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IMPACT OF CLIMATE CHANGES IN EUROPE ON EUROPEAN POLLUTION LEVELS

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Changes in climate variability and extreme weather and climate events in the 20th century, especially in 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. The following two topics are discussed:

- of the well-known scenarios predicting changes of the climate in the 21st century (taken from Houghton et al., 2001)

and

- the impact of these changes on the pollution levels in different parts of Europe.

1. Predictions for increased temperature levels in Europe

Several scenarios, called SRES, are discussed in (Houghton et al., 2001). We chose to follow the SRES A2 scenario. Resulting from it changes of the temperature in Europe are shown in Fig. 1.

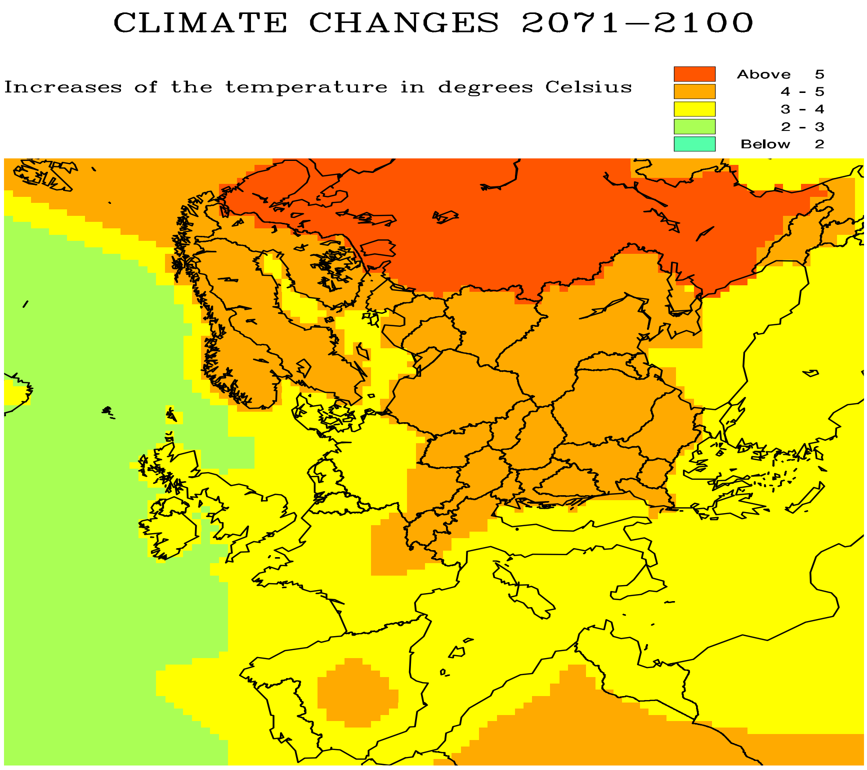

Fig. 1. Changes of the temperature in Europe according to one of the scenarios in Houghton et al. (2001)

2. Choice of scenarios

The Unified Danish Eulerian Model (UNI-DEM), see Dimov et al. (2004), Havasi and Zlatev (2002) and Zlatev(1995), has been run with many scenarios for a period of 16 years (from 1989 to 2004) on a fine resolution grid (10 km x 10 km surface cells) over a space domain covering the whole of Europe together with parts of Asia, Africa and the Atlantic Ocean. A list of the applied scenarios is given in Table 1. All these scenarios were run on powerful parallel computers at the Danish Centre for Scientific Computing. Some of the runs on these computers are discussed in Alexandrov et al. (2004) and Dimov et al. (2004).

The predicted, by the IPCC SRES A2 scenario, annual changes of the temperature, see Fig. 1, were used to produce scenario Climate 1. The extreme cases will become even stronger in the future climate; see Table 9.6 on p. 575 in (Houghton et al., 2001). It is expected that: (i) there will be higher maximum temperatures and more hot days in the land areas, (ii) there will be higher minimum temperatures, fewer cold days and fewer frost days in nearly all land areas and (iii) the diurnal temperature range will be reduced over land areas. These recommendations were taken into account in the preparation of scenario Climate 2.

It is also expected, see Table 9.6 on p. 575 in (Houghton et al., 2001), that: (i) there will be more intense precipitation events and (ii) there will be increased summer drying and associated risk of drought. These recommendations were taken into account in the preparation of scenario Climate 3. Scenarios Constant Meteorology and Constant Emissions were prepared in order to explain the necessity to run the model over a long time-period. The trend of reducing the annual means of the concentrations of most of the studied species in the period 1989-2004 is preserved when the meteorological conditions are kept constant, however, the variability of the concentrations, from one year to another, is lost. The variability of the annual means of the concentrations, from one year to another, is preserved when the emissions are kept constant, but the trend of reduction is lost.

