User's guide to the
Model of Emissions of Gases and Aerosols from Nature
(MEGAN)

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1. General Information

1.1 Background

This initial version of the Model of Emissions of Gases and Aerosols from Nature, also known as MEGAN, was developed by Dr. Alex Guenther and Dr. Christine Wiedinmyer at the National Center for Atmospheric Research (NCAR). Future MEGAN development will be a community effort organized through the International Geosphere Biosphere Program's Global Exchange and Interactions Activity (IGBP-GEIA). We expect that this effort will continue to be supported by a variety of sources including the NCAR (sponsored by the U.S. National Science Foundation, NSF) and the U.S. Environmental Protection Agency, through an interagency agreement with NSF/NCAR.

The purpose of MEGAN is to quantify the net emission of gases between the atmosphere and terrestrial ecosystems. MEGAN uses an approach similar to previous terrestrial biogenic emission models (e.g., BEIS, BEIS2 and GLOBEIS) but is easier to update, use, and expand to other compounds. MEGAN is intended for use by both research scientists and regulatory air quality modelers.

MEGAN input files, computer code, and this "User's Guide" can be downloaded from the NCAR Community Data Portal (https://cdp.ucar.edu/). You can email questions, comments or suggestions to megan@acd.ucar.edu. Messages sent to this address will be forwarded automatically to Dr. Alex Guenther and Dr. Christine Wiedinmyer.

1.2 Net Emission Rates

MEGAN calculates the net emission rate of a chemical species between a terrestrial ecosystem and the atmosphere at a specific location and time as

$$ER = AEF * MEA * DEA * HEA \quad (1)$$

where ER (μg carbon m^{-2} h^{-1}) is the net emission rate, AEF (μg carbon m^{-2} h^{-1}) is an annual emission factor, MEA (non-dimensional ratio) is a monthly emission activity factor, DEA (non-dimensional ratio) is a daily emission activity factor, and HEA (non-dimensional ratio) is an hourly emission activity factor.

This preliminary version (version 1.0) of MEGAN includes only isoprene, total terpenoids (>C5), and nonterpenoid VOC. Future versions will include individual compounds and aerosols.

2. The Community Data Portal

The MEGAN version 1.0 provides global emission rates, annual emission factors (AEF) and monthly emission activity factors (MEA) for the year 2000 at a 1 degree resolution. Future versions will include higher spatially resolved inputs (1 km) and other model years. MEGAN data files are available through the NCAR-SCD Community Data Portal (CDP). This flexible interface enables users to download global datasets or selected regions with a specified spatial resolution and file format.

To download MEGAN files from the CDP, users may go to http://cdp.ucar.edu and click on ACD/BAI/MEGAN. From this point, users can locate and download files directly from the data portal (under "Nested Datasets"). Metadata are provided with detailed descriptions of file contents. On the page for each set of data is a link called "Aggregated Dataset selection and subsetting." This link leads to an interface through which a user can chose the aerial extent of the data to be downloaded and to aggregate times. An estimate of the resulting file size will be provided by clicking the button called "ESTIMATE."

At the top of each page in the header information is a link to a registration web form ("Data Usage Registration Form"). Users of MEGAN files are asked to register through this form. Registered users will be notified of any changes and updates to MEGAN. (Note: users need only to register once.)

MEGAN version 1.0 files on the CDP include global, 1 degree AEF and MEA files for 2000 for isoprene, total terpenoids (>C5), and nonterpenoid VOC.

3. Emission Algorithms

3.1. Annual Emission Factor (AEF)

The annual emission factors (μg carbon m^{-2} h^{-1}) used for MEGAN are the weighted average of the annual emission factors for each of six plant functional types: broadleaf trees, fineleaf evergreen trees, fineleaf deciduous trees, shrubs, grass, and crops. These annual emission factors are called AEF_iso, AEF_mtp, and AEF_ovc for isoprene, total terpenoids (>C5), and nonterpenoid VOC, respectively.

3.2. Monthly Emission Ratio (MEA)

There are two types of MEA used for MEGAN version 1.0. Type 1 is used for isoprene, while Type 2 is used for other compounds.

