RECURRENCE OF AIR QUALITY FOR THE CITY OF SOFIA FOR 2013 AND 2014

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Abstract. The air is the living environment of human beings and obviously the atmospheric composition has a great importance for the quality of life and human health. Air Quality (AQ) is a key element for the well-being and quality of life of European citizens. The objectives of the present work is performing reliable, comprehensive and detailed studies of the impact of lower atmosphere composition on the quality of life and health risks for the population in Sofia city. Lately, together with the numerical weather forecast, in many European countries Systems for Chemical Weather Forecast operate, Chemical Weather being understood as concentration distribution of key pollutants in a particular area and its changes during some forecast period. In Bulgaria, a prototype of such a system was built in the frame of a project with the National Science Fund. It covers a relatively small domain including Bulgaria that requires using chemical boundary conditions from similar foreign systems. As far as this data is prepared abroad and transferred by Internet, many failures took place during the operation of the system. To avoid this problem, a new version of the system was built on the base of the nesting approach. This version is realized on five domains: Europe, Balkan Peninsula, Bulgaria, Sofia Municipality and Sofia City with increasing space resolution - from 81 km (Europe) to 1 km (Sofia City). For the Mother domain (Europe) climatic boundary conditions are applied. All other domains take their boundary conditions from the senior one. Computations start automatically at 00 UTC every day and the forecast period is 3 days. The System is based on the well-known models WRF (Meso-meteorological Model) and US EPA dispersion model CMAQ (Chemical Transport Model). As emission input the TNO data is used for the two biggest domains. For the 3 Bulgarian domains the current emission inventory prepared by Bulgarian environmental authorities is exploited.

Key words: Air Quality Indices, air quality, quality of life, health risks.

Introduction

The Air Quality is a key element for the well-being and quality of life of European citizens. According to the World Health Organization, air pollution severely affects the health of European citizens. There is increasing evidence for adverse effects of air pollution on the respiratory and the cardiovascular system as a result of both acute and chronic exposure. In particular, a significant reduction of life expectancy by a year or more is assumed to be linked to long-term exposure to high air concentrations of particulate matter (PM). 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. the Ozone daughter directive 2002/3/EC (European Parliament, 2002), requires informing the public on 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. For the purpose, modeling tools must be used in parallel with air pollution measurements. The goals of reliable air quality forecasts are the efficient control and protection of population exposure as well as possible emission abatement measures. In last years the concept of "chemical weather" arises and in many countries respective forecast systems are being developed along with the usual meteorological weather forecasts (see, for instance, Sofiev at al., 2006, Poupkou et al., 2008, Monteiro et al., 2005, San Jose et al., 2006, and others).

Air pollution easily crosses national borders. It would be cost-effective and beneficial for citizens, society and decision-makers that national chemical weather forecast and information systems were networked across Europe. For the purpose several projects in the European Framework Programs (GEMS, PROMOTE, MEGAPOLI, MACC, PASODOBLE etc.) as well as the COST Action ES0602 "Towards a European Network on Chemical Weather Forecasting and Information Systems") were launched aiming at providing a forum for harmonizing, standardizing and benchmarking approaches and practices in data exchange and multi-model capabilities for air quality forecast and (near) real-time information systems in Europe. It is supposed to examine existing, and work out new solutions for integrating the development efforts at national and international levels. One can find several CW systems' (performance and descriptions) in the Action's web-portal (http://www.chemicalweather.eu/Domains).

Modeling tools

BgCWFIS is designed in a way to fit the real-time constraints and to deliver forecasts for the next days on an hourly basis. US EPA Models-3 air quality modeling system is used, consisting of:

• CMAQ v.4.6 - Community Multi-scale Air Quality model, http://www.cmaq-model.org/, Denis et al. (1996), Byun and Ching (1999), Byun and Schere (2006), the Chemical Transport Model (CTM);

• WRF v.3.2.1 - Weather Research and Forecasting Model, http://www.wrf-model.org/, Skamarock et al. (2007), the meteorological pre-processor to CMAQ. The Weather Research and Forecasting (WRF) Model is a next generation meso-scale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. It is an evolutionary successor to the MM5 model. The creation and further development of WRF is due to the collaborative efforts of several US institutions like NCAR, NOAA, NCEP and others. The WRF is a fully compressible and non-hydrostatic model with terrain-following hydrostatic pressure coordinate. The grid staggering is the Arakawa-C type. One can find more info on http://www.wrf-model.org/index.php;

