**GRID COMPUTING FOR MULTI-SCALE ATMOSPHERIC COMPOSITION**

**MODELLING FOR THE BALKAN REGION**

Dimiter E. Syrakov1, Maria Prodanova1, Kostadin G. Ganev2, Nikolai G. Miloshev2,

Emanouil I. Atanasov3, Todor V. Gurov3, and Aneta N. Karaivanova3

1National Institute of Meteorology and Hydrology, Bulgarian Academy of Sciences,

66 Tzarigradsko Chausee, Sofia 1784, Bulgaria

2Geophysical Institute, Bulgarian Academy of Sciences, Acad. G. Bonchev Str.,

Bl.3, Sofia 1113, Bulgaria

3Institute for Parallel Processing, Bulgarian Academy of Sciences, Akad. G. Bonchev str.,

bl. 25A, Sofia 1113, Bulgaria

s

**Abstract**

*Comprehensive atmospheric composition studies require multi-scale numerical experiments to be carried out, which to clarify to some extent different scale processes interaction, but also to further specify requirements for input data (emissions, boundary conditions, large scale forcing). Model interfaces from synoptic trough meso- to local scale have to be tailored. Shortly speaking, extensive sensitivity studies have to be carried out, tailoring the model set-up and parameters – a possible forerunner of single model ensemble forecasts.*

*.........................*

*Some examples of environmental problems which are recently developed / tested / treated as grid applications are given in the present paper.*

**Key words:** *air pollution modelling, US EPA models-3 system, multi-scale modelling, loads, country-to-country pollution exchange, emergency response, grid computing*

**1. INTRODUCTION**

AQ is a key element for the well-being and quality of life of European citizens. According to the World Health Organization (WHO), air pollution severely affects the health of European citizens (WHO, 2004) (between 2.5 and 11% of the total number of annual deaths are due to air pollution (WHO, 2000)). There is considerable concern about impaired and detrimental air quality conditions over many areas in Europe, especially in urbanized areas, in spite of about 30 years of legislation and emission reduction. Current legislation (e.g. ozone daughter directive 2002/3/EC) requires informing the public on Air Quality (AQ), assessing air pollutant concentrations throughout the whole territory of Member States and indicating exceedances of limit and target values, forecasting potential exceedances and assessing possible emergency measures to abate exceedances using modelling tools.

..........................

The quoted above demonstrates very well the very high priority given by the European society and EU legislation and authorities to human health and environmental (in particular AQ) issues. Bulgarian thematic priorities do not differ from the EU ones, so the development of tools and platforms for multi-scale atmospheric composition modelling for the Balkan region certainly corresponds to both Bulgarian and European priorities.

**2. MODELING TOOLS**

All the applications are based on the US EPA Model-3 system, which was chosen as a modelling tool because it appears to be one of the most widely used models with proved simulation abilities. In the same time, this is a modelling tool of large flexibility with a range of options and possibilities to be used for different applications/purposes. Many research groups in Europe already use the Model-3 system or some of its elements and this number is going to increase rapidly.

The system consists of three components:

* MM5 - the 5th generation PSU/NCAR Meso-meteorological Model MM5 (Dudhia, 1993, Grell et al., 1994) used as meteorological pre-processor;
* CMAQ - the Community Multiscale Air Quality System (Byun et al., 1998, Byun and Ching, 1999), being the Chemical Transport Model (CTM) of the system, and
* SMOKE - the Sparse Matrix Operator Kernel Emissions Modelling System (CEP, 2003) – the emission pre-processor of Models-3 system.

Each of these models consists of number of programs that can be run in different schedules depending of the task to be solved. The output of one module is input to others. Taking into account that they had to be run for multiple days it occurred that very complicated LINUX scripts were necessary to be created. The obtained results has been visualized by several graphical packages – GRAPH, GRADS, PAVE, SURFER – supplemented by meta-languages for automation of drawing. All this presumes high experience in Linux and other programming languages.

**3. ABOUT THE GRID PHYLOSOPHY AND TECHNOLOGY**

The Computational Grid, or shortly, the Grid, is a computing environment which enables the unification of widely geographically distributed computing resources into one big (super)-computer (Atanassov et all., 2006, Foster and Kesselmann, 1998). The individual computing resources commonly consist mostly of computer clusters and several individual computers, which are interconnected by a high-speed very wide area network. The Grid is a computer system which is, at this moment, primarily intended for supporting e-Science, however the technology itself is very adaptable to the whole area of present and future computer usage. As the Grid was perceived as a viable solution for supporting e-Science, the modern Grid development was started and is pushed by the scientific community. The major goal of the Grid is to enable the clustering and unification of distributed computing and data processing resources, as to collect as much computing power usable to applications necessitating high computer strength as possible. Some of scientific application examples necessitating the Grid are applications from the fields of particle physics, climate analysis, biomedical research, meteorology etc

**4. SOME EXAMPLES OF AQ GRID APPLICATIONS**

*4.1. Multi-scale atmospheric composition modelling*

4.1.1 Application description and main features

Changes in atmospheric composition directly affect many aspects of life, determining climate, air quality and atmospheric inputs to ecosystems. In turn, these changes affect fundamental necessities for human existence: human health, food production, ecosystem health and water. Atmospheric composition change research is therefore fundamental for the future orientation of national, regional and Europe’s Sustainable Development strategy.

........................



**Fig. 1.** AOT40C values normalized by the threshold of 3000 ppb.hours. for May-July 2000.

Almost the same behaviour of the reciprocal pollution between the three countries can be observed for the other ozone indexes – NOD and ADM.

...................

