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ESTIMATES OF THE BIOGENIC VOLATILE ORGANIC COMPOUNDS EMISSION IN POLAND DURING JULY 2015

SZACOWANA WARTOŚĆ EMISJI BIOGENICZNYCH LOTNYCH ZWIĄZKÓW ORGANICZNYCH W POLSCE W LIPCU 2015 ROKU

Abstract: Natural emissions of volatile organic compounds (VOCs), especially from terrestrial plants, have significant effects on the atmospheric chemical composition and physical characteristics. They take part in the formation of new compounds, including secondary pollutants such as tropospheric ozone, as they are highly reactive and their residence time in air is relatively short. For this reason, a reliable inventory of biogenic volatile organic compounds (BVOCs) emission is of significant importance in regional air quality modelling and assessment. In the paper, the preliminary studies on the BVOCs emission in Poland were presented, with the use of the MEGAN v2.1 (Model of Emissions of Gases and Aerosols from Nature) empirical emission model driven with meteorological fields generated in the WRF v3.8 (Weather Research and Forecasting) model. The estimation of volatile organic compounds emission from vegetation in the area of Poland for July 2015 was carried out at spatial resolution of 4 km based on default 16 global PFTs (Plant Functional Types) and emission factors distributions. BVOCs emission inventories were divided into three main groups: isoprene, monoterpenes and other volatile organic compounds (OVOCs). Their total estimated emission rates, spatial distributions and daily variability were analysed. The results of the study will define directions of further research on the BVOCs emission in the area of Poland and possibilities to improve their assessment.

Keywords: MEGAN, WRF, biogenic emission, isoprene, monoterpenes, volatile organic compounds

Introduction

Volatile organic compounds (VOCs) are one of the largest groups of compounds emitted into the atmosphere. Their sources can be both anthropogenic (AVOCs) and biogenic (BVOCs), yet there is a substantial difference in characteristics and composition between them. Anthropogenic VOCs are mainly associated with fuel extraction and combustion processes, other industrial activities and transportation. Three key groups of emitted AVOCs have been distinguished: non-methane volatile organic compounds, oxygenated volatile organic compounds and halogenated hydrocarbons [1].

Unlike AVOCs, the major classes of emitted BVOCs comprise alkenes (isoprene, monoterpenes and sesquiterpenes) and oxygenated volatile organic compounds (e.g. 2-methyl-3-buten-2-ol, acetone, methanol) [2]. Biosphere components, in particular soil, oceans and land vegetation are the main sources of these emissions. Large tree clusters, especially tropical forests, are considered to be responsible for most of the global biogenic emissions from plants [3]. Estimated total global emission of VOCs from natural sources is difficult to assess and may even exceed 1000 Tg C yr⁻¹ [4], while the anthropogenic emission is only about 100-150 Tg C yr⁻¹ [5].

Substantial impact of highly reactive organic compounds on atmospheric chemistry is indisputable. As residence time in the atmosphere of the main BVOCs is distinctly short

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(from minutes to a few hours), they react rapidly with hydroxyl (OH) radicals, nitrate (NO_3) radicals and ozone (O_3) to form new products [6]. These include compounds considered as dangerous secondary air pollutants (secondary organic aerosols, tropospheric ozone and peroxyacetyl nitrate) [7]. Thus, BVOCs emissions indirectly deteriorate air quality, which is principally of major concern in modern urban areas.

