Chapter 9
Uncertainty in the Future Nitrogen Load to the Baltic Sea Due to Uncertain Meteorological Conditions

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Abstract The Norwegian Meteorological Institute has a long-term project with HELCOM Commission for regular calculation of annual atmospheric deposition of nitrogen to the Baltic Sea. In 2005, the institute received an additional project from HELCOM with the aim of estimating atmospheric nitrogen deposition to six sub-basins and catchments of the Baltic Sea for the year 2010, using nitrogen emission projections according to agreed emission ceilings under the EU National Emission Ceilings (NEC) Directive and the Gothenburg Protocol. Since, the meteorology for 2010 is unknown, model calculations were performed for four selected years with different meteorology: 1996, 1997, 1998 and 2000, which are available in the database. Final deposition values for the year 2010 were calculated as an average over the four selected years. In this way we were able to estimate the uncertainty restricted to meteorological variability. The ranges between minimum and maximum of calculated depositions to sub-basins and catchments are large indicating significant variation of the deposition depending on meteorological conditions.

9.1 Introduction

The Helsinki Commission, or HELCOM is the governing body of the "Convention on the Protection of the Marine Environment of the Baltic Sea Area" – known as the Helsinki Convention [7]. The important role of HELCOM is to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental co-operation between Denmark, Estonia, the European Community, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden, which are the Contracting Parties to HELCOM. HELCOM's vision for the future is a healthy Baltic Sea environment with diverse biological components functioning in balance, resulting in a good ecological status and supporting a wide range of sustainable economic and social activities (http://www.helcom.fi/).

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Eutrophication is one of the major problems for the Baltic Sea. Since the 1800s, the Baltic Sea has changed from an oligotrophic clear-water sea into a eutrophic marine environment. Nitrogen and phosphorus are among the main growth-limiting nutrients and as such do not pose any direct hazards to marine organisms. Eutrophication, however, is a condition in an aquatic ecosystem where high nutrient concentrations stimulate growth of algae which leads to imbalanced functioning of the system. It is mainly caused by a significant nutrient load to the Baltic Sea (http://www.helcom.fi/).

The nutrient inputs entering the Baltic Sea are either airborne or waterborne. The main pathways of nutrient input to the Baltic Sea are:

- Direct atmospheric deposition on the Baltic Sea water surface
- Riverine inputs of nutrients to the sea. Rivers transport nutrients that have been discharged or lost to inland surface waters within the Baltic Sea catchment area
- Point sources discharging directly to the sea.

Atmospheric deposition of nitrogen accounts for approximately 30% of the total nitrogen load to the Baltic Sea. Therefore, nitrogen has been regularly monitored by analysing the results of measurements and model calculations in co-operation with the Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air pollutants in Europe (EMEP). The main objective of the EMEP is to regularly provide Governments and subsidiary bodies under the Convention on Long-range Transboundary Air Pollution [8] with qualified scientific information to support the development and further evaluation of the international protocols on emission reductions negotiated under the Convention (http://www.emep.int/). A co-operation between EMEP and HELCOM was established already in 1996. Since then, three EMEP Centres have published joint reports estimating annual supply of nitrogen heavy metals and persistent organic pollutants to the Baltic Sea. Updated emissions, as well as results of measurements and their analysis are also included in the annual EMEP reports for HELCOM. Such an annual report has been recently prepared for HELCOM in 2007 [1].

In 2004 HELCOM established a project using models to assess the implications of different policy scenarios on nutrient inputs and the resulting eutrophication status in order to indicate the most cost-effective measures for the different sub-regions of the Baltic Sea. Most of the models considered under HELCOM have been ecological models related to the assessment of effects to the sea. The basis of the effect models ware the scenarios of activities on land. Therefore, the aim was to link management scenario models with ecological models in order to assess measures for reducing nutrient inputs. The aim of the project was to assess for HELCOM Contracting Parties the impact of different agricultural policy scenarios on nutrient inputs in the Baltic Sea catchment area and on the eutrophication status of the Baltic Sea. The final aim was to enable the identification of cost-effective measures in the different parts of the Baltic Sea catchment area which requires achieving a good ecological status throughout the Baltic Sea area [2].

