Influence of Future Climate Changes on Pollution Levels in Denmark and in Europe

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Changes in climate variability as well as changes in extreme weather and climate events in the 20th century, especially those which took place during the last two-three decades of the 20th century, have been discussed in many recent scientific publications. Attempts to project the results of such studies in the future have been made under different assumptions. In this paper, we have chosen one of the well-known scenarios predicting changes of the climate in world during the last 30 years of the 21st century. This scenario is used, together with several general predictions related to the future climate, to produce several climatic scenarios. The derived scenarios are used to calculate predictions for future pollution levels in Denmark and in Europe by applying an air pollution model, the Danish Eulerian Model (DEM), whose space domain contains the whole of Europe. It is first shown that this model is able to produce reliable results. After that the results that are obtained by the climatic scenarios are compared with results obtained by using some more traditional scenarios in an attempt to evaluate the size of the changes in the pollution levels that are due to warming processes in the future climate. It is shown that calculations over a long time period are essential for such a study. A time-period of ten years was actually used. The results indicate that, although the annual means of the concentrations of many pollutants are rather insensitive to the predicted climate changes, some quantities related to high ozone levels are increased considerably.

Keywords: Climate changes, Air pollution models, Scenarios, Pollution levels, Predictions for the pollution in the future

AMS Subject classification: Primary 86A10, Secondary 76N15

1. Climate Changes and Air Pollution Levels

There have been many programs designed to predict the future state of the world's climate, and to explore the effects of such changes on a variety of policy sectors, e.g., food, water, energy, socioeconomic development, and regional security (see, e.g., Houghton, et al. [5]). Environmental degradation is also of concern in future climate scenarios, and much effort has been dedicated to understand changing pressures on an already-stressed system. We focus our attention in this paper on air pollution in future climates.

Within many regions on planet earth, air pollution policy has been regionalized, e.g., in order to control and reduce transboundary pollution and in order to meet policy objectives to limit air pollution impacts on human health and sensitive ecosystems. This has been a daunting task. Within Europe, the Convention on Long Range Transport of Air Pollution (CLRTAP) has been dedicated to establishing a legal framework for reducing air pollution and assuring the safety of humans and ecosystems within prescribed limits. Limit values for a variety of pollutants have been established, where a finite number of exceedance days per year are allowable. However, in reaching compliance to the air quality directives, very few studies have considered the possibility that climate change may induce a controlling factor in the rate of reaching compliance. In this paper, we will attempt to answer the question: Will climate change add to the rate of reaching compliance to Europe's air quality policy objectives, or will it make the process of reaching compliance more difficult? Without the possibility of accessing future data, we will attempt to answer this question by carrying out a modelling study, based on scenarios of future climate states (for Europe), as published in the most recent IPCC report (Houghton, et al. [5]).

We shall introduce three scenarios for climatic changes and shall study the impact of the predicted climatic changes on different pollution levels in Europe by using the results obtained by these scenarios as input data in the Danish Eulerian Model (DEM). DEM is described in detail in Zlatev [9]. Several studies related to exceeded critical levels have already been carried out by using this model; see, for example, Zlatev et al. [10] and the references given there. The model results have systematically been been compared with measurements taken both over land (Zlatev [9], Zlatev et al. [10]) and over sea (Harrison et al., [4]). It is nevertheless necessary to answer two important questions:

- Is the air pollution model chosen, DEM, producing reliable results?

and

- What is the relationship between changes of pollution levels that are caused by variations of emissions and changes of pollution levels that are caused by variations of meteorological parameters?

In order to answer the first question, we shall compare the results obtained by using DEM over a time-period of ten years, starting from 1989 until 1998, with the corresponding measurements. It should be mentioned here that the input data, both the meteorological data and the emission data, that are used in these runs of the model are obtained from EMEP (European Monitoring and Evaluation Programme); see Sandnes Lenschow and Tsyro [7] and Vestreng and Støren [8].

In order to answer the second question, we have run DEM by using two traditional scenarios. In the first of them, we kept the emissions during the whole period, 1989-1998, the same as those in year 1989, while the same meteorology (the meteorology for year 1989) was used in the second traditional scenario for every year.

Not only are the results showing that the pollution levels are changed both when the emissions and the meteorological parameters are varied, but it becomes clear that a long time period should be used in the study of the impact of climatic changes on the pollution levels. This is why we are consistently using a time period of ten years in the whole paper, i.e. also when the influence of the climatic changes on the concentrations of different air pollutants is studied.

The content of this paper can be outlined as follows. The six scenarios that are used in this study are defined in Section 2. The validation of the results obtained with the chosen air pollution model, DEM, is discussed in Section 3. The sensitivity of the pollution levels when either only the emissions are varied or only the meteorological parameters are varied is discussed in Section 4. Different results presenting changes of the pollution levels that are caused from climatic changes are given in Section 5. Some conclusions and plans for the continuation of this research can be found in the last section, Section 6.

2. Definition of six scenarios

Six scenarios, which will be used in the following sections, are described here. The first scenario is the basic one (it will be used both in the validation tests and in comparisons with results obtained by the other six scenarios). The next two scenarios (or, at least, scenarios that are similar to the next two scenarios) are traditionally used in air pollution studies. The last three scenarios are based on some expectations for climatic and/or emission changes in the last 30 years of the 21st century (Houghton et al. [5]).

2.1. Scenario 1 - Basic Scenario

The Basic Scenario is run for the time period 1989-1998. The EMEP emission inventories, Vestreng and Støren [8], for these ten years are used together with meteorological data, Sandnes Lenschow and Tsyro [7], which are also supplied from EMEP. If the model is run for a given year, year N, $N \in [1989, 1998]$, then both the emission inventories for year N and the meteorological data for year N are used in the run.

The period 1989-1998 is an important period when air pollution levels in Europe are studied, because the European emissions were in general reduced in this period. For some countries the reductions are rather considerable. This is why long-term calculations for this period are very valuable. The results from such computations can be used in the solution of two major tasks:

- to study the impact of the emission reductions to the pollution levels in some parts of Europe

and

- to validate the model results by comparing them with measurements taken at representative stations in the EMEP network.

The second task is very important. If the model results reflect correctly the emission reductions during the period 1989-1998 (by showing reductions of the pollution levels, which do agree with measurements), then the application of the model in runs with other scenarios becomes more reliable. Some results obtained in the treatment of the second task will be presented in Section 3.

2.2. Scenario 2 - keeping the emissions unchanged

The same period of ten years is used in the second scenario. The meteorological data for year N are used when the model is run for year N, $N \in [1989, 1998]$. The **same** emission inventories, these for year 1989, are used for all years in the interval $[1989, 1998]$. Thus, the changes in the pollution levels are only caused by the variation of the meteorological parameters when this scenario is run (because only the meteorological data are varied). This explains the major purpose with the second scenario: *we should like to see to what extent the meteorological data influence the pollution levels*. The comparison of the results obtained when this scenario is run with the results from the Basic Scenario, Scenario 1, will reveal the relationship between meteorological data and pollution levels.

2.3. Scenario 3 - keeping the meteorology unchanged

In the third scenario the emissions are varied from one year to another as in Scenario 1, while the same meteorological data (the meteorological data for year 1989) are used for all years in the interval $[1989, 1998]$. The changes in the pollution levels are now caused only by the changes of the emissions (because only the emission inventories are varied in the runs). Scenarios where the emissions only are varied are often used; see, for example, Amann et al. [1].

2.4. Scenario Climate 1

Several emission scenarios, called SRES (Special Report on Emissions Scenarios), are discussed in detail in Houghton et al. [5]). We chose to follow the predicted climatic changes in the SRES A2 scenario. In fact the SRES A2 is presented in Houghton et al. [5]) on p. 532 as a storyline and scenario family which describe a very heterogeneous world. We digitalized the information related to the annual temperature changes in Europe for the period 2071-2100. The changes in the different part of Europe and its surroundings are shown in Fig. 1.

In Scenario Climate 1, we used the temperature data for 1989-1998 to simulate changes in a ten hypothetical years according to the prescribed increases of the temperatures. This means that for the given hypothetical year, corresponding to year N, we add some amount α to the temperature at each grid-square of the space domain and at every time step. Consider any grid-square and assume that this grid-square is located in a region in Fig. 1 where the prescribed by the SRES A2 scenario annual change is in the interval $[\beta, \gamma]$. The temperature at the grid-square under consideration at a time-step n, $n = 1, 2, \ldots$, is increased by an amount τ_n where τ_n is a randomly generated number in the interval $[0, \gamma - \beta]$. This means that the mathematical expectation of the annual mean at each grid-square is the quantity $(\gamma - \beta)/2$. It should be mentioned that only the temperatures are varied in this scenario. Scenario Climate 1 was run for ten hypothetical years, corresponding to the ten years that are used in the Basic Scenario.

