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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

A.Gusev, I. Ilyin, O. Travnikov, V.Sokovych

Meteorological Synthesizing Centre - East

Krasina pereulok, 16/1, room 609,
123056 Moscow, Russia
Tel.: +7 495 981 15 66
Fax: +7 495 981 15 67
E-mail: msce@msceast.org
Internet: www.msceast.org

EXECUTIVE SUMMARY

In the framework of the UNECE project “Capacity Building for Air Quality Management and the Application of Clean Coal Combustion Technologies in Central Asia” (CAPACT) evaluation of pollution levels and transboundary transport of lead and PCBs over the Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) for 2005 was carried out by Meteorological Synthesizing Centre - East of EMEP (EMEP/MSC-E). MSC-E prepared information on air concentrations and total depositions of lead and polychlorinated biphenyls (PCBs) for the Central Asian countries, evaluated transboundary transport of lead in this region and assessed contribution of different regions of the Northern Hemisphere to the pollution of Central Asia by PCBs.

The regional-scale MSCE-HM model was applied for assessment of lead pollution levels. In order to include the Central Asian countries into the model calculations, the current EMEP grid was extended eastward. Necessary input information for the extended domain (namely emissions, meteorological data, land-cover and soil properties) was collected and processed.

Particularly, required emission dataset for lead was collected using both EMEP official data and expert estimates. For the EMEP countries the most recent officially reported emission data were used and supplemented by TNO expert estimates. For the Central Asian countries national emissions inventories are not available at the moment. Therefore, different types of expert emission estimates (TNO inventory for Kazakhstan and Kyrgyzstan and GEIA data for others) were utilized for these countries.

For verification of the modelling results measurement data from the EMEP network as well as from the database on background monitoring in USSR/CIS countries were used. The calculated levels demonstrate good agreement with measurements at EMEP stations. For 80% cases the difference between modelled and observed values does not exceed a factor of two, and spatial correlation is significant. Comparison of modelling results with few available observations from Central Asian stations shows that the model also satisfactory reproduces pollution levels in this region.

According to the model estimates for 2005 concentration and deposition levels of lead in the Central Asian countries are somewhat lower than those in Europe. The highest country-averaged lead concentrations of lead in air are in Uzbekistan (4.6 ng/m^3), and the lowest – in Kyrgyzstan (2.1 ng/m^3). In contrast, Kyrgyzstan is characterized by the highest average depositions (0.9 kg/km^2/y) because of considerable precipitation in this country. The lowest average depositions are obtained for Turkmenistan (0.3 kg/km^2/y). On the other hand, spatial variation of concentration and deposition levels over territories of the Central Asian countries is very large and can exceed an order of magnitude.

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. Among them up to 30% of depositions come from the neighbouring Central Asian countries and the most significant contributors of them are Kazakhstan and Uzbekistan. On the contrary, contribution of European sources to depositions in Central Asia is minor and does not exceed few percents. 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.

Evaluation of PCB pollution levels and transboundary fluxes within the Central Asian region for 2005 was exemplified by the modeling of long-range transport and depositions of indicator congener PCB-153. Model investigation of PCB-153 pollution levels was performed using the hemispheric version of the MSCE-POP model on the basis of maximum scenario of the global emission inventory of PCBs.

Verification of obtained modeling results with the use of measurements of EMEP monitoring sites revealed that the MSCE-POP model reasonably described spatial variations of PCB-153 levels of concentrations. On average, the MSCE-POP model overestimated measured values of concentrations by about a factor of 3, which can be connected with the use of maximum estimates of PCB emissions in modeling.

On the basis of obtained modelling results for 2005 it is noted that levels of the Central Asia region pollution by PCB-153 are significantly lower in comparison to that in European region and North America. Annual mean air concentrations in the Central Asia countries vary within the range 1-4 pg/m^3. Relatively high air concentrations are noted for the western parts of Kazakhstan, Turkmenistan, and eastern part of Uzbekistan. Elevated levels of total annual depositions (0.25-0.5 $g/km^2/y$) can be seen in populated regions of the Central Asia countries. Total annual depositions of PCB-153 over the Central Asia countries for 2005 are estimated to approximately 1 tonne.

Evaluation of transboundary transport of PCB-153 demonstrates that European region and the Russian Federation can be considered as the most important external sources of the Central Asia countries pollution by PCBs. Among the Central Asian countries, the main contributors to the total annual depositions on their territories are emission sources of Kazakhstan and Uzbekistan. Following the emission inventory, used in this modeling study, emission sources of these two countries contributes almost 80% to the total PCB-153 emission within the Central Asia region.

Finally, it should be noted that the presented above analysis of airborne pollution of the Central Asian countries by lead and PCBs is mostly based on emission data obtained from expert estimates because national information on anthropogenic emissions is not available at the moment. Besides, monitoring data which can be used for the models evaluation are scarce. Therefore, development of national emissions inventories in the Central Asian countries and a background monitoring system in this region could markedly improve quality of the assessment. It is particularly relevant in connection with plans to include these countries to the EMEP operational activity since 2008.

CONTENTS

INTRODUCTION

This study was carried out in the framework of the project entitled “Capacity Building for Air Quality Management and the Application of Clean Coal Combustion Technologies in Central Asia” (CAPACT). CAPACT project was initiated by the UNECE together with cooperating agencies UNESCAP and UNEP in order to support the development of more efficient ways to produce energy in Central Asia as well as to improve quality of the environment in this region. One of the main goals of the project is to strengthen the capacity of air quality management institutions in Central Asia; to implement the UNECE Convention on Long-Range Transboundary Air Pollution; to facilitate ratification of its protocols, in particular the EMEP Protocol, the Protocol on Heavy Metals and the Protocol on Persistent Organic Pollutants.

Meteorological Synthesizing Centre East of Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP/MSC-E) at the request of the United Nations Economic Commission for Europe (UNECE) prepared information on the pollution levels of lead and polychlorinated biphenyls (PCBs) for the Central Asian countries: Kazakhstan, Kyrgyzstan, Uzbekistan, Turkmenistan and Tajikistan. Under the contract, MSC-E conducted computations of concentrations in air and total depositions of lead and PCBs for the Central Asian countries. Besides, lead transboundary transport with the emphasis on these five countries was assessed. Finally, the contribution of different regions of the Northern Hemisphere to the pollution of Central Asia by PCBs and contribution of the Central Asian emission sources to pollution of other regions was simulated. The information presented in this report could be useful for authorities of the Central Asian countries in the development of their national environmental protection programmes.

Two different models have been used for calculations of lead and PCBs transboundary atmospheric pollution in Central Asia. The reason for this is connected with marked differences in behaviour of lead and PCBs in the atmosphere. PCBs, as typical persistent organic pollutants (POPs), are the contaminants of significant long-range transport potential and persistence to the degradation. They are regarded as global-scale pollutants and therefore their atmospheric transport has been calculated with the use of hemispheric version of MSCE-POP model. Lead presents in the atmosphere bound to aerosol particles. Its atmospheric lifetime makes up about few days in Europe, but in the Central Asian region it can be longer because of much smaller precipitation. Lead is considered as regional-scale pollutant, and its pollution in the Central Asian region has been simulated by regional-scale MSCE-HM model.

The report consists of executive summary, introduction, two chapters, conclusions and two annexes. The first chapter is focused on atmospheric modelling of lead. The chapter deals with overview of the atmospheric transport model MSCE-HM and its input data. Originally the MSCE-HM model was designed to operate over the European (EMEP) region. In order to include the Central Asian countries into model calculations of pollution levels and transboundary fluxes current EMEP grid has been extended eastward. Special attention has been paid to the description of modifications of the model and its input data in order to adjust them for the Central Asian region. Verification of the modelling results against measurements is presented. Air concentrations and depositions of lead over the entire modelling domain and over the considered region in 2005 are considered. Source-receptor relationships between the Central Asian countries are characterized. The main contributors to depositions as well as main receptors of lead emitted by national sources are identified.

The second chapter is designated to modelling of PCBs. First of all, MSCE-POP model and input data are overviewed. Evaluation of the Central Asian countries pollution by PCBs is exemplified by the modelling of long-range transport and depositions of the indicator congener PCB-153. Fields of air concentrations and depositions of PCB-153 over the Northern Hemisphere as well as over the

selected Central Asian countries are described. Contributions of various regions within the Northern Hemisphere to depositions over the Central Asia region and over particular Central Asian countries caused by transboundary transport are evaluated. Obtained modelling results are verified against available measurements obtained at the EMEP monitoring sites in 2005.

The main outcomes regarding pollution levels in Central Asia in 2005 are summarized in “conclusions”. Technical information, such as detailed source-receptor matrix for lead and overview of physical-chemical properties of PCB-153, is presented in Annexes A and B, respectively. Electronic version of the report in English and Russian is available at MSC-E website www.msceast.org/publications.html.

Chapter 1

LEAD

1.1. Regional heavy metal transport model (MSCE-HM)

The European-scale atmospheric transport model MSCE-HM is actively used for operational calculations of heavy metal transboundary pollution within the European region in connection with the EMEP programme and other activities relating to the LTRAP Convention. Detailed description of the model is available in [*Travnikov and Ilyin*, 2005]. The model formulation and performance was thoroughly evaluated within the EMEP/TFMM Workshop on the model review (ECE/EB.AIR/GE.1/2006/4). A brief model description and mode modifications carried out in the framework of the project are presented below.

1.1.1. Brief model description

The EMEP/MSC-E regional model of heavy metals airborne pollution (MSCE-HM) is a three-dimensional Eulerian type chemical transport model driven by off-line meteorological data. The model considers heavy metal emissions from anthropogenic and natural sources, transport in the atmosphere, chemical transformations (of mercury only) both in gaseous and aqueous phases, and deposition to the surface. Schematically these processes are illustrated in Fig. 1.1. The model computation domain is defined on the polar stereographic projection and covers the standard EMEP region by a regular grid with 50×50 km spatial resolution at 60°N (Fig. 1.2). Modifications of the model domain for the purposes of the current project are described below. The vertical structure of the model is formulated in the sigma-pressure coordinate system. The model domain consists of 15 irregular sigma-layers and has a top at 100 hPa.

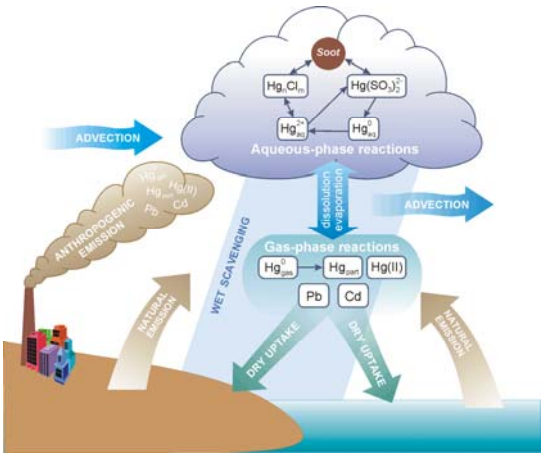


Fig 1.1. *The model scheme of heavy metal behaviour in the atmosphere*

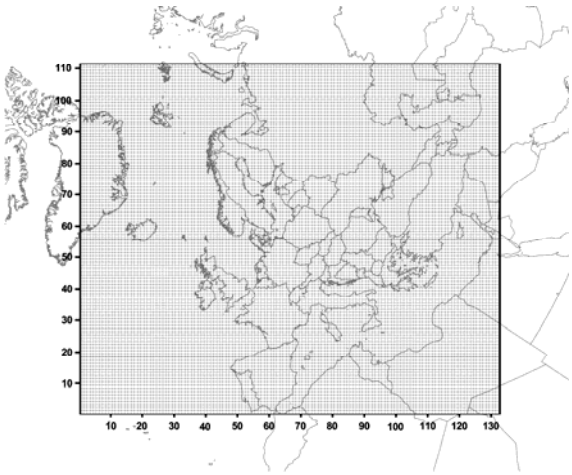


Fig. 1.2. *Standard EMEP 50×50 km^2 grid*

The atmospheric advection and the vertical transport are described in the model using mass conservative and monotone Bott's advection scheme with fourth-order area-preserving polynomials [*Bott*, 1989a; 1989b, 1992]. An implicit treatment of the vertical eddy diffusion is chosen in order to avoid restrictions on the integration time step because of possible sharp gradients of the pollutant mixing ratio.

Such heavy metals as lead and cadmium and their compounds are characterized by very low volatility. It is assumed in the model that these metals (as well as some others – nickel, chromium, zinc etc.) are transported in the atmosphere only in the composition of aerosol particles. It is believed that their possible chemical transformations do not change properties of their carrying particles with regard to removal processes. On the contrary, mercury transformations in the atmosphere include transitions between the gaseous, aqueous and solid phases, chemical reactions in the gaseous and aqueous environment.

Model description of removal processes includes dry deposition and wet scavenging. The dry deposition scheme is based on the resistance analogy approach [*Wesely and Hick*s, 2000] and allows taking into account deposition to different land cover types (forests, grassland, water surface etc.). Dry deposition of particles to vegetation is described using the theoretical formulation by *Slinn* [1982] and fitted to experimental data [*Ruijgrok et al*., 1997; *Wesely et al*., 1985]. The parameterization of dry deposition to water surfaces is based on the approach suggested by *Williams* [1982] taking into account the effects of wave breaking and aerosol washout by seawater spray. The model distinguishes in-cloud and sub-cloud wet scavenging of particulate species and highly soluble reactive gaseous mercury based on empirical data. Besides, the precipitation rate is scaled for convective precipitation according to *Walton et al.* [1988] to take into account fractional coverage of a grid cell with precipitating clouds.

MSCE-HM model is driven by off-line meteorological data pre-processed by MM5 - Fifth Generation Penn State/NCAR Mesoscale Model [*Grell et al.*, 1995]. The pre-processor utilizes the NCAR/NCEP re-analysis or ECMWF data as the input information and provides 6-hour weather prediction data along with estimates of the atmospheric boundary layer parameters with the same spatial resolution as that of the transport model.

Wind re-suspension of particle-bound heavy metals (like lead and cadmium) from soil and seawater appears to be important process affecting ambient concentration and deposition of these pollutants, particularly, in areas with low direct anthropogenic emissions. Pilot parameterization of heavy metal wind re-suspension was included into the MSCE-HM model [*Gusev et al*., 2006; *Ilyin et al*., 2007]. The parameterization is based on approaches widely applied in contemporary mineral dust production models [e.g. *Gomes et al*., 2003; *Zender et al*., 2003; *Gong et al*., 2003]. Particularly, suspension of dust aerosol from soil is considered as combination of two major processes – saltation and sandblasting – presenting horizontal movement of large soil aggregates driven by wind stress and ejection of fine dust particles, respectively. The dust suspension is estimated for non-vegetated surfaces (deserts and bare soils, agricultural soils during the cultivation period, and urban areas). Generation of sea-salt and wind suspension of heavy metals from the sea surface is also considered based on the empirical Gong-Monahan parameterization [*Gong*, 2003].

1.1.2. Model modifications and update of input data

For the purposes of the current project the model has been modified to cover the whole territory of the selected Central Asian countries. The model modifications included extension of the model domain with appropriate modification of the model code as well as collection and processing input data for the new part of the model domain:

- Emissions data;
- Meteorological data;
- Land-cover/land-use characteristics;
- Information on soil properties for parameterization of wind re-suspension.

The standard EMEP domain (135x111 gridcells) only partly covers some of the Central Asian countries of interest (western parts of Kazakhstan, Turkmenistan, and Uzbekistan) and does not cover Kyrgyzstan, Tajikistan. Therefore, the model domain has been extended eastward as shown in Fig. 1.3. Preparation of input information of the extended domain is described below.

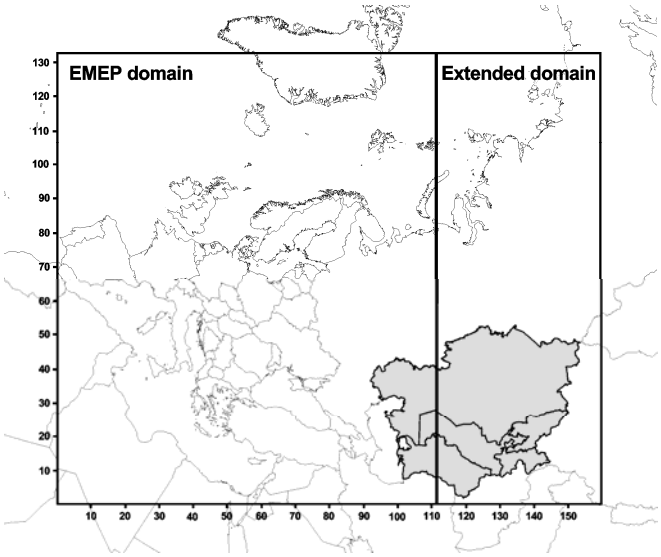


Fig. 1.3. *Extension of the model domain*

Emission data

Lead emission data for European countries in 2005 were based on officially reported information from WEBDAB (http://webdab.emep.int). For countries, which official data are not available, emission totals for 2005 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].

Official emission data for the selected Central Asian countries are not available. To fill in part of the extended model domain outside the standard EMEP grid with emissions data TNO non-official estimates [*Denier van der Gon et al*., 2005] were used along with GEIA global lead emission inventory [http://www.geiacenter.org/]. Particularly, lead emission totals for Kazakhstan and Kyrgyzstan for 2005 were derived from the TNO inventory using interpolation between 2000 estimates and projections for 2010. Lead emissions from other Central Asian countries (Uzbekistan, Tajikistan, and Turkmenistan) were obtained from the GEIA global inventory [http://www.geiacenter.org/] for 1990 expecting the same emission reduction in these countries between 1990 and 2005 as in the Russian Federation according to the EMEP official data.

Emissions 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 GEIA inventory. Besides, the GEIA emissions data were used for other Asian and African countries, falling partly or fully into the modeling domain, expecting the same emission reduction between 1990 and 2005 as for Turkey. Turkey was selected for this purpose because it is the only country in Asia, for which TNO data on lead emission changes are available. Spatial distribution of lead emissions from all these countries was obtained by interpolation of GEIA gridded emissions with 1°×1° spatial resolution into the model grid. Temporal and vertical distribution of the emission data employed in MSCE-HM model, are described in [*Travnikov and Ilyin*, 2005].

Totals of lead emission from the Central Asian countries as well as from other countries and regions of the model domain are summarized in Table 1.1. As seen from the table, the largest emission of lead among Central Asian countries was estimated for Kazakhstan (644 t/y). The lowest emission was obtained for Kyrgyzstan (about 37 t/y). Total emission of all considered Central Asian countries was about 970 t/y. This value is significantly smaller than total emission from European countries (4056 t/y) and from other Asian countries (2374 t/y) within the model domain.

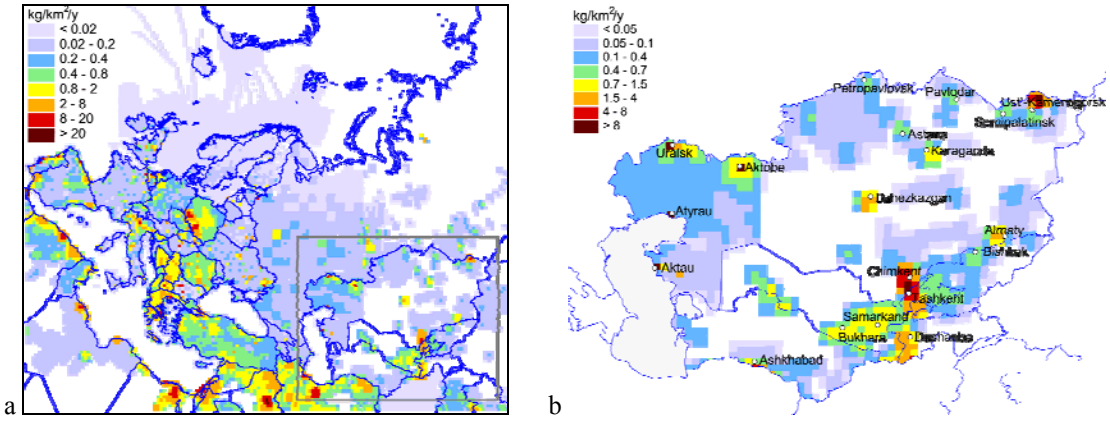
Table 1.1. *Total lead emissions in the selected Central Asian countries and other regions*

	Emission, t/y	Comments
Kazakhstan	644	TNO estimates, interpolation between 2000 and 2010
Kyrgyzstan	37	TNO estimates, interpolation between 2000 and 2010
Tajikistan	64	GEIA data for 1990; reduction between 1990 and 2005 as for Russia
Turkmenistan	40	
Uzbekistan	185	
Europe (without Russia)	4056	Combination of official data and TNO estimates
Russia	535	EMEP official data (European part) and GEIA estimates (Asian part)
Remaining Asia (within model domain)	2374	GEIA data for 1990; reduction between 1990 and 2005 as for Turkey

Spatial distribution of lead anthropogenic emissions in the model domain as a whole and in the selected Central Asian countries is shown in Fig. 1.4. As seen the most significant emission sources are located in Europe: in Poland, Balkan and Benelux countries, Italy, Turkey (Fig. 1.4a). High emissions were also estimated for Middle East countries - Iran, Iraq, Syria, Israel etc. However, emission estimates for these countries contain significant uncertainties.

Emissions of lead in Central Asian countries are relatively low compared to European emissions. Locations of the highest emissions in these countries as a rule are associated with big cities (e.g., Chimkent, Tashkent, Dushanbe, Ust'-Kamenogorsk etc.). In central regions of Kazakhstan, Uzbekistan and Turkmenistan, and east of Tajikistan anthropogenic emissions of lead are small or even negligible (Fig. 1.4b).

Rough estimates of lead emissions in the selected Central Asian countries as well as in the surrounding regions contain significant uncertainties since they are mainly based on information relating to the nineties. Emission estimates prepared by national experts of these countries could essentially improve quality of emission data and modelling results.



a b

Fig. 1.4. *Spatial distribution of lead anthropogenic emissions in 2005 in the modelling domain (a) and in selected Central Asian countries (b), kg/km²/y*

Meteorological data

Meteorological data is one of key input parameters when modelling long-range transport and deposition of atmospheric pollutants. Quality of the modelled concentrations and depositions is determined to a large extent by quality of the meteorological data. Modelling of heavy metals requires large set of meteorological parameters. As it was mentioned above the off-line meteorological dataset is prepared by the MM5 pre-processor using the NCAR/NCEP re-analysis or ECMWF data as the input information. At the moment the complete meteorological dataset have been prepared for the standard EMEP domain for the period 1990–2005. However, calculations over the extended domain require additional data for the regions not covered by the standard EMEP grid. Therefore, additional pre-processor runs were performed to obtain meteorological data required for modelling within the project. The full set of meteorological parameters prepared by the pre-processor and short description of their usage in the model are summarised in Table 1.2.

Table 1.2. *Meteorological parameters and their usage in the MSCE-HM model*

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

Land-cover/land-use data

Land cover data is required for evaluation of the dry deposition velocities and assessment of ecosystem-specific depositions. Currently a preliminary land cover dataset developed within the Working Group of Effects (WGE) for the Convention is used in the model. The dataset consider 17 land-use/land-cover categories listed in Table 1.3.

The WGE land-cover distribution dataset was developed for the standard EMEP domain (135x111 grid cells). The extension of the modeling domain caused a necessity to provide land-cover distribution for the extended area. For this purpose a global land-cover dataset prepared by Geological Survey of the United States (USGS) was utilized [*Guo and Chen*, 1994, http://edcsns17.cr.usgs.gov/glcc/]. This data contain spatial distribution of 24 land cover types with 10'x10' spatial resolution. It is worth noting that nomenclature of the USGS land-cover data differs from that provided by WGE. In order to adjust the USGS data to the nomenclature of WGE some assumptions were used (Table 1.3).

