Transboundary acidification, eutrophication and ground level ozone in Europe since 1990 to 2004

EMEP Status Report 1/2006 to support the Review of Gothenburg Protocol
Transboundary Acidification, Eutrophication and Ground Level Ozone in Europe from 1990 to 2004 in support for the review of the Gothenburg Protocol

Leonor Tarrasón, Hilde Fagerli
EMEP/MSC-W: Heiko Klein, David Simpson
Anna C Benedictow and Vigdis Vestreng

ETC/ACC: Elisabeth Rigler (UBA-V)
ICP-Forests: Lisa Emberson (SEI-York)
CCE: Maximilian Posch (NMP)
ICP M&M: Till Spranger (UBA)

EMEP Status Report 2006; August 9, 2006

ISSN 1504-6109 (print)
ISSN 1504-6192 (online)
This report has been prepared for the thirtieth session of the Steering Body to EMEP to support the review of the Gothenburg Protocol. It is a first attempt to determine the status in 2004 with respect to the goals provided by Annex II of the Gothenburg Protocol.

The analysis traces the progress in emissions, air concentrations and depositions of acidifying and eutrophying compounds and ground level ozone since the base year of the Protocol, 1990, and up to 2004. To establish the distance to the targets in 2010, the situation in 2004 is compared with the provisions in Annex II of the Gothenburg Protocol. Best available scientific methods and information have been used for the calculations.

No effort has been made here to establish different scenarios for emissions projections in 2010. The question of whether or not we will reach the Gothenburg Protocol targets by 2010 requires a separate study and should be analysed in conjunction with new projection estimates by the Parties and the Centre of Integrated Assessment Modelling (CIAM).

This report carefully documents differences between official emission estimates and MSC-W estimates of emissions, used as basis for model calculations. For the purpose of the review of the Gothenburg Protocol, Parties to the Convention on Long-range Transboundary air Pollution have been separated in: a) Parties to the Gothenburg Protocol, b) Signatory Parties, c) non-Signatories and d) all other Parties to LRTAP not included in the Gothenburg Protocol.

How far are we from reaching the emission ceilings provided in Annex II of the Gothenburg Protocol for 2010?

Over the EMEP area, the emission ceilings for sulphur oxides provided in Annex II of the Gothenburg Protocol were already reached in 2004. However, there are large
differences in the level of attainment of the Protocol goals by the different Parties. Only 50% of the Parties to the Convention have already reached the Protocol 2010 emission ceilings for SO\textsubscript{x}. The remaining half needs to reduce their emissions further. The share of countries that have already reached the ceilings for 2010 is somewhat higher for Parties to the Protocol than for other Parties. Results from both official and estimated emissions provide the same conclusions for sulphur dioxide.

The number of Parties to the Convention that have already reached the emission ceilings is higher for ammonia than for any other pollutant considered in the Gothenburg Protocol. About 65% of all Parties had already reached the 2010 emission ceilings for ammonia by 2004. The share of countries that have already reached their ceilings for ammonia emissions is somewhat lower for Parties to the Protocol than for other Parties. For Parties to the Gothenburg Protocol, official estimates indicate that the bulk of NH\textsubscript{3} emissions have already reached the 2010 Gothenburg ceilings, while MSC-W estimates indicate that ammonia emissions in the EMEP domain need to be further reduced by about 3% in order to reach the ceilings in the Protocol. Still, both the official estimates and the MSC-W estimates agree on a satisfactory level of compliance with the goals in 2010 for Parties and Signatories to the Protocol.

The situation is not so satisfactory for emissions of non-methane volatile organic compounds. Only about 40% of all Parties had reached the 2010 emission ceilings of NMVOC in 2004, and a similar share applies for Parties to the Protocol. Official and estimated emission values differ on the actual level of the distance to target. Official estimates indicate that there is a need for further emission reduction equivalent to a 2% of the 2004 emission levels for the whole EMEP area, while the estimates by MSC-W are of about 6%.

The lowest level of attainment is for emissions of nitrogen oxides. Again, only about 40% of all Parties had reached the 2010 emission ceilings of NO\textsubscript{x} in 2004. However, the share of countries that have already reached their ceilings for NO\textsubscript{x} emissions is significantly lower, about 30%, for Parties to the Protocol. Both official and MSC-W estimates agree on the need for a generalised further reduction of NO\textsubscript{x} emissions in the EMEP area by 15% in order to reach the goals in the Gothenburg Protocol. There is also a common result that further emission reductions should be largest for the Parties to the Protocol, about 20-25% in average.

Are these conclusions different for official and estimated emission values?

In general there is good agreement between officially reported emission data and MSC-W emission estimates, so that conclusions on the level of attainment of the goals in the Gothenburg Protocol are very similar for both estimates. The largest differences are for emissions of NMVOC. These differences reflect also the largest uncertainties in the calculation of emission from NMVOC sources compared to other main pollutants and the difficulties encountered by most Parties to report and allocate NMVOC emissions correctly.
MSC-W estimates are primarily intended to fill in gaps from official emission reports. This involves mainly emissions from non-Signatories and other Parties in Eastern European countries where there is a generalised lack of official emission estimates and where projections for 2010 are not provided by the Gothenburg Protocol. Thus, differences between official data and MSC-W estimates are largest in Eastern Europe, for countries not included in the Gothenburg Protocol. This has consequences for the calculated levels of depositions and air concentrations, in particular for ammonia emissions. For NH$_3$, MSC-W and CIAM estimate that emissions should be considerably reduced in Eastern European countries in order to reach the 2010 targets. New projections for 2010 are in progress and some major revisions of the current 2010 estimates for these Eastern European countries are expected, preferably in co-operation with national experts.

**Do conclusions change if targets are considered in terms of percentage reductions?**

The level of attainment of the goals prescribed in the Gothenburg Protocol is very similar whether emission ceilings or percentage reductions are used as reference.

For NMVOC there are no differences at present, despite the fact that emissions of NMVOC are generally those with highest changes due to recalculations by the reporting Parties. For sulphur and nitrogen oxides, there is only one case of a Party that reaches the Protocol emission ceilings but not the percentage reduction. For ammonia, there are 3 Parties that have managed the percentage reduction without meeting the emission ceilings and 6 Parties that have managed the emission ceilings without meeting the percentage reductions. This indicates that recalculations do not systematically affect the distance to target. This is because recalculations usually respond to methodology changes in the calculations of emissions and affect not only the base year but the full time series.

**What has been achieved in ecosystem protection from acidification and eutrophication since 1990? How far are we in 2004 from the targets set up by the Gothenburg Protocol?**

More than 50% of the Parties have already reduced their SO$_x$ emissions below the Gothenburg Protocol emission ceilings. This results in large reductions of sulphur depositions and subsequently, leads to a major reduction of the risk for acidification all over Europe. In 1990, almost all the Parties to the Protocol had 40% or more of their ecosystem areas at risk. In 2004, the area unprotected from acidification has decreased below 20% for most of the Parties to the Protocol. The largest reductions have been achieved in countries where the ecosystems are more sensitive to acidification (e.g. the Nordic countries), whilst in areas with more robust ecosystem areas (e.g. southern Europe) less progress has been made.
For oxidised nitrogen depositions, many countries are still far from reaching the
targets set by the Gothenburg Protocol. In 2004 more than half of the Parties to the
Protocol still need to reduce their depositions by 20% and more in order to reach
the Gothenburg target for 2010. This is in agreement with the generalised lack of
attainment of the goals for 2010 for nitrogen oxide emissions.

The deposition load in a country depends on the development of emissions in other
countries as well. This applies in particular to ship emissions that are projected to
increase in the future and implies that achieving the deposition levels in the Goteborg
protocol does not necessarily mean achieving the Goteborg emission ceilings. Ireland
is a good example. Irish NO$_x$ depositions in 2004 are lower than in 2010 GP, and thus
the target 2010 GP depositions are reached. But Irish NO$_x$ emissions are well above
Gothenburg Protocol emission ceilings. The reason is that the largest contributor to
depositions in Ireland is by far international ship traffic in the Atlantic sea and the
North sea. Because ship traffic emissions are expected to increase, the total oxidised
nitrogen load in 2010 is predicted to be higher than in 2004.

Despite the fact that most Signatories to the Protocol have reported lower NH$_3$
emissions in 2004 than the target for 2010, many of the Signatories to the Protocol
did not manage to reach the targeted 2010 GP reduced nitrogen deposition levels. The
reason is that the projected reductions in NH$_3$ emissions are in many cases of the same
order of magnitude as the meteorological variability of the depositions (10-20%), and
thus the expected trend is masked. This is a smaller problem when analysing sulphur
and nitrogen oxides where the target emission reductions are stronger. In order to de-
tect trends in depositions, emission reductions must be larger than the meteorological
variability of depositions. The same conclusion is applicable to the air concentrations
of ozone.

What has been achieved in ecosystem and human health protection from
ground level ozone since 1990?

Independently of the metric used to determine ecosystem and health impacts by
ozone, it is difficult to isolate the effects of emissions from those of year to year vari-
ability in meteorology. This is because emission reductions of ozone precursors imply
ozone changes of approximately the same order of magnitude as its meteorological
variability.

The use of ozone-flux as a mean of mapping the risks of ozone damage to crops
and forests has only recently been recommended as the preferred methodology within
UNECE. Maps of AFstY and trends for each Party are presented for the first time in
this report.

Calculations of SOMO35 and AOT40$^{10c}$ from the years 1990 to 2010 show that
although levels of both metrics have been reduced somewhat, the changes are modest
for most Parties. The same applies for AOT40. Simulations for SOMO35 and AOT40
show that the emissions changes expected from the year 2000 to 2010 will lead to
further reductions in both metrics in central Europe. However, some areas show increasing levels, brought about by a combination of reduced NOx titration, increasing emissions in some areas, and increasing background tropospheric ozone.

The influence of increasing levels of tropospheric ozone in particular has been identified as an important factor determining the levels of SOMO35, AOT40 and AFstY in 2010 and should be carefully analysed to determine the compliance with the goals in the Gothenburg Protocol.
Acknowledgments

The results presented here have benefited from the work and helpful discussion with a large number of colleagues at the four EMEP Task Forces, at the International Cooperative Centers (ICPs) of the working Group of Effects (WGE) and at the European Topic Center for Air Quality and Climate Change (ETC/ACC).

Special thanks are due to our colleagues at CIAM (IIASA), Janusz Cofala and Zbigniew Klimont for providing trends of emission estimates for different European countries. Thanks are due to our colleagues at NILU/CCC, Ann Mari Fjærø and Wenche Aas that provided us with measurement data from the EMEP networks, and to our colleague at met.no, Per Helmer Skaali for his assistance with the different reports.

The work on ozone fluxes has been funded by EMEP, and for Lisa Emberson by the UK Department of the Environment, Transport and the Regions. Gina Mills, Håkon Pleijel, and Per-Erik Karlsson, and many members of the ICP vegetation and forest communities are also thanked for their efforts to find solutions which are acceptable to the effects community but workable for the EMEP scale.

The work with the EMEP Unified model has been partly funded by the following EU projects: CAFE_BASELINE, CARBOSOL, IP-NEEDS and it is a free contribution to the ACCENT Network of Excellence.

This work has received support from the Research Council of Norway (Programme for Supercomputing) through computing time granted at the ORIGIN 3000 computer at the Norwegian University of Science and Technology (NTNU) in Trondheim and at the HP rx4640 computer at the University of Tromsø, Norway.
Contents

1 Introduction 1
  1.1 Review of Gothenburg Protocol 1
  1.2 Definitions, statistics used 2
  1.3 Country Codes 5
  1.4 Other Publications 7
References 8

2 Emissions: progress towards the emission ceilings in Gothenburg Protocol 9
  2.1 Official emissions and estimated emissions 10
    2.1.1 MSC-W methodology for gap filling and replacements 10
    2.1.2 Main differences between official and estimated emissions 11
  2.2 Emissions from 1990 to 2004: distance to 2010 emission ceiling 12
    2.2.1 Main activity sectors responsible for emission reductions since 1990 15
  2.3 Distance to 2010 target: percentage emission reductions 19
  2.4 Status of official projections for 2010 20
  2.5 Main uncertainties in emission data 24
  2.6 Conclusions 25
References 27

3 Acidification and eutrophication - progress towards the Gothenburg protocol target year (2010) 29
  3.1 Changes in risk damage calculations (acidification and eutrophication) since the time of the negotiations for the Gothenburg Protocol 29
  3.2 What has been achieved since 1990 and how far are we from the targets set by the Gothenburg protocol? 31
3.3 What are the main uncertainties? .......................... 44
  3.3.1 EMEP Unified model validation: status 2004 ........ 44
  3.3.2 Future changes in model calculations that may affect the cal-
     culations of risks for ecosystem damage .................. 48
3.4 Conclusions .............................................. 49
References .................................................... 50

4 Ozone .................................................................. 53
  4.1 Changes in ozone risk damage calculations since the time of the nego-
      tiations for the Gothenburg Protocol ......................... 53
     4.1.1 Changes in ozone metrics .............................. 54
  4.2 Ozone changes, 1990 - 2010 ................................. 54
  4.3 What are the main uncertainties? ......................... 55
     4.3.1 EMEP Unified model validation: status 2004 ........ 58
  4.4 Conclusions .............................................. 61
References .................................................... 61

5 Ozone fluxes - Updates ........................................ 63
  5.1 Introduction ................................................ 63
  5.2 Flux Modelling for Generic Crops and Forests ........... 65
  5.3 Results: Base-case calculations .......................... 68
  5.4 Main uncertainties? ....................................... 69
  5.5 Conclusions .............................................. 74
References .................................................... 78

A National emissions and projections.......................... A:1

B Percentage differences with official national emissions .... B:1

C Progress towards Gothenburg by Parties ......................... C:1
CHAPTER 1

Introduction

1.1 Review of Gothenburg Protocol

With the entry into force of the Gothenburg Protocol on 17th May 2005, the process of review of the Protocol was initiated. This report is intended to support the review of the Gothenburg Protocol by providing an analysis of the progress since 1990 and up to 2004.

All calculations in this report are based on best available scientific methods and information. Thus the progress from 1990 to 2004 is analysed in terms of best available emission estimates, latest atmospheric model version and the most updated data on critical load (2006 submission). The indicators used evaluating ecosystem and health impact of the pollutants considered under the Gothenburg Protocol are also the most up-to-date.

Transboundary pollution levels for 2010 are calculated based on the emission ceilings summarised in Annex II of the Protocol. For the Parties not included in the Gothenburg Protocol, projections from CIAMs current legislation plan scenario for 2010 are used instead (Amann et al. (2005a,b)). In order to account for meteorological variability, the calculations for 2010 are averaged for five different years.

All through the report a distinction is made between Parties to the Gothenburg Protocol, signatories to the Protocol, non-signatories and other Parties to the Convention.

Chapter 2 analyses the progress in controlling emissions of sulphur dioxide, nitrogen oxides, ammonia and non-methane volatile organic compounds since 1990 for all Parties to the Convention, and in particular for the Parties to the Gothenburg Protocol. The level of attainment of emission targets provided by the Gothenburg Protocol is analysed both for emission ceilings and for percentage reductions. Special attention has been given to differentiate between officially reported emissions and the MSC-W
emission estimates as used in the atmospheric model calculations.

The results in Chapter 3 are based on the MSC-W emission estimates, as well as the results in Chapter 4 because model calculations of atmospheric concentrations and depositions require complete emission datasets. Chapter 5 deals with the changes in the recommended indicators for the impact of ozone in different ecosystems. Since the time of the signature of the Gothenburg Protocol, risk impact analysis has evolved and estimates have improved in different ways. For acidification and eutrophication, the introduction of new atmospheric transport calculations with the EMEP Unified model and the availability of ecosystem specific deposition calculations has changed our understanding of the ecosystems at risk. The consequences of this change for risk calculations have been reported before and they are only summarised here. For ozone, however, the introduction of ozone fluxes is still very recent and Chapter 5 is thus dedicated to this new type of indicator.

This report does not include an evaluation of different scenarios for the situation in 2010. The 2010 values analysed here are those agreed upon in the Gothenburg Protocol. Further study of possible 2010 scenarios will be carried out in collaboration with the Parties and the CIAM in due time for the review of the Protocol.

All data included in this report will be available at the EMEP web site after its presentation at the 30th session of the EMEP Steering Body. Countries are encouraged to analyse the data and provide their own conclusions. Reactions and comments are both welcome and encouraged.

Description of the EMEP Unified model and its results, including source-receptor calculations, can be obtained from the EMEP web-site, http://www.emep.int.

1.2 Definitions, statistics used

For sulphur and nitrogen compounds, the basic units used throughout this report are \( \mu g (S \text{ or } N)/m^3 \) for air concentrations and \( mg (S \text{ or } N)/m^2 \) for depositions.

