IV.4 Ground-level ozone

IV.4.1 Air pollution by ground-level ozone in 2020

Air pollution by ground-level ozone in 2020 in relation to limit values for the protection of human health

During the three-year period 2018–2020, the ground-level ozone (O_3) limit value was exceeded[1] at 34 out of 67 stations (51%), where the O_3 concentrations were measured (Figures IV.4.1 and IV.4.2). For the previous three-year period 2017–2019, the ground-level O_3 limit value was exceeded at 36 out of 64 stations (56%), in the period 2016-2018 at 33 out of 65 stations (51%), in 2015–2017 at 21 of 71 stations (30%), and in the period 2014–2016 at 22 of 75 (29%) stations. The number of stations with exceeded pollution limit has been increasing in recent years.

The O_3 limit value was exceeded during the three-year period 2018–2020 over 62% of the territory of the CR, with approximately 52% of the population (Fig. IV.4.3). Compared to the previous five three-year periods, the extent of the area exceeding the limit value for O_3 in 2020 ranks third (71% of the territory with 57% of the population in the period 2017–2019, 80% of the territory with 52% of the population in the period 2016–2018, 31% of the territory with 9% of the population in the period 2015–2017, and 18% of the territory with 4% of the population in the period 2014–2016). Within the individual years of the period 2018–2020, the lowest occurrence of increased concentrations took place in 2020 (Fig. IV.4.4). No smog situation was announced for ground-level O_3 in 2020 (for more see Chapter VI).

The annual variation in average monthly concentrations of ground-level O_3 (maximum 8-hour average for a given month) is characterized by an increase in concentrations in spring and summer months due to favourable meteorological conditions for the formation of ground-level O_3. In 2020, the same level or decrease of concentrations in comparison with the ten-year average 2010–2019 in all months of the year except for March is evident

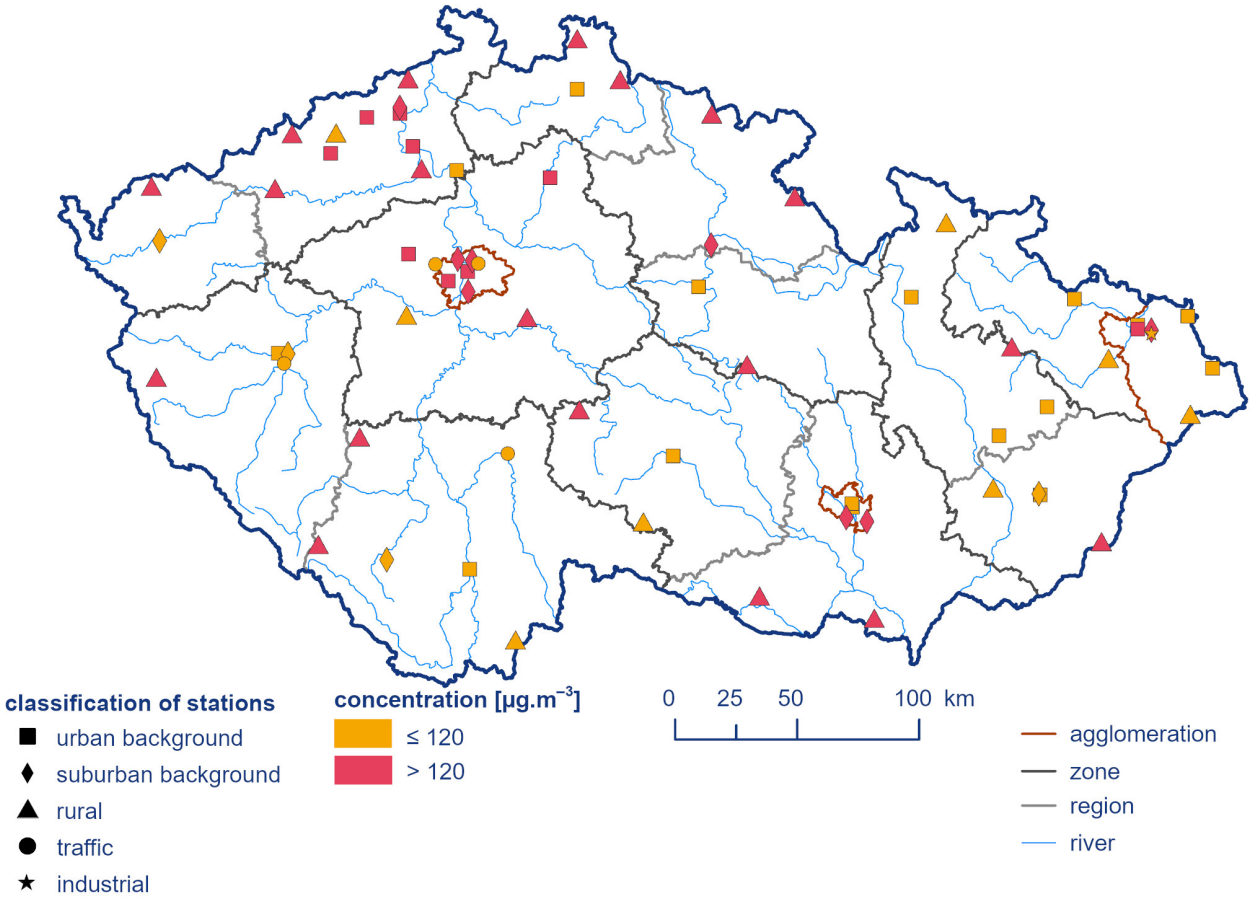

Fig. IV.4.1 The 26th highest values of maximum daily 8-hour running average of ground-level ozone concentrations (three-year average) in the ambient air quality network, 2018–2020

1 The limit value is exceeded if the O_3 maximum daily 8-hour running average was higher than 120 µg.m^{-3} at least 26 times in three-year average.

