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Biogenic Emission Estimates for 1995

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ABSTRACT

Biogenic emissions during 1995 for the contiguous United States have been estimated with the Biogenic Emissions Inventory System (BEIS2.2). Hourly emissions were computed for each county using surface observations from the National Weather Service and land use data developed specifically for biogenic emission calculations. Meteorological data were interpolated to each county with Barnes analysis. The occurrence of the first and last date of freezing, as interpolated using Barnes analysis, was used to toggle the occurrence of deciduous leaf biomass. The estimates indicate annual emissions of 17.2 million metric tons (Tg) of isoprene, 6.1 Tg of monoterpenes, 6.5 Tg of other volatile organic compounds, and 1.4 Tg of nitric oxides. These estimates are reasonably consistent with those made by other researchers and are slightly lower than estimates for 1990 made with an earlier version of BEIS2. The slight decrease in estimated 1995 emissions compared to 1990 can be attributed to the use of freezing dates, better temporal resolution of data (hourly values versus monthly diurnal averages), and year-to-year variations in meteorology.

INTRODUCTION

Biogenic emissions of volatile organic compounds (VOCs) and nitric oxide (NO) play an important role in the oxidative capacity of the global troposphere[1]. In certain locations and times, these emissions may also influence ozone exceedances and perhaps affect the selection of VOC versus NO_x emission control strategies for alleviating elevated ozone concentrations[2,3]. VOC emissions originate from vegetation, and it is thought that isoprene may help protect plants from heat stress[4] while monoterpenes serve a variety of ecological functions such as herbivore protection[5]. Other VOCs are known to be emitted, many of which have not yet been quantitatively identified with gas chromatography/mass spectroscopy[6]. These other VOCs include sesquiterpenes and oxygenated hydrocarbons (such as methanol and 2-methyl-3-buten-2-ol). NO emissions appear to originate from microbial activity in soils[7].

As part of ozone reduction planning efforts, many states and localities around the United States are required to submit periodic reports that include estimates of biogenic emissions. In this paper, we report on an effort to estimate annual biogenic emissions for the contiguous United States for 1995. This effort is based on an adaptation of the Biogenic Emissions Inventory System (BEIS2.2) using meteorological data from National Weather Service reporting stations. The objective of this work is to provide a foundation for estimates in EPA's Emission Trends Reports[8].

TECHNICAL BACKGROUND

Description of BEIS2.2

Version 2.2 of the BEIS was released on the Internet during March 1996 at the following World Wide Web address: *http://www.epa.gov/asmdnerl/biogen.html.* It is an extension of earlier versions of BEIS[9,10] to include updates in emission factors, light and temperature adjustment algorithms, and land use data. The basic equation for computing biogenic emissions is

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given by the following:

$$ER = \sum (EF_i \times A_i \times CF)$$

where ER is the emission rate (g/hr) for each county, EF_i is a standardized emission flux (μg/m²-hr) for each land use type i, A_i is the area (m^2) of each land use type i in a county, and CF is a correction factor that adjusts for the effects of solar radiation and temperature relative to a standard of 1000 μmol/m²-s of visible solar radiation and 30° C temperature. In BEIS2.2, emissions are calculated for isoprene, monoterpenes, other VOCs, and nitric oxide.

Emission Factors. Biogenic VOC emission factors for forests were adapted from Geron et al.[11] and Guenther et al.[12]. Emission factors in BEIS2.2 have been converted to areal fluxes using reported leaf biomass densities. Emission factors for other land use types are based on Novak and Pierce[13], except for corn. The emission rate from corn was set nearly to zero based of experimental results showing negligible VOC emissions[14].

Two emission factor tables have been developed for BEIS2.2, a "winter" set and a "summer" set. The winter set assumes that deciduous vegetation can be mostly ignored and the summer set assumes full leaf-biomass conditions. The choice of tables for county-level calculation is based on county freeze dates, with the "summer" table being used after the date of last freeze and before the date of first freeze.

Soil NO emission factors are based on the work of Williams et al.[15]. Emission factors have been extended to agricultural land use types not reported by Williams, by using typical nitrogen fertilizer application rates to scale between reported emission factors.

Standardized emission fluxes for land use types used in BEIS2.2 are shown in Tables 1 and 2 for summer and winter conditions respectively. These fluxes assume a temperature of 30° C and, for isoprene, a photosynthetically active radiation flux of 1000 μmol/m²-s.

Environmental corrections. VOC emissions from vegetation and NO emissions from soils respond quickly to changes in temperature. In addition, isoprene emissions respond to solar radiation and are negligible when sunlight is not present.

The algorithms for adjusting VOC emissions have been taken from Guenther et al.[16] , as reported by Geron et al[11]. The temperature adjustment equations from Williams et al.[15] have been reformulated so that standard conditions correspond to a soil temperature of 30° C.

Land use. The Biogenic Emissions Landuse Database (BELD) was specifically constructed to be consistent with the emission factor data base used in BEIS2[16]. Special emphasis was given to estimating the crown cover of high-isoprene-emitting tree species. Because tree species crown coverage is not routinely available from satellite imagery, the U.S. Forest Service's Forest Inventory Analysis dataset was extensively used. The hierarchy used for processing the various land use datasets into the final BELD is summarized in Table 3. The area and percent distribution of the top 20 BELD land use classes are shown in Table 4.

Adapting BEIS2.2 for Annual Estimates

Adapting BEIS2.2 for an annual calculation required minor changes in the FORTRAN source code and creation of meteorological data for 1995.

BEIS2.2 code changes. The personal computer version of BEIS2.2 was transferred to a UNIX platform. The first step was to remove all the DOS full-screen menu input options. Loops were then inserted to calculate hourly emissions for every county for all hours in a month. The code was also modified to read a freeze date file in order to select between a "summer" or "winter" emission factor table file. During code execution, this selection is made every day for every county. Four output files are produced: three quality-assurance files giving detailed calculations for three counties that can be selected by the user, and one monthly output file giving daily emission fluxes for each county in the contiguous United States.

Preparation of meteorological data. The meteorological data for running the annual version of BEIS2.2 consisted of hourly values of temperature and cloud cover for each county in the contiguous United States. This database was created using Barnes analysis on data from 268 first-order surface reporting stations operated by the National Weather Service. Barnes analysis is an interpolation procedure used for spatially distributing meteorological data[17] and was used to spatially interpolate data to all 3111 county/city Federal Information Processing Standard (FIPS) codes. The latitude and longitude for each FIPS code were obtained from centroids derived from a Geographical Information System. For the freeze date file, first and last freeze dates for each county were determined from the interpolated hourly temperatures.

RESULTS

Figure 1 shows daily variations in national isoprene and total biogenic VOCs (BVOC) estimated with BEIS2.2 for 1995. Emissions are markedly higher during the summer months (defined here as June, July, and August). The summer months correspond to full-leaf biomass and higher temperatures and, for isoprene, more solar radiation. Appreciable day-to-day variability can be seen and is attributable to short-term meteorological fluctuations. Biogenic NO emissions shown in Figure 2, which respond only to temperature, also peak during the summer and show some day-to-day variability across the U.S. A seasonal breakdown of emissions is given in Table 5. Isoprene emissions are negligible during the winter, while 65% of the isoprene emissions occur during the summer months. The monoterpenes and other VOC categories show a slightly more even distribution across seasons, with 6-7% of the emissions occurring during the winter months. For biogenic NO emissions, 41% occur during the summer months, and 13% occur during the winter months.