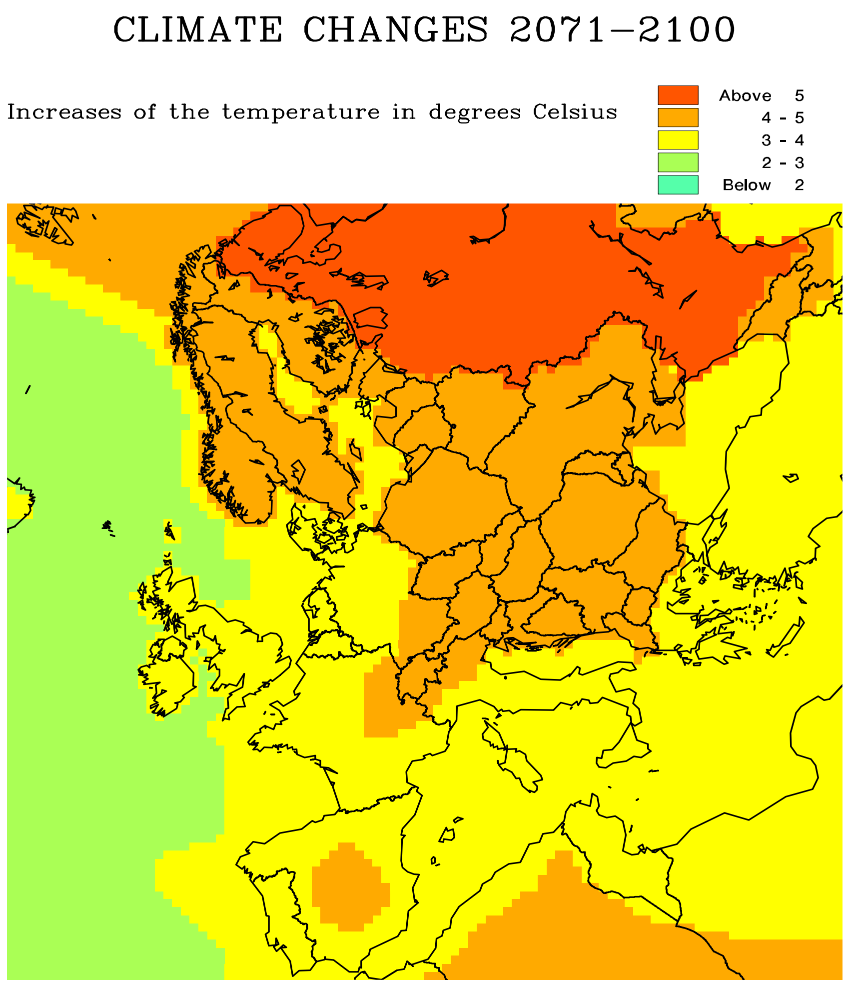

Figure 1
Predicted (by Scenario SRES A2, Houghton et al. [5]) changes of the temperatures in different parts of Europe.

2.5. Scenario Climate 2

It is emphasized many times in Houghton et al. [5] that the extreme cases will become even stronger in the future climate. In the second climate scenario an attempt to take into account this expectation has been carried out. More precisely, the following recommendations made in Table 9.6 on p. 575 in Houghton et al. [5] were taken into account when the Scenario Climate 2 was developed:

- There will be higher maximum temperatures and more hot days in the land areas.
- There will be higher minimum temperatures, fewer cold days and fewer frost days in nearly all land areas.
- The diurnal temperature range will be reduced over land areas.

It is not very easy to satisfy simultaneously all these three conditions. In this scenario we increased the temperatures during the night with a factor larger than the factor by which the daytime temperatures were increased. In this way, the second and the third requirements are satisfied. The first requirement is satisfied in the following way. During the summer periods the daytime temperatures are increased by a larger amount in hot days. It should be pointed out here that all these changes are carried out only over land. Furthermore, all changes described above are interposed over the changes made in the first climatic scenario. This means that, while the changes of the temperature are more or less smooth in the first climatic scenario, now some additional changes are imposed in order to meet the above three requirements.

In this scenario we also varied the data about cloud covers during the summer periods of the ten hypothetical years. Since there will be more hot days, it is natural to reduce the clouds covers during these periods. A factor of two has been used in the reduction of the cloud covers during the summer periods.

2.6. Scenario Climate 3

Two important recommendations are made in Table 9.6 on p. 575 in Houghton et al. [5] in connection with the amount of precipitation events in the future climate:

- There will be more intense precipitation events.
- There will be increased summer drying and associated risk of drought.

In order to satisfy these recommendations we increased the precipitation events during winter (both over land and over water). During summer, the precipitation events in the continental parts of Europe were reduced.

Similar changes in the humidity data were made. The humidity was increased during winter (both over land and over water). The humidity in the continental parts of Europe during summer was reduced.

The changes in precipitation events and humidity imply some changes of cloud covers. The cloud covers during winter were increased, while the same cloud covers as those used in the second climatic scenario were applied in the third climatic scenario.

All these changer were superimposed over the changes made in the second climatic scenario (Scenario Climate 2). The climatic scenario obtained in this way will be referred to as Scenario Climate 3.

2.7. Running the six scenarios

Each of the six scenarios was run by using (96x96x10) version of DEM over a time-period of ten years on powerful supercomputers. This is a very comprehensive computational task, which have been resolved by using an efficient parallel code (Owczarz and Zlatev [6]). The computers which were actually used were SUN computers with up to 24 processors at the Technical University of Denmark (Lyngby, Denmark). The calculated data were transmitted to workstation at the National Environmental Research Institute, where different graphical tools were used to visualize the digital information.

3. Validation of the results

The first scenario, the Basic Scenario, is used in this section to validate the results calculated by DEM by comparing measurements taken at Danish sites with corresponding model results. The sites are Tange, Keldsnor and Anholt for all species excepting ozone. Ozone concentrations are measured in Ulfborg and Frederiksborg. It should be mentioned here that all these stations belong to the EMEP network of measurement stations. The locations of these five sites are shown in Fig. 2.

The curves representing the temporal variations of the annual means of the concentrations (measured and calculated by the model) for the major species (SO_2, $SO_4^=$, NO_2, $HNO_3 + NO_3^-$, $NH_3 + NH_4^+$ and O_3) as well as for four quantities related to high ozone concentrations (AOT40 values for crops and forest trees, numbers of days in which the averaged 8-hour ozone concentrations exceed at least once the limit of 60 ppb and averaged daily ozone maxima; see

European Commission, [2], [3] or Zlatev et al. [10]) are given in Fig. 3. Curves representing the temporal variation of the averaged concentrations (over the 38 Danish grid-squares) are also given in the plots of Fig. 3.

DANISH MEASUREMENT STATIONS

Daily means of concentrations of sulphur pollutants, nitrogen pollutants and ammonia + ammonium are measured at Tange, Keldsnor and Anholt. Hourly means of ozone concentrations are measured at Ulfborg and Frederiksborg.

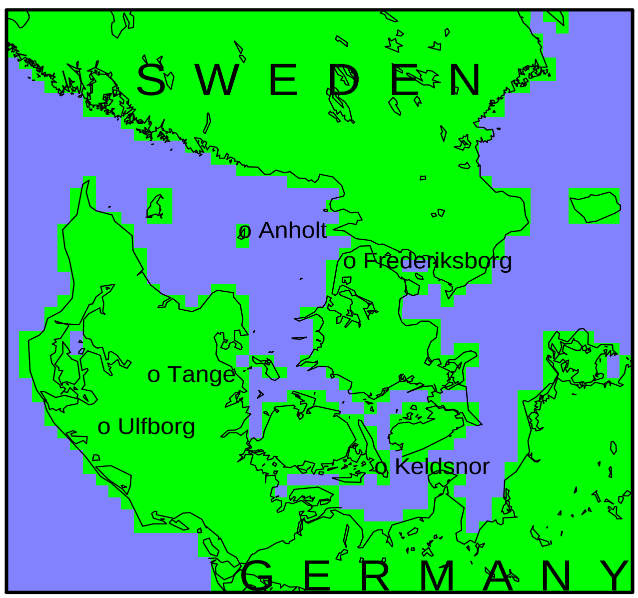

Figure 2
Locations of the Danish measurement stations which are included in the EMEP network.

The comparison is not very easy. The stations do not measure regularly. Sometimes, measurements for many years are missing (see the upper plot in Fig. 3.c). Even if the station measures for all years (from 1989 until 1998) measurements for many days are sometimes missing. This causes great problems when AOT40 values calculated by the model have to be compared with the corresponding quantities obtained by using measurements. The AOT40 values are normally calculated by using the formula

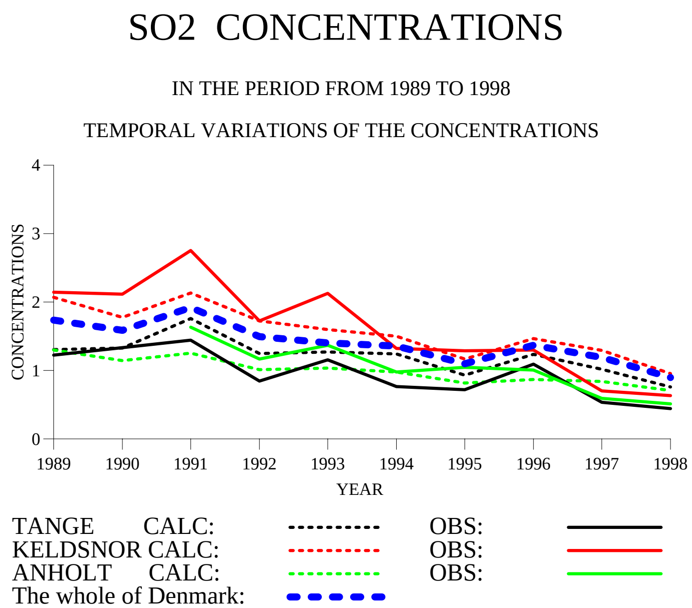

Figure 3.a

Comparison of annual means of SO_2 concentrations. The units are ppb.

