IV.4 Ground-level ozone

IV.4.1 Air pollution by ground-level ozone in 2021

Air pollution by ground-level ozone in 2021 in relation to limit values for the protection of human health

During the three-year period 2019–2021, the ground-level ozone (O_3) limit value was exceeded[1] at only 4 out of 65 stations (6 %), where O_3 concentrations were measured (Figures IV.4.1 and IV.4.2). This concerned three regional stations (Krkonoše-Rýchory, Rudolice v Horách, Sněžník) and one background suburban station (Ústí n. L.-Kočkov). For the previous three-year period 2018–2020, the ground-level O_3 limit value was exceeded at 34 out of 67 stations (51 %), in the period 2017–2019 at 36 out of 64 stations (56 %), in 2016–2018 at 33 of 65 stations (51 %), and in the period 2015–2017 at 21 of 71 (30 %) stations.

The O_3 pollution limit value was exceeded during the three-year period 2019–2021 just on 0.2 % of the territory of the CR with 0.02 % of the population (Fig. IV.4.3). Compared to the previous three-year periods (62 % of the territory of the CR with 52 % of the population in the period 2018–2020, 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, and 31 % of the territory with 9 % of the population in the period 2015–2017), the extent of the area exceeding the limit value for O_3 was exceeded on the smallest territory with the lowest population. Within the individual years of the period 2019–2021, the lowest number of cases exceeding the pollution limit value occurred at almost 70 % of the stations in 2021 (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 meteorological conditions (high intensity of solar radiation, high temperatures, lower air humidity) suitable for the formation of ground-level O_3. The highest O_3 concentrations in 2021 were measured in June, the warmest month of 2021.

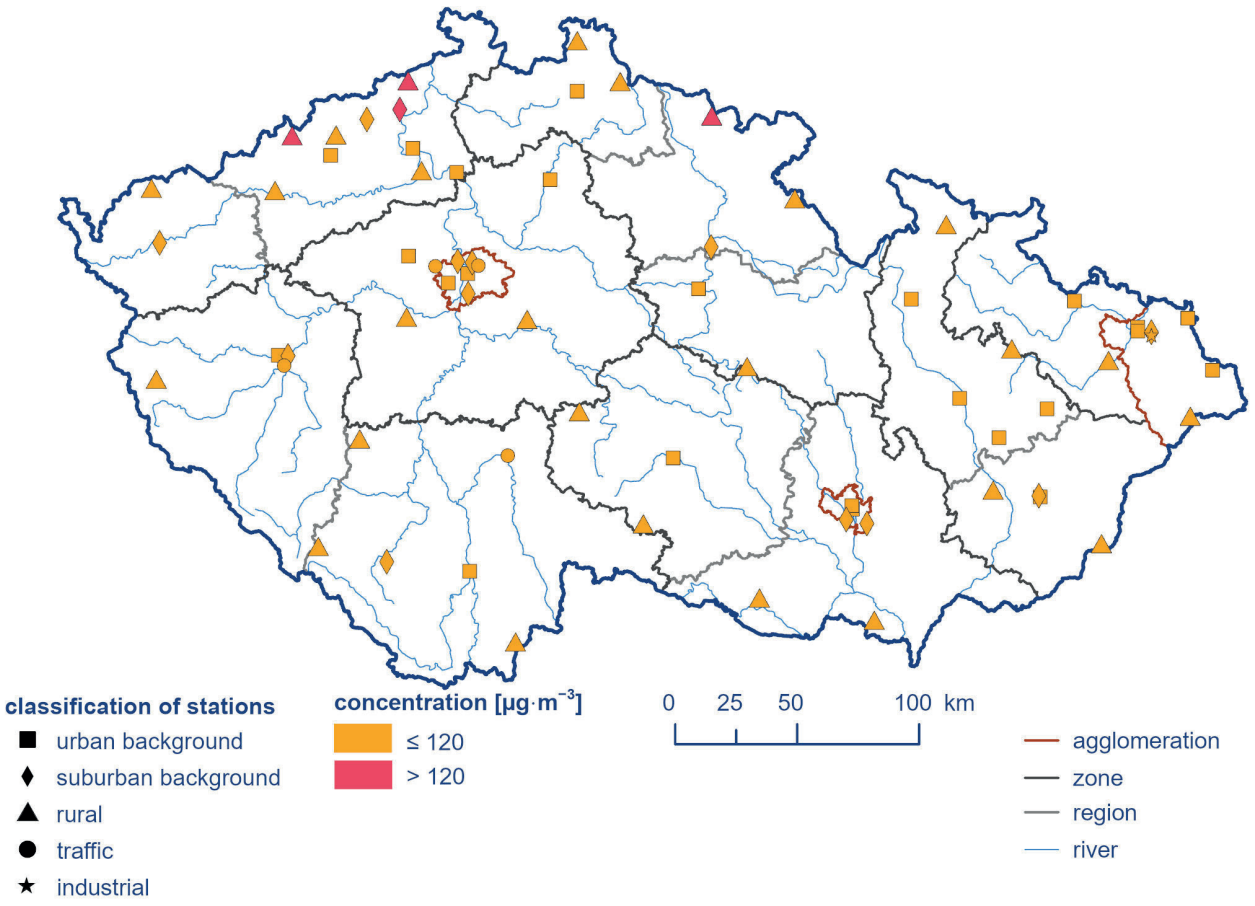

Fig. IV.4.1 The 26th highest values of maximum daily 8-hour running average of ground-level ozone concentrations (three-year average) in the ambient air quality network, 2019–2021

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.