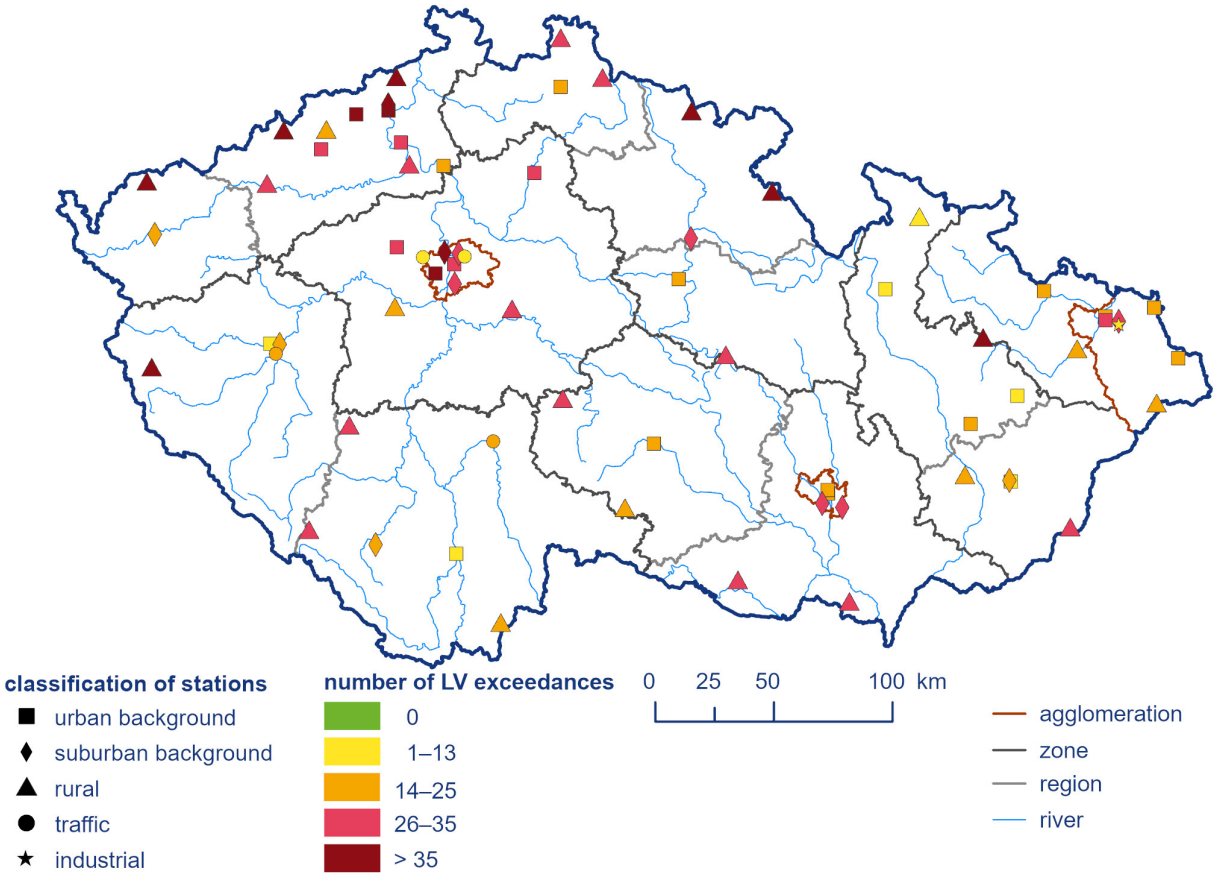

Fig. IV.4.2 Numbers of exceedances of the limit value for the maximum daily 8-hour running average of ground-level ozone concentrations in three-year average, 2018–2020

