Journal of Atomic, Molecular, Condensed Matter & Nano Physics
Vol. 7, No. 3, pp. 231–240, 2020
ISSN 2582-8215 (online)
Published by RGN Publications
DOI: 10.26713/jamcnp.v7i3.1547

http://www.rgnpublications.com

Proceedings of ICACTCE'21
High School of Technology, Moulay Ismail University Meknes, Morocco, and
Faculty of Sciences and Techniques Mohammedia, Hassan II University, Morocco
March 24 – 26, 2021, Morocco
Editors: Mariyam Ouaissa, Mariya Ouaissa, Sarah El Himer, and Zakaria Boulouard

Research Article

Assessment of Particulate Matter (PM_{10}) using Chemistry Transport Modeling in Agadir City, Morocco

Amine Ajdour*[1], Radouane Leghrib[1], Jamal Chaoufi[1], Hassan Fetmaoui[1], Mohamed Bousseta[1] and Ahmed Chirmata[2]

[1] *LETSMP, Department of Physics, Faculty of Sciences, University Ibn Zohr, Agadir, Morocco*
[2] *Department of Energy and Environment, Wilaya of Agadir, Agadir, Morocco*

Abstract. According to the *World Health Organization* (WHO), the effects of outdoor and indoor air pollution result in approximately 7 million early deaths each year. In Morocco's case, the economic cost of air quality degradation is about 1.62 percent of GDP. Also, several studies reported the significant influence of local meteorological factors on the PM_{10} daily concentration during the synoptic climate conditions and cyclonic circulation. In this sense, Agadir city is a coastal city, and its proximity to the desert makes it very exposed to particles. Accordingly, this study allows, on one hand, to evaluate the performance and to understand the limitations of the WRF-CHIMERE modeling system used to simulate the maximum concentrations of PM_{10} in the city of Agadir, based on observations made in spring and summer 2010. On another hand, in order to better understand the situation, the impact of meteorological variables and anthropogenic emissions on PM_{10} is being investigated. The preliminary results of air quality modeling pointed out some PM_{10} dispersion issues in the area of Agadir. In particular, the results highlighted the influence of temperature and wind speed, which were correlated with PM_{10} concentration. Besides, CHIMERE simulations suggested that anthropogenic emissions control is essential to reduce PM_{10} by up to 15%. The PM_{10} underestimation is attributed to the meteorological observation/model discrepancy and the effect of emissions. The results underline the importance of meteorology on PM_{10} dispersion and have significant policy considerations for Moroccan air quality strategy.

Keywords. Air quality modelling; Meteorological parameters; Anthropogenic emissions; Statistical factors; WRF-CHIMERE; Agadir city

PACS. 82.33.Tb; 92.60.Sz; 92.60.Sz; 92.60.-e

* **Corresponding author:** amine.ajdour@edu.uiz.ac.ma

1. Introduction

According to the *World Health Organization* (WHO), both long and short-term exposure to toxic substances in the air have several toxicological impacts on humans, especially respiratory and cardiovascular diseases and long-term chronic diseases, including cancer [19, 21, 23]. Most studies conclude that air pollution harms the ecosystem and especially the human health. In particular, pollution from high PM_{10} is the most critical environmental issue. Geographic diversity, meteorological, chemical, and anthropogenic activities are among the main contributing elements to *Particulate Matter* (PM) [8, 13]. This latter is a complex and non-uniform substance that can be a solid or a liquid suspended in the respiratory air. PM differs in mass, size, form, and chemical structure, giving it different solubility and reactivity [17, 22].

As known, meteorological conditions and emissions have a huge and direct impact on pollutant dispersion in a given environment. It allows researchers to study the effects of meteorological parameters on the diffusion, dilution, and distribution of pollutants. A good comprehension of the relationship between weather conditions and pollutants helps predicting the future evolution and risk scenarios. Several studies reported that local climatic conditions strongly influence PM_{10} daily variations in dry seasonal and synoptic meteorological conditions [7]. The dependence of particles of 10 μm aerodynamic diameter (PM_{10}) with meteorological conditions such as relative humidity, temperature, and wind speed has been examined in several worldwide regions [9, 10]. In particular, the impacts of such emissions on air quality and human health have become a growing concern because of the population density in coastal towns [20]. In terms of chemical composition, biomass combustion is the primary source of ambient PM_{10} concentrations [15]. In fact, the study of carbon components in particles revealed that forest fires were the dominant contributor of fine particles [14]. Analysis of emission trends is recommended for a comprehensive study of the origin of air pollution. As a result, several studies have evaluated their characteristic impacts on pollutant concentrations [16, 18].

