Chapter 4

Ammonia

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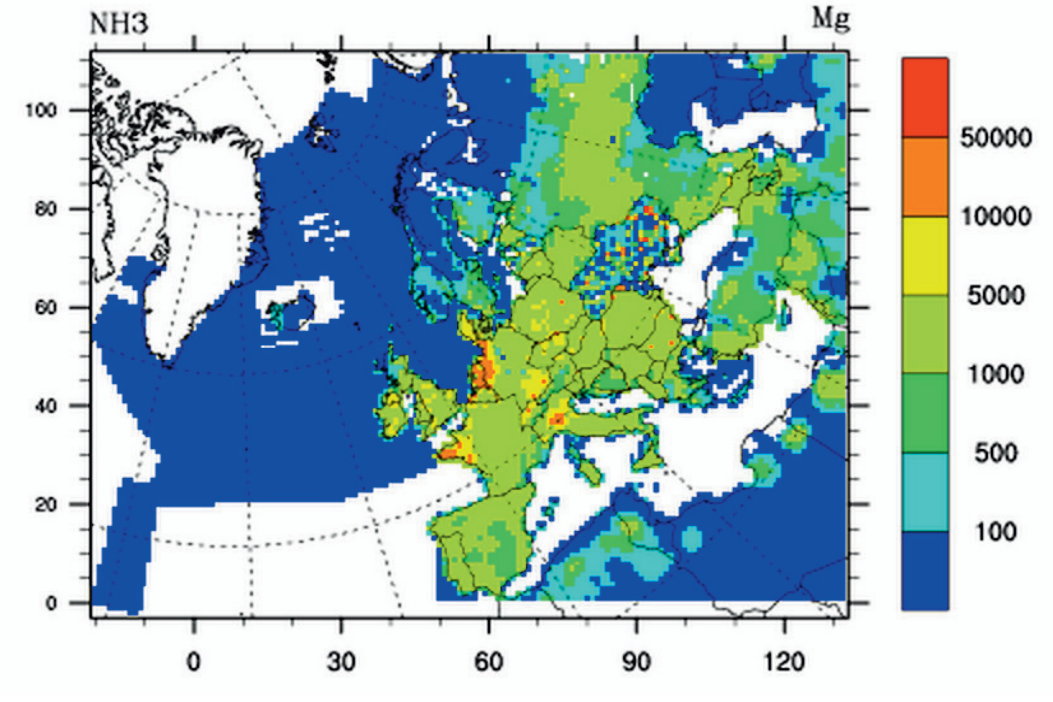
4.1 Emissions of ammonia

4.1.1 Ammonia emissions

The emissions of ammonia were in 1980 - and still are - of the same magnitude as that for nitrogen oxides, (both measured in nitrogen units). Ammonia is consequently very important for the total nitrogen deposition, and thus for the eutrophication situation in marine and terrestrial ecosystems Ammonia emissions arise mainly from husbandry and manure practices in agriculture.The estimates of ammonia emissions are more uncertain than the emissions of sulphur and nitrogen oxides.

The spatial distribution of ammonia emissions over Europe in 1980 is presented in Figure 4.1. The emissions show maxima in north-western France, Belgium and in the Netherlands. Also in parts of northern Italy, Yugoslavia and Ukraine there are grids with high ammonia emissions.

Figure 4.1 Spatial distribution of ammonia emissions in 1980. Units: tonnes/year/grid square.



FATE OF AMMONIUM IN THE ATMOSPHERE

Gaseous ammonia is readily deposited to acid particles and wet surfaces with a low pH. Ammonium ions are formed and ammonium in the form of particles may - just as sulphate and nitrate - be transported over long distances, 1000-2000 km and even further.

Ammonium ions have the same fate in the ecosystems as nitrate. It is a nutrient, which will be taken up as long as the ecosystem can use nitrogen.

When the uptake capacity is exceeded, ammonium will be leached.

4.1.2 Emission trend for ammonia 1980 - 2000

The ammonia emissions are over Europe as a whole, of a magnitude comparable to NO_x emissions. The emissions of ammonia are largest in the large countries, mainly those with extensive agriculture, such as Russian Federation, Germany, France, Ukraine, Poland, Italy Spain, United Kingdom and the Netherlands.

