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Satellite information downscaled to urban air quality in Bulgaria - Project description

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Abstract: The present paper gives a general description of the project "Satellite Information Downscaled to Urban Air Quality in Bulgaria – (SIDUAQ)", its goals, activities and expected results. The overall objective of this project is to widen the use of satellite data for studies and management of environmental issues at national level in Bulgaria and at local level for the city of Plovdiv. Satellite air quality (AQ) information has not been used for studying and solving AQ problems in Bulgaria so far, thus, the specific goal is to modify the current Bulgarian Chemical Weather Forecasting System (BgCWFS) for assimilation of satellite information and to link its output to urban scale AQ system. The current local air quality management system (LAQMS) for the city of Plovdiv will be further improved through emission inventories and expert modules for supporting the local authorities in taking decisions and measures for reducing the air pollution in the region and in the city.

Key words: air quality, satellite data assimilation, meteorological models, chemical transport models, city of Plovdiv.

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1. INTRODUCTION

The Air Quality (AQ) is a key element for the environment and the well-being and quality of life of people. It is especially important in densely populated urban areas. Legislative measures are elaborated worldwide to regulate the level of pollution with most harmful substances. European directives require informing the public on AQ, assessing air pollutant concentrations throughout the whole territory of European Union (EU) Member States and indicating exceedances of limit and target values, forecasting potential exceedances and assessing possible emergency measures to abate exceedances. All this becomes possible when using modeling tools in parallel with air pollution measurements. In the last decades, the satellites are giving their contribution to atmospheric composition qualitative and quantitative monitoring.

In Bulgaria, satellite information on atmospheric chemistry has not been used so far for studying and addressing AQ problems. Satellite images were used only occasionally for tracking of transboundary plumes towards Bulgaria. The activities presented here refer to using air pollution data from sensors on board of satellites for analysing and accessing surface level concentrations. They represent a first attempt to make use of satellite data for AQ management at city level. It is well known, that despite decrease of emissions in EU and in Bulgaria, ground level concentrations of particulate matter (PM) in a number of Bulgarian cities are still exceeding EU limit values (EEA, 2019). Thus, for national and local authorities it is important to have scientifically based estimates for the air pollution in order to prepare appropriate plans for AQ improvement.

The National Institute of Meteorology and Hydrology (NIMH) has a long-year experience in air quality studies, including observations of key pollutants, data analysis and numerical modelling over different spatial scales – from national to city and street level. A new challenge for the team working on AQ at NIMH is a recent project, funded by the European Space Agency (ESA) "Satellite Information Downscaled to Urban Air Quality in Bulgaria" (SIDUAQ). The project started on 15th June 2018 and is with duration of two years. The coordinator of the project is NIMH, and the subcontractor, responsible for the satellite information, is the Space, Research and Technology Institute at the Bulgarian Academy of Sciences (SRTI - BAS).

The overall objective of the project is to use satellite observations for improvement of air quality modeling and management at national (Bulgaria) and local level focusing on the city of Plovdiv. The goal will be achieved by synergetic use of data from ESA satellites, from in situ air quality monitoring networks, and from air pollution dispersion modeling systems at national and urban scale. The main specific objectives are: a) identification of appropriate satellites providing data for the aerosol optical depth (AOD) and the total column densities (VCD) of nitrogen dioxide (NO2) and sulphur dioxide (SO2); b) assimilation of satellite-retrieved data in the Bulgarian Chemical Weather Forecast system (BgCWFS); c) downscaling of BgCWFS results to the Local AQ management system (LAQMS) in Plovdiv; and d) elaboration of expert analysis module of the LAQM with appropriate information for AQ experts.

A description of the project follows, highlighting the main methods and challenges, the satellite data availability, the project's structure, main tasks, and expected results.

2. METHODS AND CHALLANGES

The project methodology encompasses different theoretical approaches – from analysis of a variaty of remote and in-situ atmospheric chemistry data to application of comprehensive modelling air qiality systems and elaboration of their output in a format suitable for environmental experts at city level.

In the following, the main modelling air quality systems and their linkage will be described, highlighting also the challanges to be addressed for accomplishing the project goals.