This report includes also concentrations of particulate matter (PM). The basic units throughout this report are \( \mu g/m^3 \) for PM concentrations and the following acronyms are used for different components to PM:

**SIA** - are secondary inorganic aerosols and are defined as the sum of sulphate (SO\(_4\)), nitrate (NO\(_3\)) and ammonium (NH\(_4\)). In the Unified EMEP model SIA is calculated as the sum: \( SIA = SO_4 + NO_3(fine) + NO_3(coarse) + NH_4 \)

**PPM** - denotes primary particulate matter, originating directly from anthropogenic emissions. It is usually distinguished between fine primary particulate matter, PPM\(_{2.5}\), with dry aerosol diameters below 2.5 \( \mu m \) and coarse primary particulate matter, PPM\(_{co}\), with dry aerosol diameters between 2.5\( \mu m \) and 10\( \mu m \).
PM$_{2.5}$ - denotes fine particulate matter, defined as the integrated mass of aerosol with dry diameter up to 2.5 $\mu$m. In the Unified EMEP model PM$_{2.5}$ is calculated as the sum: $\text{PM}_{2.5} = \text{SO}_4 + \text{NO}_3(\text{fine}) + \text{NH}_4 + \text{PPM}_{2.5}$

PM$_{\text{coarse}}$ - denotes coarse particulate matter, defined as the integrated mass of aerosol with dry diameter between 2.5 $\mu$m and 10 $\mu$m. In the Unified EMEP model PM$_{\text{coarse}}$ is calculated as the sum: $\text{PM}_{\text{coarse}} = \text{NO}_3(\text{coarse}) + \text{PPM}_{\text{co}}$

PM$_{10}$ - denotes particulate matter, defined as the integrated mass of aerosol with dry diameter up to 10 $\mu$m. In the Unified EMEP model PM$_{10}$ is calculated as the sum: $\text{PM}_{10} = \text{SO}_4 + \text{NO}_3(\text{fine}) + \text{NH}_4 + \text{PPM}_{2.5} + \text{NO}_3(\text{coarse}) + \text{PPM}_{\text{co}}$

For ozone, the basic units used throughout this report are ppb (1 ppb = 1 part per billion by volume) or ppm (1 ppm = 1000 ppb). At 20°C and 1013 mb pressure, 1 ppb ozone is equivalent to 2.00 $\mu$g m$^{-3}$.

A number of statistics have been used to describe the distribution of ozone within each grid square:

Mean of Daily Max. Ozone - First we evaluate the maximum modelled concentration for each day, then we take the 6-monthly mean of these values, over the 6-month period 1 April - 30 September.

SOMO35 - The Sum of Ozone Means Over 35 ppb is the indicator for health impact assessment recommended by WHO. It is defined as the yearly sum of the daily maximum of 8-hour running average over 35 ppb. For each day the maximum of the running 8-hours average for O$_3$ is selected and the values over 35 ppb are summed over the whole year.

If we let $A^d_8$ denote the maximum 8-hourly average ozone on day $d$, during a year with $N_y$ days ($N_y = 365$ or 366), then SOMO35 can be defined as:

$$\text{SOMO35} = \sum_{d=1}^{d=N_y} \max(A^d_8 - 35 \text{ ppb}, 0.0)$$

where the $\max$ function ensures that only $A^d_8$ values exceeding 35 ppb are included. The corresponding unit is ppb.days.

AOT40 - the accumulated amount of ozone over the threshold value of 40 ppb, i.e.,

$$\text{AOT40} = \int \max(O_3 - 40 \text{ ppb}, 0.0) \, dt$$

where the $\max$ function ensures that only ozone values exceeding 40 ppb are included. The integral is taken over time, namely the relevant growing season
for the vegetation concerned. The corresponding unit are ppb.hours (abbrevi-
ated to ppb.h). The usage and definitions of AOT40 have changed over the years
though, and also differ between UNECE and the EU. Mills (2004) give the lat-
est definitions for UNECE work, and describes carefully how AOT40 values are
best estimated for local conditions (using information on real growing seasons
for example), and specific types of vegetation. Further, since O₃ concentrations
can have strong vertical gradients, it is important to specify the height of the O₃
concentrations used. In previous EMEP work we have made use of modelled O₃
from 1 m or 3 m height, the former being assumed close to the top of the vegeta-
tion, and the latter being closer to the height of O₃ observations. In the Mapping
Manual (Mills 2004) there is an increased emphasis on estimating AOT40 using
ozone levels at the top of the vegetation canopy.

Although the EMEP model now generates a number of AOT-related outputs, in
accordance with the recommendations of (Mills 2004) we will concentrate in
this report on two definitions:

**AOT40³uc** - AOT40 calculated for forests using estimates of O₃ at forest-top (³uc:
upper-canopy). This AOT40 is that defined for forests by Mills (2004), but
using a default growing season of April-September.

**AOT40⁷uc** - AOT40 calculated for agricultural crops using estimates of O₃ at the
top of the crop. This AOT40 is close to that defined for agricultural crops
by Mills (2004), but using a default growing season of May-July, and a
default crop-height of 1 m.

In all cases only daylight hours are included, and for practical reasons we define
daylight for the model outputs as the time when the solar zenith angle is equal to
or less than 89°. (The proper UNECE definition uses clear-sky global radiation
exceeding 50 W m⁻² to define daylight, whereas the EU AOT definitions use
day hours from 08:00-20:00. Model outputs are also available using the EU
definition, but not presented here).

The AOT40 levels reflect interest in long-term ozone exposure which is consid-
ered important for vegetation - critical levels of 3 000 ppb.h have been suggested
for agricultural crops and natural vegetation, and 5 000 ppb.h for forests (Mills
2004). Note that recent UNECE workshops have recommended that AOT40
concepts are replaced by ozone flux estimates for crops and forests.

**AFstY** - the accumulated stomatal ozone flux over a threshold Y nmol m⁻² s⁻¹, i.e.:

\[
AFstY_{gen} = \int \max(F_{st} - Y, 0) \, dt
\]  

(1.1)

where stomatal flux \( F_{st} \), and threshold, \( Y \), are in nmol m⁻² s⁻¹, and the \( \max \)
function evaluates \( \max(A - B, 0) \) to \( A - B \) for \( A > B \), or zero if \( A \leq B \). This
integral is evaluated over time, from the start of the growing season (SGS), to the end (EGS). The definitions of flux terms are further discussed in chapter 5. For the generic crop and forest species to be discussed in chapter 5 the suffix \( \text{gen} \) is applied, e.g. \( AF_{st1,6\text{gen}} \) is used for forests.

1.3 Country Codes

Many tables and graphs in this report make use of codes to denote countries and regions in the EMEP area. Table 1.1 provides an overview of these codes and lists the countries and regions included in the present report calculations.

There are at present 50 Parties to the LRTAP Convention, after Albania ratified in December last year. Not all of these are Parties to Gothenburg Protocol. Therefore, this report distinguishes between:

1. **Parties to the Gothenburg Protocol**: these are the Parties that have ratified the Gothenburg Protocol (GP). By June 2006, there are 20 Parties to the Protocol, namely, Bulgaria, Czech Republic, Denmark, Finland, Germany, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom, United States of America and European Commission.

2. **Signatories**: these are Parties that have signed the Gothenburg Protocol but have not ratified. By June 2006, there are 13 signatory Parties: Armenia, Austria, Belgium, Canada, Croatia, France, Greece, Hungary, Ireland, Italy, Liechtenstein, Poland, Republic of Moldova.

3. **Non-Signatories**: these are Parties that have neither signed nor ratified the Gothenburg Protocol but are included in the provisions of the Protocol. There are 4 non-signatory Parties, namely, Belarus, Cyprus, the Russian Federation and Ukraine. It should be mentioned, however, that the Russian Federations provisions in the Gothenburg Protocol affect only a Designated Pollutants Emission Management Area (PEMA).

4. **Other**: only 36 Parties of the Convention are included in the provisions of Annex II in the Gothenburg Protocol. The remaining 13 Parties to the Convention (Albania, Azerbaijan, Bosnia and Herzegovina, Estonia, Georgia, Iceland, Kazakhstan, Kyrgyzstan, Malta, Monaco, Serbia and Montenegro, The Former Yugoslav Republic of Macedonia and Turkey) are considered in the calculations for 2010 according to projections for 2010 by IIASA (2005).

All Parties to the LRTAP Convention, except five, are included in this report calculations. The Parties that are excluded of the analysis are: Kyrgyzstan, Canada and United States of America, Monaco and Liechtenstein. The first three countries are not included because they lie outside the EMEP area domain. Monaco and Liechtenstein
<table>
<thead>
<tr>
<th>Code</th>
<th>Country/Region</th>
<th>Code</th>
<th>Country/Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>AL</td>
<td>Albania</td>
<td>GR</td>
<td>Greece</td>
</tr>
<tr>
<td>AM</td>
<td>Armenia</td>
<td>HR</td>
<td>Croatia</td>
</tr>
<tr>
<td>ASI</td>
<td>Remaining Asian areas</td>
<td>HU</td>
<td>Hungary</td>
</tr>
<tr>
<td>AT</td>
<td>Austria</td>
<td>IE</td>
<td>Ireland</td>
</tr>
<tr>
<td>ATL</td>
<td>Remaining N.-E. Atlantic Ocean</td>
<td>IS</td>
<td>Iceland</td>
</tr>
<tr>
<td>ATX</td>
<td>N.-E. Atlantic Ocean, external</td>
<td>IT</td>
<td>Italy</td>
</tr>
<tr>
<td>AZ</td>
<td>Azerbaijan</td>
<td>KZ</td>
<td>Kazakhstan</td>
</tr>
<tr>
<td>BA</td>
<td>Bosnia and Herzegovina</td>
<td>LT</td>
<td>Lithuania</td>
</tr>
<tr>
<td>BAS</td>
<td>Baltic Sea</td>
<td>LU</td>
<td>Luxembourg</td>
</tr>
<tr>
<td>BLS</td>
<td>Black Sea</td>
<td>LV</td>
<td>Latvia</td>
</tr>
<tr>
<td>BE</td>
<td>Belgium</td>
<td>MD</td>
<td>Republic of Moldova</td>
</tr>
<tr>
<td>BG</td>
<td>Bulgaria</td>
<td>MED</td>
<td>Mediterranean Sea</td>
</tr>
<tr>
<td>BIC</td>
<td>Boundary and Initial Conditions</td>
<td>MK</td>
<td>The FYR of Macedonia</td>
</tr>
<tr>
<td>BY</td>
<td>Belarus</td>
<td>MT</td>
<td>Malta</td>
</tr>
<tr>
<td>CH</td>
<td>Switzerland</td>
<td>NAT</td>
<td>Natural marine emissions</td>
</tr>
<tr>
<td>CS</td>
<td>Serbia and Montenegro</td>
<td>NL</td>
<td>Netherlands</td>
</tr>
<tr>
<td>CY</td>
<td>Cyprus</td>
<td>NO</td>
<td>Norway</td>
</tr>
<tr>
<td>CZ</td>
<td>Czech Republic</td>
<td>NOA</td>
<td>North Africa</td>
</tr>
<tr>
<td>DE</td>
<td>Germany</td>
<td>NOS</td>
<td>North Sea</td>
</tr>
<tr>
<td>DK</td>
<td>Denmark</td>
<td>PL</td>
<td>Poland</td>
</tr>
<tr>
<td>EE</td>
<td>Estonia</td>
<td>PT</td>
<td>Portugal</td>
</tr>
<tr>
<td>EMC</td>
<td>EMEP land areas</td>
<td>RO</td>
<td>Romania</td>
</tr>
<tr>
<td>ES</td>
<td>Spain</td>
<td>RU</td>
<td>Russian Federation</td>
</tr>
<tr>
<td>EU</td>
<td>European Community</td>
<td>RUX</td>
<td>Russian Federation, extern</td>
</tr>
<tr>
<td>FI</td>
<td>Finland</td>
<td>SE</td>
<td>Sweden</td>
</tr>
<tr>
<td>FR</td>
<td>France</td>
<td>SI</td>
<td>Slovenia</td>
</tr>
<tr>
<td>GB</td>
<td>United Kingdom</td>
<td>SK</td>
<td>Slovakia</td>
</tr>
<tr>
<td>GL</td>
<td>Greenland</td>
<td>TR</td>
<td>Turkey</td>
</tr>
<tr>
<td>GE</td>
<td>Georgia</td>
<td>UA</td>
<td>Ukraine</td>
</tr>
</tbody>
</table>

Table 1.1: Country/Region codes used in the source-receptor calculations

*Russian Federation means the part of the Russian Federation inside the EMEP official domain. The same applies to the Remaining N.E. Atlantic region and natural marine emission area as well as the countries included in North Africa and Remaining Asian areas. ATX and RUX mean the parts of the Atlantic and Russia outside the EMEP official domain but inside the EMEP domain of calculation. North Africa includes parts of Morocco, Algeria, Tunisia, Libya and Egypt. Asia includes Syria, Lebanon, Israel, parts of Uzbekistan, Turkmenistan, Iran, Iraq and Jordan. The European Community includes Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden, United Kingdom, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia.*
are not included because their emissions and geographical extents are below the accuracy of the source-receptor calculations.

As noted above, the provisions in the Gothenburg protocol for the Russian Federation apply only to its PEMA (Pollutant Emission Management Area). In the present report, we have not distinguished yet the emission in the PEMA region, but have considered instead all emissions from the Russian Federation within the EMEP area. Further work is envisaged in co-operation with national Russian experts to determine the progress towards the goals provided in the Protocol for this PEMA region.

An additional note is made also for the calculations for the European Community. At the time of the signature of the Gothenburg Protocol, the European Community consisted of 15 Member States. However, the transport model calculations presented here are for EU25. The European Community emissions and targets are established only as sum of the emissions and targets of the 25 Member States. Further analysis of the progress towards the Protocol goals for the European Community requires an agreement on how to EMEP modelling should address the change in the number of Member States.

1.4 Other Publications

This report is complemented with EMEP Status Report 4/2006 on Transboundary Particulate Matter in Europe and by country specific reports on the 2004 status of transboundary acidification, eutrophication, ground level ozone and PM.

This year, the publication of country specific reports is postponed until December 2006, because MSC-W is presently engaged in a large number of source-receptor calculations for scenario calculations. These calculations are carried out for the chemical situation of 2010 and 2020 and are intended to support the work of the Centre for Integrated Assessment Modelling for the review of the Gothenburg protocol.

In addition a number of articles have been published or accepted for publication during 2005/2006:


S. Tsyro. To what extend can aerosol water explain the discrepancy between model calculated and gravimetric PM\(_{10}\) and PM\(_{2.5}\)? *Atmos. Chem. Phys.* 5, 515-532, 2005 http://www.copernicus.org/EGU/acp/acp/5/515/acp-5-515.htm


**References**


CHAPTER 2

Emissions: progress towards the emission ceilings in Gothenburg Protocol

This chapter presents the trends in emission data between 1990-2004 and compares them with the targets for 2010 provided by Annex II of the Gothenburg Protocol. The level of attainment of the emission reductions dictated in Annex II of the Gothenburg Protocol is analyzed both according to official emission data reported to EMEP and according to MSC-W estimated emissions. Differences between official and estimated emissions values are highlighted all through this chapter, specially since in the next chapters of the report only MSC-W estimates are used in the calculations.

The chapter begins with a presentation of the methodology used for deriving MSC-W emission estimates where official emissions are either missing or inconsistent. In the next two sections, emission reductions since 1990 to 2004 are presented and are compared to the 2010 targets. The targets provided in Annex II of the Protocol are expressed both as emission ceilings and as percentage reductions. Both approaches are evaluated in separate sections. Section 2.4 presents official projections for 2010 under the latest (2006) reporting round. The presentation of the 2010 official projections is only intended as an indication of the present status as we are aware that such projections are susceptible to change in the near future and will be analyzed in a separate report. In section 2.5, an attempt of evaluating the uncertainty of emissions of main pollutants and its consequences for the attainment of the Gothenburg protocol is presented. Main conclusions and findings are summarized in section 2.6.
2.1 Official emissions and estimated emissions

Official emissions are those reported by the Parties of the LRTAP Convention to the EMEP programme every year. The latest official emission estimates included in this report are those corresponding to the 2006 reporting round, including emissions up to year 2004. The data is available via Internet at http://webdab.emep.int and it is documented and reviewed in Vestreng et al. (2006).

In cases when the official emission data are missing or are established to be inconsistent, MSC-W provides its own emission estimates for modelling purposes. EMEP modelling of the transport of air pollutants is as far as possible based on official emission estimates, however in some cases estimated emissions are used instead. The emission data used for modelling purposes in 2006 are presented in Appendix A.

This section documents the methodology used for deriving MSC-W emission estimates and analyzes the main differences between official and estimated emission data. Percentage differences in national emission totals between official estimates and MSC-W estimates for each Party are presented in Appendix B.

2.1.1 MSC-W methodology for gap filling and replacements

The methodology for gap filling and replacements of emission values is based on the analysis and review of sector emission data. Each year and in co-operation with the European Topic Centre on Air Quality and Climate Change, MSC-W carries out a review of the emission data officially reported under the Convention on Long-Range Transboundary Air Pollution (LRTAP) and the NEC Directive. The review is in accordance with the UNECE EMEP ’Draft methods and procedures’ document UN-ECE (2005) and results in a series of 50 bilateral reports with questions and comments to Parties and an annual summary report with main conclusions from the individual country reviews.

Results from the annual review are used to establish whether or not emission values should be estimated by MSC-W. Whenever the objective quality criteria are not met and expert judgment can not support the reported emissions, a replacement of officially reported data with other estimates is recommended.

MSC-W uses SNAP sectors in the modelling work for the review of the Gothenburg Protocol as basis for the gridded distribution of emissions. This is because we wish to use as much as possible gridded data reported by countries and up to now most reported gridded data is in SNAP. Also we wish to be able to compare directly with the emissions gridded data estimated in cooperation with IIASA for CAFE. Therefore, the reported emission data in NFR format were aggregated in to SNAP sectors according to the Emission Reporting Guidelines, UN-ECE (2003), Table IIIA.