3.2.1 Monthly Emission Activity Type 1

This emission activity type is estimated as

$$MEA1 = C_{LAI} * \gamma_A \quad (2)$$

Where C_{LAI} is a factor that accounts for variations in canopy leaf area and γ_A depends on leaf age. The canopy leaf area factor reflects the results of the canopy model described by Guenther et al. [1999] and relates emission activity to LAI (leaf area index, m^2 m^{-2}) as

$$C_{LAI} = 0.49 * LAI / ((1 + 0.2 * LAI*LAI)^{0.5}) \quad (3)$$

Equation 3 adjusts for variations in LAI relative to the standard condition of LAI=5.

Young leaves begin to photosynthesize soon after budbreak, but isoprene is not emitted in substantial quantities for several weeks after the onset of photosynthesis. Old leaves gradually lose their ability to photosynthesis and to produce isoprene. MEGAN divides the canopy is divided into four fractions: new foliage that emits negligible amounts of isoprene (F_{new}), growing foliage that emits isoprene at less than peak rates (F_{gro}), mature foliage that emits isoprene at peak rates (F_{mat}), and senescing foliage that emits isoprene at reduced rates (F_{sen}). The canopy weighted average factor is calculated as

$$\gamma_A = F_{new}A_{new} + F_{gro}A_{gro} + F_{mat}A_{mat} + F_{sen}A_{sen} \quad (4)$$

where A_{new} (=0.01), A_{gro} (=0.5), A_{mat} (=1), and A_{sen} (=0.33) are the relative emission factors assigned to each canopy fraction. The values of these emission factors are based on the observations of Petron et al. [2001], Goldstein et al. [1998], Monson et al. [1994], Guenther et al. [1991], and Karl et al. [2003].

The canopy is divided into leaf age groups based on differences between the LAI of the current time step (LAI_c) and the LAI of the previous time step (LAI_p). In cases where $LAI_c = LAI_p$ then $F_{mat} = 1$ and all other fractions (F_{new} , F_{gro} , F_{sen}) are equal to zero.

When $LAI_p > LAI_c$ then F_{new} and F_{gro} are equal to zero, and F_{sen} is estimated as $[(LAI_p - LAI_c)/LAI_p]$ and $F_{mat} = 1 - F_{sen}$.

In the final case, where $LAI_p < LAI_c$, $F_{sen} = 0$ and the other fractions are calculated as:

$$F_{new} = 1 - (LAI_p/LAI_c) \qquad \text{for } t <= t_i \qquad (5a)$$
$$F_{new} = [t_i/t]\,[1 - (LAI_p/LAI_c)] \qquad \text{for } t > t_i \qquad (5a)$$

$$F_{gro} = 0 \qquad \text{for } t <= t_i \qquad (5b)$$
$$F_{gro} = [(t_g-t_i)/t]\,[1 - (LAI_p/LAI_c)] \qquad \text{for } t > t_i \qquad (5b)$$

$$F_{mat} = (LAI_p/LAI_c) \quad \text{for } t <= t_m \quad (5c)$$
$$F_{mat} = (LAI_p/LAI_c) + [(t-t_m)/t]\,[1 – (LAI_p/LAI_c)] \quad \text{for } t > t_m \quad (5c)$$

where t is the length of the time step (days) between LAI_c and LAI_p, t_i is the number of days after budbreak required to induce isoprene emission, t_m is the number of days after budbreak required to reach peak isoprene emission rates, and $t_g = t_m$ for $t > t_m$ and $t_g = t$ for $t <= t_m$. Based on Petron et al. [2001], recommended values are $t_i = 12$ days and $t_m = 28$ days.

3.3.2 Monthly Emission Activity Type 2
The emission activity for this type is estimated as

$$MEA2 = LAI/5 \quad (6)$$

3.3. Daily Emission Activity (DEA)
The DEA factor is set as unity for all compounds in MEGAN version 1.0.

3.4. Hourly Emission Activity (HEA)

3.4.1 Hourly Emission Activity Type 1: Light and Temperature

Diurnal variation in BVOC Type 1 emission between a vegetation canopy and the atmosphere is primarily controlled by the influence of photosynthetic photon flux density (PPFD) and temperature on emissions and by several factors which determine canopy uptake and chemical losses. The hourly emission activity factor is calculated as

$$HEA = C_T * C_{PPFD} \quad (7)$$

where C_T and C_{PPFD} are each a normalized factor that respectively account for canopy temperature and PPFD.

