SOMO 35 at Slovak ozone monitoring stations during the period 1992–2005

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A b s t r a c t : Currently, surface ozone is the most serious regional problem of air pollution over Europe. Therefore European countries have paid fair attention to this harmful pollutant. Governments support surface ozone monitoring programmes and implement measures to control the emissions of ozone precursors. The World Health Organization (WHO) recommends a new indicator for the health impact assessment - SOMO 35 (the Sum of Ozone Means Over 35 ppb). The calculated exposures of the SOMO 35 at Slovak ozone monitoring stations during the period 1992–2005 are presented in this paper. SOMO 35 values in Slovakia range considerably (from 0 to 9536 ppb.days). The lowest ozone exposures are at typical urban stations, higher at suburban and rural stations. Maximal ozone loads are at mountain peak stations. The highest contributions to yearly sum of SOMO 35 are from April to August. SOMO 35 has considerable inter-annual variability (like ozone concentrations and other indices) caused by the variation of meteorological conditions. The highest ozone exposures appeared in 2003 at most of the stations.

Key words: surface ozone, SOMO 35, Slovak stations

1. Introduction

Ozone is only a trace gas in the atmosphere, but it plays an important role. Ozone absorbs a large part of the UV radiation. The terrestrial life would not come into existence without it. Ozone has also the important position in tropospheric photochemistry, it is the significant oxidant and it is the primary source of hydroxyl radical (OH), which is responsible for the removal of many air pollutants *(Závodský, 2001)*. Moreover, it is an effective greenhouse gas.

The most of atmospheric ozone is present in the stratosphere (more than

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90%). In the troposphere there is only less than 10%. The maximal ozone concentrations are in the layer at altitudes between 20 and 25 km. From this layer ozone penetrates the tropopause and the troposphere, and then reaches the surface, where it is destructed. This mechanism prevailed in the past when the stratosphere was the main source of ozone in the troposphere. At present the significant source of ozone is its photochemical production in the troposphere.

In the mid 1940s the episodes with high concentrations of surface ozone occurred for the first time in Los Angeles. This phenomenon was later named as the photochemical smog and it was thought to be a local problem of the air pollution only. But nowadays this problem attains more than a regional character. On the basis of historical measurements it was found that ozone concentrations in many areas of the northern hemisphere have more than doubled over the last hundred years.

The present high surface ozone concentrations are caused by the elevated tropospheric ozone production. Photochemical processes produce ozone in the troposphere from nitrogen oxides (NO_X), volatile organic compounds (VOC) and carbon monoxide (CO). Natural processes in soil and vegetation emit these compounds. But the large emissions of these gases have the origin in combustion as well, especially by motor vehicles and industrial processes.

Ozone is a harmful air pollutant. The high concentrations of surface ozone have injurious effects on the health of humans, animals and vegetation *(Baird, 1999)*. This pollutant is one of the most significant stress factors for the vegetation. Its long-term effects on agricultural crops are expressed by reduction in crop yields. Ozone also harms and reduces the lifetime of various materials.

Therefore the tropospheric ozone is an internationally important pollutant. For these reasons national governments of Europe, taking into account obligations resulting from the UN ECE Convention on long-range transboundary air pollution, support the surface ozone monitoring programmes, as well as implement measures to control the emissions of ozone precursors. Among first measures was, for example, restriction of the automobile transport in cities affected by photochemical smog and implementing three-way catalytic converters in vehicles. Primary (for protection of human health) and secondary (environmental limits) imission limits were implemented as well.

The exposure index AOT 60 (Accumulated amount of Ozone over the Threshold value of 60 ppb) was used to evaluate the long-term effect of the surface ozone on human health. At present the World Health Organization recommends a new indicator for the health impact assessment - the SOMO 35 (the Sum of Ozone Means Over 35 ppb). It is defined as the yearly sum of the daily maximum of the 8-hour running average over 35 ppb. For each day the maximum of the running 8-hours average for O_3 is selected and the values over 35 ppb are summed over the whole year. The corresponding unit is ppb.days.