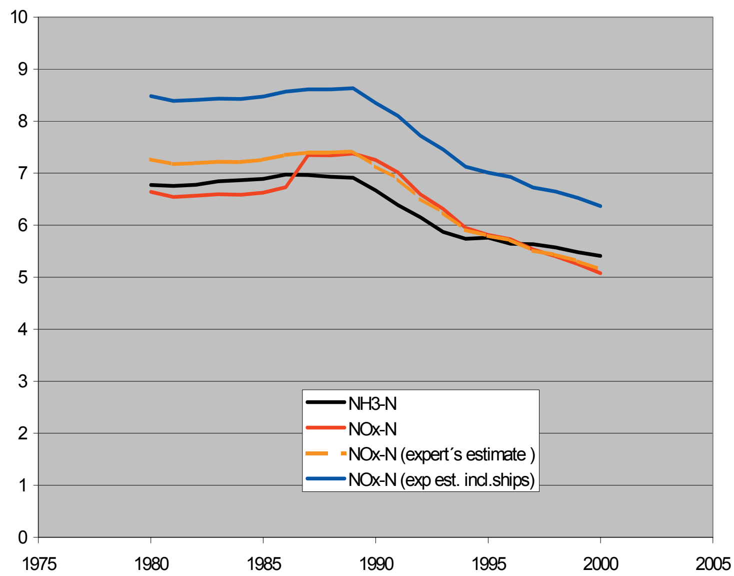


Figure 4.2 Annual ammonia emissions in European countries 1980-2000. Units: million tons NH_3-N.

For comparison the figure also presents the NO_x emissions - as officially reported total land-based emissions, as expert estimates of total land-based emissions and as total emissions incl. those from ships (million tonnes N/ year).

The Russian emissions only include the European part.

The reduction of European ammonia emissions from 1980 to 2000 is similar to that of NO_x.The trends have been somewhat different over different parts of Europe, see Figure 4.3 and Table 4.1. The largest relative decrease took place after 1990 in the eastern European countries, where the emissions went down by nearly 50%. In most areas the reduction has only been around 10%, however.

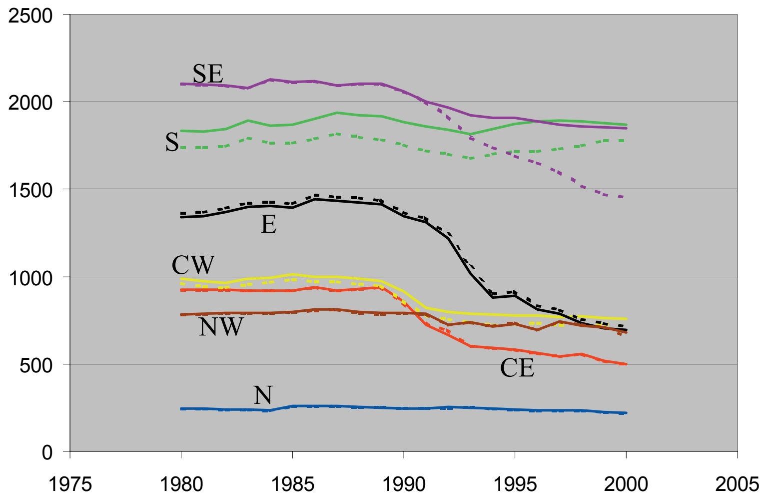


Figure 4.3 Regional trends in ammonia emissions. :Units: ktonnes of NH3/year

CE = Czech Republic, Hungary, Poland, Slovakia

CW = Austria, Germany, Switzerland

E = Estonia, Latvia, Lithuania, Russian Federation (European part).

N = Finland, Iceland, Norway, Sweden, Denmark

NW = Belgium, Ireland, Luxembourg, Netherlands, United Kingdom

S = France, Greece, Italy, Portugal, Spain

SE = Albania, Armenia, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, Georgia, Kazakhstan, Republic of Moldova, Romania, Slovenia, The FYROM Macedonia, Turkey, Ukraine, Yugoslavia

Table 4.1 Emission reductions in different parts of Europe

Countries	**Change in S emissions**	**Change in NOx emissions**	**Change in NH_X emissions**
Czech Rep., Hungary, Poland and Slovak Rep.	-73%	-42%	-46%
Austria, Switzerland and Germany	-89%	-49%	-23%
Estonia, Latvia, Lithuania and Russia (European part)*	-73%	+21%	-48%
Denmark Finland Iceland, Norway and Sweden	-87%	-21%	-10%
Belgium, Luxemburg, the Netherlands, Ireland and United Kingdom	-76%	-36%	-13%
France, Greece, Italy, Portugal and Spain	-62%	-4%	+1%
Albania, Armenia, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, Georgia, Kazakhstan, Republic of Moldova, Romania, Slovenia, The FYROM Macedonia, Turkey, Ukraine and Yugoslavia	-40%	-26%	-12%
Total Europe (excl. ships)	**-67%**	**-24%**	**-20%**

* There is an increase in the official NO_X emissions in Russia due to a missing source which was not included in the early data.