BVOCs emissions from land vegetation depend significantly on plant species, phenology and environmental factors. These emissions vary in a function of ambient temperature, light and moisture [8, 9]. For these reasons, an accurate estimation of their rates is a rather complex issue. Despite the fact that the European continent is responsible for only about 4% of BVOCs released globally [10], the reliable estimates of these emissions are of significant importance in regional air quality modelling. Neglecting these emissions may influence to a great extent the modelled concentrations of fine particulate matter and tropospheric ozone [11-13]. However, biogenic emission inventories of high temporal and spatial resolution for the area of Poland are limited. Bogacki and Smiatek [14] assessed natural emissions from forests in July 2000 using modelling approach developed in IMK-IFU - Garmisch-Partenkirchen (Germany), showing that monoterpenes and other volatile organic compounds are dominant with only 8.5% of isoprene in total BVOCs emission. Oderbolz et al. [15] estimated that almost 470-493 Gg of BVOCs were emitted in 2006 from the area of Poland using different vegetation inventories. Polish Central Statistical Office reported that 282 Gg (almost 32% of the total NMVOC emission) of non-methane volatile organic compounds were emitted in 2016 from nature in Poland [16].

In the paper the initial high-resolution assessment of biogenic volatile compounds emission from the area of Poland was presented. It was based on one-month calculations in July 2015 using the bottom-up approach implemented in MEGAN v2.1 empirical emission model developed by Guenther et al. [3]. Meteorological conditions were provided with the WRF v3.8 mesoscale model. The aim of the study was to preliminary evaluate the effectiveness of this approach using provided datasets, as well as to point out regions exposed to high emissions of BVOCs in Poland and to determine directions of future research.

Modelling design and methodology

Meteorological conditions

Calculation of meteorological conditions driving the MEGAN biogenic emission model were performed using the mesoscale WRF-ARW modelling system v3.8 developed by the National Centre for Atmospheric Research (NCAR) [17]. One-month simulation during summer season (July 2015) was chosen for the study as the expected BVOCs emission rates are the most significant in this period [18]. WRF calculations were driven using ECMWF ERA-Interim daily 6-hour reanalysis [19] dataset. Land surface parameterization was carried out using Noah scheme, and for the longwave and shortwave radiation, the RRTM and Dudhia scheme were chosen, respectively. Kain-Fritsch cumulus scheme was applied inside the coarse domain, with no cumulus parameterization in the nested domain. Default USGS land use dataset was updated using GLC2000 fields. Calculations were performed inside two domains comprising the area of Poland. For further

application in the MEGAN emission model, the inner domain (d02) with spatial resolution of 4 km was selected as the most suitable.

