Atmospheric nitrogen deposition to the Baltic Sea

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Key Message

In 2019, for the first time, it has been possible to calculate atmospheric nitrogen deposition to the Baltic Sea with the EMEP MSC-W model on 0.1° x 0.1° resolution for the whole period of 1995 to 2017. According to these calculations, depositions of oxidised, reduced and total nitrogen were, respectively, 36%, 1% and 23% lower in 2017 than in 1995. There is a clear decreasing trend in normalised annual total deposition of nitrogen, which is consistent with the decrease in nitrogen emissions from the HELCOM area. Normalised depositions of oxidised, reduced and total nitrogen in 2017 were 41%, 15% and 32% lower than in 1995.

Results and Assessment

Relevance of the BSEFS for describing developments in the environment

This fact sheet presents calculated trends in atmospheric deposition of oxidised, reduced and total nitrogen on the nine Baltic Sea sub-basins. The deposition of nitrogen compounds is based on the emission inventory as described in the BSEFS “Atmospheric nitrogen emissions to the air in the Baltic Sea area”.

Policy relevance and policy references

The HELCOM Copenhagen Ministerial Declaration of 2013 on taking further action to implement the Baltic Sea Action Plan reconfirmed the need of reaching good environmental status for a healthy Baltic Sea. The declaration includes nutrient reduction targets, and thus also concerns airborne nitrogen input to the Baltic Sea. The Declaration sets targets on Maximum Allowed Inputs (MAI) covering both water- and airborne inputs.

The relevant policy to the control of emissions of nitrogen oxides and ammonia to the atmosphere on a global scale is set in the framework of the UN ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). For EU member states the policy frame is set by the EU NEC and IED Directives. For the Russian Federation the corresponding policy frame is embraced by Federal Acts on Environment Protection and the Protection of Atmospheric Air. The Gothenburg Protocol (1999, and revised in 2012) states that nitrogen oxides emissions in 2020 will be reduced by between 18% and 56% in 31 countries, with respect to 2005 annual emissions. The largest relative reductions will be in Denmark (56%), United Kingdom (55%) and France (50%). Ammonia emissions will also be reduced, but by smaller percentages (1% to 24%). The largest relative reductions of ammonia emissions will be in Denmark (24%), Finland (20%) and Sweden (15%). In the European Union, the revised Gothenburg Protocol is implemented by the new EU NEC Directive 2016/2284/EU, which sets 2020 and 2030 emission reduction commitments for five main air pollutants, including nitrogen oxides and ammonia.

Assessment

Atmospheric depositions of oxidised and reduced nitrogen were computed in 2019 with the EMEP MSC-W model version rv4.33. The latest available emission data for the HELCOM countries and all other EMEP sources have been used in the model calculations presented here. Deposition trends for the period 1995-2017 were calculated on 0.1° latitude × 0.1° longitude resolution (approximately 11 km x 5.5 km at 60°N). Thanks to the new emission data submissions to the UN ECE LRTAP Convention in 2019 (see BSEFS on nitrogen emissions) it was possible, for the first time, to include the years 1995 to 1999 in calculations on this resolution. This partly explains the differences in reported percentage changes with respect to the reference year of 1995 between this year's BSEFS and last year's BSEFS. Also, the change in reported ship emissions, especially for the years 2015 and 2016, is an important reason for the changes in deposition results between this year's BSEFS and last year's BSEFS.

Both land-based emissions and emissions from shipping are included in these calculations and have been tabulated in the BSEFS on nitrogen emissions. Gridded emissions for all sea regions were calculated by the EMEP Centre CEIP using the CAMS global shipping emission dataset (Granier et al., 2019) for the years 2000 to 2017, developed by the Finish Meteorological Institute (FMI), and provided via the ECCAD emission data base (ECCAD, 2019). Shipping emissions from 1995 to 1999 were estimated using CAMS global shipping emissions for 2000, adjusted with trends for global shipping from EDGAR v.4.3.2 (JRC/PBL 2016).

Calculated annual oxidised, reduced and total nitrogen depositions to the Baltic Sea basin in the period 1995 – 2017 are shown in **Figure 1**.