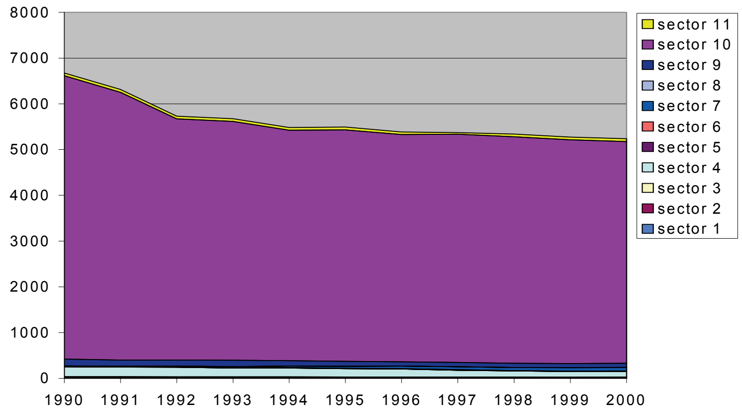


Figure 4.4 Sectorial emission of ammonia (NH_3)
Units: ktonnes/years

The emissions from agriculture, sector 10, are dominating.

Emission sectors are defined on page 16 in Chapter 2.

For the emissions of ammonia there are commitments to be fulfilled according to the Gothenburg protocol. Also, prognoses of emissions in 2010 and 2020 have been made from expected national development trends for husbandry and from national goals for ammonia emissions. Most countries in Figure 4.5 are shown in green, since the national ammonia emissions have been decreasing towards the emission ceilings of the Gothenburg protocol for 2010. In Figure 4.5a the necessary remaining reductions in tonnes are shown. Figure 4.5b shows the remaining reductions in percent of the necessary total reduction.

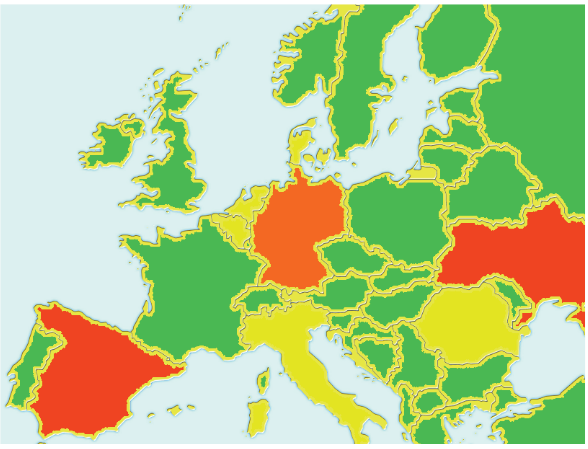


Figure 4.5a Emissions of NH_3 necessary to reduce between 2000 and 2010 to fulfil the Gothenburg protocol. Units: ktonnes/year.

Red = 100-140,
Orange = 50-99
Yellow = 10-49

In the *green-marked* countries the necessary reduction is below 5 000 tons per year. Most of them have already in the year 2000 reached their goal for 2010.

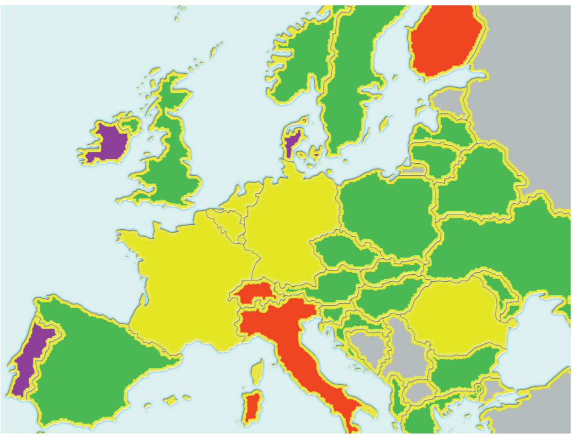


Figure 4.5b Emissions of NH3 left to reduce in 2000 in order to fulfil the agreement in the Gothenburg protocol 2010. Units: % of the total reduction required between 1990 and 2010.

