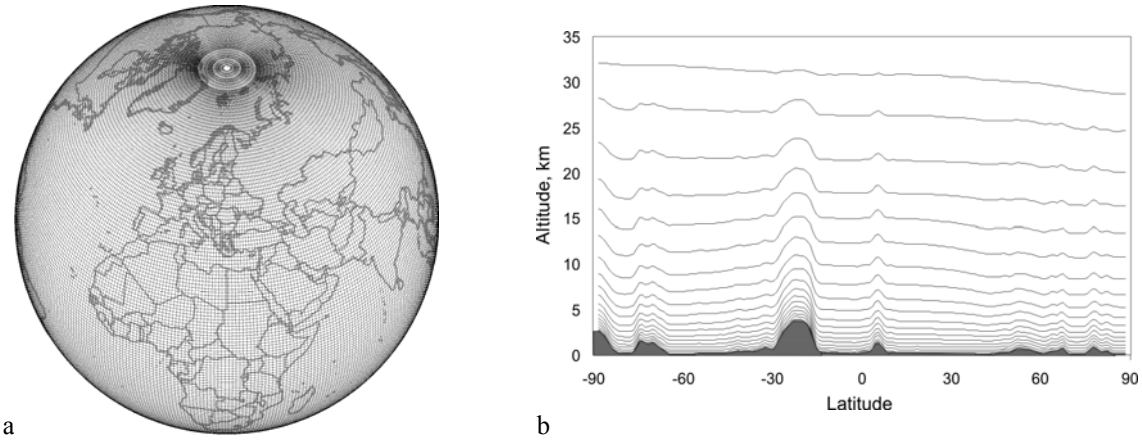


Fig. 3.7. *Configuration of the 1°×1° global model grid (a) and vertical structure of the mode domain*

Atmospheric transport module of the developed global modelling system was extensively tested within the models intercomparison study conducted under the Task Force on Hemispheric Transport of Air Pollution [TF HTAP; http://aqm.jrc.it/HTAP/]. Particularly, it has participated in the modelling experiment (TP1x) to simulate global dispersion of an artificial inert tracer. Four types of the artificial tracer have been simulated: CO-like passive tracer with the atmospheric life-time equal to 50 days and three alkane-like tracers with the life-times of 5.6, 13 and 64 days, respectively. Meteorological conditions were taken for the year 2001 and two global datasets for CO direct anthropogenic emissions and VOC anthropogenic emissions were used for CO-like and alkane-like tracers, respectively. Some results of the testing are presented below.

Figure 3.8 shows spatial distribution of the CO-like tracer concentration in the surface air simulated by GLEMOS (Fig. 3.8a) along with concentration distribution averaged over the all models ensemble (Fig. 3.8b) for comparison. As seen there is no noticeable difference between these two distribution fields indicating that the atmospheric transport module agrees in general with other transport models when simulating surface concentrations.

An example of the comparison of vertical distributions simulated by different models **is** presented in Fig. 3.9. The figure shows vertical profiles of the CO-like tracer at three selected locations - Vienna (Europe), West Point (North America), and Alert (Arctic). Coloured lines present simulation results by different models and the thick red line shows the GLEMOS results. As seen from the figure, in most cases the GLEMOS results are within the core wisp of the modelling profiles implying agreement with most other models.

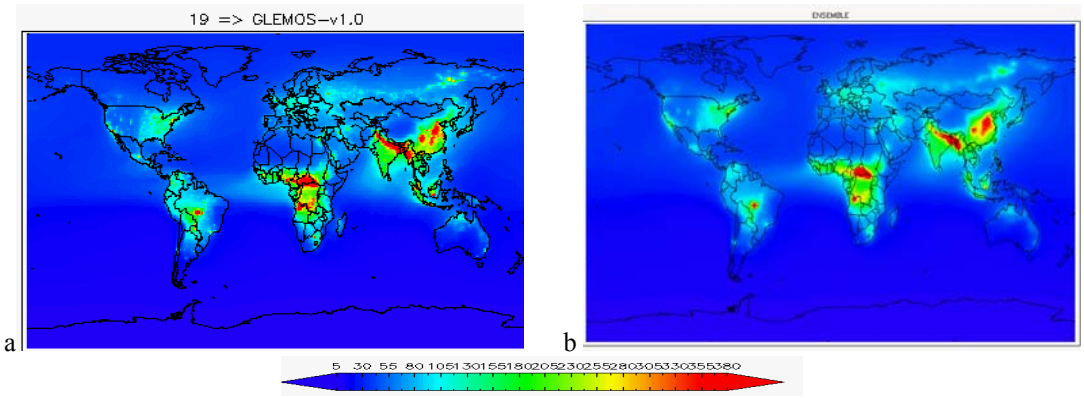


Fig. 3.8. *Spatial distribution of surface air concentration (in ppbv) of the CO-like tracer simulated by GLEMOS (a) and average over the models ensemble (b)*

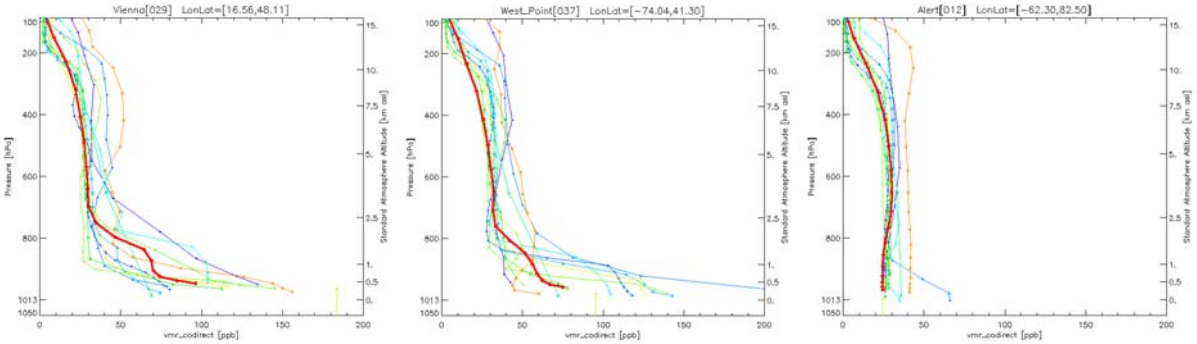


Fig. 3.9. *Vertical profiles of the CO-like tracer simulated by different models in selected locations: (a) – Europe (Vienna); (b) - North America (West Point); (c) – the Arctic (Alert). Thick red line shows GLEMOS simulation results*

To evaluate model performance in simulation of the intercontinental transport the participated models have conducted calculations of the tracer atmospheric dispersion separately from four selected source regions – Europe, North America, East Asia, and South Asia. Results of this simulation exercise are illustrated in Fig. 3.10. The diagrams show contribution of different source regions to average air concentrations of the tracer over various part of the globe simulated by GLEMOS (a) and the ensemble average (b). Each bar in the diagrams show average tracer concentration in particular receptor region, whereas different colours present relative contribution of the source regions. As seen modelling results obtain with GLEMOS are very similar to those in Europe, North America and East Asia. For South Asia GLEMOS predict somewhat higher concentration of the tracer, though relative contribution of the sources are mostly the same.

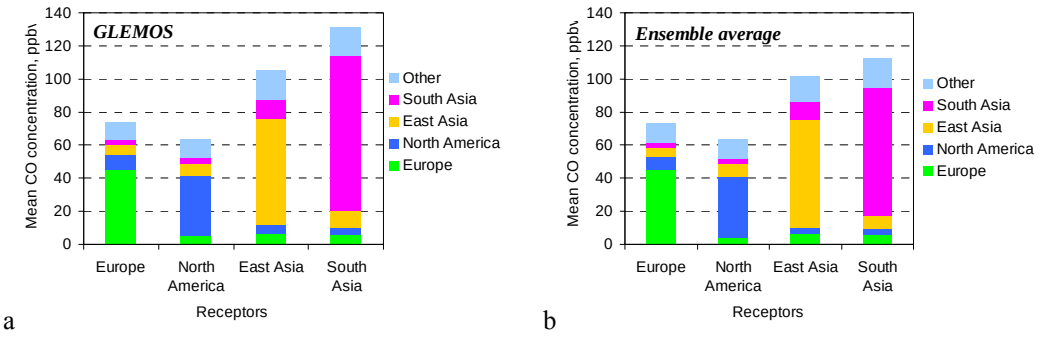


Fig. 3.10. *Contribution of different source regions to mean surface concentration of CO-like tracer in various parts of the globe: (a) – simulated by GLEMOS; (b) – ensemble average*

3.2. Transition from NCEP/DOE to ECMWF meteorological data

Meteorological information is one of the key input data for atmospheric pollution modelling. To supply MSCE-HM and MSCE-POP models with required meteorological data a meteorological pre-processor (MM5) was applied along with driving meteorological fields based on NCEP/DOE reanalysis [*Kanamitsu et al.*, 2002]. Aiming at improvement of the modelling results the Task Force on Measurements and Modelling (TFMM) has recommended MSC-E to move to the ECMWF data as a driving meteorological input. The transition from the NCEP/DOE reanalysis to the ECMWF analysis data has been initiated in 2007 [*Ilyin et al*., 2007] and has finished this year. This section presents a brief summary of the consistency analysis and sensitivity of the modelling results to replacement of the meteorological input. The whole analysis is presented in the Technical Report [*Gusev et al*., 2008].

To analyse quality of meteorological data based on the two driving datasets the generated meteorological parameters were compared against observations. Surface observational data were derived from the Computational and Information Systems Laboratory (CISL) Research Data Archive, supported by National Centre for Atmospheric Research (NCAR). This data set includes the land and marine reports received through Global Telecommunications System (GTS). For verification of upper-air parameters, namely air temperature and wind speed, the RAOB radiosonde observations were used. The RAOB dataset is developed jointly by National Climatic Data Centre (NCDC) and Forecast Systems Laboratory (FSL) and is freely available at site [http://raob.fsl.noaa.gov/]. It is based on reports available through GTS. Besides, precipitation amounts were compared with precipitation data obtained in the framework of GPCP project [*Rudolf et al*., 1994; http://cics.umd.edu/~yin/GPCP/].

Figure 3.11 shows comparison of generated meteorological parameters averaged over the model domain with mean measured values. As seen annual variation of mean surface air temperatures simulated by MM5 on the base of ECMWF and NCEP/DOE data is very close - the difference between two datasets does not exceed 1°C. Compared to the observational data, MM5 tends to slightly underestimate surface air temperature by about 1°C. Monthly mean wind speed generated on the base of ECMWF and NCEP/DOE agree within ±5% (or ±0.5 m/s in absolute values) over the most part of the extended EMEP domain. MM5 tends to overpredict the observed wind speed by around 10%, particularly, in winter. Short-term temporal variability of wind speed is reasonably well reproduced by MM5: the correlation coefficient between 6-hour predicted and observed time series is higher than 0.6 over most of stations. Monthly mean precipitation amounts averaged over the model domain agree within ±10%. However, over dry or arid areas (Sahara, the Mediterranean Sea) as well as over mountainous regions the bias can be higher. Relatively low discrepancy (below 25%) was obtained for the eastern part of Europe, north of Kazakhstan and Scandinavia. Over central part of Europe and northern Atlantic the bias can reach ±50%.

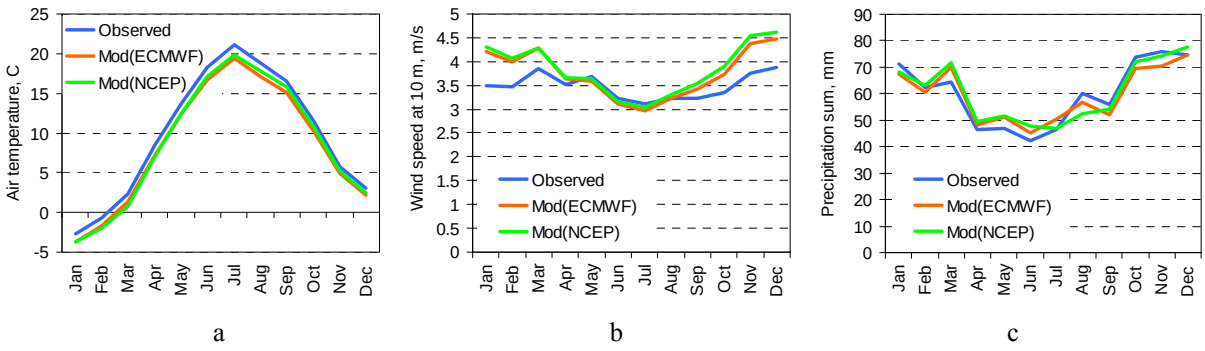


Fig. 3.11. *Annual variations of average air temperature at 2 m (a), surface wind speed at 10 m (b), and precipitation amount (c) over the extended EMEP domain in 2006*

Summarizing the carried out analysis it is possible to conclude that over most part of the extended EMEP domain discrepancies of major meteorological parameters (air temperatures, wind speeds and precipitation amounts) generated by MM5 using two different driving meteorological datasets (ECMWF and NCEP/DOE) are insignificant. This relates to both their annual mean values and temporal variability. Noticeable differences are indicated for some particular areas (e.g. coastal zones, mountainous regions etc.)

To evaluate sensitivity of modelling results to different sets of driving meteorological data surface concentration and depositions of lead and mercury simulated with the MSCE-HM model were analyzed and compared with measurements. The use of ECMWF data resulted in somewhat higher concentrations over the most part of Europe and the marginal seas (the Mediterranean Sea, the Black Sea, north-east of the Atlantic etc.) Relative bias between mean annual air concentrations of lead over the European and Central Asian countries is 2.6%, over the Atlantic – around 10%, over the Mediterranean sea – almost 15% (Fig. 3.12a). Over some areas the bias can exceed ±25%. Over the Arctic and some regions of Central Asia the concentrations based on ECMWF data are lower, compared to those based on NCEP/DOE data.

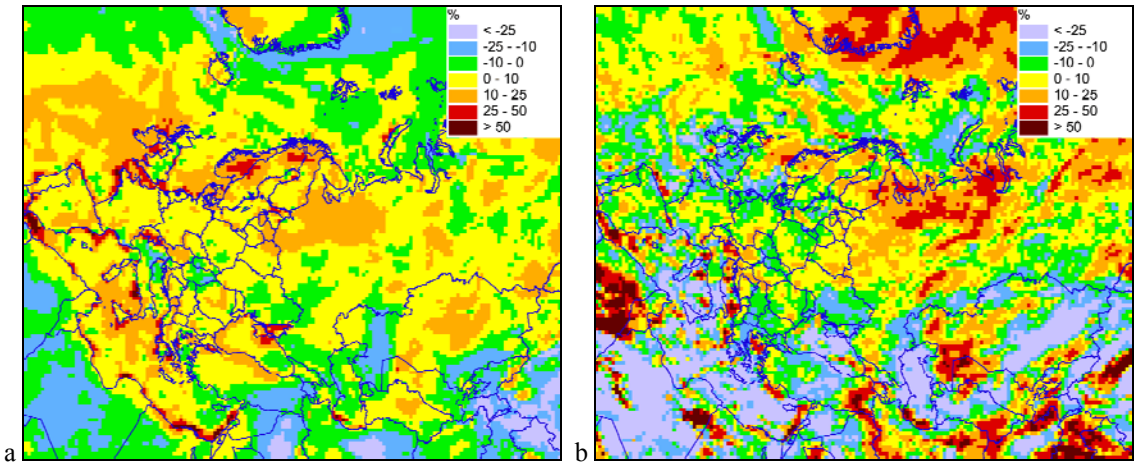


Fig. 3.12. *Relative differences for annual mean air concentrations (a) and total depositions (b) of lead, computed on the base of ECMWF and NCEP/DOE datasets*

Relative bias between atmospheric depositions simulated with the two meteorological datasets mostly does not exceed ±10% over Central and Western Europe (Fig. 3.12b). The depositions based on ECMWF data are on average by 0.7% lower over European and Central Asian countries, and about 1% higher over the Atlantic than those based on NCEP/DOE data. In some regions, e.g. over the eastern part of Europe, the Arctic, north of Atlantic and the western part of Kazakhstan ECMWF-based depositions exceed by 25-50% those based on NCEP/DOE re-analysis, whereas over the Mediterranean, Caspian and Black Seas, the British Isles, and east of Kazakhstan the situation is opposite.

Results of the presented above analysis are applicable in general to other particle-bound heavy metals (cadmium, chromium, nickel, cupper etc.). Unlike these metals, mercury is characterized by much longer atmospheric life time, and by occurrence in the atmosphere in different physical-chemical forms. Therefore, similar comparison was also carried out for concentrations of total gaseous mercury and total mercury depositions.

Annual mean TGM concentrations simulated by the model based on the two meteorological datasets agree within ±1.5%. This small difference is explained by significant influence of global (non-EMEP)

sources on TGM levels within the EMEP domain. Depositions of mercury are mainly formed by gaseous oxidized and particulate forms of mercury. Therefore, spatial distribution absolute values of the relative bias for annual depositions of mercury is similar to those of lead.

Figures 3.13-3.15 show comparison of modelling results obtained with two compared driving meteorological datasets against measurements. As seen the relative difference between two modelled sets of annual mean air concentration of lead is not significant (Fig. 3.13). On average, the concentrations based on ECMWF are 7% higher than those based on NCEP/DOE. Besides, when ECMWF input data are used, the model tends to simulate somewhat higher concentrations in precipitation and wet deposition fluxes compared to the case when NCEP/DOE data were involved (3.14). The average difference between the concentrations in precipitation at the stations is around 10%, and for wet deposition fluxes – 2.5%. The both modelled concentrations are lower than measured ones. Therefore, higher concentrations calculated with the use of the ECMWF data compared to those based on the NCEP/DOE re-analyses, favours better agreement between measurement and modelling results.

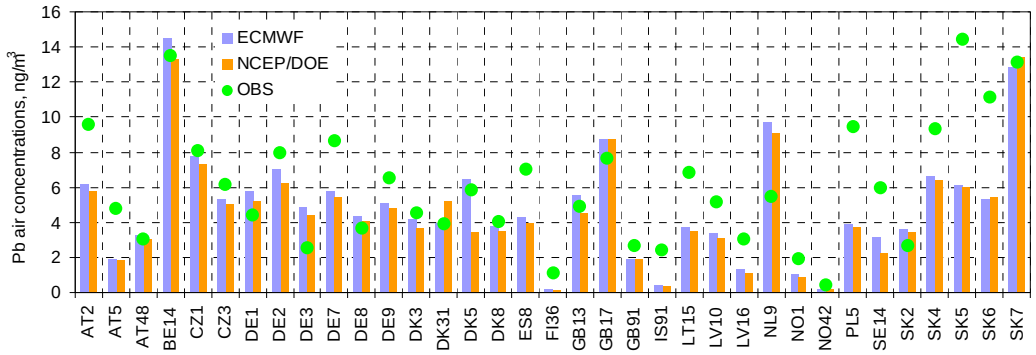


Fig. 3.13. *Comparison of annual mean air concentrations of lead modelled on the base of ECWMF and NCEP/DOE datasets with observations at EMEP stations in 2006*

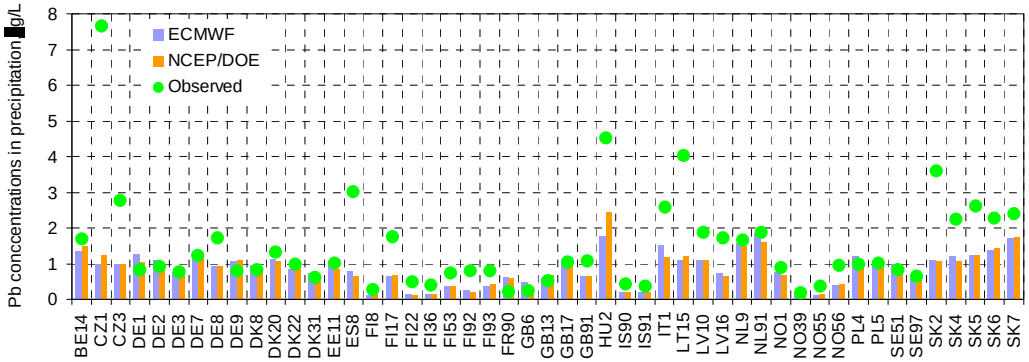


Fig. 3.14. *Comparison of annual mean concentrations of lead in precipitation modelled on the base of ECWMF and NCEP/DOE datasets with observations at EMEP stations in 2006*

As seen from Fig 3.15 the bias between annual mean mercury concentrations in precipitation simulated with to meteorological datasets does not exceed 20% for most of stations. Similar to lead, the use of ECMWF input data leads to higher concentrations in precipitation (ca. 13% on average) compared to NCEP/DOE re-analysis. In its turn, this leads to somewhat better agreement between the modelled results and observations. More detailed evaluation of the modelling results against measurements is presented in Chapter 4 of this report.

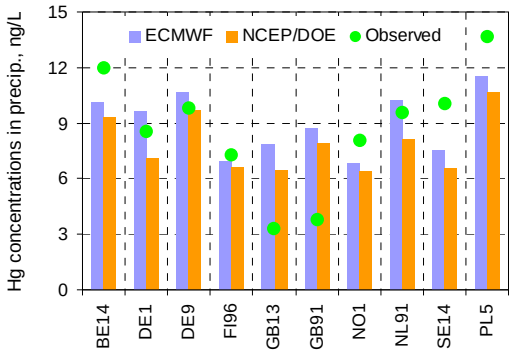


Fig. 3.15. *Comparison of annual mean concentrations of mercury in precipitation modelled on the base of ECWMF and NCEP/DOE datasets with observations at EMEP stations in 2006*

3.3. Model sensitivity to refining of vertical grid structure

One of the recommendations of TFMM aiming at improvement of the MSCE-HM model performance was refining the vertical model structure by inclusion of lowest shallow layer [*ECE/EB.AIR/GE.1/2006/4*]. To evaluate the model sensitivity to this sort of refinement a number of experimental model runs were carried out. In the first model run (run #1) the standard vertical discretization of MSCE-HM model was applied. In the second run (run #2) the lowest layer of the model domain (around 70 m depth) was split in two almost equal sub-layers. The same changes in the vertical structure were carried out in the MM5 pre-processor in order to prepare meteorological input data for the run #2. In the standard version of the MSCE-HM model pollutants were emitted into three lowest model layers. It was assumed that the emission values entering the first (lowest) layer in the run #1 were split in two equal parts for the run #2. Obviously, total amount of lead, emitted into the atmosphere by anthropogenic sources was the same in both experimental runs. Other model input data and process parameterizations were kept the same in both cases. The calculations were carried out lead atmospheric dispersion in January, 2006. In order to investigate the effect of anthropogenic sources on the near-surface concentrations, the re-suspension of lead was switched off.

Figure 3.16 illustrates results of the experiment. The figures show spatial distribution of relative difference between the two experimental runs. On average, the concentrations due to the refinement of vertical structure decrease by 15%, and depositions – by 1.5% over Europe and Central Asia. Some increase of concentrations and depositions is noted for regions with significant emission sources (e.g, Eastern Ukraine, Benelux region, Northern Italy).

The effect of refinement of the lowest model layer was studied in more detail using vertical profiles of the concentrations at different locations (Fig. 3.17). Lead air concentration in the surface layer in the gridcell located in Eastern Ukraine has increased by 5% due to the refinement of vertical structure (Fig. 3.17a). Significant emission sources located in this point results in monotonous decreasing concentration profile with the highest value near the surface. Another example of the vertical profile in area with intensive emissions is for gridcell located in South-western Poland (Fig. 3.17b). Although this point is also characterized by significant emission, the expected increase of concentrations did not occur. Most probably, it is connected with the fact that this grid cell is abundant in forests. About 30% of this gridcell is covered with forest. According to the model parameterization, dry deposition velocity over forested areas is much higher than that over low vegetation or non-vegetated areas. Dry deposition, in its turn, depends on the surface concentration and implicitly on thickness of the lowest

layer. Therefore, shallower lowest layer leads to more intensive dry deposition and, as a consequence, to lower surface concentrations. In remote regions where anthropogenic emissions are minor or absent, the refinement of the vertical structure leads to decrease of air concentrations along the whole profile (Fig. 3.17c). The refinement of the lowest model layer results in the increase of removal of the pollutant mass over emission regions and to decrease of the long-range atmospheric transport.

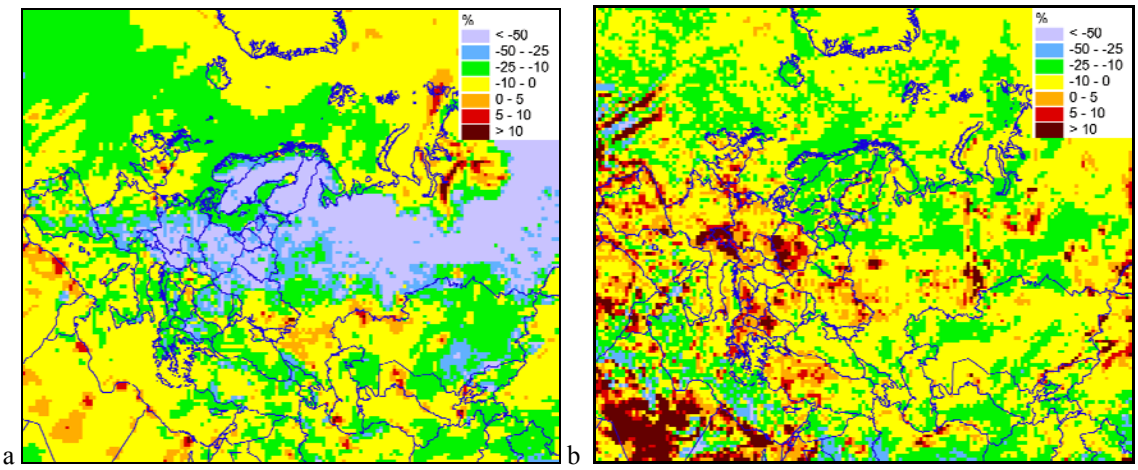


Fig. 3.16. *Relative bias between lead air concentrations (a) and depositions (b) obtained in the two model runs for January, 2006*

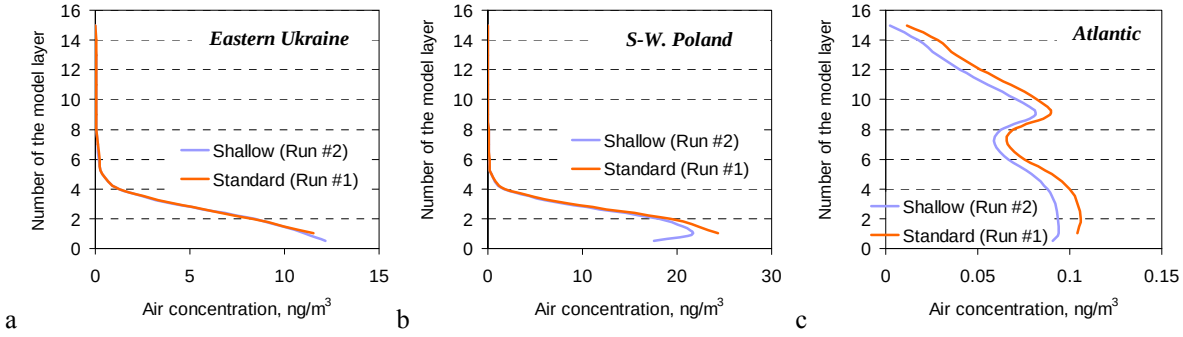


Fig. 3.17*. Vertical profiles of air concentrations of lead derived in the two experiments from individual points in Eastern Ukraine (a), South-western Poland (b),and Atlantic Ocean (c)*

Thus, the performed experiments demonstrated that increase of air concentrations takes place only over polluted regions with significant emissions. In addition to this, even over emission regions the increase does not occur if the region is covered by forests. Over the remote regions the concentrations in air decrease. One possible reason for this is substantial increase of dry deposition caused by the refinement. It is possible, that the description of the atmospheric processes in surface layer, in particular, dry deposition to forests, are not applicable for so fine vertical resolution. Besides, the experimental vertical distribution of emissions probably needs revision. Emission value entering the first model layer at standard vertical structure was split in two equal parts. Probably, if the higher fraction of emissions is assumed to enter the lowest shallow layer, the results of the experiment could be different.

The changes in the model performance can be evaluated via comparison of modelled and observed values. The comparison between monthly mean lead concentrations in air obtained in both experiments with observations at EMEP monitoring stations is demonstrated in Fig. 3.18. On average, the concentrations simulated with a shallow first model layer (run #2) are 10% lower compared to the results based on the standard discretization (run #1). Besides, lead concentrations in precipitation obtained in the run #2 (shallow lowest layer) are about 4% lower than those from run #1 (Fig.3.19). As it is shown in Chapter 4 of this report the MSCE-HM model tends to underestimate measured concentrations of lead both in air and in precipitation. Therefore, no distinct improvements in modelled air concentrations are identified after reducing the depth of the lowest model layer.

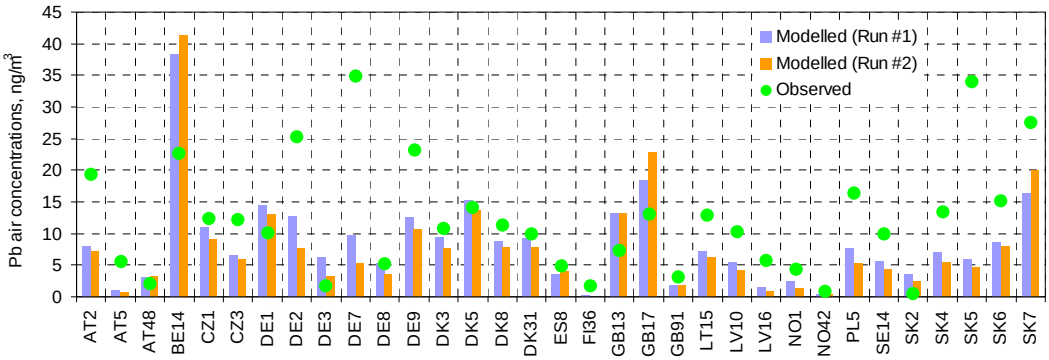


Fig 3.18. *Monthly mean air concentrations of lead calculated by the two experimental runs and observed at EMEP monitoring stations in January, 2006. Run #1 – standard vertical discretization, Run #2 – discretization with shallow lowest model layer*

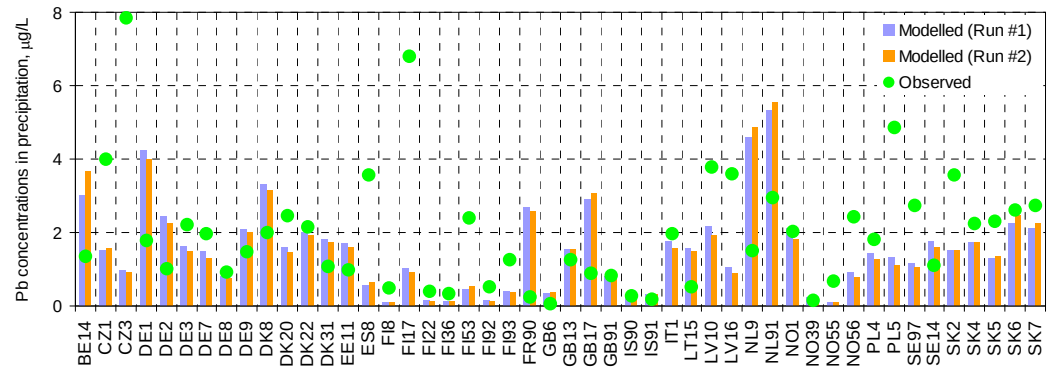


Fig. 3.19. *Monthly mean concentrations of lead in precipitation calculated by the two experimental runs and observed at EMEP monitoring stations in January, 2006. Run #1 – standard vertical discretization, Run #2 – discretization with shallow lowest model layer*

Thus, the refining of vertical model structure leads to some decrease of lead concentrations in the surface air (15% on average) and depositions (about 1.5%) over European and Central Asian countries. However, over some particular areas the changes can be higher. The comparison of the results based on the two experimental runs at locations of monitoring stations demonstrated that the reduction of lowest model layer does not lead to evident improvement of the model performance. However, it should be noted that these preliminary results are based on very limited modelling data and more comprehensive sensitivity study is required.

4. MODEL ASSESSMENT OF HEAVY METAL POLLUTION

This Chapter is devoted to the model assessment of the long-range transport of heavy metals in the atmosphere of Europe and the Northern Hemisphere. The first section contains analysis of lead, cadmium and mercury pollution levels in Europe and Central Asia in 2006, information on transboundary fluxes between the EMEP countries, and heavy metal atmospheric loads to the regional seas. Particular attention is paid to transboundary pollution of Central Asian countries that are Parties (Kazakhstan, Kyrgyzstan) or candidates (Uzbekistan, Turkmenistan and Tajikistan) to the Convention. The second section includes evaluation of the modelling results against measurements. The third section describes atmospheric dispersion of mercury on a global scale based on intercomparison of hemispheric/global mercury models. Detailed information on source-receptor relationships for all countries is presented in Annex C.

4.1. Heavy metal pollution levels in Europe in 2006

In order to include into consideration new parties to the Convention the EMEP domain was extended eastward and now it covers territories of all Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan). Pilot calculations of lead transboundary pollution over the extended EMEP domain were performed in 2007. Besides, pollution levels of lead in the Central Asian countries were evaluated within the framework of the CAPACT project [*Gusev et al,* 2007]. This section is focused on the analysis of the transboundary pollution with all three priority heavy metals (Pb, Cd and Hg) in 2006 over the extended EMEP domain.

Lead

In 2006 total anthropogenic emission of lead from the extended EMEP domain made up 4860 tonnes. This value consists of emissions from European part (4270 tonnes) and those from the Asian part of the domain (590 tonnes) including Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan) and the Asian part of Russia. Emissions from the European part of EMEP domain are around 7% lower compared to the value estimated for 2005. Total depositions of lead to European and Central Asian countries from anthropogenic sources amounted to 3370 tonnes, whereas depositions to the European part were 2860 tonnes, and to the Asian part - 510 tonnes. Compared to the results obtained for 2005, the depositions to European countries decreased by 14% [*Ilyin et al*., 2006]. Total depositions to the EMEP domain from all sources (anthropogenic, wind re-suspension and non-EMEP) made up 11750 tonnes. This value includes depositions to European countries (9240 tonnes) and to Asian part of the extended domain (2510 tonnes). The deposition values caused by wind re-suspension should be taken with caution because the parameterization of this process is under development.

Over the most part of Europe concentrations of lead in the ambient air varies from 1 to 10 ng/m^3 (Fig. 4.1a). Relatively high concentrations (over 20 ng/m^3) were obtained for the Benelux region, Poland, northern Italy, the southern part of the United Kingdom, the south of Pyrenean Peninsula, over Balkan Peninsula, and in the southern part of Kazakhstan. These elevated concentrations were caused by joint influence of high anthropogenic emissions and wind re-suspension. Over north of Russia and Scandinavian Peninsula the concentrations are the lowest and as a rule fall below 0.3 ng/m^3. Concentrations of lead in the Central Asian region range from 1-5 ng/m^3 in the steppe and deserted areas up to 20 ng/m^3 or higher nearby large emission sources. These concentrations are comparable with those obtained for Europe.

Total depositions of lead commonly ranges from 0.4 to 2 kg/km^2/y over most part of the EMEP countries (Fig, 4.1b). The highest depositions are associated with regions with significant emissions (anthropogenic and wind re-suspension) combined with high or moderate annual precipitation. These are Benelux countries, Poland, northern Italy, and the Balkan region. The lowest depositions of lead took place over northern part of Russia and Scandinavia. Depositions of lead over the most part of Central Asia are low compared to Europe. Over most of Kazakhstan, Uzbekistan and Turkmenistan the depositions ranges from 0.1 to 0.4 kg/km^2/y. The reason for this is relatively low precipitation amounts which are typical for arid central Asian region. Higher precipitation amounts take place in mountainous regions of Kyrgyzstan and Tajikistan. This leads to relatively high depositions in these countries ranging from 0.6 to 2 kg/km^2/y.