The exposure indices AOT 40 and AOT 60 in Slovakia were mapped in several phases *(Závodská et al., 1998, Kremler, 1999)*.

2. Material and methods

The continuous surface ozone monitoring in Slovakia started in 1992 when the Slovak Hydrometeorological Institute (SHMI) established a real time air pollution monitoring system of the Slovak Republic. The ozone analyzers Thermoelectron, MLU and Horriba are used. They operate on

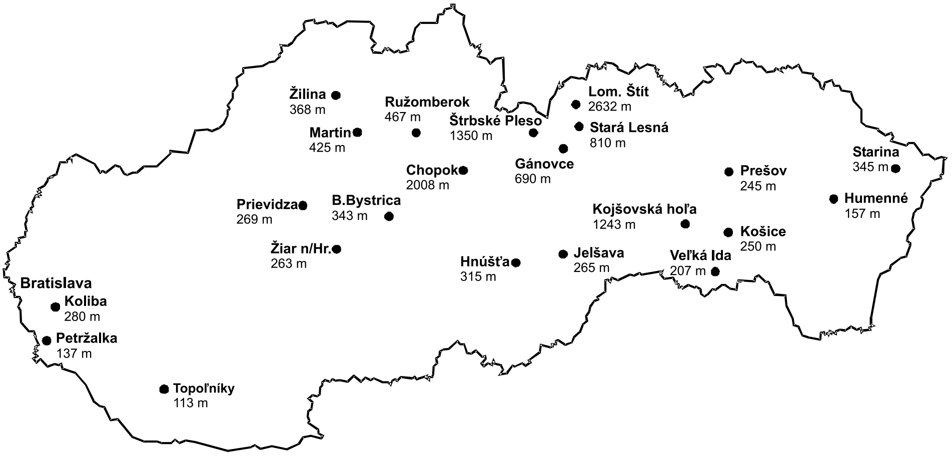

Fig. 1. Distribution of ozone monitoring stations operated by SHMI in Slovakia in 2004.

the principle of UV absorption. Their detection limit is 1 ppb. The national secondary ozone calibration standard was installed in Slovakia in 1994. Intercomparisons with the Czech primary ozone standard are regularly organized.

The quality of the ozone data was not adequate especially in first years of measurements. On some stations the various gaps in the ozone data as to duration occurred due to breakdowns of the analyzers, pumps and problems with air-conditioning. This disadvantageous state was caused by budgetary troubles of the Slovak Hydrometeorological Institute.

Besides SHMI stations in this study data from stations operated by the Forest Research Institute and Research Centre of the Tatra National Park were used. In Table 1 there are altitude and availability of data on the Slovak ozone monitoring stations. Distribution of stations (operated by SHMI) in Slovakia is shown in Fig. 1.

Measured ozone data in the electronic database of SHMI are in $\mu g.m^{-3}$. At first all mean 1-hour ozone concentrations had to be converted into ppb. Then running 8-hour means were calculated. On the basis of these means ozone exposures SOMO 35 were computed.

3. Results and discussion

The calculated values of SOMO 35 at the Slovak ozone monitoring stations are given in Table 2. They range considerably from 0 to 9536 ppb.days. Zero values occur in two cases in the year 1993 (urban stations Bratislava Trnavské Mýto and Ružomberok Sihoť). On the other hand, the maximal SOMO 35 was reached at the peak mountain station Lomnický štít in 2003. At the most stations the whole period maximum of SOMO 35 occurs in this year. The calculated values of the ozone exposure are slightly higher in 2003 and slightly lower in 2000 in comparison with values (model calculations) from the EMEP map of the SOMO 35 *(Klein et al., 2004;* and `http://ec.europa.eu/governance/impact/docs/ia_2005_2/SEC_2005_1133_1_EN.pdf`, `http://www.iiasa.ac.at/rains/CAFE_files/CAFE-baseline-full.pdf`, `http://www.iis.niva.no/ICP-waters/Vedlegg/1%20Heinz%20Gregor%2024%20WGE_comp.pdf`).

