Computers and Mathematics with Applications 65 (2013) 544–562

Contents lists available at SciVerse ScienceDirect

Computers and Mathematics with Applications

journal homepage: www.elsevier.com/locate/camwa

Influence of climatic changes on pollution levels in the Balkan Peninsula

Z. Zlatev [a,*], K. Georgiev [b], I. Dimov [c]

[a] *Department of Environmental Sciences, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark*

[b] *Department of Scientific Computing, Institute of Information and Communication Technologies, Bulgarian Academy of Sciences, Acad. G. Bonchev 25-A, 1113 Sofia, Bulgaria*

[c] *Department of Parallel Algorithms, Institute of Information and Communication Technologies, Bulgarian Academy of Sciences, Acad. G. Bonchev 25-A, 1113 Sofia, Bulgaria*

ARTICLE INFO

Keywords:
Climatic changes
Environmental models
Long-term calculations
Scenarios
Ozone concentrations
Critical levels

ABSTRACT

The aim of the paper is to study the influence of future climatic changes on some high pollution levels that can cause damages on plants, animals and human beings. The particular area of interest is the Balkan Peninsula. Four important quantities have been selected: (a) annual concentrations, (b) AOT40C (high AOT40C values can cause damages on plants and, first and foremost, crops), (c) AOT40F (high AOT40F values can cause damages on forest trees), (d) number of "bad days" (large numbers of "bad days" can cause damage to people suffering from asthmatic diseases).

Critical levels for the quantities from (b), (c) and (d) are legislated by several directives of the European Parliament (see, for example, [European Parliament Directive 2002/3/EC of the European Parliament and the Council of 12 February 2002 relating to ozone in ambient air, Official Journal of the European Communities L67 (2002) 14–30]). We are mainly interested in cases where the prescribed in the directives critical values are exceeded.

An advanced mathematical model was used to run fourteen scenarios over a period of sixteen years. Results, which are obtained in the selected domain, the Balkan Peninsula, with some of these scenarios, are carefully studied. The major conclusion is that the increase of the temperature, alone or in combination with some other factors, leads to rather considerable increases of some pollution levels, which might become dangerous for the environment.

1. Introduction

The gradual increase of the global temperature of the Earth is the most important consequence of future climate changes. Both many of the chemical reactions in which the major pollutants are involved and the biogenic emissions depend on the temperature. Therefore, it is clear that the global warming effect will necessarily cause some changes in the pollution levels. The influence of the increased temperatures on some pollution levels in the Balkan Peninsula is the major topic of this paper. More precisely, we shall be interested in the following three important issues:

(a) the contribution of air pollution from other European countries to the air pollution in the Balkan Peninsula,
(b) the impact of climate change (and, first and foremost, the increased temperature) on the pollution levels in the countries of the selected area
and
(c) the changes of the pollution levels that are due to a *combination* of the warming effect with some other important factors.

* Corresponding author.
E-mail addresses: zz@dmu.dk (Z. Zlatev), krtgeorgiev@gmail.com (K. Georgiev), ivdimov@bas.bg (I. Dimov).

0898-1221/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.camwa.2012.07.006

In connection with (c), it was important to compare the changes of the pollution levels in the studied area that are caused by future increases of the temperature with the changes that are created by several other factors (different emission sources, inter-annual variability of meteorological conditions, etc.). Such an extensive comparison has successfully been accomplished by designing four categories of scenarios:

(1) traditional scenarios,
(2) climatic scenarios,
(3) scenarios with variations of the human-made (anthropogenic) emissions,
(4) scenarios, in which the biogenic emissions were varied.

The mathematical model that was used in the present study, the Unified Danish Eulerian Model, *UNI-DEM*, was run with 14 scenarios. It was necessary to apply a long-time period in order to capture (a) the climatic changes, (b) the inter-annual variations and (c) different trends. A time-period of sixteen years was actually used.

This paper is organized in the following way:

(A) The Unified Danish Eulerian Model (UNI-DEM) is briefly described in Section 2.
(B) The fourteen scenarios that are run with UNI-DEM are sketched in Section 3.
(C) Variations of the concentrations of several pollutants as well as the contribution of European sources on the pollution levels in the Balkan Peninsula are studied in Section 4.
(D) Results obtained in connection with AOT40C values are presented and discussed in Section 5.
(E) Results obtained in connection with AOT40F values are presented and discussed in Section 6.
(F) Results obtained in connection with "bad days" are presented and discussed in Section 7.
(G) General conclusions and remarks are given in the last section.