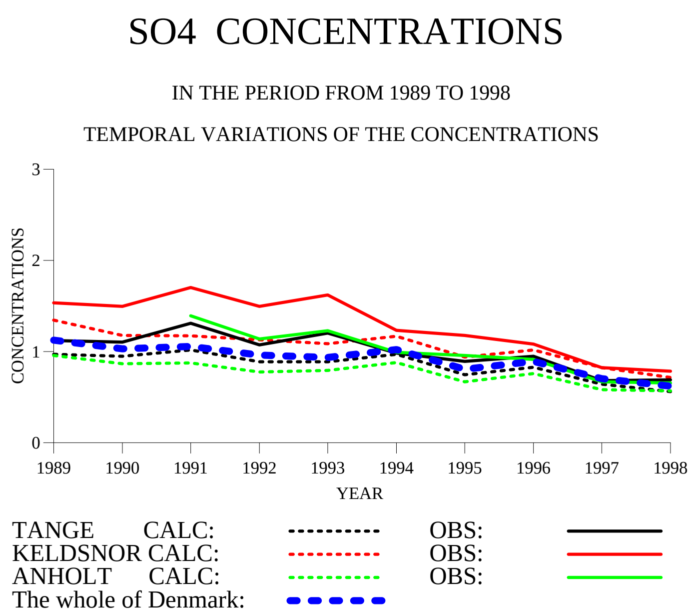

Figure 3.b

Comparison of annual means of $SO_4^=$ concentrations. The units are ppb.

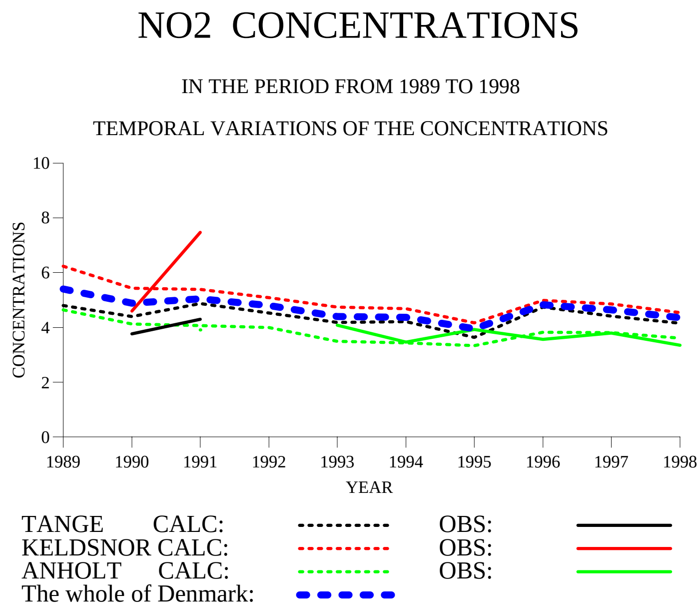

Figure 3.c

Comparison of annual means of NO_2 concentrations. The units are ppb.

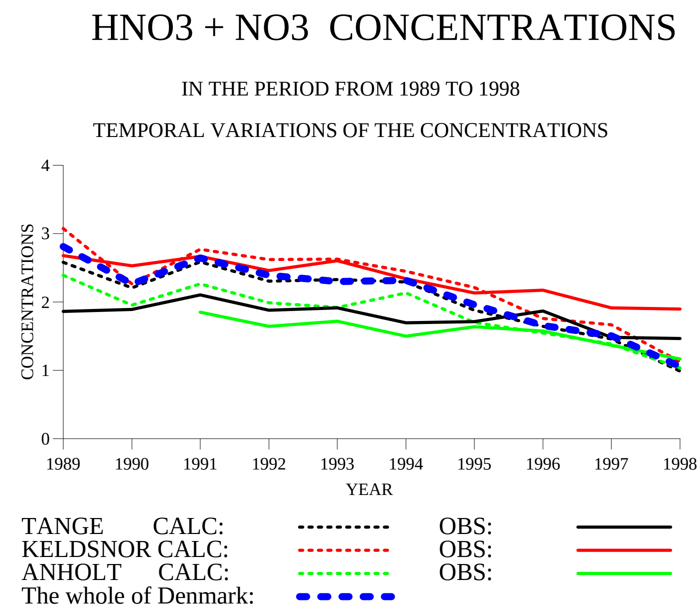

Figure 3.d

Comparison of annual means of $HNO3_3 + NO_3^-$ concentrations. The units are ppb.

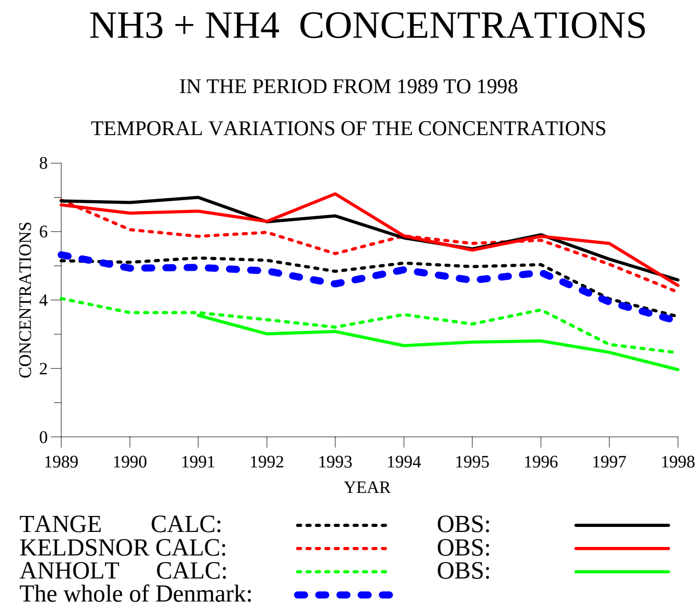

Figure 3.e

Comparison of annual means of $NH_3 + NH4^+$ concentrations. The units are ppb.

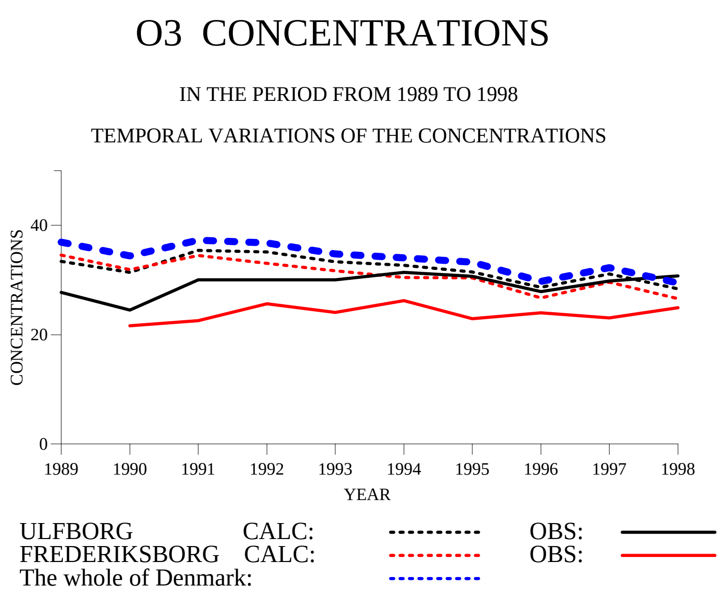

Figure 3.f

Comparison of annual means of $O3_3$ concentrations. The units are ppb.

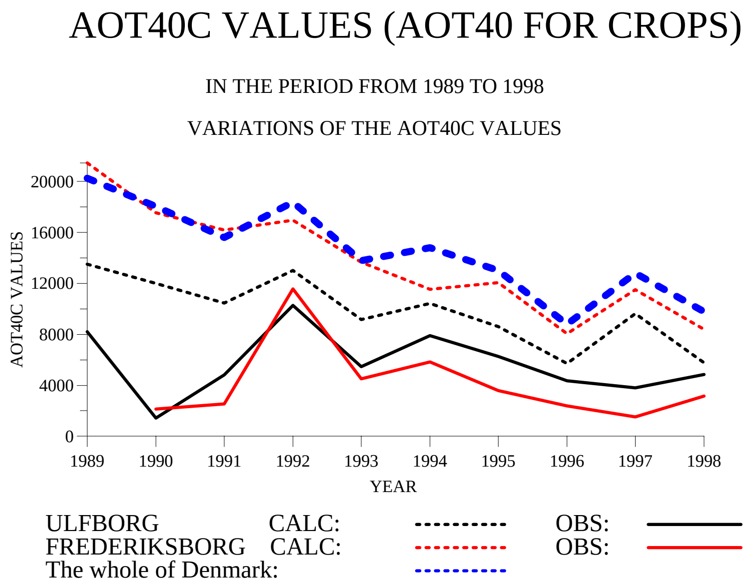

Figure 3.g
Comparison of AOT40C (AOT40 for crops) values. The units are ppb.hours.

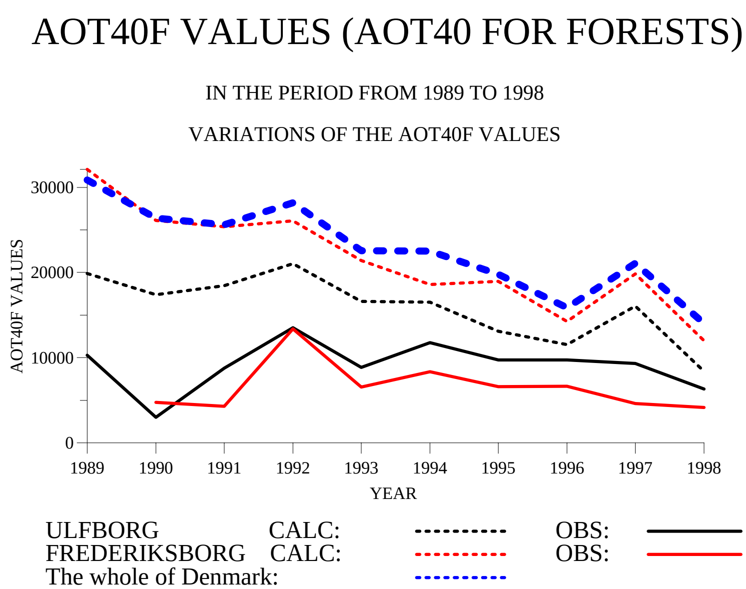

Figure 3.h
Comparison of AOT40F (AOT40 for forest trees) values. The units are ppb.hours.

