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EDITORIAL

Dear EURASAP members,

In 2006 EURASAP will support the ICUC6 in Göteborg, Sweden
and the 28th NATO/CCMS ITM in Leipzig, Germany.

EURASAP will considers continuing to edit the newsletter in 2006. We must admit though, that the wide use of electronic means for communication has led to a rise of price for mailing services. So we kindly invite you to answer the question: "Do you wish to have in future the paper copy of the EURASAP Newsletter in your hands?" to the e-mail address: Ekaterina.Batchvarova@eurasap.org with confirmation of your present mailing address

In this issue you will find papers based on bilateral collaboration and an EU FP5 project. The bilateral projects are often covering only meetings and as such not favourite for management, but they are extremely stimulating for scientists.

The Newsletter Editor

Scientists' Contributions

COMPARATIVE ASSESSMENT OF THE ATMOSPHERIC BETA RADIOACTIVITY IN FINLAND AND BULGARIA

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ABSTRACT

In Bulgaria and Finland the national networks for air radioactivity monitoring are developed in the frame of Meteorological Institutes, NIMH and FMI, giving the opportunity to take into account the influence of the atmospheric processes and parameters on the radioactive substances concentration and deposition. Some of the approaches and methods in the measurements of the atmospheric radioactivity are common. There are data records available for many years, since 1959 for Sofia and since 1960 for Finnish stations for beta radioactivity of the air particulate and deposition measured 120 hours after sampling. The contamination due to the global fallout from the nuclear tests depends both on site specific meteorological conditions, like precipitation, and on site latitude. In the present paper high correlation between Finnish stations and Sofia for mean monthly values of the 120h aerosol beta is discussed.

INTRODUCTION

The radioactivity in the atmosphere is formed from different natural sources and since the 40's of the XX century from man made sources as a consequence mainly of development of the nuclear energy and nuclear weapons.

The main natural source in the surface air layer is the diffused from the soil Radon isotopes (^{222}Rn, ^{220}Rn and much less ^{219}Rn) and their daughters usually attached to the atmospheric aerosol. Their concentration is usually in order of part of Bq to several Bq/m^3. The other group is called cosmogenic radionuclides formed in atmosphere in nuclear reactions of cosmic rays with atoms of atmospheric gases – ^{7}Be, ^{3}H, ^{14}C etc. with concentrations of order of 10^{-2}~10^{-4}Bq/m^3. It is possible to detect also natural radionuclides from ^{238}U and ^{232}Th series coming to the air by resuspension of soil material with a concentration of <~10^{-6}Bq/m3.

The main source of global contamination with technogenic radionuclides, the prevailing part of which are beta emitters, has been the testing of nuclear weapons in the atmosphere. The most of the tests performed by USA and USSR were in the last half of the fifties and the beginning of 60's. After a moratorium on atmospheric tests explosions France and Chine continue to make nuclear tests during the sixties and seventies. The last atmospheric nuclear explosion was carried out by China on 16.10.1980. According to UNSCEAR (1988) during the period 1945-1980 the total number of atmospheric nuclear tests is 423. Based on more recent information the number is increased up to almost 500, (Geoscience Australia, 2005). In late fifties of XX century when the nuclear tests in the atmosphere lead to contamination of the global fallout with the radioactive decay products the networks of atmospheric radioactivity monitoring have been developed in different countries the global fallout with the radioactive decay products the networks of atmospheric radioactivity monitoring have been developed in different countries. During and after the Chernobyl accidents such networks proved their capabilities and necessity successfully estimating the level of radioactive pollution.

MATERIALS AND METHODS

At Bulgarian Hydro meteorological service (NIMH) the measurements of atmospheric radioactivity started in Sofia in 1958. The aerosol and precipitation gross beta activity is measured initially 72 hours and since 1965, 120 hours after sampling. During the years the network of monitoring of atmospheric radioactivity in precipitation and fallout is developed and in 1962 additional 4 stations for monitoring of the gross beta activity in daily precipitation were put in operation. Since 1969 a network is enlarged to 18 - 35 stations for daily fallout collection, 5 daily aerosol stations and up to 20 monthly fallout stations.

The aerosol samples are collected on filters (paper, FPP, Synpor) by pumps at 2m high above the grass surface. Air volume is measured by flow meter. The samples are changed every day at 6:00 GMT (8:00 Local Standard Time). The volume of the samples is changed during the years from 10-15 m^3 in the beginning to 100-120m^3. The radiometric devices changed also - GM-counters (1958-1961), then bell-shaped proportional counters and since the beginning of 80-s - plastic scintilators. The callibration sources change from ^{40}K (KCl) to $^{90}Sr+^{90}Y$ since 1962, (Manolov and Teneva, 1964). The filters are measured at the 5th minute after sampling for short lived beta activity, due mainly to Radon daughters and after 120 hours (5 days) for long lived beta activity.

The 24 hours precipitation, collected in cylindrical container with the surface area of 0.2-1.0 m2 is also sampled at 6:00 GMT. The container is washed every day with distilled water to avoid influence of dry deposition in dry periods. The aliquot of 0.250l is evaporating slowly in glass beaker to few ml and then transferred to aluminum plate and evaporated to dry residue. Few ml of distilled water are used to wash the beaker, added and evaporated in Al plate. The source is measured usually 3-4 hours after sampling for short lived beta and after 120 hours for man made beta radionuclides and lead-210. The uncertainty due to the radiometry is estimated in the range of 6-7% for periods with higher concentrations up to 50% in case of low activity measurements.

