

Effects of the spatial resolution of climate data on estimates of biogenic isoprene emissions



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HIGHLIGHTS

- ▶ Modelled isoprene emissions are affected by the spatial resolution of meteorology.
- ▶ Coarse meteorological data has little influence on global isoprene emissions.
- ▶ Small scales may show discrepancies in isoprene emission of up to 150%.
- ▶ Coastal and topographically varying regions should be treated with caution.

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ABSTRACT

Volatile organic compounds of biogenic origin (BVOCs) in the atmosphere are a key component of the Earth system, influencing ozone and secondary organic aerosol formation, and the global oxidant budget. Global BVOC emissions are dominated by terrestrial vegetation, in particular the compound isoprene, whose emission rate, in common with many BVOCs, is strongly and non-linearly dependent on temperature and the photosynthetically active radiation (PAR) flux. Detailed models of BVOC emission are now starting to be deployed in global chemistry–transport and chemistry–climate models. By necessity, the spatial resolution of these models is coarse (of the order of a few degrees), and spatial averaging removes information about areas of high temperature and PAR which contribute disproportionately to the isoprene flux. By comparing output from a BVOC emission model driven by both high- and low-resolution meteorological data, we show that this averaging effect does not lead to substantial discrepancies in simulated isoprene emissions (~2%) when considering fluxes averaged over regional scales, but can lead to large discrepancies of up to ~150% at much finer scales (e.g., 10 × 10 km). These smaller scale results have implications for highly coupled chemistry–climate simulations. The application of such models for the assessment and prediction of air quality, and subsequent decisions regarding the potential for mitigation or the need for adaptation, should be conducted using climate data with the highest possible spatial resolution. In particular, isoprene emissions calculated for topographically-heterogeneous regions, including coasts, should be treated with increased caution.

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1. Introduction

Volatile organic compounds (VOCs) play a key role in the Earth system (Laothawornkitkul et al., 2009), moderating the oxidant budget of the troposphere, and hence the lifetime of climatically

relevant gases such as methane (e.g. Poisson et al., 2000), governing the rate of chemical production and loss of tropospheric ozone (e.g. Wild, 2007), and leading to the formation of secondary organic aerosol (SOA) (Went, 1960; Hallquist et al., 2009). In addition to their radiative forcing of climate (e.g. Forster et al., 2007), ozone and SOA are priority air pollutants, causing cardio-pulmonary health problems and contributing to more than a million annual deaths worldwide (e.g. WHO, 2011). Elevated surface concentrations of ozone are also known to damage crops (e.g. Mills et al., 2007), causing an estimated economic loss of \$11–18 billion globally in the year 2000 (e.g. Avnery et al., 2011).

The terrestrial biosphere is the main source of VOCs to the atmosphere. Current estimates put the total emissions of these

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reactive trace gases (excluding methane) from vegetation and soils at $\sim 1150 \text{ Tg(C) y}^{-1}$ (Guenther et al., 1995), while anthropogenic sources were estimated to amount to 186 Tg(C) y^{-1} in 2000 (Olivier et al., 2005). Of the biogenic VOCs (BVOCs) 2-methyl-1,3-butadiene (C_5H_8), commonly referred to as isoprene, is the most significant in terms of both magnitude of emissions (thought to be around $\sim 500 \text{ Tg(C) y}^{-1}$, e.g. Guenther et al., 1995, 2006; Arneth et al., 2008), and subsequent impact on the atmosphere (e.g. Atkinson and Arey, 2003; Derwent et al., 2007).

The rate of isoprene emission from any plant is primarily governed by the effects of light and temperature fluctuations on isoprene synthesis. Isoprene emission models assign a species-specific base emission rate (BER), often defined as the emission rate at standard conditions of 30°C and $1000 \mu\text{mol m}^{-2} \text{ s}^{-1}$ of photosynthetically active radiation (PAR) (see e.g. Guenther et al., 1995; $1500 \mu\text{mol m}^{-2} \text{ s}^{-1}$ PAR is used in Guenther et al., 2006). Instantaneous isoprene emissions are estimated by modifying the BER according to the response of the plant to actual environmental conditions. A schematic example of the modelled response of isoprene emission to temperature and light is shown in Fig. 1. Isoprene emission initially increases rapidly with PAR, but above $\sim 1000 \mu\text{mol m}^{-2} \text{ s}^{-1}$ the gradient decreases substantially as the plant response to PAR begins to saturate. In contrast, the rate of isoprene emission increases exponentially with temperature, displaying very high sensitivity to temperatures in the range $25\text{--}35^\circ\text{C}$, before reaching a clearly defined peak. This peak is the result of denaturing of the isoprene synthase enzyme at high temperatures (e.g. Guenther et al., 1993). The form of these curves from both empirically-based models (Guenther et al., 1995, 2006) and process-based models (Niinemets et al., 1999; Martin et al., 2000) is very similar (Arneth et al., 2007).

