INTERACTION OF AIR POLLUTION TRANSPORT SCALES – OUTLINES OF STUDIES IN BULGARIA

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Abstract. The smaller scale processes impact on larger scale air pollution patterns is a problem still far from being solved. The problem becomes even more difficult, but also more important in regions with complex terrain, like Bulgaria. That is why quite extensive studies on the subject had been carried out in our country. A brief review of these studies and some generalization of the conclusions made is the subject of the present work.

Key words: air pollution, atmospheric dynamics, transport scales, nesting, telescopic approach, mesoscale effects

Introduction

Speaking of "transport scales", obviously one has in mind a set of dynamic processes which are typical for the given scale and largely determine the respective air pollution patterns. In reality, of course, the air pollution in a given point is subject of the joint impact of all the scales, which interact in a complex way.

Traditionally the impact of larger transport scales on smaller ones is accounted for by treating the larger scale pollution pattern as a background on which smaller scale transport and transformation processes develop the air pollution details. This seems to be a fruitful and generally accepted approach.

The smaller scale processes impact on larger scale air pollution patterns, however, is a problem less studied and still far from being solved. The problem becomes even more difficult, but also more important in regions with complex terrain, like Bulgaria. That is why quite extensive studies on the subject had been carried out in our country. A brief review of these studies and some generalization of the conclusions made is the subject of the present work.

Brief description of the applied models

The studies were mostly carried out with the IMSM (Integrated Multi-Scale Model) (Ganev K. and E.Syrakov, 1994, Ganev K. and E.Syrakov, 1995, Ganev K., E.Syrakov and E.Georgieva, 1997, Georgieva E. and N.Godev N., 1987, Syrakov E., K.Ganev and N.Godev, 1987, Sirakov E., K.Ganev and N.Godev, 1988, Sirakov E., K.Ganev and N.Godev, 1988, Syrakov E. and K.Ganev, 1989, Syrakov E. et al, 1989, Syrakov E. and K.Ganev, 1993, Syrakov E., K.Ganev, 1994). The model provides an embracing and complex evaluation of the air pollution, accounting for the specific characteristics of the different transport scales (Fig.1).

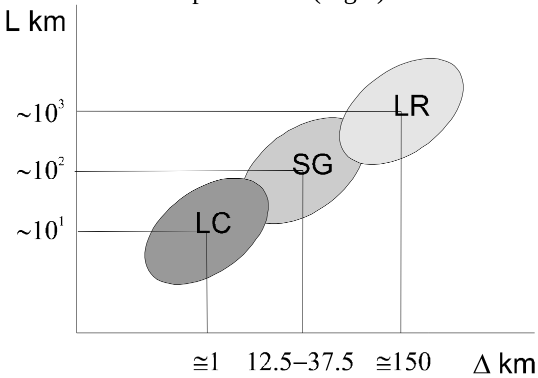

Fig.1. Range of appliance of the IMSM in dependence of the scale of horizontal transport (L) and the corresponding space discretisation Δ used in the present study. (Syrakov E., K. Ganev, 1998)

IMSM incorporates several coordinated air pollution transport models:

- a 3-D Eulerian pollution transport model;

- air pollution mass-balance relations for each of the pollutants in an arbitrary sub-region D_1 of the integration domain D, and for a time period [$0-T$], providing the balance relations between Q - the emission, P - the total quantity in the moment T, P_0 - the initial quantity, P_d - dry deposition, P_g - the pollution quantity which had passed the upper boundary of D_1, P_{wet} - wet deposition (washed-out pollution quantity), P_{out} are the wastes of the given pollutant due to chemical transformations, P_{in} are the influx of the given pollutant due to chemical transformations, F is the pollution quantity which had passed the side boundaries of D_1 ($F>0$ means inflow and $F<0$ means outflow of the pollutant):

- functions of influence problem, concerning ecologically important pollution characteristics of a given "protected" region (see also Ganev K., 1991, Ganev K. 2004)

- "Puff" model and a trajectory model (basic and back-wind trajectories).