The country to country pollution exchange can be followed in more details again from the tables. They present the emitter-receiver relations for 4 sub-domains in which the domain of integration is divided: Bulgaria (BG), Romania (RO), Greece (GR) and the other countries in the region (other). The impact of each country’s sulphur and nitrogen emissions to the oxidized sulphur, oxidized and reduced nitrogen wet, dry and total deposition in these countries themselves and in the other countries is clearly demonstrated by Tables 1-7. In the Tables, the shaded elements show the deposition quantity for each country due to its own sources.

**Table 1.**Blame matrix for oxidized sulphur **dry deposition**, May-July 2005, 1000 t(S).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Emitter**  **Receiver** | **BG** | **GR** | **RO** | **other** | **all**  **sources** |
| **BG** | 10.276 | 0.098 | 1.631 | 1.940 | 19.492 |
| **GR** | 2.464 | 2.689 | 0.464 | 3.278 | 5.645 |
| **RO** | 0.812 | 0.014 | 10.980 | 4.991 | 16.325 |
| **other** | 5.941 | 2.845 | 3.252 | 41.275 | 51.485 |
| **deposited** | 19.492 | 5.645 | 16.325 | 51.485 | 92.947 |
| **total emission [S]** | 72.425 | 26.708 | 68.374 | 180.789 | 348.297 |
| **% Rec/Emit** | 26.914 | 21.136 | 23.876 | 28.478 | 26.686 |

...........................

**ACKNOWLEDGEMENTS:**

The present work is supported by EC through 6FP NoE ACCENT (GOCE-CT-2002-500337), IP QUANTIFY (GOGE-003893), SEE-GRID-SCI project, contract № FP7 –RI-211338, COST Action 728, as well as by the Bulgarian National Science Fund (grants № Д002-161/16.12.2008 and Д002-146/2008).

Deep gratitude is due to US EPA, US NCEP and EMEP for providing free-of-charge data and software. Special thanks to the Netherlands Organization for Applied Scientific research (TNO) for providing us with the high-resolution European anthropogenic emission inventory.

**References**

1. Byun, D., Ching, J. (1999) Science Algorithms of the EPA Models-3 Community Multiscale Air Quality (CMAQ) Modeling System. EPA Report 600/R-99/030, Washington DC. <http://www.epa.gov/asmdnerl/models3/doc/science/science.html>.

2. Byun, D., J. Young, G. Gipson, J. Godowitch, F.S. Binkowski, S. Roselle, B. Benjey, J. Pleim, J. Ching, J. Novak, C. Coats, T. Odman, A. Hanna, K. Alapaty, R. Mathur, J. McHenry, U. Shankar, S. Fine, A. Xiu, and C. Jang, (1998) Description of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System, 10th Joint Conference on the Applications of Air Pollution Meteorology with the A&WMA, 11-16 January 1998, Phoenix, Arizona, pp. 264-268.

3. CEP (2003) Sparse Matrix Operator Kernel Emission (SMOKE) Modeling System, University of Carolina, Carolina Environmental Programs, Research Triangle Park, North Carolina.

4. Dudhia, J. (1993) A non-hydrostatic version of the Penn State/NCAR Mesoscale Model: validation tests and simulation of an Atlantic cyclone and cold front. Mon. Wea. Rev. **121**, pp.1493-1513.

5. EC (1998) Amended draft of the daughter directive for ozone, Directorate XI – Environment, Nuclear Safety and Civil Protection, European Commission, Brussels.

6. EC (1999) Ozone position paper, Directorate XI – Environment, Nuclear Safety and Civil Protection, European Commission, Brussels.

7. Ganev K., Prodanova M., Syrakov D. and Miloshev N , (2008a): Air pollution transport in the Balkan region and country-to-country pollution exchange between Romania, Bulgaria and Greece, Ecological Modelling, 217, pp. 255–269

8. Ganev K., Miloshev N., Prodanova M., Syrakov D. and Slavov K. (2008b): Sencitivity analysis of MM5/CMAQ modeling system for ozone formation in Southeast Europe, 17 th International Symposium ECOLOGY & SAFETY**,** June 9 - 13, 2008, Sunny Beach resort

9. Grell, G.A., Dudhia J., and Stauffer D.R. (1994) A description of the Fifth Generation Penn State/NCAR Mesoscale Model (MM5). NCAR Technical Note, NCAR TN-398-STR, 138 pp.

19. Luhar, A. K. (2002): The influence of vertical wind direction shear on dispersion in the convective boundary layer, and its incorporation in coastal fumigation models, Boundary-Layer Meteorology, 102, pp. 1–38

11. Luhar, A. K. and Young, S. A. (2002) Dispersion moments of fumigating plumes-LIDAR estimates and model simulations. Boundary-Layer Meteorology, 104 (3), pp. 411–444.

12. NRC (2005): Tracking and Predicting the Atmospheric Dispersion of Hazardous Material Releases, National Research Council of the National Academies, Committee on the Atmospheric Dispersion of Hazardous Material Releases, The National Academies Press (2005)

13. Palau, J., Perez-Landa, G., Melia, J., Segarra, D. and Millan, M. (2005) A study of dispersion in complex terrain under winter conditions using high-resolution mesoscale and Lagrangian particle models, Atmospheric Chemistry and Physics Discussion, 5, pp. 11965–12030.

14. Prodanova M., Pérez J., Syrakov D., San José R., Ganev K. and Miloshev N. (2006a) Exchange of Ozone Pollution between Romania, Bulgaria and Greece, Proc of the 26th ITM on Air Pollution Modelling and Applications, May 13-19, 2006, Leipzig, Germany, pp. 436-437.