In the case of Morocco, the economic cost of atmospheric pollution in 2018 has been estimated at 1.62 percent of the country's GDP, according to Morocco's Secretary of State for Sustainable Development. This significant number has encouraged Morocco to devote special efforts to fight against air pollution. In this perspective, many new studies in Morocco, precisely over the city of Agadir, presented the evaluation of air quality. To locally prioritize air quality issues, a survey was conducted in Agadir city, highlighting the need to periodically update the local *Air Quality Management* (LAQM) and the *Air Quality Monitoring Network* (AQMN) implementation [5]. As a result of the high investment and upkeep costs of the air quality monitoring network, a first air quality modelling based on CHIMERE_WRF was set-up and piloted for the first time in Agadir city [2].

The geographical location of Agadir as a coastal city and its proximity to the desert makes it very exposed to particulate matter. For this reason, this study provides a performance evaluation and a better understanding of the limitations of the WRF-CHIMERE modelling system used to simulate maximum PM_{10} in the city of Agadir, using observation data collected during the spring and summer of 2010. Then, to fully understand the situation, the impact of meteorological variables and anthropogenic emissions on PM_{10} is investigated. Finally, preliminary results of air quality modelling are used to highlight some PM_{10} dispersion problems in the Agadir city. This paper is structured as follows: in section 2, we will present the observational data and describe the WRF-Chimere model configuration used along with the statistical metrics. Section 3 will describe the results of the spring and summer simulation. Finally, Statistical analysis made on observed meteorological parameters and PM_{10} concentrations is presented.

2. Methodology

2.1 Observational Data

In order to assess the air quality in the city of Agadir, the Souss Massa Region has a regional mobile laboratory and a ground station for air quality monitoring since 2010. Both are equipped with Environment S.A. specific standardized analyzers to detect the harmful pollutants, along with climatic variables. In this investigation, data collected from the ground station are taken as reference observational data. The station is placed in a residential area in order to evaluate background urban pollution.

Regarding the impact of emissions, 2010 was selected as it provides temporal homogeneity between the monitoring data of pollutants and the global emissions inventory in Morocco. Based on the available data, we selected the spring and summer of 2010.

2.2 Model Configuration

The modelling part was carried out using three models. Based on WRF data, the CHIMERE model, version 2017r3, calculates the gas and aerosol concentration. The WRF (*Weather Research Forecasting*) model, version 4.0, is used to compute meteorological data. Finally, the Emis-surf model, version 2016b, provides gas and aerosol emissions.

2.2.1 Meteorological Model

The datasets are available from the University Corporation for Atmospheric Research. This NCEP FNL global (final) operational analysis data is prepared on a $1^\circ \times 1^\circ$ grid, with a resolution time of six hours. This data originates from the *Global Assimilation System* (GDAS), which continuously receives monitoring data from the *Global Telecommunication System* (GTS) and other resources for numerous assessments. For several years, the Advanced Research Modelling WRF has been under development. WRF can be used in several applications with scales ranging from meters to thousands of kilometres. As a micro-physics option, for example, we have set the WRF Single Moment 3 class scheme. It is a simple and powerful scheme with ice and snow events suitable for mesoscale grid sizes [11]. The meteorological model evaluation is performed by comparing WRF with the ground station observed data.

