4. Atmospheric Supply of Nitrogen to the Baltic Sea in 2002

Nitrogen deposition to the Baltic Sea is caused mainly by the emission sources in the HELCOM countries and ship emissions. However, in some sub-basins and catchments especially in the North, emissions from other sources in the EMEP domain have also important contribution to the deposition. Therefore, in this chapter we present the recent emission data officially submitted to EMEP for individual HELCOM countries, all HELCOM sources, ship emissions and all EMEP sources. All emission data presented here were published in the EMEP report (Vestreng *et.al*., 2004).

2.1 Nitrogen emissions

Comparisons of annual emissions of nitrogen oxides, ammonia and total nitrogen (nitrogen oxides + ammonia) from individual HELCOM countries for the years 2001 and 2002, are shown in Figures 4.1, 4.2 and 4.3. These emissions were used for computed nitrogen deposition for the years 2001 and 2002.

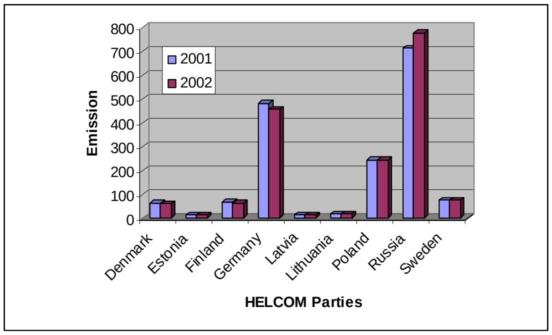


Figure 4.1. Annual emissions of nitrogen oxides from individual HELCOM countries in the years 2001 and 2002. Units: Gg N/yr.

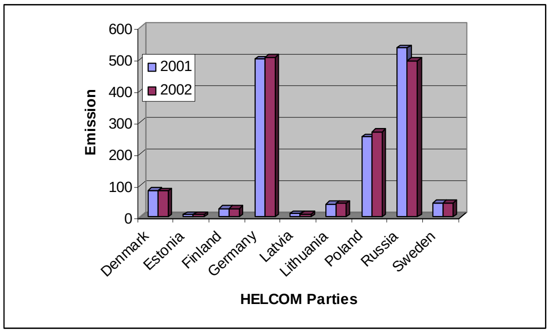


Figure 4.2. Annual emissions of ammonia from individual HELCOM countries in the years 2001 and 2002. Units: Gg N/yr.

In case of nitrogen oxides emission, out of nine HELCOM countries, reduction between 2% and 7.3% can be noticed in six countries from the year 2001 to 2002 (Figure 4.1). The largest emission reduction, 7.3%, can be seen in the country with a relatively small nitrogen oxides emissions – Lithuania. In two countries, Estonia and Russia, emissions of nitrogen oxides increased by 5.3% and 8.9%. In Poland emissions remained on the same level in 2002 as in 2001.

In case of ammonia (Figure 4.2), compared to 2001, annual emissions in the year 2002 increased in four HELCOM Parties, Germany, Lithuania, Poland and Sweden by 1.2%, 2%, 6.1% and 1.9%, respectively. In Denmark, Latvia and the Russian Federation, annual emissions were, 1%, 8.3% and 7.7% lower in 2002 than in 2001. Ammonia emissions in Estonia and Finland remained on the same level in 2001 as in 2002.

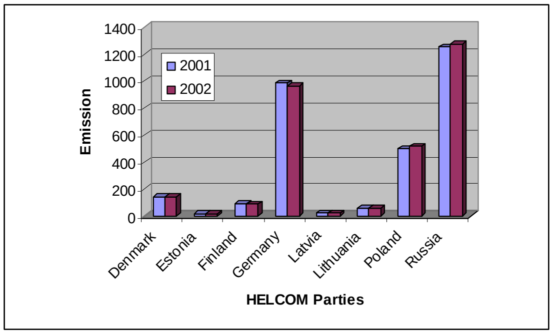


Figure 4.3. Annual emissions of total nitrogen (nitrogen oxides + ammonia) from individual HELCOM countries in the years 2001 and 2002. Units: Gg N/yr.

Concerning total nitrogen emissions (sum of nitrogen oxides and ammonia shown in Figure 4.3) reduction between 2001 and 2002 can be noticed for six HELCOM countries: Denmark, Finland, Germany, Latvia, Lithuania and Sweden by 1.4%, 4.5%, 2.3%, 5%, 0.7% and 0.8%, respectively. Increase of annual emissions can be seen in three countries Estonia, Poland and the Russian Federation by 3.2%, 3.1% and 1.8%, respectively.

It should be mentioned here that when EMEP Parties are submitting official nitrogen emissions every year the estimates for previous years can be updated as well. Therefore, for some countries the national emissions used in the model computations for 2001 are slightly different from those presented in the latest EMEP report (Vigdis et al., 2004).

Only a relatively small part of nitrogen emitted from the HELCOM Parties is deposited to the Baltic Sea basin. In Figures 4.4 and 4.5 the percent of annual emissions of nitrogen oxides and ammonia in 2002 deposited to the Baltic Sea are shown, respectively.

The largest part of nitrogen oxides emissions, 8.8% and 8.7% is deposited to the Baltic Sea from Sweden and Denmark, respectively, and lowest, 4.9% and 0.6% from Germany and Russian Federation, respectively. The largest part of ammonia emissions, 18.2% and 16.4% is deposited to the Baltic Sea from Sweden and Denmark, respectively, and lowest, 5.3% and 1.9% from Germany and Russian Federation, respectively.

Part of ammonia emissions deposited to the Baltic Sea is larger than the part of nitrogen oxides emissions because emissions of ammonia come mainly from the low agricultural sources, whereas nitrogen oxides emissions come to large extend from the high combustion sources

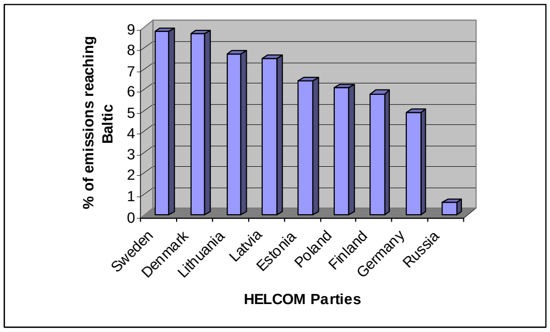


Figure 4.4. Percent of annual emissions of oxidized nitrogen from the HELCOM Parties deposited to the Baltic Sea basin in 2002.

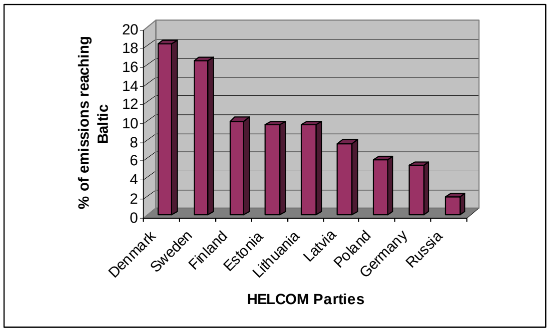


Figure 4.5. Percent of annual emissions of ammonia from the HELCOM Parties deposited to the Baltic Sea basin in 2002.