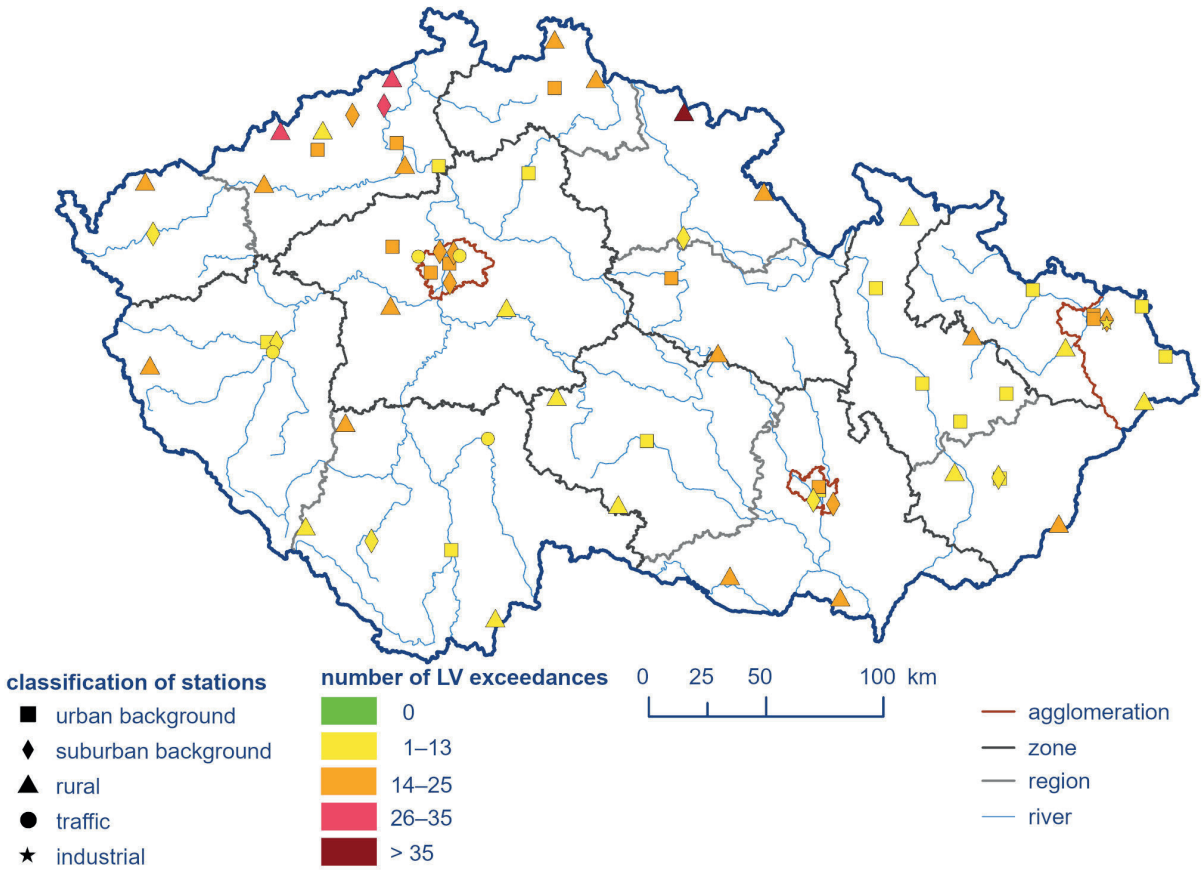

Fig. IV.4.2 Numbers of exceedances of the limit value for the maximum daily 8-hour running average of ground-level ozone concentrations in three-year average, 2019–2021