The total (wet+dry) monthly fallout is collected in cylindrical container at high of 1m above ground with a bottom covered with distilled water. The sampling is done on every 1st date of the month. The process of the liquid sample is the same as for the daily precipitation water samples.

The Finnish Meteorological Institute (FMI) began measurements of total beta activity in the air in four stations in 1960's. Daily aerosol samples have been collected with high-volume samplers onto glass fiber filters (Whatman GF/A or Munktell MGA; ∅ 24 cm) in Helsinki, Nurmijärvi, Sodankylä, and Ivalo. The samplers have a capacity of 3500 m^3 per day and they collect particles with an aerodynamic diameter less than 10-15 μm depending on the wind speed (Paatero et al., 1998). The filters are changed daily at 06 UTC. Daily precipitation samples were collected in Helsinki from 1967 and in Ivalo from 1963 up to 2001 with 1 m^2 funnels made of stainless steel (Paatero and Hatakka, 1997). During the winter the funnels were slightly heated in order to melt the deposited snow. In the laboratory 250 ml of the collected water was evaporated to a small volume and absorbed in a Whatman 42 filter.

First all the filters were measured in the laboratory with GM counters, but since 1982 two successive automatic alpha/beta analyzers have been used. They are equipped with five large-area gas flow proportional counters (Mattsson et al., 1996). The total beta activities of the aerosol and precipitation samples were measured five days after the end of sampling, when the short-lived ^{222}Rn progeny had decayed into ^{210}Pb and the ^{220}Rn progeny had decayed into stable lead. The measured total beta activity consists mainly of ^{210}Pb/^{210}Bi and possible artificial beta emitters.

RESULTS AND DISCUSSOIN

Air Concentration in Finnish and Bulgarian stations. The comparison between daily values of aerosol long-lived beta activity for the stations Sofia (42°41´N, 23°20´E), Nurmijarvi (60°30´N, 24°39´E) and Sodankyla (67°22´N, 26°39´E) show that the concentrations measured in Sofia are higher then in Finnish stations with only few exceptions, Veleva&Paatero, 2005. The monthly averaged values in Sofia were several times higher than in Finnish stations Fig.1. The exceptions were observed during December 1966 (Kauranen et al. 1967), December 1969, February 1972 (the activity ratio of Sofia to Helsinki was 0.49, to Sodankyla -0.71 and to Ivalo-0.73), May 1978 and April 1986. During this period December'68 – June'73 several atmospheric nuclear explosions on Lop Nor test site, China were performed.

The period after the summer of 1981 up to April 1986 is characterized by almost free from artificial radionuclides surface air. It is well documented by Paatero et al. (1994) that the measured beta activity consisted mainly of ^{210}Bi and ^{210}Pb in Finland. The same applies to the situation after 1987. The higher level of total beta activity in Sofia compared to Nurmijärvi can be explained by the

continental origin of ^{210}Pb. Bulgaria is surrounded by larger land areas than Finland. The ^{210}Pb concentration in Belgrade, Serbia, during 1985-1996 is in the range 800-1500 µBq/m^3 ,Todorovic et al., 2000.

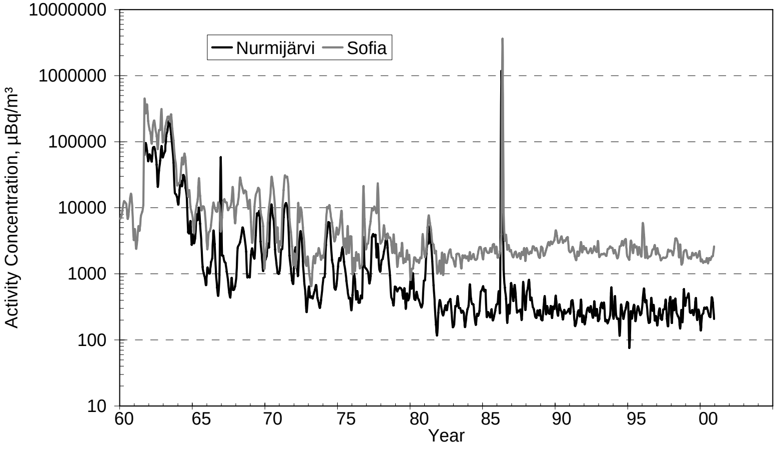

Figure 1. Monthly average concentrations of gross beta radioactivity in µBq/m^3 in Sofia and Nurmijarvi during the period 1961-2000.

Deposition of long lived beta radinuclides in Finland and Bulgaria. The data record of monthly deposited long-lived beta activity for stations Sofia, Helsinki and Ivalo is shown on Fig.2. The correlation coefficient between stations is as high as 0.77 between Sofia and Ivalo and 0.94 for Sofia-Helsinki. The Chernobyl accident caused dispersion and deposition of a number of fission and activation radionuclides: radioactive noble gases (RNG), Iodine, Tellurium, Cesium, Ruthenium, Strontium, actinide and lanthanide radionuclides, in total, excluding RNG, of about 8.10^{18}Bq. Dreicer et al. (1996).