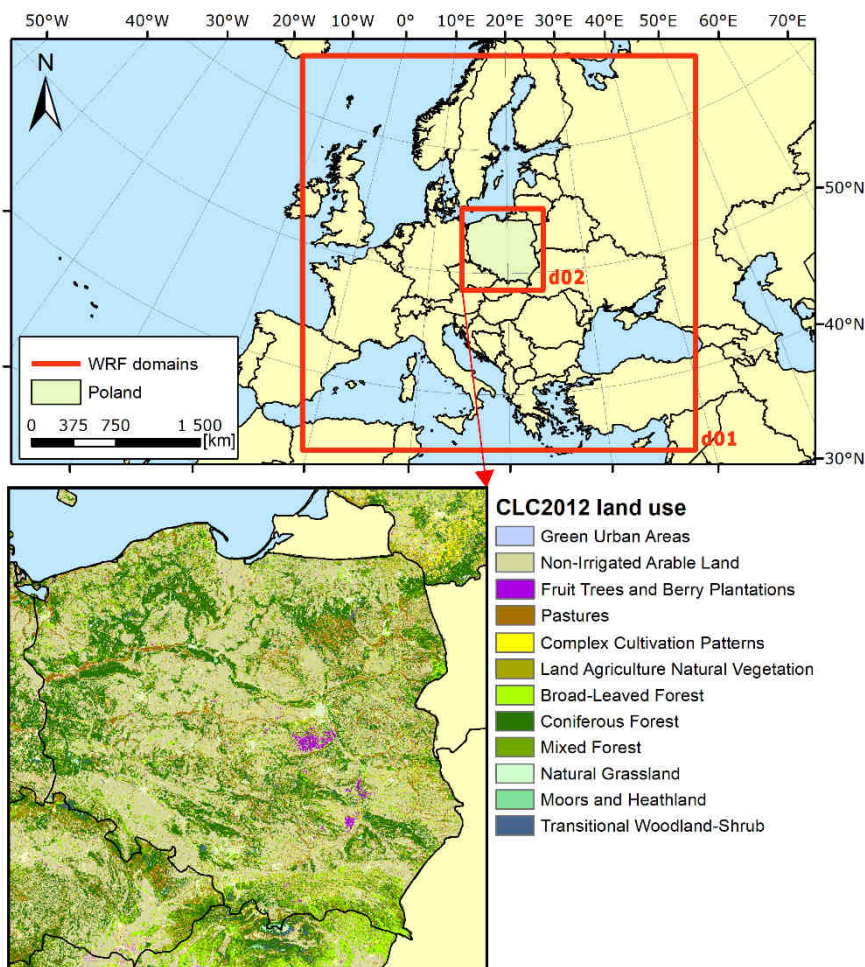


Fig. 1. Location of the WRF domains (d01 and d02) with the area of Poland presented with CLC2012 land use vegetation classes in Poland

In Figure 1 the area of research is presented together with Corine Land Cover 2012 land use classification for the area of Poland. Only the vegetation classes that are expected to emit biogenic volatile organic compounds were considered.

BVOCs emission inventory

Calculations of emissions for selected volatile organic compounds originating from nature were performed using MEGAN (Model of Emissions of Gases and Aerosols from

Nature) empirical model v2.1. It was designed for both global and regional emission inventories of trace gases from vegetation. It was implemented with five-layer canopy environment that estimates leaf temperature and photosynthetic photon flux density within canopy. For detailed description of the model the reader is referred to the work [20].

In the study, the gridded PFTs (Plant Functional Types) and global emission factors datasets provided along with the MEGAN2.1 model were used. PFT distributions describe spatial vegetation coverage divided into 16 classes, accordingly with the approach used in Community Land Model version 4 (CLM4) [21]. It is noteworthy, however, that this database is related to the year 2000 [22].

Leaf area index (LAI) required by the model was derived from GLASS MODIS 8-day product [23] for July 2014 due to the inaccessibility of more consistent datasets. Photosynthetically active radiation (PAR) was calculated based on the irradiance information from the WRF model using MCIP (Meteorology-Chemistry Interface Processor) tool [24]. However, Guenther et al. [20] found that using satellite based estimates of photosynthetically active radiation yield better results, since WRF tends to overestimate the values of incoming solar radiation [25]. Further comparative analysis shown that the sum of calculated PAR using WRF outputs is equal to 73.84% of total observed solar radiation intensity at the Bory Tucholskie-Zielonka (E 17°56'2.3", N 53°39'43.7") regional background measurement station. Theoretically, the photosynthetically active radiation should oscillate around 50% of total solar radiation [26]. Due to the unavailability of more accurate actual data, for further BVOCs emission assessment modelled PAR data was recalculated using the correction factor of 0.7.

Grouping of chemical compounds in MEGAN was performed using the RACM (Regional Atmospheric Chemistry Mechanism) scheme [27], then additional aggregation was conducted to calculate the total emission rates for three main groups of BVOCs: isoprene, monoterpenes and other volatile organic compounds (including organic acids, ketones and aldehydes). Monoterpenes are represented in RACM mechanism as the sum of two species: API (α -pinene and other cyclic terpenes with one double bond) and LIM (d-limonene and other cyclic terpenes with two double bonds) [28].