Gaps in the reported timeseries were filled by interpolation from close years when
reported data in SNAP format exists. When no or very little reported emission data were available, emission estimates from the following sources were introduced:


2. EDGAR version 3.2 emissions (http://www.mnp.nl/edgar/)

3. NH3 data from GEIA (http://www.mnp.nl/geia/) and data from a similar country scaled with population.

2.1.2 Main differences between official and estimated emissions

The amount of replacements and gap filling vary per pollutant and sector. Table 2.1 shows that official estimates constitute only 40-60% of the necessary emission data. The completeness of SOx and NOx emissions are about 60%, while the completeness of NMVOC is 45% and NH3 between 41% (Table 2.1). The completeness of the EMEP inventory clearly needs to be improved.

Officially reported data in the order of 30% per year had to be replaced by MSC-W estimates as an outcome of the review process. The NMVOC has the highest ratio of replacements, which reflects the difficulties Parties have to estimate and allocate emissions of NMVOC correctly. Parties are hence strongly encouraged to also improve the consistency and comparability of their time series.

The sectors which turned out to be the most difficult to report were sector 4, Production processes, and sector 8, Off-Road Transport. The Task Force on Emission Inventories and Projections (TFEIP) should discuss how to assist Parties to improve reporting in these sectors.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>% reported (average)</th>
<th>% replaced (average)</th>
<th>% gaps (average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOx</td>
<td>57</td>
<td>20-34 (30)</td>
<td>9-23 (13)</td>
</tr>
<tr>
<td>NOx</td>
<td>48-64 (57)</td>
<td>23-41 (30)</td>
<td>9-27 (13)</td>
</tr>
<tr>
<td>NMVOC</td>
<td>36-59 (45)</td>
<td>23-41 (34)</td>
<td>18-30 (20)</td>
</tr>
<tr>
<td>NH3</td>
<td>34-48 (41)</td>
<td>25-45 (26)</td>
<td>18-32 (23)</td>
</tr>
</tbody>
</table>

Table 2.1: Amount of reported, replaced and gaps of national total emission in the EMEP inventory (Unit: %, average values in brackets).

The emission totals per country as a result of the gap filling and replacement is presented in Appendix B. Replacements results in both higher and lower emission totals. The largest changes occur for Eastern European countries. In addition, changes occur for countries which only recalculate parts of their time series. Parties are kindly requested to recalculate the whole time series in order to avoid inconsistencies.
There is a large number of countries with differences above 10% between MSC-W estimates and reported emissions, between 14 and 19. The number of replacements is largest for NOx emissions and smallest for NH3 emissions.

Parties are welcome to bilateral discussions and individual explanations for the replacements undertaken.

2.2 Emissions from 1990 to 2004: distance to 2010 emission ceiling

In Annex II of the Gothenburg Protocol, emission ceilings for the different pollutants are provided for 2010. This section shows the degree of attainment of the absolute emission ceilings for the different Parties.

Table 2.2 presents the attainment level of officially reported data to the LRTAP Convention for countries which are included in the Protocol. For each pollutant, reported 2004 emissions and the Protocol ceilings are listed in the two first columns. The reductions from 1990 to 2004 and the relative targets in the Protocol are listed in the next two columns. Parties to the Protocol are listed first, followed by Signatories and non-Signatories. Table 2.3 is structured in the same way, but includes all LRTAP countries and refers to MSC-W estimates.

According to the Gothenburg Protocol, emissions of SOx in 2010 for all Parties to the Protocol are to be 4905 Gg (Table 2.3). Not all Parties report emission data, hence the total emissions for reporting Parties are lower and only 3209 Gg (Table 2.2). By 2004, the official reported emissions for Parties to the Protocol are 3213 Gg, hence the Protocol target has been attained. Signatories and non-Signatories have also met the target, so with respect to SOx emissions the protocol target has already been attained.

Table 2.3 shows that for MSC-W emissions estimates, the 2004 emissions are higher (5069 Gg) than the 2010 target (4905 Gg) for the Parties to the Protocol, and the emissions have still to be reduced by 3%. Signatories and `other countries’ have reduced their emissions more than the target, thus for the whole EMEP area (Table 2.3), the target of the Gothenburg Protocol had been attained by 2004.

The situation for NOx is not so good. According to the Gothenburg Protocol, emissions of NOx in 2010 for all reporting Parties to the Protocol are to be 4389 Gg. By 2004, the official reported emissions for all Parties to the Protocol are 5484 Gg. Therefore a 20% reduction of emissions is still needed in order to reach the target. Signatories are in a slightly better situation as they only have to reduce emissions by 15%. Non-Signatories already reached the target. For all reporting countries, the total
in 2004 amounts to 8857 Gg, while the target is 7391 Gg, i.e. a 17% reduction is still needed.

By including estimates for all Parties (MSC-W estimates), the total emissions for Parties raise to 7368 Gg in 2004, while the target is 5684 Gg. The reduction needed is 23%, slightly higher than for the officially reported data. Signatories have to reduce 15% and all other countries 4%. For the whole EMEP area, estimates from MSC-W provide emissions for 2004 to be 17741 Gg, while the emission target for 2010 is 15127 Gg, i.e. emissions have to be reduced by 15%.

According to the Gothenburg Protocol, emissions of NH3 in 2010 for all reporting Parties should be 1722 Gg. By 2004, the official reported emissions for all Parties to the Protocol are 1656 Gg, so the target for Parties has been reached. Signatories and non-Signatories have also reduced the target, the target for all reporting countries is reached.

When including MSC-W estimates, this situation changes slightly. The emissions for Parties in 2004 are 2359 Gg and the target is 2292 Gg, hence a reduction of 3% is
### Table 2.3: Comparison of MSC-W estimates with emission targets

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Total Signatories</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>Non-Signatories GP</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>Total Parties GP</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>Europe</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>EMEP area</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>Non-EMEP area</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
</tr>
</tbody>
</table>

needed in order to reach the target. Signatories have reached the target, while the other countries have to reduce emissions by 14%. For the whole EMEP area, estimates from MSC-W provide emissions for 2004 to be 6774 Gg, while the emission target for 2010 is 6589 Gg, i.e. emission have to be reduced by 3%.

According to the Gothenburg Protocol, emissions of NMVOC in 2010 for all reporting Parties to the Protocol are to be 4196 Gg. By 2004, the official reported emissions for all Parties to the Protocol are 4264 Gg. Therefore a 2% reduction of emissions is still needed in order to reach the target. Signatories still have to reduce emissions by 15%. Non-Signatories have already reached the target. For all reporting countries, the total in 2004 amounts to 8211 Gg, while the target is 8058 Gg and a 2% reduction is still required in order to reach the target.
When including MSC-W estimates, the total emissions for Parties raise to 5878 Gg in 2004, while the target is 5397 Gg. The reduction required to meet the target is 8% and higher than for the officially reported data. Signatories and all other countries only have to reduce emission by 4%. For the whole EMEP area, estimates from MSC-W provide emissions for 2004 to be 15247 Gg, while the emission target for 2010 is 14396 Gg, i.e. emission have to be reduced by 6%.

Table 2.3 shows that the reductions between 1990 and 2004 for the LRTAP Convention countries have been 65% for SO$_x$, 30% for NO$_x$, 38% for NMVOC and 22% for NH$_3$. The overall emission reduction is slightly higher for the reported data in Table 2.2 compared to the MSC-W estimates for all pollutants. The discrepancy is highest for NH3. The comparison also shows that except for NH3, the Parties to the Protocol have obtained the largest reductions. Non-Signatories and other countries has reduce the NH3 emission most.

The differences between reported and MSC-W emissions has been shown to be small. The largest difference is for NH3 where officially reported data indicate that the ceiling have been met, while MSC-W estimates require further reductions. The largest difference between Party and Signatory attainment is seen for NMVOC, where Signatories have to reduce emissions 7 times more than the Parties in order to meet the target.

Figures 2.1 - 2.4 below display the national total emissions of each of the Parties to the LRTAP, carefully illustrating differences between official and estimated emission values. The European Union has only been taken into account implicitly through the member states. Columns without a value indicate that no value has been officially reported or no values are provided in the Gothenburg Protocol. Note that differences between official and estimated values are generally small for all Parties to the Protocol. Differences are considerable for non-Signatory and other Parties not considered in the protocol, especially for NMVOC and NH$_3$ emissions.

The figures illustrate that while the Gothenburg target can be met for all or groups of countries, individual countries could have severe problems in reaching their ceilings.

### 2.2.1 Main activity sectors responsible for emission reductions since 1990

Table 2.4 presents the key source analysis for the Protocol pollutants and Table 2.5 presents the emission reductions in the EMEP area between 1990 and 2004 per sector. As expected, the key sectors have contributed most to the emission reductions. Sulphur reductions have been largest in S1, Combustion in energy and transformation industries...
Figure 2.1: National Total Emissions of SO$_x$ in Gg SO$_2$ for the officially reported values for 2004 and values of the Gothenburg protocol for 2010 (above) and the values for the same years used by MSC-W for modelling (below).

Figure 2.2: National Total Emissions of NO$_x$ in Gg NO$_2$ for the officially reported values for 2004 and values of the Gothenburg protocol for 2010 (above) and the values for the same years used by MSC-W for modelling (below).
Figure 2.3: National Total Emissions of NH$_3$ in Gg for the officially reported values for 2004 and values of the Gothenburg protocol for 2010 (above) and the values for the same years used by MSC-W for modelling (below).

Figure 2.4: National Total Emissions of NMVOC in Gg for the officially reported values for 2004 and values of the Gothenburg protocol for 2010 (above) and the values for the same years used by MSC-W for modelling (below).
mainly due to Flue Gas Desulphurisation processes (FGD), switching of fuel (from coal to gas) and economic recession (in Eastern Europe). The percentage reduction in the residential sector (S2) is also substantial. NOx emissions are heavily reduced both in S1, Combustion in energy and transformation industries and in S7, Road transport. The latter is due to the implementation of catalysts in different car types. The European Union has through EURO I-V EC (2001) adopted more strict emission limits for new heavy motor vehicles, both with respect to nitrogen oxides, but also with respect to emissions of small particles. The full effect of this programme is yet to be seen as it takes time to renew an old vehicle park. NMVOC has been reduced from S7, Road transport, and S6, Solvent and other product use, while ammonia reductions in the Agriculture sector, (S10), has been reduced by 22 %. Ammonia is the only pollutant for which the emissions have increased during this period, due to implementation of catalysts in mobile sources, (S7), have increased. Likewise emissions from energy production and solvent use have increased slightly.

<table>
<thead>
<tr>
<th>Key source analysis 2004 emissions (%)</th>
<th>SOx</th>
<th>NOx</th>
<th>NMVOC</th>
<th>NH3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Combustion in energy and transformation industries</td>
<td>64</td>
<td>22</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>2. Non-industrial combustion plants</td>
<td>15</td>
<td>13</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>3. Combustion in manufacturing industry</td>
<td>40</td>
<td>33</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>4. Production processes</td>
<td>4</td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Extraction and distribution of fossil fuels and geothermal energy</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Solvent and other product use</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Road transport</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Other mobile sources and machinery</td>
<td>95</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Waste treatment and disposal</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Agriculture</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Other sources and sinks</td>
<td>95</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.4: Key source analysis for 2004 emissions of pollutants included in the Gothenburg protocol

<table>
<thead>
<tr>
<th>Sector</th>
<th>SOx</th>
<th>NOx</th>
<th>NMVOC</th>
<th>NH3</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>15899</td>
<td>63</td>
<td>2679</td>
<td>41</td>
</tr>
<tr>
<td>S2</td>
<td>4312</td>
<td>77</td>
<td>363</td>
<td>32</td>
</tr>
<tr>
<td>S3</td>
<td>4611</td>
<td>67</td>
<td>1041</td>
<td>32</td>
</tr>
<tr>
<td>S4</td>
<td>1511</td>
<td>60</td>
<td>353</td>
<td>44</td>
</tr>
<tr>
<td>S5</td>
<td>28</td>
<td>23</td>
<td>116</td>
<td>64</td>
</tr>
<tr>
<td>S6</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>96</td>
</tr>
<tr>
<td>S7</td>
<td>882</td>
<td>74</td>
<td>2763</td>
<td>29</td>
</tr>
<tr>
<td>S8</td>
<td>327</td>
<td>48</td>
<td>330</td>
<td>10</td>
</tr>
<tr>
<td>S9</td>
<td>49</td>
<td>65</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>S10</td>
<td>1</td>
<td>20</td>
<td>46</td>
<td>16</td>
</tr>
<tr>
<td>TOTAL</td>
<td>27619</td>
<td>65</td>
<td>7699</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 2.5: Reduction of Emissions for the LRTAP Convention countries within the EMEP area between 1990-2004
CHAPTER 2. EMISSIONS: PROGRESS TOWARDS THE EMISSION CEILINGS IN GOTHENBURG PROTOCOL

We have analyzed the relative contribution of each sector to the total emissions from 1990 to 2004. The SOx emission share from the energy sector (S1) has increased slightly, while the residential emission share (S2) has went somewhat down. NOx emissions in energy sector (S1) decreases, off road transport, (S8), increases and S7, Road transport increases until 1994, then flattens out and decreases from year 2000 onwards (see above remark about renewal of mobile sources with catalysts in place). It is for NMVOC that we see the most dramatic changes over the period analyzed. The ratio of emissions from Road Transport (S7) to the total emissions of NMVOC have decreased substantially (41-32%), while compensated by an increased share (24-29%) in emissions from Solvent Use (S6). The NH3 emission share of NH3 from agricultural activity is fairly constant at 95% throughout the period.

2.3 Distance to 2010 target: percentage emission reductions

Table 2.2 presents the percentage reduction 1990-2004 as officially reported by Parties to the LRTAP Convention as well as the relative 2010 targets in the Gothenburgh Protocol Annex II. Some countries have not provided sufficient amount of data to be included in this analysis. Missing values are marked with an “x” in the table.

The table show that 10 Parties have attained their ammonia targets, and the corresponding numbers for SOx, NMVOC and NOx are 8, 7 and 4. This implies that the attainment level for SOx and NH3 for reported data is 53% and 67% respectively. Little difference in attainment between Parties and Signatories are found. For NOx and in particularly for NMVOC this difference is much larger. 47% of Parties have already reached the NMVOC target while only 13% of Signatories have managed it so far. The opposite is the case for NOx, where 27% of Parties and 37% of the Signatories have already reached the target. This is the same result as derived for the absolute ceilings presented in section 2.2. We see that a larger percentage of the non-Signatories have reached their target (67-100%), but as Table 2.2 shows, that there are only 3 non-Signatories to the Protocol, which should be taken into account when interpreting the results.

The total number of countries to the Protocol which have already attained their target, is very low for NOx and NMVOC. Only 36% of all the countries included in the Protocol have so far reached their targets. Table 2.2 shows further that many countries have to implement strict measures in order to reduce their NOx emissions sufficiently. The total number of countries which have already attained their NH3 targets are largest, 71%. The analysis shows that 54% of the countries have reached their SOx targets.
Despite the fact that only 50% of the countries included in the Protocol have yet met their SOx target, the total reduction is still sufficient to meet the European emissions goal set in the Protocol. The target for NH3 has also been met, while another 10% reduction is needed for NOx (2.2).

Table 2.3 presents the attainment for the MSC-W emissions. One to two more Parties attain their targets when MSC-W emissions are taken into account. 11 Parties have attained their NH3 target already, and the corresponding numbers for SOx, NMVOC and NOx are 10, 7 and 5. The same general conclusions with respect to attainment level of Parties versus Signatories also applies for MSC-W emissions.

The total number of countries which attain the targets are somehow lower than for the reported once. NH3 attainment level is 66%, NOx and NMVOC 39 % and SOx 48% when all LRTAP countries in table 2.3 are considered. While the SOx target is still met on a European level, a major difference is that the NH3 target is no longer attained.

Table 2.2 and 2.3 also displays the absolute targets for 2010 and we have compared these to the reported 2004 emissions. For the total number of Parties to the Protocol this make no difference, but for individual countries and all the Protocol countries together it does. For NH3, countries which have already in 2004 attained the absolute ceilings and not the relative ceilings are Austria, Norway, Portugal, Sweden and Ireland. It is the other way around for Finland, Netherlands, United Kingdom. The attainment for NH3 in total increase by two countries. Greece does not yet meet the relative target for SOx and NOx, but does attain the absolute ceilings. This indicate that recalculations do not systematically affect the distance to target. This is because recalculations usually respond to methodological changes in the calculations of emissions and affect only the base year but the full time series.

2.4 Status of official projections for 2010

We have analyzed the difference between the reported 2010 emissions up to and including the 2006 reporting round and the 2010 emission ceilings from the Gothenburg Protocol. Except for a few Parties to the LRTAP most Parties have reported 2010 projections. If Current Legislation projections were reported, we used these values. If not, National Totals or Current Reduction projections were considered.

For Parties to the Protocol, differences between reported projection and Protocol targets are generally small, but a for other countries emission differences of more than ± 100 Gg are observed.
CHAPTER 2. EMISSIONS: PROGRESS TOWARDS THE EMISSION CEILINGS IN GOTHENBURG PROTOCOL

If reported projections instead of 2004 emissions were compared to targets, the level of attainment increases. The largest increase is for NMVOC, with 13 more countries reported to attain. Lowest increase is seen for NH3, with an addition of 3 countries, while SOx and NOx increase by 8 countries. This means that about 68% of LRTAP countries will reach their targets when reported projections are taken into account.

Figure 2.5 shows a comparison between the reported 2010 emissions projections for SOx and the 2010 targets. 9 Parties have not yet met their target in 2004 but project to meet their targets in 2010. 5 Parties report that they will not meet their targets in 2010 according to their projections. Some eastern and northern Parties project to have higher SOx emissions in 2010 than in 2004. The Ukraine reported SOx emissions for 2004 lower than the target, but will not meet the target in 2010. Emission differences of more than ± 100 Gg is reported from Bulgaria, United Kingdom, Hungary, Italy, Belarus and Ukraine.