Annual emissions of oxidized nitrogen, ammonia and total nitrogen from all HELCOM sources (sum of emissions from nine HELCOM countries) in the years 2001 and 2002 are shown in Figure 4.6. Total emission of nitrogen oxides from all HELCOM Parties slightly increased - 1.6%, emission of ammonia slightly decreased - 1.3% and emission of total nitrogen practically remain on the same level with 0.2% increase from 2001 to 2002.

Annual emissions of oxidized nitrogen, ammonia and total nitrogen from the entire EMEP domain (sum of emissions from all EMEP countries and seas) in the years 2001 and 2002 are shown in Figure 4.7. In this case, all emissions of nitrogen practically remain on the same level, with 0.3% reduction from 2001 to 2002.

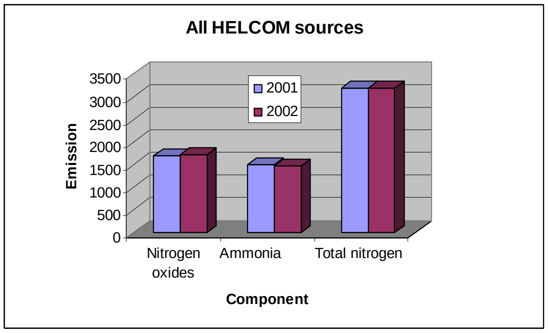


Figure 4.6. Annual emissions of oxidized nitrogen, ammonia and total nitrogen (nitrogen oxides + ammonia) from all HELCOM countries (sum of individual emissions) in the years 2000 and 2001. Units: Gg N/yr

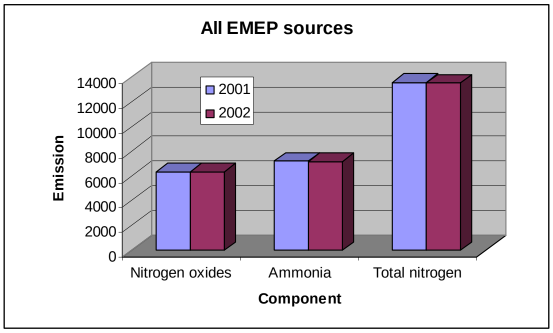


Figure 4.7. Annual emissions of oxidized nitrogen, ammonia and total nitrogen (nitrogen oxides + ammonia) from all HELCOM countries (sum of individual emissions) in the years 2001 and 2002. Units: Gg N/yr.

Spatial distribution of annual 2002 emissions of nitrogen oxides on and around the Baltic Sea is shown in Figure 4.8. Emissions from the international ship traffic on the Baltic

Sea, which are described in more detail later in this Chapter, are included in Figure 4.8. Major local sources of nitrogen oxides are related to large cities around the Baltic Sea and to intensive ship traffic on the sea.

A map with spatial distribution of annual 2002 ammonia emissions is shown in Figure 4.9. Ammonia emission sources are mostly located in the south and south-west cost, mainly affecting Kattegat and the Belt Sea sub-basin of the Baltic Sea. In this case, there are no emission sources on the sea. A clear south to north gradient of emissions can be noticed in Figure 4.9.

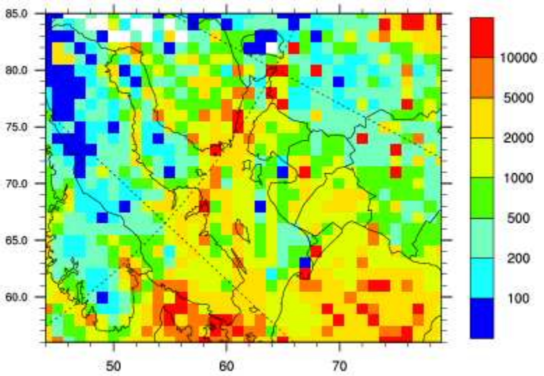


Figure 4.8. Map of annual emission of oxidized nitrogen in the Baltic Sea region in 2002. Units: Mg of N per year and per 50×50 km grid cell.

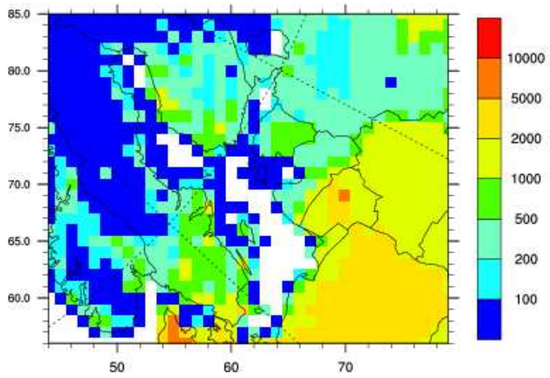


Figure 4.9. Map of annual emission of ammonia in the Baltic Sea region in 2002. Units: Mg of N per year and per 50×50 km grid cell.

In the previous years, national nitrogen emissions (NO_2 and NH_3) have been reported to EMEP in 11 SNAP sectors. SNAP stands for Selected Nomenclature for Air Pollution and the SNAP sectors are defined in the EMEP-CORINAIR Emission Inventory Guidebook. Definitions of these sectors, used in the EMEP model computations are given in the Table 4.1.

This year, most of the Parties reported 2002 emissions in so called NFR sectors. NFR stands for “Nomenclature for Reporting” and NFR emission sectors are defined in the ECE publication (ECE/EB.AIR.80, ECE 2003). At present, the EMEP model uses SNAP sectors as basis for e.g definition of effective emission heights and distribution of emissions over the year. In addition, the distribution of the reported emissions into sectors is still based on SNAP sectors (see EMEP Status Report 1/2004, Tarrasón *et al*. 2004). Thus, we base our further discussion on the SNAP codes, as well.

Annual 2002 nitrogen oxides emissions from the HELCOM Parties split into SNAP sectors are presented in Figure 4.10. For all HELCOM Parties, transport (sectors 7 and 8) and combustion (sectors 1, 2 and 3) are the main sources of nitrogen oxides emissions into the Atmosphere. The transport sectors dominate in all HELCOM countries except Poland and the Russian Federation with the road transport (sector 8) being the major source of nitrogen oxides pollution. In Poland and the Russian Federation, sector 1 (Combustion in energy and transformation industry) is the major contributor to emissions, however, road transport (sector 7) is the next on the list also in these countries.

Table 4.1. The list of 11 SNAP emissions sectors as specified in the EMEP-CORINAIR Emission Inventory Guidebook.