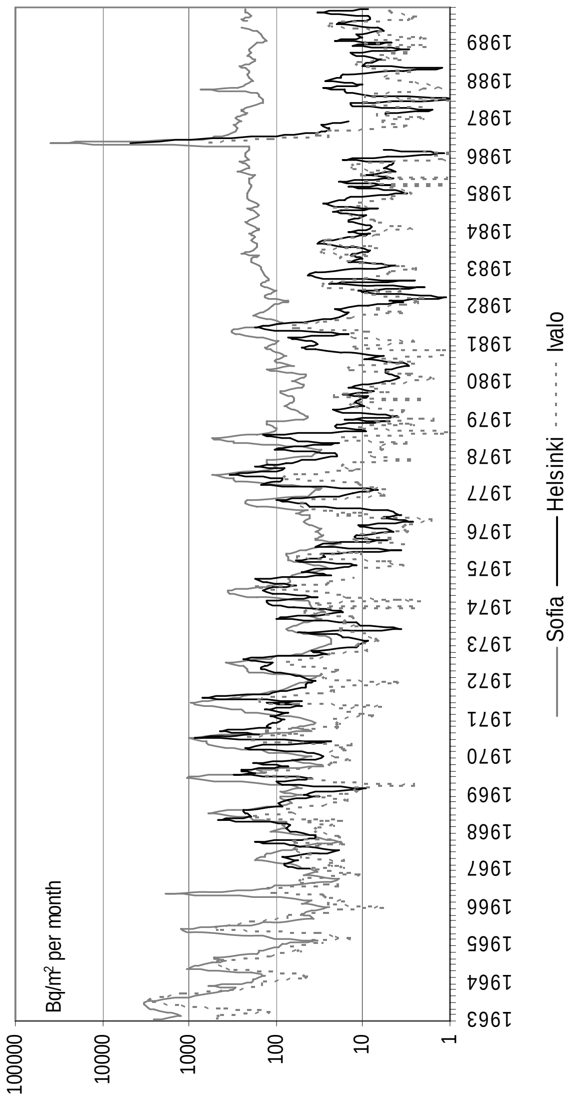

Figure 2. Monthly deposited long-lived beta activity.

The Chernobyl peak in gross beta activity in May'86 is well seen, on Fig. 3 (see next page). The concentrations of long lived beta aerosol rose from background values of about or less than 1 mBq/m^3 to 18 Bq/m^3 in Nurmijarvi, 52.8 Bq/m^3 in Sofia and up to 163 Bq/m^3 in Varna, due to the enrichment of the sample with hot particles. In both countries the fresh contamination with $^{239+240}$Pu, ^{238}Pu and other transuranium radionuclides is registered, Paatero (2000), Veleva et al. (1994).

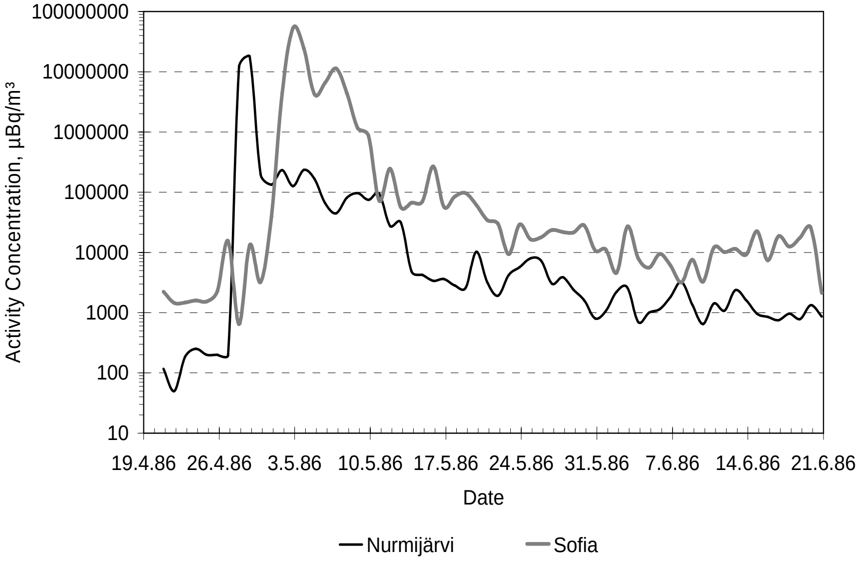

Figure 3. Daily values of long-lived beta activity in aerosol in Sofia and Nurmijarvi during the period of direct Chernobyl fallout

The years with highest annual radioactive fallout were 1962, 1963 and 1986 respectively. The annual sums for some Bulgarian and Finnish stations for the most affected by man made radioactivity years are presented on Table 1 (see next page).

Table 1. Deposited by precipitation long-lived beta activity during the years with highest fallout in kBq/m^2 per year.

Year	Sofia	Karnobat	Kjustendil	Gramada	Helsinki*	Ivalo*
1962	17.5	12.6	14.8	11.1	-	-
1963	28.7	15.8	13.9	10.5	-	9.6
1964	4.5	2.4	3.0	2.8	-	2.3
1986	14.4	15.3	11.1	0.7	6.0	0.8
1993	0.24	0.19	0.34	0.10	0.08	0.05

** For Finnish stations the total monthly deposition is given.*

The cases of global bomb fallout and Chernobyl releases differ not only by mean of how long is the period with air contamination, but also in isotopic mixture of the radioactive cocktail. It is interesting to mention that the region of Sofia the radioactive fallout reach a value of more than 28 kBq/m^2 in 1963 compare to about 14.4 kBq/m^2 in 1986, year of Chernobyl accident. The value for 1986 probably is underestimated because the deposition and precipitation samples are evaporated for pre-concentration of the sample, and during that process lost of volatile radionuclides may occur, ^{131}I for example.