2.1. The Bulgarian chemical weather forecast system

The Bulgarian Chemical Weather Forecast System (BgCWFS), developed at NIMH works operationally from the beginning of 2012 (http://info.meteo.bg/cw2.1/ and http://info.meteo.bg/cw2.2/). It provides timely and informative 3-days forecast products in the form of hourly AQ maps at surface level for ozone (O3), sulphur dioxide (SO2), nitrogen dioxide (NO2) and particulate matter with diameter less than 10 µm (PM10), (Syrakov et al., 2013a, 2013b, 2014). The system's results were evaluated in model intercomparison exresices (e.g. in AQMEII - 2, Syrakov et al., 2016), also with application of European Commission recommended tools (Georgieva et al., 2015)

BgCWFS is designed on the base of US Environmental Protection Agency (EPA) Models-3 air quality modelling system and the current version exploits the following models: CMAQ v4.6 (Chemical Transport Model), WRF v3.6.1 (Mesometeorological Model, pre-processor to CMAQ), MCIP v3.6 (Meteorology-Chemistry Interface Processor) and SMOKE v2.4 (the emission pre-processor to CMAQ). The nesting capabilities of WRF and CMAQ are used to downscale the forecasts from European region (81 km horizontal resolution), through Balkan Peninsula (27 km), Bulgaria (9 km), Sofia - district (3 km) to Sofia - city (1 km). The Netherlands Organisation for Applied Scientific Research (TNO) emission inventory (for 2011) is used as emission input for the larger domains Europe and Balkans. For the three Bulgarian domains, the emission inventory prepared by Bulgarian environmental authorities (for 2015) is exploited. The initial (IC) and boundary conditions (BC) for meteorology calculations are taken from the US National Centers for Environmental Prediction (NCEP) Global Forecast System/ "Final" analysis (GFS/FNL) data. In normal operational conditions, chemical IC is the previous day calculations. In the off-line version of the system, climatic pollution profiles (provided in the CMAQ package) are used for chemical IC at the most outer domain (Europe) and several day integrations are performed before starting calculations for the period of interest. The continuous acting of the pollution sources decreases the errors due to this hard IC. The same approach is used for the chemical BC at EU-domain following the presumption that the errors introduced will decrease quickly due to the same reason - continuous acting of the pollution sources. All other domains receive their boundary conditions from the previous domain in the hierarchy. Figure 1 shows the information flow diagram in the BgCWFS.

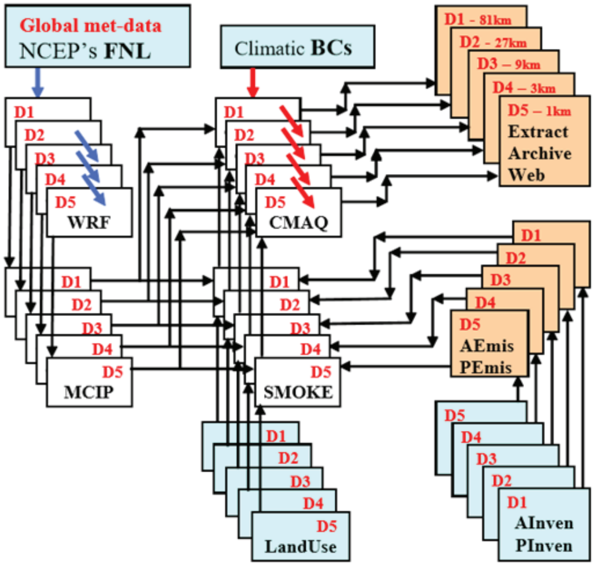

Fig.1. Information flow diagram (white boxes –models; cyan boxes – input information; brown boxes – own FORTRAN programs; blue arrows – transfer of meteorological BC between nested domains; red arrows – transfer of chemical BC; black arrows – exchange of information between model components for each domain)

For the SIDUAQ purposes, a modification of the CMAQ code has to be carried out in order to produce as output extinction coefficients at all model levels allowing to calculate the Aerosol Optical Depth (AODmod). The AOD calculation in a model is not a trivial tasks, different algorithms have been developed and embedded in the model (Binkowski and Roselle, 2003). Part of the project activities are related to analysis of different methods and selection of appropriate one for further work. Another challange consists in the approaches for assimilation of the satellite retrieved AOD (AODsat). The AOD from satellite data has to be collocated in space and time with AODmod before applying algorithms for assimilation. This refers also to the other satellite data – VCD of NO2 and SO2. An overveiw of possible assimilation techniques in the literature reveals a variaty of approaches – from rather simple profile modifications to very complex ones (4D-Var). As SIDUAQ is our first attempt in using satellite data in air qiality modeling system, we opted for a simple assimilation technique based on correction of model calculated AOD and vertical column denstities with a factor representing the satellite values - AODmod^A (AOD with assimilated satellite data). The ratio between AODmod^A and AODmod is then used to correct the first guess profile concentrations of different species. Figure 2 sketches the foreseen assimilation procedure for AOD.