Sector 1	Combustion in energy and transformation industry
Sector 2	Non-industrial combustion plants
Sector 3	Combustion in manufacturing industry
Sector 4	Production processes
Sector 5	Extraction and distribution of fossil fuels and geothermal energy
Sector 6	Solvent and other product use
Sector 7	Road transport
Sector 8	Other mobile sources and machinery (including ship traffic)
Sector 9	Waste treatment and disposal
Sector 10	Agriculture
Sector 11	Other sources and sinks

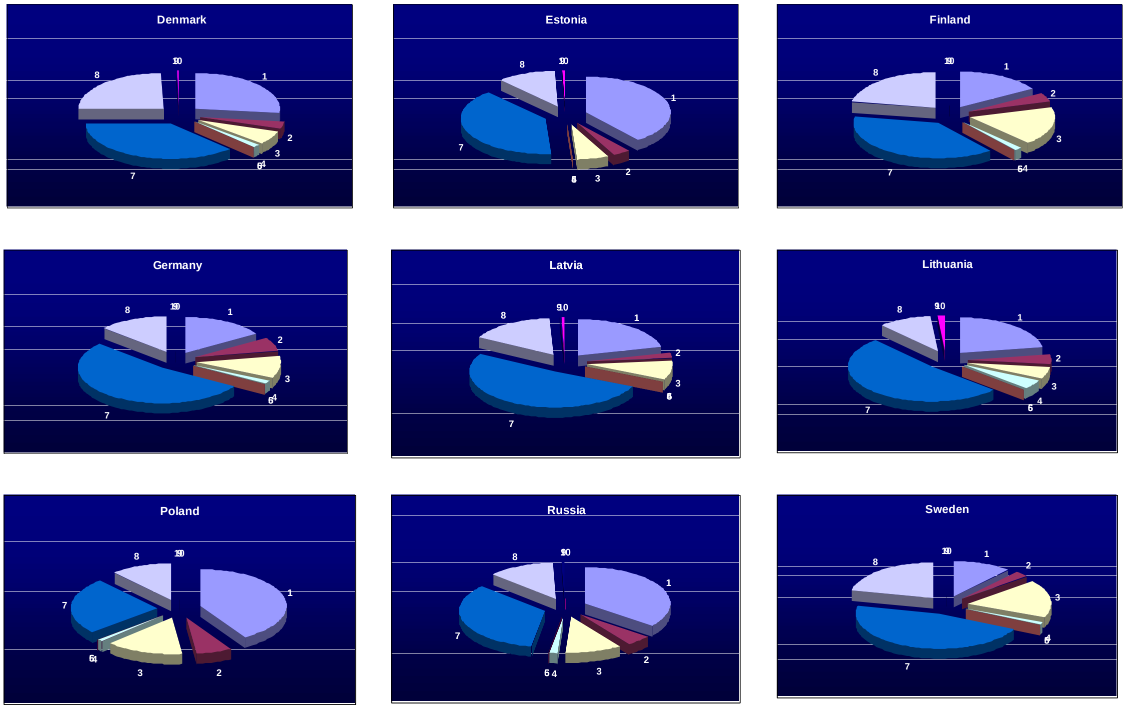


Figure 4.10. Annual 2002 nitrogen oxides emissions from the HELCOM Parties split into the SNAP sectors.

Annual 2002 ammonia emissions from the HELCOM Parties split into the SNAP sectors are presented in Figure 4.11. In this case emissions from the agriculture (sector10) are much higher than emission from any other sector in all HELCOM countries. Contribution of agricultural emissions to annual total ammonia emissions in 2002 is: 95% for Denmark, 92% for Estonia, 92% for Finland, 92% for Germany, 96% for Latvia, 86% for Lithuania, 90% for Poland, 95% for Russia and 80% for Sweden. Contribution from other sectors to ammonia emission is one order of magnitude lower in all HELCOM countries. In case of Lithuania, 12% contribution from the sector 4 (Industrial processes) can be noticed and in case of Sweden, 10% contribution from the sector 9 (Waste treatment and disposal) is relatively high.

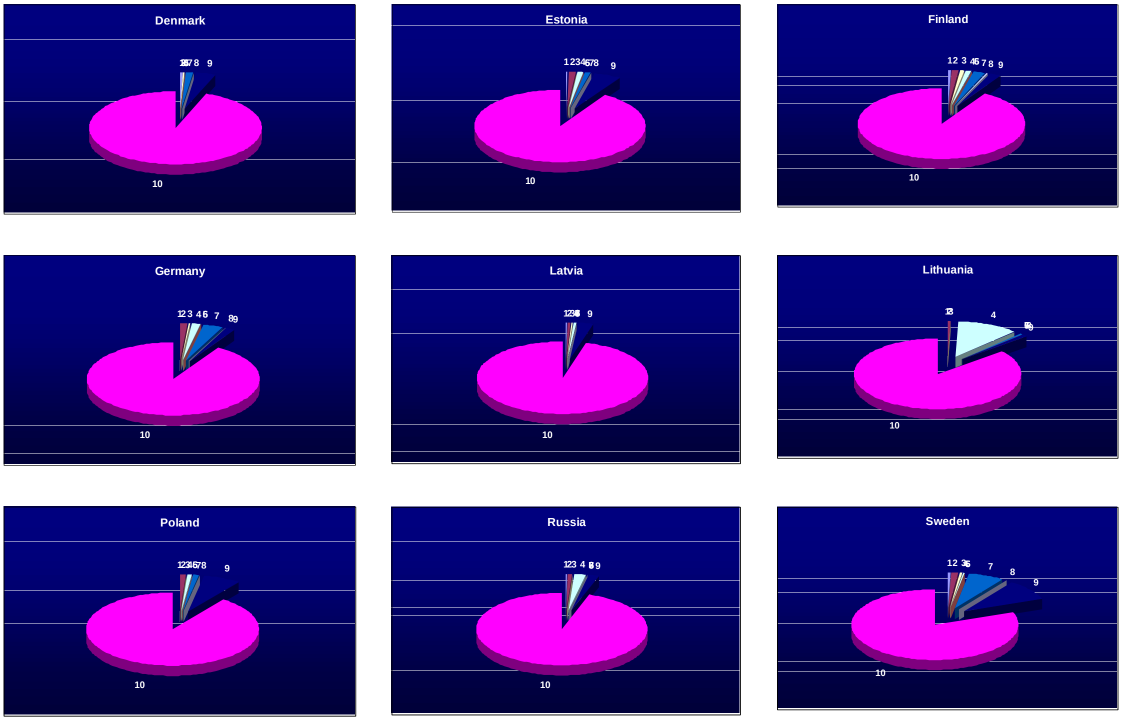


Figure 4.11. Annual 2002 ammonia emissions from the HELCOM Parties split into the SNAP sectors.

Nitrogen oxides emissions from the international ship traffic on the Baltic Sea, are still only available for one year – 1990. Total annual emissions of nitrogen oxides from the international shipping operation on the Baltic Sea are relatively high, 353 ktonnes as NO_2, compared to annual emissions from the individual HELCOM countries, for the same year. The 1990 ship emissions were also used in the model runs for the year 2002.

According to recent estimates (EEB, 2004), nitrogen oxides emissions from the international ship traffic on the European seas increased by more than 28% from the year 1990 to 2000. Unfortunately, these recent estimates for the Baltic Sea are not available to EMEP grid system yet.

Map of annual nitrogen oxides emissions from the ship traffic on the Baltic Sea in 1990, used for 2002 calculations presented in this report is shown in Figure 4.12.

