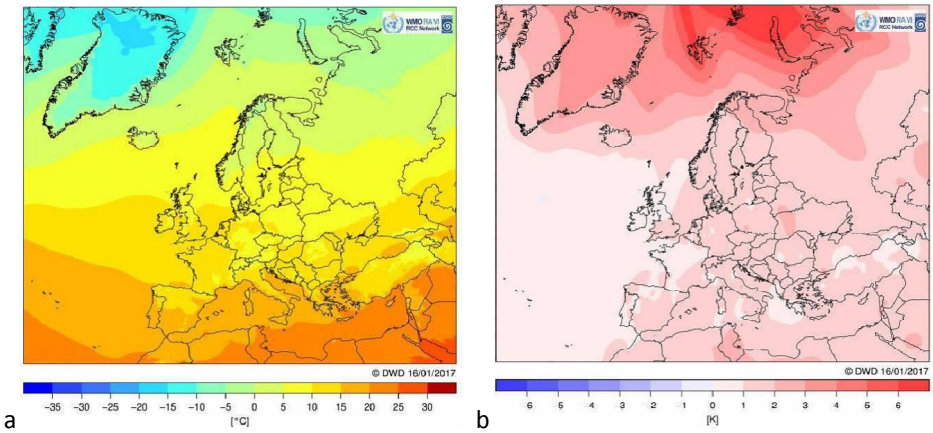
Chapter 1. INPUT INFORMATION FOR MODEL ASSESSMENT

1.1. Meteorology

Meteorological information is very important for modelling of atmospheric transport and deposition of heavy metals and POPs. In particular, wind patterns and atmospheric stability affect dispersion of the pollutants in the atmosphere. Atmospheric precipitation is responsible for wet scavenging of the pollutants. Rates of chemical reactions affecting POPs and Hg transformations depend on air temperature.

Meteorological information for modelling is generated by the WRF meteorological pre-processor (version 3.7.1) [*Skamarok et al*., 2008]. Data of atmospheric analyses at pressure levels obtained from ECMWF were used as input information. For generation of gridded meteorological parameters over the EMEP domain a nesting approach was used. Cloud microphysics is calculated using the WSM3 scheme [*Hong and Lim*, 2006]. Boundary layer parameterization is based on Mellor-Yamada-Janjic approach, which original version is described in [*Mellor and Yamada*, 1982]. The convection scheme is based on modified version of the Kain-Fritsch approach [*Kain*, 2004].

Atmospheric conditions observed in 2016 compared to the climatic levels are characterized by wide range of peculiarities and anomalies occurred in different parts of the EMEP region. In the European region this year was warmer by 0.58 °C compared to the mean value over the period from 1991 to 2010 [*WMO*, 2018]. The highest anomalies (3-6 °C) of near-surface air temperatures occurred in the Arctic region (Fig. 1.1). Over the northern part of Scandinavia the anomaly is 2-3 °C. The lowest anomalies took place in France and Ireland, north of the United Kingdom, some parts of Spain and Portugal. It is interesting to note that all annual mean anomalies over the considered region were positive.



a b

Fig. 1.1. *Mean annual temperature in °C (a) and anomalies (b) for 2016. (reference period 1961-1990, source: http://www.dwd.de/rcc-cm).*

Over most of the EMEP region annual sums of atmospheric precipitation were close to climatic mean values both in absolute (Fig 1.2a) and relative terms (Fig. 1.2b). Positive anomalies around 10-30 mm/month (from +25% to +67%) were noted for the north of Scandinavian Peninsula, the eastern part of Europe, some Balkan (Romania, Serbia, Albania) and central European countries (Hungary, Slovakia, Austria). Stronger relative anomaly (up to +150%) took place in the near-Caspian region.

Conditions drier than normal occurred in the northern part of Spain, southern regions of France and some regions of Italy, Germany and Scandinavia.