• SMOKE v.2.4 - Sparse Matrix Operator Kernel Emissions Modelling System, http://www.smoke-model.org/, Coats and Houyoux (1996), Houyoux and Vukovich (1999), CEP (2003), the emission pre-processor to CMAQ. CMAQ demands its emission input in specific format reflecting the time evolution of all pollutants accounted for by the chemical mechanism used (CB-IV in this case). Emission inventories are used as row data for anthropogenic emission processing. The inventories are made on annual basis for big territories; many pollutants are estimated as groups (VOC and PM2.5 for instance). Preparation of emission input to a Chemical Transport Model requires emission processing. Such emission processing component in EPA Models-3 system is SMOKE but it is partly used, here, because it's quite strong relation to US emission sources specifics. In BgCWFIS, SMOKE is used only for calculating BgS emissions and for merging AS-, LPS- and BgS-files into a CMAQ emission input file. The area source emissions and the large point source emissions are prepared by the interface programs AEmis and PEmis.

In the System, WRF is driven by the NCEP GFS (Global Forecast System) data that can be accessed freely from http://www.ftp.ncep.noaa.gov/data/nccf/com/gfs/prod/. This data is global weather forecast in GRIB-2 format with space resolution of 1°×1° and 6-hour time resolution. The downloading of this data is invoked automatically every day at 00:00Z. 84-hour runs starting at 12:00Z of the previous day are used; the first 12 hours of the period being spinning-up followed by a 3-day weather forecast. The chemical weather forecast duration is from 00:00Z of the current day to 00:00Z of the fourth day after (3-day forecast).

TNO inventory for 2005 (Denier van der Gon et al., 2010) is exploited partly for Bulgaria domain, TNO being the Netherlands's Organization for Applied Scientific Research. For Bulgaria itself and for the other Bulgarian domains, the National inventory for 2010 as provided by Bulgarian Executive Environmental Agency is used. That means TNO inventory is used only for the territories outside Bulgaria in the mother CMAQ's domain.

The TNO produced several sets of inventories for different years. The anthropogenic sources in this inventories are distributed over 10 SNAPs (Selected Nomenclature for Air Pollution) classifying them according to the processes leading to harmful material release into the atmosphere (EMEP/CORINAIR, 2002). The 2010 TNO inventory has resolution of 0.125°×0.0625° (about 7×8 km). It is distributed as a comma- or tab-delimited text-file. Each line of the file contains data for a single box, namely the center of mesh coordinates, the country, the type of source (A/P), the SNAP, and the yearly emissions of

8 pollutants. The SNAP 7 (road transport) is presented as 5 sub-SNAPs. The pollutants are: methane (CH4), carbon oxide (CO), nitric oxides (NOx), sulfur oxides (SOx), non-methane volatile organic compounds (NMVOC), ammonia (NH3), Particulate Matter with d<10μm (PM10) and Particulate Matter with d<2.5μm (PM2.5).

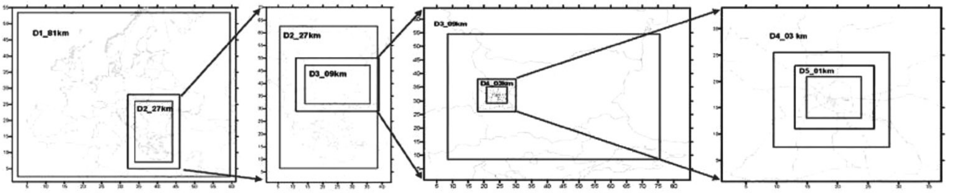

Fig. 1. Five computational domains of BgCWFIS, (CMAQ domain nested in WRF one)

The nesting capabilities of WRF and CMAQ are used to downscale the forecasts from European region to Sofia city area. The resolution of the mother domain (Europe) is 81 km, big enough as to correspond to the GFS met-data space resolution. Four other domains are nested in it and in each other – Balkan Peninsula (27km resolution), Bulgaria (9 km), Sofia municipality (3 km) and Sofia city (1 km) as shown in Fig. 1.

In BgCWFIS, climatic data is used for chemical boundary conditions following the presumption that the errors introduced by this assumption will decrease quickly to the center of the domain due to the continuous acting of the pollution sources. All other domains receive their boundary conditions from the previous domain in the hierarchy.