Violet = 60% or more
Red = 30 - 59%
Yellow = 1 - 29%
Green = the goal is achieved already 2000.

The *grey* countries are not included in the protocol or it is not possible to evaluate the progress in reduction.

4.2 Trends in concentrations of ammonium in air and precipitation

4.2.1 Ammonium pollution in the 1980s

The ammonium pollution situation in 1980 and 1990 were similar. The maps in Figure 4.6 show the spatial distribution of air concentrations of gaseous ammonia and particulate ammonium (total ammonium) over Europe.

4.2.2 Trends in ammonium in air

Measurements indicate that ammonium concentrations in air have decreased in many areas in Europe. The decrease in total ammonium is similar to that of total nitrate (Figure 4.7). There is no pronounced trend in the Swiss data, but the time series are maybe not long enough to indicate trends. The data from Norway, Denmark and United Kingdom indicate a 20- 30% decrease in air concentrations, similar for total nitrate and total ammonia. The national ammonia emission reductions are between 10 - 15%. The relatively larger reduction of total ammonia in air compared to the national emission reductions may be due to influence not only from local but also from more distant contributions. In addition, the trends may be due to changes in the rates of chemical interactions between pollutants, due to a changing atmospheric composition, see further below.

a) b)

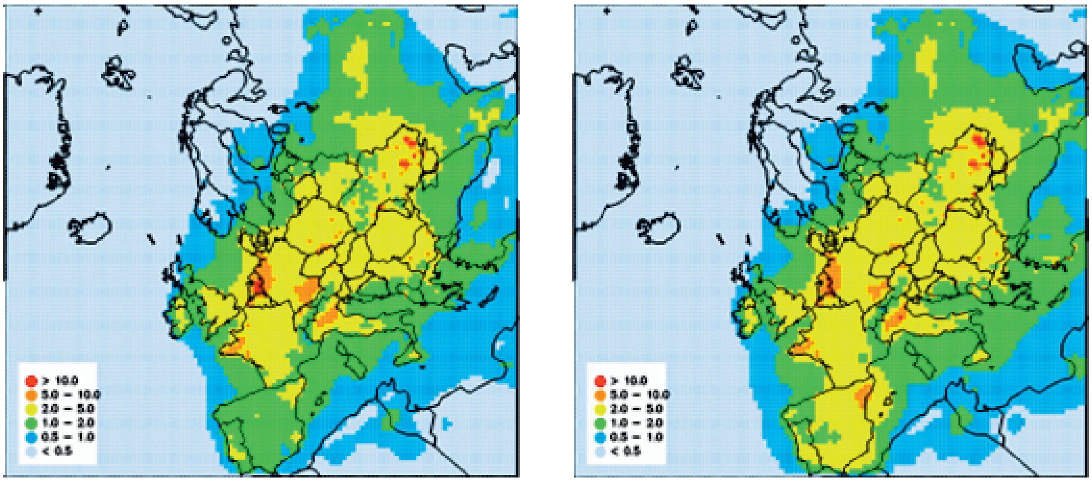


Figure 4.6 Spatial distribution of air concentrations of gaseous ammonia and particulate ammonium (total ammonium) over Europe in a) 1980 and b) 1990. Units: µg N/m^3.