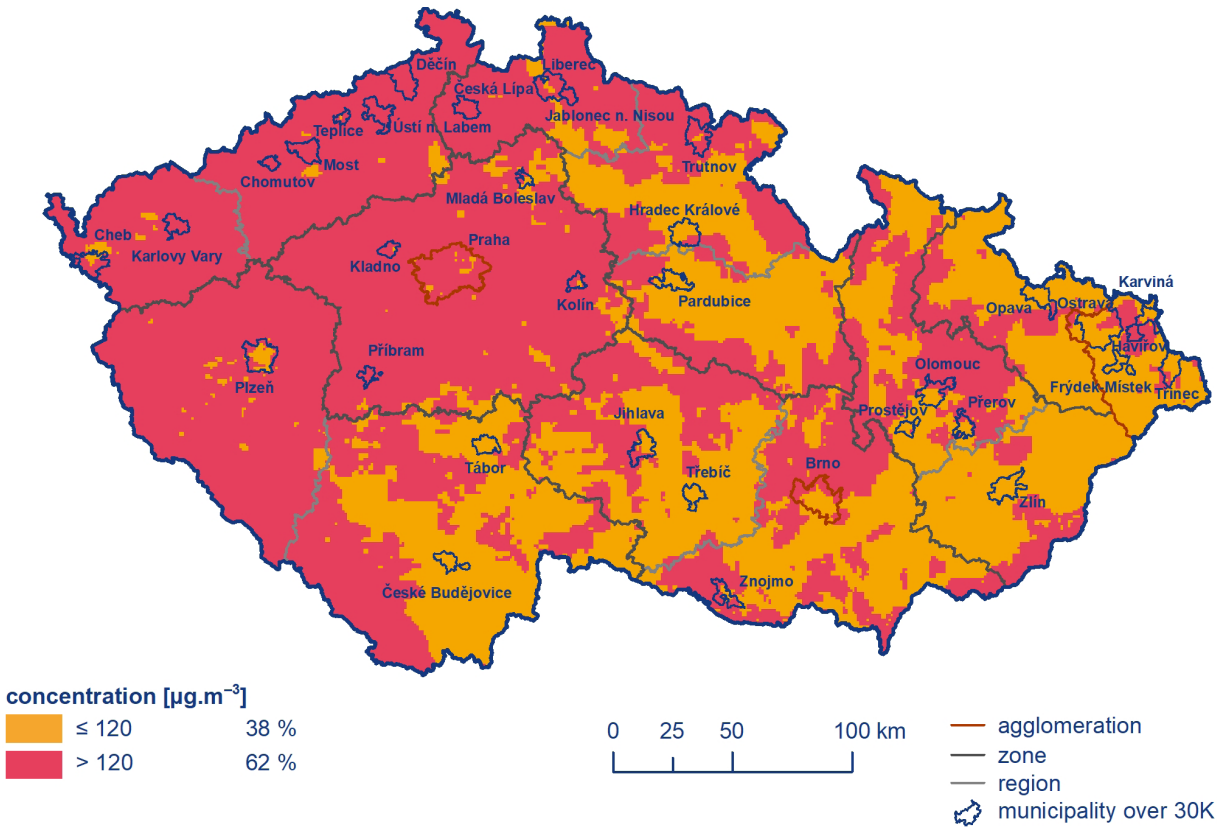

Fig. IV.4.3 Field of the 26th highest maximum daily 8-hour running average of ground-level ozone concentration in three-year average, 2018–2020

Fig. IV.4.4 Number of exceedances of 8-hour limit value of ground-level ozone per year for selected stations, 2018–2020

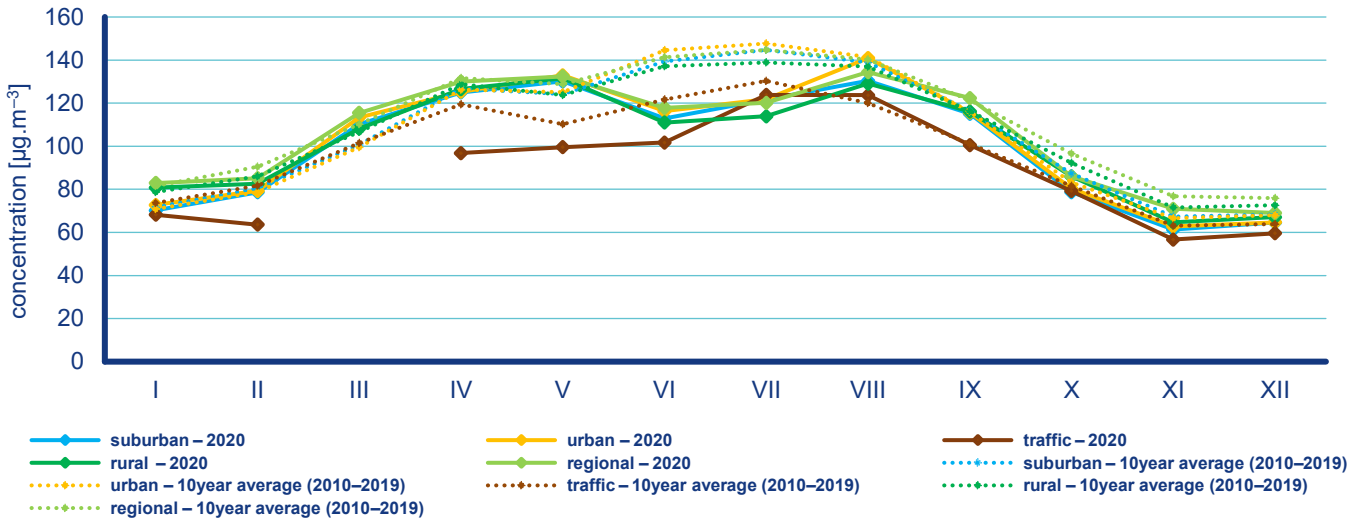

Fig. IV.4.5 Annual course of average monthly concentrations of max. 8-hour running average of O_3 (averages for the given type of station), 2020