The PPFD and temperature of leaves in different parts of vegetation canopies can differ substantially from above canopy conditions. Leaves that are in direct sunlight often experience temperatures that are a degree or more higher than ambient air, while shaded leaves are often somewhat cooler than ambient air temperature. PPFD can be very low on shaded leaves and the PPFD of sun leaves depends on the angle between the sun and the leaf. Guenther et al. [1995] used a relatively simple canopy environment model to estimate PPFD on sun and shade leaves at several canopy depths and assumed that leaf temperature was equal to air temperature. The non-linear relationships between isoprene emission and environmental conditions, coupled with the strong correlation between PPFD and temperature, will result in a significant underprediction of isoprene emissions if canopy or daily average PPFD and temperature are used (rather than calculating emissions for each part of the canopy and each part of the day). Guenther et al. [1999]

used a more sophisticated canopy radiation model and added a leaf energy balance model that predicts leaf temperature based on the solar radiation, air temperature, wind, and humidity at each canopy depth. Lamb et al. [1996] evaluated the use of several canopy environment models for predicting whole canopy isoprene fluxes and found that the results from both simple and complex canopy models were within the uncertainty range of observed isoprene fluxes. Although complex canopy environment models may not substantially improve isoprene emission estimates for some modeling tasks, due to other factors that also contribute to total uncertainties, these complex models are useful for investigating how changes in environmental conditions will perturb isoprene emission rates.

The MEGAN HEA factors can be calculated on-line within a model using estimates of leaf level PPFD and temperature for sun and shade leaves at each canopy level and the leaf level relationships recommended by Guenther et al. [1999] or other values available from the land surface model component of a weather or earth system model. In this case, note that the HEA factors are normalized so that $C_{PPFD} = 1$ for an above canopy PPFD of 1500 and $C_T = 1$ for a canopy temperature of 30 C.

If canopy environment parameters are not available, then whole canopy PPFD and temperature dependent emission variations can be estimated as

$$C_{PPFD} = 1.21\ [(\alpha * PPFD) / ((1 + \alpha^2 * PPFD^2)^{0.5})] \qquad (8)$$

where $\alpha = 0.001$ and PPFD is the photosynthetic photon flux density (μmol m^{-2} s^{-1}) at the top of the canopy and

$$C_T = E_{opt} * [C_{T2} * \exp(C_{T1} * x) / (C_{T2} - C_{T1} * (1 - \exp(C_{T2} * x)))] \qquad (9)$$

where $x = [((1 / T_{opt}) - (1 / T)) / 0.00831]$, $E_{opt} = 2.26$, $C_{T1} = 70$, $C_{T2} = 200$, $T_{opt} = 317$, and T is air temperature (^{o} K) directly above the canopy. Equations 8 and 9 are based on a series of simulations using the Guenther et al. [1999] model and tend to be less than 10% of the model value except at very high light and temperature.

PPFD can be approximated from incoming short wavelength solar radiation in W m^{-2} by assuming 4.766 (μmol m^{-2} s^{-1}) per (W m^{-2}) and assuming that half of the short wavelength radiation is in the 400 to 700 nm waveband. For example, to convert the global short wave (GSW) variable in the MM5 and WRF weather models:

$$PPFD = GSW * 4.766 * 0.5 \qquad (10)$$

3.4.2 Hourly Emission Activity Type 2: Temperature

Diurnal variations in BVOC Type 2 emission between a vegetation canopy and the atmosphere is primarily controlled by the influence of temperature on emissions. The hourly emission activity factor is calculated as

$$HEA = C_T \qquad (11)$$

where C_T is a normalized factor that accounts for canopy temperature and is calculated as:

$$C_T = \exp[0.09 *(T-303.15)] \qquad (12)$$

where T is canopy temperature (^{o} K).

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