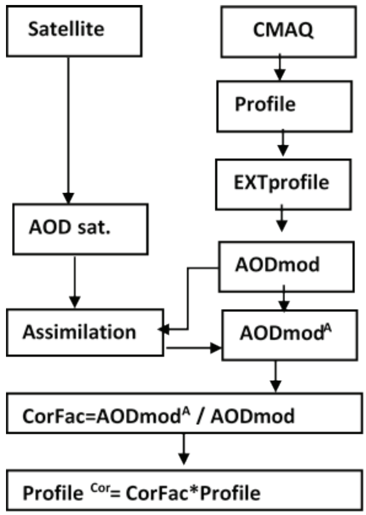

Fig. 2. Data flow in assimilating satellite retrieved AOD, used for correction of pollutants' profiles

2.2. Downscaling from Bulgarian chemical weather forecast system to the Local AQ management system

At present, the space resolution of the available satellite AQ data is not fine enough to be directly used in local AQ systems. The modified BgCWFS gives outputs with already assimilated satellite information but even its finest horizontal resolution of 1x1 km is not sufficient to describe the pollution concentration distribution in a complex urban infrastructure. Appropriate techniques for downscaling the output products of BgCWFS to urban scale models have to be developed and tested. The local scale AQ models used in the Plovdiv's Local Air Quality Management System (LAQMS) will refine the data from BgCWFS. Another advantage and challenge of the downscaling concerns emission determination methods. LAQMS uses the bottom-up approach, which is the better way to take into account the emission from different road segments and other space-restricted emission sources in the city. BgCWFS uses the top-down approach for emission determination, which is the only reasonable approach when one considers a large domain with many urbanized areas, but is not appropriate for the case of complex urban infrastructure. The combined use of BgCWFS and LAQMS gives the advantage of getting background concentrations containing the satellite information from BgCWFS and refining them with local AQ models and bottom-up emissions.

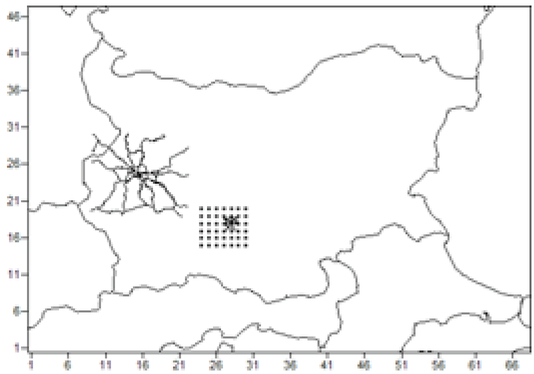

Fig. 3a. Downscaling the 9 km BG-domain to set of points for Plovdiv area

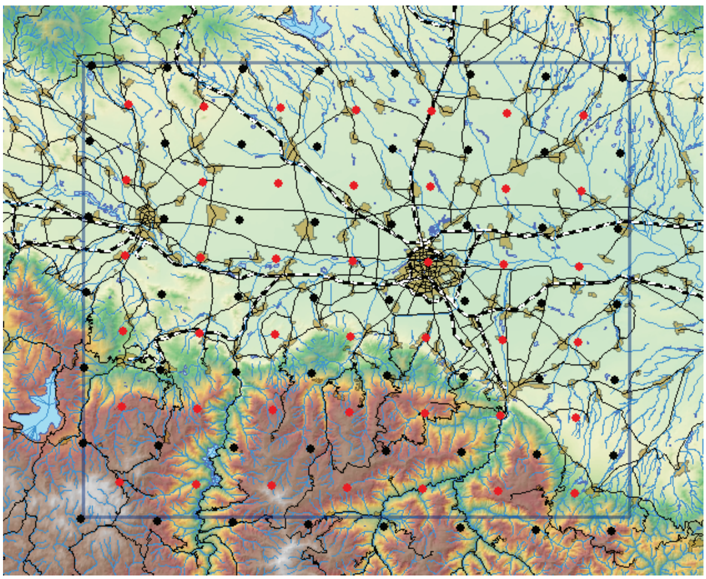

Fig. 3b. Modeling domain of LAQMS and some of the geographical objects. Black dots – data from WRF; red dots – data from CMAQ

As mentioned in Section 2.1, BgCWFS operates in nested domains of different size. Figure 3a shows the BG-domain (9 km resolution), together with a set of selected points in the Plovdiv region; Figure 3b shows the domain of the LAQMS, some geographical objects, and WRF and CMAQ points of the BgCWFS in this domain. Various approaches for downscaling the BgCwFS model results to the area around the city of Plovdiv shall be examined. One suitable approach, selected here, consists in extraction of time dependent profiles of required parameters from the BG modelling domain to those grid nodes falling within the local model domain for the city of Plovdiv.