The presented data for gross beta deposition in Bilthoven, Netherlands are 18 kBq/m^2 for year 1986 and 0.08 kBq/m^2 during 1993, RIVM Rep., 2002. The period between sampling and analysis for gross alpha and beta in Netherlands is 5 to 10 days. Year 1993 is given as a representative for the calm and almost free from artificial beta radionuclides atmosphere

CONCLUSION

The historical data records on gross beta radioactivity of the surface air, measured 120 hours after sampling, in Finland and Bulgaria presented here show the long lasting contamination due to the nuclear tests in the atmosphere and prompt and reliable response in case of accidental releases after Chernobyl.

The daily and monthly values of long-lived aerosol beta activity are usually higher in Sofia, than in Finnish stations with few exceptions.

High correlation is observed between monthly average values of long-lived aerosol beta activity proving the reliable work of the atmospheric radioactivity monitoring networks in both countries.

To provide further adequate to the EU requirements monitoring of atmospheric radioactivity it is necessary to develop at NIMH modern methods and equipment for operational sampling and radiometry under the special project in the frame of EU pre-accession funding for Bulgaria.

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THE IMPACT OF URBAN SPRAWL ON AIR QUALITY AND POPULATION EXPOSURE: A CASE STUDY IN THE GERMAN RUHR AREA

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SUMMARY

Compact city forms are associated with minimal consumption of land and energy, hence they are often promoted as being the more sustainable thus preferred mode of urban development. In this context, numerical simulations were performed to evaluate the effect of urban sprawl on air quality and associated human exposure. Working on a highly urbanised area in the German Ruhrgebiet, models dealing with satellite data processing, traffic flows, pollutant emission and atmospheric dispersion were applied, under conditions representative of the urbanised area as it is today.

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A fair agreement was obtained between simulated and observed pollutant concentrations. Subsequently, an urban sprawl scenario was defined and implemented using spatial modelling techniques, relocating 10 % of the urban population to the cities' periphery. The resulting updated land cover and population density maps of the area were then used as input for the traffic and atmospheric dispersion simulations, showing that total traffic kilometres, associated emissions, and domain-average pollutant concentrations increased by approximately 10 to 15 %. However, despite the overall concentration increases, an analysis of human exposure to atmospheric pollution revealed that the urban-sprawl scenario leads to lower rather than higher exposure values in the case of PM_{10}, while for ozone the exposure remains almost unchanged.

1. INTRODUCTION

Cities exert significant pressures on the environment owing to high levels of consumption of resources related to, among other things, car traffic and building heating. The proximity of these activities to people's living space leads to situations with increased risk to human health. European citizens, of whom around three quarters live in urban areas, are increasingly concerned about the quality of their environment. A related problem is that of urban sprawl. Indeed, over the past decades there has been a tendency for people to leave cities to settle in the surrounding greener areas. Not only has this led to a significant loss of natural landscapes, it has also induced an enhanced transport demand.

The work described here investigates the effects of urban sprawl on road traffic and air quality, including human exposure, at the

scale of a large urban area and its surroundings. The specific case studied was one of urban sprawl, which is characterized by people leaving the densely populated central part of the study area to settle in the greener surroundings, and an associated increase in built-up surface at the city edges. The study area consists of a highly urbanised region in the Ruhr area, located in central North Rhine-Westphalia, in the north-western part of Germany, with a total population in excess of 5.5 million.

The remainder of this paper is organised as follows. In Section 2, a description is given of the techniques to map land cover and to model land cover changes. A scenario of so-called 'urban sprawl' is defined, in which a certain fraction of the population is relocated from the densely populated city towards the greener surroundings, with an associated increase in built-up surface at the city edges, thus leading to a less compact city structure. Section 3 describes the traffic simulation methodology, both for the reference (i.e., present) situation as for urban sprawl. Section 4 then describes the methodology to calculate pollutant emissions from the simulated traffic flows. These emissions are subsequently used in a 3-D regional-scale air quality model, simulating ozone and fine particulate matter. In Section 5 simulated pollutant concentrations are used to calculate population exposure to air pollution and the associated damage costs, and Section 6 presents the conclusions.

2. LAND COVER MAPPING AND MODELLING

Land use maps for the current situation were derived from satellite imagery of the Landsat Thematic Mapper (TM) instrument, using the 'stepwise discriminant analysis' image classification technique together with ground truth data. From Figure 1 it can be seen that built-up land use types cover a significant proportion of the study domain.

The geographical distribution of land use is characterised by the concentration of built-up areas along the rivers, together with extensions in the north and a few in the south. Most industrial areas are located in the centre of the district and are embedded in the urban structure. Many of these are now abandoned and are thus considered derelict areas, ready for transformation into new city functions. Apart from the land use characterisation, two other types of geographical information were required, that is, the spatial distribution of population and job density. Both are needed as input for the traffic model; population density is also required in the analysis of human exposure, at a later stage. The spatial distribution of population was obtained from census information, and this information was aggregated to a limited number of zones to suit the requirements of the traffic model. The spatial distribution of jobs was obtained using data provided for a limited number of administrative zones of the area. These data were also processed to be compatible with the traffic zones.

