Evaluation of the temporal and spatial distribution of non-methane hydrocarbon emissions from the forests in Slovakia

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ABSTRACT: The paper presents the first detailed inventory of non-methane hydrocarbon emissions from forest vegetation in Slovakia. Emissions rates of monoterpene, isoprene and other volatile organic compounds (VOC) were calculated for each main tree species separately using the relevant parameters such as temperature and leaf biomass density. The GIS technology was used for the analysis of spatial distribution of VOC emissions. The annual total VOC emissions from forests in Slovakia ranged from 77 to 98 ktonnes during the period 1990–2000. The percentage of isoprene, monoterpene, and other VOC emissions is relatively stable and varies in the narrow intervals: isoprene emissions (17–23%), monoterpene emissions (65–73%), and other VOC emissions (10–15%). The major contribution of VOC (especially monoterpenes) comes from the Norway spruce (*Picea abies*) forests (45.7% in 2000) due to their abundance and high leaf biomass density with domination in the montane belt. The oak species (*Quercus* sp.) are the second important VOC emittors (18.2%) with domination in the thermo-colline and colline belt of the Carpathian Mts.

Keywords: biogenic emissions; isoprene; monoterpenes; volatile organic compounds; Slovak forests

The interest in fluxes of biogenic hydrocarbons to the atmosphere is connected with the biogenic contribution to the atmospheric carbon budget, and subsequently in response to ozone and other secondary pollutant production from anthropogenic emissions of nitrogen oxides and hydrocarbons (Isidorov 1994).

It is known that plants contain a number of volatile organic compounds (VOC) including isoprene, mono- and sesquiterpenes, alcohols, aldehydes, ketones, and esters which may be widely distributed throughout plant organs. Biogenic VOC is also a rather loose term for a wide range of compounds, of which only a few are generally of more interest. A wide variety of organic compounds including oxygenated species has been observed as biogenic emissions from vegetation. Despite the wide range of volatile compounds emitted, only isoprene and selected monoterpenes have been extensively studied as emission products from vegetation. Isoprene is generally the compound of highest importance for photochemistry modelling for example, and it is useful to inventory this compound specifically (Guenther et al. 1994; Simpson, Winiwarter 1998).

The need for emission reductions of predominant air pollutants has been widely accepted by the policy makers of many countries including the Slovak Republic. Although there are some attempts to estimate national biogenic VOC emissions in various countries (Lamb et al. 1987; Guenther et al. 1994; Andreani-Aksoyoglu, Keller 1995; Simeonidis et al. 1999), no detailed study has been carried out in Slovakia.

In this paper, estimations of emission rates of isoprene, monoterpenes and other VOC from the forest ecosystems in Slovakia are reported. We provide

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a detailed description of an extrapolation scheme based on remote sensing data (land-use) and GIS tools. This methodology for assessing base emission rates represents a significant improvement over existing VOC inventory results and will improve attempts to estimate biogenic VOC emissions in Slovakia.

METHODOLOGY

According to the characteristics of emitted gases, VOC emissions are grouped into three main categories (Guenther et al. 1994; Simpson, Winiwarter 1998): 1. *High isoprene emittors* (deciduous species – sp. *Quercus, Populus, Salix*), 2. *Nonisoprene emittors* or other VOC emittors (deciduous species – sp. *Fagus*, *Carpinus, Acer, Fraxinus*), and 3. *Monoterpene emittors* (coniferous species – sp. *Picea, Pinus*). Emission categories were defined on the basis of the tendency of normalized emission rates in tree genera to fall within certain ranges, and on the properties of dominant emitted hydrocarbons (Guenther et al. 1994; Isidorov 1994).

Three basic parameters are required for developing a biogenic hydrocarbon emission inventory (Simpson, Winiwarter 1998): emission factors for the vegetation species, biomass (or leaf) density factors and prevailing environmental conditions such as temperature, season, radiation, etc.