This approach insures not only boundary and control values, but initial conditions for running the local model as well. The pollutants and meteorological variables necessary for the local model are estimated to be around 30. Thus, different C-shell scripts have to be elaborated for the extraction of the variables in space and for the lowest 11 model vertical levels.

2.3. Local AQ management system

Plovdiv is the second largest city in Bulgaria with population of about 370 000 people. The climate of the region is characterized by often calm weather and surface temperature inversions, a precondition for high levels of pollution near the ground. The AQ problems in the city are mainly related to violations of the particulate matter and NOx targets. Since 2004, a Local Air Quality Management System is operating in the city, developed by NIMH (Atanassov et al., 2006; Atanassov et al., 2014). The main functions of the LAQMS are: 1) monitoring of the AQ and meteorological parameters; 2) dispersion modeling of emitted air pollutants; 3) analysis of the contribution of different emission sectors (SNAPs). All functions are performed automatically in real time. Sketch of the LAQMS structure is presented in Figure 4. The system has been developed gradually, starting with one AQ monitoring station and dispersion modelling of emissions from industrial sources in the city. Later on, second AQ monitoring station starts operating, other emission sectors have been included. The considered pollutants have been updated several times. The LAQMS has two main parts – monitoring system and modeling system.

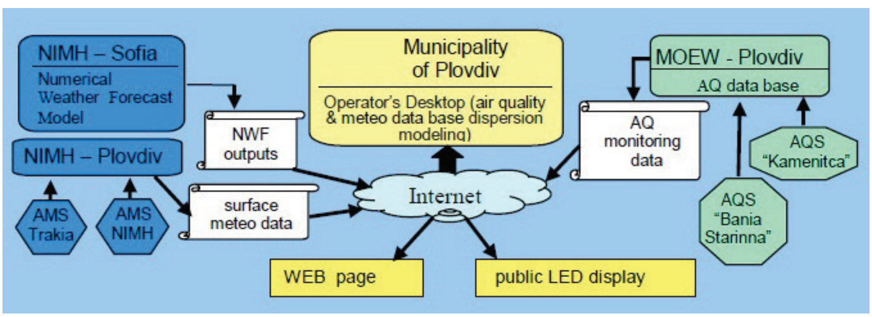

Fig. 4. Structure and data flow diagram of the Plovdiv's LAQMS. (AQS -air quality station, AMS -automatic meteorological station, MOEW -Ministry of Environment and Waters)

The data from the two AQ stations (one urban background measuring PM10, PM2.5, NO, NO2, NOx, O3, NH3, SO2, H2S, CO hydrocarbons, non-methane hydrocarbons and benzol) and one traffic oriented (measuring PM10, NO, NO2, NOx, SO2, benzol, toluene, P-Xylene) are transmitted to the Municipality and saved. The data from surface meteorological stations are also saved.

The modeling system is composed of meteorological preprocessor, emission and dispersion models and postprocessing analyzer.

The meteorological preprocessor in the current version is supplied with information from a Numerical Weather Forecast (NWF) model and from local automatic meteorological stations (AMS). Recently, a new meteorological preprocessor for optional use was developed. Surface layer parameters are determined by a modification of US EPA AERMET model. Vertical profiles of wind and eddy diffusivity are determined according to Gryning et al. (2007) and Kumar and Sharan (2012). In the frame of the SIDUAQ project, the preprocessor will be supplied with information from the WRF model of BgCWFS.

The dispersion model PolTran is a combination of an Eulerian advection scheme and numerical calculation of the turbulent diffusion (Atanassov,D., 2003). It operates in two domains: Plovdiv region, in an area of 60x40 km, with 2km grid cell and Plovdiv city, in an area 11x10km, with 250m grid cell. Pollutants considered by the current version of the modeling system are: PM10, PM2.5, NO2, SO2, benzo(a)piren (BaP). The system calculates separately dispersion from the following sources: the domestic heating in the city, the industrial sources in the city and the industrial sources outside the city located in the domain “region”. Results are presented in a form of hourly maps of pollutant concentrations caused by the mentioned three groups of sources. In case of accidentally released pollutant(s), the operator of the system can start simulation to forecast the dispersion and alarm the corresponding authorities. The post processing analyser calculates and plots maps of total concentrations caused by all sectors as well as map of the sector’s contribution –example, in Figure 5.