In dependence of the transport scale specifics an appropriate combination of dynamics and transport models is chosen and so, according to Fig.1., three basic operational regimes of the IMSM exist - $IMSM_{LC}$, $IMSM_{SG}$, $IMSM_{LR}$:

- $IMSM_{LC}$ describes the pollution transport in the local domain around a given source LC (<20-25 km). It contains a splited-up 3D Eulerian model, which treats the vertical diffusion numerically, and applies a Gausian distribution in horizontal direction. It utilizes a PBL model (stationary or evolutionary) parameterized either in accordance with the resistance laws, accounting for inversions, baroclynicy, terrain slope, or in accordance with the Pasquill-Turner stability classes (for details see Syrakov E., K.Ganev (2002, 2003, 2004));

- $IMSM_{LR}$ describes the pollution transport in the LR area (~10^3km). It treats the above stated set of models numerically. A PBL model parameterized by external aerologo-synoptical parameters is used for the purpose;

- $IMSM_{SG}$ describes intermediate (in respect with the LR and LC scales) sub-grid (SG) effects of pollution in a grid nested (in the present with Δ =37.5km) in the standard EMEP one, with a more detailed emission inventory and accounting of topography effects. A mass-balance diagnostic model (Ganev K., E.Syrakov and E.Georgieva, 1997, Georgieva E. and N.Godev N., 1987, Syrakov E. et al, 1989) is used for the purpose, with a procedure for coordinated surface and aerological data interpolation, especially designed in correspondence of the physical-geographic specifics of the country. A convincing proof of the consistency of this approach is demonstrated in Zerefos et al (1998, 2000, 2004)

A three-dimensional hydrostatic mesoscale model (Ganev K., 1981, Ganev K., 1993,Ganev K. 1996) was also applied in some studies for constructing the meteorological fields in this spatial scale.

Main problems addressed

Local to regional transport of pollution from Thermal Power Plants (TPP)

Accounting for sub-scale pollution effects is especially important for powerful source, located in or close to regions with complex. These effects can lead to significant corrections of the standard long-range pollution characteristics in regions close around the sources, as well as for the integral characteristics of the corresponding cell from the EMEP grid. That is why studying the pollution from the TPP is important from both scientific and applied point of view.

The high and powerful sources from the Maritza-East complex cause significant air pollution, which can be followed in the three transport scales. As it can be seen from climatic evaluations for the biggest source (M-2), obtained by applying the mass-balance approach to the calculated annual pollution roses, obtained in a cylindrical domain with a radius of 25km (Table 1) the predominating part of the pollutants (about 98% for Sulphur and 99% for the Nitrogen compounds) leaves the local domain and thus becomes a subject of the larger transport scales.

20 basic synoptic situations, representative for advective or none-gradient meteorological conditions, typical for the country, were chosen, after extended synoptic and climatic expertise, for studying the interaction of the LR and SG effects. Two different assessments of the pollution characteristics f (concentrations, depositions, acid rain, etc.) are made for the territory of the country (Syrakov E., K. Ganev, 1998):

$$f = f_{LR} \qquad (1)$$

where f_{LR}, accounts for the long range transport only and is calculated by $IMSM_{LR}$, and the assessment specified with accounting for the SG effects:

$$f = f_{LR}^{red} + f_{SG} \qquad (2)$$

where f_{LR}^{red} is obtained like (1), with the only difference that emissions from the considered major TPP are subtracted from the EMEP emissions for the corresponding cells, and f_{SG} is obtained by the $IMSM_{SG}$, with a more detailed topography description, accounting only for the major (excluded from the f_{LR}^{red} simulations) Bulgarian TPP.

Table 1 Annual pollution balance components for M-2 source for a cylindrical region with radius 25km

	Q	P	P_d	P_{out}	P_{in}	P_{wet}	F
NO[t(N)]	4637.0	0.167	0	38330	-34450	0	-755
NO_2[t(N)]	159.2	0.828	2.605	34890	-38380	0	-3652
HNO_3[t(N)]	0.	0.032	1.750	5	-206	8	-192
PAN[t(N)]	0	0.005	0.058	53	-181	0	-128
NO_3[t(N)]	0	0.098	0.302	7	-67	16	-42
SO_2[t(S)]	184100	41.620	866.8	4025	0	2973	-176200
SO_4[t(S)]	6460	2.505	9.860	0	-4025	574	-9897
total S [t]	4797	1.131	4.715	73280	-73280	24	-4768
total N [t]	190600	44.120	876.6	4025	-4025	3547	-186100

On the basis of inter-comparison of f_{LR}^{red} and f_{SG} ,correspondingly of f_{LR} and $f_{LR}^{red} + f_{SG}$, it can be detected the significance of the sub-grid correction to the long range estimations.