Emission factors for the vegetation species

The selection of the regression equations from the literature was done on the basis of the literature overview (Andreani-Aksoyoglu, Keller 1995; Guenther et al. 1994; Janson 1993; Lamb et al. 1987; Simeonidis et al. 1999; Simpson, Winiwarter 1998, etc.), analysis of climatic conditions, and current tree species composition of Slovak forests. The emission rates depending on air temperatures have been calculated according to the following equations:

High isoprene emittors

Regression equation:

$$\log E(T) = 0.0416\ T - 0.109 \text{ (day)} \quad (1)$$
(isoprene)

$$\log E(T) = 0.0416\ T - 0.786 \text{ (night)} \quad (2)$$
(Lamb et al. 1987)

$$E(T) \text{ total} = E\ (T, \text{isoprene}) \times 1.2 \quad (3)$$

where: $E(T)$ – emission in μg/g(dw)/h,
T – air temperature.

Other VOC emittors

Regression equation:

$$\log E(T) = 0.032\ T - 0.638 \text{ (day, night)} \quad (4)$$
(Veldt 1988)

$$E(T) \text{ total} = k \times E(T) \quad (5)$$

where: $E(T)$ – emission in μg/g(dw)/h,
T – air temperature,
k = 1.4 for beech, hornbeam, k = 3 for maple, and k = 1 for ash (parameter k is derived from the standard emission potentials for all types of VOC emissions based on the published data of Simpson, Winiwarter 1998).

Monoterpene emittors

Regression equation:

$$E(20) = E(T) \times 10^{0.04 \times dT} \text{ (day)} \quad (6)$$
(Janson 1993)

$$E(T) = 0.5\ E\ (T, \text{day}) \text{ (night)} \quad (7)$$

$$E(T) \text{ total} = k \times E(T)$$

where: $E(T)$ – emission in μg/g(dw)/h,
dT – air temperature difference from 20°C,
k = 2 for Norway spruce, fir, pine, and larch (parameter k is derived from the standard emission potentials for all types of VOC emissions based on the published data of Simpson, Winiwarter 1998).

It is doubtless that NMVOC emissions from some forest tree species show quite a strong dependence on light intensity. Concrete regression dependencies were also derived, e.g. for isoprene emittors (e.g. Simeonidis et al. 1999). There still remains a methodological problem how to apply such regression dependencies at a national level (large territories) in the landscape with very variable and complex terrain and limited number of meteorological stations measuring solar radiation. Therefore we decided to apply only the dependence on air temperature for the calculation of VOC emissions from forest stands.

Leaf biomass data

A leaf biomass density was estimated for each grid in the data set based on the data adopted from Veldt (1988) and modified according the individual tree species (Table 1).

GIS tools

Due to visualization of the results and utilization of spatial modelling we used the GIS tools (Idrisi 32)

Table 1. General overview of VOC emittor categories and leaf biomass data used in VOC calculations

Tree species	Leaf biomass data (t/km)	Category of VOC emittors		
		high isoprene emittors	other VOC emittors	mono-terpene emittors
Picea abies	1,500 (1,000*)			x
Abies alba	1,400			x
Pinus sylvestris	700			x
Larix decidua	300			x
Pinus mugo	100			x
Fagus sylvatica	400		×	
Quercus sp.	320	×		
Carpinus betulus	300		×	
Robinia sp.	300		×	
Fraxinus sp.	300		×	
Acer sp.	300		×	
Populus sp.	300	×		
Alnus sp.	300	×		
Betula sp.	300		×	
Sorbus sp.	300		×	

*above 1,450 m a.s.l.

with the grid resolution 250 × 250 m. Several supporting layers were constructed for this purpose: digital elevation map, tree species composition map, and mean monthly air temperature map. The information on the spatial distribution of the tree species composition came from the satellite image data LANDSAT Thematic Mapper (6 scenes from 1990–1993, resolution 30 × 30 m – generalized to 250 × 250 m grids) of the analysis made by BUCHA (1999). Due to a high portion of mixed forest stands in Slovakia we assigned area-averaged VOC emission rate estimates to each of the woodland landscape in our database by emission rates associated with the dominant tree species. Spatial distribution of mean monthly air temperatures was modelled by simple linear or non-linear regression between altitude and monthly air temperature based on the data from 172 meteorological stations in Slovakia (Fig. 1).