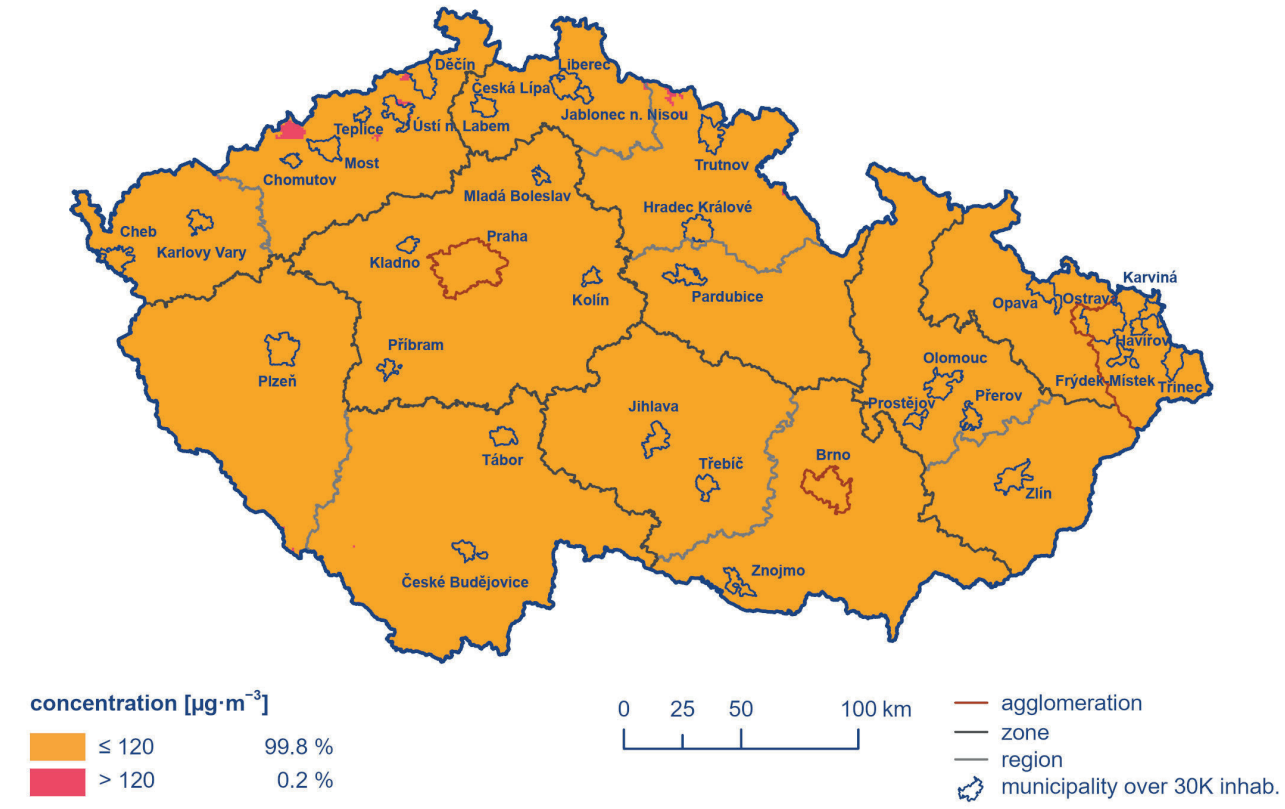

Fig. IV.4.3 Field of the 26th highest maximum daily 8-hour running average of ground-level ozone concentration in three-year average, 2019–2021

From the annual variation of average monthly concentrations, it follows that the significant drop in O_3 concentrations in 2021 was caused by a decrease in concentrations during warmer months of the year. These months typically experience high to the highest concentrations of the calendar year, leading sometimes to announcement of a smog situation. The drop in concentrations of about 7–17 % in April, May, July and August of 2021 compared to the 2011–2020 ten-year average corresponds to mostly normal to strongly below normal temperatures, and normal to above normal precipitation in these months (i.e., suppression of meteorological conditions adequate for the formation of ground-level ozone).

