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IMPACT OF COVID-19 LOCKDOWN TO AIR QUALITY IN TWO LARGEST CITIES IN ESTONIA

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Abstract: The impact of COVID-19 lockdown to the pollution of particulate matter and nitrogen oxides in two largest cities of Estonia in spring of 2020 is analysed by means of concentrations measured in monitoring stations. For Tallinn, the capital and largest city of Estonia, the model runs for pre-lockdow, lockdown, partial relaxation and full relaxation periods in 2020 and equivalent time intervals in 2019 were performed, keeping in mind realistic vehicle and residential heating emissions due to lockdown and the business and usual (BAU) scenario and using the Gaussian plume model AEROPOL. Intercomparison of modelled and measured concentrations affirms the certain reduction of concentrations in urban traffic hotspots due to lockdown measures, but reveals the weakness of AEROPOL in reproducing the daily course and spread of emissions from streets to more remote urban areas, which leads to the tremendous overestimation of daily maxima and thus, overestimation of average concentrations of NOx. The results are valuable for further refinement of dispersion prametrization in AEROPOL model.

Key words: *COVID-19, lockdown, particulate matter, nitrogen oxides, Gussian plume model, AEROPOL***.**

INTRODUCTION

This study is about changes in air quality due to COVID-19 lockdown measures in Tallinn, the capital and largest city in Estonia (400 thousand inhabitants) and second largest city Tartu (100 thousand inhabitants), which together accommodate about 40% of country´s population. In Estonia the full lockdown started in mid-March 2020 without partial phase, was partially relaxed from beginning of May and fully relaxed from beginning of June. The lockdown measures included closing the bars, restaurants and most of shops, distant learning in schools and universities, strongly encouraging the office workers to work from home and decreasing the number of public busses and trains. In general, the industrial enterprises continued to operate, lockdown measures were taken in case of immediate outbreak of virus in certain enterprise.

The yearly course of dispersion conditions and emissions was affected by unusual weather patterns in Baltic region: the winter of 2020 was extremely mild and late spring (the partial relaxation period in May) rather cold, with severe night frosts. The Gaussian plume model AEROPOL (Kaasik & Kimmel, 2004, Geertsema & Kaasik, 2018) was used to distinguish the lockdown-induced and weather-induced effects. On the other hand, this study appeared valuable for validation of AEROPOL model.

DATA AND METHODS

Air quality data

The hourly-based concentrations of PM_{10}, $PM_{2.5}$ and NOx were acquired from governmental air quality monitoring system, operated by Estonian Environmental Research Centre (EERC). Following phases of COVID-19 lockdown in 2020 were distinguished:

- Pre-lockdown, February 14 – March 14;
- Full lockdown, March 15 – May 1;
- Partial relaxation, May 2 – May 31;
- Full relaxation, June 1 – June 30.

For comparison the concentrations measured during equivalent dates of previous year (2019) were used.

The concentrations from three stations in Tallinn, the single one within urban area of Tartu and two rural background stations were acquired. The rural station Lahemaa was assumed the regional background for Tallinn and the Saarejärve station for Tartu. The coordinates of monitoring stations are given in Table 1.

Table 1. Coodinates of monitoring stations considered in this study

Station name	Latitude (deg. N)	Longitude (deg. E)	Type
Tallinn - Liivalaia	59.43112	24.76047	Urban-street
Tallinn - Rahu	59.44728	24.71544	Urban-industrial
Tallinn - Õismäe	59.41413	24.64923	Urban background
Lahemaa	59.51533	25.92929	Rural background
Tallinn - Harku	59.39810	24.60280	Meteorological
Tartu-Karlova	58.37060	26.73485	Urban background
Saarejärve	58.70146	26.75471	Rural background
Tartu -Tõravere	58.26420	27.46140	Meteorological

Model input

The single-site hourly meteorological data (wind speed and direction, ambient temperature, precipitation amount, solar radiation flux) were used for air pollution dispersion modelling for each urban domain. Meteorological stations of Estonian Weather Service near Tallinn and Tartu are listed in Table 1.

The data on street traffic emissions are based on traffic flow modelling (reference year 2017) and lockdown traffic data by Stratum OÜ. The vehicle emission coefficients by EURO categories originate from inventory of TU Graz (2009), tyre and road emissions based on adapted and simplified method by Norman et al (2016). Heating emissions originate from inventory by Estonian Environmental Research Centre, with contribution of the author (reference year 2013); increased by 30% for lockdown, as an expert estimation. Both the traffic flow and heating data include realistic daily courses. Measured background concentrations of PM2.5 from Lahemaa rural monitoring station (see Table 1) were added to the modelled urban concentrations in Tallinn.