Results and discussion

The results of BVOCs emission inventory for the area of Poland revealed that the emission of volatile compounds other than isoprene (16.33 Gg) and monoterpenes (20.58 Gg) is the most dominant with the total of 45.50 Gg emitted in July 2015. This amount results mainly from high modelled emissions of methanol and acetone. As these compounds are released primarily from agricultural lands [29] which constitute to almost 51% of the total area of Poland (based on CLC 2012 dataset), their emission is quite significant in value and evenly distributed. Moreover, similarly to the monoterpenes, other volatile organic compounds (OVOCs) pool emission occurs during night hours as well, since it is light-independent. The isoprene synthesis emission, however, is strongly determined by solar radiation and during night it completely decreases to zero [7], as shown in Figure 2.

Total estimated biogenic emission in July 2015 equals to 66.08 Gg and it is quite significant. Possible overestimation of the outcomes may result from inaccuracy of the

modelled meteorological conditions, since solar radiation and ambient temperature can meaningfully affect estimated emission rates [29]. Quite considerable emission of isoprene would confirm this conclusion, since previous studies using different modelling approaches suggest that yearly averaged isoprene estimates should not exceed 15% of total BVOCs emission in the case of Poland [15]. Furthermore, MEGAN tends to overestimate the isoprene emission rates, as previously found in [30].

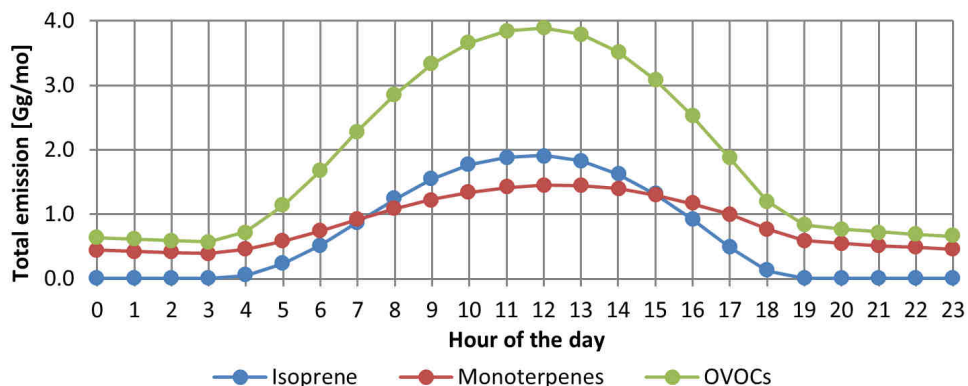


Fig. 2. Total emissions of selected BVOCs during hours of the day in July 2015 for the area of Poland

Presented emission inventories in Figures 3-5 reflect quite accurately forests location shown in Figure 1, proving, that in the area of Poland biogenic emission from forests (accounting for almost 31% of total country area) remains the most intensive.

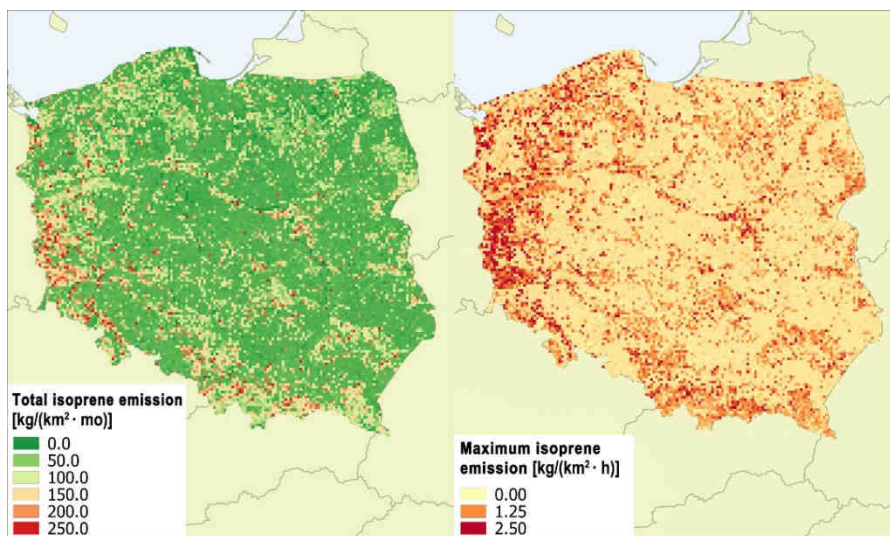


Fig. 3. Total isoprene emission (left) and maximum 1-h emission rates (right) for the area of Poland during July 2015 calculated with MEGAN

