Environmental Modelling & Software 25 (2010) 1845–1856

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

A model for European Biogenic Volatile Organic Compound emissions: Software development and first validation

Anastasia Poupkou [a,*], Theodoros Giannaros [a,1], Konstantinos Markakis [a], Ioannis Kioutsioukis [a], Gabriele Curci [b], Dimitrios Melas [a,2], Christos Zerefos [c]

[a] Laboratory of Atmospheric Physics, Aristotle University of Thessaloniki, PO Box 149, 54124 Thessaloniki, Greece
[b] CETEMPS, Università degli Studi dell'Aquila, via Vetoio, 67010 Coppito – L'Aquila, Italy
[c] Laboratory of Climatology and Atmospheric Environment, National and Kapodistrian University of Athens, 15784 Athens, Greece

ARTICLE INFO

Article history:
Received 28 January 2010
Received in revised form
29 April 2010
Accepted 6 May 2010
Available online 17 June 2010

Keywords:
Emission model
Biogenic emissions
Isoprene
Monoterpenes
Europe

ABSTRACT

A grid-oriented Biogenic Emission Model (BEM) has been developed to calculate Non-Methane Volatile Organic Compound (NMVOC) emissions from vegetation in high spatial and temporal resolutions. The model allows the emissions calculation for any modeling domain covering Europe on the basis of: 1) the U.S. Geological Survey 1-km resolution land-use database, 2) a land-use specific, monthly isoprene, monoterpene and Other Volatile Organic Compound (OVOC) emission potentials and foliar biomass densities database, 3) temperature and solar radiation data provided by the mesoscale meteorological model MM5. The model was applied for Europe in 30-km spatial resolution for the year 2003. The European total emissions for 2003 consist of 33.0% isoprene, 25.5% monoterpenes and 41.5% OVOC. BEM results are compared with those from the well-documented global Model of Emissions of Gases and Aerosols from Nature (MEGAN). The BEM total emissions compare well with the MEGAN ones. In July 2003, the results of both models agree within a factor of 1.2 for total isoprene emissions and within a factor of 2 for total monoterpene emissions. The comparison of the spatial distributions of the July 2003 isoprene and monoterpene emissions calculated with BEM and MEGAN shows that, in the greater part of the study area, the differences are below the current uncertainty limit for the estimation of spatially-resolved biogenic VOC emissions in Europe being equal to about ±600 kg km^{-2} month^{-1}. Differences that are above this limit are found mainly in the eastern European countries for isoprene and in the Mediterranean countries for monoterpenes.

1. Introduction

Vegetation naturally releases organic compounds in the atmosphere, which are collectively referred to as Biogenic Non-Methane Volatile Organic Compounds (BNMVOC). BNMVOC play a prominent role in the chemistry of the atmosphere and more particularly in the formation of tropospheric ozone (Curci et al., 2009; Wang et al., 2008; Bell and Ellis, 2004; Zerefos et al., 2002) and secondary organic aerosols (Kleindienst et al., 2007; Kanakidou et al., 2005). Curci et al. (2009) simulated an average 5% increase in summer daily ozone maxima over Europe due to BNMVOC emissions with peaks over Portugal and the Mediterranean region (+15%). Brasseur et al. (2003) demonstrated that BNMVOC may produce 30–270 Tg particles at global scale annually. BNMVOC suppress concentrations of the hydroxyl radical (OH), enhance the production of peroxy (HO_2 and RO_2) radicals and generate organic nitrates that can sequester NO_x and allow long-range transport of reactive N (Fehsenfeld et al., 1992). Since the surface fluxes of these compounds are critical in controlling the OH concentration in the troposphere, they determine the growth rate of atmospheric methane and CO concentrations and play a key role in the global climate and global carbon cycle (Poisson et al., 2000; Roelofs and Lelieveld, 2000; Guenther et al., 1995).

Total global BNMVOC emissions are estimated to range from 700 to 1150 TgC per year and represent about 90% of total NMVOC emissions (including anthropogenic sources) (Lathière et al., 2005; Guenther et al., 1995). However, at regional scale, the mass ratio of biogenic versus anthropogenic NMVOC emissions may change significantly. In Europe, for example, anthropogenic and biogenic

* Corresponding author. Tel.: +30 2310998009; fax: +30 2310998090.
E-mail addresses: poupkou@auth.gr (A. Poupkou), thgian@auth.gr (T. Giannaros), melas@auth.gr (D. Melas).
[1] Tel.: +30 2310998088; fax: +30 2310998090.
[2] Tel.: +30 2310998124; fax: +30 2310998090.

1364-8152/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.envsoft.2010.05.004

NMVOC emissions are estimated to have comparable magnitudes (Simpson et al., 1999), while in the Mediterranean area, NMVOC emissions are dominated by emissions from vegetation during summertime (Symeonidis et al., 2008; Simpson et al., 1999).

Due to their importance in atmospheric chemistry, BNMVOC emissions must be considered in numerical Chemistry Transport Models (CTMs) simulations. The modeling of BNMVOC emissions is rather complicated because of their great sensitivity to environmental parameters (mainly temperature and radiation), vegetation type and leaf area (Guenther et al., 1995). BNMVOC emissions were first included as inputs to oxidant models in mid 80's; by the 90's they were routinely included in CTMs, but typically as static emission inventories of usually low spatial and temporal resolution. Such emission inventories have been compiled at global (Guenther et al., 1995), continental (Simpson et al., 1999, 1995; Lamb et al., 1993) and regional scales (Parra et al., 2004; Simeonidis et al., 1999; Benjamin et al., 1997) with various degrees of sophistication and reliability. However, BNMVOC emission models, which can be integrated into regional and global CTMs, are required (Smiatek, 2008; Yarwood et al., 2007; Guenther et al., 2006; Smiatek and Steinbrecher, 2006; SMOKE 2.6, 2009 (Biogenic Emissions Inventory System (versions 2, 3.09 and 3.14))). The use of such models facilitates the studies of the earth system interactions and feedbacks, and ensures the consistency between land-use and weather variables used for atmospheric process models (Guenther et al., 2006). In addition, ozone and particle biogenic precursors originate from diffuse and highly complex sources (e.g. forests, grassland) and as a result BNMVOC emission inventories should require detailed input data of land-use with a high spatial resolution (Steinbrecher et al., 2009; Arneth et al., 2008a). In this context, the BNMVOC emission models are also useful since they can provide emissions estimates at high spatial and temporal resolutions.

