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ASSESSING THE IMPACT OF THE COVID-19 LOCKDOWNS: RESULTS AND IMPLICATIONS FROM A MODELLING APPLICATION IN TWO MEDITERRANEAN CITIES

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Abstract:
Activity restrictions implemented to control the spread of the COVID-19 virus imposed a significant effect on the air quality of cities across the world. The initiative of the World Meteorological Organisation / Global Atmospheric Watch for studying effects of the 2020 COVID-19 lockdowns on air quality has produced two sets of analysis results for cities across the world, based on observational data and modelling, respectively. The modelling study aims to evaluate the modelling tools in a regime involving significant changes of activity, and at the same provide insights on the effect of selectively reduced emissions on the chemistry and composition of urban pollutants. For most of the cities, a reduction on NO_x average concentrations between 11% and 70% was calculated for the lockdown period, while PM_{10} was reduced by 8% up to 35% in a good agreement with measured reductions observed during the 2020 lockdown period compared to the corresponding period of 2019. Taking advantage of an operational Air Quality Modelling System, which is in continuous application in the cities of Thessaloniki and Nicosia, the contribution of sectoral emissions and the role of meteorology over the observed concentration reductions was assessed. The study reveals that in both cities, observed reductions of urban $PM_{2.5}$, PM_{10} and NO_x concentration patterns can be mainly attributed to the corresponding emissions reductions in the transport and heating sectors, while O_3 is strongly affected by titration near the city centre. At the same time, meteorological patterns appear to strongly influence and even mask these effects in terms of daily averages, while the impact of imposed large-scale boundary conditions on the modelling results can also be significant.

Key words: air quality, urban air quality, emissions, lockdown, COVID-19

INTRODUCTION

Activity restrictions related to lockdowns are causing an unprecedented effect regarding air quality, particularly in urban areas. Modelling tools are instrumental in assessing the magnitude of the effects, as well as apportion contributions of individual activity sectors, particularly where no observations are present. As a result, the lockdown periods provided a unique opportunity for testing and validating simulation models in activity levels and regimes hard to observe under normal conditions. The present study presents preliminary results from a modelling study coordinated by the World Meteorological Organisation / Global Atmospheric Watch (WMO/GAW) aiming to assess effects of the 2020 COVID-19 lockdowns on air quality. Detailed results are further presented for the cities of Thessaloniki, Greece and Nicosia, Cyprus where an Operational Air Quality Management System (AQMS) was in continuous application throughout 2019 and 2020.

METHODOLOGY

In the frame of the WMO/GAW coordinated study regarding the effects of the 2020 COVID-19 lockdowns on air quality, two sets of analysis results have been produced based on data originating from measurements and from modelling results, respectively. The main goal of the modelling study lies in evaluating the modelling tools in a regime involving substantial changes of activity, as well as to provide a detailed understanding of the effect of selectively reduced emissions on the chemistry and composition of urban pollutants.

Most of the 16 groups participating in this study applied process-based chemical dispersion models under two different emission scenarios for the year 2020: a counterfactual “business as usual” (baseline or BAU)

scenario, under the working assumption that normal level activities occurred without any lockdown effects, as well as a "lockdown" scenario (COVID-19) taking into account the activity reductions during the lockdown periods applied in each individual city. For the European study areas, the emissions reduction scenario (COVID-19) was based on a set of sectoral activity emissions quantified as reduction factors provided by the CAMS consortium and calculated at the BSC (Guevara et al., 2021). In order to isolate effects of meteorology, a common set of meteorological driver fields was used for both scenarios. A harmonized approach was used for the comparative performance evaluation of models and analysis of results in terms of several pollutants, with emphasis on secondary substances including O_3, NO_x, O_x and SOA, as well as BC, OC and inorganic aerosol components. A detailed presentation of the analysis is under preparation.

The AQMS developed by the Laboratory of Heat Transfer and Environmental Engineering of the Aristotle University of Thessaloniki (LHTEE/AUTh) (Moussiopoulos et al., 2010; Moussiopoulos et al., 2012) was utilized for the assessment of different activity and emissions scenarios in Greece and Cyprus, based on quantified activity restriction data in economic sectors and activities that have been affected by the lockdown measures. Local gridded emissions for both study areas are based on national inventories developed and maintained by the AUTh group and provide separate contributions for the main activity sectors.

The simulations cover the period of March to mid-April 2020, consisting of three distinct phases, namely the pre-lockdown phase (1/3 - 8/3), the partial lockdown phase (9/3 - 22/3) and the full lockdown phase (23/3 – 12/4). During the pre-lockdown phase, slight decreases in the emissions of specific sectors such as aviation and road transport can already be noticed. Within the partial lockdown phase, these reductions gradually increase, while during the full lockdown phase the emissions of the main sectors remain constantly at notably low levels, especially for the case of NO_x. Figure 1 depicts the activity reduction factor (per sector) compared to a baseline situation for both cities under investigation.

