Appendix D: Calculation of normalised deposition to the Baltic Sea Basin

D.1 Introduction

In the frame of co-operation between HELCOM and EMEP, estimation of atmospheric nitrogen deposition has been carried out for each year of the period 1995-2011. Annual depositions, monthly depositions, as well as annual source-allocation budgets for nitrogen deposition have been calculated using the EMEP MSC-W model. The main purpose of this appendix is a description and explanation how nitrogen deposition, source-allocation budgets and especially normalised nitrogen deposition to the Baltic Sea are calculated. We focus on nitrogen here, but normalised depositions of heavy metals and persistent organic pollutants are calculated in very similar way.

D.2 Annual deposition

The routine runs of the EMEP MSC-W model are performed every ear with updated input data for the purpose of LRTAP Convention and in the frame of co-operation between HELCOM and EMEP. The input data necessary for routine runs of the EMP model are: emissions, meteorological data and land use data. Emissions and meteorological fields must be updated each year for routine runs. The land used data are updated each time when better information about the land use is available.

Both anthropogenic and biogenic emissions are required for the EMEP MSC-W model runs. Concerning anthropogenic emissions, as much as possible, data officially reported by EMEP Contracting Parties are used for the purpose of modelling. Annual national totals for each country should be reported every year to EMEP and they are distributed to each grid cell of the model. In addition, approximately every five years, the distribution of national emissions in the EMEP gird is updated by the Contracting Parties. The main conditions for using official data are availability and quality good enough. When the officially reported data is not available or the data quality is not good enough, the expert estimates are used instead for the model runs. The procedures used for collecting anthropogenic emissions, filling-in gaps, and for spatial distribution can be found in Vestreng (2003). Emissions of eight species are necessary for routine runs of the EMEP model: SO_2, NO_x NH_3, CO, NMVOC, primary $PM_{2.5}$ and PM_{10}. These emission fields must be available and updated in the model grid for routine annual runs.

Meteorological data include both, three dimensional fields and two dimensional fields on the surface layer. Meteorological fields available in 3-D are the following: velocity, pressure, temperature and humidity. Precipitation is one example of 2-D meteorological data. The land use data include matrices with different types of land cover which are variable in space in time, especially for different seasons of the year.

Computational diagram for calculating atmospheric oxidised, reduced and total nitrogen deposition to sub-basins of the Baltic Sea and to the entire Baltic Sea Basin using the EMEP MSC-W model is illustrated in Fig. D1.