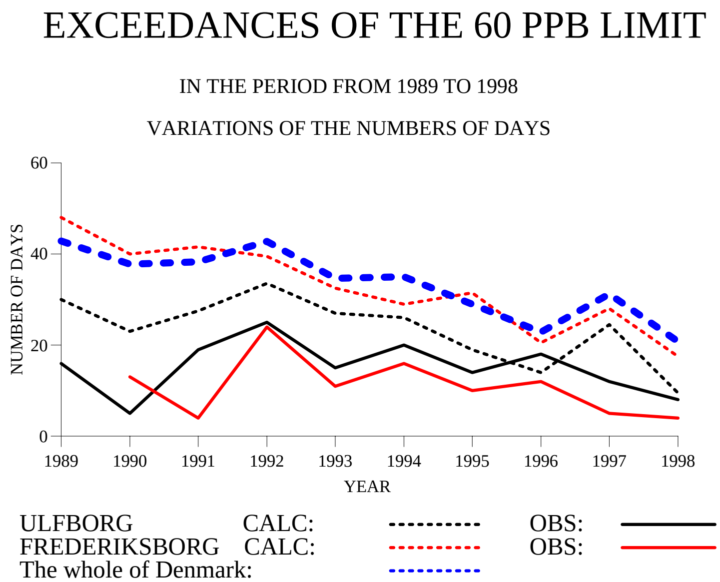

Figure 3.i

Comparison of numbers of days in which the 8-hour averaged ozone concentrations exceed at least once the limit of 60 ppb. The units are days.

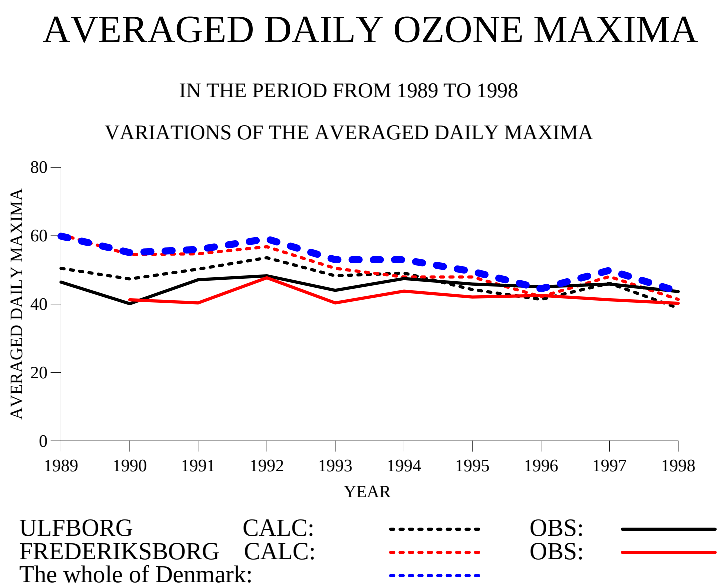

Figure 3.j

Comparison of average daily maxima of ozone concentrations. The units are ppb.

$$\mathrm{AOT40} = \sum_{i=1}^{N} \max(c_i - 40, 0), \tag{1}$$

where N is the number of day-time hours in the period under consideration (for crops this period contains the months May, June and July, while the period from April to September is used for forest trees), c_i is the calculated by some model or measured at some station ozone concentration.

With a model we can calculate c_i for **all** i, $i = 1, 2, \ldots, N$. However, when many measurements at the stations under consideration are missing, then one should expect the values at the stations to be considerably less than the model results. From Fig. 3.g and Fig. 3.h it is seen that precisely this happens in our comparisons, because many measurements are missing (see Table 1 in Zlatev et al. [10]).

Missing measurements cause similar problems also when numbers of days in which the 8-hour averaged ozone exceed at least once the limit of 60 ppb.

The missing measurements do not cause great problems when the averaged ozone maxima are compared. In this case we can use the number of measurements at a given station in order to obtain the averaged value, This is why the results of the comparison are much better (see Fig. 3.j)

It should also be emphasized that some of the quantities that are related to high ozone concentrations (AOT40 values for crops and forest trees and numbers of days in which the averaged 8-hour ozone concentrations exceed at least once the limit of 60 ppb) are very sensitive to small errors.

It is clearly seen (Fig. 3) that the reductions in the European emissions in the period 1989-1998 do result in some reductions of the concentrations (both the measured and the calculated concentrations) of most of the pollutants in Denmark. An exception is the variation of the ozone concentrations. While the calculated results show a slight trend of reduction, the measurements at the two Danish stations show a slight trend of increasing. Note, however, that the model results are closer to the measurements in the end of the period.

4. Variations of emissions and of meteorological parameters

Comparing the results obtained with the second and the third scenarios with the results obtained with the Basic scenario (the first scenario) will allow us to evaluate (i) the sensitivity of the concentrations to the variations of the meteorological parameters and (ii) the sensitivity of the concentrations to the variations of the emissions.

Some results are given in Fig. 4 for the same compounds as those used in the previous section and in Fig. 3). Three major conclusions can be derived by studying these plots:

- The comparison of the results obtained by the Basic Scenario with the results obtained by using the second scenario (in which the emissions are kept constant) shows that (i) the variations of the concentrations are similar (when the concentrations from one year to the next year are increasing for the Basic Scenario they are also increasing for the second scenario, while when they are decreasing for the Basic Scenario, they are also decreasing for the second scenario) and (ii) while a trend of decreasing can be seen for the Basic Scenario, no trend can be seen for the second scenario.
- The comparison of the results obtained by the Basic Scenario with the results obtained by using the third scenario (in which the meteorology is kept constant) shows that (i) there is a clear trend of reductions of the concentrations for both scenarios and (ii) the results obtained by using the Basic Scenario show a clear variability from one year to another, while the curves representing the variations obtained by the third scenario are very smooth.
- The immediate consequence from the previous two conclusions is that using meteorology from one year only is not sufficient for reliable conclusions. It is necessary to run the model over a long period of time in order to investigate the model response to the variability of the meteorology. This is why a time period of ten years is simulated in the three climatic scenarios.

5. Results from the climatic scenarios

The use of the tool chosen by us, the Danish Eulerian Model, was justified in Section 3. The need to run this model over a long time period was justified in Section 4. In this way we are ready to start the investigation of the influence of the climate changes on pollution levels. The climatic scenarios from Section 2 are used in the experiments.

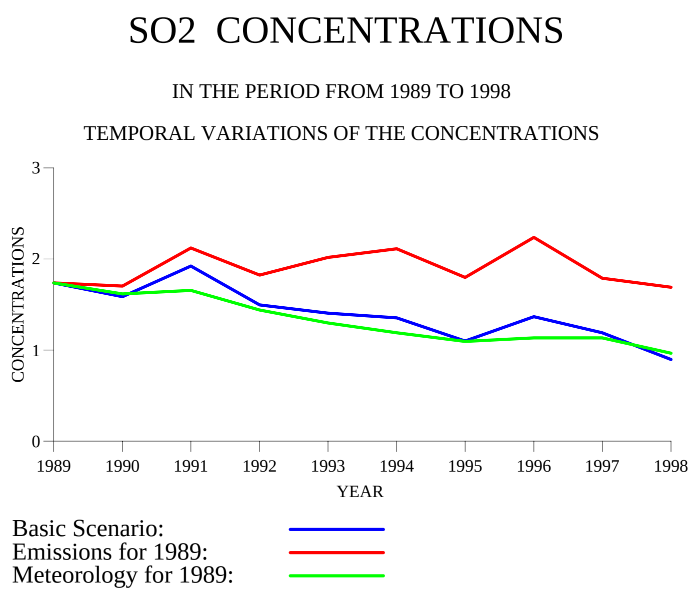

Figure 4.a
Averaged (over the Danish cells) annual means of SO_2 concentrations. The units are ppb.

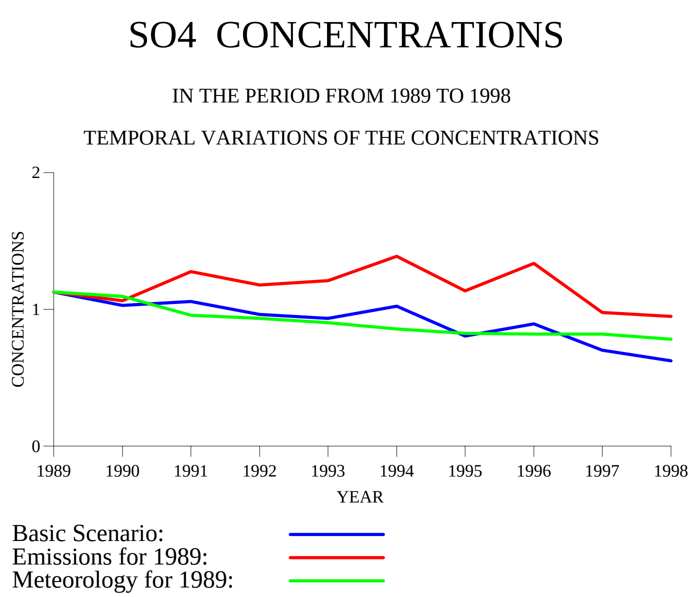

Figure 4.b
Averaged (over the Danish cells) annual means of $SO_4^=$ concentrations. The units are ppb.