In 2005 HELCOM considered airborne nitrogen pollution and decided to include nitrogen air depositions into the ongoing HELCOM Project. To evaluate the implications of different policy scenarios on nutrient inputs, HELCOM agreed that EMEP should be charged with the task of assessing the changes in atmospheric nitrogen deposition under the condition that nitrogen emission targets according to the Gothenburg protocol to the LRTAP Convention and the EU NEC Directive as projected for 2010 are fulfilled. Based on the above decision, EMEP has received a project from HELCOM.

As requested by HELCOM, all nitrogen depositions as well as source allocation budgets have been calculated for the six sub-basins and catchments of the Baltic Sea for the year 2010 using the EMEP Unified model [10] (http://www.emep.int/). Names and acronyms of the sub-basins and catchments used in the model calculations are given below:

1. Gulf of Bothnia (GUB)
2. Gulf of Finland (GUF)
3. Gulf of Riga (GUR)
4. Baltic Proper (BAP)
5. Belt Sea (BES)
6. The Kattegat (KAT)

Depositions and source allocation budgets have been also calculated for the entire basin and the entire catchment of the Baltic Sea. Geographical borders of sub-basins and catchments used in the computations are shown in Fig. 9.1.

Emissions and meteorological fields are the main input into the EMEP Unified model which calculates transport and deposition of air pollutants over Europe. For the historical calculations, meteorological fields are available from the Numerical Weather Prediction model HIRLAM [3] which is run operationally at the Norwegian Meteorological Institute in Oslo. Since the meteorological fields are not known for 2010, we have used the meteorological fields from the past years, which are

Fig. 9.1 Locations of six sub-basins and catchments of the Baltic Sea for which the nitrogen depositions for 2010 have been calculated

available in the EMEP database. Variability between different meteorological years in the past create significant uncertainty in the model results for 2010. Analysis of this specific uncertainty is the main subject of the current paper.

9.2 Nitrogen Emissions

Emission input to the EMEP Unified model requires information about annual nitrogen oxides and ammonia emissions from all sources located in the EMEP domain.

Projections for 2010 assume nitrogen oxides and ammonia national emissions as specified in the NEC Directive [9] for selected 15 EU countries. National nitrogen oxides and ammonia emissions as specified in the Gothenburg Protocol [4] are assumed for all countries listed therein except for those already mentioned in the NEC Directive. Emissions for the Russian Federation and Estonia are taken from the HELCOM publication [6]. Finally, 2010 projections of nitrogen emissions due to international ship traffic on the Europeans seas are taken from the EMEP database following Entec projections [5]. All remaining emission sources of nitrogen are taken from the EMEP database http://www.emep.int/.

9.2.1 National Emission Ceilings According to EU NEC Directive

2010 national emission ceilings for nitrogen oxides (units: kt of NO_2 per year) and ammonia (units: kt of NH_3 per year) according to the EU NEC Directive [9] are shown in Table 9.1.

The national emission ceilings presented in Table 9.1 were designed with the aim of broadly meeting the interim environmental objectives set out in Article 5 of the Directive. It is supposed that the Community area with depositions of nutrient nitrogen in excess of the critical loads will be reduced by about 30% compared to 1990.