Figures 4-6 show the spatial distribution of biogenic emissions estimated for 1995. The isoprene emissions in Figure 4 are concentrated in areas having high percentages of deciduous forests, near the Appalachian mountains and west of the Mississippi River from Missouri to the Gulf Coast. Other areas with high isoprene emission densities occur in areas with relatively extensive spruce and aspen forests and parts of the western U.S. that are heavily wooded. Total VOC emissions shown in Figure 5 largely mimic the isoprene pattern, because isoprene comprises such a large percentage (58%) of the total biogenic VOC inventory. In addition to those areas with high isoprene emissions, the western U.S. and New England show relatively high concentrations of BVOC owing to the high percentages of coniferous forests, which tend to emit monoterpenes rather than isoprene. Biogenic NO emissions shown in Figure 6 are confined mostly to agricultural areas, especially the corn belt of the Great Plains. Other notable areas of high concentrations of NO emissions include a few counties in southern Texas, where the U.S. agricultural data indicated large areas of sorghum and where mean temperatures are high, and in agricultural portions of south-central Pennsylvania. Forested areas of the U.S. are estimated as having low emissions of biogenic NO.

DISCUSSION

The estimates made for 1995 are comparable with other estimates, although some differences can be seen in Table 6. Estimates for 1995 are slightly less than those made with BEIS2 for 1990 using a different methodology. It is believed that use of the frost dates in this work caused most of the reduction in VOCs, as evidenced in a winter-time reduction in BVOC from 1.4 Tg in 1990 to 0.9 Tg in 1995. In addition, minor fixes to the land use data since the 1990 estimates probably affected the NO emissions. The NO emissions for 1995 are about 10% less than those computed for 1990, but the corn acreage (which has a relatively high NO emission flux) in the earlier calculations was too high by as much as a factor of two in many Midwestern counties. A processing error caused much of the soybean acreage in these counties to be mistakenly coded as corn. Differences in meteorology between the two years also are likely to affect the calculations, but hourly data from 1990 were not available in time for this paper to investigate its impact on the calculations. Year-to-year variations due to meteorology will be the subject of future work.

Total VOC emissions (29.8 Tg) are similar to those of Lamb et al.[18,19], who reported values ranging from 19.4 Tg - 29.1 Tg. However, isoprene emissions in the BEIS2.2 inventory are much higher than Lamb et al., 17.2 Tg versus 2.7 Tg - 5.9 Tg. This increase can be attributed to newer isoprene emission factors in BEIS2.2 that treat each high-emitting tree species and a land use inventory that tracks each tree genus type. In addition, Lamb et al. used a geometric mean that resulted in a mean isoprene emission factor about a factor of two lower than if a arithmetic mean had been used. The emission factors used in BEIS2.2 are based on arithmetic means.

Although the work of Williams et al.[15] serves as the basis of much of the NO emissions algorithm in BEIS2.2, the two annual estimates vary by a factor of two. In this work, annual emissions were estimated at 1.4 Tg as compared to Williams et al. estimate of 0.7 Tg. Our higher estimates may be attributed to the following differences in assumptions: (1) including the contribution of natural biomes (many of which are considered grass and shrubland in BEIS2 and have a modest NO flux), which were ignored by Williams et al., (2) including the contributions from crops other than corn, wheat, soybeans, which were ignored by Williams et al. because of a lack of emission factor data, (3) assuming the same emission factors for these four crops for the entire growing season, which were assumed by Williams et al. to be negligible during September - March, and (4) using hourly temperature data for 1995, which in Williams et al. were based on monthly climatic averages. Differences arising from these assumptions highlight some of the uncertainty surrounding calculation of annual emissions of biogenic NO.

Limitations exist with these and other biogenic emission estimates[7,19]. Emission factors have changed rapidly during the past few years, and further refinements are likely as additional field study data become available. Evidence of this change can be found in the factor of five increase of isoprene that occurred between BEIS1 and BEIS2 for short-term estimates related to ozone modeling studies. Biogenic NO emissions are particularly uncertain, owing to a lack of knowledge on the application of nitrogen-based fertilizer, the influence of soil moisture, and uptake by vegetation of NO_x before NO can escape into the free troposphere. Another limitation with biogenic emission calculations is the land use data. Year-to-year changes in land use distribution have not yet been accounted for in this analysis. For agricultural data, this can be significant. For example, reports from the news media (News and Observer, Raleigh, NC, August 12, 1996) indicate that ~12% more corn is being grown in 1996 than in 1995. This increase in corn production will almost certainly result in increased estimates of biogenic NO emissions. Our knowledge of tree cover in urban areas is also lacking. While this does not affect emissions much on a national scale, it can greatly affect urban scale calculations. Fortunately, the U.S. Forest Service is undertaking a study in the northeastern U.S. during the summer of 1996 to improve this knowledge base. The land use data base should also be viewed as particularly uncertain in the western U.S., where broadly-defined categories from the U.S. Geological Survey's database are used to infer emission fluxes. Meteorological data suffer from uncertainties in spatial interpolation. Areas with significant topographical changes relative to nearby surface observation stations, such as mountainous and coastal areas, should be viewed as somewhat suspect. Use of the frost dates to estimate leaf biomass may introduce some uncertainty. Because satellite imagery offers the possibility for estimating vegetation biomass, we are investigating the use of satellite imagery to temporally model leaf biomass in future versions of BEIS.

Despite these limitations, this dataset attempts to provide a scientifically-credible estimate of biogenic emissions for 1995 suitable for inclusion in EPA's emission trend reports. Estimates for other years between 1985-1995 are expected to be available in the near future.

ACKNOWLEDGMENTS and DATA AVAILABILITY

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Data files of the daily estimates are available via anonymous ftp at *monsoon.rtpnc.epa.gov*. The directory name is *~/pub/beis2/trend/1995.* Questions may be directed to *tep@hpcc.epa.gov.*

DISCLAIMER

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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Table 1. Standardized "summer" emission fluxes used in BEIS2.2. Columns represent the genus id, isoprene flux, monoterpene flux, other VOC flux, soil NO flux, leaf area index, and a description. Fluxes are given in units of μg/m^2-hr and are standardized to 30 C. Isoprene flux is based on a light intensity of 1000 μmol/m^2-s.