2. Mathematical description of the unified Danish Eulerian model

The Unified Danish Eulerian model (UNI-DEM) has primarily been developed for studying air pollution levels in the whole of Europe. Different features of this model are fully described in [1–4]. UNI-DEM was extensively used for performing different investigations related to air pollution in

- Bulgaria [5,6],
- Denmark [7,4,8],
- England [9],
- Europe [10–16],
- Hungary [17–19] and
- the North Sea [20].

A previous version of UNI-DEM has also been used in some inter-comparisons of European large-scale air pollution models [21,2].

UNI-DEM is described mathematically by a system of partial differential equations (PDEs). Five important physical processes are taken into account during the derivation of this system: (a) horizontal transport (advection), (b) horizontal diffusion, (c) non-linear chemical reactions plus emissions, (d) dry and wet deposition and (e) vertical transport. The system of PDEs can be written in the following form:

$$\begin{aligned}
\frac{\partial \mathbf{c_i}}{\partial \mathbf{t}} &= -\mathbf{u}\frac{\partial \mathbf{c_i}}{\partial \mathbf{x}} - \mathbf{v}\frac{\partial \mathbf{c_i}}{\partial \mathbf{y}} \quad \text{horizontal transport (advection)} \\
&+ \frac{\partial}{\partial \mathbf{x}}\left(\mathbf{K_x}\frac{\partial \mathbf{c_i}}{\partial \mathbf{x}}\right) + \frac{\partial}{\partial \mathbf{y}}\left(\mathbf{K_y}\frac{\partial \mathbf{c_i}}{\partial \mathbf{y}}\right) \quad \text{horizontal diffusion} \\
&+ \mathbf{Q_i}\left(\mathbf{t}, \mathbf{x}, \mathbf{y}, \mathbf{z}, \mathbf{c}_1, \mathbf{c}_2, \ldots, \mathbf{c}_q\right) + \mathbf{E_i}(\mathbf{t}, \mathbf{x}, \mathbf{y}, \mathbf{z}) \quad \text{chemical reactions + emissions} \\
&+ (\mathbf{k_{1i}} + \mathbf{k_{2i}})\ \mathbf{c_i} \quad \text{dry and wet depositions} \\
&- \mathbf{w}\frac{\partial \mathbf{c_i}}{\partial \mathbf{z}} + \frac{\partial}{\partial \mathbf{z}}\left(\mathbf{K_z}\frac{\partial \mathbf{c_i}}{\partial \mathbf{z}}\right), \quad \text{vertical transport} \\
&\mathbf{i} = \mathbf{1}, \mathbf{2}, \ldots, \mathbf{q} \quad \text{number of equations (chemical species).}
\end{aligned} \tag{1}$$

The different quantities involved in (1) are briefly described below:

- $\mathbf{c_i} = \mathbf{c_i}(\mathbf{t}, \mathbf{x}, \mathbf{y}, \mathbf{z})$ is the concentration of the chemical species **i** at point $(\mathbf{x}, \mathbf{y}, \mathbf{z})$ of the space domain and at time **t** of the time-interval,
- $\mathbf{u} = \mathbf{u}(\mathbf{t}, \mathbf{x}, \mathbf{y}, \mathbf{z})$, $\mathbf{v} = \mathbf{v}(\mathbf{t}, \mathbf{x}, \mathbf{y}, \mathbf{z})$ and $\mathbf{w} = \mathbf{w}(\mathbf{t}, \mathbf{x}, \mathbf{y}, \mathbf{z})$ are wind velocities along the **Ox**, **Oy** and **Oz** directions respectively at the spatial point $(\mathbf{x}, \mathbf{y}, \mathbf{z})$ and time **t**,
- $\mathbf{K_x} = \mathbf{K_x}(\mathbf{t}, \mathbf{x}, \mathbf{y}, \mathbf{z})$, $\mathbf{K_y} = \mathbf{K_y}(\mathbf{t}, \mathbf{x}, \mathbf{y}, \mathbf{z})$ and $\mathbf{K_z} = \mathbf{K_z}(\mathbf{t}, \mathbf{x}, \mathbf{y}, \mathbf{z})$ are diffusivity coefficients at the spatial point $(\mathbf{x}, \mathbf{y}, \mathbf{z})$ and time **t** (it is often assumed that $\mathbf{K_x}$ and $\mathbf{K_y}$ are non-negative constants, while the calculation of $\mathbf{K_z}$ is normally rather complicated),