(Fig. IV.4.5). The decrease in concentrations in 2020 is also evident in the warmer months of the year, when high concentrations of O_3 were measured in previous years, sometimes leading to the announcement of smog situations. The drop in concentrations in June (by 18%) and July (by 17%) in 2020 corresponds to an extremely above-normal total precipitation in June and normal temperatures in June and July (suppressing suitable conditions for formation of ground-level ozone). The highest O_3 concentrations in 2020 were measured in August, the warmest month of 2020 (Chapter III), but they were still at a lower level than the ten-year average 2010–2019. An increase in O_3 concentrations compared to the ten-year average occurred in March, mostly at city stations (14%). In March, a state of emergency was declared in the CR and a significant decrease in traffic followed (see Annex II). The in-

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crease in O_3 concentrations in the urban environment due to the decrease in NO_x emissions from traffic during lockdowns is also confirmed by some studies (Brancher 2021, Sicard 2020). Due to the complicated atmospheric chemistry of ozone and the number of factors that influence its formation and depletion, it is difficult to evaluate the change in March concentrations in more detail.

The lowest concentrations of ground-level O_3 are measured at localities subject to traffic loads (Fig. IV.4.5 and IV.4.9) where ground-level O_3 is decomposed by chemical reactions with NO (NO forms a part of NO_x). It can be assumed that O_3 concentrations are also lower or below the limit in other areas with heavy traffic where, however, this probable reduction cannot be documented using current methods of map preparation because of the lack of measurements. The values of ground-level O_3 concentrations at rural, suburban and urban stations reach similar levels, and are higher compared to concentrations at traffic stations (Fig. IV.4.5). This is also confirmed by the study by Paoletti et al. (2014), where between 1990 and 2010 a decreased difference was observed between the concentrations measured at rural and urban stations in Europe and the USA. Simultaneously, the maximum values measured at these stations also decreased. The aforementioned decrease in the concentrations of ground-level ozone is attributed, amongst other things, to the reduction in emissions of its precursors, especially NO_x, in developed countries. The reduction in concentrations in relatively clean areas is attributed to the reduction of both NO_x and VOC emissions on a wider (European to global) scale (Sicard et al. 2013).

Ground-level ozone in 2020 in relation to the limit value for the protection of ecosystems and vegetation

The ground-level O_3 limit value for the protection of vegetation of 18,000 $\mu g.m^{-3}.h$ (five-year average, Tab. I.2) was exceeded at 18 stations (46.2%) of the total number of 39 rural and suburban stations for which calculation of the exposure index AOT40 is relevant according to legislation (concerning the 2016–2020 average). The highest values of the AOT40 index for the last 11 years (evaluation period 2010–2020) were found in 2019, followed by 2010 and 2018 (on average for 32 rural and suburban stations with the complete time series 2010–2020). In 2020, the values of the AOT40 index were the fourth highest for the period 2010–2020 (Fig. IV.4.6, IV.4.10). The highest values of the AOT40 index were found in 2020 at the Rudolice v Horách, Prague 6-Suchdol, Sněžník, Krkonoše-Rýchory and Kuchařovice stations. The occurrence of above-limit AOT40 values occurred in 2020 mainly in the mountain areas of the Ústí nad Labem and Liberec regions, as well as in the Šumava, Central Bohemia and South Moravia regions (Fig. IV.4.7).

The annual values of the AOT40 index have long exceeded the value of the long-term pollution limit value (6,000 $\mu g.m^{-3}.h$, Tab. I.2) at all rural and suburban stations (the same set of stations for the last five years, Fig. IV.4.8). For the evaluated five-year period, the values of the AOT40 index in 2020 were the lowest at most stations.