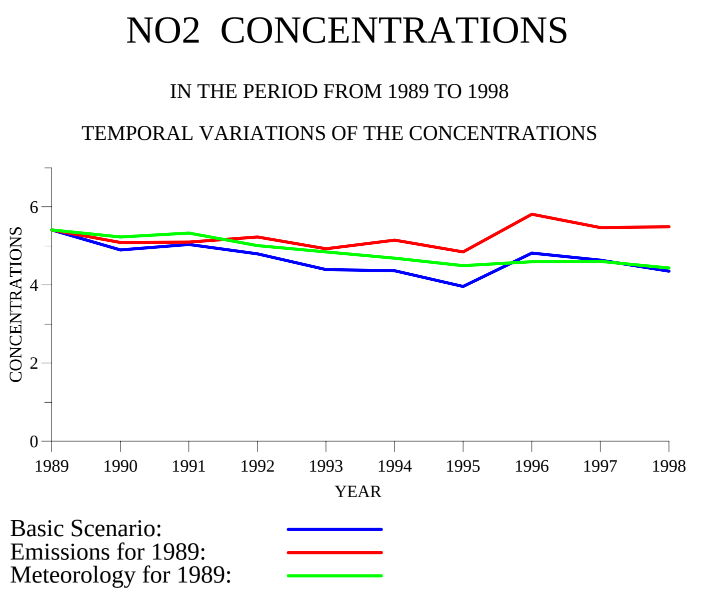

Figure 4.c

Averaged (over the Danish cells) annual means of NO_2 concentrations. The units are ppb.

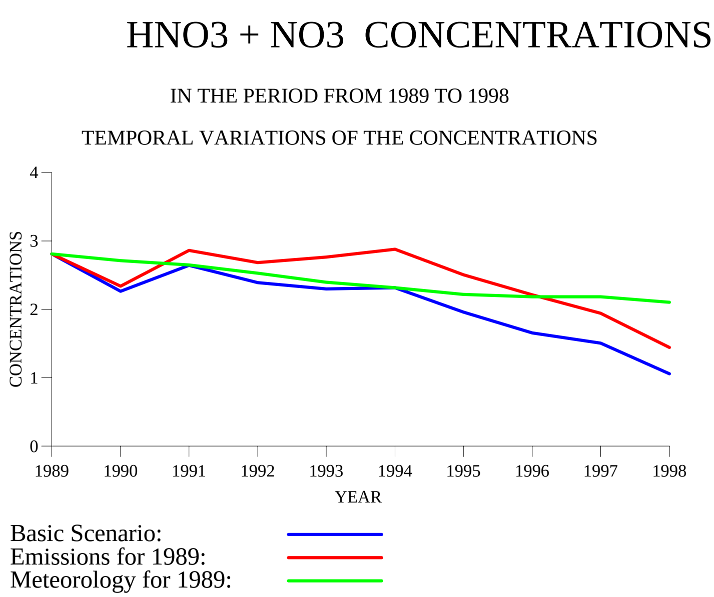

Figure 4.d

Averaged (over the Danish cells) annual means of $HNO3_3 + NO_3^-$ concentrations. The units are ppb.

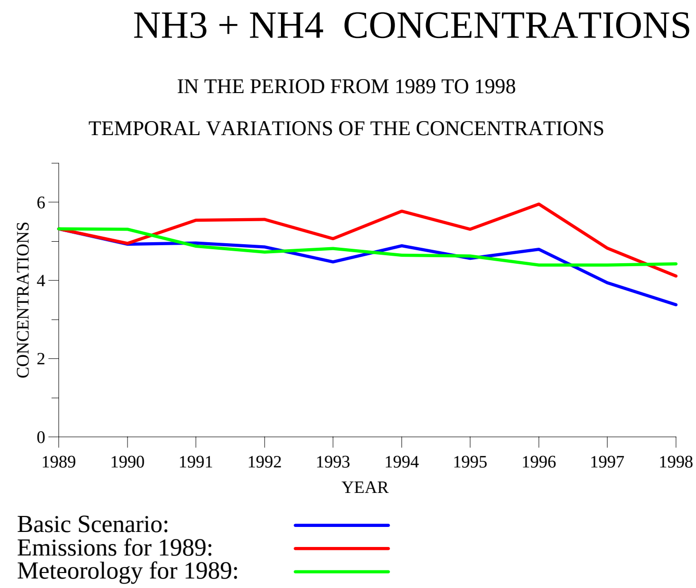

Figure 4.e

Averaged (over the Danish cells) annual means of $NH_3 + NH4^+$ concentrations. The units are ppb.

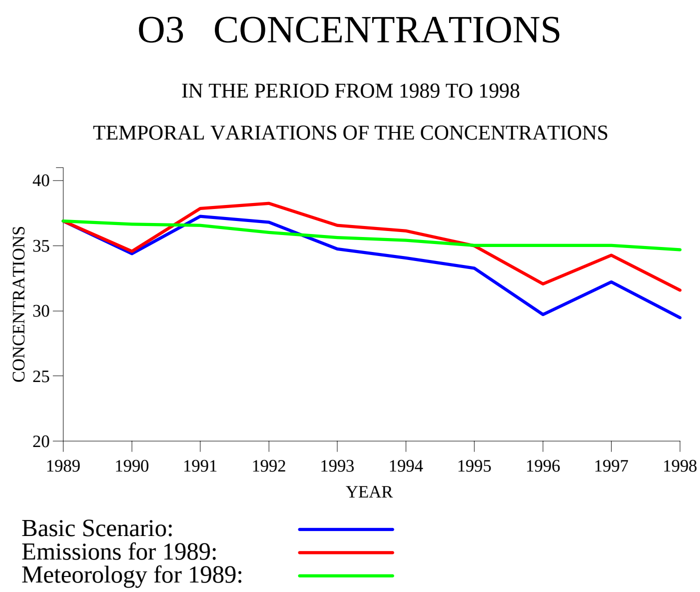

Figure 4.f

Averaged (over the Danish cells) annual means of $O3_3$ concentrations. The units are ppb.

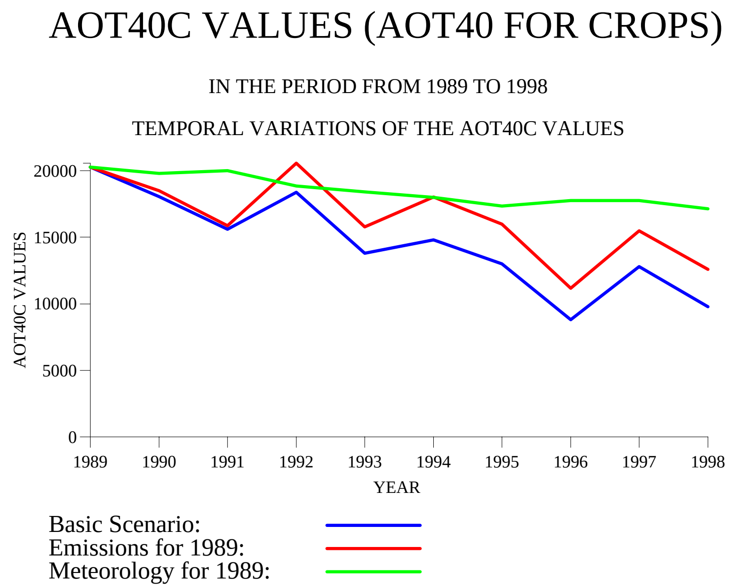

Figure 4.g

AOT40C (AOT40 for crops) values for 3 scenarios. The units are ppb.hours.

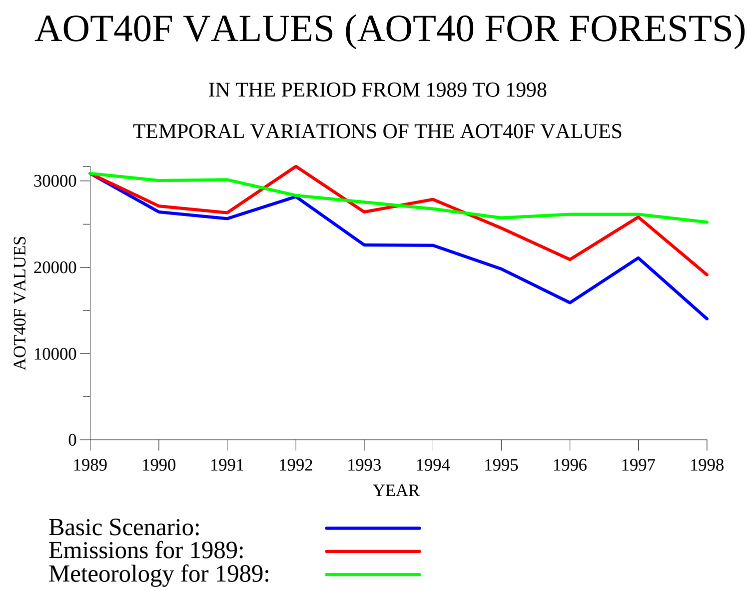

Figure 4.h

AOT40F (AOT40 for forest trees) values for three scenarios. The units are ppb.hours.

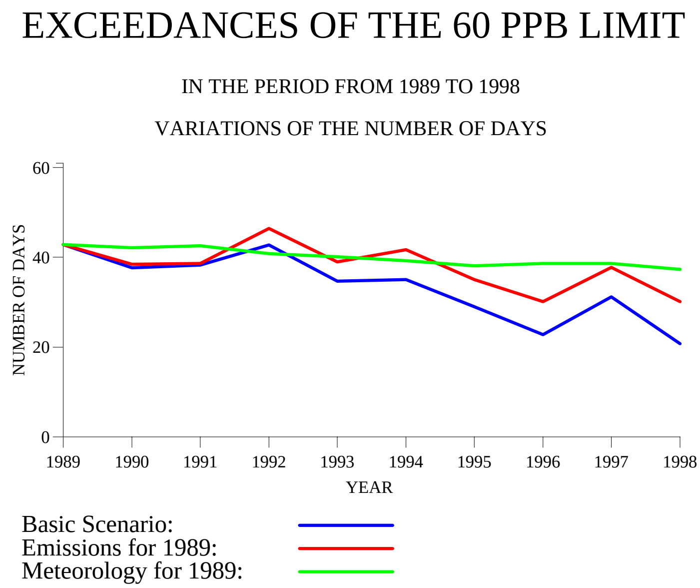

Figure 4.i

Comparison of numbers of days in which the 8-hour averaged ozone concentrations exceed at least once the limit of 60 ppb. The units are days.