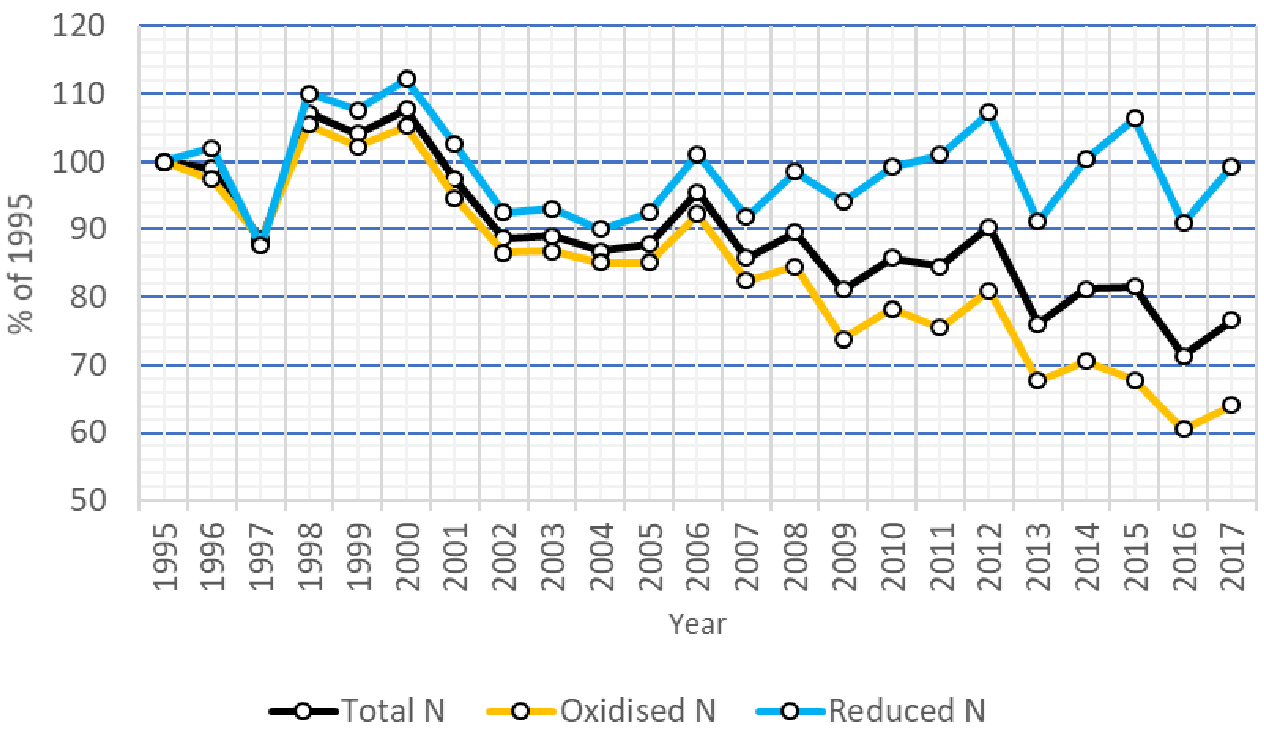


Figure 1. Atmospheric deposition of oxidised, reduced and total nitrogen to the entire Baltic Sea basin for the period 1995-2017, given as percentage of the respective 1995 values.

Large inter-annual variability in all types of nitrogen deposition to the Baltic Sea basin is seen during the considered period, and large reductions in depositions are calculated for both oxidised and total nitrogen in 2017, by 36% and 23%, respectively, as compared to the 1995 values. However, annual deposition of reduced nitrogen was only 1% lower in 2017 compared to 1995.

The annual depositions of reduced nitrogen and total nitrogen to the Baltic Sea both peaked in the year 2000 (with 119 Gg(N)/year and 320 Gg(N)/year, respectively), while the deposition of oxidised nitrogen peaked in 1998 (202 Gg(N)/year).

Mainly related to inter-annual variability in meteorological conditions, annual nitrogen deposition to the Baltic Sea and its sub-basins varies significantly from one year to another. Therefore, it has been common practice to "weather-normalize" depositions in order to filter out the inter-annual variability in meteorology. The method was described in detaile in Appendix D of Bartnicki et al. (2017). Basically, for each year we ask the question as to what the nitrogen deposition *would have been* with this year's emissions but with another year's meteorology. For each year, we thus calculate the depositions for all other meteorological years. Currently we have data for 23 different meteorological years, i.e. for each year we obtain 23 different deposition values. We define the median among those as the *normalized deposition*, but in addition report the minimum and the maximum value for each year (**Figure 2**). The trend in the normalized deposition largely reflects the trend in emissions and thus is most policy-relevant, while the deposition values in Figure 1 show the actual deposition values based on the respective years actual meteorology.

A quick inspection of Figure 2 indicates a clearly decreasing pattern in normalised annual total deposition of nitrogen, which corresponds to the generally decreasing trend in nitrogen emissions in the HELCOM area that is most relevant for nitrogen deposition on the Baltic Sea. Normalised depositions of oxidised, reduced, and total nitrogen in 2017 were 41% and 15% and 32%, lower than in 1995.

Calculated annual total nitrogen deposition to the nine sub-basins of the Baltic Sea in the period 1995 – 2017 are presented in **Figure 3**. For convenience, the definitions of the sub-basins along with a map of the Baltic Sea area are given in **Figure 4**.

Annual deposition of oxidised nitrogen is clearly lower (by 33 to 42%) in 2017 than in 1995 in all sub-basins. The decrease is particularly large in the BOP (42%), ARC (41%), and BOS (40%). Also the deposition of total nitrogen is lower in 2017 compared to 1995, ranging from 11% (WEB) to 36% (BOB). Annual deposition of reduced nitrogen is higher in 2017 than in 1995 in four out of the nine sub-basins, and in particular in those located in the western Baltic Sea: WEB (17%), KAT (8%), and SOU (9%). It is lower in the other five sub-basins, ranging from 13% (GUR) to 22% (BOB). There is a significant inter-annual variability in annual nitrogen deposition to individual sub-basins.