Figure 2.6 shows a comparison between the reported 2010 emissions projections for NOx and the 2010 targets. 9 Parties report that they have not yet met the target in 2004 but project to meet their targets in 2010. 9 Parties will not meet their targets in 2010 according to their projections. Largest discrepancy is found for Italy. 7 Parties project to have higher NOx emissions in 2010 than in 2004. Hungary reported NOx emissions for 2004 lower than the target, but will not meet the target in 2010. Emission differences of more than ± 100 Gg are reported from France, Italy, Belarus and Ukraine.

Figure 2.7 shows the projections for NMVOC. 14 Parties have reported to be not on track in 2004 but project to meet their targets in 2010. 5 Parties will not meet their targets in 2010 according to their projections. 6 Parties project to have higher VOC emissions in 2010 than in 2004. The Ukraine reported VOC emissions for 2004 lower than the target, but will not meet the target in 2010. Germany, United Kingdom, France, Italy and Ukraine report emission differences of more than ± 100 Gg.

As indicated in Figure 2.8 5 Parties are not on track in 2004 but project to meet their targets in 2010 for ammonia emissions. 5 Parties report that they will not meet their targets in 2010 according to their projections. 7 Parties project to have higher NH3 emissions in 2010 than in 2004. France reported NH3 emissions for 2004 lower than the target, but will not meet the target in 2010. Ukraine is the only country for which the difference is larger than ± 100 Gg.
Figure 2.5: Projections for SO\textsubscript{x} for 2010 reported under LRTAP (blue) and Gothenburg protocol targets (brown); *Signatories the Gothenburg Protocol, **Non-signatories; all other countries are Parties to the Gothenburg Protocol. European community ceilings (4059 Gg) and Ukraine reported emissions (2310 Gg) are larger than displayed.

Figure 2.6: Projections for NO\textsubscript{x} for 2010 reported under LRTAP (blue) and Gothenburg protocol targets (brown); *Signatories the Gothenburg Protocol, **Non-signatories; all other countries are Parties to the Gothenburg Protocol. European Community ceilings (6671 Gg) are larger than displayed.
CHAPTER 2. EMISSIONS: PROGRESS TOWARDS THE EMISSION CEILINGS IN GOTHENBURG PROTOCOL

Comparison between NMVOC emissions reported under LRTAP and the GP 2010 emissions ceilings

Figure 2.7: Projections for NMVOC for 2010 reported under LRTAP (blue) and Gothenburg protocol targets (brown); *Signatories the Gothenburg Protocol, **Non-signatories; all other countries are Parties to the Gothenburg Protocol. European community ceilings (6600 Gg) are larger than displayed.

Comparison between NH₃ emissions reported under LRTAP and the GP 2010 emissions ceilings

Figure 2.8: Projections for NH₃ for 2010 reported under LRTAP (blue) and Gothenburg protocol targets (brown); *Signatories the Gothenburg Protocol, **Non-signatories; all other countries are Parties to the Gothenburg Protocol. European community ceilings (3139 Gg) are larger than displayed.
2.5 Main uncertainties in emission data

The EMEP inventory consists of a mixture of officially reported emission data and MSC-W estimates. The sources of MSC-W estimates in turn are of different origin as documented in section 2.1. In order to assess the overall uncertainty of emission data within the EMEP domain, we also have to take the uncertainty in each of those into account.

Information about the uncertainty of officially reported emissions was compiled from published data for individual countries. It is not mandatory for the Parties to the LRTAP Convention to provide uncertainty assessments, but some Parties do this in their Informative Inventory Report (IIR). The IPPC, IPCC (2000) Good Practice Guidance recommends two different methods for calculation, the simple Tier 1 method and the Tier 2, Monte Carlo analysis. A TNO study TNO (2004) showed surprisingly little difference in total uncertainty from Tire 1 to Tire 2 approach (maximum of 4%).

Table 2.6 gives an overview of the published uncertainties per country and pollutant together with the estimation technique and data source.

<table>
<thead>
<tr>
<th>Country/Pollutant</th>
<th>SOx</th>
<th>NOx</th>
<th>NMVOC</th>
<th>NH3</th>
<th>CO</th>
<th>Estimation Technique</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>7</td>
<td>16</td>
<td>39</td>
<td>-</td>
<td>44</td>
<td>IPCC(2000), Tier 1</td>
<td>Illerup et al. (2006)</td>
</tr>
<tr>
<td>France</td>
<td>4.3</td>
<td>23</td>
<td>34</td>
<td>26</td>
<td>38</td>
<td>IPCC(2000), Tier 1</td>
<td>CITEPA (2004)</td>
</tr>
<tr>
<td>Norway</td>
<td>4</td>
<td>12</td>
<td>18</td>
<td>21</td>
<td>-</td>
<td>Statistical Methods</td>
<td>Rypdal and Zhang (2001)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>3</td>
<td>8</td>
<td>10</td>
<td>20</td>
<td>20</td>
<td>IPCC(2000), Tier 2 Monte Carlo</td>
<td>Dore (2006)</td>
</tr>
</tbody>
</table>

Table 2.6: Uncertainties in officially reported data

Uncertainties regarded representative for Western Europe are lowest for SOx emissions and 3-7%. NOx emission uncertainty is larger and has larger variation, 8-23%. The uncertainty range for NH3 emissions is 17-26%, while the NMVOC uncertainty is 10-39%. CO uncertainty varies between 20-44%. Only one Eastern European country provided uncertainty estimates. The uncertainties are mostly around 20% for main pollutants, and highest for NMVOC. From this overview no firm conclusion on the overall uncertainty in Eastern Europe compared to West can be drawn. However, it is quite clear from the review work undertaken that the uncertainty is substantially higher for many Eastern European countries.

Emission estimates for combustion of fuels are generally considered reliable. The sectors for which the estimates of SOx are regarded most uncertain is **cement and metal production** (S4) and **waste incineration** (S9). NOx emissions from **agricultural soil** (S10) and **transport** (S7/S8) is above 10%. Uncertainty connected with **off road**
transport (S8) and residential combustion (S2) together with the petroleum industry (both refining (S4) and fugitive emission from fuels (S5)) is high for NMVOC. The NH3 emission uncertainty is associated with the uncertainty from the agriculture (S10) and transport (S7/S8) sectors.

As documented in Table 2.1, officially reported country data constitutes maximum 60% of the data in the EMEP inventory, the remaining 40% are MSC-W estimates. The largest source of MSC-W estimates is emission data from the regional European RAINS model. The uncertainty in these emissions is expected to be larger than the uncertainties in officially reported data, because the countries in general have better access to country specific activity data, emission factors and abatement measures in place. Largest uncertainty is expected for the global inventories in the EDGAR database version 3.2 (http://www.mnp.nl/edgar/) and the GEIA 1x1 degree gridded inventories (http://www.mnp.nl/geia/).

2.6 Conclusions

The SOx target in the Gothenburg Protocol has already by 2004 been attained at European level. The distance to target for NH3 and NMVOC is short. NOx emissions still have to be reduced by about 20%.

There are little differences in Protocol target attainment between officially reported data and MSC-W emission estimates.

European emission reduction between 1990 and 2004 is about 65% for SOx, and 20%, 38% and 22% for NOx, NMVOC and NH3 respectively. The reductions were largest in key source sectors.

The number of Parties to the Protocol which report to have attained their targets is 53%, 27%, 47% and 67% for SOx, NOx, NMVOC and NH3 respectively. The corresponding numbers for MSC-W estimates and for all the LRTAP countries are 48%, 39%, 39%, 66%. This means that individual countries still have to reduce their emissions even though the target is reached at European level.

Some countries have reported projections which indicate that they will not meet their 2010 targets. About 68% of LRTAP countries would have reached their emission ceilings if targets were compared against reported projections.

The largest difference between Party and Signatory attainment is seen for NMVOC, where Signatories have to reduce emission 7 times more than the Parties in order to meet the target. For other pollutants differences are small.
There are little difference in attainment between relative and absolute targets except for NH3. The number of countries attaining the NH3 absolute ceilings are higher than those for relative targets when all countries included in the Gothenburg protocol are taken into account. The recalculations do not systematically affect the distance to target, because not only the base year but the full time series have been recalculated.

The completeness of the EMEP inventory is low and consistency and comparability of reported data needs to be improved. 40-60% of emission data is MSC-W estimates. About 30% constitutes replacements.

Uncertainties regarded representative for Western Europe are lowest for SOx emissions and 3-7%. NOx emission uncertainty is larger and has larger variation, 8-23%. NH3 emissions uncertainty range is 17-26%, while the NMVOC uncertainty is 10-39%. The uncertainty is larger in Eastern European countries and for MSC-W estimates.
CHAPTER 2. EMISSIONS: PROGRESS TOWARDS THE EMISSION CEILINGS IN GOTHENBURG PROTOCOL

References


CHAPTER 3

Acidification and eutrophication - progress towards the Gothenburg protocol target year (2010)

Hilde Fagerli, Till Spranger and Maximilian Posch

In this chapter we analyse the progress from the base year of the Gothenburg Protocol (1990) to the target year (2010) based on modelled depositions and exceedances of critical loads for the years 1990, 1995, 2000, 2004 and 2010 (Gothenburg protocol emission ceilings), using the best available emission estimates. All these emissions are documented in Appendix A

3.1 Changes in risk damage calculations (acidification and eutrophication) since the time of the negotiations for the Gothenburg Protocol

Since the final negotiations for the Gothenburg protocol, the scientific community has refined and improved their evaluation of depositions and also their impact in ecosystems. The risk levels for acidification and eutrophication derived from the new calculations are considerably higher than those estimated back in 1998. An analysis of the factors that have given the largest changes in the calculations of risk damage to ecosystems and the reasons behind the new estimates were presented in (Tarrasón et al. 2004, chapter 7). Here we briefly summarise the results from this study and compare them to calculations performed this year.

The increase in the risk calculations can not be attributed to one single factor, but
is a result of

1. Update and revision of emissions
2. Update and revision of critical loads
3. Change from $150 \times 150 \text{km}^2$ to $50 \times 50 \text{km}^2$ grid resolution
4. Change from a Lagrangian model to a Eulerian model
5. Change from grid averaged depositions to ecosystem specific depositions

The changes in the emission estimates for the base year of the protocol, 1990, did not change a lot between the time of the negotiations for the Gothenburg Protocol and 2004 (around 15%, but more for some components in some areas). These changes did not give systematic increases or decreases in depositions and therefore no systematic changes in the calculation of exceedances. The effect was only a few percentage for the EMEP area as a whole.

This year there has been a major revision of the emissions (see chapter 2), which have resulted in greater changes compared to the emission estimates available at the time of the negotiations of the Gothenburg Protocol. The largest changes compared to the emission estimates applied in Tarrasón et al. (2004) are in the estimates for the non-Signatories to the Gothenburg Protocol for which better estimates have become available. These changes are of the same magnitude for the whole time series (1990 to 2004), resulting in similar changes in exceedances of critical loads for all the years. We have here focused on the year 1990 to enable a comparison with the results from Tarrasón et al. (2004). Below we discuss some of the changes in the 1990 estimates and the implications for the modelled depositions and ecosystem exceedances.

The 1990 estimates for SO$_x$ emissions for the Russian Federation together with a series of other non-Signatory Parties have increased by 20% or more, resulting in a significant increase of modelled depositions in Russia followed by increased risks of ecosystem damage. For NO$_x$ emissions, the Polish and Czech 2006 emission estimates for 1990 are significantly higher (around 25%) than in the 2004 estimates, in addition to several estimates for non-Signatories. Emission estimates are 5-10% lower for Belgium, Spain, the UK, Austria, Germany and Ireland. For ammonia, the estimates are significantly higher for many countries, but lower for some EU countries like Germany and Belgium.

For acidification, only small changes are seen in the EU25 estimates as the majority of the emission estimates have remained unchanged for these countries, at least for SO$_x$ emissions (which are most important for acidification). However, the estimate for the EMEP area as a whole increases (from 34% to 41.37%) in 1990. For eutrophication, unprotected ecosystem area in the EMEP area increase from 44.1% to 66.2% in the new estimates for 1990 due to higher NO$_x$ and NH$_3$ emission estimates for many non-EU countries. For EU25, the unprotected ecosystem area at risk decreases somewhat,
from 88.2% to 81.7% due to lower NO\textsubscript{x} and NH\textsubscript{3} emission estimates in some of the EU25 countries.

In Tarrasón et al. (2004) it was concluded that the two most important changes since the time of the negotiations for the Gothenburg Protocol were the change from a two-dimensional Lagrangian model to a Eulerian model together with the transition from grid averaged depositions to ecosystem specific depositions. Both of these changes result in an increase of the risk for acidification and eutrophication, with a combined effect of 30-50%. The results from this year show that new emission estimates for non-Signatories and reported recalculation of emissions increase the overall exceedances on a European scale by 20-50% with respect to the estimates from 2004. For EU25 there are small changes for acidification, but a decrease of around 10% in nutrient nitrogen unprotected area.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EU25</td>
<td>39.2</td>
<td>27.1</td>
<td>23.4</td>
<td>14.7</td>
<td>15.5</td>
</tr>
<tr>
<td>Europe</td>
<td>41.4</td>
<td>18.9</td>
<td>14.5</td>
<td>10.0</td>
<td>10.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EU25</td>
<td>81.7</td>
<td>74.0</td>
<td>74.9</td>
<td>65.7</td>
<td>64.2</td>
</tr>
<tr>
<td>Europe</td>
<td>66.2</td>
<td>54.3</td>
<td>50.0</td>
<td>47.3</td>
<td>47.8</td>
</tr>
</tbody>
</table>

Table 3.1: Unprotected ecosystem area (%) for EU and Europe (EMEP area)

### 3.2 What has been achieved since 1990 and how far are we from the targets set by the Gothenburg protocol?

The EMEP Unified model has been run for the years 1990, 1995, 2000 and 2004 using the appropriate meteorology. The most recent emission estimates (Vestreng et al. 2006), covering all the years of interest, are applied. For the calculations of exceedances of critical loads, the same set of updated (2006) critical loads data was used for all the years. In this way we ensured a consistent set of data.

In addition, a 2010 scenario using the Gothenburg emission ceilings has been calculated. For countries which do not have a target in the Gothenburg Protocol, the 2010 CLE scenario emissions from Amann et al. (2005a,b) were applied. Because the future meteorology cannot be predicted, an average over climatologically representative years (1996, 1997, 1998, 2000 and 2003) is used for 2010.

Ship emission estimates have been updated according to Whall and Stavrakaki for 2000 and 2010. Ship emissions for 1990, 1995 and 2004 were deduced by applying a
increase factor of 2.5% per year on cargo vessel traffic and 3.9% per year on passenger vessel traffic. The factors are the same as used in the deduction of 2010 emissions from 2000 in Whall and Stavrakaki. Emission factors were assumed to be constant over time. This resulted in an increase of ship emissions of about 2.6% per year, consistent with the increase of international shipping emissions from 1995-2000 in Endresen et al. (2003).

In the analysis performed in this section, the 2010 target is defined as the depositions resulting from the calculations using the Gothenburg protocol emission ceilings (hereafter referred to as 2010 GP).

We present depositions for all the Parties to the Convention that are inside the EMEP Unified model domain, and exceedances of critical loads for those where critical loads data are available (Posch et al. 2005, and updates on www.mnp.nl/cce). We discuss the distance from the 2010 target by comparing the reductions in depositions achieved from 1990 to 2004 to the reduction target set by the 2010 GP depositions.

It should be noted that even if the depositions in 2004 are lower than in 2010 GP, and thus the target 2010 GP depositions are reached, this does not necessarily imply that the country already comply with Gothenburg Protocol emission ceilings. The deposition load in a country is a result of deposition of the countries own emissions, but also export and import of emissions to and from other countries. Therefore, the trend in the deposition will depend on the development of emissions in other countries as well. This applies in particular to ship emissions that are projected to increase in the future. Ireland is a good example, as the dominant part of the deposition originates from international ship traffic. Therefore, the oxidised nitrogen depositions in the 2010 GP scenario are higher than in 2004, despite that the projected NO\textsubscript{x} emissions for Ireland are lower than in 2004.

Another significant effect to consider when analysing the distance to 2010 GP target loads is that the meteorological year-to-year variability may mask the expected trends in depositions. This is especially important for the reduced nitrogen depositions as the projected reductions are in the same order as the meteorological variability (10-20% according to van Loon et al. (2005)). Thus, the difference between 2004 and 2010 GP is not caused only by differences in emissions, but also by different meteorological conditions.

**Sulphur deposition**

In figure 3.3 we present maps of modelled sulphur deposition for 1990, 1995, 2000, 2004 and 2010. There has been large reductions in sulphur depositions over the years since 1990. In 1990, many areas had sulphur depositions as high as 3000 mg(S)m\textsuperscript{-2}. Already in 1995 the highest deposition areas did no receive more than approximately 1000-2000 mg(S)m\textsuperscript{-2}, and in 2004 only parts of eastern Europe received sulphur depositions above 1000 mg(S)m\textsuperscript{-2}. During the last fifteen years there has been a shift in location of the areas that receive the highest deposition loads. In 1990 the highest sulphur deposition areas were found in the central-east European areas in countries
such as Germany, Poland, Czech Republic and Slovakia. At present the highest load, although lower than previously, are found in eastern European countries such as Bulgaria, Romania, Serbia and Bosnia and Herzegovina.