Although many other environmental conditions and processes affect isoprene emissions, it is clear that small scale variations in temperature, and to a lesser extent PAR, are potentially very important for emission rates. As the dependence of isoprene emission on temperature and PAR is distinctly non-linear, the use of spatially or temporally averaged values may produce a substantially different isoprene emission rate than would be the case at a higher resolution. Ashworth et al. (2010) recently demonstrated the importance of this effect when choosing the temporal resolution of the temperature data input for isoprene emission modelling. However, spatial resolution may also be important, particularly for

variations in altitude or land cover affecting temperature or for variations in cloud cover driving changes in PAR. Here, we investigate the hypothesis that the spatial resolution of input meteorological data will also alter global isoprene emission estimates.

Whilst current global isoprene emission estimates are usually conducted using meteorological analysis data with a resolution of $\sim 0.5^\circ \times 0.5^\circ$ (Guenther et al., 2006), studies looking at future global BVOC emissions rely on coarse resolution meteorological forecast data from climate models to drive the emission algorithms, where the resolution is limited by the need for long timescale simulations at an acceptable computational cost (Table 1).

In this study we concentrate on emissions of isoprene, for which emission mechanisms are best understood, and which is most commonly incorporated in large-scale models of chemistry and climate. We use different spatial resolutions of meteorological data to drive the widely-used empirical BVOC emission model MEGAN (Model of Emissions of Gases and Aerosols from Nature; Guenther et al., 2006). However, given the similarity in temperature and PAR response curves, our results are relevant for all BVOC emission models. We also test the importance of the spatial resolution of the land cover data, which affects the size and location of isoprene emitting areas.

2. Methods

2.1. Meteorological data

The Weather Research and Forecasting (WRF) model (Skamarock et al., 2008) version 3.2 was used to generate a realistic distribution of meteorological conditions at a spatial resolution of $10 \text{ km} \times 10 \text{ km}$. At this resolution, global simulations are computationally expensive, and therefore we chose three geographic domains for which substantial isoprene emissions have been modelled; South America, South-East Asia and South-East USA. Simulations were conducted for 14 day periods, as detailed in Table 2, using $1^\circ \times 1^\circ$ National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) analysis data (<http://nomads.nccdc.noaa.gov/data.php>) for the year 2006. Given the typically short duration of individual weather events, 14 days are expected to be long enough to give a representative calculation for this experiment. Output surface temperature and PAR were re-gridded to $0.1^\circ \times 0.1^\circ$, $0.5^\circ \times 0.5^\circ$ and $2.0^\circ \times 2.0^\circ$ to provide fine, medium and coarse meteorological data respectively for MEGAN. The temporal resolution of the WRF output supplied to MEGAN was hourly.

2.2. Emission modelling

Biogenic isoprene emissions were calculated using the community version of the Model of Emissions of Gases and Aerosols from Nature, MEGAN v2.04 (available at <http://cdp.ucar.edu/>) which implements the Parameterised Canopy Environment Emission Activity (PCEEA) version of the algorithms described by Guenther et al. (2006). The flux, F , of isoprene (in $\text{mg m}^{-2} \text{ h}^{-1}$) from each grid cell was calculated as shown in Equation (1),

$$F = \varepsilon \cdot \gamma, \quad (1)$$

where ε is the base emission rate at standard conditions of 30°C , $1500 \mu\text{mol m}^{-2} \text{ s}^{-1}$ of PAR and a leaf area index (LAI) of 5, and γ is a dimensionless activity factor that scales the emission rate according to the actual environmental conditions. This activity factor is derived empirically from laboratory and field observations of the variation of emission rate with temperature, PAR, leaf area and age, and soil moisture, and is given by:

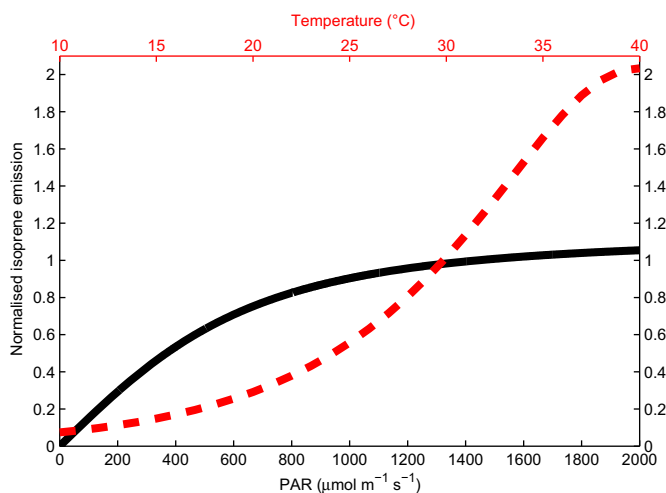


Fig. 1. Schematic response of dimensionless isoprene emission flux to PAR (solid line) and temperature (dashed line). Isoprene flux is normalised to the standard conditions defined in Guenther et al. (2006) (30°C temperature, $1500 \mu\text{mol m}^{-2} \text{ s}^{-1}$ PAR).

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