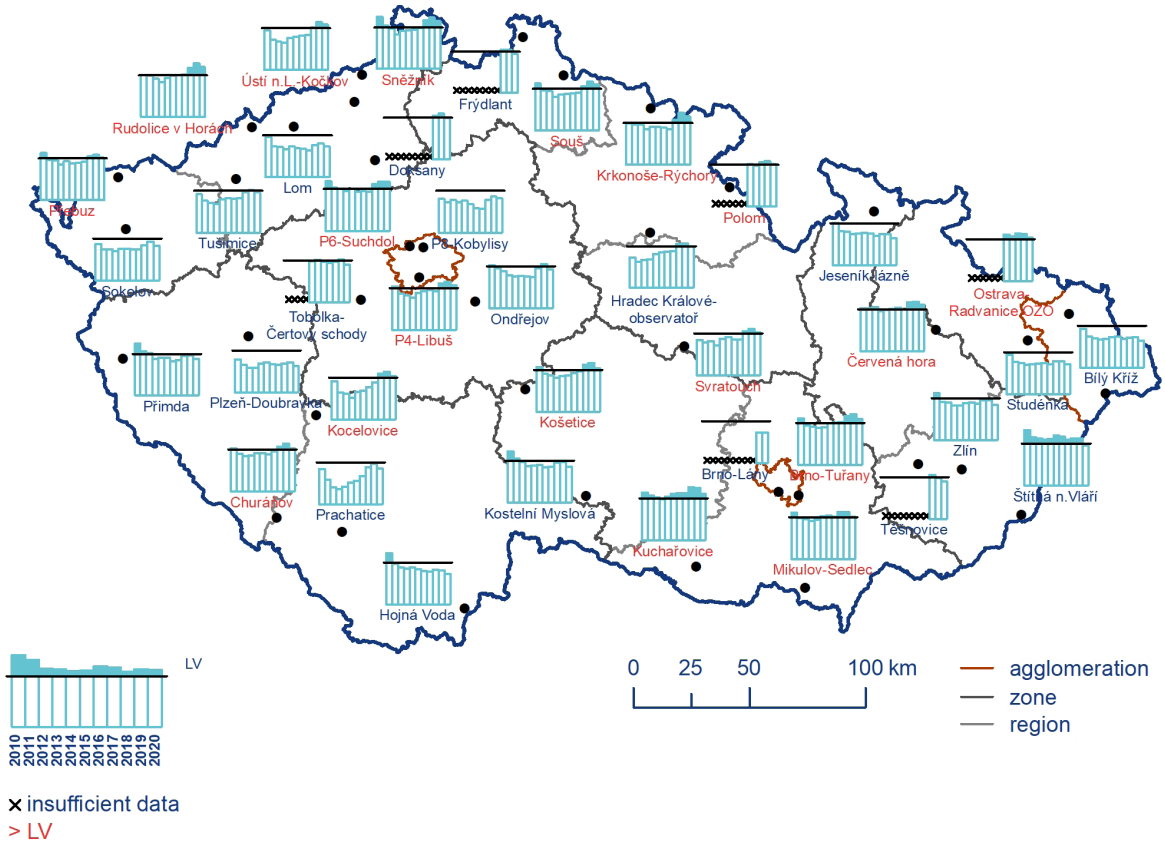

Fig. IV.4.6 Exposure index AOT40 values at selected stations, average of 5 years, 2010–2020