After the establishment of the maps for the reference case, spatial modelling techniques were applied to simulate changes in land use, population, and job density, according to the urban-sprawl scenario. The purpose was to relocate 10 % of the current population to areas near the city. As far as the re-distribution of land use is concerned, spatial simulations were done using the so-called 'potential model', which models the probablility of transition to a given land use type

of all the grid cells in the domain. In the present study, a natural area has a high probability of being converted into a built-up area if it is mainly surrounded by already existing built-up areas; otherwise it does not change its state. Already built-up categories remain, and newly created built-up areas are always of the non-industrial type, while existing industrial areas do not change.

The results of this procedure are contained in Figure 1. The main result here is that, for the urban-sprawl situation, the urbanised area in the study domain increases by almost 75 %. This high figure may appear rather drastic, but is related to the fact that residential housing in the periphery of a city is of a much lower density than housing inside cities.

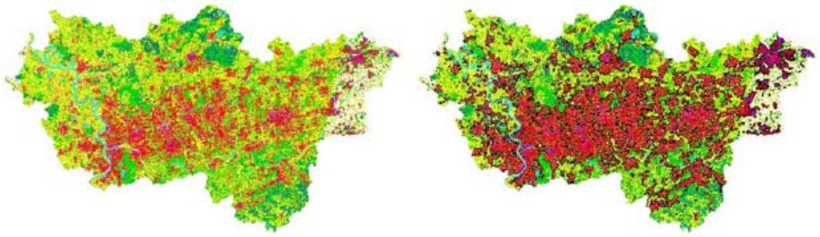

Figure 1. Land use of the reference state (left) and the sprawl scenario (right). Light grey corresponds to vegetated areas (pasture, forests), while medium-dark grey tones represent the current urban surface cover, including industrial areas. In the right panel, the dark grey indicates locations of residential land use, added in the urban-sprawl scenario.

The resulting land use map for the urban-sprawl scenario was then used to update the corresponding spatial distribution of people and jobs. As far as the population distribution is concerned, the procedure followed a two-step approach. First, the number of people per grid cell containing a non-industrial built-up land use type was taken constant per zone, using the same value as in the reference case. In the second step, a normalisation was carried through in the whole area to ensure that the total number of people remained the same as in the reference situation, as required. The re-allocation of jobs for the sprawl scenario was treated in a similar way, the main difference being that, within each zone, jobs were distributed uniformly over both built-up categories, i.e., industrial and non-industrial, the latter corresponding to jobs in the services sector. As before, the population and jobs data were interpolated towards a limited number of zones (polygons), for use in the traffic model.

3. TRAFFIC MODELLING

Traffic modelling was done with the Czech AUTO model, which uses the traditional four-step methodology. Developed during the major transportation studies in the 1950's and 1960's, this methodology consist of four sub-models that deal with trip generation, trip distribution, modal choice and traffic assignment.

The first step in the traffic modelling consisted of the creation of a simplified network for the study domain, consisting of highways and other major roads. Apart from using this network, the traffic model also subdivided the study area into different zones (typically a few hundred). For each zone the following parameters were specified from the previously processed spatial data maps: the number of inhabitants and jobs, the area in square metres and the percentage of built-up non industrial, industrial and green land use. For the reference situation, the number of car trips to and from each zone (i.e., the traffic volume) was calculated from the number of inhabitants and jobs as well as the number of day car trips per inhabitant or per job. As a next step, matrices were created containing the traffic volumes between zones in the area. This was done using a so-called gravity model, which calculates the number of trips between any two zones following the number of trips produced in each zone as well as the number of trips attracted to each zone, the probability of travel between two zones decreasing with their interdistance.

This information regarding traffic relations between individual zones was then used to calculate the traffic relations between individual network nodes, which constitute the actual traffic origins and destinations in the study domain. In order to obtain realistic spatial distribution of traffic loads for the reference case, a calibration procedure was carried out using data from the most recent traffic census in the area.

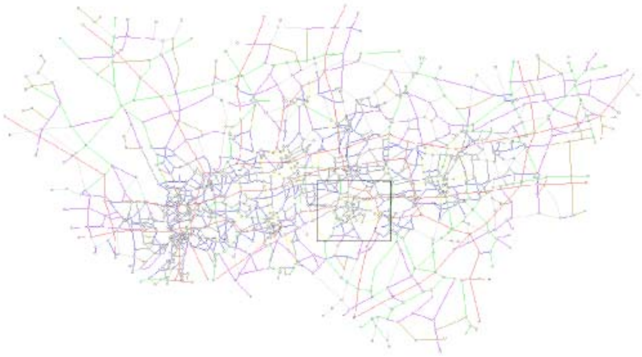

Figure 2. Road network of the study area used by the traffic model.

In order to simulate the effect of the urban sprawl scenario on traffic volumes and their spatial distribution, the traffic origins and destinations for each zone were recalculated based on the changes in land use, number of inhabitants and number of jobs. The network, including the characteristics of the individual segments and the spatial distribution of the zones were taken identical as for the reference state. As was the case for the reference calculations, the new traffic volumes between any two zones for the urban sprawl scenario were calculated with the help of the gravity model. Traffic intensities differ from the reference case because of the changed patterns of land use, inhabitants and jobs. The main result here is that passenger car traffic increased by 17 % for the urban-sprawl scenario.