2.2.2 Air Quality Model

CHIMERE is a chemical transport model using a multi-scale Eulerian chemical transport process [12]. It is developed to generate daily forecasts pollutants, for reproducing long-term emission scenarios and studying typical cases. Several data inputs are used in this model, such as weather, land use, and emissions. Chemical boundary conditions are taken from the three-dimensional global chemistry-climate model LMDz-INCA, whereas aerosol boundary conditions are taken from the global models GOCART and LMDz-AERO [1]. The EDGAR-HTAP v2 global emission inventory prepared for 2010 is used for anthropogenic emissions estimation. The horizontal resolution is set to 0.1 degree.

2.2.3 Statistical Indicators

In this work, meteorological and air quality modelling results are compared with monitoring data. The performance of these models in the Agadir area is evaluated based on seven statistical indicators, including the *Mean Fractional Bias* (MFB), the *Mean Fractional Error* (MFE), the *Mean Normalized Bias* (MNB), the *Mean Normalized Bias* (MNE), the *Correlation Coefficient* (R), the *Mean Bias* (MB), and the *Mean Squared Error* (RMSE).

3. Results and Discussion

3.1 Model Performance

The comparative analysis between the monitoring meteorological values and the WRF values are listed in Table 1. These results indicate a good correlation factor, with very acceptable errors and RMSE, in good agreement with the literature [4]. Concerning the Spring period, temperature and wind speed present a correlation of 80% and 60% respectively, which corresponds to a strong relationship between modelled and observed data. The MB values suggest an underestimation of temperature and an overestimation of wind speed. In the summer period, the meteorological parameters show weak statistical performance, compared to the spring. For example, modelled temperature, with MB of 2.12 °C and RMSE of 3.10 °C, indicates a weak relationship between modelled and monitored data. Due to the scale difference, namely: local scale for measurement and global scale for modelling, the wind speed correlation is 42%.

Table 1. Summary of WRF result evaluation for wind speed and temperature

	Spring		Summer	
	T	WS	T	WS
Mean. Obs	20.10	1.34	27.10	1.59
Mean. Mod	20.00	1.34	25.00	1.64
MB	–0.10	0.01	2.12	0.04
RMSE	0.28	0.10	3.10	0.12
R	0.81	0.64	0.73	0.42

From Table 2, the statistical indicators of maximal PM_{10} show an underestimation of CHIMERE outcomes, in comparison to observations, and a low correlation between observation and model. In the summer, the BIAS = $-34.76\ \mu g/m^3$ means an underestimation of PM_{10} by CHIMERE, the MFE = 57.55% and the RMSE = $34.79\ \mu g/m^3$ are significant even if they are normal compared to other studies and other models, where MFE = 60% and RMSE = $41\ \mu g/m^3$ [1]. Underestimation may be due to input emission data issues and the effect of the meteorological conditions. In reality, in marine regions, sea salts may be greater than predicted, leading to the limitations of transport modelling and needs additional statistical processing to assimilate modelling values in the absence of exact emission data. Seasonal comparison, based on statistical factors, shows good model performance, and the performance goal is achieved in the spring (MFB ≤ ±30% and MFE ≤ 50%) while, in the summer, the model performance is acceptable and meets the criteria (MFB ≤ ±60% and MFE ≤ 75%) [3].

Table 2. Summary of CHIMERE's statistical analysis of PM_{10}

	Spring	Summer
Mean. Obs	67.54	78.91
Mean. Mod	50.67	44.14
MB	–16.86	–34.76
MFB	–25.83%	–57.55%
MFE	25.83%	57.55%
MNB	–21.94%	–44.57%
MNE	21.94%	44.57%
R	0.40	0.51
RMSE	21.36	34.79

3.2 Effect of Meteorological Factors

Observation data analysis, reported in Tables 1 and 2, indicate that the air *temperature* (T) increases from spring to summer. The measured *wind speed* (WS) is between 1.34 m/s in spring and 1.59 m/s in summer. Maximum seasonal PM_{10} concentrations ranged from 67.54 ug/m^3 in spring to 78.91 ug/m^3 in July. From all these information, we can highlight the trend between the PM_{10} and the climatic factors. In particular, Table 1 shows the correlations between PM_{10} and two meteorological factors, namely; temperature and wind speed. For air temperature, a strong positive relationship of 80% is observed. The summer correlation is more marked compared to the spring. Typically, clean days coincide with a lower temperature and vice versa, reflecting the strong correlation between PM_{10} concentration and temperature. The availability of solar heat can cause a more intense residence of PM_{10}, resulting in a higher accumulation and dispersion of the particles in the atmosphere [6].