Table 9.1 2010 national emission ceilings for nitrogen oxides (units: kt of NO_2 per year) and for ammonia (units: kt of NH_3 per year) according to the EU NEC Directive [9]

Country	NO_x	NH_3	Country	NO_x	NH_3
Austria	103	66	Belgium	176	74
Denmark	127	69	Finland	170	31
France	810	780	Germany	1,051	550
Greece	44	73	Ireland	65	116
Italy	90	419	Luxembourg	11	7
Netherlands	260	128	Portugal	250	90
Spain	847	353	Sweden	148	57
United Kingdom	1,167	297	**EC15**	**6,519**	**3,110**

Table 9.2 2010 national emission ceilings of nitrogen oxides (units: kt of NO_2 per year) and ammonia (units: kt of NH_3 per year) according to the 1999 Gothenburg Protocol [4]

Country	NO_x	NH_3	Country	NO_x	NH_3
Armenia	46	25	Austria	107	66
Belarus	255	158	Belgium	181	74
Bulgaria	266	108	Croatia	87	30
Czech Republic	286	101	Denmark	127	69
Finland	170	31	France	860	780
Germany	1,081	550	Greece	344	73
Hungary	198	90	Ireland	65	116
Italy	1,000	419	Latvia	84	44
Liechtenstein	0.37	0.15	Lithuania	110	84
Luxembourg	11	7	Netherlands	266	128
Norway	156	23	Poland	879	468
Portugal	260	108	Republic of Moldova	90	42
Romania	437	210	Russian Federation (PEMA)	265	49
Slovakia	130	39	Slovenia	45	20
Spain	847	353	Sweden	148	57
Switzerland	79	63	Ukraine	1,222	592
United Kingdom	1,181	297	**European Community**	**6,671**	**3,129**

Among the EU-15 countries, United Kingdom (1,167 kt NO_2) and Germany (1,051 kt NO_2) are the main NO_2 emitters in 2010. France (780 kt NH_3) and Germany (550 kt NH_3) are the main NH_3 sources.

During the EU accession process national emission ceilings were reduced for Latvia to 61 kt NO_2. This most recent value for Latvia [6] and the nitrogen emissions shown in Table 9.2 were used for the EMEP model run. The same emission sources are also considered in the Gothenburg Protocol, however NEC emissions of nitrogen oxides and ammonia projected for 2010 are lower or the same as those projected by the Gothenburg Protocol presented in the next section.

9.2.2 National Emission Ceilings According to Gothenburg Protocol

The national emission ceilings for nitrogen oxides and ammonia specified in the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone done in Gothenburg, Sweden on 30 November 1999 [4] are shown in Table 9.2.

For the Russian Federation the Protocol specifies only the emission ceilings for the so-called Pollutant Emissions Management Area (PEMA). In the EMEP domain, 2010 nitrogen oxide and ammonia emissions for the entire Russian Federation are 2,653 kt NO_2 and 1,179 kt NH_3, respectively.

Compared to emission levels in 1990, main reductions of nitrogen oxides emissions should occur in the Czech Republic (61%), Germany (60%), Sweden

(56%) and United Kingdom (56%). Main reductions of ammonia emissions in 2010 compared to 1990 are expected in Denmark (43%), Netherlands (43%), Slovakia (37%) and Czech Republic (35%).

9.2.3 Nitrogen Emission Projections Used in the Model Runs

Projected national annual total emissions of nitrogen oxides and ammonia used in the model runs are shown in Table 9.3 for 2010. All anthropogenic sources in the EMEP area are taken into account in Table 9.3, including emissions from the HELCOM parties and from the international ship traffic on the Baltic Sea.

The numbers in Table 9.3 are based on total emission targets for each country, including areas outside the Baltic Sea Catchment, which explains high values for, e.g. Russia and Germany. Not all emissions in the Contracting Parties end up in the Baltic Sea. For 2010, the total nitrogen oxide emissions target in the EMEP area is approximately 19.7 million tones of NO_2, whereas the total ammonia emissions target in the EMEP area is about 7.3 million tones of NH_3.