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

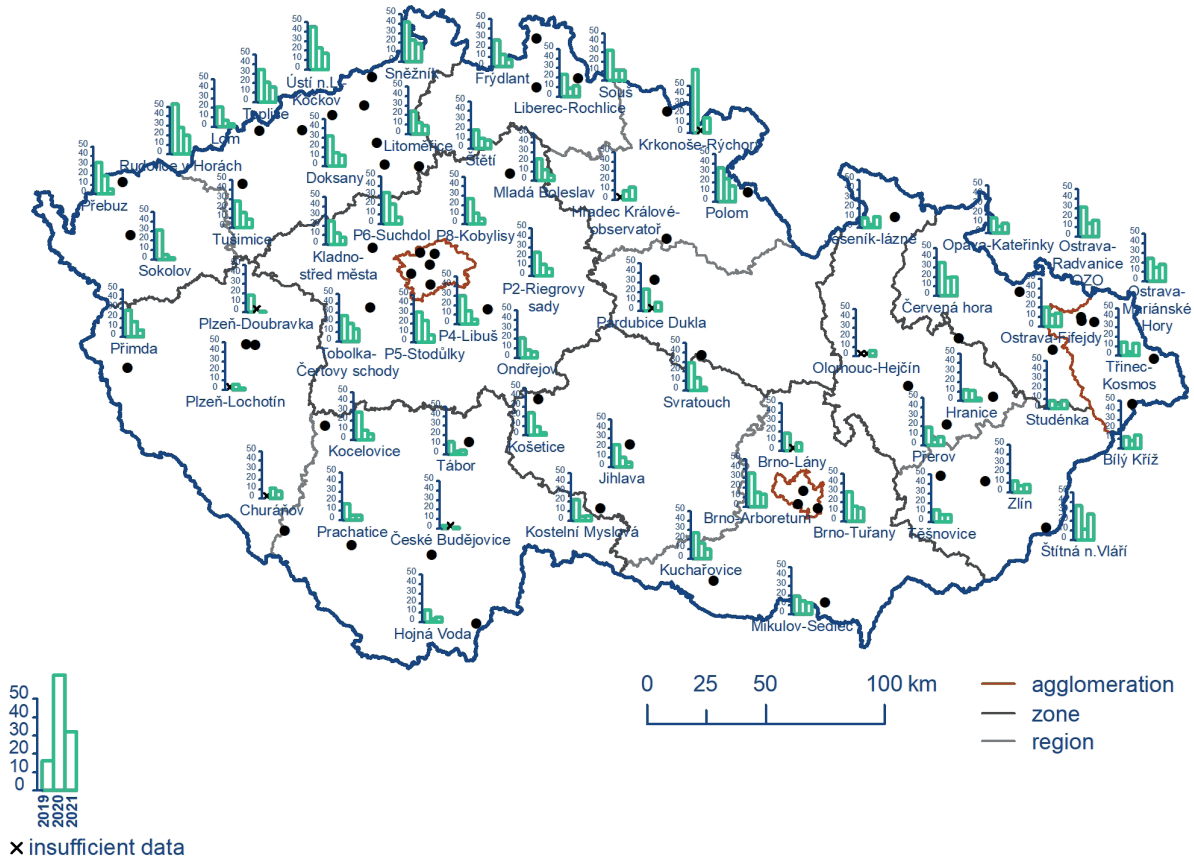

Fig. IV.4.4 Number of exceedances of 8-hour limit value of ground-level ozone per year for selected stations, 2019–2021

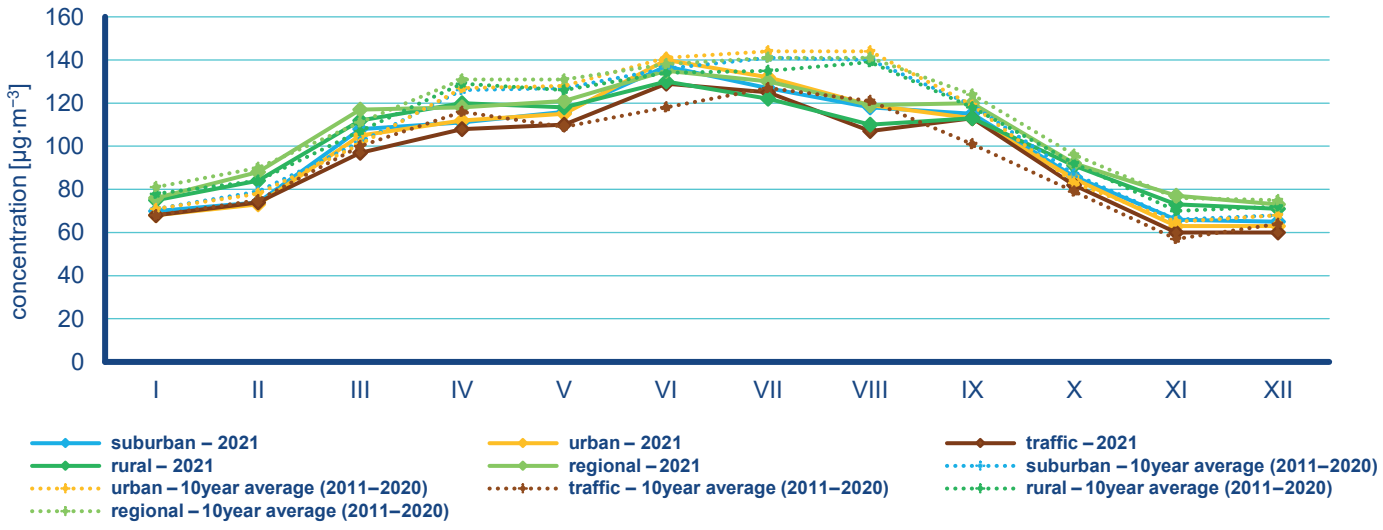

Fig. IV.4.5 Annual course of average monthly concentrations of max. 8-hour running average of O_3 (averages for the given type of station), 2021

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).