For the wind speed, the relation with PM_{10} depends on the season. In spring, a weak negative correlation is noted ($r = -0.22$), whereas, in summer, the correlation is positive ($r = 0.25$). In the spring period, PM_{10} concentration and wind speed are inversely related. Under weak wind conditions, PM_{10} has the ideal conditions to reach a high concentration, whereas, if the wind speed is high, then, PM_{10} is carried away and dispersed in the atmosphere, resulting in a decrease of its concentration. Hence, the strong horizontal dispersion is responsible for the negative correlation of PM_{10} with wind speed. In turn, the summer period shows that high PM_{10} concentrations are related to high wind speeds. Therefore, the positive correlation results from strong winds which may have contributed to the liberation and transport of dust particles from the Saharian soil surface [24].

In this sense, the impact of temperature on PM_{10} shows a good convergence between the model and the observation. However, the wind speed effect shows a difference, especially in the summer season. The underestimation of PM_{10} by the model, particularly in the summer, can be justified by the weak correlation between modeled and observed wind, which means that the observation shows a considerable influence of wind speed on PM_{10} ($r = 0.25$).

Table 3. Statistical correlation between PM_{10} and meteorological parameters

	T		WS	
	Obs	Mod	Obs	Mod
Spring	0.44	0.49	−0.22	−0.2
Summer	0.80	0.76	0.25	−0.1

3.3 Effect of Anthropogenic Emission

In order to determine the influence of anthropogenic emissions, we focused only on the spring period. Anthropogenic emission effects are evident in the case of PM_{10}. In fact, the cancellation of anthropogenic emissions reduces PM_{10} by 15%, as illustrated in Figure 1.

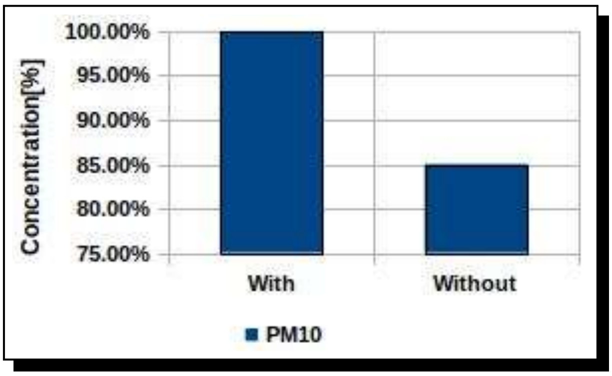

Figure 1. The PM_{10} monthly mean concentration with and without anthropogenic emission

Figure 2 shows the monthly average PM_{10} variation with and without anthropogenic emissions. The geographical location of the city of Agadir, at the frontiers of the Moroccan Sahara, makes it more strongly affected by the PM_{10} of Saharan origin.