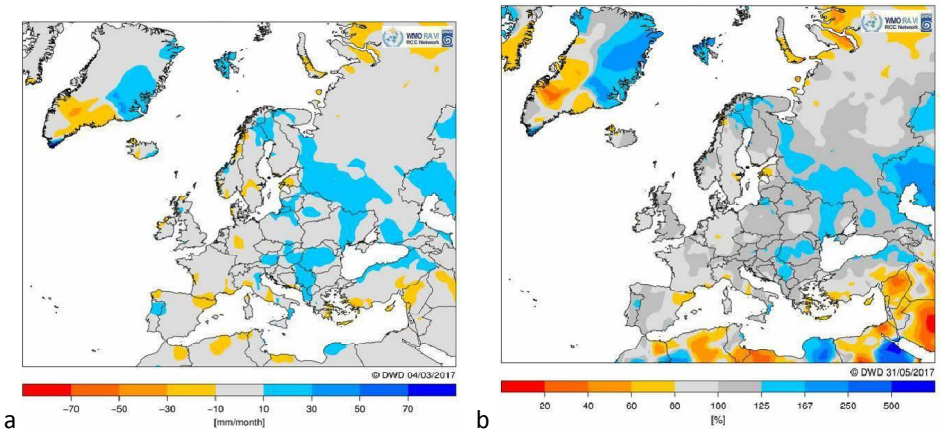


Fig. 1.2. *Absolute (a, mm/month) and relative (b, %) anomaly of annual precipitation sums in 2016 relative to climatic mean value for the period from 1961 to 1990. Source: http://www.dwd.de/rcc-cm*

Annual sums of precipitation over the EMEP region in 2016 vary considerably. Over most part of land area of the EMEP region precipitation sums range from 500 to 1000 mm/year (Fig. 1.3). In mountainous regions and along the western coasts of the temperate zone the annual sums increase up to 2000 mm/year and in some regions even exceed this value. In the northern part of the Central Asia the precipitation sums amount to 200-400 mm/year, and in the southern part, characterized by arid climate, they lie below 200 mm/year.

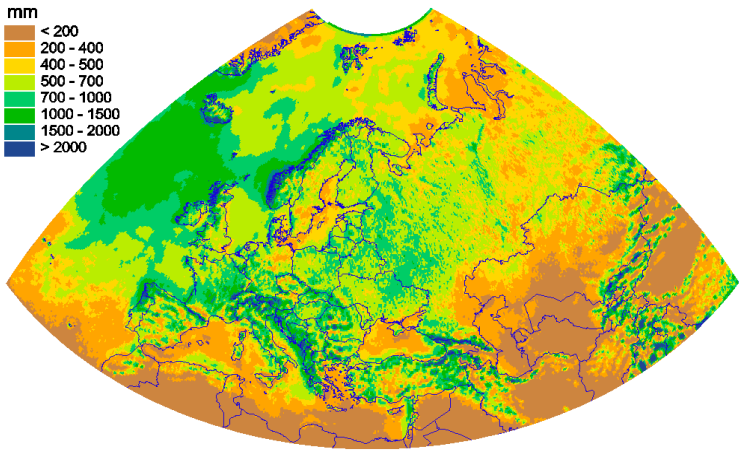


Fig. 1.3. *Annual sums of atmospheric precipitation in 2016*

Strength and direction of winds depends on spatial gradient of atmospheric pressure. In 2016 spatial distribution of annual mean sea level pressure in the European region is presented by Icelandic low extended from southern Greenland to Iceland and Azores high spreading across southern and central Europe to European Russia. Anomalies of the atmospheric pressure in 2016 are relatively low (±2 hPa) over most part of the region. Intensity of zonal component of atmospheric circulation in the middle troposphere is close to normal over most of the year, and it is somewhat lower than normal in the autumn [*HMCR*, 2018]. The meridianal component of the circulation is close to normal throughout the year.

1.2. Anthropogenic emissions

Model assessment of heavy metal pollution in the EMEP countries for 2016 has been performed for the first time over the new EMEP grid. It is based on the most recent dataset of heavy metal emissions available at the moment of the study, which was prepared by CEIP on the new EMEP grid for 2015 [*http://www.ceip.at*][2]. Detailed information on heavy metal emissions in each country, as well as the gap-filling methods that have been used for the 2015 GNFR inventory can be found in the CEIP Technical Report 01/2017 [*Tista et al.*, 2017]. The total values of heavy metal anthropogenic emissions in the EMEP countries are estimated for 2015 at 3704 t/y for Pb, 200 t/y for Cd, and 142 t/y for Hg. More detailed analysis of emission changes in the EMEP countries due to national recalculations can be found in [*Ilyin et al.,* 2017]. Spatial distributions of gridded anthropogenic emissions of Pb, Cd, and Hg are shown in Fig. 1.4. According to available data, elevated emissions of heavy metals are characteristics of Central and Southern Europe, as well as in some regions of Central Asia. Significant emissions also take place from individual large point sources located in other parts of the EMEP region.