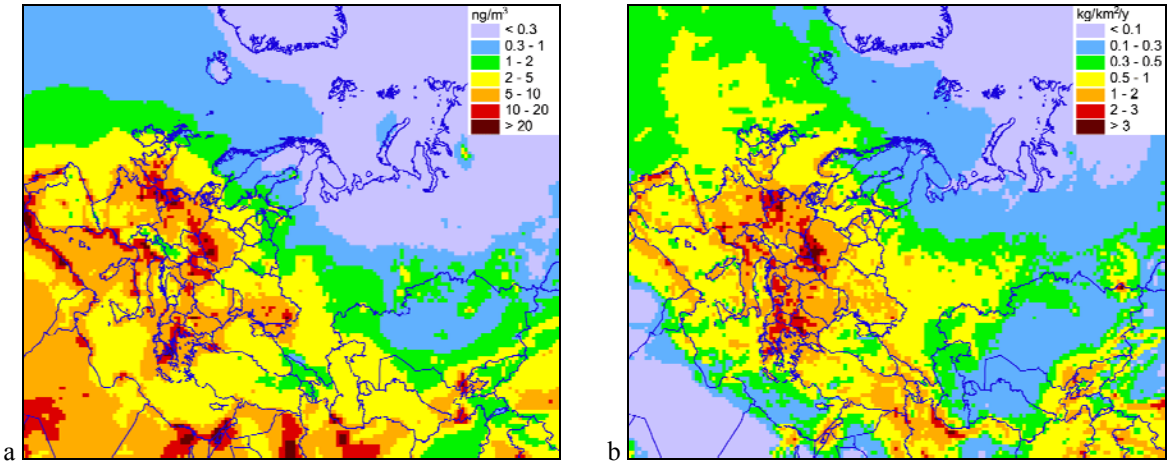


Fig. 4.1. *Annual mean concentrations in the ambient air (a) and total annual deposition (b) of lead in Europe and Central Asia in 2006*

The highest country-averaged flux of lead total deposition was calculated for Slovakia, Monaco, the FYR of Macedonia and Belgium (Fig. 4.2). The average fluxes in the Central Asian region are relatively low compared to Europe. They range from 0.3 kg/km^2/y in Turkmenistan to 0.8 kg/km^2/y in Kyrgyzstan. As seen from the figure, the contribution of wind re-suspension to total depositions is comparable to the anthropogenic one for the majority of countries. This contribution consists of two fractions, which cannot be separated: purely natural emission, and re-suspension of long-term (historic) depositions from anthropogenic sources. It is also important to stress that current estimates of natural and historical emissions are subject of significant uncertainty. The contribution of non-EMEP sources (both natural and anthropogenic) varies from 1-4% in some European countries (Poland, Belgium, the Netherlands) to 30-55% in Central Asian and Caucus countries. However, for the majority of countries their contribution is less than 25%. The contribution of these non-EMEP sources was estimated via prescribed observation-based air concentrations of lead at the EMEP region boundaries. Besides, lead emissions from African and Asian countries were also taken into account.

Relative contribution of the transboundary transport to anthropogenic depositions ranges from almost 100% in Monaco and 96% in Iceland to 14% in Portugal (Fig. 4.3). In 37 countries this contribution exceeds 50%, and in 13 countries – 80%. Contribution of the transboundary transport to depositions is controlled by a number of factors including size of a country's territory, magnitude of national emissions, peculiarities of typical meteorological conditions (wind transport patterns, precipitation amounts etc.) In countries with significant emissions the contribution of national sources to deposition is relatively high, and thus the contribution of external anthropogenic sources is typically low. For example, in Poland the contribution is around 20%, in Italy - 30%. Relatively low contribution of the

external sources is also typical for remote countries, especially if they are situated in the “upwind” direction relative to major emission sources (e.g., United Kingdom, Spain, Ireland). Among the countries of Central Asia the highest contribution of the transboundary transport from EMEP and Central Asian anthropogenic sources was estimated for Kazakhstan (about 80%), the lowest – for Uzbekistan (33%).

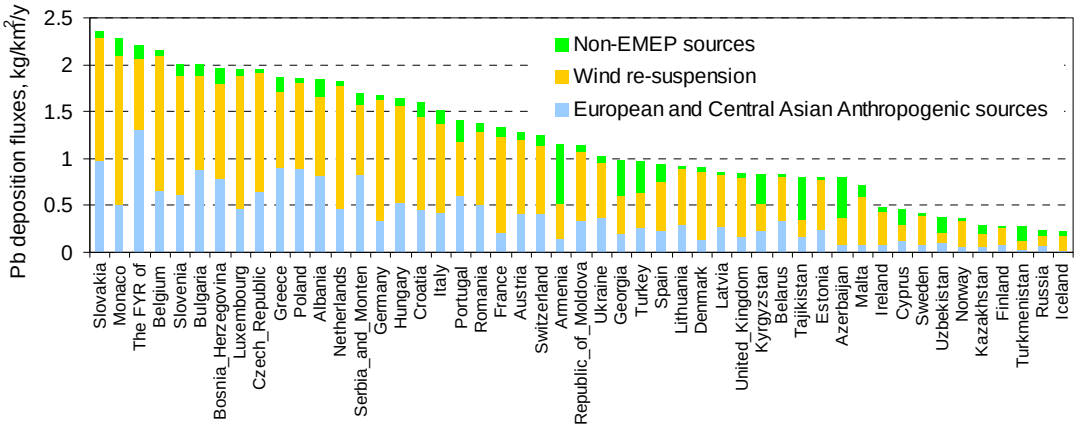


Fig 4.2. *Country-averaged deposition fluxes of lead from European anthropogenic, natural/historical and non-EMEP sources in 2006*

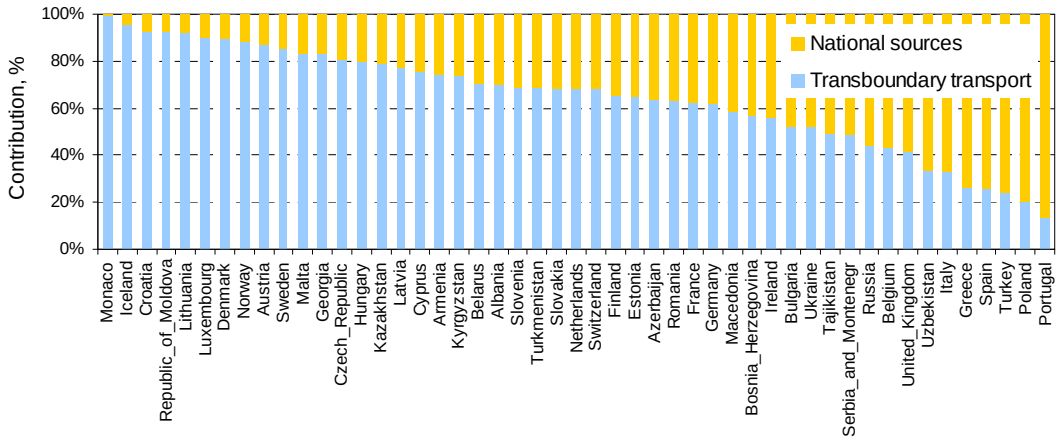


Fig. 4.3. *Relative contribution of the transboundary transport and national sources to anthropogenic lead depositions in European countries in 2006*

Contribution of countries to transboundary pollution was evaluated as mass of the pollutant, emitted by national sources and transported outside country’s territory. Again this contribution depends on magnitude of national emissions, area and configuration of a country territory, predominant meteorological conditions etc. The largest contribution to the transboundary transport in 2006 was made by Greece (almost 400 tonnes) (Fig. 4.4). Other significant contributors are Turkey (above 300 tonnes) and Poland (220 tonnes). Among the Central Asian countries the largest contribution is made by Uzbekistan (155 tonnes), the lowest – by Kyrgyzstan (25 tonnes). Fraction of emitted mass of lead entering the transboundary transport ranges from 60 to 90% for majority of countries. The exception is Russia (hereafter, a part of the territory of the Russian Federation covered by the extended EMEP domain is considered only, see Fig. 2.7), where this fraction is about 20%. The reason for this is a large territory of the country, and location of most sources relatively far from the state borders.

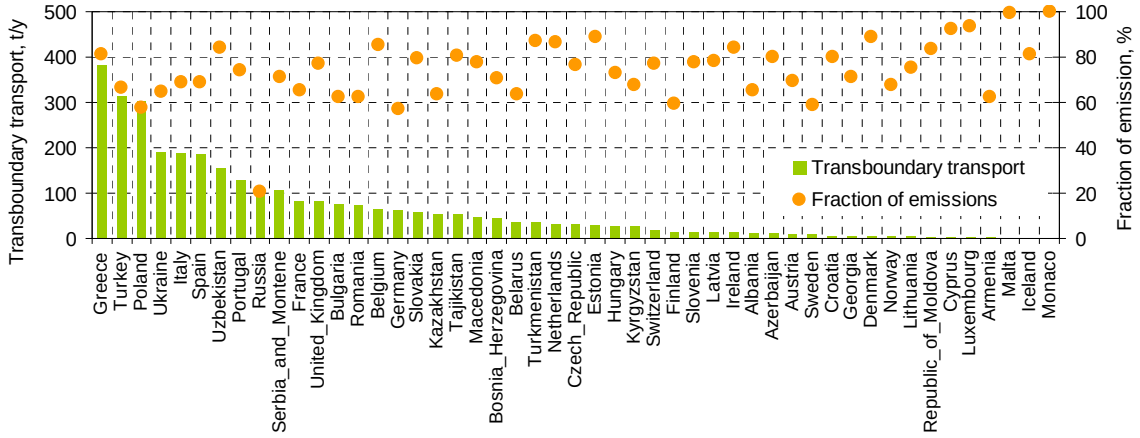


Fig. 4.4. *Absolute contribution of European countries to lead transboundary transport in Europe in 2006 and relative fraction of national emissions involved into the transboundary pollution*

Cadmium

Total emission of cadmium within the extended EMEP domain in 2006 was about 290 tonnes, including 240 tonnes emitted from European sources and 50 tonnes - from Central Asian sources and the Asian part of Russia. Total deposition to the European and the Central Asian countries in 2006 was 227 tonnes, including 179 tonnes deposited to the European part, and 48 tonnes – to the Asian part of EMEP domain. In comparison with estimates for 2005 [*Ilyin et al*., 2007], total depositions to European countries were changed insignificantly (less than by 1%). The depositions from all sources (anthropogenic, wind re-suspension, and non-EMEP sources) in 2006 amounted to 440 tonnes. This value consists of depositions to European countries (330 tonnes) and to the Asian part of the EMEP domain (110 tonnes). Similar to lead, estimates of contribution of wind re-suspension should be taken with certain caution because of pilot character of this process parameterization used in the study.

Over the major part of Europe concentrations of cadmium range from 0.02 to 0.3 ng/m^3 (Fig. 4.5a). Poland, the Balkan region, Benelux countries, eastern Ukraine and the south-east of Russia are characterized by relatively high concentrations of cadmium (more than 0.3 ng/m^3). High concentrations in these regions are associated with considerable emissions (Fig. 2.8b). Lowest concentrations were obtained for the Arctic and sub-Arctic regions (northern Scandinavian and the north of Russia). Annual mean cadmium concentrations over the Central Asian region are within 0.02-0.1 ng/m^3. Higher concentrations (up to 0.5 ng/m^3) were obtained for the north and south of Kazakhstan and the east of Uzbekistan. The elevated concentrations were found for regions with relatively high emissions.

Annual cadmium depositions over the most part of the EMEP area varies from 10 to 50 g/km^2/y (Fig. 4.5b). The highest depositions (50-200 g/km^2/y) were predicted for regions with high anthropogenic emissions (e.g. Poland, Balkans, Benelux etc.). However, over the Central Asian region the depositions are relatively low (3-10 g/km^2/y), mainly because of low precipitation amounts. Low depositions are also seen over the northern part of the EMEP region and in desert areas of northern Africa. Calculated depositions of cadmium in the Central Asian region are significantly lower than those obtained for Europe. Over most of the region they range from 3 to 30 g/km^2/y.

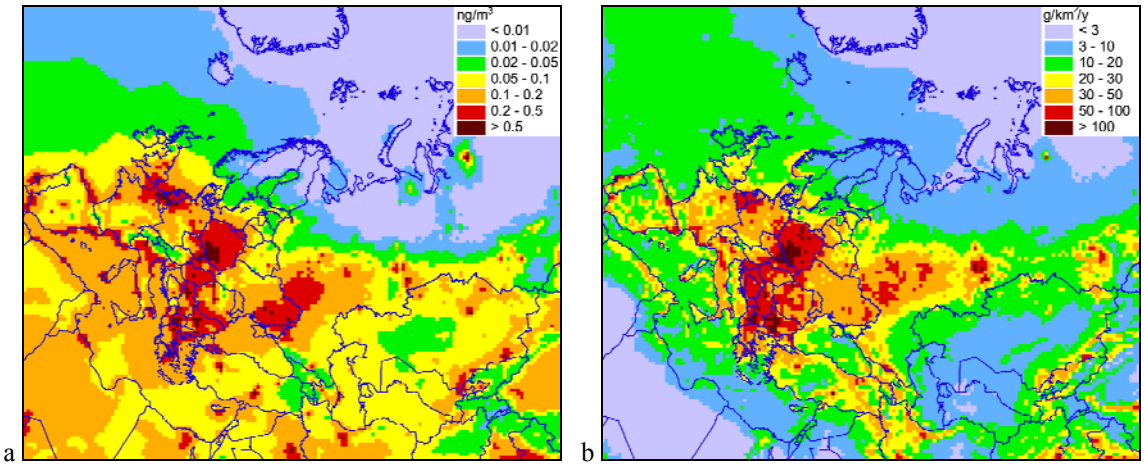


Fig. 4.5. *Annual mean concentrations in the ambient air (a) and total annual deposition (b) of cadmium in Europe and Central Asia in 2006*

Country-averaged depositions of cadmium in European countries in 2006 varied from 155 g/km^2/y in The FYR of Macedonia to 10 g/km^2/y in Finland (Fig. 4.6). In Central Asian countries the average flux varied from 21 g/km^2/y (Kyrgyzstan) to 7 g/km^2/y (Turkmenistan). The deposition fluxes consist of three components: input from anthropogenic sources of the European and Central Asian countries, from wind re-suspension and from non-EMEP sources. In 29 countries (of 49) deposition from anthropogenic sources dominates over that caused by wind re-suspension. The contribution of non-EMEP sources varies from about 1% in Poland to 60% in Tajikistan. Similar to lead, this contribution is the lowest in regions with significant national emissions and located far from EMEP boundaries. High contribution of non-EMEP sources is estimated for the Central Asian countries and Transcaucasia because of the influence of Asian emission sources.

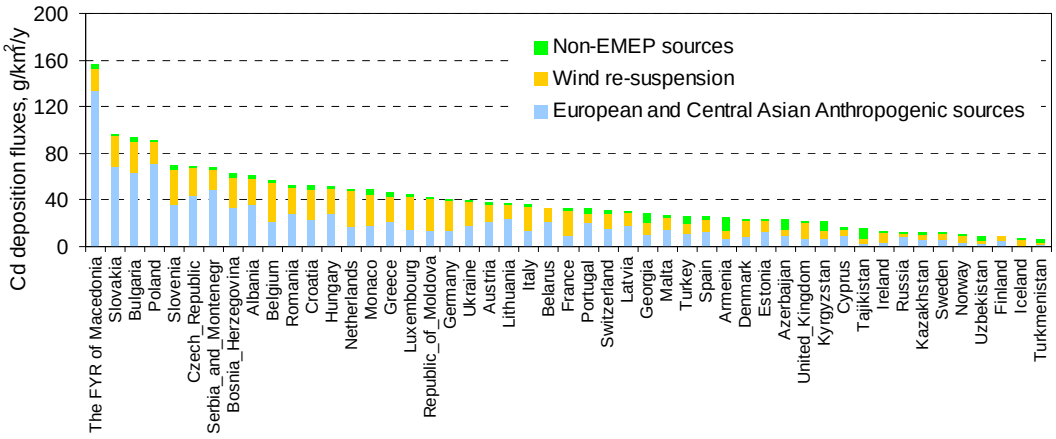


Fig 4.6. *Country-averaged deposition fluxes of cadmium from European anthropogenic, natural/historical and non-EMEP sources in 2006*

Contribution of transboundary transport of cadmium to depositions from anthropogenic sources varies from 98% in Monaco to 14% in Spain (Fig. 4.7). In 35 countries of Europe and Central Asia the contribution exceeds 50%, in 16 countries – 80%. Among Central Asian countries the contribution ranges from almost 70% (Uzbekistan) to above 90% (Tajikistan). The exception is Kazakhstan where

the contribution is much smaller (about 37%), basically due to significant national sources of cadmium.

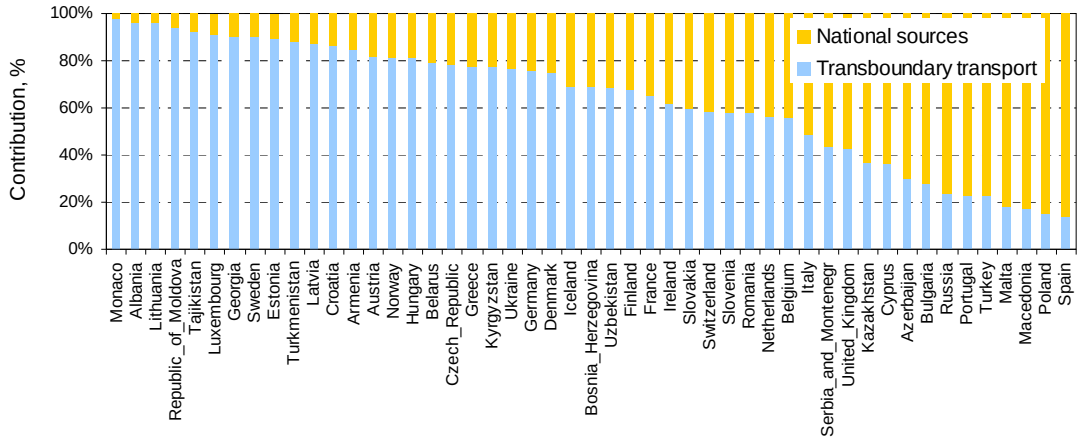


Fig. 4.7. *Relative contribution of the transboundary transport and national sources to anthropogenic cadmium depositions in European countries in 2006*

Contribution of European and the Central Asian countries to transboundary transport of cadmium ranges from 23 tonnes (Poland) to some few kilograms (Monaco) (Fig. 4.8). Other important contributors are Russia, Kazakhstan, Turkey and Spain. Their high contribution is mainly explained by essential national emissions of cadmium. The fraction of national emissions of cadmium engaged into the transboundary transport typically varies from 60 to 90%. Similar to lead, Russia is an exception, which supply only about 20% of national emissions to the trasboundary pollution. As a rule, this fraction is higher either in small countries irrespective their national emissions (Belgium, Republic of Moldova), or countries with dry climate (Turkmenistan, Uzbekistan). When a country is small, emitted mass of cadmium (or other heavy metal) rapidly quits the country's territory and deposits elsewhere. If a country is known for arid climatic conditions, the emitted cadmium is not removed by precipitation and freely transported outside the country.

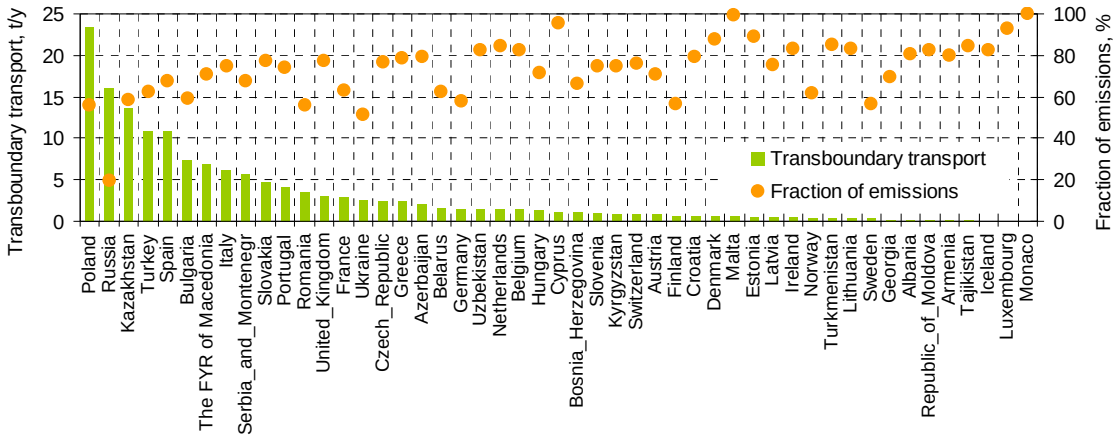


Fig. 4.8. *Absolute contribution of European countries to cadmium transboundary transport in Europe in 2006 and relative fraction of national emissions involved into the transboundary pollution*

Mercury

Total anthropogenic emission of mercury from the European and the Central Asian countries in 2006 was 241 tonnes. It includes 173 tonnes from European countries and 68 tonnes from the Central Asian countries and the Asian part of Russia. Compared to the European emission value for 2005, mercury emission in 2006 is practically the same. Total deposition of mercury to European and Central Asian countries from anthropogenic sources made up 82 tonnes, including 58 tonnes deposited to the European part and 24 tonnes to the Asian part of the EMEP domain. Depositions from anthropogenic sources to European countries in 2006 were about 5% higher than those in 2005. Depositions of mercury to the European and the Central Asian countries from all sources (anthropogenic, natural, re-emission, and non-EMEP) amounted to 236 tonnes. Among them 144 tonnes were deposited to Europe and 92 tonnes – to Central Asia and the Asian part of Russia.

Spatial variability of annual mean concentration of total gaseous mercury in the ambient air is low. Over the most part of the EMEP domain mercury concentration varies from 1.4 to 1.7 ng/m^3 (Fig. 4.9a). Relatively high concentrations in Poland, southern Kazakhstan and over the Balkan region resulted from significant anthropogenic emissions. Low concertinos over Greenland, southern Scandinavia, Caucasus and over Central Asian mountain systems are explained by elevation of these regions above see level and a consequent decrease of air density and mass concentration.

Over the major part of the EMEP domain annual deposition flux ranges from 7 to 30 g/km^2/y (Fig. 4.9b). In general, mercury deposition pattern is similar to that of other metals like lead and cadmium since mercury deposition over industrial regions is mostly formed by short-lived oxidized forms directly emitted from anthropogenic sources. Therefore, high deposition fluxes were predicted over central Poland, the Balkan region, southern Russia, and the south-east of Kazakhstan where significant emission sources were located or considerable precipitation took place. The Arctic and the Central-Asian dessert areas are characterized by the lowest deposition fluxes. In the Central Asian region elevated deposition fluxes (12-30 g/km^2/y) took place over areas with significant anthropogenic emissions. In the western part of Turkmenistan and Uzbekistan and the south-west of Kazakhstan mercury deposition were low (3-5 g/km^2/y or even lower) because of small precipitation amount and lack of significant emission sources.

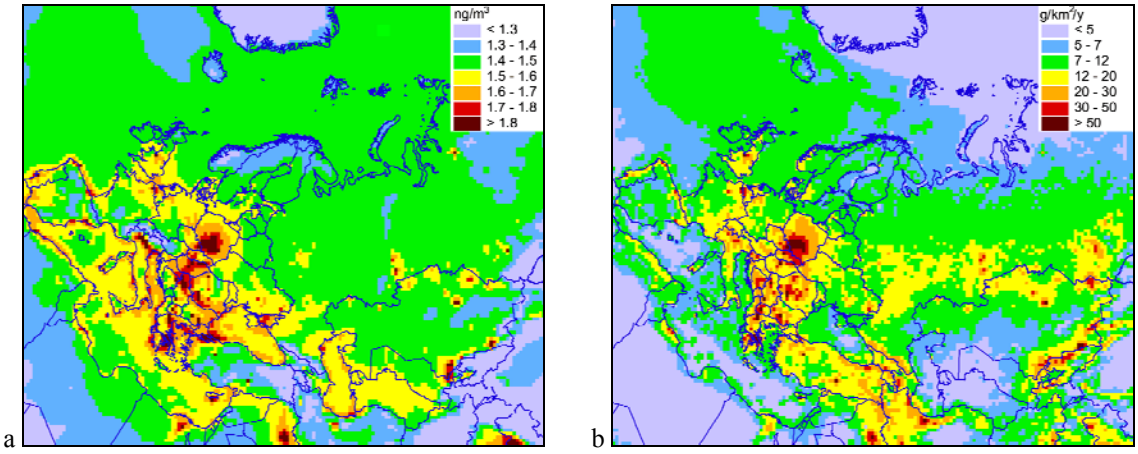


Fig. 4.9. *Annual mean concentrations in the ambient air (a) and total annual deposition (b) of mercury in Europe and Central Asia in 2006*

Country-averaged depositions of mercury in of the European and the Central Asian countries in 2006 varied from 4 to 32 g/km^2/y (Fig. 4.10). The highest deposition levels took place in Slovakia, followed by Poland, the FYR of Macedonia and Greece. The lowest deposition flux was obtained for the Central Asia countries: Uzbekistan, Kyrgyzstan, Turkmenistan and Tajikistan. Two major types sources are responsible for depositions of mercury: anthropogenic emissions in Europe and Central Asia and non-EMEP anthropogenic and natural emission sources. Contribution of natural and re-emission sources located in the EMEP domain is minor. It is expected that mercury is emitted from natural sources and re-emitted in the elemental gaseous form. This mercury form is characterized by very long residence time in the atmosphere. As a result the most part of these emissions is transported beyond the boundaries of the model domain not being deposited. Only in 17 of 49 of the European and the Central Asian countries contribution of their anthropogenic sources exceeds contribution of external non-EMEP sources. The comparison of these two components clearly indicates that sources located outside the EMEP domain considerably affect mercury depositions in Europe and Central Asia. Therefore, it is highly important to apply global-scale modelling in order to evaluate the contributions of these sources more accurately.

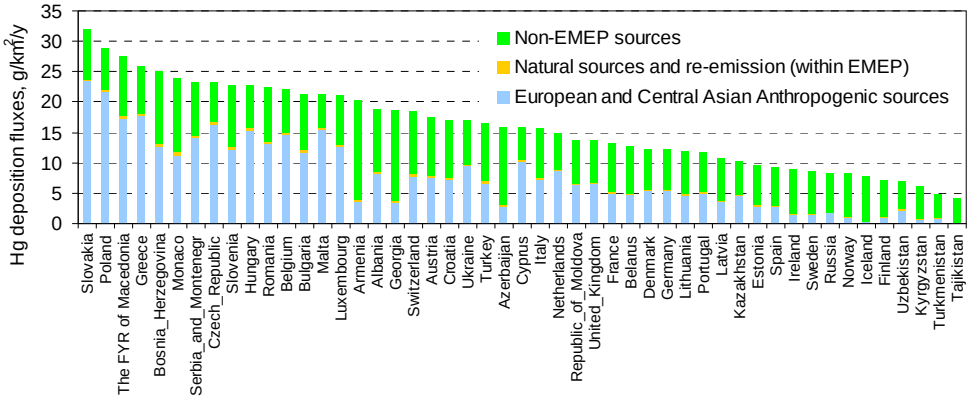


Fig 4.10. *Country-averaged deposition fluxes of mercury from European anthropogenic, natural/historical and non-EMEP sources in 2006*

Contribution of the transboundary transport to anthropogenic deposition of mercury in Europe varies essentially from country to country (Fig. 4.11). The highest contribution of the transboundary transport was estimated for Iceland and Latvia (more than 98%). In Malta the contribution is the lowest (6%). In 27 countries this contribution exceeds 50%, and in 9 countries – 80%. Among the Central Asian countries the highest contribution was obtained for Tajikistan (90%) and the lowest – for Kazakhstan (14%).

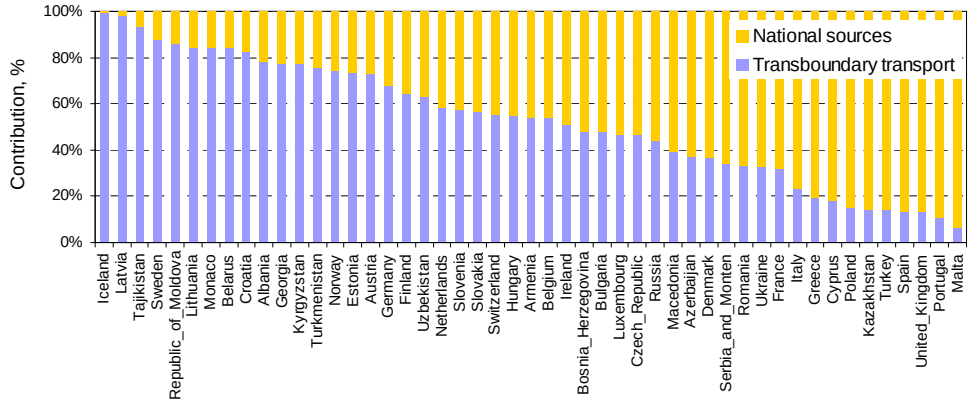


Fig. 4.11. *Relative contribution of the transboundary transport and national sources to anthropogenic mercury depositions in European countries in 2006*

On the other hand, Kazakhstan is characterized by the highest (31 tonnes) contribution to the transboundary pollution by mercury (Fig. 4.12). Other significant contributors are Russia, Turkey and Poland. The fraction of national mercury emissions involved into the transboundary transport ranges from 70% for Russia to over 95% for Kyrgyzstan, Iceland, Tajikistan, Malta and Monaco. This fraction of mercury emissions is higher than that of other heavy metals (lead or cadmium). The reason for this is in considerable part of mercury emitted in elemental gaseous form. This form of mercury is slowly scavenged from the atmosphere and readily enters the transboundary and global transport.

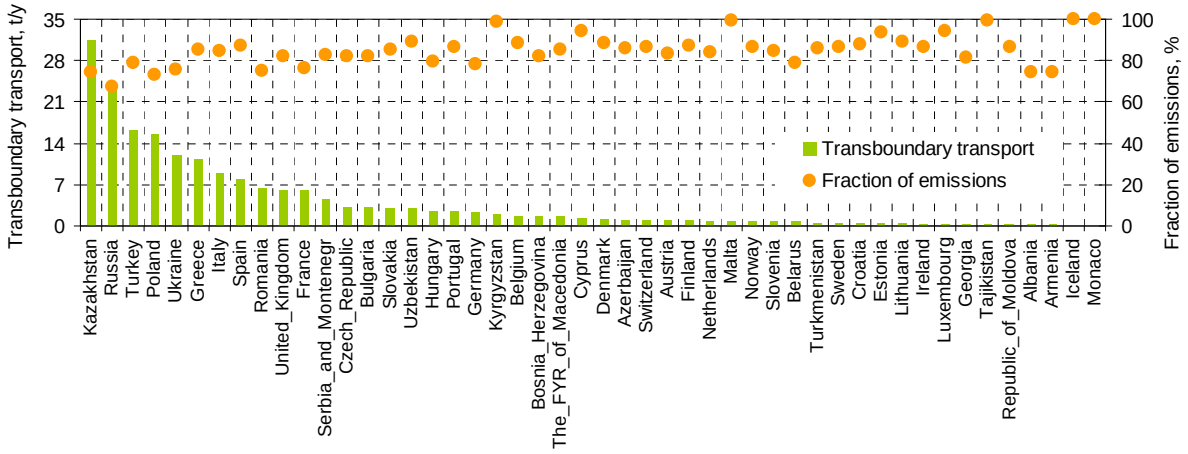


Fig. 4.12. *Absolute contribution of European countries to mercury transboundary transport in Europe in 2006 and relative fraction of national emissions involved into the transboundary pollution*

Transboundary pollution in the Central Asian Region

This section contains summarized information on transboundary pollution of the Central Asian countries by heavy metals. Figure 4.13 shows estimated contribution of different types of sources to heavy metal depositions in the Central Asian countries. As seen from the figure contribution of wind re-suspension and non-EMEP sources is comparable with or even exceed that of anthropogenic sources in this region. Particularly, contribution of anthropogenic sources to total deposition varies from 12% to 27% for lead, from 11% to 46% for cadmium, and from 4% to 44% for mercury. Contribution of wind re-suspension to depositions of lead and cadmium ranges from 20% to almost 50%. However, these estimates are quite uncertain since parameterization of this process is still under development. Besides, these estimates are based on very limited information on concentrations of lead and cadmium in soils. In this concern, co-operation with national experts from Central Asian countries is highly appreciated.

Unlike that in European countries, the contribution of non-EMEP sources is relatively high in this region and for lead and cadmium in some countries it exceeds 50%. This contribution reflects the joint effect of the influence of sources located outside the EMEP domain and sources in other Asian and African countries covered by the EMEP domain (China, India, Iran, etc.). Besides, the non-EMEP sources are principle mercury depositions over the Central Asian region (Fig. 4.13c). Contribution of these sources varies from 55% in Kazakhstan to almost 90% in Kyrgyzstan. Except for Kazakhstan, the contribution of non-EMEP sources in Central Asia is higher compared to the majority of European countries.

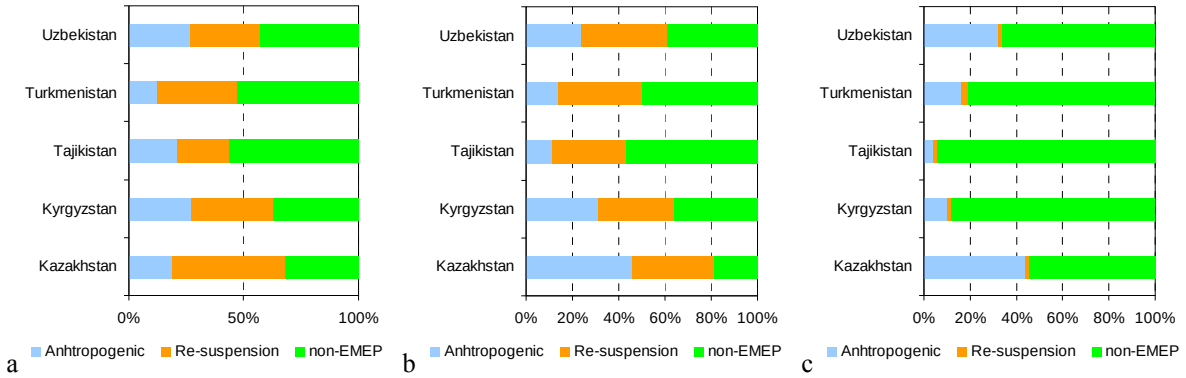


Fig. 4.13 . *Contribution of different source types to total depositions of lead (a), cadmium (b) and mercury (c) in Central Asian countries in 2006*

An effect of the transboundary transport on depositions of heavy metals in Central Asian countries is illustrated in Fig. 4.14. The figure shows relative contribution of major source countries to anthropogenic depositions of lead, cadmium and mercury in the Central Asian countries in 2006. As seen the main contribution to depositions was typically made by national sources. Besides, significant contributors to deposition in all countries was Kazakhstan and Uzbekistan, which are characterized by the largest emissions in this region. An exception is the estimated contribution of Kazakhstan to deposition of lead. It should be noted that these estimates are based on preliminary emissions data provided by national experts, which are considerably lower available expert estimates by TNO [*Denier van der Gon et al*., 2005]. Overall contribution of European countries (except Russia) to depositions is typically low (3-20%).

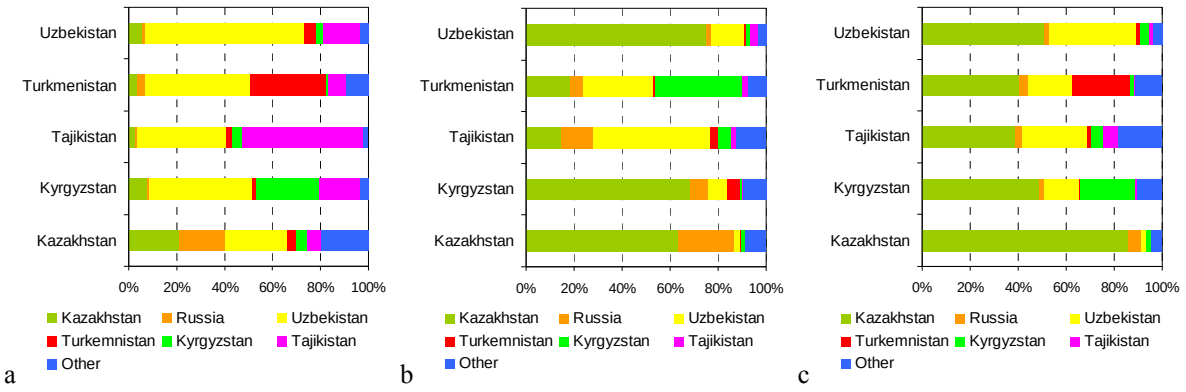


Fig. 4.14 . *Relative contribution of different sources to anthropogenic depositions of lead (a), cadmium (b) and mercury (c) in Central Asian countries in 2006*

Depositions to regional seas

Following the workplan MSC-E carried out calculations of depositions of lead, cadmium and mercury to seas surrounding Europe (Black, Azov, North, Mediterranean, Baltic and Caspian). The North Sea is characterized by the highest average deposition of lead (0.7 kg/km^2/y; Fig. 4.15) and by the second highest deposition of cadmium (18 g/km^2/y) and mercury (9 g/km^2/y). Relatively high heavy metal deposition levels to the North Sea are explained by the proximity of pollution sources in the countries washed by the sea. The highest average deposition levels of cadmium and mercury were obtained for the Black and Azov Seas. The Caspian Sea is the most remote from the anthropogenic sources of heavy metals and is characterized by the lowest deposition fluxes.