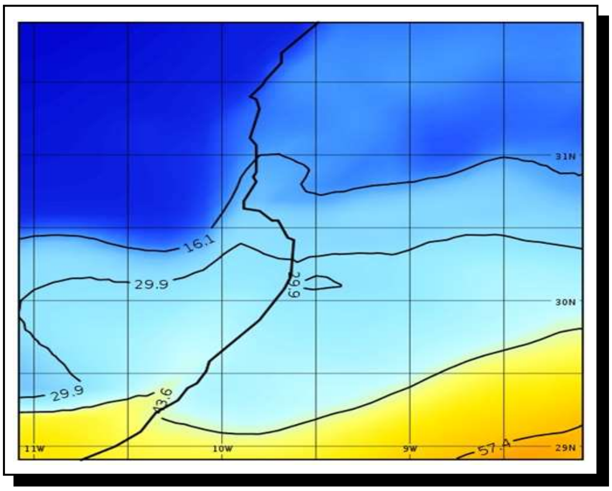

Figure 2. PM_{10} dispersion over Agadir city

The maximum PM_{10} dispersion analysis reveals two main sources, the western part (Atlantic Ocean) and the southern part (Moroccan Sahara), as shown in Figure 3. However, the highest concentrations of PM_{10} come from the East-South direction. As known, mineral dust is a dominant component of atmospheric particles. Then, the geographical location of Agadir, close to the desert, makes it vulnerable to this type of desert particle. Furthermore, the dominant winds over this period blow from the south and west of Morocco, as illustrated in Figure **??** which attributes the high density of PM_{10} reported in Agadir to the high density generated in the Moroccan Sahara and the Atlantic Ocean. Further research should be dedicated to this issue, and a microscopic study must be conducted to confirm such observations.

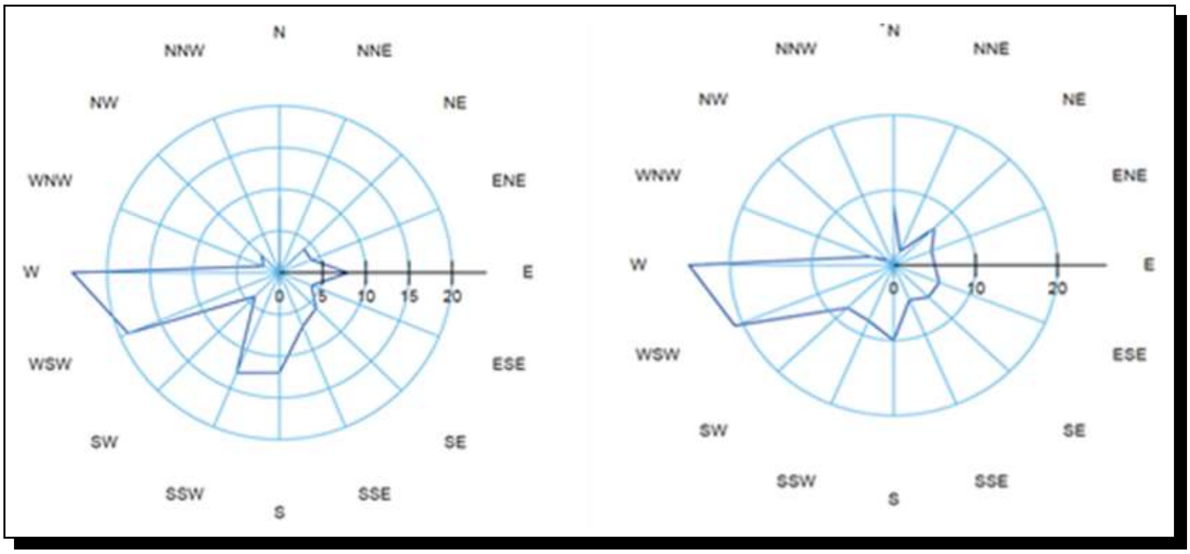

Figure 3. Monthly Wind Rose on May (left), on April (right)

4. Conclusion

This study presents a chemical transport model implementation applied to air quality modeling on the Moroccan territory, more precisely on the Agadir city, using WRF coupled with the CHIMERE model and a set of measured data collected from a fixed ground station. The results suggest an underestimation of temperature and PM_{10}, against an overestimation of wind speed, especially in summer. On one side, the underestimation of PM_{10} by the model, especially in the summer, can be justified by the low estimation of wind and temperature, thereby highlighting the considerable influence of both factors on the observed PM_{10}. On another hand, the anthropogenic emissions present an important factor that explains 15% of the concentration origin, which justifies the PM_{10} underestimation.

In future studies, we will need to determine the relationship between meteorological conditions and pollutants and to extend the study period to detect any seasonal variability together with an inventory of high-resolution emissions that is not available for the moment over Agadir city, and to provide a sufficient number of monitoring stations.

Acknowledgements

We acknowledge the Wilaya and the Region of the Souss Massa for their collaboration in this research work, under the leadership of the Wali and the president of the Region of Souss Massa, to whom we present our great and special thanks.

