

TROPOSPHERIC OZONE IN THE CZECH REPUBLIC, 1994-2000

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ABSTRACT

Air pollution is changing the ecosystems, especially in Europe. Tropospheric ozone may adversely affect tree growth, with critical levels for ozone being exceeded in many parts of Europe, especially in the Czech Republic. This research reports the information on exceedances of ozone threshold values for the period 1994 to 2000 and gives an evaluation of the observed exceedances of the thresholds during the vegetation period (April-September) and from May to July at the Bílý Kříž station. The threshold for warning of the public ($240 \mu\text{g m}^{-3}$ as hourly average concentration) was not exceeded at the Bílý Kříž station for the studied period. The threshold value for information to the population ($180 \mu\text{g m}^{-3}$ as hourly average concentration) was exceeded in 1994 (July and August), 1995 (May and July), 1998 (August) and 2000 (June). The threshold value set for the protection of human health population ($120 \mu\text{g m}^{-3}$ as eight-hourly average concentration) was exceeded for all period at the Bílý Kříž station.

KEYWORDS: annual concentration, Bílý Kříž station, daily value, eight-hour value, one-hour value, exceedances, tropospheric ozone

INTRODUCTION

Ozone is a natural constituent of the atmosphere with a vital role in many atmospheric processes (Hjellbrekke, 2000). While ozone in the stratosphere has beneficial role, the ozone close to the planet's surface, in the region known as the troposphere, displays a destructive side. Because it reacts strongly with other molecules, it severely damages the living tissue of plants and animals. It is one of key pollutants in "smog" that hangs over many cities around the world. However, man made emissions of volatile organic compounds and nitrogen oxides have influenced the production of tropospheric ozone (EEA, 1997; Beck *et al.*, 1998; Matyssek and Innes, 1999; Hjellbrekke, 2000; Hůnová *et al.*, 2000). Of this various different types of air pollutants currently impacting for-

est in the Czech Republic, the greatest concern surrounds ozone (Rožnovský and Blažek, 1996; Hůnová *et al.*, 2000; Pelikán *et al.*, 2000; Svoboda, 2000; De Leeuw *et al.*, 1999, 2000; Hjellbrekke, 2000; Tshiamala and Rožnovský, 2000a, b, c). Tropospheric ozone, a major air pollutant in industrialised countries (Matyssek and Innes, 1999; Jackson *et al.*, 2000; Polle *et al.*, 2000), is transported across national boundaries (EEA, 1998).

Ozone is a strong photochemical oxidant which may cause serious health problems and damage to materials and ecosystems (Andreani-Aksoyoglu, 1996; Rožnovský and Blažek, 1996; Matyssek and Innes, 1999; De Leeuw *et al.*, 1999, 2000; Polle *et al.*, 2000). Ozone in the troposphere has also of relevance to the climate change issue since it is a

greenhouse gas (EEA, 1998). Emissions of nitrogen oxides (NO_x) are responsible for much of the ozone formation occurring in rural areas (EEA, 1998; Matyssek and Innes, 1999). Tropospheric ozone is a secondary pollutant formed by photochemical reaction of primary pollutants known as precursors (nitrogen oxides: NO_x , carbon monoxide: CO, volatile organic compounds: VOCs) in the presence of sunlight. Since weather conditions (sunshine, high temperatures and low winds) have an important part in the formation of ozone, pollution episodes occur mainly in summer, in urban, periurban and rural areas.

Human exposure to elevated levels of ozone concentrations can give rise to inflammatory responses and decreases in lung function (Fally *et al.*, 1995; APPA, 1998; De Leeuw *et al.*, 1999, 2000). Ozone exposure of ecosystems and agricultural crops results in invisible foliar injury and in reductions in crop yield and seed production, and loss in forest productivity (Fally *et al.*, 1995; Rožnovský and Blažek, 1996; Matyssek and Innes, 1999; De Leeuw *et al.*, 2000; Jackson *et al.*, 2000; Polle *et al.*, 2000). Threshold values set for the protection of human health, vegetation and ecosystems are exceeded frequently in most cities (and stations) of the Czech Republic and therefore widespread adverse effects on the Czech population, crops and natural vegetation may be expected (Hůnová *et al.*, 2000; Svoboda, 2000; Tshiamala and Rožnovský, 2000a, b, c).