Table 9.3 2010 national total emissions of nitrogen oxides (units: kt of NO_2 per year) and ammonia (units: kt of NH_3 per year) used in the model runs

Source	NO_x	NH_3	Source	NO_x	NH_3
Albania	27.9	25.9	Armenia	46.0	25.0
Austria	102.9	66.2	Azerbaijan	43.0	25.0
Baltic Sea	457.5	0.0	Belarus	254.9	157.8
Belgium	176.1	74.4	Black Sea	154.8	0.0
Bosnia and Herz.	54.0	17.3	Bulgaria	265.5	107.6
Croatia	97.3	30.1	Cyprus	21.1	6.3
Czech Republic	286.1	101.4	Denmark	126.7	69.3
Estonia	59.0	28.4	Finland	170.3	30.8
France	810.3	780.3	Georgia	30.0	97.0
Germany	1,051.2	549.8	Greece	344.5	72.5
Hungary	198.4	89.5	Iceland	30.0	3.0
Ireland	65.0	115.8	Italy	990.1	418.88
Kazakhstan	50.2	19.0	Latvia	60.8	43.8
Lithuania	110.4	84.4	Luxembourg	11.0	7.1
Macedonia	5.9	1.4	Mediterranean Sea	2,382	80.0
Moldova, Republic of	90.6	41.6	Netherlands	260.3	128.3
North Africa	96.0	235.0	North Sea	862.4	0.0
Norway	156.0	23.0	Norway	156.0	23.0
Poland	878.3	467.9	Remaining Asiatic ar.	9.0	178.0
Remaining NE Atlantic	740.5	0.0	Romania	436.5	209.7
Russian Federation	2,653.0	1,178.8	Serbia and Montenegro	167.8	69.3
Slovakia	130.2	19.9	Spain	148.4	57.3
Switzerland	79.3	62.6	Turkey	851.8	240.6
Ukraine	1,222.2	591.9	United Kingdom	1,167.4	296.6
EMEP	**19,686.3**	**7,345.2**			

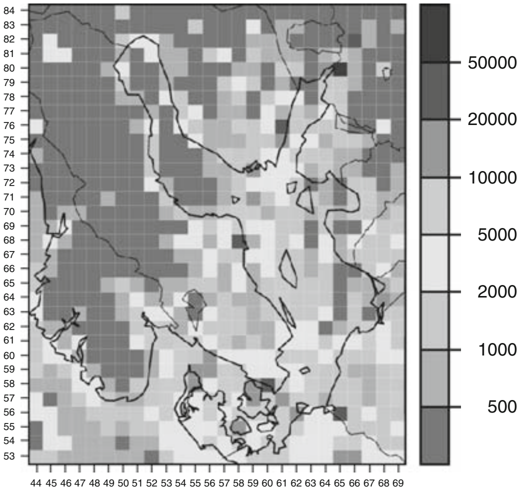


Fig. 9.2 Spatial distribution of nitrogen oxide emissions around the Baltic Sea for 2010, used in the EMEP model computations. Units: tonnes of NO_2 per year and per 50 km × 50 km grid cell

The total nitrogen oxides emissions and ammonia emissions targets in the HELCOM Parties are estimated to be 5.3 million tones of NO_2 and 2.5 million tones of NH_3, respectively.

Table 9.3 exhibits that the Russian Federation and ship traffic on the Mediterranean Sea are the largest emitters of nitrogen oxides in 2010, with 2,653 and 2,383 kt NO_2, respectively. These two sources are approximately twice as large than the next on the list: Ukraine (1,222 kt NO_2), United Kingdom (1,167 kt NO_2), Germany (1,051 kt NO_2) and Italy (990 kt NO_2).