Table 1.3. *Combination of WGE and USGS land-cover types (for the extension of the modeling domain)*

WGE types	USGS types
1. Temperate coniferous forest	Deciduous needleleaf forest Evergreen needleleaf forest Mixed forest
2. Temperate deciduous forest	Deciduous broadleaf Evergreen broadleaf Shrubland (if latitude >55°N)
3. Mediterranean needleleaf forest	n/a*
4. Mediterranean broadleaf forest	n/a
5. Temperate crops	Dryland crops and pastures Irrigated crops and pastures Mixed Dry/Irrigated crops and pastures Cropland / Grassland mosaic Cropland / Wood mosaic
6. Mediterranean crops	n/a
7. Root crops	n/a
8. Grasslands	Grassland Mixed shrubland/grassland Savanna
9. Wheat	n/a
10. Semi-natural	n/a
11. Mediterranean scrub	Shrubland (if latitude <55°N)
12. Wetlands	Herbaceous wetlands Wooded wetlands
13. Tundra	Herbaceous tundra Wooden tundra Mixed tundra Bare ground tundra
14. Desert/Barren	Bare or sparse vegetation
15. Water	Water bodies
16. Ice	Snow or Ice
17. Urban	Urban

* - not available in USGS data base

Soil characteristics data and wind re-suspension

Wind erosion and heavy metal re-suspension from soil strongly depends on soil properties such as size distribution of soil grains and heavy metal content in the upper soil layer. To derive spatially resolved data of soil size distribution we utilized global soil characteristics dataset from the International Satellite Land-Surface Climatology Project (ISLSCP), Initiative II [http://islscp2.sesda.com]. Different soil types were classified according to the classic sand/silt/clay triangle of texture composition [*Hillel*, 1982]. Resulting spatial distribution of different soil types in Europe and Central Asia is presented in Fig. 1.5. As seen, according to this data, loam soils prevail over Central and Eastern Europe, whereas Southern Europe is dominated by clay loam. Sandy soils are characteristics of Africa and Central Asia.

For estimation of heavy metal emission with dust suspension from soils detailed measurement data on heavy metals concentration in topsoil from the Geochemical Atlas of Europe developed under the auspices of the Forum of European Geological Surveys (FOREGS) [*Salminen et al.*, 2005; *www.gtk.fi/publ/foregsatlas/*] were used. The kriging interpolation was applied to obtain spatial distribution of heavy metal concentration in soil. For eastern part of Europe, Central Asia and for the rest of the model domain we used a default concentration value of lead (15 mg/kg) based on the literature data [e.g., Riemann and Caritat, 1998].

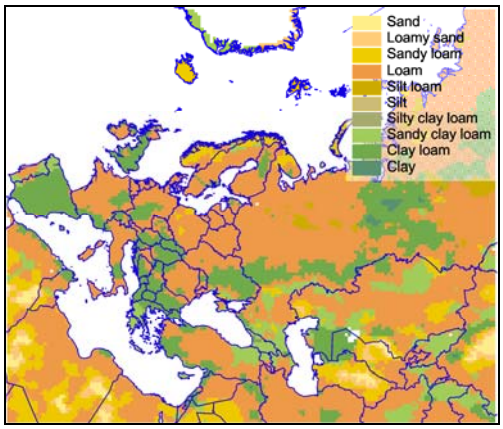


Fig. 1.5. *Spatial distribution of soil texture types in Europe and Central Asia*

The soil properties data were used for evaluation of lead re-suspension because of wind erosion. Spatial distribution of wind re-suspension fluxes of lead from European and Central Asian soils and from seawater in 2005 are presented in Fig. 1.6. Lead re-suspension from soil is presented for dust particles size below 10 μm (PM10). As seen the most significant re-suspension fluxes were obtained for Europe and some areas in Africa and Central Asia (Fig. 1.6a). In Europe the elevated fluxes are resulted from combination of relatively high concentration in soil and significant dust suspension from agricultural and urban areas. Whereas high natural fluxes of lead in African and Central Asian desert areas are conditioned by significant mineral dust suspension. In the considered Central Asian countries elevated lead natural emission or re-suspension fluxes are characteristics of Karakum and Kyzylkum deserts and some urban areas (Fig. 1.6b).

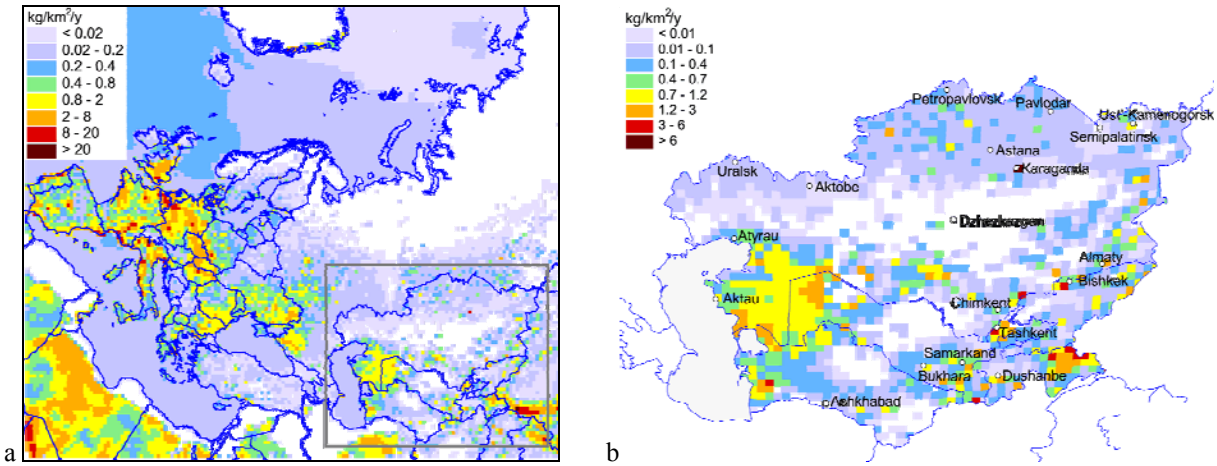


Fig. 1.6. *Spatial distribution of lead re-suspension from soil and seawater in 2005 in the modelling domain (a) and in selected Central Asian countries (b), kg/km²/y*

1.1.3 Model evaluation vs. measurements

Evaluation of modelling results against observations is a routine procedure allowing assessment of the model performance and supporting improvement of the model parameterization. Approaches to verification of modelling results of MSCE-HM model are described in [*Ilyin and Travnikov*, 2005] in detail. This section contains the comparison of modelled concentrations of lead in air and in precipitation with available measurement data. As a rule, the model results are compared with the measurements from the EMEP monitoring network. There are about sixty stations reported measured atmospheric levels of lead in 2005. Most of these stations are situated in the northern and western parts of Europe. More detailed description of the comparison for 2005 as well as description of EMEP measurement network and quality of monitoring data is available in [*Ilyin et al*., 2007, *Uggerud and Hjellbrekke*, 2007].

In addition to this, the comparison with measurement data from background monitoring stations of Central Asian region was performed. These data were derived from data base on background monitoring in USSR/CIS countries [*Paramonov*, 1998]. The most recent Central Asian data characterize pollution levels taken place well before 2005. Besides, very little information is available about quality of these measurement data. That is why the comparison with measurements from Central Asian stations is presented separately from the comparison with EMEP data.

EMEP data

Comparison of modelled and measured annual mean lead concentrations in air and precipitation for 2005 is presented in Fig. 1.7. In general the model underestimates observations by 20-30%. Correlation coefficients are significant and amount to about 0.7 and 0.6 for concentrations in air and precipitation, respectively. In 80% of cases difference between modelled and measured concentrations does not exceed a factor of two. Modelled air concentrations well match the observed values at sites located in the western part Europe and Southern Scandinavia (Belgium, Germany, Denmark, the Netherlands, Norway, and Sweden). However, at some sites in the central part of Europe (the Czech Republic, Slovakia, Poland) and Northern Scandinavia (Norway, Finland) the model tends to underestimate observations.

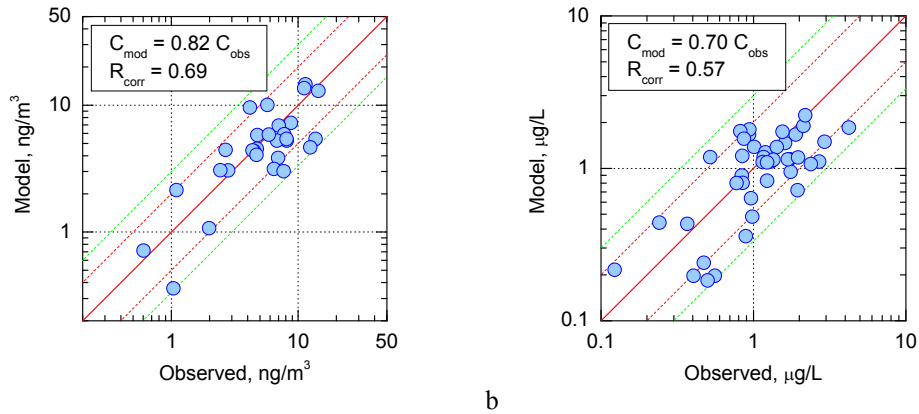


Fig. 1.7. *Comparison of modelled annual mean lead concentrations in air (a) and precipitation (b) with measurements from the EMEP monitoring network in 2005. Red solid line delineates 1:1 ratio, red and green dashed lines show deviation by a factor of two and three, respectively*

To evaluate the model ability to reproduce atmospheric transport and short-term variations of lead air concentrations we performed comparison of modelling results with daily or weekly observations using raw measured data provided by EMEP. Figure 1.8 illustrates an example of the comparison of daily mean data at Danish site DK8. As seen the model successfully capture most of the observed peaks of lead concentrations at site DK8, particularly, in April, September, October, November, December, and in the beginning of February. The use of wind re-suspension favours better agreement between the modelled and measured concentrations. However, some peaks (e.g. the episode in the end of February) were not captured by the model. It can be partly explained by effect of emission sources (anthropogenic or re-suspension) not covered by current emissions dataset used in the modelling.

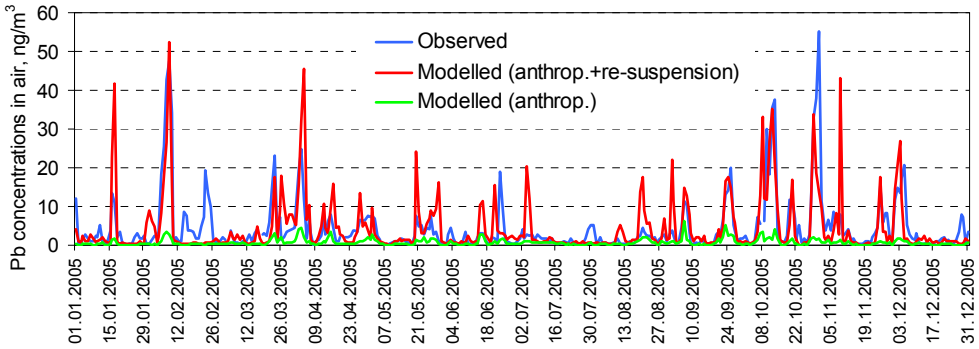


Fig. 1.8. *Comparison of modelled lead concentrations in air with daily measurements at station DK8 (Anholt, Denmark) in 2005, ng/m^3*

Another example is devoted to comparison of modelled and measured weekly-mean concentrations in precipitation at station NO1 (Birkenes, Norway, Fig. 1.9). Similar to concentrations in air, the model mostly reproduces temporal variability of the observed concentrations in precipitation. It is seen that both occurrence of peaks and their magnitudes are captured by the model. As a rule, modelling of concentrations in precipitation is more challenging task. Additional uncertainties in the model results are originated from the uncertainties of pre-processing of precipitation amounts. Therefore, some large discrepancies between measured and modelled concentrations in precipitation can be connected with both uncertainties of the emission data and complexity of modelling of precipitation amount by meteorological pre-processor.

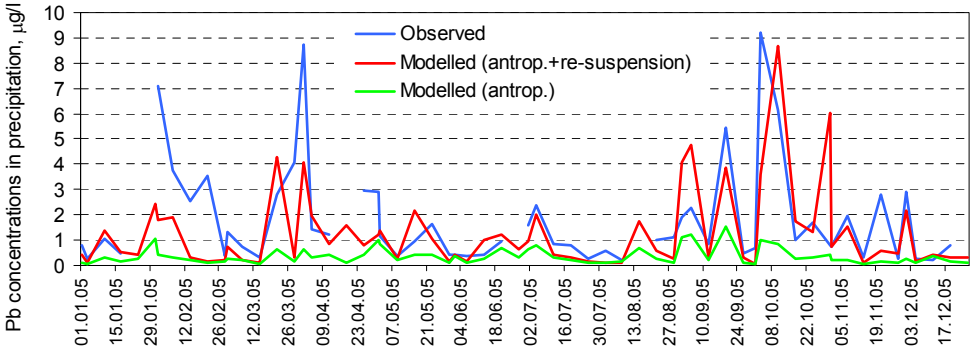


Fig. 1.9. *Comparison of modelled lead concentrations in precipitation with weekly measurements at station NO1 (Birkenes, Norway) in 2005, µg/l*

Central Asian data

Several stations in Central Asian region were involved into background monitoring of lead in air and in precipitation. From the data base on background monitoring in USSR/CIS countries, developed within Institute of Global Climate and Ecology (IGCE, Russia, Moscow) the information from four stations were obtained [*Paramonov*, 1998, *Gromov et al*., 2002]. In addition to this, information on concentrations of lead in air from Russian station Astrakhanskiy Biospheric Reserve (BR), located close to western border of Kazakhstan, was derived from [*Gromov and Paramonov*, 2000]. Among the mentioned stations three of them measure concentrations in air, one in precipitation and one in both media. Location of these stations is shown in Fig. 1.10. As seen from the figure, measurement information is available from the southern and the northern parts of the Central Asian region. The remaining vast areas of the Central Asia region are not covered by background monitoring activity.

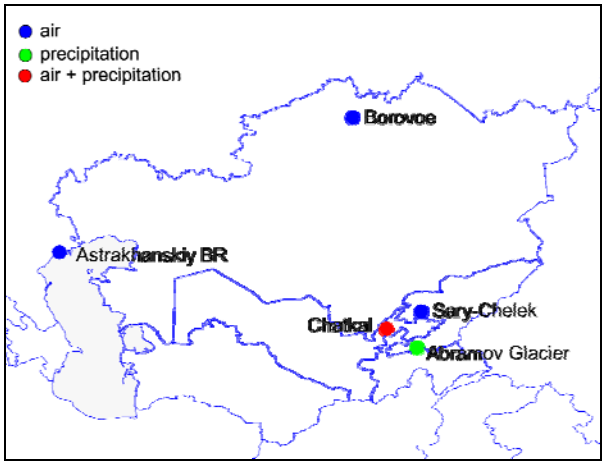


Fig. 1.10. *Location of background measurement stations in Central Asian region*

Measurement data are available for different periods. For example, data on air concentrations from the site Sary-Chelek are referred to the period from 1985 to 1991, from Chatkal – to years 1989-2001 (Fig. 1.11). No data are available for 2005.

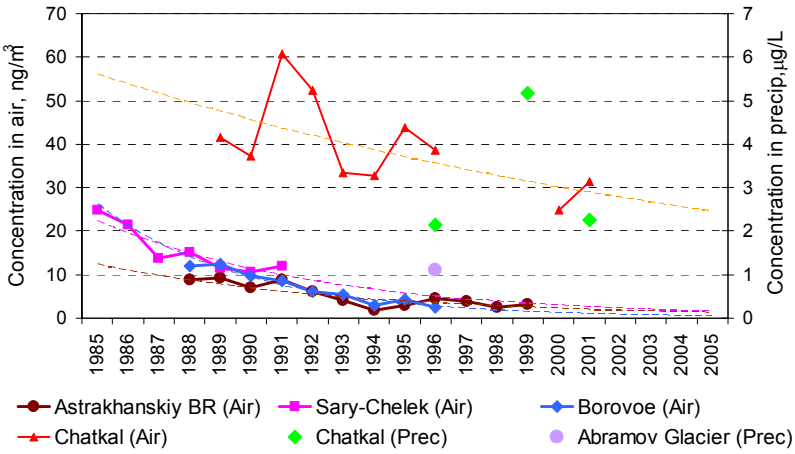


Fig. 1.11. *Annual mean concentrations of lead in air and in precipitation measured at Central Asian stations. Dashed lines denote exponential approximations*

On one hand, the observed concentrations in air demonstrate distinguished decline for the period of monitoring. On the other hand, most of the data refer to late eighties – nineties, and the most recent value was observed at the site Chatkal in 2001. Comparison of modelled results with measurements derived for different years gives rise to additional uncertainties. Nevertheless, the most recent available observed values were involved into the verification. The alternative approach is to adjust these data to the situation of 2005 by taking into account probable emission decrease in Central Asia and the surrounding regions. To do this, time series of measured concentrations in air were approximated by the exponent function. The exponents for each station were extrapolated to 2005 and these extrapolated values were used in the model verification. In case of concentrations in precipitation, number of individual annual mean values is very limited. Hence, approximations of their time series were not reasonable and for the verification the most recent value was used.

Comparison of modelled lead concentration in air both with the most recent available measurements and with approximated values for the year 2005 is presented in Fig. 1.12a. Results of the comparison differ for different stations and types of the reference data. Modelled air concentration at station Borovoe well agrees with measured value for 1996. Relative bias between the observed and modelled values is around 20%. On the other hand, the modelled concentration considerably overestimates the value estimated for 2005 using the exponential approximation. However, it is quite possible that in the case of this station the exponential extrapolation predicts too significant decrease (up to 85%) of lead concentration for the period 1996-2005 (see Fig. 1.11). Similar situation was obtained for station Astrakhanskiy BR: The model well captured the observed air concentration for 1999 (the relative bias does not exceed 10%) but somewhat overpredicts the approximated value. For station Sary-Chelek the model underestimates the most resent available observation for 1991 by a factor of four. It is not surprising because the emissions are expected to decline significantly since 1991. Therefore, the approximated value for this station better agree with the modelled one. Besides, at station Chatkal the model underpredicts by a factor of two the observed value for 2001 and by 35% the value approximated for 2005.

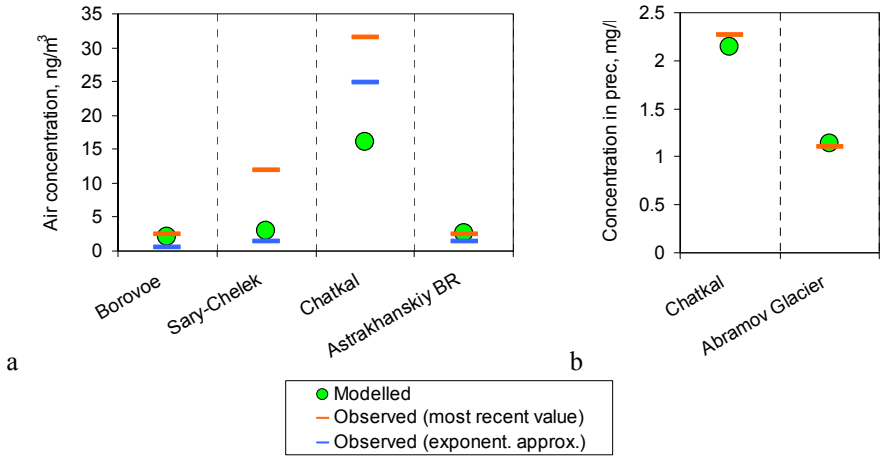


***Fig. 1.12**. Comparison of modelled and measured annual mean concentrations in air (a) and in precipitation (b)*

Modelled concentrations in precipitation were compared with ones measured at stations Chatkal in 2002 and Abramov Glacier in 1996. The deviation of modelled values from the observed ones ranges within the range ±5% (Fig. 1.12b). However, it is necessary to realize that marked changes in pollution levels could take place between 1996 or 2002 and 2005. For example, measured lead concentration in precipitation at Chatkal station in 2000 was 2.5 times higher than that in 2002 or than the modelled

value. Besides, the annual mean concentration at station Abramov Glacier is based only on few monthly-mean values, which is not enough to characterize the entire year.

Thus, summarizing the presented above analysis one can conclude that the model is capable of simulating concentrations of lead in air and in precipitation in the European region with significant accuracy. For 80% cases the difference between modelled and observed values is better than factor of two. Spatial correlation coefficients are significant. In most cases the model manages to reproduce short-term variability of the observed concentrations. To some extent these favourable results can be explained by numerous up-to-date measurement data, which serve as a basis for the verification of the model.

Evaluation of the modelling results for stations in Central Asia was based on very limited measurement data. Nevertheless, comparison of modelling results with available observations demonstrates that the model satisfactory reproduces pollution levels in this region. It should be noted that the development of a background monitoring system in the Central Asian region can markedly improve quality of the assessment, both by presenting information on actual pollution levels and by providing data for validation of long-range transport models. In addition to this, information on emissions from Central Asia is highly important for reliable model assessments for this region.

1.2. Transboundary pollution of the Central Asian countries by lead

The modified MSCE-HM model has been used for evaluation of transboundary pollution of the selected Central Asian countries by lead. The calculations were performed for the year 2005 using emissions dataset described in Section 1.1. Influence of emission sources located outside the model domain was taken into account by setting appropriate boundary conditions. Analysis of the modelling results is presented below. Particularly, levels of lead concentration in the ambient air and its deposition to the ground in the Central Asian countries are considered in comparison with those in Europe and other adjacent areas. Besides, transboundary fluxes and contribution of different sources to lead deposition in these countries are analysed.

1.2.1 Air concentration and deposition levels

Estimated air concentrations and depositions characterize background levels of lead pollution resulted from long-range atmospheric transport rather than high levels in urban environment or in the vicinity of strong emission sources. Figure 1.13 shows estimated spatial distribution of lead concentration in the ambient air in 2005 both over the whole model domain and over the selected Central Asian countries. As seen elevated concentrations of lead (up to 20 ng/m^3) are characteristics of Central and Western Europe and some Middle East countries (Fig. 1.13a). The lowest lead concentrations were obtained for the Arctic and the north-eastern regions of Russia (below 0.5 ng/m^3). In general, the concentration levels obtained for the Central Asian countries are somewhat lower than those in major industrial regions. An exception is relatively high lead concentrations (above 20 ng/m^3) in southern Kazakhstan and eastern Uzbekistan around Chimkent and Tashkent cities where strong emission sources are located (Fig. 1.13b). Besides, considerable concentrations (up to 10 ng/m^3) were also predicted for areas around other cities (Dushanbe, Samarkand, Bukhara, Aktobe etc.). The lowest concentrations (below 1.5 ng/m^3) were obtained for central territories of Kazakhstan, eastern part of Kyrgyzstan and southern part of Tajikistan.

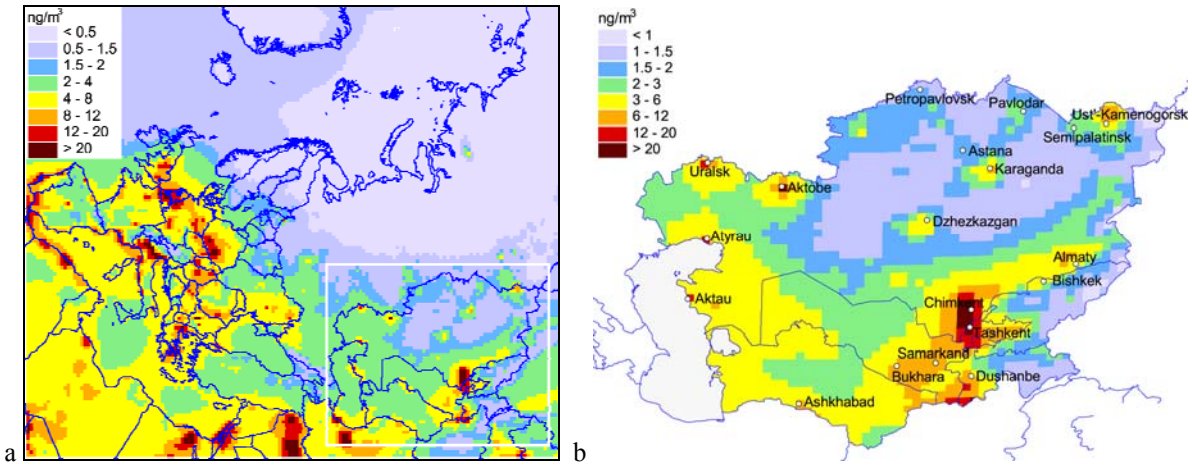


Fig. 1.13. *Spatial distribution of lead air concentration over the modelling domain (a) and over the selected Central Asian countries (b) in 2005, ng/m^3*

Comparison of lead concentration levels in five selected Central Asian countries is presented in Fig. 1.14. The bars in the diagram show country-average value of concentration in a certain country, the whiskers present variation of the concentration over territory of a country. As seen the highest average lead concentration level was obtained for Uzbekistan and the lowest for Kyrgyzstan. However, all countries are characterized by very high variability of the concentration. For example, in Kazakhstan the estimated concentrations vary from 0.05 to 33 ng/m^3. The lowest variation of lead air concentration is characteristics of Turkmenistan.