Modelling

The model runs for Tallinn city were made for pre-lockdown, full lockdown, partial and full relaxation periods in 2020 and respective time intervals in 2019. The similar modelling study for Tartu is in progress.

The model runs were made with Gaussian plume model AEROPOL (basic features: Kaasik & Kimmel, 2004). Using the version 5.3.2 (release year 2018), the Gryning (1987) dispersion parametrization scheme is applied, as described by Geertsema & Kaasik (2018). Due to absence of directly measured surface heat flux, it was assumed that 40% of incoming solar radiation is converted into turbulent heat flux in daytime in urban environment. In night time the Pasquill classification was applied.

In urban domain of Tallinn, dimensions 15 by 12 km, the concentrations were modelled with grid resolution of 0.2 km and in addition for exact locations of monitoring stations (see Table 1). In order to facilitate modelling in reasonable computing time, but still reproduce the daily course, the 4-hour time step was applied, averaging the initial hourly meteorological data. In post-processing the daily averages of concentrations and then, based on daily values, the averages, medians and standard deviations for lockdown-related time intervals were calculated. For lockdown and partial relaxation periods in 2020 two parallel scenarios were modelled: (1) with real lockdown emission data and (2) with business as usual (BAU) emissions.

RESULTS AND DISCUSSION

Measured concentrations

Averages through lockdown-related periods in 2020 and equivalent time intervals in 2019 are presented in Figure 1. It is remarkable that in winter and spring of 2019 the concentrations were remarkably higher than in 2020. This may be a result of lower temperatures, less precipitation and slightly weaker winds in 2019. Peaking concentrations of PM10 in March and April 2019 in urban stations are most probably related to a dust episode after snowmelt in beginning of March, which is known phenomenon in Northern Europe (Omstedt et al, 2009). In winter of 2020 there was almost no snow, thus the dust episode was not observed.

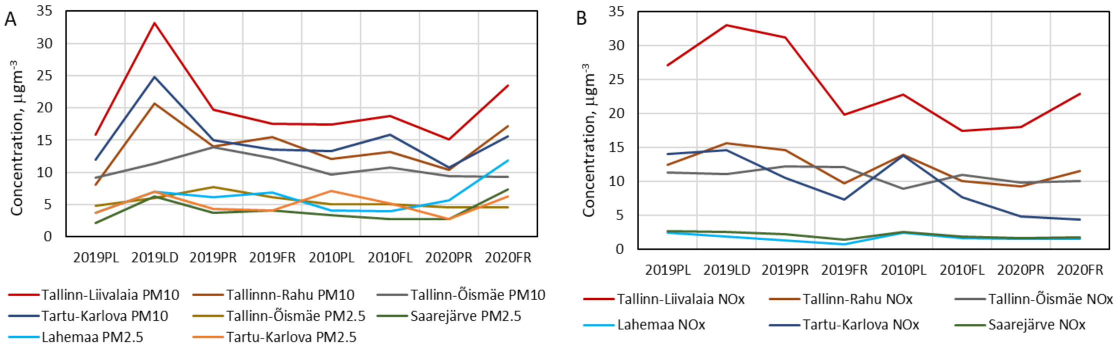

Figure 1. Average measured PM (A) and NOx (B) concentrations during pre-lockdown (PL), full lockdown (FL), partial relaxation (PL) and full relaxation (FR) in 2020 and equivalent time intervals in 2019.

Model results and comparison with measurement

The modelled average concentrations of lockdown periods and equivalent time intervals in 2019, compared to the BAU scenario and measured concentrations, are presented in Figures 2 (PM_{10}) and 3 (NOx). The contributions of sources in total modelled concentration in lockdown scenario are given cumulatively.

It is evident that AEROPOL model tends to overestimate the concentrations in the street station and underestimate in more remote urban areas. The tendency is more pronounced in case of NOx. Remarkably, the fit of PM_{10} in Liivalaia street station is nearly perfect through 2019 and pre-lockdown and lockdown periods in 2020, but difference increases dramatically during the partial and full relaxation, whereas the lockdown scenario gives only marginal improvement in respect to BAU during partial relaxation. The overestimation of NOx in Liivalaia is pronounced through all the periods, but increases even more dramatically in relaxation.