Contribution of different countries to depositions of heavy metals to each of the mentioned above seas was also evaluated (Annex C). Two examples demonstrating contributions European and the Central Asian countries to cadmium depositions to the North Sea and the Caspian Sea in 2006 are shown in Fig. 4.16. Total deposition of cadmium from anthropogenic sources to the North Sea were about 3.5 tonnes. The main contributor to depositions was the United Kingdom (28%), followed by Poland (15%) and France (10%). Cadmium depositions from anthropogenic sources to the Caspian Sea amounted to about 1.1 tonnes. Emission sources in Azerbaijan and Russia account for the major part of cadmium deposition to this sea. Contributions of these two countries were 31% and 27%, respectively. Other principle contributors were Kazakhstan (17%) and Turkey (9%).

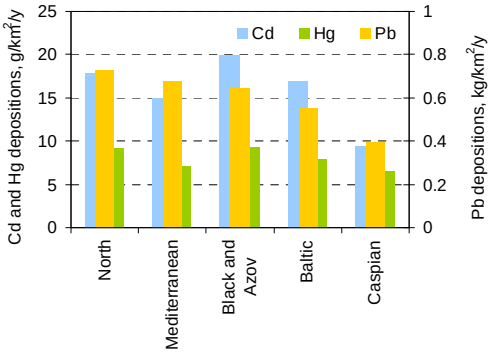
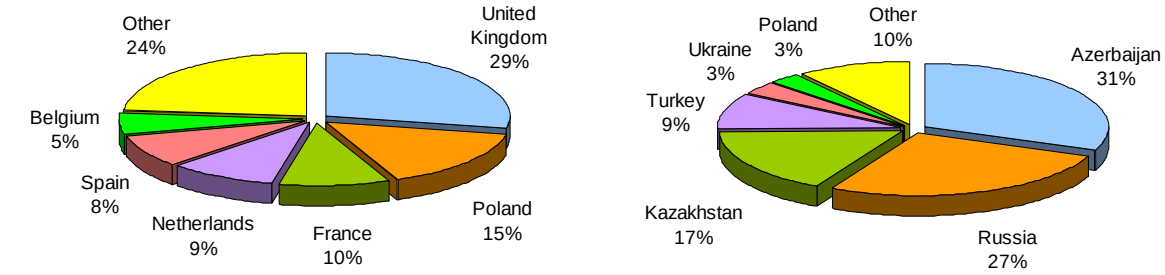


Fig. 4.15. *Averaged deposition fluxes of lead, cadmium and mercury to regional seas in 2006*



a b

Fig. 4.16. *Contribution of different countries to anthropogenic depositions of cadmium to the North Sea (a) and the Caspian Sea (b) in 2006*

4.2. Evaluation of modelling results

Evaluation of modelling results against observations is a routine procedure allowing assessment of the model performance and supporting improvement of the model parameterization. This section contains the comparison of modelled concentrations of lead, cadmium and mercury in air and in precipitation with measurements from the EMEP monitoring network in 2006. Special attention is paid to analysis of discrepancies between the modelling results and observations obtained at a number of stations. More detailed analysis of the model performance is presented in the Technical report [*Gusev et al*., 2008].

Lead

Comparison of modelled and measured annual mean lead concentrations in air for 2006 is presented in Fig. 4.17. The model slightly (around 20%) underestimates measured concentrations. Correlation coefficient between annual mean measured and modelled air concentrations is significant (0.7). Around 40% of measurement-modelling pairs of values agree within ±30%, and 70% - within ±50%. Comparison of annual mean values differs for individual sites. Relatively good agreement is indicated for stations in Austria, Germany, Denmark, and the United Kingdom. Some underestimation of measured concentrations was obtained for Polish, Swedish and Slovak sites and essential (up to an order of magnitude) – for Finnish site FI36 and Icelandic site IS91.

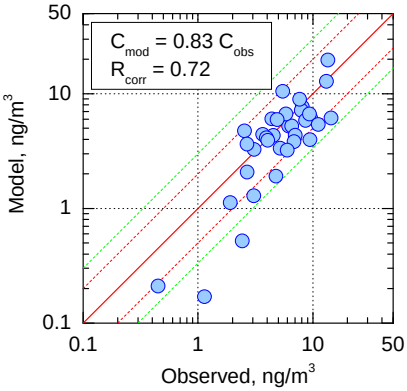
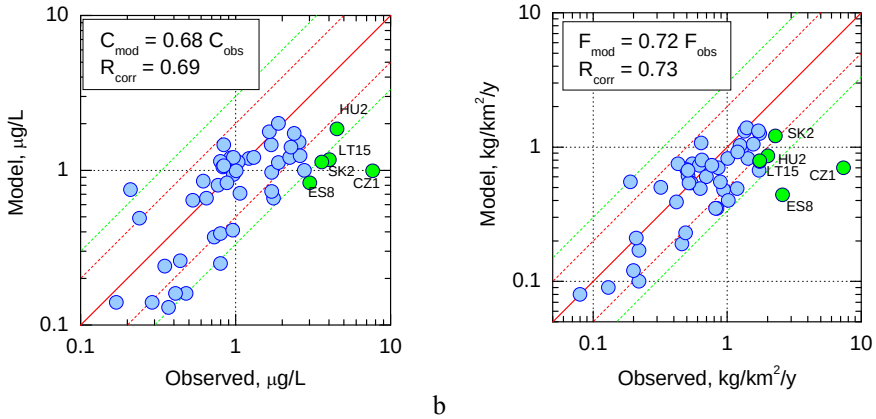


Fig. 4.17. *Comparison of modelled and measured annual mean concentrations of lead in air. Red solid line delineates 1:1 ratio, red and green dashed lines show deviation by a factor of two and three, respectively*

Figure 4.18 shows comparison of measured and calculated lead concentrations in precipitation and wet deposition fluxes. Measurements at a number of sites (CZ1, ES8, HU2, LT15, and SK2 coloured in green) were considered in detail and classified as outliers [see *Gusev et al.*, 2008]. Comparison with these measurements was not included into statistics. As seen from the figure, in general, the model underestimates measured concentrations in precipitation and wet deposition fluxes by about 30%. However, the model performance at individual stations is very different. Particularly, concentrations and wet deposition fluxes were reasonably well reproduced for stations in Belgium, Germany, the United Kingdom, Poland, Sweden and the Netherlands. At most stations in these countries modelled and measured values of wet deposition and concentration in precipitation agree within ±40%. The most significant underestimation took place for Finnish and Slovak sites. Nevertheless, the model manage to reproduce spatial variability of the observed concentrations and fluxes: Appropriate correlation coefficients between measured and calculated values amount to about 0.7.



a b

Fig. 4.18. *Comparison of modelled and measured annual mean lead concentrations in precipitation (a) and wet deposition flux (b). Red solid line delineates 1:1 ratio, red and green dashed lines show deviation by a factor of two and three, respectively*

Short-term variability of the observed lead concentrations in air was well captured by the model, particularly, for stations located in Germany, Denmark, the Netherlands, Belgium, and the Czech Republic. Comparison of weekly mean lead concentrations in air at station DE9 (Zingst, Germany) is shown in Fig. 4.19 as an example demonstrating good agreement between modelled and measured concentrations of lead in air. Most of weekly-mean measured values were caught by the model.

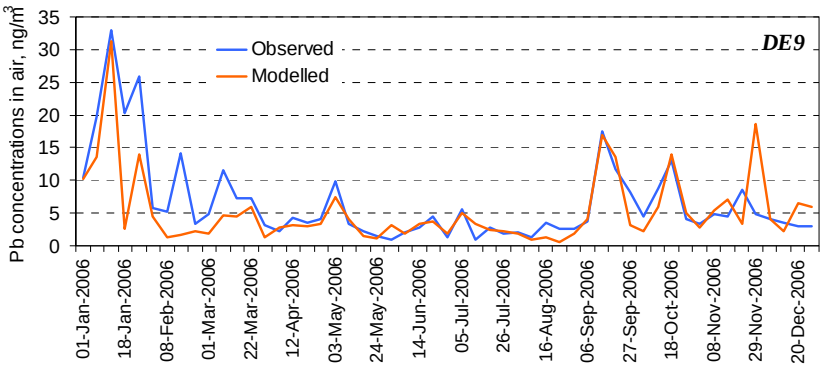


Fig 4.19. *Comparison of modelled lead concentrations in air with weekly measurements at station DE9 (Zingst, Germany)*

Significant underestimation of measured concentrations of lead in precipitation was indicated for most Finnish sites. More detailed analysis of monthly data demonstrates that significant underestimation takes place in some particular months, whereas in other months the model reasonably well reproduces the observations. For example, at stations FI22 and FI93 measured and modelled concentrations and wet deposition fluxes in June agree within ±30%, while in August the difference reaches an order of magnitude (Fig. 4.22). Similar situation was also obtained for other Finnish sites. To reveal the reason of the underestimation an analysis of back trajectories arriving these stations in different months was performed. As seen from Fig. 4.20 air masses arriving Finnish stations in August came mostly from Russian territory, in particular, from the region of St. Petersburg and Kola Peninsula. On the contrary, in June the air masses arrived to the stations with the highest probability from Scandinavian Peninsula.

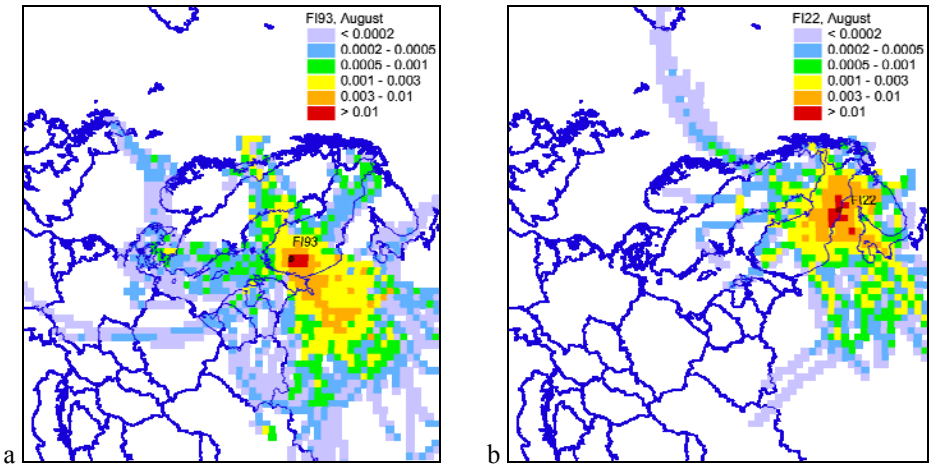


Fig 4.20. *Monthly mean spatial distribution of back trajectories arriving Finnish stations FI93 (a) and FI22 (b) in August*

Essential underestimation of the observed concentrations in precipitation in months when air masses were transported from the Russian territory may indicate that emissions in the north-west of Russia are likely underestimated. In order to test this hypothesis, two numerical experiments were performed. In the first one the officially submitted emission of lead for the Russian Federation (Fig. 4.21a) was replaced by that prepared within the ESPREME project [http://espreme.ier.uni-stuttgart.de, Fig. 4.21b]. In the second experiment the ESPREME emissions were increased selectively in some regions of Russia: by a factor of 5 over the St. Petersburg region and by a factor of 20 over Kola Peninsula (Fig. 4.21c). This rough approach can hardly reveal particular missing sources or underestimation of emissions but rather indicate potential uncertainties of emissions spatial distribution.

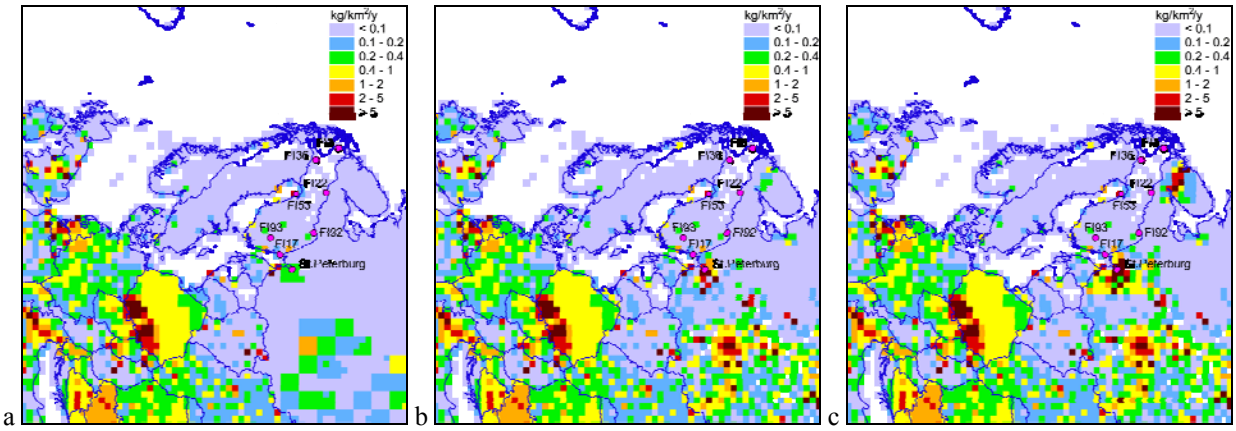


Fig. 4.21. *Emission data used in the numerical experiments. a) – official emission data; b) – ESPREME estimates for Russia, c) - ESPREME estimates increased selectively by a factor of 5 over the St. Petersburg region and by a factor of 20 over Kola Peninsula*

The use of the original ESPREME emissions resulted in better agreement between measured and modelled wet deposition fluxes in particular months. For example, at stations FI17 and FI93 the agreement between the measurements and modelling were significantly improved in August (Fig. 4.22). The second emission set resulted in marked improvements of the model-to-measurement agreement at most of the stations. For example, the difference between the modelled and observed values decreased in October at stations FI17 and FI93, in May at FI22 and FI92, in March at FI17, FI22 and FI93 (Fig 4.22). However, in some other months the modelled deposition fluxes remained almost the same or changed slightly despite the changes in emission data. According to the analysis of back trajectories, the air mass transport in these months takes place mostly from other regions.

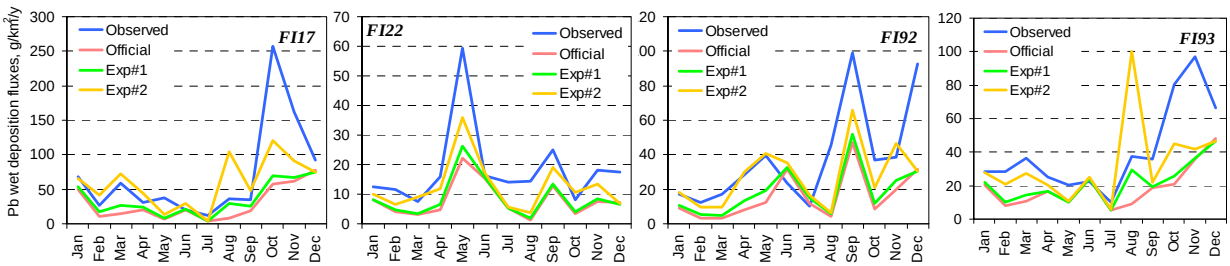


Fig. 4.22. *Comparison of modelled wet deposition fluxes of lead with monthly measurements at Finnish stations in 2006*

Thus, the performed numerical experiments have demonstrated that discrepancies between modelling results and observation at Finnish stations can be explained to significant extent by uncertainties in spatial distribution of emissions sources in the Russian Federation. Therefore, revision of both the reported emission totals and spatial distribution of lead emissions could significantly improve quality of the modelling results.

Measured air concentrations of lead at Slovak stations were significantly underestimated by the model. Monthly mean modelled air concentrations reproduce in general seasonal variability of measured concentration, but are significantly lower (up to 3 times) than the observed ones (Fig. 4.23). Monthly measured and modelled wet deposition fluxes agree within 25%. However, some peak monthly depositions are missed by the model (Fig. 4.24). According to the analysis of back trajectories regions the most significantly affected the pollution levels at Slovak stations are Poland, western part of the Ukraine and Hungary.

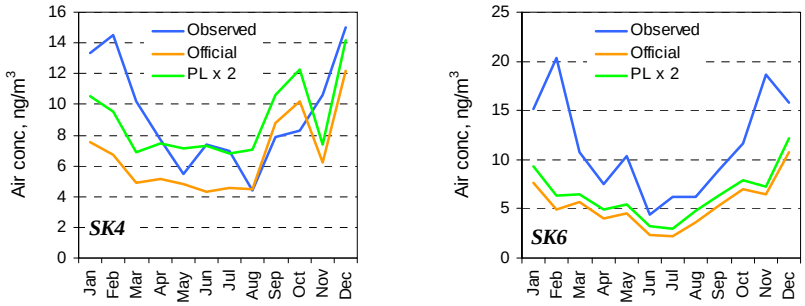


Fig. 4.23. *Comparison of modelled lead concentrations in air with monthly measurements at Slovak stations in 2006. PL×2 refers to the2-fold experimental increase of official emissions in Poland*

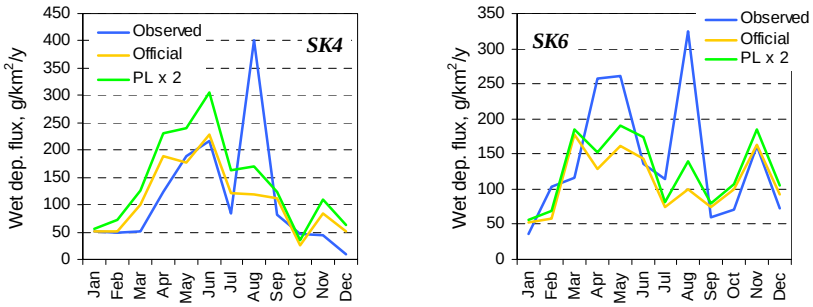


Fig. 4.24. *Comparison of modelled wet deposition flux of lead with monthly measurements at Slovak stations in 2006. PL×2 refers to the 2-fold experimental increase of official emissions in Poland*

Several experimental model runs have been performed to reveal possible reasons of the discrepancy between modelling result and measurements. The replacement of the official emissions of Hungary and the Ukraine by much larger estimates from the ESPREME database (by a factor of 2.5 for Hungary and a factor of 4 for the Ukraine), or experimental 2-fold increase of Slovak official emissions did not result in noticeable positive changes in the modelled air concentrations and wet depositions. In additional experiment the official emissions of Poland were also increased by a factor of two. It is worth stating that this increased Polish emission is most likely unrealistically high. Officially reported emission of lead in Poland is already the highest among the EMEP countries. Besides, officially reported Polish emission of lead for 2006 (524 tonnes) is even greater than the expert estimates from the ESPREME project related to 2000 (446 tonnes). Nevertheless, even this experimental increase of the Polish emissions did not result in significant increase of modelled air concentrations and deposition fluxes. (Fig. 4.23, 4.24).

Thus, the experiments with emissions modification have demonstrated that even significant changes of emissions in Slovakia and surrounding countries do not allow the model to reproduce available peak concentrations and wet deposition fluxes Therefore, the underestimation may be possibly caused by the influence of local emission sources not taken into account by regional scale modelling or by specific meteorological conditions.

Cadmium

Figure 4.25 presents comparison of modelled and measured annual mean concentrations of cadmium in air in 2006. In general the model somewhat underestimate observed values (by 20%). For almost 60% of stations the difference between observed and modelled concentrations does not exceed ±50%. Correlation coefficient is as large as 0.67. Agreement between observed and calculated values significantly varies among different stations. Observed concentrations at Czech, British, Lithuanian and most of German stations were simulated by the model reasonably well: the difference between modelled and measured quantities is less then ±35%. Underestimation of the observed concentrations takes place for Austrian, Scandinavian, Latvian and Hungarian stations. At some Slovak stations the agreement between model and observations is satisfactory but for some other stations the model underestimates measured values.

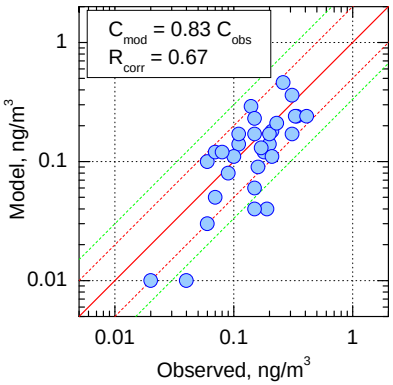
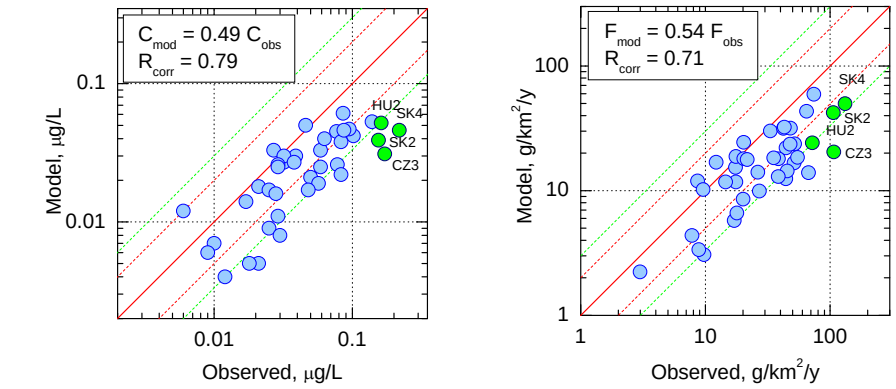


Fig. 4.25. *Comparison of modelled and measured annual mean concentrations of cadmium in air. Red solid line delineates 1:1 ratio, red and green dashed lines show deviation by a factor of two and three, respectively*

Comparison of modelled and measured cadmium concentrations in precipitation and wet deposition fluxes is shown in Fig. 4.26. As for lead, measurements of cadmium in precipitation at a number of stations (CZ3, HU2, SK2, SK4, coloured in green) were thoroughly analysed and classified as outliers [*Gusev et al.*, 2008]. These measurements were excluded from the statistics. In general annual mean concentrations of cadmium in precipitation and wet depositions fluxes were underestimated by the model by 50% (Fig. 4.26). Nevertheless, spatial variability was reproduced satisfactorily: Correlation coefficient between modelled and measured values is around 0.8 for concentrations in precipitation and about 0.7 for wet deposition fluxes. Model performance for cadmium concentrations in precipitation varies between different stations. Measured concentrations at German, Dutch and British stations were simulated relatively well by the model: The agreement between measured and modelled concentrations is mostly within ±30%, and for wet deposition fluxes – within ±40%. Some underestimation of concentrations in precipitation and the fluxes is noted for Swedish, Belgium, and Lithuanian stations. Higher underestimation is noted for Latvian, Polish and Finnish stations.



a b

Fig. 4.26. *Comparison of modelled and measured annual mean cadmium concentrations in precipitation (a) and wet deposition flux (b). Red solid line delineates 1:1 ratio, red and green dashed lines show deviation by a factor of two and three, respectively*

At a number of stations (e.g., at German, Belgium, Dutch, Lithuanian stations) the model successively reproduced short-term variability of cadmium concentrations. An example demonstrating modelled and measured weekly mean concentrations at station LT15 (Preila, Lithuania) is shown in Fig. 4.27. Most of the observed peaks were captured by the model, As seen from the figure, the modelled concentrations are mainly originated from anthropogenic sources. However, the introduction of wind re-suspension significantly improves the model performance. For example, peaks of measured concentrations in the end of January, end of April and middle of October are much better reproduced due to effect of wind re-suspension.

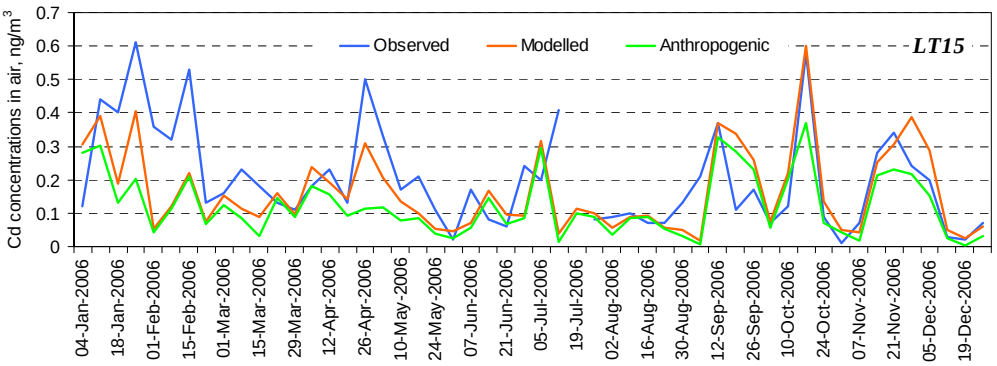


Fig 4.27. *Comparison of modelled cadmium concentrations in air with weekly measurements at station LT15 (Preila, Lithuania)*

Significant underestimation of concentrations in precipitation and wet deposition fluxes is noted for Finnish and some Slovak stations. Seasonal variation of monthly cadmium concentrations in air and wet depositions is very similar to that of lead. Therefore, the main outcomes of the experiments carried out for lead in order to reveal reasons of the underestimation at Finnish and Slovak stations are in general valid also for cadmium.

Mercury

Comparison of modelled and measured mean annual mercury concentrations in air for 2006 is presented in Fig. 4.28. As seen the model slightly underestimate observed values. Discrepancy between simulated and measured concentrations does not exceed 20%. The largest difference was obtained for stations BE14, DE2 and NO1. It should be noted that these monitoring stations measured mercury in air are located in the north-western part of Europe and can hardly characterize the model performance in the rest of the models domain. Therefore, extension of the mercury monitoring network eastward and southward is highly required for more comprehensive evaluation of the model.

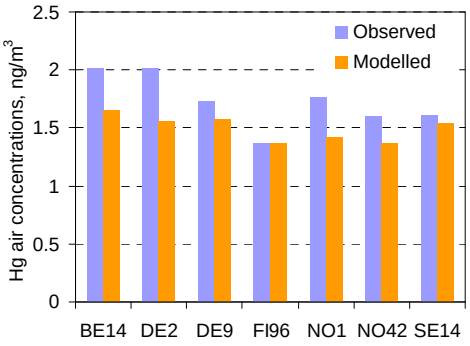
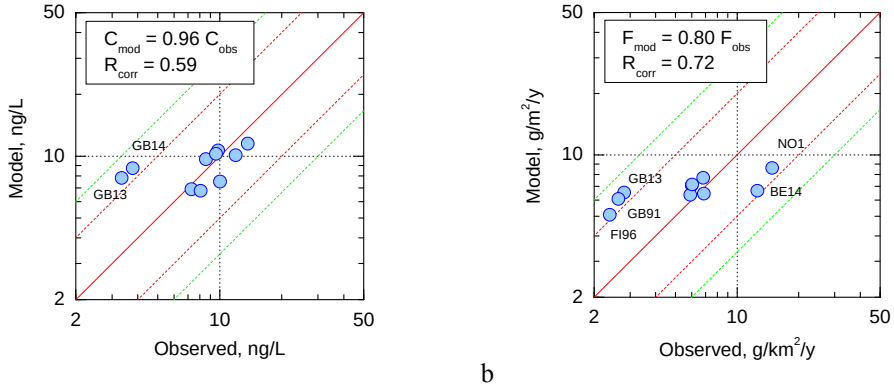


Fig. 4.28. *Comparison of annual mean modelled and measured total gaseous concentrations mercury in air*

Agreement between annual mean calculated and measured concentrations of mercury in precipitation lies within ±25%. An exception is two British stations: GB13 and GB91, where predicted concentrations exceed the observed ones by a factor of 2.3 (Fig. 4.29a). It should be noted that mercury concentrations measured at these sites seem unexpectedly low – they 2-3 times lower than measurements at other sites in Europe. Annual wet deposition fluxes of mercury were on average underestimated by the model by about 20% (Fig. 4.29b). At some stations (e.g. BE14, NO1, FI96) agreement between the model and observations is better for concentrations in precipitation than for wet deposition fluxes because of noticeable differences in modelled and measured precipitation amounts. Spatial variability of the observed values is satisfactorily well reproduced by the model: the correlation coefficient amounts to 0.6 for concentration in precipitation and 0.72 for wet deposition.



a b

Fig. 4.29. *Comparison of annual mean modelled and measured concentrations of mercury in precipitation (a) and wet deposition fluxes (b) Red solid line delineates 1:1 ratio, red and green dashed lines show deviation by a factor of two and three, respectively*

Similar to lead and cadmium, modelled concentrations of mercury were compared with higher temporally resolved observations. Examples showing the comparison of mercury concentrations in precipitation at stations DE1 (Westerland, Germany) and NL91 (De Zilk, the Netherlands) are presented in Figs. 4.30 and 4.31. Measurements were performed on weekly basis. Most minimums and maximums of mercury concentrations in precipitation were successfully captured by the model. Seasonal pattern, characterized by higher concentrations in summer and lower concentrations in winter, was also reproduced.

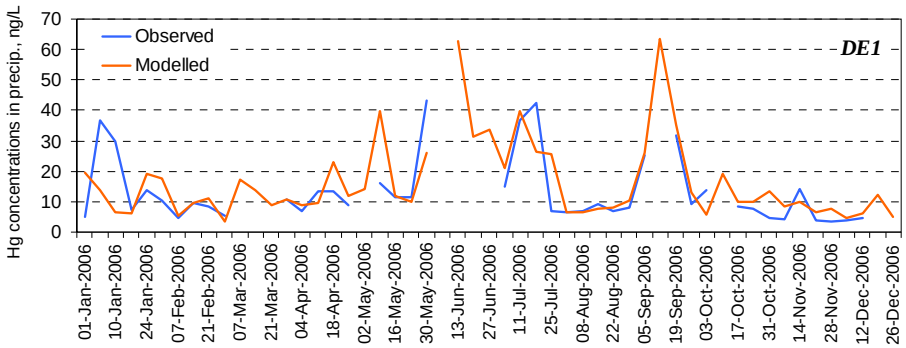


***Fig. 4.30**. Weekly mean modelled and measured concentrations of mercury in precipitation in 2006 at station DE1 (Westerland, Germany)*

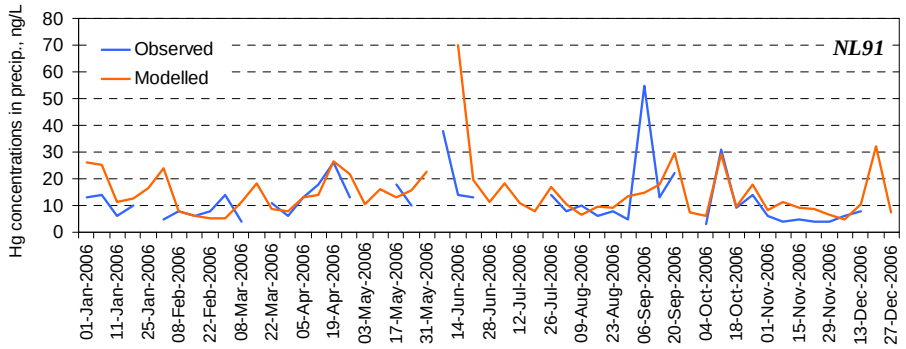


***Fig. 4.31.** Weekly mean modelled and measured concentrations of mercury in precipitation in 2006 at station NL91 (De Zilk, the Netherlands)*

4.3. Global atmospheric transport of mercury: Intercomparison of global/hemispheric mercury models

The current analysis has been performed for the AMAP/UNEP Technical Report on Sources of Mercury to the Atmosphere [*AMAP/UNEP*, 2008] and partly under financial support of AMAP and UNEP. Besides, the modelling results used in the study were obtained under the conditions of the model intercomparison within the Task Force on Hemispheric Transport of Air Pollution (TF HTAP) [http://aqm.jrc.it/HTAP/] and also published in the *UNEP F&T report* [2008] along with short description of participated models. All the models have conducted simulation of mercury global or hemispheric dispersion for 2001 using the most suitable model parameterizations and input data. Besides, the models performed a number of the perturbation runs for evaluation of mercury deposition response to emission reduction in different region of the Northern Hemisphere.

Participated models include three global models (CTM-Hg, GEOS-Chem, GRAHM) and one hemispheric model (MSCE-HM). The models significantly differ in their formulation. Particularly, spatial resolution of the models varies from 8×10 geographical degrees of CTM-Hg down to 2×2 degrees of GRAHM. On the other hand, CTM-Hg includes the most complicated chemical scheme in comparison with other three models. CTM-Hg and GRAHM contain the chemical mechanism of mercury oxidation by reactive halogens that is particularly important for the marine boundary layer. Besides, GRAHM include explicit treatment of the AMDE phenomenon in the Polar Regions (mechanistic parameterization of MSCE-HM was not used in this study). Only one of four models (GEOS-Chem) explicitly considered cycling of mercury between the atmosphere and the ocean using coupled mixed-layer slab ocean model. Thus, comparison of the modelling results obtained with these models allows estimating uncertainty level of current state-of-the knowledge mercury modelling.

Along with the model parameterization each of the models used their own estimates of anthropogenic and natural emissions. It particularly relates to the latter type which commonly includes mercury emissions from pure natural sources (volcanoes, evasion from mercury enriched soils etc.) and re-emission of previously deposited mercury. Table 4.1 presents global emission estimates used by the models in this study. All the models utilized anthropogenic emissions data based on the global emissions inventory for 2000 [*Pacyna et al*., 2006]. However, the original data were modified for GEOS-Chem increasing emissions by 50% in Asia and by 30% in other parts of the globe and including additional sources (artisanal mining). Therefore, anthropogenic emissions used by this model were about 55% higher in total than those used by other models.

The difference of natural emission and re-emission estimates between the models is much larger. The highest natural emission value was estimated by GEOS-Chem model (5830 t/y). As it was mentioned above this model includes explicit treatment of mercury cycling between different media and predicts re-emission process dynamically, whereas other models utilize prescribed fluxes of natural emission and re-emission. The lowest value (1800 t/y) was used by MSCE-HM model and it was based on the global estimate by *Lamborg et al.* [2002]. Taking into account more resent estimates [*UNEP F&T*, 2008] this value appears to underestimate the global natural emission of mercury and can be considered as the lower limit of existing estimates. Thus, total values of global mercury emission from anthropogenic and natural sources vary from 4000 to 9230 t/y.

Table 4.1. *Global estimates of mercury emissions utilized by the models, t/y*

Emission type	CTM-Hg	GEOS-Chem	GRAHM	MSCE-HM (*)
Anthropogenic	2200 (34%)	3400 (37%)	2200 (39%)	2200 (55%)
Natural and re-emission	4340 (66%)	5830 (63%)	3500 (61%)	1800 (45%)
Total	**6540**	**9230**	**5700**	**4000**

(*) Global estimates used for preparation of emissions data for the hemispheric model

Spatial patterns of mean concentration of bulk atmospheric mercury species – gaseous elemental mercury (Hg^0) – in the ambient air simulated by al the models are presented in Fig. 4.32. The original simulated patterns with the model intrinsic resolutions were interpolated to the 1°×1° grid for the comparison purposes. Circles at the figure present long-term observations of Hg0 concentration from several monitoring networks and individual sites. As seen all the models predict elevated concentrations (above 1.6 ng/m^3) in major industrial regions – East and South Asia, Europe, North America, South Africa. In general, it agrees with available measurements. GEOS-Chem demonstrates somewhat higher concentrations in East Asia, probably, because of larger anthropogenic emission estimates used for this region. On the other hand, this model predicts the lowest concentrations in other parts of the Northern Hemisphere. The difference between the models is the most pronounced in the Arctic. Three global models show evident gradient of mercury concentration between the Northern and Southern Hemispheres.

In spite of mentioned above differences in spatial distributions, the absolute values of Hg^0 concentrations predicted by different models vary insignificantly. Figure 4.33a shows model simulated concentrations of elemental gaseous mercury in different parts of the globe. Configuration of the receptor-regions considered in the analysis is presented in Fig. 4.34. They include the source regions themselves, several terrestrial (South America, Africa, Australia) and aquatic (the Arctic, North Atlantic and Pacific) regions. As seen from the figure variation of Hg^0 concentrations simulated by different models does not exceed 15%. The highest concentrations were obtained for East Asia and the lowest for Australia.