Ozone concentrations vary widely from region to region, with the time of year, and with time of day. Typically, high concentrations of ozone are observed in periods with anticyclonic conditions (Hjellbrekke, 2000). National authorities and international organisations have therefore formulated critical levels for ozone. According to the European Union ozone directive No 0068/99/EC, the threshold values for protection of human health are $120 \mu\text{g m}^{-3}$ for eight-hourly mean and for the protection of material $40 \mu\text{g m}^{-3}$ for annual mean. In addition, information should be given to the population when hourly means exceed $180 \mu\text{g m}^{-3}$ and a warning should be issued if hourly mean exceeds the $240 \mu\text{g m}^{-3}$. This Directive about the air pollution by ozone aims to establish a harmonised procedure in the European Union for monitoring, exchanging information, and informing and warning the population.

MATERIALS AND METHODS

The Czech Hydrometeorological Institute has its regional offices in all the former regional capitals, which are mainly concerned with measurements, data collection and initial processing within their respective regions. The ozone concentration measurement is based on ultraviolet absorption photometry, by UV analyser by Te Instruments, model 49. The presented method with automatic pressure and temperature compensation meets the challenging requirements for ozone measurement.

The assessment of air pollution by ozone in the region of Beskids was based on observation of Automated Monitoring Station (AMS) from 1st March 1994 to 31st December 2000 at Bílý Kříž. These results are selected on measurements at the experimental ecological station Bílý Kříž at $49^\circ 30' 17''$ northern latitude and $18^\circ 32' 28''$ eastern longitude. This station is located at an altitude of 908 m in the region of Beskids, at the eastern part of the Czech Republic. The region of the Beskids, especially Bílý Kříž, is about 30 to 40 km from important emission sources in the regions of Karviná and Ostrava.

The assessment of the state of ambient air pollution is based on air pollution standards set down by the new directives of European Union. Assessment of the status of the air pollution is based on air pollution standards as specified by new European directives published on 22 April 1999 No. 0068/99 for tropospheric ozone and is based on Czech standards for ozone.

RESULTS AND DISCUSSION

Short-term (1 hour) and prolonged (8 hours) exposures to ambient ozone have been linked to a number of health effects of concern. The long-term (e.g. 3 months, 6 months, one year) of ozone exposure affects vegetation and ecosystems, reduces the plant growth, increases the plant susceptibility to disease.

Hour values of ozone

The ambient air pollution hourly limit value of ozone for human information is $180 \mu\text{g m}^{-3}$. At the Bílý Kříž station, the one-hour values of ozone concentration were ranged between 11.0 and $210.0 \mu\text{g m}^{-3}$ for 1994 to 2000 (Fig. 1) and numbered 18 days and 80 hours when this limit was exceeded (Table 1). The highest hour mean val-

Table 1. Occurrence of exceedances of one-hour limit of $180 \mu\text{g m}^{-3}$ (a) and $200 \mu\text{g m}^{-3}$ (b) for 1994 to 2000.

Year	days (a)	hours (a)	days (b)	hours (b)
1994	8	42	4	4
1995	8	30	2	2
1996	0	–	–	–
1997	0	–	–	–
1998	1	5	–	–
1999	0	–	–	–
2000	1	3	–	–
Sum	18	80	6	6