Figure 3.1 a) shows progress towards the 2010 GP situation achieved already in 2004. The distance to target is defined as the difference between the present day situation (2004) and the 2010 GP modelled depositions with respect to the targeted reductions (1990-2010 GP). More than half of the Parties to the Gothenburg Protocol have already reached the 2010 GP levels, some are even more than 20% below the sulfur deposition reduction targeted by the emission ceilings in the Protocol. A few countries; Spain, the Netherlands, the UK, Luxembourg and Slovenia still needs additional reductions of about 10-15% compared to the target reduction.

The same situation applies to Signatories that have not ratified the Protocol; most of the countries are already below the target, whilst France, Croatia and Belgium should experience further reductions in their sulphur depositions if the Gothenburg Protocol emission ceilings will be met. For the non-Signatories, no 2010 emission ceilings exists, and the distance to target simply signify the expected change to 2010 based on scenario emissions. For some of these countries the differences between 2004 and 2010 are large (e.g. for Turkey and Malta). However, new projections for 2010 are in progress and major revisions of the current 2010 estimates are expected.

Major improvements in the sulphur deposition loads until 2010 can only be expected if reductions in emissions will go beyond the Gothenburg protocol. If and where this will happen can be better answered when the new projections for 2010 are ready.
Oxidised nitrogen deposition

In figure 3.4 we present maps of modelled oxidised nitrogen deposition (N$_{ox}$) for 1990, 1995, 2000, 2004 and 2010. Large reductions of N$_{ox}$ depositions were achieved during the 1990's in parts of Europe, especially for Germany, Czech Republic and the eastern European countries such as Estonia, Lithuania, Latvia, Ukraine and Bulgaria. However, many countries are still far from reaching the targets set by the Gothenburg protocol as indicated in figure 3.1b). Only two of the Parties to the Protocol (Romania and Bulgaria) have in 2004 managed to reduce oxidised nitrogen deposition to below the 2010 GP modelled depositions. More than half of the Parties to the protocol still lack 20% or more of the targeted reduction of N$_{ox}$ deposition, and many countries are as much as 30-40% off. The same situation apply to the other Parties to the Convention, although Greece and the Republic of Moldova are well off. Despite the fact that the emission estimates for Ireland are almost twice as high in 2004 as in the 2010 GP emission ceilings, the depositions of oxidised nitrogen are expected to be higher in 2010, thus in the distance to target plot they come out better than expected from their compliance with reduction measures. The reason is that the by far largest contributor to depositions in Ireland are international ship traffic emissions in the Atlantic sea and the North sea. Because ship traffic emissions are increasing, the total oxidised nitrogen load in 2010 is higher than in 2004.

Overall, the Parties to the Convention are some distance away from reducing oxidised nitrogen depositions to the level targeted by the Gothenburg protocol emission ceilings.

Reduced nitrogen deposition

The largest reductions of ammonia took place in the eastern European countries after 1990, where emissions went down by nearly 50%. For other countries, emission reductions have been small, in the order of 10%. The modelled deposition maps in figure 3.5 show that this has resulted in a decrease in reduced nitrogen deposition for East Europe, whilst no large changes are seen for other parts of Europe. Despite that most Signatories reported lower emissions in 2004 than the target for 2010, many of the Signatories to the Protocol are far from reaching the targeted 2010 GP deposition levels. For instance do both the UK, Italy and France have higher reduced nitrogen depositions in 2004 than in 1990, despite that they have reduced their ammonia emissions (see figure 3.2). As noted in the introduction, meteorological variability is large, and the expected reductions of emissions are less than 10%, which is smaller than the meteorological variability in depositions. Thus, except for the countries where large ammonia emission reductions were expected (e.g. Belarus, Czech Republic, Bulgaria), the distance to target in 2004 cannot be interpreted as a result of emission reductions but is rather a sign of the meteorological conditions in 2004. The important message is that in order to detect trends in depositions, emission reductions must be higher than the meteorological variability or monitored over several years.
Figure 3.1: Distance to target in 2004 for a) sulphur and b) oxidised nitrogen deposition (%) for all Parties to the Convention. The percentage is given relative to the difference between 1990 and 2010, e.g. +20% indicate that 80% of the target reduction in the Protocol has been achieved already in 2004. Parties to the Gothenburg Protocol, first, then *=Signatories to the Gothenburg protocol, and then **=non-Signatories and other Parties.
Figure 3.2: Distance to target in 2004 for reduced nitrogen deposition (%) for all Parties to the Convention. The percentage is given relative to the difference between 1990 and 2010, e.g. +20% indicate that 80% of the target reduction in the Protocol has been achieved already in 2004. More than 100% signify that depositions are higher in 2004 than in 1990. Note that the projected reductions in ammonia emissions are in the same order as meteorological variability, thus the difference between 1990, 2004 and 2010 GP depositions are as much a result of meteorological variability as of emission reductions. Parties to the Gothenburg Protocol, first, then *=Signatories to the Gothenburg Protocol, and then **=non-Signatories and other Parties.

Acidification

The large reductions in sulphur since 1990, and partly oxidised nitrogen depositions, have resulted in an improved situations for the ecosystems at risk (see figure 3.8 and 3.9). The countries that have experiences the largest improvements are Czech Republic, Germany and Poland, where the accumulated exceedances have decreased from around 3000 eq ha$^{-1}$yr$^{-1}$ to less than 500 eq ha$^{-1}$yr$^{-1}$ at present. The ecosystem areas at risk in these countries have decreased from almost 100% to 75% (Czech Republic), 55% (Germany) and 58% (Poland). For other countries similar improvements have been achieved. In 1990, almost all the Parties to the Protocol had 40% or more of their ecosystem areas at risk. In 2004, the unprotected area have decreased to below 20% for most of the Parties to the Protocol (except Czech Republic, Germany, Lithuania and the Netherlands). According to our calculations, the situation in 1990 were in general
better for the Signatories that have not ratified the protocol, than for the Parties to the Protocol (except for Poland, Belgium and Croatia), with unprotected ecosystem areas of 20% or less. The situations for these countries have also improved, and in 2004 only around 10% or less of the ecosystem areas are at risk. For the non-Signatories, the change of the situation has been more variable. Cyprus and Estonia did not have areas at risk for acidification in 1990 and do neither in 2004. For Ukraine and Russia, the ecosystem areas at risk for acidification have largely decreased. For Belarus and The Former Yugoslav Republic of Macedonia, smaller improvements have been made.

In general, there has been large improvements in the risk damage of acidification to ecosystems all over Europe (see figure 3.6). The largest reductions have been achieved in countries where the ecosystems are more sensitive to acidification (e.g. the Nordic countries), whilst in areas with more robust ecosystem areas (e.g. southern Europe), less progress in the levels of air pollution have been made.

Eutrophication

Reductions in NO\textsubscript{x} and NH\textsubscript{3} emissions have led to a decrease of nitrogen depositions in Europe followed by lower exceedances of nutrient nitrogen critical loads. Figure 3.7 a) show that for most Signatories to the protocol, the accumulated exceedances have decreased by 20-30% since 1990. However, only for a few Parties to the protocol, significant reductions in the unprotected ecosystem areas are achieved. In general, the improvements have been made for the countries where the accumulated exceedances and ecosystem areas at risk were among the lowest in 1990. For instance, for Sweden, the area unprotected to nutrient nitrogen exceedances were more than 70% in 1990, whilst in 2004 this has been reduced to less than 20%. Switzerland, Finland and the Netherlands had 65-80% of their ecosystem areas at risk in 1990. This has been reduced to 45-65% in 2004. Of the Signatories that have not ratified the protocol, only Croatia has achieved significant reductions of risk damage (from more than 70% to around 50%). For the non-Signatories for which critical load data are available, Estonia, Belarus and Russia have significantly improved their protection of ecosystems. For most countries however, nearly 100% of the ecosystem areas were at risk for eutrophication in 1990, and the situation has not improved much in 2004 despite that the accumulated exceedances have decreased in all countries. The reason is that even if the accumulated exceedances have decreased, the critical levels are still exceeded. Thus, further reductions in the depositions of nitrogen are needed in order to reduce the percentage areas at risk.
Figure 3.3: Deposition of sulphur (mg(S)m$^{-2}$).
Figure 3.4: Deposition of oxidised nitrogen (mg(N)m$^{-2}$).
Reduced Nitrogen deposition, 1990
(a) 1990

Reduced Nitrogen deposition, 1995
(b) 1995

Reduced Nitrogen deposition, 2000
(c) 2000

Reduced Nitrogen deposition, 2004
(d) 2004

Reduced Nitrogen deposition, 2010 Gothenburg protocol
(e) 2010 Gothenburg protocol

Figure 3.5: Deposition of reduced nitrogen (mg(N) m\(^{-2}\)).
Figure 3.6: Accumulated exceedances of acidity (eq ha$^{-1}$yr$^{-1}$).

Figure 3.7: Accumulated exceedances of nutrient nitrogen (eq ha$^{-1}$yr$^{-1}$).
Figure 3.8: Calculated exceedances of critical loads for acidity in 1990, 2004 and 2010(GP) for Parties to the Convention for which critical loads data are available. Parties to the Gothenburg Protocol, first, then *=Signatories to the Gothenburg Protocol, and then **=non-Signatories and other Parties.
Figure 3.9: Calculated exceedances of critical loads for nutrient nitrogen in 1990, 2004 and 2010 (GP) for Parties to the Convention for which critical loads data are available. Parties to the Gothenburg Protocol, first, then *=Signatories to the Gothenburg Protocol, and then **=non-Signatories and other Parties.
3.3 What are the main uncertainties?

There are several sources of uncertainty in the calculations of depositions and the exceedances of critical loads. Firstly, uncertainty in emissions (see chapter 2) will of course be directly transferred to the modelled depositions. For several countries, officially reported emissions were not available or not reliable for the years that we have analysed in this chapter, and thus replaced with expert estimates. The uncertainty both in reported emissions and the expert estimates are not very well known, but probably SO\textsubscript{x} and NO\textsubscript{x} emissions are more certain than NH\textsubscript{3} emissions.

In our analysis of the progress towards the 2010 GP target, it should be noted that for countries that do not have a target in the Gothenburg Protocol scenario emissions have been used. These projections are under revision, thus these results should be interpreted with care.

Secondly, uncertainties in the model formulation itself give rise to uncertain deposition estimates. The combined uncertainty from these two factors can to some extent be estimated from a comparison of the model results against measurements, see next section. The meteorological variability of depositions of nitrogen and sulphur can be as high as 10-20\%, and they may thus mask trends of depositions if the emission reductions are lower or of the same order as the meteorological variability.

Finally, uncertainties in the critical loads data itself and the concept to assess acidification and eutrophication adds on in the assessment of ecosystem risk damage. In section 3.3.2 we discuss how future changes in model calculations may affect the calculations of risks of ecosystem damage.

A new concept for the calculation of risks of acidification and eutrophication is in progress (dynamic modelling), but it is yet unknown how this will affect our understanding of risks of ecosystem damage in Europe.

3.3.1 EMEP Unified model validation: status 2004

The model calculations for 2004 discussed in the earlier sections are validated against EMEP measurements for 2004.

In Fagerli et al. (2003b) we presented an extensive evaluation of the acidifying and eutrophying components for the years 1980, 1985, 1990 and 1995 to 2000. In Fagerli et al. (2003a), a comparison of observations and modelled results for 2001 was conducted, and in Fagerli (2004) we presented results for 2002 with an updated EMEP Unified model, version 2.0. This version differed slightly from the 2003 version, as described in Fagerli (2004), however the main conclusions on the model performance was the same. Last year we presented results for the year 2003 in Fagerli (2005). It has been shown that the EMEP model performance is rather homogeneous over the years (Fagerli et al. 2003b), but depend on geographical coverage and quality of the measurement data. The EMEP model has also been validated for nitrogen compounds in Simpson et al. (a) and for dry and wet deposition of sulphur, and wet depositions for nitrogen in Simpson et al. (b) with measurements outside the EMEP network.
Table 3.2: Comparison of model results and observations for 2004. Annual averages over all EMEP sites with measurements more than 5 out of 7 days a week. \( N_{\text{stat}} \) = number of stations, wd=wet deposition, cp= concentration in precipitation, Corr.= spatial correlation coefficient.

Since last year, no changes with significant effect on the results for acidifying and eutrophying compounds have been introduced in the model. Moreover, the comparison between model results and observations for 2004 give similar correlation coefficients and bias as the comparisons performed for earlier years. The previous evaluations of the model are thus still valid. Therefore, we refer to previous reports and papers for detailed analysis of model performance for each component and do not repeat these here. Scatter plots as well as a table with an overview of the results for 2004 are included here in order to enable comparisons with results published in earlier EMEP Status reports.

The modelled air concentrations of sulphur and nitrogen compounds agree with EMEP measurements to within 15-20%. With respect to spatial correlation, the secondary compounds (sulphate, nitrate, ammonium) in general agree better with the observations than the primary pollutants (SO\(_2\), NH\(_3\)). For wet depositions and concentrations in precipitation, model calculations are lower than the observations by 5-30%. Thus, the comparison with measurements suggests that the overall uncertainty in the modelled depositions are within 30%.
Figure 3.10: Scatter-plots of modelled versus observed concentrations in air of sulphur dioxide, sulfate, sum of ammonia and ammonium aerosol ammonium, sum of nitrate and nitric acid and aerosol nitrate (units: \(\mu g(S) \text{ m}^{-3}\) and \(\mu g(N) \text{ m}^{-3}\)).
Figure 3.11: Scatter-plots of modelled versus observed wet deposition of sulfate, ammonium and nitrate (mg(S or N)m$^{-2}$ and precipitation (mm)).
3.3.2 Future changes in model calculations that may affect the calculations of risks for ecosystem damage

The EMEP model change as new scientific knowledge becomes available and subsequently is implemented in the code. For instance, the later years more evidence of the so-called ‘co-deposition’ of SO$_2$ and NH$_3$ have been presented (Fowler et al. 2005, Erisman et al. 2001) and has allowed for a parametrisation that has been implemented in the Unified EMEP model (Simpson et al. 2003, Fagerli et al. 2003b). Other processes, such as a better parametrisation of the formation of coarse nitrate and an implementation of ammonia emissions coupled to meteorological conditions are under progress. These and other changes in the model formulation may lead to differences in the modelled depositions, although we do not expect major changes such as the ones seen for the transition to the Eulerian model or from grid averaged depositions to ecosystem specific depositions.

In the future, the grid resolution of the EMEP model will probably decrease. Meteorological fields on a 20×20km$^2$ or even 10×10km$^2$ grid resolution will become available for the EMEP domain. In order to fully exploit the advantages of meteorology on a finer grid resolution, emissions on a finer scale are also necessary. It is unclear when or if this will become available for the full EMEP domain. However, several institutions have started to use the EMEP model on a fine scale for their own country (Croatia, UK), and other will probably follow as the Unified EMEP model code becomes publicly available. Thus, fine scale deposition estimates that can be used in the calculations of risks for ecosystem damage for larger areas will become available.

Many countries map critical loads at high resolution (e.g. Germany: 0.25 km spatial units). These are compared to lower-resolution deposition data for mapping critical load exceedances. This procedure systematically underestimates high percentiles of critical load exceedances as obtained from combining critical load and deposition data of identical, high spatial resolution (Spranger et al. 2001). This is policy relevant, since European air pollution policies aim at removing all critical load exceedances, and the high percentile exceedances will be more difficult to remove when reducing emissions. Spranger et al. (2001) showed 95th percentile critical load exceedances in German EMEP grids based on high resolution deposition data to be 60% and 150% higher (mean values for nutrient nitrogen and acidity, respectively) than critical load exceedances based on 150×150 km$^2$ deposition data from the Lagrangian EMEP deposition model. The biases were smaller, but still present, if low resolution, but land cover specific deposition rates were used.

Thus, although changing the grid resolution from 150×150km$^2$ to 50×50km$^2$ cause only minor changes when the results are averaged to the same (coarser) grid resolution, the scale may become more important in the future at the time when (if) exceedances are reduced to levels close to the critical loads.
3.4 Conclusions

In this chapter we have analysed the progress from the base year of the Gothenburg Protocol (1990) to the target year (2010) based on modelled depositions and exceedances to critical loads for the years 1990, 1995, 2000, 2004 and 2010 (Gothenburg protocol emission ceilings), using the best available emission estimates.

Many of the Signatories to the protocol have already reduced their $\text{SO}_x$ emissions to below the Gothenburg protocol emission ceilings, with large reductions of sulphur depositions as a result. Subsequently, this has lead to a major improvement in the risk damage of acidification to ecosystems all over Europe. In 1990, almost all the Parties to the Protocol had 40% or more of their ecosystem areas at risk. In 2004, the unprotected area have decreased to below 20% for most of the Parties to the Protocol.

The largest reductions have been achieved in countries where the ecosystems are more sensitive to acidification (e.g. the Nordic countries), whilst in areas with more robust ecosystem areas (e.g. southern Europe), less progress in the levels of air pollution have been made.

For oxidised nitrogen depositions, many countries are still far from reaching the targets set by the Gothenburg Protocol. In 2004 more than half of the Parties to the protocol still lack 20% or more of the targeted reduction of $\text{NO}_x$ deposition, and some countries are as much as 30-40% off.

Despite that most Signatories to the Protocol have reported lower $\text{NH}_3$ emissions in 2004 than the target for 2010, many of the Signatories to the Protocol were in 2004 some distance away from reaching the targeted 2010 GP reduced nitrogen deposition levels. The reason is that the projected reductions in $\text{NH}_3$ emissions for many countries is of the same order as the meteorological variability of the depositions (10-20%), thus the expected trend is masked. This is a smaller problem when analysing trends in $\text{SO}_x$ and $\text{NO}_x$ depositions as the reductions in emissions are larger.