Spatial model of monthly air temperatures was based on the values of regression equations for respective months (r^2 = 0.86–0.96), subsequently at points representing meteorological stations the difference was calculated between modelled value and actual value of air temperature. These differences were interpolated for the whole territory of Slovakia by means of non-linear dependence – $1/dx^2$

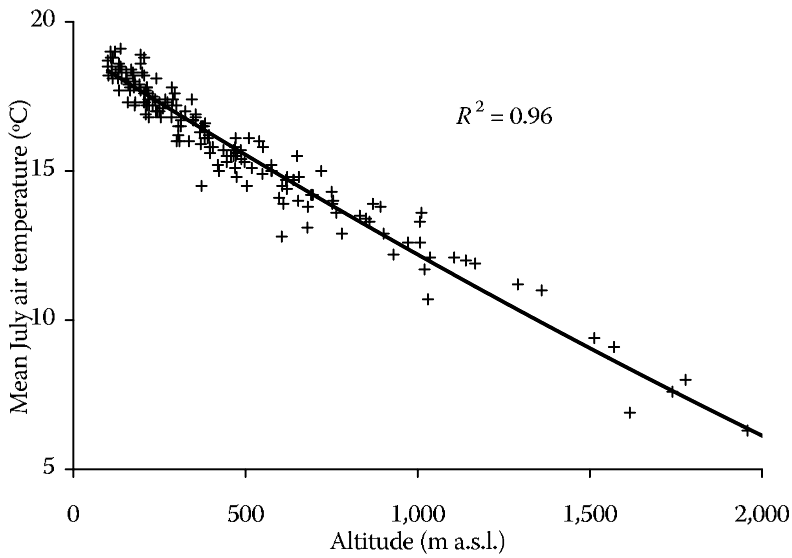

Fig. 1. Dependence of mean July air temperature on altitude in Slovakia

Table 2. Comparison of VOC emissions between selected European countries (Simpson, Winiwarter 1998) (data in kilotonnes)

	Isoprene	Other VOC	Monoterpenes
Austria	32	78	30
Germany	121	190	249
Hungary	82	16	23
Poland	63	176	113
Switzerland	5	17	30
Romania	154	83	55
Slovakia – this paper (2000)	19	14	63

(where *dx* is the distance from a meteorological station) and then this layer was counted with the layer obtained from regression model. Similar methodical approaches were used also in other countries (Jeffrey 2001).

RESULTS AND DISCUSSION

Tree species are the main source of VOC emissions from forest ecosystems, the emission portion of other ecosystem compartments (herbs, litter layer, soil) is usually negligible (Hanson, Hoffman 1994). Therefore only VOC emission rates from forest tree species were included into calculations.

It is important to point out that calculations were carried out only for the period April–September of the year. This assumption seems to be correct for deciduous tree species, but for coniferous ones it may lead to underestimation of total VOC emissions. On the other hand, most experimental studies are focused on the measurements during the vegetation season with the ambient air temperatures usually between 10 and 30°C. Experimental results from the winter time are missing and regression equations are derived mainly from the results during the vegetation season (Janson 1993).

A large fraction of the Slovak forests (57%) is broadleaved stands, as seen in Table 3. Among the broadleaved trees, the main species is beech (*Fagus sylvatica*), which takes up about 29% of all the forest trees. The percentages of oak species (*Quercus robur, Q. petraea, Q. pubescens, Q. cerris*), hornbeam (*Carpinus betulus*) and other broadleaves (*Acer* sp., *Fraxinus* sp., *Poplar* sp., *Robinia* sp. etc.) are in the range 2–11% (Table 3).

Various studies carried out with oak and poplar trees showed that isoprene is the predominant VOC emitted from this species (Tingey 1981; Lamb et al. 1987; Isidorov 1994; Simpson, Winiwarter 1998). Because the area of oak forests in Slovakia is relatively high (11%, Table 3), the emission of isoprene is an important part of the total VOC emissions. On the other hand, the beech forests which cover about 29% of the total forest area, and other