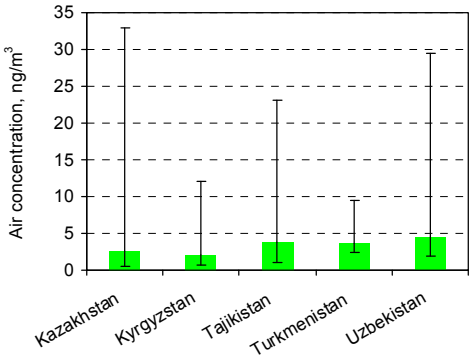


Fig. 1.14. *Average air concentration of lead in the selected Central Asian countries in 2005. Whiskers show variation over territory of a country, ng/m^3*

Spatial distribution of lead deposition in Europe and Central Asia is shown in Fig. 1.15. The most significant deposition fluxes were obtained for countries in Western and Southern Europe (up to 2.5 kg/km^2/y). In general, the estimated deposition fluxes in Central Asia are considerably lower and commonly do not exceed 0.5 kg/km^2/y. The reasons for that include relative small density of emission sources in this region and insignificant precipitation amount. As in the case of air concentrations, an exception from this is the area covering southern Kazakhstan, eastern Uzbekistan and western parts of Kyrgyzstan and Tajikistan, where deposition levels are comparable with those in Europe (1-2 kg/km^2/y). The elevated depositions in this area are defined by considerable lead emissions from sources located in large cities (Bishkek, Chimkent, Tashkent, Dushanbe). Another area with high depositions of lead (more than 2 kg/km^2/y) is in north-eastern Kazakhstan in the vicinity of Ust'-Kamenogorsk where strong emission sources are located according to the available emissions data (see Fig. 1.4). The lowest depositions were obtained for arid arias in the western part of the region (below 0.2 kg/km^2/y). It can be explained by remoteness of these areas from major emission sources. Besides, lead depositions are also restricted by low precipitation amount and small roughness of the underlying surface.

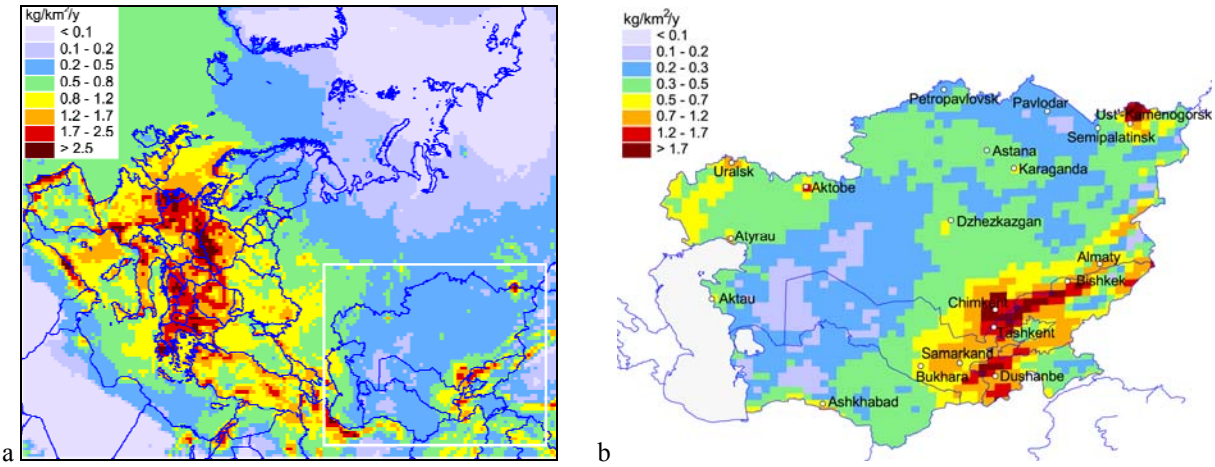


Fig. 1.15. *Spatial distribution of lead deposition over the modelling domain (a) and over the selected Central Asian countries (b) in 2005, kg/km^2/y*

Average levels of lead deposition in the Central Asian countries are presented in Fig. 1.16 along with annual precipitation amount. The highest country-average depositions were predicted for Kyrgyzstan and Tajikistan (0.7-0.9 kg/km^2/y). These countries are located in the mountain region of Pamir and Tyan' Shan' and characterized by considerable precipitation amount (Fig. 1.16b), which enhances atmospheric depositions. On the other hand, as in the case of air concentration, variation of lead deposition fluxes over territory of the countries is very large. The largest maximum depositions were obtained for Kazakhstan (3 kg/km^2/y). Again, the lowest spatial variation of depositions is characteristics of Turkmenistan.

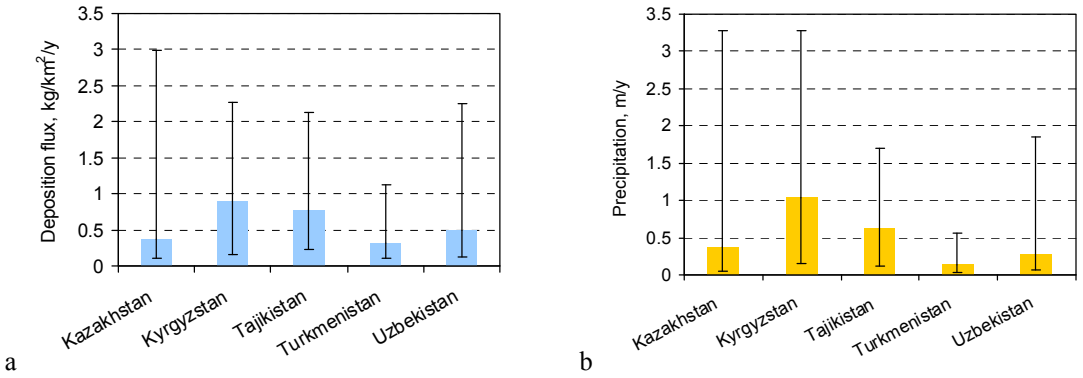


Fig. 1.16. *Average lead deposition flux, kg/km^2/y (a) and precipitation amount, m/y (b) in the selected Central Asian countries in 2005. Whiskers show variation over territory of a country*

Figure 1.17 illustrates seasonal variation of the estimated concentration and deposition levels in the considered countries. As seen from the figure lead concentration in the surface air is higher during cold season (winter, early spring, late fall) in most countries except two of them located in the mountain region (Kyrgyzstan and Tajikistan). This seasonal variability can be explained by more stable conditions of the atmospheric boundary layer during wintertime, which, in their turn, lead to less intensive vertical mixing of the pollutant and higher concentration near the ground surface. In summer, instead, intensive convection causes significant vertical dispersion of the pollutant mass and decreases the surface concentrations. In the mountain region the atmospheric circulation has more complicated character. Therefore, the seasonal pattern of lead concentration in Kyrgyzstan and Tajikistan is less pronounced.

Total deposition of lead to the ground consists of two components: wet scavenging and dry uptake by the surface. The first one is determined by precipitation amount, whereas the second component depends on air concentration of the pollutant near the ground surface, surface properties and the atmospheric conditions. In general, wet deposition prevails over the dry one except for the regions with very rare precipitation events. Therefore, total deposition commonly follows variation of precipitation amount. However, some exceptions take place, for example, in Kazakhstan during summer as well as in Turkmenistan and Uzbekistan during winter and early spring. In the first case, significant precipitation during summertime does not lead to elevated depositions because of lower lead concentrations in air. It results in quick removal of the pollutant from the atmosphere and restricts amount of depositions. In the second case, on the contrary, high air concentrations in winter/spring lead to elevated depositions in spite of relatively low precipitation amount.

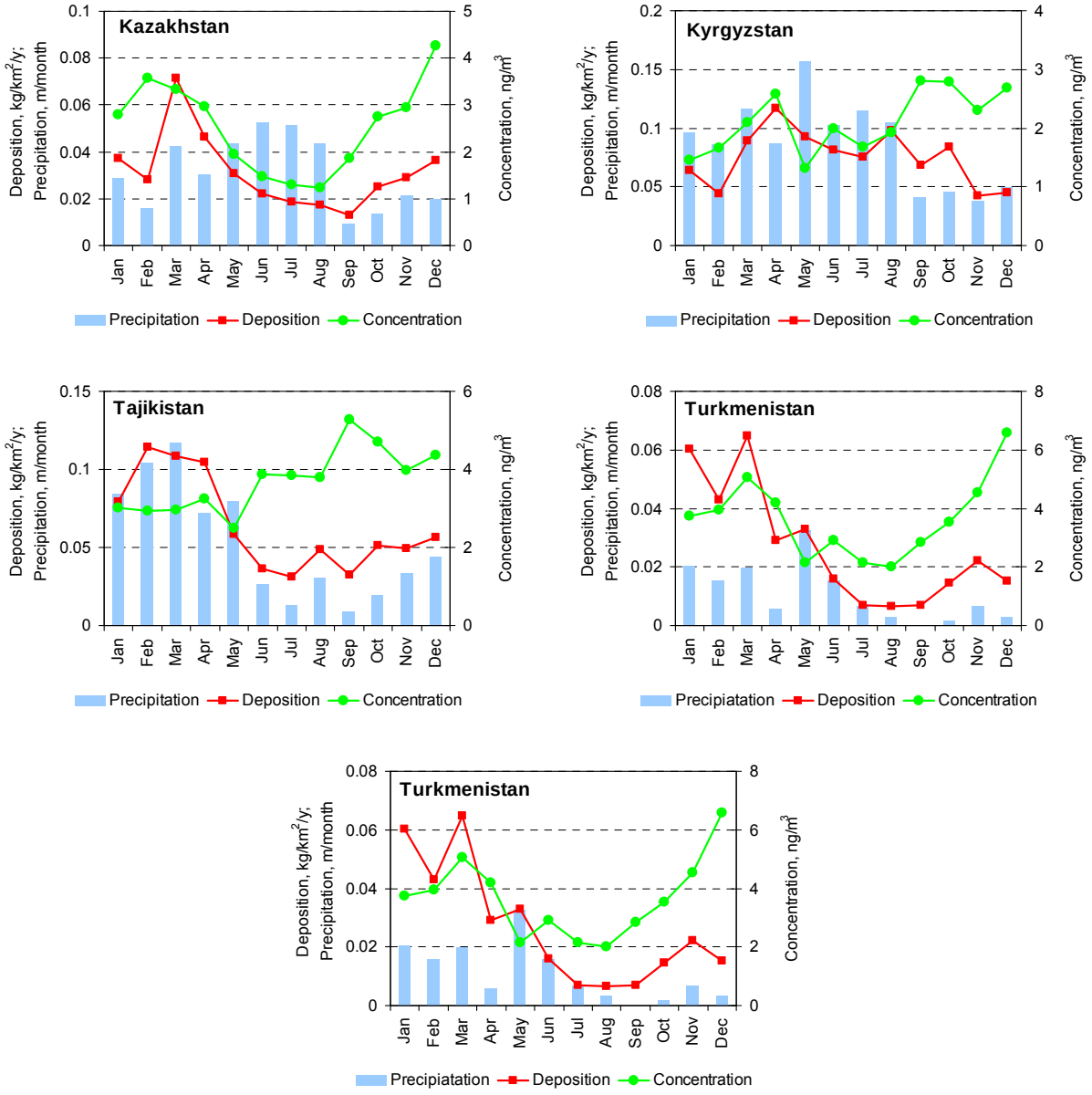


Fig. 1.17*. Seasonal variation of average lead concentration in air (ng/m^3), deposition flux (kg/km^2/y) and precipitation (m/month) in the selected Central Asian countries in 2005*

1.2.2. Transboundary atmospheric transport

For each country of the Central Asian region various aspects of transboundary transport of lead were evaluated. Contribution of different regions to total deposition was estimated. The source regions taken into account were five countries of Central Asia, Russia, EMEP countries and region “Asia and Africa”. EMEP countries represent European countries (except Russia) as one separate source region. Region “Asia and Africa” comprises countries in Africa, remaining part of Asia within the modelling domain and sources located outside the model domain (e.g., China, Iran, Afghanistan, Pakistan etc…). The contribution of sources located outside the modelling domain was accounted for by setting appropriate boundary concentrations. Besides, wind re-suspension was considered as a separate source. Other aspects of transboundary transport aimed at characterizing source-receptor relationships, presented in this report, include spatial variation of transboundary transport contribution to lead deposition over a country territory as well as spatial patterns and relative contribution of lead deposition from a country’s national sources to other regions. The detailed source-receptor matrix for lead is presented in Annex A.

Kazakhstan

Total deposition of lead to Kazakhstan from all sources in 2005 were estimated at 1013 tonnes. Contribution of national sources made up about a quarter, and of wind re-suspension about one third of total depositions (Fig. 1.18). Among other Central Asian countries the main contributor to depositions to Kazakhstan is Uzbekistan (4%). Russia contributes 3%. It is worth noting that contribution of other Asian and African sources model domain is quite significant (35%). The role of European countries is relatively small in pollution of Kazakhstan by lead, mainly because of remoteness of Europe from this country.

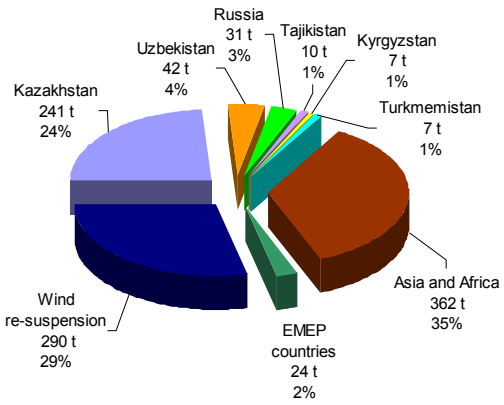


Fig. 1.18. *Contribution of different sources to depositions of lead to Kazakhstan in 2005*

The contribution of transboundary transport to anthropogenic depositions is distributed unevenly over the territory of Kazakhstan (Fig. 1.19). The highest contribution takes place along the southern and eastern state borders of the country. It is explained by the significant influence of Asian emission sources and some smaller influence of countries of Central Asian region. Along the northern and western border the contribution is smaller, mainly because of smaller impact of very remote sources in Europe and Russia. The smallest contribution was obtained nearby cities, where main national emission sources are situated.

Contribution of external Central Asian sources (from Kyrgyzstan, Uzbekistan, Turkmenistan, Tajikistan) to anthropogenic depositions decreases gradually from about 20% on the south to less then 4% on the north and north-west of the country (Fig. 1.20). This spatial pattern of the contribution is explained by the fact that all these external Central Asian countries are located on the south of Kazakhstan.

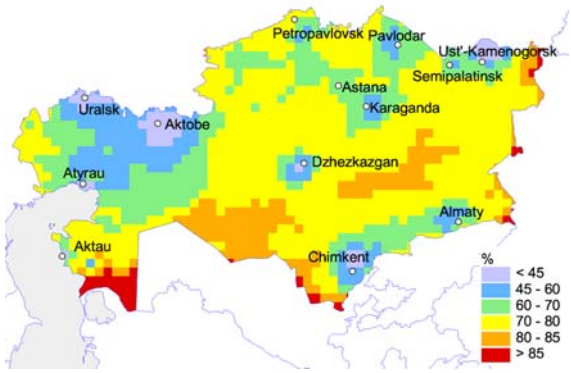


Fig. 1.19. *Contribution of transboundary transport to anthropogenic depositions of lead in Kazakhstan in 2005*

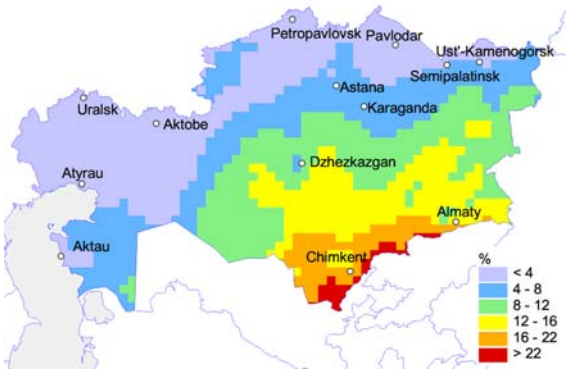


Fig. 1.20. *Contribution of transboundary transport from* ***Central Asian*** *sources to anthropogenic depositions of lead in Kazakhstan in 2005*

Spatial distribution of lead depositions from anthropogenic sources in Kazakhstan is demonstrated in Fig. 1.21. The zones with the highest depositions take place in the north-west, east, south and centre of Kazakhstan, which is conditioned by location of large national sources. As seen, the northward, westward and south-westward transport is more pronounced than the transport to the south-east. It is connected with location of mountains in the southern part of the country, which prevent air masses from transporting southward. Depositions from Kazakh national sources to the territory of Kazakhstan exceed 100 g/km^2/y in regions with high emissions and range from 20 to 50 g/km^2/y in regions with relatively low emissions and atmospheric precipitation. Depositions over most of Kyrgyzstan and Uzbekistan varied from 20 to 50 g/km^2/y, and over Turkmenistan and Tajikistan – within 1 – 20 g/km^2/y.

Total emission of Kazakhstan in 2005, accepted in this study, was 644 tonnes. As much as 241 tonnes of lead emitted in Kazakhstan, was deposited onto its territory (Fig. 1.22). Therefore, around 400 tonnes (about 63%) entered transboundary transport. Among them, 200 tonnes was deposited to Russia, 21 tonnes– to Kyrgyzstan, 16 tonnes - to Uzbekistan. More than 90 tonnes left the calculation domain.

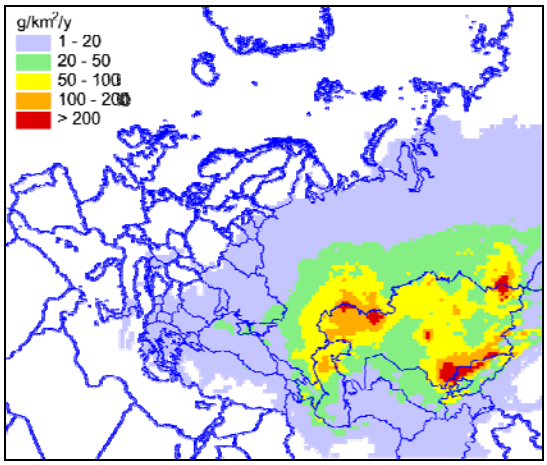


Fig. 1.21. *Spatial distribution of lead depositions fro sources of Kazakhstan in 2005*

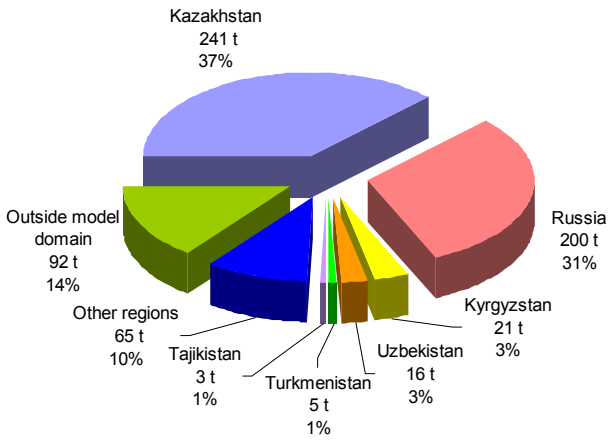


Fig. 1.22. *Transboundary transport of lead from source Kazakhstan in 2005*

Kyrgyzstan

Depositions to Kyrgyzstan from all emission sources in 2005 amounted to 178 tonnes. Among Central Asian countries the most important source of transboundary pollution of lead to Kyrgyzstan is Kazakhstan (Fig. 1.23). Its contribution to total depositions is almost 12%. Other important sources are Uzbekistan (10%) and Tajikistan (3.6%). The largest external contributor is source Asia and Africa (44%). National sources are responsible for 7% of depositions. The influence of European sources is relatively small (1.4%).

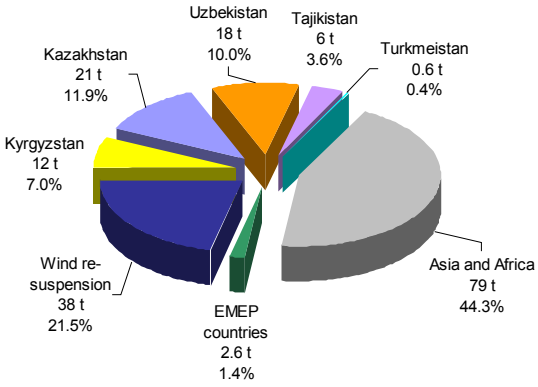


Fig. 1.23*. Contribution of different sources to depositions of lead to Kyrgyzstan in 2005*

Because of low national emissions the contribution of national sources to pollution levels in Kyrgyzstan is not high (7%). Therefore, the contribution of transboundary transport to total depositions from anthropogenic sources is essential. Over territory of Kyrgyzstan it ranges from about 80% to more than 97% (Fig. 1.24). Higher contribution is found for regions near the state borders and lower – in the vicinities of large cities (e.g. Bishkek, Osh).

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. 1.25).

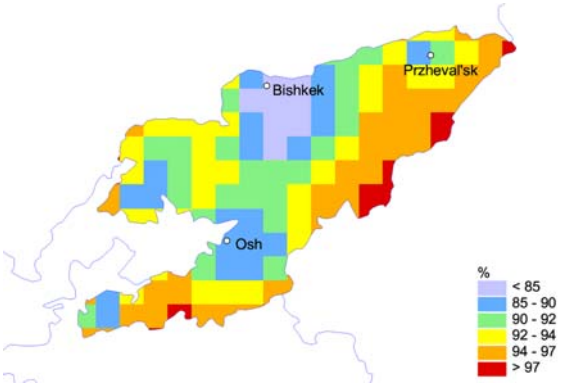


Fig. 1.24. *Contribution of transboundary transport to anthropogenic depositions of lead in Kyrgyzstan in 2005*

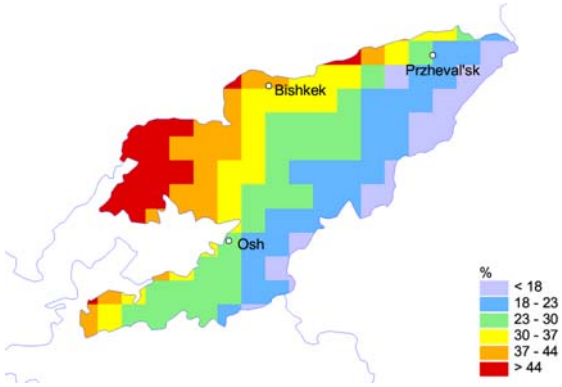


Fig. 1.25 . *Contribution of transboundary transport from* ***Central Asian*** *sources to anthropogenic depositions of lead in Kyrgyzstan in 2005*

Atmospheric transport of lead from Kyrgyzstan is more pronounced in northward and westward directions and relatively weak towards south or south-east (Fig. 1.26). This peculiarity is explained by the fact that southward from Kyrgyzstan vast mountainous region is located, while northward and westward from the country the terrain is lower and flatter. Depositions of lead caused by sources in Kyrgyzstan exceed 30 g/km^2/y over own territory. Over eastern part of Kazakhstan they range from 1 to 30 g/km^2/y. Over west of Kazakhstan, Turkmenistan, west of Uzbekistan and the Caspian Sea the depositions vary from 0.1 to 1 g/km^2/y.

Total emission of lead in Kyrgyzstan in 2005 used in model calculations was 36.6 tonnes. About 34% of this value (12.4 tonnes) deposited within territory of Kyrgyzstan (Fig. 1.27). The rest of emitted mass of lead entered transboundary transport. As much as 7 tonnes deposited on Kazakhstan, 1.6 tonnes – on Uzbekistan, about 1 tonne – on Tajikistan. Around one forth (10 tonnes) of emitted lead was transported outside the modelling domain.