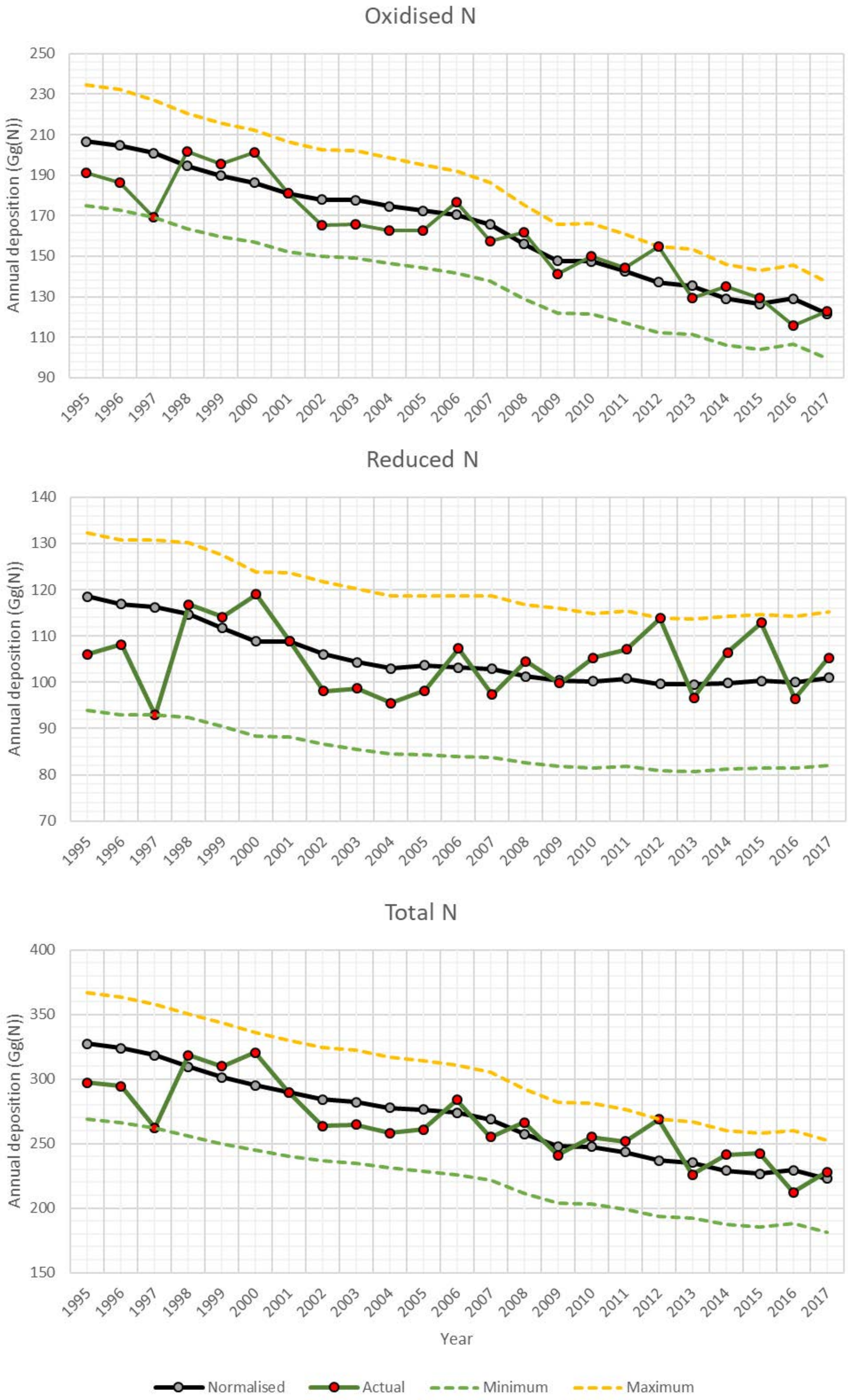
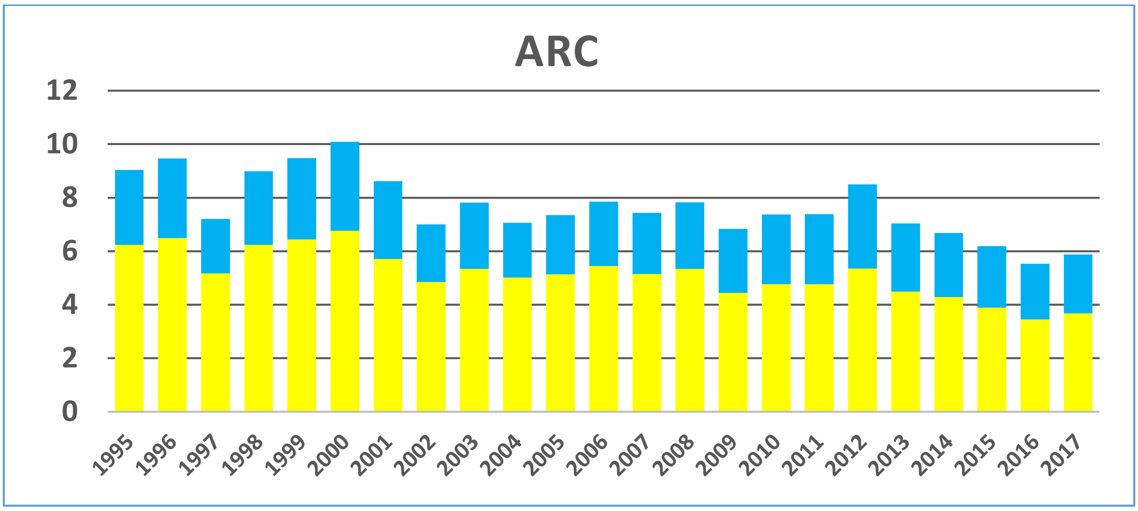
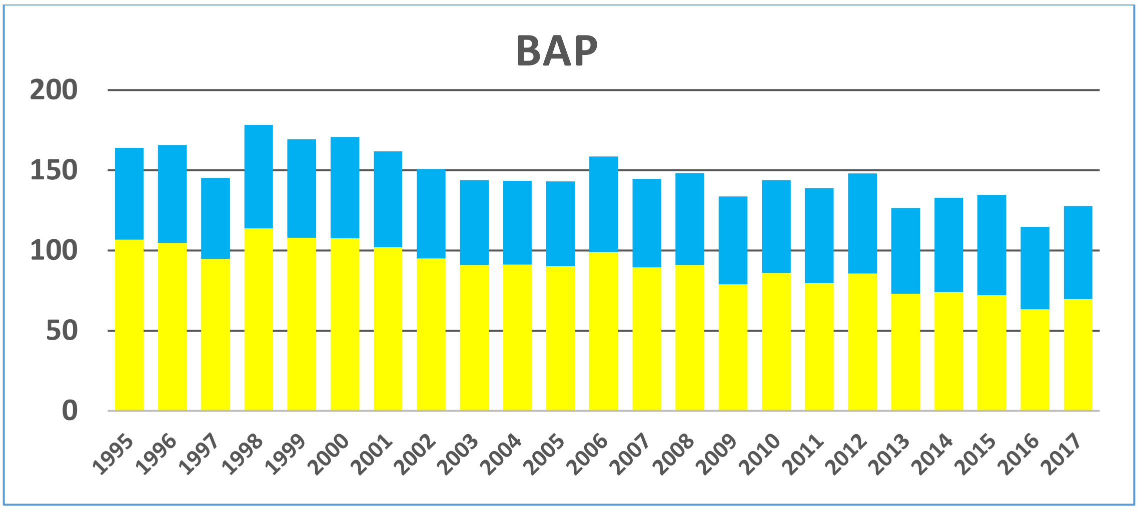