Operational Performance of BgCWFIS

Fourteen σ-levels with varying thickness determine the vertical structure of CMAQ model. The Planetary Boundary Layer (PBL) is presented by the lowest 8 of these levels.

The CMAQ v.4.6 input consists of various files containing concentration, deposition, visibility and other variables. The concentration output is a NetCDF file with 3-D hourly data for 78 pollutants - gases and aerosols.

The post-processing program XtrCON extracts part of the pollutants for archiving and further handling. Only surface values of the most important pollutants are saved - 8 gases and 11 aerosols (including PM10 and PM2.5). Part of these pollutants is more or less monitored and they are referred in the European legislation with the respective thresholds.

For the moment it presents 4 main pollutants - Ozone, NO_2, SO_2 and PM10 which are used to calculate the Air Quality Indices (AQI).

Calculation of the Air Quality (AQ) impact on human health and quality of life in Sofia city is the objective of the present study. The impact is calculated in the terms of the so called AQI – an integral characteristic directly measuring the effects of AQ on human health. The calculations are made on the basis of long term AQ simulations, which make it possible to reveal the climate of AQI spatial/temporal distribution and behavior.

The AQI is defined as a measure of air pollution seen in the context of its impact on human health. It provides an integrated assessment of the impact of the whole range of pollutants on human health and is calculated based on the concentration of various pollutants obtained from measurements or numerical modeling. The index is defined in several segments (EPA, 2009), each of which is a linear function of the concentration of each considered pollutant:

$$I = ((I\,high - I\,low) / (C\,high - C\,low))(C - C\,low) \quad (1)$$

where:

I = the AQI,

C = the pollutant concentration,

C low - the concentration breakpoint that is ≤ C,

C high - the concentration breakpoint that is ≥ C,

I low - the index breakpoint corresponding to C low ,

I high - the index breakpoint corresponding to C high.

In that calculation the index falls in one of the ranges of the dimensionless scale. In each range index values are associated with an intuitive color code, a linguistic description and a health description.

Pretty often in order to evaluate the air quality situation in European cities, all detailed measurements are transformed into a single relative figure: the Common Air Quality Index (CAQI) and this index have 5 levels using a scale from 0 (very low) to > 100 (very high). The index is based on 3 pollutants of major concern in Europe: PM10, NO_2, O_3 and will be able to take into account to 3 additional pollutants (CO, PM2.5 and SO_2).

One of the most commonly used air quality index is the UK Daily Air Quality Index (Leeuw, F. de, Mol, W., 2005), also used in Bulgaria (Etropolska et al. 2010), (Syrakov et al, 2012, 2013, 2014a, 2014b, 2015), (Georgieva, I., 2014), (Georgieva et al. 2015), (Georgieva, I. and Ivanov, V., 2017, 2018) and (Ivanov, V. and Georgieva, I., 2017).

Compute the AQI

To calculate the AQI requires several steps:

- Air pollutant concentrations (from measurements or model)
- Convert this air pollutant concentration to a AQI. The index is defined for each pollutant in a different way converting the concentrations into a dimensionless scale, associated with an intuitive color code (green to purple) and a linguistic description (Low to Very High).
- AQI values are divided into ranges, and each range is assigned a color code and health descriptor.

- An overall air AQI is constructed to describe the ambient pollutant mix – It's set to the highest value of each of the pollutant considered.

The breakpoints between index values are defined for each pollutant separately and the overall index is defined as the maximum value of the index. Different averaging periods are used for different pollutants. Each of the bands comes with advice for at-risk groups and the general population (Table 1).

Table 1 Boundaries Between Index Points for Each Pollutant

Index	O_3 Running 8 hourly mean (μg/m³)	NO_2 Hourly mean (μg/m³)	SO_2 15 minute mean (μg/m³)	PM10 Particles, 24 hour mean (μg/m³)	PM2.5 Particles, 24 hour mean (μg/m³)
1 (Low)	0-33	0-66	0-88	0-11	0-16
2 (Low)	34-65	67-133	89-176	12-23	17-33
3 (Low)	66-99	134-199	177-265	24-34	34-49
4 (Moderate)	100-120	200-267	266-354	35-41	50-58
5 (Moderate)	121-140	268-334	355-442	42-46	59-66
6 (Moderate)	141-159	335-399	443-531	47-52	67-74
7 (High)	160-187	400-467	530-708	53-58	75-83
8 (High)	188-213	468-534	709-886	59-64	84-91
9 (High)	214-239	535-599	887-1063	65-69	92-99
10 (Very High)	≥240	≥600	≥1064	≥70	≥100

The reference levels and Health Descriptor used in the Table 2 are based on health-protection related limit, target or guideline values set by the EU, at national or local level or by the WHO.