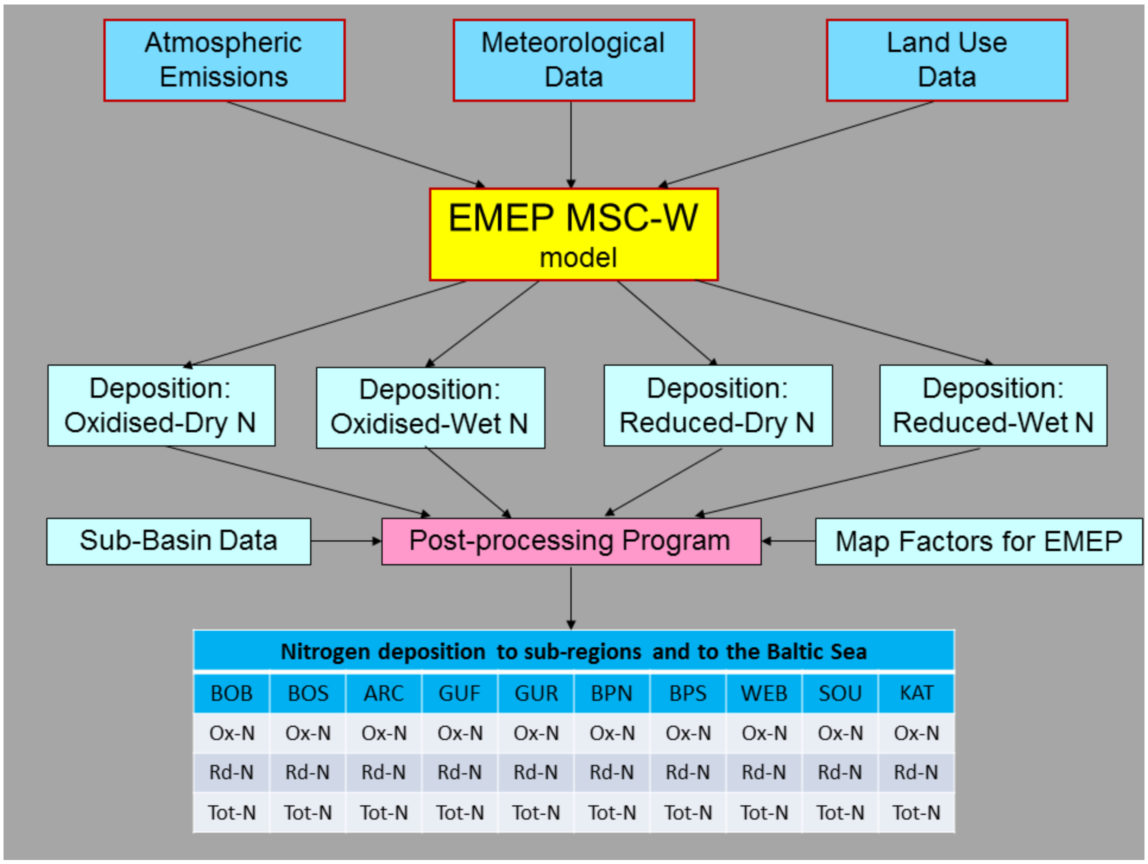


Fig. D1. Computational diagram for calculating oxidised, reduced and total nitrogen deposition to sub-basins of the Baltic Sea and to the entire Baltic Sea Basin using the EMEP MSC-W model.

Using input data with updated emissions, land use and meteorology for the current year, the EMEP MSC-W model is run to calculate annual, monthly and daily values of oxidized-dry, oxidized-wet, reduced-dry and reduced-wet nitrogen deposition (in mg N m^{-2}) in each grid square of the EMEP grid systems. Calculated annual and monthly depositions are used for the purpose of HELCOM.

Four output files from the EMEP model run, with annual nitrogen depositions are then used as input for the post-processing program. The file defining the sub-basins of the Baltic Sea in the EMEP grid and the file with map factors for the EMEP grid system are also used by the post-processing program. The output from the post-processor program includes annual total depositions (in tonnes of N) of oxidised, reduced and total (oxidised + reduced) nitrogen to each of ten sub-basins of the Baltic Sea, as requested by HELCOM. Annual depositions of oxidised, reduced and total nitrogen the entire Baltic Sea basin are calculated as the sum of depositions to all sub-basins. The deposition files shown in Fig. 1 are also used for creating annual deposition maps for HELCOM, shown in Chapter 3.

D. 3 Contributions from individual sources

The procedure for calculating contribution of individual emission sources to nitrogen deposition is a bit complicated in that sense that nitrogen deposition depends not only on nitrogen emissions, but other emissions as well (EMEP Status Report, 2006). As emission sources we consider both country sources (emissions from individual EMEP contracting Parties) and other sources (international ship emissions, volcanoes etc.). There are altogether 55 country sources and other sources which are taken into account in the EMEP model calculations every year.

To calculate the contributions from individual sources to nitrogen deposition into the Baltic Sea and its sub-basins the model is run with complete emissions first. In the next step, four model runs are performed for each contributing source. In the first run emissions of nitrogen oxides from the source under consideration are reduced by 15%. In the second run, emissions of ammonia are reduced by 15%. In the third model run, VOC emissions are reduced by 15% and finally in the fourth run emissions of VOC are reduced by 15%. Atmospheric deposition of oxidised-dry, oxidized-wet, reduced-dry and reduced-wet nitrogen is calculated for each of the model runs. The contribution of country (or other source) ***n*** to oxidised nitrogen deposition to each grid of the model domain is calculated as:

$$d_{oxdry}^{n}(i,j) = \Big[\Big(d_{oxdry}^{tot}(i,j) - d_{oxdry}^{SOx-15\%}(i,j)\Big) + \Big(d_{oxdry}^{tot}(i,j) - d_{oxdry}^{NOx-15\%}(i,j)\Big) + \Big(d_{oxdry}^{tot}(i,j) - d_{oxdry}^{NO3-15\%}(i,j)\Big) + \Big(d_{oxdry}^{tot}(i,j) - d_{oxdry}^{VOC-15\%}(i,j)\Big)\Big] \times \frac{100}{15} \qquad \text{(D1)}$$

where:

$d_{oxdry}^{n}(i,j)$ - is the contribution of source ***n*** to oxidised nitrogen deposition in the model grid square ***(i,j)***,

$d_{oxdry}^{tot}(i,j)$ - is the oxidised nitrogen deposition in model grid ***(i,j)*** calculated with all emission sources,

$d_{oxdry}^{SOx-15\%}(i,j)$ - is the deposition calculated with 15% reduction of SO_x emissions in source ***n***,

$d_{oxdry}^{NOx-15\%}(i,j)$ - is the deposition calculated with 15% reduction of NO_x emissions in source ***n***,

$d_{oxdry}^{NH3-15\%}(i,j)$ - is the deposition calculated with 15% reduction of ammonia emissions in source ***n***,

$d_{oxdry}^{VOC-15\%}(i,j)$ - is the deposition calculated with 15% reduction of VOC emissions in source ***n***.

The same procedure is used to calculate contributions of source ***n*** to oxidized-wet $d_{oxwet}^{n}(i,j)$, reduced-dry $d_{rddry}^{n}(i,j)$ and reduced-wet $d_{rdwet}^{n}(i,j)$ nitrogen deposition to each grid of the EMEP model. The contribution of the source ***n*** to nitrogen deposition into the Baltic Sea is calculated as a sum of contributions from each model grid square belonging to the Baltic Sea basin. For example, contribution of source n to oxidised nitrogen deposition into the Baltic Sea is calculated in the following way:

$$D_{oxdry}^{n} = \sum_{(i,j)\in Baltic}\left(d_{oxdry}^{n}(i,j)\times S(i,j)\right) \quad \text{(D2)}$$

Where D_{oxdry}^{n} is the contribution of source ***n*** to deposition of oxidised dry nitrogen into the Baltic Sea basin and $S(i,j)$ is the surface of the grid ***(i,j)*** belonging to the Baltic Sea basin. Similar calculations are made for contribution of source n to oxidized-wet - D_{oxwet}^{n}, reduced-dry - D_{rddry}^{n} and reduced-wet - D_{rdwet}^{n} nitrogen deposition. The most important for HELCOM are depositions of oxidised nitrogen - D_{ox}^{n}, reduced nitrogen – D_{rd}^{n} and total nitrogen - D_{tot}^{n} to the Baltic Sea basin. These depositions are defined as:

$$\begin{aligned} D_{ox}^{n} &= D_{oxdry}^{n} + D_{oxwet}^{n} \\ D_{rd}^{n} &= D_{rddry}^{n} + D_{rdwet}^{n} \\ D_{tot}^{n} &= D_{ox}^{n} + D_{rd}^{n} \end{aligned} \quad \text{(D3)}$$

The calculations described by Equations (D1)-(D3) are performed for all emissions sources in the EMEP domain in order to calculate all contributions. The sum of these contributions is equal to total deposition of nitrogen to the Baltic Sea basin.

D.4 Source-receptor matrices

Assuming linearity, or at least local linearity, the source-receptor matrices describe the relation between emissions of nitrogen in the EMEP sources and nitrogen deposition to the Baltic Sea basin. With the simplified linearity assumption, the source-receptor matrices are defined in the following as:

$$A_{ij}(iy) = \frac{D_i(iy)}{E_j(iy)} \qquad \text{(D4)}$$

where:

$E_j(iy)$ - is the annual emission from the source ***j*** in year ***iy***,

$D_i(iy)$ - is the annual deposition in the receptor ***i*** in year ***iy***,

$A_{ij}(iy)$ - is the source-receptor matrix for the year ***iy***.

The source-receptor matrix gives the amount of annual emission in the source ***j*** deposited in the receptor ***i*** for a given year. The dimension of the source-receptor matrix for a given year is $(ne \times ns)$, where ***ne*** is the number of receptors and ***ns*** is the number of emission sources. In our case, we are only interested in one receptor, namely the Baltic Sea basin and the index ***i*** can be omitted. In this case, the source-receptor matrices for oxidized and reduced nitrogen become vectors and are defined as:

$$A_i^{ox}(iy) = \frac{D_i^{ox}(iy)}{E_i^{ox}(iy)}$$
$$A_i^{rd}(iy) = \frac{D_i^{rd}(iy)}{E_i^{rd}(iy)} \qquad \text{(D5)}$$

where:

$E_i^{ox}(iy)$ - is the annual emission of nitrogen oxides from the source ***i*** in the year ***iy***,

$E_i^{rd}(iy)$ - is the annual emission of ammonia from the source ***i*** in the year ***iy***,

$D_i^{ox}(iy)$ - is the annual deposition of oxidised nitrogen from the source ***i*** in the year ***iy***,

$D_i^{rd}(iy)$ - is the annual deposition of reduced nitrogen from the source ***i*** in the year ***iy***,

$A_i^{ox}(iy)$ - is the source-receptor matrix (vector) for oxidized nitrogen the year ***iy***,

$A_i^{rd}(iy)$ - is the source-receptor matrix (vector) for reduced nitrogen for the year ***iy***.

The total nitrogen deposition to the Baltic Sea basin in the year ***iy*** can be calculated as:

$$D^{tot}(iy) = D^{ox}(iy) + D^{rd}(iy) = \sum_{i=1}^{ns1} A_i^{ox}(iy) \times E_i^{ox}(iy) + \sum_{i=1}^{ns2} A_i^{rd}(iy) \times E_i^{rd}(iy) \qquad \text{(D6)}$$

where $D^{ox}(iy)$ and $D^{rd}(iy)$ is the annual total deposition of oxidized and reduced nitrogen, respectively, to the Baltic Sea in the year ***iy***. The numbers of emission sources contributing to oxidized nitrogen deposition (***ns1***) and reduced nitrogen (***ns2***) are different in general, because some sources (e.g. ship traffic on the Baltic Sea) emit only oxidized nitrogen.

D.5 Normalised depositions

The calculated nitrogen depositions to the Baltic Sea vary from one year to another, not only because of different emissions, but because of different meteorological conditions for each year. Some model runs with constant emissions and variable meteorology performed for 12 years period (Bartnicki et al. 2010) show that calculated annual nitrogen depositions can differ up to 60% for different years. Therefore, the best way to reduce the influence of meteorology on computed annual nitrogen depositions would be to run the EMEP model with the same emissions from one particular year, but with all available different meteorological years and then average the results over the years or calculate the median depositions. The annual depositions calculated in this way can be called as "normalised" in the sense of meteorological variability. Unfortunately, the direct calculations of "normalized" nitrogen depositions are difficult, time consuming and expensive. Therefore, a simplified approach was applied using the source-receptor matrices for oxidized and reduced nitrogen, described in the previous section. The source receptor matrices differ from one year to another depending mainly on meteorological conditions. Therefore, they are often used for prediction of future depositions with a given scenario when meteorological conditions are not known. They have been also used in our approach for calculating normalised depositions to the Baltic Sea basin. In this approach, we have used the source-receptor matrices and depositions as defined in Eq. (D5-D6) and calculated for each of 17-year period 1995-2011 with available EMEP model runs. The "normalised" depositions to the Baltic Sea were calculated for oxidized, reduced and total nitrogen and for each year of the period 1995-2011. In the first step of this process, the annual depositions were calculated for each combination of meteorological and emission year:

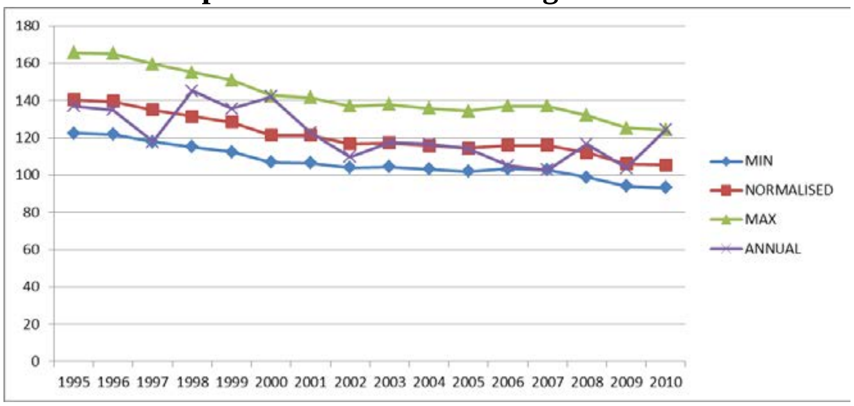
$$D^{ox}(ie,im) = \sum_{i=1}^{ns1} A^{ox}(im) \times E^{ox}(ie) + R^{ox}(ie,im)$$
$$D^{rd}(ie,im) = \sum_{i=1}^{ns2} A^{rd}(im) \times E^{rd}(ie) + R^{rd}(ie,im) \qquad \text{(D7)}$$