4. AIR QUALITY SIMULATIONS

Regional air quality was simulated using VITO's AURORA modelling system, which employs meteorological fields (wind vectors, diffusion coefficients, radiation, temperature and humidity) produced by the meso-scale atmospheric model ARPS to calculate dispersion of pollutants emitted by traffic, industry, and building heating. Advection is treated using the Walcek approach, and diffusion is solved with the Crank-Nicholson scheme. Chemical reactions are calculated with the Carbon-Bond IV model, which was upgraded to include the effects of biogenic isoprene.

The simulation domain is shown in Figure 3. Land use-dependent parameters were specified as a function of land cover type, which were interpolated from the CORINE land cover map. Terrain height was interpolated from the Global 30 Arc-Second Elevation Data Set

(GTOPO30) distributed by the U.S Geological Survey. Sea surface temperature was derived from NOAA/NASA Pathfinder Advanced Very High Resolution Radiometer (AVHRR) SST imagery. Vegetation abundance was specified as a function of the Normalised Difference Vegetation Index (NDVI) contained in imagery from the VEGETATION instrument onboard the SPOT satellite platform, linearly relating vegetation percentage cover to the NDVI. In order to account for the effect of large-scale atmospheric features, the ARPS model was nested in 6-hourly analysis fields of the global model operated by the European Centre for Medium-Range Weather Forecasting (ECMWF). AURORA itself was nested within pollutant concentration fields of the CHIMERE transport-chemistry model.

A three-week period, 1-20 May 2000, was selected to perform the AURORA simulations on. This period was characterized by the presence of a blocking anticyclone over southern Scandinavia, producing weak south-easterly winds, clear skies, and moderately high temperatures over the Ruhr area. The nice weather ended abruptly on the 17th, when a cold front swept over the area. Emissions from industry, shipping and building heating were obtained from the 'Landesumweltamt Nordrhein-Westfalen', the local environmental administration. Traffic-related emissions were calculated using VITO's MIMOSA model, which uses the COPPERT III methodology to calculate geographically and temporally distributed traffic emissions using traffic information (including fluxes of vehicles and their speeds), which were provided by the AUTO traffic flow model (see above). Apart from the above-mentioned anthropogenic emissions, biogenic emissions from forests (isoprene) were also calculated. The simulations carried out here focused on ground-level ozone and primary PM_{10}, both pollutants having major effects on human health.

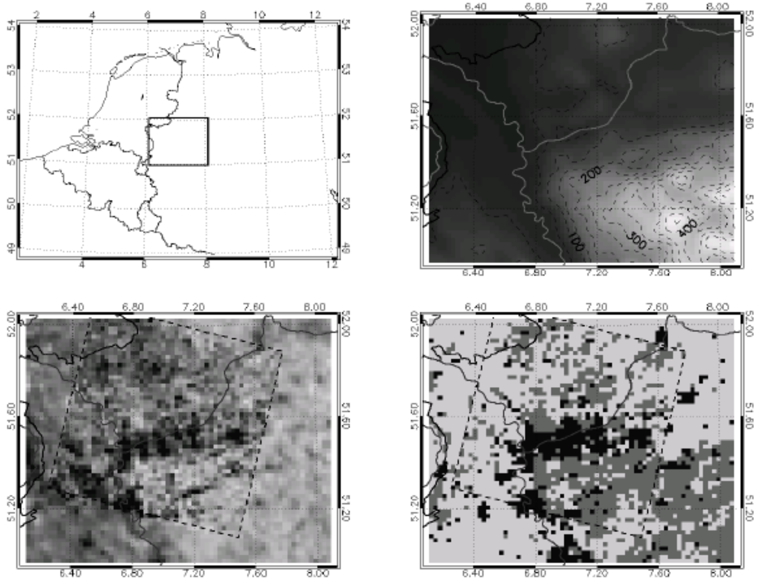

Figure 3. The position of the atmospheric simulation domain is shown by the black square in the upper left panel, with centre at longitude 7.1 degrees and latitude 51.5 degrees. The upper right panel shows terrain height in metres. The lower left panel displays percentage vegetation cover (dark areas corresponding to less vegetation), and the lower right panel gives land cover types. For the latter, the darkest tones correspond to urban surfaces, the areas in medium grey are forests, and the ligher grey represents short vegetation cover (grass, crops). The squares bounded by a dashed line in the lower panels indicate the area covered by the Landsat image used here.

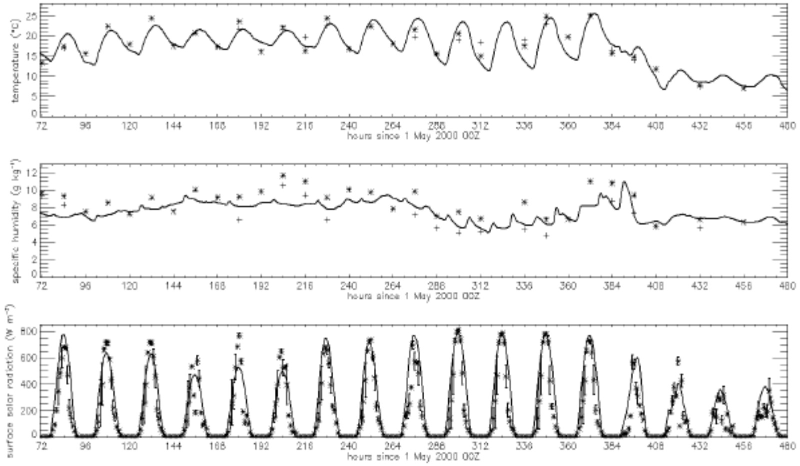

Figure 4. Validation of simulated surface air temperature, humidity and global solar radiation, the solid lines corresponding with the simulation result and the symbols with the observed values.