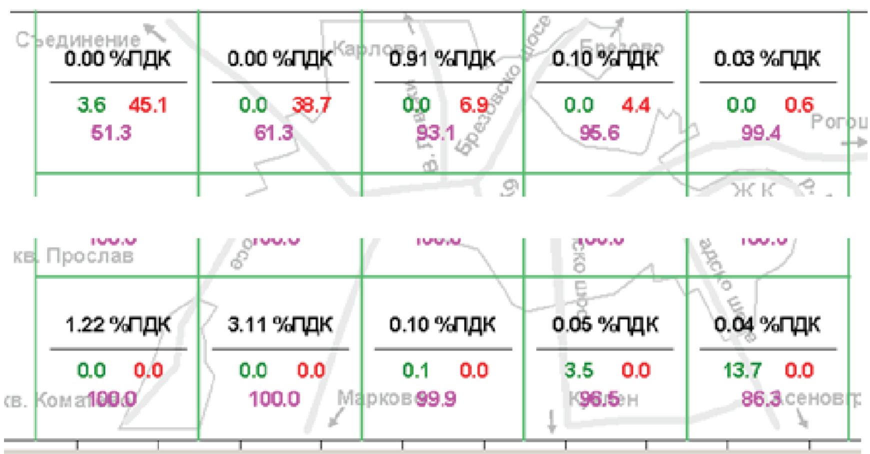

Fig. 5. Map of SO2 pollution as part (%) of the AQ limit value (black), contribution of the industrial sources outside the city (green), industrial sources in the city (red), and the domestic heating in the city (violet) at 22:00 on 23.01.2011. Only the northern and southern parts of the city are shown in the figure.

An expert analysis module (post-processing) will produce maps of AQ violations and AQ indexes as well as exposure of the population. The contribution of different emission sources to the resulting air pollution will be determined, prompting in such way priority measures for AQ improvement.

The LAQMS needs some important extensions, namely to add the emissions from the traffic sector and to obtain forecasting abilities. Both will be achieved in the frame of SIDUAQ project. The background concentrations will be taken from the modified BgCWFS, thus indirectly benefit from the assimilated satellite AQ data.

3. SELECTION OF SATELLITE DATA FOR USE IN BgCWFS

The satellite data to be used by the modelling system BgCWFS should have proper spatial and temporal resolution. In the perfect case, the satellite data have to be with the same space resolution for the whole covered area of interest, but it is not the case.

We consider three satellites – *MetOp A*, *B* and *C* with the same instrument GOME-2. Data from the first two satellites are mainly to be used in SIDUAQ. Data from GOME-2 have spatial resolution 40x40 km and are suitable for use in the first two domains (Europe and Balkans) of BgCWFS. Data from the TROPOMI instrument, on board of Sentinel-5P satellite, are with 3.5x7 km resolution and are appropriate for the model domains Bulgaria and Sofia or Plovdiv. However, Metop C and Sentinel 5P satellites were launched in 2018 and 2017, respectively and there are relatively short data series from these satellites in comparison with Metop A and B. Their data will be used after careful quality checking.

The time difference between two orbital passes of the same satellite is about 100 minutes. If all three *MetOp* satellites are used for building one dataset, the time difference could decrease to about 50 minutes that gives a possibility to use such a dataset at one computing time step of BgCSWF.

The *MetOp* orbits are from north-east towards south-west direction. The covered area changes from day to day and not-every-day single orbital pass of one satellite covers the whole area. Thus, we have a different spatial resolution of satellite data in the different domains. Figure 6 shows the second domain of BgCWFS and the spatial coverage from *MetOp* A and B satellites. In the domain Bulgaria of BgCWFS there is a small amount (100-150) of measurement points (less than 100 points for *MetOp A* and less than 50 points for *MetOp B*).

MetOp A and B satellites cross the Balkan Peninsula every day between 10am and 11am regional time (09am UTC), but on different orbits. In order to achieve better spatial resolution, a combination of data from both satellites will be used.

The process of preparing satellite retrieved data for BgCWFS starts with obtaining the needed track for both *MetOp A* and *B* satellites. Data for the absorbing aerosol index AAI, and VCD of NO_2 and SO_2 are extracted at geographical points (lat- lon coordinates) from one single orbit of each satellite. Then, data are imported in ArcGIS and the area of interest (the Balkans in this case) is extracted. The data are processed and erroneous data are removed. The next step is to convert the data in units as needed for BgCWFS. The last step is to aggregate the data from both satellites.