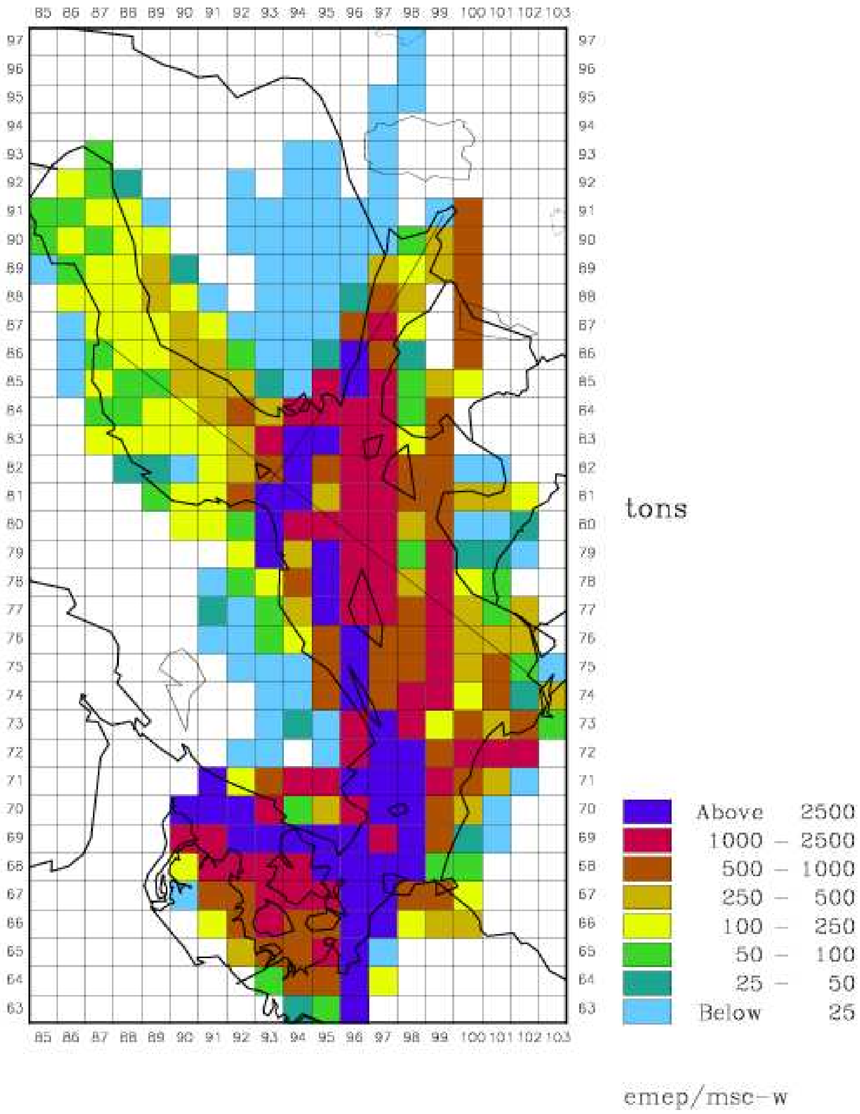


Figure 4.12 Map of annual emissions of nitrogen oxides from the international ship traffic on the Baltic Sea in 1990. Units: Gg of N per year and per 50×50 km grid cell.

4.2 Annual deposition of nitrogen

Spatial distributions of annual 2002 deposition fluxes of oxidized, reduced and total (oxidized + reduced) nitrogen, on and around the Baltic Sea, are shown in Figures 4.13, 4.14 and 4.15, respectively. There is a clear south-East to North-West gradient in the deposition fluxes. For all three: oxidized, reduced and total nitrogen, the highest deposition fluxes can be noted in the Belt Sea (BES) sub-basin/catchment and the lowest in the Bothnian Bay (BOB) sub-basin/catchment.

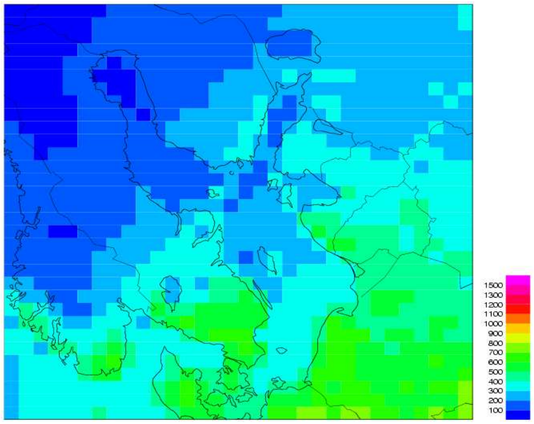


Figure 4.11. Map of annual deposition flux of oxidised nitrogen (dry + wet) in 2002. Units: mg N m^{-2} yr^{-1}.

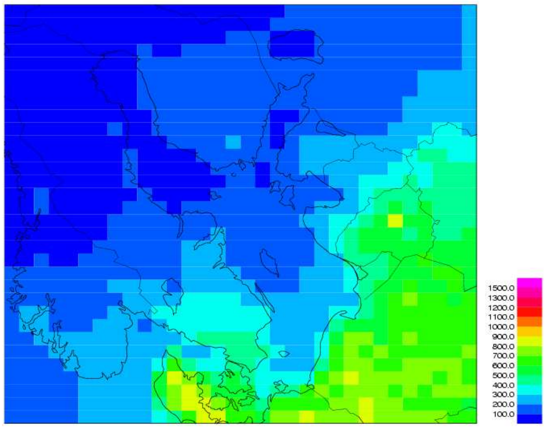


Figure 4.12. Map of annual deposition flux of reduced nitrogen (dry + wet) in 2002. Units: mg N m^{-2} yr^{-1}.

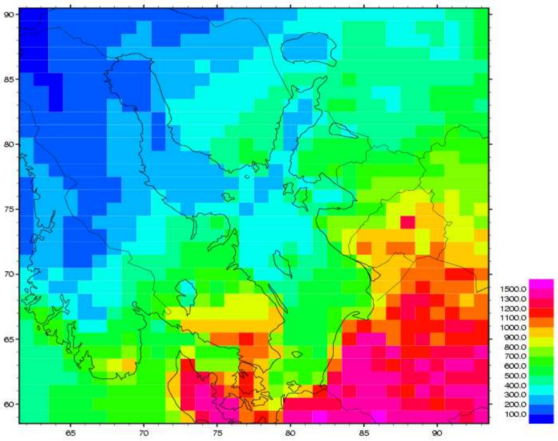


Figure 4.13. Map of annual deposition flux of total (oxidized + reduced) nitrogen in 2002. Units: mg N m^{-2} yr^{-1}.

Dry and wet annual 2002 deposition fluxes of total (oxidized and reduced nitrogen), on and around the Baltic Sea, are shown in Figures 4.14 and 4.15, respectively. Wet deposition is definitely larger than dry deposition over the entire Baltic Sea region.

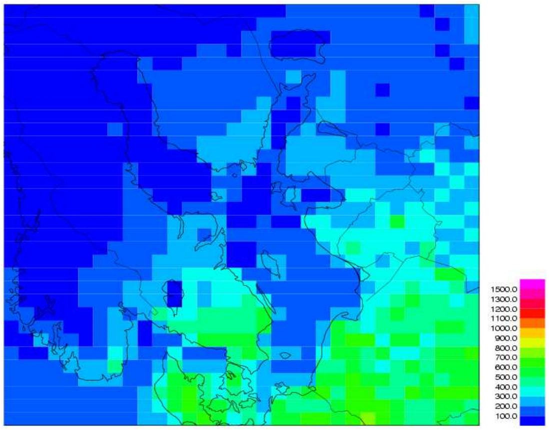


Figure 4.14. Map of annual dry deposition flux of total nitrogen (oxidized + reduced) in 2002. Units: mg N m^{-2} yr^{-1}.