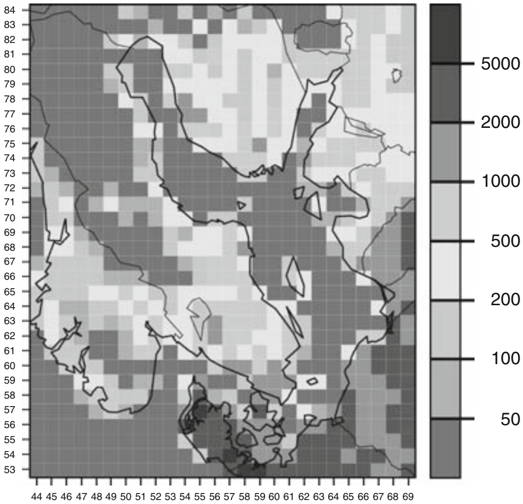
The Russian Federation (1,179 kt NH_3), France (780 kt NH_3), Ukraine (592 kt NH_3) and Germany (550 kt NH_3) belong to the four highest emitters of ammonia in 2010. The emission targets for the rest of the countries are much lower with Poland (550 kt NH_3) and Italy (468 kt NH_3) taking the fifth and sixth places, respectively.

To run the EMEP model, the emissions should be distributed in the model grid system. Maps with the 2010 nitrogen oxides and ammonia emissions in 2010 spatially distributed over the Baltic Sea region are shown in Figs. 9.2 and 9.3 respectively.

9.3 Computed Nitrogen Depositions for 2010

Nitrogen emission inventories described in the previous chapter have been used in order to estimate nitrogen depositions in 2010. Since, the meteorology for 2010 is unknown, model calculations had to be performed with existing meteorological data from the past years. Meteorological data for the years 1996, 1997, 1998 and 2000 and emission projections for the year 2010 have been used for the EMEP Unified model runs. Final deposition values for the year 2010 were calculated as the average over the four selected years.

Fig. 9.3 Spatial distribution of ammonia emissions around the Baltic Sea for 2010, used in the EMEP model computations. Units: tonnes of NH_3 per year and per 50 km × 50 km grid cell



9.3.1 *Unified EMEP Model*

The Unified EMEP model is an Eulerian model that has been developed at the Meteorological Synthesizing Centre West of EMEP (EMEP/MSC-W) for simulating atmospheric transport and deposition of acidifying and eutrophying compounds as well as photo-oxidants in Europe. The model has been documented in the EMEP Status Report [10]. Here we only give a short description of the basic features of the model. Model details as well as recent changes and updates can be found on the EMEP web site http://www.emep.int/.

The model domain covers Europe and the Atlantic Ocean. The model grid (of the size 170 × 133) has a horizontal resolution of 50 km at 60°N, which is consistent with the resolution of emission data reported to EMEP. In the vertical, the model has 20 sigma layers reaching up to 100 hPa. Approximately 10 of these layers are placed below 2 km to obtain a high resolution for the boundary layer which is of special importance for the long range transport of air pollution.

The EMEP unified model uses 3-hourly resolved meteorological data from the PARLAM-PS model, a dedicated version of the HIRLAM (High Resolution Limited Area Model) Numerical Weather Prediction model operational at the Norwegian Meteorological Institute [3].

The emission input consists of gridded national annual emissions of sulphur dioxide, nitrogen oxides, ammonia, non-methane volatile organic compounds (VOC) and carbon monoxide. They are available in each of the 50 km × 50 km model grid cells. These emissions are distributed temporally according to monthly and daily factors derived from data provided by the University of Stuttgart (IER).

Concentrations of 71 species are computed in the Unified EMEP model (56 are advected, 15 are short-lived and not advected). The sulphur and nitrogen chemistry is coupled to the photo-chemistry, which allows a more sophisticated description of, e.g. the oxidation of sulphur dioxide to sulphate.

Dry deposition is calculated using the resistance analogy and is a function of the pollutant type, meteorological conditions and surface properties. Parameterization of wet deposition processes includes both in-cloud and sub-cloud scavenging of gases and particles using scavenging coefficients.

9.3.2 Calculated Depositions to Sub-basins and Catchments of the Baltic Sea

Calculated nitrogen depositions to sub-basins and catchments of the Baltic Sea are given in Tables 9.4 and 9.5, respectively. Calculated depositions are shown for each sub-basin and catchment, and for four meteorological years used in the computations. The deposition in 2010 was calculated as an average over four meteorological years.