Figure 2. Normalised depositions of oxidised (top), reduced (middle) and total (bottom) nitrogen for the period 1995-2017, depicted by the black line/grey dots. Unit: Gg(N)/year. Minimum, maximum and actual values of the depositions are also shown. The actual values correspond to the values listed in Tables 1, 2 and 3, while the normalized values are listed in Table 4. Note that the vertical scale does not start at zero, in order to make the trends more visible.





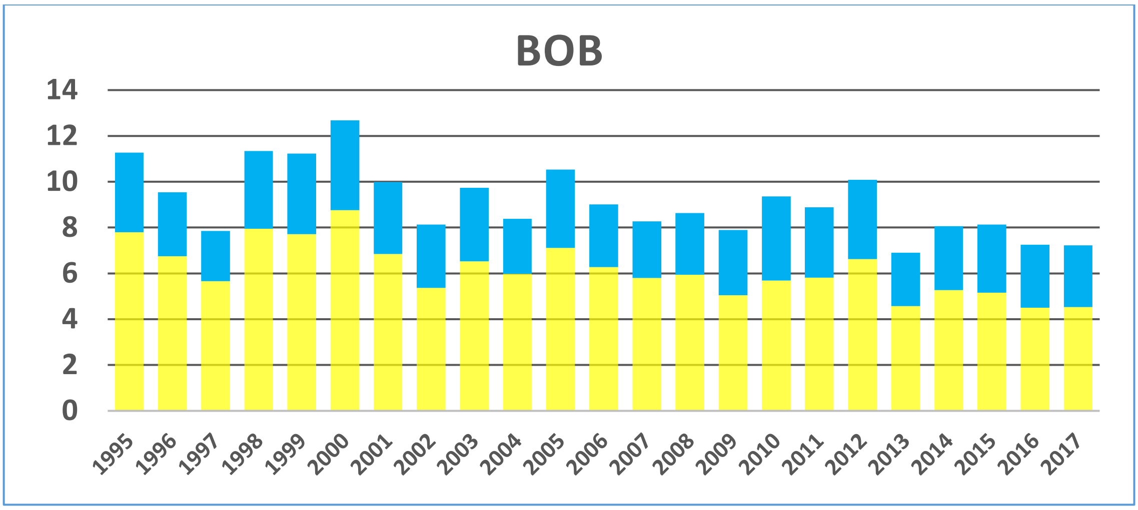


Figure 3. Atmospheric deposition of oxidised nitrogen (yellow) and reduced nitrogen (blue) to the nine sub-basins of the Baltic Sea in the period 1995 - 2017. Unit: Gg(N)/year. Note that the vertical scales in the plots are different. The figure continues on the next 2 pages. For definition of sub-basins see Figure 4.