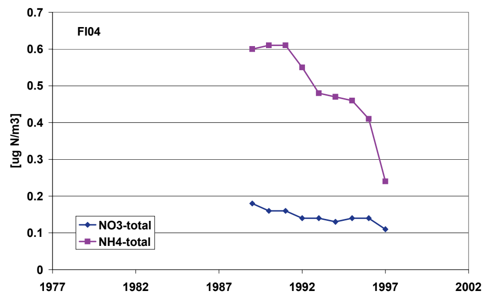
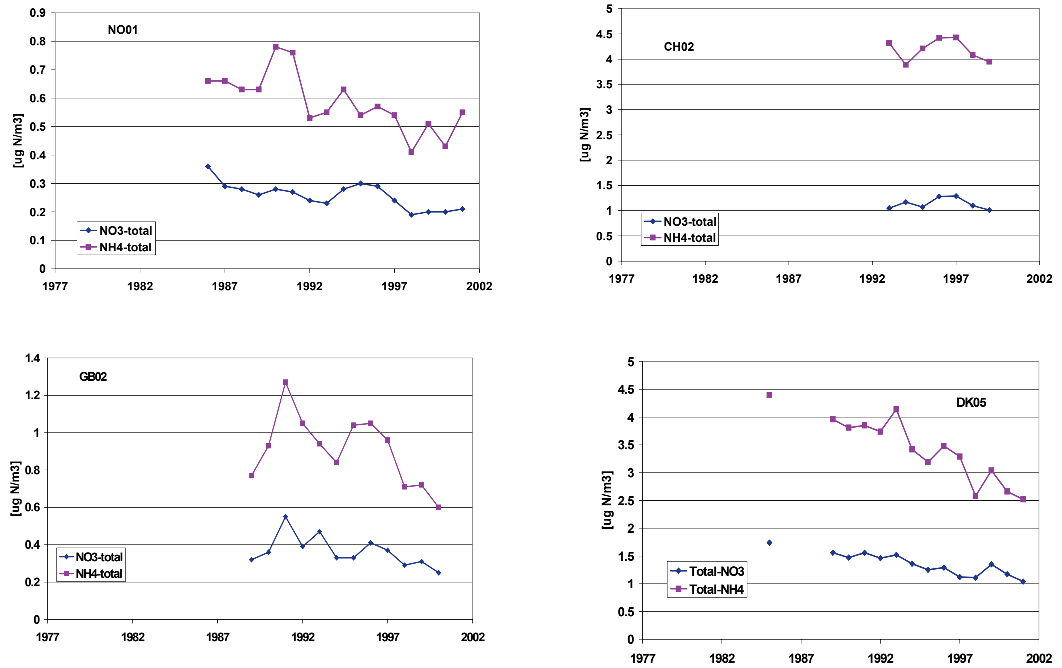


Figure 4.7 Time series for annual means of total nitrate and total ammonium in air at some EMEP sites in Europe 1980 – 2000. Units: µg N/m^3.