Abie	170.0	5100.0	2775.0	4.5	7	Abies (fir)
Acac	79.3	2380.0	1295.0	4.5	5	Acacia
Acer	42.5	680.0	693.7	4.5	5	Acer (maple)
Aesc	42.5	42.5	693.7	4.5	5	Aesculus (buckeye)
Aila	42.5	42.5	693.7	4.5	5	Ailanthus
Aleu	42.5	42.5	693.7	4.5	5	Aleurites (tung-oil tree)
Alfa	19.0	7.6	11.4	12.8	0	Alfalfa
Alnu	42.5	42.5	693.7	4.5	5	Alnus (European alder)
Amel	42.5	42.5	693.7	4.5	5	Amelanchier (serviceberry)
Asim	42.5	42.5	693.7	4.5	5	Asimina (pawpaw)
Avic	42.5	42.5	693.7	4.5	5	Avicennia (black mangrove)
Barl	7.6	19.0	11.4	256.7	0	Barley
Barr	0.0	0.0	0.0	0.0	0	Barren
Betu	42.5	85.0	693.7	4.5	5	Betula (birch)
Borf	910.0	713.0	755.0	4.5	5	Boreal forest (AVHRR/Guen et al 94)
Bume	42.5	42.5	693.7	4.5	5	Bumelia (gum bumelia)
Carp	42.5	680.0	693.7	4.5	5	Carpinus (hornbean)
Cary	42.5	680.0	693.7	4.5	5	Carya (hickory)
Casp	42.5	42.5	693.7	4.5	5	Castanopsis (chinkapin)
Cast	42.5	42.5	693.7	4.5	5	Castanea (chestnut)
Casu	29750.0	42.5	693.7	4.5	7	Casuarina (Austl pine)
Cata	42.5	42.5	693.7	4.5	5	Catalpa
Cedr	79.3	1269.3	1295.0	4.5	7	Cedrus (Deodar cedar)
Celt	42.5	85.0	693.7	4.5	5	Celtis (hackberry)
Cerc	42.5	42.5	693.7	4.5	5	Cercis (redbud)
Cham	170.0	340.0	2775.0	4.5	7	Chamaecyparis (prt-orford cedar)
Citr	42.5	680.0	693.7	4.5	5	Citrus (orange)
Cnif	745.4	1366.6	993.9	4.5	9	BEIS conifer forest
Conf	1550.0	1564.0	1036.0	4.5	6	Conifer forest (AVHRR, Guen)
Corn	0.5	0.0	0.0	577.6	0	Corn
Coru	42.5	680.0	693.7	4.5	5	Cornus (dogwood)
Coti	42.5	42.5	693.7	4.5	5	Cotinus (smoke tree)
Cott	7.6	19.0	11.4	256.7	0	Cotton
Crat	42.5	42.5	693.7	4.5	5	Crataegus (hawthorn)
Cswt	1050.0	660.0	770.0	0.2	2	Herbaceous Wetlands (AVHRR, Guen)
Desh	65.0	94.5	56.7	57.8	0	Desert shrub (AVHRR, Guen)
Dios	42.5	42.5	693.7	4.5	5	Diospyros (persimmon)
Euca	29750.0	1275.0	693.7	4.5	5	Eucalyptus
Fagu	42.5	255.0	693.7	4.5	5	Fagus (american beech)
Frax	42.5	42.5	693.7	4.5	5	Fraxinus (ash)
Gled	42.5	42.5	693.7	4.5	5	Gleditsia (honeylocust)
Gord	42.5	42.5	693.7	4.5	5	Gordonia (loblolly-bay)
Gras	56.2	140.5	84.3	57.8	0	Grass
Gymn	42.5	42.5	693.7	4.5	5	Gymnocladus (KY coffeetree)
Hale	42.5	42.5	693.7	4.5	5	Halesia (silverbell)
Harf	8730.0	436.0	882.0	4.5	5	Hardwood forest (AVHRR, Guen)
Hay	37.8	94.5	56.7	12.8	0	Hay
Ilex	42.5	85.0	693.7	4.5	5	Ilex (holly)
Jugl	42.5	1275.0	693.7	4.5	5	Juglans (black walnut)
Juni	79.3	476.0	1295.0	4.5	7	Juniperus (east. red cedar)
Lagu	42.5	42.5	693.7	4.5	5	Laguncularia (white mangrove)
Lari	42.5	42.5	693.7	4.5	5	Larix (larch)
Liqu	29750.0	1275.0	693.7	4.5	5	Liquidambar (sweetgum)
Liri	42.5	85.0	693.7	4.5	5	Liriodendron (yellow poplar)
Macl	42.5	42.5	693.7	4.5	5	Maclura (osage-orange)
Magn	42.5	1275.0	693.7	4.5	5	Magnolia
Malu	42.5	42.5	693.7	4.5	5	Malus (apple)
Meli	42.5	42.5	693.7	4.5	5	Melia (chinaberry)
Mixf	11450.0	1134.0	1140.0	4.5	5	Mixed forest (AVHRR, Guen)
Moru	42.5	85.0	693.7	4.5	5	Morus (mulberry)
Mscp	7.6	19.0	11.4	12.8	0	Misc crops

Nmxf	10150.0	1100.0	850.0	4.5	5	Northern Mixed Forest (AVHRR, Guen)
Nyss	5950.0	255.0	693.7	4.5	5	Nyssa (blackgum)
Oak	3108.3	255.5	894.2	4.5	6	BEIS oak forest
Oats	7.6	19.0	11.4	256.7	0	Oats
Odcd	2112.4	368.8	871.8	4.5	6	BEIS other deciduous forest
Ofor	56.2	140.5	84.3	4.5	0	Open forest
Oksv	7350.0	100.0	600.0	4.5	2	Oak Savannah (AVHRR, Guen)
Ostr	42.5	42.5	693.7	4.5	5	Ostrya (hophornbeam)
Othe	56.2	140.5	84.3	57.8	0	Other (unknown, assume grass)
Oxyd	42.5	255.0	693.7	4.5	5	Oxydendrum (sourwood)
Pacp	55.0	79.8	47.9	35.3	0	Pasture cropland (AVHRR, Guen)
Past	56.2	140.5	84.3	57.8	0	Pasture
Paul	42.5	42.5	693.7	4.5	5	Paulownia
Pean	102.0	255.0	153.0	12.8	0	Peanuts
Pers	42.5	255.0	693.7	4.5	5	Persea (redbay)
Pice	23800.0	5100.0	2775.0	4.5	7	Picea (spruce)
Pinu	79.3	2380.0	1295.0	4.5	3	Pinus (pine)
Plan	42.5	42.5	693.7	4.5	5	Planera (water elm)
Plat	14875.0	42.5	693.7	4.5	5	Platanus (sycamore)
Popu	29750.0	42.5	693.7	4.5	5	Populus (aspen)
Pota	9.6	24.0	14.4	192.5	0	Potato
Pros	42.5	42.5	693.7	4.5	5	Prosopis (mesquite)
Prun	42.5	42.5	693.7	4.5	5	Prunus (cherry)
Pseu	170.0	2720.0	2775.0	4.5	7	Pseudotsuga (douglas fir)
Quer	29750.0	85.0	693.7	4.5	5	Quercus (oak)
Rang	37.8	94.5	56.7	57.8	0	Range
Rhiz	42.5	42.5	693.7	4.5	5	Rhizophora (red mangrove)
Rice	102.0	255.0	153.0	0.2	0	Rice
Robi	5950.0	85.0	693.7	4.5	5	Robinia (black locust)
Rye	7.6	19.0	11.4	12.8	0	Rye
Sabl	5950.0	42.5	693.7	4.5	5	Sabal (cabbage palmetto)
Sali	14875.0	42.5	693.7	4.5	5	Salix (willow)
Sapi	42.5	42.5	693.7	4.5	5	Sapium (chinese tallow tree)
Sass	42.5	42.5	693.7	4.5	5	Sassafras
Scru	37.8	94.5	56.7	57.8	0	Scrub
Scwd	2700.0	349.0	651.0	31.2	2	Scrub woodland (AVHRR, Guen)
Sere	14875.0	42.5	693.7	4.5	5	Serenoa (saw palmetto)
Shrf	10750.0	530.0	910.0	4.5	5	Southeast/Western Deciduous Forest
Smxf	17000.0	1500.0	1250.0	4.5	4	Southeast Mixed Forest
Snow	0.0	0.0	0.0	0.0	0	Snow
Sorb	42.5	42.5	693.7	4.5	5	Sorbus (mountain ash)
Sorg	7.8	19.5	11.7	577.6	0	Sorghum
Soyb	22.0	0.0	0.0	12.8	0	Soybean
Spin	1460.0	1983.0	1252.0	4.5	3	Southern pine (AVHRR, Guen)
Swie	42.5	42.5	693.7	4.5	5	Swietenia (W. Indies mahogany)
Taxo	42.5	1275.0	693.7	4.5	5	Taxodium (cypress)
Thuj	170.0	1020.0	2775.0	4.5	7	Thuja (W. red cedar)
Tili	42.5	42.5	693.7	4.5	5	Tilia (basswood)
Toba	0.0	58.8	235.2	256.7	0	Tobacco
Tsug	79.3	158.7	1295.0	4.5	7	Tsuga (Eastern hemlock)
Tund	2411.7	120.6	150.7	0.2	0	Tundra
Ufor	1988.7	663.7	920.0	4.5	0	BEIS urban forest
Ugra	56.2	140.5	84.3	57.8	0	BEIS urban grass
Ulmu	42.5	42.5	693.7	4.5	5	Ulmus (American elm)
Uoth	11.2	28.1	16.9	11.6	0	Urban other (assume 20% grass)
Urba	408.6	161.9	200.5	12.5	0	BEIS urban (.2 grass/.2 forest)
Utre	5140.0	1000.0	959.0	4.5	5	Urban trees (.5 Harf/.5 Conf)
Vacc	42.5	42.5	693.7	4.5	5	Vaccinium (blueberry)
Wash	5950.0	42.5	693.7	4.5	5	Washingtonia (fan palm)
Wate	0.0	0.0	0.0	0.0	0	Water
Wcnf	4270.0	1120.0	1320.0	4.5	5	W Coniferous Forest (AVHRR, Guen)
Wdcp	2550.0	663.0	2053.0	8.7	3	Woodland/cropland (AVHRR, Guen)
Wetf	3820.0	923.0	1232.0	0.2	5	Wetland forest (AVHRR, Guen)
Whea	15.0	6.0	9.0	192.5	0	Wheat
Wmxf	5720.0	620.0	530.0	4.5	4	Western Mixed Forest (AVHRR, Guen)
Wwdl	525.0	250.0	360.0	4.5	3	Western Woodlands (AAVHRR, Guen)

