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Trends in ambient ozone concentrations at twelve sites of the Czech Republic over the past three decades

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Ambient ozone (O₃) remains a serious air pollution problem (O₃) of Northern Hemisphere, and still represents a considerable threat both for human health and ecosystems. In Europe, the critical levels of O₃ are permanently exceeded over vast areas (EEA, 2019). In the Czech Republic (CR), monitoring of O₃ has been operated since 1993, currently at 50 sites, including both rural and urban stations covering the country (CHMU, 2019). O₃ exposures in the CR are relatively high (Hůnová, Schreiberová, 2012; Hůnová et al., 2016), and may result in negative endpoints, both regarding human health (Hůnová et al. 2013) and vegetation (Hůnová et al., 2011). O₃ is highly meteorology dependent and shows considerable year-to-year variations (Hůnová et al., 2019 a, b). Two to three-decade time series allows for a sound trend analysis, hence O₃ concentrations for trends at Czech long-term monitoring sites were already analysed using Mann-Kendall non-parametric test (Hůnová, Bäumelt, 2018).

This time, however, our approach for time analysis was different. We applied a generalized additive model, GAM (Wood, 2017; Hastie & Tibshirani, 1990) framework as a flexible, semiparametric regression approach to address nonlinear trend shapes in a formalized and unified way. In particular, we employed penalized spline approach with cross-validated penalty coefficient estimation. We have examined daily mean O₃ concentrations measured at twelve Czech sites representing different environments, geographical areas, and altitudes across the country; four urban, for rural and four mountain sites. We used long-term data series from the time period of 1994–2018.

Our results show inconsistent behaviour of sites before 1998 when the strict emission limits were introduced with an immediate consequence of substantial decrease in O₃ precursor emissions. The highest concentrations and the most dynamic O₃ decrease in this time period was recorded at the Praha 4-Libus urban background site, the lowest concentrations and the steepest increase in O₃ were recorded at the Rudolice mountain site in the former Black Triangle Area. Two local maxima – around 2003 for some sites and 2006 for other sites – and a local minimum around 2013 are indicated. Steady increase in O₃ concentrations for all sites is evident after 2014 up to now, most likely due to recent five hot and dry summer seasons. Seasonal O₃ course averaged for the entire measuring period is similar for all sites, with clear maximum in May-June. The highest O₃

in summer and lowest in winter were observed at the Usti nad Labem-Kockov site, relatively most flat curve, with the least differences between summer and winter was recorded at the Churanov site, in the Sumava Mts. More interesting is to compare the seasonal O₃ curves for individual years.

In contrast with Mann-Kendall test standardly used for this kind of analysis, the GAM approach offers a detailed view on both time trend and seasonality curve and facilitates the analysis and interpretation of the results.