Table 2. Air quality indices and their health impact (de Leeuw and Mol, 2005).

Banding	Value	Health Descriptor
Low	1-3	Effects are unlikely to be noticed even by individuals who know they are sensitive to air pollutants
Moderate	4-6	Mild effects, unlikely to require action, may be noticed amongst sensitive individuals.
High	7-9	Significant effects may be noticed by sensitive individuals and action to avoid or reduce these effects may be needed (e.g. reducing exposure by spending less time in polluted areas outdoors). Asthmatics will find that their 'reliever' inhaler is likely to reverse the effects on the lung.
Very High	10	The effects on sensitive individuals described for 'High' levels of pollution may worsen.

Results

Annual recurrence of AQI in "Low", "Moderate", "High" and "Very High" bands over territory of Sofia city for 2013 and 2014: Figures 2 and 3 demonstrate the spatial and diurnal variation of the annual recurrence of different AQI categories for the chosen hours 06:00 and 18:00GMT for 2013 and 2014. The picture shows the sum of recurrences of the AQI in each range - Low, Moderate and High range. What can be also noticed is: the recurrence in Low and Moderate range is different for both years, as in 2013 the recurrence in Low band is smaller than 2014, and reverse in Moderate range. In High range there is no any difference between both years.

In the Low range the air is most clean, so high recurrence values mean more cases with clean air and lower recurrence values mean, less cases with clean air (worse AQ status). In the other 2 plots (Moderate and High ranges) - high recurrence values means less favorable and respectively bad AQ status. It can be seen that most areas with high recurrence of cases with lower AQI status are in the city center and over the Vitosha Mountain early in the morning due to the weather conditions, higher NO_2 concentrations from the road transport and higher O_3 concentration in the mountain. This could be seen at Low and Moderate range maps in the morning hours. The major NO_2 sources in the city are the surface sources (road transport) and the surface NO_2 concentrations are higher early in the morning and much smaller at noon (the atmosphere is mostly unstable, and so the turbulence transports the NO_2 aloft more intensively). The maximal concentrations which are directly linked to the worse AQI status are formed in the city center and along the boulevard with most busy traffic.

In Moderate band at 18:00 GMT it can be also noticed about 20% recurrence with not so good AQI status over Vitosha mountain. Higher values over the Vitosha Mountain in the afternoon are due to the higher concentration of O_3 in mountain areas and intensive ozone transport from higher levels (intensive turbulence during midday). The behavior of the surface ozone is complex. The O_3 in Bulgaria is to a great extent due to transport from abroad (Gadzhev et al. 2013), (Kaleyna et al. 2013a, 2013b, 2014) and (Tcherkezova et al. 2013). This is the reason why the O_3 concentrations early in the morning are smaller (less intensive transport from higher levels), and higher at noon and afternoon (turbulence atmosphere and O_3 photochemistry)

High recurrence of cases with most polluted air (High band) appears again in the city center. In the city center can be observed about 20% "High" pollution in the morning and 10% in the afternoon. Bad AQI status from the High band never disappears.

Conclusions

The simulations for Sofia city show that the air quality status of Sofia is not so good (evaluated with a spatial resolution of 1km).

AQI status falls mostly in Low and Moderate bands, but the recurrence of cases with High pollution is close to 20% mostly at the city center.

The recurrence of Low band for 2013 is smaller than 2014, which means that in 2014 almost 90% the days have been with cleaner air.