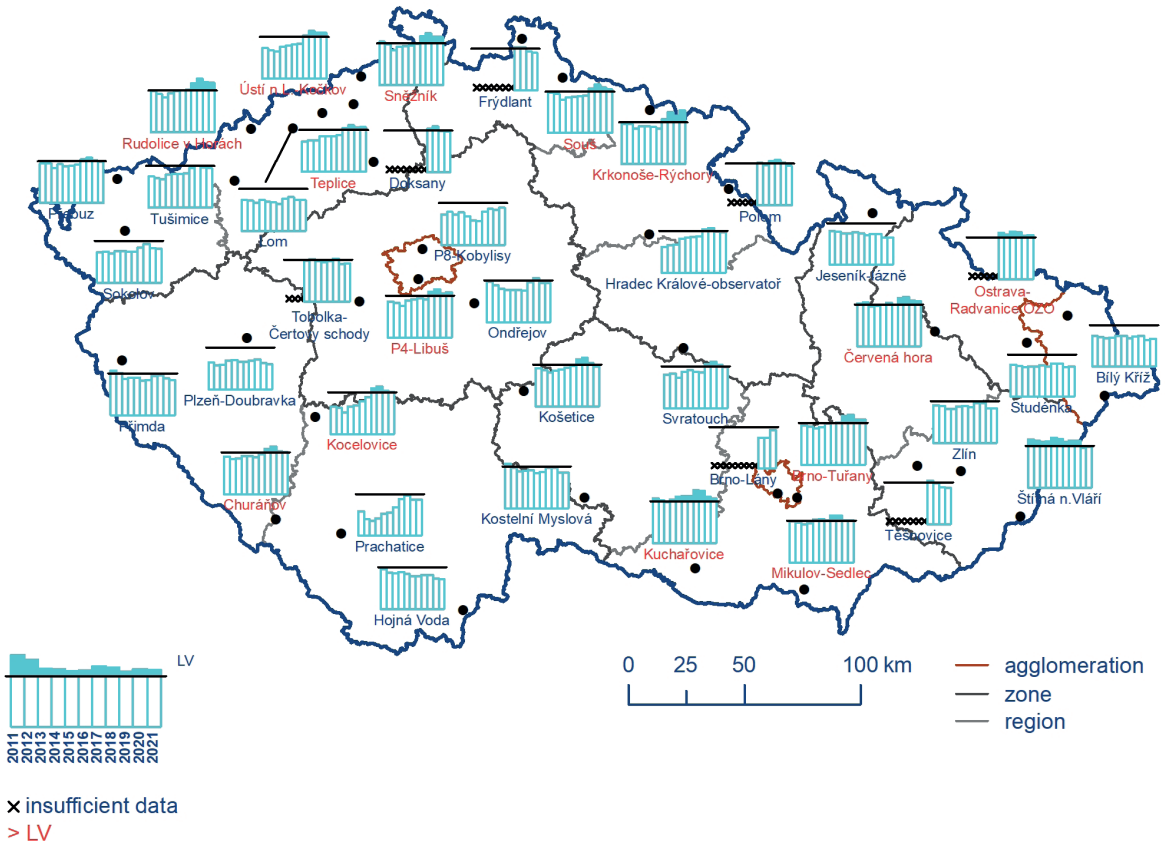

Fig. IV.4.6 Exposure index AOT40 values at selected stations, average of 5 years, 2011–2021

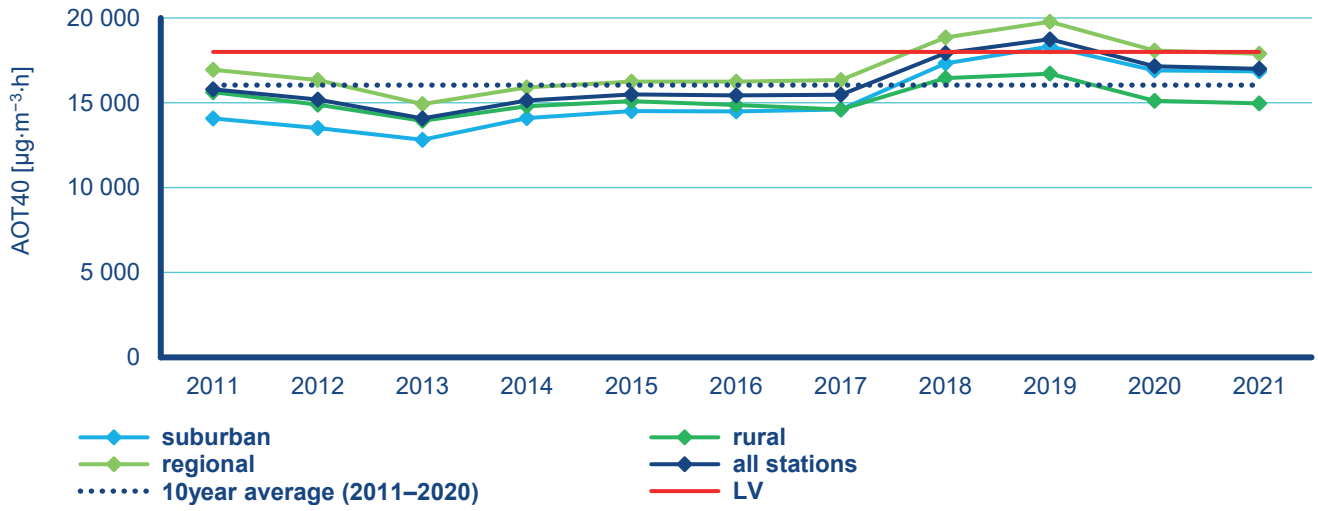

Fig. IV.4.7 Exposure index AOT40 values, average of 5 year, 2011–2021

Ground-level ozone in 2021 in relation to the limit value for the protection of ecosystems and vegetation