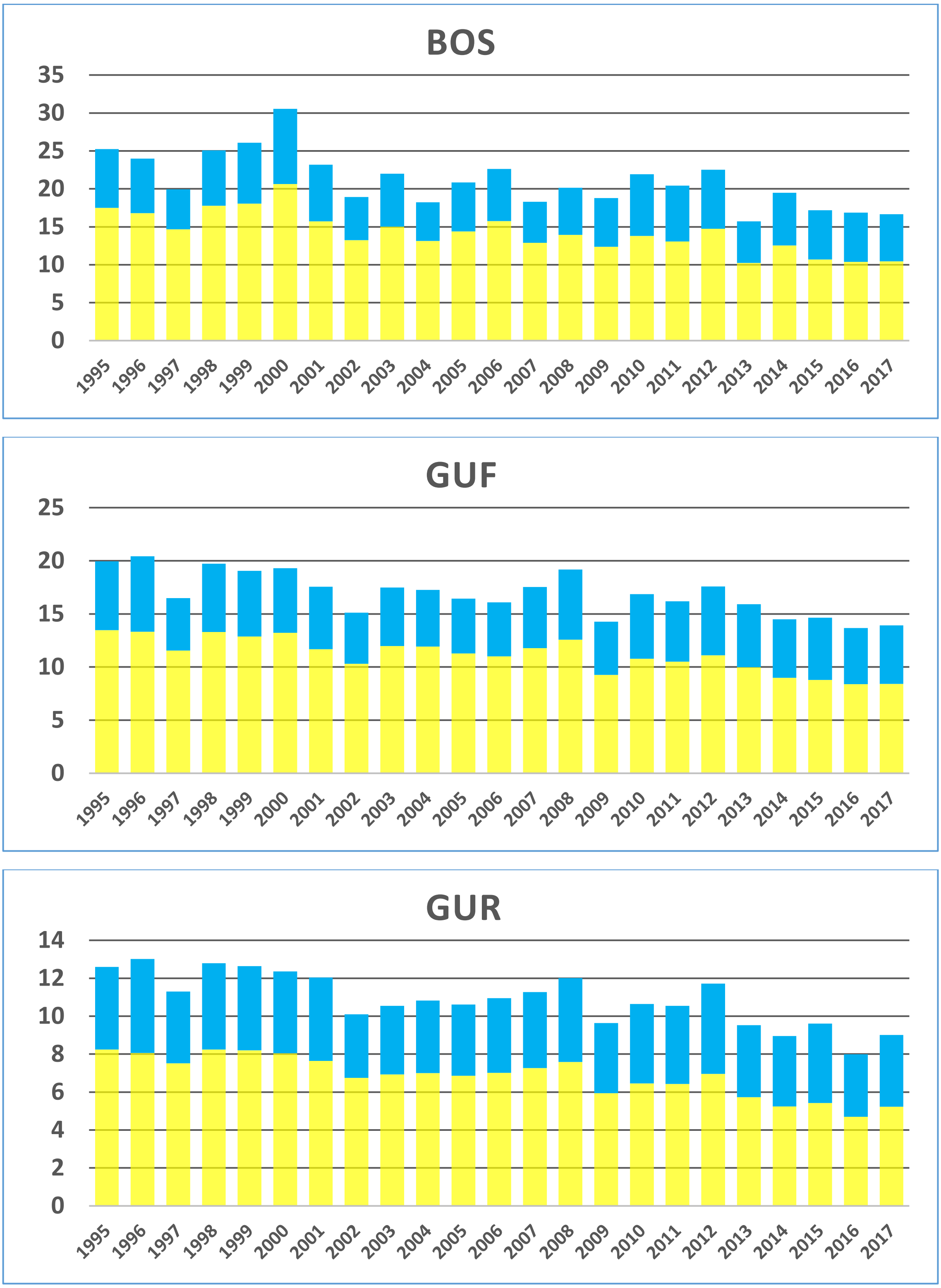
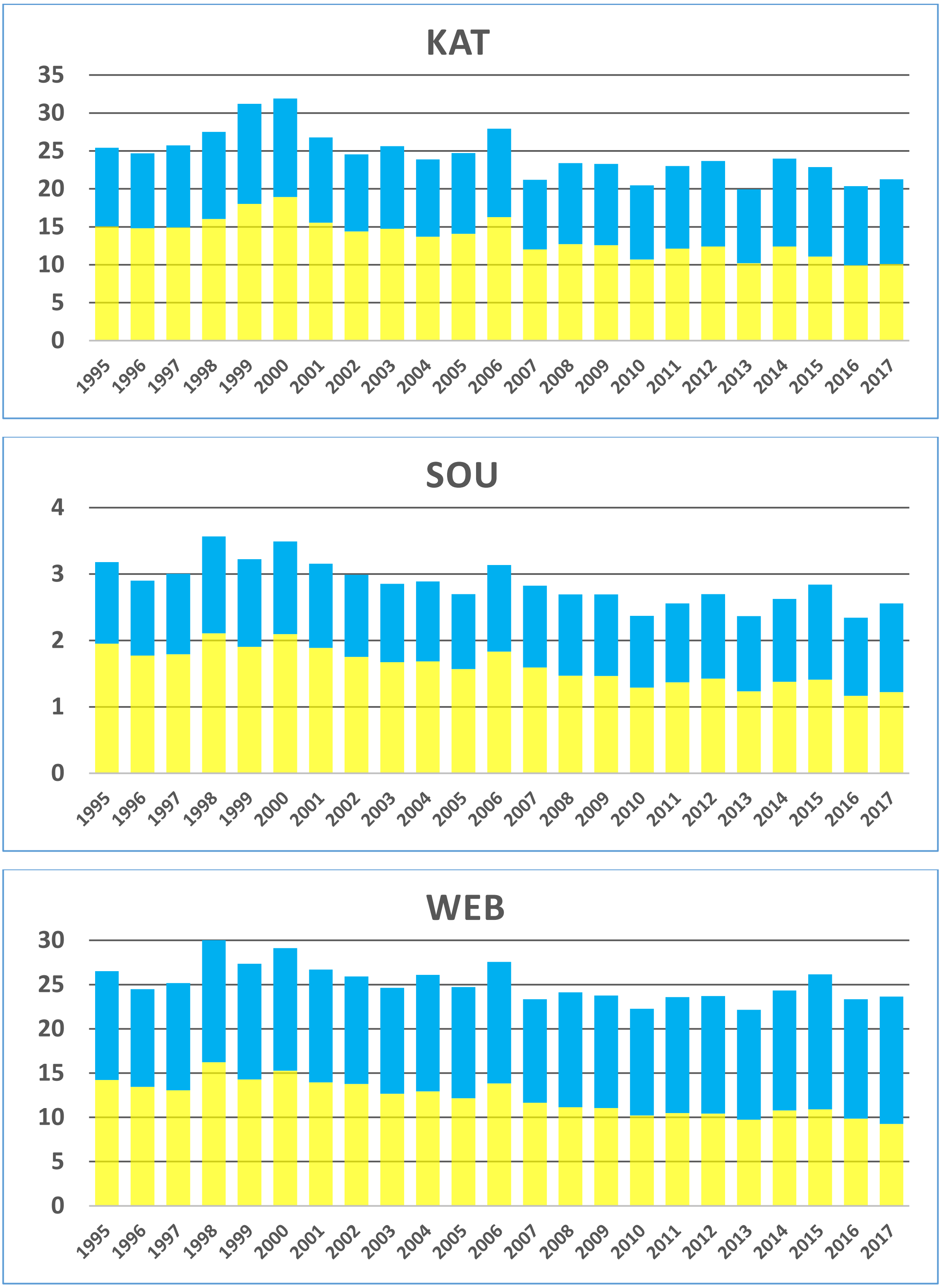