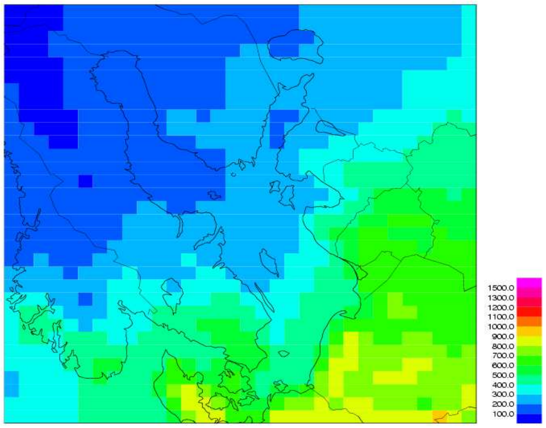


Figure 4.15. Map of annual wet deposition flux of total nitrogen (oxidized + reduced) in 2002. Units: mg N m^{-2} yr^{-1}.

Annual 2002 dry, wet and total depositions, as well as total deposition fluxes of oxidized, reduced and total nitrogen are given in Tables 4.2, 4.3 and 4.4 respectively. Table 4.5 presents annual 2002 nitrogen depositions and deposition fluxes of total nitrogen to all catchments of the Baltic Sea. These tables confirm the domination of wet deposition of nitrogen in all sub-basins and catchments of the Baltic Sea.

Table 4.2. Annual dry, wet, and total depositions (ktonnes year^{-1}) and total deposition fluxes (mg m^{-2} year^{-1}) of oxidized nitrogen to the Baltic Sea sub-basins in 2002.

Deposition	**GUB**	**GUF**	**GUR**	**BAP**	**BES**	**KAT**	**Baltic Sea**
Dry	6.3	2.8	2.1	24.6	3.4	2.9	42.3
Wet	11.0	3.7	3.0	40.7	6.4	6.0	70.7
Total	17.4	6.5	5.1	65.3	9.7	8.9	112.9
Flux	149	218	275	310	475	382	271

Table 4.3. Annual dry, wet, and total depositions (ktonnes year^{-1}) and total deposition fluxes (mg m^{-2} year^{-1}) of reduced nitrogen to the Baltic Sea sub-basins in 2002.

Deposition	**GUB**	**GUF**	**GUR**	**BAP**	**BES**	**KAT**	**Baltic Sea**
Dry	1.8	0.6	0.6	11.7	5.1	3.2	23.1
Wet	8.7	2.7	2.4	33.2	7.2	5.7	59.8
Total	10.5	3.3	3.0	44.9	12.3	8.9	82.9
Flux	89	111	161	214	597	384	200

Table 4.4. Annual dry, wet, and total depositions (ktonnes year^{-1}) and total deposition fluxes (mg m^{-2} year^{-1}) of total nitrogen to the Baltic Sea sub-basins in 2002.

Deposition	**GUB**	**GUF**	**GUR**	**BAP**	**BES**	**KAT**	**Baltic Sea**
Dry	8.1	3.5	2.7	36.4	8.5	6.2	65.3
Wet	19.7	6.4	5.3	73.9	13.5	11.6	130.5
Total	27.8	9.9	8.1	110.3	22.0	17.8	195.8
Flux	239	328	436	524	1071	766	471

Table 4.5. Annual dry, wet, and total depositions (ktonnes year^{-1}) and total deposition fluxes (mg m^{-2} year^{-1}) of total nitrogen to the Baltic Sea catchments in 2002.

Deposition	**GUB**	**GUF**	**GUR**	**BAP**	**BES**	**KAT**	**Baltic Sea catchment**
Dry	47.7	59.5	34.1	273.2	21.7	35.0	471.2
Wet	88.9	104.3	62.4	424.7	32.6	48.4	761.2
Total	136.6	163.8	96.4	697.9	54.3	83.5	1232.5
Flux	226	365	615	915	1163	771	591

4.3 Monthly depositions of nitrogen

Monthly 2002 depositions of oxidized, reduced and total nitrogen to the entire Baltic Sea basin and the Baltic Sea catchment are shown in Figures 4.16 and 4.17, respectively. Deposition patterns for the Baltic Sea basin and Baltic Sea catchment are similar. Characteristic are local minima for all types of deposition in August and December, and local maxima of the depositions in October and November. Deposition of oxidised nitrogen to the entire Baltic Sea basin is larger than the deposition of reduced nitrogen for all months except for March and April, when the deposition of reduced nitrogen is slightly larger or on the same level as the deposition of oxidized nitrogen. For the Baltic Sea catchment, deposition of reduced nitrogen is larger than the deposition of oxidized nitrogen in March, April and May when intensive agricultural activities take place over the land, and is on the same level in September and October. Absolute maximum of monthly oxidized, reduced and total nitrogen deposition to the Baltic Sea basin with 15, 10 and 25 kt N, respectively, was calculated for November 2002. Absolute maximum of monthly oxidized, reduced and total nitrogen deposition to the Baltic Sea catchment was calculated for January (76 kt N of oxidised deposition) and March (67 kt N of reduced deposition, 122 kt N of total nitrogen deposition).

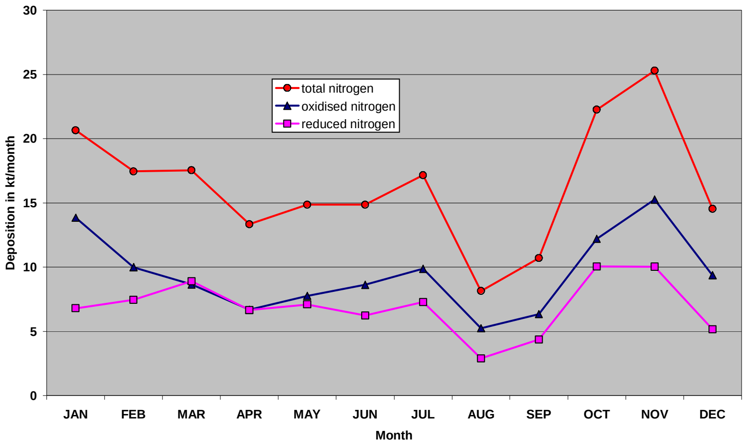


Figure 4.16. Monthly depositions of oxidized, reduced and total (oxidized +reduced) nitrogen to the entire Baltic Sea basin in 2002. Units: ktonnes N month^{-1}.

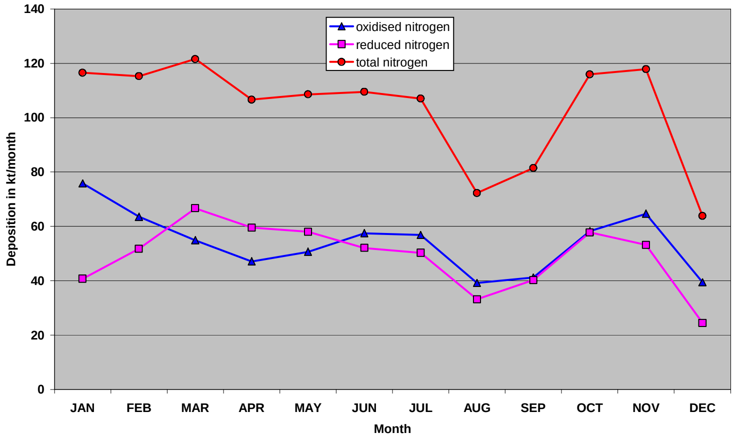


Figure 4.17. Monthly depositions of oxidized, reduced and total (oxidized +reduced) nitrogen to the entire Baltic Sea catchment in 2002. Units: ktonnes N month^{-1}.