Table 2. Standardized "winter" emission fluxes used in BEIS2.2. Columns represent the land use id, isoprene flux, monoterpene flux, other VOC flux, soil NO flux, leaf area index, and a description. Fluxes are given in units of μg/m^2-hr and are standardized to 30 C. Isoprene flux based on a light intensity of 1000 μmol/m^2-s.

Abie	170.0	5100.0	2775.0	4.5	7	Abies (fir)
Acac	0.0	0.0	0.0	4.5	5	Acacia
Acer	0.0	0.0	0.0	4.5	5	Acer (maple)
Aesc	0.0	0.0	0.0	4.5	5	Aesculus (buckeye)
Aila	0.0	0.0	0.0	4.5	5	Ailanthus
Aleu	0.0	0.0	0.0	4.5	5	Aleurites (tung-oil tree)
Alfa	0.0	0.0	0.0	12.8	0	Alfalfa
Alnu	0.0	0.0	0.0	4.5	5	Alnus (European alder)
Amel	0.0	0.0	0.0	4.5	5	Amelanchier (serviceberry)
Asim	0.0	0.0	0.0	4.5	5	Asiminia (pawpaw)
Avic	42.5	42.5	693.7	4.5	5	Avicennia (black mangrove)
Barl	0.0	0.0	0.0	256.7	0	Barley
Barr	0.0	0.0	0.0	0.0	0	Barren
Betu	0.0	0.0	0.0	4.5	5	Betula (birch)
Borf	640.0	706.0	634.0	4.5	5	Boreal forest (AVHRR/Guen et al 94)
Bume	42.5	42.5	693.7	4.5	5	Bumelia (gum bumelia)
Carp	0.0	0.0	0.0	4.5	5	Carpinus (hornbean)
Cary	0.0	0.0	0.0	4.5	5	Carya (hickory)
Casp	0.0	0.0	0.0	4.5	5	Castanopsis (chinkapin)
Cast	0.0	0.0	0.0	4.5	5	Castanea (chestnut)
Casu	29750.0	42.5	693.7	4.5	7	Casuarina (Austl pine)
Cata	0.0	0.0	0.0	4.5	5	Catalpa
Cedr	79.3	1269.3	1295.0	4.5	7	Cedrus (Deodar cedar)
Celt	0.0	0.0	0.0	4.5	5	Celtis (hackberry)
Cerc	0.0	0.0	0.0	4.5	5	Cercis (redbud)
Cham	170.0	340.0	2775.0	4.5	7	Chamaecyparis (prt-orford cedar)
Citr	42.5	680.0	693.7	4.5	5	Citrus (orange)
Cnif	0.0	1353.0	835.0	4.5	9	BEIS conifer forest
Conf	1400.0	1548.0	870.0	4.5	6	Conifer forest (AVHRR, Guen)
Corn	0.0	0.0	0.0	577.6	0	Corn
Coru	0.0	0.0	0.0	4.5	5	Cornus (dogwood)
Coti	0.0	0.0	0.0	4.5	5	Cotinus (smoke tree)
Cott	0.0	0.0	0.0	256.7	0	Cotton
Crat	0.0	0.0	0.0	4.5	5	Crataegus (hawthorn)
Cswt	1050.0	660.0	770.0	0.2	2	Herbaceous Wetlands (AVHRR, Guen)
Desh	0.0	0.0	0.0	57.8	0	Desert shrub (AVHRR, Guen)
Dios	0.0	0.0	0.0	4.5	5	Diospyros (persimmon)
Euca	29750.0	1275.0	693.7	4.5	5	Eucalyptus
Fagu	0.0	0.0	0.0	4.5	5	Fagus (american beech)
Frax	0.0	0.0	0.0	4.5	5	Fraxinus (ash)
Gled	0.0	0.0	0.0	4.5	5	Gleditsia (honeylocust)
Gord	0.0	0.0	0.0	4.5	5	Gordonia (loblolly-bay)
Gras	0.0	0.0	0.0	57.8	0	Grass
Gymn	0.0	0.0	0.0	4.5	5	Gymnocladus (KY coffeetree)
Hale	0.0	0.0	0.0	4.5	5	Halesia (silverbell)
Harf	0.0	371.0	185.0	4.5	5	Hardwood forest (AVHRR, Guen)
Hay	0.0	0.0	0.0	12.8	0	Hay
Ilex	42.5	85.0	693.7	4.5	5	Ilex (holly)
Jugl	0.0	0.0	0.0	4.5	5	Juglans (black walnut)
Juni	79.3	476.0	1295.0	4.5	7	Juniperus (east. red cedar)
Lagu	42.5	42.5	693.7	4.5	5	Laguncularia (white mangrove)
Lari	0.0	0.0	0.0	4.5	5	Larix (larch)
Liqu	0.0	0.0	0.0	4.5	5	Liquidambar (sweetgum)
Liri	0.0	0.0	0.0	4.5	5	Liriodendron (yellow poplar)
Macl	0.0	0.0	0.0	4.5	5	Maclura (osage-orange)
Magn	42.5	1275.0	693.7	4.5	5	Magnolia
Malu	0.0	0.0	0.0	4.5	5	Malus (apple)
Meli	0.0	0.0	0.0	4.5	5	Melia (chinaberry)
Mixf	0.0	1077.0	581.0	4.5	5	Mixed forest (AVHRR, Guenther)
Moru	0.0	0.0	0.0	4.5	5	Morus (mulberry)
Mscp	0.0	0.0	0.0	12.8	0	Misc crops