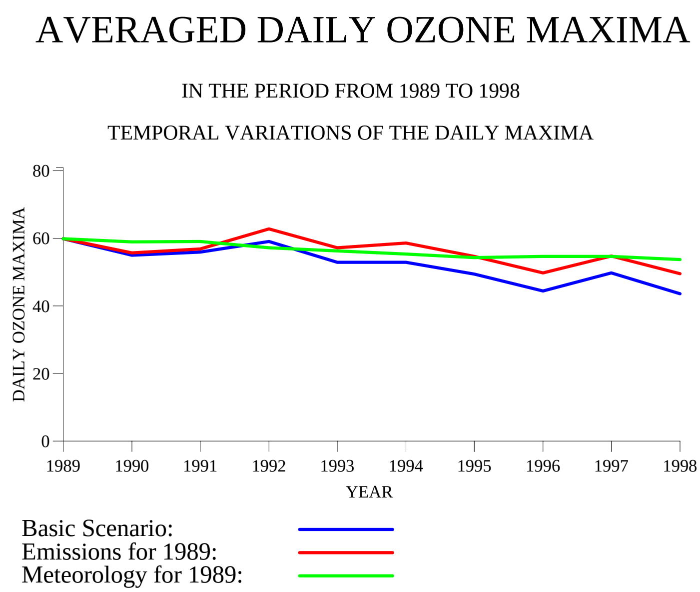

Figure 4.j

Averaged daily maxima of ozone concentrations for three scenarios. The units are ppb.

We shall first compare the variation of the mean Danish concentrations of major pollutants (averaged over the Danish cells of the grid) for the three climatic scenarios with the variation obtained when the Basic Scenario is used. After that we shall consider the changes of some quantities related to ozone levels for the whole of Europe. In the first case we shall consider the period of ten years as in the previous sections, while results for a representative year (year 1997) will be compared in the second case.

5.1. Temporal variations of the concentrations

The results obtained when the three climatic scenarios were run for ten hypothetical years, each of them corresponding to one year in the period 1989-1998 (see Section 2), are compared with the corresponding results obtained by using the Basic Scenario in Fig. 5 for the same compounds as those used in the previous two sections. The following major conclusions can be drawn from this comparison.

- The results obtained by the three climatic scenarios are very similar to these obtained by the Basic Scenario. For some pollutants, as for example SO_2 it is very difficult to distinguish the different curves. The differences are slightly more considerable for ozone, but also here the changes are with a few percent only.
- The the annual Danish ozone concentrations are reduced when the three climatic scenarios are used (see Fig. 5.f). The reductions, are rather small.
- The quantities related to high ozone concentrations are slightly increased when the climatic scenarios are used (see Fig. 5.g - Fig. 5.j). In the next sub-section we shall show that the increase of these quantities when the climatic scenarios are used is rather in some parts of Europe.

5.2. Changes in other parts of Europe

Changes in Denmark were studied until now. It is also interesting to investigate the changes in other parts of Europe. High ozone levels can cause damages to plants, animals and human health when these exceed certain critical levels. Therefore, we shall concentrate our attention to the quantities related to high ozone levels. We choose again the quantities studied in the previous sections: (i) AOT40C values (causing damages to crops when the critical level of

3000 ppb.hours is exceeded), (ii) AOT60F values (causing damages to forest trees when the critical level of 10000 ppb.hours is exceeded), (iii) numbers of days in which the 8-hour average of the ozone concentrations exceeds at least once the critical value of 60 ppb (causing health damages for certain groups of humans) and (iv) averaged daily maxima of ozone concentrations. Some results for 1997, obtained when the Basic Scenario and Climatic Scenario 3 are used, are compared in Fig. 6. In all plots of this figure the relative changes, in percent, of the considered ozone levels are drawn (i.e. at each cell of the grid the result obtained by using the Climatic Scenario 3 is divided by the results obtained by the Basic Scenario and the obtained ratio is multiplied by 100).

It is seen from Fig. 6 that the quantities related to high ozone concentrations are in general increased when Climatic Scenario 3 is used. For some parts of Europe the increases are rather considerable.

5.3. Why are the high ozone levels increased?

It has already been mentioned (§5.1) that while the annual means of the ozone concentrations in Denmark are reduced when the climatic scenarios are used, the quantities related to high ozone concentrations tend to be increased (compare the results given in Fig. 5.f with the corresponding results in Fig. 5.g - Fig. 5.j). For 1997, the increases of the quantities related to high ozone concentrations are rather considerable in some parts of Europe (Fig. 6). This particular behaviour of quantities related to ozone deserves some additional explanation.

In a typical day during summer, the ozone concentration have a maximum during the afternoon and a minimum during the night. The photochemical reactions play an essential role in the production of ozone, while the destruction of ozone takes place when these reactions are deactivated (which happens during the night. If the temperature is higher and the cloud cover is lower, then one should expect more ozone to be produced. This is precisely what should be expected in a typical summer day in the future climate (and, thus, has been taken into account in the determination of the the climate scenarios). The conclusion is that we should expect the climatic scenarios to produce more ozone during daytime in summer, because the photochemical reactions are producing ozone in a higher rate. Some experiments were carried out in order to confirm this conclusion. In Fig. 7.a, we show the averaged diurnal variation of the ozone concentrations at the Danish site Frederiksborg for July 1997. It is seen that during the day the

Climatic Scenario 3 produces more ozone than the Basic Scenario. It is also seen that the patterns of the diurnal variation for the two scenarios are very similar to the pattern of the diurnal variations of the measured concentrations.

The ozone concentrations in summer are higher than the ozone concentrations in winter. This means that the photochemical reactions (which cause production of ozone) are more active in clear summer days, while they do not play an essential role in cloudy winter days. In some such days the photochemical reactions can be fully deactivated. When this happens one cannot anymore observe considerable increase of the ozone concentrations during the day. This is illustrated in Fig. 7.b, where the averaged diurnal variation of the ozone concentrations at the Danish site Frederiksborg for July 1997 is given for the Basic Scenario, the Climatic Scenario 3 and the observations. It is again seen that the patterns of the diurnal variation for the two scenarios are very similar to the pattern of the diurnal variations of the measured concentrations. In this case it is even more important that the ozone concentrations produced by the Basic Scenario are higher than those produced by the Climatic Scenario 3.

The results shown in Fig. 7a - Fig. 7b together with the analysis presented above explain the difference in the behaviour of the annual means of the ozone concentrations and in the behaviour of the quantities related to high ozone concentrations.

6. Conclusions and plans for future work

The results presented in this paper indicate that the annual values of the concentrations of the pollutants will not be influenced strongly by the climate changes. However, the influence of the climate changes on some quantities (AOT40C, AOT40F, days in which the rolling averages of the ozone concentrations exceed at least once the critical limit of 60 ppb and daily maxima of the ozone concentrations) related to high ozone levels is rather considerable. This is important, because recent investigations show that these quantities have damaging effects when certain critical levels are exceeded, see European Commission ([2], [3]) or Zlatev et al. [10].

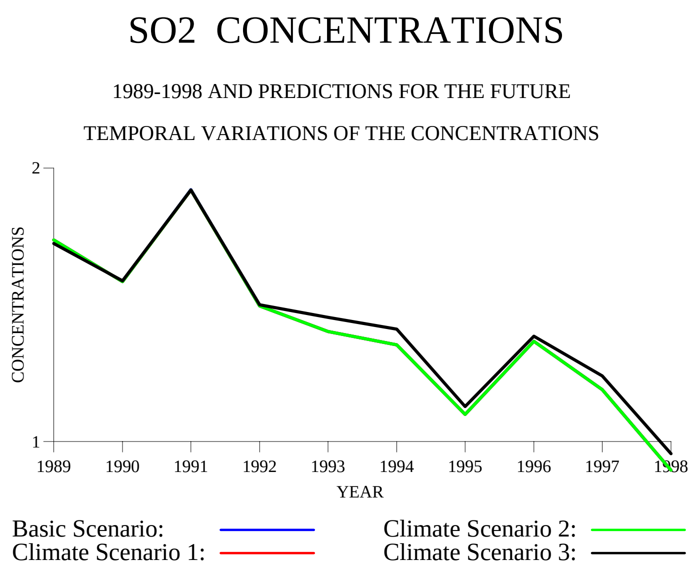

Figure 5.a
Comparison of SO_2 concentrations (climatic scenarios vs the Basic Scenario).
The units are ppb.