Fig. 2 shows the relation between the mean values of SOMO 35 from the

Table 1. Altitude and percentage of available 1-hour ozone concentration averages at Slovak stations (BA means Bratislava, BB Banská Bystrica and KE Košice)

Station	Alt.	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
BA Koliba	287				52.9	84.7	67.9	72.2	53.1	95.0	97.0	97.2	96.0	97.7	93.1
BA Petržalka	136	81.1	92.2	81.2	95.1	91.6	90.3	94.5	99.4	81.8	97.7	97.9	97.1	98.1	96.0
BA Trnavské Mýto	136	68.7	75.0	34.9											
BB Nám. Slobody	343	83.1	86.2	51.6	89.3	80.9	94.9	97.6	97.8	97.6	93.2	98.3	99.4	98.3	99.9
Hnúšťa	315			45.2	96.0	98.5	97.0	81.0	95.9	97.8	97.4	94.7	94.3	93.3	98.0
Hukavský Grúň	850													70.6	74.6
Humenné	160			79.2	49.5	6.6	67.7	98.3	87.7	97.2	97.7	98.2	96.8	97.9	97.8
Chopok	2008	5.3		23.7	82.9	58.2	82.6	57.3	45.0	73.3	35.0	90.6	58.7	89.9	98.4
Jelšava	255						64.8	99.4	95.9	83.9	98.6	92.2	95.0	98.0	99.9
KE Podhradová	248					85.1	90.0	78.9	73.1	91.9	96.8	96.8	99.4	99.4	74.7
KE Štúrova	199						59.4	96.9	69.9						
Kojšovská hoľa	1248								16.1	76.7	93.8	99.0	92.5	97.8	70.5
Liesek	692													60.7	70.6
Lomnický štít	2635											30.5	94.1	85.6	78.6
Martin	396			1.9	43.3	99.7	81.5	99.1	95.0	99.1	10.0	54.2	91.8	32.4	
Mochovce	260								76.9	29.2					
Poprad Gánovce	694								84.9	76.8	94.7	96.6	99.3	75.8	73.2
Predná Poľana	1360												2.2	62.8	83.6
Prešov Solivar	255							52.3	90.4	87.2	97.7	99.5	96.7	99.6	99.4
Prievidza	269	35.4	56.3	62.3	43.0			64.3	70.3	91.8	91.6	92.5	97.6	98.5	87.3
Ružomberok Riadok	476								53.5	94.5	93.8	99.2	98.2	83.6	100.0
Ružomberok Sihoť	485	72.2	82.1	33.1	97.3	99.4	67.1								
Senica	212				98.5	97.0	85.6								
Skalnaté Pleso	1770											90.5			
Smokovec	1000													69.6	89.2
Solisko	1840												28.6	73.1	88.8
Stará Lesná	808	99.9	76.7	85.6	92.6	85.4	86.6	66.3	92.9	94.7	98.1	99.6	96.3	98.5	98.7
Starina	345				90.4	94.4	85.2	91.7	97.6	92.2	97.0	99.7	98.8	83.0	95.4
Svit	725			75.9	69.9	87.7	17.0								
Šaľa	115			85.0	96.2	93.4	23.3								
Štart	1200													71.2	96.8
Štrbské Pleso	1354									30.7	89.2	99.8	96.9	96.5	73.7
Topoľníky	113			89.5	98.5	64.5		37.3	90.6	91.1	78.4	99.1	99.2	98.2	96.1
Veľká Ida	207	57.4					90.9	87.5	96.0	67.1	86.0	95.1	59.2	96.6	97.9
Žiar nad Hronom	263	79.4	78.9	56.2	77.6	97.3	97.4	97.7	95.8	48.4	38.5	94.8	99.5	99.6	100.0
Žilina Vlčince	368			96.5	91.1	99.0	51.5	95.4	94.8	90.6	98.9	96.3	98.0	99.8	99.8

period 2001 - 2005 and altitude of the stations. On the basis of points (representing the station position) we can divide stations into several groups or clusters. Mountain stations situated in the High Tatras with altitude above 1000 m (Lomnický štít, Solisko, Štrbské Pleso, Štart, and Smokovec) together with Chopok and Predná Poľana form the first cluster. SOMO 35 increases linearly with altitude of these stations (values range from 2423 to 7222 ppb.d).