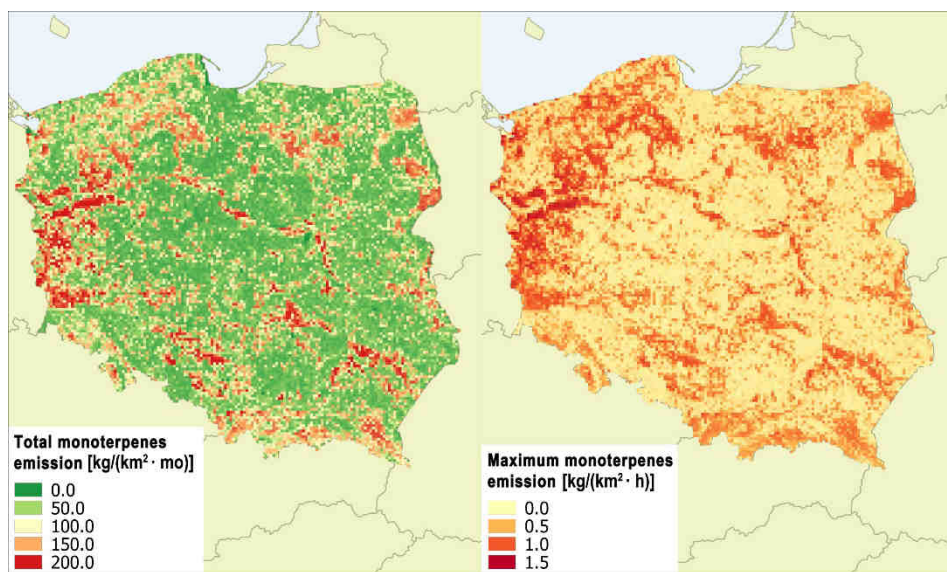


Fig. 4. Total monoterpenes emission (left) and maximum 1-h emission rates (right) for the area of Poland during July 2015 calculated with MEGAN

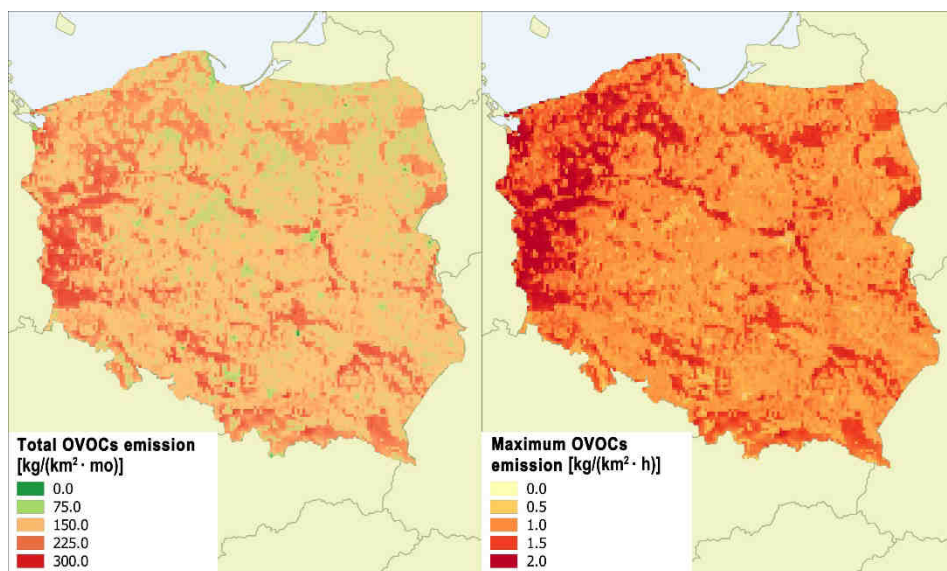


Fig. 5. Total OVOCs emission (left) and maximum 1-h emission rates (right) for the area of Poland during July 2015 calculated with MEGAN