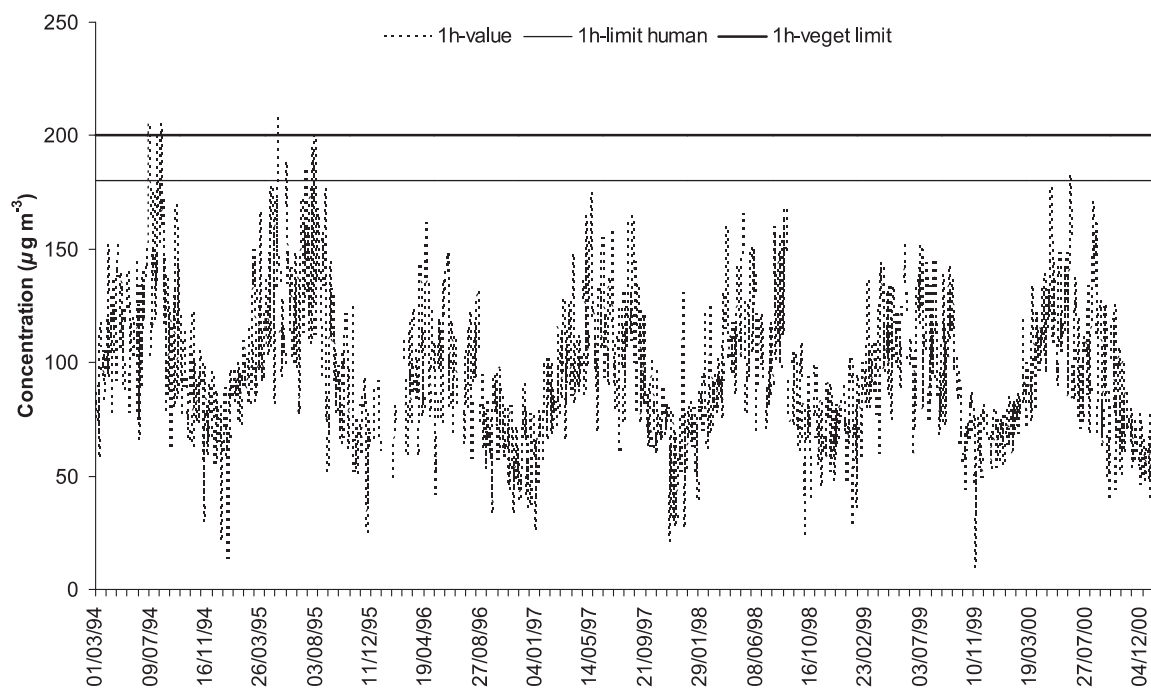


Figure 1. Daily hour ozone concentrations with hour limits at the Bílý Kříž station, 1994-2000

Table 2. Observed exceedances of the threshold for information of the public (1-hour concentration higher than $180 \mu\text{g m}^{-3}$) from April to September.

Period	Maximum observed hourly concentration	Date of exceedance	Time of exceedance
1994	$206 \mu\text{g m}^{-3}$	4 th July	17.00
1995	$210 \mu\text{g m}^{-3}$	6 th May	20.00
1996	$162 \mu\text{g m}^{-3}$	20 th April	–
1997	$175 \mu\text{g m}^{-3}$	16 th May	–
1998	$188 \mu\text{g m}^{-3}$	12 th August	11.00
1999	$153 \mu\text{g m}^{-3}$	28 th May	–
2000	$183 \mu\text{g m}^{-3}$	22 th June	18.00

Table 3. Occurrence of exceedances of eight-hour limit for April to September (based on three non-overlapping eight hourly averages between 00.00-08.00, 08.00-16.00 and 16.00-24.00; 12.00-20.00; 10.00-18.00)

Period	00.00-08.00,08.00-16.00,16.00-24.00		12.00-20.00		10.00-18.00	
	$\mu\text{g m}^{-3}$		$\mu\text{g m}^{-3}$		$\mu\text{g m}^{-3}$	
	120	160	120	160	120	160
1994	64	8	62	9	57	8
1995	57	6	86	11	84	14
1996	8	–	15	–	15	–
1997	35	–	29	–	29	–
1998	40	3	36	2	39	1
1999	36	–	32	–	34	–
2000	44	3	44	1	40	1
Sum	284	20	304	23	298	24

ues were found on July 1994, on May 1995, on April 1996, on May 1997, on August 1998, on May 1999 and on June 2000 (Table 2). The 1-hour critical level for ozone for the protection of human health, $180 \mu\text{g m}^{-3}$, was exceeded for 8 days during 1994 and 1995 and one day during 1998 and 2000. In Central Europe, like the Czech Republic, the variation is characterised by a broad summer maximum with high monthly means from May to August (Beck *et al.*, 1998; Hjellbrekke, 2000; Tshiamala and Rožnovský, 2000a, b, c). The one-hour limit of $200 \mu\text{g m}^{-3}$ for the protection of vegetation was exceeded (Table 1) on July and August 1994 (4 days and 4 hours), on May and July 1995 (2 days and 2 hours). The highest one-hour concentration of ozone in 1998 was also registered at the same month at the other stations throughout the Europe (Beck *et al.*, 1998; Hjellbrekke, 2000).