The last six scenarios in Table 1 are emission scenarios. These are mainly used to demonstrate the fact that the relative part of the biogenic emissions is increased and this should be taken into account in large climatic studies.

Only a few results from some of the scenarios (Basic, Climate 1, Climate 2 and Climate 4) will be reported in this paper.

Table 1. Different scenarios run in connection with the climatic studies

Scenario	**Meteorology**	**Anthropogenic emissions**	**Biogenic emissions**
Basic	EMEP and NERI	EMEP and NERI	Basic
Constant meteorology	Meteorology for 1989	as in the Basic Scenario	as in the Basic Scenario
Constant emissions	as in the Basic Scenario	Emissions for 1989	as in the Basic Scenario
Climate 1	Increased temperatures as predicted in SRES A2	as in the Basic Scenario	as in the Basic Scenario
Climate 2	as in Climate 1 + diurnal and seasonal variations	as in the Basic Scenario	as in the Basic Scenario
Climate 3	as in Climate 2 + new humidity and precipitation	as in the Basic Scenario	as in the Basic Scenario
2010	as in the Basic Scenario	Obtained by using IIASA factors; Annan et al. (2001)	as in the Basic Scenario
MFR	as in the Basic Scenario	Obtained by using IIASA factors; Annan et al. (2001)	as in the Basic Scenario
Climate 2010	as in Climate 3	as in Scenario 2010	as in the Basic Scenario
Climate MFR	as in Climate 3	as in Scenario MFR	as in the Basic Scenario
Biogenic 2010	as in Climate 3	as in Scenario 2010	Increased
Biogenic MFR	as in Climate 3	as in Scenario MFR	as in Biogenic 2010

Remarks related to the climatic scenarios given in Table 1:

1. Basic Biogenic emissions are produced by applying ideas proposed in Simpson et al. (1995) and Lübkert and Schöpp (1989); see Geernaert and Zlatev (2004).
2. Increased Biogenic emissions are produced by applying ideas from Anastasi et al. (1991).
3. MFR refers to the IIASA scenario with **Maximum Feasible Reductions** of the anthropoggenic emissions; see Amann at al. (2001).

3. Computational aspects

The performance of the computations, which are related to the scenarios given in Table 1, is a very difficult task. The air pollution model used (UNI-DEM, see Section 1) is described mathematically with a system of partial differential equations. After the application of suitable splitting procedures and the discretization of the spatial derivatives, several huge systems of ordinary differential equations are to be treated at every time-step. Each of these systems of ordinary differential equations consists of more than **eight million equations**. The number of time-steps is greater than 200000. The total number of runs is equal to the product of the number of scenarios and the number of years (i.e. about 200). It is clear that both powerful parallel computers and efficient software, by which the potential power of the available computers can successfully be utilized, are needed. The development of such software is discussed in detail in Alexandrov et al. (2004) and Dimov et al. (2003,2004). Therefore the computational aspects will not be further discussed in this paper. However, it should be emphasized, once again, that it was possible to accomplish the huge task of running the scenarios that are listed in Table 1 **only because** very efficient software was developed and powerful computers were available.

4. Temporal results related to high ozone levels

High ozone levels might cause damages to crops, forest trees and human health. Therefore several critical levels have been established in the European Union, see the Directive 2002/3EC in European Parliament (2002). According to one of these critical levels, the 8-hour average values of the ozone concentrations should not exceed 60 ppb in more than 25 days (called also “bad days in Fig. 2 and Fig. 3).

The temporal variations of the numbers of days in which the limit of 60 ppb is exceeded at least in one period of 8 hours is given in Fig. 2 for the Danish site Ulfborg. It is seen that

- the EU limit of 25 “bad days” is clearly exceeded in the beginning of the interval of 16 years, but gradually the situation is improved (due to the reduction of the European anthropogenic emissions in the 90ies),