Nmxf	175.0	1100.0	850.0	4.5	5	Northern Mixed Forest (AVHRR, Guen)
Nyss	0.0	0.0	0.0	4.5	5	Nyssa (blackgum)
Oak	0.0	217.0	188.0	4.5	6	BEIS oak forest
Oats	0.0	0.0	0.0	256.7	0	Oats
Odcd	0.0	313.0	183.0	4.5	6	BEIS other deciduous forest
Ofor	0.0	0.0	0.0	4.5	0	Open forest
Oksv	0.0	100.0	200.0	4.5	2	Oak Savannah (AVHRR, Guen)
Ostr	0.0	0.0	0.0	4.5	5	Ostrya (hophornbeam)
Othe	0.0	0.0	0.0	57.8	0	Other (unknown, assume grass)
Oxyd	0.0	0.0	0.0	4.5	5	Oxydendrum (sourwood)
Pacp	0.0	0.0	0.0	35.3	0	Pasture cropland (AVHRR, Guen)
Past	0.0	0.0	0.0	57.8	0	Pasture
Paul	0.0	0.0	0.0	4.5	5	Paulownia
Pean	0.0	0.0	0.0	12.8	0	Peanuts
Pers	42.5	255.0	693.7	4.5	5	Persea (redbay)
Pice	23800.0	5100.0	2775.0	4.5	7	Picea (spruce)
Pinu	79.3	2380.0	1295.0	4.5	3	Pinus (pine)
Plan	0.0	0.0	0.0	4.5	5	Planera (water elm)
Plat	0.0	0.0	0.0	4.5	5	Platanus (sycamore)
Popu	0.0	0.0	0.0	4.5	5	Populus (aspen)
Pota	0.0	0.0	0.0	192.5	0	Potato
Pros	0.0	0.0	0.0	4.5	5	Prosopis (mesquite)
Prun	0.0	0.0	0.0	4.5	5	Prunus (cherry)
Pseu	170.0	2720.0	2775.0	4.5	7	Pseudotsuga (douglas fir)
Quer	0.0	0.0	0.0	4.5	5	Quercus (oak)
Rang	0.0	0.0	0.0	57.8	0	Range
Rhiz	42.5	42.5	693.7	4.5	5	Rhizophora (red mangrove)
Rice	0.0	0.0	0.0	0.2	0	Rice
Robi	0.0	0.0	0.0	4.5	5	Robinia (black locust)
Rye	0.0	0.0	0.0	12.8	0	Rye
Sabl	5950.0	42.5	693.7	4.5	5	Sabal (cabbage palmetto)
Sali	0.0	0.0	0.0	4.5	5	Salix (willow)
Sapi	0.0	0.0	0.0	4.5	5	Sapium (chinese tallow tree)
Sass	0.0	0.0	0.0	4.5	5	Sassafras
Scru	0.0	0.0	0.0	57.8	0	Scrub
Scwd	0.0	332.0	332.0	31.2	2	Scrub woodland (AVHRR, Guen)
Sere	14875.0	42.5	693.7	4.5	5	Serenoa (saw palmetto)
Shrf	0.0	0.0	0.0	4.5	5	SE/W Deciduous Forest (AVHRR, Guen)
Smxf	0.0	1500.0	500.0	4.5	4	SE Mixed Forest (AVHRR, Guen)
Snow	0.0	0.0	0.0	0.0	0	Snow
Sorb	0.0	0.0	0.0	4.5	5	Sorbus (mountain ash)
Sorg	0.0	0.0	0.0	577.6	0	Sorghum
Soyb	0.0	0.0	0.0	12.8	0	Soybean
Spin	0.0	1963.0	1052.0	4.5	3	Southern pine (AVHRR, Guen)
Swie	42.5	42.5	693.7	4.5	5	Swietenia (W. Indies mahogany)
Taxo	42.5	1275.0	693.7	4.5	5	Taxodium (cypress)
Thuj	170.0	1020.0	2775.0	4.5	7	Thuja (W. red cedar)
Tili	0.0	0.0	0.0	4.5	5	Tilia (basswood)
Toba	0.0	0.0	0.0	256.7	0	Tobacco
Tsug	79.3	158.7	1295.0	4.5	7	Tsuga (Eastern hemlock)
Tund	0.0	0.0	0.0	0.2	0	Tundra
Ufor	0.0	631.0	469.0	4.5	0	BEIS urban forest
Ugra	0.0	0.0	0.0	57.8	0	BEIS urban grass
Ulmu	0.0	0.0	0.0	4.5	5	Ulmus (American elm)
Uoth	0.0	0.0	0.0	11.6	0	Urban other (assume 20% grass)
Urba	0.0	154.0	102.0	12.5	0	BEIS urban (.2 grass/.2 forest)
Utre	700.0	960.0	528.0	4.5	5	Urban tree (.5 Harf/.5 Conf)
Vacc	0.0	0.0	0.0	4.5	5	Vaccinium (blueberry)
Wash	5950.0	42.5	693.7	4.5	5	Washingtonia (fan palm)
Wate	0.0	0.0	0.0	0.0	0	Water
Wcnf	3500.0	1120.0	1200.0	4.5	5	W Coniferous Forest (AVHRR, Guen)
Wdcp	0.0	630.0	1047.0	8.7	3	Woodland/cropland (AVHRR, Guen)
Wetf	0.0	877.0	628.0	0.2	5	Wetland forest (AVHRR, Guen)
Whea	0.0	0.0	0.0	192.5	0	Wheat
Wmxf	0.0	620.0	330.0	4.5	4	Western Mixed Forest (AVHRR, Guen)
Wwdl	0.0	250.0	360.0	4.5	3	Western Woodlands (AVHRR, Guen)

Table 3. Hierarchial rules used for processing the land use data in the Biogenic Emissions Landuse Database (BELD) for each county in the contiguous United States.

Priority	Description of raw data	Resulting BELD data
I	U.S. Forest Service's Forest Inventory database for the eastern U.S. (circa 1990), containing information from ~97,000 1-acre ground survey plots resolved to the county level. Tree species and diameter measurements are used to estimate crown cover by genus.	Total forest area, crown cover by tree genus for counties in the eastern U.S.
II	U.S. Geological Survey's Land Cover Characteristics Dataset, based on classification of imagery from the AVHRR satellite; resolved into 1-km pixels.	Inland water
IIIa	U.S. Census Bureau, urbanized areas from 1990.	Total urban area
IIIb	U.S. Forest Service (Dave Nowak, personal communication) fraction of urban area assumed to be forested, based on potential natural vegetation and relative percentage of native tree species in areas surrounding urban regions.	Total urban forest area and tree genus composition
IV	U.S. Department of Agriculture, 1987 crop statistics by county.	Area of specific crop types
V	U.S. Department of Agriculture, 1987 farm areas by county.	Area assumed as miscellaneous crop
VI	U.S. Geological Survey's Land Cover Characteristics Dataset, land use classes assigned to Guenther et al.[12] land use types; used extensively for the western U.S.	Areas of generalized land use types
VII	Undesignated, area in a county lacking classification.	Area of other

Table 4. Abundance of the top 20 land use types found in the Biogenic Emissions Landuse Database (BELD) for the contiguous United States.

Land use type	Area (million hectares)	Percent of total
Grass	144.8	18.3
Miscellaneous crops	97.4	12.3
Other (assumed grass)	66.3	8.4
Western coniferous forest	59.4	7.5
Scrub	54.7	6.9
Quercus (oaks)	34.4	4.3
Barren	32.1	4.1
Corn	25.0	3.2
Open forest (assumed grass)	24.0	3.0
Hay	23.3	2.9
Wheat	21.5	2.7
Soybeans	21.5	2.7
Water	20.3	2.6
Western woodlands	18.6	2.4
Pinus (pines)	19.3	2.4
Urban other (assumed 20% grass)	12.5	1.6
Acer (maples)	12.2	1.5
Woodland/cropland	9.5	1.2
Western mixed forest	8.1	1.0
Carya (hickory)	6.6	0.8
Cumulative total	**711.5**	**89.8**

Table 5. Seasonal breakout of biogenic emissions estimated for the contiguous United States for 1995. Emissions reported in units of million metric tons. Numbers may not add up exactly because of rounding.