Reductions in $\text{NO}_x$ and $\text{NH}_3$ emissions have led to a decrease of nitrogen depositions in Europe followed by lower exceedances of nutrient nitrogen critical loads. For most Signatories to the Protocol, the accumulated exceedances have decreased by 20-30% since 1990. However, only for a few Parties to the protocol, significant reductions in the unprotected ecosystem areas are achieved, and more than half of the Parties to the Convention have more than 90% of their ecosystem areas at risk for eutrophication. The reason is that even if the accumulated exceedances have decreased, the critical levels are still exceeded. Thus, further reductions in the depositions of nitrogen is needed in order to reduce the percentage ecosystem areas at risk.
References


D. Simpson, H. Fagerli, S. Hellsten, K. Knulst, and O. Westling. Comparison of modelled and monitored deposition fluxes of sulphur and nitrogen to ICP-forest sites in Europe. b. accepted for publication in Biogeosciences.


In this chapter we analyse the progress from the base year of the Gothenburg Protocol (1990) to the target year (2010) based on calculated AOT40 and SOMO35 statistics for the years 1990, 1995, 2000, 2004 and 2010 (Gothenburg protocol emission ceilings), using the best available emission estimates as documented in Chapter 2 and in Appendix A.

4.1 Changes in ozone risk damage calculations since the time of the negotiations for the Gothenburg Protocol

Since the final negotiations for the Gothenburg protocol, the scientific community has refined and improved their evaluation of ozone metrics for both health and ecosystems. As noted in chapter 3 there have also been large changes in emissions, and very large changes in model structure – from the Lagrangian 150×150km² Lagrangian model framework to the current 50×50km² grid Eulerian model.

Another change in procedure for calculating future scenarios is that we now allow for increases in the background tropospheric ozone, in order to account to some extent for the observed trends in this compound. We assume an increase of 3 ppb (over the mean 1990s level) for year 2010 simulations (or 4.5 ppb for year 2020 simulations), which is consistent with available data. However, both measurements and model calculations of future trends cover a wide range, so any trend estimate is very approximate.
(e.g. Jonson et al. 2006, Dentener et al. 2005, Stevenson et al. 2005).

4.1.1 Changes in ozone metrics

The SOMO35 metric (defined in chapter 1) has now been accepted as a better measure of health-related ozone damage than the AOT60 which was used as the basis for the Gothenburg Protocol negotiations.

For crops and forests, AOT40 is no longer recommended by the Effects community for integrated assessment work, except for seminatural vegetation. The AOT metrics has been replaced by the flux-based metrics as discussed in detail in chapter 5. Where AOT40 is used, the revised Mapping Manual stresses that it should be calculated from ozone concentrations at the top of the vegetation canopy. This is in contrast to the earlier practise within EMEP and elsewhere to base AOT40 upon $O_3$ at measurement height (defined as AOT40$_{3m}$ and AOT40$_{3m}$ in chapter 1). For forests, ozone is usually somewhat higher at the top of the canopy than at 3 m, so AOT40$_{uc}$ is usually greater than AOT40$_{3m}$. For crops, concentrations at the top of the canopy ($\sim 1$ m) are lower than concentrations at 3 m, so AOT40$_{uc}$ is often substantially lower than AOT40$_{3m}$. The implications of these differences with regard to AOT40 outputs has been documented in Simpson et al. (2006). Here we will present some results for AOT40$_{uc}$ for comparison with earlier approaches, and since these results will be rather similar to the AOT40 requested by the effects community for seminatural vegetation.

When AOT40 is used to indicate risk of ozone to forests, the critical level has now been lowered, to 5000 ppb.h, instead of the 10000 ppb.h used when the Protocol was developed. This lowering of the CL means of course that larger areas are in exceedance than with the older CL.

4.2 Ozone changes, 1990 - 2010

The EMEP Unified model has been run for the years 1990, 1995, 2000 and 2004 using the appropriate meteorology. As in chapter 3 the most recent emission estimates (Vestreng et al. 2006), covering all the years of interest, are applied.

Figures 4.1-4.2, (a)-(d), illustrate the calculated SOMO35 and AOT40$_{uc}$ values for these years. Both SOMO35 levels and AOT40 levels are lower in 2004 than in 1990, although levels have not changed greatly in most areas. For AOT40 all years show extensive exceedance of the critical level of 5000 ppb.h.

It is difficult to isolate the effects of emissions from those of year to year variability in meteorology from these results, however. In order to more systematically evaluate the effects of emissions and boundary conditions for at least the period 2000 to 2010, we have conducted two further tests using year-2000 meteorology, but with emissions from the year 2010 (Gothenburg Protocol, GP).

Figures 4.1-4.2,(e), show the calculated SOMO35 and AOT40 levels using this year 2000 meteorology, but with emissions and external boundary conditions (BCs) from
the Gothenburg Protocol (GP) scenario. The change in BCs assumed here use year 2010-BCs, which include a 3 ppb O\textsubscript{3} increase compared to the mean BCs employed during the 1990s, as discussed above.

Figs. 4.1-4.2, (f), show similar GP scenario calculations, but without this increased level of BCs (i.e. using the year 2000-BCs).

At first sight, the results of both 2010 scenarios look rather similar to that of the year 2000 simulations, although lower SOMO35 and AOT40 values are apparent in many areas, for example over Spain and northern Italy. Fig. 4.3 illustrates \( \Delta \)SOMO35 values, defined as year 2010 results minus year 2000 results. The scenario with year-2010 BCs (Fig. 4.3(a)) show decreases in SOMO35 in central Europe, but increases elsewhere (e.g. for the United Kingdom, or around the Black sea). The scenario using year 2000-BCs (Fig. 4.3(b)) shows much greater reductions in SOMO35 over a larger area of Europe. Only a few regions show significant increases in SOMO35. These increases can be explained by a reduction in the NO\textsubscript{x} titration effect over the United Kingdom (as NO\textsubscript{x} emissions are reduced), and by increased NO\textsubscript{x} emissions in many parts of south-eastern Europe.

### 4.3 What are the main uncertainties?

For calculations of SOMO35 relevant to population exposure, the main uncertainty is probably that related to the EMEP grid size. Ozone concentrations in urban areas are usually substantially lower than in rural areas, and we cannot capture this in a model with grid-sizes measuring tens of 10 km. In addition, ozone formation is a non-linear process, and finer grid sizes would presumably lead to a more accurate treatment of the ozone chemistry, and hence of responses to emissions control.

Uncertainties concerning emissions have been discussed in see Chapter 2. In addition to these anthropogenic emissions, a major uncertainty for ozone formation is that of biogenic VOC emissions Simpson et al. (1999).

Uncertainties concerning AOT40 levels arise from the high threshold value (Sofiev and Tuovinen 2001), and also arise when ozone estimates need to be made for the top of a vegetation canopy, rather than at typical measurement heights (Simpson et al. 2006).

Finally, an important factor in determining the levels of SOMO35 and AOT40 in 2010 and beyond is the influence of increasing levels of tropospheric ozone on the results. The increase of 3 ppb (over the mean 1990s level) which we have assumed seems consistent with available data. It should be noted though that both measurements and model calculations cover a wide range (e.g. Jonson et al. 2006, Dentener et al. 2005, Stevenson et al. 2005).
Figure 4.1: SOMO35
Figure 4.2: Calculated AOT40\textsuperscript{uc} values for forests, calculated over April-September.
4.3.1 EMEP Unified model validation: status 2004

The model calculations for 2004 discussed in the earlier sections are validated against EMEP measurements for 2004.

In Simpson et al. (2003) we presented an extensive evaluation of the ozone predictions over a number of years between 1990 and 2000. Further results for 2002-2003 were presented in Jonson et al. (2004) and Simpson et al. (2005).

As for the acidifying pollutants, these studies showed that the EMEP model performance is rather homogeneous over the years, but depend on geographical coverage and quality of the measurement data. Table 4.1 complements these earlier studies with a summary of results from the year 2004 simulations.

Table 4.1: Comparison of Modelled Versus Observed Ozone for Year 2004. Concentrations are 12-monthly Means of Daily Maximum Ozone Values. Correlation coefficient \( r \) are also between daily max values. Only sites with more than 275 valid observation days (N) are shown.

<table>
<thead>
<tr>
<th>Code</th>
<th>Station</th>
<th>N</th>
<th>Obs.</th>
<th>Mod.</th>
<th>( r )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(days)</td>
<td>(ppb)</td>
<td>(ppb)</td>
</tr>
</tbody>
</table>

Nordic Countries

continued on next page
<table>
<thead>
<tr>
<th>Code</th>
<th>Station</th>
<th>N</th>
<th>Obs.</th>
<th>Mod.</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>DK05</td>
<td>Keldsnor</td>
<td>301</td>
<td>37.20</td>
<td>38.60</td>
<td>0.75</td>
</tr>
<tr>
<td>DK31</td>
<td>Ulborg</td>
<td>318</td>
<td>37.22</td>
<td>38.34</td>
<td>0.69</td>
</tr>
<tr>
<td>FI09</td>
<td>Utoe</td>
<td>320</td>
<td>40.95</td>
<td>39.01</td>
<td>0.62</td>
</tr>
<tr>
<td>FI17</td>
<td>Virolahti II</td>
<td>357</td>
<td>38.46</td>
<td>34.98</td>
<td>0.66</td>
</tr>
<tr>
<td>FI22</td>
<td>Oulanka</td>
<td>333</td>
<td>38.50</td>
<td>31.25</td>
<td>0.43</td>
</tr>
<tr>
<td>FI37</td>
<td>Aehtaeri II</td>
<td>360</td>
<td>36.82</td>
<td>31.79</td>
<td>0.46</td>
</tr>
<tr>
<td>NO01</td>
<td>Birkenes</td>
<td>362</td>
<td>38.27</td>
<td>37.28</td>
<td>0.66</td>
</tr>
<tr>
<td>NO15</td>
<td>Tustervatn</td>
<td>364</td>
<td>40.60</td>
<td>35.13</td>
<td>0.55</td>
</tr>
<tr>
<td>NO39</td>
<td>Kaarvatn</td>
<td>365</td>
<td>39.46</td>
<td>36.67</td>
<td>0.42</td>
</tr>
<tr>
<td>NO42</td>
<td>Spitzbergen, Zeppelin</td>
<td>364</td>
<td>38.83</td>
<td>37.03</td>
<td>0.49</td>
</tr>
<tr>
<td>NO43</td>
<td>Prestebakke</td>
<td>363</td>
<td>38.96</td>
<td>36.89</td>
<td>0.70</td>
</tr>
<tr>
<td>NO55</td>
<td>Karasjok</td>
<td>363</td>
<td>39.46</td>
<td>32.99</td>
<td>0.48</td>
</tr>
<tr>
<td>NO56</td>
<td>Hurdal</td>
<td>365</td>
<td>37.83</td>
<td>34.55</td>
<td>0.68</td>
</tr>
<tr>
<td>SE11</td>
<td>Vavi hill</td>
<td>361</td>
<td>38.10</td>
<td>37.25</td>
<td>0.74</td>
</tr>
<tr>
<td>SE12</td>
<td>Aspvreten</td>
<td>348</td>
<td>38.61</td>
<td>35.97</td>
<td>0.66</td>
</tr>
<tr>
<td>SE13</td>
<td>Esrange</td>
<td>365</td>
<td>39.16</td>
<td>33.18</td>
<td>0.46</td>
</tr>
<tr>
<td>SE32</td>
<td>Norra-Kvill</td>
<td>362</td>
<td>40.46</td>
<td>36.31</td>
<td>0.64</td>
</tr>
<tr>
<td>SE35</td>
<td>Vindeln</td>
<td>365</td>
<td>37.89</td>
<td>33.14</td>
<td>0.43</td>
</tr>
<tr>
<td>CZ01</td>
<td>Svratouch</td>
<td>356</td>
<td>43.02</td>
<td>40.63</td>
<td>0.71</td>
</tr>
<tr>
<td>CZ03</td>
<td>Kosetice</td>
<td>350</td>
<td>42.47</td>
<td>40.61</td>
<td>0.78</td>
</tr>
<tr>
<td>EE09</td>
<td>Lahemaa</td>
<td>362</td>
<td>37.81</td>
<td>33.40</td>
<td>0.53</td>
</tr>
<tr>
<td>EE11</td>
<td>Vilsandy</td>
<td>356</td>
<td>42.16</td>
<td>37.95</td>
<td>0.63</td>
</tr>
<tr>
<td>HU02</td>
<td>K-puszta</td>
<td>323</td>
<td>40.46</td>
<td>43.93</td>
<td>0.48</td>
</tr>
<tr>
<td>LV10</td>
<td>Rucava</td>
<td>337</td>
<td>33.82</td>
<td>36.30</td>
<td>0.63</td>
</tr>
<tr>
<td>PL02</td>
<td>Jarczew</td>
<td>365</td>
<td>51.56</td>
<td>38.89</td>
<td>0.10</td>
</tr>
<tr>
<td>PL03</td>
<td>Sniezka</td>
<td>364</td>
<td>44.65</td>
<td>39.19</td>
<td>0.57</td>
</tr>
<tr>
<td>PL04</td>
<td>Leba</td>
<td>365</td>
<td>40.58</td>
<td>40.36</td>
<td>0.29</td>
</tr>
<tr>
<td>PL05</td>
<td>Diabla Gora</td>
<td>355</td>
<td>38.20</td>
<td>37.03</td>
<td>0.54</td>
</tr>
<tr>
<td>SI08</td>
<td>Iskrba</td>
<td>357</td>
<td>45.04</td>
<td>42.96</td>
<td>0.74</td>
</tr>
<tr>
<td>SI31</td>
<td>Zarodnje</td>
<td>361</td>
<td>40.49</td>
<td>43.31</td>
<td>0.75</td>
</tr>
<tr>
<td>SI32</td>
<td>Krvavec</td>
<td>362</td>
<td>53.89</td>
<td>43.89</td>
<td>0.75</td>
</tr>
<tr>
<td>SI33</td>
<td>Kovk</td>
<td>330</td>
<td>44.16</td>
<td>42.97</td>
<td>0.79</td>
</tr>
<tr>
<td>AT02</td>
<td>Illmitz</td>
<td>345</td>
<td>44.75</td>
<td>42.73</td>
<td>0.80</td>
</tr>
<tr>
<td>AT05</td>
<td>Vorhegg</td>
<td>363</td>
<td>46.59</td>
<td>45.11</td>
<td>0.59</td>
</tr>
<tr>
<td>AT30</td>
<td>Pillersdorf</td>
<td>349</td>
<td>44.05</td>
<td>40.99</td>
<td>0.81</td>
</tr>
<tr>
<td>AT32</td>
<td>Sulzberg</td>
<td>358</td>
<td>48.82</td>
<td>42.86</td>
<td>0.70</td>
</tr>
<tr>
<td>AT33</td>
<td>Stolzalpe</td>
<td>351</td>
<td>45.49</td>
<td>44.31</td>
<td>0.61</td>
</tr>
<tr>
<td>CH02</td>
<td>Payerne</td>
<td>360</td>
<td>42.04</td>
<td>42.58</td>
<td>0.73</td>
</tr>
<tr>
<td>CH03</td>
<td>Taenikon</td>
<td>365</td>
<td>43.24</td>
<td>42.20</td>
<td>0.75</td>
</tr>
<tr>
<td>CH04</td>
<td>Chaumont</td>
<td>365</td>
<td>49.11</td>
<td>42.69</td>
<td>0.77</td>
</tr>
<tr>
<td>CH05</td>
<td>Rigi</td>
<td>360</td>
<td>48.93</td>
<td>42.61</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Continued on next page.
<table>
<thead>
<tr>
<th>Code</th>
<th>Station</th>
<th>N</th>
<th>Obs.</th>
<th>Mod.</th>
<th>$r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE01</td>
<td>Westerland/Wenn.</td>
<td>365</td>
<td>46.35</td>
<td>36.60</td>
<td>0.67</td>
</tr>
<tr>
<td>DE02</td>
<td>Lang./Waldhof</td>
<td>337</td>
<td>39.10</td>
<td>36.95</td>
<td>0.84</td>
</tr>
<tr>
<td>DE03</td>
<td>Schauinsland</td>
<td>359</td>
<td>50.85</td>
<td>41.11</td>
<td>0.81</td>
</tr>
<tr>
<td>DE07</td>
<td>Neuglobsow</td>
<td>358</td>
<td>39.98</td>
<td>37.62</td>
<td>0.82</td>
</tr>
<tr>
<td>DE09</td>
<td>Zingst</td>
<td>365</td>
<td>38.33</td>
<td>35.36</td>
<td>0.68</td>
</tr>
<tr>
<td>DE12</td>
<td>Bassum</td>
<td>340</td>
<td>34.74</td>
<td>37.60</td>
<td>0.82</td>
</tr>
<tr>
<td>DE26</td>
<td>Ueckermuende</td>
<td>365</td>
<td>39.18</td>
<td>38.39</td>
<td>0.83</td>
</tr>
<tr>
<td>DE35</td>
<td>Lueckendorf</td>
<td>358</td>
<td>40.58</td>
<td>39.66</td>
<td>0.81</td>
</tr>
<tr>
<td>DE39</td>
<td>Aukrug</td>
<td>343</td>
<td>34.97</td>
<td>36.10</td>
<td>0.75</td>
</tr>
<tr>
<td>FR08</td>
<td>Donon</td>
<td>353</td>
<td>44.63</td>
<td>40.61</td>
<td>0.79</td>
</tr>
<tr>
<td>FR09</td>
<td>Revin</td>
<td>354</td>
<td>40.30</td>
<td>38.99</td>
<td>0.84</td>
</tr>
<tr>
<td>FR10</td>
<td>Morvan</td>
<td>350</td>
<td>40.96</td>
<td>40.87</td>
<td>0.74</td>
</tr>
<tr>
<td>FR12</td>
<td>Iraty</td>
<td>310</td>
<td>55.41</td>
<td>43.40</td>
<td>0.69</td>
</tr>
<tr>
<td>FR13</td>
<td>Peyrusse Vieille</td>
<td>351</td>
<td>43.12</td>
<td>39.56</td>
<td>0.72</td>
</tr>
<tr>
<td>FR14</td>
<td>Montandon</td>
<td>347</td>
<td>37.09</td>
<td>41.73</td>
<td>0.74</td>
</tr>
<tr>
<td>GB02</td>
<td>Eskdalemuir</td>
<td>328</td>
<td>34.80</td>
<td>38.49</td>
<td>0.73</td>
</tr>
<tr>
<td>GB13</td>
<td>Yarner Wood</td>
<td>357</td>
<td>40.20</td>
<td>38.48</td>
<td>0.78</td>
</tr>
<tr>
<td>GB14</td>
<td>High Muffles</td>
<td>364</td>
<td>39.98</td>
<td>36.65</td>
<td>0.68</td>
</tr>
<tr>
<td>GB15</td>
<td>Strath Vaich Dam</td>
<td>303</td>
<td>43.77</td>
<td>38.00</td>
<td>0.70</td>
</tr>
<tr>
<td>GB31</td>
<td>Aston Hill</td>
<td>326</td>
<td>39.98</td>
<td>37.87</td>
<td>0.74</td>
</tr>
<tr>
<td>GB32</td>
<td>Bottesford</td>
<td>360</td>
<td>35.56</td>
<td>33.80</td>
<td>0.79</td>
</tr>
<tr>
<td>GB33</td>
<td>Bush</td>
<td>360</td>
<td>35.46</td>
<td>35.47</td>
<td>0.70</td>
</tr>
<tr>
<td>GB34</td>
<td>Glazebury</td>
<td>350</td>
<td>35.15</td>
<td>33.16</td>
<td>0.73</td>
</tr>
<tr>
<td>GB35</td>
<td>Great Dun Fell</td>
<td>362</td>
<td>37.02</td>
<td>37.76</td>
<td>0.66</td>
</tr>
<tr>
<td>GB36</td>
<td>Harwell</td>
<td>330</td>
<td>39.87</td>
<td>35.68</td>
<td>0.80</td>
</tr>
<tr>
<td>GB37</td>
<td>Ladybower</td>
<td>309</td>
<td>40.82</td>
<td>32.92</td>
<td>0.74</td>
</tr>
<tr>
<td>GB38</td>
<td>Lullington Heath</td>
<td>346</td>
<td>41.74</td>
<td>38.74</td>
<td>0.77</td>
</tr>
<tr>
<td>GB39</td>
<td>Sibton</td>
<td>350</td>
<td>37.03</td>
<td>35.63</td>
<td>0.76</td>
</tr>
<tr>
<td>GB44</td>
<td>Somerton</td>
<td>347</td>
<td>38.21</td>
<td>37.03</td>
<td>0.74</td>
</tr>
<tr>
<td>GB45</td>
<td>Wicken Fen</td>
<td>341</td>
<td>39.92</td>
<td>34.47</td>
<td>0.84</td>
</tr>
</tbody>
</table>