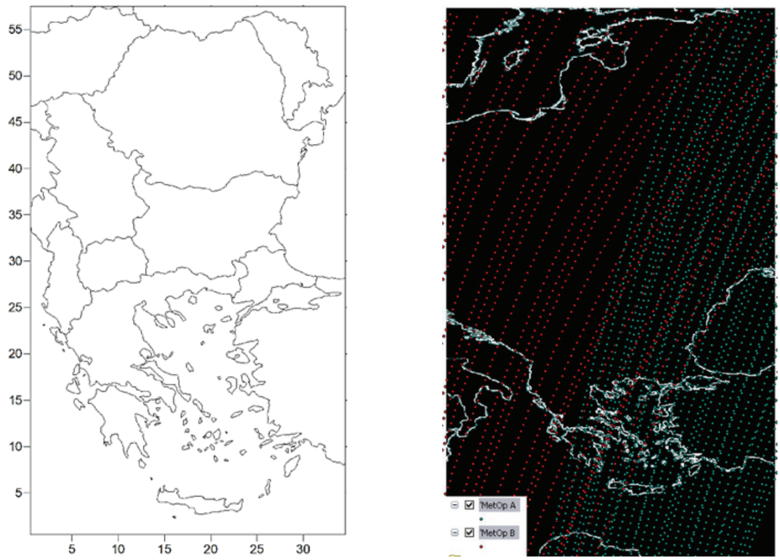

Fig. 6. The Balkan domain of BgCWFS (left) and the corresponding area covered by one track of *MetOp* A (red dots) and one of *MetOp* B satellites (blue dots

The Absorbing Aerosol Index (AAI) indicates the presence of elevated absorbing aerosols in the Earth's atmosphere. It is less sensitive to cloud cover than the AOD is. The aerosol types that are mostly seen in the AAI are desert dust, biomass burning and volcano ash. A challange for the activities in SIDUAQ is the conversion of AAI to AOD for data from both *MetOp A* and *B* satellites.The AAI values from *MetOp A* satellite are much smaller than those from *MetOp B* satellite, most probably because MetOp A satellite is older and its scanning width becomes smaller. For this reason, we use different formulas for AAI to AOD data conversion for *MetOp A* and *B* satellites. The values for NO2 and SO2 from both satellites are fully comparable.

For the project purposes, it is optimal to use GOME-2 data for the Balkan region either as input for BgCWFS or for investigation of past events. The mission of recently launched ESA satellite Sentinel-5P promises to image air pollutants in more detail than ever before bringing the issue of air pollution sharply into focus. The resolution of TROPOMI instrument is high (7×3.5 km) and has the potential to detect air pollution over individual cities. Data from TROPOMI will be collected and processed but long-term series of data and further analysis are needed to propose the use of its AI for assimilation in BgCWFS.

4. SIDUAQ ACTIVITIES AND PROJECT STRUCTURE

The project activities are grouped in several interlinked working packages (WP), briefly outlined below.

WP on satellite data from different sources. The main tasks include analysis of available satellite data level 2 for AOD, and columnar NO2 and SO2 over the Balkans provided by different instruments (GOME-2, OMI, MODIS, and TROPOMI) on-board of different satellites, and selection of optimal ones to be used as input in the BgCWFS (see Section 3). The data have to be screened for errors and prepared in a format suitable for assimilation. Other tasks include analysis of seasonal changes in air pollution over Bulgaria and the Balkans based on archive of satellite-retrieved data for the past 10 years and more.

WP on satellite AOD-to-PM10 and PM2.5 conversion. The main tasks include collection and archiving of both satellite data (including the new TROPOMI instrument on-board of Sentinel 5P) and in-situ observations from the regular air quality monitoring network in Bulgaria. The challenges are in developing and testing of different techniques (deterministic and statistic models) that could be used for estimation of the particulate matter (PM10 and PM2.5) distribution over Bulgaria with fine horizontal resolution.

WP on assimilation of satellite data in BgCWFS. The core activities are related to: modification of the off-line version of the system so that satellite data could be used in it; creation of assimilation techniques for the AOD and VCD of NO2 and SO2; and development of a downscaling approach for providing necessary data to the local system LAQMS for the region of Plovdiv (see Sections 2.1 and 2.2).

WP on LAQMS simulations and interactive interfaces to users. The main tasks include: creation of emission inventory, taking into account household heating and traffic emissions; selection and/or adaptation of urban scale dispersion model; and elaboration of expert modules as interactive interfaces for local authorities at Plovdiv Municipality. Challenges are seen not only in compiling bottom-up emission inventory, but also in the set-up of appropriate dispersion model, that has to be linked to the output of the coarse scale BgCWFS. The urban scale model has to be able to describe adequately the dispersion of emissions from all type of sources. Appropriate candidates are the following models: PolTran (NIMH, now operating – Eulerian type) AUSTAL (German - Lagrangian), AERMET (US EPA recommended - new generation Gaussian). The choice of the model or models will be done after validation of the results against in-situ AQ measurements.