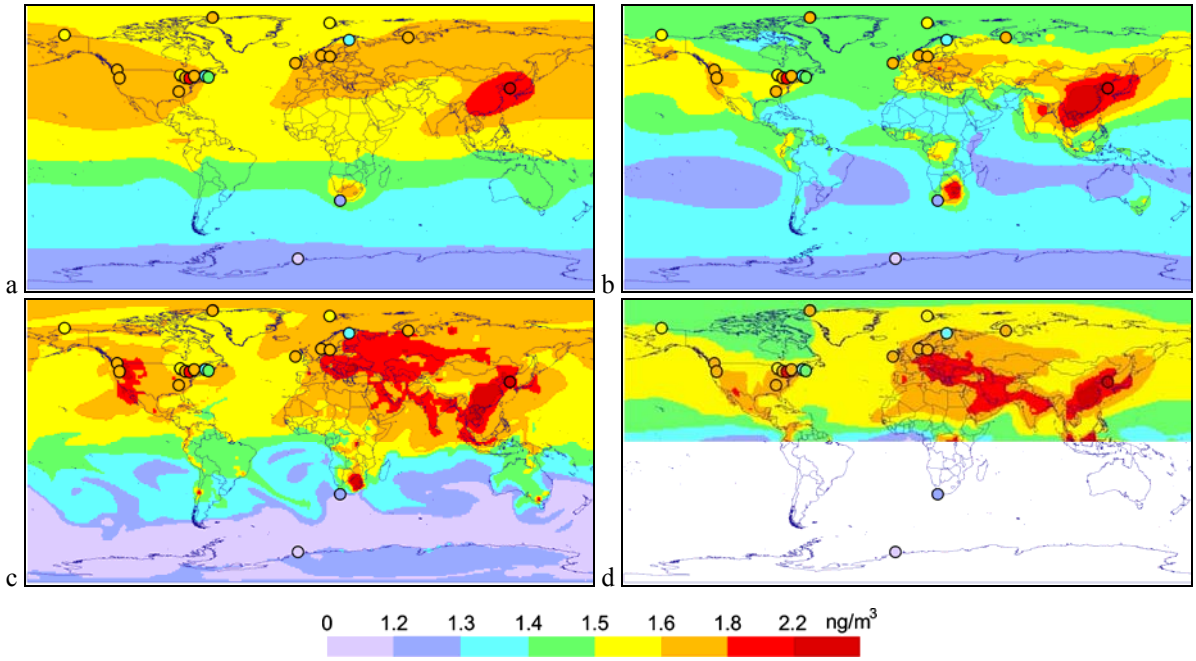


Fig. 4.32. *Global distribution of annual mean concentration of gaseous elemental mercury in the ambient air in 2001 simulated by CTM-Hg (a), GEOS-Chem (b), GRAHM (c), and MSCE-HM (d). Circles present long-term observations from the AMAP, EMEP, CAMnet networks and at some other monitoring sites: Look Rock, USA [Valente et al., 2007]; Mt. Bachelor Observatory, USA [Jaffe et al., 2005]; Cape Point, South Africa [Baker et al., 2002], Kang Hwa, Korea [Kim et al., 2002], Neumayer Station, Antarctica [Temme et al., 2003]*

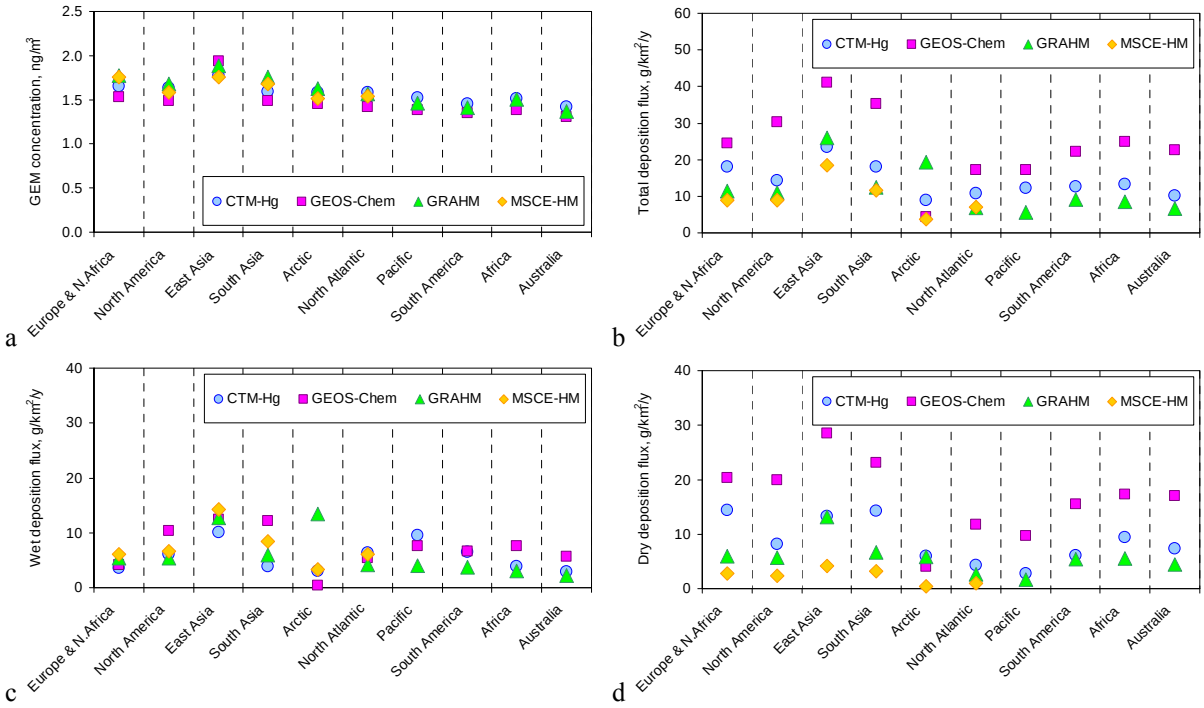


Fig. 4.33. *Average concentration of gaseous elemental mercury (a), total deposition (b), wet deposition (c) and dry deposition (d) in different regions of the globe in 2001*

The difference between the simulated mercury depositions is much higher than in the case of Hg0 concentrations (Fig. 4.35). Both spatial patterns and absolute values of deposition flux significantly vary from model to model. All the models predict enhanced depositions in major industrial regions but in other parts of the globe their estimates are different. In general, the largest depositions were simulated by GEOS-Chem (Fig. 4.35b) and the lowest – by MSCE-HM (Fig. 4.35d). It well agrees with the total emission estimates used by the models (see Table 4.1). In particular, GEOS-Chem obtained considerably higher depositions over the oceans. GRAHM and MSCE-HM, in general, agree in simulation of mercury depositions in temperate latitudes but the former predicts much higher depositions in high latitudes (Fig. 4.35c). These elevated depositions in the polar regions result from rapid oxidation of Hg^0 and its following deposition during the atmospheric mercury depletion events. Total mercury depositions averaged over different regions are presented in Fig. 4.33b. The highest deposition levels were obtained for East and South Asia, the lowest – over the oceans. Estimates of different models vary within a factor of two. To analyze discrepancies of the modelling results wet and dry components of the total deposition are considered below separately.

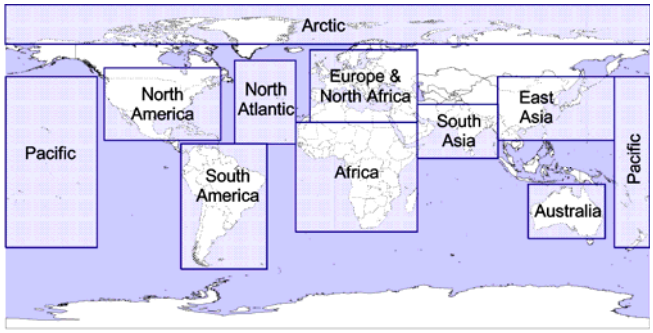


Fig. 4.34. *Location of receptor regions considered in the analysis*

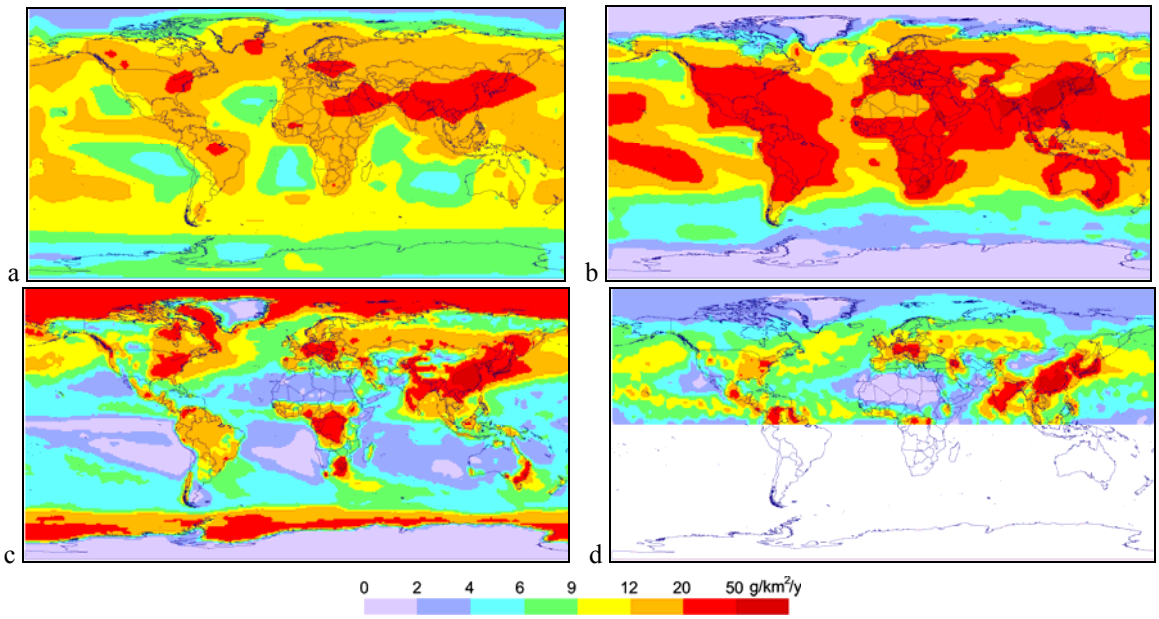


Fig. 4.35. *Global distribution of total (wet and dry) deposition of mercury in 2001 simulated by CTM-Hg (a), GEOS-Chem (b), GRAHM (c), and MSCE-HM (d)*

Figure 4.36 shows global distributions of wet mercury deposition simulated by the models and measured at monitoring sites of the EMEP and MDN networks. As seen from the figure the difference between wet deposition fields simulated by different models is not such considerable as in the case of total deposition. Wet depositions of mercury depend on combination of two factors: precipitation amount and availability of oxidized mercury forms. The most significant wet depositions are predicted in temperate latitudes: in the vicinity of emission sources and in remote areas with intensive precipitation. An exception is high depositions in the polar regions predicted by GRAHM due to influence of AMDEs (Fig. 4.36c). All four models generally reproduce wet deposition levels measured

in North America and Europe. GEOS-Chem tends to underestimate wet deposition at northern sites, CTM-Hg and GRAHM somewhat overestimate observed depositions in the northeastern coast of North America, and three of four models (CTM-Hg, GRAHM, MSCE-HM) underestimate elevated depositions at southwestern North American sites. Nevertheless, the discrepancies are not significant. Thus, the highest deviation of modelling results is characteristics of regions where no regular measurements of mercury deposition are available: over the oceans, in the Arctic, South Asia, Africa etc. (Fig. 4.33c).

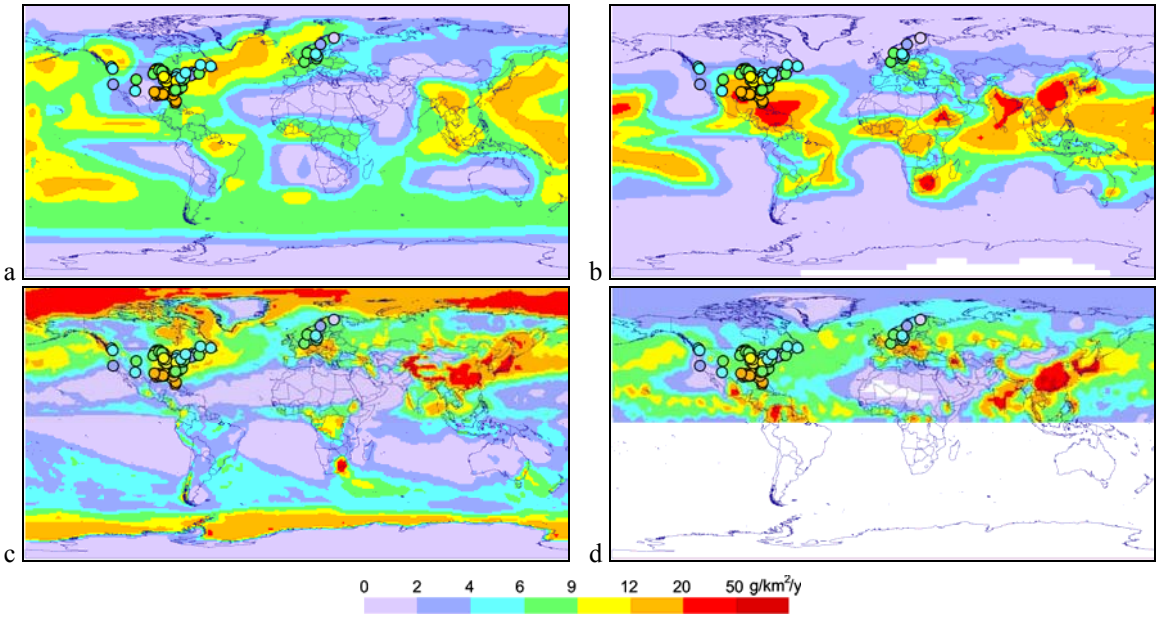


Fig. 4.36. *Global distribution of wet deposition of mercury in 2001 simulated by CTM-Hg (a), GEOS-Chem (b), GRAHM (c), and MSCE-HM (d).). Circles present long-term observations from the EMEP and MDN monitoring networks*

The most significant deviation of modelling results takes place for dry deposition (Fig. 4.37). It reflects differences in both models parameterization and emissions data used for simulation. In contrast to wet deposition that is partly constrained by available measurements, dry deposition is highly uncertain because of absence of any systematic observations. Given observed values of elemental mercury concentration and wet depositions can be successfully reproduced by a model using quite different emissions and dry deposition parameterization. As seen from Figs. 4.37 and 4.33d values of dry deposition simulated by different models vary by an order of magnitude. All the models predict larger dry depositions over land then over the ocean. The highest dry depositions are predicted by GEOS-Chem, whereas the lowest – by MSCE-HM. Large difference between the models can be explained by significant different emissions data (see Table 4.1) and dry deposition parameterization used by the models (e.g. removal with seasalt over the ocean and deposition of Hg0 over land). Thus, higher deposition can be compensated by higher evasion from the surface maintaining realistic levels of air concentration.

Summarizing the presented above analysis one can conclude that contemporary models successfully reproduce elemental mercury concentration in the ambient air (uncertainty does not exceed 15-20%). Uncertainty of model simulation of short-lived mercury species (not considered here) is much higher and is directly connected with uncertainty of mercury deposition. Processes governing mercury deposition are poorly known and uncertainty of simulated total depositions is much higher – a factor of two. The largest contribution to the deposition uncertainty is made by dry deposition. Factors the most significantly affecting uncertainty of mercury deposition include emissions data (anthropogenic and

natural), parameters of chemical reactions leading to oxidation of elemental mercury to short-lived forms, characteristics of dry deposition. An important factor restraining further improvement of mercury model is lack of regular measurement data, particularly, on air concentration of short-lived mercury species, dry and wet deposition.

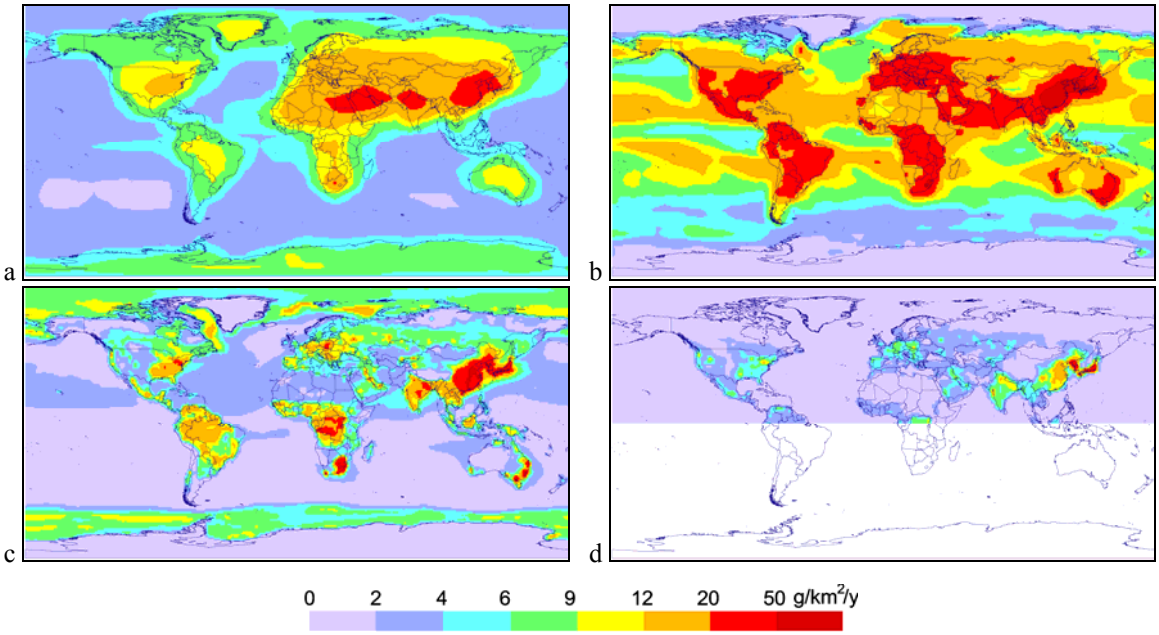


Fig. 4.37. *Global distribution of dry deposition of mercury in 2001 simulated by CTM-Hg (a), GEOS-Chem (b), GRAHM (c), and MSCE-HM (d)*

To evaluate response of mercury depositions to emission reduction in different sources regions all participated models conducted a number of the perturbation runs with anthropogenic emissions decreased by 20% in four major source regions – Europe and North Africa, North America, East Asia and South Asia – with respect to the base case discussed in the previous section. Configuration of four source regions along with spatial distribution of anthropogenic mercury emissions in 2000 according to [*Pacyna et al*., 2006] are shown in Fig. 4.38a. Figure 4.38b presents relative contribution of the source regions to the global emission. As seen almost 40% of global mercury emission is originated in East Asia. It should be noted that one of the participated models (GEOS-Chem) utilized an updated emissions data that which are about 55% larger (see Table 4.1). Nevertheless, relative contributions of the considered source regions were practically the same in the updated dataset.

In order to facilitate the analysis the modelling results were aggregated for a number of receptor regions all over the globe (Fig. 4.34). The aggregated results are presented in Fig. 4.39 in a form of bar charts. Each bar of the charts presents relative decrease of mercury deposition in particular region due to emission reduction in all four selected source regions. Contributions of different source regions are presented by different colours.

In spite of significant discrepancies between mercury deposition levels simulated by different models discussed in previous section, the models in general agree quantifying relative deposition response to emission reduction. All the models predict the highest decrease of deposition among the source regions in East Asia (8-15%) and the lowest in North America (5-10%). Besides, depositions to all sources regions are the most sensitive to emission reduction of own sources. Exclusion is North America: two of four models (CTM-Hg and GEOS-Chem) predict higher sensitivity to reduction of East Asian emissions. Reduction East Asian emissions also the most significantly contribute to deposition decrease over all remotes regions. Along with these similarities the total sensitivity of mercury

deposition to emission reduction considerably varies between the models. The highest deposition decrease predicted by MSCE-HM is almost twice larger than decrease simulated by CTM-Hg. The reason of this discrepancy can be easily understood taking into account relative contribution of anthropogenic emissions to total mercury emissions used by the models (Table 4.1). Larger contribution of anthropogenic emissions leads to higher sensitivity to emission reduction since the other part of emission was taken unchangeable (except GEOS-Chem which took into account short-term response of re-emission from the ocean to deposition decrease).

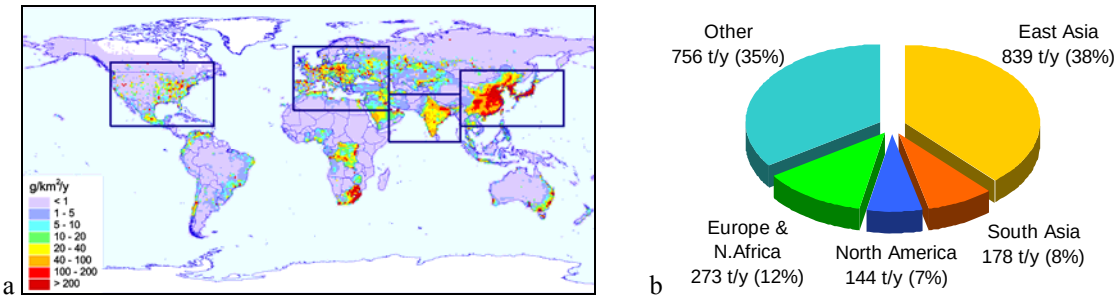


Fig. 4.38. *Global distribution of anthropogenic mercury emissions in 2000 according to [Pacyna et al., 2006] (a) and relative contribution of four considered source regions to global mercury emission (b). Rectangles show location of the four source regions – Europe and North Africa, North America, East Asia and South Asia*

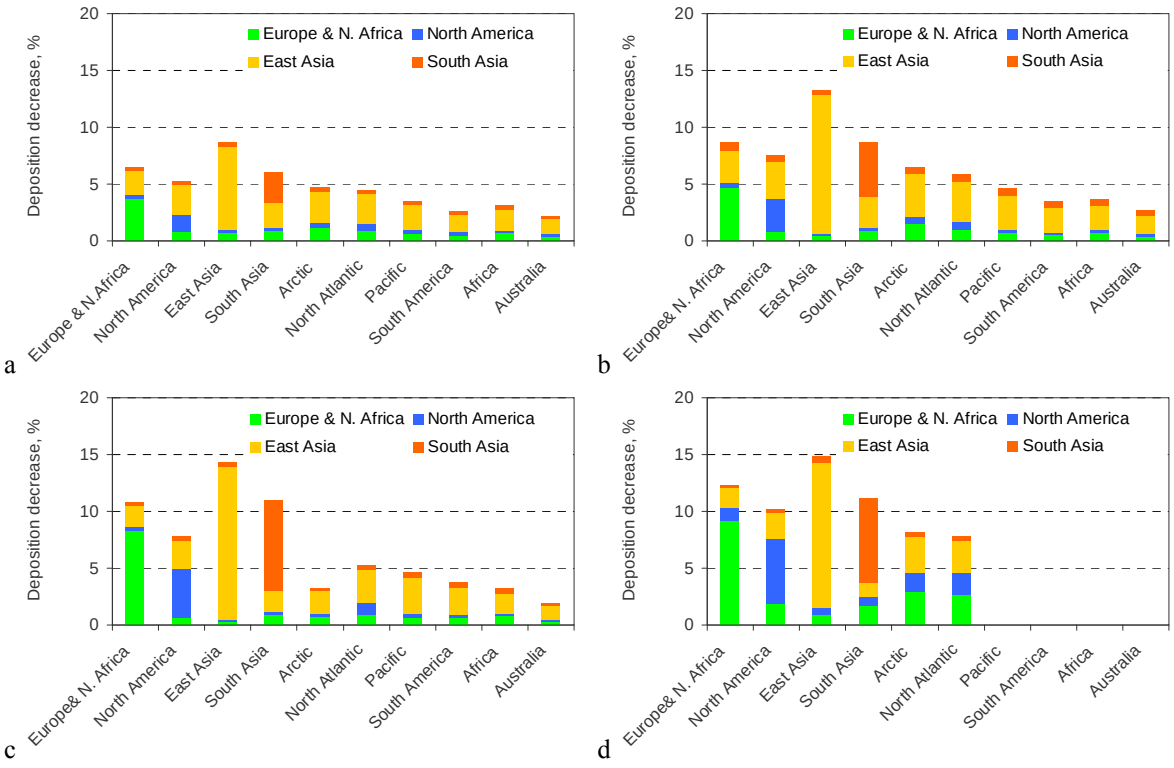


Fig. 4.39. *Relative decrease of mercury deposition due to 20% emission reduction in the four source regions simulated by CTM-Hg (a), GEOS-Chem (b), GRAHM (c), and MSCE-HM (d)*

Thus, presented above analysis demonstrates essential role of natural emission estimates and circulation of mercury between media for evaluation of mercury pollution response to reduction of anthropogenic emissions. Particularly, long-term decrease of mercury depositions could be significantly higher because of lagged response of land and the ocean.

5. CRITICAL LOADS FOR CD, PB AND HG FOR EUROPE AND NORTHERN ASIA

Gert Jan Reinds[1)]
Jean-Paul Hettelingh[2)]

[1] Alterra, Wageningen University and Research Centre (WUR), P.O. Box 47, NL-6700 AA Wageningen, Netherlands. E-mail: Gertjan.Reinds@wur.nl. Telephone +31 317 486508
[2] Coordination Centre for Effects, MNP/LED, P.O. Box 303, NL-3720 AH Bilthoven, Netherlands.

Methods

Critical loads for cadmium (Cd), lead (Pb) and mercury (Hg) for forests were computed using the methods described in the Mapping Manual [*UBA*, 2004].

The critical load is defined as:

$$CL(M) = M_u + M_{le(crit)} \tag{5.1}$$

where: $CL(M)$ = critical load of heavy metal M (g ha-1 a-1); M_u = removal of heavy metals by biomass harvesting or net uptake in forest ecosystems, respectively, from the mineral topsoil (g ha-1 a-1); $M_{le(crit)}$ = critical leaching of heavy metals from the mineral topsoil (g ha-1 a-1).

The critical load thus consist of metal uptake and a critical metal leaching determined by a critical metal concentration related to effects on the ecosystem.

Data

The most recent version of the European background database was used for calculating the critical loads. This data base is described in *Reinds et al.* [2008]. Critical loads were computed for forests only. When variables were not found in existing databases, the recommendations and transfer functions in the Mapping Manual [*UBA*, 2004] were followed as closely as possible.

A map with computational units was created by overlaying maps on soil, vegetation and forest growth regions. Overlaying these maps and merging polygons with common soil, vegetation and region characteristics within blocks of 10×10 km resulted in about 3.8 million computational units. In the model runs, we used only computational units larger than 1 km2 reducing their number to 1.3 M but occupying 96% of the total area.

Metal uptake was computed from data on forest growth (obtained from existing databases) multiplied by metal contents in stem wood from the Mapping Manual. Critical leaching rates were computed as the water flux leaving the root zone multiplied by a critical metal concentration. Water fluxes were computed with a regional hydrological model using detailed meteorological data; details can be found in *Reinds et al.* [2008]. The critical concentration for Cd and Hg was based on ecotoxicological effect on soil organisms, and computed as a function of soil pH and the concentration of dissolved organic carbon (DOC). For Hg the critical concentration was derived from a critical Hg content in soil organic matter and a fractionation ratio that relates the concentration of Hg in soil solution to the concentration in solids. Details can be found in *UBA* [2004].

Results

Critical loads

For each of the EMEP 50 × 50 km grid cells, the frequency distribution of critical loads was computed. From this distribution, we used the 5th percentile critical load to represent the grid cell in order to protect 95 % of the forested area. Critical loads for Cd and Pb show strong regional patterns (Fig. 5.1). Lowest critical loads are found in areas with low metal uptake and leaching: arid regions in southern Europe and in the New Independent States with high pH values in the soils. Highest critical loads are found in area with high precipitation excess such as north-western Europe and in areas with acidic soils where the critical concentration is relatively high such as in parts of Germany, Poland and Russia.

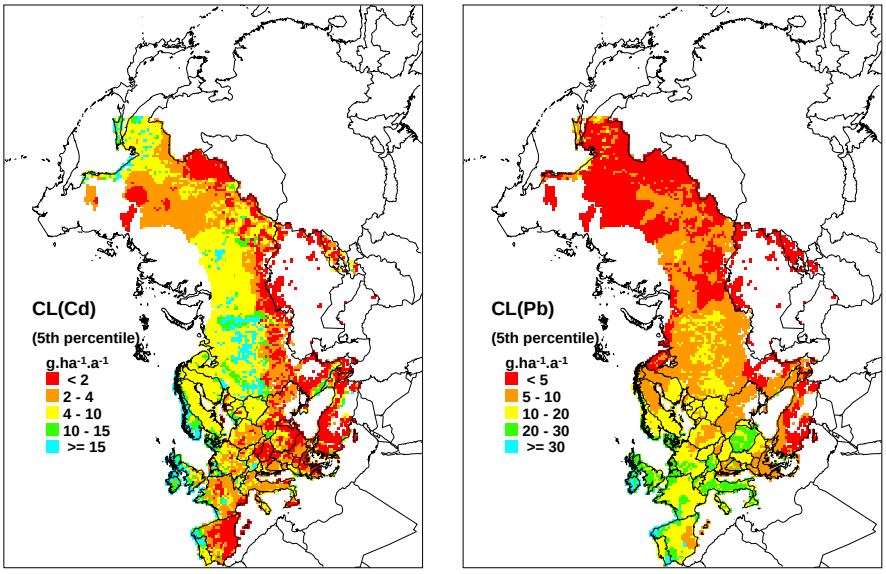


Fig. 5.1. *5th percentile critical loads for Cd and Pb for forests*

Critical loads of Hg are high in areas with a high precipitation excess, e.g. along the west-coast of Europe (Fig. 5.2). Critical concentrations of Hg decrease with decreasing DOC concentration in the soils, so that low critical loads are also found in area with poor sandy soils poor in organic matter. In areas with organic rich soils, critical loads are high (e.g. parts of Finland and the United Kingdom).

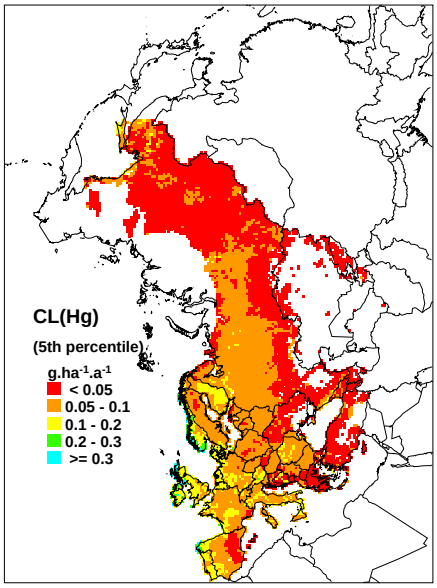


Fig. 5.2. *5th percentile critical load for Hg for forests*

Exceedances

For each of the metals, the Average Accumulated Exceedance (AAE) was computed. The AAE is the area-weighted average exceedances over all ecosystems in the EMEP grid cell. Exceedances of critical loads for Cd are limited to areas with high depositions and low critical loads such as parts of

central Europe and the Ruhr area in Germany (Fig. 5.3). Critical loads for Pb are exceeded in large parts of central and south-eastern Europe were depositions are high. Noticeable are also the exceedances along the European Mediterranean coast caused by relatively high Pb depositions.

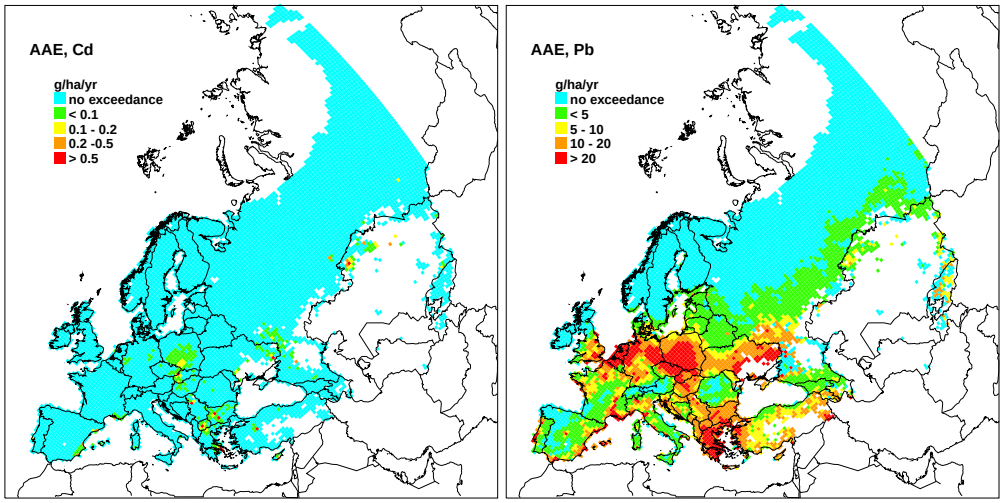


Fig. 5.3. *Average accumulated exceedances for Cd and Pb*

For Hg, critical load exceedances occur in almost all of Europe and northern Asia. Since the regional variability in critical loads for Hg is limited, the magnitude of the average accumulated exceedances for Hg strongly follow the patterns in deposition with highest exceedances in central and southern Europe, southern Russia and the New Independent states.

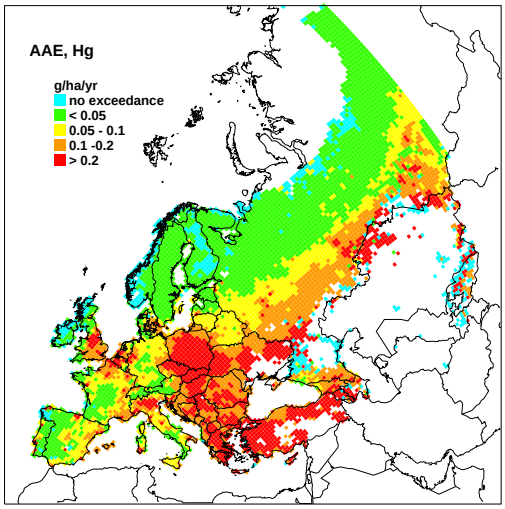


Fig. 5.4. *Average accumulated exceedance for Hg*

Conclusions

The new CCE background database formed a proper basis for computing critical loads for Cd, Pb and Hg. Results obtained in this study are in good agreement with the heavy metal critical loads maps for Europe provided in *Slootweg et al.* [2005]. Uncertainties in the computed critical loads are substantial as critical concentrations are computed as a function of pH and DOC concentration defined as a function of soil type, but it is known that both pH and DOC can strongly vary within soil types as a function of e.g. climate and parent material.

6. CO-OPERATION

6.1. Task Force on Hemispheric Transport of Air Pollution

MSC-E continued cooperation with the EMEP Task Force on Hemispheric Transport of Air Pollution (TF HTAP). Particularly, the Centre participates in the intercomparison study of hemispheric and global models organised in the framework of TF HTAP. The aim of the study is assessment of intercontinental source-receptor relationships for different pollutants including mercury and selected POPs, evaluation of current models variability and uncertainties, and guidance of future model developments.

The first set of the model experiments for mercury included evaluation of the hemispheric transport in 2001 and estimates of sensitivity of mercury concentration and deposition levels to emission reduction in major source regions of the Northern Hemisphere. Preliminary results of the intercomparison study of hemispheric/global mercury models were discussed at the TF HTAP Workshop in Rome, Italy, in April 2008. Besides, a detailed analysis of the models intercomparison results was carried out for the joint UNEP and AMAP report on emission sources of mercury to the atmosphere [*AMAP/UNEP*, 2008]. A summary of this analysis is presented in Section 4.3.

Within a framework of joint development of the EMEP global modelling system by the EMEP modelling Centres MSC-E has extended the existing hemispheric model (MSCE-HM-Hem) to the global scale. The new global (GLEMOS) model has inherited major process parameterisations and numerical techniques from the hemispheric one. The atmospheric transport module of the GLEMOS model was thoroughly tested in the tracer experiment carried out as a part of the TF HTAP intercomparison study. Some results of the testing are illustrated in Section 3.1 of the current report and in more details in the joint EMEP Centres Technical report [*Tarrason and Gusev*, 2008].

6.2. Task Force on Measurements and Modelling

MSC-E reported to the TFMM on the progress in the development of the EMEP global modelling framework and on output of joint technical meeting of CCC, MSC-E and MSC-W held in March 2008 in Gjerdrum (Norway). The main objectives of the meeting were to foster the collaboration between the scientists involved in the EMEP work, to discus common reporting to the Steering Body to EMEP and to agree further plans on improving EMEP global model activity.

Task Force participants were informed on current status and main principles of the common EMEP global model development including flexibility, modular structure for evaluation of different pollutants and linked global, regional and local scales. It was noted that the current stage of the common work was focused on the unification of land cover, LAI data, testing of meteorological pre-processors, and on the development and testing of two pilot global models based on the existing at MSC-E and MSC-W approaches. Detailed information on this issue is described in Section 3.1 and in the Joint Technical report of the EMEP Centres [*Tarrason and Gusev*, 2008].

6.3. Task Force on HMs

The 5th meeting of the Task Force on Heavy Metals (TF on HMs) held in London (the UK) in June 2008 was focused upon consideration of possible assistance to countries with economies in transition in their efforts to ratify Convention Protocols. Task Force participants were overviewed on the EMEP activity towards EECCA countries. Information on available emission datasets including emission expert estimates, expansion of the EMEP monitoring network, validated data on concentrations, depositions and transboundary fluxes of lead, cadmium and mercury for 2006 over the extended EMEP domain was presented.

It was noted that only 5 EECCA countries (Armenia, Belarus, Moldova, Russia, and the Ukraine) officially reported on heavy metal emissions. Monitoring information has not been available from these countries for the time being. Nevertheless, it is significant that establishment of new monitoring stations in Armenia, Kazakhstan, Georgia and Republic of Moldova is in progress now under the methodological supervision and technical assistance of CCC and financial support of some EMEP countries. Taking into account that monitoring data are scarce in EECCA countries, measurement-modelling approach was suggested to use for the evaluation of pollution levels.