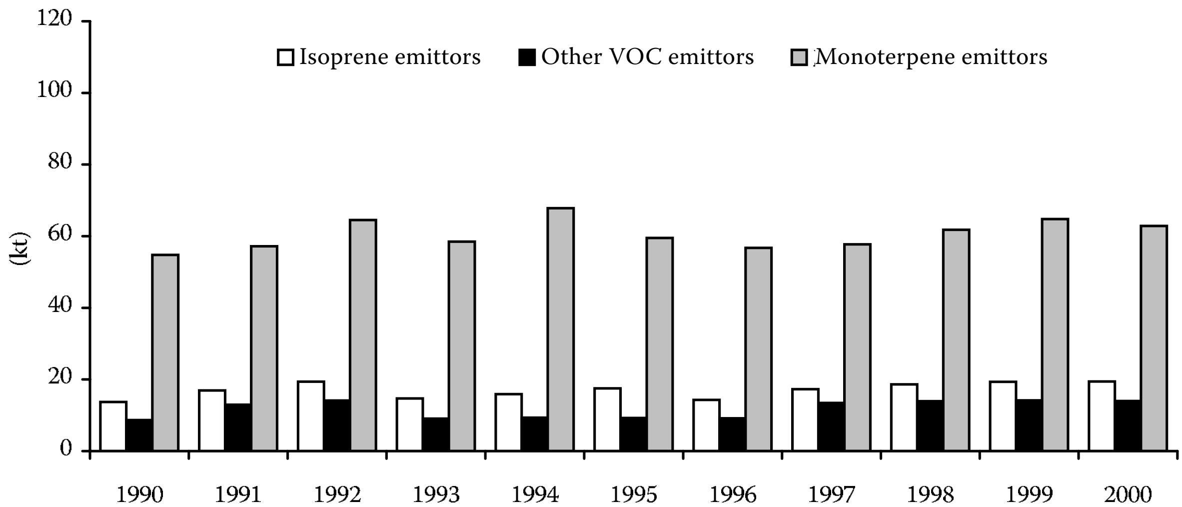

Fig. 2. Temporal changes in annual VOC emissions during the years 1990–2001 in Slovakia

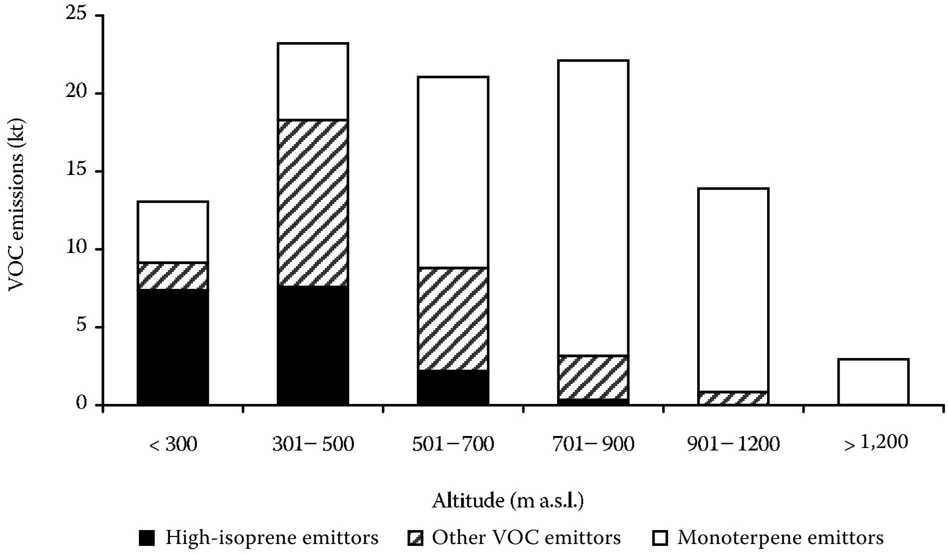

Fig. 3. Altitudinal distribution of VOC emissions in relation to individual emittor groups for the inventory year 2000

species (ash, maple sp., hornbeam, etc.) are reported to emit no isoprene but some terpenes (Isidorov 1994; Simpson, Winiwarter 1998). Therefore the only source of isoprene emissions from the deciduous trees is likely oak and poplar forests.