WP on validation of project products. The main tasks include: identification and compilation of suitable data from various observational networks, elaboration of evaluation methodology; and evaluation of model performance for selected periods of about one month. It is foreseen to use data from the European air quality database AirBase (URL1), maintained by the European Environment Agency (EEA), also observational data from the Aeronet (URL2) and Earlinet (URL3) networks in order to check the AOD and extinction coefficients estimated by BgCWFS. The validation methodology has to be tailored to the type of observational and model data and shall include widely used statistical indicators and graphical representations (time series, scatterplots, etc.). It is foreseen to analyse the model's performance upon results from other comprehensive modelling systems as the one at CAMS (the Copernicus Atmosphere Monitoring Service, URL4) and the European EMEP-MSC-W (used by EEA for regular reporting on the AQ status in Europe, URL5).

The activities within SIDUAQ project are presented in Figure 7.

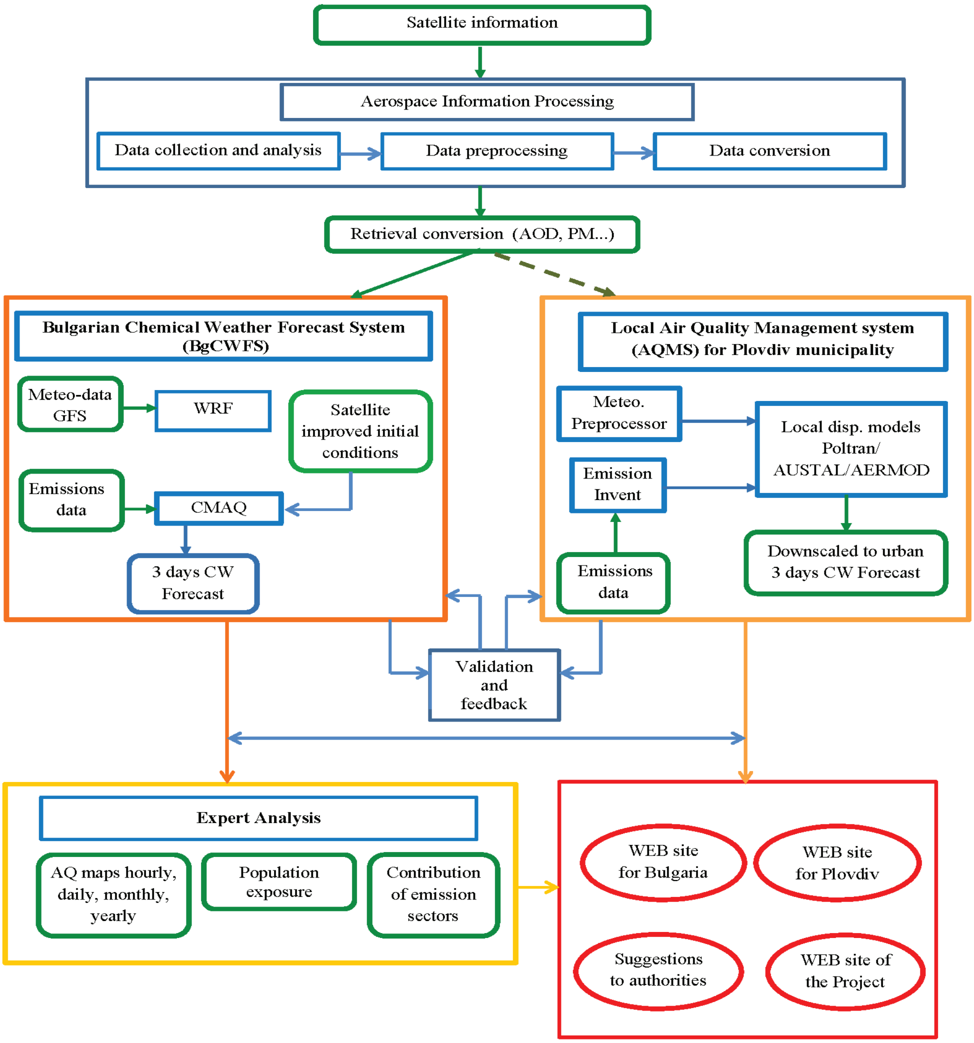

Fig. 7. Sketch of SIDUAQ project activities and expected results (Green – data & results; blue – models; red – final outcome)

5. EXPECTED RESULTS AND FUTURE PERSPECTIVES

Satellite data of atmospheric pollutants are becoming more widely used in the decision-making and environmental management activities of public, private sector and non-profit organizations. They are employed for estimating emissions, tracking pollutant plumes, supporting air quality forecasting activities, providing evidence for "exceptional event" declarations, monitoring regional long-term trends, and evaluating air quality model output. However, many air quality managers are not taking full advantage of the data for these applications.