6.4. Eastern Europe, Caucasus and Central Asia (EECCA) countries

In line with EMEP priorities, a particular attention of MSC-E activity in the field of heavy metal transboundary pollution was paid to EECCA countries. In 2008 territories of Kazakhstan and Kyrgyzstan as well as Tajikistan, Turkmenistan and Uzbekistan that are going to join the Convention in the nearest future were fully covered by the extended EMEP domain. In particular, the extension eastward of the EMEP grid allows to provide the Central Asian countries with the same information on transboundary fluxes and pollution levels as the other Parties to the Convention annually receive. In order to support EECCA countries with information required for air quality management and implementation of the selected CLRTAP Protocols status reports for individual countries are planned to be prepared in Russian language starting from 2008.

MSC-E took part in the Workshop for countries with economies in transition to promote ratification of the HM Protocol organized by the CLRTAP Task Force on Heavy Metals in May 2008 in Yerevan (Armenia). The aim of the meeting was to raise awareness and interest of EECCA and SEE countries and to involve them further in the activities carried out under the Convention. Countries were gotten acquainted with information on officially reported emission data and emission expert estimates, measurement and atmospheric modelling data, technologies and technical measures for emission reduction, as well as with the methodological tools available in Russian language such as EMEP/CORINAIR Emission Inventory Guidebook and EMEP Manual for sampling and technical analysis.

Besides, workshop participants were informed of the steps being taken by EMEP towards EECCA countries, in particular the extension of the geographical scope of EMEP eastwards to cover the Central Asian countries. Existence of donor, technical and methodological assistance of CCC for the development of the monitoring network in Armenia, Georgia, Kazakhstan and Moldova was highlighted.

MSC-E at the request of the United Nations Economic Commission for Europe (UNECE) prepared information on the pollution levels of lead for the Central Asian countries: Kazakhstan, Kyrgyzstan,

Uzbekistan, Turkmenistan and Tajikistan in the framework of CAPACT (Capacity Building for Air Quality Management and the Application of Clean Coal Combustion Technologies in Central Asia) project. The CAPACT project was initiated by the UNECE together with cooperating agencies UNESCAP and UNEP. Particularly, concentrations, depositions and transboundary fluxes of lead in the Central Asian countries were evaluated over the extended EMEP domain for 2005.

It was found that transboundary transport significantly contributes to lead deposition in the Central Asian countries: from about 50% to 70% of total depositions are determined by external anthropogenic sources. The highest contribution of transboundary transport took place along the state borders. For example, in Kyrgyzstan the contribution of transboundary transport to anthropogenic depositions along the state borders exceeds 90%, while in the middle of country – below 85% (Fig. 6.1). Contribution of external Central Asian sources (from Kazakhstan, Uzbekistan, Tajikistan and Turkmenistan) to depositions from anthropogenic sources gradually declines from north-western border (more than 44%) towards south-east (less than 18%) (Fig. 6.2).

Among other external sources the most significant contribution (35-60%) is made by sources located in other parts of Asia (Middle East, Southern Asia etc.). However, these estimates contain very large uncertainty because of very limited and outdated emissions data available for these regions.

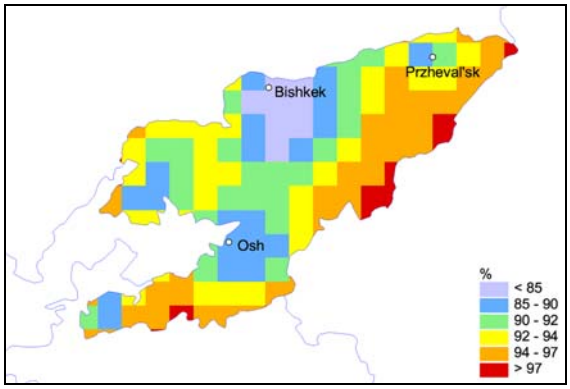


Fig. 6.1. *Contribution of transboundary transport to anthropogenic depositions of lead in Kyrgyzstan in 2005*

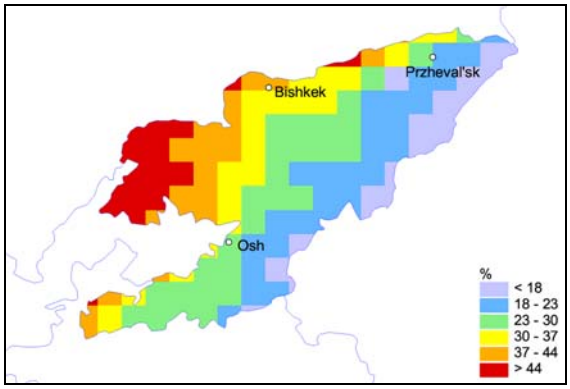


Fig. 6.2. *Contribution of transboundary transport from Central Asian sources to anthropogenic depositions of lead in Kyrgyzstan in 2005*

Significant part of lead emitted in the considered countries (60-85%) is transported beyond the national boundaries and contributed to lead pollution in other countries. For example, 35% of mass of lead, emitted by anthropogenic sources of Kyrgyzstan, deposit to its own territory, and the rest 65% enters transboundary transport (Fig. 6.3). The prevailing directions of the transport are northward and westward because in other directions the Central Asian region is enclosed by the mountain ridges restricting the atmospheric transport.

Along with direct anthropogenic sources, depositions of lead are also affected by natural sources and wind re-suspension. Contribution of these sources to lead deposition in the Central Asian region is significant and varies from 20 to 30% in different countries in 2005.

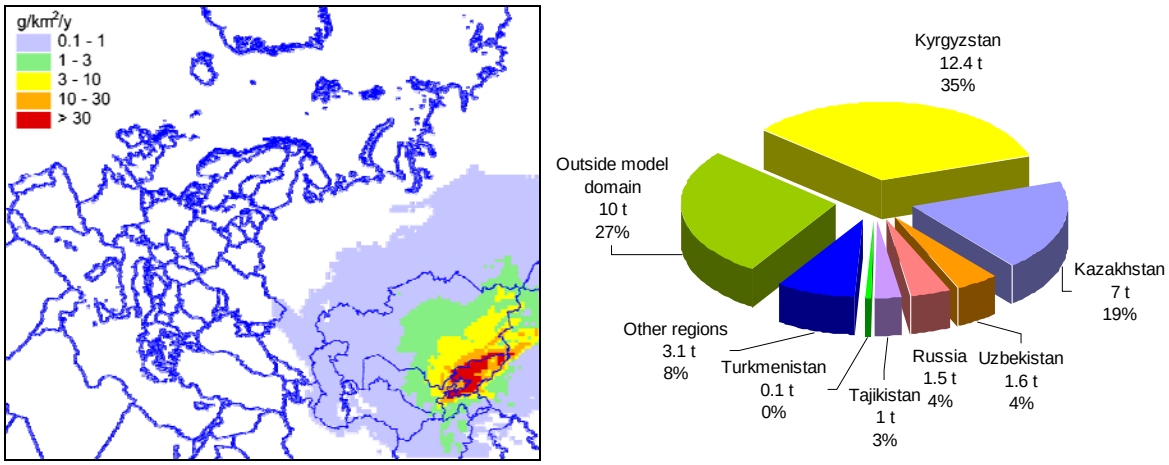


Fig. 6.3. *Transboundary transport of lead from sources of Kyrgyzstan in 2005*

6.5. United Nations Environment Programme

MSC-E contributed to the UNEP report "Atmospheric emissions of mercury: Inventory, sources and transport" co-ordinated by the Arctic Monitoring and Assessment Programme (AMAP). This work was partly funded by UNEP and AMAP. The report will be presented to the 25th session of the UNEP Governing Council in 2009. In particular, MSC-E took part in drafting the overview of contemporary modelling approaches applied for assessment of mercury pollution levels on a global scale. It also performed comparative analysis of the results of mercury atmospheric modelling on a global scale obtained under conditions of the TF HTAP intercomparison study. Main results of the analysis are presented in Section 4.3 of the current report.

6.6. European Commission and national experts

In 2008 MSC-E takes part in the EU HEIMTSA project launched in 2007 under the 6th Framework Programme of the European Commission (EC). The project aims to support the Environment and Health Action Plan (EHAP) by extending health impact assessment (HIA) and cost benefit analysis (CBA) methods and tools so that environment and health impacts of policy scenarios in key sectors can be evaluated reliably at the European level. 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 and POPs and their concentration in different environmental media.

6.7. OSPAR Commission

In the framework of cooperation programme between EMEP and OSPAR Commission (Convention for the Protection of Marine Environment of the North-East Atlantic) MSC-E contributed to the 2009 CAMP (Comprehensive Atmospheric Monitoring Programme) data assessment report preparing information on emissions and atmospheric depositions of heavy metals in the OSPAR maritime area in the period 1990-2005.

Model assessment of atmospheric depositions of lead, cadmium and mercury to the OSPAR Convention Waters has been performed. Particularly, annual depositions for each year of the period 1990-2005 were calculated for the main regions of the OSPAR maritime area and for 13 sub-regions of the OSPAR Region II (Greater North Sea). Contribution of key emission source categories to lead, cadmium and mercury deposition over the OSPAR region was assessed. The modelling results were evaluated against available monitoring data from the OSPAR monitoring network (CAMP).

Fig. 6.4 shows deposition flux of lead to the OSPAR maritime area and to the Region II (Greater North Sea). Over the region *Arctic Waters* the depositions range mainly from 0.05 – to 0.3 mg/m^2/y, over *Wider Atlantic* – from 0.3 to 0.5 mg/m^2/y (Fig. 6.4a). The highest depositions (0.8 - 1.2 mg/m^2/y) were indicated for Region *Grater North Sea*. The highest depositions over the Greater North Sea (> 1.4 mg/m^2/y) are found in regions along coast of the southern part of Norway and coasts of Belgium, the Netherlands, and Germany (Fig. 6.4b). In the former case the elevated depositions are explained by high precipitation amounts typical for this region of Europe, while in the later case – by the proximity to anthropogenic emission sources. Similar spatial distributions were obtained also for other heavy metals (cadmium and mercury).

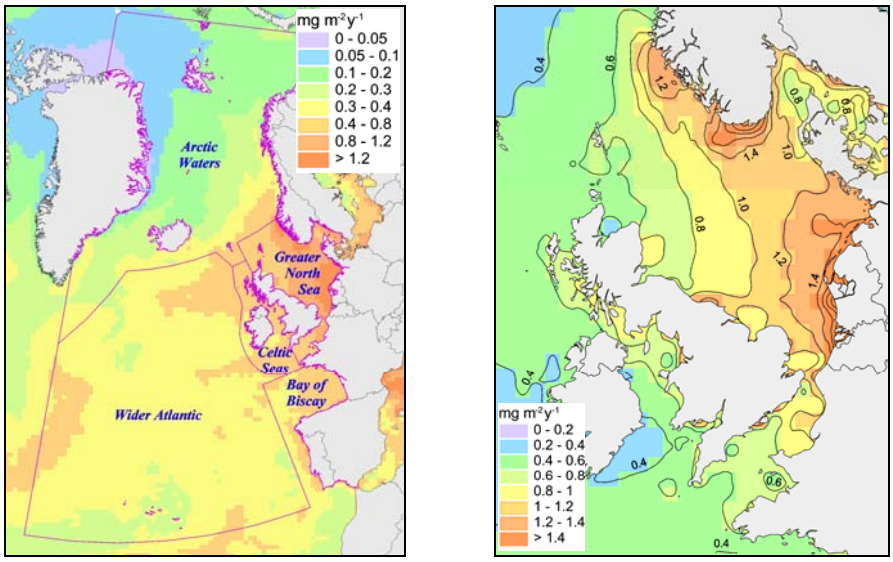


Fig. 6.4. *Spatial distribution of annual total deposition flux of lead over the five main OSPAR regions (a) and over the OSPAR Region II (Greater North Sea) (b) in 2005*

Figure 6.5 demonstrates long-term trends of total depositions and net depositions fluxes (depositions minus wind re-suspension) of lead over five main OSPAR maritime regions. The more pronounced decline of depositions for 1990 – 2005 is seen for regions *Greater North Sea*, *Bay of Biscay* and *Celtic Sea*. This decline is explained by substantial emission reduction in Europe since 1990. Over regions *Wider Atlantic* and *Arctic Waters* the decline is minor, mostly due to remoteness of these regions from main anthropogenic emission sources. Depositions of cadmium and mercury also decrease but the rate of decline is smaller than that for lead.

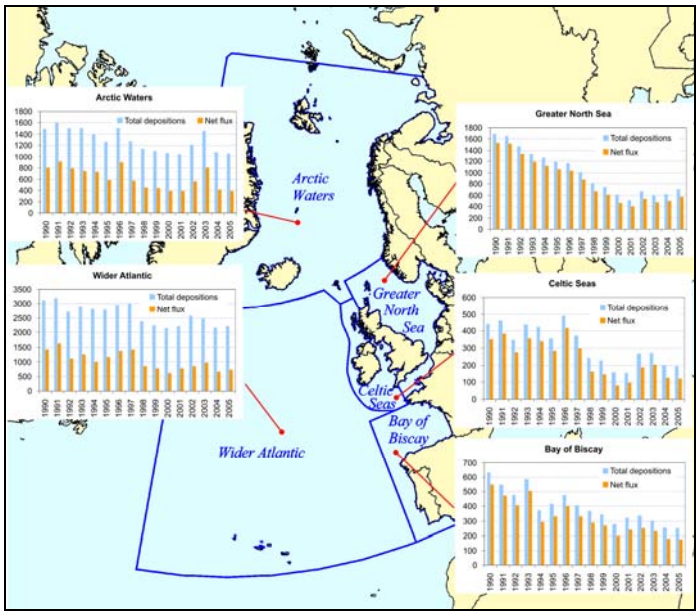


Fig. 6.5. *Time series of modelled total annual deposition and net atmospheric input of cadmium to the five main OSPAR regions*

The highest decrease of total depositions took place in the Region IV (Bay of Biscay) and made up to 60% for lead and cadmium. The lowest decrease was obtained for Region V (Wider Atlantic) and amounted to 30% for lead and 25% for cadmium. As for mercury, the highest decrease of deposition during the period 1990–2005 took place in the Regions II (Greater North Sea) and III (Celtic Seas) – 35% and 25%, respectively.

The report was approved by the OSPAR Commission, recommended to be published on its website and it was decided to include products of this work as contribution into the 2009 CAMP data assessment report.

6.8. Helsinki Commission

During 2007 MSC-E prepared contribution to the joint EMEP Centres annual report for HELCOM devoted to the evaluation of airborne pollution load to the Baltic Sea in 2005 [*Bartnicki et al*., 2007]. MSC-E was responsible for providing the information on atmospheric transport and depositions of lead, cadmium, and mercury to the Baltic Sea. The depositions and atmospheric transport were assessed on the base of EMEP officially submitted emission data. Besides, this report provided detailed information about emissions of heavy metals in HELCOM countries and comparison of modelling results against measurement data collected in the HECLOM region in 2005.

In addition to the joint annual report, MSC-E prepared environmental indicator reports with the updated information on atmospheric emissions of heavy metals and their depositions to the Baltic Sea for 1990 – 2005 period. These reports are available in the Internet at the web site of the Helsinki Commission [www.helcom.fi].

According to the officially reported emission data, cadmium emissions in HELCOM countries declined by 45%, mercury – by 46% and lead by 86% for the period from 1990 to 2005 (Fig. 6.6). Generally, the reduction of heavy metal emissions in this area is caused by extensive use of unleaded gasoline and application of cleaner production technologies. Besides, it is partly connected with economic re-

structuring which has taken place in Poland, Estonia, Latvia, Lithuania, and Russia since early 1990s. The highest decrease of cadmium emissions took place in Lithuania (90%) and Estonia (87%). In case of lead emission, the most significant decrease can be seen for Denmark and Sweden where the emissions in 2005 were more than 20 times lower than in 1990. Mercury emission most significantly decreased in Germany (86%) and Sweden (80%). Essential reduction of annual lead emission of HELCOM countries from 2003 to 2004 is mostly caused by the change of emission in Russia.

Following the reduction of atmospheric emissions, depositions of heavy metals decreased for the period 1990 – 2005 (Fig. 6.7). Depositions of lead are characterized by the most significant decline (65%). The decrease of cadmium depositions made up 43%, and mercury – 33%. When considering individual sub-basins of the Baltic Sea the highest decrease of cadmium and lead depositions was revealed for the Gulf of Finland (64% and 73%, respectively). For mercury, the most significant decline in depositions was obtained for the Kattegat (51%).

In 2005 the highest modelled depositions of heavy metals were indicated for the southern-western part of the Baltic Sea (the Belt Sea and the Kattegat). Poland, Germany and Russia are the major contributors to atmospheric depositions of heavy metals to the Baltic Sea in 2005 among HELCOM countries.

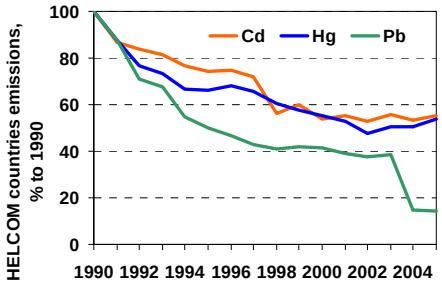


Fig. 6.6. *Trend of anthropogenic emissions of cadmium, mercury, and lead from HELCOM countries in 1990-2005 according to official emissions data*

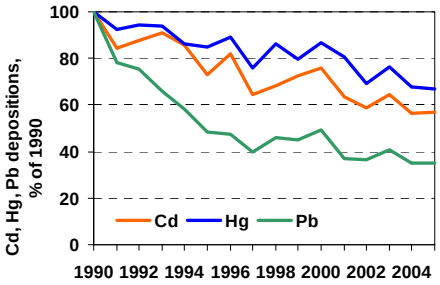


Fig. 6.7. *Temporal variations of cadmium, mercury, and lead depositions to the Baltic Sea in 1990-2005*

7. FUTURE ACTIVITIES

In order to further improve the quality of modelling results of lead, cadmium and mercury pollution over the EMEP region, the following activities are proposed for 2009:

1. Regional-scale model development

    1.1. Consider nationally available measurements on dry deposition of Hg to forests to evaluate measurement uncertainties and improve model parameterization.

    1.2. Continue to develop the heavy metal model parameterization including improvement of the wind re-suspension scheme and implementation of aerosol size-segregated description and removal processes.

    1.3. Update the Hg chemical scheme in the regional and global models based on new findings of the research community.

    1.4. Investigate the possibility to update meteorological drivers by application of WRF (Weather Research and Forecasting Model).

2. Global model development

    2.1. Evaluate the effect of using different geophysical and emission data in the existing global models used at the two Centres.

    2.2. Evaluate means for the flexible introduction of different meteorological drivers to be used in the common EMEP global model.

    2.3. Identify the changes in existing model routines that are necessary to facilitate common modules for the global modelling in EMEP.

    2.4. Participate in the TFHTAP model intercomparison for mercury with the global model.

3. Input data preparation

    3.1. Review heavy metal emissions for modelling purposes.

    3.2. Elaborate a data set of validated and complete emission data submitted during the 2009 reporting round by 15 April 2009 for use in the EMEP 2007 assessments. Increase the transparency in use of non-Party estimates for modelling.

    3.3. Prepare input meteorological data set for modelling purposes on the base of ECMWF analyses data.

4. Evaluation of pollution

    4.1. Provide validated data on concentrations, depositions and transboundary fluxes of heavy metals (mercury (Hg), lead (Pb) and cadmium (Cd)) for 2007 over the extended (eastward) EMEP domain, and update source-allocation calculation, including EECCA countries.

    4.2. Evaluate ecosystem-dependent depositions of heavy metals and contribute to the development of the effect-based approach.

4.3. Prepare individual country status reports; update web access to electronic source allocation information with validated data for heavy metals.

4.4. Review, store and make available the 2008 monitoring data; assess uncertainties in, and the representativeness of, monitoring data required by the EMEP monitoring strategy.

4.5. Contribute to the TFHTAP 2010 assessment report on intercontinental transport of air pollution.

4.6. Consider and propose further actions to close the gap between official emission data for heavy metals and modelling results in close collaboration with the modelling community.

4.7. Continue to co-operate with EU, HELCOM, UNEP, etc. Continue support and training in EECCA countries.

CONCLUSIONS

The main activities of EMEP Centres in the field of monitoring and modelling of heavy metals in 2008 were focused on evaluation of pollution levels of lead, cadmium and mercury over the extended EMEP domain, including Europe and Central Asia. MSC-E continued implementation of the recommendations formulated by TFMM aimed at evaluation and further improvement of the MSC-E heavy metal model. Particular attention was paid to development of the EMEP global modelling framework in close co-operation with MSC-W. Besides, MSC-E co-operated with the Task Force on Measurements and Modelling and contributed to the Task Force on Heavy Metals and the Task Force on Hemispheric Transport of Air Pollution. The main conclusions on the activities, undertaken by CCC and MSC-E, are presented below.

Monitoring of heavy metals

1. Monitoring information on lead and cadmium in air and in precipitation for 2006 was reported by 65 stations. Among them at 29 stations the concentrations were measured in both media. Measurement data on at least one mercury form were reported by 16 stations. Nevertheless, spatial coverage with measurements of the southern and eastern parts of Europe remains insufficient.

2. The lowest concentrations of lead, cadmium and mercury were observed in the northern part of Scandinavia. The concentrations tend to increase southward. The highest concentrations of the measured species are noted for Slovakia, Hungary and the Czech Republic.

3. Results of the annual intercomparison of analytical methods in national laboratories demonstrate marked improvement of the EMEP measurements since 1995. Quality of analyses in most of laboratories participated in the intercomparison comply with data quality objectives. However, problems with analytical processing of measurement data were indicated for some countries. In addition to this, some countries do not participate in the intercomparison, and therefore their measurement data are of unknown quality.

Emissions

1. In 2008 the emission data on lead, cadmium and mercury were officially reported by 31 EMEP countries for 2006 reporting year. Information on gridded emissions was presented by 26 countries at least for one year in the period 1990-2006. In addition to this, the emissions by sectors were presented by 31 countries.

2. Information on recalculations of emission data previously reported for the period 1990-2005 was submitted by 21 countries. In most countries the changes of emissions due to the revision did not exceed ±10%. However, for some countries (e.g, Ireland, Cyprus, Romania, Finland, Latvia) the changes made up a factor of 2-3.7.

3. Data on heavy metal emissions by source category were officially reported by 31 countries. The main contributor to lead and cadmium emissions was the source category “Manufacturing Industries and Construction”, providing 36% of lead and 38% of cadmium emissions. As for mercury, the main contributor was “Public Electricity and Heat Production” (34%).

Model development

1. Following the recommendations of the EMEP Steering Body Bureau MSC-W and MSC-E have started to work on gradual development of the common EMEP global modelling system. According to the adopted 2008 workplan the Centres concentrated their efforts on collection and evaluation of various input data (meteorological data, emissions, land-cover etc.) for the global modelling system and testing the available atmospheric transport modules.

2. Transition from NCEP/DOE re-analyses to ECMWF analysis as driving input for preparation of meteorological data has been completed. To analyse quality of meteorological data based on the two driving datasets the generated meteorological parameters were compared against observations. Besides, pollution levels calculated with the use of the two meteorological datasets were also evaluated. The comparison of calculated concentrations in air and in precipitation with measurements demonstrates that the use of ECMWF data leads to somewhat better agreement of modelled and measured values compared to the use of NCEP/DOE data.

3. The model sensitivity to refining the vertical model structure by inclusion of lowest shallow layer was investigated. The numerical experiments has shown that the refining of vertical structure leads to some decrease of lead concentrations in the surface air (15% on average) and depositions (about 1.5%) over the European and the Central Asian countries. However, over some particular areas the changes can be higher. The comparison of the results based on the two experimental runs with measurements demonstrated that reduction of the lowest model layer does not lead to evident improvement of the model performance.

Model assessment of heavy metals

1. According to the modelling results concentrations and depositions of lead, cadmium and mercury in 2006 varied significantly over Europe and Central Asia. The highest depositions were estimated for Poland, the Benelux region, Balkan countries, and the northern part of Italy. The highest concentrations are found in the same regions as well as in the southern part of Kazakhstan. Whereas depositions of heavy metals in the Central Asian countries are relatively low due to low precipitation amounts.

2. Contribution of wind re-suspension to depositions of lead and cadmium in the European and the Central Asian countries is comparable with that from the anthropogenic sources, and in case of lead, even exceeds it. However, the current estimates of wind re-suspension are subject of significant uncertainty because of developing status of the model dust suspension scheme. In case of mercury the contribution of anthropogenic emissions is comparable with the contribution of sources located outside EMEP domain.

3. The influence of the transboundary transport on heavy metal depositions in Europe and Central Asia is significant. Contribution of transboundary transport to depositions from anthropogenic sources exceeds 50% in 37, 35 and 27 countries for lead, cadmium and mercury, respectively. On the other hand, fraction of national emissions contributing to the transboundary transport in Europe and Central Asia varies from 60% to 90% for lead and cadmium. In case of mercury, this fraction is commonly higher than 70%.

4. Contribution of wind re-suspension and non-EMEP sources is comparable with or even exceeds that of anthropogenic sources in the Central Asian countries (Kazakhstan, Kyrgyzstan,

Uzbekistan, Turkmenistan and Tajikistan). As for mercury, the major contribution to depositions is made by non-EMEP sources. The most important contributors to anthropogenic depositions of lead in the Central Asian countries are Kazakhstan and Uzbekistan.

5. Evaluation of modelling results via comparison with measurements demonstrates that spatial variability of pollution levels (air concentrations, concentrations in precipitation, wet deposition fluxes) was reproduced reasonably well. On average, the modelled levels of lead underestimated the observed values by 20-30%. Cadmium air concentrations were underestimated by 20%, and concentrations in precipitation and wet deposition fluxes – by 50%. Mercury calculated levels were slightly (by 20%) lower than the measured ones.

6. The agreement between measured and modelled values varied in different regions. The most significant underestimation of the observed concentrations was identified for stations locating in Scandinavia and the Central Europe. The numerical experiments reveal that in some cases the underestimation can result from uncertainties in spatial distribution of emission sources in regions potentially affecting the considered area. However, in some other cases the reason of the underestimation can be connected with local emission sources not taken into account by regional scale modelling.

7. Intercomparison of mercury transport models has been performed on a global scale under conditions of the TF HTAP. Obtained results have shown that variation of elemental mercury concentrations simulated by different models does not exceed 15%. The difference between the simulated mercury depositions is much higher and can reach a factor of two. The largest contribution to the deposition uncertainty is made by dry deposition. In spite of significant discrepancies in simulated mercury deposition levels the models in general agree quantifying relative deposition response to emission reduction.

8. Critical loads of lead, cadmium and mercury were evaluated by the Coordinating Centre for Effects (CCE) of the Working Group on Effects (WGE) over Europe and Central Asia. Besides, on the base of deposition data exceedances of these metals were calculated. The new CCE background database formed a proper basis for computing critical loads for lead, cadmium and mercury. Results obtained in this study were in good agreement with previously published heavy metal critical loads maps for Europe. Sources of critical load uncertainties were indicated.

Co-operation

1. In the framework of co-operation with the Task Force on Heavy Metals (TFHM) MSC-E overviewed the EMEP activity towards EECCA countries. The TFHM was informed about emissions and pollution levels (concentrations, depositions, transboundary fluxes) of lead, cadmium and mercury over the extended EMEP domain, as well as an expansion of monitoring activity in Georgia, Armenia, Republic of Moldova and Kazakhstan. Task Force welcomed EMEP outreach for EECCA countries.

2. In line with EMEP priorities, a particular attention of MSC-E activity in the field of heavy metal transboundary pollution was paid to the EECCA countries. In 2008 territories of the Central Asian countries (Kazakhstan, Kyrgyzstan, Uzbekistan, Turkmenistan and Tajikistan) were fully covered by the extended EMEP domain. It allows to provide the Central Asian countries with

the same information on transboundary fluxes and pollution levels as the other Parties to the Convention annually receive.

3. MSC-E reported to the Task Force on Measurements and Modelling (TFMM) on the progress in the development of the EMEP global modelling framework and on output of joint technical meeting of CCC, MSC-E and MSC-W held in March 2008 in Gjerdrum (Norway). The main objectives of the meeting were to foster the collaboration between the scientists involved in the EMEP work, to discus common reporting to the Steering Body to EMEP and to agree further plans on improving EMEP global model activity.

4. MSC-E also contributed to the Task Force on Hemispheric Transport of Air Pollution (TF HTAP). It participates in the intercomparison study of hemispheric models organised within the framework of TF HTAP and devoted to the assessment of intercontinental source-receptor relationships for different pollutants, evaluation of current models variability and uncertainties, and guidance of future model developments

5. In the framework of co-operation with the OSPAR Commission MSC-E has performed model assessment of atmospheric depositions of lead, cadmium and mercury to the OSPAR Convention Waters. Particularly, annual depositions of lead, cadmium and mercury for 1990-2005, and contribution of key emission source categories for 2005 were assessed. The modelling results were evaluated against available monitoring data. The highest decrease of total depositions of lead and cadmium for 1990 -2005 took place in the Region IV (Bay of Biscay) and made up to 60%. As for mercury, the highest decrease of deposition took place in the Regions II (Greater North Sea) and III (Celtic Seas) – 35% and 25%, respectively.

6. 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, AMAP, UNEP). The main results were discussed at a number of scientific conferences, workshops and expert meetings.

REFERENCES

Aas W. and Breivik K. [2007] Heavy metals and POP measurements, 2005. EMEP/CCC-Report 6/2007.

Aas W. and Breivik K. [2008] Heavy metals and POP measurements, 2006. EMEP/CCC-Report 4/2008

AMAP/UNEP [2008] AMAP/UNEP Report on sources of mercury to the atmosphere. Technical background document. Draft for review (http://www.chem.unep.ch/mercury/).

Baker P.G.L., Brunke E.-G., Slemr F., Crouch A.M. [2002] Atmospheric mercury measurements at Cape Point, South Africa. *Atmos. Environ.* vol.36, pp.2459-2465.

Bartnicki J., A. Gusev, W. Aas, H.Fagerli [2007] Atmospheric Supply of Nitrogen, Lead, Cadmium, Mercury and Dioxins/Furans to the Baltic Sea in 2005. MSC-W Technical Report 3/2007.

Berdowski J.J.M., Baas J., Bloos J.P.J., Visschedijk A.J.H. and P.Y.J.Zandveld [1997] The European Emission Inventory of Heavy Metals and Persistent Organic Pollutants for 1990. TNO Institute of Environmental Sciences, Energy Research and Process Innovation, UBA-FB report 104 02 672/03, Apeldoorn, 239 p.

Denier van der Gon D. H.A.C., van het Bolscher M., Visschedijk A.J.H. and Zandveld P.Y.J. [2005]. Study to the effectiveness of the UNECE Heavy Metals Protocol and costs of possible additional measures. Phase I: Estimation of emission reduction resulting from the implementation of the HM Protocol. TNO-report B&O-A R 2005/193.

Gusev A., Ilyin I., Shatalov V. and Sokovych V. [2008] Modelling of transboundary atmospheric pollution by heavy metals and POPs in Europe and Central Asia. EMEP/MSC-E Technical Report 1/2008.

Gusev A., Ilyin I., Travnikov O., and Sokovych V. [2007] Model assessment of transboundary pollution by lead and PCB-153 of the Central Asian Countries: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan. EMEP/MSC-E contribution to the UN ECE CAPACT project. 55p. +annexes.

Ilyin I., Rozovskaya O., Sokovykh V., and Travnikov O. [2007] Atmospheric modelling of heavy metal pollution in Europe: Further development and evaluation of the MSCE-HM model. EMEP/MSC-E Technical Report 2/2007., 52 p.

Jaffe D., Prestbo E., Swartzendruber P., Weiss-Penzias P., Kato S., Takami A., Hatakeyama S., Yoshizumi K., [2005] Export of atmospheric mercury from Asia. *Atmospheric Environment,* vol.38, pp. 3029–3038.

Kanamitsu M., Ebisuzaki W., Woolen J., Yang S-K., Hnilo J.J., Fiorino M. and Potter G.L. [2002] NCEP-DOE AMIP-II reanalysis (R-2). Bulletin of American Meteorological Society, 11, pp. 1631 – 1643.

Kim, K.-H., Kim, M.-Y., Kim, J., Lee, G. [2002] The concentrations and fluxes of total gaseous mercury in a western coastal area of Korea during late Mart 2001. *Atmospheric Environment*, vol. 36, pp. 3413-3427.

Lamborg, C. H., Fitzgerald, W. F., O'Donnell, J., Torgersen, T. [2002] A non-steady-state compartmental model of global-scale mercury biogeochemistry with interhemispheric atmospheric gradients. Geochimica et Cosmochimica Acta 66, pp.1105-1118.

Pacyna E. G., Pacyna J. M., Steenhuisen F. and Wilson S. [2006] Global anthropogenic mercury emission inventory for 2000. *Atmos. Environ.* vol. 40, No. 22, pp.4048-4063.

Pacyna J.M., Scholtz M.T, and Li Y.-F (Arthur). [1995]. Global budget of trace metal sources. *Environ. Rev*,. 3(2): pp.145–159.

Pacyna, J.M. and Pacyna, E.G. [2001] An assessment of global and regional emissions of trace metals to the atmosphere from anthropogenic sources worldwide. *Environmental Reviews*, vol. 9: pp.269-298.

Reinds, G.J., M. Posch, W. de Vries, J. Slootweg and J.-P. Hettelingh [2008]. Critical Loads of Sulphur and Nitrogen for Terrestrial Ecosystems in Europe and Northern Asia Using Different Soil Chemical Criteria. *Water Air and Soil Pollution.* DOI 10.1007/s11270-008-9688-x.

Rudolf B., Hauschild H., Rueth W. and U. Schneider [1994] Terrestrial precipitation analysis: operational method and required density of point measurements. NATO ASI Series, Vol. I 26, Global Precipitation and Climate Change. Ed. by F. Desalmand. Springer-Verlag Berlin Heidelberg, pp. 173 – 186.

Slootweg, J., Hettelingh, J.-P., Posch, M., Dutchak, S. & Ilyin, I. (Eds.): [2005]. Critical Loads of Cadmium, Lead and Mercury in Europe; Collborative Report by WGE, ICP M&M Coordinating Centre for Effects and EMEP MSC East, CCE Report, Netherlands Environmental Assessment Agency, Report 259101015/2005, 145 pp.

Tarrason L and A. Gusev [2008] Towards the development of a common EMEP global modelling framework. EMEP/MSC-W Technical Report 1/2008. July 2008.

Temme C., Einax J.W., Ebinghaus R., Schroeder W.H. [2003] Measurements of atmospheric mercury species at a coastal site in the Antarctic and over the south Atlantic Ocean during polar summer. *Environmental Science and Technology*, vol.37, pp. 22–31.

Travnikov O. and I.Ilyin [2005] Regional Model MSCE-HM of Heavy Metal Transboundary Air Pollution in Europe. EMEP/MSC-E Technical Report 6/2005, 59 pp.

UBA [2004] Manual on methodologies and criteria for modelling and mapping critical loads & levels and air pollution effects, risks and trends, UNECE convention on Long Range Transboundary Air Pollution, Federal Environmental Agency (Umweltbundesamt), Berlin.

UNEP F&T report [2008] Mercury Fate and Transport in the Global Atmosphere: Measurements, models and policy implications. Eds: N. Pirrone and R. Mason. In press.

Valente R., Shea C., Humes K.L., Tanner R. [2007] Atmospheric mercury in the Great Smoky Mountains compared to regional and global levels. *Atmos. Environ*. vol. 41, pp.1861–1873.

Annex A

EMEP WORK-PLAN FOR HMs IN 2008

[ECE/EB.AIR/GE.1/2007/10]

2.2. Atmospheric measurements and modelling

Description/objectives

To support the implementation of protocols to the Convention; provide the measurement and modelling tools necessary for further abatement policies; compile and evaluate information on transboundary air pollution; and implement the EMEP monitoring strategy adopted in 2004. The Task Force on Measurements and Modelling, led by France and co-chaired by WMO: reviews and assesses the scientific and operational activities of EMEP related to monitoring and modelling; evaluates their contribution to the effective implementation and further development of the protocols; and reviews national activities related to measurement, modelling and data validation.

Main activities and time schedule for monitoring:

(b) Review, store and make available the 2007 monitoring data (CCC, MSC-West, MSC-East), and assess uncertainties relating to, and the representativeness of, monitoring data on heavy metals and POPs (CCC, MSC-East);

(k) Review heavy metals and persistent organic pollutants (POPs) monitoring data generated in the framework of the Working Group on Effects, and make recommendations for their use in model validation (CCC, MSC-East).

(l) Consider nationally available measurements on dry deposition of mercury to forests to evaluate measurement uncertainties, and improve model parameterization (CCC, MSC-East, Parties).