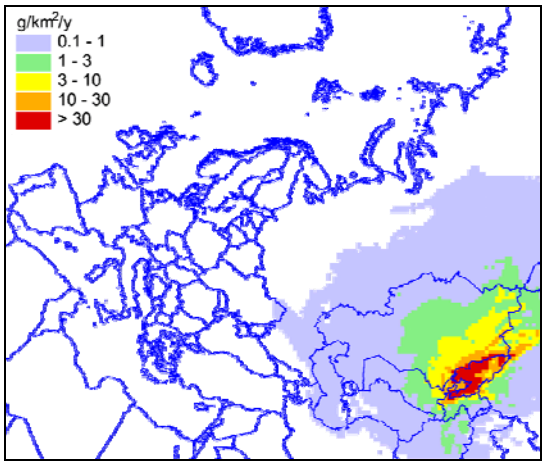


Fig. 1.26. *Spatial distribution of lead depositions from sources of Kyrgyzstan in 2005*

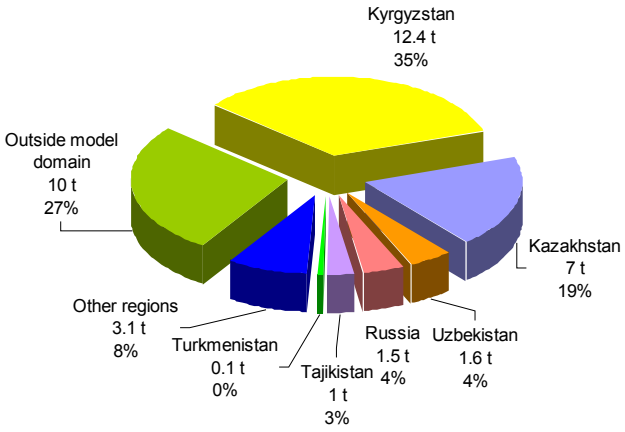


Fig. 1.27. *Transboundary transport of lead from sources of Kyrgyzstan in 2005*

Tajikistan

Total deposition of lead from all emission sources to Tajikistan in 2005 was equal to 108 tonnes. The major contributor to the total depositions was source denoted as “Asia and Africa” (Fig. 1.28), representing mainly the influence of Asian countries located outside Central Asian region (Afghanistan, Iran, China etc.). Its high contribution (57%) is explained by close location of Tajikistan to these countries and by relatively low national emissions. The most important contributors among Central Asian countries are Uzbekistan (8%) and Kazakhstan (3%). The contribution of national depositions amounts to 11%, and wind re-suspension – 18%.

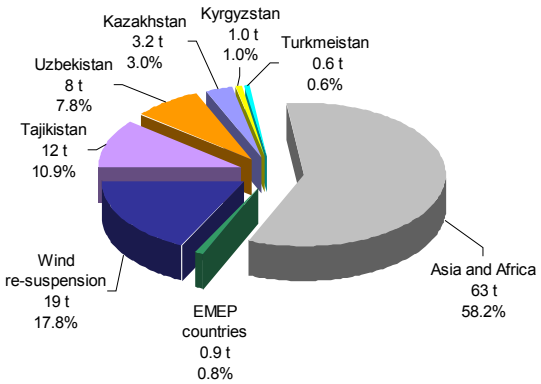


Fig. 1.28. *Contribution of different sources to depositions of lead to Tajikistan in 2005*

As follows from the Figure 1.28, only small part of depositions to Tajikistan originates from national sources, while the influence of transboundary pollution is essential. That is why the contribution of transboundary transport to depositions from anthropogenic sources in Tajikistan exceeds 75% almost all over territory of the country (Fig. 1.29). The highest contribution (more than 98%) is obtained for the eastern part of the country, which is

mostly influenced by sources located in southern Asia. On the west the contribution is the lowest due to the influence of national emissions (e.g., Dushanbe city).

The contribution of external Central Asian sources (from Kazakhstan, Kyrgyzstan, Turkmenistan and Uzbekistan) reaches the highest magnitude (more than 30%) in the north-west of Tajikistan (Fig. 1.30), mainly because of influence of sources of Uzbekistan located in Fergana valley. The contribution gradually declines to values less then 4% in the east.

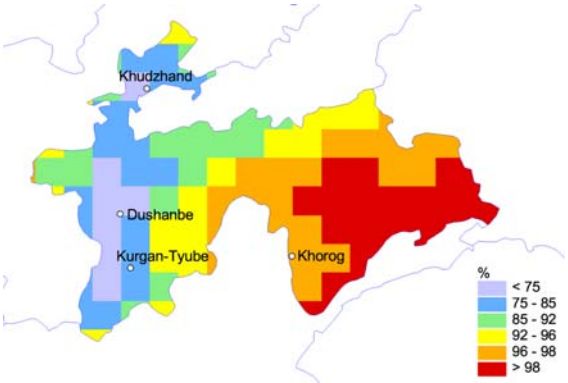


Fig. 1.29. *Contribution of transboundary transport to anthropogenic depositions of lead in Tajikistan in 2005*

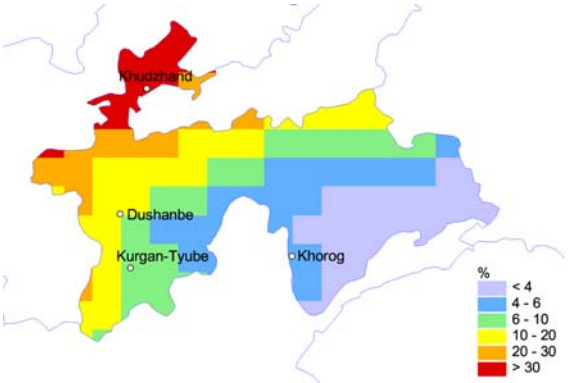


Fig. 1.30 . *Contribution of transboundary transport from* ***Central Asian*** *sources to anthropogenic depositions of lead in Tajikistan in 2005*

Atmospheric transport of lead emitted from Tajik sources took place mainly in the northern direction (Fig. 1.31). Spread of atmospheric depositions form these sources eastward or south-eastward is not so extensive. The reason of this is connected with mountain region situated to the south and south-east of country (Hindu Kush, Pamir, Karakoram etc.), which prevents the atmospheric transport southward. Depositions in Uzbekistan and Turkmenistan caused by Tajik sources vary mainly from 1 g/km^2/y on the west to 10 g/km^2/y on the east of the countries. Over Kyrgyzstan these depositions were mainly over 10 g/km^2/y. Over most of Kazakhstan the depositions ranged from 1 to 10 g/km^2/y and only in its western part they fall down below 1 g/km^2/y.

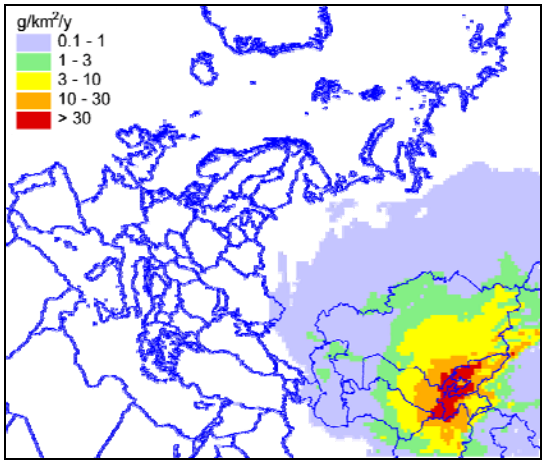


Fig. 1.31. *Spatial distribution of lead depositions from sources of Tajikistan in 2005*

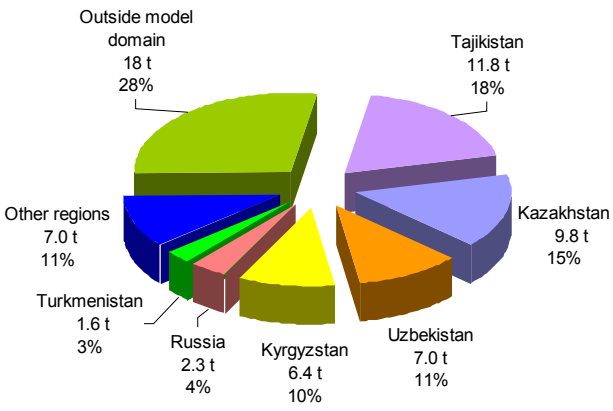


Fig. 1.32. *Transboundary transport of lead from sources of Tajikistan in 2005*

Estimated emission of lead in Tajikistan in 2005 was 63.7 tonnes. Around 12 tonnes of emitted lead were deposited onto territory of Tajikistan, and the rest (about 80%) was transported outside borders of Tajikistan (Fig. 1.32). The main receptor countries of depositions from the Tajik sources were Kazakhstan (9.8 tonnes), Uzbekistan (7.0 tonnes) and Kyrgyzstan (6.4 tonnes). As much as 18 tonnes of lead (around 30% of emission) left the modelling domain.

Turkmenistan

As much as 147 tonnes of lead was deposited to Turkmenistan in 2005. Diagram demonstrating contributions of different sources to depositions of lead is presented in Fig. 1.33. Relatively small national emissions and close location to countries of Middle East and Southern Asia caused essential (almost 60%) contribution of the source "Asia and Africa". A quarter of depositions is explained by wind re-suspension. Contributions of national sources and other Central Asian countries are relatively minor – from 0.1 to 5%.

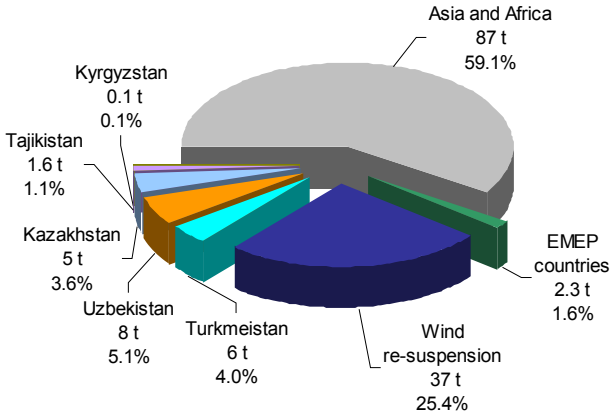


Fig. 1.33. *Contribution of different sources to depositions of lead to Turkmenistan in 2005*

Contribution of transboundary transport to anthropogenic depositions is large (higher than 80%) over all territory of Turkmenistan because of low national emissions (Fig. 1.34). The contribution is the highest in the north-western and south-western parts of the country where it can exceed 98%. The lowest contribution (about 80%) is noted for the northern and southern parts of the country, which is connected with the location of national emission sources.

The contribution of external sources from other Central Asian countries to anthropogenic depositions grows from south-west to north-east (Fig. 1.35). Along the north-eastern border, where the influence of Central Asian neighbours is the highest, the contribution exceeds 25%. In the south-west of the country the influence of Central Asian countries diminishes to less then 6%, and the influence of other Asian and EMEP sources increases.

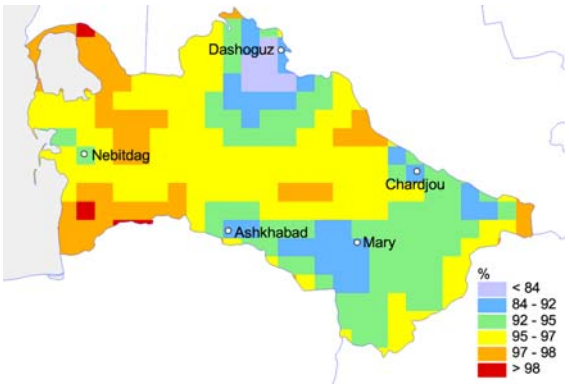


Fig. 1.34. *Contribution of transboundary transport to anthropogenic depositions of lead in Turkmenistan in 2005*

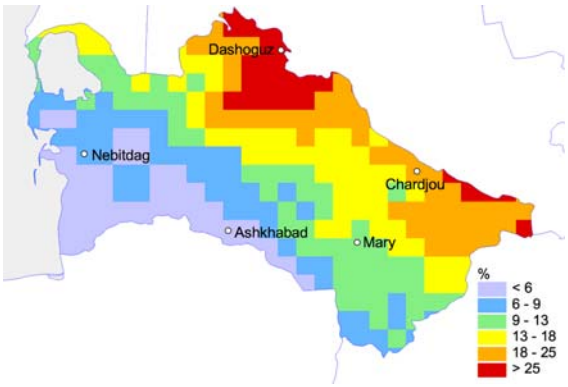


Fig. 1.35 *Contribution of transboundary transport from* ***Central Asian*** *sources to anthropogenic depositions of lead in Turkmenistan in 2005*

Depositions of lead emitted from sources in Turkmenistan spread northward more distinctly than to the south (Fig. 1.36). Mountain ridges in the south (Kopet-Dag, Hindu Kush) do not favour atmospheric transport southward. The highest depositions caused by Turkmenistan emission sources take place in the southern, northern and south-eastern parts of the country. In these regions they range from 10 to 20 g/km^2/y, and somewhere exceed 20 g/km^2/y. Over the Caspian Sea and most of Uzbekistan the depositions from Turkmenistan emissions vary from 3 to 20 g/km^2/y. Over major part of Kazakhstan the depositions lay within 1-3 g/km^2/y.

Turkmenistan emission of lead in 2005 used in evaluation of transboundary transport was 40 tonnes. Among them 5.9 tonnes deposited within the country's territory (Fig. 1.37). Hence, the remaining 85% of emitted lead was transferred through the state borders. The major receptor countries of this mass of lead were Kazakhstan (4.5 tonnes), Russia (3.8 tonnes) and Uzbekistan (2.6 tonnes). Tajikistan and Kyrgyzstan received 0.6 tonnes each. As much 13 tonnes left the modelling domain.

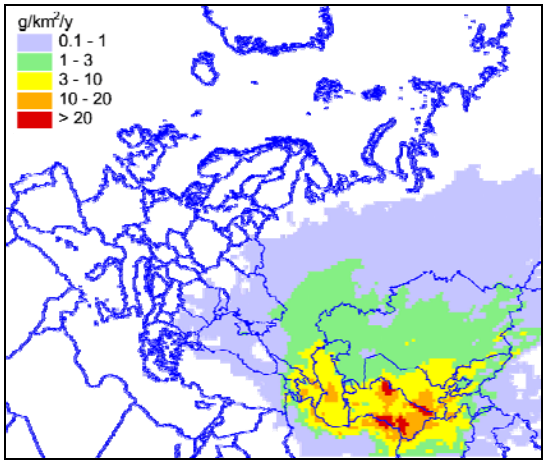


Fig. 1.36. *Spatial distribution of lead depositions from sources of Turkmenistan in 2005*

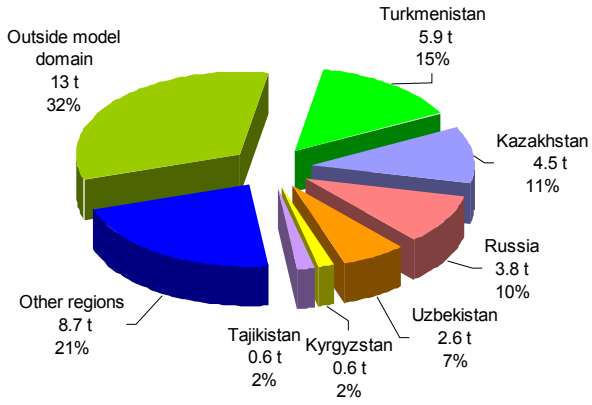


Fig. 1.37. *Transboundary transport of lead from sources of Turkmenistan in 2005*

Uzbekistan

Total lead depositions to Uzbekistan in 2005 made up 214 tonnes. The major contributors of transboundary pollution of this country are emission sources situated in other parts of Asia ("Asia and Africa", Fig. 1.38). The role of these sources accounts for almost one half of total depositions to Uzbekistan. Among Central Asian countries the main contributors are Kazakhstan (8%) and Tajikistan (3%). Almost a quarter of depositions come from wind re-suspension. National emission sources are responsible for 15% of depositions.

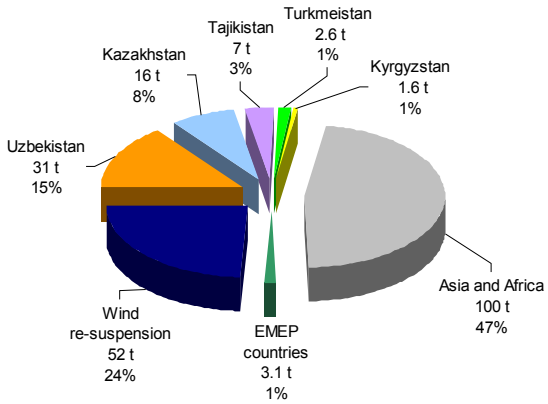


Fig. 1.38. *Contribution of different sources to depositions of lead to Uzbekistan in 2005*

Contribution of external sources to anthropogenic depositions in Uzbekistan is the highest in the north-western part of the country (Fig. 1.39), where it exceeds 95%. It is explained by minor national emission sources in this part of the country. However, it is worth mentioning that absolute values of lead depositions in this area are not high (Fig. 1.15). The strip of relatively low contribution spreading from Bukhara to Tashkent and Fergana valley is characterized by most significant national emissions, and hence, relatively low contribution of the transboundary transport. The lowest contribution of transboundary pollution (below 66%) is obtained in the vicinity of Tashkent.

The contribution of transboundary transport of other Central Asian countries to anthropogenic depositions in Uzbekistan (Fig. 1.40) is the highest in the north-eastern part of the country (over 30%). This part of the country is characterized by the highest absolute depositions of lead. In spite of location of significant national emissions sources in this area (e.g., Tashkent city), the influence of external Central Asian sources is also relatively high. Another area of elevated contribution from external Central Asian sources is the north-western part of Uzbekistan. The contribution ranges from 15 to 30% and is caused mostly by sources of Kazakhstan. However, absolute values of depositions in this part of the country are relatively low. The lowest contribution was obtained nearby the Samarkand and Bukhara region (below 10%).

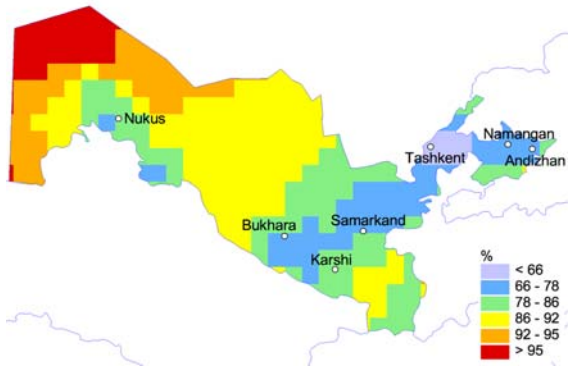


Fig. 1.39. *Contribution of transboundary transport to anthropogenic depositions of lead in Uzbekistan in 2005*

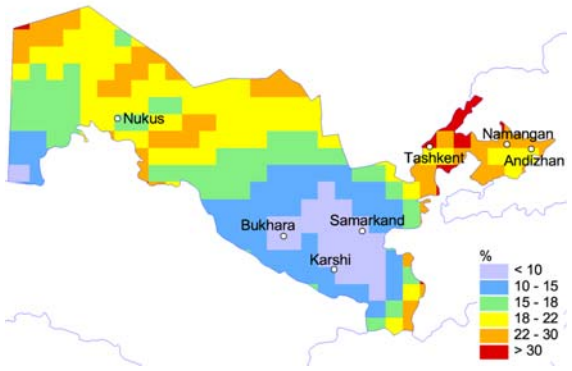


Fig. 1.40. *Contribution of transboundary transport from* ***Central Asian*** *sources to anthropogenic depositions of lead in Uzbekistan in 2005*

Lead emitted by the Uzbek sources was transported by the atmospheric flows mainly northward or westward (Fig. 1.41). The transport in the eastern or south-eastern direction was limited mainly due to mountain ridges acting as barriers. In the eastern part of Uzbekistan the depositions from national sources exceed 80 g/km^2/y, and in the western part they range from 5 to 20 g/km^2/y. Depositions from Uzbek sources in Kazakhstan ranges from approximately 80 g/km^2/y in the south to 1-5 g/km^2/y in the north. Depositions over the Caspian Sea vary within the range 1–5 g/km^2/y.

According to our estimates magnitude of emissions of lead in Uzbekistan in 2005 amounted to 185 t. Depositions to its own territory were equal to 31 tonnes, and other 154 tonnes (83% of emission) were transported outside the country (Fig. 1.42). Kazakhstan is the major receptor of lead from Uzbekistan. The depositions from Uzbekistan sources to this country amounted to 42 tonnes. Other important receptor countries were Kyrgyzstan (18 tonnes), Russia (12 tonnes), Tajikistan and Turkmenistan (8 tonnes). As much as 47 tonnes (25%) of lead emitted by Uzbek national sources were transported outside the modelling domain.

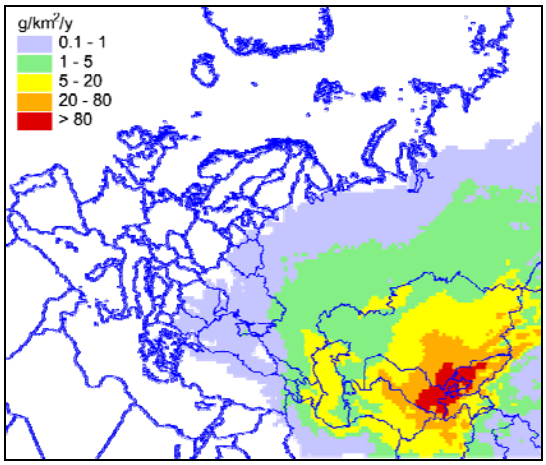


Fig. 1.41. *Spatial distribution of depositions of lead from sources of Uzbekistan in 2005*

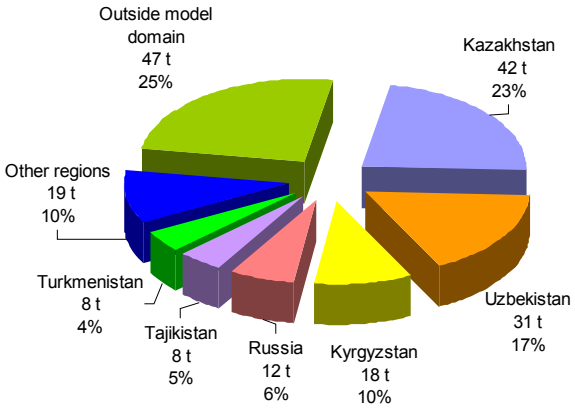


Fig. 1.42. *Transboundary transport of lead from sources of Uzbekistan in 2005*

Chapter 2

POLYCHLORINATED BIPHENYLS

2.1. MSCE-POP hemispheric transport model

The hemispheric MSCE-POP model has been developed in MSC-E to meet the requirements of the Convention on Long-Range Transboundary Air Pollution on the evaluation of intercontinental transport of persistent organic pollutants (POPs) within the northern hemisphere in order to support the regional pollution modelling within the EMEP region. This section presents brief description of the hemispheric MSCE-POP model and its input data. Detailed description of the model is available in [*Gusev et al.*, 2005].

2.1.1. Model description

MSCE-POP is a multi-compartment three-dimensional model of Eulerian type. The model computation domain covers the whole northern hemisphere with spatial resolution 2.5° x2.5° both in zonal and meridional directions (Fig. 2.1). To avoid a singularity at the pole point, peculiar to the spherical coordinates, the grid has a special circular mesh of radius 1.25° including the North Pole. In the vertical direction the model domain consists of eight irregular levels up to the height of approximately 12 km. The terrain-following sigma-pressure (σ-p) coordinates are used defined as a ratio of local atmospheric pressure to the ground surface pressure [*Jacobson*, 1999].

The model considers main environmental compartments (atmosphere, soil, seawater, vegetation) and includes description of basic processes of POP behavior: emission, long-range transport, deposition, degradation, gaseous exchange between the atmosphere and the underlying surface as well as the processes within the environmental compartments (Fig. 2.2). Selection of compartments and processes is based on current understanding of their importance with regard to the description of POP dispersion and accumulation in the environment.

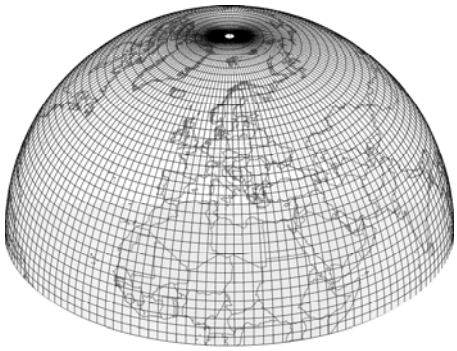


Fig.2.1. *Horizontal structure of the hemispheric MSCE-POP model domain. Geographical coordinates with 2.5° x 2.5° resolution and the pole grid cell*

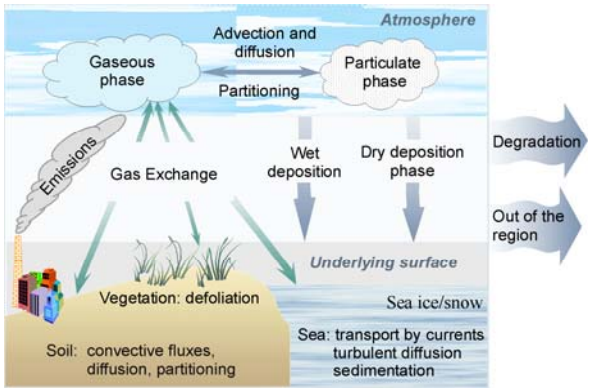


Fig. 2.2. *The scheme of processes included into the MSCE-POP model*

The atmospheric part of MSCE-POP model considers the following processes: advection, turbulent diffusion, partitioning of a pollutant between the gaseous and particulate phase, wet deposition of both phases to the underlying surface, dry deposition of POPs in particulate phase, and degradation. The model description of atmospheric transport is based on the three-dimensional advection-diffusion equation adapted to the (σ–p) coordinate [*Jacobson*, 1999]. The horizontal advection is described using the Bott flux-form advection scheme [*Bott*, 1989a; 1989b]. The original Bott scheme has been derived in the Cartesian coordinates. To apply the scheme to the transport in spherical coordinates it has been modified taking into account peculiarities of the spherical geometry. Detailed description of the Bott advection scheme in the spherical coordinates is presented in [*Travnikov*, 2001]. Vertical advection is described using the Bott scheme generalized for a grid with variable step $\Delta\sigma$. Vertical eddy diffusion process is taken into account to consider air mass mixing. Partitioning of POPs between the gaseous and particulate phase within the atmosphere is performed using the Junge-Pankow model [*Junge*, 1977; *Pankow*, 1987].