The ARPS simulation results were validated by comparing model output with observed meteorological parameters. Figure 4 shows validation results for surface air temperature, humidity, and global solar radiation. The simulated values are in fair agreement with the observations, and in particular the abrupt transition a few days before the end of the simulation period – caused by a frontal passage – is well captured.

Air quality simulations performed with the aurora model for the reference situation were validated by comparing model results with available observations from two stations in the area that measured ozone (Figure 5). Even though the simulations overestimate the ozone peak concentrations somewhat, the diurnal cycle as well as the behaviour of the model over the entire three-week period is rather satisfactory. In particular the difference of nighttime concentrations between the two locations, which is due to the titration effect (reduction of ozone by no emissions) caused by the intenser traffic at bottrop, is well captured by the model, meaning that the spatial distribution of traffic emissions as well as the chemical processes accounted for in the model perform correctly. Also, the abrupt decrease of ozone concentrations towards the end of the simulation period, caused by a frontal passage, is relatively well simulated.

After the completion of the simulations for the reference case, the aurora model was run on the urban-sprawl scenario established PREVIOUSLY, using the modified land use characteristics as well as the correspondingly modified traffic flows as inputs. The associated simulated percentage change of ground-level ozone is shown in Figure 6. Owing to the dominant south-easterly wind direction during this episode, increased ozone values are simulated in a plume extending at the north-west side of the urban agglomeration. The titration effect, on the other hand, which is the consequence of increased traffic emissions, slightly depresses ozone concentrations in the central portion of the domain, i.e., where the highest population densities occur.

5. IMPACT ANALYSIS

The main findings of the present study with respect to the impacts of the urban-sprawl case are summarised in Table 1, expressed in terms of changes induced by the spatial developments of the urban-sprawl scenario as compared to the reference case.

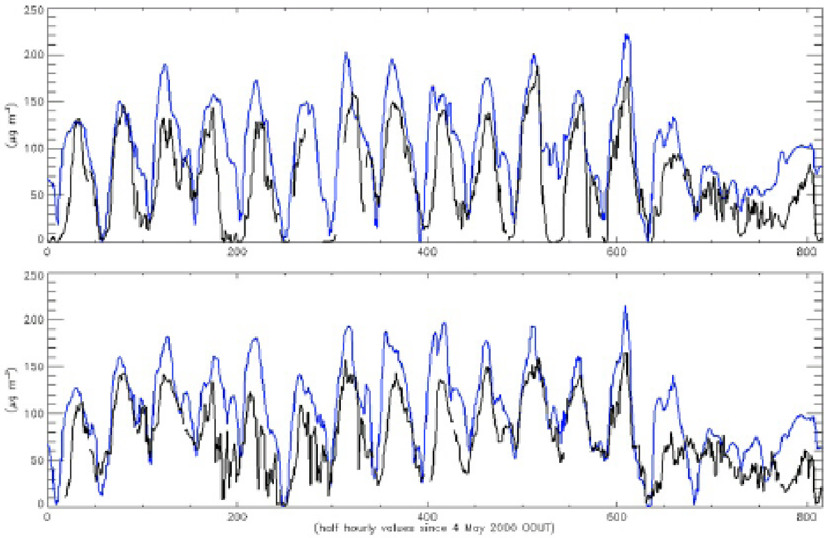

Figure 5. Simulated (grey line) as compared to observed (black line) ground-level ozone concentrations for the stations Bottrop (upper panel) and Essen (lower panel).

In terms of land consumption the urban-sprawl scenario induces an increase of built-up areas by 75 %. Owing to the increased average distance between people's homes and working places, as well as to the increased number of car trips, the total amount of daily passenger traffic kilometres increases by 17 %. As a direct consequence of the increased number of vehicle kilometres, the related overall energy consumption and associated emissions increase. In particular, CO_2 emissions increase by 12.7 %, thus having an adverse effect on global warming. Likewise, emissions of pollutants that are harmful to health (PM_{10}, O_3 precursors, ...) increase, and so do the domain-average concentrations of these pollutants. However, the exposure of people to PM_{10} *decreases*.

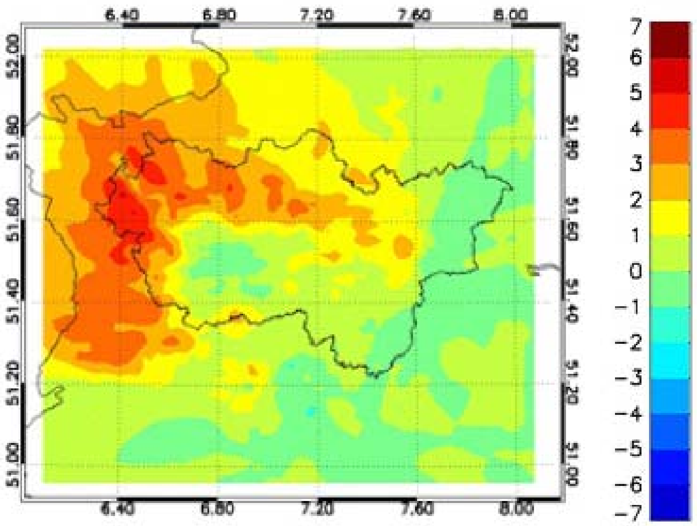

Figure 6. Concentration change (in µg m^{-3}) of ozone following the land use change of the urban-sprawl scenario. The upper left portion of the image displays ozone concentrations increased by up to 5-6 %.