Southerly-located mountain stations (Kojšovská hoľa and Hukavský grúň) belong to the second cluster. They have higher values of ozone load (4967 and 4540 ppb.d) than stations from the first group at the same altitude. Station Predná Poľana (from the first cluster) is situated very close to station Hukavský grúň and its altitude is higher. In spite of this, Predná Poľana has a lower value of SOMO 35 (3462 ppb.d). It can be explained by the fact that the average on this station was calculated only on the basis of two years (2004 and 2005) and fair-sized data gaps (mainly in 2004).

Next cluster consist of 2 EMEP background stations (Stará Lesná, Liesek) and Poprad Gánovce, which have similar values of SOMO 35 (2655 – 2825 ppb.d) like the lowest stations from the first group, but they are in lower altitude.

The fourth cluster is very compact (values: 2869–3238 ppb.d). It consists of 8 stations: 2 EMEP background stations (Topoľníky and Starina), Humenné, Jelšava, Žiar nad Hronom, Bratislava Koliba, Hnúšťa and Košice Podhradová. The linear increase of SOMO 35 with altitude in this cluster is faster than at the High Tatras stations.

Typical urban stations (Ružomberok Riadok, Veľká Ida, Martin, Prievidza, Žilina, Prešov, Banská Bystrica, and Bratislava-Petržalka) can be assigned to the fifth cluster. Values of the ozone load vary in wide range (from 1229 to 2739 ppb.d) in this group and they are not dependent on altitude. Surface ozone concentrations at urban stations are lower due to the reaction of O_3 with NO, which comes from vehicle emissions. An extreme case is station Bratislava-Trnavské Mýto, where values of SOMO 35 were 162 in 1992 and 0 ppb.d in 1993. This station was unfavorably located near frequent crossing and influenced by high fresh emissions from transport. Therefore measurements on this station were terminated after 2 years.

The layout of stations in Fig. 2 is partly similar to the position of points representing the mean ozone concentrations dependence on the altitude, which can be found in the paper by *Bičárová et al. (2005)*.

In Table 3 there are mean contributions of the individual months to yearly sum of SOMO 35. Annual course of these contributions for selected Slovak stations can be seen in Fig. 3. The highest monthly sums of maximal daily running 8-hour means are at mountain stations, where these sums are higher than 0 ppb.days in the whole year. At the remaining stations the monthly values of SOMO 35 are equal or close to zero from November to January. High values occur at stations in the summer period (maximal values in the yearly course mainly in April/May and in August).

The SOMO 35 values have considerable interannual variability (see Fig. 4). It is caused by meteorological conditions in particular. It is interesting that values at all three stations in Fig. 4 are considerably diverse before the year 2002, and after this year they are quite near to each other. At the stations Banská Bystrica and Bratislava-Petržalka there is a small increasing trend, fractionally due to worse data in the first years of ozone measurements. Data gaps in summer season can significantly lower the final yearly sum of SOMO 35.