Chemical	Winter (DJF)	Spring (MAM)	Summer (JJA)	Fall (SON)
Isoprene	0.10	2.98	11.13	2.95
Monoterpenes	0.42	1.21	3.09	1.36
Other VOCs	0.38	1.26	3.36	1.46
Total BVOC	0.90	5.46	17.58	5.76
NO	0.18	0.32	0.59	0.35

Table 6. Comparison of various estimates of annual biogenic emissions (million metric tons) for the contiguous United States.

Source	Isoprene	Total VOC	Biogenic NO
This work	17.2	29.8	1.4
BEIS2 for 1990[8]	17.8	30.5	1.5
Lamb et al. (1987)[18]	2.7	19.4	--
Lamb et al. (1993)[19]	5.9	29.1	--
Williams et al.[15]	--	--	0.7

LIST OF FIGURES

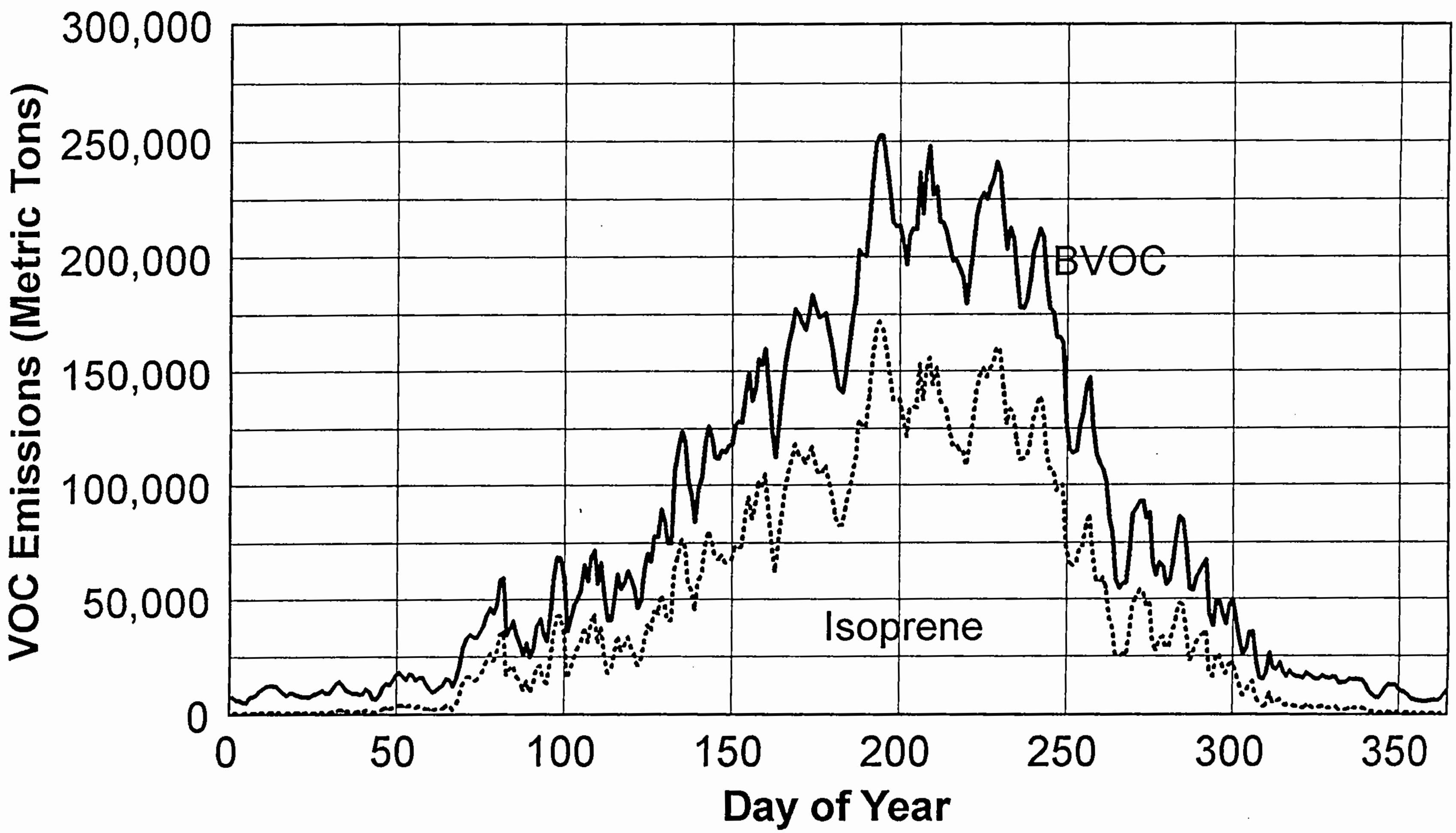
Figure 1. Daily emissions of isoprene and biogenic VOCs for the contiguous United States estimated with BEIS2.2 for 1995.

Figure 2. Daily emissions of biogenic NO for the contiguous United States estimated with BEIS2.2 for 1995.

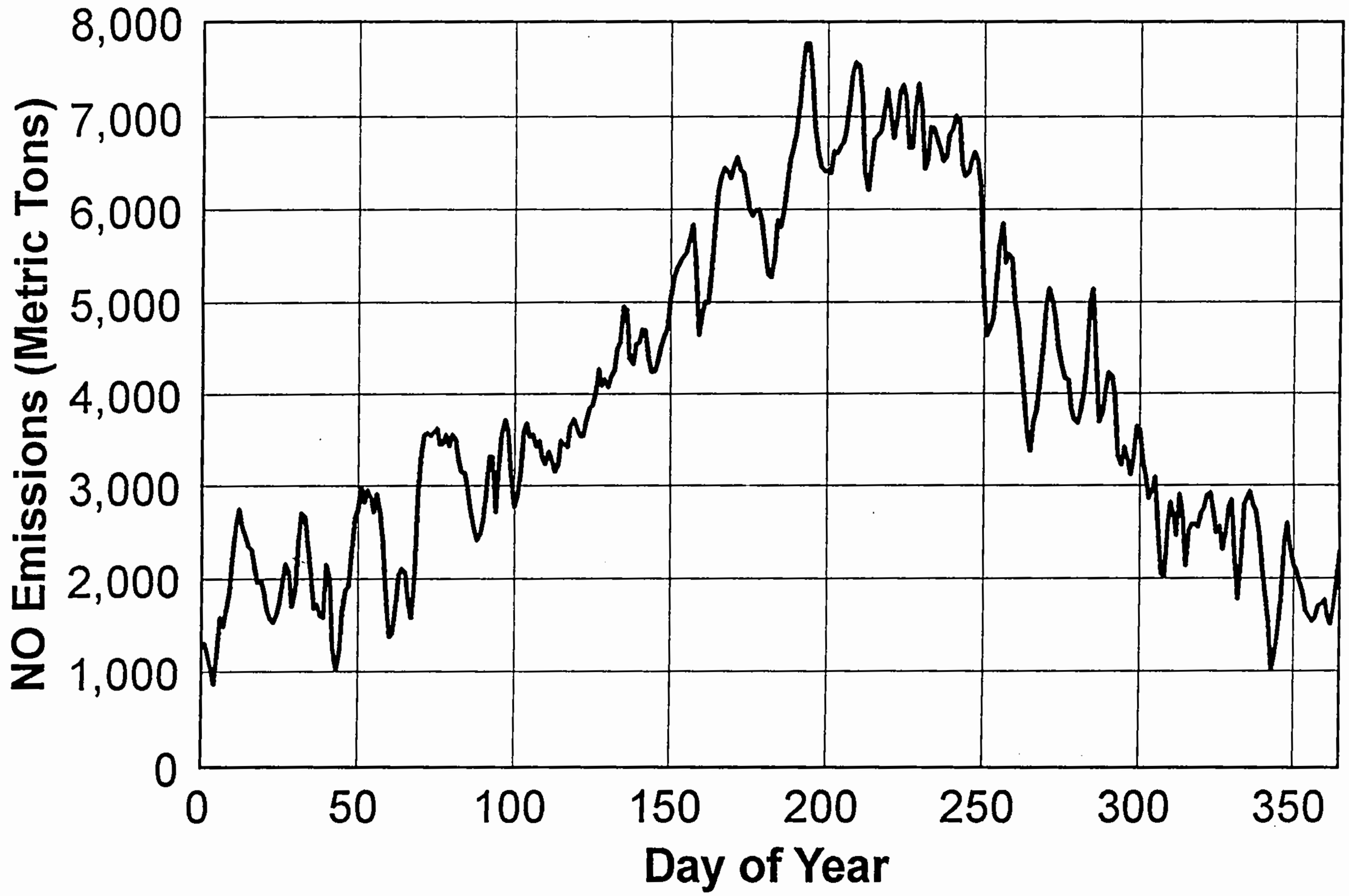
Figure 3. Spatial distribution of isoprene emissions estimated with BEIS2.2 for 1995.