*Mediterranean Countries*

<table>
<thead>
<tr>
<th>Code</th>
<th>Station</th>
<th>N</th>
<th>Obs.</th>
<th>Mod.</th>
<th>$r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES07</td>
<td>Viznar</td>
<td>360</td>
<td>49.40</td>
<td>46.55</td>
<td>0.72</td>
</tr>
<tr>
<td>ES08</td>
<td>Niembro</td>
<td>358</td>
<td>42.49</td>
<td>44.11</td>
<td>0.74</td>
</tr>
<tr>
<td>ES09</td>
<td>Campisabalos</td>
<td>345</td>
<td>46.91</td>
<td>44.29</td>
<td>0.76</td>
</tr>
<tr>
<td>ES10</td>
<td>Cabo de Creus</td>
<td>342</td>
<td>50.39</td>
<td>44.48</td>
<td>0.76</td>
</tr>
<tr>
<td>ES11</td>
<td>Barcarrota</td>
<td>343</td>
<td>44.62</td>
<td>44.24</td>
<td>0.75</td>
</tr>
<tr>
<td>ES12</td>
<td>Zarra</td>
<td>344</td>
<td>49.51</td>
<td>46.13</td>
<td>0.83</td>
</tr>
<tr>
<td>ES13</td>
<td>Penausende</td>
<td>360</td>
<td>46.53</td>
<td>43.24</td>
<td>0.78</td>
</tr>
<tr>
<td>ES14</td>
<td>Els Torms</td>
<td>357</td>
<td>47.10</td>
<td>45.70</td>
<td>0.80</td>
</tr>
<tr>
<td>ES15</td>
<td>Risco Llano</td>
<td>349</td>
<td>56.13</td>
<td>45.45</td>
<td>0.81</td>
</tr>
<tr>
<td>IT01</td>
<td>Montelibretti</td>
<td>348</td>
<td>43.80</td>
<td>47.48</td>
<td>0.62</td>
</tr>
<tr>
<td>IT04</td>
<td>Ispra</td>
<td>292</td>
<td>22.82</td>
<td>48.08</td>
<td>0.73</td>
</tr>
</tbody>
</table>
4.4 Conclusions

We have presented calculations of SOMO35 and AOT40\textsubscript{uc} from the years 1990 to 2010. Although levels of both metrics have been reduced somewhat, the changes are modest. Simulations of year-2010 SOMO35 and AOT40 show that the emissions changes expected from the year 2000 to 2010 will lead to further reductions in both metrics in central Europe. Some areas show increasing levels, however, brought about by a combination of reduced NOx titration, increasing emissions in some areas, and increasing background tropospheric ozone.

References


5.1 Introduction

One of the main reasons for running the EMEP model is to generate results for use in integrated assessment modelling (IAM), and for studies on the risks and damages caused by pollution. For the development of the Gothenburg Protocol, the metric used for assessing the risk to vegetation was AOT40, which is an indicator of the ozone concentrations in ambient air that accumulates only those concentrations above 40 ppb since these were considered more biologically important in terms of causing damage.

It is generally accepted that ozone molecules only cause significant damage to vegetation when entering through the stomata. Many situations exist when ambient ozone concentrations can be high, but when stomatal uptake is limited. For example, in very hot, dry, conditions (often associated with ozone episodes), plants have to reduce their water loss. The restriction in stomatal openings reduces both the flux of water from the stomates, and the flux of ozone into the stomates. The importance of stomatal control on ozone fluxes (uptake) has lead to an increasing interest in the development of a risk-indicator which reflects these ozone fluxes (i.e. AFstY), rather than one which reflects just ozone concentrations (e.g. AOT40).

The first estimates of stomatal flux at the European scale were presented in Emberson et al. (2000a), and clearly showed that the distribution of flux was much more uniform than that of AOT40. These early calculations made use of the EMEP Lagrangian photo-oxidant model (Simpson 1992, 1993, 1995), with a horizontal res-
olution of ca. 150×150 km$^2$, and a single-layer vertical formulation with a depth of typically 1 km. Since these early calculations, much work has been done to improve the deposition model (now denoted DO$_3$SE, for Deposition of Ozone and Stomatal Exchange), and the EMEP model system has moved to a full 3-D Eulerian system with horizontal resolution of ca. 50×50 km$^2$ and 20 vertical layers (Simpson et al. 2003a).

The first systematic comparison of the AOTX and AFstY metrics using the updated definitions and Eulerian EMEP MSC-W photo-oxidant model was presented in Simpson et al. (2006). This paper compared AOT40 metrics derived from 3 m and canopy-top ozone values, and then AFstY values, for representative crop (wheat) and forest tree (beech) species. Simpson et al. (2006) also investigated how these metrics may change over the coming two decades, in response to anticipated emission reductions in Europe and changes in the background concentrations of ozone and methane.

On 15-19 November, 2005, a workshop on the “Critical levels of ozone and further applying and developing the flux-based concept” took place in Obergurgl, Austria. This workshop is the most recent of a total of six UNECE workshops that have dealt with developing ozone risk assessment methods for vegetation. Earlier workshops focused on developing concentration based risk assessment methods, and the flux based concept was only introduced and discussed in any detail at the two most recent workshops. The Obergurgl workshop resulted in an agreement on the use of the flux-based approach as a common method to assess the risk for effects of ozone on forest- and agro-ecosystems in integrated assessment modelling as well as an optional method for regional and local scale risk and damage assessment modelling. However, it was felt that the flux-based approach could not be applied to assess risk for effects on semi-natural vegetation as, at this stage, flux methods are not so well advanced for this species group. As such, risk assessments for semi-natural vegetation will remain based upon AOTX approaches.

The decisions reached at this workshop were developed further at the 19th ICP Vegetation Task Force Meeting, Caernarfon, Wales, 30th Jan - 2nd Feb, 2005. In addition, a forest sub-group was established to finalise the application of flux-based methods for forest trees. This group had extensive email exchange and was advised by members of the ICP vegetation, ICP Forests and Working Group on Effects Communities. The group held an ad-hoc meeting in Antwerp, Belgium, on 14-15 June 2006 where flux methods for forest trees for use in Integrated Assessment Modelling were finalised.

The above meetings agreed to the following general approach:

1. For large scale and integrated assessment modelling, a first requirement is an indication of the spatial variation in risk of damage for which the simplest acceptable flux model will be used. For this purpose one generic crop species was defined, and two generic forest species.

2. Once some realistic emission control options are available, the EMEP model will be re-run for specific vegetation categories for which sufficient details are
available. These extra runs are intended to provide best-estimate maps of AFstY to real-species, for use by the effects-community.

The stage (1) approach to generate maps for IAM was adopted because it was recognised that our knowledge of many critical inputs (e.g. growing seasons and phenology, conductance parameters, elevation effects, soil water parameters, etc.) is too uncertain to allow accurate mapping of the real ozone flux to specific species. On the other hand the spatial distribution of fluxes is so different to that of AOT (Simpson et al. 2006) that calculation of fluxes to a generic species was seen as an improvement upon the continued use of AOT. It was also stressed by MSC-W and IIASA that the integrated assessment modelling (IAM) process could not take into account many different types of vegetation, and that only a few flux-maps could be included in the IAM optimisation work.

Analogies to SOMO35

No critical level is defined for the new flux metrics for generic crops and forests. Although a break with tradition within the vegetation communities, the new AFstY metrics are now rather similar in function to the SOMO35 metric used for health studies. The target for all such metrics is now zero. Such a concept fits naturally with the way in which the flux-concept was developed. Plots of yield loss versus AFstY have shown rather linear relationships across the range of AFstY values. The tolerance of a plant to ozone is represented not by a CL, but by the flux threshold Y, that is intended to represent the plants innate detoxication capacity. As such, any accumulation of fluxes above these thresholds or cut-offs is seen as a risk.

5.2 Flux Modelling for Generic Crops and Forests

Deposition of ozone within a grid square is calculated using a resistance approach, as documented in Emberson et al. (2000b), and Simpson et al. (2001, 2003a). The stomatal conductance (\( g_{sto} \)) is calculated with a multiplicative algorithm, incorporating factors for phenology, light, temperature, vapour pressure deficit (VPD) and soil water potential (SWP). The basic algorithm is that developed by Emberson et al. (2000a,b), but modified for the AFstY calculations in that parameters apply only to the upper-canopy sunlit leaves. The temperature function has been modified also, as detailed in Mills (2004), Simpson et al. (2003a). The DO\(_3\)SE model has been extensively evaluated and shown to perform well for a number of different species under different climate regimes (Emberson et al. 2000c, Hole et al. 2004, Tuovinen et al. 2001, 2004).

Although there are obvious similarities in the methods used to model upper-canopy stomatal fluxes (\( F_{st} \)) for the calculation of AFstY, and modelling of full-canopy fluxes for deposition purposes, these calculations have important differences. The \( F_{st} \) values
Table 5.1: Values of flux threshold (Y), Phenology Astart and Aend parameters, cross-wind leaf dimension, and $\sum CPD_{crit}$ assumed for generic crop and forest species

<table>
<thead>
<tr>
<th></th>
<th>Y</th>
<th>Astart</th>
<th>Aend</th>
<th>L</th>
<th>$\sum CPD_{crit}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEN-CR</td>
<td>3.0</td>
<td>= SGS</td>
<td>= EGS</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>GEN-DF</td>
<td>1.6</td>
<td>= SGS</td>
<td>= EGS</td>
<td>7</td>
<td>NA</td>
</tr>
<tr>
<td>GEN-MF</td>
<td>1.6</td>
<td>80</td>
<td>320</td>
<td>3.5</td>
<td>NA</td>
</tr>
</tbody>
</table>

Notes: SGS and EGS are defined in Table 5.2. Usage of $\sum CPD_{crit}$ as defined in Mills (2004). NA = Not applicable.

required for AFstY represent maximum uptake to a small portion of the canopy, not net uptake to the whole canopy. These $F_{st}$ calculations are therefore performed as a parallel exercise to the deposition modelling, being performed from within the EMEP model’s deposition routines, but having no feedback to the canopy-scale deposition calculations required for the model’s atmospheric chemistry calculations.

Generic species

The three generic species implemented for the stage (1) European scale modelling are:

GEN-CR the generic crop, with characteristics based largely upon wheat

GEN-DF the generic deciduous forest, with characteristics based largely upon beech

GEN-MF the generic Mediterranean evergreen forest, with characteristics based largely upon Holm oak.

New sets of parameters for these generic species have been agreed. A few parameters are needed only for these AFstY calculations, and not for general deposition calculations. These are given in Table 5.1. Some of the remaining parameters (in particular concerning growing seasons) have been transferred to the landcover characteristics of the standard EMEP vegetation classes. For completeness, Table 5.2-5.3 list the parameters of all the vegetative landcover classes used in the EMEP model. Deposition parameters for other landuse types are treated exactly as in Emberson et al. (2000b), apart from some minor notation changes. It should be noted that the form of the equation used for phenology has been changed to accommodate the new species, although the shape of the function remains the same for the standard EMEP species. The new equations are given in Table 5.3.
Coverage

A tiny fraction of GEN-CR, GEN-DF and GEN-MF are added to each grid square where any vegetation is present, so we can calculate fluxes even in grids where the landuse data suggest no such species are present, providing a more comprehensive and easier to interpret spatial indication of risk.

Thus, the coverage of these generic species is much greater than the coverage of their real counterparts. For example, wheat does not grow in Arctic areas, and certainly not Holm oak. Still, all landuse maps have uncertainties, and we do not have maps showing the exact distribution of real species. Further, the calculation of fluxes is independent of the actual coverage of a species within the grid square: AFstY being calculated per square meter of upper-canopy sunlit leaf area (projected) rather than for the grid square as a whole. Rather than risk missing grid-squares which are later found to have such species, we simply calculate to all grid-squares and make this data available to those wishing to combine it with realistic distributions. Further, the procedure adopted will allow the effects-community to make use of these calculated fluxes with revised versions of land-use maps as they become available.

Growing seasons

Growing seasons are set using simple latitude functions, which capture the main features of south-north differences in growing season, but do not of course capture the effects of local climates or elevation. In future, satellite images, or temperature-based algorithms will probably provide a superior methodology, but even with such methods it is difficult to cope with the variability in growing season expected within an EMEP grid (e.g. in Alpine areas with very great differences in temperature within small horizontal distances).

For generic crops, an extended (3-month) accumulation period is assumed. This long period is designed to bracket the likely growing season of crops at each latitude, recognising the uncertainties of identifying the real growing season for each location. This 3-month period is centred around the date of mid-anthesis estimated using a simple latitude function.

For the generic forest trees, a similar latitude model is used for the deciduous forest which estimates both start and end of the growing season, i.e. both the length as well as the timing of the growth period can vary across the south-north European gradient. For the Mediterranean evergreen forest (as its name would suggest) a year round growing season is assumed.

Phenology

For GEN-CR we set $f_{\text{phen}} = 1.0$ always. This decision reflects the difficulties of identifying the rather short periods when crops are sensitive to ozone damage (outside of which $f_{\text{phen}}$ should be lower than 1.0) on a European scale.
For generic forest species the phenology functions are given in Table 5.3.

**Soil moisture**

For the generic crop and forest species, there is assumed to be no soil water potential limitation to stomatal fluxes ($f_{SWP}=1.0$). This is an important assumption, but ensures that AFstY is maximised. For crops this assumption also corresponds to conditions expected for irrigated areas.

For the Mediterranean evergreen forest (CR-MF), the phenology function displays an extended period of low $f_{phen}$, which captures to some extent the effects of summertime dry conditions in this region.

**LAI and height**

For the generic crop species, green LAI is set at the maximum value (3.5 m$^2$/m$^2$) over the period of the growth season, with total surface area (SAI) set accordingly to LAI+1.5. A height of 1 m is assumed throughout this period.

For the generic forest species the LAI annual cycle is defined according to the parameters defined in Table 5.2, applied within the confines the growth periods.