Notably, the Pearson correlations between modelled and measured daily values of PM_{10} in Liivalaia are mostly in range of 0.3 – 0.5, with lowest value of 0.21 (pre-lockdown equivalent period in 2019) and highest 0.83 (in partial relaxation equivalent, 2019). In Rahu and Liivalaia stations the correlations are higher in general, due to contribution of rural (Lahemaa) background that is included in to modelling. The modelled-measured concentrations of NOx are even higher, in range of 0.62 – 0.84 through all the periods in Liivalaia. Thus, AEROPOL model seems to reproduce the basic features of day-to-day variations. In case of NOx, the correlations in Rahu and Õismäe are somewhat lower, mostly 0.4 – 0.7.

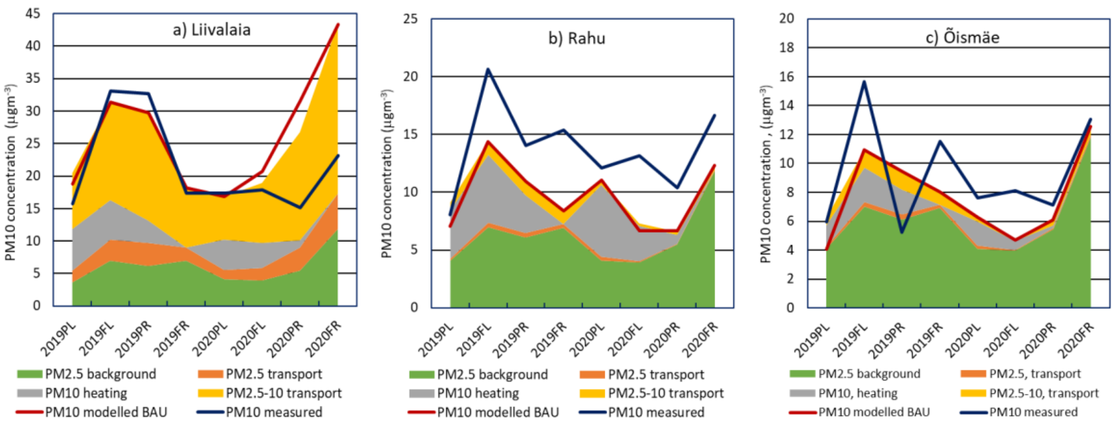

Figure 2. Modelled lockdown scenario concentrations of PM_{10} (cumulative contributions of sources) compared to BAU scenario and measured values in monitoring stations in Tallinn. Labels for periods, see Figure 1.

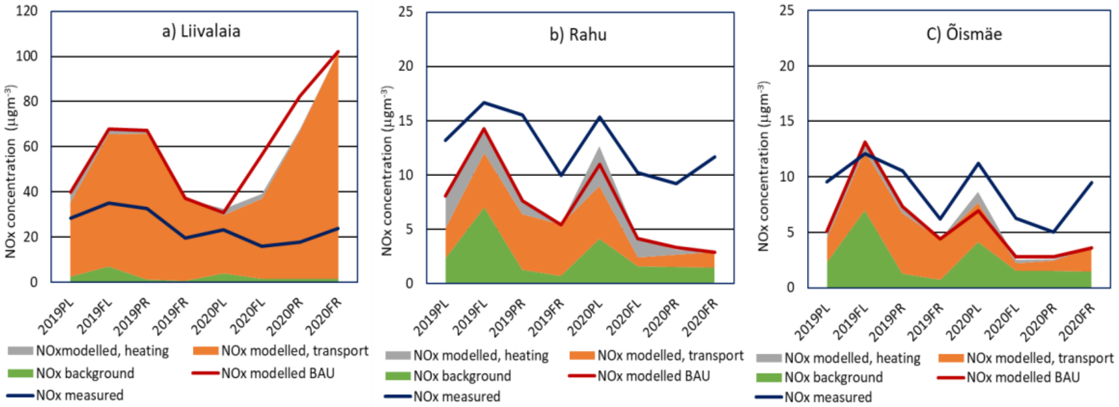

Figure 3. Modelled lockdown scenario concentrations of NOx (cumulative contributions of sources) compared to BAU scenario and measured values in monitoring stations in Tallinn. Labels for periods, see Figure 1.