Locations of minimum and maximum deposition are slightly different for different sub-basins and catchments and for different deposition types. However, for most sub-basins and catchments, the lowest deposition values can be observed for the meteorological year 1997 and the highest for the meteorological year 2000.

For all meteorological years and all sub-basins and catchments, wet nitrogen deposition is significantly higher, sometimes two times higher than dry deposition of nitrogen.

Depositions of oxidized and reduced nitrogen to all sub-basins are approximately on the same level, but deposition of oxidized nitrogen is slightly higher than deposition of reduced nitrogen in the north and in the middle (GUB, GUF, GUR and BAP sub-basins). In the south (BES and KAT sub-basins) deposition of reduced nitrogen is higher. Deposition of oxidized nitrogen is also higher than deposition of reduced nitrogen to the entire basin of the Baltic Sea. In general, there is more oxidized nitrogen then reduced nitrogen deposition into sub-basins of the Baltic Sea.

In the case of catchments, oxidized nitrogen deposition is higher than reduced nitrogen deposition for GUB, GUF and KAT catchments. For GUR, BAP, BES catchments and the for entire catchment of the Baltic Sea, the relation between oxidized and reduced nitrogen deposition is opposite. In general, there is more reduced nitrogen then oxidized nitrogen deposition into catchments of the Baltic Sea.

9.4 Uncertainty Due to Meteorological Variability

Inspection of Tables 9.4 and 9.5 gives the first impression of uncertainty restricted to meteorological variability. To asses the variability of computed depositions due to varying meteorological conditions the standard deviation (σ_{N-1}) was calculated for each of the deposition type and each of sub-basin and catchment of the Baltic Sea.

The ranges between minimum and maximum can also indicate the uncertainty of computed depositions due to variable meteorological conditions. This is an

Table 9.4 2010 nitrogen depositions to sub-basins of the Baltic Sea and to the entire basin of the Baltic Sea calculated with the help of the meteorology from four different years and as average over these years. Units: kt N

Sub-basin	Meteo	Oxidized dry	Oxidized wet	Reduced dry	Reduced wet	Total
GUB	1996	6.1	11.8	2.9	8.9	29.7
GUB	1997	5.2	10.2	2.4	6.8	24.6
GUB	1998	6.5	15.0	2.8	11.0	35.3
GUB	2000	6.9	18.7	3.9	15.7	45.1
GUB	Mean	6.2	13.9	3.0	10.6	33.7
GUF	1996	2.9	5.2	1.9	5.4	15.3
GUF	1997	2.5	4.1	1.6	3.7	11.9
GUF	1998	3.0	5.5	2.1	4.9	15.4
GUF	2000	3.1	6.4	2.3	5.5	17.3
GUF	Mean	2.9	5.3	2.0	4.9	15.0
GUR	1996	2.2	3.3	1.8	3.7	11.0
GUR	1997	1.9	3.3	1.4	3.2	9.8
GUR	1998	2.2	3.5	1.8	3.4	10.9
GUR	2000	2.4	3.9	2.0	3.9	12.2
GUR	Mean	2.2	3.5	1.7	3.6	11.0
BAP	1996	23.1	40.1	23.3	39.7	126.2
BAP	1997	19.6	33.3	20.2	31.4	104.4
BAP	1998	22.2	47.1	23.9	43.8	136.9
BAP	2000	22.9	47.1	26.3	44.1	140.4
BAP	Mean	21.9	41.9	23.4	39.7	127.0
BES	1996	2.6	4.9	5.1	6.3	18.9
BES	1997	2.4	3.9	5.6	5.4	17.3
BES	1998	2.5	5.8	v5.5	7.8	21.6
BES	2000	2.5	5.8	6.1	7.3	21.7
BES	Mean	2.5	5.1	5.6	6.7	19.9
KAT	1996	2.5	4.4	3.5	5.0	15.4
KAT	1997	2.3	4.1	3.4	4.6	14.4
KAT	1998	2.3	5.4	3.5	5.7	16.9
KAT	2000	2.6	6.5	4.0	6.7	19.8
KAT	Mean	2.4	5.1	3.6	5.5	16.6
BAS	1996	39.4	69.7	38.5	68.9	216.6
BAS	1997	33.9	58.9	34.6	55.0	182.4
BAS	1998	38.7	82.3	39.5	76.5	237.0
BAS	2000	40.3	88.4	44.5	83.2	256.5
BAS	Mean	38.1	74.8	39.3	70.9	223.1