4.4 Source allocation of nitrogen deposition

Not only local emission source of nitrogen (HELCOM Parties, Ship traffic) but also distant emission sources (e.g. UK and Italy) contribute to nitrogen deposition into the Baltic Sea. Comparison of contributions of nitrogen oxides emissions from the HELCOM Parties to oxidized nitrogen deposition into the Baltic Sea Basin in the years 1997 and 2000 was given in the previous report (Bartnicki *et al.* 2003). Similar comparison for ammonia emissions and reduced nitrogen depositions was also shown in the same report.

Ten countries (sources) with highest contributions of nitrogen oxides emissions to annual deposition of oxidized nitrogen into the Baltic Sea basin in the year 2000 are shown in Figure 4.18. Ten countries with highest contributions of ammonia emissions to annual deposition of reduced nitrogen into the Baltic Sea basin in the year 2000 are shown in Figure 4.19.

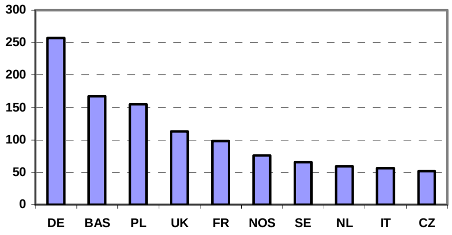


Figure 4.18. Top ten countries (sources) with highest contributions of nitrogen oxides emissions to annual deposition of oxidized nitrogen into the Baltic Sea basin in the year 2000. Units: 100 tonnes N year^{-1}.

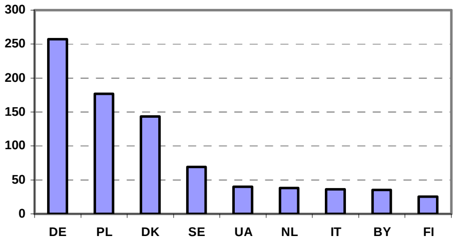


Figure 4.19. Top ten countries with highest contributions of ammonia emissions to annual deposition of reduced nitrogen into the Baltic Sea basin in the year 2000. Units: 100 tonnes N year^{-1}.

Both, for oxidized and reduced nitrogen deposition, Germany is definitely the largest contributor. In case of oxidized nitrogen deposition, contribution of emissions from the international ship traffic on the Baltic Sea is the second largest and it is approximately of the same order as contribution of Polish sources (third largest). In this case, contribution of distant sources, like UK, French and Italian emissions, is also significant. It is interesting to observe that the contribution of emissions from the international ship traffic over North Sea is also large – number six in the list.

In case of reduced nitrogen deposition, contribution of emissions from the HELCOM Parties, and especially from Germany, Poland, Denmark and Sweden, dominate in the deposition. However distant countries, such as Netherlands and Italy are also among ten major contributors to the deposition.

Source-receptor matrices for oxidized, reduced and total (oxidized + reduced) nitrogen deposition to sub-basins of the Baltic Sea in the year 2000 are presented in the Appendix C, in Tables C1, C2 and C3, respectively. Annual total emissions from the EMEP Contracting Parties, as well as emissions from the international ship traffic on the European seas are the nitrogen emission sources included in the SR matrices. Six sub-basins of the Baltic Sea and the entire Baltic Sea basin are on the receptor side, where the annual nitrogen deposition in the year 2000 is calculated.

Source-receptor matrices for oxidized, reduced and total (oxidized + reduced) nitrogen deposition to the catchments of the Baltic Sea in the year 2000 are presented in the Appendix C, in Tables C4, C5 and C6, respectively.

First three most important contributors to the deposition of total (oxidized + reduced) nitrogen to sub-basins and catchments of the Baltic Sea are shown in Tables 4.6 and 4.7, respectively.

Table 4.6. Three main contributors to annual total (oxidised + reduced) nitrogen deposition to the sub-basins of the Baltic Sea in the year 2000. Units: kt N yr^{-1} $region^{-1}$.

GUB	GUF	GUR	BAP	BES	KAT
DE – 5.59	DE – 1.97	DE – 1.63	DE – 29.21	DE – 9.32	DK – 5.88
PL – 5.20	RU – 1.07	PL – 1.34	PL – 25.49	DK – 5.27	DE – 5.41
SE – 4.40	PL – 1.34	BAS – 0.83	BAS – 9.76	FR – 2.00	FR – 2.27

Table 4.7. Three main contributors to annual total (oxidised + reduced) nitrogen deposition to the catchments of the Baltic Sea in the year 2000. Units: kt N yr^{-1} $region^{-1}$.

GUB	GUF	GUR	BAP	BES	KAT
FI – 26.0	RU – 45.2	PL – 14.2	PL – 236	DE – 43.2	DE – 22.1
DE – 23.2	FI – 20.8	BY – 13.4	DE – 139	DK – 20.4	DK – 21.0
SE – 22.6	DE – 20.0	DE – 11.1	CZ – 42	GB – 8.4	SE – 11.4

Germany, Poland, Denmark, Russian Federation, Sweden, France and emissions from the Baltic Sea ship traffic are the main contributors to total nitrogen deposition to different sub-basins of the Baltic Sea. Finland, Germany, Poland, Denmark, Russian Federation, Sweden, Czech Republic and the United Kingdom are the main contributors to total nitrogen deposition to different catchments of the Baltic Sea.

4.5 Comparison of model results with measurements

The EMEP Unified Eulerian model system has undergone a major overhaul the last years, where the previous EMEP models (Lagrangian as well as Eulerian) have been merged and re-written in order to produce the Unified EMEP Eulerian model. The model has been carefully documented in EMEP Status Report 1/2003, Part I and verified against measurement data at EMEP stations for ten different years (1980, 1985, 1990, 1995-2001) in EMEP Status Report 1/2003. The Unified EMEP model has been slightly revised this year, and the changes in the model have been documented in EMEP Status report 1/2004. In the same report, we presented verification of the model results for 2002 against measurements for all EMEP stations.

The agreement between model predicted and observed concentrations in air and precipitation heavily depends upon an adequate description of emissions. This includes both a reasonable estimates of national totals, gridded (source sector) data and temporal distribution of emissions. The emissions are undergoing a continuous process of review and revision, and this year for the first time the general annual review of emission inventory quality indicators (timeliness, completeness, internal consistency) has been extended to include a series of more detailed comparability analysis. In addition, the spatial distribution of the emissions used as input to the Unified EMEP model has been thoroughly revised and a new methodology for allocating emissions by sector has been proposed and tested. Thus, the results presented this year differ from previous years calculations due to 1) revision of the Unified EMEP model and 2) review and revision of the emissions.