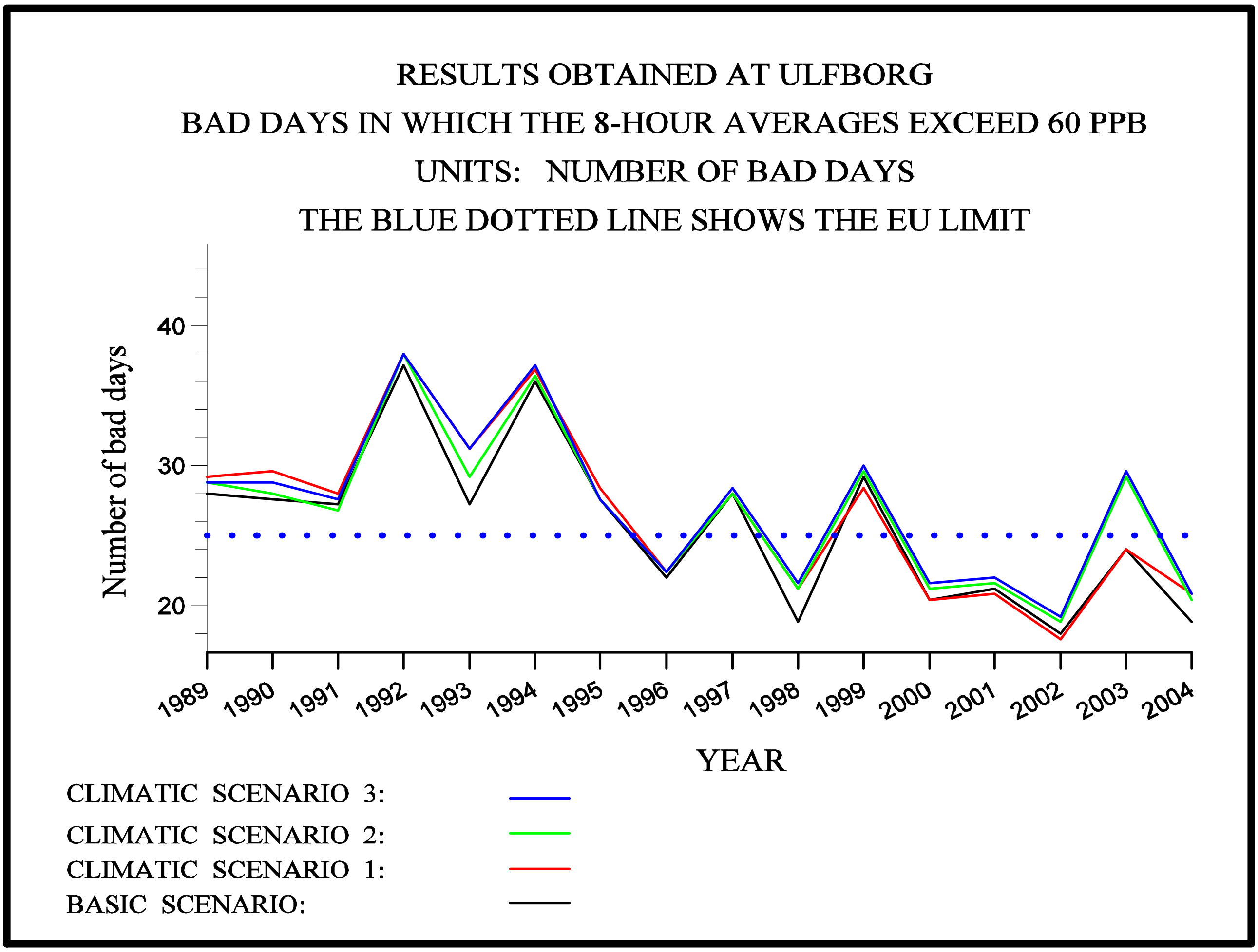

Fig. 2. Variation of the numbers of "bad days" (days in which the 8-hour average values of the ozone concentrations exceeding at least once the critical value of 60 ppb). The EU limit of 25 days is given by the blue dotted line. The resu are for the Basic Scenario and for three climatic scenarios.

- there is a clear annual variability of the number of "bad days",
- at this Danish site, the climatic scenarios are producing more "bad days" than the Basic Scenario (but the difference is not very big).

5. Spatial results related to high ozone levels

Results related to the distribution of the numbers of days in the space domain for year 1997 are given in Fig. 3. It is seen that the following conclusions can be drawn from the results shown in Fig. 3.

- The numbers of "bad days" in a large part of Western Europe are not changed too much (the changes been between 100% and 120%). There are however, some exceptions; mainly in France and Spain.
- Scenario Climate 3 gives biggest increases of the numbers of "bad days" in the regions where the predicted by the SRES A2 scenarios changes of temperatures are also biggest (compare the increases of the temperatures in Fig. 1 and the increases of the numbers of "bad days" in Fig.3).

Conclusions

The main conclusion is that the climatic scenarios are giving significant increase (by more than 60%) of the number of "bad days" in some parts in Europe. This is unfortunate, because the increase of the "bad days" is expected to have damaging effects on human health.