The ground-level O_3 pollution limit value for the protection of vegetation of 18 000 µg·m^{-3}·h (five-year average, Tab. I.2) was exceeded at 14 stations (5.9 %) of the total number of 39 rural and suburban stations for which calculation of the exposure index AOT40 is relevant according to legislation (relating to the 2017–2021 average). The highest values of the AOT40 index for the evaluation period 2011–2021 were found in 2018 and 2019 (on average for 32 rural and suburban stations with the complete time series 2011–2021). In 2021, the values of the AOT40 index were the fourth highest for the period 2011–2021 (Fig. IV.4.6, Fig. IV.4.7). The highest values of the AOT40 index in 2021 were found at the Krkonoše-Rýchory, Rudolice v Horách, Sněžník, Ústí n. L.-Kočkov, and Praha 4-Libuš stations. The occurrence of above-limit AOT40 values occurred in 2021 mainly in the mountain areas of the Ústí nad Labem and Liberec regions, as well as in the South Moravia and a border of the Prague and Central Bohemia regions (Fig. IV.4.8).

The annual values of the AOT40 index have long exceeded the value of the long-term pollution limit value (6 000 µg·m^{-3}·h) at all rural and suburban stations (the same set of stations for the last five years, Fig. IV.4.9). For the evaluated five-year period, the values of the AOT40 index in 2021 were the second lowest or the lowest at most stations.

IV.4.2 Trends in ground-level ozone concentrations

Unlike the previous assessment based mainly on three-year periods, an evaluation is carried out using maximum 8-hour average concentration and 26th highest maximum 8-hour average concentration in a given year. The first of these pollution characteristics can be compared with the long-term air pollution target for ground-level ozone or with the pollution limit value (120 µg·m^{-3}), respectively. Maximum annual 8-hour average concentration (in an average for all stations for which the measurement is available for the whole evaluated period) ranged from approx. 135 µg·m^{-3} to 173 µg·m^{-3} in the 2011–2021 period, and the 26th highest 8-hour average concentration from approx. 109 µg·m^{-3} to 129 µg·m^{-3}.

Maximum daily 8-hour concentrations and the 26th highest 8-hour average O_3 concentrations have not shown any significant trend since 2011 (Fig. IV.4.10 and Fig. IV.4.11); the highest concentrations were measured in 2013, 2015 and 2018. All these years were characterized by the occurrence of meteorological conditions adequate 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 series of tropical days. The years 2015 and 2018 were exceptionally above average in terms of temperature and highly below average in terms of precipitation (CHMI 2016, 2019). Concentrations in 2021 (135 µg·m^{-3} for the maximum daily 8-hour concentration and 109 µg·m^{-3} for 26th highest maximum daily 8-hour average