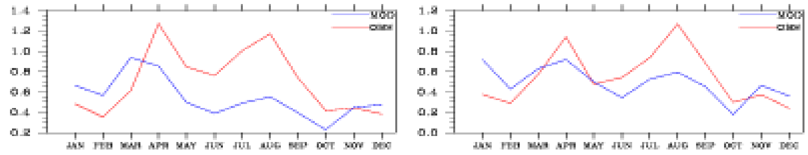
In this section we will concentrate on the model performance for nitrogen compounds at the HELCOM sites. Note that the agreement between model results and observations depends not only on the model performance and the adequacy of emissions, but also on the quality and representativeness of the measurement sites. Thus, the following discussion on model *underestimation* and *overestimation* simply imply that the calculated values are lower or higher than the observations, and does not refer to model deficiency only.

4.5.1 Air concentrations

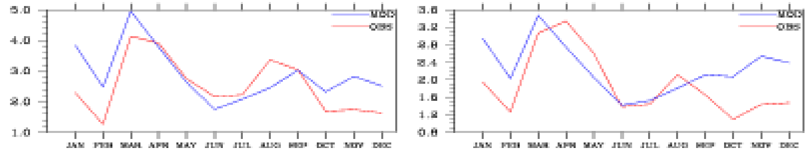
Measurements of particulate ammonium and nitrate are available only from four sites, DE09, DK05, DK08 and DK20. Therefore, it is difficult to conclude anything on the model performance for these compounds based on the HELCOM measurements. However, observations for the sum of ammonia plus ammonium and total nitrate (nitric acid plus particulate nitrate) have been reported by a number of HELCOM sites, and in Figure 4.20 we present monthly time series for model versus observations for 11 of them. The overall agreement between measurement and model is good. It is especially encouraging that the model manages to reproduce the seasonal cycle of ammonia plus ammonium. The model shows, however, a tendency to overestimate winter concentrations and underestimate summer concentrations. In (Fagerli *et al*. 2003) it was suggested that the overestimation in winter is caused by an overestimation of ammonium aerosol. The underestimation of summer concentrations compared to measurements is probably due to problems in the modeling of the spatially variable ammonia gas in combination with influence of local sources on measurements.

In Figure 4.21 we present monthly time-series for the sum of nitric acid and nitrate in air for 11 HELCOM stations for 2002. The observed seasonal variation of total nitrate in air is well reproduced by the model. However, the model predicts somewhat higher nitrate concentrations in air than measurements, especially in winter. This may be caused by too high conversion of nitric acid too nitrate in the cold periods. The revised model version contains a more comprehensive equilibrium chemistry module (EQSAM, Metzger *et al*. (2002a), Metzget *et al*. (2002b)) which gives total nitrate concentrations in better agreement with observations than the model version used in last years report. However, the model still overestimate nitrate somewhat in the winter.

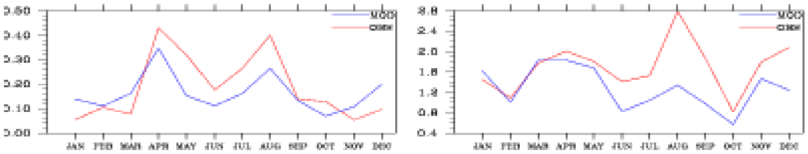
Figure 4.20. Monthly time-series for modelled versus measured concentrations of ammonia plus ammonium in air in 2002.
Units: mg N m^{-3}.



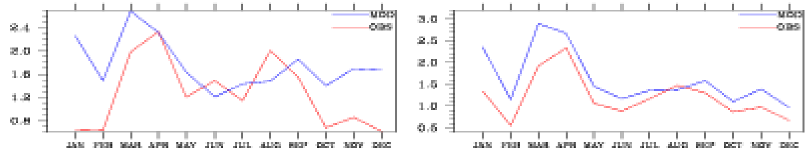
(a) FI17 (b) FI09



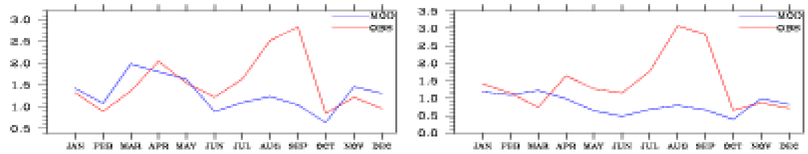
(c) DK05 (d) DE09



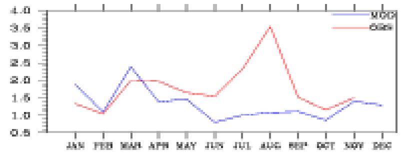
(e) SE05 (f) LT15

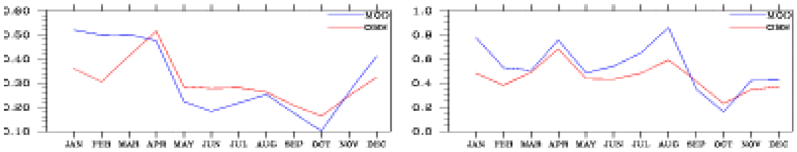


(g) SE11 (h) DK08

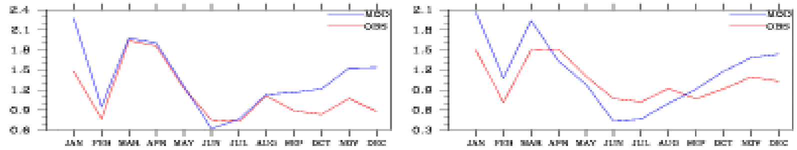


(i) LV10 (j) LV16

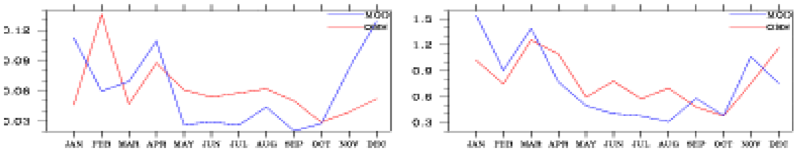




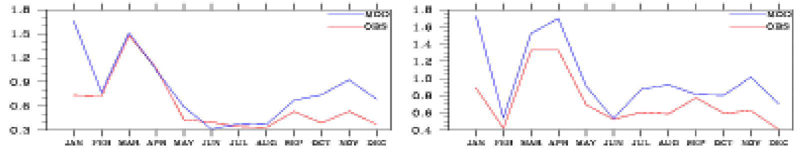
(a) FI17 (b) FI09



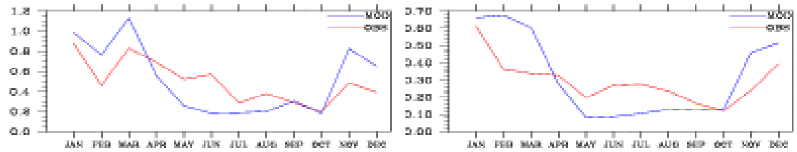
(c) DK05 (d) DE09



(e) SE05 (f) LT15



(g) SE11 (h) DK08



(i) LV10 (j) LV16

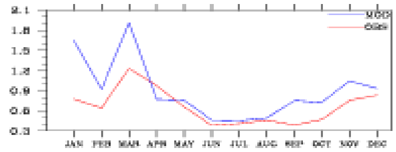


Figure 4.21. Monthly time-series for modelled versus measured concentrations of nitric acid plus ammonium nitrate in air in 2002. Units: µg N m^{-3}.