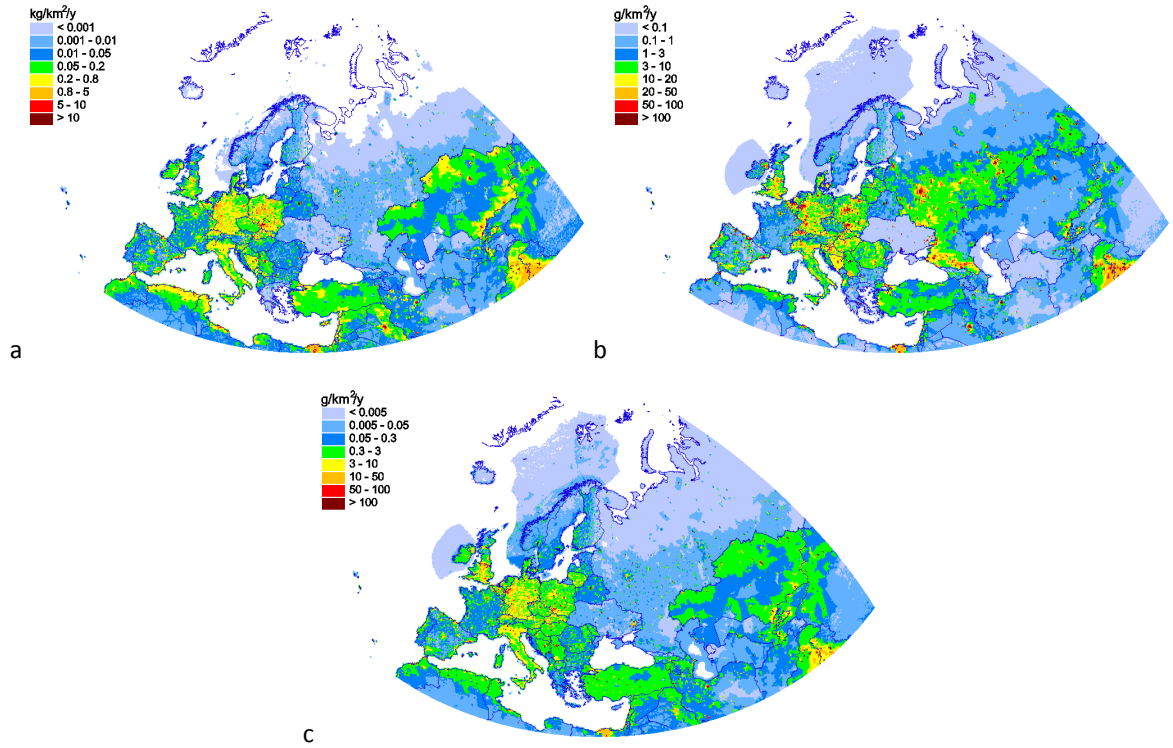


Fig. 1.4. *Spatial distributions of Pb (a), Cd (b), and Hg (c) anthropogenic emissions in 2015*

Additional emission parameters required for heavy metal modelling were prepared by MSC-E. They include seasonal variation, vertical distribution of emissions of all three metals as well as chemical speciation of Hg emissions. Seasonal variation of emissions was estimated using parameterization developed by *van der Gon et al.* [2011]. For implementation of the parameterization into the model gridded annual emissions of heavy metals from individual sectors were multiplied by sector-specific scaling factors (Fig. 1.5). The 'Public power' and 'Residential combustion' sectors are characterised by

[2] *Update of the modelling results based on the new emission data for 2016 is available at the MSC-E web site [www.msceast.org].*

maximum emissions in the cold season and minimum emissions during the warm one (Fig. 1.5a). Seasonality of industrial and transport emissions is relatively small (Fig. 1.5b). Considerable seasonal variation is characteristics of the sector 'Field burning in agriculture' with maximum during the spring cultivation period (Fig. 1.5c) but its contribution to total emissions of heavy metals in the EMEP countries is insignificant (Fig. 1.5d). Seasonal variation of emissions from other sectors was neglected.