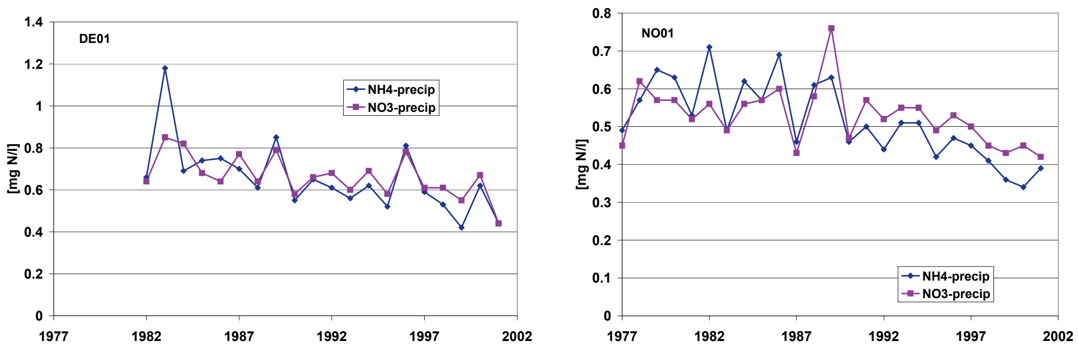


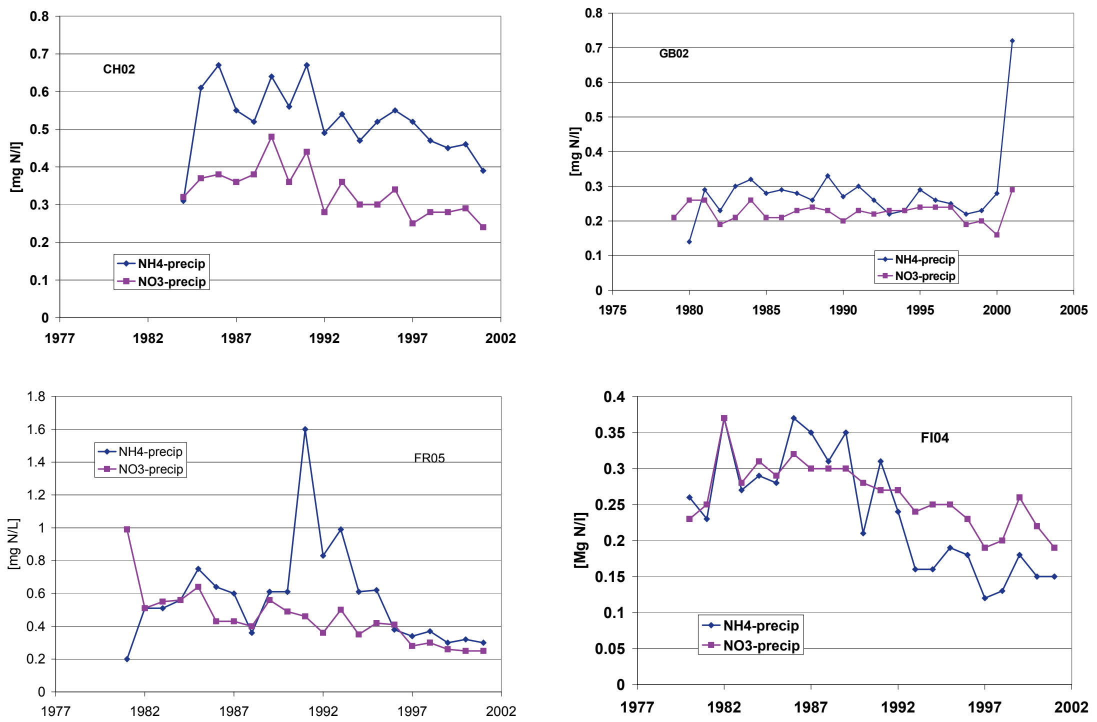
4.2.3 Trends in ammonium in precipitation

Like in air, concentrations of ammonium in precipitation have decreased in many areas over the period 1980 – 2000, although the variations between years are large and trends in most cases are not statistically significant, see Figure 4.8. Generally, concentrations of ammonium in precipitation seem to decrease to the same extent as nitrate, sometimes more than the national emission reductions. Over Europe as a whole, the trend for ammonium in precipitation is similar to the trend in ammonia emission. On this scale, the time series for nitrogen compounds in precipitation show similar development to those for total nitrate and total ammonium in air.

Ammonia plays an important role in the air chemistry and interacts with both sulphur dioxide and nitrogen compounds in the air, and contribute to the non-linearities discussed in the sulphur chapter. This can clearly be deduced especially in areas with considerable ammonia pollution, e.g. in the Netherlands. As a result of the strong decrease in SO_2 emission in Western Europe, SO_2 concentrations show a strong decline. In most areas this has led to a decline in dry deposition of SO_2. However, wet deposition does not show the same decline.

Figure 4.8 Time series for nitrate and ammonium in precipitation at some EMEP sites in Europe.





This is assumed to be explained by the lifting of the SO_2 excess as the result of the increased neutralisation by ammonia. There is a complex interaction between SO_2 and NH_3, which becomes important when the emission of one of the two gases changes differently from the other, which has been the case in Europe - and the USA - during the last decade. In situations where NH_3 emission increased or SO_2 decreased, atmospheric and surface wetness chemistry induced higher SO_4 formation leading to important non-linearity's in sulphur emission – deposition relationships.

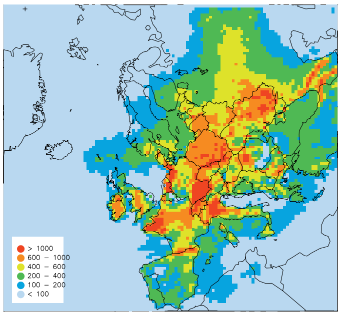
If the pH increases in aqueous solutions, such as cloud droplets, aerosols and surface wetness, the solubility of SO_2 increases as well as its oxidation rate. The consequence is that despite the large sulphur emission reductions, SO_4 aerosol and wet deposition in remote areas has decreased much less. Furthermore, despite NO_x emission reductions, wet deposition of NO_3 did not decrease in remote areas. Again this is the result of the SO_2 and NH_3 interactions: in SO_2 source areas excess SO_2 decreased due to the strong emission reductions. NH_3 primarily forms $(NH_4)_2 SO_4$ in aerosol or cloud droplets and the excess NH_3 is in equilibrium with HNO_3 and HCl to form ammonium nitrate and chloride. Because the SO_4 production is limited by the SO_2 availability, there is more NH_3 available to form nitrates. The transport distance of nitrate aerosol is substantially longer than the rapidly deposited HNO_3. Inputs in remote areas are dominated by aerosol input and wet deposition, which therefore declined much less than emissions.