The aim of this paper is to present a grid-oriented emission model for the estimation of BNMVOC surface fluxes in spatial and temporal resolutions defined by the user. Gridded emissions are calculated for any domain covering part or whole of the European continent and can support air-quality modeling studies. In Section 2, the model methodology, input/output data, structure and procedures are described in detail. Hourly isoprene, monoterpene and OVOC emission fluxes were calculated in Europe and adjacent countries/areas with 30-km resolution for the year 2003. In Section 3, the spatial distribution and temporal variation of these emissions are discussed. In Section 4, the monthly isoprene and monoterpene emissions for January and July 2003 are compared with the estimates of the model MEGAN (Guenther et al., 2006) and the differences are discussed. A comparison between the observed and the CAMx model simulated isoprene concentrations is also shown. The conclusions are drawn in the final section of the paper.

2. Model description

The grid-oriented Biogenic Emission Model (BEM) consists of four parts: 1) a geospatially referenced land-use database, 2) a land-use and chemical species-specific emission potentials and land-use specific foliar biomass densities database, 3) temperature and solar radiation data provided by the meteorological model MM5 (version 3) and 4) a Fortran90 code developed to process all input data and perform the calculation of emissions (Giannaros, 2007). BEM is available to the modeling community upon request from the developers (Giannaros T., Poupkou A., Melas D.). Fig. 1 shows the flow chart of the BEM procedures.

The model uses the methodology described in Guenther et al. (1995) for the calculation of isoprene "synthesis" emissions (depending on both temperature and light) and monoterpene and Other Volatile Organic Compound (OVOC) "pool" emissions (depending on temperature only). The model also accounts for the light dependency of monoterpene emissions from some vegetation species. According to this methodology, for a given land-use i and chemical species j, the emission $E(i,j)$ (μg h^{-1}) is estimated as:

$$E(i,j) = A(i)\ \varepsilon(i,j)\ D(i)\ \gamma(j) \quad (1)$$

where $A(i)$ (m^2) is the area of the emitting land-use, $\varepsilon(i,j)$ (μg g-dry weight foliage^{-1} h^{-1}) is an emission potential at a standard temperature (=303 K) and Photosynthetically Active Radiation (PAR) (=1000 μmoles-photons (400–700 nm) m^{-2} s^{-1}), $D(i)$ (g-dry weight foliage m^{-2}) is the foliar biomass density and $\gamma(j)$ is a unitless environmental correction factor, used in order to account for the effect of leaf temperature and radiation variations on emissions. In BEM, a non-canopy approach is adopted. This approach assumes that leaf temperature and PAR flux within the canopy are identical to the ambient levels and that the use of branch-level emission potentials, which are typically a factor of 1.75 smaller than the leaf-level values (Guenther et al., 1994), accounts for the shading effects (Simpson et al., 1999).

The emission model can be operated in a grid mode. For each grid cell of the modeling area, the grid cell area A, the grid cell average emission potentials ε, the grid cell average foliar biomass density D and the meteorological data on temperature and light intensity are required. A more comprehensive description of the model's input/output data, architecture and procedures is given in the following sections.

2.1. Input data

2.1.1. Land-use

The main source of the land-use data is the Eurasia Land Cover Characteristics database (version 2) developed from satellite observations and freely distributed by the U.S. Geological Survey (USGS) (http://edc2.usgs.gov/glcc/eadoc2_0.php, last accessed 20 Apr 2010). The data have 1-km spatial resolution. The main dataset used is the "Seasonal Land Cover Regions" (SLCR) Legend that assigns each 1-km^2 area of Eurasia's surface to one of 253 different land-use classes The European continent (and adjacent countries/areas) is covered by 196 SLCR land-use classes (vegetation species and/or ecosystem types) that emit BNMVOC. It should be noted that originally, the SLCR dataset does not include a land-use class for the urban areas. For this reason the "International Geosphere Biosphere Programme" (IGBP) dataset, which includes the urban land-use class, is also used. Both the SLCR and IGBP datasets come in flat, headerless, raster format (binary) and share the same projection (Lambert Azimuthal Equal Area). The model combines the SLCR and IGBP datasets and creates a new hybrid SLCR dataset with the addition of a new land-use class for the urban areas.

2.1.2. Foliar biomass densities and emission potentials

Foliar biomass densities (g-dry weight foliage m^{-2}) and isoprene (synthesis), monoterpene (pool and synthesis) and OVOC (pool) emission potentials (μg g-dry weight foliage^{-1} h^{-1}) have been assigned for every month of the year to each of the hybrid SLCR land-use classes that emit BNMVOC. The methodology adopted for assigning foliar biomass densities and emission potentials values by land-use class is presented and discussed in detail in Symeonidis et al. (2008). The database of foliar biomass densities and emission potentials presented in Symeonidis et al. (2008) was used, having been updated and extended in order to include values for additional land-use classes covering the European continent and the adjacent countries/areas. The foliar biomass densities and emission potentials values were selected from the list of references given in Symeonidis et al. (2008) and from additional