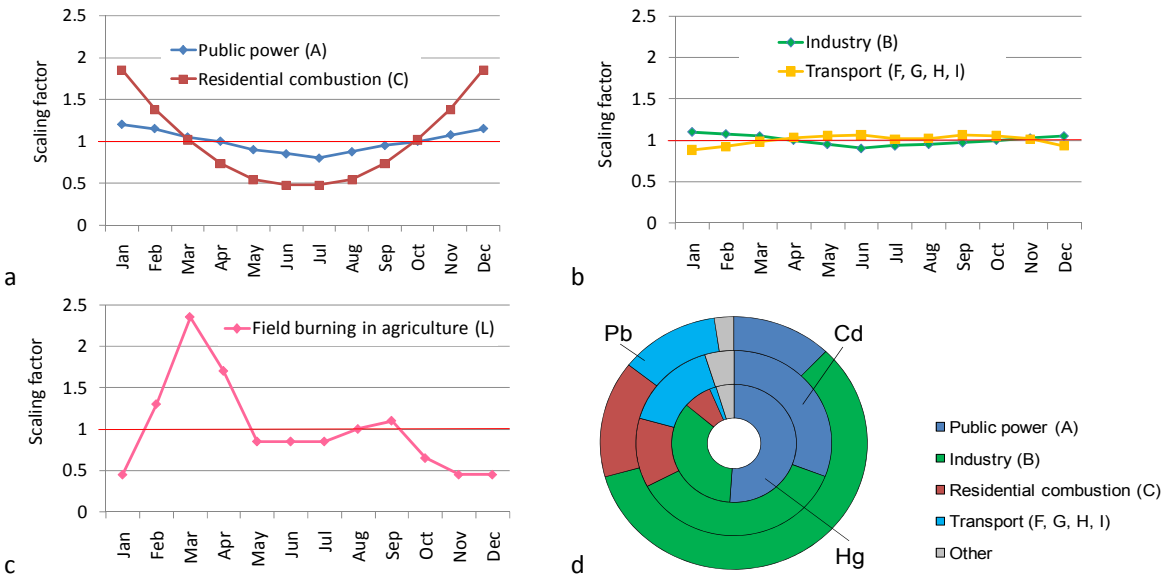


Fig. 1.5. *Seasonal variation of major sectors of heavy metal emissions (a-c) and contribution of the sectors to total emissions of Pb, Cd, and Hg in the EMEP countries in 2015 (d)*

A new scheme of emissions distribution with height was applied in the current model assessment. It is based on parameterisation suggested by *Bieser et al*. [2011] and consists of application of sector-specific vertical profiles (Fig. 1.6) derived by averaging of emission heights for various meteorological conditions and various pollutants. According to the applied approach emissions from the 'Public power' sector take place mostly at heights 300-500 m. The 'Industry' sector share emissions between 50 and 150 m. The 'Waste incineration' mostly emits heavy metals at 150-250 m. It is assumed that heavy metal emissions from other sectors occur near the ground.