The activities within SIDUAQ project aim at elaborating a prototype of a modern AQ system with assimilated satellite information. The outcomes of the activities will have both scientific and social impact. The experience gained by the project team will improve the capacity and readiness for extension of the off line prototype to operational forecasting system, that would be able to account for events "seen" by satellites, but not accounted for in the models, such as Saharan Dust storms, forest fires, volcanic ash. The concept for a reliable near real time (NRT) air quality forecast and management system at urban scale is a state of the art approach to integrate the available (satellite, in-situ) data and processing tools.

This system will support local authorities in taking decisions and appropriate measures for air pollution reduction, and thus will contribute to address health and quality of life issues. The created technology for Plovdiv could be modified and applied for other Bulgarian cities as well.

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REFERENCES

Atanassov D., S. Shilev, E. Naydenova, H. Chervenkov, T. Yankova (2014): Air Quality Management System of the City of Plovdiv – Annual Analysis For 2013, 16th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, 8-11 September 2014, Varna, Bulgaria, http://www.harmo.org/Conferences/Proceedings/_Varna/publishedSections/H16-020-Atanassov-EA.pdf.

Atanassov, D., (2003) Validation of the Eulerian Pollution Transport Model PolTran on the Kincaid Data Set, Int. J. Environment & Pollution, vol. 20, No.1-6, 105-113.

Atanassov, D., S. Spassova, D. Grancharova, S. Krastev, T. Yankova, L. Nikolov, M. Chakarova, P. Krasteva, N. Genov, J. Stamenov, E. Dimitrov, (2006), Air Pollution Monitoring and Modeling System of the Town of Plovdiv (phase I), Journal of Environmental Protection and Ecology, 7, No.2, 260-268.

Binkowski F.S. and Roselle S.J., 2003, Models-3 Community Multiscale Air Quality (CMAQ) model aerosol component1. Model description, J. Geophys. Res.,108, D6, 4183, doi:10.1029/2001JD001409

EEA, 2019 Air quality in Europe - 2019 report (2019) European Environmental Agency, Report No.10, 104 pp., ISBN 978-92-9480-088-6, ISSN 1977-8449, doi:10.2800/822355, https://www.eea.europa.eu/publications/air-quality-in-europe-2019

Georgieva E, Syrakov D, Prodanova M, Etropolska I, Slavov K (2015) Evaluating the performance of WRF-CMAQ air quality modelling system in Bulgaria by means of the DELTA tool. Int J Environ Pollut 57(3/4), pp.272 – 284, DOI: 10.1504/IJEP.2015.074512

Gryning, S.E., E.Batchvarova, B. Brümmer, H. Jørgensen, S. Larsen, (2007): On the extension of the wind profile over homogeneous terrain beyond the surface boundary layer. Boundary Layer Meteorol. 124, 251–268.

Kumar, P and M. Sharan, (2012): Parameterization of the eddy diffusivity in a dispersion model over homogeneous terrain in the atmospheric boundary layer. Atmospheric Research, 106, 30–43.

Syrakov, D., Prodanova, M., Slavov, K., Etropolska, I., Ganev, K., Miloshev, N., Ljubenov, T. (2013a): Bulgarian System for Air Pollution Forecast, Journal of International Scientific Publications ECOLOGY & SAFETY, Volume 7, Part 1, ISSN: 1313-2563, pp.325-334.

Syrakov, D., Etropolska, I., Prodanova, M., Slavov, K., Ganev, K., Miloshev, N., Ljubenov, T. (2013b): Downscaling of Bulgarian Chemical Weather Forecast from Bulgaria region to Sofia city, American Institute of Physics, Conf. Proc. 1561, pp. 120-132, http://dx.doi.org/10.1063/1.4827221.

Syrakov, D., Prodanova, M., Etropolska, I., Slavov, K., Ganev, K., Miloshev, N., Ljubenov, T. (2014): A Multy-Domain Operational Chemical Weather Forecast System, in I. Lirkov et al. (Eds.): LSSC 2013, LNCS 8353, pp. 413–420, DOI: 10.1007/978-3-662-43880-0 55, © Springer-Verlag Berlin Heidelberg 2014

Syrakov, D., Prodanova, M., Georgieva, E., Etropolska, I., Slavov, K. (2016): Simulation of European air quality by WRF-CMAQ models using AQMEII-2 infrastructure, Journal of Computational and Applied Mathematics, Volume 293, pp. 232-245.

URL1 AirBase: http://data.europa.eu/euodp/data/dataset/data_airbase-the-european-air-quality-database-7

URL2 Aeronet: https://aeronet.gsfc.nasa.gov/

URL3 Earlinet: https://www.earlinet.org

URL4 CAMS services: (https://atmosphere.copernicus.eu/

URL5 EMEP-MSC-W model: https://emep.int/mscw/mscw_moddata.html