Coniferous trees are known to emit mainly monoterpenes such as α-pinene, β-pinene, and others depending on the emitting species (Tingey 1981; Isidorov 1994; Janson 1993; Simpson, Winiwarter 1998). Among the coniferous trees, Norway spruce (*Picea abies*) is the most abundant one (27%). The main species emitted from these trees are α-pinene, β-pinene, and limonene (Janson 1993; Isidorov 1994). Scots pine (*Pinus sylvestris*), which is reported to emit α-pinene, limonene, α-pinene, β-phellandrene, and camphene (Janson 1993), covers about 8% of the total forests in Slovakia. Fir (*Abies alba*) is the third important coniferous species (5%). Small amounts of *Pinus mugo* and *Larix decidua* (3%) are also included in the group of monoterpene emittors.

Generally, we can conclude that the percentage of individual VOC emittor groups in Slovakia is as follows: (*i*) high-isoprene emittors (16%), (*ii*) other VOC emittors (43%), and (*iii*) monoterpene emittors (41%).

Temporal changes in VOC emissions

Calculations carried out using the monthly averaged temperatures over the period 1990–2000 showed that the highest emission rates took place in 1992 and 1999 (Fig. 2). It is evident from this figure that the major biogenic VOC emitted by the forests are monoterpenes whereas isoprene and other VOC account for a lower fraction of total emissions.

The annual total VOC emissions from forests in Slovakia ranged from 77 to 98 ktonnes (Fig. 2). The percentage of isoprene, monoterpenes and other VOC emissions is relatively stable and varies in the narrow intervals: isoprene emissions (17–23%), monoterpene emissions (65–73%) and other VOC emissions (10–15%). Temporal changes in the total VOC emissions are connected with the temporal and spatial changes in monthly air temperatures in individual years.

Table 2 summarizes the calculated total VOC emissions in selected European countries using various methods. Presented results from Slovakia are included in the range of the European values.

The calculated biogenic VOC emissions account for about 29% of anthropogenic emissions estimated for the year 1990 but for the year 2000 this value exceeded 100% (108%). The reason is a marked decrease in anthropogenic VOC emissions in Slovakia from 262 ktonnes (1990) to 89 ktonnes in 2000 (Minďáš 2001).

Spatial distribution of total VOC emissions

The spatial distribution of the emissions is quite different, due to the different air temperature and tree species distribution (Fig. 4). The most substantial biogenic VOC emissions in 2000 (24%) are in the altitudinal interval of 301–500 m a.s.l. (Fig. 3) with the largest oak sp. and beech forest coverage where isoprene and other VOC emissions are dominant. About 23% of the annual emissions are expected to be in the interval of 701–900 m a.s.l. (Fig. 3) where the largest Norway spruce forest coverage occurs with the domination of monoterpene emissions. The altitudinal distribution of VOC emissions is