Eight-hour concentrations

The current ambient air pollution limit value for human protection is $120 \mu\text{g m}^{-3}$, the eight-hour mean. The Czech standard of ozone for the protection of human health is $160 \mu\text{g m}^{-3}$. The considered eight-hour is 00.00-08.00, 08.00-16.00, 16.00-24.00, 12.00-20.00 according to the European standard and 10.00-18.00 according to the Czech Standard.

- a) Based on three non-overlapping eight hourly averages between 0.00-8.00, 8.00-16.00 and 16.00-24.00:
The eight-hour limit was exceeded for 2.4 to 21% of cases at the Bílý Kříž station. The high-

est eight-hour concentrations were registered from April to September for the all measured period and varied from 21.8 to $193.1 \mu\text{g m}^{-3}$. The high eight-hour values were registered for 64, 57, 8, 35, 40, 36 and 44 days from 1994 to 2000, respectively. The number of exceedances was of 23 days on July 1994, more than 10 days on April 1994, May, July and August 1995, August 1998, May, June and August 2000. According the Czech standards of $160 \mu\text{g m}^{-3}$ for human health, we numbered 8, 6 and 3 days when this limit was exceeded in 1994, 1995 and 1998, 2000 at the Bílý Kříž station (Table 3).

- b) Based on the eight hourly values between 12.00-20.00:
The eight-hour values exceeded the 8-hour limit by 62, 86, 15, 29, 36, 32 and 44 days for 1994 to 2000, respectively. The highest ozone concentration was recorded on July 1994, May 1995, April 1996, May 1997, August 1998, May 1999 and June 2000. The Czech limit of $160 \mu\text{g m}^{-3}$ for human protection was exceeded by 9, 11, 2 days and one day on 1994, 1995, 1998 and 2000, respectively (Table 3).
- c) Based on the eight hourly according the Czech Republic standards, 10.00-18.00
The eight-hour values exceeded the eight-hour limit of $120 \mu\text{g m}^{-3}$ by 57, 84, 15, 29, 39, 34 and 40 days for 1994 to 2000, respectively. According the Czech republic standards of $160 \mu\text{g m}^{-3}$ for eight-hour value, this value was exceeded by 8, 14 days and one day in 1994, 1995 and 1998, 2000 (Table 3).