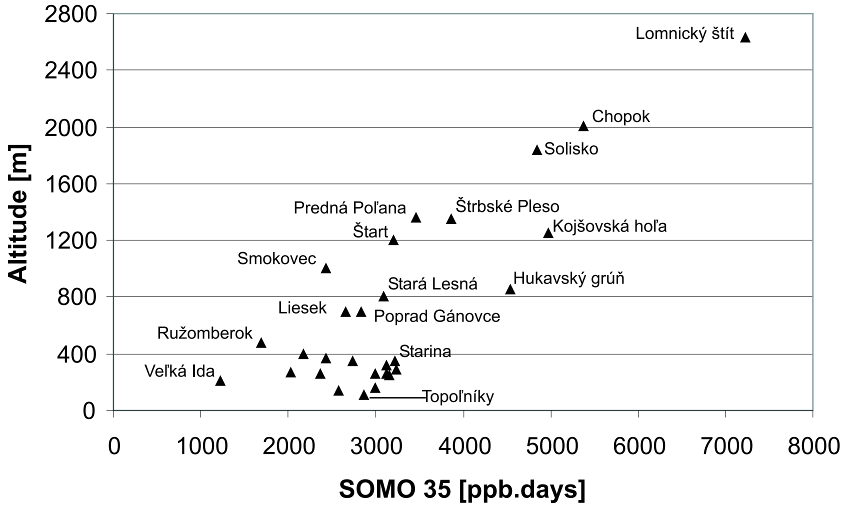

Fig. 2. Relation between the mean values of SOMO 35 from the period 2001–2005 and altitude of the Slovak ozone monitoring stations.

Table 2. SOMO 35 values in ppb.days at Slovak ozone monitoring stations. Maxima are marked by bold font

Station	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
BA Koliba				1438	1824	3476	1606	503	2043	2279	2632	**4820**	3029	3433
BA Petržalka	1730	2832	1098	1167	256	154	214	1021	909	1503	2285	**3594**	2228	3241
BA Trnavské Mýto	**162**	0												
BB Nám. Slobody	1221	1317	1071	1960	629	1613	2779	2804	2618	2731	2411	**3555**	2221	2778
Hnúšťa			1346	3232	3656	2525	3285	1693	2431	2747	3306	**4397**	2480	2686
Hukavský Grúň													**4616**	4463
Humenné			2166	1379		958	1568	1039	1501	1219	2785	**4556**	2997	3438
Chopok				5028	3755	3079	2539	2804	2631	4279	5667	5345	5510	**6088**
Jelšava						2633	3091	3180	2083	2764	2884	**4115**	2788	2443
KE Podhradová					1305	653	319	293	1460	1217	3890	**4531**	3094	3018
KE Štúrova						602	**860**	638						
Kojšovská hoľa									**6007**	5321	4852	5506	4786	4368
Liesek													1870	**3440**
Lomnický štít												**9536**	6330	5799
Martin				420	2765	2100	2735	2112	1864		1502	**2857**		
Mochovce								**3355**						
Poprad Gánovce								2755	1431	1513	2853	**4133**	2502	3126
Predná Poľana													3064	**3859**
Prešov Solivar							277	1246	2259	2442	2232	**3326**	1533	2285
Prievidza		2022	**3417**				795	1390	2433	1874	1382	3118	2005	1743
Ružomberok Riadok								170	1343	1706	1859	876	1602	**2390**
Ružomberok Sihoť	637	0		**3331**	949	473								
Senica				1625	**2226**	1685								
Skalnaté Pleso											**6534**			
Smokovec													2109	**2737**
Solisko													**5322**	4369
Stará Lesná	3555	2276	2926	3615	3384	2757	1622	**4264**	3639	2910	2421	3735	2937	3489
Starina				2003	2864	1313	1541	1984	2393	2520	2969	**4591**	3121	2907
Svit			3665	2225	**3670**									
Šaľa			**2293**	1505	1467									
Štart													**3595**	2799
Štrbské Pleso										3542	3839	**5066**	3430	3401
Topoľníky			2888	2039	1125			2176	990	927	1690	**5274**	3166	3290
Veľká Ida	**2559**					1359	1195	1294	1320	1257	2316	441	922	1211
Žiar nad Hronom	1172	1276	1594	493	1072	722	952	910	509		2310	**4298**	3109	2749
Žilina Vlčince			3169	2843	2225	1040	2295	1802	2682	1838	2674	**3603**	2017	2045

Table 3. Share of individual months on yearly sum of SOMO 35 in ppb.days at Slovak ozone monitoring stations