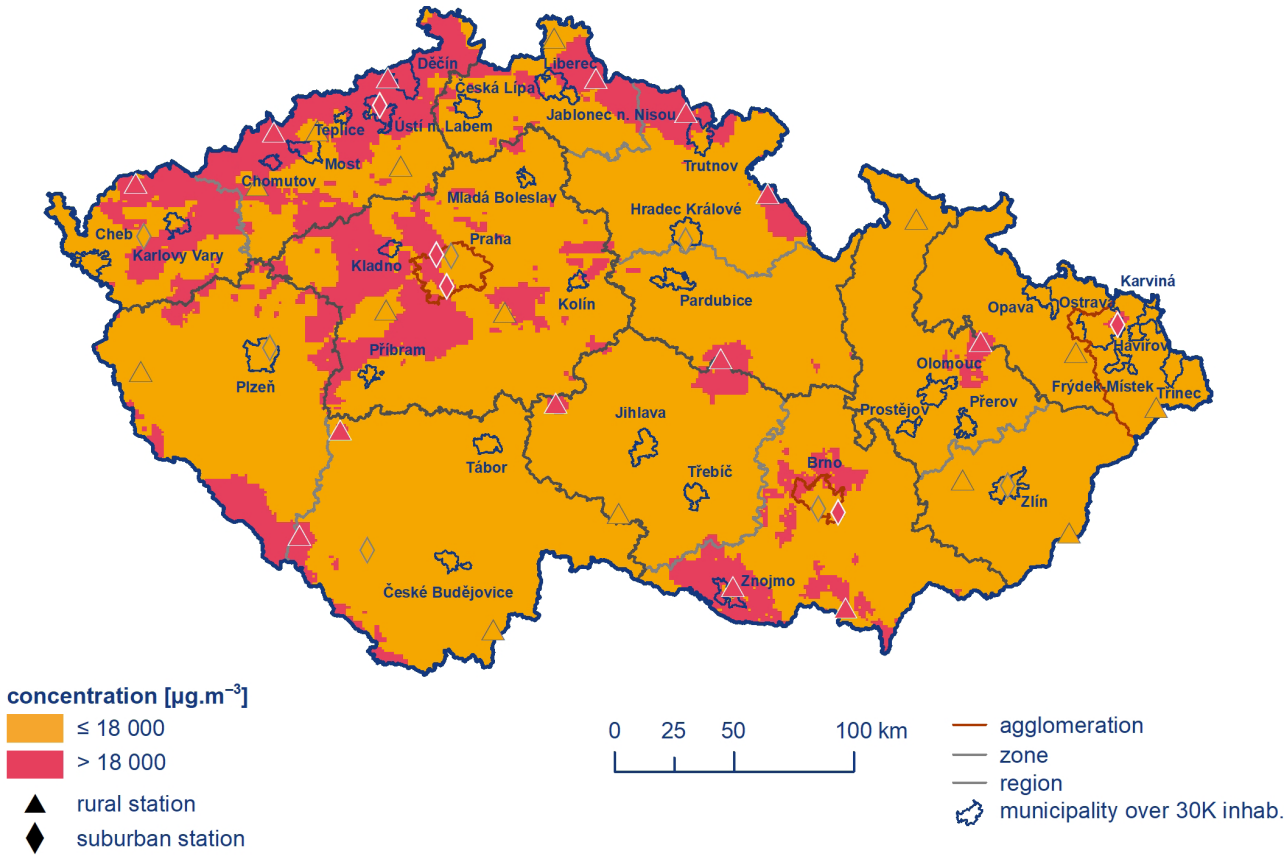

Fig. IV.4.7 Field of AOT40 exposure index values, average of 5 years, 2016–2020

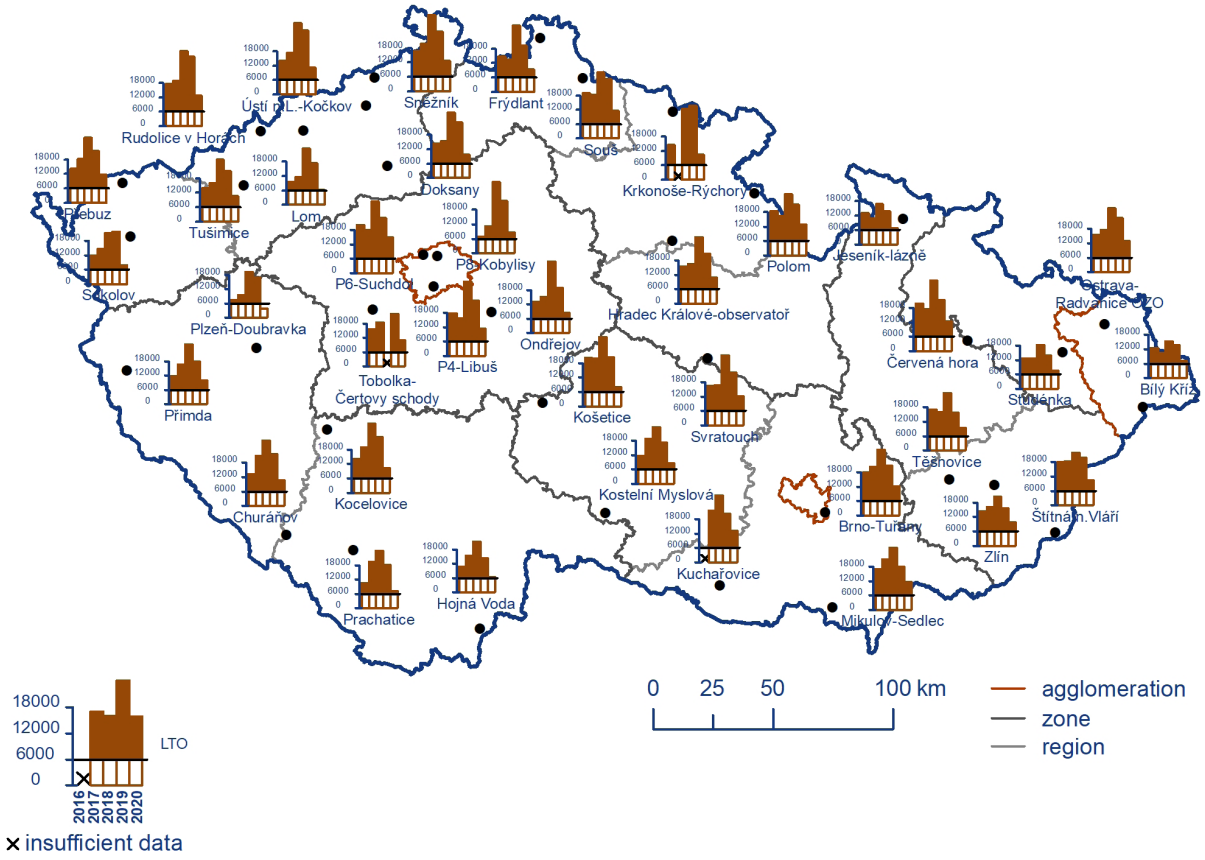

Fig. IV.4.8 Annual exposure index AOT40 values at selected stations in comparison with the long-term objective, 2016–2020

IV.4.2 Trends in ground-level ozone concentrations

Unlike previous assessments based mainly on three-year periods, trends of ground-level ozone concentrations are based on air pollution characteristics in one year, specifically on the average maximum daily 8-hour concentrations for a given type of station and for all stations. This air pollution characteristic can be compared with the long-term air pollution target for ground-level ozone (120 μg.m^{-3}, Tab. I.2). Maximum daily 8-hour concentrations (average for all stations for which the measurement is available for the whole evaluated period) ranged from approx. 136 μg.m^{-3} to 173 μg.m^{-3} in the 2010–2020 period.

Ozone average maximum daily 8-hour concentrations have not shown a significant trend since 2010 (Fig. IV.4.9); the highest concentrations were measured in 2013, 2015 and 2018. All these years were characterized by the occurrence of favourable meteorological conditions (more in Chap. IV.4.3) for the formation of ozone – in 2013 high concentrations of ground-level O_3 occurred especially at the turn of July and August during a number of tropical days. The years 2015 and 2018 are evaluated as exceptionally above average in terms of temperature and highly below average in terms of precipitation (CHMI 2016, 2019). The value of the ground-level O_3 concentration in 2020 (average maximum daily 8-hour concentration, aforementioned 136 μg.m^{-3}) ranks last in the eleven-year evaluation period 2010–2020, and is therefore the lowest for the evaluated period; compared to the ten-year average for the period 2010–2019 (153 μg.m^{-3}) it is 11% lower. The decrease in the annual characteristics of ground-level O_3 is the result of aforementioned significant decreases in concentrations during June and July and occurrence of average to slightly below average concentrations in the warmer part of the year (April – September), when temperatures were highly below normal for half of the month (May) to normal (June, July) and total precipitations during four months were normal (May), above-normal (August and September) to extremely above-normal (June) (more in Chapter III).