The uncertainties of the results from the computations with the scenarios shown in Table 1 should be carefully analyzed. The uncertainties are mainly due to

- uncertainties in the input data (both the emission data and the meteorological data),
- uncertainties in the description of the physical and chemical processes in the model (the uncertainties of the available descriptions of the chemical reactions being important),
- errors caused by the numerical algorithms and the splitting procedures

and also

- several other sources of uncertainties.

It is necessary to continue this study by taking into consideration:

- other critical levels

and

- the impact of the emission scenarios in Table 1 on the pollution levels.

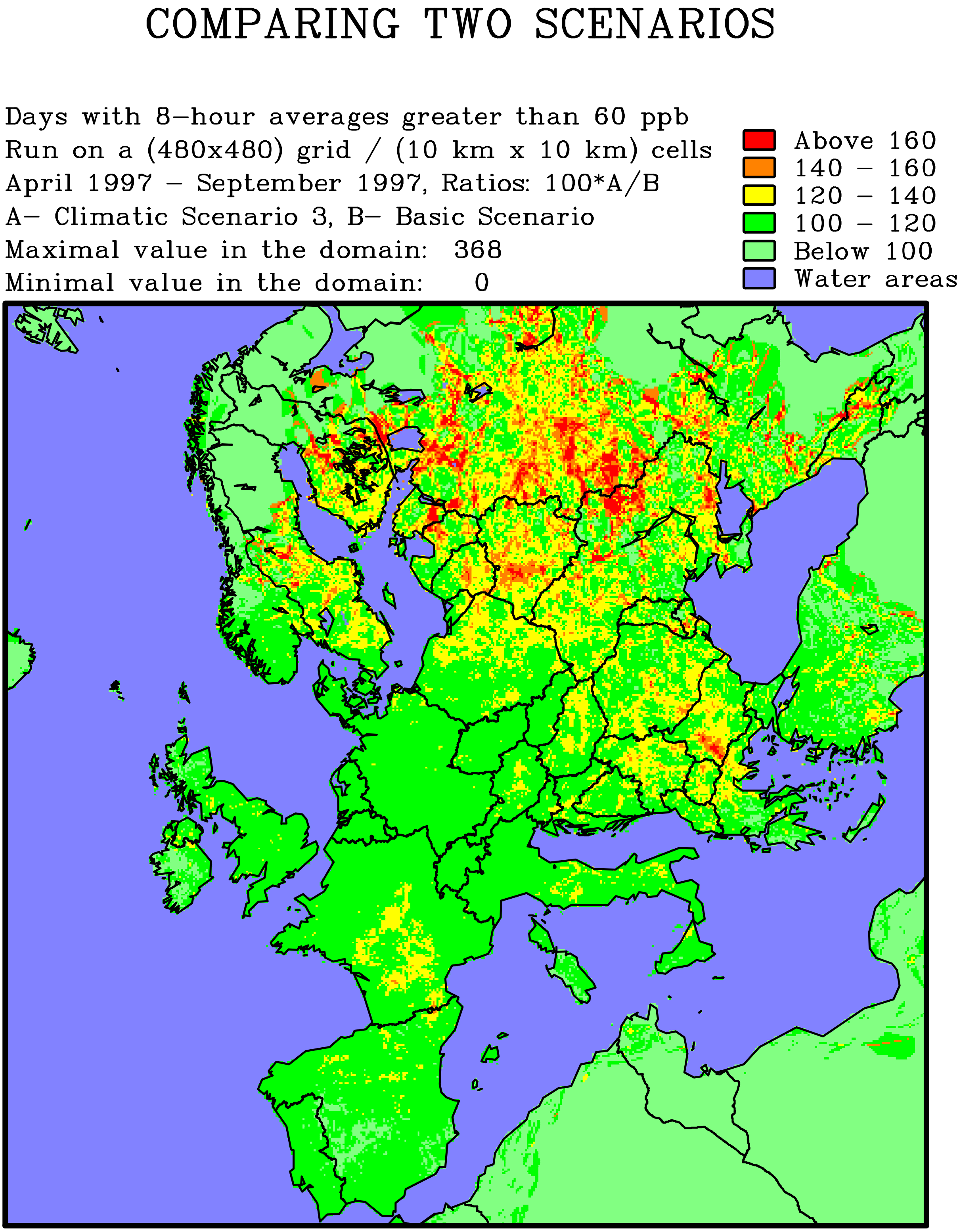

Fig. 3 The distribution of the ratios of numbers of bad days for the scenario Climate 3 and the Basic Scenario for 1997. The numbers are multiplied by 100 in order the get the changes in percent.

Acknowledgement

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