Conclusions

Presented inventory is consistent with other findings and studies on the BVOCs emissions in Central Europe using MEGAN, suggesting that during summer season, the emission of isoprene can exceed the monoterpene emissions in the area of Poland. However, other results obtained using different approaches suggest that natural isoprene emission should be significantly lower than other volatile organic compounds. The attempt to develop updated emission factors with regional tree species distribution taken into account should provide more reliable results for these emissions [31]. In the case of isoprene it may lower the estimates, since overestimated emission factors for this compound were found in Southeast Texas, USA [30]. Nevertheless, assigning appropriate emission factor to each tree species still remains a great task, as direct measurement data of BVOCs emissions in Central Europe are limited [20].

Moreover, quite significant total amount of biogenic emissions (about 66.08 Gg for July 2015) may be connected with the model sensitivity to key input parameters. MEGAN is well known for considerable dependency on the variability of LAI, PAR and other meteorological parameters. Using PAR input data based on satellite derived data rather than model calculations, should lead to important changes in MEGAN output and lower the bias of the outcomes [32]. High values of emitted isoprene may partially yield from the struggle of the WRF model to simulate the maximum peaks of temperature during day hours. Isoprene emission is strongly influenced by temperature, and after reaching the maximum at 308-318 K, it rapidly decreases [7, 33]. However, a thorough evaluation of the WRF outputs is required for more detailed discussion regarding above issues.

Acknowledgments

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SZACOWANA WARTOŚĆ EMISJI BIOGENICZNYCH LOTNYCH ZWIĄZKÓW ORGANICZNYCH W POLSCE W LIPCU 2015 ROKU

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Abstrakt: Naturalne emisje lotnych związków organicznych (LZO), w szczególności z roślinności lądowej, mają znaczący wpływ na skład chemiczny i właściwości fizyczne atmosfery. Ze względu na ich dużą reaktywność i stosunkowo krótki czas przebywania w powietrzu uczestniczą one w tworzeniu nowych związków, w tym wtórnych zanieczyszczeń, takich jak ozon troposferyczny. Z tego powodu wiarygodna inwentaryzacja emisji biogenicznych lotnych związków organicznych (BLZO) ma niepomijalne znaczenie w regionalnym modelowaniu i ocenie jakości powietrza. W pracy przedstawiono wstępne badania nad emisją BLZO w Polsce z wykorzystaniem modelu empirycznego MEGAN v2.1 (Model of Emissions of Gases and Aerosols from Nature) i pól meteorologicznych pochodzących z modelu WRF v3.8 (Weather Research and Forecasting). Emisję lotnych związków organicznych z roślinności na terenie Polski w lipcu 2015 roku oszacowano w siatce o rozdzielczości przestrzennej 4 km, wykorzystując domyślne 16 globalnych klas PFT (Plant Functional Types) i przestrzenne rozkłady wskaźników emisji. Inwentaryzację emisji BLZO podzielono na trzy główne grupy związków: izopren, monoterpeny oraz pozostałe lotne związki organiczne. Analizie poddano całkowitą wielkość emisji powyższych związków, rozkłady przestrzenne oraz ich zmienność dobową. Wyniki badań określają kierunki dalszych badań nad emisjami BLZO na terenie Polski oraz wskażą możliwości poprawy wiarygodności ich oszacowania.

Słowa kluczowe: MEGAN, WRF, emisja biogeniczna, izopren, monoterpeny, lotne związki organiczne