For the description of removal of POPs from the atmosphere the following processes are included into the model: dry deposition, wet scavenging, and degradation. The dry deposition scheme for particle-bound POPs is based on the resistance analogy approach and allows taking into account deposition to different land cover types (forests, seawater, and soil). The description of dry deposition of particle-bound POPs to forest is based on [*Ruijgrok et al*., 1997]. Two types of forest are distinguished in the model: deciduous forest and coniferous forest. For the description of POP removal with precipitation wet deposition of POPs in gaseous and particulate phase is distinguished in the MSCE-POP model. Degradation process of POPs in the atmosphere is considered as the gas-phase reaction of pollutants with hydroxyl radicals.

To take into account the influence of POP distribution and accumulation in underlying surface and re-emission the MSCE-POP model contains three modules which describe processes taking place for POPs within the soil, seawater, and vegetation compartments. The gaseous exchange of POPs between the atmosphere and underlying surface (soil, vegetation, and seawater) is described on the basis of the resistance analogy.

The soil module is based on the soil a modification of the model developed by *C.M.J. Jacobs and W.A.J. van Pul* [1996]. The soil compartment is represented by upper 20 cm soil layer which is separated into seven horizontal sub-layers of different thickness. The following soil-related processes are included: partitioning of a POP between various phases in soil, vertical transport due to diffusion and convective water fluxes, bioturbation, gaseous exchange with the atmosphere, and the degradation. Several phases of POPs within the soil are considered in the model: gaseous phase, dissolved phase, phase sorbed on the dissolved organic carbon, and phase sorbed on organic carbon within the solid soil fraction. To take into account the dynamic character of the redistribution between POP sorbed on solid organic carbon and other POP phases in soil, total content of solid organic carbon (OC) was split into two separate fractions: easily accessible and potentially accessible [*Vassilyeva and Shatalov,* 2002]. It is assumed that the equilibrium between all POP phases except the sorbed on potentially accessible soil OC fraction is established instantaneously. The exchange of POPs between easily and potentially accessible OC fractions takes place according to first-order dynamic equation.

The vegetation compartment in the model is represented by the following types of vegetation: coniferous forest, deciduous forest, and grass. The information on vegetation types is based on the land cover data. Coefficients governing exchange processes between the atmosphere and vegetation are determined separately for each of the above vegetation types. The degradation of POPs within the vegetation is not considered at present due to the lack of information regarding this process.

The model considers the forest litter as an intermediate medium between vegetation and soil. For the description of defoliation process it is assumed that the part of POP transported from vegetation to the forest litter is proportional to the decrease of leaf area index for deciduous forest and grass during the spring, summer, and autumn seasons. For coniferous trees defoliation was described as a first-order process with a half-life $T_{1/2}$ = 2 years. The transmission of a pollutant from fallen leaves to the underlying soil is described as a first order process with the half-life of about 10 years as a preliminary rough hypothesis.

Important feature of MSCE-POP model is the description of POP transport within the seawater and the exchange with the atmosphere in presence of sea ice cover. Sea ice plays the role of a screen between the seawater and the atmosphere in Polar Regions. The process of POP exchange with the atmosphere takes place on the upper snow-ice surface. POP trapped by the sea ice and snow may be transported with ice drift. The scheme of basic processes in the atmosphere/snow/ice/seawater system is presented in Fig. 2.3. Detailed description of the seawater model can be found in [*Strukov*, 2006].

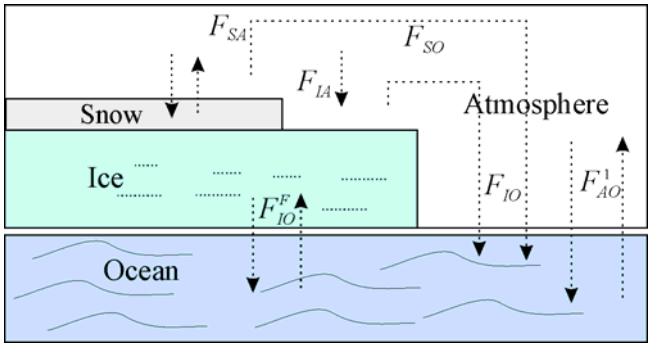


Fig. 2.3. *The scheme of POP fluxes in the system atmosphere-snow/ice-seawater*

F_{SA} – flux between the atmosphere and the snow pack (snow on the ice surface), F_{SO} - flux from the upper surface of the snow pack into seawater, F_{IA} – flux from the atmosphere onto the upper ice surface (no snow), F_{IO} – flux into the seawater from the upper ice surface (no snow), F^{p}_{IO} – flux between the seawater and the ice medium (particle phase only).

The seawater computation domain is divided into 15 vertical layers with non-uniform depths down to approximately 4600 metres. Horizontal resolution is 1.25x1.25 degrees, that is, two times less than the atmospheric one. For the description of POP transport within seawater the following processes are considered: advection, turbulent diffusion, degradation and sedimentation. Fields of sea current velocities, and the depth of the upper mixed layer, used to calculate vertical turbulent diffusion, are taken from the ocean dynamic model OGCM developed in Russian Hydrometeorological Center [*Resnyansky and Zelenko*, 1991; 1992; 1999]. The model considers the redistribution of POPs between the dissolved phase, and the phase associated with particles within seawater. It is assumed that the equilibrium between these phases is established instantaneously.

Computation of POP exchange between the atmosphere and ice compartment in MSCE-POP model requires the following input information: ice compactness, ice cover thickness, snow cover thickness, ice and snow melting rates, surface temperature. These data were obtained from the CSIM2 model developed at NCAR in the framework of CCSM model project [*Bruce et al.*, 2001] and adapted to MSCE-POP model grid system [*Shatalov et al.*, 2003].

2.1.2. Input data

The MSCE-POP model input information includes emission data, meteorological and geophysical information, and physical-chemical properties of POPs. Brief description of these data and their sources is presented in this section.

PCB emission data

For the evaluation of PCB intercontinental transport the global inventory of PCB usage and emission in period 1930-2000 [*Breivik et al*., 2002] was selected. This inventory includes information on temporal and spatial variations of emissions of 22 PCB congeners to the atmosphere. The inventory provides historical emissions of PCBs on the basis of available data on production and consumption of PCBs. It should be noted that emission totals for individual countries as well as their spatial distribution are rather uncertain. In particular, spatial distribution of PCB emission was made on the basis of population density since PCB consumption is generally linked with the use of electrical equipment. Since there was no information on seasonal variation of PCB emission to the atmosphere it was assumed that it is uniformly distributed over a year. Inventory includes three different scenarios of global PCB emissions, namely, minimum scenario, default scenario, and maximum scenario. At this stage of investigations of PCB pollution levels at the hemispheric scale the modelling was performed using the maximum scenario representing maximum levels of pollution since model results obtained with their use were closer to available measurements.

For the evaluation of PCB pollution levels for 2005 model simulations were performed for the period 1970-2005. It was assumed that PCB emission in 2001-2005 was decreasing with same rate as in period 1996-2000. On the basis of these data total annual emission of PCB-153 within the northern hemisphere for 2005 amounted to 8 t. The spatial distribution of PCB-153 annual emission for 2005 with resolution 1x1 degree is presented in Fig. 2.4. It can be seen that the most significant levels of PCB-153 emission fluxes are the characteristic of European region. For model simulations spatial distribution of PCB emissions was redistributed to the MSCE-POP model grid system with resolution 2.5° x2.5°.

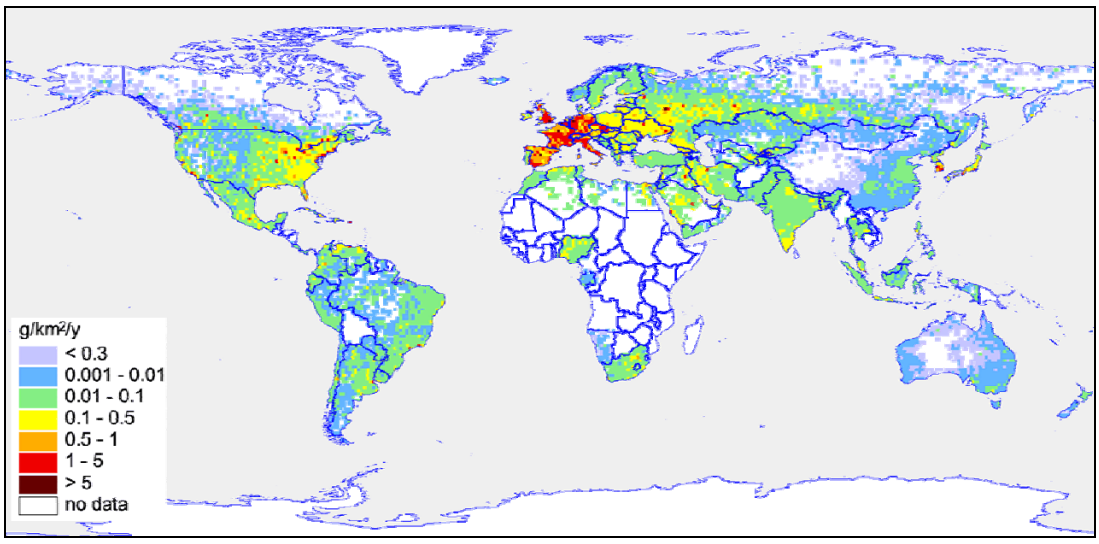


Fig. 2.4. *Spatial distribution of PCB-153 annual emission for 2005, g/km^2/y*

For the evaluation of intercontinental transport the following groups of emission sources within the northern hemisphere were considered: Central Asian countries, European region, Americas, Russia, Africa, Southwest Asia, and Southeast Asia (Fig. 2.5a). The contributions of the above source groups to the total PCB-153 emission within the northern hemisphere are shown in Fig. 2.5b.

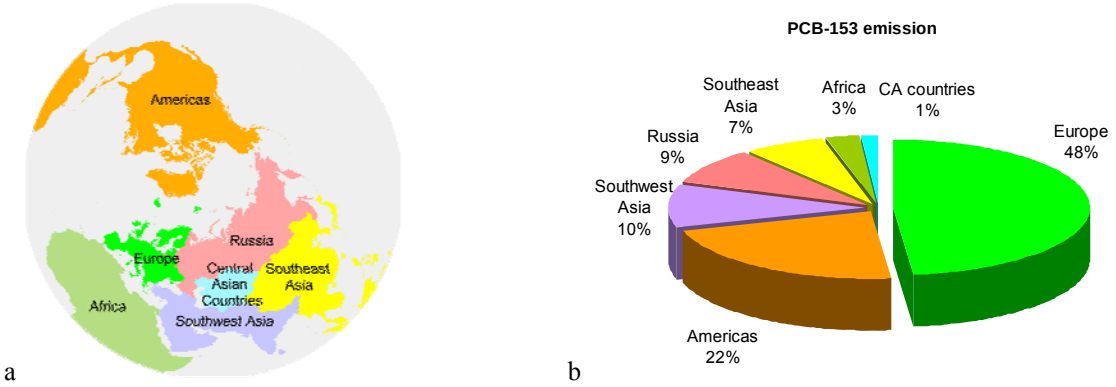


Fig. 2.5. *Selected groups of emission sources (a) and their contributions (b) to the total annual PCB-153 emission within the northern hemisphere*

The most significant contribution (about 50%) to the total annual emission of PCB-153 for 2005 within the northern hemisphere is made by European region. The European region is followed by Americas with contribution of 22%. Southwest Asia contributes about 10%. Contributions of other regions of northern hemisphere are less significant. PCB-153 emission of the Central Asian countries contributes to the total emission within the northern hemisphere about 1.5%.

Annual total emissions of PCB-153 for the selected Central Asian countries as well as for other selected groups of emission sources within the northern hemisphere are summarized in Table 2.1. The most significant emissions among the Central Asian countries in 2005 were estimated for Kazakhstan (0.05 tonnes) and Uzbekistan (0.05 tonnes). PCB-153 emissions of other three Central Asian countries Kyrgyzstan, Tajikistan, and Turkmenistan were about 0.01 tonnes. Total emission of selected Central Asian countries in 2005 amounted to 0.11 tonnes. It should be noted that this value is significantly smaller than total emission from European region (3.8 tonnes), Americas (1.7 tonnes), Southwest Asia (0.8 tonnes), and Russia (0.7 tonnes).

Table 2.1. *Annual PCB-153 emission of the Central Asian countries and other regions of the northern hemisphere for 2005, tonnes*

Source region / country	Emission
Kazakhstan	0.05
Kyrgyzstan	0.01
Tajikistan	0.01
Turkmenistan	0.01
Uzbekistan	0.05
Russia	0.7
Europe	3.8
Americas	1.7
Southeast Asia	0.5
Southwest Asia	0.8
Africa	0.2
Total	7.9

Spatial distribution of PCB-153 annual atmospheric emissions with emphasis to the Central Asian regions is given in Fig. 2.6. It can be seen that in comparison to the emissions of the Russian Federation PCB emission of the Central Asian countries is comparatively lower.

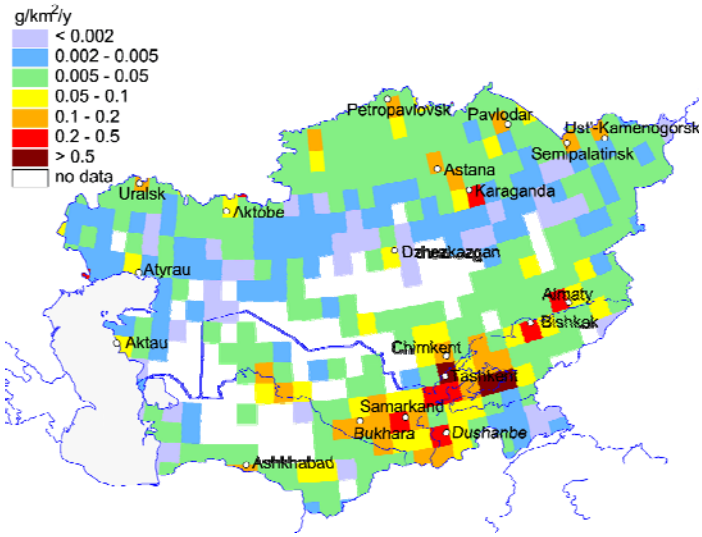


Fig. 2.6. *Spatial distribution of PCB-153 emission within the Central Asia region for 2005, g/km²/y*

Meteorological data

The meteorological information necessary for MSCE-POP model is generated by the System of Diagnosis of the Lower Atmosphere (SDA) developed by Hydrometeorological Centre of Russia [*Frolov et al.*, 1994; *Rubinstein et al.*, 1997,1998; *Frolov et al.*, 1997 a,b,c]. The horizontal resolution of the data produced by SDA system is 2.5ºx2.5º. Along the vertical σ-coordinates are used with 9 layers up to the level of 0.26 hPa. The system is based on the hydrodynamic prognostic model and additional units responsible for preparation of initial data, boundary conditions, post-processing, and quality control and correction of errors. The list of output parameters required by the MSCE-POP model is presented in Table 2.2.

Table 2.2. *Meteorological parameters supplied by the SDA system for the Northern Hemisphere with resolution of 2.5ºx2.5º*

Parameter	Type	Usage
Components of wind velocity	3D	Air density, atmospheric transport
Air temperature	3D	Air density, atmospheric transport, degradation, deposition
Precipitation rate	3D	Wet deposition
Water vapour mixing ratio	3D	Air density, dry deposition
Vertical eddy diffusion coefficient	3D	Vertical eddy diffusion
Surface pressure	surface	Atmospheric transport
Surface temperature	surface	Gaseous exchange with underlying surface
Roughness of the underlying surface	surface	Dry deposition
Friction velocity	surface	Dry deposition
Monin-Obukhov length	surface	Dry deposition
Soil humidity	surface	Gaseous exchange with underlying surface
Snow cover height	surface	Gaseous exchange with underlying surface

Geophysical data

The geophysical information required by MSCE-POP model includes data on land cover, leaf area index, sea currents and seawater properties.

Land cover information is used for correct description of deposition and exchange processes between atmosphere and different types of underlying surface. For this purpose the 24-category USGS Land Use/Land Cover dataset obtained from NCAR Mesoscale Modeling System (MM5) [*Guo and Chen*, 1994] was used. This selection is conditioned by the availability of more detailed information on underlying surface types with high spatial resolution (10'x10'). Since the formulation of the vegetation sub-model included in MSCE-POP model does not require detailed specification of data on the underlying surface, the original 24-categories of land cover were reduced to six general categories (deciduous forests, coniferous forests, grassland, urban and built-up land, bare land and glaciers, water bodies) and redistributed over the model grid.

Leaf Area Index (LAI) data set is used for the description of POP gaseous exchange between the atmosphere and vegetation. The Leaf Area Index for a given cell implies the ratio between the area of leaves in the cell to its total area. The geographically resolved LAI data with monthly resolution was adopted from CD-ROM of NASA Goddard Space Flight Center [*Sellers et al.*, 1994,1995] and redistributed to the MSCE-POP model grid system.

Fields of sea current velocities, depth of the upper mixed layer, and sea water properties were taken from the general ocean circulation model (OGCM) developed in Russian Hydrometeorological Center [*Resnyansky and Zelenko*, 1991; 1992; 1999].

Physical-chemical properties of PCB-153 and substance-specific parameters

Basic differences in the long-range transport of POPs mainly result from peculiarities of their physical-chemical properties and degradation rates in the main environmental media. The key characteristics required for POP modelling are the following:

- subcooled liquid vapour pressure (p^0_L);
- Henry's law constant (K_H);
- washout ratio for the particulate (W_p) and gaseous phase (W_g);
- degradation rate constants for different environmental compartments;
- coefficients of partitioning between different media (octanol-water partition coefficient (K_{OW}), octanol-air partition coefficient (K_{OA}), organic carbon-water partition coefficient (K_{OC}));
- molecular diffusion coefficients (D_A, D_W).

These physical-chemical properties were prepared for the evaluation of environmental pollution by PCB-153 with MSCE-POP model. The mentioned above characteristics used for modelling are presented below in Annex B. The selection of parameters was carried out on the basis of literature data on PCB physical-chemical properties and measurement data.

2.2. Transboundary pollution of the Central Asia countries by PCB-153

Evaluation of the Central Asia countries pollution by PCBs was carried out on the basis of computations of PCB long-range transport and accumulation within environmental compartments performed with hemispheric MSCE-POP model. Simulations were made for one indicator congener PCB-153.

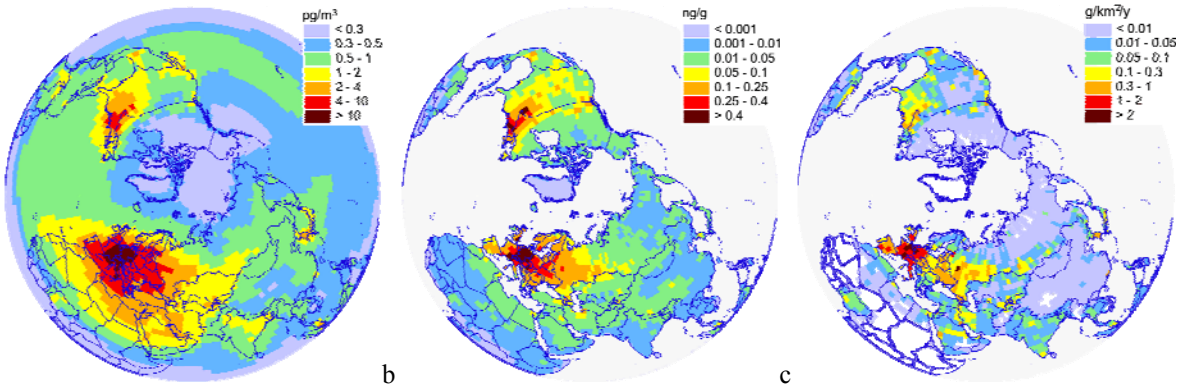
Modelling of PCB-153 long-range transport was performed on the basis of the global emission inventory of PCBs prepared by *Breivik et al.* (2002). The inventory includes three different scenarios of global PCB emissions, namely, minimum scenario, default scenario, and maximum scenario. At this stage of investigations of PCB pollution levels at the hemispheric scale the modelling was performed using the maximum scenario since the modeling results obtained with maximum emission estimates are most close to the observed levels of PCB concentrations.

2.2.1. Air concentrations and deposition levels

The computations of long-range transport of PCB-153 congener carried out for 2005 permitted to evaluate the distribution of pollution levels within the northern hemisphere and the Central Asian region and estimate contributions of other regions to the pollution of selected five Central Asian countries.

Air concentration and deposition levels of PCB-153 within the northern hemisphere

Spatial distributions of annual mean PCB-153 concentrations in surface air and in upper soil layer are shown in Fig 2.7a and b. It can be seen that most significant levels of air concentrations (4–10 pg/m^3 and above) are characteristic of European region, North America, and European part of Russia. This distribution corresponds with the spatial distribution of PCB-153 annual emission within the northern hemisphere (Fig. 2.7c).



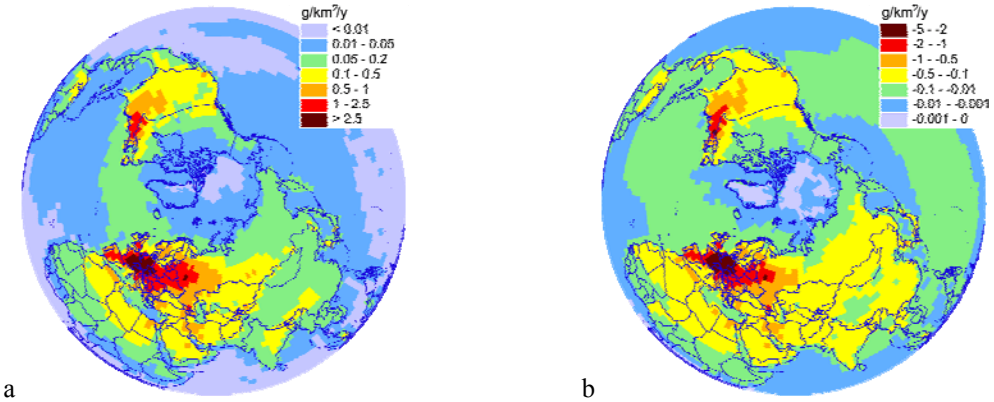
a b c

Fig. 2.7. *Spatial distribution of PCB-153 annual mean concentrations in air (a), pg/m^3, in soil (b), ng/g, and annual emissions (c), g/km^2/y, within the northern hemisphere for 2005*

At the same time essential PCB air concentrations can be noted for the Northern Atlantic, Southwest Asia, and Central Asian countries where elevated levels of concentrations can be explained by the long-range transport of the pollutant from the areas with significant PCB emission. Levels of annual mean PCB-153 concentrations in air within the Central Asian region are in the range 1-4 pg/m^3.

The distribution of PCB-153 concentrations in upper soil layer represents the accumulation of this pollutant in soil compartment. Pollutant accumulation in soil is determined by a long-term deposition process. Essential level of concentrations (0.25 ng/g and above) can be seen in areas of significant historical emission of PCBs, in particular, eastern part of North America, Germany, and European part of Russia. The Central Asian countries are characterized by comparatively low concentrations of PCB-153 in soil (about 0.01-0.05 ng/g).