MEMO was initialized with vertical profiles originating from the Global Forecast System (GFS; ULR1). Initial and boundary conditions for pollutant concentration fields were derived from the CAMS-ensemble operational output (URL2). Topography and land use data were obtained from the high-resolution satellite elevation datasets of NASA's Shuttle Radar Topography Mission - SRTM/90 m database (URL3) and the Corine Land Cover 2006 (URL4) database, respectively.

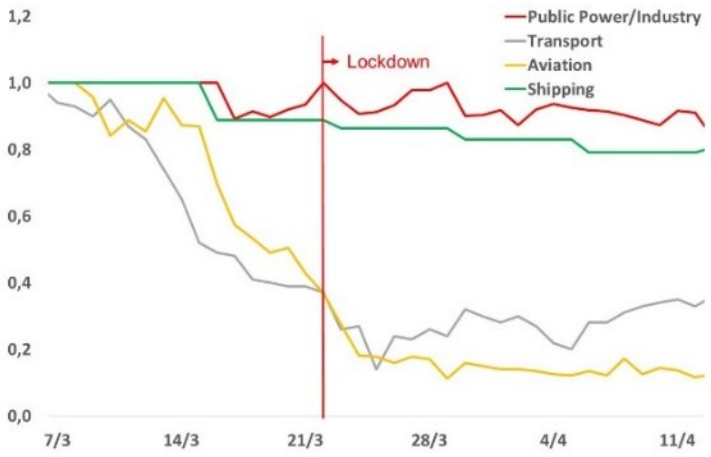

Figure 1. Sectoral activity reductions provided by CAMS/BSC, compared to the baseline situation as used for Thessaloniki and Nicosia (shipping activities relevant only regarding the Cyprus simulations)

RESULTS

Figures 2 and 3 depict a set of preliminary results from the WMO/GAW modelling study regarding NO_x and PM_{10}. In these figures, a comparison of average concentrations under the baseline and the lockdown scenario is presented for the set of 19 cities under investigation. For most of the cities, a reduction on NO_x

average concentrations between 11% and 70% was calculated for the lockdown period, while PM_{10} was reduced by 8% up to 35% in a good agreement with measured reductions observed during the 2020 lockdown period compared to the corresponding period of 2019. The magnitude of reductions attributed to activity patterns is similar to the day-by-day influence of meteorology, however a clear reduction trend for the lockdown period is reproduced.

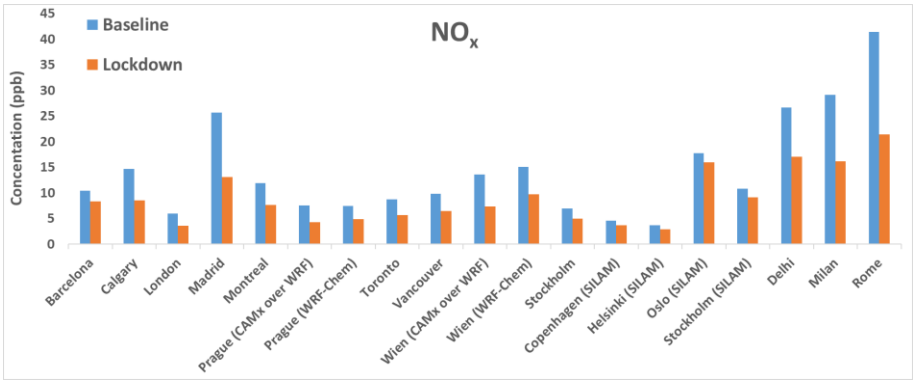

Figure 2. Comparison of modelling results regarding the baseline and lockdown scenarios for the 19 cities of the WMO/GAW study analysis as regards NO

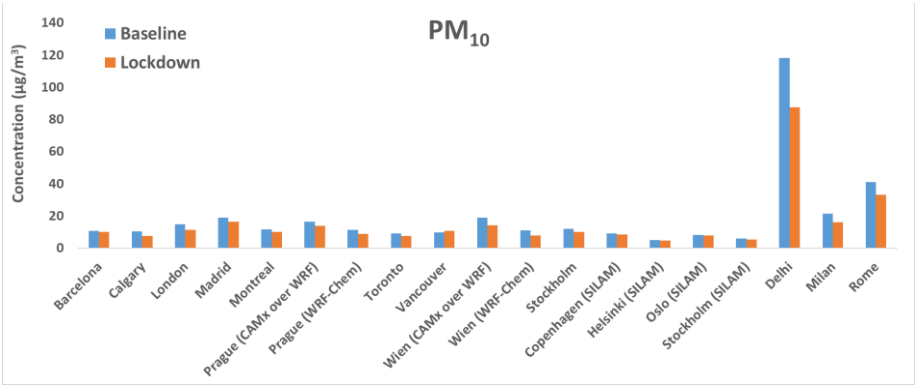

Figure 3. Comparison of modelling results regarding the baseline and lockdown scenarios for the 19 cities of the WMO/GAW study analysis as regards PM_{10}