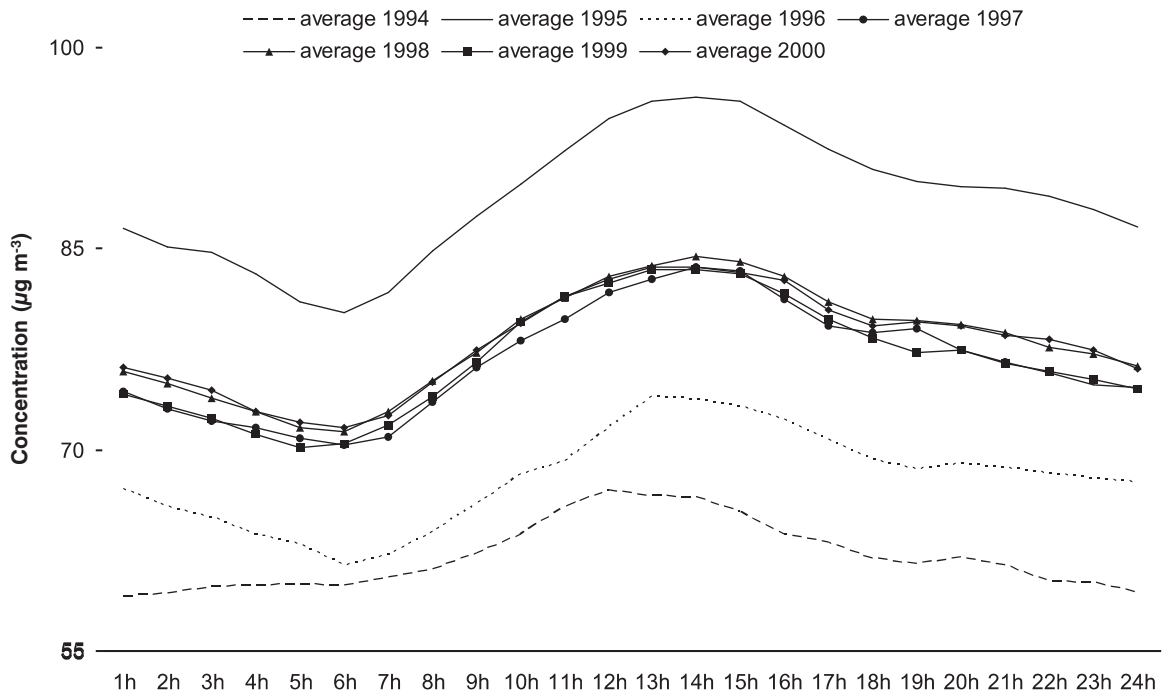


Figure 2. Hourly averages of ozone concentration per year at Bílý Kříž, 1994-2000

Diurnal values

In general the lowest concentrations are found in early morning and the highest in the afternoon (Hjellbrekke, 2000). The low concentrations were registered at Bílý Kříž between 05.00 and 07.00 (Fig. 2). The high concentrations were found between 11.00 and 20.00 during the summer months. The highest ones were registered on the afternoon and on the evening. The pronounced diurnal peak during the summer months is due to photochemical generation of ozone during daytime as a result of higher temperature and insolation during this time of the day (Hjellbrekke, 2000).

Daily values

The Bílý Kříž site registered for 1994 to 2000 the daily average of ozone concentration between 5.2 and 173.6 $\mu\text{g m}^{-3}$ (Fig. 3). From 1994 to 2000, the percentage of days when the daily limit of 65 $\mu\text{g m}^{-3}$ was exceeded was 78.4, 71.3, 49.3, 64.4, 69.5, 63.3 and 64.1% respectively. The highest daily ozone value was found on July 1994, May 1995, April 1996, June 1997, August 1998, April 1999 and June 2000. In warm months from April to September, 100.0, 89.4, 64.6, 89.1, 89.8, 86.8 and 42.5% of cases exceeded the daily limit from 1994

to 2000 at Bílý Kříž. During cold months (from December to March), 90.1, 51.0, 39.6, 42.7, 86.8 and 21.6% of days exceeded the limit of 65 $\mu\text{g m}^{-3}$ from 1994 to 2000.

Seasonal variation

The concentrations show a clear pattern with maximum values during spring or summer and a minimum in winter. Matyssek and Innes (1999) and Hjellbrekke (2000) describe this situation. The warm months had the high ozone concentrations, it proved that the forest received the high values of ozone from April to September in accordance with Rožnovský and Blažek (1996), APPA (1998), Petružela *et al.* (1999), Tshiamala and Rožnovský (2000b). The highest monthly ozone concentration from daily averages was on July 1994 and 1995, on June 1996 and 1997, on August 1998, on May 1999 and 2000. With the reference to the monthly concentrations for all period, the peaks were observed on May and July. The highest monthly ozone maximum was found on July (151.8 $\mu\text{g m}^{-3}$), July (152.9 $\mu\text{g m}^{-3}$), June 1996 (111.3 $\mu\text{g m}^{-3}$), August 1997 (122.1 $\mu\text{g m}^{-3}$), August 1998 (132.9 $\mu\text{g m}^{-3}$), May 1999 (121.3 $\mu\text{g m}^{-3}$) and May 2000 (127.5 $\mu\text{g m}^{-3}$) at the Bílý Kříž station.