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

References

[1] C. Abdallah, C. Afif, N. El Masri, F. Öztürk, M. Keleş and K. Sartelet, A first annual assessment of air quality modeling over Lebanon using WRF/Polyphemus, *Atmospheric Pollution Research* **9** (2018), 643 – 654, DOI: 10.1016/j.apr.2018.01.003.

[2] A. Ajdour, R. Leghrib, J. Chaoufi, A. Chirmata, L. Menut and S. Mailler, Towards air quality modeling in Agadir City (Morocco), *Materials Today Proceedings* **24**(1) (2020), 17 – 23, doi: DOI: 10.1016/j.matpr.2019.07.438.

[3] J.W. Boylan and A.G. Russell, PM and light extinction model performance metrics, goals, and criteria for three-dimensional air quality models, *Atmospheric Environment* **40**(26) (2006), 4946 – 4959, DOI: 10.1016/j.atmosenv.2005.09.087.

[4] L.T. Carbonell, G.C. Mastrapa, Y.F. Rodriguez, L.A. Escudero, M.S. Gacita, A.B. Morlot, I.B. Montejo, E.M. Ruiz and S.P. Rivas, Assessment of the Weather Research and Forecasting model implementation in Cuba addressed to diagnostic air quality modeling, *Atmospheric Pollution Research* **4**(1) (2013), 64 – 74, DOI: 10.5094/APR.2013.007.

[5] A. Chirmata, R. Leghrib and I.A. Ichou, Implementation of the Air Quality Monitoring Network at Agadir City in Morocco, *Journal of Environmental Protection* **8**(4) (2017), 540 – 567, DOI: 10.4236/jep.2017.84037.

[6] S. Fuzzi, U. Baltensperger, K. Carslaw, S. Decesari, H. Denier van der Gon, M.C. Facchini, D. Fowler, I. Koren, B. Langford, U. Lohmann, E. Nemitz, S. Pandis, I. Riipinen, Y. Rudich, M. Schaap, J.G. Slowik, D.V. Spracklen, E. Vignati, M. Wild, M. Williams and S. Gilardoni, Particulate matter, air quality and climate: Lessons learned and future needs, *Atmospheric Chemistry and Physics* **15**(14) (2015), 8217 – 8299, DOI: 10.5194/acp-15-8217-2015.

[7] H. Hassan, M.T. Latif, L. Juneng, N. Amil, Md.F. Khan, D.J. Yik and N.A. Abdullah, Interaction of PM_{10} concentrations with local and synoptic meteorological conditions at different temporal scales, *Atmospheric Research* **241** (2020), 104975, DOI: 10.1016/j.atmosres.2020.104975.

[8] F.J. Kelly and J.C. Fussell, Size, source and chemical composition as determinants of toxicity attributable to ambient particulate matter, *Atmospheric Environment* **60** (2012), 504 – 526, DOI: 10.1016/j.atmosenv.2012.06.039.

[9] M. Khoshsima, F. Ahmadi-Givi, A.A. Bidokhti and S. Sabetghadam, Impact of meteorological parameters on relation between aerosol optical indices and air pollution in a sub-urban area, *Journal of Aerosol Science* **68** (2014), 46 – 57, DOI: 10.1016/j.jaerosci.2013.10.008.

[10] H.C. Kim, E. Kim, C. Bae, J.H. Cho, B.U. Kim and S. Kim, Regional contributions to particulate matter concentration in the Seoul metropolitan area, South Korea: Seasonal variation and sensitivity to meteorology and emissions inventory, *Atmospheric Chemistry and Physics* **17**(17) (2017), 10315 – 10332, DOI: 10.5194/acp-17-10315-2017.

[11] J.O.J. Lim, S.Y. Hong and J. Dudhia, The WRF-single-moment-microphysics scheme and its evaluation of the simulation of mesoscale convective systems, *Bulletin of the American Meteorological Society* **85** (2004), 2707 – 2710, URL: `https://ams.confex.com/ams/84Annual/techprogram/paper_73180.htm`.