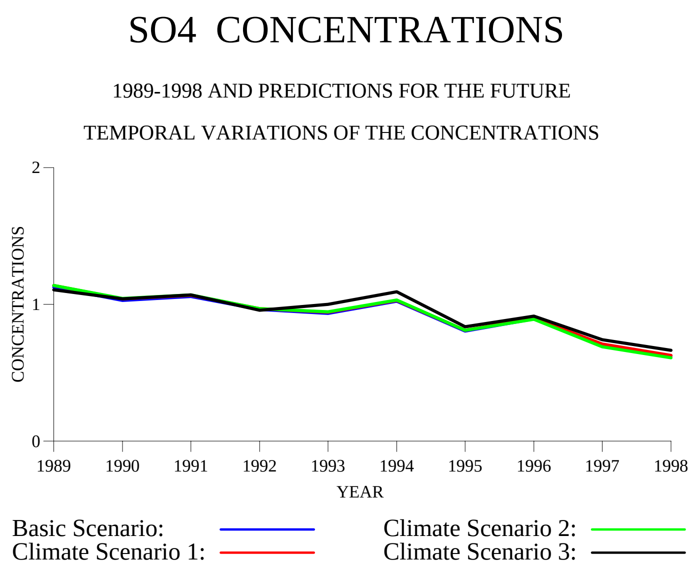

Figure 5.b
Comparison of $SO_4^{=}$ concentrations (climatic scenarios vs the Basic Scenario).
The units are ppb.

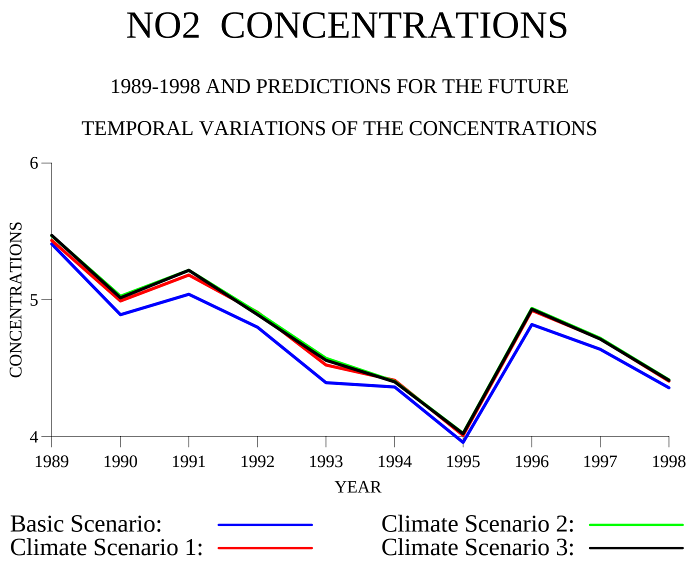

Figure 5.c
Comparison of NO_2 concentrations (climatic scenarios vs the Basic Scenario). The units are ppb.

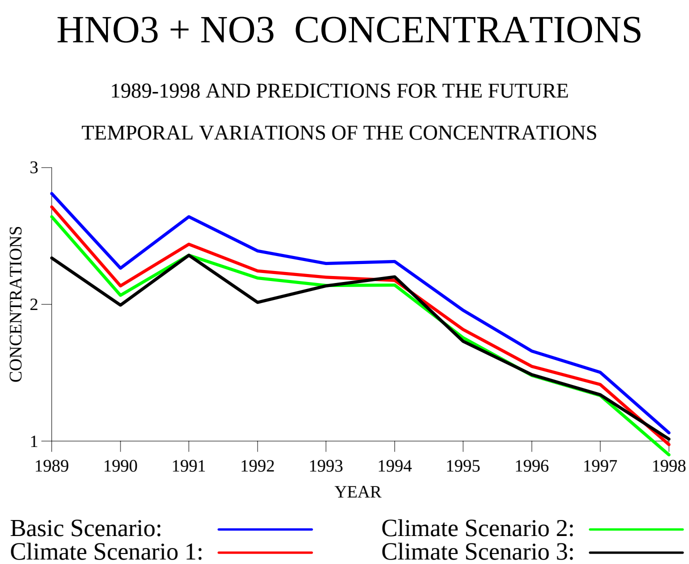

Figure 5.d
Comparison of $HNO_3 + NO_3^-$ concentrations (climatic scenarios vs the Basic Scenario). The units are ppb.

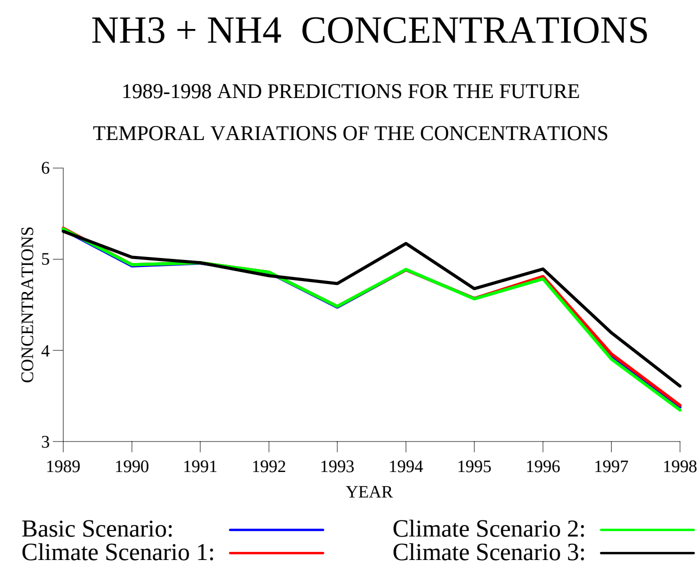

Figure 5.e

Comparison of $NH_3 + NH_4^+$ concentrations (climatic scenarios vs the Basic Scenario). The units are ppb.

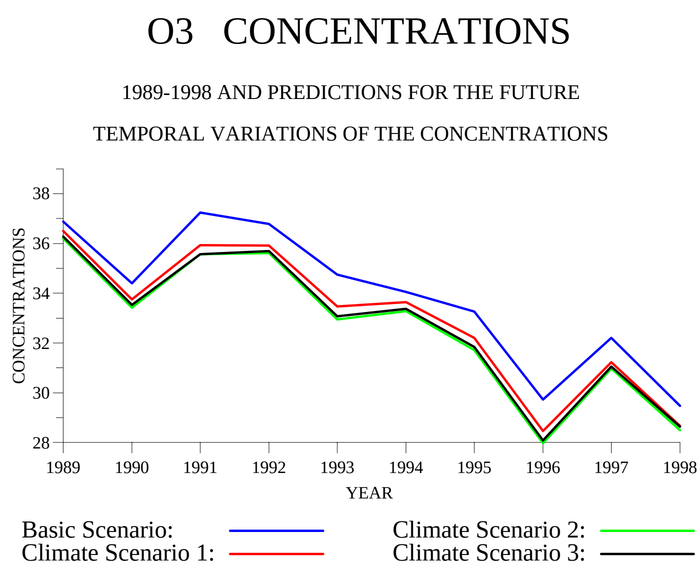

Figure 5.f

Comparison of O_3 concentrations (climatic scenarios vs the Basic Scenario). The units are ppb.

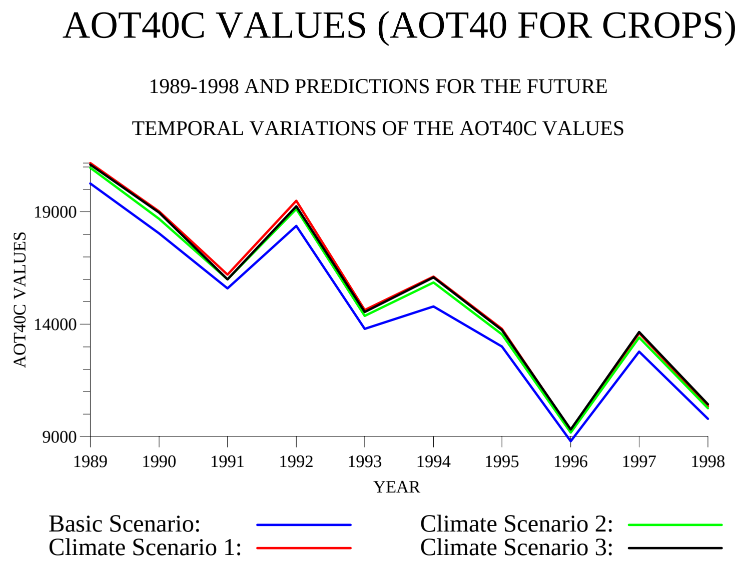

Figure 5.g
AOT40C (AOT40 for crops) values (climatic scenarios vs the Basic Scenario). The units are ppb.hours.

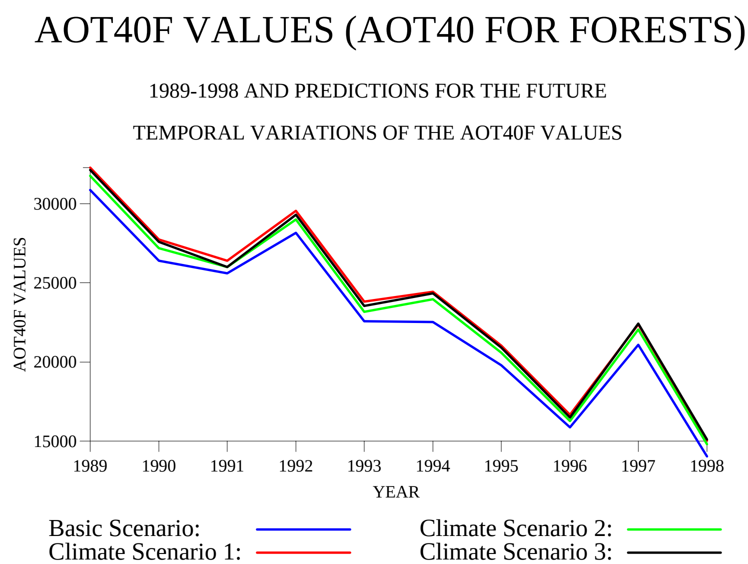

Figure 5.h
AOT40F (AOT40 for forest trees) values (climatic scenarios vs the Basic Scenario). The units are ppb.hours.