In comparing concentrations, emissions of precursors and meteorological conditions, i.e. the intensity and length of sunshine, temperature, wind speed and precipitation or relative air humidity, respectively, play crucial roles (Blanchard et al. 2010; Ooka et al. 2011). However, the relationship between the amount of precursors emitted and ground-level O_3 concentrations is not linear. This non-linearity is caused by the complicated atmospheric chemistry of O_3 formation and decomposition, long-range transport of O_3 and its precursors, and other factors including meteorological conditions and climate change, emissions of non-methane volatile organic compounds (NMVOC) from vegetation and forest fires (EEA 2013). With regard to the above-mentioned factors, it is not possible to comment on the year-to-year changes in detail.

Based on the results of long-term monitoring in the CR, where a 25-year series of ground-level O_3 concentrations is available at a number of stations, long-term trends can be meaningfully evaluated despite the high year-to-year variability of O_3 (Weatherhead et al. 1998). A detailed analysis of spatio-temporal trends of long-term monitoring by 26 stations of varying types (urban, rural, mountain) for the 1994–2015 period indicated that despite a substantial decrease of precursor emissions and of ground-level O_3 pollution concentrations at a majority of stations, ground-level O_3 still represents a considerable problem for the CR. It has been clearly demonstrated that for an adequate decrease of ground-level O_3 levels, the NO/NO_2 ratio is critical and a concurrent substantial decrease of NO_x emissions alone is not therefore sufficient for a decrease of ground-level O_3 concentrations (Hůnová, Bäumelt 2018). The analysis of changes in the spatial distribution of O_3, specifically characteristics of the AOT40 index for the 2000–2015 period, indicated that the area permanently affected by high exposure is mainly the southern part of the CR, probably related to the length and intensity of solar radiation (Hůnová et al. 2019a). The significant statistical influence of meteorological conditions and air pollution on the daily variability of ground-level O_3 concentrations was also confirmed through the measured data. In addition to the influence of individual explanatory variables on daily ground-level O_3 concentrations, the interactions between certain meteorological characteristics, such as between air temperature and solar radia-

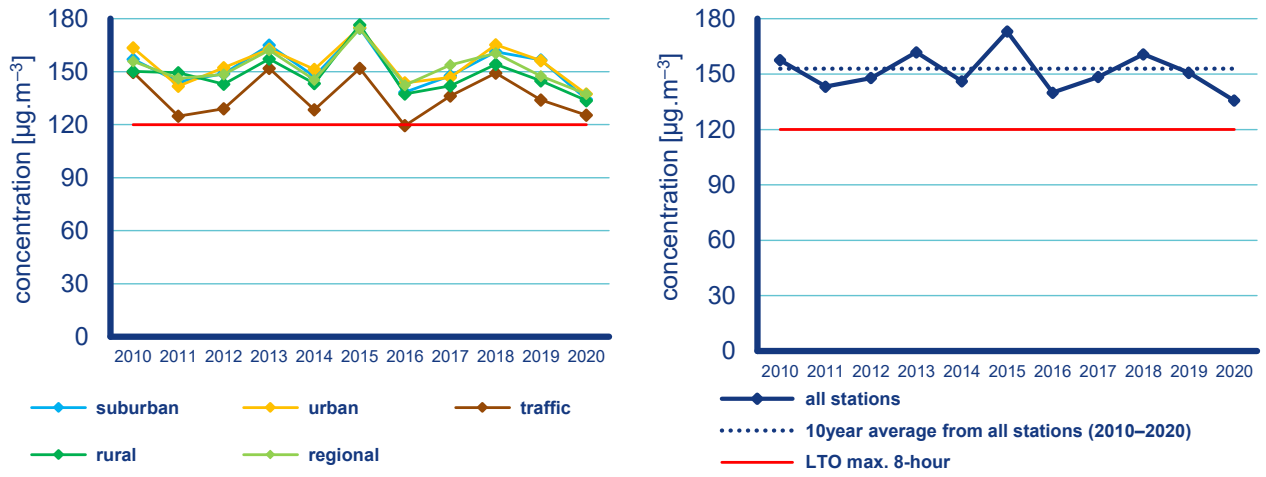

Fig. IV.4.9 Concentrations of ground-level ozone (maximum daily 8-hour running average), at particular types of stations, 2010–2020

tion, air temperature and relative humidity, and solar radiation and air relative humidity, are also statistically significant for daily ground-level O_3 variability (Hůnová et al. 2019b).

IV.4.3 Formation of ground-level ozone

Ground-level O_3 does not have a significant source of its own in the atmosphere. This is a "secondary" substance formed by a number of complicated non-linear photochemical reactions (e.g. Seinfeld and Pandis 2006). Precursors of ground-level O_3 include nitrogen oxides (NO_x) and non-methane volatile organic compounds (NMVOC), while methane (CH_4) and carbon monoxide (CO) play roles on a global scale. The photolysis of carbon dioxide (NO_2) by solar radiation with wavelength of 280–430 nm is an important reaction, forming nitric oxide (NO) and atomic oxygen (O). Ground-level O_3 molecules are formed by the reaction of atomic (O) and molecular oxygen (O_2) in the presence of a catalyst. Simultaneously, O_3 is titrated by nitrogen monoxide, NO, with the formation of NO_2 and O_2. If ground-level O_3 is replaced by radicals in this reaction, its concentration increases in the atmosphere. The OH radical plays an especially important role in this reaction (in more detail e.g. Hůnová, Bäumelt 2018). NO_x are formed in all combustion processes. NMVOC are emitted from a number of anthropogenic sources (transport, manipulation with petroleum and its derivatives, refineries, the use of paint and solvents, etc.), and also natural sources (e.g. biogenic emissions from vegetation).