Main activities and time schedule for atmospheric modelling in general:

(b) Further develop and validate the regional as well as hemispheric/global scale EMEP models, and report on progress, taking into account the recommendations of the Task Force experts (MSC-East, MSC-West);

(d) Complement EMEP monitoring data with quality-checked data from other international programmes, and make a comprehensive comparison of observations with model results (CCC, MSC-East, MSC-West, Parties);

(e) Initiate work for a common global modelling system for MSC-East and MSC-West by testing new meteorological drivers. MSC-East will test GEM and PUM meteorological weather prediction models, while MSC-West will test the ECMWF IFS and WRF meteorological weather prediction models;

(f) Initiate work for a common global modelling system for MSC-East and MSC-West by compiling and unifying common model input data such as land-use from MM5 (MSC-West), identify independent land-use sources and compare these sets if appropriate (MSC-East), start to compile the global data on soil properties; begin to compile soil chemical composition data for the EMEP region for validation purposes (MSC-East, MSC-West), prepare information on leaf area index (MSC-East), and present information on climatological data and spatial distribution of emission sources and population (MSC-West).

Main activities and time schedule for atmospheric modelling for HMs:

(a) Prepare information on lead, cadmium, and mercury for 2006 at the regional scale for: air concentrations and ecosystem-dependent depositions over Europe, comparison of modelling results (concentration in air and precipitation, deposition fluxes) with monitoring data, country-to-country deposition matrices, and estimates of depositions on regional seas (Mediterranean, Baltic, Black and North Seas) (MSC-East, CCC);

(b) Evaluate ecosystem-dependent depositions of heavy metals and contribute to the development of the effect-based approach (MSC-East, Coordinating Centre for Effects (CCE));

(c) Improve the mercury (Hg) hemispheric/global model in accordance with recent scientific findings, and prepare information on Hg dispersion at the hemispheric scale for the evaluation of boundary conditions for the regional modelling (MSC-East);

(d) Improve the regional heavy metals model with respect to size-aggregated description of aerosol atmospheric transport and removal processes (MSC-East);

(e) Further develop and evaluate heavy metal re-suspension scheme for the regional heavy metals model (MSC-East);

(f) Prepare input data for the model application, employ the ECMWF analysis data for meteorological pre-processing, and prepare mapped anthropogenic emission data for regional modelling based both on official and expert estimates (MSC-East).

2.4. Hemispheric transport of air pollution

Description/objectives:

To develop a fuller scientific understanding of the hemispheric transport of air pollution and estimate the hemispheric transport of specific air pollutants, the Task Force on the Hemispheric Transport of Air Pollution, led by the United States and the European Community, coordinates activities, including collaboration with other international bodies, programmes and networks both within and outside the UNECE region with related interests.

Main activities and time schedule:

(c) Continue the HTAP Model Intercomparison and model evaluation exercise (Task Force; CCC, MSC-East, MSC-West);

(d) Continue the work on an integrated observation system relevant for the assessment of intercontinental transport of air pollution, including the development of intercomparison tools and information infrastructure, and an observational database for model evaluation for ozone, PM, Hg and POPs, as well as improved emission inventories;

(h) Hold the fourth Task Force meeting and consider assessing intercontinental transport of air pollution by Hg and POPs in April 2008 in Rome.

Annex B

PERCENTAGE CHANGES IN THE TOTAL NATIONAL EMISSIONS OF Pb, Cd AND Hg AFTER THE RECALCULATIONS

[100*($E_{current}$-$E_{previous}$)/$E_{previous}$, %]

The highest changes are flagged.

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Austria	Pb	0.2	0.3	0.4	0.5	0.4	-0.012	-0.0001	-0.4	0.0003	-1.1	0.4	-1.9	-0.7	-0.9	-0.6	1
	Cd	0.2	0.3	0.5	0.5	0.5	0.6	0.4	-0.2	0.5	-0.5	1.3	-0.8	-0.3	0.001	0.2	2.4
	Hg	0.02	0.02	0.03	0.03	0.02	0.03	-0.04	-0.3	-0.05	-0.4	-0.02	-0.7	-0.6	1.4	-0.4	2.1
Belarus	Pb	0.001	0.001	0.002	0.002	0.003	0.021										
	Cd	-1.7	-1.4	-0.1	-0.2	-0.1	0.5										
	Hg	0.4	0.2	-0.06	0.2	0.3	0.2										
Belgium	Pb							-17	-7.2	-6.8	-11						-1.3
	Cd							-0.4	4	0.7	-0.6						-16
	Hg							-34	11	-13	51						-5
Cyprus	Pb	-0.1	-0.03	-0.06	-0.09	-0.06	-0.06	-0.06	-0.06	-0.1	-0.1	-54	-60	-59	-54		
	Cd				-1.4			1.4					-1.1				
	Hg	-25	-23	-23	-23	-22	-24	-24	-22	-21	-19	-21	-20	-18	-23		
Denmark	Pb	-1.9	1.5	1.6	5.2	13	14	6	-0.03	0.1	0.2	-2.3	-2.5	-3.9	-0.8	-2.9	2.5
	Cd	-0.02	5.9	5.9	5.7	5.6	5.7	0.4	-0.2	0.9	1.3	-0.3	-1	0.3	1.9	0.04	4.4
	Hg	-3.3	4.2	4.4	4.7	6.9	6.9	-0.1	-0.02	0.1	0.1	-5.9	-5	-7.7	-1.8	-6.1	4.8
Finland	Pb	0.3	0.3	-0.2	-1.1	-3.2	-0.5	-0.3	-3.7	5.1	7	-3.3	2.3	1.8	2.1	2.2	
	Cd	0.6	2.7	3.8	-3.2	-8.8	-3.1	-1.4	-22	-3.5	-6.3	-4.6	0.1	-0.05			
	Hg	2.6	-3.9	-7.8	1.4	-6.2	1.8	-4.5	-5	9.5	187	-0.5	0.3	0.09	-0.5		
France	Pb	-0.2	-0.4	-0.3	-0.2	-0.2	-0.02	0.3	0.4	0.3	0.4	1.1	0.7	1	8.1	5.2	2.8
	Cd	5.5	6.7	5.8	5.8	5.8	6.5	6.4	7.2	6.5	7.1	6.8	6.9	7.6	10	12	10
	Hg	-0.03	0.008	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.5	0.2	0.7	0.7	6.2
Germany	Pb						0.1	-0.1	-0.4	-0.2	-0.5	-0.1	-0.1	0.1	-2	-2.8	0.4
	Cd	-0.3	-0.5	-0.9	-1.2	-1.8	-2.1	-2.4	-2.2	-2.3	-2.1	-2.1	-2.1	-1.9	-3	-2.8	-0.8
	Hg						3	-1.4	-1.9	-1.1	-3.5	0.5	-0.04	1.7	1.7	0.9	2.4
Ireland	Pb	10	3	12	8	8	5	1	27	13	72	106	61	84	94	94	109
	Cd	-0.3	-0.5	-0.2	-0.2	-0.6	-0.6	-0.8	-0.8	-0.9	-1.1	-1.1	-1.4	-1.8	-2.1	-2	0.6
	Hg	0.1	0.03	0.1	0.02	-0.1	-0.2	-0.3	-0.4	-0.5	-0.8	-0.8	-0.9	-0.9	-0.9	-0.8	2.5
Italy	Pb	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.3	0.1	0.5	0.7	0.8	0.9
	Cd	-0.1	-0.1	-0.08	-0.08	-0.09	-0.09	-0.1	-0.1	-0.1	-0.1	-0.05	-0.1	-0.1	0.11	0.02	0.1
	Hg											0.3	0.03	0.01	0.4	0.3	0.3
Latvia	Pb	0.09	0.04	0.14	0.05	0.03	0.02	0.03	0.02	-6.2	-2.4	-5.7	-6.1	-3.2	-6.1	-3.5	-15
	Cd	1.5	0.8	2.2	0.9	0.8	0.7	0.5	0.6	-22	-20	-36	-38	-19	-12	-12	-7.9
	Hg	2.4	1.3	3	1.2	1	0.9	0.8	0.9	0.8	-2.8	-8.3	-11	-5.5	-5.6	-3.1	54
Malta	Pb															-58	-57
	Cd															-6.1	-5.3
	Hg															-3.2	-2.6
Monaco	Pb	-2.1	-2.8	-2.9	-3.1	-4	-4.3	-3.5	-9	-6.1	-8.1	-1.4	-1	-1.3	-1.3	-1.5	
	Cd	-0.9	-0.8	-0.9	-1.3	6.4	6	-2.8	-4.4	2.8	3.8	-6.1	-1.5	-1.8	-2	-1.5	
	Hg	-0.8	-0.9	-1.3	-1.3	-1.7	-0.6	-0.8	-1.4	-1.5	-1.7	-0.8	-1	-1.3	-1.3	-1.5	
Nether-lands	Pb	-0.5	-1.5	-0.6	-0.1	-1	-1.5	-7.4	-14	4.2	5.1	4.7	3.7	3.3	2.6	-2.6	-12
	Cd	-0.02	-0.1	-0.05	-0.02	-0.1	-0.2	-43	-34	-0.2	-0.2	-0.2	-0.1	-0.1	-0.09	-0.1	-2.3
	Hg	-24	0.2	0.2	0.2	0.1		-18	-13		0.003	0.003				-0.001	-20
Portugal	Pb	-4.5	-5.4	-5.4	-5.7	-6.3	-7.1	-7.4	-8	-9.5	-14	-27	-26	-27	-25	-26	-27
	Cd	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.5	-1.4	-1.5	-1.3	-1.5	1.6	3.7
	Hg	-0.01	-0.01	-0.02	-0.01	-0.01	-0.009	0.01	0.007	0.03	-4.2	-16	-17	-17	-19	-20	-21
Romania	Pb																-25
	Cd																267
	Hg																181
Slovenia	Pb	-29	-27	-28	-25	-24	0.3	-17	-14	-10	-6	2.7	51	23	21	20	20
	Cd	-25	-28	-30	-34	-35	-36	-40	-40	-37	-37	-37	-37	-35	-34	-31	-31
	Hg																
Spain	Pb		-0.002	-0.007	-0.0002	-0.004	-0.001	0.02	0.03	0.03	0.03	0.04	0.05	0.08	0.08	-0.1	0.4
	Cd	0.05	0.02	0.01	0.04	0.02	0.04	0.1	0.1	0.1	0.1	0.1	0.1	0.09	0.09	0.08	0.6
	Hg		-0.02	-0.04	-0.001	-0.02	-0.005	0.1	0.2	0.1	0.1	0.08	0.1	0.04	0.02	-0.002	1.1
Sweden	Pb	2.6	3	3.2	6.8	22	34	40	40	42	38	34	26	20	8.8	-1.1	-12
	Cd	-0.7	-0.9	-1	-1.1	-1.6	-1.9	-1.9	-1.9	-2.2	-2.7	-2.8	-2.5	-2.9	-3	-3	-3
	Hg	-0.2	-0.4	0.01	0.5	0.2	0.007	0.09	0.3	0.1	0.02	0.1		0.01	0.02	-1.8	-2.2
Switzer-land	Pb	1.9	2	2.3	2.7	2.9	3.9	4.5	4.9	5.5	12	20	20	20	22	23	21
	Cd	0.05	0.08	0.09	0.02	0.2	0.07	-0.3	-0.6	-0.6	-0.4	0.02	0.08	-0.4	-0.06	-0.05	0.6
	Hg	0.004	0.005	0.005	0.003	0.01	0.001	-0.02	-0.1	-0.1	-0.1	0.04	0.3	-0.1	1.5	2.8	4.6
United Kingdom	Pb	0.007	0.007	0.008	0.009	0.01	0.01	0.14	0.09	0.01	-0.3	-1.2	-1	-1	-1.1	-0.4	-0.5
	Cd	-0.2	-0.2	-0.2	-0.3	-0.8	-0.4	-0.8	-0.4	-0.3	-1.2	-1	-1.3	-1.9	-2.2	-2.6	-2
	Hg	0.9	0.9	0.9	1.5	1.5	1.7	2.5	2.3	0.1	-5.1	-5.5	-6.2	-7	-6.4	-6.9	-5.3

ANNEX C

COUNTRY-TO-COUNTRY DEPOSITION MATRICES FOR 2006

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

Country/Region/Sea	Code	Country/Region/Sea	Code
Albania	AL	Monaco	MC
Armenia	AM	Netherlands	NL
Austria	AT	Norway	NO
Azerbaijan	AZ	Poland	PL
Belarus	BY	Portugal	PT
Belgium	BE	Republic of Moldova	MD
Bosnia and Herzegovina	BA	Romania	RO
Bulgaria	BG	Russian Federation (European part)	RU
Croatia	HR	Russian Federation (Asian part)	RUA
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	Tajikistan	TJ
Greece	GR	Turkey	TR
Hungary	HU	Turkmenistan	TM
Iceland	IS	Ukraine	UA
Ireland	IE	United Kingdom	GB
Italy	IT	Uzbekistan	UZ
Kazakhstan	KZ		
Kyrgyzstan	KY	Baltic Sea	BAS
Latvia	LV	Black Sea	BLS
Lithuania	LT	Caspian Sea	CAS
Luxembourg	LU	North Sea	NOS
Malta	MT	Mediterranean Sea	MDT

***Table C.2**. Matrix of lead country-to-country depositions from anthropogenic sources in 2006, kg/y*

Receptors ↓ Emitters →

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CS	CY	CZ	DE	DK	
AL	**6997**	0.7	13.8	0.9	271.9	12.8	1096.7	19.7	19.9	2765	1.6	31.3	31.9	1.2	**AL**
AM	6.5	**1032**	0.9	463.0	6.7	1.7	19.1	4.6	1.5	17.7	8.4	2.1	3.4	0.2	**AM**
AT	113.2	1.0	**4345**	2.4	589.7	459.5	334.5	91.7	986.0	1117.8	0.5	1731	2766	20.7	**AT**
AZ	11.1	255.2	1.9	**2787**	12.2	4.0	37.6	21.8	3.0	33.9	11.9	5.2	8.2	0.6	**AZ**
BA	855.7	0.8	152.3	2.0	**17630**	70.4	627.6	48.0	85.8	6042	0.8	371.1	240.0	7.7	**BA**
BE	6.5	0.1	23.4	0.1	18.8	**11424**	11.8	10.2	88.8	26.4	0.02	44.2	989.7	8.1	**BE**
BG	927.7	9.0	59.8	17.2	760.0	46.6	**46811**	218.6	50.7	7189.7	12.6	178.2	144.4	7.6	**BG**
BY	162.3	5.7	181.7	14.7	501.4	364.9	675.5	**20641**	159.4	1303.0	0.6	894.9	889.8	88.4	**BY**
CH	33.1	0.1	71.5	0.3	129.2	286.7	66.9	8.6	**5518**	160.5	0.1	59.7	600.3	4.9	**CH**
CS	2750	2.6	145.9	5.1	4060	91.4	5049.5	96.8	87.1	**43837**	4.5	424.6	295.9	11.5	**CS**
CY	5.9	1.0	0.3	0.6	3.7	0.4	11.2	1.0	0.5	10.2	**298.7**	0.6	0.9	0.0	**CY**
CZ	54.5	1.0	862.9	2.5	261.1	510.6	267.5	135.8	402.6	691.9	0.3	**9967**	2958	36.5	**CZ**
DE	89.5	1.4	1151	3.4	321.5	12433	233.7	180.6	4305	626.8	0.3	2899	**46206**	302.5	**DE**
DK	7.7	0.2	16.9	0.5	19.1	667.6	23.0	18.1	34.9	40.6	0.02	81.1	937.8	**678.1**	**DK**
EE	11.3	0.3	29.8	0.6	40.6	160.8	34.2	315.4	38.8	93.8	0.03	157.5	326.8	34.5	**EE**
ES	185.1	0.3	45.6	0.6	349.0	442.0	200.0	11.3	190.2	431.1	0.2	73.7	267.5	7.7	**ES**
FI	24.0	2.1	51.2	4.8	59.8	418.1	92.9	488.3	84.7	174.5	0.2	301.0	790.4	126.6	**FI**
FR	374.2	1.0	245.9	2.2	980.5	7372	478.2	57.2	2700	1176	0.6	405.2	4003	36.2	**FR**
GB	41.0	0.2	57.3	0.5	77.6	2517	79.6	51.5	158.6	148.6	0.1	153.5	1337	38.2	**GB**
GE	25.2	412.6	5.5	748.5	35.4	10.6	170.6	39.1	6.4	126.1	17.6	19.0	22.1	1.4	**GE**
GR	1475	6.1	34.7	8.5	424.0	30.9	6384	113.0	43.2	2523	26.1	93.7	84.0	4.3	**GR**
HR	455.9	0.9	274.2	2.0	3578	68.3	462.7	46.9	98.5	2876	0.7	444.9	264.6	6.9	**HR**
HU	280.1	1.4	481.6	3.1	1893	145.8	1127	112.8	141.7	6057	1.4	1003	540.6	16.3	**HU**
IE	8.7	0.04	9.9	0.1	16.8	303.1	15.9	10.6	25.6	28.7	0.01	29.2	198.1	3.6	**IE**
IS	0.3	0.02	1.7	0.04	0.8	62.4	0.7	2.6	12.6	1.3	0.003	4.9	45.9	2.2	**IS**
IT	1606	2.4	549.2	4.8	3040	250.5	1764	103.4	1254	3653	4.8	601.7	864.7	16.5	**IT**
KY	10.3	26.5	1.8	64.3	10.8	5.2	25.5	11.7	3.7	26.9	6.9	5.0	9.8	0.5	**KY**
KZ	167.1	354.4	56.9	1115	296.9	141.2	853.6	558.8	88.1	821.8	34.6	173.8	271.8	19.3	**KZ**
LT	34.1	0.6	73.5	1.5	86.8	254.2	126.8	1381	71.8	235.6	0.1	405.3	561.5	57.9	**LT**
LU	0.9	0.01	3.2	0.0	2.6	258.4	1.3	1.0	13.9	3.4	0.003	5.7	131.0	0.5	**LU**
LV	25.0	0.5	57.2	1.2	73.6	241.9	76.8	787.3	64.5	179.1	0.1	316.0	534.3	57.6	**LV**
MC	0.05	0.0	0.03	0.0	0.1	0.02	0.1	0.005	0.1	0.2	0.0	0.03	0.1	0.001	**MC**
MD	80.4	3.5	13.0	9.2	113.7	16.5	630.4	134.2	12.9	448.3	1.3	49.7	50.4	4.5	**MD**
MK	1501	0.8	12.5	1.3	197.6	9.9	3259	23.8	12.8	3118	2.4	36.5	29.4	1.2	**MK**
MT	0.6	0.01	0.05	0.01	0.5	0.1	0.7	0.02	0.1	1.0	0.02	0.1	0.1	0.002	**MT**
NL	5.0	0.04	16.9	0.1	14.2	5558	9.1	7.1	44.8	22.1	0.01	37.1	1201	13.1	**NL**
NO	39.3	2.1	86.0	4.9	97.1	1255	114.0	201.3	137.3	212.3	0.2	345.9	1512	274.9	**NO**
PL	180.4	4.5	818.7	11.6	836.4	1773	809.8	2436	637.4	2204	0.7	8370	6585	433.7	**PL**
PT	11.2	0.05	4.4	0.1	24.8	47.4	12.7	0.9	16.3	26.8	0.01	7.9	29.6	0.9	**PT**
RO	1111	21.0	259.0	50.6	2707	203.7	7537	606.7	189.2	12141	11.8	751.8	624.4	27.9	**RO**
RU	1117	721.2	536.1	2599	2015	1747	5389	16068	669.6	5813	79.3	2234	3596	393.7	**RU**
RUA	241.7	263.4	103.3	661.4	371.4	303.6	902.2	912.6	166.8	990.2	25.2	337.9	630.1	50.9	**RUA**
SE	36.0	2.7	127.7	6.2	118.8	1758	110.3	722.6	213.8	270.0	0.2	644.4	2847	1010	**SE**
SI	79.8	0.3	329.4	0.8	452.6	37.7	147.6	18.2	61.2	563.8	0.2	204.4	174.4	2.8	**SI**
SK	127.9	0.9	339.8	2.4	735.4	143.5	545.7	133.4	115.6	2016	0.4	1837	520.1	17.7	**SK**
TJ	3.1	8.7	0.6	24.8	3.4	1.6	7.7	3.5	1.2	8.3	2.4	1.6	3.0	0.2	**TJ**
TM	5.4	46.5	1.6	194.7	6.6	4.6	19.0	14.1	3.3	17.8	4.1	4.8	8.6	0.6	**TM**
TR	666.8	707.1	56.7	380.8	506.2	74.4	2715	299.5	85.4	1757	497.4	131.7	167.2	8.4	**TR**
UA	849.8	56.6	317.3	153.2	1744	418.6	5326	5083	268.7	5504	16.4	1358	1230	105.5	**UA**
UZ	6.4	42.1	1.7	146.2	8.1	4.8	20.8	17.6	3.8	20.8	4.5	5.8	9.6	0.7	**UZ**
BAS	50.8	1.7	182.2	3.9	179.9	2371	163.0	966.5	310.5	408.2	0.2	1043	4849	961.2	**BAS**
BLS	508.2	79.3	67.7	121.9	518.1	77.2	4148	550.7	75.0	2269	40.3	199.2	213.4	20.3	**BLS**
CAS	20.1	168.9	6.0	1491.5	25.5	15.8	113.2	97.2	11.3	87.3	10.6	24.5	33.8	3.2	**CAS**
MDT	7851	50.0	468.2	45.1	6127	580.0	9139	319.5	882.6	10319	924.3	792.4	981.1	26.2	**MDT**
NOS	133.6	3.1	248.3	6.7	277.6	9356	296.9	188.7	508.6	561.3	0.4	757.0	5772	679.2	**NOS**
	AL	**AM**	**AT**	**AZ**	**BA**	**BE**	**BG**	**BY**	**CH**	**CS**	**CY**	**CZ**	**DE**	**DK**	

***Table C.2**. Matrix of lead country-to-country depositions from anthropogenic sources in 2006, kg/y (continued)*

Receptors ↓ Emitters →

	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KY	KZ	
AL	5.4	220.8	2.8	91.2	14.4	0.8	5205	24.1	71.3	2.1	0.004	1779	0.04	2.5	**AL**
AM	1.5	14.1	0.8	5.3	2.0	184.4	112.7	0.8	2.9	0.2	0.001	31.6	1.8	23.1	**AM**
AT	29.6	491.1	15.5	872.1	350.9	1.4	474.7	222.5	702.0	30.6	0.05	6020	0.1	3.5	**AT**
AZ	5.8	24.7	2.7	10.0	5.5	270.5	181.9	1.6	6.2	0.6	0.003	55.1	12.3	92.5	**AZ**
BA	13.3	446.0	7.8	249.5	72.5	1.5	1995	566.3	1146	8.2	0.02	3580	0.1	4.6	**BA**
BE	11.9	457.1	7.4	4060	994.0	0.1	21.4	4.4	10.5	64.8	0.05	202.5	0.01	0.7	**BE**
BG	36.2	303.0	17.7	151.4	52.2	20.1	14532	69.3	479.4	6.4	0.02	1477	0.6	34.7	**BG**
BY	656.6	388.2	211.6	484.8	391.7	11.8	828.1	96.2	644.6	36.4	0.1	1375	1.0	30.8	**BY**
CH	5.3	647.5	3.7	1610	228.1	0.2	109.9	37.1	45.7	24.8	0.02	6438	0.01	0.5	**CH**
CS	22.6	453.1	12.8	262.5	99.7	4.7	5992	251.1	1716	11.1	0.02	3494	0.2	10.9	**CS**
CY	0.2	4.3	0.1	2.3	0.5	0.8	201.1	0.4	1.1	0.1	0.0	20.0	0.02	0.2	**CY**
CZ	30.5	292.3	13.6	695.8	402.3	1.4	252.5	95.7	754.5	35.8	0.1	1211	0.1	3.7	**CZ**
DE	136.0	2805	64.8	11646	5580	1.7	355.0	74.2	322.3	422.8	0.4	3489	0.2	9.3	**DE**
DK	19.9	196.7	7.3	520.2	837.4	0.3	37.2	4.2	30.5	62.8	0.1	116.0	0.02	0.7	**DK**
EE	**3889**	63.0	285.8	153.5	140.6	0.4	36.9	8.7	55.2	11.5	0.03	172.8	0.04	1.9	**EE**
ES	4.7	**84601**	4.0	2729	473.1	0.5	897.9	65.4	102.2	90.2	0.1	3226	0.04	2.6	**ES**
FI	3044	255.7	**10091**	424.6	633.3	2.4	108.7	12.1	96.5	57.6	0.3	266.4	0.3	7.1	**FI**
FR	40.0	25732	23.6	**44409**	4420	1.6	1380	222.6	347.5	513.4	0.3	12192	0.1	7.0	**FR**
GB	48.0	2518	23.3	2974	**24337**	0.4	118.1	14.9	45.3	1920	0.7	544.2	0.03	3.2	**GB**
GE	7.0	44.1	3.3	21.2	17.2	**2243**	441.8	4.7	24.2	2.2	0.01	122.7	2.1	36.2	**GE**
GR	18.0	431.1	9.5	177.4	36.3	9.2	**87175**	42.0	194.4	4.8	0.01	1884	0.4	20.3	**GR**
HR	10.6	502.1	5.7	255.2	69.4	1.6	1395	**1792**	1443	7.3	0.02	4259	0.1	4.0	**HR**
HU	18.5	420.7	10.2	293.3	130.7	3.0	1152	587.5	**9879**	12.8	0.02	2993	0.1	5.9	**HU**
IE	6.7	490.9	2.7	339.5	892.8	0.1	19.2	2.9	6.3	**2580**	0.1	104.6	0.004	0.5	**IE**
IS	1.6	154.6	3.2	100.4	134.4	0.0	1.7	0.4	0.9	40.9	**37.1**	30.8	0.03	0.3	**IS**
IT	32.1	2830	18.7	1975	230.9	4.0	7540	778.4	930.2	29.8	0.05	**85680**	0.2	12.1	**IT**
KY	6.6	39.2	3.6	14.6	6.2	21.1	144.4	1.5	5.6	0.7	0.004	55.8	**11888**	3524	**KY**
KZ	246.2	437.4	126.9	236.5	196.3	404.7	1586	35.3	186.8	22.0	0.2	898.5	6502	**31325**	**KZ**
LT	203.6	143.4	80.5	282.6	252.6	1.0	157.8	17.4	127.8	21.3	0.04	332.6	0.1	4.3	**LT**
LU	0.5	49.6	0.3	426.8	53.1	0.0	2.6	0.6	1.5	3.9	0.004	29.9	0.001	0.1	**LU**
LV	656.0	119.1	147.1	250.8	231.7	0.8	106.5	14.8	99.0	18.3	0.04	289.7	0.1	3.8	**LV**
MC	0.002	0.2	0.001	0.5	0.01	0.0	0.2	0.03	0.04	0.002	0.0	3.9	0.0	0.001	**MC**
MD	16.2	59.8	8.2	33.0	18.7	7.4	824.8	12.5	72.2	2.0	0.01	231.6	0.3	14.9	**MD**
MK	5.5	96.9	2.9	47.2	10.3	1.2	8424	16.4	91.7	1.3	0.003	615.8	0.04	3.4	**MK**
MT	0.005	1.2	0.003	0.7	0.1	0.01	8.4	0.1	0.1	0.0	0.0	6.2	0.0	0.0	**MT**
NL	9.4	387.3	5.6	2087	1257	0.1	15.5	3.1	8.8	78.7	0.1	137.0	0.01	0.6	**NL**
NO	228.2	824.6	232.6	1192	2830	2.2	143.3	19.6	152.6	307.3	1.4	569.5	0.2	4.3	**NO**
PL	240.6	895.1	125.5	1954	1487	6.2	802.5	229.2	1961	138.5	0.2	2782	0.7	23.9	**PL**
PT	0.4	6367	0.4	165.7	56.5	0.0	58.6	5.0	7.4	13.4	0.02	210.7	0.01	0.1	**PT**
RO	89.1	768.5	43.6	461.0	200.0	43.2	6858	283.5	2301	22.2	0.1	4074	1.4	69.9	**RO**
RU	16687	2459	5265	2240	2308	1781	10800	292.5	1707	227.9	1.2	5873	124.0	8977	**RU**
RUA	674.1	826.4	449.5	493.5	408.3	294.9	2200	53.6	297.5	48.2	0.8	1371	1390	18058	**RUA**
SE	1102	725.5	2237	1545	2092	2.9	139.4	26.0	203.5	179.7	0.7	703.5	0.3	8.1	**SE**
SI	4.6	210.7	2.3	122.6	32.9	0.5	300.8	414.3	319.1	3.2	0.01	2885	0.04	1.3	**SI**
SK	16.6	202.9	9.9	236.0	115.0	1.5	531.2	219.8	2946	11.2	0.02	1588	0.1	5.5	**SK**
TJ	1.8	12.4	1.0	4.4	1.8	7.0	44.2	0.5	1.7	0.2	0.001	17.2	1015	672.2	**TJ**
TM	6.3	18.6	3.0	8.7	7.3	54.7	79.3	1.0	4.6	0.8	0.004	36.1	168.9	555.1	**TM**
TR	47.0	784.3	25.0	332.1	95.4	466.1	21452	57.7	217.2	12.9	0.04	2525	6.2	107.2	**TR**
UA	444.7	1017	192.9	734.4	459.0	148.2	7612	275.4	2102	48.5	0.1	3737	7.2	322.6	**UA**
UZ	8.2	23.1	3.9	9.9	7.7	46.3	89.8	1.1	5.8	0.9	0.01	42.9	1399	2439	**UZ**
BAS	3209	827.3	3015	2079	1995	2.0	176.3	40.4	263.2	159.8	0.2	953.1	0.2	8.1	**BAS**
BLS	64.4	318.1	32.1	178.8	124.0	455.6	9363	54.0	276.0	16.4	0.1	1362	5.4	137.5	**BLS**
CAS	31.5	35.1	13.3	24.9	27.0	251.8	277.6	3.2	20.9	2.8	0.02	107.8	95.9	525.0	**CAS**
MDT	60.6	17961	32.9	5483	618.4	54.7	124981	996.5	1402	91.4	0.1	53225	3.1	77.1	**MDT**
NOS	209.0	5523	94.7	9586	26067	4.0	441.2	57.5	313.5	1661.9	2.2	2075	0.4	8.2	**NOS**
	EE	**ES**	**FI**	**FR**	**GB**	**GE**	**GR**	**HR**	**HU**	**IE**	**IS**	**IT**	**KY**	**KZ**	

***Table C.2**. Matrix of lead country-to-country depositions from anthropogenic sources in 2006, kg/y (continued)*

Receptors ↓ Emitters →

	LT	LU	LV	MC	MD	MK	MT	NL	NO	PL	PT	RO	
AL	1.6	0.4	4.3	0.1	7.7	2975	5.0	6.1	0.8	293.7	52.4	282.6	**AL**
AM	0.3	0.05	0.7	0.003	0.9	9.8	0.2	0.8	0.2	26.4	5.0	18.5	**AM**
AT	10.4	21.1	33.7	0.3	8.8	168.5	1.4	215.5	9.1	7223	155.8	387.4	**AT**
AZ	1.4	0.1	3.5	0.005	2.2	16.9	0.3	2.2	0.7	74.6	8.6	43.8	**AZ**
BA	5.4	2.3	14.7	0.3	10.6	496.9	3.6	38.3	3.9	2611	119.8	745.4	**BA**
BE	1.2	113.0	4.0	0.04	0.3	7.3	0.1	991.8	6.1	286.1	113.0	12.3	**BE**
BG	13.2	1.5	32.9	0.1	152.0	3751	4.7	26.1	4.9	1854	86.5	7094	**BG**
BY	684.6	9.1	798.2	0.1	131.0	268.6	1.2	208.8	46.6	18645	117.9	1772	**BY**
CH	1.1	15.4	4.4	0.6	1.2	37.2	0.7	96.5	2.1	433.5	171.2	53.0	**CH**
CS	9.3	2.8	24.8	0.2	41.2	4026	5.4	52.2	5.5	3296	119.2	3701	**CS**
CY	0.1	0.01	0.1	0.002	0.3	9.1	0.1	0.2	0.03	6.6	1.1	7.3	**CY**
CZ	18.4	18.8	51.6	0.1	7.6	108.2	0.4	308.6	13.7	26572	99.8	345.3	**CZ**
DE	41.3	509.3	196.5	0.5	8.5	119.1	1.1	7316	81.7	17230	844.9	332.9	**DE**
DK	5.6	8.1	28.4	0.02	1.2	12.3	0.04	562.3	21.4	1071	51.3	39.3	**DK**
EE	119.8	3.3	685.7	0.02	3.7	14.6	0.1	94.2	19.0	2762	13.9	74.9	**EE**
ES	1.3	9.3	4.6	0.5	3.5	183.5	8.0	168.4	4.8	534.9	17838	127.6	**ES**
FI	129.6	8.4	624.2	0.04	11.4	38.5	0.2	260.3	220.9	5089	69.5	215.5	**FI**
FR	7.2	355.8	25.5	8.3	7.8	370.5	8.7	1809	24.0	2605	3879	367.0	**FR**
GB	8.9	30.5	37.6	0.1	2.0	49.3	0.2	1287	30.6	1315	975.7	69.6	**GB**
GE	2.6	0.2	6.4	0.01	12.9	47.1	0.6	6.0	1.4	282.6	16.3	283.1	**GE**
GR	6.8	1.1	17.0	0.1	50.6	4633	15.8	16.0	2.9	900.4	102.1	1473	**GR**
HR	4.8	2.5	12.4	0.3	8.7	308.3	3.5	34.2	3.7	2741	129.3	532.2	**HR**
HU	10.5	4.9	25.4	0.2	20.4	523.0	1.9	80.8	6.8	6664	108.9	2432	**HU**
IE	1.7	5.1	6.1	0.01	0.4	9.8	0.03	137.6	3.1	236.5	290.4	10.3	**IE**
IS	0.3	1.4	1.1	0.01	0.0	0.4	0.01	29.4	8.3	49.3	96.0	1.2	**IS**
IT	10.3	10.3	32.6	5.0	28.3	1418	29.7	116.0	7.9	4432	718.6	1076	**IT**
KY	0.9	0.2	2.3	0.01	1.3	14.8	0.3	2.5	0.8	62.7	13.0	24.2	**KY**
KZ	36.4	3.5	103.1	0.1	74.4	287.3	2.6	73.9	30.5	2551	155.7	1222	**KZ**
LT	**1490**	5.7	1141	0.04	18.8	55.9	0.3	146.0	23.7	8540	37.3	268.6	**LT**
LU	0.1	**124.4**	0.3	0.01	0.0	0.9	0.01	31.6	0.3	32.9	13.2	1.5	**LU**
LV	609.3	5.1	**3855**	0.03	9.5	35.4	0.2	141.0	25.0	5889	31.0	164.4	**LV**
MC	0.0	0.001	0.002	**0.02**	0.001	0.05	0.001	0.01	0.0	0.2	0.1	0.05	**MC**
MD	7.7	0.5	17.6	0.02	**821.8**	163.0	0.5	10.1	2.6	946.5	17.4	2165.3	**MD**
MK	1.8	0.3	4.5	0.04	9.8	**13771**	1.9	5.2	0.8	324.2	25.9	385.7	**MK**
MT	0.0	0.003	0.0	0.001	0.0	0.6	**5.2**	0.0	0.0	0.5	0.2	0.4	**MT**
NL	1.4	16.1	6.2	0.03	0.3	5.7	0.04	**5307**	7.4	270.0	95.2	10.7	**NL**
NO	41.3	19.3	157.7	0.1	11.5	58.6	0.2	843.8	**2431**	3979	207.5	259.2	**NO**
PL	298.6	46.8	619.1	0.3	64.8	314.1	1.5	1014	101.2	**221071**	261.7	2122	**PL**
PT	0.1	0.9	0.5	0.03	0.3	12.1	0.5	19.5	0.6	58.7	**46023**	8.4	**PT**
RO	40.8	6.6	98.4	0.3	703.7	2038	5.7	114.2	15.4	8532	192.5	**44445**	**RO**
RU	1062	39.0	2812	0.6	533.5	2068	12.4	1021	457.4	37812	797.2	8272	**RU**
RUA	76.1	7.9	231.5	0.2	76.9	407.1	3.5	166.6	110.7	4713	304.1	1342	**RUA**
SE	200.5	29.6	974.9	0.1	24.2	53.7	0.3	1199	943.7	9766	186.9	344.9	**SE**
SI	1.8	1.5	5.4	0.2	3.3	79.6	1.0	17.2	1.4	1161	53.7	165.9	**SI**
SK	13.3	5.0	28.9	0.1	12.6	233.7	0.8	78.5	6.7	16528	61.8	1070	**SK**
TJ	0.3	0.05	0.7	0.002	0.4	4.3	0.1	0.8	0.2	20.4	4.3	7.8	**TJ**
TM	0.9	0.1	2.5	0.003	1.8	8.1	0.2	2.7	0.8	67.2	7.1	28.2	**TM**
TR	17.3	2.3	39.3	0.2	108.0	1262	22.2	38.0	7.1	1578	202.4	2352	**TR**
UA	223.6	12.8	446.8	0.3	1083	1737	6.4	234.1	58.2	28358	285.0	12154	**UA**
UZ	1.1	0.1	3.0	0.004	2.3	9.4	0.2	2.7	1.0	84.2	9.3	33.0	**UZ**
BAS	424.6	46.4	3100	0.1	29.9	74.9	0.4	1522	163.8	19370	190.1	427.0	**BAS**
BLS	32.5	2.0	79.9	0.1	357.3	1166	6.3	46.8	14.8	3369	89.1	5334	**BLS**
CAS	6.6	0.3	17.5	0.01	11.0	35.1	0.4	10.1	3.3	401.7	10.8	169.7	**CAS**
MDT	21.7	19.2	60.2	4.8	138.7	6934	334.4	253.8	17.7	5876	3065	4219	**MDT**
NOS	43.3	93.0	179.3	0.4	12.5	173.2	0.7	7306	631.0	7762	1681	434.9	**NOS**
	LT	**LU**	**LV**	**MC**	**MD**	**MK**	**MT**	**NL**	**NO**	**PL**	**PT**	**RO**	