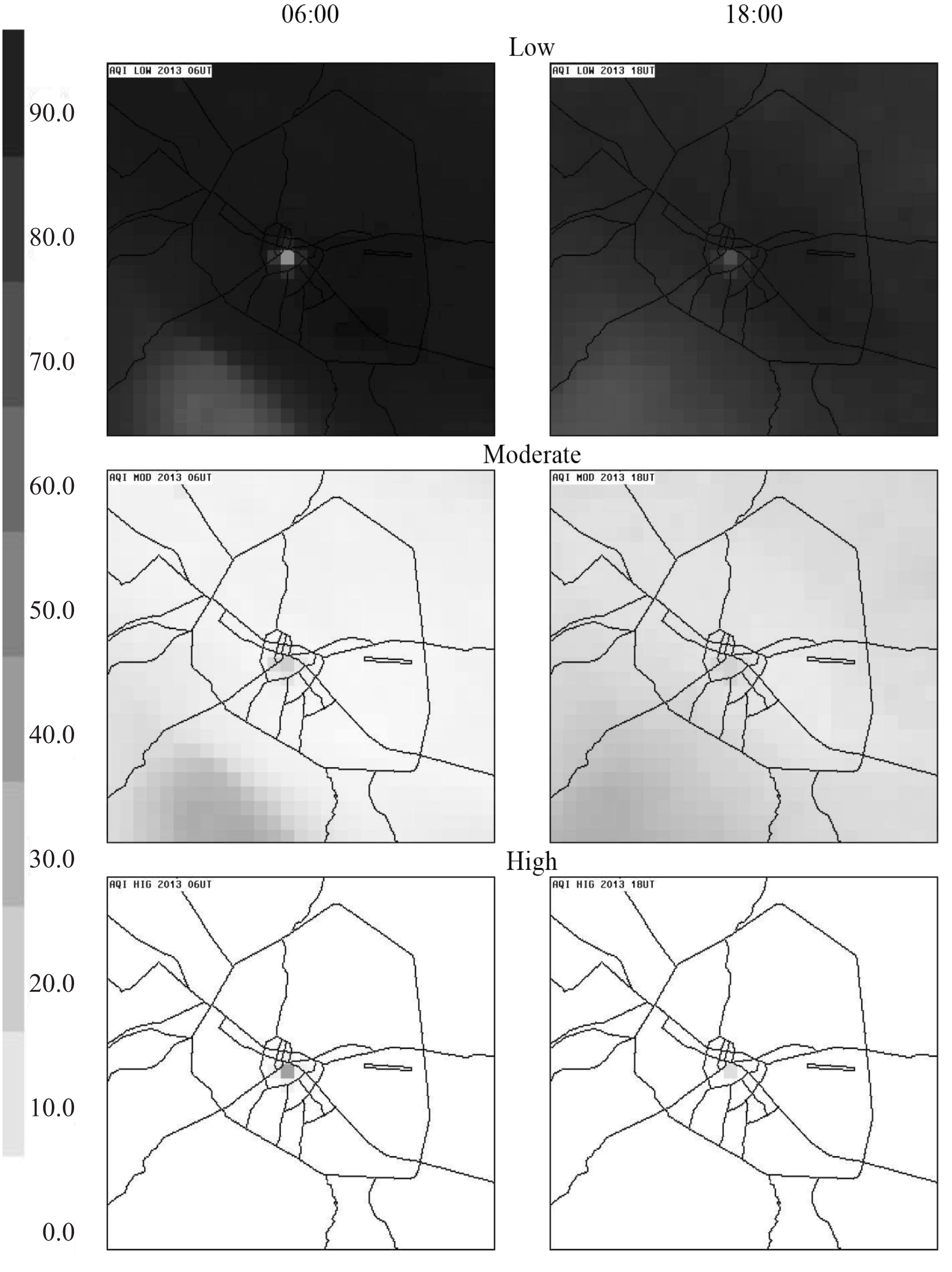

Fig. 2. Annual plots of the recurrence [%] of the AQI - Low, Moderate, and High bands in Sofia for 2013.