It is natural the analysis of the results to start with a discussion of the 24h averaged surface concentrations C (the SO_2 is chosen for demonstrations from the 10 simulated Sulphur and Nitrogen compounds), when (3) obtains the form $C = C_{LR}^{red} + C_{SG}$. The isolines of C_{SG}, together with the C_{LR}^{red} values for the corresponding EMEP cells are shone on Fig.2. The analysis of all the situations, including the demonstrated in Fig. 2., shows that the relation between C_{LR}^{red} and C_{SG} strongly depends on the synoptic conditions, when in most of the situations there are areas in which $C_{SG} >> C_{LR}^{red}$, i.e. the sub-grid corrections are very significant. These areas, usually with radius ~ 50-70 km, around ore shifted from the sources, in which the sub-grid correction is especially significant, can be defined from the condition $C_{SG} \geq C_{LR}^{red}$. Generally speaking the maximal SG-effects can be observed when the wind direction coincides with the line formed by the 4 sources from the Maritza complex, at relatively low or medium wind speed, or blocking local circulation (alternated wind directions, sharp changes in wind speed or direction, etc.), caused by the complex topography influences. The SG effects are smaller at winds with bigger speed and direction perpendicular to the line around which the discussed sources are located, at ventilating canal topography effects, etc.

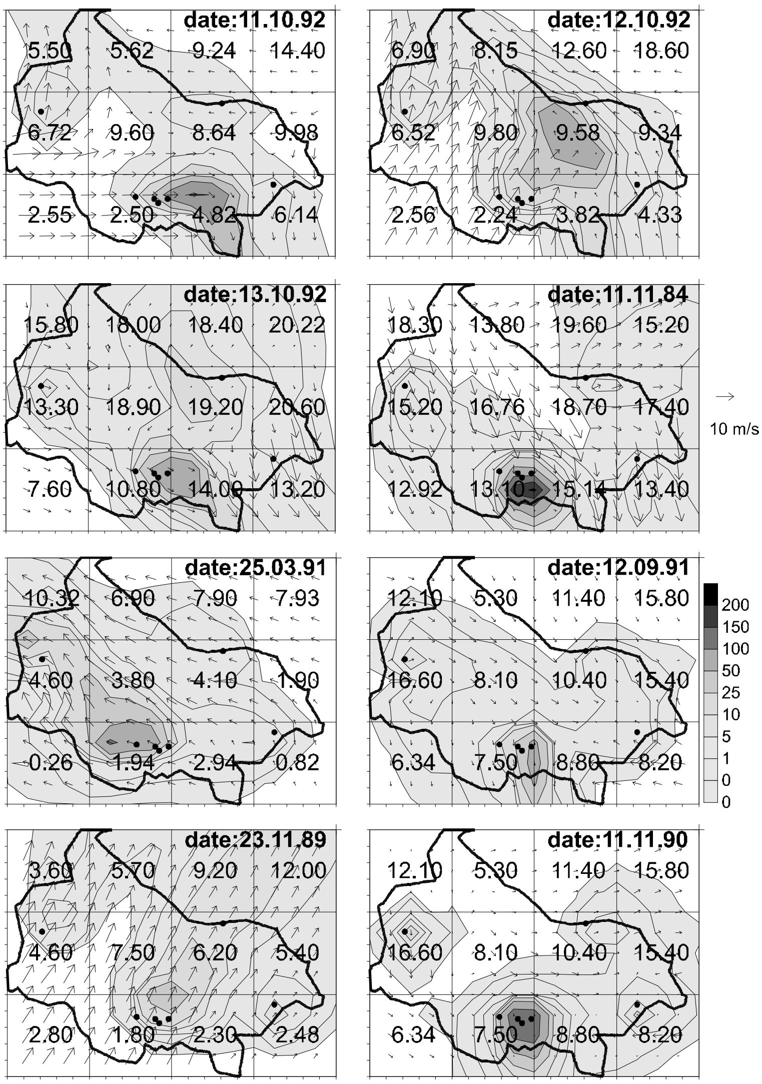

Fig. 2. Isolines of the surface values of C_{SG} (for SO_2) and the values of C_{LR}^{red} (for SO_2) [$\mu g/m^3$] for the corresponding EMEP cells. The cell, which contains the four TPP from the "Maritza" complex is the (33,18) cell from the EMEP grid (Syrakov E., K. Ganev, 1998).

Analogical effects can be followed for all the balance components (Syrakov E., K. Ganev, 1998).

An example for the interaction of local and synoptic transport scales - a case study

The same telescopic approach was applied for numerical simulation and interpretation of the evolution of daily averaged concentrations at Background Station (BS) "Rojen" - (see fig.2.) for the period 07.-13..10.1987. Experimental data for the same characteristics is available (see the Report of the V th IJE) and had been used for comparison and verification of the approach Two different telescopic grids with steps Δ_1 and Δ_2 (mesoscale models MM1 and MM2) are used, and the corresponding mesoscale corrections to the concentrations simulated for the "Rojen" BS were calculated (Syrakov E. et al, 1989, Ganev K., E.Syrakov and E.Georgieva, 1997). The comparison of the simulated vs. measured concentrations decisively demonstrates the importance of accounting for mesoscale dynamic processes for interpretation of the experimental results, even if BS (where it is supposed the pollution to be subject mostly to LR processes) are concerned. Moreover, the study proved that improving the simulation results is not due to the better spatial resolution, but mostly to the better accounting for mesoscale dynamic phenomena by the SG simulations.