In Figures 4 to 7, the results of MARS-aero simulations for the baseline and the COVID-19 lockdown scenarios are presented and compared with observational data for selected locations in the areas under investigation. In the case of Nicosia, the model accurately reproduces the observed concentration reductions in urban hotspot for the case of NO_2. The magnitude of reductions attributed to activity patterns is similar to the day-by-day influence of meteorology, however a clear reduction trend for the lockdown period is reproduced. As regards Thessaloniki, the model also reproduces the observed reduction in downtown traffic locations, with less accuracy though.

The model is also capable of reproducing the observed increases in suburban sites for O_3, which can be attributed to the corresponding decreases in NO_2 in titration-dominated regions. In the case of the Panorama residential station, a clear increasing trend is observed during the lockdown period (see Figure 5). More specifically, throughout the partial lockdown phase, the average calculated concentrations for the COVID-19 scenario are increased by 6.5%, while during the full lockdown phase this elevation reaches 11.4%.

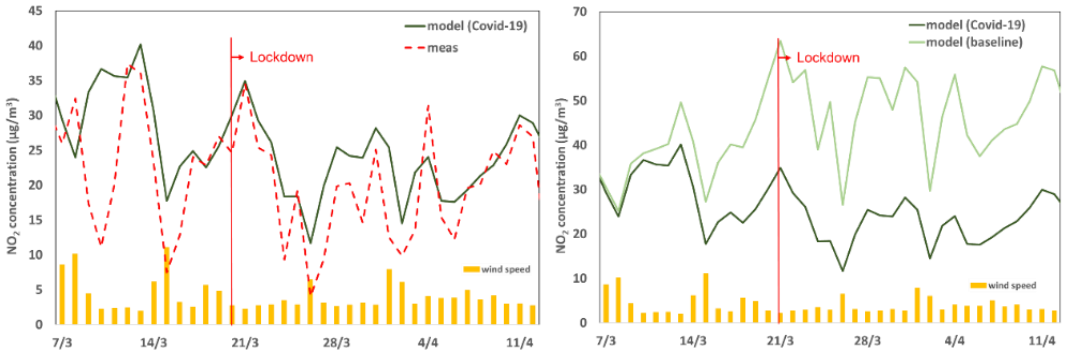

Figure 4. MARS-aero simulations for NO_2 for an urban hot spot of Thessaloniki (Ag. Sofias)

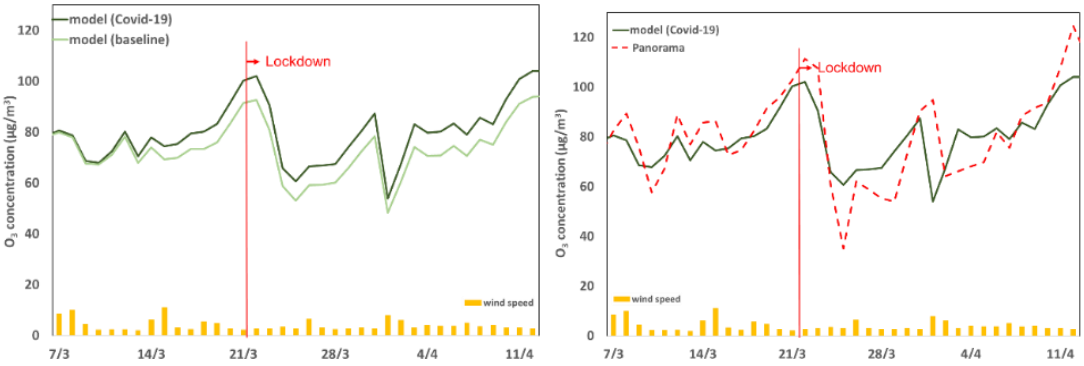

Figure 5. MARS-aero simulations for O_3 for a suburban location of Thessaloniki (Panorama)