***Table C.2**. Matrix of lead country-to-country depositions from anthropogenic sources in 2006, kg/y (continued)*

Receptors ↓ Emitters →

	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	Total, t/y	
AL	81.7	2.0	26.9	108.0	0.1	1.2	313.1	312.5	1.6	**23.16**	**AL**
AM	148.6	0.4	1.5	5.3	3.6	86.0	1614	86.9	68.6	**4.03**	**AM**
AT	144.5	18.2	1412	2128	0.1	2.8	125.0	425.1	3.3	**34.27**	**AT**
AZ	752.3	1.5	2.8	12.0	21.0	385.5	1898	293.9	323.6	**7.71**	**AZ**
BA	132.1	8.2	246.3	1232	0.1	2.8	261.5	535.3	3.6	**40.70**	**BA**
BE	28.5	6.3	11.1	22.2	0.01	0.1	5.1	17.1	0.1	**20.11**	**BE**
BG	988.7	13.2	90.1	692.7	0.5	21.7	4944	4429	27.1	**97.84**	**BG**
BY	3468	174.9	205.8	1868	1.4	14.5	645.4	9336	19.8	**69.46**	**BY**
CH	23.8	3.7	113.6	80.7	0.01	0.3	21.2	56.7	0.4	**17.21**	**CH**
CS	315.4	13.3	196.3	1669	0.2	7.7	953.5	1303	9.9	**84.94**	**CS**
CY	8.9	0.1	0.5	1.8	0.03	0.3	593.3	16.8	0.3	**1.21**	**CY**
CZ	160.5	23.1	297.5	2371	0.1	2.9	96.5	381.6	3.6	**50.82**	**CZ**
DE	335.0	123.2	212.8	728.9	0.3	3.3	105.7	440.6	4.1	**122.30**	**DE**
DK	33.1	70.9	10.6	65.2	0.02	1.0	11.7	59.9	1.1	**6.41**	**DK**
EE	569.7	106.9	22.5	140.3	0.04	0.7	19.0	277.8	0.8	**10.99**	**EE**
ES	41.7	6.6	127.0	157.3	0.04	0.7	137.8	148.8	1.0	**113.91**	**ES**
FI	2333	1307	30.4	253.7	0.3	7.6	91.8	776.1	9.2	**29.10**	**FI**
FR	150.7	29.3	473.7	575.5	0.1	2.0	258.0	378.1	2.6	**118.46**	**FR**
GB	131.2	30.5	35.0	95.5	0.1	0.3	25.2	107.5	0.5	**41.44**	**GB**
GE	1250	3.2	8.1	56.2	3.7	139.5	5711	761.0	109.0	**13.31**	**GE**
GR	621.3	7.0	56.6	309.6	0.4	9.4	6021	2457	13.0	**117.97**	**GR**
HR	117.1	6.2	1039	1407	0.1	2.6	230.6	451.8	3.4	**25.36**	**HR**
HU	235.7	12.7	782.5	9028	0.1	4.2	381.0	1222	5.5	**48.86**	**HU**
IE	22.5	3.0	6.1	12.1	0.01	0.0	5.5	16.7	0.1	**5.86**	**IE**
IS	12.2	3.7	1.6	2.8	0.04	0.1	0.9	4.1	0.2	**0.85**	**IS**
IT	362.8	18.4	2059	1466	0.3	5.2	1320	1285	7.1	**128.18**	**IT**
KY	441.4	1.5	2.6	10.2	7905	657.9	739.3	126.4	19571	**45.50**	**KY**
KZ	28039	61.1	66.0	407.3	8665	5494	7547	7434	38850	**148.26**	**KZ**
LT	672.7	110.9	48.5	411.5	0.1	1.9	73.6	899.8	2.4	**18.87**	**LT**
LU	2.1	0.4	1.4	3.0	0.001	0.0	0.7	1.8	0.0	**1.21**	**LU**
LV	633.5	134.5	38.7	284.4	0.1	1.4	51.8	638.8	1.9	**16.90**	**LV**
MC	0.02	0.001	0.1	0.1	0.0	0.0	0.04	0.04	0.0	**0.01**	**MC**
MD	412.3	8.7	19.7	160.2	0.4	10.1	911.4	2984	12.2	**11.54**	**MD**
MK	100.5	1.9	18.8	128.3	0.05	2.2	583.5	360.5	2.8	**33.25**	**MK**
MT	0.2	0.0	0.1	0.2	0.001	0.003	3.1	0.7	0.01	**0.03**	**MT**
NL	21.0	7.4	8.2	17.4	0.01	0.1	3.7	13.7	0.1	**16.71**	**NL**
NO	534.1	450.6	52.0	383.2	0.2	9.5	86.8	591.7	10.6	**20.92**	**NO**
PL	1389	281.2	604.3	7445	0.9	12.9	375.9	4370	16.8	**276.16**	**PL**
PT	2.4	0.9	10.4	12.8	0.01	0.04	7.8	8.3	0.1	**53.24**	**PT**
RO	1971	39.6	383.2	3860	1.2	61.8	4916	10780	75.3	**119.74**	**RO**
RU	**257998**	1479	578.6	4153	202.2	2742	28279	71523	3999	**527.56**	**RU**
RUA	165951	184.9	107.1	643.3	1705	1921	6921	6613	7242	**231.25**	**RUA**
SE	1462	**5786**	70.5	540.3	0.3	10.9	114.5	1333	12.7	**39.89**	**SE**
SI	43.5	2.4	**3937**	508.3	0.03	1.0	56.7	151.0	1.2	**12.56**	**SI**
SK	171.2	13.7	467.7	**14906**	0.1	3.4	158.1	874.5	4.5	**47.06**	**SK**
TJ	128.9	0.4	0.8	3.3	**12425**	577.9	233.5	38.4	9063	**24.36**	**TJ**
TM	565.2	1.5	2.1	10.6	1201	**5176**	665.7	188.6	7255	**16.46**	**TM**
TR	3789	16.8	93.7	399.7	11.6	224.7	**161252**	6962	213.2	**212.77**	**TR**
UA	12782	169.9	445.9	5500	10.8	162.8	10724	**104890**	226.6	**219.05**	**UA**
UZ	714.5	1.9	2.3	13.5	6754	2258	679.1	224.9	**29850**	**45.01**	**UZ**
BAS	1737	1780	106.9	697.6	0.2	6.6	95.3	1360	7.9	**55.36**	**BAS**
BLS	6775	36.7	96.0	615.7	6.6	98.5	30590	19214	141.3	**89.35**	**BLS**
CAS	3156	8.2	7.0	52.9	171.1	1875	2474	1412	1841.4	**15.19**	**CAS**
MDT	2029	33.1	1447	2160	3.5	29.8	46144	7096	49.4	**323.43**	**MDT**
NOS	360.7	341.9	152.9	723.2	0.4	10.2	168.5	661.7	11.9	**85.58**	**NOS**
	RU	**SE**	**SI**	**SK**	**TJ**	**TM**	**TR**	**UA**	**UZ**	**Total, t/y**	

***Table C.3**. Matrix of cadmium country-to-country depositions from anthropogenic sources in 2006, kg/y*

Receptors ↓ Emitters →

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CS	CY	CZ	DE	
AL	**38.43**	0.02	1.15	0.16	7.46	0.28	98.24	0.82	0.90	153.78	0.45	2.29	0.76	**AL**
AM	0.03	**29.32**	0.06	64.37	0.16	0.03	1.69	0.18	0.06	0.84	2.26	0.13	0.07	**AM**
AT	0.56	0.03	**330.90**	0.47	15.19	9.98	30.31	3.69	44.65	71.61	0.11	107.20	74.67	**AT**
AZ	0.05	7.23	0.13	**542.63**	0.30	0.08	3.49	0.90	0.13	1.67	3.26	0.36	0.19	**AZ**
BA	4.13	0.02	12.54	0.42	**539.90**	1.45	56.09	1.92	3.71	390.28	0.18	26.29	5.60	**BA**
BE	0.03	0.002	1.53	0.03	0.43	**297.50**	0.93	0.41	4.08	1.36	0.00	2.94	26.85	**BE**
BG	4.68	0.23	4.90	3.51	21.34	0.98	**5053**	8.98	2.32	410.17	3.06	13.14	3.50	**BG**
BY	0.75	0.14	13.33	2.82	12.30	7.75	60.75	**929.19**	6.94	71.23	0.12	68.87	21.42	**BY**
CH	0.16	0.003	7.20	0.05	3.06	6.54	5.53	0.32	**270.02**	9.11	0.02	3.92	12.91	**CH**
CS	13.87	0.07	12.31	1.03	117.45	1.89	447.88	3.96	3.84	**2774**	1.15	31.15	7.06	**CS**
CY	0.03	0.03	0.02	0.09	0.10	0.01	1.12	0.04	0.02	0.53	**52.94**	0.04	0.02	**CY**
CZ	0.28	0.03	64.29	0.48	6.58	10.94	25.07	5.84	18.15	41.11	0.06	**735.72**	69.51	**CZ**
DE	0.42	0.04	78.25	0.66	7.77	289.87	20.04	7.54	205.32	35.21	0.08	207.92	**1126**	**DE**
DK	0.04	0.01	1.20	0.09	0.45	13.71	2.13	0.75	1.53	2.07	0.003	5.92	27.95	**DK**
EE	0.05	0.01	2.14	0.11	0.93	3.39	2.80	12.28	1.68	4.83	0.01	11.61	8.08	**EE**
ES	0.90	0.01	3.70	0.11	8.69	9.42	17.42	0.42	8.81	23.44	0.04	5.00	6.13	**ES**
FI	0.11	0.05	3.50	0.83	1.40	8.62	7.93	18.95	3.58	8.80	0.05	21.08	19.03	**FI**
FR	1.77	0.02	18.43	0.41	23.08	185.79	38.80	2.14	131.34	63.45	0.15	26.61	98.19	**FR**
GB	0.18	0.01	3.69	0.10	1.78	54.65	6.31	1.97	7.01	7.44	0.02	10.18	34.12	**GB**
GE	0.12	11.91	0.40	156.94	0.85	0.20	15.58	1.52	0.27	6.38	4.62	1.29	0.47	**GE**
GR	7.72	0.16	2.73	1.54	11.36	0.64	746.75	4.52	1.94	117.09	7.28	6.46	1.95	**GR**
HR	2.23	0.02	23.98	0.42	80.38	1.46	43.17	1.93	4.37	206.49	0.16	32.35	6.50	**HR**
HU	1.32	0.03	45.13	0.63	47.91	3.06	102.47	4.74	6.22	366.24	0.30	75.53	13.14	**HU**
IE	0.04	0.001	0.63	0.02	0.36	6.67	1.18	0.39	1.16	1.35	0.003	1.87	4.63	**IE**
IS	0.00	0.00	0.11	0.01	0.02	1.25	0.06	0.11	0.53	0.06	0.001	0.32	1.03	**IS**
IT	7.94	0.06	50.33	0.91	75.80	5.43	157.27	3.97	56.17	203.37	1.28	42.05	20.60	**IT**
KY	0.05	0.65	0.12	9.45	0.25	0.10	2.15	0.42	0.16	1.24	1.88	0.30	0.20	**KY**
KZ	0.79	9.00	3.96	197.22	7.34	2.91	82.91	23.07	3.88	41.77	9.22	11.84	6.10	**KZ**
LT	0.15	0.02	5.42	0.29	2.15	5.47	11.16	60.49	3.24	12.51	0.02	30.41	14.23	**LT**
LU	0.004	0.00	0.21	0.004	0.06	7.97	0.10	0.04	0.65	0.17	0.001	0.36	2.98	**LU**
LV	0.11	0.01	4.17	0.23	1.75	5.13	6.55	31.52	2.85	9.47	0.01	23.51	13.48	**LV**
MC	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.002	0.001	**MC**
MD	0.38	0.09	0.95	2.01	2.88	0.34	58.13	5.63	0.55	22.81	0.26	3.69	1.17	**MD**
MK	8.01	0.02	1.04	0.24	5.50	0.21	259.24	0.98	0.58	116.65	0.64	2.68	0.71	**MK**
MT	0.003	0.00	0.00	0.001	0.01	0.002	0.07	0.001	0.01	0.05	0.004	0.005	0.003	**MT**
NL	0.02	0.001	1.09	0.02	0.33	107.56	0.77	0.31	2.05	1.20	0.003	2.56	36.54	**NL**
NO	0.19	0.05	5.81	0.80	2.24	26.38	9.70	7.72	5.84	10.04	0.03	23.18	38.35	**NO**
PL	0.84	0.12	62.13	2.32	20.41	38.38	72.31	115.88	28.35	122.94	0.17	701.78	171.08	**PL**
PT	0.06	0.001	0.34	0.02	0.59	0.98	1.13	0.03	0.76	1.41	0.003	0.49	0.67	**PT**
RO	5.47	0.54	19.84	10.74	74.77	4.20	718.27	24.71	8.29	699.77	2.57	55.59	14.54	**RO**
RU	5.19	19.34	37.61	529.56	49.12	35.51	502.18	715.35	28.40	301.92	19.71	158.08	83.47	**RU**
RUA	1.07	6.60	7.08	111.37	8.69	6.29	78.39	34.85	7.14	47.70	6.24	22.69	14.20	**RUA**
SE	0.18	0.07	8.69	1.09	2.84	36.56	9.70	28.98	9.24	13.86	0.04	44.66	73.83	**SE**
SI	0.40	0.01	33.05	0.17	11.59	0.83	13.43	0.77	2.79	39.09	0.04	14.32	4.55	**SI**
SK	0.60	0.02	30.82	0.46	17.98	3.14	49.91	5.72	5.25	118.66	0.08	171.05	12.93	**SK**
TJ	0.01	0.22	0.04	3.85	0.08	0.03	0.65	0.12	0.05	0.39	0.67	0.10	0.06	**TJ**
TM	0.03	1.23	0.12	36.39	0.17	0.10	1.81	0.59	0.15	0.94	1.24	0.34	0.20	**TM**
TR	3.16	19.08	4.22	56.19	13.05	1.52	273.26	12.64	3.75	89.29	132.45	8.95	3.77	**TR**
UA	4.10	1.50	23.48	32.12	44.95	8.75	506.28	226.95	11.50	301.07	3.67	104.49	28.71	**UA**
UZ	0.03	1.07	0.13	25.53	0.21	0.11	1.91	0.74	0.18	1.06	1.27	0.41	0.23	**UZ**
BAS	0.24	0.04	12.29	0.70	4.17	48.98	14.03	39.41	13.15	21.03	0.04	72.53	123.80	**BAS**
BLS	2.39	2.08	4.81	23.42	13.32	1.49	393.13	22.56	3.16	112.16	9.74	13.47	4.71	**BLS**
CAS	0.10	4.50	0.43	333.87	0.65	0.30	11.17	3.92	0.50	4.28	2.85	1.69	0.75	**CAS**
MDT	36.86	1.29	37.10	7.25	151.59	11.83	878.11	12.15	39.01	496.59	291.14	51.27	21.75	**MDT**
NOS	0.62	0.07	16.06	1.09	6.33	186.85	24.32	7.07	21.86	27.43	0.06	49.21	162.39	**NOS**
	AL	**AM**	**AT**	**AZ**	**BA**	**BE**	**BG**	**BY**	**CH**	**CS**	**CY**	**CZ**	**DE**	

***Table C.3**. Matrix of cadmium country-to-country depositions from anthropogenic sources in 2006, kg/y (continued)*

Receptors ↓ Emitters →

	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	
AL	0.13	0.08	12.97	0.13	2.89	0.51	0.02	42.23	2.45	3.48	0.06	0.002	**AL**
AM	0.02	0.02	0.79	0.03	0.16	0.06	6.30	0.66	0.07	0.12	0.01	0.00	**AM**
AT	2.25	0.41	27.59	0.73	30.92	12.08	0.04	3.14	21.07	31.04	0.89	0.02	**AT**
AZ	0.06	0.08	1.44	0.12	0.33	0.19	10.68	1.10	0.13	0.27	0.02	0.001	**AZ**
BA	0.83	0.19	25.94	0.37	7.90	2.44	0.04	12.82	59.48	49.84	0.23	0.01	**BA**
BE	0.94	0.17	24.04	0.35	169.65	41.09	0.002	0.13	0.35	0.42	2.04	0.02	**BE**
BG	0.81	0.55	17.74	0.83	4.98	1.83	0.57	79.13	6.62	22.64	0.19	0.01	**BG**
BY	9.49	10.59	21.33	10.28	16.84	13.92	0.34	5.19	8.26	30.60	1.06	0.04	**BY**
CH	0.53	0.07	36.28	0.16	68.61	8.65	0.00	0.70	3.04	1.90	0.72	0.01	**CH**
CS	1.26	0.32	26.36	0.59	8.45	3.32	0.14	41.75	25.56	77.26	0.31	0.01	**CS**
CY	0.003	0.002	0.26	0.004	0.08	0.02	0.02	1.34	0.04	0.05	0.002	0.00	**CY**
CZ	4.24	0.46	15.94	0.70	24.49	14.17	0.04	1.61	8.86	33.04	1.06	0.02	**CZ**
DE	39.02	1.98	147.99	2.97	414.97	206.74	0.05	2.22	6.28	13.41	12.75	0.17	**DE**
DK	**87.52**	0.30	10.29	0.37	18.35	31.17	0.01	0.24	0.35	1.29	1.89	0.03	**DK**
EE	3.79	**60.61**	3.44	12.86	5.40	5.06	0.01	0.21	0.71	2.40	0.34	0.01	**EE**
ES	0.83	0.07	**5141**	0.20	82.84	18.69	0.01	5.90	5.85	4.47	2.81	0.03	**ES**
FI	13.52	47.46	13.79	**560.01**	14.58	22.09	0.07	0.65	0.98	4.17	1.69	0.12	**FI**
FR	4.16	0.56	1425.0	1.12	**1711**	185.99	0.04	8.62	18.73	14.50	15.99	0.14	**FR**
GB	4.36	0.68	141.37	1.03	109.25	**908.67**	0.01	0.75	1.19	1.81	61.83	0.28	**GB**
GE	0.13	0.10	2.53	0.15	0.67	0.56	**73.75**	2.69	0.39	1.07	0.06	0.003	**GE**
GR	0.45	0.27	24.79	0.43	5.64	1.26	0.27	**644.48**	3.93	8.52	0.14	0.005	**GR**
HR	0.78	0.15	28.61	0.28	8.25	2.39	0.04	8.80	**176.26**	63.73	0.21	0.01	**HR**
HU	1.84	0.27	23.33	0.51	9.80	4.47	0.08	7.37	57.85	**495.75**	0.37	0.01	**HU**
IE	0.41	0.10	28.96	0.12	12.68	37.09	0.002	0.12	0.23	0.24	**84.87**	0.06	**IE**
IS	0.23	0.02	8.35	0.15	3.40	4.70	0.001	0.01	0.03	0.04	1.21	**14.55**	**IS**
IT	1.70	0.43	168.22	0.86	66.90	8.30	0.11	47.94	70.31	41.56	0.86	0.02	**IT**
KY	0.05	0.08	2.19	0.14	0.45	0.19	0.61	0.85	0.11	0.22	0.02	0.002	**KY**
KZ	1.93	3.61	25.61	5.88	8.09	6.88	13.05	9.88	2.95	8.08	0.63	0.06	**KZ**
LT	6.21	2.92	7.85	3.96	10.21	9.14	0.03	0.93	1.54	5.92	0.62	0.02	**LT**
LU	0.06	0.01	2.61	0.02	11.26	2.12	0.00	0.02	0.05	0.06	0.12	0.002	**LU**
LV	6.32	9.57	6.48	6.98	8.94	8.33	0.02	0.60	1.26	4.44	0.54	0.02	**LV**
MC	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.001	0.003	0.002	0.00	0.00	**MC**
MD	0.47	0.25	3.35	0.40	1.08	0.64	0.22	4.86	1.09	3.49	0.06	0.003	**MD**
MK	0.14	0.08	5.69	0.13	1.51	0.37	0.04	65.16	1.59	4.23	0.04	0.001	**MK**
MT	0.00	0.00	0.07	0.00	0.02	0.00	0.00	0.05	0.01	0.01	0.00	0.00	**MT**
NL	1.64	0.15	19.78	0.28	78.20	50.53	0.002	0.10	0.25	0.37	2.45	0.02	**NL**
NO	31.61	3.37	43.55	12.08	42.78	100.33	0.06	0.92	1.57	6.32	9.19	0.57	**NO**
PL	53.35	3.62	48.52	6.62	69.24	54.82	0.19	4.81	20.58	95.94	4.14	0.08	**PL**
PT	0.10	0.01	379.33	0.02	5.48	2.22	0.001	0.40	0.43	0.31	0.42	0.01	**PT**
RO	2.95	1.31	44.31	2.04	15.20	6.77	1.25	43.28	26.50	125.06	0.63	0.02	**RO**
RU	40.32	285.70	136.42	260.92	75.47	79.40	58.16	68.15	24.54	77.08	6.51	0.46	**RU**
RUA	5.15	9.62	45.69	20.80	16.44	13.77	8.98	13.48	4.35	12.48	1.35	0.31	**RUA**
SE	110.91	16.22	38.31	117.34	54.14	76.33	0.09	0.90	2.15	8.68	5.41	0.28	**SE**
SI	0.31	0.07	12.00	0.12	4.11	1.17	0.02	1.96	38.43	14.58	0.09	0.003	**SI**
SK	2.05	0.25	11.41	0.52	8.26	4.20	0.04	3.24	20.00	145.11	0.34	0.01	**SK**
TJ	0.01	0.02	0.70	0.04	0.14	0.06	0.21	0.26	0.04	0.07	0.01	0.00	**TJ**
TM	0.06	0.09	1.21	0.14	0.32	0.26	1.92	0.50	0.09	0.22	0.02	0.002	**TM**
TR	0.87	0.72	45.10	1.16	10.51	3.32	10.91	133.22	5.10	9.79	0.37	0.02	**TR**
UA	11.56	6.90	56.28	9.32	24.38	16.21	4.31	47.80	24.85	115.65	1.42	0.06	**UA**
UZ	0.08	0.12	1.45	0.18	0.37	0.28	1.54	0.55	0.10	0.27	0.03	0.003	**UZ**
BAS	116.74	49.58	43.10	155.68	71.32	72.83	0.06	1.08	3.31	11.06	4.68	0.09	**BAS**
BLS	1.91	0.93	17.84	1.46	5.64	4.13	11.35	56.93	4.59	12.38	0.44	0.02	**BLS**
CAS	0.32	0.44	2.07	0.57	0.85	0.91	8.90	1.68	0.26	0.92	0.08	0.01	**CAS**
MDT	2.63	0.84	1152.0	1.46	171.91	21.53	1.50	758.85	90.34	58.51	2.57	0.05	**MDT**
NOS	80.01	2.87	292.43	4.27	338.91	981.59	0.11	2.82	4.53	12.63	50.15	0.90	**NOS**
	DK	**EE**	**ES**	**FI**	**FR**	**GB**	**GE**	**GR**	**HR**	**HU**	**IE**	**IS**	

***Table C.3**. Matrix of cadmium country-to-country depositions from anthropogenic sources in 2006, kg/y (continued)*

Receptors ↓ Emitters →

	IT	KY	KZ	LT	LU	LV	MC	MD	MK	MT	NL	NO	
AL	58.83	0.002	0.48	0.08	0.01	0.13	0.02	0.25	529.86	3.58	0.26	0.06	**AL**
AM	0.90	0.06	6.99	0.01	0.001	0.02	0.00	0.03	1.39	0.13	0.03	0.01	**AM**
AT	123.80	0.004	0.80	0.59	0.52	0.98	0.06	0.25	24.76	0.91	8.90	0.68	**AT**
AZ	1.59	0.50	33.34	0.07	0.003	0.11	0.001	0.07	2.44	0.21	0.09	0.04	**AZ**
BA	94.87	0.004	0.95	0.29	0.05	0.45	0.05	0.33	70.89	2.52	1.56	0.29	**BA**
BE	5.00	0.00	0.12	0.07	3.24	0.12	0.01	0.01	1.02	0.05	50.94	0.53	**BE**
BG	42.46	0.03	7.65	0.66	0.04	1.01	0.02	5.07	409.97	3.25	1.07	0.35	**BG**
BY	30.77	0.04	7.78	23.94	0.22	27.80	0.02	3.81	37.86	0.78	8.64	3.46	**BY**
CH	146.86	0.00	0.11	0.07	0.38	0.12	0.10	0.03	5.17	0.43	4.16	0.16	**CH**
CS	97.57	0.01	2.41	0.48	0.07	0.75	0.04	1.29	511.55	3.74	2.12	0.41	**CS**
CY	0.70	0.001	0.05	0.003	0.00	0.00	0.00	0.01	1.51	0.10	0.01	0.00	**CY**
CZ	26.24	0.005	0.95	1.01	0.45	1.60	0.02	0.22	15.81	0.27	12.56	1.10	**CZ**
DE	82.00	0.01	1.79	3.27	13.54	6.07	0.09	0.24	16.77	0.71	307.03	6.73	**DE**
DK	2.59	0.001	0.15	0.47	0.20	0.90	0.003	0.03	1.85	0.03	23.79	1.86	**DK**
EE	3.60	0.002	0.36	11.01	0.08	25.39	0.003	0.10	1.88	0.06	4.00	1.33	**EE**
ES	126.15	0.002	0.40	0.07	0.22	0.13	0.09	0.10	28.04	5.58	7.55	0.38	**ES**
FI	6.31	0.02	1.94	10.03	0.20	19.88	0.01	0.32	5.22	0.15	10.62	13.16	**FI**
FR	355.28	0.003	1.10	0.42	9.34	0.75	1.53	0.21	53.05	5.88	89.00	1.98	**FR**
GB	12.98	0.001	0.47	0.62	0.78	1.12	0.02	0.05	6.50	0.14	62.66	2.58	**GB**
GE	3.33	0.10	12.80	0.12	0.01	0.19	0.002	0.40	6.66	0.44	0.23	0.09	**GE**
GR	62.93	0.02	3.94	0.32	0.02	0.50	0.02	1.63	690.50	11.41	0.64	0.21	**GR**
HR	112.02	0.004	0.87	0.26	0.06	0.40	0.05	0.27	46.52	2.44	1.43	0.28	**HR**
HU	68.86	0.01	1.37	0.55	0.12	0.81	0.04	0.61	74.53	1.29	3.30	0.52	**HU**
IE	2.34	0.00	0.08	0.10	0.13	0.18	0.002	0.01	1.19	0.02	6.45	0.24	**IE**
IS	0.66	0.001	0.08	0.02	0.03	0.03	0.001	0.00	0.06	0.01	1.22	0.34	**IS**
IT	**2139.2**	0.01	2.24	0.57	0.25	0.95	0.90	0.84	213.72	22.21	4.69	0.57	**IT**
KY	1.60	**298.9**	631.42	0.04	0.003	0.06	0.001	0.04	2.05	0.21	0.09	0.05	**KY**
KZ	23.87	325.92	**9836.4**	1.89	0.08	3.15	0.01	2.32	41.44	1.69	3.02	1.97	**KZ**
LT	7.51	0.01	0.90	**60.95**	0.14	41.53	0.01	0.55	7.69	0.19	6.18	1.81	**LT**
LU	0.75	0.00	0.01	0.005	**3.36**	0.01	0.001	0.00	0.13	0.01	1.52	0.03	**LU**
LV	6.30	0.005	0.77	79.95	0.13	**148.50**	0.01	0.28	4.67	0.14	5.95	1.85	**LV**
MC	0.10	0.00	0.00	0.00	0.00	0.00	**0.004**	0.00	0.01	0.00	0.00	0.00	**MC**
MD	5.86	0.01	3.71	0.36	0.01	0.55	0.003	**27.54**	22.75	0.32	0.39	0.19	**MD**
MK	19.11	0.002	0.67	0.09	0.008	0.14	0.01	0.33	**2817.2**	1.28	0.21	0.05	**MK**
MT	0.28	0.00	0.002	0.00	0.00	0.00	0.00	0.00	0.10	**4.28**	0.00	0.00	**MT**
NL	3.27	0.00	0.10	0.11	0.43	0.20	0.004	0.01	0.83	0.03	**264.86**	0.65	**NL**
NO	12.12	0.01	1.35	2.77	0.47	4.87	0.01	0.32	8.27	0.12	36.29	**207.17**	**NO**
PL	61.09	0.03	5.90	15.44	1.14	20.95	0.05	1.89	42.13	1.04	42.10	8.29	**PL**
PT	6.26	0.00	0.03	0.01	0.02	0.01	0.01	0.01	1.86	0.34	0.87	0.05	**PT**
RO	102.67	0.07	17.84	1.98	0.15	3.01	0.05	21.36	300.41	3.85	4.51	1.11	**RO**
RU	143.38	5.83	1472.6	55.53	0.91	93.17	0.10	16.45	303.31	8.23	40.99	28.39	**RU**
RUA	34.29	54.50	5719.0	4.06	0.18	6.88	0.02	2.26	56.84	2.24	6.57	6.18	**RUA**
SE	15.51	0.02	2.25	15.94	0.71	30.60	0.02	0.70	7.89	0.20	50.53	63.50	**SE**
SI	70.85	0.002	0.32	0.11	0.04	0.17	0.03	0.10	11.94	0.76	0.73	0.11	**SI**
SK	34.96	0.01	1.20	0.65	0.12	0.94	0.02	0.36	32.38	0.53	3.27	0.53	**SK**
TJ	0.50	11.57	93.59	0.01	0.001	0.02	0.00	0.01	0.60	0.06	0.03	0.01	**TJ**
TM	1.06	6.16	148.89	0.05	0.003	0.08	0.001	0.06	1.26	0.12	0.11	0.05	**TM**
TR	80.38	0.23	27.61	0.82	0.05	1.23	0.04	3.63	184.45	15.73	1.54	0.50	**TR**
UA	92.70	0.32	71.98	10.29	0.30	14.53	0.05	36.17	255.67	4.24	9.45	4.39	**UA**
UZ	1.23	35.37	452.42	0.06	0.003	0.09	0.001	0.07	1.42	0.13	0.11	0.07	**UZ**
BAS	20.69	0.01	1.79	40.54	1.10	99.14	0.02	0.86	10.37	0.24	62.95	12.19	**BAS**
BLS	35.43	0.22	31.69	1.55	0.05	2.37	0.02	11.79	163.43	4.29	1.82	1.03	**BLS**
CAS	2.75	3.27	183.95	0.33	0.01	0.54	0.002	0.34	5.13	0.29	0.38	0.22	**CAS**
MDT	1925.14	0.12	13.38	1.05	0.44	1.70	0.85	4.14	976.42	257.85	10.24	1.25	**MDT**
NOS	45.81	0.02	1.77	3.00	2.29	5.35	0.06	0.32	24.06	0.47	328.26	52.07	**NOS**
	IT	**KY**	**KZ**	**LT**	**LU**	**LV**	**MC**	**MD**	**MK**	**MT**	**NL**	**NO**	

***Table C.3**. Matrix of cadmium country-to-country depositions from anthropogenic sources in 2006, kg/y (continued)*

Receptors ↓ Emitters →

	PL	PT	RO	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	Total	
AL	21.53	1.17	15.17	13.74	0.07	1.79	7.20	0.00	0.01	8.62	7.32	0.01	**1039.9**	**AL**
AM	1.78	0.13	0.76	15.73	0.01	0.08	0.31	0.01	0.80	51.49	2.09	0.63	**190.8**	**AM**
AT	431.49	3.52	24.71	26.15	0.61	98.42	213.00	0.00	0.03	4.15	7.55	0.03	**1791.4**	**AT**
AZ	5.74	0.22	1.83	65.53	0.05	0.17	0.78	0.05	3.60	69.91	7.77	3.21	**772.2**	**AZ**
BA	171.84	2.92	48.47	21.51	0.28	16.01	87.49	0.00	0.03	7.58	9.76	0.03	**1740.8**	**BA**
BE	18.16	2.30	0.66	4.62	0.22	0.68	2.47	0.00	0.001	0.18	0.30	0.001	**666.0**	**BE**
BG	140.16	2.02	307.76	137.96	0.47	6.12	45.11	0.001	0.20	136.97	106.42	0.25	**7020.8**	**BG**
BY	1829.17	2.69	90.99	719.45	6.58	13.23	128.36	0.003	0.13	19.25	151.31	0.16	**4430.0**	**BY**
CH	25.13	3.49	2.91	3.59	0.12	7.13	7.15	0.00	0.002	0.66	1.05	0.003	**648.3**	**CH**
CS	225.70	2.87	218.19	49.38	0.46	13.29	110.55	0.00	0.07	28.04	25.97	0.09	**4895.9**	**CS**
CY	0.46	0.03	0.33	0.80	0.00	0.04	0.12	0.00	0.003	21.44	0.42	0.003	**82.8**	**CY**
CZ	1419.54	2.08	23.07	31.47	0.83	20.65	771.52	0.00	0.03	3.33	6.48	0.03	**3422.0**	**CZ**
DE	1146.0	16.18	20.51	62.73	4.36	13.68	80.93	0.00	0.03	3.79	7.28	0.03	**4621.3**	**DE**
DK	91.78	0.98	2.44	6.45	2.38	0.67	6.83	0.00	0.01	0.41	1.05	0.01	**352.5**	**DK**
EE	244.39	0.26	4.05	105.77	4.20	1.41	15.42	0.00	0.01	0.57	4.60	0.01	**571.3**	**EE**
ES	33.77	384.71	7.18	5.56	0.22	8.45	12.49	0.00	0.01	3.79	3.02	0.01	**5974.7**	**ES**
FI	437.05	1.37	12.03	363.45	49.57	1.85	24.93	0.001	0.07	3.61	14.51	0.08	**1749.4**	**FI**
FR	155.23	76.07	20.82	20.85	1.02	30.53	48.34	0.00	0.02	7.51	6.80	0.02	**4861.7**	**FR**
GB	89.07	17.71	3.48	21.82	1.03	2.10	9.69	0.00	0.002	0.86	1.85	0.004	**1594.2**	**GB**
GE	19.32	0.41	11.03	160.39	0.11	0.49	3.05	0.01	1.39	221.80	18.34	1.09	**744.4**	**GE**
GR	63.35	2.34	64.55	86.42	0.24	3.70	20.11	0.00	0.09	163.22	60.46	0.11	**2837.0**	**GR**
HR	180.23	3.10	36.60	18.51	0.22	67.39	114.07	0.00	0.02	6.97	8.44	0.03	**1293.1**	**HR**
HU	457.96	2.31	197.63	33.36	0.45	54.36	398.21	0.00	0.04	11.64	19.32	0.05	**2595.7**	**HU**
IE	15.16	6.83	0.42	3.79	0.10	0.36	1.47	0.00	0.00	0.19	0.29	0.001	**222.5**	**IE**
IS	3.42	2.36	0.08	1.94	0.11	0.09	0.30	0.00	0.001	0.03	0.08	0.001	**47.1**	**IS**
IT	277.22	18.24	60.60	54.47	0.61	134.73	120.45	0.00	0.05	38.60	26.59	0.06	**4150.2**	**IT**
KY	4.10	0.31	1.03	46.32	0.05	0.15	0.62	18.94	5.29	27.15	2.82	240.17	**1303.3**	**KY**
KZ	186.21	3.88	54.04	3594.45	2.09	4.01	23.93	18.12	48.59	286.89	188.68	387.81	**15527.1**	**KZ**
LT	907.88	0.72	13.66	236.46	4.30	3.27	43.35	0.00	0.02	2.09	13.29	0.02	**1547.4**	**LT**
LU	1.93	0.25	0.09	0.35	0.01	0.09	0.32	0.00	0.00	0.02	0.03	0.00	**37.8**	**LU**
LV	561.16	0.54	8.68	150.92	5.31	2.54	31.66	0.00	0.01	1.52	10.23	0.02	**1173.5**	**LV**
MC	0.02	0.002	0.003	0.002	0.00	0.01	0.01	0.00	0.00	0.001	0.001	0.00	**0.2**	**MC**
MD	81.67	0.38	56.22	57.37	0.31	1.25	8.64	0.001	0.09	25.56	57.85	0.11	**465.9**	**MD**
MK	23.21	0.63	18.72	15.77	0.07	1.25	8.66	0.00	0.02	15.34	8.38	0.02	**3406.6**	**MK**
MT	0.03	0.003	0.02	0.02	0.00	0.01	0.01	0.00	0.00	0.10	0.02	0.00	**5.2**	**MT**
NL	18.67	1.94	0.63	3.73	0.27	0.51	1.75	0.00	0.001	0.13	0.24	0.001	**604.6**	**NL**
NO	283.63	4.16	15.15	86.50	16.69	3.12	33.12	0.00	0.08	3.35	10.10	0.08	**1112.4**	**NO**
PL	**18756.5**	5.60	153.61	371.10	10.86	41.33	752.45	0.002	0.13	12.32	62.12	0.16	**22064.8**	**PL**
PT	3.41	**1409.5**	0.47	0.40	0.03	0.68	1.00	0.00	0.00	0.23	0.17	0.00	**1820.5**	**PT**
RO	641.76	4.37	**2858.6**	274.24	1.41	25.67	208.76	0.003	0.57	151.26	213.47	0.66	**6746.4**	**RO**
RU	3169.0	17.68	380.90	**43800.5**	51.84	35.69	288.38	0.45	24.98	1058.8	1767.2	34.57	**56397.5**	**RU**
RUA	343.57	6.75	62.53	22316.5	6.11	6.38	42.54	3.33	17.25	264.59	148.03	67.25	**29682.6**	**RUA**
SE	847.08	3.66	19.26	253.30	**229.26**	4.38	53.93	0.001	0.10	4.36	24.58	0.11	**2288.4**	**SE**
SI	73.15	1.27	11.05	7.49	0.08	**308.96**	46.82	0.00	0.01	1.86	2.95	0.01	**732.7**	**SI**
SK	1126.5	1.44	90.47	29.88	0.50	32.42	**1365.0**	0.00	0.03	4.73	12.83	0.04	**3350.8**	**SK**
TJ	1.32	0.11	0.33	13.56	0.01	0.05	0.20	**18.60**	4.08	8.56	0.86	84.13	**246.1**	**TJ**
TM	5.05	0.20	1.24	67.83	0.05	0.14	0.67	1.95	**52.69**	26.84	5.09	72.88	**440.6**	**TM**
TR	115.83	5.02	97.29	325.91	0.59	5.89	24.18	0.02	2.16	**6594.6**	178.93	1.92	**8511.0**	**TR**
UA	2625.7	6.21	613.00	2214.2	6.34	29.55	253.73	0.02	1.46	328.27	**2494.0**	1.87	**10690.7**	**UA**
UZ	6.32	0.26	1.43	88.21	0.07	0.15	0.78	13.94	18.88	26.07	5.87	**320.70**	**1011.5**	**UZ**
BAS	1873.3	3.46	22.60	345.73	69.00	6.65	75.70	0.001	0.06	3.26	22.22	0.07	**3551.9**	**BAS**
BLS	254.55	2.00	178.97	484.84	1.25	5.90	32.11	0.02	0.87	921.32	472.36	1.18	**3333.1**	**BLS**
CAS	29.82	0.27	7.07	285.12	0.28	0.42	3.21	0.37	16.60	97.86	35.98	16.97	**1073.2**	**CAS**
MDT	354.80	78.93	189.63	225.83	1.09	92.06	152.41	0.01	0.27	1415.18	163.28	0.40	**10164.6**	**MDT**
NOS	536.41	30.66	25.18	59.55	10.90	8.99	60.59	0.001	0.08	5.94	10.38	0.09	**3486.8**	**NOS**
	PL	**PT**	**RO**	**RU**	**SE**	**SI**	**SK**	**TJ**	**TU**	**TR**	**UA**	**UZ**	**Total**	