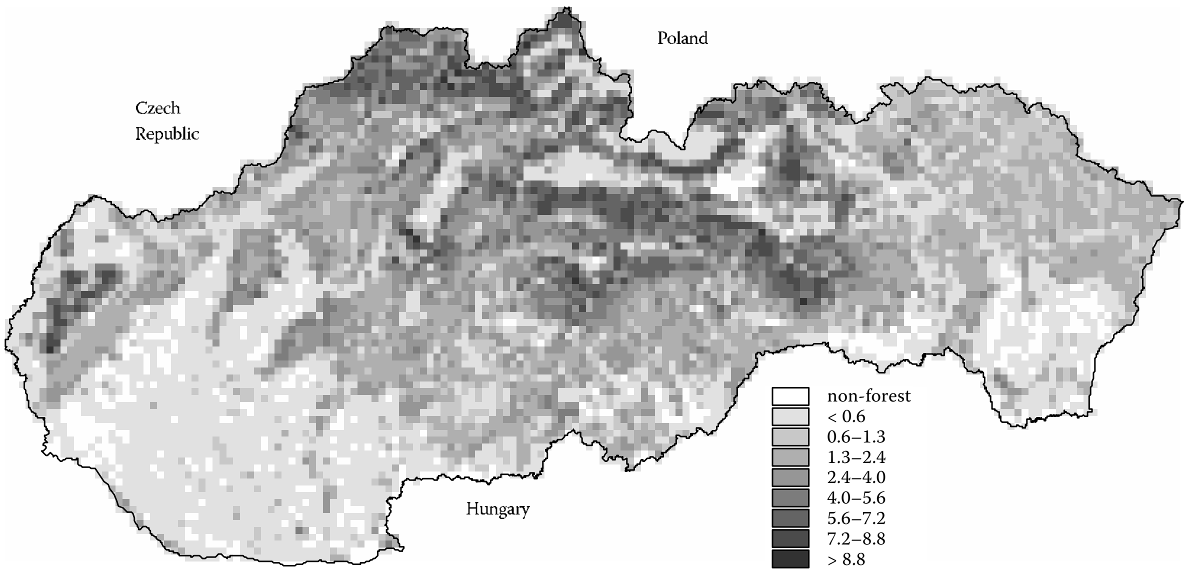

Fig. 4. Spatial distribution of total VOC emissions from forest vegetation within the Slovak territory in grid resolution 2.5 × 2.5 km (data in tonnes/km^2)

determined by air temperature spatial distribution and is different from year to year, but the maximum of total VOC emissions during the whole period (1990–2000) is in the range of 301–900 m a.s.l.

Table 3 shows the results of altitudinal distribution of total VOC emissions according to the individual tree species. The highest total (and monoterpene) emission rates are in the Norway spruce forests (45.7%) throughout the montane belt of the Carpathian Mts., which has the largest forest coverage in Slovakia. The second important tree species due to high isoprene emissions is oak sp. (18.2%) with domination in the thermo-colline and colline belt of the Carpathian Mts. Beech and pine forests contribute about more than 20% to the total VOC emissions (both individually more than 10%). The low contribution of beech forests (their portion is 29% out of the total forested area in Slovakia) to the

Table 3. Altitudinal distribution of total VOC emissions according to the individual tree species (2000)

Tree species	Portion in Slovak forests (%)	Total VOC emissions (data in tonnes)						
		altitude (m a.s.l.)						
		≤ 300	301–500	501–700	701–900	901–1,200	> 1,200	Total
Norway spruce *Picea abies*	27	231.8	2,300.3	9,213.4	**16,528.6**	12,665.1	3,083.7	44,022.9
Fir *Abies alba*	4	15.6	340.1	2,493.6	**3,944.0**	1,406.3	45.3	8,244.9
Scots pine *Pinus sylvestris*	7	**3,991.2**	2,987.8	2,154.5	525.4	42.1	1.6	9,702.6
Larch *Larix decidua*	2	52.4	47.4	15.8	283.9	**388.4**	0.7	788.6
Mountain pine *Pinus mugo*	1	0.0	0.0	0.0	0.0	35.2	**270.1**	305.3
Beech *Fagus sylvatica*	31	574.5	3,378.0	**3,432.0**	2,125.1	754.9	44.8	10,309.3
Oak sp. *Quercus* sp.	11	6,783.4	**8,176.4**	2,384.5	210.8	0.0	0.0	17,555.1
Hornbeam *Carpinus betulus*	6	546.5	**1,189.8**	280.2	4.6	0.0	0.0	2,021.1
Other broadleaves	11	**1,106.8**	584.5	715.2	621.7	257.1	52.9	3,338.2

VOC emissions is due to low emission rates (equations 4 and 5).

Uncertainties

Emissions of biogenic VOC are determined by a number of ecological factors whose relative importance is not presently well understood. To obtain accurate estimates, especially for the mountainous complex terrain with different forest stands, requires a better control of the uncertainties in the factors involved on a regional scale (Simeonidis et al. 1999). The uncertainties of determination of emission inventory are in general very high due to several reasons: uncertainty in determination of emission factors, uncertainty in determination of the values of ecological factors (air temperature, radiation, land use data) and lack of direct balance measurements. There is a considerable lack of knowledge of variability in NMVOC emissions within individual tree species growing under various ecological conditions (Andreani-Aksoyoglu 1995).

The comparison of the VOC emission rates calculated for different air temperature variables measured within the beech canopy (actual 10min values, averaged hourly values, averaged daily temperatures, maximum and minimum daily air temperature) and for air temperatures interpolated from the nearest meteorological station (by gradient method) showed that the difference between these calculated values did not exceed 7% (Minďáš 2001). But it is clear that the main source of uncertainty is connected with the high variability in the VOC emission rates within the canopy and with multifactorial influence on the emission process from foliage.