4.5.2 Concentrations in precipitation

The correlation between model and measurements for concentrations in precipitation and wet depositions depend to a large extent on the modeled precipitation field. However, the precipitation field pattern is very patchy (e.g. influenced by local topographic effects), and the regional scale EMEP model is unable to resolve this sub grid scale distribution. A typical problem arises with small scale showers. In reality precipitation is high in a small area of a given grid, but a large fraction of the grid should remain dry. Within the model, however, this precipitation is averaged out to cover the whole grid at a lower intensity. Thus, even though average precipitation amounts may be simulated well, the model experiences precipitation more often, but in lower amounts, than occur in reality.

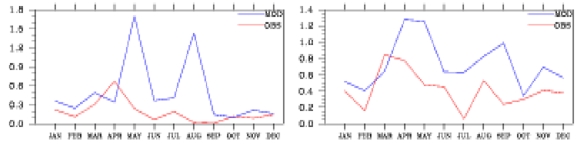
For the reasons given above, it is clear that the comparison between model and measurements for components in precipitation are expected to be worse than those for air concentrations.

In Figures 4.22 and 4.23 we compare modeled and measured monthly concentrations of oxidized and reduced nitrogen in precipitation. For the majority of the stations, the modeled and measured concentrations agree well. However, a more thorough analysis of results at all EMEP stations indicates that concentrations of ammonium and nitrate in precipitation are somewhat underestimated. Further work is needed in order to fully understand the reason for the discrepancy between modeled and measured nitrate and ammonium concentrations in precipitation.

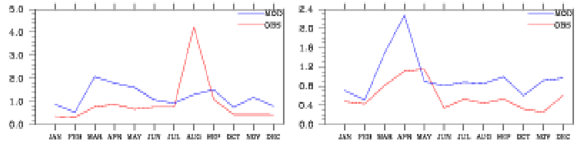
4.5.3 Concluding remarks

In general, the comparison between model and measurements for concentrations of nitrogen compounds is good and comparable to the model performance for the EMEP sites. Thus, the model provides a reliable tool in order to assess the nitrogen supply to the Baltic sea.

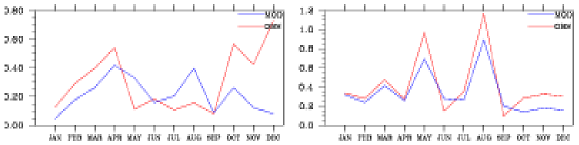
It should be noted, however, that in order to make a proper evaluation of model performance, monthly measurements are not satisfactory. For example, it happens that measurements are contaminated or that a measurement site is closed down for a day or two during a month. When comparing the model and the measurement data, the comparison should be done only for days when both modeled and measured data are available. In addition, daily data is needed in order to examine e.g. how the model performs during specific meteorological situations. Thus, to a large extent we rely on the evaluation of the Unified EMEP model against daily measurements from the total EMEP network when drawing conclusions on the model performance for the HELCOM sites.



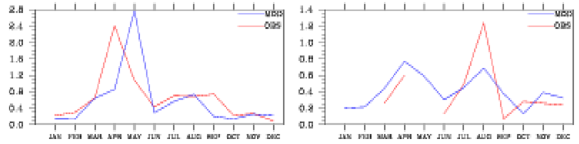
(a) EE09 (b) DK08



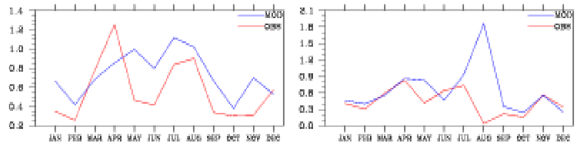
(c) DK05 (d) DE09



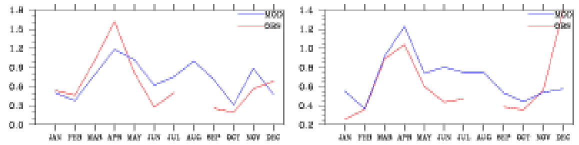
(e) FI53 (f) FI17



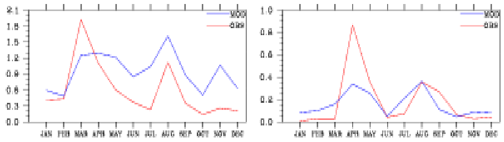
(g) FI09 (h) EE11



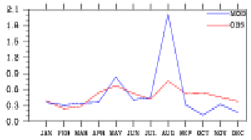
(i) PL04 (j) LV16



(k) LV10 (l) LT15

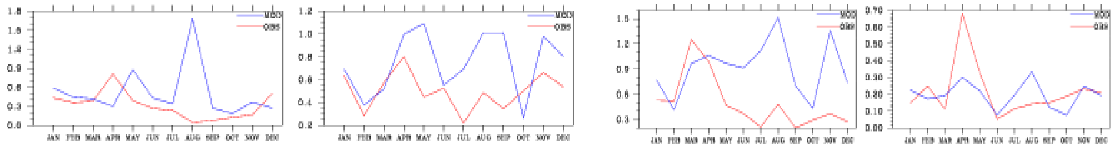


(m) SE11 (n) SE05

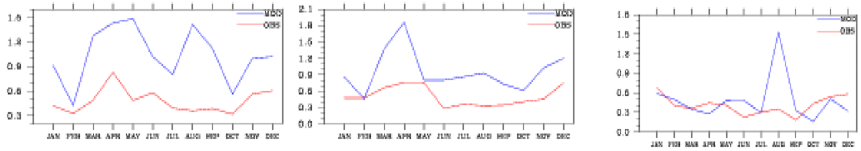


(o) RU16

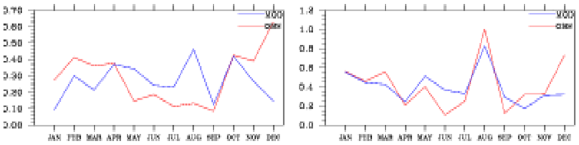
Figure 4.22. Monthly time-series for modelled versus measured concentrations of ammonium in precipitation in 2002. Units: µg N l^{-1}.



(a) EE09 (b) DK08 (m) SE11 (n) SE05

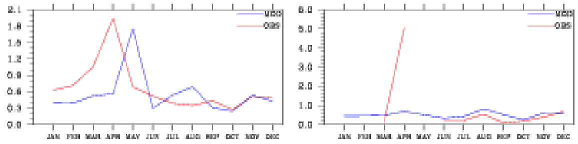


(c) DK05 (d) DE09 (o) RU16

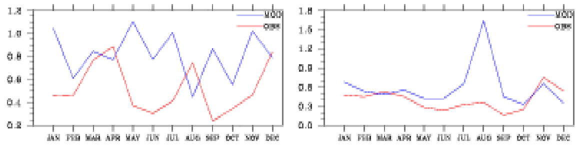


(e) FI53 (f) FI17

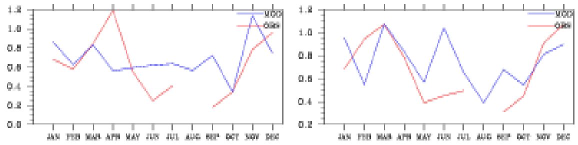
Figure 4.23. Monthly time-series for modelled versus measured concentrations of oxidized nitrogen in precipitation in 2002. Units: µg N m^{-1}.



(g) FI09 (h) EE11



(i) PL04 (j) LV16



(k) LV10 (l) LT15