Station	I	II	III	IV	V	VI	VII	VII	IX	X	XI	XII
BA Koliba	2	77	221	397	460	434	446	469	188	20	0	1
BA Petržalka	0	20	90	222	291	264	306	276	133	12	4	0
BA Trnavské Mýto	34	0	0	0	4	0	12	4	0	7	0	0
BB Nám. Slobody	3	25	149	353	393	396	399	408	126	5	2	1
Hnúšťa	3	109	288	491	539	414	449	434	159	48	3	2
Hukavský Grúň	34	214	696	830	540	519	525	602	335	166	37	26
Humenné	12	87	233	371	331	332	320	377	138	26	8	3
Chopok	178	265	316	571	602	463	509	652	420	318	218	233
Jelšava	7	71	238	481	578	498	425	441	198	32	2	4
KE Podhradová	2	67	185	251	319	292	325	359	164	18	7	8
KE Štúrova	0	15	62	153	158	114	111	145	19	0	0	0
Kojšovská hoľa	130	245	429	530	766	716	591	748	487	247	131	160
Liesek	34	294	598	618	471	422	377	334	225	41	27	0
Lomnický štít	368	555	678	804	839	856	822	753	564	540	390	498
Martin	4	49	164	288	300	420	333	456	144	37	1	2
Mochovce	12	17	176	495	771	502	507	326	305	19	0	0
Poprad Gánovce	7	80	256	393	481	381	370	385	222	36	4	2
Predná Poľana	33	274	541	481	448	537	555	309	193	161	90	75
Prešov Solivar	0	39	140	249	436	341	302	385	143	24	0	0
Prievidza	0	33	127	253	398	300	403	358	150	13	4	0
Ružomberok Riadok	0	28	127	297	341	265	217	202	51	8	0	0
Ružomberok Sihoť	8	30	114	210	206	187	150	108	40	3	8	3
Senica	0	63	119	281	311	358	356	280	66	10	0	0
Skalnaté Pleso	324	409	716	87	909	801	858	858	574	308	375	313
Smokovec	3	116	464	455	440	356	300	314	205	55	1	4
Solisko	159	266	284	663	558	523	694	764	344	266	119	14
Stará Lesná	33	163	401	583	529	397	362	412	215	71	22	15
Starina	22	154	361	477	408	355	262	328	131	56	15	12
Svit	11	197	390	427	326	434	589	506	157	91	28	2
Šaľa	0	40	102	292	226	312	371	252	58	5	0	0
Štart	19	162	476	553	587	414	425	444	237	137	27	34
Štrbské Pleso	105	202	419	506	610	580	378	440	250	126	82	129
Topoľníky	5	75	195	323	361	338	340	426	192	32	2	2
Veľká Ida	1	31	94	234	347	233	177	234	73	12	15	35
Žiar nad Hronom	3	38	159	273	287	246	301	251	115	11	0	17
Žilina Vlčince	13	28	184	449	441	387	351	388	126	18	8	2