In our study we did not make a direct estimation of uncertainties due to the lack of information on the uncertainties of all input parameters. Moreover, there is a problem of determination of spatial error in interpolation in relation to the rate of uncertainty of air temperature determination and used regression equations. This problem requires further study.

Knowledge from the comparison of direct experimental measurements of NMVOC emissions and calculated values of NMVOC emissions (by means of emission factors) shows a possible rate of uncertainty within ± 50% (Guenther et al. 1994).

SUMMARY AND CONCLUSIONS

Biogenic VOC emissions from the forests in Slovakia were calculated using temperature dependent emission rate algorithms. Each species is known to emit isoprene, monoterpenes or other VOC, using the corresponding emission rate algorithm, leaf biomass density, and forest coverage in grid resolution 250 × 250 m. The annual total VOC emissions from forests in Slovakia ranged from 77 to 98 ktonnes during the period 1990–2000 and these values correspond with European values. The percentage of isoprene, monoterpenes and other VOC emissions is relatively stable and varies in the narrow intervals: isoprene emissions (17–23%), monoterpene emissions (65–73%) and other VOC emissions (10–15%). The major contribution of VOC (especially monoterpenes) comes from the Norway spruce (*Picea abies*) forests (45.7% in 2000) due to their abundance and high leaf biomass density with domination in the montane belt. The oak species (*Quercus* sp.) are the second important VOC emittors (18.2%) with domination in the thermo-colline and colline belt of the Carpathian Mts. Beech and pine forests contribute about more than 20% to the total VOC emissions (both individually more than 10%). The low contribution of beech forests (their portion is 29% out of the total forested area in Slovakia) to the VOC emissions is due to low emission rates.

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Hodnotenie časovej a priestorovej distribúcie emisií nemetánových uhľovodíkov z lesných porastov na Slovensku

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ABSTRAKT: Práca prezentuje výsledky prvej detailnej inventarizácie emisií prchavých nemetánových uhľovodíkov z lesnej vegetácie na Slovensku. Emisie monoterpénov, izoprénu a ostatných nemetánových uhľovodíkov sa vypočítali pre jednotlivé skupiny hlavných lesných drevín pri použití relevantných parametrov, ako je teplota vzduchu a hustota listov biomasy. Pre analýzy priestorovej distribúcie emisií prchavých organických látok (VOC) sa využili nástroje GIS. Celkové ročné emisie VOC z lesov na Slovensku sa pohybovali v rozsahu 77–98 tisíc ton v priebehu rokov 1990–2000. Percentuálny podiel na emisiách pre izoprén, monoterpény a ostatné VOC je relatívne stabilný a pohybuje sa v úzkom intervale: emisie izoprénu (17–23 %), emisie monoterpénov (65–73 %) a ostatných VOC (10–15 %). Hlavný príspevok k emisiám VOC (hlavne monoterpénov) reprezentujú smrekové lesy (*Picea abies*) (45,7 % v roku 2000) z dôvodu ich vysokého plošného podielu v stredohorských polohách a vysokej hustoty biomasy ihličia. Dubové lesy (*Quercus* sp.) sú druhým dôležitým zdrojom emisií VOC (18,2 % v roku 2000) s dominanciou v pahorkatinných oblastiach Karpát.

Kľúčové slová: biogénne emisie; izoprén; monoterpény; prchavé organické látky; lesy Slovenska

Interakčné vzťahy medzi atmosférou a lesnými ekosystémami predstavujú významný článok vo fungovaní a v prejavoch lesa. Medzi lesnými drevinami ako hlavnou zložkou lesných spoločenstiev a atmosférou prebieha neustála výmena plynov najmä prostredníctvom asimilačného aparátu (listov, resp. ihličia). Výmena plynov pritom prebieha oboma smermi, t.j. les je zároveň sinkom aj emitorom plynov najrozličnejšieho chemického zloženia.

Zvláštnou skupinou plynov sú prchavé organické látky (VOC) zväčša aromatického charakteru. Tieto prchavé uhľovodíky sú uvoľňované biofyzikálnymi a biochemickými procesmi z listov, resp. ihličia, kôry, živice a z organického opadu drevín a pre každdú lesnú drevinu majú uvedené plyny špecifické zloženie. Je potrebné si uvedomiť, že ide o proces prírodný, ktorý môže človek ovplyvňovať len nepriamo prostredníctvom zmeny v druhovom zložení a rozlohe lesov.