Levels of PCB-153 total annual deposition and re-emission fluxes over the northern hemisphere are shown in Fig 2.8. The most significant deposition fluxes (1 g/km^2/y and above) are characteristic of European region, North America, and European part of Russia. Essential level of deposition fluxes are noted also for the Central Asian countries (0.1 – 0.5 g/km^2/y). Similar spatial distribution is a characteristic of re-emission fluxes (Fig. 2.8b). The re-emission of PCBs resulted from long-term accumulation in environmental compartments can have essential contribution to the total PCB emission to the atmosphere especially when the primary PCB emissions are declining. It can be seen that re-emission fluxes for 2005 over the selected Central Asian countries (-0.5 - -0.1 g/km^2/y) are comparable in magnitude with the total annual deposition fluxes.



a b

Fig. 2.8. *Spatial distribution of PCB-153 total annual deposition (a) and re-emission (b) fluxes over the northern hemisphere, g/km^2/y*

Evaluation of modeling results for PCB-153

Verification of MSCE-POP modelling results for PCBs was carried out in a number of studies on evaluation of POP pollution levels within the northern hemisphere and the EMEP region. One of these studies was devoted to the evaluation of pollution levels of the Arctic region by PCBs using hemispheric MSCE-POP model [*Dutchak et al.*, 2002]. It was concluded that most of model predictions of PCB air concentrations were within a factor of four with regard to measurements. Modelled concentrations of considered PCB congeners (PCB-28, PCB-118, PCB-153, and PCB-180) reasonably correlated with available measurements of air concentrations for the period 1989-1996. Computed concentrations of selected congeners in precipitation also agreed quite well with measured ones.

The performance of regional MSCE-POP model was evaluated during the model review carried out in the framework of EMEP Task Force on Measurements and Modelling. In particular, MSCE-POP model results on long-range transport of indicator congener PCB-153 for the EMEP region and the period 1990-2003 were compared with measurements of EMEP monitoring network and observations of other studies within the European region. One of the main conclusions of the TFMM Workshop on the Review of the EMEP Models on Heavy Metals and Persistent Organic Pollutants held in Moscow in

2005 was that MSCE-POP model represents the state of the science and fit for the purpose of evaluating the contribution of long-range transport to the environmental impacts caused by POPs (ECE/EB.AIR/GE.1/2006/4). It was recognized that the MSCE-POP model reasonably reproduced spatial and temporal variations of observed atmospheric levels of the selected POPs in Europe. The model provided reasonable agreement with long-term temporal trends of air pollution at most EMEP monitoring sites.

For the verification of modelling results obtained in framework of this study the comparison of computed mean annual concentrations of indicator congener PCB-153 in air and in precipitation with measurements of EMEP monitoring sites for 2005 was carried out. Most of stations performing monitoring of PCB concentrations are located in the northern and western parts of Europe (Fig. 2.9). No available information on measured PCB-153 concentrations in air and precipitation within the Central Asian region for 2005 were found.

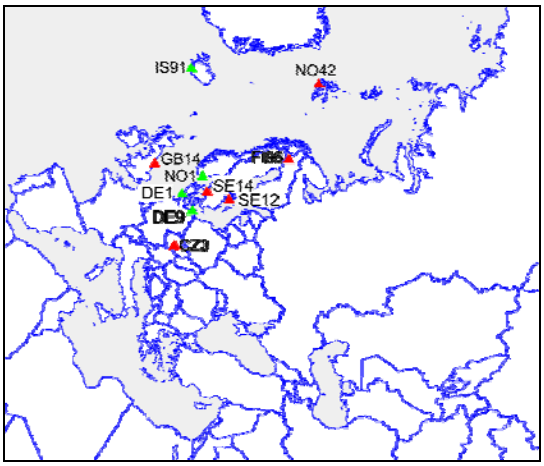


Fig. 2.9. *Location of monitoring sites performed measurements of PCB-153 concentrations in air (red triangles) and in precipitation (green triangles) in 2005*

Results of the comparison of computed annual mean concentrations in air and precipitation with measurements of EMEP sites are presented in Table. 2.3. This comparison has a preliminary character since the hemispheric MSCE-POP model uses rather rough spatial resolution 2.5x2.5 degrees and therefore it is difficult to expect good agreement with measurements of sites within the Europe.

Computed mean annual air concentrations of PCB-153 were compared with measurements of eight EMEP sites. Significant spatial correlation between observations and model results obtained for 2005 can be noted. The model reasonably reproduces elevated annual mean PCB-153 air concentrations in Central Europe for the site CZ3 and low concentrations in the remote regions, in particular, in Northern Atlantic (IS91) and the Arctic region (NO42). For the majority of sites computed values of concentrations in air overestimate measured values. On average, model predictions are higher than observed values of air concentrations by about a factor of 3. The overestimation is most likely connected with the usage of maximum estimates of PCB emission provided by the inventory of [*Breivik et al.*, 2002].

To compare mean annual computed and observed concentrations the data of four EMEP sites on PCB-153 in precipitation were used. It can be seen that the model reproduced low concentrations for the remote site IS91 and elevated levels for the sites in Western Europe (DE9). At the same time, significant overestimation of observed concentrations in precipitation can be seen for DE1 and NO1 which can be caused by the rough spatial resolution of the model and the uncertainties in spatial distribution of emission.

It should be noted that the comparison of calculated and measured concentrations in precipitation is complicated by several factors and should be considered as indicative. In particular, differences can be connected with the description of wet deposition process in the model, where precipitation is equally distributed in model grid cell with resolution 2.5x2.5 degrees while in reality rainfall is restricted to rather limited area. Additional discrepancies can be caused by different amount of precipitation used in the model and obtained at the monitoring sites.

Table 2.3. *Comparison of computed annual mean air concentrations of PCB-153 in air and in precipitation with measurements of EMEP monitoring sites for 2005*

Station	Observed	Computed	Comp/ Obs
Concentrations in air (pg/m^3)			
SE14	1.60	3.73	2.3
FI96	0.29	1.16	4.0
CZ3	10.40	10.63	1.0
NO42	0.18	0.40	2.3
IS91	0.12	0.48	4.1
NO1	1.29	3.62	2.8
SE12	0.58	2.73	4.7
GB14	0.75	3.27	4.3
Average	1.9	3.3	
Concentrations in precipitation (ng/L)			
DE1	0.04	0.50	11.6
DE9	0.24	0.66	2.7
IS91	0.02	0.06	2.5
NO1	0.06	0.38	6.9
Average	0.09	0.40	

In conclusion, it can be noted that MSCE-POP model is capable of reasonably reproducing spatial variations of the pollution levels by PCBs as within the European region and within the northern hemisphere. Results of the comparison of MSCE-POP model predictions with available measurement revealed that the deviations between computed and observed concentrations of PCB-153 were, in general, within a factor of four. Thus, it is believed that modelling results for PCB-153 obtained in the framework of this study reasonably describe spatial variations of PCB-153 concentrations and levels of depositions within the Central Asian region.

Air concentrations and deposition levels within the Central Asian region

Figure 2.10 illustrates spatial distribution of mean annual PCB-153 air concentrations in 2005 for selected five Central Asian countries. There is a clear gradient of air concentrations from Russian Federation and Southwest Asia to Central Asian countries. This can be explained by the spatial distribution of PCB-153 emission and significant long-range transport from emission sources of Russia and Southwest Asia. Relatively high air concentrations (1.5-3 pg/m^3) are noted for the western parts of Kazakhstan, Turkmenistan, and eastern part of Uzbekistan. Lowest levels of concentrations are the characteristic of eastern Kazakhstan, Kyrgyzstan, and Tajikistan (about 1 pg/m^3 and below).

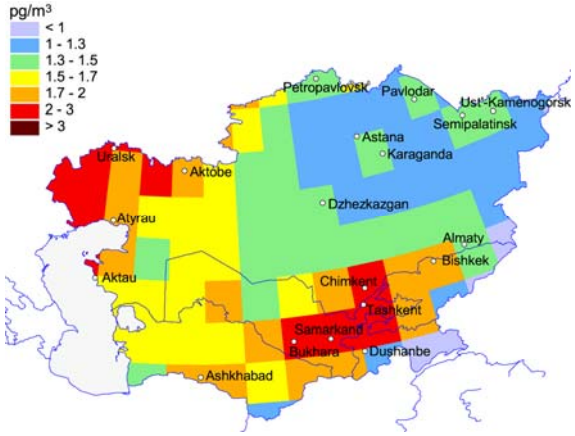


Fig. 2.10. *Mean annual PCB-153 concentrations for 2005 in surface air, pg/m^3*

Spatial distribution of mean annual PCB-153 concentrations in upper soil layer for 2005 is shown in Fig. 2.11a. The distribution of soil concentrations is somewhat different in comparison with that of air concentrations over the Central Asian countries. This is connected with the long-term accumulation of PCB-153 in soil due to deposition and gaseous exchange processes. Elevated levels of PCB-153 concentrations (0.05-0.1 ng/g) in soil can be seen in northern and eastern areas of Kazakhstan, in Kyrgyzstan and Tajikistan. Lowest levels of soil concentrations (0.01-0.02 ng/g and below) were obtained for the southern part of Kazakhstan, western Uzbekistan, and northern part of Turkmenistan. The properties of soil, in particular, organic matter content, also plays significant role in the accumulation of PCBs in soil compartment. Soils with essential fraction of organic matter will accumulate more PCBs in comparison to soils with low organic matter content. In particular, northern areas of Kazakhstan are characterized by more significant organic matter content.

The spatial distribution of PCB-153 annual total deposition fluxes is shown in Fig. 2.11b. In general, the pattern of deposition fluxes correlates with the distribution of emission sources in the Central Asian countries (see Fig. 2.6 in section 2.1.2 PCB emission data). Elevated levels (0.25-0.5 g/km^2/y) are seen for populated regions of the Central Asian countries, in particular, northern Kazakhstan, eastern part of Uzbekistan, Kyrgyzstan, and Tajikistan. Lowest levels of depositions (0.1-0.25 g/km^2/y and below) are characteristic of the southern part of Kazakhstan, western Uzbekistan, and northern part of Turkmenistan.

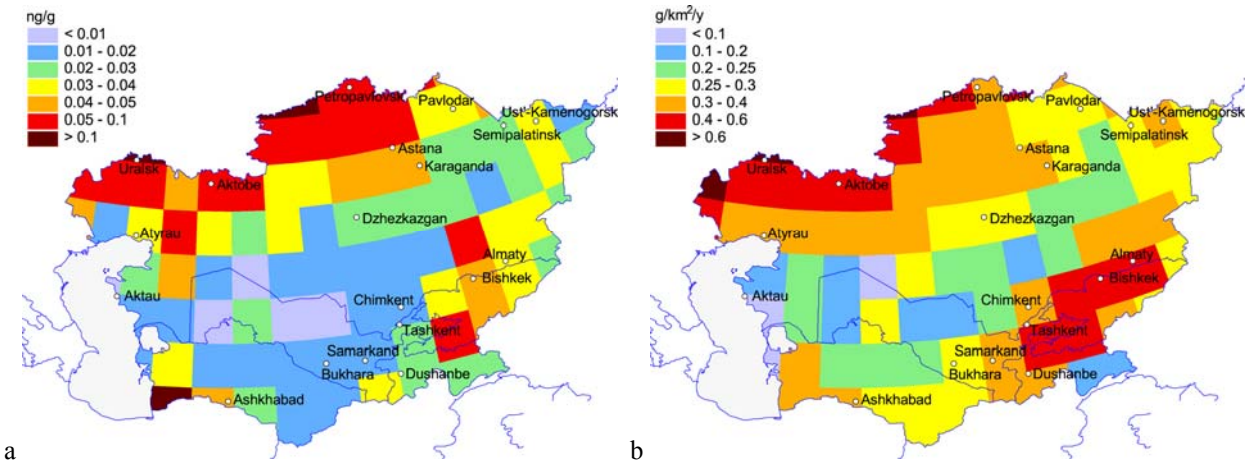
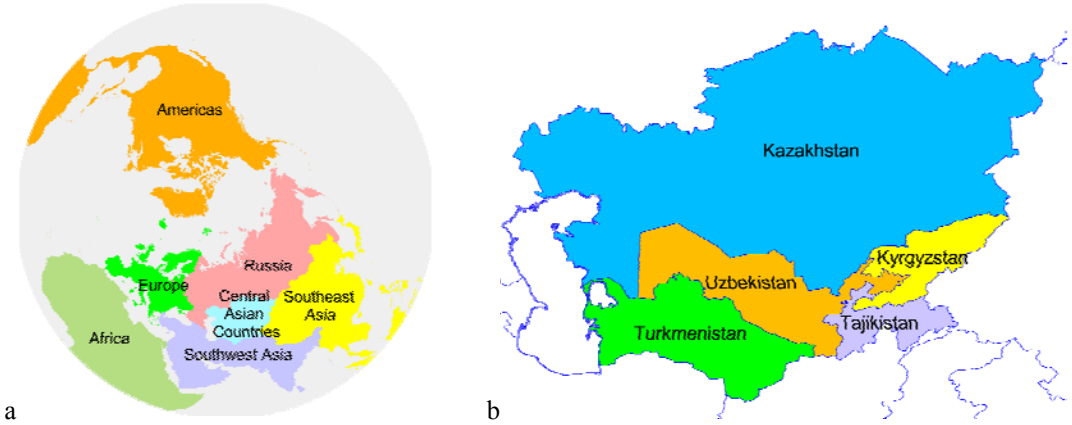


Fig. 2.11. *Mean annual PCB-153 concentrations in the upper soil layer (b), ng/g and total annual depositions of PCB-153 over the Central Asian regions for 2005, g/km^2/y*

2.2.2. Transboundary atmospheric transport

This section presents the description of evaluation of PCB-153 transboundary transport for the selected Central Asian countries, namely, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. For the evaluation of contributions to the pollution of the Central Asian countries several groups of emission sources were considered: Europe, Americas, Southwest Asia, Southeast Asia, Africa, Russia, and Central Asian countries. Selected groups of emission sources within the northern hemisphere are shown in Fig. 2.12a. In addition to the investigation of contributions of these large source groups, the contributions of national emissions of each of the five Central Asian countries were evaluated (Fig. 2.12b).

To evaluate the contributions of particular emission source to the pollution of selected five Central Asian countries separate model runs were made for each of the selected groups of emission sources. On the basis of obtained modelling results the distribution of PCB-153 depositions between the selected regions (Fig. 2.12) was evaluated.



a b

Fig. 2.12*. Groups of emission sources within the northern hemisphere selected for the evaluation of PCB-153 transboundary transport (a) and the Central Asian countries (b)*

Contributions of major hemispheric emission sources

Total annual depositions of PCB-153 over the territory of the Central Asian countries for 2005 were estimated to approximately 1 tonne. These depositions are comprised from contributions of emissions of 2005 from selected groups of emission sources and re-emission of PCB-153 accumulated in environmental compartments during previous years. For PCB-153, due to its physical-chemical properties, the accumulation in soil compartment is rather significant. In particular, re-emission of PCB-153 within the northern hemisphere contributes to the total annual depositions over the Central Asian countries almost 74%. Contribution of PCB-153 emitted from emission sources in 2005 is accounted for about 26%. The analysis of contributions to annual PCB-153 depositions for 2005, presented further in this section, considers the part of total annual depositions originated from the emissions of 2005.

The contributions of selected groups of sources to annual depositions of PCB-153 to the entire Central Asian region are given in Fig. 2.13a. It can be seen that about 60% of PCB-153 deposited to the territory of the Central Asian countries is originated from external emission sources. Thus, PCB emission sources of European region contribute about 24% to the depositions over the Central Asian countries. Contributions of Russia, Southwest Asia, and Americas amounted to 23%, 8%, and 4%, respectively. Thus European region and Russian Federation can be considered as the most important external emission sources of PCBs for the Central Asian region as a whole.

The Fig. 2.13b characterizes the transboundary transport of PCB-153 from the emission sources of the Central Asian countries and distribution of depositions to the selected receptor regions for 2005. More than 60% of PCB-153 emitted from the Central Asian emission sources is deposited over the territories of these countries. About 17% is deposited over the Southwest Asia, 12% over the Russia, and 10% to other receptor regions. It can be seen that emission sources of the Central Asian countries provide the most significant contributions to the pollution of Southwest Asia and Russia among other neighboring regions.

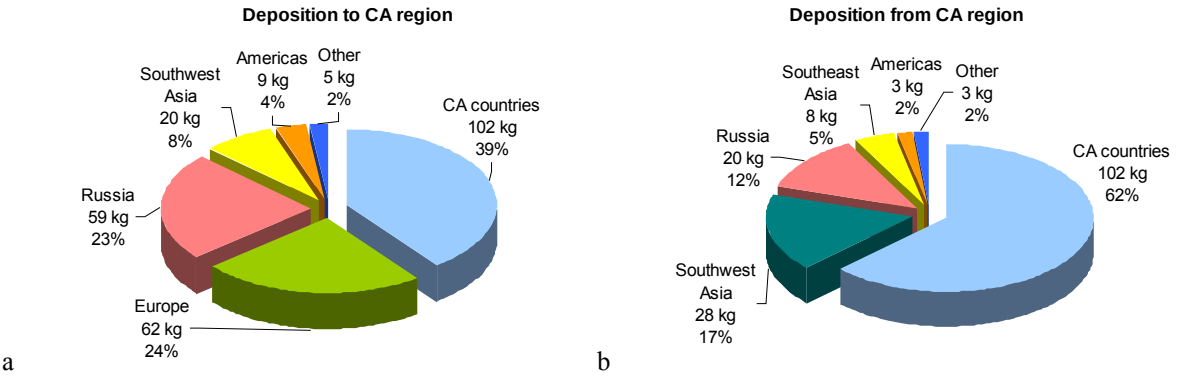


Fig. 2.13. *Contributions of selected groups of emission sources to annual PCB-153 depositions over the Central Asian countries (a) and distribution of total annual depositions of PCB-153 from emission sources of the Central Asian countries within the northern hemisphere (b) for 2005*

Transboundary transport

Kazakhstan

Total annual depositions of PCB-153 over Kazakhstan for 2005 were estimated to 0.7 tonnes. The contribution of emissions of 2005 to the total annual PCB-153 depositions over the Kazakhstan is accounted for 24% (0.16 t). Other 76% of total annual depositions belong to re-emission. As it is seen from Fig. 2.14a major contribution to the depositions from emissions of 2005 belongs to Russian emission sources (31%) due to neighboring of Kazakhstan with southern regions of Russian Federation. The European emission sources also provide essential contribution to the deposition of PCB-153 over Kazakhstan territory (28%). Own sources of Kazakhstan contribute to the annual total depositions 21%.

Among the Central Asian countries essential contribution belongs to emission sources of Uzbekistan (7%). Kyrgyzstan, Tajikistan, and Turkmenistan contribute 2%, 1%, and 0.4%, respectively. Contribution of other groups of emission sources within the northern hemisphere is accounted for 10%.

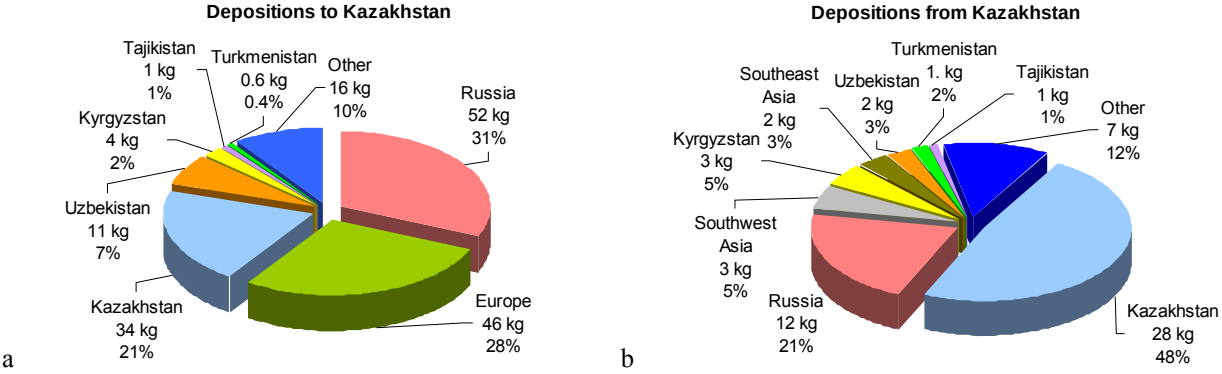


Fig. 2.14. *Contributions of different emission sources to depositions of PCB-153 over Kazakhstan (a) and distribution of PCB-153 depositions originated from Kazakhstan emission sources (b) for 2005*

The distribution of PCB-153 annual depositions from Kazakhstan emission sources over the selected receptor regions within the northern hemisphere is shown in Fig. 2.14b. Annual PCB-153 emission from Kazakhstan sources in 2005 is accounted for 0.05 tonnes. Almost half of PCB-153 emitted in Kazakhstan in 2005 (48%) is deposited over its own territory. Depositions to other regions are distributed as follows: 23% over Russia, 5% over Southwest Asia, and 3% over Southeast Asia. Depositions to other Central Asian countries, namely, Kyrgyzstan, Uzbekistan, Turkmenistan, and Tajikistan account for 5%, 3%, 2%, and 1% of annual Kazakhstan emission respectively. The share of depositions to other regions amounted to 12%.

Kyrgyzstan

Computed total annual PCB-153 depositions over Kyrgyzstan for 2005 accounted for 0.07 tonnes. Emissions of 2005 contributed to the total annual PCB-153 depositions in Kyrgyzstan 34% (0.02 t). Other 66% of total annual depositions are comprised by re-emission. The most significant contributions to the depositions from emissions of 2005 (Fig. 2.15a) belong to Uzbekistan (32%), Kyrgyzstan (20%), and Kazakhstan (14%). The European region and Southwest Asia contribute to PCB-153 depositions 13% and 7%, respectively. Contribution of other countries and groups of emission sources is less than 15%. Noticeable contribution belongs to the emission sources of Tajikistan (5%).

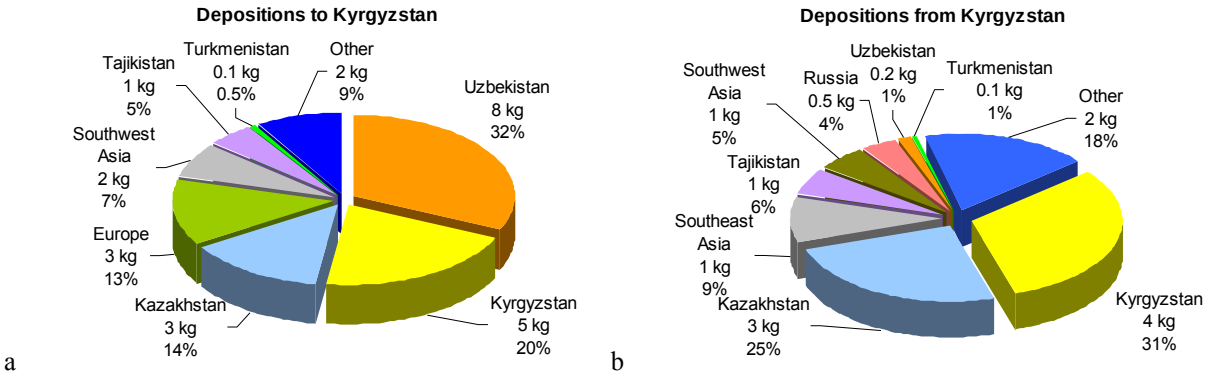


Fig. 2.15. *Contributions of different emission sources to depositions of PCB-153 over Kyrgyzstan (a) and distribution of PCB-153 depositions originated from Kyrgyzstan emission sources (b) for 2005*

Annual depositions of PCB-153 from Kyrgyzstan emission sources over the selected receptor regions within the northern hemisphere are given in Fig. 2.15b. Annual PCB-153 emission from Kyrgyzstan sources in 2005 is accounted for 0.01 tonnes. 31% of this emission is deposited over the territory of Kyrgyzstan. Other 69% of annual Kyrgyzstan emission is transported outside. In particular, 25% is deposited over Kazakhstan, 9% over Southeast Asia, 5% over Southwest Asia, and 4% over Russia. Depositions to other Central Asian countries are distributed as follows: 6% over Tajikistan, 1% over Uzbekistan, and 1% over Turkmenistan. Depositions to other regions accounted for 18%.