Daily course of NOx and statistical correction of overestimation

Searching for the reason of overshooting of average concentrations, let´s look at 4-hourly time series (Figure 4), revealing the tremendously high daily maxima at traffic site, whereas the night-time minima are in realistic range or often even underestimated. This pattern appears both in PM and NOx time series, but is more pronounced for NOx. The discrepancy may occur due to the way, how AEROPOL model handles the condition of PBL, projecting the parametrization of Gryning (1987), which was initially developed for elevated sources, to the low-level street emissions. In addition, AEROPOL may underestimate the wet deposition due to the high precipitation rate (average about 3 mm per day) during the full relaxation period, 2020, as the parametrization based on (McMahon & Denison, 1979) may be outdated.

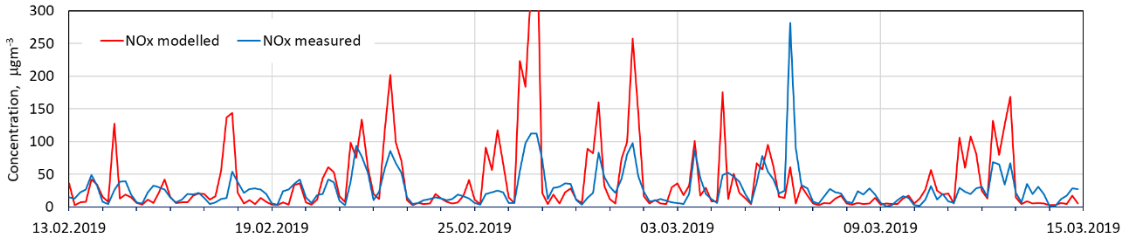

Figure 4. Modelled and measured 4-hourly concentrations of NOx in Liivalaia station during lockdown-equivalent period in 2019.

Based on all 4-hourly measured and modelled NOx concentrations in Liivalaia, Rahu and Õismäe stations during all considered periods in 2019, a power-law regression formula was fitted:

$$C_{fit} = 4.7433 C_{modelled}^{0.409} \qquad (1)$$

(R^2=0.41). Applying this formula (1) as correction to the modelled 4-hourly values through periods in 2020, more realistic results are achieved (Figure 5). In Liivalaia station the pre-lockdown concentrations appear underestimated now, but the partial and full relaxation concentrations are still slightly overestimated. The lockdown scenario concentrations fit remarkably better than BAU, as the reduction of street emissions has high impact. In Rahu station the concentrations are moderately underestimated, but less than without correction (1). In Liivalaia station the modelled concentrations fit to the measured course in general, but the differences between periods are less pronounced. The lockdown scenario makes marginal correction in respect to BAU.

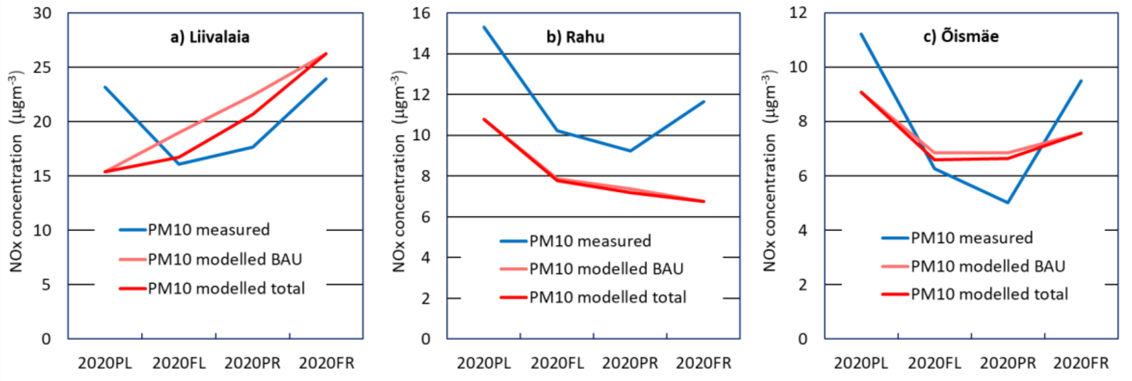

Figure 5. Modelled, daily-course-corrected (Eq. 1) 2020 lockdown scenario concentrations of NOx compared to BAU scenario and measured values in monitoring stations in Tallinn. Labels of periods, see Figure 1.

CONCLUSIONS

The modelling results affirm the reduction of concentrations of PM_{10} and NOx in an urban hotspot of medium-sized town Tallinn due to COVID-19 lockdown in spring of 2020. However, the Gaussian plume model AEROPOL performs rather poorly in modelling the daily course of vehicle-induced pollution and its spread from streets to remote urban areas. Keeping in mind further development of the model, the dispersion parameters for low-level sources, as well as the algorithm for washout should be revised.

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