4.2.4 Deposition of ammonium

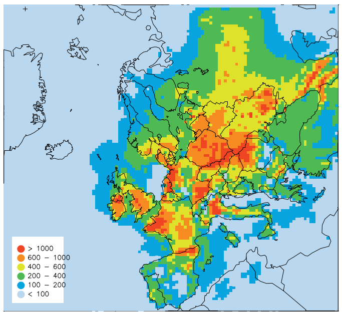
Since there is a decrease in concentrations of ammonium in precipitation (Figure 4.8), and no trends in precipitation amount has been detected, the wet deposition of ammonium has decreased as well.

The total deposition of ammonia is the sum of the wet and dry deposition contributions. No routine measurements for dry deposition are available, therefore estimates of dry and total deposition have to rely mainly on model calculations. Maps over model calculated total deposition 1980 - 2000 are shown in Figure 4.9.

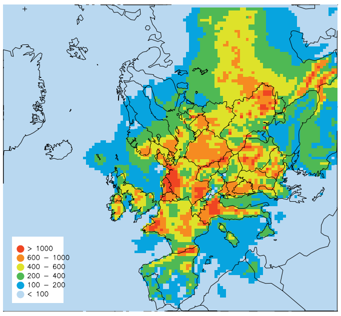
Figure 4.9 Time series for annual deposition of ammonium over Europe. Units g m^{-2}.



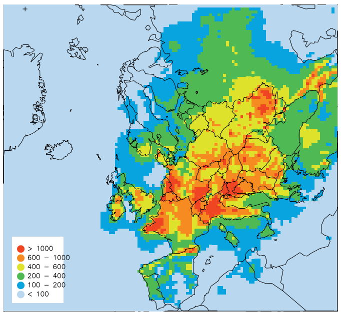
1980



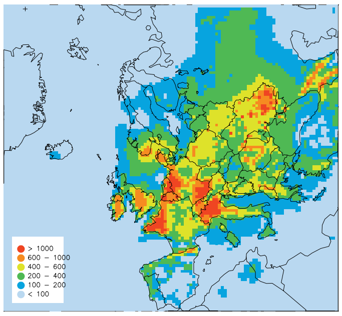
1985



1990



1995



2000

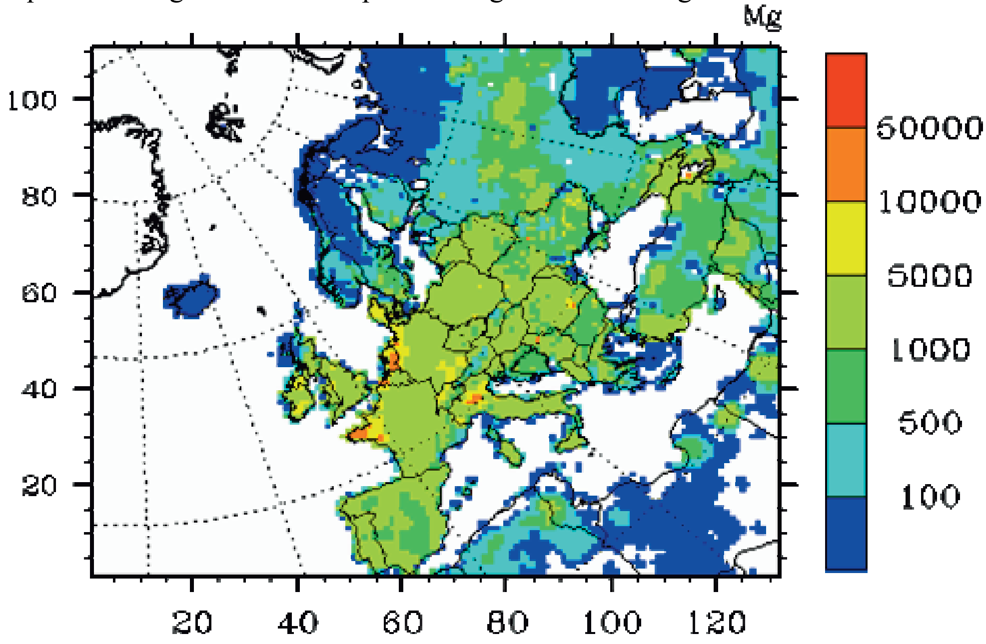
The Figure indicates that there have been changes in deposition over Europe during the period 1980-2000. Deposition in Germany, Poland and towards east, had a maximum during the 1980s. In 2000, the deposition in these areas was lower. On the other hand, the maximum deposition in France, for example, was observed around 1995.