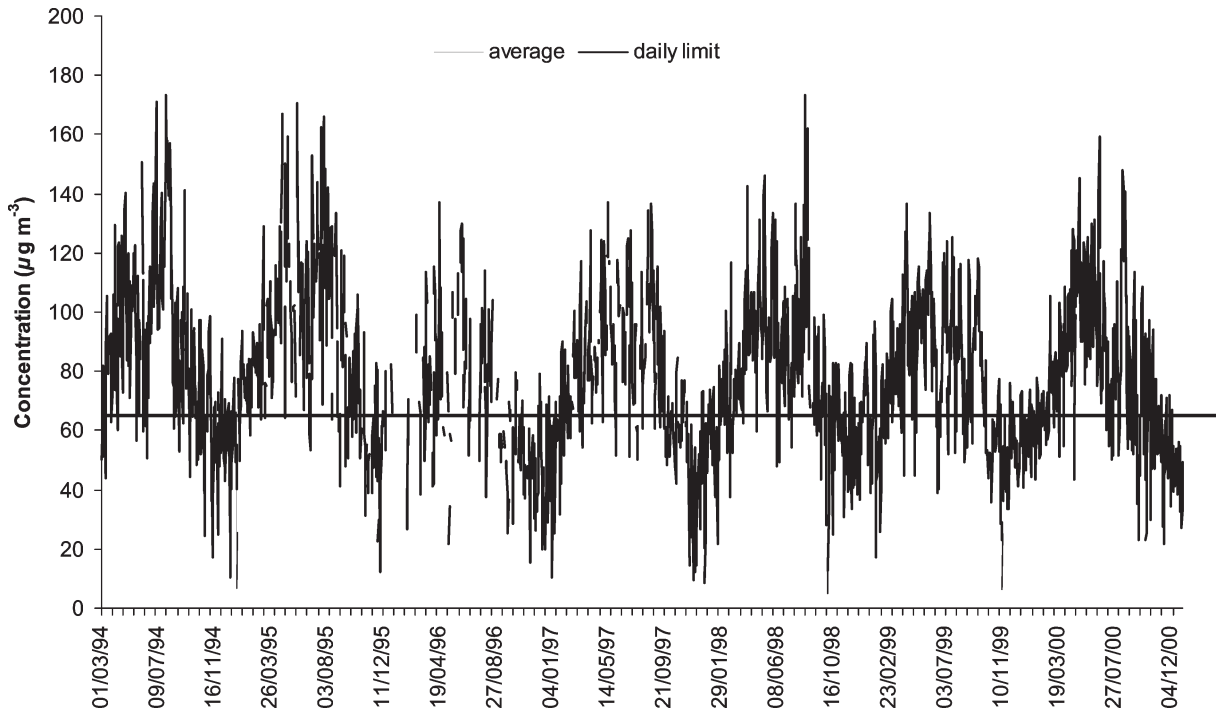


Figure 3. Daily ozone values with daily limit of $65 \mu\text{g m}^{-3}$ at the Bily Kriz site, 1994-2000

Annual values

The annual limit for the protection of vegetation is at $40 \mu\text{g m}^{-3}$. For 1994 to 2000, the most elevat-

ed annual value was observed in 1995 and the lowest one in 1996 (Tshiamala and Rožnovský, 2000a). The years from 1996 to 2000 have regis-



Figure 4. Annual ozone concentrations with annual limit of $40 \mu\text{g m}^{-3}$ at the Bílý Kříž station, 1994-2000

tered the annual value lower than $80 \mu\text{g m}^{-3}$ (Tshiamala and Rožnovský, 2000b). The annual values for other years have been more than twice higher than the annual limit of $40 \mu\text{g m}^{-3}$ (Fig. 4). From 1994 to 2000 the highest annual ozone concentration was of $88.9 \mu\text{g m}^{-3}$ in 1995. Figure 4 shows that from 1994 to 2000 the annual ozone values fluctuated between 67.4 and $88.9 \mu\text{g m}^{-3}$. The increase from 1996 to 1998 was found through the Czech Republic for the same time (Petružela *et al.*, 1999; Tshiamala and Rožnovský, 2000a, b) and through Europe (Beck *et al.*, 1998; Závodská *et al.*, 1998; Molnárová and Mindaš, 1999; Hjellbrekke, 2000).

CONCLUSION

Studies made in the Bílý Kříž station found that the concentration of ozone in this area is markedly higher from the levels generally accepted as natural. The highest monthly ozone concentration in the region of Beskids occurred in July and in the beginning of August. But the tropospheric ozone presently increased markedly, especially from 1996 at the Bílý Kříž station. The all critical indexes for ozone are exceeded considerably for the considered period. The human health, material and forest such as vegetation were markedly damaged by tropospheric ozone at the Bílý Kříž station, in the region of Beskids.

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