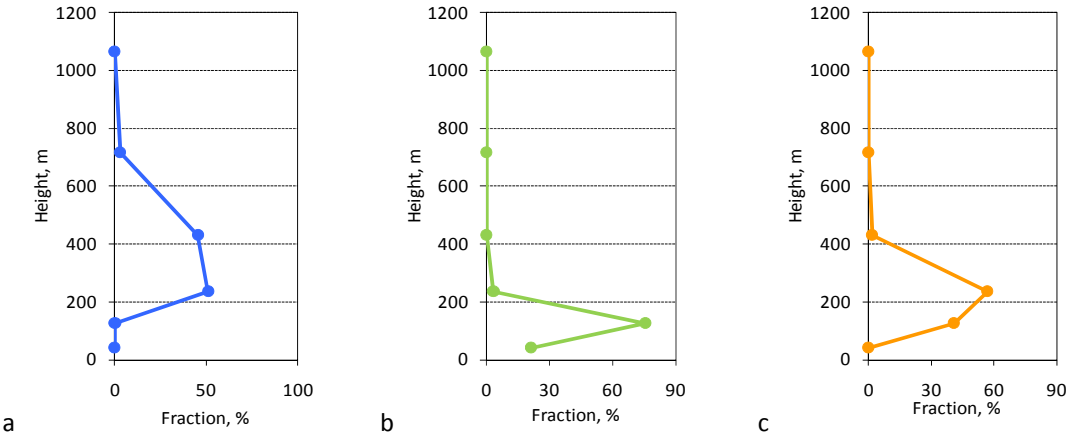


Fig. 1.6. *Vertical distribution of heavy metal emissions for selected emission sectors: (a) – Public power; (b) – Industry; (c) – Waste incineration.*

Mercury is emitted to the atmosphere in various chemical forms: elemental (Hg^0), gaseous oxidized ($HgII_{gas}$) and particulate ($HgII_{part}$). Atmospheric behaviour of Hg strongly depends on its form. The speciation of Hg emissions is not included in the information reported by the Parties to the Convention. Therefore, expert estimates of Hg emission speciation have been derived by MSC-from a global emission dataset [*AMAP/UNEP*, 2013]. According to these data about 70% (52-90%) of Hg is emitted in the EMEP countries in the elemental form. The contributions of the oxidized forms are 24% (7-38%) and 6% (0-10%) for the gaseous oxidized and the particulate forms, respectively (Fig. 1.7).

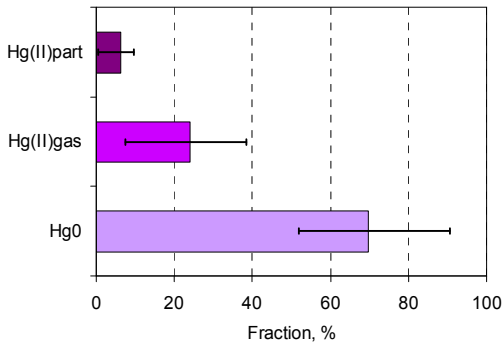


Fig. 1.7. *Chemical speciation of Hg emissions in the EMEP countries based on [AMAP/UNEP, 2013]. Bars present average values; whiskers show variation of the values among the countries.*

1.3. Secondary emissions (wind re-suspension)

Wind re-suspension is important contributor to atmospheric emissions of heavy metals in the EMEP region. It represents suspension of dust particles or sea salt aerosol from the underlying surface by action of wind. The suspended dust particles contain heavy metals (Pb and Cd) which can have natural origin or can came from the accumulation over long-term period of deposition from anthropogenic sources. Parameterization of this process used in the model is described in [*Gusev et al.*, 2006; 2007]. It is assumed that re-suspension occurs from water surface, arable lands in spring and autumn, from lands not covered by vegetation (e.g., deserts) and from urban territories. Total annual re-suspension of Pb from territories of the EMEP countries is 3700 tonnes, and Cd – 72 tonnes. On one hand, these values are comparable with the anthropogenic emissions in the EMEP countries (3704 and 200 tonnes, respectively). On the other hand, uncertainty of these estimates is high.

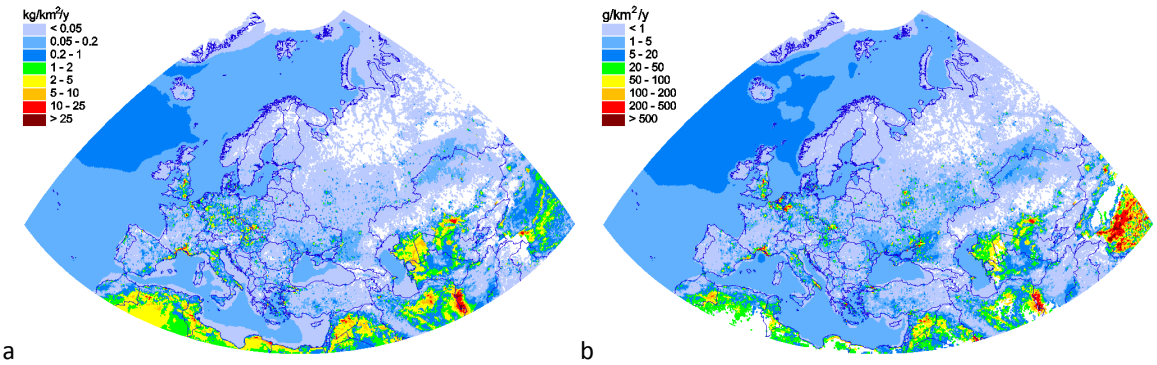


Fig. 1.8. *Wind re-suspension flux of Pb (a) and Cd (b) in the EMEP region in 2016.*