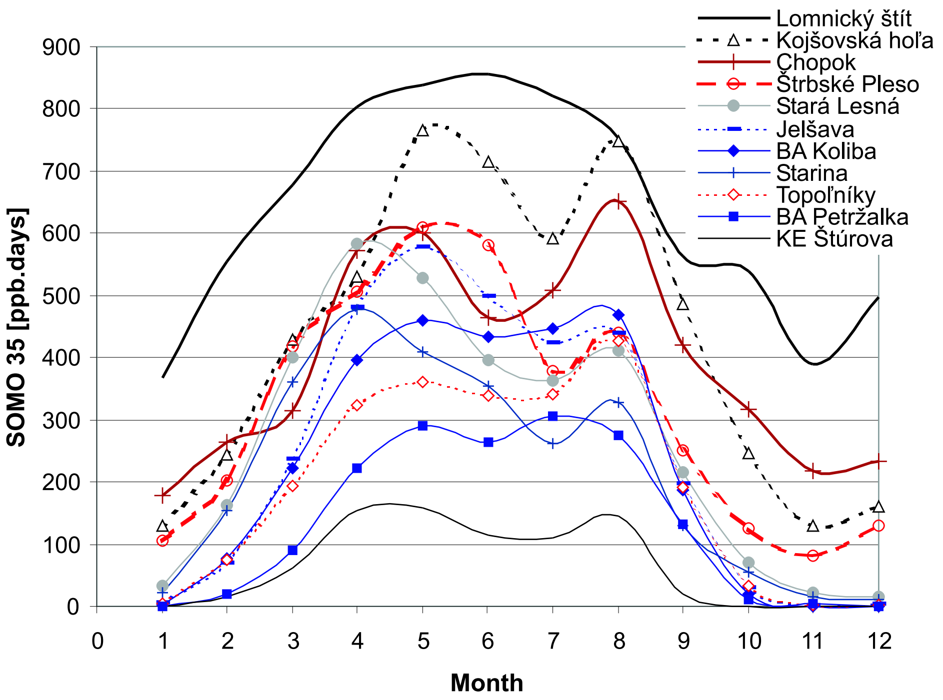

Fig. 3. Annual course of month shares on yearly sum of SOMO 35 at selected Slovak ozone monitoring stations.

4. Conclusion

The long-term influence of the surface ozone concentrations on human health is evaluated on the basis of SOMO 35 values. In this study the exposure index SOMO 35 at Slovak ozone monitoring stations is calculated and analyzed for the period 1992–2005.

The SOMO 35 values in Slovakia range noticeably (from 0 to 9536 ppb.days). The lowest ozone exposures are at typical urban stations (in town centers and localities near crossing and roads with dense transport). The values increase toward the outskirts of towns and rural country (suburban and rural stations). The mean ozone load at EMEP background stations is about 3000 ppb.d. The highest exposure indices are in mountains (peak stations).

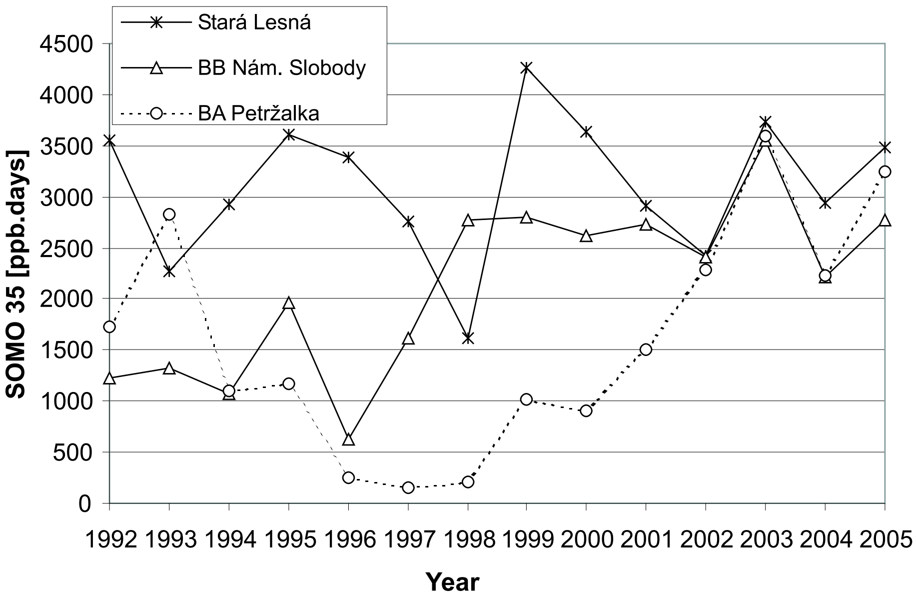

Fig. 4. Course of SOMO 35 during the period 1992 – 2005 at 3 selected Slovak ozone monitoring stations.

Besides urban stations SOMO 35 raises with increasing altitude of stations. However, this increase with altitude is not for the whole Slovakia (stations can be divided into 5 clusters).

The highest contributions to the yearly sum of SOMO 35 are from April to August. At the most of stations these contributions are equal or close to 0 ppb.days in winter months (mountain stations represent the exception).

The SOMO 35 has considerable interannual variability (like ozone concentrations and other indices) caused by the variation of meteorological conditions. The highest ozone exposures appear in 2003 at most of the stations.

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