***Table C.4**. Matrix of mercury country-to-country depositions from anthropogenic sources in 2006, kg/y*

Receptors ↓ Emitters →

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CS	CY	CZ	DE	
AL	**51.38**	0.02	0.34	0.02	2.99	0.11	7.17	0.07	0.27	39.61	0.12	0.94	0.22	**AL**
AM	0.03	**47.51**	0.04	13.43	0.09	0.03	0.24	0.03	0.04	0.24	0.57	0.12	0.05	**AM**
AT	0.46	0.02	**169.02**	0.07	6.52	3.80	1.99	0.44	19.13	16.52	0.03	72.32	16.75	**AT**
AZ	0.06	9.80	0.09	**151.48**	0.19	0.09	0.51	0.10	0.10	0.52	0.86	0.31	0.15	**AZ**
BA	3.23	0.02	3.87	0.05	**342.47**	0.51	3.36	0.21	1.12	95.68	0.05	10.44	1.47	**BA**
BE	0.02	0.002	0.47	0.01	0.14	**207.44**	0.07	0.04	1.54	0.25	0.00	1.47	16.87	**BE**
BG	3.01	0.14	1.45	0.29	7.73	0.41	**682.11**	0.78	0.73	74.23	1.19	5.02	0.99	**BG**
BY	0.45	0.12	4.16	0.39	4.29	2.73	4.89	**153.32**	2.57	12.86	0.03	27.03	6.90	**BY**
CH	0.13	0.004	2.07	0.01	1.12	2.74	0.37	0.05	**146.18**	1.77	0.01	2.10	3.95	**CH**
CS	11.52	0.05	3.70	0.11	56.65	0.62	23.70	0.40	1.17	**945.60**	0.36	12.14	1.78	**CS**
CY	0.02	0.03	0.01	0.02	0.04	0.01	0.15	0.01	0.01	0.11	**77.49**	0.03	0.01	**CY**
CZ	0.20	0.02	27.67	0.07	2.49	3.68	1.62	0.67	6.82	8.20	0.02	**687.73**	22.69	**CZ**
DE	0.32	0.04	32.18	0.12	2.92	97.61	1.45	0.94	89.83	7.18	0.03	140.20	**611.28**	**DE**
DK	0.04	0.01	0.41	0.02	0.17	4.48	0.21	0.14	0.56	0.46	0.002	3.20	9.87	**DK**
EE	0.03	0.01	0.65	0.02	0.29	1.01	0.17	1.43	0.60	0.74	0.003	4.46	2.32	**EE**
ES	0.37	0.01	0.88	0.02	1.92	2.29	0.97	0.07	2.61	2.84	0.02	1.82	1.72	**ES**
FI	0.08	0.06	1.02	0.17	0.56	2.77	0.66	1.88	1.20	1.72	0.02	7.94	5.48	**FI**
FR	1.06	0.03	5.25	0.08	6.48	84.00	2.61	0.28	58.01	9.46	0.07	12.33	44.42	**FR**
GB	0.13	0.01	1.08	0.03	0.62	18.99	0.49	0.20	2.26	1.40	0.01	4.10	10.98	**GB**
GE	0.11	12.55	0.16	27.45	0.38	0.12	1.81	0.14	0.17	1.24	1.27	0.60	0.22	**GE**
GR	6.25	0.12	0.81	0.20	3.98	0.30	124.96	0.40	0.65	21.27	2.47	2.58	0.67	**GR**
HR	1.74	0.02	7.54	0.05	37.62	0.55	2.49	0.18	1.36	53.08	0.05	13.94	1.68	**HR**
HU	0.81	0.03	16.26	0.08	21.02	1.14	5.31	0.53	2.11	84.78	0.09	36.83	3.78	**HU**
IE	0.02	0.002	0.18	0.01	0.10	1.83	0.07	0.03	0.38	0.20	0.003	0.67	1.16	**IE**
IS	0.003	0.001	0.05	0.005	0.03	0.34	0.03	0.02	0.17	0.06	0.002	0.20	0.31	**IS**
IT	6.51	0.06	15.19	0.15	28.23	2.20	11.22	0.42	22.82	36.74	0.31	18.23	5.48	**IT**
KY	0.03	0.26	0.06	0.54	0.11	0.06	0.23	0.03	0.07	0.29	0.24	0.19	0.10	**KY**
KZ	0.97	8.81	2.43	33.81	4.77	2.27	11.14	2.74	2.68	12.33	3.43	8.24	4.00	**KZ**
LT	0.08	0.02	1.48	0.05	0.68	1.71	0.82	9.68	1.14	2.03	0.01	11.62	4.35	**LT**
LU	0.003	0.00	0.06	0.001	0.02	2.75	0.01	0.004	0.24	0.03	0.00	0.19	1.51	**LU**
LV	0.06	0.01	1.15	0.04	0.49	1.64	0.42	4.12	0.96	1.35	0.01	8.51	3.97	**LV**
MC	0.00	0.00	0.001	0.00	0.00	0.00	0.00	0.00	0.002	0.002	0.00	0.001	0.00	**MC**
MD	0.24	0.05	0.30	0.17	1.02	0.15	6.16	0.67	0.19	3.98	0.07	1.57	0.41	**MD**
MK	7.67	0.02	0.31	0.03	2.16	0.09	21.38	0.09	0.19	36.03	0.22	1.07	0.21	**MK**
MT	0.003	0.00	0.001	0.00	0.01	0.001	0.01	0.00	0.002	0.01	0.001	0.003	0.001	**MT**
NL	0.02	0.002	0.36	0.01	0.11	52.97	0.06	0.04	0.74	0.25	0.001	1.40	25.86	**NL**
NO	0.17	0.05	1.77	0.15	0.94	7.65	0.92	0.97	2.03	2.26	0.02	9.64	10.57	**NO**
PL	0.51	0.09	18.79	0.29	6.84	11.19	5.26	19.69	9.79	21.33	0.05	316.18	72.40	**PL**
PT	0.02	0.001	0.07	0.004	0.11	0.22	0.06	0.01	0.20	0.16	0.002	0.17	0.16	**PT**
RO	3.30	0.30	6.54	0.96	30.98	1.64	64.05	2.62	2.79	151.50	0.83	23.77	4.46	**RO**
RU	3.83	17.27	14.63	80.25	20.40	15.27	48.51	89.54	13.27	60.24	5.47	70.91	31.07	**RU**
RUA	1.49	6.37	4.94	18.13	7.14	6.05	13.20	5.59	5.36	18.97	2.51	19.30	10.70	**RUA**
SE	0.17	0.07	2.75	0.21	1.16	10.98	1.05	3.39	3.34	2.77	0.02	19.94	22.28	**SE**
SI	0.27	0.01	12.85	0.02	4.68	0.33	0.75	0.08	0.94	8.31	0.01	7.94	1.09	**SI**
SK	0.33	0.02	10.79	0.06	6.75	1.11	2.76	0.62	1.80	22.64	0.02	78.88	3.71	**SK**
TJ	0.01	0.09	0.02	0.22	0.04	0.02	0.08	0.01	0.02	0.10	0.09	0.06	0.03	**TJ**
TM	0.05	1.40	0.13	7.87	0.20	0.14	0.48	0.11	0.16	0.54	0.48	0.46	0.25	**TM**
TR	2.13	22.73	1.64	8.98	5.03	0.99	53.12	1.28	1.76	16.98	43.17	4.88	1.83	**TR**
UA	2.52	1.07	7.70	3.75	16.79	3.52	47.35	28.66	4.24	55.67	1.00	41.67	9.38	**UA**
UZ	0.06	1.15	0.14	4.82	0.23	0.15	0.51	0.13	0.17	0.61	0.49	0.49	0.27	**UZ**
BAS	0.20	0.06	4.05	0.17	1.49	15.76	1.28	5.36	4.99	3.71	0.02	34.38	42.48	**BAS**
BLS	1.58	1.69	1.40	3.00	4.51	0.72	65.15	2.24	1.08	17.81	2.65	5.01	1.54	**BLS**
CAS	0.14	4.37	0.29	85.50	0.49	0.23	1.56	0.37	0.34	1.35	0.96	1.04	0.45	**CAS**
MDT	36.48	1.05	11.41	1.22	57.66	4.73	120.61	1.47	12.17	92.80	222.83	22.99	7.78	**MDT**
NOS	0.50	0.07	4.87	0.21	2.47	75.00	2.12	0.98	7.84	5.85	0.05	22.70	56.67	**NOS**
	AL	**AM**	**AT**	**AZ**	**BA**	**BE**	**BG**	**BY**	**CH**	**CS**	**CY**	**CZ**	**DE**	

***Table C.4**. Matrix of mercury country-to-country depositions from anthropogenic sources in 2006, kg/y (continued)*

Receptors ↓ Emitters →

	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	
AL	0.08	0.03	1.52	0.02	1.61	0.35	0.01	46.65	0.58	1.77	0.02	0.002	**AL**
AM	0.02	0.01	0.22	0.02	0.20	0.11	3.27	0.92	0.02	0.13	0.01	0.001	**AM**
AT	1.62	0.15	4.25	0.13	21.89	8.34	0.02	3.78	5.12	24.77	0.26	0.01	**AT**
AZ	0.07	0.05	0.49	0.05	0.47	0.34	6.41	1.70	0.05	0.29	0.01	0.004	**AZ**
BA	0.46	0.06	3.01	0.07	4.50	1.51	0.02	12.14	18.07	35.38	0.06	0.005	**BA**
BE	0.62	0.04	3.56	0.03	149.54	30.21	0.002	0.15	0.07	0.26	0.54	0.003	**BE**
BG	0.43	0.17	2.47	0.14	3.01	1.32	0.15	86.75	1.26	11.78	0.06	0.01	**BG**
BY	6.29	3.90	3.88	1.39	11.44	9.35	0.12	6.10	1.54	16.44	0.31	0.02	**BY**
CH	0.37	0.03	5.71	0.03	48.14	6.40	0.003	0.84	0.68	1.17	0.22	0.00	**CH**
CS	0.63	0.10	3.22	0.10	4.72	1.92	0.04	33.96	7.56	51.82	0.08	0.01	**CS**
CY	0.00	0.00	0.06	0.002	0.06	0.03	0.01	2.04	0.01	0.04	0.001	0.00	**CY**
CZ	2.76	0.15	2.55	0.12	16.17	8.26	0.02	1.51	1.73	24.00	0.26	0.01	**CZ**
DE	35.28	0.69	21.33	0.47	289.62	119.82	0.03	2.59	1.38	8.77	3.01	0.04	**DE**
DK	**149.65**	0.13	1.57	0.09	10.94	20.17	0.004	0.34	0.08	0.89	0.48	0.01	**DK**
EE	2.80	**33.17**	0.78	2.22	3.29	3.25	0.01	0.22	0.13	1.23	0.10	0.005	**EE**
ES	0.48	0.04	**1196**	0.09	41.90	9.52	0.01	4.27	0.86	1.86	0.63	0.02	**ES**
FI	8.77	18.84	2.87	**126.83**	9.03	15.16	0.05	0.97	0.21	2.24	0.52	0.04	**FI**
FR	2.92	0.23	217.76	0.25	**1843.7**	130.88	0.02	9.23	3.49	7.12	4.50	0.04	**FR**
GB	3.17	0.25	22.65	0.20	76.18	**1370.4**	0.01	1.17	0.25	1.08	22.88	0.03	**GB**
GE	0.10	0.05	0.69	0.05	0.72	0.50	**52.66**	3.75	0.10	0.62	0.02	0.004	**GE**
GR	0.28	0.10	3.50	0.10	3.49	1.05	0.09	**1881**	0.89	4.63	0.05	0.01	**GR**
HR	0.46	0.05	3.36	0.06	5.14	1.62	0.02	8.11	**70.97**	53.09	0.06	0.004	**HR**
HU	1.13	0.10	3.14	0.10	6.52	3.09	0.03	5.19	18.21	**642.58**	0.10	0.01	**HU**
IE	0.27	0.03	4.72	0.03	7.14	27.86	0.002	0.14	0.04	0.14	**50.24**	0.01	**IE**
IS	0.17	0.02	1.27	0.08	1.89	2.74	0.001	0.06	0.01	0.06	0.34	**0.07**	**IS**
IT	1.10	0.17	22.05	0.20	43.97	6.10	0.05	49.93	17.61	24.19	0.25	0.02	**IT**
KY	0.04	0.02	0.39	0.03	0.36	0.23	0.12	0.82	0.03	0.17	0.01	0.003	**KY**
KZ	2.03	1.63	9.41	1.69	10.72	9.61	6.28	19.21	1.18	6.96	0.40	0.10	**KZ**
LT	4.69	1.10	1.37	0.52	6.29	5.61	0.01	0.98	0.25	2.92	0.17	0.01	**LT**
LU	0.04	0.00	0.37	0.002	7.32	1.33	0.00	0.02	0.01	0.03	0.03	0.00	**LU**
LV	4.40	3.83	1.25	1.01	5.68	5.28	0.01	0.58	0.19	2.05	0.16	0.01	**LV**
MC	0.00	0.00	0.002	0.00	0.02	0.00	0.00	0.001	0.00	0.001	0.00	0.00	**MC**
MD	0.29	0.09	0.55	0.07	0.79	0.54	0.06	5.75	0.22	2.00	0.02	0.003	**MD**
MK	0.08	0.03	0.81	0.02	0.95	0.28	0.01	67.44	0.37	2.29	0.01	0.002	**MK**
MT	0.00	0.00	0.01	0.00	0.01	0.002	0.00	0.06	0.00	0.00	0.00	0.00	**MT**
NL	1.51	0.05	2.67	0.04	52.49	32.26	0.001	0.12	0.05	0.25	0.59	0.004	**NL**
NO	22.13	1.34	6.59	2.72	23.63	61.54	0.04	1.43	0.37	3.70	2.42	0.06	**NO**
PL	36.96	1.16	7.46	0.90	39.89	31.10	0.07	4.62	3.76	56.49	0.98	0.03	**PL**
PT	0.05	0.01	39.93	0.01	2.15	1.00	0.001	0.22	0.05	0.12	0.08	0.00	**PT**
RO	1.85	0.47	6.57	0.36	10.23	4.98	0.36	45.82	6.17	82.46	0.19	0.02	**RO**
RU	27.73	140.10	33.49	38.88	62.75	65.34	24.65	89.06	6.02	47.17	2.39	0.35	**RU**
RUA	6.25	5.13	19.65	7.23	25.46	25.77	4.51	29.58	2.16	14.21	1.12	0.38	**RUA**
SE	107.43	5.59	7.10	32.77	32.13	49.39	0.05	1.43	0.48	5.06	1.47	0.06	**SE**
SI	0.22	0.02	1.43	0.02	2.68	0.86	0.01	2.17	12.28	10.29	0.03	0.002	**SI**
SK	1.18	0.09	1.64	0.09	5.23	2.71	0.02	2.30	4.81	146.60	0.09	0.005	**SK**
TJ	0.01	0.01	0.14	0.01	0.12	0.07	0.04	0.28	0.01	0.06	0.00	0.001	**TJ**
TM	0.11	0.07	0.65	0.09	0.68	0.57	1.09	1.34	0.06	0.35	0.02	0.01	**TM**
TR	0.75	0.35	8.59	0.38	8.15	3.63	5.38	199.05	1.23	6.36	0.17	0.03	**TR**
UA	6.89	2.60	9.61	1.52	17.13	12.18	1.43	56.03	5.10	60.73	0.45	0.05	**UA**
UZ	0.12	0.09	0.74	0.10	0.75	0.64	0.81	1.48	0.07	0.39	0.03	0.01	**UZ**
BAS	172.53	26.05	8.19	33.82	44.28	48.92	0.04	1.55	0.65	6.73	1.34	0.04	**BAS**
BLS	0.98	0.41	3.47	0.39	4.27	3.07	5.75	88.78	0.88	6.12	0.14	0.02	**BLS**
CAS	0.26	0.19	0.99	0.17	1.17	1.04	4.16	3.18	0.12	0.76	0.04	0.01	**CAS**
MDT	2.16	0.50	258.54	0.67	143.43	15.70	0.63	1601.80	27.74	34.32	0.79	0.07	**MDT**
NOS	74.75	1.11	44.77	0.92	259.92	751.91	0.06	4.15	0.99	7.65	14.04	0.09	**NOS**
	DK	**EE**	**ES**	**FI**	**FR**	**GB**	**GE**	**GR**	**HR**	**HU**	**IE**	**IS**	

***Table C.4**. Matrix of mercury country-to-country depositions from anthropogenic sources in 2006, kg/y (continued)*

Receptors ↓ Emitters →

	IT	KY	KZ	LT	LU	LV	MC	MD	MK	MT	NL	NO	
AL	15.15	0.002	0.23	0.03	0.03	0.002	0.03	0.10	43.54	0.87	0.06	0.02	**AL**
AM	0.45	0.03	2.74	0.01	0.01	0.001	0.002	0.02	0.12	0.03	0.01	0.01	**AM**
AT	69.74	0.003	0.42	0.27	1.41	0.01	0.13	0.11	1.56	0.15	2.35	0.23	**AT**
AZ	0.95	0.21	15.65	0.04	0.02	0.003	0.004	0.04	0.23	0.06	0.04	0.04	**AZ**
BA	32.07	0.004	0.41	0.10	0.13	0.01	0.08	0.12	3.84	0.39	0.33	0.09	**BA**
BE	1.87	0.00	0.07	0.03	11.43	0.002	0.01	0.00	0.05	0.01	18.50	0.12	**BE**
BG	11.86	0.02	2.42	0.24	0.10	0.01	0.04	2.30	28.08	0.60	0.24	0.12	**BG**
BY	11.75	0.03	3.40	13.31	0.56	0.55	0.05	1.55	2.02	0.13	1.91	1.05	**BY**
CH	88.02	0.00	0.10	0.04	1.09	0.002	0.23	0.02	0.32	0.08	1.12	0.06	**CH**
CS	28.75	0.01	0.83	0.17	0.15	0.01	0.07	0.49	40.83	0.69	0.41	0.12	**CS**
CY	0.19	0.00	0.04	0.002	0.002	0.00	0.001	0.01	0.09	0.02	0.003	0.002	**CY**
CZ	10.75	0.003	0.41	0.42	1.17	0.02	0.03	0.09	0.92	0.06	2.85	0.31	**CZ**
DE	34.00	0.01	1.08	1.22	36.68	0.06	0.17	0.11	0.98	0.13	115.93	1.97	**DE**
DK	1.09	0.001	0.14	0.27	0.45	0.01	0.01	0.02	0.14	0.01	5.49	0.87	**DK**
EE	1.47	0.003	0.37	5.41	0.17	0.85	0.01	0.04	0.10	0.01	0.83	0.44	**EE**
ES	27.62	0.003	0.32	0.05	0.41	0.003	0.15	0.04	0.94	0.72	0.95	0.15	**ES**
FI	2.84	0.03	2.46	4.06	0.45	0.32	0.01	0.13	0.36	0.04	2.17	4.23	**FI**
FR	139.79	0.01	0.91	0.21	35.02	0.01	5.59	0.09	2.41	1.10	19.24	0.63	**FR**
GB	5.01	0.003	0.47	0.23	1.67	0.01	0.03	0.03	0.36	0.06	14.46	0.80	**GB**
GE	1.57	0.04	4.67	0.05	0.02	0.003	0.01	0.16	0.49	0.10	0.06	0.05	**GE**
GR	17.97	0.01	1.65	0.13	0.07	0.01	0.04	0.70	69.09	2.61	0.16	0.09	**GR**
HR	46.11	0.003	0.37	0.10	0.16	0.005	0.10	0.10	2.25	0.35	0.33	0.08	**HR**
HU	28.58	0.01	0.64	0.23	0.31	0.01	0.08	0.27	3.53	0.20	0.77	0.17	**HU**
IE	0.89	0.00	0.09	0.03	0.26	0.002	0.004	0.004	0.05	0.01	1.01	0.08	**IE**
IS	0.38	0.003	0.27	0.02	0.06	0.001	0.002	0.003	0.02	0.00	0.17	0.14	**IS**
IT	**1663**	0.01	1.34	0.26	0.72	0.01	2.99	0.32	11.80	5.93	1.23	0.24	**IT**
KY	0.60	**28.72**	61.62	0.02	0.01	0.001	0.00	0.02	0.13	0.03	0.03	0.02	**KY**
KZ	19.10	294.37	**10672**	1.12	0.43	0.07	0.07	1.22	4.38	0.61	1.17	1.12	**KZ**
LT	2.61	0.01	0.61	**46.48**	0.33	0.62	0.01	0.23	0.39	0.03	1.32	0.53	**LT**
LU	0.27	0.00	0.01	0.002	**17.50**	0.00	0.002	0.00	0.01	0.00	0.45	0.01	**LU**
LV	2.22	0.01	0.63	52.48	0.31	**4.16**	0.01	0.12	0.22	0.03	1.32	0.57	**LV**
MC	0.07	0.00	0.00	0.00	0.00	0.00	**0.02**	0.00	0.00	0.00	0.00	0.00	**MC**
MD	1.91	0.01	1.21	0.18	0.03	0.01	0.01	**29.89**	1.17	0.06	0.11	0.07	**MD**
MK	5.64	0.002	0.25	0.03	0.02	0.002	0.01	0.14	**267.07**	0.31	0.05	0.02	**MK**
MT	0.15	0.00	0.001	0.00	0.00	0.00	0.00	0.00	0.01	**5.37**	0.00	0.00	**MT**
NL	1.19	0.00	0.09	0.05	1.00	0.003	0.01	0.004	0.05	0.01	**131.23**	0.18	**NL**
NO	5.71	0.02	1.72	1.39	0.95	0.08	0.03	0.15	0.62	0.04	6.78	**92.49**	**NO**
PL	22.50	0.02	2.48	6.63	2.43	0.21	0.09	0.78	2.24	0.16	8.85	2.41	**PL**
PT	1.32	0.00	0.04	0.01	0.03	0.00	0.01	0.003	0.05	0.04	0.09	0.02	**PT**
RO	35.37	0.03	5.66	0.84	0.41	0.04	0.11	10.73	16.21	0.66	1.06	0.40	**RO**
RU	70.82	2.94	833.37	25.42	2.83	1.84	0.29	7.11	18.69	1.85	10.01	9.92	**RU**
RUA	32.88	29.30	3358	3.06	1.06	0.19	0.14	1.56	6.78	0.89	2.93	4.02	**RUA**
SE	7.08	0.02	2.83	6.93	1.62	0.40	0.04	0.33	0.62	0.05	10.35	24.96	**SE**
SI	43.25	0.001	0.15	0.04	0.11	0.002	0.06	0.04	0.60	0.11	0.19	0.04	**SI**
SK	13.11	0.004	0.51	0.27	0.30	0.01	0.04	0.15	1.49	0.08	0.73	0.16	**SK**
TJ	0.21	1.15	9.33	0.01	0.00	0.00	0.00	0.01	0.04	0.01	0.01	0.01	**TJ**
TM	1.20	5.89	148.04	0.05	0.03	0.003	0.005	0.05	0.24	0.05	0.07	0.06	**TM**
TR	24.30	0.13	12.11	0.45	0.21	0.02	0.09	1.78	11.07	2.98	0.49	0.32	**TR**
UA	33.93	0.14	29.49	4.96	0.80	0.22	0.12	24.25	13.21	0.77	2.31	1.42	**UA**
UZ	1.36	37.42	502.69	0.06	0.03	0.004	0.01	0.06	0.26	0.06	0.07	0.07	**UZ**
BAS	8.95	0.02	2.43	21.78	2.51	2.63	0.05	0.41	0.72	0.06	14.87	4.94	**BAS**
BLS	11.99	0.13	14.58	0.64	0.14	0.03	0.04	7.11	9.18	0.86	0.39	0.35	**BLS**
CAS	2.33	1.34	161.26	0.14	0.04	0.01	0.01	0.16	0.60	0.10	0.12	0.11	**CAS**
MDT	815.59	0.09	8.12	0.64	1.14	0.03	2.57	1.86	59.06	121.51	2.36	0.71	**MDT**
NOS	18.82	0.02	1.86	1.37	5.18	0.07	0.11	0.15	1.57	0.17	88.53	20.33	**NOS**
	IT	**KY**	**KZ**	**LT**	**LU**	**LV**	**MC**	**MD**	**MK**	**MT**	**NL**	**NO**	

***Table C.4**. Matrix of mercury country-to-country depositions from anthropogenic sources in 2006, kg/y (continued)*

Receptors ↓ Emitters →

	PL	PT	RO	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	Total	
AL	3.60	0.15	6.42	1.00	0.02	0.32	1.53	0.00	0.004	2.91	3.92	0.01	**235.8**	**AL**
AM	0.58	0.04	0.50	1.58	0.01	0.03	0.13	0.002	0.28	27.69	1.35	0.17	**103.1**	**AM**
AT	94.90	0.57	10.13	2.23	0.16	18.98	38.51	0.00	0.01	1.66	6.71	0.01	**627.7**	**AT**
AZ	1.67	0.08	1.18	9.23	0.03	0.06	0.31	0.02	1.51	29.79	5.32	0.98	**241.7**	**AZ**
BA	30.65	0.35	16.96	1.71	0.07	2.80	18.57	0.00	0.01	2.30	7.43	0.01	**656.2**	**BA**
BE	2.91	0.36	0.26	0.37	0.05	0.11	0.29	0.00	0.001	0.09	0.28	0.001	**450.2**	**BE**
BG	23.73	0.32	203.21	11.49	0.12	0.95	10.47	0.001	0.04	58.09	65.19	0.06	**1305.3**	**BG**
BY	355.51	0.57	34.56	64.97	1.44	2.14	27.98	0.001	0.05	6.74	167.90	0.06	**978.8**	**BY**
CH	4.83	0.58	1.15	0.42	0.04	1.66	1.16	0.00	0.00	0.33	0.88	0.002	**326.3**	**CH**
CS	39.82	0.39	102.84	3.67	0.10	2.27	26.30	0.00	0.02	8.47	17.38	0.02	**1435.8**	**CS**
CY	0.15	0.01	0.22	0.14	0.002	0.01	0.04	0.00	0.001	13.35	0.32	0.002	**94.8**	**CY**
CZ	373.34	0.37	9.62	2.48	0.19	3.33	49.86	0.00	0.01	1.26	6.33	0.01	**1283.2**	**CZ**
DE	201.60	2.73	7.97	5.75	1.03	2.54	11.02	0.00	0.01	1.63	7.61	0.02	**1901.4**	**DE**
DK	19.32	0.21	1.08	0.73	1.00	0.12	1.18	0.00	0.003	0.20	1.20	0.004	**237.4**	**DK**
EE	39.63	0.10	1.34	8.84	1.01	0.22	1.88	0.00	0.004	0.25	4.42	0.01	**126.3**	**EE**
ES	5.36	68.20	2.20	0.85	0.09	1.15	1.62	0.00	0.01	1.06	1.72	0.01	**1384.8**	**ES**
FI	62.70	0.40	4.57	31.61	12.47	0.31	3.32	0.001	0.04	1.76	11.93	0.06	**355.4**	**FI**
FR	26.59	10.91	6.94	2.85	0.32	5.51	6.85	0.00	0.01	2.95	5.09	0.02	**2717.3**	**FR**
GB	12.24	3.13	1.45	2.16	0.26	0.37	1.18	0.00	0.004	0.59	1.64	0.01	**1584.8**	**GB**
GE	3.69	0.11	5.46	8.52	0.04	0.11	0.85	0.003	0.44	90.36	10.41	0.28	**233.0**	**GE**
GR	10.69	0.38	29.86	7.72	0.08	0.65	4.08	0.001	0.03	84.83	34.45	0.04	**2325.3**	**GR**
HR	34.13	0.35	12.98	1.46	0.06	13.37	22.95	0.00	0.01	2.10	6.11	0.01	**406.7**	**HR**
HU	105.49	0.34	78.51	3.16	0.12	10.38	316.15	0.00	0.01	3.93	22.59	0.02	**1428.5**	**HU**
IE	1.92	1.07	0.18	0.35	0.03	0.07	0.15	0.00	0.001	0.12	0.24	0.002	**101.8**	**IE**
IS	0.89	0.37	0.11	0.65	0.05	0.03	0.08	0.00	0.002	0.06	0.23	0.01	**11.5**	**IS**
IT	49.84	1.99	21.89	4.82	0.19	40.66	20.30	0.001	0.02	11.49	15.54	0.04	**2168.0**	**IT**
KY	0.91	0.06	0.50	2.48	0.02	0.04	0.17	1.64	0.49	4.67	1.20	18.55	**126.4**	**KY**
KZ	45.92	1.67	31.40	688.13	0.98	1.44	8.04	9.09	20.76	119.77	132.45	204.07	**12426.1**	**KZ**
LT	147.06	0.18	5.19	14.60	0.94	0.45	5.73	0.00	0.01	0.83	15.26	0.01	**301.0**	**LT**
LU	0.31	0.04	0.03	0.03	0.003	0.01	0.04	0.00	0.00	0.01	0.03	0.00	**32.7**	**LU**
LV	87.51	0.16	3.00	11.18	1.21	0.35	3.75	0.00	0.01	0.60	10.58	0.01	**227.6**	**LV**
MC	0.00	0.00	0.00	0.00	0.00	0.002	0.001	0.00	0.00	0.00	0.00	0.00	**0.14**	**MC**
MD	17.78	0.07	49.64	5.86	0.07	0.22	2.98	0.00	0.02	8.72	67.76	0.02	**213.2**	**MD**
MK	4.03	0.09	8.34	1.19	0.02	0.23	1.86	0.00	0.005	5.69	4.81	0.01	**441.6**	**MK**
MT	0.01	0.00	0.01	0.00	0.00	0.002	0.003	0.00	0.00	0.03	0.01	0.00	**5.7**	**MT**
NL	3.37	0.32	0.28	0.38	0.08	0.08	0.27	0.00	0.001	0.07	0.28	0.001	**310.8**	**NL**
NO	46.22	0.88	5.86	9.45	4.45	0.59	4.93	0.001	0.03	1.58	9.99	0.05	**357.1**	**NO**
PL	**5726**	1.03	52.78	24.71	2.31	6.17	135.99	0.001	0.04	4.65	86.87	0.06	**6755.7**	**PL**
PT	0.56	**392.69**	0.14	0.10	0.01	0.07	0.11	0.00	0.001	0.08	0.13	0.00	**440.3**	**PT**
RO	138.92	0.75	**2089**	26.45	0.37	4.77	80.44	0.001	0.13	56.80	205.24	0.14	**3127.4**	**RO**
RU	560.32	5.30	166.15	**5411**	12.86	7.64	63.08	0.18	8.12	376.65	1336	9.60	**9951.0**	**RU**
RUA	110.31	3.56	43.70	5773	3.58	2.72	16.67	1.43	6.17	113.34	141.64	24.99	**9943.1**	**RUA**
SE	133.51	0.96	8.12	22.09	**78.30**	0.80	7.80	0.00	0.05	2.07	22.82	0.06	**642.9**	**SE**
SI	15.63	0.15	4.05	0.62	0.03	**105.10**	8.21	0.00	0.00	0.69	2.15	0.00	**248.5**	**SI**
SK	275.74	0.22	29.43	2.61	0.12	5.69	**497.25**	0.00	0.01	1.75	15.79	0.01	**1139.7**	**SK**
TJ	0.30	0.02	0.17	0.78	0.01	0.01	0.06	**1.61**	0.35	1.59	0.39	6.57	**24.2**	**TJ**
TM	2.36	0.12	1.23	13.56	0.05	0.08	0.40	1.64	**89.40**	12.48	4.88	66.10	**365.3**	**TM**
TR	25.91	1.04	59.21	45.27	0.29	1.31	7.21	0.01	0.76	**4443**	116.53	0.58	**5153.4**	**TR**
UA	573.45	1.31	277.64	247.45	1.51	5.26	106.73	0.01	0.43	124.97	**3838**	0.49	**5686.1**	**UA**
UZ	2.64	0.14	1.37	18.11	0.06	0.09	0.45	13.20	14.84	11.98	5.42	**359.83**	**984.6**	**UZ**
BAS	336.55	1.03	10.54	28.89	26.88	1.14	11.15	0.001	0.04	1.76	25.01	0.05	**960.5**	**BAS**
BLS	40.06	0.48	115.39	92.64	0.35	0.97	8.56	0.01	0.29	564.23	403.30	0.35	**1494.7**	**BLS**
CAS	6.02	0.17	3.99	46.82	0.11	0.17	0.98	0.13	9.54	34.48	21.51	5.34	**404.7**	**CAS**
MDT	73.06	9.20	88.53	29.12	0.58	21.37	29.03	0.01	0.17	828.98	101.28	0.26	**4874.8**	**MDT**
NOS	95.79	5.52	9.99	7.41	3.67	1.56	9.57	0.001	0.04	3.02	10.86	0.06	**1625.3**	**NOS**
	PL	**PT**	**RO**	**RU**	**SE**	**SI**	**SK**	**TJ**	**TM**	**TR**	**UA**	**UZ**	**Total**	