Figure 3. Continued.



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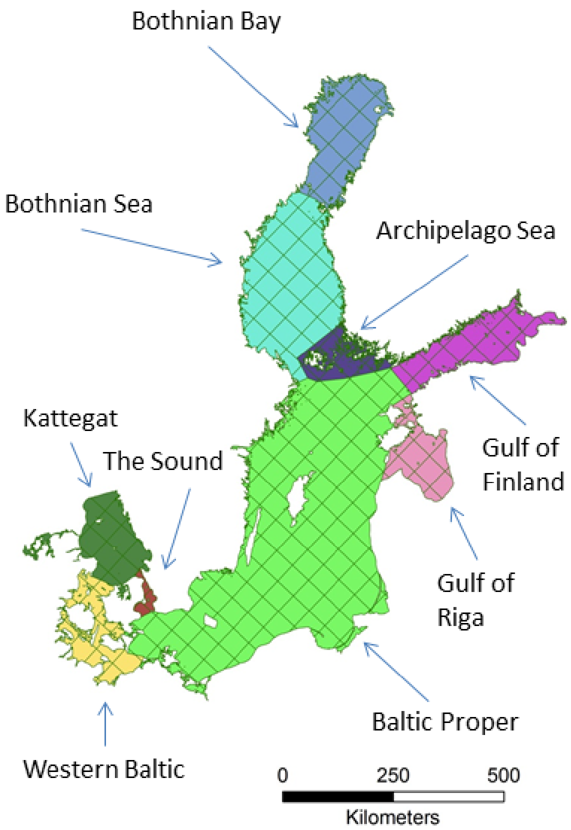

Sub-basin	Abbreviation	Area in km^2
Archipelago Sea	ARC	13405
Baltic Proper	BAP	209258
Bothnian Bay	BOB	36249
Bothnian Sea	BOS	65397
Gulf of Finland	GUF	29998
Gulf of Riga	GUR	18646
Kattegat	KAT	23659
The Sound	SOU	2328
Western Baltic	WEB	18647
Baltic Sea basin	**BAS**	**417587**

Fig 4. Locations of the nine sub-basins of the Baltic Sea, used for all nitrogen deposition calculations presented in this report. The original figure with the sub-basins was provided by the Baltic Nest Institute (BNI).

References

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JRC/PBL: Emission Database for Global Atmospheric Research (EDGAR), Global Emissions EDGAR v4.3.1., European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL), URL http://edgar.jrc.ec.europa.eu, 2016.

Data

Table 1. Annual deposition of oxidised nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1995-2017. Unit: Gg(N)/year. For definitions of sub-basins see Figure 4. "BAS": Baltic Sea (sum of all sub-basins).