Hlavným zdrojom emisií VOC z lesných porastov sú lesné dreviny (resp. ich asimilačné orgány), podiel ostatných zložiek (bylinný kryt, pokrývkový humus) je z hľadiska celkovej bilancie zanedbateľný. Nakoľko lesné dreviny tvoria plošne rozsiahle lesné porasty, tak z hľadiska emitovania prchavých uhľovodíkov tvoria typický plošný zdroj. Jednotlivé dreviny sa svojimi emisnými charakteristikami vzájomne dosť odlišujú, a to ako kvalitatívne (chemickým zložením VOC), tak aj kvantitatívne (množstvom emitovaných VOC). Z tohto hľadiska významnú úlohu zohráva drevinové zloženie lesov Slovenska, kde najrozšírenejšími drevinami sú buk, smrek, borovica a dub.

Biogénne emisie prchavých organických látok (VOC) sa počítali pomocou závislosti emisného množstva od teploty vzduchu podľa jednotlivých lesných drevín. Každá drevina má špecifické zloženie emisií VOC a spravidla ich rozdeľujeme na tri skupiny: 1. Izoprénové emitory (najmä duby, topole a vŕby); 2. Monoterpénové emitory (ihličnaté dreviny, najmä smrek a borovice) a ostatné VOC emitory (najmä buky a javory); 3. Výpočty sa realizovali s využitím prostredia GIS v gridovom rozlíšení 250 × 250 m a výsledné emisné množstvá sa prezentovali v mapovom vyjadrení v rozlíšení 2,5 × 2,5 km.

Celková emisia VOC z lesných porastov Slovenskej republiky napríklad za rok 2000 predstavovala hodnotu 96 288 ton, z čoho na vysokoizoprénové emitory pripadla čiastka 19 438 ton (20,2 %), na neizoprénové emitory čiastka 13 980 ton (14,5 %) a na monoterpénové emitory 62 870 ton (65,3 %) (tab. 3, obr. 2). Výsledné emisie za rok 2000 korešpondujú s hodnotami v období rokov 1990–1999, pričom časová variabilita celkových emisií VOC je primárne určovaná teplotnými podmienkami vo vegetačnom období v jednotlivých rokoch. Priestorové rozloženie emisií VOC je výslednicou priestorového rozloženia teploty vzduchu a plošného výskytu jednotlivých lesných drevín. Najviac emisií je viazaných na polohy v intervale nadmorských výšok 301–500 m (24 % v roku 2000) s dominanciou bukovo-dubových lesov (obr. 3, tab. 3). Druhou najvýznamnejšou oblasťou je interval nadmorských výšok 701–900 m (23 % v roku 2000) s dominanciou monoterpénových emisií zo smrekových porastov (obr. 3, tab. 3).

Predpokladaný ďalší vývoj emisií VOC z lesných porastov na Slovensku bude spojený najmä s aktuálnym vývojom teplotných pomerov v budúcich rokoch. Z tohto hľadiska možno roky 1994, 1998 až 2000 (ako teplotne nadpriemerné) s ich emisiami brať ako základ pre odhad priemerných emisií VOC z lesných porastov pre začiatok 21. storočia, čo teda znamená, že priemerné emisie by sa mohli pohybovať na úrovni 95 až 105 tisíc ton. Zmena v drevinovej štruktúre našich lesov je proces dlhodobý a v priebehu najbližších 10–20 rokov neovplyvní množstvo ani štruktúru emisií VOC.

Samozrejme uvedené výsledky je potrebné vnímať v súvislosti s použitou metodikou a z nej vyplývajúcich nepresností spôsobených skutočnosťou, že bilančný výpočet je prevádzaný nepriamo, cez jeden faktor prostredia (teplota vzduchu) a nie na základe priamych bilančných metód založených na meraní. Napriek tomu korelačné koeficienty jednotlivých regresných závislostí dosahujú pomerne vysoké hodnoty a vzhľadom na charakter celého procesu prirodzenej emisie biogénnych VOC môžeme tento postup považovať za dostatočne presný pre rámcový odhad hodnôt VOC z lesných porastov.

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