In the formation of ground-level O_3, not only the absolute amount of precursors but also their relative ratio is important (Sillman et al. 1990; Fiala, Závodský 2003). In rural areas where the reaction is limited by NO_x, characterized by relatively low concentrations of NO_x and high concentrations of VOC, the O_3 concentrations increase with increasing NO_x concentrations, but only minimally with increasing VOC concentrations. On the other hand, in areas with reactions limited by VOC, the O_3 concentrations decrease with increasing NO_x concentrations and increase with increasing VOC concentrations. An increase in O_3 concentrations due to a decrease in NO_x emissions (modernization and denitrification of large emission sources) was observed in north-western Bohemia (Hůnová, Bäumelt 2018). The study by Brancher et al. (2021), which deals with the change in ground-level O_3 concentrations during a coronavirus pandemic, points to an increase in ground-level O_3 concentrations due to a decrease in NO_x emissions during lockdowns and subsequent decreased ground-level O_3 titration by nitric oxide. Sicard et al. (2020) even points to the possibility of increasing VOC emissions during lockdowns due to home and garden activities (cleaning, grilling, biomass combustion). This study also points to the fact that VOC emissions are declining more slowly than NO_x emissions.

Areas with a high NO_x/VOC ratio are typically polluted areas around the centres of large cities. The dependence of the formation of ground-level O_3 on the initial concentrations of VOC and NO_x is frequently expressed by ozone isopleth diagrams, which depict the maximum attained ground-level O_3 concentration as a function of the initial NO_x and VOC concentrations (Moldanová 2009). Aside from the concentrations of precursors, meteorological conditions also play an important role in the formation of ground-level O_3 (Colbeck, Mackenzie 1994). The pollution concentrations of ground-level O_3 increase with increasing ultraviolet radiation and temperature, but decrease with increasing relative air humidity. These relations were also demonstrated from the results of long-term CHMI measurements (Hůnová et al. 2019a). High concentrations are often related to prolonged anticyclone situations. In addition to the above-described photochemical mechanisms, ground-level O_3 concentrations can also increase in episodes as a result of the penetration of stratospheric O_3 into the troposphere and also during thunderstorms. Recently, there has also been an increase in the importance of long-range ground-level O_3 transport in the northern hemisphere to Europe and North America from source areas in south-east Asia. Ground-level O_3 is removed from the atmosphere by reaction with NO, the mechanism of dry or wet deposition and interaction with plants (stomatal uptake).

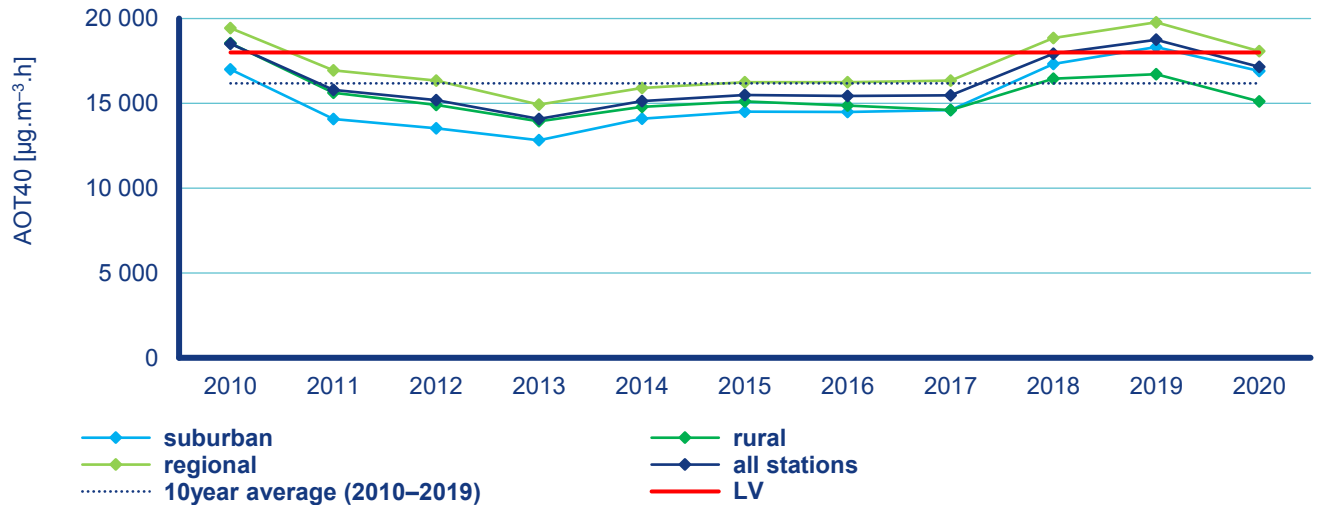

Fig. IV.4.10 Exposure index AOT40 values, average of 5 year, 2010–2020