important indicator of uncertainty from the practical point of view in the decision-making process. The relative ranges and relative standard deviations were expressed in per cent of the mean value of the calculated deposition. The results are presented in Tables 9.6 and 9.7 for sub-basins and catchments, respectively.

Table 9.5 2010 nitrogen depositions to six catchments of the Baltic Sea and to the entire catchment of the Baltic Sea calculated with the help of the meteorology from four different years and as average over these years. Units: kt N

Catchment	Meteo	Oxidized dry	Oxidized wet	Reduced dry	Reduced wet	Total
GUB	1996	36	48	14	39	137
GUB	1997	31	44	12	31	118
GUB	1998	34	58	13	44	150
GUB	2000	42	74	19	59	193
GUB	Mean	36	56	15	43	149
GUF	1996	47	70	22	69	207
GUF	1997	41	66	23	63	194
GUF	1998	51	76	27	72	227
GUF	2000	56	82	31	75	244
GUF	Mean	49	74	26	70	218
GUR	1996	23	34	25	46	128
GUR	1997	20	37	23	49	130
GUR	1998	23	37	26	51	136
GUR	2000	25	36	29	46	136
GUR	Mean	23	36	26	48	132
BAP	1996	128	187	198	273	786
BAP	1997	118	178	202	264	761
BAP	1998	132	209	206	293	840
BAP	2000	138	205	225	279	848
BAP	Mean	129	195	208	277	809
BES	1996	7	11	12	15	46
BES	1997	7	9	13	13	42
BES	1998	7	14	13	19	52
BES	2000	7	14	14	18	53
BES	Mean	7	12	13	16	48
KAT	1996	18	19	14	21	72
KAT	1997	16	18	14	20	68
KAT	1998	16	23	14	24	78
KAT	2000	18	30	16	31	96
KAT	Mean	17	23	15	24	78
BAS	1996	258	370	286	463	1,376
BAS	1997	233	353	288	441	1,314
BAS	1998	264	417	300	503	1,483
BAS	2000	286	442	334	507	1,569
BAS	Mean	260	395	302	478	1,436

The relative ranges are roughly twice as high as the standard deviations and these two measures of uncertainty are well correlated for all kinds of nitrogen depositions. The relative ranges can be interpreted as the worst case scenario when the meteorology in the reference year and in the year 2010 gives the most different results in

Table 9.6 Relative ranges and standard deviations (in brackets) of nitrogen depositions to sub-basins of the Baltic Sea and to the entire basin of the Baltic Sea, calculated for 2010 with meteorology from four different years. Units: per cent of mean nitrogen deposition over four years

Sub-basin	Oxidized dry	Oxidized wet	Reduced dry	Reduced wet	Total
GUB	28 (12)	61 (27)	48 (21)	84 (38)	61 (36)
GUF	22 (10)	42 (17)	35 (15)	38 (17)	36 (15)
GUR	24 (10)	18 (8)	38 (16)	19 (8)	22 (9)
BAP	16 (7)	33 (16)	26 (11)	32 (15)	28 (13)
BES	6 (2)	38 (18)	17 (7)	36 (16)	22 (11)
KAT	10 (5)	47 (21)	15 (7)	38 (17)	32 (14)
BAS	17 (8)	39 (18)	25 (10)	40 (17)	33 (14)