Even though this may seem surprising initially, there is a straightforward explanation. Indeed, notwithstanding the increase of domain-average PM_{10} concentrations, in the urban-sprawl scenario a significant share of the population is relocated to areas outside the dense conurbation, to areas where pollutant concentrations are lower, hence exposure is reduced. Ground-level ozone being a non-local pollutant (unlike primary particulate matter), its effect on human exposure is not so clear. On the one hand the ozone concentrations in the urban plume increase, but the effects of that are partly compensated by a decrease in the urbanized portions of the area. As a result, population exposure to ozone increases slightly, by 0.3 %.

Table 1. Simulated changes following urban sprawl in the German Ruhr area.

item	simulated change
residential areas	+75 %
CO_2 emissions	+12.7 %
PM_{10} exposure	-5.7 %
O_3 exposure	+0.3 %
damage cost	-15 M€

The air pollution-related public health damage, together with changes in CO_2 emissions, were used for the calculation of the damage costs using the ExternE methodology. Compared to the reference state, CO_2 emissions increase when there is urban sprawl, resulting in higher damage costs related to climate change. The changes in damage costs related to public health, themselves related to changes in primary particulate matter and ground-level ozone, were determined by the changes in exposure, which in turn reflect the combined effect of changes in concentrations as well as changes in the spatial distribution of population density in the study area. Among the impacts mentioned above – CO_2 emissions, and exposure to O_3 and PM_{10} – it is the latter that has the most significant weight in the calculation of the total damage caused by the scenarios, owing to the severe health impacts attributed to this pollutant. Therefore, the overall costs very closely reflect PM_{10} exposure, and actually it is found that – in terms of damage costs – there is a beneficial effect of urban sprawl. In fact, our study gave as a result that urban sprawl induces lower (i.e., avoided) damage costs, by an amount of approximately 15.0 M€ per year.

However, there is an important caveat here. Indeed, even though population exposure to PM_{10} concentrations was found to decrease in the urban-sprawl scenario, it was also found that this decrease was largely due to relocating a certain number of people to the edge of the city, characterised by cleaner air. This means that people that are wealthy enough to leave the polluted inner city attain a healthier living environment, while those that cannot afford leaving the city find themselves in more polluted air. Stated otherwise, the gains in air quality for those settling in the green fringes of the city comes at the expense of a loss in air quality for those who, often unwantedly, stay.

6. CONCLUSIONS

A brief overview was given of an interdisciplinary study aiming at contributing to the understanding of the relation between city compactness and (exposure to) air pollution, using models to simulate land use, traffic, and air pollution. The selected study domain consisted of a cluster of cities in the German Ruhr area, and the case investigated was one of urban sprawl.

The methodology was based on evaluating the simulated differences in air pollution exposure between the current situation, and the artificial situation in which 10 % of the area's population was relocated to the green areas surrounding the cities. As a main result it was found that, despite enhanced domain-wide pollutant concentrations, population exposure to fine particulate matter decreased by almost 6 % for PM_{10}, while it remained almost unchanged for O_3. Following a detailed analysis, this phenomenon was ascribed to relocating a certain number of people to comparatively less-polluted residential neighbourhoods in the urban-sprawl scenario. The resulting avoided damage costs of urban sprawl, mainly composed of avoided PM_{10}-related health costs, amounted to 15 M€ per year. While not contesting the evident advantages of compact cities with respect to a host of sustainability indicators, these results indicate that compact cities may also induce adverse effects, which should be taken into account by policy makers when making choices regarding urban development.

More detailed information regarding the study presented here, including references, can be obtained via www.vito.be/bugs, www.bugs-group.com, or from the corresponding author (koen.deridder@vito.be).

Acknowledgements
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Calendar

28th NATO/CCMS International Technical Meeting on Air Pollution Modelling and its Application, 15-19 May 2006, Leipzig, Germany, http://www.dao.ua.pt/itm, e-mail: itm@ua.pt, itm2006@tropos.de; Extended abstracts by 1 February 2006.

6th International Conference on Urban Climate (ICUC6), Göteborg, Sweden, June 12 – 16, 2006, http://www.gvc.gu.se/ icuc6/, Extended abstracts by 10 April 2006.

6th Annual Assembly of the European Meteorological Society, *Ljubljana, Slovenia, 3-7 September 2006, Abstract deadline: 28 April 2006,* INFO & Abstract submission: http://meetings.copernicus.org/ems2006/annotation.html

The Euroscience Open Forum 2006, July 15th-19th 2006, Munich, Germany. View the conference programme and register at www.esof2006.org

International Conference "Living with climate variability and change: Understanding the uncertainties and managing the risks", Espoo, Finland, 17-21 July 2006 – www.livingwithclimate.fi