Table 2. Some integral air pollution characteristics [tonnes as S] and the corresponding mesoscale corrections [%] (in the parenthesis)

Episodes with larger mean surface SO_2 concentrations for Bulgaria			Episodes with larger mean surface SO_2 concentrations for Northern Greece		
P	Pd	F	P	Pd	F
499(-25)	423(22)	-1500(0)	51.2(-3)	24.4(-14)	-155(-5)
1190(41)	415(21)	-999(-32)	353(57)	99.1(14)	2.7(3805)
738(63)	284(29)	-1300(-31)	638(78)	190(58)	452(116)
349(29)	271(25)	-1710(-5)	203(40)	128(44)	-194(29)
402(40)	237(28)	-1600(-11)	289(57)	103(41)	-88.6(-34)
716(-44)	353(-35)	-1730(34)	197(35)	70.1(0)	39.3(413)
717(32)	528(29)	-1670(7)	130(1)	80.7(-49)	-389(45)
736(67)	474(58)	-1950(2)	334(25)	51.1(-121)	109(48)
704(21)	461(-12)	-1470(-35)	62(48)	90.4(76)	-470(59)
319(34)	259(-1)	-1860(-4)	76.2(18)	36.5(-1)	-156(-14)

An example for the interaction of local and synoptic transport scales - a case study

Another demonstration of this effect is given below. Calculations of the transport of SO_2 from Bulgarian sources over the Balkan Peninsula have been carried out for different synoptic episodes, with and without accounting for the mesoscale dynamic effects (Dimitrova R. and K.Ganev 1999). The simulations proved that the mesoscale disturbances of the wind fields are significant and reflect some typical effects like the tendency of air flow channeling along the Danube river, some blocking by the mountains with cyclone like rotation in the concave regions, etc. The comparison of the orders of the wind velocity and the corresponding differences shows that the mesoscale effects are not only qualitatively but also quantitatively well displayed.

The evaluations of the integral pollution characteristics, made for all the synoptic episodes show that the relative differences can be quite large - sometimes exceeding 100%, and in most of the cases more the 10% for a cell of the standard 150x150 km grid. Even for larger domains - the whole territory of Bulgaria, these differences can be significant - up to 70% for the columnar pollution contents and 35% for the pollution cross-border flows.

The simulations made for cases of especially large mean sulfur concentrations in Bulgaria or Northern Greece (Ganev K. et al, 2003) showed similar effects (see Table 2.).

Conclusions

The following main conclusions can be made from the above brief review:

1.) The importance of the accounting for the SG effects caused by powerful sources in regions with complex topography is convincingly demonstrated.

2.) The proposed relatively simple procedure, which consists of the solution of the long-range transport problem with exclusion of the sources from the studied SG area and in addition a more precise treatment (in a nested grid and accounting for the topography effects) of the pollution from these sources, can be successfully applied for accounting for the SG effects.

3.) For regions with proved significance of the SG effects it may be appropriate the environmental loads also to be treated in a more precise way, according to the approach followed in this work:

4.) In many cases the daily averaged pollution concentrations at a BS over a complex terrain can not be explained by a LRM only, so the measured data may not be representative as a background value, especially if shorter intervals (synoptic episodes) are considered. In such a case mesoscale simulations can be used for making the corresponding corrections and obtaining the real background (representative for the long-range transport) values;

5.) Mesoscale phenomena can really effect the large scale pollution characteristics. For Bulgaria, for which it is known that it’s domestic sources always largely contribute to the country’s pollution, a specification of the order of 30-50% is by all means important. The mesoscale corrections of the pollution characteristics have there signs - depending on the meteorological conditions they may lead to an increase or to a decrease of the estimated values. That is why, if the estimations are made for longer time periods (a month or a year), the mesoscale corrections will be probably much smaller. Nevertheless several day episodes with steady meteorological conditions often occur, and in these cases the mesoscale corrections to the large scale pollution characteristics may be important.

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Взаимодействие на мащаби на пренос на атмосферно замърсяване – преглед на изследванията в България

А.Тодорова, Г.Гаджев

Резюме: Влиянието на процесите с малки мащаби върху замърсяването в по-големи мащаби е проблем, който все още не е решен. Задачата става дори по – трудна, но също така и много по - важна в райони със сложен терен като България. Поради тази причина в нашата страна са направени доста мащабни изследвания по тази тема. Цел на настоящата работа е да направи кратък преглед на тези изследвания и някои обобщаващи заключения.