Terms $R^{ox}(ie,im)$ and $R^{rd}(ie,im)$ are introduce mainly because of the contribution of BIC (Initial and Boundary Conditions) in the model calculations, additional source for which emissions cannot be specified. For the Baltic Sea basin this additional source is only contributing to oxidized nitrogen deposition, so $R^{rd}(ie,im) = 0$. The normalised deposition of total nitrogen for the emission year ***ie - DN(ie)*** is defined as:

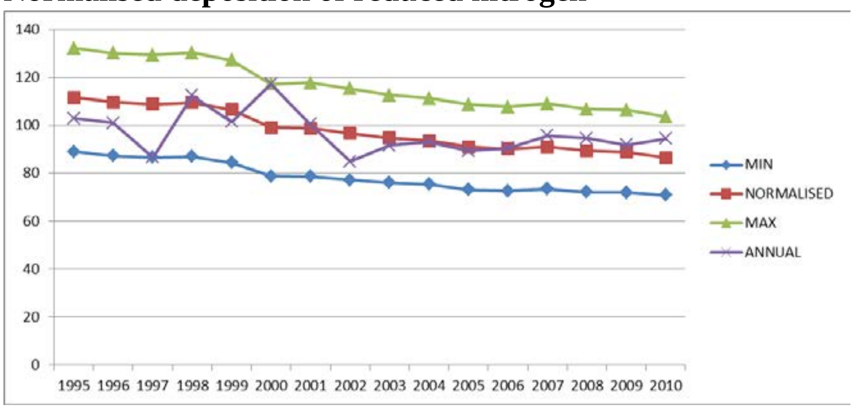
$$DN(ie) = MED\{D^{ox}(ie,1) + D^{rd}(ie,1), \ldots, D^{ox}(ie,im) + D^{rd}(ie,im), \ldots$$
$$\ldots, D^{ox}(ie,im) + D^{rd}(ie,im) \qquad \text{(D8)}$$

In Eq. (D8), MED is the median taken over 16 values which correspond to 17 meteorological years. In addition, the maximum and minimum values are also calculated for each emission year. The results of these calculations for the years 1995-2011 are shown in Figs. 3.12-3.14, for oxidised, reduced and total nitrogen deposition. The normalised depositions for nitrogen are also included in in the Indicator Fact Sheet for nitrogen deposition available on the HELCOM web site. The normalised depositions for HMs and PCDD/Fs are calculated in a very similar way to this described for nitrogen. They are included in the corresponding Indicator Fact sheets for HMs and PCDD/Fs, with the links given in Appendix C.

Normalised deposition of oxidized nitrogen



Normalised deposition of reduced nitrogen



Normalised deposition of total nitrogen

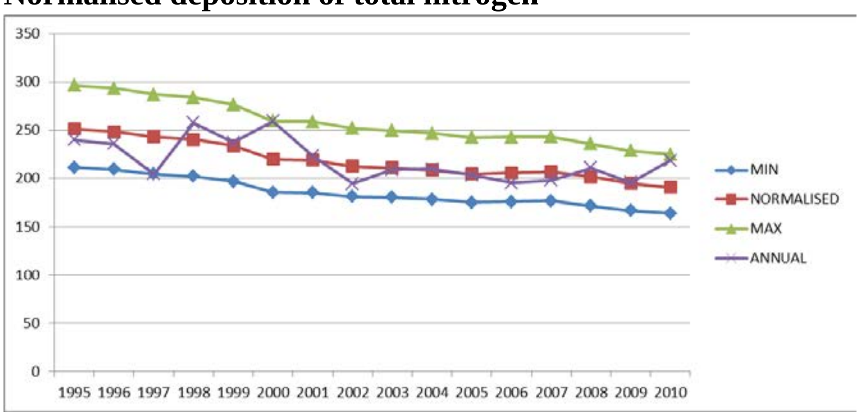


Fig. D2. Normalised depositions of oxidized, reduced and total nitrogen for the period 1995-2010. Minimium, maximum and actual annual values of the deposition are also shown.