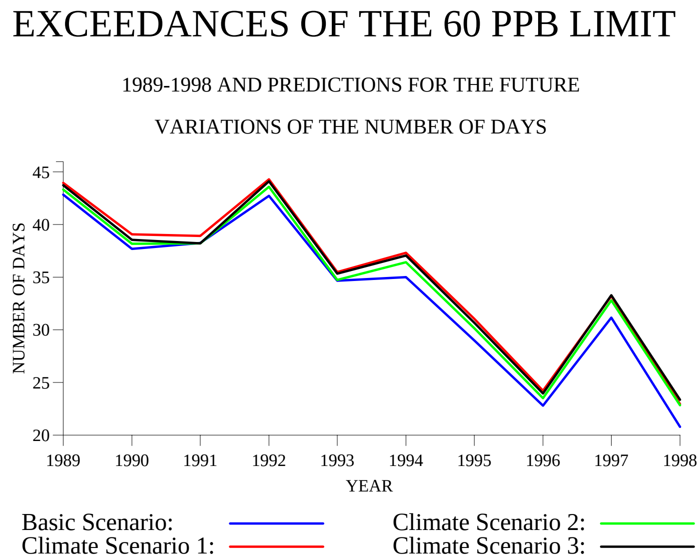

Figure 5.i

Comparison of numbers of days in which the 8-hour averaged ozone concentrations exceed at least once the limit of 60 ppb (climatic scenarios vs the Basic Scenario). The units are days.

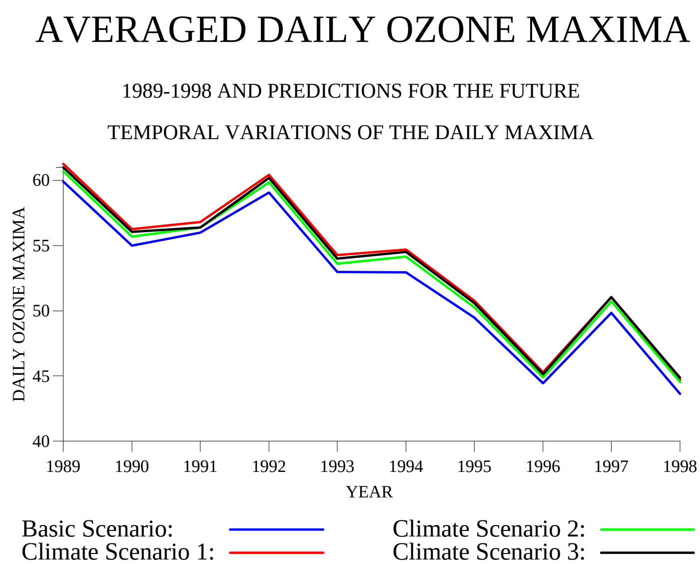

Figure 5.j

Averaged daily maxima of ozone concentrations (climatic scenarios vs the Basic Scenario). The units are ppb.

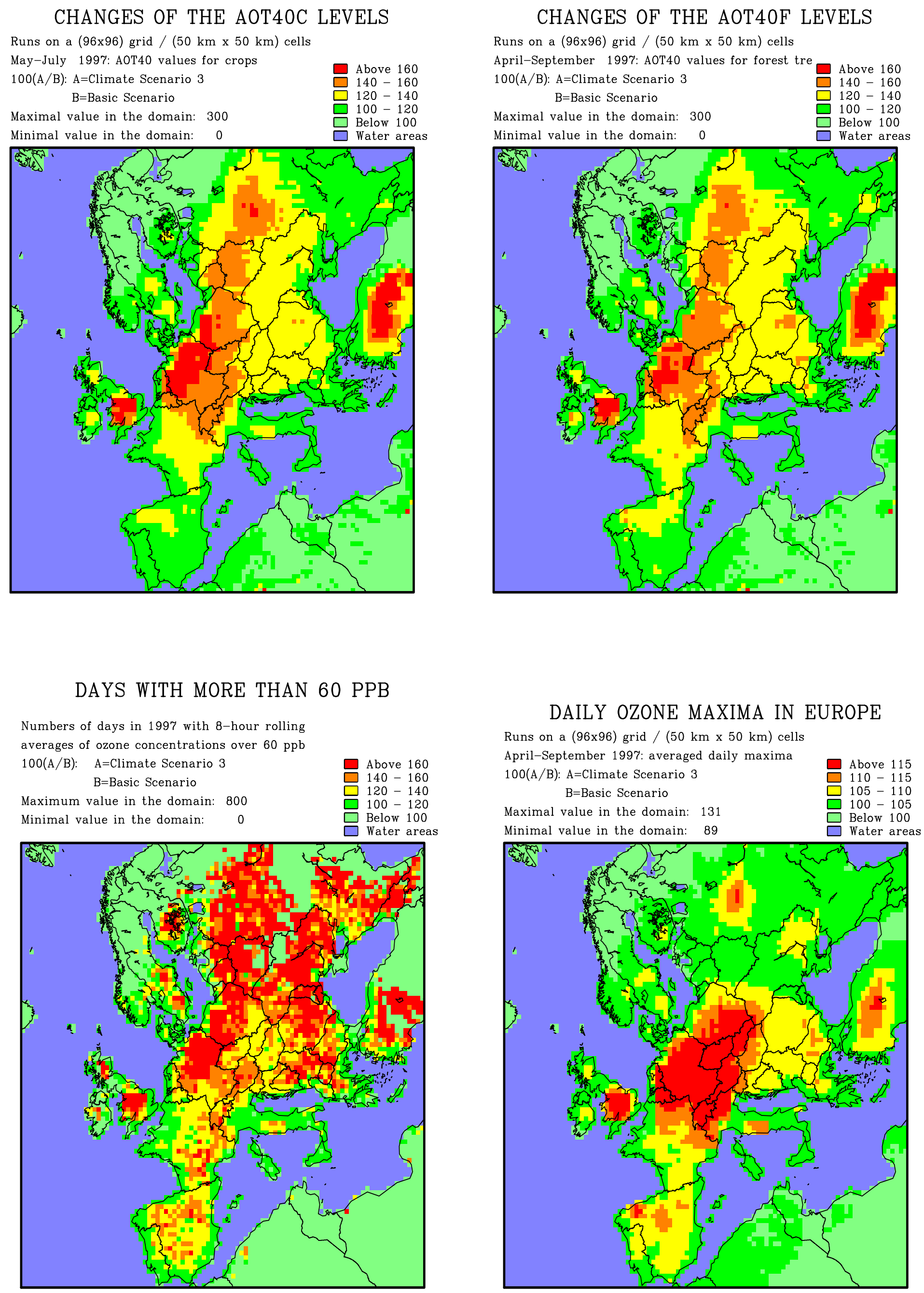

Figure 6

Relative changes (in percent) of quantities related to high ozone levels when Climatic Scenario 3 is used instead of the Basic Scenario.

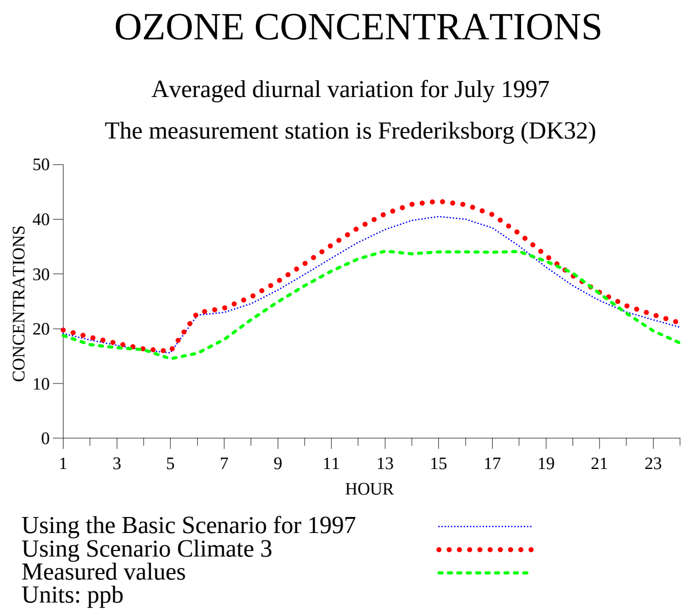

Figure 7.a

Averaged diurnal patterns of the ozone concentrations at Frederiksborg for July 1997.

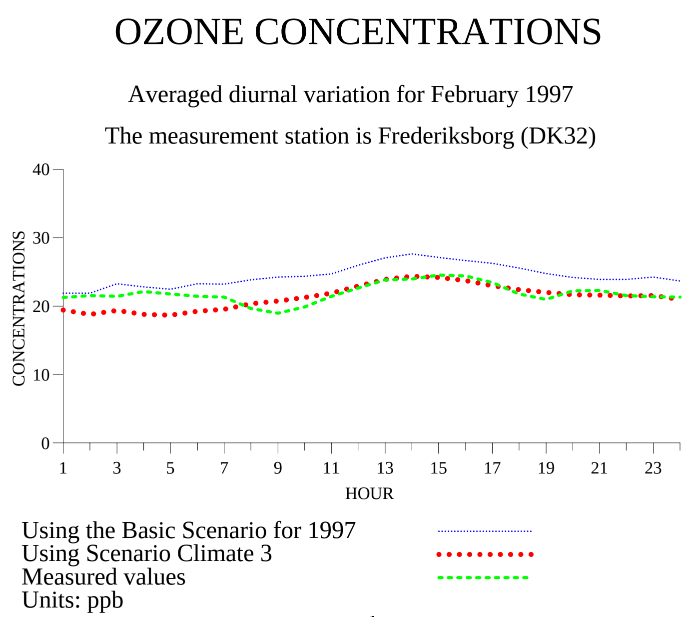

Figure 7.b

Averaged diurnal patterns of the ozone concentrations at Frederiksborg for February 1997.

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