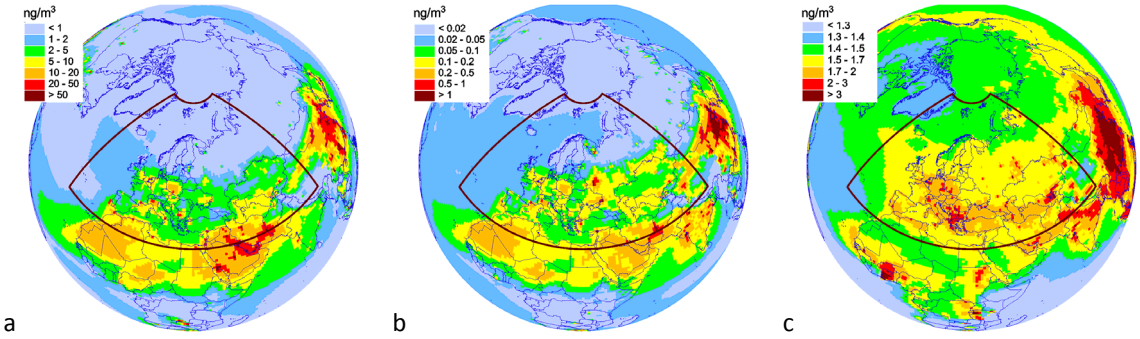
Re-suspension flux depends not only on land-cover characteristics, but also on meteorological conditions, in particular, on soil wetness and near-surface wind velocity. Therefore, this flux is highly

variable in space and time. The highest re-suspension fluxes of Pb (Fig 1.8a) and Cd (Fig. 1.8b) occur in the southern and south-eastern parts of the EMEP domain because of large areas of deserts. Besides, high levels are seen in the central part of Europe and near large cities. It is explained by assumed accumulation of the metals in soils over recent decades and by large fraction of urban territories. The lowest re-suspension fluxes take place in the northern part of the EMEP domain.

1.4. Boundary conditions for regional modelling

Lead and Cd emitted in the neighbouring regions of the EMEP domain can reach the EMEP countries. In case of Hg contribution of intercontinental transport can even exceed the contribution of the EMEP sources (see section 2.2). In order to establish concentrations of the considered metals at the EMEP boundaries global scale calculations are carried out using GLEMOS calculations on a global scale.

Global scale concentrations of Pb and Cd are the highest in the south-eastern part of Asia, mainly because of emissions in China (Fig. 1.9a and 1.9b). Besides, comparatively high levels are noted for the south-western part of Asia, Middle East and the northern part of Africa. It is explained by significant dust suspension in these regions and, hence, contribution of secondary emission sources to atmospheric concentrations. The lowest levels occur over the North Atlantic and the Arctic.



a b c

Fig. 1.9. *Global annual mean concentrations of Pb (a), Cd (b) and elemental Hg (c) in 2016. Dark frame denotes boundaries of the EMEP region.*

China, Indonesia (Asia) and Ghana (Africa) are characterized by the highest concentrations of elemental Hg mostly because of large anthropogenic emissions (Fig. 1.9c). Over other parts of the Northern Hemisphere the concentrations are distributed relatively homogeneously. Somewhat higher levels are seen at the southern and eastern boundaries of the EMEP region due to influence of anthropogenic emission sources, and partly because of natural emissions in the southern part of Europe. The lowest concentrations are noted in the Arctic.

Model concentrations of Pb, Cd and Hg at boundaries of the EMEP region strongly depend on global-scale emission data. However, present-time gridded emission data of Pb and Cd over the global scale are not available. Assumptions used to estimate these emissions give rise to uncertainties of the modelling results over the global scale, and further, in the EMEP countries. ***In order to improve quality of model assessment of concentrations and deposition in the EMEP region contemporary gridded global-scale heavy metal emissions are needed.***