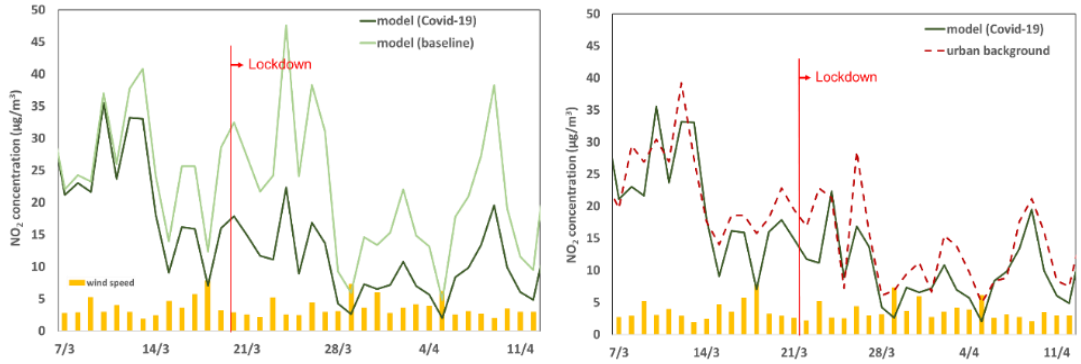

Figure 6. MARS-aero simulations for NO_2 for a residential location of Nicosia

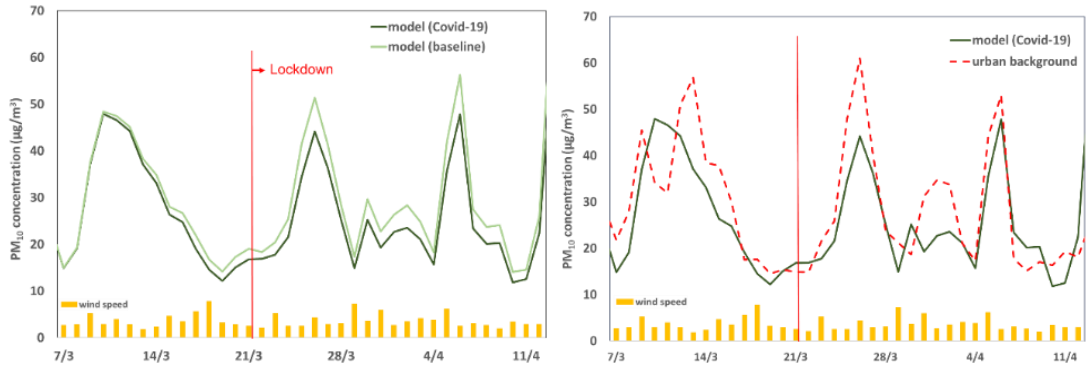

Figure 7. MARS-aero simulations for PM_{10} for a residential location of Nicosia

As indicated from the performance statistics over the application period (Table 1), the model exhibits a fairly good agreement with the observed values regarding NO_2 for urban hotspots in both cities under investigation. This is also the case for O_3 with respect to the suburban location of Panorama. On the other hand, the calculated results for PM_{10} reproduce the observed values with less accuracy, particularly in the timing and magnitude of strong episodic peaks. These shortcomings can be directly attributed to limited accuracy of the boundary conditions.

Table 1. Statistics regarding the accuracy of the model in the frame of the present case studies

	CC	BIAS (μg/m^3)	NMSE	IoA
Thessaloniki centre – NO_2	0.73	5.98	0.15	0.71
Thessaloniki centre – PM_{10}	0.53	-7.34	0.31	0.64
Thessaloniki suburban – O_3	0.85	-1.10	0.03	0.84
Nicosia residential – NO_2	0.76	-1.60	0.08	0.82
Nicosia residential – PM_{10}	0.67	-2.10	0.12	0.69
Nicosia residential – O_3	0.84	3.29	0.04	0.82

CONCLUSIONS

Modelling simulations of air quality under the 2020 COVID-19 lockdowns in several cities all over the world are coordinated in the framework of an WMO/GAW initiative. Preliminary results show a consistent reduction of urban NO_2 concentrations between 11% and 70%, while PM_{10} was reduced by 8% up to 35% compared to a BAU scenario. These results are in a good general agreement with reductions observed in monitoring data between 2020 and the corresponding period of 2019. Detailed calculations for two Eastern-Mediterranean cities confirm the significant decrease in urban NO_2 concentrations during the COVID-19 lockdown, which can be directly attributed to the corresponding reductions in NO_x emissions, particularly on the transport sector, while O_3, as a secondary pollutant, displayed a more complicated response. In the case of PM, calculated concentrations indicate a slight decrease in the COVID-19 scenario during the lockdown phase. However, since seasonal PM patterns were BCs-dominated, reflecting a strong influence of large-scale effects such as Saharan dust episodes, regional-scale scenarios should be utilized in order to more accurately simulate the total lockdown effects on PM levels. Uncertainties, in particular in diurnal PM patterns, could be further reduced by improving the representation of heating emissions, especially for the case of Thessaloniki. It is also evident that imposed BCs largely dominate both O_3 and coarse PM_{10} (due to dust transport) and can partly mask the local emissions signal even for NO_x, less so for $PM_{2.5}$. These effects indicate that the multiscale approach, also favoured in the frame of the ongoing WMO/GAW initiative, will be necessary to minimise such uncertainties and provide reliable sectoral attribution.

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