Year	Sub-basin									**BAS**
	ARC	BAP	BOB	BOS	GUF	GUR	KAT	SOU	WEB	
1995	6.2	107	7.8	17.5	13.5	8.2	15.1	2.0	14.2	191
1996	6.5	105	6.8	16.8	13.3	8.1	14.8	1.8	13.4	186
1997	5.2	94.7	5.7	14.7	11.6	7.5	14.9	1.8	13.1	169
1998	6.2	114	8.0	17.8	13.3	8.2	16.0	2.1	16.2	202
1999	6.4	108	7.7	18.1	12.9	8.2	18.0	1.9	14.3	196
2000	6.8	108	8.8	20.7	13.2	8.1	18.9	2.1	15.3	201
2001	5.7	102	6.8	15.7	11.7	7.6	15.5	1.9	14.0	181
2002	4.9	95.1	5.4	13.2	10.3	6.7	14.4	1.8	13.8	165
2003	5.3	91.0	6.5	15.0	12.0	6.9	14.7	1.7	12.7	166
2004	5.0	91.3	6.0	13.1	11.9	7.0	13.7	1.7	12.9	163
2005	5.1	90.2	7.1	14.4	11.3	6.9	14.1	1.6	12.2	163
2006	5.4	99.0	6.3	15.8	11.0	7.0	16.3	1.8	13.8	176
2007	5.2	89.3	5.8	12.9	11.8	7.3	12.0	1.6	11.7	158
2008	5.3	90.9	5.9	13.9	12.6	7.6	12.7	1.5	11.2	162
2009	4.4	78.9	5.0	12.4	9.3	5.9	12.6	1.5	11.0	141
2010	4.8	86.1	5.7	13.8	10.8	6.5	10.7	1.3	10.2	150
2011	4.8	79.7	5.8	13.1	10.5	6.4	12.1	1.4	10.5	144
2012	5.3	85.7	6.6	14.8	11.1	7.0	12.4	1.4	10.4	155
2013	4.5	73.1	4.6	10.3	10.0	5.7	10.2	1.2	9.7	129
2014	4.3	74.1	5.3	12.5	9.0	5.2	12.4	1.4	10.8	135
2015	3.9	72.2	5.2	10.7	8.8	5.4	11.1	1.4	10.9	130
2016	3.4	63.3	4.5	10.4	8.4	4.7	9.9	1.2	9.9	116
2017	3.7	69.7	4.5	10.5	8.4	5.2	10.1	1.2	9.2	123

Table 2. Annual deposition of reduced nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1995-2017. Unit: Gg(N)/year. For definitions of sub-basins see Figure 4. ”BAS”: Baltic Sea (sum of all sub-basins).

Year	Sub-basin									**BAS**
	ARC	BAP	BOB	BOS	GUF	GUR	KAT	SOU	WEB	
1995	2.8	57.3	3.5	7.8	6.5	4.4	10.4	1.2	12.3	106
1996	3.0	61.1	2.8	7.2	7.1	5.0	9.9	1.1	11.0	108
1997	2.0	50.6	2.2	5.3	4.9	3.8	10.8	1.2	12.1	92.9
1998	2.7	64.5	3.4	7.3	6.4	4.6	11.5	1.5	14.9	117
1999	3.0	61.3	3.5	8.0	6.2	4.4	13.2	1.3	13.1	114
2000	3.3	63.2	3.9	9.9	6.1	4.3	13.0	1.4	13.9	119
2001	2.9	59.8	3.1	7.5	5.9	4.4	11.2	1.3	12.7	109
2002	2.1	55.8	2.8	5.7	4.8	3.3	10.2	1.2	12.1	98.1
2003	2.5	52.9	3.2	7.0	5.5	3.6	10.9	1.2	12.0	98.7
2004	2.0	52.2	2.4	5.1	5.3	3.8	10.2	1.2	13.2	95.5
2005	2.2	52.9	3.4	6.5	5.2	3.8	10.6	1.1	12.6	98.2
2006	2.4	59.6	2.7	6.9	5.1	3.9	11.6	1.3	13.7	107
2007	2.3	55.3	2.5	5.4	5.8	4.0	9.2	1.2	11.7	97.4
2008	2.5	57.3	2.7	6.2	6.6	4.4	10.7	1.2	13.0	105
2009	2.4	54.8	2.8	6.4	5.0	3.7	10.7	1.2	12.7	99.8
2010	2.6	57.7	3.7	8.1	6.1	4.2	9.8	1.1	12.1	105
2011	2.6	59.1	3.1	7.3	5.7	4.1	10.9	1.2	13.1	107
2012	3.1	62.4	3.5	7.8	6.5	4.8	11.3	1.3	13.3	114
2013	2.6	53.4	2.3	5.5	5.9	3.8	9.7	1.1	12.4	96.7
2014	2.4	58.7	2.8	6.9	5.5	3.7	11.6	1.2	13.5	106
2015	2.3	62.6	3.0	6.5	5.9	4.2	11.8	1.4	15.2	113
2016	2.1	51.5	2.7	6.5	5.3	3.3	10.4	1.2	13.5	96.4
2017	2.2	58.0	2.7	6.2	5.5	3.8	11.2	1.3	14.4	105

Table 3. Annual deposition of total nitrogen to the sub-basins and the entire basin of the Baltic Sea in the period 1995-2017. Unit: Gg(N)/year. For definitions of sub-basins see Figure 4. ”BAS”: Baltic Sea (sum of all sub-basins).