[12] L. Menut, B. Bessagnet, D. Khvorostyanov, M. Beekmann, N. Blond, A. Colette, I. Coll, G. Curci, G. Foret, A. Hodzic, S. Mailler, F. Meleux, J.-L. Monge, I. Pison, G. Siour, S. Turquety, M. Valari, R. Vautard and M.G. Vivanco, CHIMERE 2013: A model for regional atmospheric composition modelling, *Geoscientific Model Development* **6**(4) (2013), 981 – 1028, DOI: 10.5194/gmd-6-981-2013.

[13] U. Pöschl, Atmospheric aerosols: composition, transformation, climate and health effects, *Angewandte Chemie International Edition* **44**(46) (2005), 7520 – 7540, DOI: 10.1002/anie.200501122.

[14] W. Phairuang, P. Suwattiga, T. Chetiyanukornkul, S. Hongtieab, W. Limpaseni, F. Ikemori, M. Hata and M. Furuuchi, The influence of the open burning of agricultural biomass and forest fires in Thailand on the carbonaceous components in size-fractionated particles, *Environmental Pollution* vol. 247, pp. 238–247, 2019, DOI: 10.1016/j.envpol.2019.01.001.

[15] I.O. Ribeiro, R.V. Andreoli, M.T. Kayano, T.R. Sousa, A.S. Medeiros, R.H.M. Godoi, A.F.L. Godoi, S. Duvoisin, S.T. Martin and R.A.F. Souza, Biomass burning and carbon monoxide patterns in Brazil during the extreme drought years of 2005, 2010, and 2015, *Environmental Pollution* **243** (2018), 1008 – 1014, DOI: 10.1016/j.envpol.2018.09.022.

[16] H. Shahbazi and V. Hosseini, Impact of mobile source emission inventory adjustment on air pollution photochemical model performance, *Urban Climate* **32** (2020), 100618, DOI: 10.1016/j.uclim.2020.100618.

[17] A.M. Taiwo, D.C.S. Beddows, Z. Shi and R.M. Harrison, Mass and number size distributions of particulate matter components: comparison of an industrial site and an urban background site, *Science of The Total Environment* **475** (2014), 29 – 38, DOI: 10.1016/j.scitotenv.2013.12.076.

[18] J. Tan, Y. Zhang, W. Ma, Q. Yu, J. Wang and L. Chen, Impact of spatial resolution on air quality simulation: a case study in a highly industrialized area in Shanghai, China, *Atmospheric Pollution Research* **6**(2) (2015), 322 – 333, DOI: 10.5094/APR.2015.036.

[19] WHO, *WHO: Air pollution and health: Summary*, 2018, URL: `https://www.who.int/airpollution/ambient/about/en/`.

[20] S.-P. Wu, M.-J. Cai, C. Xu, N. Zhang, J.-B. Zhou, J.-P. Yan, J.J. Schwab and C.-S. Yuan, Chemical nature of $PM_{2.5}$ and PM_{10} in the coastal urban Xiamen, China: insights into the impacts of shipping emissions and health risk, *Atmospheric Environment* **227** (2020), 117383, DOI: 10.1016/j.atmosenv.2020.117383.

[21] S.S. Yamamoto, R. Phalkey and A.A. Malik, A systematic review of air pollution as a risk factor for cardiovascular disease in South Asia: Limited evidence from India and Pakistan, *International Journal of Hygiene and Environmental Health* **217**(2-3) (2014), 133 – 144, DOI: 10.1016/j.ijheh.2013.08.003.

[22] J.D. Yanosky, C.C. Tonne, S.D. Beevers, P. Wilkinson and F.J. Kelly, Modeling exposures to the oxidative potential of PM_{10}, *Environmental Science & Technology* **46**(14) (2012), 7612 – 7620, DOI: 10.1021/es3010305.

[23] W. Zhang, C.N. Qian and Y.X. Zeng, Air pollution: A smoking gun for cancer, *Chinese Journal of Cancer* **33**(4) (2014), 173 – 175, URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3975182/, DOI: 10.5732/cjc.014.10034.

[24] H. Zhang, Y. Wang, J. Hu, Q. Ying and X. Hu, Relationships between meteorological parameters and criteria air pollutants in three megacities in China, *Environmental Research* **140** (2015), 242 – 254, DOI: 10.1016/j.envres.2015.04.004.