### 5.3 Results: Base-case calculations

Figures 5.1-5.3, (a)-(d), illustrate the calculated AFstY values for the generic crop and forest classes, for the year 1990, 1995, 2000 and 2004. Of these years, the year 1990 shows the highest values of AFstY for all species, and 2004 the lowest. Discussion of the spatial distribution of these AFstY values compared to AOT40 can be found in Simpson et al. (2006), and will not be repeated here, but we can note that the values calculated for the new Mediterranean forest, GEN-MF, are substantially lower than those calculated for the generic crop (GEN-CR) or deciduous (GEN-DF) forests. The large difference is primarily caused by the new phenology functions for GEN-MF, which severely limit ozone uptake during the summer months. We can also note that the absolute values for AFstY calculated for GEN-DF and GEN-CR here are significantly larger than those calculated by Simpson et al. (2006). These increases are due to a combination of new emission estimates, revised deposition parameters for the standard deciduous forest classes, and the sensitivity of AFstY values to even small changes in calculated ozone values (Tuovinen et al. 2006).

It is difficult to isolate the effects of emissions from those of year to year variability in meteorology from these results, however. In order to more systematically evaluate the effects of emissions and boundary conditions for at least the period 2000 to 2010, we have conducted two further tests using year-2000 meteorology, but year 2010 (Gothenburg Protocol, GP) emissions.
Figures 5.1-5.3, (e), show the calculated concentrations using year 2000 meteorology, but with emissions and external boundary conditions (BCs) from the Gothenburg Protocol (GP) scenario. The change in BCs assumed here use year 2010-BCs, which include a 3 ppb O₃ increase compared to the mean BCs employed during the 1990s (see chapter 4). Figs. 5.1-5.3, (f), show similar GP scenario calculations, but without this increased level of BCs (i.e. using the year 2000-BCs). Both these scenarios use year-2000 meteorology, and so can be compared directly to the ‘real’ year-2000 scenarios as shown in Figs. 5.1-5.3, (c).

At first sight, the results of both 2010 scenarios look rather similar to that of the year 2000 simulations. However, there are important differences, as shown in Fig. 5.4 which gives Δ AFstY, defined as year 2010 results minus year 2000 results. For all vegetation categories, the scenario with year-2010 BCs (Fig. 5.4, left) show decreases in AFstY in central Europe, but increases elsewhere (e.g. Portugal, or around the Black sea). The scenario using year 2000-BCs (Fig. 5.4, right) shows much greater reductions in AFstY over a larger area of Europe. Only a few regions show significant increases in AFstY. These increases can be explained by a reduction in the NOx titration effect over the United Kingdom (as NOx emissions are reduced), and by increased NOx emissions in many parts of south-eastern Europe.

5.4 Main uncertainties?

The modelling of ozone flux involves many assumptions, all of which involve uncertainties, but these are rather difficult to quantify because of the lack of detailed flux measurements (e.g. Simpson et al. 2003b, Tuovinen et al. 2006). It is perhaps useful to consider the uncertainties in the modelling that relate to achieving appropriate flux estimates at both the seasonal and diurnal temporal scale, since different model formulations and parameterisations will be responsible for determining these key drivers of AFstY.

Seasonally, accuracy in flux estimates will be most sensitive to the assumptions in the methods used to estimate plant phenology parameters. These include the methods to identify the start, end and in some cases, length of the growing season, and the evolution of LAI and physiological activity of the plant (represented by fphen) within this growing season. These variables will be crucial to ensuring that the seasonal flux (Fst) patterns are simulated accurately and hence entire seasonal AFstY is estimated appropriately. For the IAM modelling, the methods used tend towards a pessimistic or worst-case scenario estimate of seasonal flux (i.e. the parameterisation used will tend to over rather than under-estimate the length of the growth or flux accumulation period). This ensures that all peak ozone episodes that could potentially contribute to flux (but may be towards the end, or more likely, start of the growth period) are captured in the modelling. For Stage 2 modelling, methods to improve the identification, for key species, of the growing season length and timing, and the associated development of key plant characteristics (e.g. LAI, SAI, fphen) within this period will be developed
Figure 5.1: Calculated ozone fluxes ($AF_{st,3_{gen}}$, mmol m$^{-2}$) to generic crops. Note that calculations are carried out to all vegetated grid squares, in order to allow later mapping against the actual distribution of relevant species.
Figure 5.2: Calculated ozone fluxes ($AF_{st1.6_{gen}}$, mmol m$^{-2}$) to generic deciduous forests. Note that calculations are carried out to all vegetated grid squares, in order to allow later mapping against the actual distribution of relevant species.
Figure 5.3: Calculated ozone fluxes ($AF_{st1.6_{gen}}$, mmol m$^{-2}$) to generic Mediterranean evergreen. Note that calculations are carried out to all vegetated grid squares, in order to allow later mapping against the actual distribution of relevant species.
Figure 5.4: Calculated changes ($\Delta$ AFstY, mmol m$^{-2}$) in AFstY for generic crop and forest species, from year 2000 to year 2010 emissions. Calculations with standard 2010 Boundary Conditions (BCs) on left, and with year-2000 BCs. All meteorology for year 2000. Note that scales are different for each vegetation class.
and evaluated.

In terms of diurnal flux, perhaps the key parameter identified in many of the valuation studies that have to date been conducted, is $g_{\text{max}}$, which determines the magnitude of the stomatal conductance term used in the flux estimates (Emberson et al. 2000c, Tuovinen et al. 2001, 2004, 2006). For the generic species, a median $g_{\text{max}}$ value has been identified from the literature and applied across the whole of Europe. For Stage 2 the challenge will be to identify $g_{\text{max}}$ values that are truly representative of a species over its European distributional range and there is some evidence to suggest that this parameter may well vary according to the prevailing climatic conditions. Diurnal flux will also be strongly regulated by soil moisture and methods to more accurately define this parameter and its influence on stomatal conductance will be necessary for application in the stage 2 process.

Further, a disadvantage of both AFstY and AOTX approaches is that the thresholds (X,Y) lead to a significant sensitivity to uncertainties in the input ozone concentrations and flux calculations. These uncertainties have been explored for AOT40 by Sofiev and Tuovinen (2001) and Tuovinen (2000), and for both metrics using a recent model setup by Tuovinen et al. (2006).

The assumptions concerning changes in background ozone up to the year 2010 also represent a large source of uncertainty. The assumed increase of 3 ppb O$_3$ in 2010 (compared to the mean 1990s levels) seems consistent with available data, but both measurements and model calculations cover a wide range (e.g. Jonson et al. 2006, Dentener et al. 2005, Stevenson et al. 2005).

An important point made in the Simpson et al. (2006) paper is that since both AOTX and AFstY metrics aim to do the same thing, namely indicate the risk of ozone-damage to vegetation, the clear differences between them are not easily reconciled, and suggest that one metric should give a more realistic picture than the other. On biological grounds there is a clear preference for the AFstY metric, but unfortunately we have no large-scale data against which we can verify the predicted maps. This shortcoming points to a strong need to expand the European measurement networks for vegetation damage, so that flux-approaches may be fully evaluated, and in order to evaluate the validity of the EMEP model results as presented here.

## 5.5 Conclusions

The use of ozone-flux as a means of mapping the risks of ozone damage to crops and forests has only recently been recommended as the preferred methodology within UNECE. Maps of AFstY should thus supercede the earlier use of AOT40, and this chapter has presented the latest calculations. This chapter has presented calculations made with methodologies which have been decided at the ‘Obergurgl!’ workshop and subsequent meetings.

The AFstY maps presented here are for generic crop and forest species, intended for use in IAM optimisation work. The next step will be develop methods for ‘real’
species that will start to incorporate more realistic simulations of the effects of phenology, soil moisture deficit and climatic influences on stomatal flux calculations.
Table 5.2: Landcover specific parameters used in EMEP deposition and ozone-flux modules.

<table>
<thead>
<tr>
<th>Landcover</th>
<th>height</th>
<th>b</th>
<th>Alb</th>
<th>SGS50</th>
<th>DSGS</th>
<th>EGS50</th>
<th>DEGS</th>
<th>LAImin</th>
<th>LAImax</th>
<th>LAIs</th>
<th>LAIe</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF</td>
<td>20</td>
<td>14</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>366</td>
<td>0</td>
<td>3.4</td>
<td>4.5</td>
<td>192</td>
<td>96</td>
</tr>
<tr>
<td>DF</td>
<td>20</td>
<td>14</td>
<td>16</td>
<td>100</td>
<td>1.5</td>
<td>307</td>
<td>-2.0</td>
<td>0.0</td>
<td>4.5</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>NF</td>
<td>15</td>
<td>14</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>366</td>
<td>0</td>
<td>3.5</td>
<td>3.5</td>
<td>192</td>
<td>96</td>
</tr>
<tr>
<td>BF</td>
<td>15</td>
<td>14</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>366</td>
<td>0</td>
<td>3.5</td>
<td>3.5</td>
<td>192</td>
<td>96</td>
</tr>
<tr>
<td>TC</td>
<td>1</td>
<td>14</td>
<td>20</td>
<td>123</td>
<td>2.57</td>
<td>213</td>
<td>2.57</td>
<td>0.0</td>
<td>3.5</td>
<td>70</td>
<td>22</td>
</tr>
<tr>
<td>MC</td>
<td>2</td>
<td>14</td>
<td>20</td>
<td>123</td>
<td>2.57</td>
<td>213</td>
<td>2.57</td>
<td>0.0</td>
<td>3.0</td>
<td>70</td>
<td>44</td>
</tr>
<tr>
<td>RC</td>
<td>1</td>
<td>14</td>
<td>20</td>
<td>130</td>
<td>0</td>
<td>250</td>
<td>0</td>
<td>0.0</td>
<td>4.2</td>
<td>35</td>
<td>65</td>
</tr>
<tr>
<td>SNL</td>
<td>0.5</td>
<td>14</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>366</td>
<td>0</td>
<td>2.0</td>
<td>3.0</td>
<td>192</td>
<td>96</td>
</tr>
<tr>
<td>GR</td>
<td>0.5</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>366</td>
<td>0</td>
<td>2.0</td>
<td>3.5</td>
<td>140</td>
<td>135</td>
</tr>
<tr>
<td>MS</td>
<td>3</td>
<td>14</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>366</td>
<td>0</td>
<td>2.5</td>
<td>2.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>GEN-CR</td>
<td>1</td>
<td>14</td>
<td>20</td>
<td>123</td>
<td>2.57</td>
<td>213</td>
<td>2.57</td>
<td>3.5</td>
<td>3.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>GEN-DF</td>
<td>20</td>
<td>14</td>
<td>16</td>
<td>105</td>
<td>1.5</td>
<td>307</td>
<td>-2.0</td>
<td>0.0</td>
<td>4.0</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>GEN-MF</td>
<td>8</td>
<td>14</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>366</td>
<td>0</td>
<td>5.0</td>
<td>5.0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Notes. For background information, see Emberson et al. (2000b) and Mills (2004) *CF=temperate/boreal coniferous forest, DF=temperate/boreal deciduous forest, NF=Mediterranean needle-leaf forest, BF=Mediterranean broadleaf forest, TC=temperate crops, MC=Mediterranean crops, RC=root crops, SNL=seminatural/moorland, GR=grasslands, MS=Mediterranean scrublands, GEN-CR = generic crop for integrated assessment modelling (IAM), GEN-DF = generic deciduous forest for IAM, GEN-MF = generic Mediterranean deciduous forest for IAM.* North of 60°N, heights of forest reduced b = Albedo, SGS, EGS = start, end of growing season at 50°N. DSGS, DEGS give increment in days of SGS, EGS with each degree of latitude. \( SGS(\phi) = SGS(50°) + DSGS \times (\phi - 50) \), where \( \phi \) is latitude in °. LAIs gives length of period when LAI increases from LAImin to LAImax, and LAIe gives period when LAI decreases from LAImax to LAImin. See Emberson et al. (2000b) (but note small notation changes).
Table 5.3: Landcover specific parameters, cont.

<table>
<thead>
<tr>
<th>Landcover</th>
<th>$f_{\text{phen}}$ parameters</th>
<th>$g_{\text{max}}$ (nmole m$^{-2}$ s$^{-1}$)</th>
<th>$f_{\text{min}}$</th>
<th>flight</th>
<th>$T_{\text{min}}$</th>
<th>$T_{\text{opt}}$</th>
<th>$T_{\text{max}}$</th>
<th>$\text{VPD}_{\text{max}}$</th>
<th>$\text{VPD}_{\text{min}}$</th>
<th>$\text{SWP}_{\text{max}}$</th>
<th>$\text{PWP}_{\text{root}}$</th>
<th>root-depth m</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF</td>
<td>0.2 0.2 1.0 0.2 130 130</td>
<td>160</td>
<td>0.1</td>
<td>0.0083</td>
<td>1</td>
<td>18</td>
<td>36</td>
<td>0.6</td>
<td>3.3</td>
<td>-0.76</td>
<td>-1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>DF</td>
<td>0.3 0.3 1.0 0.3 50 50</td>
<td>134</td>
<td>0.13</td>
<td>0.006</td>
<td>-5</td>
<td>22</td>
<td>35</td>
<td>0.93</td>
<td>3.4</td>
<td>-0.55</td>
<td>-1.3</td>
<td>0.9</td>
</tr>
<tr>
<td>NF</td>
<td>0.3 0.3 1.0 0.3 110 150</td>
<td>180</td>
<td>0.13</td>
<td>0.013</td>
<td>4</td>
<td>20</td>
<td>37</td>
<td>0.4</td>
<td>1.6</td>
<td>-0.4</td>
<td>-1</td>
<td>0.9</td>
</tr>
<tr>
<td>BF</td>
<td>1.0 1.0 0.3 1.0 130 60</td>
<td>175</td>
<td>0.02</td>
<td>0.009</td>
<td>2</td>
<td>23</td>
<td>38</td>
<td>2.2</td>
<td>4.0</td>
<td>-1.1</td>
<td>-2.8</td>
<td>0.9</td>
</tr>
<tr>
<td>TC</td>
<td>0.1 0.1 1.0 0.1 45 0</td>
<td>300</td>
<td>0.01</td>
<td>0.009</td>
<td>12</td>
<td>26</td>
<td>40</td>
<td>0.9</td>
<td>2.8</td>
<td>-0.3</td>
<td>-1.1</td>
<td>0.7</td>
</tr>
<tr>
<td>MC</td>
<td>0.1 0.1 1.0 0.1 45 0</td>
<td>156</td>
<td>0.019</td>
<td>0.0048</td>
<td>0</td>
<td>25</td>
<td>51</td>
<td>1.0</td>
<td>2.5</td>
<td>-0.11</td>
<td>-0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>RC</td>
<td>0.2 0.2 1.0 0.2 45 0</td>
<td>360</td>
<td>0.02</td>
<td>0.0023</td>
<td>8</td>
<td>24</td>
<td>50</td>
<td>0.31</td>
<td>2.7</td>
<td>-0.44</td>
<td>-1.0</td>
<td>0.7</td>
</tr>
<tr>
<td>SNL</td>
<td>0.1 0.1 1.0 0.1 45 0</td>
<td>60</td>
<td>0.01</td>
<td>0.009</td>
<td>1</td>
<td>18</td>
<td>36</td>
<td>88.8</td>
<td>99.9</td>
<td>-9.99</td>
<td>-99.9</td>
<td>0.7</td>
</tr>
<tr>
<td>GR</td>
<td>1.0 1.0 1.0 1.0 0 0</td>
<td>270</td>
<td>0.01</td>
<td>0.009</td>
<td>12</td>
<td>26</td>
<td>40</td>
<td>1.3</td>
<td>3.0</td>
<td>-0.49</td>
<td>-1.5</td>
<td>0.8</td>
</tr>
<tr>
<td>MS</td>
<td>0.2 0.2 1.0 0.2 130 130</td>
<td>213</td>
<td>0.014</td>
<td>0.012</td>
<td>4</td>
<td>20</td>
<td>37</td>
<td>1.3</td>
<td>3.0</td>
<td>-1.1</td>
<td>-3.1</td>
<td>0.8</td>
</tr>
<tr>
<td>GEN-CR</td>
<td>0.0 1.0 1.0 1.0 1 1</td>
<td>450</td>
<td>0.01</td>
<td>0.0105</td>
<td>12</td>
<td>26</td>
<td>40</td>
<td>1.2</td>
<td>3.2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>GEN-DF</td>
<td>0.0 0.0 1.0 0.0 15 20</td>
<td>150</td>
<td>0.1</td>
<td>0.006</td>
<td>0</td>
<td>21</td>
<td>35</td>
<td>1.0</td>
<td>3.25</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>GEN-MF</td>
<td>1.0 1.0 0.3 1.0 130 60</td>
<td>175</td>
<td>0.02</td>
<td>0.009</td>
<td>2</td>
<td>23</td>
<td>38</td>
<td>2.2</td>
<td>4.0</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Notes. See Table 5.2 for land-cover codes. The following formulations are used for the $f_{\text{phen}}$ function:

- $f_{\text{phen}} = 0$ when $dd \leq SGS$ or $dd \geq EGS$ ($dd =$ year day)
- $SGS < dd < A_{\text{start}}$
- $A_{\text{start}} \leq dd < A_{\text{start}} + f_{\text{phen}}$
- $A_{\text{start}} + f_{\text{phen}} \leq dd < A_{\text{end}} - f_{\text{phen}}$
- $A_{\text{end}} - f_{\text{phen}} \leq dd < EGS$

For DF and GEN-DF, EGS as defined in Table 5.2 represents leaf-fall. For phenology calculations we replace this by EGS-10, as stomatal conductance is assumed to fall to zero 10 days before leaf-fall. NA = Not applicable.
References


L.R. Hole, A. Semb, and K. Tørseth. Ozone deposition to a temperate coniferous forest in Norway; gradient method measurements and comparison with the EMEP deposition module. 38, pages 2217–2223, 2004.