Figure 4. Spatial distribution of biogenic VOC emissions estimated with BEIS2.2 for 1995.

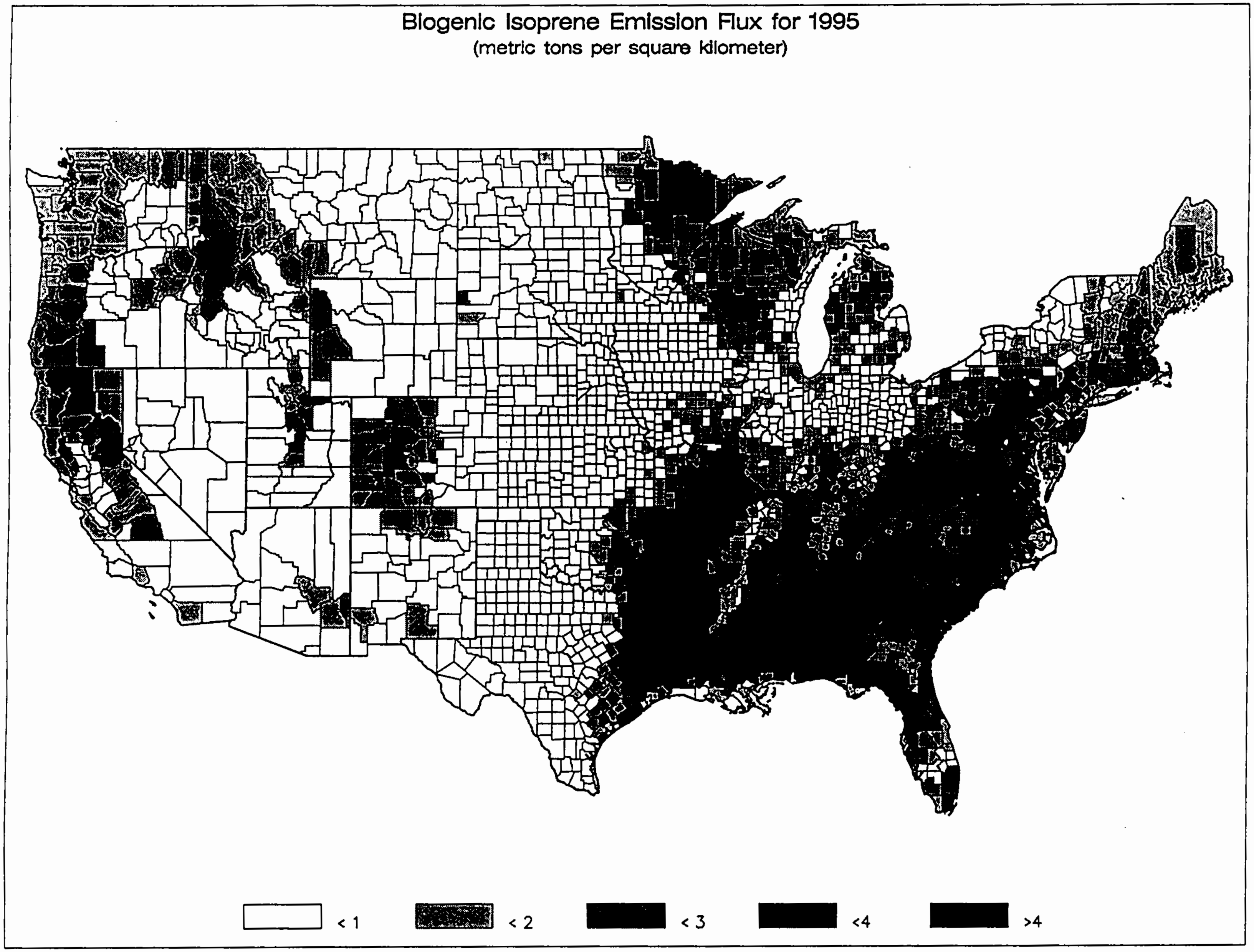
Figure 5. Spatial distribution of biogenic NO emissions estimated with BEIS2.2 for 1995.



300,000
250,000
200,000
150,000
100,000
50,000
0
VOC Emissions (Metric Tons)
0
50
100
150
200
250
300
350
Day of Year
BVOC
Isoprene