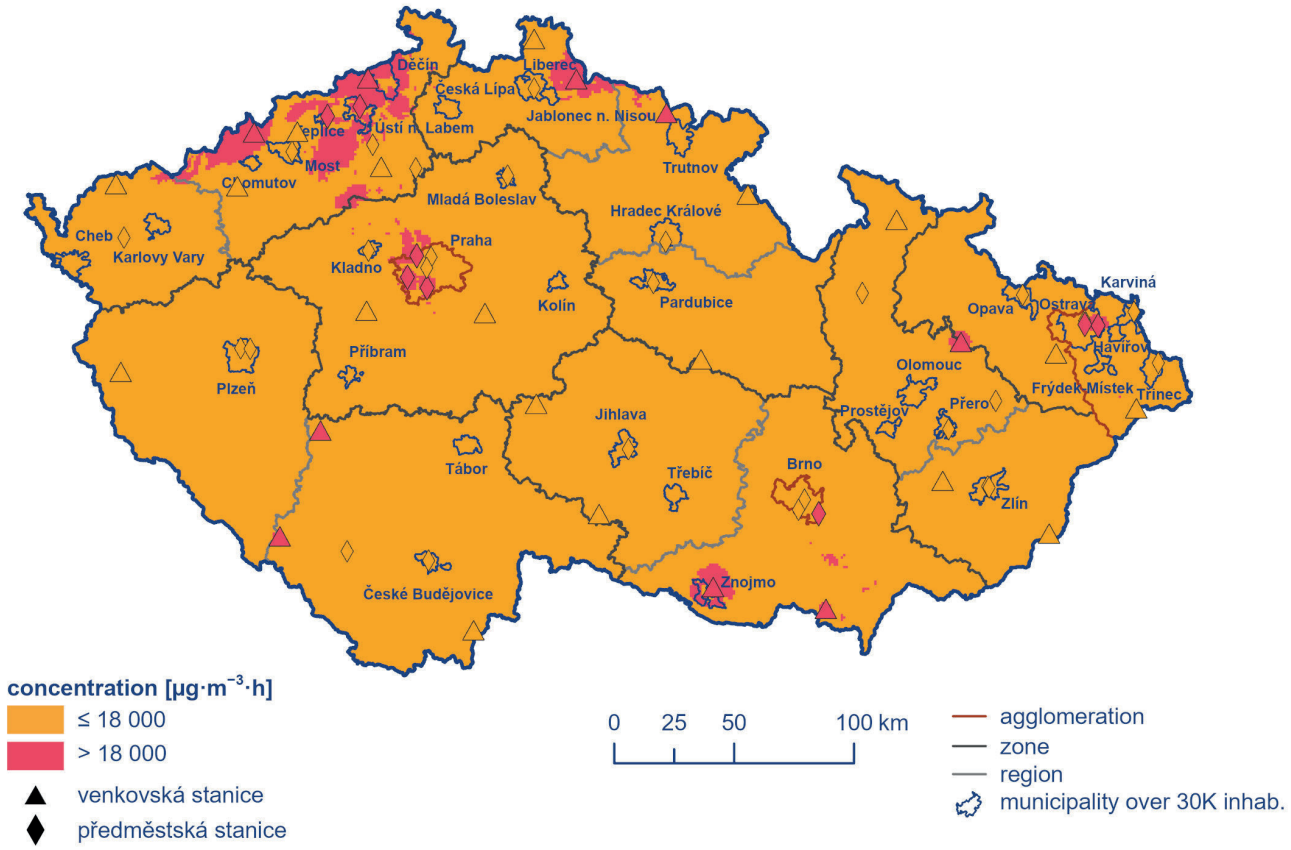

Fig. IV.4.8 Field of AOT40 exposure index values, average of 5 years, 2017–2021

concentration) were the lowest in the eleven-year evaluation period 2011–2021 (together with 2020 for the maximum daily 8-hour concentration). Compared to the ten-year average at 151 $\mu g \cdot m^{-3}$ and 117 $\mu g \cdot m^{-3}$ concentrations decreased by 11 % and 7 %, respectively. The decrease in the annual characteristics of ground-level ozone is a result of aforementioned drops in concentrations during warmer part of the year (April–September, except July).

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).

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 nitrogen 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 com-

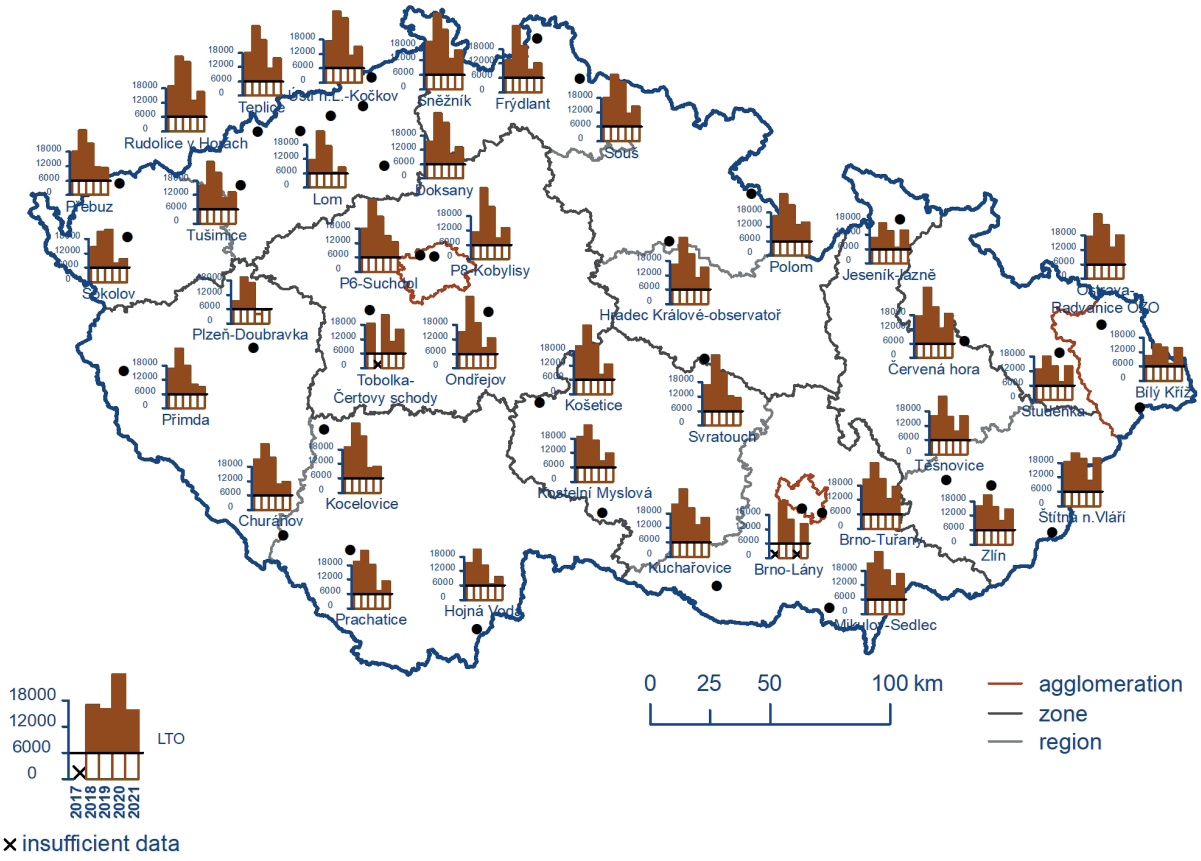

Fig. IV.4.9 Annual exposure index AOT40 values at selected stations in comparison with the long-term objective, 2017–2021