Table 9.7 Relative ranges and standard deviations (in brackets) of nitrogen depositions to the catchments of the Baltic Sea and to the entire catchment of the Baltic Sea, calculated for 2010 with meteorology from four different years. Units: per cent of mean nitrogen deposition over four years

Sub-basin	Oxidized dry	Oxidized wet	Reduced dry	Reduced wet	Total
GUB	30 (13)	53 (24)	46 (20)	64 (27)	50 (21)
GUF	31 (13)	22 (10)	36 (16)	17 (7)	23 (10)
GUR	20 (8)	10 (4)	21 (9)	10 (5)	6 (3)
BAP	16 (7)	16 (8)	13 (6)	10 (4)	11 (5)
BES	3 (1)	39 (18)	16 (6)	35 (16)	22 (11)
KAT	16 (8)	52 (24)	15 (7)	45 (20)	35 (15)
BAS	20 (8)	22 (10)	16 (7)	14 (7)	18 (8)

calculated nitrogen deposition. This is the maximum uncertainty estimated from the four years meteorological database. This can be the case if only one meteorological year is taken as a basis for verification of the emission reductions effects in 2010.

The relative standard deviation shows the deviation from the mean deposition over four years. Therefore, the averaging effect is already included in this measure of uncertainty.

For all sub-basins except GUR the uncertainty of computed wet deposition of both oxidized and reduced nitrogen is much higher than the uncertainty of computed dry deposition. In the extreme case of BES sub-basin, uncertainty of computed wet deposition is several times higher than the uncertainty of computed dry deposition for this sub-basin. The reason is a patchy and irregular pattern of precipitation fields, both in space and time.

The largest uncertainty due to meteorological variability can be noticed for GUB (Gulf of Bothnia) sub-basin and catchment with relatively low nitrogen deposition and significant contribution of nitrogen from the long-range transport to the deposition. On the other hand, for BES and KAT sub-basin uncertainty of computed dry oxidized deposition is relatively small, because these sub-basins are located close to the large emissions sources of nitrogen

The uncertainties of the depositions due to variable meteorology are rather large, both for sub-basins and catchments of the Baltic Sea. However, uncertainties of nitrogen deposition to the catchments are in general lower than the uncertainties of nitrogen deposition to sub-basins of the Baltic Sea. The reason is a larger area of the catchment compared to the area of corresponding sub-basin and therefore more likely compensation of different types of uncertainties for the catchments.

Taking into account that uncertainties in nitrogen deposition caused by changing meteorology are larger than the expected emission reductions, one cannot expect a proportional impact of emission reduction on the deposition for one specific year 2010. For example, 10% reduction of nitrogen emission in all EMEP sources can give 6% increase of nitrogen deposition in the entire basin of the Baltic Sea in 2010, if meteorological conditions are the same as in the year 2000. However, the uncertainty due to variable meteorology is decreasing when more years are included in the verification period for the effects of emission reductions.

9.5 Conclusions

The largest uncertainty due to meteorological variability in computed nitrogen deposition for 2010 can be noticed for GUB (Gulf of Bothnia) sub-basin and catchment with relatively low deposition fluxes.

The relative ranges and deviations of the depositions due to variable meteorology are rather large compared to expected emission reductions, both for sub-basins and catchments of the Baltic Sea. For the deposition of oxidized and reduced nitrogen to sub-basins and to the entire basin of the Baltic Sea there is more uncertainty in wet than in dry deposition. The uncertainty of nitrogen deposition to the catchments are in general lower than the uncertainty of nitrogen deposition to sub-basins of the Baltic Sea.

The main conclusion from the decision making perspective is that even significant efforts in reducing nitrogen emissions do not need to become immediately visible in modelled and measured nitrogen depositions to the Baltic Sea due to inter-annual variability of meteorological conditions. In order to notice significant deposition changes caused by the emission reduction it is necessary to wait at least several years. It is very important to take this type of uncertainty into account in future policy actions concerning the improvement of the Baltic Sea environment (http://www.helcom.fi/).

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