Year	Sub-basin									**BAS**
	ARC	BAP	BOB	BOS	GUF	GUR	KAT	SOU	WEB	
1995	9.0	164	11.3	25.2	19.9	12.6	25.4	3.2	26.5	297
1996	9.5	166	9.5	24.0	20.4	13.0	24.7	2.9	24.5	294
1997	7.2	145	7.8	19.9	16.5	11.3	25.7	3.0	25.2	262
1998	9.0	178	11.3	25.1	19.7	12.8	27.5	3.6	31.1	318
1999	9.5	169	11.2	26.1	19.1	12.6	31.2	3.2	27.4	310
2000	10.1	171	12.7	30.5	19.3	12.4	31.9	3.5	29.1	320
2001	8.6	162	10.0	23.2	17.5	12.0	26.8	3.2	26.7	290
2002	7.0	151	8.1	18.9	15.1	10.1	24.6	3.0	25.9	264
2003	7.8	144	9.7	22.0	17.5	10.6	25.6	2.9	24.6	265
2004	7.1	143	8.4	18.2	17.3	10.8	23.9	2.9	26.1	258
2005	7.3	143	10.5	20.9	16.4	10.6	24.7	2.7	24.7	261
2006	7.9	159	9.0	22.6	16.1	11.0	27.9	3.1	27.5	284
2007	7.4	145	8.3	18.3	17.5	11.3	21.2	2.8	23.3	255
2008	7.8	148	8.6	20.1	19.2	12.0	23.4	2.7	24.1	266
2009	6.8	134	7.9	18.8	14.3	9.6	23.3	2.7	23.8	241
2010	7.4	144	9.4	21.9	16.9	10.6	20.5	2.4	22.3	255
2011	7.4	139	8.9	20.4	16.2	10.6	23.0	2.6	23.6	251
2012	8.5	148	10.1	22.5	17.6	11.7	23.7	2.7	23.7	269
2013	7.0	126	6.9	15.7	15.9	9.5	20.0	2.4	22.1	226
2014	6.7	133	8.1	19.5	14.5	9.0	24.0	2.6	24.3	241
2015	6.2	135	8.1	17.2	14.6	9.6	22.9	2.8	26.1	242
2016	5.5	115	7.2	16.9	13.7	8.0	20.4	2.3	23.4	212
2017	5.9	128	7.2	16.7	13.9	9.0	21.3	2.6	23.7	228

Table 4. Normalized depositions of oxidised, reduced and total nitrogen to the Baltic Sea basin in the period 1995-2017. Unit: Gg(N)/year. The total may slighly differ from the sum due to the normalization of either reduced and normalized depositions separately and than adding up the two medians or of taking the median of the sum in all years.

Year	Oxidised Nitrogen	Reduced Nitrogen	Total Nitrogen
1995	206.7	118.5	327.3
1996	204.7	116.9	323.7
1997	200.8	116.2	318.3
1998	194.5	114.7	309.6
1999	189.6	111.7	301.4
2000	186.2	108.8	295.0
2001	180.9	108.8	289.7
2002	178.0	106.0	284.0
2003	177.7	104.3	282.1
2004	174.7	103.0	277.7
2005	172.5	103.7	276.2
2006	170.5	103.2	273.7
2007	165.7	102.9	268.6
2008	156.1	101.3	257.3
2009	147.6	100.4	248.0
2010	147.3	100.2	247.5
2011	142.7	100.8	243.4
2012	137.0	99.7	236.7
2013	135.5	99.5	235.0
2014	129.1	99.8	228.9
2015	126.3	100.3	226.6
2016	129.1	100.1	229.2
2017	121.6	101.0	222.9

Metadata

Technical information

1. Source: EMEP MSC-W.

2. Description of data: The atmospheric depositions of oxidised and reduced nitrogen were calculated with the latest version of EMEP MSC-W model in Oslo. The latest available official emission data for the HELCOM countries have been used in the model computations. Emissions of two nitrogen compounds for each year of this period were officially reported to the UN ECE Secretariat by the HELCOM Contracting Parties. Missing information was estimated by experts. Both official data and expert estimates were used for modeling atmospheric transport and deposition of nitrogen compounds to the Baltic Sea - http://www.ceip.at/ .

3. Geographical coverage: Atmospheric depositions of oxidised and reduced nitrogen were computed for the entire EMEP domain, which includes Baltic Sea basin and catchment.

4. Temporal coverage: Time series of annual atmospheric depositions are available for the period 1995 – 2017.

5. Methodology and frequency of data collection:

Atmospheric input and source allocation budgets of nitrogen (oxidised, reduced and total) to the Baltic Sea basins and catchments were computed using the latest version of EMEP MSC-W model. EMEP MSC-W model is a multi-pollutant, three-dimensional Eulerian model, which takes into account processes of emission, advection, turbulent diffusion, chemical transformations, wet and dry depositions and inflow of pollutants into the model domain. A complete description of the model and its applications is available on the web (direct link to web page of the model: https://github.com/metno/emep-ctm)

Calculations of atmospheric transport and deposition of nitrogen compounds are performed annually on the basis of emission data officially submitted by Parties to CLRTAP Convention and expert estimates. In order to filter out inter-annual variability in meteorology, the depositions are also reported as "weather-normalized" depostions; the method for this was described in Appendix D of Bartnicki et al. (2017).

Quality information

6. Strengths and weaknesses:

Strength: annually updated information on atmospheric input of oxidised and reduced nitrogen to the Baltic Sea and its sub-basins.

Weakness: gaps and uncertainties in officially submitted by countries time series of nitrogen emissions to air increase the uncertainty of computed depositions.

7. Uncertainty:

The results of the EMEP MSC-W model are routinely compared with available measurements at EMEP and HELCOM stations. The comparison of calculated versus measured data indicates that the model predicts the observed air concentrations of nitrogen within an accuracy of approximately 30%.

8. Further work required:

Further work is required on reducing uncertainties in emission data and better parameterization of physical processes in the EMEP MSC-W model.