Tajikistan

PCB-153 total annual depositions over Tajikistan for 2005 amounted to 0.04 tonnes. The contribution of emissions of 2005 to the total annual PCB-153 depositions to Tajikistan amounted to 37% (0.01 tonnes). Other 63% of total annual depositions belong to re-emission. Essential contributions (Fig. 2.16a) to the depositions from emissions of 2005 belong to Uzbekistan (42%), Tajikistan itself (16%), and Europe (12%). The Southwest Asia contributes to PCB-153 depositions over Tajikistan about 10%. Contributions of Kyrgyzstan, Kazakhstan, and Turkmenistan, are 6%, 5%, 0.7%, respectively. Other emission sources of the northern hemisphere contribute 8% to total annual depositions over Tajikistan.

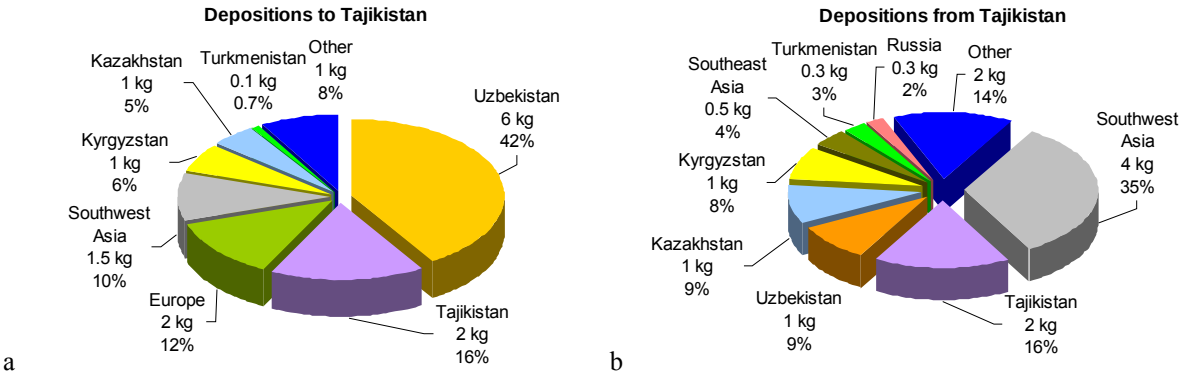


Fig. 2.16. *Contributions of different emission sources to depositions of PCB-153 over Tajikistan (a) and distribution of PCB-153 depositions originated from Tajikistan emission sources (b) for 2005*

The distribution of PCB-153 annual depositions from Tajikistan emission sources within the northern hemisphere is shown in Fig. 2.16b. Annual PCB-153 emission from Tajikistan sources in 2005 is accounted for 0.01 tonnes. 16% of PCB-153 emitted from Tajikistan sources is deposited over its own territory. Depositions to other regions are distributed as follows: 35% over Southwest Asia, 4% over Southeast Asia, and 2% over Russia. Depositions to other Central Asian countries, namely, Uzbekistan, Kazakhstan, Kyrgyzstan, and Turkmenistan, account for 9%, 9%, 8%, and 3% of annual Tajikistan emission respectively. 14% is deposited to other regions of the northern hemisphere.

Turkmenistan

Total annual PCB-153 depositions over Turkmenistan for 2005 amounted to 0.11 tonnes. The contribution of emissions of 2005 to the total annual PCB-153 depositions to Turkmenistan amounted to 28% (0.03 tonnes). Contribution of re-emission to total annual depositions is accounted for 72%. Emission sources mostly contributed to the depositions over Turkmenistan from emissions of 2005 are as follows: Southwest Asia (27%), Europe (22%), and Uzbekistan (14%). Depositions from emission sources of Turkmenistan itself accounted for 11%. Other Central Asian countries, namely, Kazakhstan, Tajikistan, and Kyrgyzstan, contributed 4%, 1, and 0.3% to the total depositions. Contribution of other countries and groups of emission sources is 16%.

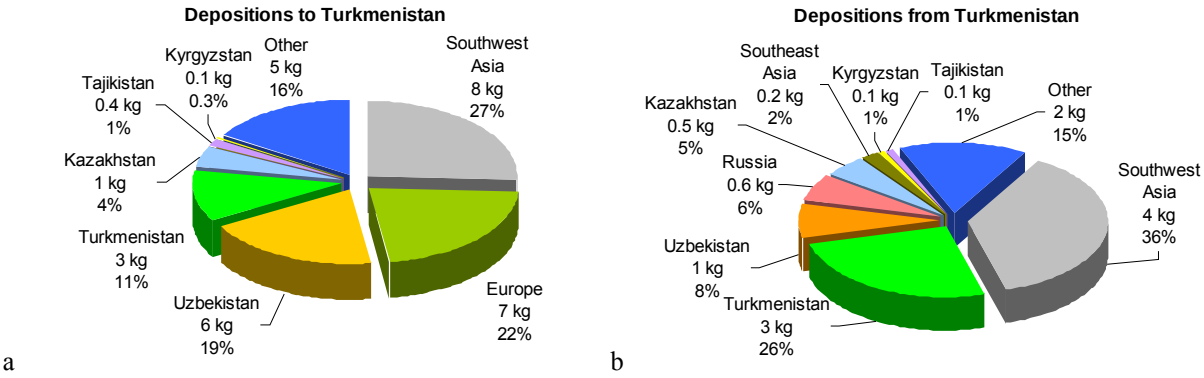


Fig. 2.17. *Contributions of different emission sources to depositions of PCB-153 over Turkmenistan (a) and distribution of PCB-153 depositions originated from Turkmenistan emission sources (b) for 2005*

Distribution of annual PCB-153 depositions originated from Turkmenistan emissions over the selected receptor regions is presented in Fig. 2.17b. Annual PCB-153 emission from Turkmenistan sources in 2005 is accounted for 0.01 tonnes. About quarter of Turkmenistan emission in 2005 (26%) is deposited over its territory. 36% is deposited over Southwest Asia, 6% over Russia, and 2% over Southeast Asia. Depositions to other Central Asian countries accounted for 8% over Uzbekistan, 5% over Kazakhstan, 1% over Kyrgyzstan, and 1% over Tajikistan. The contribution of depositions to other regions amounted to 15%.

Uzbekistan

Computed total annual PCB-153 depositions over Uzbekistan for 2005 accounted for 0.08 tonnes. Emissions of 2005 contributed to the total annual PCB-153 depositions in Uzbekistan 32% (0.02 tonnes). Re-emission is responsible for other 68% of total annual depositions. The most significant contributions to the depositions over its territory from emissions of 2005 are shown in Fig. 2.18a. As it can be seen the most significant contribution to the depositions belongs to emission sources of Uzbekistan itself (40%). Contribution of other Central Asian countries to the depositions over Uzbekistan amounted to about 18%. In particular, emission sources of Kazakhstan contributed 8%, of Tajikistan - 5%, of Turkmenistan - 4%, and of Kyrgyzstan - 0.8%. The European region and Russia contribute to PCB-153 depositions 19% and 11%, respectively. Contribution of other countries and groups of emission sources is about 12%.

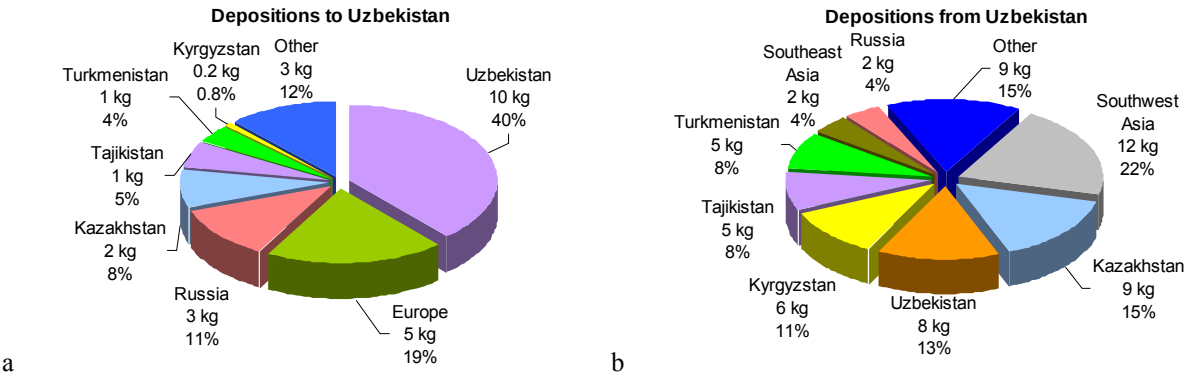


Fig. 2.18. *Contributions of different emission sources to depositions of PCB-153 over Uzbekistan (a) and distribution of PCB-153 depositions originated from Uzbekistan emission sources (b) for 2005*

Annual PCB-153 emission from Uzbekistan sources in 2005 is accounted for 0.05 tonnes. The distribution of annual depositions of PCB-153 within the northern hemisphere emitted from Uzbekistan emission sources is shown in Fig. 2.18b. Depositions to other Central Asian countries, namely, Kazakhstan, Kyrgyzstan, Tajikistan, and Turkmenistan, accounted for 15%, 11%, 8%, and 8% of annual Uzbekistan emission respectively. Depositions to the territory of Uzbekistan from its own emission sources are accounted for 13%. Depositions to other regions are distributed as follows: 22% over Southwest Asia, 4% over Southeast Asia, and 4% over Russia. About 15% of Uzbekistan emission is deposited to other regions of the northern hemisphere.

CONCLUSIONS

Model assessment of atmospheric pollution of the Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) by lead and PCB-153 has been performed for the year 2005. Particularly, concentrations of the pollutants in the ambient air and their depositions have been evaluated and atmospheric transboundary transport has been assessed. Lead pollution levels were simulated with the regional heavy metal model MSCE-HM, whereas hemispheric version of the MSCE-POP model was used for evaluation of PCB-153 pollution. The calculated levels of lead and PCB-153 were verified via comparison with the available measurement data. The main conclusions of this work are summarized below.

Model assessment of lead pollution levels in Central Asia

- In order to carry out model assessment of lead pollution levels over the Central Asian region, the EMEP model domain was extended. Necessary input information for the extended domain (namely emissions, meteorological data, land-cover and soil properties) was collected and processed. Evaluation of modelling results vs. available observations demonstrates that the model satisfactory reproduces pollution levels both in Europe and in Central Asia.

- According to the model estimates concentration and deposition levels in the Central Asian countries are somewhat lower than those in Europe. The highest country-averaged concentrations of lead in air are in Uzbekistan (4.6 ng/m^3), and the lowest – in Kyrgyzstan (2.1 ng/m^3). In contrast, Kyrgyzstan is characterized by the highest average depositions (0.9 kg/km^2/y) because of considerable precipitation in this country. The lowest average depositions are obtained for Turkmenistan (0.3 kg/km^2/y). On the other hand, spatial variation of concentration and deposition levels over territories of the Central Asian countries is very large and exceeds an order of magnitude.

- Modelled concentrations and depositions in Kazakhstan, Turkmenistan and Uzbekistan exhibit distinguished seasonal variability reaching maximum values in winter and minimum in summer. In Kyrgyzstan and Tajikistan the seasonal variation of pollution levels is less pronounced because of more complicated atmospheric circulation in the mountainous regions.

- 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. Among them up to 30% of depositions come from the neighbouring Central Asian countries and the most significant contributors of them are Kazakhstan and Uzbekistan. On the contrary, contribution of European sources to depositions in Central Asia is minor and does not exceed few percents.

- 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.

- Contribution of the transboundary transport significantly varies over territories of each Central Asian country. The highest transboundary pollution is characteristics of areas located close to

boundaries of a country. The lowest contribution of the transboundary transport characterizes depositions in the vicinity of large national emission sources.

- 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. 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.

Model assessment of PCB-153 pollution levels in Central Asia:

- Evaluation of pollution of the Central Asian countries by PCBs for 2005 was exemplified by the modeling of long-range transport and depositions of indicator congener PCB-153. Computed annual mean concentrations of PCB-153 reasonably correlate with the levels of concentrations measured at EMEP monitoring sites. At the same time, the model overestimates measured values of concentrations by about a factor of 3, which can be caused by the usage of maximum estimates of PCB emissions.

- Computed levels of PCB-153 in air within the Central Asian region are significantly lower comparing to regions with high PCB-153 emissions (Europe, North America). Annual mean concentrations in air for the Central Asian countries are in the range 1-4 pg/m^3. Relatively high air concentrations (1.5-3 pg/m^3) are noted for the western parts of Kazakhstan, Turkmenistan, and eastern part of Uzbekistan. Lowest levels of concentrations are the characteristic of eastern Kazakhstan, Kyrgyzstan, and Tajikistan (about 1 pg/m^3 and below).

- The pattern of PCB-153 deposition fluxes correlates with the distribution of emission sources in the Central Asia countries. Elevated levels (0.25-0.5 g/km^2/y) can be seen in populated regions, in particular, northern Kazakhstan, eastern part of Uzbekistan, Kyrgyzstan, and Tajikistan. Lowest levels of depositions (0.1-0.25 g/km^2/y and below) are characteristic of the southern part of Kazakhstan, western Uzbekistan, and northern part of Turkmenistan.

- Total annual depositions of PCB-153 over the Central Asia countries for 2005 are estimated to approximately 1 tonne. The contribution of PCB-153 emitted from emission sources in 2005 is accounted for about 25%. Significant contribution to total annual depositions (75%) is made by re-emission of PCB-153 within the Northern Hemisphere as a result of its long-term accumulation in environmental compartments.

- Among the emission sources of 2005 the European region and the Russian Federation can be considered as the most important external sources of PCB emission for the Central Asian countries. The contribution of European emission sources varies for the individual Central Asian countries from about 10% to 30%. Emission sources of the Russian Federation contribute most significantly to depositions over Kazakhstan and Uzbekistan (about 30% and 10%, respectively). Among the Central Asian countries Kazakhstan and Uzbekistan most significantly contributes to the pollution of Central Asian region by PCB-153.

- More than 60% of PCB-153 emitted from the Central Asian emission sources is deposited over the territories of these countries. About 17% is deposited over the Southwest Asia, 12% over the Russia, and 10% over other receptor regions.

It should be noted that the presented above analysis of airborne pollution of the Central Asian countries is mostly based on emission data obtained from expert estimates because national information on anthropogenic emissions is not available at the moment. Besides, monitoring data which can be used for the models evaluation are scarce. Therefore, development of national emissions inventories in the Central Asian countries and a background monitoring system in this region could markedly improve quality of the assessment. It is particularly relevant in connection with plans to include these countries to the EMEP operational activity since 2008.

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Annex A

COUNTRY-TO-COUNTRY LEAD DEPOSITION MATRIX FOR 2005

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

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

Table A.2*. Matrix of lead country-to-country depositions from anthropogenic sources in 2005, kg/y*

Receptors ↓ Emitters →

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CS	CY	CZ	DE	
AL	**4242**	0.2	11.3	0.9	302.8	12.4	628.0	8.9	13.9	2800	0.5	30.3	27.9	**AL**
AM	5.6	**500.4**	0.9	406.7	8.3	1.7	20.4	4.5	1.3	22.9	6.9	2.5	3.6	**AM**
AT	46.5	0.3	**4471**	1.2	613.0	575.6	332.8	105.6	755.0	1441	0.3	1891	2953	**AT**
AZ	12.2	119.9	2.4	**2878**	18.6	5.5	49.0	16.6	3.5	53.0	12.3	7.4	11.3	**AZ**
BA	507.2	0.4	163.8	1.2	**21636**	86.9	780.7	38.5	62.6	8067	1.3	462.3	276.2	**BA**
BE	3.0	0.0	17.9	0.0	11.8	**13266**	9.4	10.2	74.5	22.9	0.0	41.3	902.4	**BE**
BG	598.7	4.0	67.1	19.9	746.4	71.2	**46349**	185.1	42.2	8284	3.7	246.4	188.7	**BG**
BY	101.4	6.2	133.8	31.6	408.6	274.9	924.3	**18518**	87.3	1320	1.9	849.0	762.1	**BY**
CH	7.2	0.0	75.7	0.3	51.0	333.5	19.6	13.4	**5033**	70.5	0.1	86.1	793.8	**CH**
CS	1587	1.1	170.5	3.9	5103	112.3	4707	76.2	69.4	**56989**	2.4	587.9	342.1	**CS**
CY	6.5	0.3	0.5	0.4	6.7	0.6	15.0	0.6	0.6	18.4	**250.3**	1.1	1.4	**CY**
CZ	19.2	0.2	803.7	1.3	284.6	596.9	182.7	153.5	282.7	856.5	0.1	**11178**	3149	**CZ**
DE	30.4	0.4	1217	2.8	212.1	13048	152.8	336.1	3595	490.2	0.4	3446	**46535**	**DE**
DK	1.3	0.0	16.6	0.1	5.6	661.4	6.3	47.9	33.1	15.5	0.0	126.9	861.3	**DK**
EE	2.8	0.2	17.9	1.3	23.0	99.0	26.6	300.0	18.1	64.1	0.1	112.6	217.7	**EE**
ES	36.5	0.1	32.3	0.3	140.7	507.5	59.0	10.1	145.3	180.4	0.1	46.1	318.4	**ES**
FI	9.7	0.8	74.4	3.7	70.4	446.5	91.2	760.3	92.5	232.4	0.3	493.9	858.8	**FI**
FR	135.4	0.2	210.0	0.9	592.5	7502	235.0	78.1	2366	766.9	0.5	387.5	4390	**FR**
GB	4.3	0.1	47.7	0.3	22.9	2725	15.2	24.1	151.4	49.0	0.0	170.9	1351	**GB**
GE	16.6	210.0	5.2	805.6	32.2	10.8	109.1	32.8	5.7	107.3	18.9	17.9	21.9	**GE**
GR	1185	2.4	35.4	11.2	540.5	51.4	5097	79.9	38.0	3138	11.8	115.1	112.0	**GR**
HR	327.4	0.3	266.2	0.9	4395	75.8	675.6	35.6	71.9	5066	0.9	466.3	253.6	**HR**
HU	161.4	0.4	423.3	1.3	2136	123.4	1073	96.2	91.5	7529	0.6	1019	456.4	**HU**
IE	0.5	0.0	2.4	0.0	2.1	149.3	1.1	1.0	16.7	3.8	0.0	6.3	93.9	**IE**
IS	0.6	0.0	1.3	0.2	1.6	39.4	2.8	3.6	7.6	3.3	0.1	7.1	45.2	**IS**
IT	1097	0.8	486.4	3.9	3348	296.4	1103	68.3	1094	3852	2.5	546.1	816.6	**IT**
KY	10.0	11.7	3.3	56.7	19.4	8.6	42.6	15.4	5.5	50.5	5.3	10.4	17.3	**KY**
KZ	96.0	136.2	55.4	927.4	219.2	144.5	716.5	541.8	66.8	718.3	32.9	216.0	301.2	**KZ**
LT	16.5	0.5	62.3	2.9	108.7	163.2	132.8	1261	47.1	304.4	0.2	372.8	449.1	**LT**
LU	0.3	0.0	2.5	0.0	1.3	296.7	0.9	1.1	13.3	2.3	0.0	4.6	128.5	**LU**
LV	10.0	0.6	41.7	3.5	75.4	166.7	88.1	790.6	36.4	205.6	0.2	246.1	412.9	**LV**
MC	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	**MC**
MD	33.2	1.1	10.5	5.0	89.4	19.1	524.0	121.5	8.3	370.4	0.9	51.0	45.4	**MD**
MK	1005	0.3	12.7	1.4	225.2	12.8	2206	13.8	10.2	3759	0.6	42.6	33.1	**MK**
MT	0.6	0.0	0.1	0.0	0.8	0.1	0.6	0.0	0.1	1.3	0.0	0.1	0.2	**MT**
NL	2.6	0.0	18.7	0.1	11.4	5976	7.5	14.8	47.8	22.3	0.0	58.5	1270	**NL**
NO	8.3	0.2	82.1	1.3	40.1	1354	66.6	155.0	129.5	144.3	0.1	439.7	1759	**NO**
PL	86.9	1.0	632.8	4.7	789.5	1545	708.6	2417	420.7	2387	0.8	8632	5996	**PL**
PT	0.8	0.0	1.2	0.0	4.1	45.8	1.1	0.6	8.4	4.2	0.0	2.1	23.1	**PT**
RO	645.4	6.4	264.0	29.7	2748	243.0	9617.0	469.1	130.2	14578	4.4	1065	693.9	**RO**
RU	643.0	445.2	556.9	3141	1922	1809	5366	14446	566.0	6052	118.1	2879	3975	**RU**
SE	12.5	0.4	99.2	2.4	52.3	1548	104.6	465.0	153.1	219.8	0.2	688.0	2616	**SE**
SI	49.7	0.1	296.3	0.5	668.8	46.6	219.8	18.5	52.9	1110	0.1	177.3	162.9	**SI**
SK	61.5	0.2	275.0	1.0	635.6	137.6	428.8	121.7	77.6	2063	0.2	1953	479.7	**SK**
TJ	3.1	5.4	1.0	24.8	6.2	2.6	13.1	5.0	1.7	15.8	2.1	3.0	5.1	**TJ**
TR	433.9	262.5	65.5	268.3	590.3	96.3	2691.7	316.5	70.3	2139	487.4	209.4	223.5	**TR**
TU	6.0	16.4	2.5	136.0	12.0	7.6	33.7	25.0	3.4	35.6	5.1	9.5	15.2	**TU**
UA	374.2	36.4	265.9	170.2	1379	493.8	4517	4043	177.3	5133	22.3	1484	1237	**UA**
UZ	8.5	17.2	3.5	106.8	17.3	9.7	45.6	33.6	4.8	49.6	4.9	12.0	19.0	**UZ**
BAS	15.1	0.6	146.2	3.6	110.4	1815	132.8	843.7	211.1	365.3	0.2	1050	3889	**BAS**
BLS	271.7	50.4	74.6	166.5	578.7	116.3	4031	571.3	57.3	2695	56.7	286.3	270.0	**BLS**
CAS	21.2	92.1	9.7	1488	44.0	23.6	160.9	84.7	10.6	152.4	14.8	33.7	44.7	**CAS**
MDT	4836	11.7	595.5	32.3	7354	766.0	7203	184.7	1069	11325	677.2	950.3	1436	**MDT**
NOS	22.9	0.5	215.6	2.7	116.6	9856	128.6	190.9	430.5	281.9	0.4	991.0	6471	**NOS**
	AL	**AM**	**AT**	**AZ**	**BA**	**BE**	**BG**	**BY**	**CH**	**CS**	**CY**	**CZ**	**DE**	

Table A.2*. Matrix of lead country-to-country depositions from anthropogenic sources in 2005, kg/y (continued)*