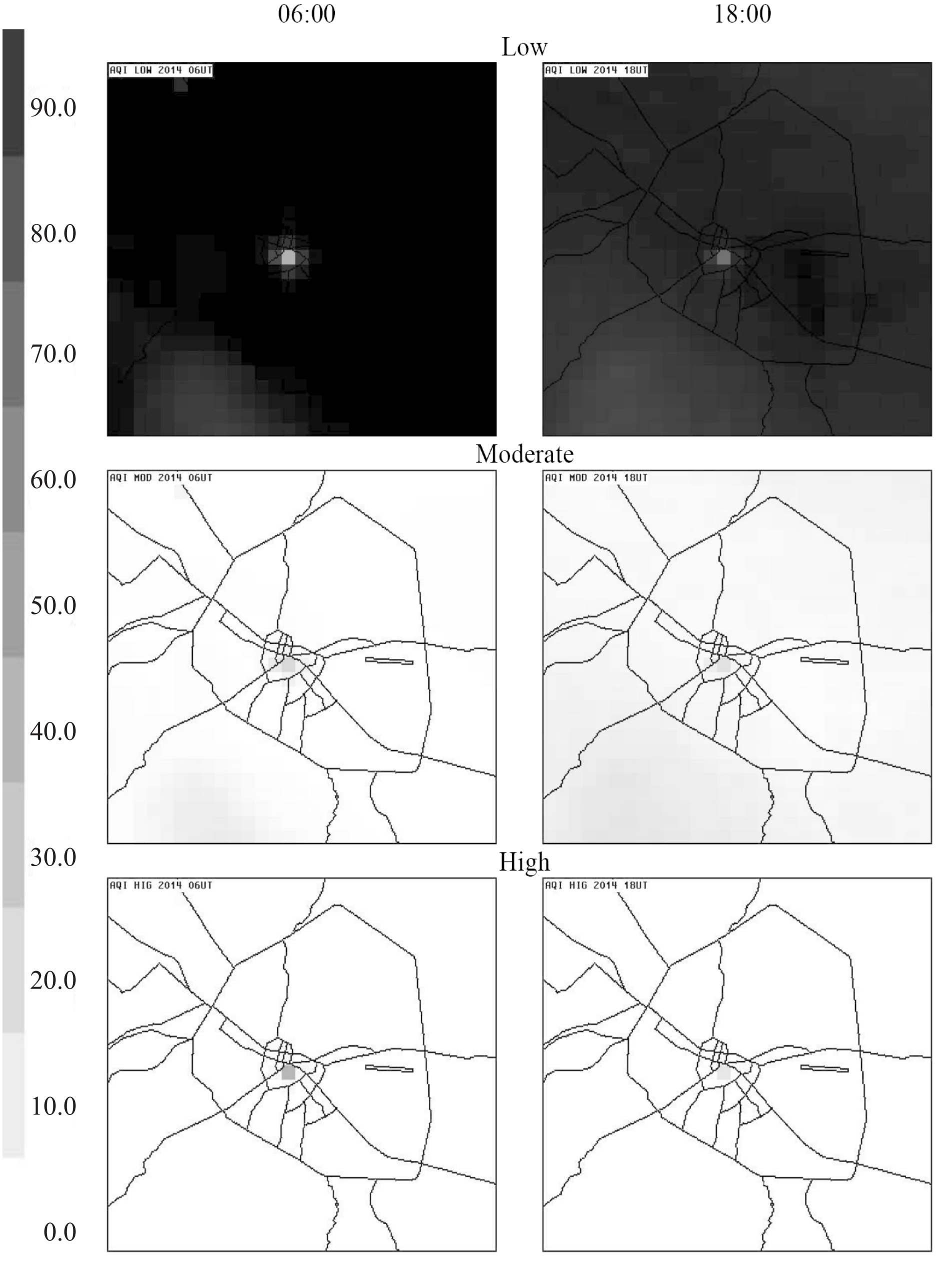

Fig. 3. Annual plots of the recurrence [%] of the AQI - Low, Moderate, and High bands in Sofia for 2014.

The pollution in the city is probably due to the surface sources like road transport and also the TPPs in the city.

Apart from these general features the climatic behavior of the AQI probabilities is rather complex with significant spatial, seasonal and diurnal variability. The areas with slightly worse AQ status are not necessarily linked to the big pollution sources. Wide rural and even mountain regions can also have significant probability for AQI from the Moderate range.

The hot spot in Sofia city, where index with higher impact (High band) is in the city center. The (High band) is relatively high - about 20 % in the morning and 10% in the afternoon.

Acknowledgments

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Оценка на качеството на въздуха за град София за 2013 и 2014

Г. Гаджев

Резюме: В настоящето изследване са представени средногодишните Индекси за качеството на въздуха през 2013 и 2014 за територията на град София. Използвани са данни за приземните концентрации на някои замърсители, моделирани от Българската система за прогноза на химическото време за изчисление на индексите. Чрез използването на математически апарат са определени индексите за качеството на въздуха, а от там и съответните повторяемости в трите категории „Ниско“, „Средно“ и „Високо“за двете години 2013 и 2014. Установяват се т.н. горещи точки, в които категория „Високо“ достига до 20%. Изказано е предположение за високите концентрации в центъра на града, че най-вероятно се дължат на приземните източници и ТЕЦ-те в града.