bustion 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 or, respectively, an increase in NO_2/NO proportion (modernization and denitrification of large emission sources) was observed in north-western Bohemia (Hůnová, Bäumelt 2018).

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).

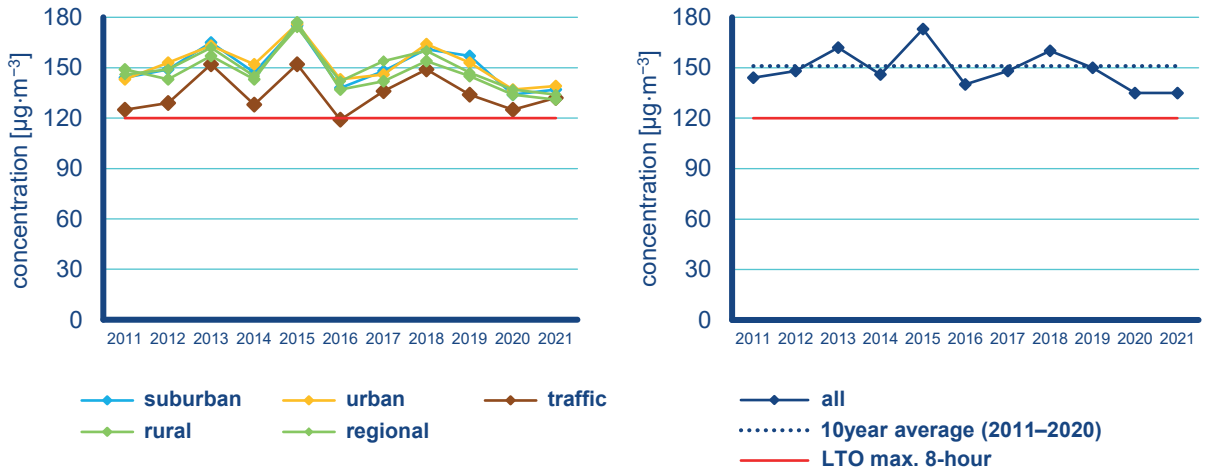

Fig. IV.4.10 Concentrations of ground-level ozone (maximum daily 8-hour running average), at particular types of stations, 2011–2021

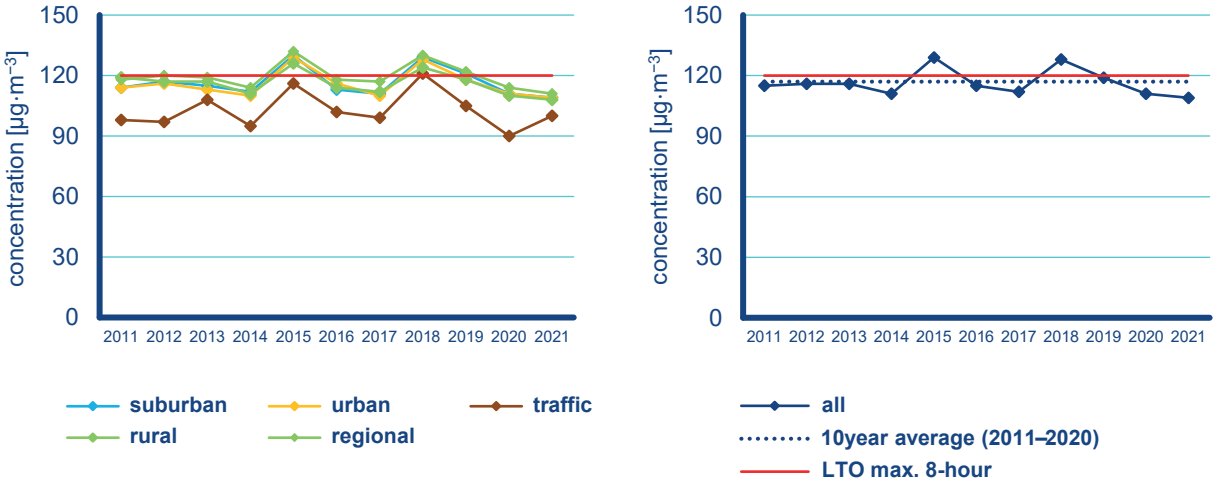

Fig. IV.4.11 Concentrations of ground-level ozone (the 26th highest values maximum daily 8-hour running average), at particular types of stations, 2011–2021