4.3 What has been achieved during 25 years Need for further reduction of ammonia

The spatial distribution of ammonia emissions over Europe in 2001 (Figure 4.10) shows that there is a maximum in north-western France, Belgium and in the Netherlands, but also areas in northern Italy, Yugoslavia and Ukraine have grids with high ammonia emissions.

Conclusions for the overall European development over time are limited by the data available. There are few series of total ammonium data covering the period of interest. The total deposition of ammonium nitrogen has decreased over larger parts of Europe. In many areas the problem is not considered to be very important, while over central Europe and especially in areas with extensive farming, the nitrogen input to ecosystems from the atmosphere is a significant environmental threat. Exceedances of critical loads (NIlsson, 1986; Nilsson and Grennfelt, 1988) are expected to occur in many areas even when the emissions goals of the Gothenburg protocol are reached.

Figure 4.10 Spatial distribution of ammonia emissions over Europe 2001. Units: Tonnes/year/grid square. The figure can be compared to Figure 4.1 showing the emissions in 1980.



Ammonium deposition contributes together with nitrogen oxides deposition to acidification and to eutrophication of ecosystems. Figure 2.25 (in Chapter 2 Sulphur) shows the exceedance of critical loads for acidification. Figure 3.10 (in Chapter 3 Nitrogen oxides) shows exceedance of critical loads for eutrophication by the total nitrogen deposition in 1980 and 2000. A forecast for 2010 is also included in the Figure 3.10. The maps show the change achieved between 1980 and 2000. There has been a significant reduction in exceedance of critical loads for acidity, mainly due to the large decreases in sulphur emissions. Also for the exceedance of critical loads for eutrophication a certain reduction is seen. Generally, the maps show that the improved situation in 2000 is not good enough to protect the ecosystems. Further reductions are necessary both for sulphur and nitrogen emissions. The maps for 2000 point out the areas in which the largest deposition decreases are necessary.

4.4 Conclusions for the trends of ammonia pollution in the environment

- Ammonia is mainly emitted from agricultural activities. The ammonia emissions introduce - as a total over Europe - similar amounts of nitrogen into the atmosphere as the nitrogen emitted in the form of nitrogen oxides.

- When deposited, the nitrogen from ammonia will have similar nutrient effects upon ecosystems as nitrogen oxides. In calculations of critical loads exceedances, they both contribute. It is therefore of importance to reduce ammonia emissions as well as nitrogen oxides emissions.

- The emissions have decreased by approximately 20% all over Europe, even if there are large differences between regions. The largest reductions are reported in eastern European countries such as the Baltic States, Czech Republic, Hungary, Poland, Russian Federation and Slovak Republic. In most other parts of Europe the decrease has been around 10%. In some individual countries such as the Netherland the ammonia emission decrease has been around 40% between 1990 and 2000. In southern Europe the emissions have been on a more or less constant level for the last 10 years.

- The levels of ammonium pollution over Europe vary between regions. There is a maximum of deposition in north-western Europe. Decreases in ammonium concentrations in air and precipitation are similar to those of nitrate in air and precipitation. This is related to the fact that the overall European emission reductions are similar for nitrogen oxides and ammonia.

- The data from the EMEP measurement sites suggest that the reductions of ammonium in air and precipitation also depend on the air concentration of sulphate and nitrate.

4.5 References

Nilsson, J. (Ed) (1986) Critical Loads for nitrogen and sulphur. Report from a Nordic Working Group. Nordiska Ministerrådet (Nordic Council of Ministers), Report 1986:11, Copenhagen (Denmark).

Nilsson, J. and Grennfelt, P. (1988). Critical Loads for Sulphur and Nitrogen. Nordic Council of Ministers. Report 1988:15. Copenhagen (Denmark).

Data from EMEP databases on emissions and monitoring data.