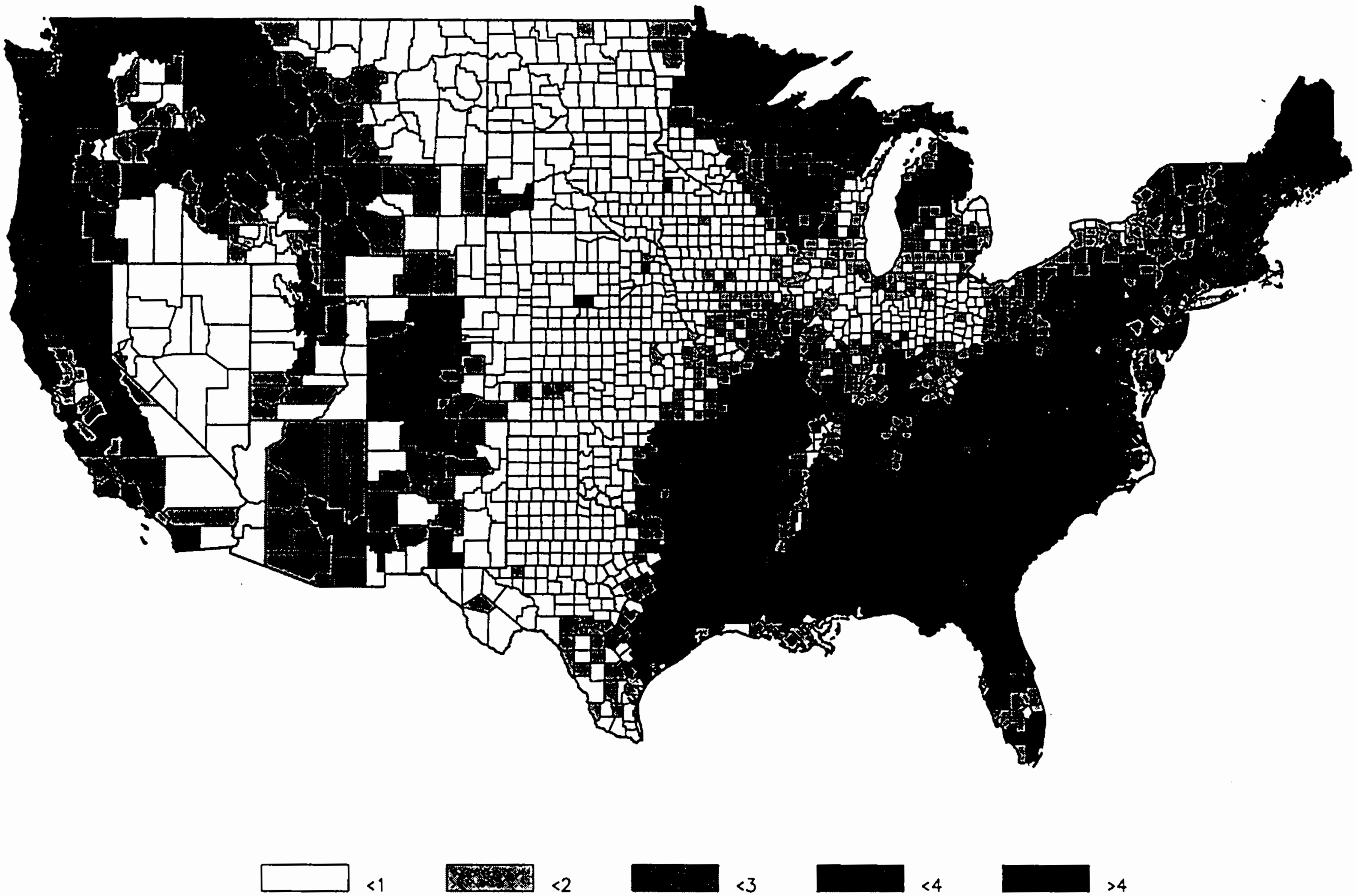


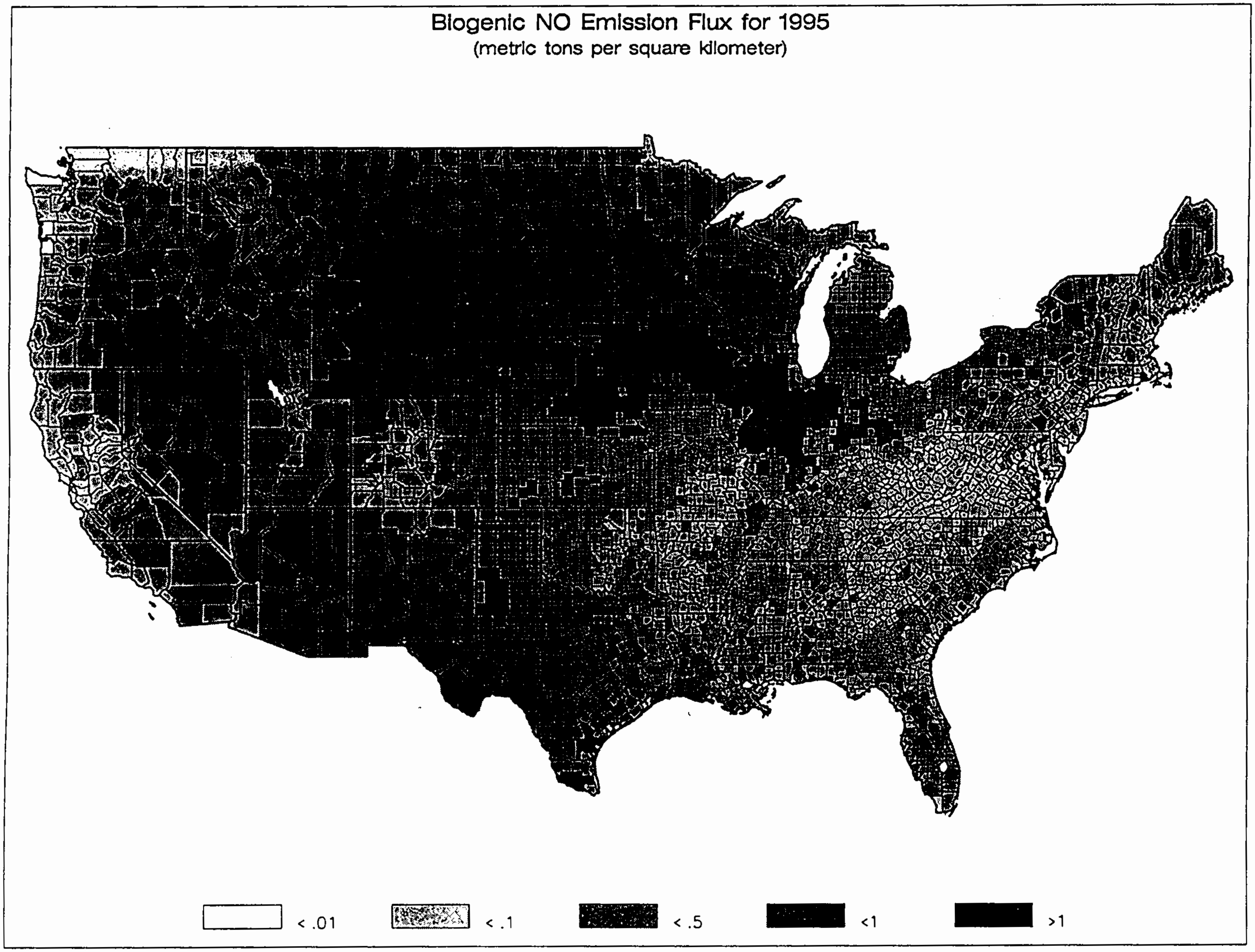
NO Emissions (Metric Tons)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0
50
100
150
200
250
300
350
Day of Year


Biogenic Isoprene Emission Flux for 1995
(metric tons per square kilometer)
< 1
< 2
< 3
<4
>4

Biogenic VOC Emission Flux for 1995

(metric tons per square kilometer)




Biogenic NO Emission Flux for 1995
(metric tons per square kilometer)
< .01
< .1
< .5
<1
>1

TECHNICAL REPORT DATA

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

Biogenic emissions during 1995 for the contiguous United States have been estimated with the Biogenic Emissions Inventory System (BEIS2.2). Hourly emissions were computed for each county using surface observations from the National Weather Service and land use data developed specifically for biogenic emission calculations. Meteorological data were interpolated to each county with Barnes analysis. The occurrence of the first and last date of freezing, as interpolated using Barnes analysis, was used to toggle the occurrence of deciduous leaf biomass. The estimates indicate annual emissions of 17.2 million metric tons (Tg) of isoprene, 6.1 Tg of monoterpenes, 6.5 Tg of other volatile organic compounds, and 1.4 Tg of nitric oxides. These estimates are reasonably consistent with those made by other researchers and are slightly lower than estimates for 1990 made with an earlier version of BEIS2. The slight decrease in estimated 1995 emissions compared to 1990 can be attributed to the use of freezing dates, better temporal resolution of data (hourly values versus monthly diurnal averages), and year-to-year variations in meteorology.

17. KEY WORDS AND DOCUMENT ANALYSIS

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