Receptors ↓ Emitters →

	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KY	KZ	
AL	143.3	1.4	84.7	16.2	0.6	4184	49.6	65.7	0.9	0.01	1491	0.03	33.4	**AL**
AM	14.1	0.7	5.2	1.9	144.3	167.0	1.6	2.7	0.1	0.0	30.6	0.7	454.8	**AM**
AT	433.1	9.7	893.7	351.9	1.1	313.0	387.0	1064	12.2	0.1	5100	0.04	53.5	**AT**
AZ	33.5	3.1	13.5	6.2	239.8	346.4	3.6	6.7	0.3	0.0	68.0	9.3	2922	**AZ**
BA	297.4	6.5	260.6	76.1	1.2	2174	1313	1196	3.4	0.02	3515	0.03	41.0	**BA**
BE	466.9	3.2	4452	1220	0.1	25.3	4.6	7.1	29.5	0.1	183.6	0.0	1.1	**BE**
BG	326.7	17.5	174.8	70.2	21.8	17211	138.1	480.2	3.3	0.03	1508	0.4	796.4	**BG**
BY	310.7	197.2	310.9	268.1	22.6	1171	111.8	548.3	9.6	0.1	808.1	1.2	687.5	**BY**
CH	539.1	1.7	1664	264.8	0.2	62.8	31.1	31.0	12.0	0.04	4678	0.01	4.2	**CH**
CS	337.0	10.1	266.8	96.9	4.7	4899	648.1	2116	4.3	0.03	3369	0.1	127.8	**CS**
CY	5.5	0.1	2.8	0.7	0.5	315.6	1.2	1.6	0.04	0.0	26.6	0.0	4.8	**CY**
CZ	276.8	14.7	651.7	413.9	1.0	131.3	165.2	999.4	13.1	0.1	1101	0.1	44.9	**CZ**
DE	2925	70.4	12054	5603	2.1	241.1	95.6	374.9	149.9	0.9	3076	0.1	54.0	**DE**
DK	238.1	16.3	529.7	779.7	0.1	11.0	2.2	14.8	22.8	0.2	74.7	0.01	4.5	**DK**
EE	59.4	371.7	96.4	133.4	0.8	27.7	7.8	39.4	4.9	0.04	73.3	0.1	47.8	**EE**
ES	**81023**	4.3	2935	737.8	0.2	247.3	54.3	34.1	58.7	0.2	1812	0.02	5.9	**ES**
FI	285.6	**9959**	472.8	587.3	2.8	101.7	22.0	170.1	24.8	0.3	324.0	0.6	194.3	**FI**
FR	22363	21.1	**48086**	6412	0.7	843.1	248.8	175.0	276.7	0.7	11216	0.1	22.8	**FR**
GB	2007	16.7	3251	**25166**	0.3	38.0	10.8	27.1	899.4	1.4	312.8	0.04	5.4	**GB**
GE	48.4	3.3	21.8	13.1	**2338**	555.1	7.2	19.0	0.6	0.0	113.6	1.0	867.4	**GE**
GR	378.4	7.1	206.6	58.4	10.3	**96985**	94.8	205.1	3.1	0.02	1933	0.2	353.1	**GR**
HR	269.8	5.9	259.2	61.8	1.2	1506	**3383**	1670	2.6	0.02	3980	0.04	35.1	**HR**
HU	219.4	13.3	251.0	99.0	1.9	1021	1000	**10517**	3.6	0.03	2608	0.1	48.7	**HU**
IE	417.6	1.6	348.2	1108	0.0	4.0	0.7	1.1	**1321**	0.3	29.2	0.01	0.6	**IE**
IS	143.7	8.3	61.0	136.5	0.3	12.0	0.5	0.7	14.8	**37.6**	22.9	0.01	1.8	**IS**
IT	2364	11.4	2405	307.4	2.5	7376	1347	782.7	15.6	0.1	**80777**	0.1	153.4	**IT**
KY	75.0	4.8	24.1	11.8	18.5	213.5	4.3	8.5	0.6	0.01	87.6	**12370**	21070	**KY**
KZ	490.5	119.0	253.4	188.6	297.9	2170	54.1	178.1	9.4	0.1	755.3	6982	**241029**	**KZ**
LT	139.8	115.1	177.2	163.9	1.8	136.9	37.1	139.6	6.3	0.1	331.2	0.1	70.6	**LT**
LU	50.0	0.4	462.4	56.6	0.01	2.3	0.5	0.9	1.6	0.01	25.8	0.0	0.1	**LU**
LV	102.5	214.5	158.7	192.0	1.9	77.0	24.1	89.5	7.5	0.1	220.6	0.2	94.9	**LV**
MC	0.1	0.0	0.6	0.02	0.0	0.1	0.03	0.02	0.0	0.0	3.3	0.0	0.0	**MC**
MD	48.1	7.5	31.6	18.2	7.2	775.5	16.0	65.0	0.7	0.01	179.2	0.2	169.0	**MD**
MK	88.9	1.8	48.5	13.3	1.1	9228	35.4	97.0	0.7	0.0	600.6	0.03	48.1	**MK**
MT	1.3	0.0	0.7	0.1	0.0	11.5	0.2	0.1	0.0	0.0	5.5	0.0	0.1	**MT**
NL	396.2	4.4	2346	1526	0.1	19.0	4.5	9.8	33.4	0.2	128.6	0.0	1.8	**NL**
NO	793.4	168.1	1304	3260	0.9	71.5	12.0	93.4	138.6	1.8	299.2	0.1	78.7	**NO**
PL	1149	181.7	1660	1200	5.2	769.0	367.9	1854	39.8	0.4	2477	0.3	153.3	**PL**
PT	6316	0.3	172.5	72.3	0.03	7.0	1.6	1.4	6.8	0.03	63.0	0.0	0.6	**PT**
RO	538.4	47.5	432.6	213.6	35.8	7535	533.8	2681	8.9	0.1	3446	0.6	1022	**RO**
RU	3004	5548	2348	2561	2051	12243	458.0	1752	115.0	1.8	5541	1541	199504	**RU**
SE	739.8	1491	1339	1957	1.5	109.0	16.9	164.1	71.9	0.7	380.6	0.4	127.0	**SE**
SI	117.0	2.2	131.9	34.2	0.4	272.1	756.0	429.5	1.4	0.01	2724	0.0	26.0	**SI**
SK	135.9	16.7	190.5	116.1	1.0	451.5	275.8	2645	3.9	0.04	1213	0.1	37.5	**SK**
TJ	22.8	1.2	7.3	3.4	7.2	69.8	1.3	2.4	0.2	0.0	28.4	1042	3227	**TJ**
TR	703.8	29.1	291.5	109.4	448.5	24124	120.6	287.7	5.6	0.04	2240	2.1	2073	**TR**
TU	33.0	4.9	15.0	8.2	27.0	153.9	2.6	6.5	0.4	0.0	44.2	147.3	5296	**TU**
UA	776.8	183.8	656.5	446.5	214.3	8285	353.2	1976	17.0	0.2	2740	9.0	5110	**UA**
UZ	44.6	6.7	19.8	12.1	28.1	207.4	3.9	9.2	0.6	0.01	66.5	1597	16458	**UZ**
BAS	992.4	2718	1627	1711	2.1	148.6	44.1	256.1	57.5	0.4	625.6	0.4	131.0	**BAS**
BLS	322.9	48.5	196.3	131.1	544.2	10938	121.9	391.3	6.0	0.04	1337	2.3	4767	**BLS**
CAS	65.8	10.9	41.0	29.0	200.2	580.2	10.3	33.3	1.4	0.01	149.7	107.9	18439	**CAS**
MDT	16823	26.4	7632	981.2	38.5	119373	2052	1285	47.2	0.3	56996	1.1	936.3	**MDT**
NOS	4977	145.4	10100	27848	2.5	200.6	48.2	164.8	780.4	5.7	1210.2	0.2	78.0	**NOS**
	ES	**FI**	**FR**	**GB**	**GE**	**GR**	**HR**	**HU**	**IE**	**IS**	**IT**	**KY**	**KZ**	

***Table A.2**. Matrix of lead country-to-country depositions from anthropogenic sources in 2005, kg/y (continued)*

Receptors ↓ Emitters →

	LT	LU	LV	MC	MD	MK	MT	NL	NO	PL	PT	
AL	0.8	0.4	2.4	0.1	4.5	2480	0.02	6.4	0.4	241.4	32.7	**AL**
AM	0.3	0.1	0.7	0.0	0.8	15.9	0.02	1.0	0.1	26.4	4.8	**AM**
AT	10.7	25.3	25.6	0.5	9.9	144.3	0.2	274.1	7.6	7496	129.2	**AT**
AZ	1.2	0.2	3.0	0.01	2.1	35.7	0.05	3.2	0.5	81.8	11.8	**AZ**
BA	5.8	2.7	17.0	0.3	11.0	609.0	0.1	50.3	3.0	2984	81.2	**BA**
BE	2.8	104.8	11.5	0.1	0.3	6.1	0.1	1313	4.0	347.7	132.0	**BE**
BG	12.0	1.9	25.3	0.2	170.6	4596	0.2	42.9	3.2	2295	99.6	**BG**
BY	531.0	6.2	555.7	0.1	127.4	342.8	0.9	200.8	24.7	17210	111.8	**BY**
CH	1.8	16.7	4.1	0.8	0.7	13.1	0.05	121.7	1.8	525.1	123.7	**CH**
CS	9.1	3.3	24.3	0.3	38.9	4591	0.1	63.3	4.2	4121	92.3	**CS**
CY	0.05	0.02	0.1	0.0	0.3	15.9	0.0	0.3	0.02	9.2	1.2	**CY**
CZ	18.0	18.9	46.7	0.2	8.9	64.1	0.3	397.7	13.3	27587	81.7	**CZ**
DE	76.1	543.6	268.8	0.8	10.2	73.6	1.3	8475	76.6	22275	854.2	**DE**
DK	11.7	7.7	46.8	0.03	0.5	3.1	0.2	567.3	18.8	1642	113.5	**DK**
EE	109.9	1.9	620.7	0.02	3.5	9.8	0.4	80.9	17.7	2045	18.1	**EE**
ES	3.1	13.6	11.9	0.5	0.8	61.8	0.2	190.6	3.6	335.1	16161	**ES**
FI	181.7	8.6	821.3	0.1	12.4	34.1	5.9	315.1	173.0	8135	61.8	**FI**
FR	17.7	362.2	67.1	11.3	4.9	224.8	0.7	2066	20.8	2899	3555	**FR**
GB	6.8	34.8	30.6	0.1	0.6	9.0	1.2	1483	24.0	1603	894.2	**GB**
GE	1.8	0.3	3.8	0.01	8.7	52.7	0.1	6.5	0.5	204.5	15.6	**GE**
GR	5.6	1.4	12.2	0.2	45.8	5407	0.1	28.0	1.6	1015	77.7	**GR**
HR	5.2	2.7	15.1	0.4	10.7	414.2	0.1	41.1	2.2	2790	63.2	**HR**
HU	12.4	4.1	31.4	0.3	20.9	497.8	0.1	73.9	4.3	6256	58.6	**HU**
IE	0.4	3.3	2.2	0.01	0.0	0.8	0.2	74.4	2.0	69.0	232.5	**IE**
IS	1.0	0.8	4.7	0.01	0.1	1.5	2.6	22.0	8.4	92.8	117.0	**IS**
IT	7.8	12.0	21.4	7.1	17.6	1327	0.2	132.7	4.9	3475	447.4	**IT**
KY	1.2	0.3	3.4	0.02	1.7	29.8	0.1	4.8	1.0	111.7	27.1	**KY**
KZ	38.2	3.8	99.2	0.1	66.0	345.2	2.8	86.5	17.9	2749	170.7	**KZ**
LT	**1418**	3.4	1020	0.05	15.5	53.5	0.4	120.4	18.4	7633	52.0	**LT**
LU	0.3	**132.4**	1.1	0.01	0.0	0.6	0.0	37.5	0.2	33.7	13.5	**LU**
LV	540.8	3.1	**3525**	0.04	11.1	33.9	0.5	133.9	21.6	4532	33.8	**LV**
MC	0.0	0.0	0.0	**0.03**	0.0	0.01	0.0	0.01	0.0	0.1	0.0	**MC**
MD	6.8	0.5	13.4	0.02	**906.9**	139.7	0.1	12.0	1.0	780.0	13.3	**MD**
MK	1.3	0.4	3.3	0.1	7.8	**16015**	0.02	7.1	0.5	339.8	24.3	**MK**
MT	0.0	0.0	0.0	0.0	0.0	0.8	**0.0**	0.04	0.0	0.6	0.2	**MT**
NL	3.6	19.0	15.4	0.05	0.3	4.9	0.2	**6307**	7.2	537.6	117.4	**NL**
NO	34.6	22.3	148.1	0.1	4.9	27.7	281.8	957.2	**1940**	5062	224.0	**NO**
PL	342.7	37.2	678.2	0.4	63.1	271.8	1.5	1092	75.8	**218973**	380.1	**PL**
PT	0.2	1.1	0.8	0.02	0.04	1.2	0.02	17.4	0.3	17.4	**48738**	**PT**
RO	38.9	6.4	89.2	0.4	805.8	2616	0.5	145.9	10.0	10145	161.7	**RO**
RU	1081	40.6	2959	0.8	560.2	2318	112.0	1277	401.6	45355	997.5	**RU**
SE	131.3	26.6	754.4	0.1	13.1	42.4	5.4	1168	753.0	10662	264.6	**SE**
SI	2.0	1.8	4.9	0.2	4.1	114.1	0.02	22.6	0.8	1044	28.3	**SI**
SK	15.1	4.1	37.5	0.1	11.9	191.0	0.1	88.8	4.8	15905	39.8	**SK**
TJ	0.4	0.1	1.0	0.0	0.5	9.0	0.04	1.4	0.3	32.3	8.3	**TJ**
TR	19.0	2.7	40.1	0.2	132.0	1363	0.4	57.4	5.0	2237	189.5	**TR**
TU	1.6	0.2	4.1	0.0	1.6	19.9	0.1	4.2	0.8	116.0	11.6	**TU**
UA	194.2	12.5	367.3	0.3	1094	1462	1.8	315.1	28.5	27624	239.4	**UA**
UZ	2.1	0.3	5.4	0.0	2.4	27.6	0.1	5.5	1.1	146.7	15.9	**UZ**
BAS	397.1	32.8	3055	0.2	15.8	51.0	2.0	1399	164.7	18957	344.4	**BAS**
BLS	32.3	2.7	66.8	0.1	410.0	1099	0.5	74.6	6.8	3636	92.2	**BLS**
CAS	4.9	0.6	12.0	0.0	12.6	72.6	0.2	14.0	1.6	408.0	20.8	**CAS**
MDT	17.8	27.4	55.9	7.8	96.5	7054	0.8	360.8	17.9	6110	2065	**MDT**
NOS	56.9	94.7	245.4	0.4	6.0	61.9	7.0	8466	459.7	9794	1682	**NOS**
	LT	**LU**	**LV**	**MC**	**MD**	**MK**	**MT**	**NL**	**NO**	**PL**	**PT**	

Table A.2*. Matrix of lead country-to-country depositions from anthropogenic sources in 2005, kg/y (continued)*

Receptors ↓ Emitters →

	RO	RU	SE	SI	SK	TJ	TR	TU	UA	UZ	Total, t	
AL	324.3	37.2	1.4	20.1	89.1	0.03	270.6	0.6	112.3	0.7	**17.8**	**AL**
AM	29.2	116.2	0.4	1.3	4.8	1.6	1646	95.7	41.9	69.0	**3.9**	**AM**
AT	937.8	119.6	17.2	1166	2352	0.04	181.4	1.3	356.4	1.6	**35.1**	**AT**
AZ	72.2	664.5	1.5	2.9	12.9	21.6	1953	633.4	142.1	489.7	**11.0**	**AZ**
BA	1861	71.2	10.6	247.2	1168	0.04	513.7	1.0	311.0	1.0	**48.9**	**BA**
BE	16.5	9.5	7.9	6.3	15.4	0.0	13.5	0.0	11.8	0.1	**22.8**	**BE**
BG	13800	1228	12.3	80.8	722.0	0.5	7049	16.3	3283	17.5	**111.1**	**BG**
BY	3360	3429	141.7	104.3	1610	2.5	1169	27.3	6473	38.4	**64.1**	**BY**
CH	48.6	17.9	3.4	56.2	47.3	0.01	27.2	0.1	29.3	0.2	**14.8**	**CH**
CS	6868	203.1	15.3	209.2	2056	0.1	1277	3.3	857.3	3.3	**102.1**	**CS**
CY	15.5	8.0	0.1	0.7	2.6	0.01	617.5	0.2	9.2	0.2	**1.3**	**CY**
CZ	835.6	130.8	35.3	229.7	2618	0.1	92.1	1.2	345.6	1.7	**53.9**	**CZ**
DE	594.9	334.5	186.2	162.9	973.1	0.2	195.7	1.8	483.1	2.5	**129.8**	**DE**
DK	23.4	45.6	87.5	3.6	54.6	0.01	8.0	0.1	36.8	0.2	**6.7**	**DK**
EE	154.6	663.0	132.8	10.4	111.6	0.2	31.2	1.5	211.3	2.2	**10.3**	**EE**
ES	62.9	18.5	7.8	64.8	46.6	0.02	31.7	0.2	28.2	0.3	**105.5**	**ES**
FI	651.7	2692	1747	32.3	503.3	1.0	133.1	4.7	732.2	9.1	**34.9**	**FI**
FR	365.9	102.4	46.6	298.2	262.5	0.1	166.3	0.8	176.7	1.2	**117.1**	**FR**
GB	45.7	30.5	34.3	15.9	66.3	0.04	26.3	0.3	29.6	0.5	**40.7**	**GB**
GE	276.8	1051	1.8	6.3	36.2	2.2	5577	168.5	437.1	113.7	**13.4**	**GE**
GR	2570	460.0	5.8	51.3	295.9	0.3	7319	6.8	1118	7.9	**129.1**	**GR**
HR	1647	66.9	7.7	916.1	1466	0.04	508.2	0.8	293.0	0.9	**31.1**	**HR**
HU	5427	130.1	15.5	564.1	9244	0.07	444.6	1.3	785.4	1.5	**52.5**	**HU**
IE	3.0	2.6	2.3	0.9	2.7	0.0	2.0	0.03	1.6	0.1	**3.9**	**IE**
IS	4.0	13.3	12.3	0.7	1.9	0.01	22.5	0.1	7.8	0.1	**0.9**	**IS**
IT	1409	208.1	13.8	1578	985.7	0.1	1144	3.3	534.9	3.8	**119.6**	**IT**
KY	68.1	627.8	2.7	3.7	17.0	6355	850.1	637.9	97.2	17757	**60.8**	**KY**
KZ	2118	30585	61.0	51.2	406.9	9753	6887	4453	4758	42265	**361.9**	**KZ**
LT	577.9	633.3	115.6	44.1	389.1	0.3	114.4	2.9	617.2	4.3	**17.4**	**LT**
LU	2.0	1.2	0.6	0.8	2.1	0.0	1.2	0.01	1.2	0.01	**1.3**	**LU**
LV	413.5	778.4	153.9	28.7	249.5	0.4	85.8	3.4	496.5	5.2	**15.3**	**LV**
MC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	**MC**
MD	3785	526.6	4.8	11.1	131.9	0.2	1020.6	4.2	2379	5.1	**12.4**	**MD**
MK	594.2	61.9	1.8	17.0	132.5	0.04	434.7	1.0	185.3	1.1	**35.3**	**MK**
MT	0.6	0.2	0.01	0.1	0.2	0.0	2.4	0.0	0.3	0.0	**0.03**	**MT**
NL	15.8	13.0	10.8	5.9	22.9	0.0	10.6	0.1	16.1	0.1	**19.0**	**NL**
NO	263.1	325.0	490.6	18.1	241.5	0.2	63.6	1.6	217.4	2.3	**21.2**	**NO**
PL	3478	1105	359.4	448.1	6579	0.5	462.7	4.9	3187.3	7.2	**271.8**	**PL**
PT	2.3	1.2	0.6	1.9	2.2	0.0	1.4	0.0	1.0	0.0	**55.5**	**PT**
RO	**84726**	2232	40.4	301.2	3988	0.7	5648	29.0	8145	31.4	**166.3**	**RO**
RU	16445	**408786**	1901	439.2	4629	2341	39869	3837	45110	11684	**887.9**	**RU**
SE	493.2	962.0	**6437**	27.9	464.6	0.6	111.8	2.4	588.2	4.2	**36.8**	**SE**
SI	438.8	38.5	2.4	**3368**	498.0	0.02	96.8	0.5	122.6	0.6	**13.1**	**SI**
SK	2051	119.1	19.5	273.9	**14438**	0.1	138.7	1.1	603.4	1.3	**45.3**	**SK**
TJ	20.0	183.8	0.7	1.2	4.9	**11781**	330.0	614.3	26.7	8463	**26.0**	**TJ**
TR	5545	4069	16.5	85.0	501.6	4.0	**184984**	147.3	4443	131.2	**242.4**	**TR**
TU	58.1	716.5	2.5	2.4	14.4	1612	610.7	**5851**	149.9	7512	**22.7**	**TU**
UA	21050	13928	133.5	266.7	5247	16.1	14669	167.0	**75982**	232.7	**203.7**	**UA**
UZ	86.8	1099	3.6	3.6	19.8	7034	728.0	2611	173.4	**31302**	**62.1**	**UZ**
BAS	727.2	1787	2344	66.5	728.2	0.7	133.0	3.4	863.7	5.7	**52.2**	**BAS**
BLS	11894	8946	26.8	91.8	748.9	3.4	38821	117.4	15148	144.0	**109.5**	**BLS**
CAS	410.7	3407	5.6	9.4	69.3	269.0	2748	2334	1010	2647	**35.3**	**CAS**
MDT	5944	1258	37.5	1464	1806	1.1	41729	21.7	2614	26.8	**313.4**	**MDT**
NOS	342.6	292.6	450.5	70.5	455.2	0.2	167.5	2.8	293.7	3.9	**88.1**	**NOS**
	RO	**RU**	**SE**	**SI**	**SK**	**TJ**	**TR**	**TU**	**UA**	**UZ**	**Total, t**	

Annex B

PHYSICAL-CHEMICAL PROPERTIES AND SUBSTANCE-RELATED PARAMETERS FOR PCB-153

The values of the physical-chemical properties and degradation rates in the main environmental media (atmosphere, soil and seawater) of PCB-153 used in the simulations with the MSCE-POP model are given below.

1. Subcooled liquid vapour pressure

Temperature dependence for subcooled liquid vapour pressure (p0L, Pa) is obtained on the basis of data from [*Schenker et al.*, 2005]:

$$p_{OL} = p_{OL}^{0} \exp\left[- a_P \left(\frac{1}{T} - \frac{1}{T_0} \right) \right],$$

where T the ambient temperature, K;

T_0 = 283.15 the reference temperature, K;

p_{OL}^{0} = 7.35E-05 the value of p_{OL} at the reference temperature T_0;

a_P = 11340 the coefficient of the vapour pressure temperature dependence, K.

2. Henry's law constant

Temperature dependence of the Henry's law constant (dimensionless form) is obtained on the basis of data from [*Schenker et al.*, 2005]:

$$K'_H = \frac{K_{H0}}{RT} \exp\left[- a_H \left(\frac{1}{T} - \frac{1}{T_0} \right) \right],$$

where T the ambient air temperature, K;

T_0 = 283.15 the reference temperature, K;

R the universal gas constant, J/(mol·K),

a_H = 8501 the coefficient of Henry's law constant temperature dependence, K;

K_{H0} = 4.04E+00 the value of Henry's law constant at reference temperature T_0, Pa·m^3/mol.

3. Washout ratio

Total dimensionless washout ratio WT :

$$W_T = W_g (1 - \varphi) + W_P \varphi,$$

where $W_g = 1/K'_H$ the washout ratio of the gas phase;

$W_P = 1.5 \cdot 10^5$ the washout ratio of a substance associated with aerosol particles (experimentally determined value in [*Sweetman and Jones*, 2000]);

φ the substance fraction associated with aerosol particles in the atmosphere.

4. Degradation in the atmosphere

Degradation in the atmosphere is considered as the gas-phase reaction of pollutants with hydroxyl radicals and all other reactions are neglected. In MSCE-POP model, the degradation process in the atmosphere is expressed by the equation of the second order. Temperature dependence of degradation rate constant of the gas-phase reaction with OH-radical is taken in the form of Arrenius equation on the basis of [*Anderson and Hites*, 1996; *Beyer and Matthies*, 2001]:

$$k_{air} = A \cdot \exp(-E_a / RT),$$

where A = $8.12 \cdot 10^{-11}$ the pre-exponential multiplier; $cm^3/(molec \cdot s)$;
E_a = 15380 the activation energy of interaction with OH-radical in air, J/mol;
R the universal gas constant, J/(mol · K);
T the ambient temperature, K.

5. Degradation in soil

k_{soil} = $1.17 \cdot 10^{-9}$ [*Sinkkonen and Paasivirta*, 2000].

6. Degradation in seawater

k_{sea} = $1.6 \cdot 10^{-9}$ [*Sinkkonen and Paasivirta*, 2000].

7. Octanol-water partition coefficient

Temperature dependence of octanol-water partition coefficient ($K_{OW,}$ dimensionless) is obtained on the basis of [*Schenker et al.*, 2005]:

$$K_{OW} = K_{OW}^{0} \exp\left[a_{kow} \left(1/T - 1/T_0 \right) \right],$$

where K_{OW}^{0} = 1.28E+07 the value of K_{OW} at reference temperature T_0 = 283.15 K (10 °C),
T the ambient temperature (K),
a_{kow} = 3199 the coefficient of temperature dependence (1/°K).

8. Organic carbon-water partition coefficient

Organic carbon-water partition coefficient (K_{OC}, m^3/kg) is calculated from K_{OW} values for 25°C on the basis [*Karikhoff*, 1981]:

$$K_{OC} = 2.97E+03$$

9. Octanol-air partition coefficient

Temperature dependence of octanol-air partition coefficient ($K_{OA,}$ dimensionless) is obtained on the basis of [*Schenker et al*., 2005]:

$$K_{OA} = K_{OA}^{0} \exp\left[a_K \left(\frac{1}{T} - \frac{1}{T_0} \right) \right],$$

where T_0 = 283.15 K the reference temperature;

K_{OA}^{0} = 2.14E+10 the KOA value at the reference temperature;

a_K = 11402 the coefficient of KOA temperature dependence, K.

10. Molecular diffusion coefficients

D_A = 4.59·10-6 (cm^2/s)

D_W = 5.14·10-10 (cm^2/s)

11. Molar volume

V_{mol} = 310 cm^3/mol